Appendix A:
REFERENCES and USEFUL WEBSITES

APPENDIX A: REFERENCES and USEFUL WEBSITES

Allen, C.R., Wyss, M., Brune, J.N., Grantz, A., and Wallace, R.E., 1972, Displacements on the Imperial, Superstition Hills, and San Andreas faults triggered by Borrego Mountain earthquake; in The Borrego Mountain earthquake of April 9, 1968: U.S. Geological Survey Professional Paper 787, pp. 87-104.

Alquist-Priolo Earthquake Fault Zoning Act, California Public Resources Code, Chapter 7.5 Earthquake Fault Zones, Section 2621 et seq., last updated October 2, 2007.

American Red Cross, 1994, Your Guide to Home Chemical Safety and Emergency Procedures, 24p.

American Society for Testing Materials (ASTM) E-108, Standard Test Methods for Fire Tests of Roof Coverings.

Anbar, M., Guttmann, S., and Lewitus, Z., 1959, The mode of action of perchlorate ions on the iodine uptake of the thyroid gland: International Journal on Application of Radiating Isotopes, Vol. 7, pp. 87-96.

Anderson, K., 2006, The Use of Fire by Native Americans in California; in Sugihara, N.G., van Wagtendonk, J.W., Shaffer, K.E., Fites-Kaufman, J., and Thode, A.E., (editors), 2006, Fire in California's Ecosystems: University of California Press, Berkeley and Los Angeles, California, pp. 417-430.

Andrews, R., 1995, Emergency response and recovery after the Northridge earthquake; in Woods, M.C., and Seiple, W.R., (editors), The Northridge, California, Earthquake of 17 January 1994: California Department of Conservation, Special Publication 116, pp. 241-245.

Association of Bay Area Governments (ABAG), 1990, Database of Hazardous Materials Releases Which have Occurred Due to Earthquakes: Oakland, California (as referenced in Seligson et al., 1992).

ASTM International, 2003, E1943-98 Standard guide for remediation of ground water by natural attenuation at petroleum release sites: ASTM Book of Standards, v. 11.04, 43 p.

Baldwin, J.E., 1987, Martinez Mountain rock avalanche; in Guptil, P.D., Gath, E.M., and Riff, R.W. (editors), Geology of the Imperial Valley, California: South Coast Geological Society, Annual Field Trip Guidebook, Vol. 14, pp. 37-38.

Barrows, A.G., 1974, A Review of the Geology and Earthquake History of the Newport-Inglewood Structural Zone: Southern California: California Division of Mines and Geology Special Report 114, 115p.

Barrows, A.G., Irvine, P.J., and Tan, S.S, 1995, Geologic surface effects triggered by the Northridge earthquake; in Woods, M.C., and Seiple, W.R. (editors), The Northridge, California, Earthquake of 17 January 1994: California Division of Mines and Geology Special Publication 116, pp 65-88.

Barrows, A.G., Tan, S.S., and Irvine, P.J., 1994, Investigation of Surface Geologic Effects and Related Land Movement in the City of Simi Valley Resulting from the Northridge Earthquake of January 14, 1994: California Division of Mines and Geology Open File Report 94-09, 41p., 1 plate.

Berh, W.M., Rood, D.H., Fletcher, K.E., Guzman, N., Finkel, R., Hanks, T.C., Hudnut, K.W., Kendrick, K.J., Platt, J.P., Sharp, W.D., Weldon, R.J., and Yule, J.D., 2010, Uncertainties in Slip-Rate Estimates for the Mission Creek Strands of the Southern San Andreas Fault at Biskra Palms Oasis, Southern California: Bulletin of the Geological Society of America, Vol. 122, pp. 1360-1377, doi:10.1130/B30020.1

Bergmann, M., Rockwell, T.K., Miles, D.K., Hirabayashi, C.K., Hushebeck, M.A., Haraden, C.C., Thomas, A., and Patterson, A., 1993, Preliminary assessment of the late Holocene slip rate for the Wildomar fault, Murrieta, California: Technical report to the U.S. Geological Survey, Reston, Virginia, under Contract 14-08001-G2062, 12p.

Bilham, R., and Williams, P., 1985, Sawtooth segmentation and deformation processes on the southern San Andreas fault, California: Geophysical Research Letters, Vol. 12, pp. 557-560.

Blake, T. F., 2000, EQFAULT, A Computer Program for the Estimation of Peak Horizontal Ground Acceleration from 3D Fault Sources.

Blake, T.F., Hollingsworth, R.A., and Stewart, J.P. (editors), 2002, Recommended Procedures for Implementation of DMG Special Publication 117, Guidelines for Analyzing and Mitigating Landslide Hazards in California: Southern California Earthquake Center, 110p. + Appendix A.

Blythe, A.E., Crow-Willard, E., Kleinsasser, E., Latin, M., Linden, E., Utevsky, E., and Wros, J., 2011, Active deformation along the Blue Cut fault in Joshua Tree Park: Results from an undergraduate field mapping project (Abstract): Geological Society of America Abstracts with Programs, Vol. 43, No. 5, p. 296.

Bodin, P., Bilham, R., Behr, J., Gomberg, J., and Hudnut, K.W., 1994, Slip triggered on southern California faults by the 1992 Joshua Tree, Landers, and Big Bear Earthquakes: Bulletin of the Seismological Society of America, Vol. 84, No. 3, pp. 806-816, June 1994.

Bolt, Bruce A., 1999, Earthquakes: W.H. Freeman and Company, New York, Fourth Edition, 320p.

Boore, D.M., Joyner, W.B., and Fumal, T.E., 1997, Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes: A Summary of recent work: Seismological Research Letters, Vol. 68, No. 1, pp. 128-153, plus erratum.

Borchardt, G., and Kennedy, M.P., 1979, Liquefaction Potential in Urban San Diego – A Pilot Study: California Geology, Vol. 32, pp. 217-221.

Bray, J.D., 2001, Developing Mitigation Measures for the Hazards Associated with Earthquake Surface Fault Rupture; *in* A Workshop on Seismic Fault-Induced Failures – Possible Remedies for Damage to Urban Facilities: Research Project 2000 Grant-in-Aid for Scientific Research (No. 12355020), Japan Society for the Promotion of Science, Workshop Leader, Kazuo Konagai, University of Tokyo, Japan, pp. 55-79, January 11-12, 2001.

Brewer, L., 1992, Preliminary damage and intensity survey: Earthquakes and Volcanoes, Vol. 23, No. 5, pp. 219-226.

Brown, R.D., Jr., 1990, Quaternary Deformation; *in* Wallace, R.E. (editor), The San Andreas Fault System, California: U.S. Geological Survey Professional Paper 1515, pp. 83-114.

Bryant, W.A., 1986, Fault Evaluation Report for the Western North Frontal Fault Zone and Related Faults, San Bernardino County, California: California Division of Mines and Geology FER-186, 16p. + figures.

Bryant, W.A., and Lundberg, M.M., (compilers), 2002, Fault number 1 J, San Andreas fault zone, Coachella section; *in* Quaternary Fault and Fold Database of the United States: U.S. Geological Survey website at http://geohazards.usgs.gov/cfusion/qfault/qf_web_disp.cfm?qfault_or=762&ims_cf_cd=cf&disp_cd=C, accessed August 26, 2011.

Buchanan and Associates, Inc., D. M., 2008, *Masonry Structures Study: City of Coachella*; report dated March 2008.

Building Technology, Inc., 1990a, Financial Incentives for Seismic Rehabilitation of Hazardous Buildings – An Agenda for Action. Volume 1: Findings, Conclusions and Recommendations: Federal Emergency Management Agency Publication No. 198, 104p.

Building Technology, Inc., 1990b, Financial Incentives for Seismic Rehabilitation of Hazardous Buildings – An Agenda for Action. Volume 2: State and Local Case Studies and Recommendations: Federal Emergency Management Agency Publication No. 199, 130p.

Building Technology, Inc., 1990c, Financial Incentives for Seismic Rehabilitation of Hazardous Buildings – An Agenda for Action. Volume 3: Applications Workshops Report: Federal Emergency Management Agency Publication No. 216, 200p.

Cadena, A.M., Rubin, C.M., Rockwell, T.K., Walls, C., Lindvall, S., Madden, C., Khatib, F., and Owen, L., 2004, Late Quaternary activity of the Pinto Mountain Fault at the Oasis of Mara: Implications for the Eastern California Shear Zone: Geological Society of America Abstracts with Programs, Vol. 36, No. 5, pp. 137. [Paper presented at the Annual Meeting in Denver, Colorado, Paper No. 51-5, Nov. 7-10, 2004.]

California Building Standards Commission (CBSC), 2013, California Building Code, Title 24, Part 2, 2 Volumes.

California Building Standards Commission (CBSC), 2013, California Historical Building Code, Title 24, Part 8.

California Building Standards Commission (CBSC), 2013, California Existing Building Code, Title 24, Part 10.

California Department of Water Resources (DWR), 1964, Coachella Valley Investigation: Bulletin No. 108, 145p. + plates., dated July 1964.

California Department of Water Resources (DWR), 1984, Dams within the Jurisdiction of the State of California: Department of Water Resources, Bulletin 17-84, 94p.

California Department of Water Resources (DWR), 1986, Statutes and Regulations Pertaining to Supervision of Dams and Reservoirs: Division of Safety of Dams, 46p.

California Department of Water Resources (DWR), 2004, California's Groundwater: CDWR Bulletin 118, February 27, 2004 update.

California Division of Mines and Geology (CDMG), 1974a, Alquist-Priolo Special Studies Map of the Indio 7-1/2 Minute Quadrangle, California, Official Map released July 1, 1974, Scale 1:24,000.

California Division of Mines and Geology (CDMG), 1974b, Alquist-Priolo Special Studies Map of the Thermal Canyon 7-1/2 Minute Quadrangle, California, Official Map released July 1, 1974, Scale 1:24,000.

California Division of Mines and Geology (CDMG), 1992, Recommended Criteria for Delineating Seismic Hazard Zones in California: Special Publication 118, May 1992, revised July 1999.

California Division of Mines and Geology (CDMG), 1997, Guidelines for Evaluating and Mitigating Seismic Hazards in California: Special Publication 117.

California Division of Mines and Geology (CDMG), 1998, Maps of known active fault near-source zones in California and adjacent portions of Nevada, to be used with the 1997 Uniform Building Code: International Conference of Building Officials.

California Environmental Quality Act, California Public Resources Code, Section 21000 et seq.

California Geological Survey (CGS), 2002, Alquist-Priolo Earthquake Fault Zones: CD-ROM 2001-05.

California Geological Survey (CGS), 2004, Hazards from "mudslides", debris avalanches and debris flows in hillside and wildfire areas: CGS Note 33, available online at http://www.consrv.ca.gov.cgs/information/publications/cgs_notes/note_33/index.htm.

California Geological Survey (CGS), 2004, Guidelines for Evaluating the Hazard of Surface Fault Rupture: CGS Note 49, available online at http://www.consrv.ca.gov/CGS/rghm/ap/index.htm.

California Geological Survey (CGS), 2008, Guidelines for Evaluating and Mitigating Seismic Hazards in California: Special Publication 117, 74p., revised September 11, 2008 and available online at http://www.conservation.ca.gov/cgs/shzp/Pages/shmppgminfo.aspx.

California Office of Planning and Research (OPR), 1987, General Plan Guidelines.

California Seismic Safety Commission (CSSC), 2000, Status of the Unreinforced Masonry Building Law (Government Code Section 8875 *et. seq.*), 2000 Year Report to the Legislature, Adopted April 13, 2000, SSC 00-02.

California Seismic Safety Commission (CSSC), 2003, Status of the Unreinforced Masonry Building Law, 2003 Report to the Legislature, Adopted June 12, 2003.

California Seismic Safety Commission (CSSC), 2006, Status of the Unreinforced Masonry Building Law, 2006 Report to the Legislature, Adopted November 9, 2006, SSC Publication No. 2006-04, 12p. + 2 appendices.

Campbell, K.W., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, Vol. 68, pp. 154-179.

Campbell, K.W., and Bozorgnia, Y., 2000, New empirical models for predicting near-source horizontal, vertical, and V/H response spectra: Implications for design, in Proceedings, 6th International Conference on Seismic Zonation, Palm Springs, California.

Campbell, K.W., and Bozorgnia, Y., 2003a Erratum, Updated Near-Source Ground-Motion (Attenuation) Relations for the Horizontal and Vertical Components of Peak Ground Acceleration and Acceleration Response Spectra: Bulletin of the Seismological Society of America, Vol. 93, No. 4., p. 1872.

Campbell, K.W., and Bozorgnia, Y., 2003b, Erratum: Updated near-source ground motion (attenuation) relations for the horizontal and vertical components of peak ground acceleration and acceleration response spectra: Bulletin of the Seismological Society of America, Vol. 93, p. 1413.

Campbell, K.W., and Bozorgnia, Y., 2003c, Updated Near-Source Ground-Motion (Attenuation) Relations for the Horizontal and Vertical Components of Peak Ground Acceleration and Acceleration Response Spectra: Bulletin of the Seismological Society of America, Vol. 93, No. 1, pp. 314-331.

Campbell, R.H., 1975, Soil slips, debris flows, and rainstorms in the Santa Monica Mountains and vicinity, southern California: U.S. Geological Survey Professional Paper 851, 51p.

Campbell, R.H., Fleming, R.W., Prior, DB., Nichols, D.R., Varnes, D.J., Hampton, M.A>, Sangrey, D.A. and Brabb, E.E., 1989, Landslide Classification and Identification of Mud Flows and Other Landslides; *in* Sadler, P.M., and Morton, D.M., (editors), Landslides in a Semi-Arid Environment with Emphasis on the Inland Valleys of Southern California: The Inland Geological Society, Volume 2, pp. 1-27.

Cannon, S.H., 2001, Debris-Flow Generation from Recently Burned Watersheds: Environmental & Engineering Geosciences, Vol. VII, No. 4, November 2001, pp. 321-341.

Cao, T., Bryant, W.A., Rowshandel, B., Branum, D., and Wills, C.J., 2003, The revised 2002 California probabilistic seismic hazard maps, dated June 2003, 11p., available at http://www.consrv.ca.gov/cgs/rghm/psha/index.htm.

Chang, S.E., 2003, Evaluating disaster mitigations: methodology for urban infrastructure systems: American Society of Civil Engineers, Natural Hazards Review, Vol. 4, No. 4, November 1, 2003, pp. 186-196.

Chin, E.H., Aldridge, B.N., and Longfield, R.J., 1991, Floods of the February 1980 in Southern California and Central Arizona, U.S. Geological Survey Professional Paper 1494

Clark, M.M., 1984, Map showing recently active breaks along the San Andreas fault and associated faults between Salton Sea and Whitewater River-Mission Creek, California: U.S. Geological Survey Miscellaneous Investigations Map I-1483, 6p. pamphlet, 2 sheets, scale 1:24,000.

Claypole, E.W., 1900, The Earthquake at San Jacinto, December 25, 1899: The American Geologist, Vol. XXV, Feb. 1900, pp. 106-108, plate III.

Coachella Valley County Water District, 1967, Whitewater River Basin, Coachella Valley California, dated April, 1967.

Coachella Valley Water District, 2009, 2008-09 Annual Review & Water Quality Report.

Coachella Valley Water District, 2008, 2007-08 Annual Review & Water Quality Report.

Coachella Valley Water District, 2010, 2009-10 Annual Review & Water Quality Report.

Coachella Valley Water District, 2010, Operating Capital and Improvement Budgets, Fiscal Year 2010-2011.

Coachella Valley Water District, 2012, Coachella Valley Water Management Plan Update, Final Report, published January 2012.

Coachella Valley Water District, 2013, Operating Budget, Fiscal Year 2013-2014.

Crippen, R.E., and Spencer, A.L., 1984, Landsat thematic mapper revealment of Blue Cut fault, Pinto Basin, California: Geological Society of America Abstracts with Programs, Vo. 16, p. 479.

Dawson, T.E., Weldon, R.J., II, and Biasi, G.P., 2008, Appendix B: Recurrence Interval and Event Age Data for Type A Faults: U.S. Geological Survey Open File Report 2007-1437B, California Geological Survey Special Report 203B, Southern California Earthquake Center Contribution #1138B, Version 1.0, 38p.

Deng, J., and Sykes, L.R., 1996, Triggering of 1812 Santa Barbara earthquake by a great San Andreas shock: implications for future seismic hazards in Southern California: Geophysical Research Letters, Vol. 23, pp. 1155-1158.

Dibblee, T.W., Jr., 1954, Geology of the Imperial Valley Region, California: California Division of Mines and Geology Bulletin 170, Chapter 2.

Dibblee, T.W., Jr., 2008, Geologic Map of the Palm Desert & Coachella 15 Minute Quadrangles, Riverside County, California: Dibblee Geology Center Map #DF-373, Scale: 1:62,500.

EAR Engineering, Construction & Support Services, 2010, Onsite Confirmation Soil Sampling Report, Former Sossa's Food Mart, 48975 Grapefruit Boulevard (Hwy 11) (sic), Coachella, CA 92236: Unpublished consulting report submitted to County of Riverside Department of Environmental Health, EAR Project No. 010014, dated September 24, 2010.

Earth Consultants International, Inc., 2000, Natural Hazard Mapping, Analysis, and Mitigation; A Technical Background Report in Support of the Safety Element of the New Riverside County 2000 General Plan: Report prepared for the Department of Regional Planning, County of Riverside, dated August 2000.

Earthquake Engineering Research Institute (EERI), 1992, Special Report, Landers and Big Bear Earthquakes of June 28 and 29, 1992, Double Event Shakes Southern California: Oakland, California, 12p.

Earthquake Engineering Research Institute (EERI), 1994, Northridge Earthquake, January 17, 1994, Preliminary Reconnaissance Report: Oakland, California, 96p.

Earthquake Engineering Research Institute (EERI), 1995, Northridge, California, 1994 Earthquake, Vol. 11, Issues S1 and S2.

Earth Systems Consultants Southern California (Earth Systems), 1996, Fault Hazard Evaluation Report, The Hills, Indio, California: Unpublished consultants' report for Landmark Golf Company, Job No. B7-1182-P3, 96-10-707, dated October 9, 1996.

Eguchi, R.T., and Ghosh, S., 2008, The ShakeOut Scenario, Supplemental Study: Hazardous Materials: U.S. Geological Survey Open File Report 2008-1150, California Geological Survey Preliminary Report 25, version 1.0, dated May 2008, 11p.

El-Aghel, A.M., 1984, An Analysis of the Movement of Wind-Blown Sand and its Relation to Land-Use Practices in the Coachella Valley During the last Twenty-Five Years: PhD Dissertation, University of California, Riverside, 179p.

Ellen, S.D., and Fleming, R.W., 1987, Mobilization of debris Flows from soil slips, San Francisco Bay region, California; *in* Costa, J.E. and Wieczorek, G.F. (editors), Debris flows/avalanches: Process, recognition, and mitigation: Geological Society of America Reviews in Engineering Geology, Vol. VII, pp. 31-40.

Engstrom, W.N., 1996, The California storm of January 1862: Quaternary Research, Vol. 46, pp. 141-148.

Federal Emergency Management Agency (FEMA), 2014, Review of Changes to the Policy for Flood Risk Analysis and Mapping, FEMA Daily Digest Bulletin, March 18, 2014.

Federal Emergency Management Agency (FEMA), 2013a, Policy for Flood Risk Analysis and Mapping, published August, 2013

Federal Emergency Management Agency (FEMA), 2013b, Analysis and Mapping Procedures for Non-Accredited Levees – New Approach, published July, 2013

Federal Emergency Management Agency (FEMA), 2011, New Levee Analysis and Mapping Approaches Being Developed, dated May 16, 2011.

Federal Emergency Management Agency (FEMA), 2009a, Letter of Map Revision, City of La Quinta, Case No. 09-09-0397P, dated January 21, 2009.

Federal Emergency Management Agency (FEMA), 2009b, Letter of Map Revision, City of La Quinta, Case No. 09-09-0538P, dated January 21, 2009.

Federal Emergency Management Agency (FEMA), 2009c, Guide to Flood Maps, FEMA 258, December 2009.

Federal Emergency Management Agency (FEMA), 2008a, Flood Insurance Study, Riverside County, California and Unincorporated Areas, Vol. 1 of 4, latest revision dated August 28, 2008.

Federal Emergency Management Agency (FEMA), 2008b, Flood Insurance Rate Maps (FIRMs) for Coachella; Community Panel Nos. 06065C2254G, 06065C2260G, 06071C2262G, 06065C2270G, dated August 28, 2008.

Federal Emergency Management Agency (FEMA), 1998, Home Builder's Guide to Seismic Resistant Construction: Earthquake Hazard Reduction Series, FEMA-232, 75p.

Federal Emergency Management Agency (FEMA), 1998, Seismic Rehabilitation of Buildings: Strategic Plan 2005: Earthquake Hazard Reduction Series FEMA-315, 40p.

Federal Emergency Management Agency (FEMA), 1995, (Second Edition), Typical Costs for Seismic Rehabilitation of Existing Buildings: Volume 2: Supporting Documentation. Second Edition: Prepared for FEMA by the Hart Consultant Group, Inc., Santa Monica, California, 102p., supersedes 1988 version.

Federal Emergency Management Agency (FEMA), 1994, (Second Edition), Typical Costs for Seismic Rehabilitation of Existing Buildings: Volume 1: Summary: Prepared for FEMA by the Hart Consultant Group, Inc., Santa Monica, California, 70p., supersedes 1988 version.

Federal Emergency Management Agency (FEMA), 1991, Flood Insurance Study, City of La Quinta, California, Riverside County, 13 pgs.

Federal Emergency Management Agency (FEMA), 1989, FEMA-178, A Handbook for Seismic Evaluation of Existing Buildings (Preliminary): Applied Technology Council (ATC-22); Earthquake Hazard Reduction Series No. 47, 169p.

Federal Emergency Management Agency (FEMA), 1989, FEMA-175, Seismic Evaluation of Existing Buildings: Supporting Documentation: Applied Technology Council (ATC-22-1); Earthquake Hazard Reduction Series No. 48, 160p.

Federal Emergency Management Agency (FEMA), 1989, FEMA-174, Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings – A Handbook Building Systems Development, Inc., Integrated Design Services and Rubin, Claire B.; Earthquake Hazard Reduction Series No 45, 122p.

Federal Emergency Management Agency (FEMA), 1989, FEMA-173, Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings – Supporting Report: Building Systems Development, Inc., Integrated Design Services and Rubin, Claire B.; Earthquake Hazard Reduction Series No 46, 190p.

Federal Emergency Management Agency (FEMA), 1988, FEMA-155, Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation: Applied Technology Council (ATC-21-1), Earthquake Hazards Reduction Series No. 42, 137p.

Federal Emergency Management Agency (FEMA), 1988, FEMA-154, Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook: Applied Technology Council (ATC21), Earthquake Hazards Reduction Series No. 41, 185p.

Federal Emergency Management Agency (FEMA), 1987, FEMA-139, Abatement of Seismic Hazard to Lifelines: Proceedings of a Workshop on Development of an Action Plan – Volume 5: Papers on Gas and Liquid Fuel Lifelines: Building Seismic Safety Council; Earthquake Hazard Reduction Series No. 30, 134p.

Federal Emergency Management Agency (FEMA), 1987, FEMA-135, Abatement of Seismic Hazard to Lifelines: Water and Sewer Lifelines and Special Workshop Presentations: Earthquake Hazard Reduction Series No. 2, 181p.

Federal Emergency Management Agency (FEMA), 1987, The Los Angeles – Whittier Narrows Earthquake of October 1, 1987: Federal/State Hazard Mitigation Survey Team Report: Federal Emergency Management Agency Region IX, California Governor's Office of Emergency Services, Southern California Earthquake Preparedness Project and Planning Division.

Federal Emergency Management Agency (FEMA), 1985, Comprehensive Earthquake Preparedness Planning Guidelines: City: Earthquake Hazard Reduction Series 2, FEMA-73, 80p.

Field, E.H., Dawson, T.E., Felzer, K.R., Frankel, A.D., Gupta, V., Jordan, T.H., Parsons, T., Petersen, M.D., Stein, R.S., Weldon, R.J., and Wills, C.J., 2009, Uniform California earthquake rupture forecast, version 2: Bulletin of the Seismological Society of America, Vol. 99, pp. 2053-2107.

Fletcher, K.E., Sharp, W.D., Kendrick, K.J., Behr, W.M., Hudnut, K.W., and Hanks, T.C., 2010, ^{230}Th/U Dating of a Late Pleistocene Alluvial Fan Along the Southern San Andreas Fault: Bulletin of the Geological Society of America, Vol. 122, pp. 1347-1359, doi: 10.1130/B30018.1

Flyn, Jennifer D., 2009, Fire Service Performance Measures: National Fire Protection Association, Fire Analysis and Research Division, Quincy, Massachusetts, 43p., November.

Frey Environmental, Inc., 2009, Former EZ Serve Truck Stop, 84-425 Indio Boulevard, Indio, California (RWQCB ID #7T2-201-041, Global ID#T0606500674: Unpublished consulting report, Project No. 627-01, dated May 29, 2009, obtained from the GeoTracker website at www.geotracker.ca.gov.

Fuis, G.S., and Mooney, W.D., 1990, Lithospheric structure and tectonics from seismic-refraction and other data; *in* Wallace, R.E., (editor), The San Andreas Fault System, California, U.S. Geological Survey Professional Paper 1515, pp. 207-238.

Fumal, T.E., Rymer, M.J., and Seitz, G.G., 2002, Timing of large earthquakes since A.D. 800 on the Mission Creek strand of the San Andreas fault at Thousand Palms Oasis, near Palm Springs: Bulletin of the Seismological Society of America, Special Issue on Paleoseismology of the San Andreas Fault System, Vol. 92, No.7 , pp. 2841-2860.

Fumal, T.E., Weldon II, R.J., Biasi, G.P., Dawson, T.E., Seitz, G.G., Frost, W., and Schwartz D.P., 2002, Evidence for large earthquakes on the San Andreas fault at the Wrightwood, California, Paleoseismic site: A.D. 500 to present: Bulletin of the Seismological Society of America, Special Issue on Paleoseismology of the San Andreas Fault System, Vol. 92, No. 7, pp. 2726-2760.

Garrison, T., 2002, Oceanography – An Invitation to Marine Science: Wadsworth Publishing House, Belmont, California, 4th Edition.

Goldrath, D.A., Wright, M.T., and Belitz, K., 2009, Ground-Water Quality Data in the Coachella Valley Study Unit, 2007: Results from the California GAMA Program: U.S. Geological Survey in cooperation with the California State Water Resources Control Board, Data Series 373, 70p.

Goklany, I.M., 2007, Death and Death Rates due to Extreme Weather Events: Global and U.S. Trends, 1900-2006: The Civil Society Report on Climate Change: International Policy Press, London.

Gosnold, William D., Jr., LeFever, Julie A., Todhunter, Paul E., and Osborne, Leon F., Jr., 2000, Rethinking Flood Prediction: Why the Traditional Approach Needs to Change: Geotimes, Vol. 45, No. 5, pp. 20-23.

Graf, W.P., 2008, Woodframe Buildings: Supplemental Study to The ShakeOUt Scenario: U.S. Geological Survey Open File Report 2008-1150 and California Geological Survey Preliminary Report 25 version 1.0.

Graf, W.P., and Seligson, H.A., 2011, Earthquake Damage to Wood-Framed Buildings in the ShakeOut Scenario: Earthquake Spectra, Vol. 27, No. 2, pp. 351-373.

Greenwood, R.B., 1998, Section 1 - Liquefaction Evaluation Report: Liquefaction zones in the Long Beach 7.5-Minute Quadrangle, Los Angeles County, California: California Division of Mines and Geology Seismic Hazard Zone Report for the Long Beach 7.5-Minute Quadrangle, Los Angeles County, California, Open File Report No. 98-19, pp. 3-20.

Griggs, G.B., Marshall, J.S., Rosenbloom, N.A., and Anderson, R.S., 1991, Ground Cracking in the Santa Cruz Mountains; *in* Baldwin, J.E. and Sitar, N. (editors), Loma Prieta Earthquake: Association of Engineering Geologists, Engineering Geologic Perspectives, Special Publication No. 1, pp. 25-41.

Hall, W. J, Hon, M., and O'Rourke, T. D., 1991, Seismic Behavior and Vulnerability of Pipelines; *in* Cassaro, Michael A., (editor), Lifeline Earthquake Engineering: American Society of Civil Engineers, Los Angeles, California, pp. 761-773.

Halsey, D.D., and Marsh, A.W., 1967, Pea Gravel Envelopes For Tile Drains in Coachella Valley, *in* California Agriculture, December, 1967.

Hargis + Associates, Inc., 2010, Annual Groundwater Monitoring Report, July 2010, Foster-Gardner, Coachella, California: Consultants' report dated September 22, 2010, signed by Kenneth R. Puentes, PG 7136, CHG 714, Principal Hydrogeologist (available from http://www.envirostor.dtsc.ca.gov/public/profile_report.asp?global_id=33280137).

Harp, E.L., and Jibson, R.W., 1996, Landslides triggered by the 1994 Northridge, California, Earthquake: Bulletin of the Seismological Society of America, Vol. 86, No. 1B, pp. S319-S332.

Hart, E.W., and Bryant, W.A., 2007 Interim Revision, Fault-Rupture Hazard Zones in California, Alquist-Priolo Earthquake Fault Zoning Act with Index to Earthquake Fault Zones Maps: California Division of Mines and Geology Special Publication 42, 42p., available from the web at http://www.consrv.ca.gov/cgs/rghm/ap/Pages/disclose.aspx

Hart, E.W., and Bryant, W.A., 1999, Fault-Rupture Hazard Zones in California, Alquist-Priolo Earthquake Fault Zoning Act with Index to Earthquake Fault Zones Maps: California Division of Mines and Geology Special Publication 42.

Haukson, E., Jones, L.M., and Hutton, K., 2002, The 1999 Mw 7.1 Hector Mine, California, earthquake sequence: Complex conjugate strike-slip faulting: Bulletin of the Seismological Society of America, Vol. 92, No. 4, pp. 1154-1170.

Hauksson, E., Stock, J., Hutton, K., Yang, W., Vidal-Villegas, J.A., and Kanamori, H., 2010, The 2010 Mw 7.2 El Mayor-Cucapah Earthquake Sequence, Baja California, Mexico and Southernmost California, USA: Active Seismotectonics along the Mexican Pacific Margin: Pure and Applied Geophysics, printed online 16 November 2010, 23p., doi: 10.1007/s00024-010-0209-7.

Henry, A.J., 1916, Floods of January-February, 1916, in the lower Mississippi and in Southern California: Monthly Weather Review, Washington D.C., dated February 29, 1916.

Hereford and Longpre, 2009, Climate History of the Mojave Desert Region, 1982-1996, Including Data from 48 Long-Term Weather Stations and an Overview of Regional Climate Variation: U.S. Geological Survey, http://mojave.usgs.gov/climate-history/.

Holzer, T.L., 1984, Ground failure induced by ground-water withdrawal from unconsolidated sediment: man-induced land subsidence: Reviews in Engineering Geology, Vol. 6, pp. 67-105.

Hope, R.A., 1969a, The Blue Cut fault, southeastern California: U.S. Geological Survey Professional Paper 650-D, pp. 116-121.

Hope, R.A., 1969b, Map showing recently active breaks along the San Andreas and related faults between Cajon Pass and Salton Sea: U.S. Geological Survey Open-File Map 69-130, scale 1:24,000.

Hough, S. E., Moil, J., Sembera, E., Glassmoyer, G., Mueller, C. and Lydeen, S., 1993, Southern surface rupture associated with the 1992 M 7.4 Landers earthquake: did it all happen during the mainshock?: Geophysical Research Letters, Vol. 20, pp. 2615-2618.

Hudnut , K.W., Seeber, L., and Rockwell, T., 1989, Slip on the Elmore Ranch fault during the past 330 years and its relation to slip on the Superstition Hills fault: Bulletin of the Seismological Society of America, Vol. 79, No. 2, pp. 330-341.

Iida, K., 1963, Magnitude, energy, and generation mechanisms of tsunamis and a catalog of earthquakes associated with tsunamis; *in* Proceedings of the 10th Pacific Science Congress Symposium: International Union of Geodesy and Geophysics Monograph No. 24, pp. 7-18.

Ikehara, M.E., Predmore, S.K., and Swope, D.J., 1997, Geodetic network to evaluate historical elevation changes and to monitor land subsidence in lower Coachella Valley, California, 1996; USGS Water-Resources Investigations Report 97-4237.

Imamura, A., 1949, List of Tsunamis in Japan: Journal of the Seismological Society of Japan, Vol. 2, pp. 22-28 (in Japanese, as referenced in McCulloch, 1985).

International Code Council (ICC), 2012, International Building Code.

International Conference of Building Officials (ICBO), 1997, Uniform Building Code.

International Conference of Building Officials (ICBO), 2001, California Historical Building Code, California Building Standards Commission, Part 8, Title 24, California Code of Regulations.

Jacoby, G.C. Jr., Sheppard, P.R., and Sieh, K.E., 1988, Irregular Recurrence of Large Earthquakes along the San Andreas Fault: Evidence from Trees: Science, Vol. 241, No. 4862, pp. 196-199.

Jennings, Charles W., 1994, Fault Activity Map of California and Adjacent Areas with Location and Ages of Recent Volcanic Eruptions: California Division of Mines and Geology, California Geologic Data Map Series, Map No. 6, Map Scale: 1:250,000. (CD-2000-06: Digital Database of Fault Activity Map of California and Adjacent Areas).

Johnson, I.A., 1998, Land Subsidence Due to Fluid Withdrawal in the United States - An Overview *in* Borchers, J.W. (editor), Land Subsidence, Case Studies and Current Research: Association of Engineering Geologists, Proceedings of the Dr. Joseph F. Poland Symposium on Land Subsidence, Special Publication 8, pp.51-57.

Jones, L.M., 1995, Putting Down Roots in Earthquake Country: Southern California Earthquake Center (SCEC) Special Publication, Los Angeles, California.

Jones, L.M., Bernknopf, R., Cox, D., Goltz, J., Hudnut, K., Mileti, D., Perry, S., Ponti, D., Porter, K., Reichle, M., Seligson, H., Shoaf, K., Treiman, J., and Wein, A., 2008, The ShakeOut Scenario: U.S. Geological Survey Open File Report 2008-1150, California Geological Survey Preliminary Report 25, version 1.0, 308p.

Jones, L., Mori, J., and Hauksson, E., 1995, The Landers Earthquake: Preliminary Instrumental Results: Earthquakes and Volcanoes, Vol. 23, No. 5, pp. 200-208.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, Vol. 95, No. 4, pp. 406-421.

Keefer, D.K., and Wilson, R.C., 1989, Predicting earthquake-induced landslides with emphasis on arid and semi-arid environments; *in* Sadler, P.M., and Morton, D.M., (editors), Landslides in a Semi-Arid Environment with Emphasis on the Inland Valleys of Southern California: Inland Geological Society of Southern California, Volume 2, pp. 118-149.

Keller, E.A., Bonkowski, M.S., Korsch, M.S., and Shlemon, R.J., 1982, Tectonic geomorphology of the San Andreas fault zone in the southern Indio Hills, Coachella Valley, California: Geological Society of America Bulletin, Vol. 93, No. 1, pp. 46-56.

Lagasse, P.F., Schall, J.D., Johnson, F., Richardson, E.V., Richardson, J.R., Chang, F., 1991, Stream stability at highway structures: U.S. Department of Transportation No. FHWA-IP-90-014 Hydraulic Engineering Circular 20, 195p.

Lamar, D.L., Merifield, P.M., and Proctor, R.J., 1973, Earthquake recurrence intervals on major faults in southern California; *in* Moran, D.E., Slosson, J.E., Stone, R.O., and Yelverton, C.A., (editors), Geology, seismicity, and environmental impact: Association of Engineering Geologists Special Publication, pp. 265-276.

Lander, J.F., 1968, Seismological Notes: March and April 1968: Bulletin of the Seismological Society of America, Vol. 58, No. 5, pp. 1709-1714.

Langenheim, V.E., and Powell, R.E., 2009, Basin geometry and cumulative offsets in the Eastern Transverse Ranges, southern California: Implications for transrotational deformation along the San Andreas fault system: Geosphere (a publication of the Geological Society of America), Vol. 5, No. 1 (February edition), pp. 1-22; DOI: 10.1130/GES00177.1.

Larson, L., 2009, How Certain Are We About Our Flood Risk?: Nation Hazards Observer, Vol. XXXIII, No. 6, dated July 2009.

Lazarte, C.A., Bray, J.D., Johnson, A.M., and Lemmer, R.E., 1994, Surface Breakage of the 1992 Landers Earthquake and its Effects on Structures: Bulletin of the Seismological Society of America, Vol. 84, No. 3, pp 547-561.

Lott, N., and Sittel, M., 1995, January and March 1995: A California Cloudburst: National Climatic Data Center (NCDC), Technical Report 95-01, 11p.

Louderback, G.D., 1949, Seismological Notes, Desert Hot Springs Earthquake: Bulletin of the Seismological Society of America, Vol. 39, No. 1, pp. 57-65.

Louderback, G.D., 1954, Seismological Notes, 1954 San Jacinto Earthquake: Bulletin of the Seismological Society of America, Vol. 44, No. 3, pp. 529-542.

Louie, J.N., Allen, C.R., Johnson, D.C., Haase, P.C., and Cohn, S.N., 1985, Fault Slip in Southern California: Bulletin of the Seismological Society of America, Vol. 75, pp. 811-833.

Lund, Le Val, 1994, Lifelines Performance in the Landers and Big Bear (California) Earthquakes of 28 June 1992: Bulletin of the Seismological Society of America, v. 84, no. 3, pp. 562-572.

Lund, Le Val, 1996, Lifeline Utilities Performance in the 17 January 1994 Northridge, California Earthquake: Bulletin of the Seismological Society of America, Vol. 86, No. 1B, pp. S350-S361.

Lyons, S., and Sandwell, D., 2003, Fault creep along the southern San Andreas from InSAR, permanent scatterers, and stacking: Journal of Geophysical Research, Vol. 108, No. B1, pp. 2047+, doi:10.1029/2002JB001831.

Madden, C.L., Rubin, C.M., and Streig, A., 2006, Holocene and latest Pleistocene activity on the Mesquite Lake Fault near Twentynine Palms, Eastern California Shear Zone: Implications for Fault Interaction: Bulletin of the Seismological Society of America, Vol. 96, No. 4A, pp. 1305-1320, DOI 10.1785/0120020120.

Magistrale, H., Jones, L., and Kanamori, H., 1989, The Superstition Hills, California, Earthquakes of 24 November 1987: Bulletin of the Seismological Society of America, Vol. 79, No. 2, pp. 239-251.

MAP IX – Mainland, 2009, Riverside County Essential Facilities Risk Assessment (RCEFRA) Project Report; Consulting Report prepared for the Department of Homeland Security – Federal Emergency Management Agency, EMF-2003-CO-0047, Task Order 040, dated June 2009.

Matti, J.C., and Morton, D.M., 1993, Paleogeographic evolution of the San Andreas fault in southern California: a reconstruction based on a new cross-fault correlation; in Powell, R.E., Weldon, R.J., II, and Matti, J.C., (editors), The San Andreas Fault System: Displacement, Palispastic Reconstruction, and Geologic Evolution: Geological Society of America Memoir, Vol. 178, pp. 107-159.

Matti, J.C., Morton, D.M., and Cox, B.F., 1992, The San Andreas fault system in the vicinity of the central Transverse Ranges province, southern California: U.S. Geological Survey Open-File Report No. 92-354, 40p., map at 1:250,000 scale.

McCulloch, D. S., 1985, Evaluating Tsunami Potential; in Ziony, I., (editor), Evaluating Earthquake Hazards in the Los Angeles Region: United States Geological Survey Professional Paper 1360, pp. 375-413.

McGarr, A., Vorhis, R. C., 1968, Seismic seiches from the March 1964 Alaska earthquake: U.S. Geological Survey Professional Paper 544-E, 43p.

McGill, S.F., Dergham, S., Barton, K., Berney-Ficklin, T., Grant, D., Hartling, C., Hobart, K., Minnich, R. Rodriguez, M., Runnerstrom, E., Russell, J., Schmoker, K., Stumfall, M., Townsend J., and Williams J., 2002, Paleoseismology of the San Andreas Fault at Plunge Creek, near San Bernardino, Southern California: Bulletin of the Seismological Society of America, Vol. 92, pp. 2803-2840, doi:10.1785/0120000607.

McGlashan, H.D., and Ebert F.C., 1918, Southern California Floods of January 1916, U.S. Geological Survey Water Supply Paper 426.

Medall, Aragon, Worswick & Associates, Inc., 1981, Fault and Seismicity Investigation, Portions of Sections 20 &21, T5S, R8E, Near Tyler Street and Dillon Road, Coachella, California: Unpublished consulting report, Project No. S1884, dated March 23, 1981, signed by Harry D. Pouncey, Project Geologist, Paul Davis, CEG 320, Chief Geologist, and Claude Corvino, RCE 31072.

Meisling, K.E., 1984, Neotectonics of the north frontal fault system of the San Bernardino Mountains, southern California; Cajon Pass to Lucerne Valley: California Institute of Technology, unpublished Ph.D. dissertation.

Meltzner, A.J., Rockwell, T.K., and Owen, L.A., 2006, Recent and long-term behavior of the Brawley Fault Zone, Imperial Valley, California: An escalation in slip rate?: Bulletin of the Seismological Society of America, Vol. 96, No. 6, pp. 2304-2328; DOI: 10.1785/0120050233.

Millman, D.E., and Rockwell, T.K., 1986, Neotectonics of the Elsinore fault in Temescal Valley, California; in Ehlig, P., (editor), Guidebook and Volume on Neotectonics and Faulting in Southern California: Geological Society of America, Cordilleran Section, pp. 159-166.

Montgomery-Watson-Harza (MWH), 2005, Coachella Valley Water District, Urban Water Management Plan, Final Report, dated December 2005.

Morton, D.M., Campbell, R.H., Jibson, R.W., Wesson, R.L., and Nicholson, C., 1989, Ground fracturing and landsliding produced by the July 8, 1986 North Palm Springs Earthquake; in Sadler, P.M., and

Morton, D.M. (editors), Landslides in a Semi-Arid Environment with Emphasis on the Inland Valleys of Southern California: Inland Geological Society, Volume 2, pp. 183-196.

Morton, D.M., and Matti, J.C., 1993, Extension and contraction within an evolving divergent strike-slip fault complex: The San Andreas and San Jacinto fault zones at their convergence in southern California: Geological Society of America Memoir 178, pp. 217-230.

Morton, D.M., Matti, J.C., and Tinsley, J.C., 1987, Banning fault, Cottonwood Canyon, San Gorgonio Pass, southern California: Geological Society of America Centennial Field Guide-Cordilleran Section.

Morton, D.M., and Sadler, P.M., 1989, Landslides flanking the northeastern Peninsular Ranges and the San Gorgonio Pass area of southern California; *in* Sadler, P.M., and Morton, D.M. (editors), Landslides in a Semi-Arid Environment with Emphasis on the Inland Valleys of Southern California, Inland Geological Society, Vol. 2, pp. 338-255.

Mueller, K.J., 1984, Neotectonics, alluvial history and soil chronology of the southwestern margin of the Sierra de los Cucapas, Baja California Norte: Unpublished M.Sc. Thesis, San Diego State University, San Diego, California, 363p.

Mueller, K.J., and Rockwell, T.K., 1995, Late Quaternary activity of the Laguna Salada fault in northern Baja California, Mexico: Geological Society of America Bulletin, Vol. 107, No. 1, pp. 8-18.

MWH, 2010, Coachella Valley Water Management Plan, 2010 Update, draft report dated December 2010.

MWH, 2011, 2010 Urban Water Management Plan, Public Draft, prepared for the Coachella Valley Water District, dated May 2011.

National Climatic Data Center, 2010, Various Event Record Details, www4.ncdc.noaa.gov.

National Earthquake Information Center (NEIC) USGS Earthquake Hazards Program http://neic.usgs.gov/neis/epic/epic_rect.html

National Oceanic & Atmospheric Administration (NOAA), 2005a, NOAA identifies causes for latest wet weather in west: NOAA News Online (Story 2395) at www.noaanews.noaa.gov.

National Oceanic & Atmospheric Administration (NOAA), 2005b, Worsening drought in northwest, record rain in the southwest in January: NOAA News Online (Story 2389), at www.noaanews.noaa.gov.

National Research Council, Committee on Alluvial Fan Flooding, 1996, Alluvial Fan Flooding, ISBN: 0-209-5542-3, 182p.

National Research Council, Committee on FEMA Flood Maps, 2009, Mapping the Zone – Improving Flood Map Accuracy: National Academies Press, ISBN: 0-309-13058-1, 136p.

Nordland, O.J., 1978, Coachella Valley's Golden Years, History of the Coachella Valley County Water District, Revised Edition, published by the Coachella Valley County Water District.

O'Rourke, Michael J., and X. Liu, 1999, Response of Buried Pipelines Subject to Earthquake Effects: American Society of Civil Engineers, Multidisciplinary Center for Earthquake Engineering Research Monograph #3, Buffalo, New York, 249p.

Oskin, M., Perg, L., Blumentritt, D., Muckopadhyay, S., and Iriondo, A., 2007, Slip rate of the Calico fault: implications for geologic versus geodetic rate discrepancy in the Eastern California Shear Zone: Journal of Geophysical Research - Solid Earth, Vol. 112, DOI:10.1029/2006JB004451.

Perry, S., Jones, L., and Cox, D., 2011, Developing a Scenario for Widespread Use: Best Practices, Lessons Learned: Earthquake Spectra, Vol. 27, No. 2, pp. 263-272.

Perry, R.W., and Lindell, M.K., 1995, Earthquake-initiated hazardous materials release: Lessons Learned from the Northridge Earthquake: George Washington University and Arizona State University.

Person, W. J., 1986, Earthquakes: July - August 1986: Earthquakes and Volcanoes, Vol. 19, No. 1, pp. 32-35.

Person, W. J., 1992, Earthquakes: March - April 1992: Earthquakes and Volcanoes, Vol. 23, No. 5, pp. 227-233.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., and Reichle, M.S., (California Division of Mines and Geology), Frankel, A.D., Lienkaemper, J.J., McCrory, P.A., and Schwartz, D.P., (U.S. Geological Survey), 1996, Probabilistic seismic hazard assessment for the State of California: California Division of Mines and Geology Open-File Report 96-08 and U.S. Geological Survey Open-File Report 96-706, 64 p.

Petersen, M. D. and Wesnousky, S.G., 1994, Fault slip rates and earthquake histories for active faults in southern California: Bulletin of the Seismological Society of America, Vol. 84, No. 5, pp. 1608-1649.

Petra Geotechnical, Inc. (Petra), 2006, Geotechnical Fault Investigation Report for Planning Purposes, 90-Acre Property, Avenue 50 and Fillmore Street, City of Coachella, Riverside County, CA: Unpublished consulting report for Monaco Development, LLC, Job No. 283-06, dated October 24, 2006, Revised November 17, 2006.

Petra Geotechnical, Inc. (Petra), 2007a, Geologic Map, Lomas Del Sol, City of Coachella, California: Unpublished consultant's map, Job No. 480-04, dated January 2007, Scale 1"=400'.

Petra Geotechnical, Inc. (Petra), 2007b, Fault Investigation Report Lots 1 through 71 and 76 through 95, Phase 1 of the Las Villas Project Located Northeast of the Intersection of Tyler Street and Vista Del Norte, City of Coachella, California: Unpublished consulting report for the Mayer-Luce Development Group, Job No. 389-06, dated January 26, 2007.

Petra Geotechnical, Inc. (Petra), 2007c, Fault Investigation Report for Land Planning Purposes, Alpine ~280 Property Located East of Tyler Street, West of Polk Street, South of I-10 and North of Avenue 48, City of Coachella, Riverside County, California: Unpublished consulting report for Avenue 48 Investment Group LLC, Job No. 621-05, dated April 9, 2007.

Philibosian, B., Fumal, T.E., and Weldon, R.J., 2011, San Andreas Fault Earthquake Chronology and Lake Cahuilla History at Coachella, California: Bulletin of the Seismological Society of America, Vol. 101, No. 1, pp. 13-38, doi: 10.1785/0120100050

Pickett, M.A., 2008, Assessing the Impacts of a M7.8 Southern San Andreas Fault Earthquake on Hospitals: Supplemental Study to the ShakeOut Scenario: U.S. Geological Survey Open File Report 2008-1150, California Geological Survey Preliminary Report 25 version 1.0, 22p.

Pinault, C.T., and Rockwell, T.K., 1984, Rates and sense of Holocene faulting on the southern Elsinore fault: further constraints on the distribution of dextral shear between the Pacific and North American plates: Geological Society of America Abstract with Programs, Vol. 16, No. 6, p. 624.

Popenoe, F. W., 1959, Geology of the Southeastern Portion of the Indio Hills, Riverside County, California, Master Thesis dated June, 1959.

Porter K., Wein, A., Alpers, C., Baez, A., Barnard, P., Carter, J., Corsi, A., Costner, J. Das, T., Dettinger, M., Done, J., Eadie, C., Eymann, M., Ferris, J., Gunturi, P., Hughes, M., Jarrett, R., Johnson, L., Le-Griffin, H., Mitchell, D., Morman, S., Neiman, P., Olsen, A., Perry S., Plumlee, F., Ralph, M., Reynolds, D., Rose, A., Schaefer, K., Serakos, J., Siembieda, W., Stock, J., Strong, D., Wing, I., Tang, A., Thomas, P., Topping, K., and Wills, C., Jones, L. (chief scientist), and Cox, D. (project manager), 2011, Overview of the Arkstorm Scenario, U.S. Geological Survey Open File Report 2010-1312, 183p. plus appendices.

Press-Enterprise, 1980, The Floods of February, Riverside County, 1980, collected photos and newspaper articles.

Proctor, R.J., 1968, Geology of the Desert Hot Springs – Upper Coachella Valley area, California: California Division of Mines and Geology Special Report 94.

Psomas, 2009, Master Drainage Plan, prepared for the City of La Quinta, dated March 2009.

Psomas, 2008, Downtown Area Drainage Study for City of La Quinta, dated January 4, 2008.

Ralph, F.M., and Dettinger, M.D., 2011, Storms, Floods, and the Science of Atmospheric Rivers, in EOS, Transactions, American Geophysical Union, Vol. 92, No. 32, dated 9 August 2011.

Rasmussen, Gary S., & Associates, 1978, Engineering Geology Investigation of Parcel No. 13 and Preliminary Engineering Geology Investigation of Parcel No. 12, As Shown on Riverside County Assessor's Map Book 601, Page 40; SE ¼ of the SE ¼ of Section 20, T5S, R8E, Coachella, California; Consultants Report, Project No. 1319, dated April 21, 1978, signed by Gary S. Rasmussen, CEG 925.

Rasmussen, Gary S., & Associates, 1999, Subsurface Engineering Geology Investigation, Coachella Transfer Station, Coachella Area, Riverside County, California; Consultants Report, Project No. 3133.1, dated July 21, 1999, signed by Frank J. Jordan, Jr., CEG 1913.

Real, C.R., Pridmore, C.L., and Loyd, R.C., 2008, ShakeOut Scenario Appendix G: Preliminary Liquefaction Deformation Analysis at Lifeline Crossings: U.S. Geological Survey Open File Report 2008-1150 and California Geological Survey Preliminary Report 25G.

Reneau, S.L., and Dietrich, W.E., 1987, The importance of hollows in debris flow studies; examples from Marin County, California; _in_ Costa, J.E. and Wieczorek, G.F. (editors), Debris flows/avalanches: Process, recognition, and mitigation: Geological Society of America Reviews in Engineering Geology, Vol. VII, pp. 165-179.

Richardson, E.V., Harrison, L.J., Richardson, J.R., and Davis, S.R., 1993, Evaluating scour at bridges (2d ed.): U.S. Department of Transportation Hydraulic Engineering Circular 18, 132p.

Rico, H., Hauksson, E., Given, D., Friberg, P., and Frechette, K., 2004, The CISN Display – Reliable delivery of real-time earthquake information and Shakemap to Critical End-users: Abstract, Seismological Society of America Meeting, April 14-16, Palm Springs, California.

Riverside County Flood Control and Water Conservation District, 2010, NPDES Municipal Permit, Colorado River Watershed, Base Map #6, dated January 2010.

Riverside County Flood Control & Water Conservation District (RCFCWCD), 2009, District History, http://www.floodcontrol.co.riverside.ca.us

RM Environmental, 2001, Coachella Ultramar, 50980 Highway 86, Coachella, CA, Boring/Well Construction Logs for Well Numbers MW-4, MW-5, MW-6, MW-7, and MW-8, drilled 3/27/2001 and 8/23/2001: Unpublished consultant's boring logs for Project No. 00-342, obtained from the GeoTracker website at www.geotracker.ca.gov.

RM Environmental, 2011, Report of Installation and Development of Groundwater Monitoring Wells MW-13 through MW-16 and Soil Vapor Extraction Wells VE-5, VE-6, VE-7, and VE-14, SoCo Apple Market #4 (Coachella Ultramar), 50980 Harrison Street (Highway 86), Coachella, Riverside County, California: Unpublished consulting report, Project No. 00-342, dated February 8, 2011, obtained from the GeoTracker website at www.geotracker.ca.gov.

Rockwell, T.K., Lindvall, S., Herzberg, M., Murbach, D., Dawson, T., and Berger, G., 2000, Paleoseismology of the Johnson Valley, Kickapoo and Homestead Valley faults: clustering of earthquakes in the Eastern California Shear Zone: Bulletin of the Seismological Society of America, Vol. 90, pp. 1200-1237.

Rockwell, T.K., McElwain, R.S., Millman, D.E., and Lamar, D.L., 1986, Recurrent late Holocene faulting on the Glen Ivy North strand of the Elsinore fault at Glen Ivy marsh; _in_ Ehlig, P.L., (editor), Neotectonics and faulting in southern California: Geological Society of America, 82nd Annual Meeting of the Cordilleran Section, Guidebook and Volume, pp. 167-175.

Rogers, T.H., 1965, Geologic map of California: Santa Ana sheet: California Division of Mines and Geology, Scale 1:250000.

Rymer, M.J., 2000, Triggered surface slips in the Coachella Valley area associated with the 1992 Joshua Tree and Landers, California, earthquakes: Bulletin of the Seismological Society of America, Vol. 90, No. 4, pp. 832-848; DOI: 10.1785/0119980130.

Rymer, M.J., Boatwright, J., Seekins, L.C., Yule, J.D., and Liu, J., 2002, Triggered surface slips in the Salton Trough associated with the 1999 Hector Mine, California, earthquake: Bulletin of the Seismological Society of America, Vol. 92, No. 4, pp. 1300-1317.

San Bernardino County Flood Control District, 2009, Flood History, http://www.co.san-bernardino.ca.us.

Savage, W.U., 1995, Utility Lifelines Performance in the Northridge Earthquake; _in_ Woods, M.C., and Seiple, W.R., (editors), The Northridge Earthquake of 17 January 1994: California Division of Mines and Geology Special Publication 116, p. 153-162.

Schell, B.A., and Schell, W.A., 1994, Blue Cut fault, Riverside County, southern California: South Coast Geological Society Annual Field Trip Guidebook No. 22, pp. 208-221.

Seed, R.B., Cetin, K.O., Moss, R.E.S., Kammerer, A.M., Wu, J., Pestana, J.M., Rimer, M.F., Sancio, R.B., Bray, J.D., Kayen, R.E., and Faris, A., 2003, Recent advances in soil liquefaction engineering: A unified and consistent framework: Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley, EERC Report No. 2003-06, 71p.

Seismic Hazards Mapping Act, California Public Resources Code, Section 2690 et seq., last updated May 13, 2003.

Seligson, H.A., Eguchi, R.T., and Tierney, K.J., 1992, A methodology for assessing the risk of hazardous materials release following earthquakes – a demonstration study for the Los Angeles area: Proceedings of the 4th U.S.-Japan Workshop on Earthquake Disaster Prevention for Lifeline Systems, U.S. Government Printing Office, Washington D.C., pp. 437-450.

Seligson, H.A., Eguchi, R.T., Tierney, K.J., and Richmond, K., 1996, Chemical Hazards, Mitigation and Preparedness in Areas of High Seismic Risk: A Methodology for Estimating the Risk of Post-Earthquake Hazardous Materials Release: National Center for Earthquake Engineering Research (NCEER) Technical Report 96-0013, dated November 7, 1996.

Seligson, Hope, 2008, HAZUS Enhancements and Implementation for the ShakeOut Scenario: Supplemental Study for the ShakeOut Scenario, Report prepared for the U.S. Geological Survey and the California Geological Survey, to accompany U.S. Geological Survey Open File Report 2008-1150, California Geological Survey Preliminary Report 25 version 1.0, and U.S. Geological Survey Circular 1324, California Geological Survey Special Report 207 version 1.0.

Sharp, R.P., 1964, Wind-driven sand in Coachella Valley, California: Geological Society of America Bulletin, Vol. 75, pp. 785-804.

Sharp, R.P., 1980, Wind-driven sand in Coachella Valley, California: Further data. Geological Society of America Bulletin, Vol. 91, pp. 724-730.

Sharp, R.V., Budding, K.E., Boatwright, J., Ader, M.J., Bonilla, M.G., Clark, M.M., Fumal, T.E., Harms, K.K., Lienkaemper, J.J., Morton, D.M., O'Neil, B.J., Ostergren, C.L., Ponti, D.J., Rymer, M.J., Saxton, J.L., and Sims, J.D., 1989, Surface faulting along the Superstition Hills Fault Zone and nearby faults associated with the earthquakes of 24 November 1987: Bulletin of the Seismological Society of America, Vol. 79, No. 2, pp. 252-281.

Sharp, R.V., and Leinkaemper, J.J., 1982, Preearthquake and postearthquake near-field leveling across the Imperial fault and the Brawley fault zone; _in_ The Imperial Valley, California, Earthquake of October 15, 1979, U.S. Geological Survey Professional Paper 1254, pp.169-182.

Shifflett, H., Gray, M.G., Grannell, R., and Ingram, B.L., 2002, New evidence on the slip rate, renewal time, and late Holocene surface displacement, southernmost San Andreas fault, Mecca Hills, California: Bulletin of the Seismological Society of America, Special Issue on Paleoseismology of the San Andreas Fault Zone, Vol. 92, No. 7, pp. 2861-2877.

Shoaf, K., 2008, Chapter 6. Casualties; _in_ Jones, L.M., Bernknopf, R., Cox, D., Goltz, J., Hudnut, K., Mileti, D., Perry, S., Ponti, D., Porter, K., Reichle, M., Seligson, H., Shoaf, K., Treiman, J., and Wein, A., 2008, The ShakeOut Scenario: U.S. Geological Survey Open File Report 2008-1150 and California Geological Survey Preliminary Report 25, Version 1.0, pp. 200-208.

Sieh, K., 1978, Slip along the San Andreas fault associated with the great 1857 earthquake: Bulletin of the Seismological Society of America, Vol. 68, No. 4, pp. 1421-1448.

Sieh, K., 1982, Slip along the San Andreas fault associated with the earthquakes; _in_ Johnson, C.E., and others (editors), The Imperial Valley, California earthquake of October 15, 1979: U.S. Geological Survey Professional Paper 1254, pp. 155-159.

Sieh, K., 1986, Slip rate across the San Andreas fault and prehistoric earthquakes at Indio, California: Eos, Transactions of the American Geophysical Union, Vol. 67, No. 55, p. 1200.

Sieh, K., Jones, L., Hauksson, E., Hudnut, K., Eberhart-Phillips, D., Heaton, T., Hough, S., Hutton, K., Kanamori, H., Lilje, A., Lindvall, S., McGill, S., Mori, J., Rubin, C., Spotila, J. A., Stock, J., Thio, H., Treiman, J., Wernicke, B., and Zachariasen, J., 1993, Near-field investigations of the Landers Earthquake sequence, April to July, 1992: Science, Vol. 260, pp. 171-176.

Sieh, K., and Matti, J.C., 1992, The San Andreas Fault System Between Palm Springs and Palmdale, Southern California: Field Trip Guidebook; _in_ Earthquake Geology, San Andreas Fault System, Palm Springs to Palmdale: Association of Engineering Geologists, 35th Annual Meeting, October 2-9, 1992, pp. 1-12.

Sieh, K., Stuiver, M. and Brillinger, D., 1989, A more precise chronology of earthquakes produced by the San Andreas fault in southern California: Journal of Geophysical Research, Vol. 94, pp. 603-623.

Sieh, K. and Williams, P., 1990, Behavior of the southernmost San Andreas fault during the past 300 years: Journal of Geophysical Research, Vol. 95, pp. 6629-6645.

Sieh, K., Yule, D. and Spotila, J., 1996, Field Trip Along the Southern San Andreas and San Jacinto Faults: Southern California Earthquake Center Annual Meeting, unpublished notes, 21 figures.

Sladden Engineering, 2006, Geologic Investigation of Potential Onsite Faulting, 317 Acre Belk Site, Fillmore Street Between Avenue 50 and Avenue 52, Coachella, California: Unpublished consulting report, Project No. 566-06199, S V V 06-09-010, dated October 10, 2006.

Sneed, M., and Brandt, J.T., 2007, Detection and Measurement of Land Subsidence Using Global Positioning Surveying and Interferometric Synthetic Aperture Radar, Coachella Valley, California, 1996-2005: U.S. Geological Survey, Scientific Investigations Report 2007-5251, 31p.

Sneed, M., Ikehara, M.E., Galloway, D.L., and Amelung, F., 2001, Detection and Measurement of Land Subsidence Using Synthetic Aperture Radar and Global Positioning System, Coachella Valley, California, 1996-1998: U.S. Geological Survey, Water-Resources Investigations Report 01-4093, 26p.

Sneed, M., Stork, S.V., and Ikehara, M.E., 2002, Detection and Measurement of Land Subsidence Using Synthetic Aperture Radar and Global Positioning System, Coachella Valley, California, 1998-2000: U.S. Geological Survey, Water-Resources Investigations Report 02-4039, 27p.

Southern California Earthquake Center (SCEC), 2002, Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigation Landslide Hazards in California: Blake, T.F., Hollingsworth, R.A., and Stewart, J.P. (editors), 110p. + Appendix.

Southern California Earthquake Center (SCEC-DC), 2001, Big Bear earthquake, http://www.data.scec.org/chrono_index/bigbear.html.

Southern California Earthquake Center, Southern California Earthquake Data Center, http://www.data.scec.org/catalog_search/date_mag_loc.php.

Southern California Earthquake Center (SCEC), 1999, Recommended procedures for implementation of DMG SP117 Guidelines for Evaluating and Mitigating Seismic Hazards in California – Liquefaction Hazards in California: Martin, G.R., and Lew, M. (editors), 63p.

Spittler, T.E., Harp, E.L., Keefer, D.K., Wilson, R.C., and Sydnor, R.H., 1990, Landslide Features and other Coseismic Fissures Triggered by the Loma Prieta Earthquake, Santa Cruz Mountains, California; *in* McNutt, S.R., and Sydnor, R.H. (editors), The Loma Prieta (Santa Cruz Mountains), California, Earthquake of 17 October 1989: California Division of Mines and Geology Special Publication 104, pp. 59-66.

Stermitz, F., 1964, Effects of the Hebgen Lake Earthquake on Surface Water: U.S. Geological Survey Professional Paper 435, pp. 139-150.

Stewart, C.A., Colby, N.D, Kent, R.T., Egan, J.A., and Hall, N.T., 1998, Earth Fissuring, Ground-Water Flow, and Ground-Water Quality in the Chino Basin, California; *in* Borchers, J.W. (editor), Land Subsidence, Case Studies and Current Research: Association of Engineering Geologists Special Publication No. 8, Proceedings of the Dr. Joseph F. Poland Symposium on Land Subsidence.

Stewart, J.P., Bray, J.D., McMahon, D.J., and Knopp, A.I., 1995, Seismic performance of hillside fills: Reprint from "Landslides under static and dynamic conditions-analysis, monitoring, and mitigation:" Geotechnical Engineering Division/ASCE meeting held on October 23-27, 1995, San Diego, California.

Stewart, J.P., Bray, J.D., Seed, R.B., and Sitar, N. (editors), 1994, Preliminary report on the principal geotechnical aspects of the January 17, 1994 Northridge earthquake: University of California at Berkeley, College of Engineering Report No. UCB/EERC 94-08, 245p.

Sylvester, A.G., and Damte, A., 1999, Geology of the Mecca Hills, in Rifting, Transpression, and Neotectonics in the Central Mecca Hills, Salton Trough: Fall Fieldtrip and Guidebook, Pacific Section SEPM, Book 85, dated September 25-26, 1999.

Synolakis, C.E., Borrero, J., and Eisner, R., 2002, Developing Inundation Maps for Southern California; *in* Ewing, L. and Wallendorf, L., (editors), Solutions to Coastal Disasters '02: Conference

Proceedings of the meeting held in San Diego, California on February 24-27, 2002: American Society of Civil Engineers, Reston, Virginia, pp. 848-862.

Tan, S.S., 1998, Slope failure and erosion assessment of the fire areas at Fillmore (April 1996) and Piru (August 1997), Ventura County: California: California Division of Mines and Geology Open-File Report 98-32.

Taylor, W.L., and Taylor, R.W., 2007, The Great California Flood of 1862: The Fortnightly Club of Redlands, California.

The Earth Technology Corporation, 1990, Seismic Geologic Report for Three Existing Buildings at the Coachella Sanitary Landfill, Riverside County, California; Consultants Report, Project No. 90-663, dated March 14, 1990, signed by Grant F. Miller, CEG 1397, Sr. Geologists, Paul D. Guptill, CEG 1081, Associate, Suji Somasundaram, PE 44199, Sr. Engineer, and Kris Khilnani, PE 39661, Vice President.

Tierney, K.J., 1994, Emergency Preparedness and Response; *in* Practical Lessons from the Loma Prieta Earthquake: National Academy Press, Washington DC, pp. 105-128.

Tierney, K.J., 1995, Social aspects of the Northridge earthquake; *in* Woods, M.C., and Seiple, W.R., (editors), The Northridge, California, Earthquake of 17 January 1994: California Department of Conservation, Special Publication 116, pp. 255-262.

Tinsley, J.C., and Fumal, T.E., 1985, Mapping Quaternary Sedimentary Deposits for Aerial Variations in Shaking Response; *in* Ziony, J.I. (editor), Evaluating Earthquake Hazards in the Los Angeles Region – An Earth Science Perspective: U.S. Geological Survey Professional Paper 1360, pp. 101-125.

Tinsley, J.C., Youd, T.L., Perkins, D.M., and Chen, A.T.F., 1985, Evaluating Liquefaction Potential; *in* Ziony, J.I. (editor), Evaluating Earthquake Hazards in the Los Angeles Region – An Earth Science Perspective: U.S. Geological Survey Professional Paper 1360, pp. 263-316.

TKE Engineering and Planning, 2011, 2010 Urban Water Management Plan, City of Coachella (draft), dated June 2011.

Toppozada, T.R., Real, C.R., and Parke, D.L., 1981, Preparation of Isoseismal Maps and Summaries of Reported Effects for Pre-1900 California Earthquakes: California Division of Mines and Geology Open File Report 81-11 SAC.

Toppozada, T.R., and Parke, D.L., 1982, Areas damaged by California earthquakes 1900-1949: California Division of Mines and Geology Open File 82-17, 65p.

Toppozada, T.R., Borchardt, G., Hallstrom, C.L., and others, 1993, Planning Scenario for a Major Earthquake on the San Jacinto Fault in the San Bernardino Area: California Division of Mines and Geology, Special Publication 102, 221p.

Townley, S.D., 1939, Earthquakes in California, 1769 to 1928: Bulletin of the Seismological Society of America, Vol. 29, No. 1, pp. 21-252.

Treiman, J.A., 1994, The San Gorgonio Pass, Banning and Related Faults, Riverside County, California: California Division of Mines and Geology Fault Evaluation Report FER-235, dated September 27, 1994.

Treiman, J.A., 1995, The San Gorgonio Pass, Banning and Related Faults, Riverside County, California: California Division of Mines and Geology Fault Evaluation Report FER-235, Supplement No. 1, dated May 15, 1995.

Treiman, J.A. (compiler), 1998, Fault Number 126, Elsinore fault zone; *in* Quaternary fault and fold database of the United States: U.S. Geological Survey website, http://earthquakes.usgs.gov/regional/qfaults.

Treiman, J.A., Kendrick, K.J., Bryant, W.A., Rockwell, T.K., and McGill, S.F., 2002, Primary surface rupture associated with the Mw 7.1 16 October 1999 Hector Mine earthquake, San Bernardino County, California: Bulletin of the Seismological Society of America, Vol. 92, No., 4, pp. 1171-1191.

Treiman, J.A., Real, C.R., Wilson, R.I., Silva, M.A., Pridmore, C.L., McCrink, T.P., Loyd, R.C., and Reichle, M.S., 2008, ShakeOut Scenario Appendix E: Fault Rupture Impacts at Areas of Lifeline Concentration: U.S. Geological Survey Open File Report 2008-1150 and California Geological Survey Preliminary Report 25E, 26p.

Troxell, H.C., 1942, Floods of March 1938 in southern California: U.S. Geological Survey Water-Supply Paper 844.

Tsihrintzis, V.A, Murillo, B.N., Mulvihill, M.E., Trott, W.J., Baine, J.T., Tiamzon, N., 1991, Flood control design for development on alluvial fans: Hydraulic Engineering: Proceedings of the National Conference on Hydraulic Engineering, pp. 417-422.

Unreinforced Masonry Law, California Public Resources Code, Chapter 12.2 Building Earthquake Safety, Section 8875 et seq.

U.S. Census Bureau, Population Division, 2008, Table 4: Annual Estimates of the Population for Incorporated Places in California, Listed Alphabetically; April 1, 2000 to July 1, 2007 (SUB-EST2007-04-06), released July 10, 2008.

U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, 2006, Coachella Canal Area, Resource Management Plan / Environmental Assessment, Boulder Canyon Project Act, All-American Canal System, Coachella Canal Unit, Riverside County, California, Chapter 5: Affected Environment and Environmental Consequences, pp. 67-83, and Biological Inventory of the Coachella Canal Area Appendix, dated April and September 2004, pp. App.1 – App. 20.

U.S. Geological Survey, 2000, Landslide hazards, USGS Fact Sheet FS-071-00, available at http://pubs.usgs.gov/fs/fs-0071-00.

U.S. Geological Survey, 1988a, Martinez Mountain quadrangle, 7.5 Minute Series (Topographic) Scale 1:24,000.

U.S. Geological Survey, 1988b, Rancho Mirage quadrangle, 7.5 Minute Series (Topographic) Scale 1:24,000.

U.S. Geological Survey, 1988c, Toro Peak quadrangle, 7.5 Minute Series (Topographic) Scale 1:24,000.

U.S. Geological Survey, 1980d, La Quinta quadrangle, 7.5 Minute Series (Topographic) Scale 1:24,000.

U.S. Geological Survey, 1972a, Indio quadrangle, 7.5 Minute Series (Topographic) Scale 1:24,000.

U.S. Geological Survey, 1972b, Valerie quadrangle, 7.5 Minute Series (Topographic) Scale 1:24,000.

van der Woerd, J., Klinger, Y., Sieh, K., Tapponnier, P., and Ryerson, F.J., 2001, First long-term slip rate along the San Andreas fault based on ^{10}Be-^{26}Al surface exposure dating – the Biskra Palms site, 23 mm/yr for the last 30,000 years (abstract): Eos, Transactions of the American Geophysical Union, Vol. 82, p. 934.

van der Woerd, J., Klinger, Y., Sieh, K., Tapponnier, P., Ryerson, F.J., and Meriaux, A.-S., 2006, Long-term slip rate of the southern San Andreas fault from ^{10}Be-^{26}Al surface exposure dating of an offset alluvial fan: Journal of Geophysical Research, Vol. 111, B04407, 17p., doi: 10.1029/2004JB003559.

Varnes, D.J., 1978, Slope movement types and processes; in Schuster, R.L. and Krizek, R.J. (editors), Landslides – Analysis and Control: National Academy of Sciences Transportation Research Board Special Report 176, pp. 12-33.

Vaughan, P. and Rockwell, T., l986, Alluvial stratigraphy and neotectonics of the Elsinore fault zone at Agua Tibia Mountain, southern California; _in_ Ehlig, P. (editor), Guidebook, and Volume on Neotectonics and Faulting in Southern California: Geological Society of America, Cordilleran Section, pp. 177-192.

Vaughan, P.R., Thorup, K., and Rockwell, T.K., 1999, Paleoseismology of the Elsinore fault at Agua Tibia Mountain, southern California: Bulletin of the Seismological Society of America, Vol. 89, pp. 1447-1457.

Waananen, A.O., 1969, Floods of January and February 1969 in central and southern California: U.S. Geological Survey, Water Resources Division, Open-File Report.

Wald, D.J., Quitorino, V., Heaton, T.H., and Kanamori, H., 1999, Relationships between peak ground acceleration, peak ground velocity, and Modified Mercalli Intensity in California: Earthquake Spectra, the Professional Journal of the Earthquake Engineering Research Institute (EERI), Vol. 15, No. 3, pp. 557-564.

Ware, G.C., 1958, Geologic map of part of the Mecca Hills, Riverside County, California: M.A. thesis, California University of California at Los Angeles (as referenced by the California Division of Mines and Geology, 1974, Special Studies Zones, Thermal Canyon Quadrangle, Official Map, dated July 1, Scale 1:24,000.)

Weeks, L.O., Longenecker Jr., W.H., Berghorn, H., 1967, Whitewater River Basin, Coachella Valley California, published by the Coachella Valley County Water District, April 1967.

Wei, M., Sandwell, D., Fialko, Y., and Bilham, R., 2011, Slip on faults in the Imperial Valley triggered by the 4 April 2010 Mw 7.2 El Mayor-Cucapah earthquake revealed by InSAR: Geophysical Research Letters, Vol. 38, L01308, doi:10.1029/2010GL045235.

Weldon, R.J., 2010, communication to the Southern California Earthquake Center's El Mayor – Cucapah Earthquake response team; available on the web at http://response.scec.org/node/273.

Weldon, R.J., Fumal, T.E., and Biase, G.P., 2004, Implications from a long window of observation: the San Andreas fault at Wrightwood, California: Seismological Society of America, Abstracts, Annual Meeting, April 14-16, Palm Springs, California.

Wells, W.G., 1987, The effects of fire on the generation of debris flows in Southern California; *in* Costa, J.E. and Wieczorek, G.F. (editors), Debris flows/avalanches: Process, recognition, and mitigation: Geological Society of America, Reviews in Engineering Geology, Vol. VII, pp. 105-114.

Wesnousky, S.G., 1986, Earthquakes, Quaternary faults, and seismic hazards in southern California: Journal of Geophysical Research, Vol. 19, No. B12, pp. 12587-12631.

Williams, P., 2009, Paleoseismic displacement history: Coachella Valley segment, San Andreas fault: 2009 Southern California Earthquake Center Annual Meeting, September 13 (referenced in Philibosian et al., 2011).

Williams, P.L., McGill, S., Sieh, K., Allen, C.R., and Louie, J.L., 1986, North Palm Springs earthquake: Bulletin of the Seismological Society of America, Vol. 78, pp. 1112-1122.

Wills, C.J., Weldon II, R.J., and Bryant, W.A., 2008, Appendix A: California fault parameters for the National Seismic Hazard Maps and Working Group on California Earthquake Probabilities 2007: U.S. Geological Survey Open File Report 2007-1437A, California Geological Survey Special Report 203A, Southern California Earthquake Center Contribution #1138A, Version 1.0, 48p.

Wilson, R.C., and Keefer, D.K., 1985, Predicting areal limits of earthquake-induced landsliding; *in* Ziony, J.I. (editor), Evaluating Earthquake Hazards in the Los Angeles Region - An Earth-Science Perspective: U.S. Geological Survey Professional Paper 1360, pp. 316-345.

Wood, H.O., 1937, The Terwilliger Valley earthquake of March 25, 1937: Bulletin of the Seismological Society of America, Vol. 27, No. 4, pp. 305-312.

Working Group on California Earthquake Probabilities (WGCEP), 1988, Probabilities of Large Earthquakes Occurring in California on the San Andreas Fault: U.S. Geological Survey Open-File Report 88-398, 62 pp.

Working Group on California Earthquake Probabilities (WGCEP), 1992, Future Seismic Hazards in Southern California, Phase I, Implications of the Landers Earthquake Sequence: National Earthquake Prediction Council, California Earthquake Prediction Evaluation Council, and Southern California Earthquake Center, 42p.

Working Group on California Earthquake Probabilities (WGCEP), 1995, Seismic Hazards in Southern California: Probable Earthquakes, 1994 to 2024: Bulletin of the Seismological Society of America, Vol. 85, No. 2, pp. 379-439.

2007 Working Group on California Earthquake Probabilities, 2008, The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2): USGS Open File Report 2007-1437, CGS Special Report 203, SCEC Contribution #1138, Version 1.0.

Wyllie, D.C., and Norrish, N.I., 1996, Stabilization of rock slopes; *in* Turner, A.K., and Schuster, R.L. (editors), Landslides – investigation and mitigation: Transportation Research Board Special Publication 247, pp. 474-504.

Yashinsky, M., Simek, J., Murugesh, G., and Mualchin, L., 2002, Highway performance during the 16 October 1999 Hector Mine, California, earthquake: Bulletin of the Seismological Society of America, Vol. 92, No. 4, pp. 1621-1632.

Yule, D., Maloney, S., and Cummings, S., 2006, Using pollen to constrain the age of the youngest rupture of the San Andreas fault at San Gorgonio Pass: Seismological Research Letters, Vol. 77, No. 2, p. 245.

Yule, D., and Sieh, K., 2003, Complexities of the San Andreas fault near San Gorgonio Pass: Implications for large earthquakes: Journal of Geophysical Research, Vol. 108, No. B11, pp. 2548.

Zappe, D.P., 1997, Testimony of David P. Zappe, General Manager-Chief Engineer, Riverside County Flood Control and Water Conservation District, Impact of the Endangered Species Act of Flood Control Activities; available online at www.House.gov/resources/105cong/fullcomm/apr10.97/zappe.htm

Ziony, J.I., and Yerkes, R.F., 1985, Evaluating earthquake and surface-faulting potential; *in* Ziony, J.I. (editor), Evaluating Earthquake Hazards in the Los Angeles Region – An Earth-Science Perspective: U.S Geological Survey Professional Paper 1360, pp. 33-91.

Useful Websites

Geologic Hazards in General

http://geohazards.cr.usgs.gov/
USGS Hazard Team website. Hazard information on commonly recognized hazards such as earthquakes, landslides, and volcanoes. Contains maps and slide shows.

http://www.usgs.gov/themes/hazard.html
A webpage by the USGS on hazards such as hurricanes, floods, wildland fire, wildlife disease, coastal storms and tsunamis, and earthquakes. Also has information on their Hazard Reduction Program.

http://www.consrv.ca.gov/cgs/index.htm
Homepage for the California Geologic Survey (formerly the Division of Mines and Geology). Information their publications (geologic reports and maps), programs (seismic hazard mapping, Alquist-Priolo Earthquake Fault Study Zone maps); and other brochures (asbestos, natural hazard disclosure).

www.oes.ca.gov/
California Governor's Office of Emergency Services website. Contains information on response plans regarding natural disasters (earthquakes), terrorist attacks, and electrical outages, and information on past emergencies.

Geologic Maps

http://wrgis.wr.usgs.gov/wgmt/scamp/scamp.html
Homepage for the Southern California Aerial Mapping Project (SCAMP), which is the USGS' program to update geologic maps of Southern California at a 1:100,000 scale and release these in a digital GIS format.

Seismic Hazards, Faults, and Earthquakes

http://gmw.consrv.ca.gov/shmp/
Shows the current list of seismic hazard maps available from the California Geologic Survey. These can be downloaded in a pdf format.

www.scecdc.scec.org.
Southern California Earthquake data center (hosted by SCEC, USGS, and Caltech. Shows maps and data for recent earthquakes in Southern California and worldwide. Catalogs of historic earthquakes.

http://www.consrv.ca.gov/cgs/rghm/quakes/index.htm
List of California earthquakes (date, magnitude, latitude longitude, description of damage).

http://geohazards.cr.usgs.gov/eq/html/canvmap.html
Website at the USGS Earthquake Hazard's Program that lists seismic acceleration maps available for downloading.

www.seismic.ca.gov/
Homepage of the California Seismic Safety Commission. Contains information on California earthquake legislation, safety plans, and programs designed to reduce the hazards from earthquakes. Includes several publications of interest, including "The Homeowner's Guide to Earthquake Safety." Also contains a catalog of recent California earthquakes.

http://neic.usgs.gov/
Homepage of the National Earthquake Information Center. Maintains an extensive global seismic database on earthquake parameters. Its mission is to rapidly determine the location and size of all destructive earthquakes worldwide, and disseminate that information as quickly as possible to concerned national and international agencies, scientists, and the public in general.

http://www.scsn.org/
Site where Shakemaps for actual and scenario earthquakes can be obtained.

Landslides and Debris Flows

http://landslides.usgs.gov/index.html
USGS Landslide webpage. Links to their publications, recent landslide events, and bibliographic databases.

http://gmw.consrv.ca.gov/shmp/
California Geologic Survey website on Seismic Hazard maps.

http://vulcan.wr.usgs.gov/Glossary/Lahars/framework.html
USGS Volcanic Observatory website list of links regarding mudflows, debris flows and lahars.

http://www.fema.gov/hazards/landslides/landslif.shtm
Federal Emergency Management Agency (FEMA) fact sheet website about landslides and mudflows.

Flooding, Dam Inundation, and Erosion (Note: the information on some of these web sites has been removed due to safety concerns; but may be posted again in the future in limited form).

http://vulcan.wr.usgs.gov/Glossary/Sediment/framework.html
US Geological Survey Volcanic Observatory website list of links regarding sediment and erosion.

http://www.usace.army.mil/public.html#Regulatory
US Army Corps of Engineers website regarding waterway regulations.

http://www.fema.gov/fima/
FEMA website about the National Flood Insurance Program.

www.fema.gov/levees
Numerous recently updated webpages discussing facts about levees and levee flood risk.

http://www.worldclimate.com/
Precipitation rates at different rain stations in the world measured over time.

http://waterdata.usgs.gov
Stream gage measurements for rivers throughout the US.

Others

http:// www.bsc.ca.gov
Site of the California Building Standards Commission. Provides information regarding the status of the building codes being considered for future approval in California.

Appendix B:
GLOSSARY

APPENDIX B: GLOSSARY

Acceleration – The rate of change for a body's magnitude, direction, or both over a given period of time.

Active fault – For implementation of Alquist-Priolo Earthquake Fault Zoning Act (APEFZA) requirements, an active fault is one that shows evidence of having experienced surface displacement within the last 11,000 years. APEFZA classification is designed for land use management of surface rupture hazards. A more general definition by the National Academy of Sciences (1988) is "a fault that on the basis of historical, seismological, or geological evidence has the finite probability of producing an earthquake." The American Geological Institute (1972) defines an active fault as one along which there is recurrent movement, usually indicated by small, periodic displacements or seismic activity.

Acute – Quick, one-time exposure to a chemical.

Adjacent grade – Elevation of the natural or graded ground surface, or structural fill, abutting the walls of a building. See *highest adjacent grade* and *lowest adjacent grade*.

Aeolian (or eolian) – Related to or pertaining to the wind; carried, eroded or deposited by wind action.

Aftershocks – Minor earthquakes following a greater one and originating at or near the same location.

Aggradation – The building up of earth's surface by deposition of sediment.

Alluvial – Pertaining to, or composed, of alluvium, or deposited by a stream or running water.

Alluvial fan – A low, outspread relatively flat to gently sloping surface consisting of loose sediment that is shaped like an open fan, deposited by a stream at the place where the stream comes out of a narrow canyon onto a broad valley or plain. Alluvial fans are steepest near the mouth of the canyon, and spread out, gradually decreasing in gradient, away from the stream source.

Alluvium – Surficial sediments of poorly consolidated gravels, sand, silts, and clays deposited by flowing water.

Amplitude – The height of a wave between its crest (high point) and its mid-point.

Anchor – To secure a structure to its footings or foundation wall in such a way that a continuous load transfer path is created and so that it will not be displaced by flood, wind, or seismic forces.

Aplite – A light-colored igneous rock with a fine-grained texture and free from dark minerals. Aplite forms at great depths beneath the earth's crust.

Apparatus – Fire apparatus includes firefighting vehicles of various types.

Aquifer – A body of rock or sediment that contains sufficient saturated permeable material to allow the flow of ground water and to yield economically significant quantities of ground water to wells and springs.

Argillic – Alteration in which certain minerals of a rock or sediments are converted to clay. Also said of a soil horizon characterized by the illuvial accumulation of clay.

Armor – To protect slopes from *erosion* and *scour* by *flood* waters. Techniques of armoring include the use of riprap, gabions, or concrete.

Artesian – An adjective referring to ground water confined under hydrostatic pressure. The water level in wells drilled into an **artesian** aquifer (also called a confined aquifer) will stand at some height above the top of the aquifer. If the water reaches the ground surface, the well is referred to as a "flowing" **artesian** well.

Aspect – The direction a slope faces.

Attenuation – The reduction in amplitude of a wave with time or distance traveled.

Automatic Aid Agreement – An agreement between two or more agencies whereby such agencies are automatically dispatched simultaneously to predetermined types of emergencies in predetermined areas.

A zone – Under the *National Flood Insurance Program*, area subject to inundation by the *100-year flood* where wave action does not occur or where waves are less than 3 feet high, designated Zone A, AE, A1-A30, A0, AH, or AR on a *Flood Insurance Rate Map* (FIRM).

Base flood – *Flood* that has as 1-percent probability of being equaled or exceeded in any given year. Also known as the *100-year flood*.

Base Flood Elevation (BFE) – Elevation of the *base flood* in relation to a specified datum, such as the *National Geodetic Vertical Datum* or the *North American Vertical Datum*. The Base Flood Elevation is the basis of the insurance and *floodplain management* requirements of the *National Flood Insurance Program*.

Basement – Under the *National Flood Insurance Program*, any area of a building having its floor subgrade on all sides. (Note: What is typically referred to as a "walkout basement," which has a floor that is at or above grade on at least one side, is not considered a basement under the *National Flood Insurance Program*.)

Beaufort Scale – A scale devised in 1805 by Admiral Francis Beaufort of the British Navy to classify wind speed based on the wind's effect on the seas and vegetation. The scale goes from 0 (calm) to 12 (hurricane).

Bedding – The arrangement of a sedimentary rock or deposit in beds or layers of varying thickness and character.

Bedrock – Designates hard rock that is in its natural intact position and underlies soil or other unconsolidated surficial material.

Bench – A grading term that refers to a relatively level step excavated into earth material on which fill is to be placed. A bench is also a long, narrow, relatively level or gently inclined platform of land or rock bounded by steeper slopes above and below.

Bioregion – A major, regional ecological community characterized by distinctive life forms and distinctive plant and animal species.

Biotite – A general term to designate all ferromagnesian micas. More specifically, biotite is a widely distributed and important rock-forming mineral that is usually black, brown or dark green, and that is an original constituent of igneous and metamorphic rocks, or a detrital constituent of sedimentary rocks.

Blind thrust fault – A thrust fault is a low-angle reverse fault (where the top block is being or has been pushed over the bottom block). A "blind" thrust fault refers to one that does not reach the surface.

Braided stream – A stream that divides into or follows an interlacing or tangled network of several, small, branching and reuniting shallow channels separated from each other by channel bars. Also referred to as an **anastomosing** stream.

Brush – A collective term that refers to stands of vegetation dominated by shrubby, woody plants, or low-growing trees.

Brushfire – A fire burning in vegetation that is predominantly shrubs, brush, and scrub growth.

Building code – Regulations adopted by local governments that establish standards for construction, modification, and repair of buildings and other structures.

Carcinogen – Material capable of causing cancer in humans.

Cast-in-place concrete – Concrete that is poured and formed at the construction site.

CEQA – The California Environmental Quality Act (Chapters 1 through 6 of Division 13 of the Public Resources Code). A state statute that requires state and local agencies to identify the significant environmental impacts of their actions and to avoid or mitigate those impacts, if feasible.

Chronic – Continual or repeated exposure to a hazardous material.

Cladding – Exterior surface of the building envelope that is directly loaded by the wind.

Clay – A rock or mineral fragment having a diameter less than 1/256 mm (4 microns, or 0.00016 in.). A clay commonly applied to any soft, adhesive, fine-grained deposit.

Claystone – An indurated clay having the texture and composition of shale, but lacking its fine lamination. A massive mudstone in which clay predominates over silt.

Climate – The average condition of weather over time in a given region.

Code official – Officer or other designated authority charged with the administration and enforcement of the code, or a duly authorized representative, such as a building, zoning, planning, or *floodplain management* official.

Collapse – A relatively sudden change in the volume of a soil mass resulting in the local settlement of the ground surface, with the potential to cause significant damage to overlying structures. If due to strong ground shaking, the soil grains in the soil column are re-arranged by the shaking so that the pore space between grains is reduced and the grains become more tightly packed, resulting in the overall reduction of the thickness of the soil column. This is referred to as earthquake-induced subsidence. Collapse can also occur in certain types of sediments, where with the introduction of water (due to an increase in irrigation, for example), the cement between soil grains dissolves, allowing the soil particles to become more tightly packed, again resulting in the local settlement of the ground surface. This process is also referred to as **hydro-collapse** or **hydroconsolidation**.

Column foundation – Foundation consisting of vertical support members with a height-to-least-lateral-dimension ratio greater than three. Columns are set in holes and backfilled with compacted material. They are usually made of concrete or masonry and often must be braced. Columns are sometimes known as posts, particularly if the column is made of wood.

Community at Risk – Wildland interface community in the vicinity of Federal lands that is at high risk from wildfire.

Complex (Fire) –Two or more individual incidents located in the same general area and assigned to a single incident commander or unified command.

Compressible soil – Geologically young unconsolidated sediment of low density that may compress under the weight of a proposed fill embankment or structure.

Concrete Masonry Unit (CMU) – Building unit or block larger than 12 inches by 4 inches by 4 inches made of cement and suitable aggregates.

Conglomerate – A coarse-grained sedimentary rock composed of rounded to subangular fragments larger than 2 mm in diameter set in a fine-grained matrix of sand or silt, and commonly cemented by calcium carbonate, iron oxide, silica or hardened clay. The consolidated equivalent of gravel.

Connector – Mechanical device for securing two or more pieces, parts, or members together, including anchors, wall ties, and fasteners.

Consolidation – Any process whereby loosely aggregated, soft earth materials become firm and cohesive rock. Also the gradual reduction in volume and increase in density of a soil mass in response to increased load or effective compressive stress, such as the squeezing of fluids from pore spaces.

Corrosion-resistant metal – Any nonferrous metal or any metal having an unbroken surfacing of nonferrous metal, or steel with not less than 10 percent chromium or with not less than 0.20 percent copper.

Coseismic rupture - Ground rupture occurring during an earthquake but not necessarily on the causative fault.

Cretaceous – The final period of the Mesozoic era (before the Tertiary period of the Cenozoic era), thought to have occurred between about 136 and 65 million years ago.

Dead load – Weight of all materials of construction incorporated into the building, including but not limited to walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding, and other similarly incorporated architectural and structural items and fixed service equipment.

Debris – (Seismic) The scattered remains of something broken or destroyed; ruins; rubble; fragments. (Flooding, Coastal) Solid objects or masses carried by or floating on the surface of moving water.

Debris Burning – Any fire originally set for the purpose of clearing land or for burning rubbish, garbage, range, stubble, or meadow burning.

Debris impact loads – Loads imposed on a structure by the impact of flood-borne debris. These loads are often sudden and large. Though difficult to predict, debris impact loads must be considered when structures are designed and constructed.

Debris flow – A saturated, rapidly moving saturated earth flow with 50 percent rock fragments coarser than 2 mm in size which can occur on natural and graded slopes.

Debris line – Line left on a structure or on the ground by the deposition of debris. A debris line often indicates the height or inland extent reached by *flood* waters.

Defensible space – An area, either natural or manmade, where material capable of causing a fire to spread has been treated, cleared, reduced, or changed in order to provide a barrier between an advancing wildland fire and the loss to life, property, or resources. In practice, defensible space is defined as an area with a minimum of 100 feet around a structure that is cleared of flammable brush or vegetation. Distance from the structure and the degree of fuels treatment vary with vegetation type, slope, density, and other factors.

Deflected canyons – A relatively spontaneous diversion in the trend of a stream or canyon caused by any number of processes, including folding and faulting.

Deformation - A general term for the process of folding, faulting, shearing, compression, or extension of rocks.

Design flood – The greater of either (1) the *base flood* or (2) the *flood* associated with the *flood hazard area* depicted on a community's flood hazard map, or otherwise legally designated.

Design Flood Elevation (DFE) – Elevation of the *design flood*, or the flood protection elevation required by a community, including wave effects, relative to the *National Geodetic Vertical Datum*, *North American Vertical Datum*, or other datum.

Development – Under the *National Flood Insurance Program*, any manmade change to improved or unimproved real estate, including but not limited to buildings or other structures, mining, dredging, filling, grading, paving, excavation, or drilling operations or storage of equipment or materials.

Differential settlement – Non-uniform settlement; the uneven lowering of different parts of an engineered structure, often resulting in damage to the structure. Sometimes included with liquefaction as ground failure phenomenon.

Dike – A tabular shaped, igneous intrusion that cuts across bedding of the surrounding rock.

Diorite – A group of igneous rocks that form at great depth beneath the earth's crust. These rocks are intermediate in composition between acidic and basic rocks.

Dispatch – The implementation of a command decision to move a resource or resources from one place to another.

Displacement - The length, measured in kilometers (km), of the total movement that has occurred along a fault over as long a time as the geologic record reveals.

DMA 2000 - Disaster Mitigation Act of 2000. Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended by Public Law 106-390, October 30, 2000. DMA 2000 is intended to establish a continuing means of assistance by the Federal Government to State and local governments in carrying out their responsibilities to alleviate the suffering and damage which result from disasters by (1) revising and broadening the scope of existing disaster relief programs; (2) encouraging the development of comprehensive disaster preparedness and assistance plans, programs, capabilities, and organizations by the States and by local governments; (3) achieving greater coordination and responsiveness of disaster preparedness and relief programs; (4) encouraging individuals, States, and local governments to protect themselves by obtaining insurance coverage to supplement or replace governmental assistance; (5) encouraging hazard mitigation measures to reduce losses from disasters, including development of land use and construction regulations; and (6) providing Federal assistance programs for both public and private losses sustained in disasters .

Dynamic analysis – A complex earthquake-resistant engineering design technique capable of modeling the entire frequency spectra, or composition, of ground motion. The method is used to evaluate the stability of a site or structure by considering the motion from any source or mass, such as that dynamic motion produced by machinery or a seismic event.

Earth flow – Imperceptibly slow-moving surficial material in which 80% or more of the fragments are smaller than 2 mm, including a range of rock and mineral fragments.

Earthquake – Vibratory motion propagating within the Earth or along its surface caused by the abrupt release of strain from elastically deformed rock by displacement along a fault.

Earth's crust – The outermost layer or shell of the Earth.

Effective Flood Insurance Rate Map (FIRM) – See *Flood Insurance Rate Map*.

El Niño – Phenomenon that originates, every few years, typically in December or early January, in the southern Pacific Ocean, off of the western coast of South America, characterized by warmer than usual water. This warmer water is statistically linked with increased rainfall in both the southeastern and southwestern United States, droughts in Australia, western Africa and Indonesia, reduced number of earthquakes in the Atlantic Ocean, and increased number of hurricanes in the Eastern Pacific.

Emergency Planning and Community Right to Know (EPCRA) – The portion of SARA that specifically outlines how industries report chemical inventory to the community.

Encroachment – Any physical object placed in a floodplain that hinders the passage of water or otherwise affects the flood flows.

Engineering geologist – A geologist who is certified by the State as qualified to apply geologic data, principles, and interpretation to naturally occurring earth materials so that geologic factors affecting planning, design, construction, and maintenance of civil engineering works are properly recognized and used. An engineering geologist is particularly needed to conduct investigations, often with geotechnical engineers, of sites with potential ground failure hazards.

Environmental Protection Agency (EPA) – Federal agency tasked with ensuring the protection of the environment and the nation's citizens.

Ephemeral stream – A stream or reach of a stream that flows only briefly in direct response to precipitation.

Epicenter – The point at the Earth's surface directly above where an earthquake originated.

Erodible soil – Soil subject to wearing away and movement due to the effects of wind, water, or other geological processes during a flood or storm or over a period of years.

Erosion – Under the *National Flood Insurance Program*, the process of the gradual wearing away of landmasses. In general, erosion involves the detachment and movement of soil and rock fragments, during a flood or storm or over a period of years, through the action of wind, water, or other geologic processes.

Erosion analysis – Analysis of the short- and long-term *erosion* potential of soil or strata, including the effects of wind action, *flooding* or *storm surge*, moving water, wave action, and the interaction of water and structural components.

Evacuation – Movement of people from an area, typically their homes, to another area considered to be safe, typically in response to a natural or man-made disaster that makes an area unsafe for people.

Expansive soil – A soil that contains clay minerals that take in water and expand. If a soil contains sufficient amount of these clay minerals, the volume of the soil can change significantly with changes in moisture, with resultant structural damage to structures founded on these materials.

Extremely hazardous substance – A substance that shows high acute or chronic toxicity, carcinogenity, bioaccumulative properties, is persistent in the environment, or is water reactive (California Code of Regulations, Title 22).

Fanglomerate – A sedimentary rock consisting of a heterogeneous mix of fragments of all sizes, originally deposited in an alluvial fan and subsequently cemented into a firm rock. Generally said of the coarser, consolidated rock material that occurs in the upper part of an alluvial fan.

Fault – A fracture (rupture) or a zone of fractures along which there has been displacement of adjacent earth material.

Fault segment – A continuous portion of a fault zone that is likely to rupture along its entire length during an earthquake.

Fault slip rate – The average long-term movement of a fault (measured in cm/year or mm/year) as determined from geologic evidence.

Federal Emergency Management Agency (FEMA) – Independent agency created in 1979 to provide a single point of accountability for all Federal activities related to disaster mitigation and emergency preparedness, response and recovery. FEMA administers the *National Flood Insurance Program*.

Federal Insurance Administration (FIA) – The component of the *Federal Emergency Management Agency* directly responsible for administering the flood insurance aspects of the *National Flood Insurance Program*.

Federal Responsibility Areas (FRA) – Areas within which a federal government agency has the financial responsibility of preventing and suppressing fires.

Feldspar – The most widespread of any mineral group; constitutes ~60% of the earth's crust. Feldspars occur as components of all kinds of rocks and, on decomposition, yield a large part of the clay of a soil.

Fill – Material such as soil, gravel, or crushed stone placed in an area to increase ground elevations or change soil properties.

Fire behavior – The manner in which a fire reacts to the influences of fuel, weather and topography.

Fire flow – The flow rate of a water supply expressed in gallons per minute (gpm), measured at 20 pounds per square inch (psi) residual pressure, that is available for fire fighting.

Fire frequency – The number of fires occurring within a defined area in a given time period.

Fire regime – The long-term fire pattern characteristic of a region or ecosystem described using a combination of seasonality, fire return interval, size, spatial complexity, intensity, severity, and fire type.

Fire resistant – A characteristic of a plant species that allows individuals to resist damage or mortality during a fire. Also used to describe construction materials that resist damage to fire.

First responders – A group designated by the community as those who may be first to arrive at the scene of a fire, accident, or chemical release.

Fire weather – The weather conditions that influence fire behavior, including air temperature, atmospheric moisture, atmospheric stability, clouds and precipitation.

Five-hundred (500)-year flood – *Flood* that has as 0.2% probability of being equaled or exceeded in any given year.

Flash flood – A local and sudden flood or torrent overflowing a stream channel in an usually dry valley, carrying an immense load of mud and rock fragments, and generally resulting from a rare and brief but heavy rainfall over a relatively small area having steep slopes.

Flood – A rising body of water, as in a stream or lake, which overtops its natural and artificial confines and covers land not normally under water. Under the *National Flood Insurance Program*, either:

(a) a general and temporary condition or partial or complete inundation of normally dry land areas from:

(1) the overflow of inland or tidal waters,

(2) the unusual and rapid accumulation or runoff of surface waters from any source, or

(3) mudslides (i.e., mudflows) which are proximately caused by flooding as defined in (2) and are akin to a river of liquid and flowing mud on the surfaces of normally dry land areas, as when the earth is carried by a current of water and deposited along the path of the current, or

(b) the collapse or subsidence of land along the shore of a lake or other body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels or suddenly caused by an unusually high water level in a natural body of water, accompanied by a severe storm, or by an unanticipated force of nature, such as flash flood or abnormal tidal surge, or by some similarly unusual and unforeseeable event which results in flooding as defined in (1), above.

Flood-damage-resistant material – Any construction material capable of withstanding direct and prolonged contact (i.e., at least 72 hours) with floodwaters without suffering significant damage (i.e., damage that requires more than cleanup or low-cost cosmetic repair, such as painting).

Flood elevation – Height of the water surface above an established elevation datum such as the *National Geodetic Vertical Datum*, *North American Vertical Datum*, or *mean sea level*.

Flood hazard area – The greater of the following: (1) the area of special flood hazard, as defined under the *National Flood Insurance Program*, or (2) the area designated as a flood hazard area on a community's legally adopted flood hazard map, or otherwise legally designated.

Flood insurance – Insurance coverage provided under the National Flood Insurance Program.

Flood Insurance Rate Map (FIRM) – Under the *National Flood Insurance Program*, an official map of a community, on which the *Federal Emergency Management Agency* has delineated both the special hazard areas and the risk premium zones applicable to the community. (Note: The latest FIRM issued for a community is referred to as the *effective FIRM* for that community.)

Flood Insurance Study (FIS) – Under the *National Flood Insurance Program*, an examination, evaluation, and determination of *flood* hazards and, if appropriate, corresponding *water surface elevations*, or an examination, evaluation, and determination of mudslide (i.e., mudflow) and/or flood-related erosion hazards in a community or communities. (Note: The *National Flood Insurance Program* regulations refer to Flood Insurance Studies as "flood elevation studies.")

Flood-related erosion area or flood-related erosion prone area – A land area adjoining the shore of a lake or other body of water, which due to the composition of the shoreline or bank and high water levels or wind-driven currents, is likely to suffer *flood*-related *erosion* damage.

Flooding – See *Flood*.

Floodplain – Under the *National Flood Insurance Program*, any land area susceptible to being inundated by water from any source. See *Flood*.

Floodplain management – Operation of an overall program of corrective and preventive measures for reducing *flood* damage, including but not limited to emergency preparedness plans, flood control works, and *floodplain management regulations*.

Floodplain management regulations – Under the *National Flood Insurance Program*, zoning ordinances, subdivision regulations, building codes, health regulations, special purpose ordinances (such as floodplain ordinance, grading ordinance, and erosion control ordinance), and other applications of police power. The term describes such state or local regulations, in any combination thereof, which provide standards for the purpose of *flood* damage prevention and reduction.

Floodway – The channel of a river or other watercourse, and the adjacent land areas that must be kept free of encroachment in order to discharge the base flood without cumulatively increasing the water surface elevation more than a certain height.

Flow failure – A type of liquefaction-induced failure that generally occurs in slopes greater than 3 degrees, and that is characterized by the displacement, often over tens to hundreds of feet, of blocks of soil riding on top of the liquefied substrate.

Footing – Enlarged base of a foundation wall, pier, post, or column designed to spread the load of the structure so that it does not exceed the soil bearing capacity.

Footprint – Land area occupied by a structure.

Freeboard – Under the *National Flood Insurance Program*, a factor of safety, usually expressed in feet above a *flood* level, for the purposes of *floodplain management*. Freeboard tends to compensate for the many unknown factors that could contribute to flood heights greater than the heights calculated for a selected size flood and floodway conditions, such as the hydrological effect of urbanization of the watershed.

Fuel – The source of heat that sustains the combustion process. In wildland fires, fuel is the combustible plant biomass, including grass, leaves, ground litter, shrubs, plants and trees.

Fuel load – The amount of fuel that is potentially available for combustion.

Fuel moisture – The moisture content expressed as a percentage of the dry weight of the fuel.

Gabbro – A group of dark-colored intrusive igneous rocks composed principally of plagioclase. The approximate intrusive equivalent of basalt.

Geomorphology – The science that treats the general configuration of the Earth's surface. The study of the classification, description, nature, origin and development of landforms, and the history of geologic changes as recorded by these surface features.

Geotechnical engineer – A licensed civil engineer who is also certified by the State as qualified for the investigation and engineering evaluation of earth materials and their interaction with earth retention systems, structural foundations, and other civil engineering works.

Gneiss – A metamorphic rock in which bands of granular minerals alternate with bands in which mineral have a flaky or prismatic habit, with less than 50 percent of the minerals showing preferred parallel orientation.

Grading – Any excavating or filling or combination thereof. Generally refers to the modification of the natural landscape into pads suitable as foundations for structures.

Granite – Broadly applied, any completely crystalline, quartz-bearing, plutonic rock.

Ground failure – Permanent ground displacement produced by fault rupture, differential settlement, liquefaction, or slope failure.

Ground lurching – A form of earthquake-induced ground failure where soft, saturated soils move in a wave-like manner in response to intense seismic ground shaking, forming ridges or cracks at the surface.

Ground oscillations – A type of liquefaction-induced failure where liquefaction occurs at depth, in an area where the ground surface is too level to permit the lateral displacement of the overlying soil blocks. The blocks instead separate from one another and oscillate above the liquefied layer. This may result in the opening and closing of fissures or cracks, and the formation of sand boils or volcanoes.

Ground rupture – Displacement of the earth's surface as a result of fault movement associated with an earthquake.

Hazardous material (HAZMAT) – Substance that has the ability to harm humans, property or the environment. The United States Environmental Protection Agency defines hazardous waste as substances that:

1) may cause or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness;
2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of or otherwise managed; and
3) whose characteristics can be measured by a standardized test or reasonably detected by generators of solid waste through their knowledge of their waste.

Hazardous waste is also ignitable, corrosive, or reactive (explosive) (EPA 40 CFR 260.10). A material may also be classified as hazardous if it contains defined amounts of toxic chemicals.

Hazardous Waste Operations and Emergency Response (HAZWOPER) – The Occupational Safety and Health Agency (OSHA) regulation that covers safety and health issues at hazardous waste sites and response to chemical incidents.

Hazard reduction – Any treatment of a hazard that reduces the threat of ignition and fire intensity or rate of spread.

Highest adjacent grade – Elevation of the highest natural or regarded ground surface, or structural fill, that abuts the walls of a building.

Holocene – An epoch of the Quaternary period spanning from the end of the Pleistocene to the present time (the past about 11,000 years).

Hornblende – The most common mineral of the amphibole group. It is a primary constituent in many intermediate igneous rocks.

Hydrocompaction – Settlement of loose, granular soils that occurs when the loose, dry structure of the sand grains held together by a clay binder or other cementing agent collapses upon the introduction of water.

Hydrodynamic loads – Loads imposed on an object, such as a building, by water flowing against and around it. Among these loads are positive frontal pressure against the structure, drag effect along the sides, and negative pressure on the downstream side.

Hydrostatic loads – Loads imposed on a surface, such as a wall or floor slab, by a standing mass of water. The water pressure increases with the square of the water depth.

Hypocenter – The earthquake focus, that is, the place at depth, along the fault plane, where an earthquake rupture started.

Igneous – Type of rock or mineral that formed from molten or partially molten magma.

Ignition point – The location of the ignition.

Ignition source – The origin or source of a fire.

Infiltration – The process by which water seeps into the soil, as influenced by soil texture, soil structure, and vegetation cover.

Intensity – A measure of the effects of an earthquake at a particular place. Intensity depends on the earthquake magnitude, distance from the epicenter, and on the local geology.

Invasive plants – Plants that aggressively expand their ranges over the landscape, typically at the expense of native plants that are displaced or destroyed by the newcomers. Invasive species are typically considered a major threat to biological diversity.

ISO – Insurance Services Office. Private organization that formulates fire safety ratings based on fire threat and responsible agency's ability to respond to the threat. ISO ratings from one (excellent) to ten (no fire protection). Many insurance companies use ISO ratings to set insurance premiums. ISO may establish multiple ratings within a community, such as a rating of 5 in the hydranted areas and one of 8 in the non-hydranted areas.

Jet stream – A relatively narrow stream of fast-moving air in the middle and upper troposphere. Surface cyclones develop and move along the jet stream.

Jetting (of piles) – Use of a high-pressure stream of water to embed a pile in sandy soil.

Joist – Any of the parallel structural members of a floor system that support, and are usually immediately beneath, the floor.

ka – thousands of years before present.

Lacustrine flood hazard area – Area subject to inundation by *flooding* from lakes.

Landslide – A general term covering a wide variety of mass-movement landforms and processes involving the downslope transport, under gravitational influence, of soil and rock material en masse.

Lateral force – The force of the horizontal, side-to-side motion on the Earth's surface as measured on a particular mass; either a building or structure.

Lateral spreading – Lateral movements in a fractured mass of rock or soil which result from liquefaction or plastic flow or subjacent materials.

Left-lateral fault – A strike-slip fault across which a viewer would see the block on the opposite side of the fault move to the left.

Level-of-service standard (LOS standard) – Quantifiable measures against which services being delivered by a service provider can be compared. Standards based upon recognized and accepted professional and county standards, while reflecting the local situation within which services are being delivered. Levels-of-service standards for fire protection may include response times, personnel per given population, and emergency water supply. LOS standards can be used to evaluate the way in which fire protection services are being delivered, for use in countywide fire planning efforts.

Lifeline system – Linear conduits or corridors for the delivery of services or movement of people and information (e.g., pipelines, telephones, freeways, railroads)

Lineament – Straight or gently curved, lengthy features of earth's surface, frequently expressed topographically as depressions or lines of depressions, scarps, benches, or change in vegetation.

Liquefaction – Changing of soils (unconsolidated alluvium) from a solid state to weaker state unable to support structures; where the material behaves similar to a liquid as a consequence of earthquake shaking. The transformation of cohesionless soils from a solid or liquid state as a result of increased pore pressure and reduced effective stress.

Litter – Recently fallen plant material that is only partially decomposed, forming a surface layer on some soils.

Live loads – *Loads* produced by the use and occupancy of the building or other structure. Live loads do not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load, or dead load. See *Loads*.

Load-bearing wall – Wall that supports any vertical load in addition to its own weight.

Loads – Forces or other actions that result from the weight of all building materials, occupants and their possessions, environmental effects, differential movement, and restrained dimensional changes. Permanent loads are those in which variations over time are rare or of small magnitude. All other loads are variable loads.

Lowest floor – Under the *National Flood Insurance Program*, the lowest floor of the lowest enclosed area (including basement) of a structure. An unfinished or *flood*-resistant enclosure, usable solely for parking of vehicles, building access, or storage in an area other than a basement is not considered a building's lowest floor, provided that the enclosure is not built so as to render the structure in violation of *National Flood Insurance Program* regulatory requirements.

Lowest horizontal structural member – In an elevated building, the lowest beam, *joist*, or other horizontal member that supports the building. *Grade beams* installed to support vertical foundation members where they enter the ground are not considered lowest horizontal structural members.

Ma – millions of years before present.

Macroburst – A strong downdraft over 2.5 miles in diameter that can cause damaging winds lasting 5 to 20 minutes. Formed by an area of significantly rain-cooled air that after hitting ground levels spreads out in all directions.

Magnitude – A measure of the size of an earthquake, as determined by measurements from seismograph records. Also refers to both a fire's intensity and severity.

Main shock – The biggest earthquake of a sequence of earthquakes that occur fairly close in time and space. Smaller shocks before the main shock are called **foreshocks**; smaller shocks that occur after the main shock are called **aftershocks**.

Major earthquake – Capable of widespread, heavy damage up to 50+ miles from epicenter; generally near Magnitude range 6.5 to 7.0 or greater, but can be less, depending on rupture mechanism, depth of earthquake, location relative to urban centers, etc.

Manufactured home – Under the *National Flood Insurance Program*, a *structure*, transportable in one or more sections, which is built on a permanent chassis and is designed for use with or without a permanent foundation when attached to the required utilities. The term "manufactured home" does not include a "recreational vehicle."

Masonry – Built-up construction of combination of building units or materials of clay, shale, concrete, glass, gypsum, stone, or other approved units bonded together with or without mortar or grout or other accepted methods of joining.

Mass casualty – Incident in which the number of victims exceeds the capability of the emergency management system to manage the incident effectively.

Material Safety Data Sheets (MSDS) – Information sheets for employees that provide specific information about a chemical that they may come in contact at their place of work, with attention to health effects, handling, and emergency procedures.

Maximum Contaminant Level (MCL) – Federal drinking water standard: "the maximum permissible level of a contaminant in water which is delivered to any user of a public water system" (Code of Federal Regulations [CFR], Title 40, Part 141.2).

Maximum Magnitude Earthquake (Mmax) – The highest magnitude earthquake a fault is capable of producing based on physical limitations, such as the length of the fault or fault segment.

Maximum Probable Earthquake (MPE) – The design size of the earthquake expected to occur within a time frame of interest, for example within 30 years or 100 years, depending on the purpose, lifetime or importance of the facility. Magnitude/frequency relationships are based on historic seismicity, fault slip rates, or mathematical models. The more critical the facility, the longer the time period considered.

Mediterranean climate – The climate characteristic of the Mediterranean region and most of California, characterized by hot, dry summers, and cool, wet winters.

Metamorphic rock – A rock whose original mineralogy, texture, or composition has been changed due to the effects of pressure, temperature, or the gain or loss of chemical components.

Mean sea level (MSL) – Average height of the sea for all stages of the tide, usually determined from hourly height observations over a 19-year period on an open coast or in adjacent waters having free access to the sea. See *National Geodetic Vertical Datum*.

Microburst – A very localized zone of sinking air, less than 2.5 miles in diameter, producing damaging, straight-line, divergent winds at or near the ground surface lasting 2 to 5 minutes.

Mitigation – Any action taken to reduce or permanently eliminate the long-term risk to life and property from natural hazards.

Mitigation Directorate – Component of *Federal Emergency Management Agency* directly responsible for administering the flood hazard identification and *floodplain management* aspects of the *National Flood Insurance Program*.

Moderate earthquake – Capable of causing considerable to severe damage, generally in the range of Magnitude 5.0 to 6.0 (Modified Mercalli Intensity <VI), but highly dependent on rupture mechanism, depth of earthquake, and location relative to urban center, etc.

Modified Mercalli Intensity – A qualitative measure of the size of an earthquake based on people's description of how strongly the earthquake was felt, and the damage it caused to the built environment. The scale has 12 divisions, ranging from I (felt by only a very few people) to XII (total damage).

Mutual Aid Agreement – A reciprocal aid agreement between two or more agencies that defines what resources each will provide to the other in response to certain predetermined types of emergencies. Mutual aid response is provided upon request.

National Fire Incident Reporting System (NFIRS) – A database of fire incident reports compiled at the local fire department level. NFIRS was an outgrowth of the 1974 National Fire Prevention and Control Act, Public Law 93–498. The U.S. Fire Administration (USFA), an entity of the Department of Homeland Security, developed NFIRS as a means of assessing the nature and scope of the fire problem in the United States.

National Fire Protection Association (NFPA) – A group that issues fire and safety standards for industry and emergency responders.

National Flood Insurance Program (NFIP) – Federal program created by Congress in 1968 that makes *flood* insurance available in communities that enact and enforce satisfactory *floodplain management regulations*.

National Geodetic Vertical Datum (NGVD) – Datum established in 1929 and used as a basis for measuring flood, ground, and structural elevations, previously referred to as Sea Level Datum or *Mean Sea Level*. The *Base Flood Elevations* shown on most of the *Flood Insurance Rate Maps* issued by the *Federal Emergency Management Agency* are referenced to NGVD or, more recently, to the *North American Vertical Datum*.

Natural Attenuation – Reduction in mass or concentration of a compound in groundwater over time or distance from the source of constituents of concern due to naturally occurring physical, chemical, and biological processes, such as biodegradation, dispersion, dilution, adsorption, and volatilization. (American Society for Testing and Materials, 2003).

Near-field earthquake – Used to describe a local earthquake within approximately a few fault zone widths of the causative fault which is characterized by high frequency waveforms that are destructive to above-ground utilities and short period structures (less than about two or three stories).

New construction – For the purpose of determining flood insurance rates under the *National Flood Insurance Program*, *structures* for which the start of construction commenced on or after the effective date of the initial *Flood Insurance Rate Map* or after December 31, 1974, whichever is later, including any subsequent improvements to such structures. (See *Post-FIRM structure*.) For *floodplain management* purposes, new construction means *structures* for which the *start of construction* commenced on or after the effective date of a *floodplain management regulation* adopted by a community and includes any subsequent improvements to such structures.

Non-coastal A zone – The portion of the *Special Flood Hazard Area* in which the principal source of *flooding* is runoff from rainfall, snowmelt, or a combination of both. In non-coastal A zones, *flood* waters may move slowly or rapidly, but waves are usually not a significant threat to buildings. See *A zone* and *coastal A zone*. (Note: the *National Flood Insurance Program* regulations do not differentiate between non-coastal A zones and *coastal A zones*.)

Non-load-bearing wall – Wall that does not support vertical loads other than its own weight. See *Load-bearing wall*.

North American Vertical Datum (NAVD) – Datum used as a basis for measuring flood, ground, and structural elevations. NAVD is used in many recent *Flood Insurance Studies* rather than the *National Geodetic Vertical Datum*.

Oblique-reverse fault – A fault that combines some strike-slip motion with some dip-slip motion in which the upper block, above the fault plane, moves up over the lower block.

Offset ridge – A ridge that is discontinuous on account of faulting.

Offset stream – A stream displaced laterally or vertically by faulting.

One hundred (100)-year flood – See *Base flood*.

Orthoclase – One of the most common rock-forming minerals; colorless, white, cream-yellow, flesh-reddish, or grayish in color.

Paleoseismic – Pertaining to an earthquake or earth vibration that happened decades, centuries, or millennia ago.

Peak flood – The highest discharge or stage value of a flood.

Peak Ground Acceleration (PGA) – The greatest amplitude of acceleration measured for a single frequency on an earthquake accelerogram. The maximum horizontal ground motion generated by an earthquake. The measure of this motion is the acceleration of gravity (equal to 32 feet per second squared, or 980 centimeter per second squared), and generally expressed as a percentage of gravity.

Pedogenic – Pertaining to soil formation.

Pegmatite – An igneous rock with extremely large grains, more than a centimeter in diameter.

Perched ground water – Unconfined ground water separated from an underlying main body of ground water by an unsaturated zone.

Perennial Stream – A stream that flows continuously throughout the year.

Plagioclase – One of the most common rock forming minerals.

Playa – Term used in the Southwestern US to describe a flat-floored, typically unvegetated area composed of thin, stratified sheets of fine clay, silt or sand that represent the bottom or central part of a shallow, completely closed or undrained desert lake basin where water accumulates after a rainstorm and quickly evaporates, leaving behind deposits of soluble salts.

Plutonic – Pertaining to igneous rocks formed at great depth.

Plywood – Wood structural panel composed of plies of wood veneer arranged in cross-aligned layers. The plies are bonded with an adhesive that cures on application of heat and pressure.

Pore pressure – The stress transmitted by the fluid that fills the voids between particles of a soil or rock mass.

Post foundation – Foundation consisting of vertical support members set in holes and backfilled with compacted material. Posts are usually made of wood and usually must be braced. Posts are also known as columns, but columns are usually made of concrete or masonry.

Post-FIRM structure – For purposes of determining insurance rates under the *National Flood Insurance Program*, structures for which the *start of construction* commenced on or after the effective date of an initial *Flood Insurance Rate Map* or after December 31, 1974, whichever is later, including any subsequent improvements to such structures. This term should not be confused with the term *new construction* as it is used in *floodplain management*.

Potentially active fault – According to the Alquist-Priolo Earthquake Fault Zone Act guidelines, a fault showing evidence of movement within the last 1.6 million years but that has not been shown conclusively whether or not it has ruptured in the past about 11,000 years ago. The U.S. Geological Survey considers a fault potentially active if it has moved in the time period between about 11,000 years ago (the Holocene) and 750,000 years ago, and that is thought capable of generating damaging earthquakes.

Precast concrete – Structural concrete element cast elsewhere than its final position in the structure. See *Cast-in-place concrete*.

Prescribed Fire – A fire ignited under known conditions of fuel, weather, and topography to achieve specific objectives.

Primary fault rupture - Fissuring and displacement of the ground surface along a fault that breaks in an earthquake.

Project – A development application involving zone changes, variances, conditional use permits, tentative parcel maps, tentative tract maps, and plan amendments.

Quartzite – A metamorphic rock consisting mostly of quartz.

Quartz monzonite – A plutonic rock containing major plagioclase, orthoclase and quartz; with increased orthoclase it becomes a granite.

Quaternary – The second period of the Cenozoic era, consisting of the Pleistocene and Holocene epochs; covers the last approximately 1.6 to 2 million years.

Rain shadow – A reduction in precipitation in an area on the leeward side of a mountain or range of mountains, caused by the release of moisture on the windward side.

Resonance – Amplification of ground motion frequencies within bands matching the natural frequency of a structure and often causing partial or complete structural collapse; effects may demonstrate minor damage to single-story residential structures while adjacent 3- or 4-story buildings may collapse because of corresponding frequencies, or vice versa.

Recurrence interval – The time between earthquakes of a given magnitude, or within a given magnitude range, on a specific fault or within a specific area.

Reinforced concrete – *Structural concrete* reinforced with steel bars.

Remote shutoff – Valve that can be used to shut off the flow of a substance or chemical from a location away from the spill or break.

Reportable quantity – A term used by the EPA and the Department of Transportation (DOT) to denote a quantity of chemicals that require some kind of action, such as reporting an inventory or reporting an accident involving a certain amount of chemicals.

Response spectra – The range of potentially damaging frequencies of a given earthquake applied to a specific site and for a particular building or structure.

Response Time – The time that elapses between the moment a 911 call is placed to the emergency dispatch center and the time that a first-responder arrives on scene. Response time includes dispatch time, turnout time (the time it takes firefighters to travel to the fire station, don their personal protection equipment, and prepare the apparatus), and travel time.

Retrofit – Any change made to an existing structure to reduce or eliminate damage to that structure from flooding, *erosion*, high winds, earthquakes, or other hazards.

Revetment – Facing of stone, cement, sandbags, or other materials placed on an earthen wall or embankment to protect it from *erosion* or *scour* caused by *flood* waters or wave action.

Rhyolite – A group of extrusive igneous rocks, generally exhibiting flow texture, with large crystals (phenocrysts) of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass. The approximate extrusive equivalent of granite.

Ridgetop shattering – An earthquake-induced type of ground failure that occurs along at or along the top of ridges, forming linear, fault-like fissures, and leaving the area looking like it was plowed.

Right-lateral fault – A strike-slip fault across which a viewer would see the block on the opposite side of the fault move to the right.

Riprap – Broken stone, cut stone blocks, or rubble that is placed on slopes to protect them from *erosion* or *scour* caused by *flood* waters or wave action.

Rockfall – Free-falling to tumbling mass of bedrock that has broken off steep canyon walls or cliffs.

Sand boil – An accumulation of sand resembling a miniature volcano or low volcanic mound produced by the expulsion of liquefied sand to the sediment surface. Also called sand blows, and sand volcanoes.

Sandstone – A medium-grained, clastic sedimentary rock composed of abundant rounded or angular fragments of sand size set in a fine-grained matrix and more or less firmly united by a cementing material.

Santa Ana (or Santana) wind – Strong, typically extremely dry offshore winds that characteristically blow through southern California and northern Baja California in late fall and winter. They typically originate in the Great Basin or upper Mojave Desert, and can be either hot or cold. The winds tend to funnel down the valleys and canyons, where gusts can attain speeds of 60 to 90 miles per hour (mph). Several devastating wildfires in southern California have been associated with Santa Ana winds.

Saturated – Said of the condition in which the interstices of a material are filled with a liquid, usually water.

Scarp – A line of cliffs produced by faulting or by erosion. The term is an abbreviated form of escarpment.

Schist – A metamorphic rock characterized by a preferred orientation in grains resulting in the rock's ability to be split into thin flakes or slabs.

Scour – Removal of soil or fill material by the flow of *flood* waters. The term is frequently used to describe storm-induced, localized conical erosion around pilings and other foundation supports where the obstruction of flow increases turbulence. See *Erosion*.

Secondary fault rupture - Ground surface displacements along faults other than the main traces of active regional faults.

Sediment – Solid fragmental material that originates from weathering of rocks and is transported or deposited by air, water, ice, or that accumulates by other natural agents, such as chemical precipitation from solution, and that forms in layers on the Earth's surface in a loose, unconsolidated form.

Seiche – A free or standing-wave oscillation of the surface of water in an enclosed or semi-enclosed basin (such as a lake, bay, or harbor), that is initiated chiefly by local changes in atmospheric pressure, aided by winds, tidal currents, and earthquakes, and that continues, pendulum-fashion, for a time after cessation of the originating force.

Seismic Moment – A measure of the size of an earthquake that is associated with the amount of energy released (the force that was necessary to overcome the friction along the fault plane), the area of the fault rupture, and the average amount of slip.

Seismogenic – Capable of producing earthquake activity.

Seismograph – An instrument that detects, magnifies, and records vibrations of the Earth, especially earthquakes. The resulting record is a seismogram.

Shearwall – *Load-bearing wall* or *non-load-bearing wall* that transfers in-plane lateral forces from lateral *loads* acting on a structure to its foundation.

Sheet flow – An overland flow or downslope movement of water taking the form of a thin, continuous film over relatively smooth soil or rocks surfaces and not concentrated into channels larger than rills.

Shutter ridge – That portion of an offset ridge that blocks or "shutters" the adjacent canyon.

Sidehill fill – A wedge of artificial fill typically placed on the side of a natural slope to create a roadway or a level building pad.

Silt – A rock fragment or detrital particle smaller than a very fine sand grain and larger than coarse clay, having a diameter in the range of 1/256 to 1/16 mm (4-62 microns, or 0.00016-0.0025 in.). An indurated silt having the texture and composition of shale but lacking its fine lamination is called a siltstone.

Slip Rate – The speed at which a fault is moving, typically expressed in millimeters per year (mm/yr), and generally estimated by measuring the amount of offset that has occurred in a given, known amount of time.

Slope ratio – Refers to the angle or gradient of a slope as the ratio of horizontal units to vertical units. For example, in a 2:1 slope, for every two horizontal units, there is a vertical rise of one unit (equal to a slope angle, from the horizontal, of 26.6 degrees).

Slump – A landslide characterized by a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface.

Soft-story building – Building with a story, generally the ground or first floor, lacking adequate strength or toughness due to too few shear walls. Examples of this type of structure include apartments above glass-fronted stores, and buildings perched atop parking garages.

Soil horizon – A layer of soil that is distinguishable from adjacent layers by characteristic physical properties such as structure, color, or texture.

Special Flood Hazard Area (SFHA) – Under the *National Flood Insurance Program*, an area having special *flood*, mudslide (i.e., mudflow) and/or flood-related erosion hazards, and shown on a Flood Hazard Boundary Map or *Flood Insurance Rate Map* as Zone A, AO, A1-A30, AE, A99, AH, V, V1-V30, VE, M or E.

Spot fire – Ignition resulting from embers from the fireline transported aerially in front of the fireline and often increasing fire spread.

Standardized Emergency Management System (SEMS) – (Government Code § 8607). The group of principles developed for coordinating state and local emergency response in California. SEMS provides for organization of a multiple-level emergency response, and is intended to structure and facilitate the flow of emergency information and resources within and between the organizational levels--the field response, local government, operational areas, regions and the state management level. SEMS incorporates by reference: the Incident Command System (ICS); multi-agency or inter-agency coordination; the State's Mutual Aid Program; and Operational Areas.

State Responsibility Area (LRA) – Per California Public Resources Code 4125-4127, the lands in which the State has primary financial responsibility for preventing and suppressing fires.

Storage capacity – Dam storage measured in acre-feet or decameters, including dead storage.

Strike-slip fault – A fault with a vertical to sub-vertical fault surface that displays evidence of horizontal and opposite displacement.

Structural concrete – All concrete used for structural purposes, including *plain concrete* and *reinforced concrete*.

Structural engineer – A licensed civil engineer certified by the State as qualified to design and supervise the construction of engineered structures.

Structural fill – Fill compacted to a specified density to provide structural support or protection to a *structure*. See *Fill*.

Structure – Something constructed, such as a building, or part of one. For *floodplain management* purposes under the *National flood Insurance Program*, a walled and roofed building, including a gas or liquid storage tank, that is principally above ground, as well as a manufactured home. For insurance coverage purposes under the NFIP, structure means a walled and roofed building, other than a gas or liquid storage tank, that is principally above ground and affixed to a permanent site, as well as a *manufactured home* on a permanent foundation. For the latter purpose, the term includes a building while in the course of construction, alteration, or repair, but does not include building materials or supplies intended for use in such construction, alteration, or repair, unless such materials or supplies are within an enclosed building on the premises.

Subsidence – The sudden sinking or gradual downward settling of the Earth's surface with little or no horizontal motion.

Swale – In hillside terrace, a shallow drainage channel, typically with a rounded depression or “hollow” at the head.

Talus – The cone-shaped accumulation of angular fragments of rock or soil at the base of a cliff that has experienced rockfalls.

Tectonic plate – Any of several large pieces, or blocks, of the Earth’s lithosphere that are slowly moving relative to each other as part of the process called plate tectonics.

Tornado – A localized but violently destructive windstorm occurring over land (at sea it is called a waterspout) characterized by a funnel-shaped cloud extending toward the ground.

Thrust fault – A fault, with a relatively shallow dip, in which the upper block, above the fault plane, moves up over the lower block.

Transform system – A system in which faults of plate-boundary dimensions transform into another plate-boundary structure when it ends.

Transpression – In crustal deformation, an intermediate stage between compression and strike-slip motion; it occurs in zones with oblique compression.

Tsunami – Great sea wave produced by submarine earth movement, volcanic eruption, oceanic meteor impact, or underwater nuclear explosion.

Typhoon – Name given to a *hurricane* in the area of the western Pacific Ocean west of 180 degrees longitude.

Unconfined aquifer – Aquifer in which the upper surface of the saturated zone is free to rise and fall.

Unconsolidated sediments – A deposit that is loosely arranged or unstratified, or whose particles are not cemented together, occurring either at the surface or at depth.

Underground Storage Tank (UST) – Tank, commonly used to store gasoline, diesel or other chemical, that is buried under the ground.

Undermining – Process whereby the vertical component of erosion or scour exceeds the depth of the base of a building foundation or the level below which the bearing strength of at the foundation is compromised.

Unreinforced Masonry (URM) structure – Building without adequate anchorage of the masonry walls to the roof and floor diaphragms and lack of steel reinforcement, of limited strength and ductility, and as a result, that tends to perform poorly when shaken during an earthquake.

Uplift – Hydrostatic pressure caused by water under a building. It can be strong enough lift a building off its foundation, especially when the building is not properly anchored to its foundation.

Upper bound earthquake – Defined as a 10% chance of exceedance in 100 years, with a statistical return period of 949 years.

Variance – Under the *National Flood Insurance Program*, grant of relief by a community from the terms of a *floodplain management regulation*.

Violation – Under the *National Flood Insurance Program*, the failure of a structure or other development to be fully compliant with the community's *floodplain management regulations*. A *structure* or other *development* without the elevation certificate, other certifications, or other evidence of compliance required in Sections 60.3(b)(5), (c)(4), (c)(10), (d)(3), (e)(2), (e)(4), or (e)(5) of the NFIP regulations is presumed to be in violation until such time as that documentation is provided.

Watershed – A topographically defined region draining into a particular river or lake.

Water surface elevation – Under the *National Flood Insurance Program*, the height, in relation to the *National Geodetic Vertical Datum* of 1929 (or other datum, where specified), of *floods* of various magnitudes and frequencies in the *floodplains* of coastal or riverine areas.

Water table – The upper surface of groundwater saturation of pores and fractures in rock or surficial earth materials.

Water year – The 12-month period from October 1 through September 30 of the following year.

Weather – The short-term state of the air or atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness, or any other meteorologic phenomena.

X zone – Under the *National Flood Insurance Program*, areas where the *flood* hazard is less than that in the *Special Flood Hazard Area*. Shaded X zones shown on recent *Flood Insurance Rate Maps* (B zones on older maps) designate areas subject to inundation by the *500-year flood*. Un-shaded X zones (C zones on older *Flood Insurance Rate Maps*) designate areas where the annual probability of flooding is less than 0.2 percent.

CHAPTER 1: SEISMIC HAZARDS

Earthquake-triggered geologic effects include ground shaking, surface fault rupture, landslides, liquefaction, subsidence, tsunamis and seiches. Some of these hazards can occur in the city of Coachella, as discussed in detail below. Earthquakes can also lead to reservoir failures, urban fires, and toxic chemical releases.

In seismically active southern California, an earthquake has the potential to cause far-reaching loss of life or property, and economic damage. This is because damaging earthquakes are relatively frequent, affect widespread areas, trigger many secondary effects, and can overwhelm the ability of local jurisdictions to respond. Although it is not possible to prevent earthquakes, their destructive effects can be minimized. Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning, public education, emergency exercises, enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can significantly reduce the scope of an earthquake's effects and avoid disaster. The record shows that local government, emergency relief organizations, and residents can and must take action to develop and implement policies and programs to reduce the effects of earthquakes. Thus, this document not only discusses the potential seismic hazards that can impact the city of Coachella, but also provides action items and programs that can help the City become more self-sufficient in the event of an earthquake.

1.1 Seismic Context – Earthquake Basics

The outer 10 to 70 kilometers of the Earth consist of enormous blocks of moving rock called ***tectonic plates***. There are about a dozen major plates, which slowly collide, separate, and grind past each other. In the uppermost brittle portion of the plates, friction locks the plate edges together, while plastic movement continues at depth. Consequently, the near-surface rocks bend and deform near plate boundaries, storing strain energy. Eventually, the frictional forces are overcome and the locked portions of the plates move. The stored strain energy is then released in seismic waves that radiate out in all directions from the rupture surface causing the Earth to vibrate and shake as the waves travel through. This shaking is what we feel in an earthquake. Most earthquakes occur on or near plate boundaries. Southern California has many earthquakes because it straddles the boundary between the North American and Pacific plates, and fault rupture accommodates their motion.

By definition, the break or fracture between moving blocks of rock is called a ***fault***, and such differential movement produces a fault rupture. Few faults are simple, planar breaks in the Earth. They more often consist of smaller strands, with a similar orientation and sense of movement. A strand is mappable as a single, fairly continuous feature. Sometimes geologists group strands into segments, which are believed capable of rupturing together during a single earthquake. The more extensive the fault, the bigger the earthquake it can produce. Therefore, multi-strand fault ruptures produce larger earthquakes.

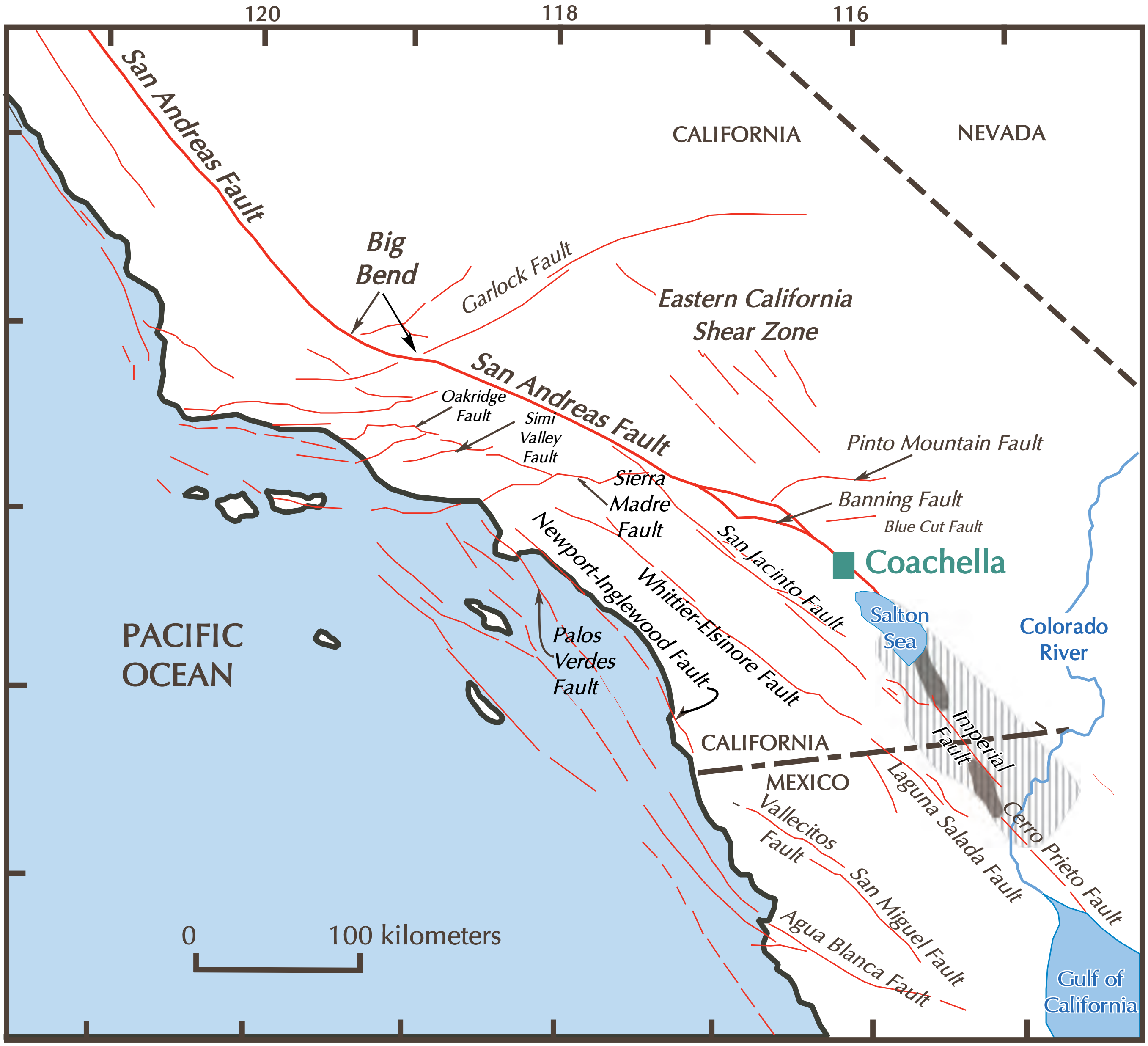
Total ***displacement*** is the length, measured in kilometers (km), of the total movement that has occurred along a fault over as long a time as the geologic record reveals. It is usually estimated by measuring distances between geologic features that have been split apart and separated (offset) by the cumulative movement of the fault over many earthquakes. ***Slip rate*** is a speed, expressed in millimeters per year (mm/yr). Slip rate is estimated by measuring an amount of offset accrued during a known amount of time, obtained by dating the ages of geologic features. Slip rate data also are used to estimate a fault's earthquake recurrence interval. Sometimes referred to as "repeat time" or "return interval," the ***recurrence interval*** represents the average amount of time that elapses between major earthquakes on a fault. The most specific way to derive the recurrence interval for a given fault is to excavate trenches across the fault to obtain ***paleoseismic*** evidence of earthquakes that have occurred during prehistoric time. Paleoseismic studies show that faults with high slip rates generally have shorter recurrence intervals between major earthquakes. This is so because a high slip rate indicates rocks that, at depth, are moving relatively quickly, and the stored energy trapped within the locked, surficial rocks needs to be released in frequent (geologically speaking), large earthquakes.

Most of the city of Coachella, like most of the western part of southern California, is riding on the Pacific Plate, which is moving northwesterly (relative to the North American Plate), at about 50 millimeters per year (mm/yr), or about 165 feet in 1,000 years. This is about the rate at which fingernails grow, and seems unimpressive. However, it is enough to accumulate enormous amounts of strain energy over tens to thousands of years. Despite being locked in place most of the time, in another 15 million years (a short time in the context of the Earth's history), due to plate movements, Los Angeles (which, like the western portion of Coachella is on the Pacific Plate) will be almost next to San Francisco (which is on the North American Plate). The easternmost section of the Coachella General Plan study area is on the North American plate because it is east of the San Andreas fault, the main dividing fault between the Pacific and North American plates. This means that the eastern portion of the study area is slowly moving south relative to the rest of the city of Coachella.

Although the San Andreas fault marks the main separation between the Pacific and North American plates, only about 60 to 70 percent of the plate motion actually occurs on this fault. The rest is distributed along other faults of the San Andreas system, including the San Jacinto, Whittier-Elsinore, Newport-Inglewood, Palos Verdes, and several offshore faults. To the east of the San Andreas fault, slip is distributed among faults of the Eastern California Shear Zone, including those responsible for the 1992 M_W 7.3 Landers and 1999 M_W 7.1 Hector Mine earthquakes. (M_W stands for ***moment magnitude***, a measure of earthquake energy release, discussed further below.) Thus, the zone of plate-boundary earthquakes and ground deformation covers an area that stretches from Nevada to the Pacific Ocean (see Figure 1-1).

Because the Pacific and North American plates are sliding past each other, with relative motions to the northwest and southeast, respectively, all of the faults mentioned above trend northwest-southeast, and are strike-slip faults. On average, ***strike-slip faults*** are nearly vertical breaks in the rock, and when a strike-slip fault ruptures, the rocks on either side of the fault slide horizontally past each other. However, there is a kink in the San Andreas fault commonly referred to as the "Big Bend," located about 186 miles (300 km) northwest of Coachella (Figure 1-1). Near the Big Bend, the two plates do not slide past each other. Instead, they collide, causing localized compression, which results in folding and thrust faulting. ***Thrusts*** are a type of dip-slip fault where rocks on opposite sides of the fault move up or down relative to each other. When a thrust fault ruptures, the top block of rock moves up and over the rock on the opposite side of the fault.

In southern California, ruptures along thrust faults have built the Transverse Ranges geologic province, a region with a unique east-west trend to its landforms and underlying geologic structures that is a direct consequence of the plates colliding at the Big Bend. Many of southern California's most recent damaging earthquakes have occurred on thrust faults that are uplifting the Transverse Ranges, including the 1971 M_W 6.7 San Fernando, 1987 M_W 5.9 Whittier Narrows, 1991 M_W 5.8 Sierra Madre, and 1994 M_W 6.7 Northridge earthquakes. Thrust faults in southern California have been particularly hazardous because many are "***blind***," that is, they do not extend to the surface of the Earth, and have therefore been difficult to detect and study before they rupture. Some earthquakes in southern California, including the 1987 Whittier Narrows earthquake and the 1994 Northridge earthquake, occurred on previously unknown blind thrust faults. As a result, a great amount of research in the last 15 years has gone into learning to recognize subtle features in the landscape that suggest the presence of a buried thrust fault at depth, and developing techniques to confirm and study these structures. Some geologists have started



Source: Modified from Fuis and Mooney, 1990.

MAP EXPLANATION

Fault

Onshore Spreading Center

New Crust (late Cenozoic)

Earth Consultants International

Project Number: 3106
Date: 2011

Regional Fault Map

Figure 1-1

to develop paleoseismic data for these buried thrust faults, including recurrence interval, estimates of the maximum magnitude earthquake these faults are capable of generating, and displacement per event.

A smaller kink in the San Andreas fault occurs in the vicinity of San Gorgonio Pass, to the northwest of Palm Springs. This kink (or "knot" as it is often called) is a result of a slight bend and a step in the main fault's surface trace. As with the Big Bend, complex fault patterns, including thrust faulting, have developed in this area to accommodate these changes. Consequently, the Coachella Valley area, including the city of Coachella, is exposed to risk from multiple types of earthquake-producing faults. The highest risks are due to movement on the San Andreas (strike-slip, right-lateral) fault zone (which includes the San Gorgonio Pass thrust fault), the San Jacinto (strike-slip, right-lateral) fault zone, faults in the Eastern California Shear Zone (including the right-lateral strike-slip Burnt Mountain, Eureka Peak, Pisgah-Bullion Mountain-Mesquite Lake, and Landers faults), and the Pinto Mountain fault (strike slip, left-lateral). These faults or fault zones will be discussed in more detail in Section 1-4 below.

1.2 Regulatory Context

1.2.1 Alquist-Priolo Earthquake Fault Zoning Act

The Alquist-Priolo Special Studies Zones Act was signed into law in 1972 (in 1994 it was renamed the Alquist-Priolo Earthquake Fault Zoning Act). The primary purpose of the Act is to mitigate the hazard of fault rupture by prohibiting the location of structures for human occupancy across the trace of an active fault (Hart and Bryant, 1999; 2007). This State law was passed in direct response to the 1971 San Fernando earthquake, which was associated with extensive surface fault ruptures that damaged numerous homes, commercial buildings and other structures.

The Act requires the State Geologist (i.e., the Chief of the California Geological Survey) to delineate "Earthquake Fault Zones" along faults that are "sufficiently active" and "well defined." These faults show evidence of Holocene (the time period between today and the past about 11,000 years) surface displacement along one or more or their segments (sufficiently active) and are clearly detectable by a trained geologist as a physical feature at or just below the ground surface (well defined). The boundary of an "Earthquake Fault Zone" is generally about 500 feet from major active faults, and 200 to 300 feet from well-defined minor faults. Alquist-Priolo Earthquake Fault Zone maps are distributed to all affected cities and counties for their use in planning and controlling new or renewed construction. The Act dictates that cities and counties withhold development permits for sites within an Earthquake Fault Zone until geologic investigations demonstrate that the sites are not threatened by surface displacements from future faulting (Hart and Bryant, 2007). Projects include all land divisions and most structures for human occupancy. State law exempts single-family wood-frame and steel-frame dwellings that are less than three stories and are not part of a development of four units or more. However, local agencies can be more restrictive. A section of the Alquist-Priolo-zoned San Andreas fault extends through the eastern and northeastern portions of the city of Coachella. The California Geological Survey has also zoned other faults in the northern and southeastern portions of the Coachella General Plan area (see Section 1.5).

1.2.2 Seismic Hazards Mapping Act

The Alquist-Priolo Earthquake Fault Zoning Act only addresses the hazard of surface fault rupture and is not directed toward other earthquake hazards. Recognizing this, in 1990 the State passed the Seismic Hazards Mapping Act (SHMA), which addresses non-surface fault rupture earthquake hazards, including strong ground shaking, liquefaction and seismically induced landslides. The California Geological Survey (CGS) is the principal State agency charged with implementing the Act. Pursuant to the SHMA, the CGS is directed to provide local governments with seismic hazard zone maps that identify areas susceptible to liquefaction, earthquake-induced landslides and other ground failures. The goal is to minimize loss of life and property by identifying and mitigating seismic hazards. The seismic hazard zones delineated by the CGS are referred to as "zones of required investigation." Site-specific geological hazard investigations are required by the SHMA when construction projects fall within these areas.

The CGS, pursuant to the 1990 SHMA, has been releasing seismic hazards maps since 1997, with emphasis on the large metropolitan areas of Los Angeles, Orange and Ventura counties (funding for this program limits the geographic scope of these studies to these three counties in southern California). As a result, at this time, there are no State-issued (and thus official) seismic hazard zone maps for the city of Coachella. Nevertheless, the methodology that the CGS uses to prepare these maps is well documented, and can be duplicated in areas that the CGS has yet to map. To that end, and for the purposes of this study, we have followed a simplified version of the CGS methodology to identify areas in Coachella that are susceptible to liquefaction or earthquake-induced slope instability. These hazards are discussed in more detail in Section 1.6.

1.2.3 California Building Code

The International Conference of Building Officials (ICBO) was formed in 1922 to develop a uniform set of building regulations; this led to the publication of the first Uniform Building Code (UBC) in 1927. In keeping with the intent of providing a safe building environment, building codes were updated on a fairly regular basis, but adoption of these updates at the county- and city-level was not mandatory. As a result, the building codes used from one community to the next were often not the same. In 1980, recognizing that many building code provisions, like building exits, are not affected by local conditions, and that industries working in California should have some uniformity in building code provisions throughout the State, the legislature amended the State's Health and Safety Code to require local jurisdictions to adopt, at a minimum, the latest edition of the Uniform Building Code Insert (UBC). The law states that every local agency, such as individual cities and counties, enforcing building regulations must adopt the provisions of the California Building Code (CBC) within 180 days of its publication, although each jurisdiction can require more stringent regulations, issued as amendments to the CBC. The publication date of the CBC is established by the California Building Standards Commission and the code is known as Title 24 of the California Code of Regulations. Based on the publication cycle of the UBC, the CBC used to be updated and republished every three years.

Then, in 1994, to further the concept of uniformity in building design, the ICBO joined with the two other national building code publishers, the Building Officials and Code Administrators International, Inc. (BOCA) and the Southern Building Code Congress International, Inc. (SBCCI), to form a single organization, the International Code Council, (ICC). In the year 2000, the group published the first International Building Code (IBC) as well as an entire family of codes, (i.e. building, mechanical, plumbing and fire) that were coordinated with each other. As a result, the last (and final) version of the UBC was issued in 1997. However, the California Building Standards Commission, after careful review of the 2000 IBC, chose not to use the IBC, but instead continued to adopt the older 1997 UBC as the basis for the CBC. The 2001 CBC (based on the 1997 UBC) was used throughout the State from 2001 to 2007, often with local, more restrictive amendments based upon local geographic, topographic or climatic conditions.

In 2007 the California Building Standards Commission (BSC) issued the 2007 edition of the CBC based on the 2006 IBC, and more recently, the 2010 edition of the CBC based on the 2009 IBC. Updates of the IBC and CBC have been issued every three years since then. The 2013 CBC became effective on January 1, 2014. [For updates and additional information regarding the CBC, refer to the California Building Standards Commission website at www.bsc.ca.gov/].

The CBC provides requirements for structural design that apply to the construction, alteration, replacement, and demolition of every building or structure and any appurtenances connected or attached to such buildings or structures throughout the state of California. The code is meant to safeguard the public's health, safety and general welfare through structural strength, general stability and means of egress by regulating and controlling the design, construction, quality of materials, use and occupancy, location, and maintenance of all buildings and structures within its jurisdiction. It is important to recognize, however, that building codes provide **minimum** standards. With respect to seismic shaking, for example, the provisions of the building code are designed to prevent the catastrophic collapse of structures during a strong earthquake; however, structural damage to buildings, and potential loss of functionality, are expected. Specific provisions contained in the California Building Code that pertain to seismic and geologic hazards are discussed further in other sections of this document.

1.2.4 Unreinforced Masonry Law

Enacted in 1986, the Unreinforced Masonry Law (Senate Bill 547, codified in Section 8875 et seq. of the California Government Code) required all cities and counties in zones near historically active faults (Seismic Zone 4 per the Building Code at the time of the bill passage) to identify potentially hazardous unreinforced masonry (URM) buildings in their jurisdictions, establish an URM loss-reduction program, and report their progress to the State by 1990. The owners of such buildings were to be notified of the potential earthquake hazard these buildings posed. Some jurisdictions implemented mandatory retrofit programs, while others established voluntary programs. A few cities only notified the building owners, but did not adopt any type of strengthening program. Starting in 1997, California required all jurisdictions to enforce the 1997 Uniform Code for Building Conservation (UCBC) Appendix Chapter 1 as the model building code, although local governments could adopt amendments to that code under certain circumstances (ICBO, 2001; CSSC, 2006). The UCBC standards were meant to significantly reduce but not necessarily eliminate the risk to life from collapse of the structure. Prior to 1997, local governments could adopt other building standards that preceded the UCBC, and in fact, in many jurisdictions, retrofits were conducted in accordance with local ordinances that only partially complied with the latest UCBC. The 2013 California Building Code (CBC) includes building standards for historical buildings (2013 California Historical Building Code, Part 8 of Title 24), and building standards for existing buildings (2013 California Existing Building Code, Part 10 of Title 24) based on the 2012 International Existing Building Code.

According to the 2000, 2003 and 2006 reports by the Seismic Safety Commission on the "*Status of the Unreinforced Masonry Building Law*," the City of Coachella's initial survey indicated that there were 14 unreinforced masonry (URM) buildings in the city. However, a review of these buildings using metal detectors later showed that thirteen of these are reinforced. The one true URM in the city was reported as destroyed in a fire in 1994.

1.2.5 Real Estate Disclosure Requirements

Since June 1, 1998, the Natural Hazards Disclosure Act has required that sellers of real property and their agents provide prospective buyers with a "Natural Hazard Disclosure Statement" when the property being sold lies within one or more State-mapped hazard areas. For example, if a property is located in a Seismic Hazard Zone as shown on a map issued by the State Geologist, the seller or the seller's agent must disclose this fact to potential buyers. The law specifies two ways in which this disclosure can be made: (1) Using the Natural Hazards Disclosure Statement as provided in Section 1102.6c of the California Civil Code, or (2) using the Local Option Real Estate Disclosure Statement as provided in Section 1102.6a of the California Civil Code. The Local Option Real Estate Disclosure Statement (Option 2) can be substituted for the Natural Hazards Disclosure Statement (Option 1) only if the Local Option Statement contains substantially the same information and substantially the same warnings as the Natural Hazards Disclosure Statement.

California State law also states that when a house built before 1960 is sold, the seller must give the buyer a completed earthquake hazards disclosure report and a copy of the booklet entitled "The Homeowner's Guide to Earthquake Safety." This publication was written and adopted by the California Seismic Safety Commission. The most recent edition of this booklet is available from the web at www.seismic.ca.gov/. The booklet includes a sample of a residential earthquake hazards report that buyers are required to fill in, and describes structural weaknesses common in homes that if they fail in an earthquake can result in significant damage to the structure. The booklet then provides detailed information on actions that homeowners can take to strengthen their homes.

Those regions in the study area that have the potential of being impacted by seismically induced surface fault rupture (see Section 1.5) and liquefaction or slope instability (see Section 1.6), as identified in this report, should be disclosed to prospective buyers, following the provisions of the Natural Hazards Disclosure Act.

1.2.6 California Environmental Quality Act

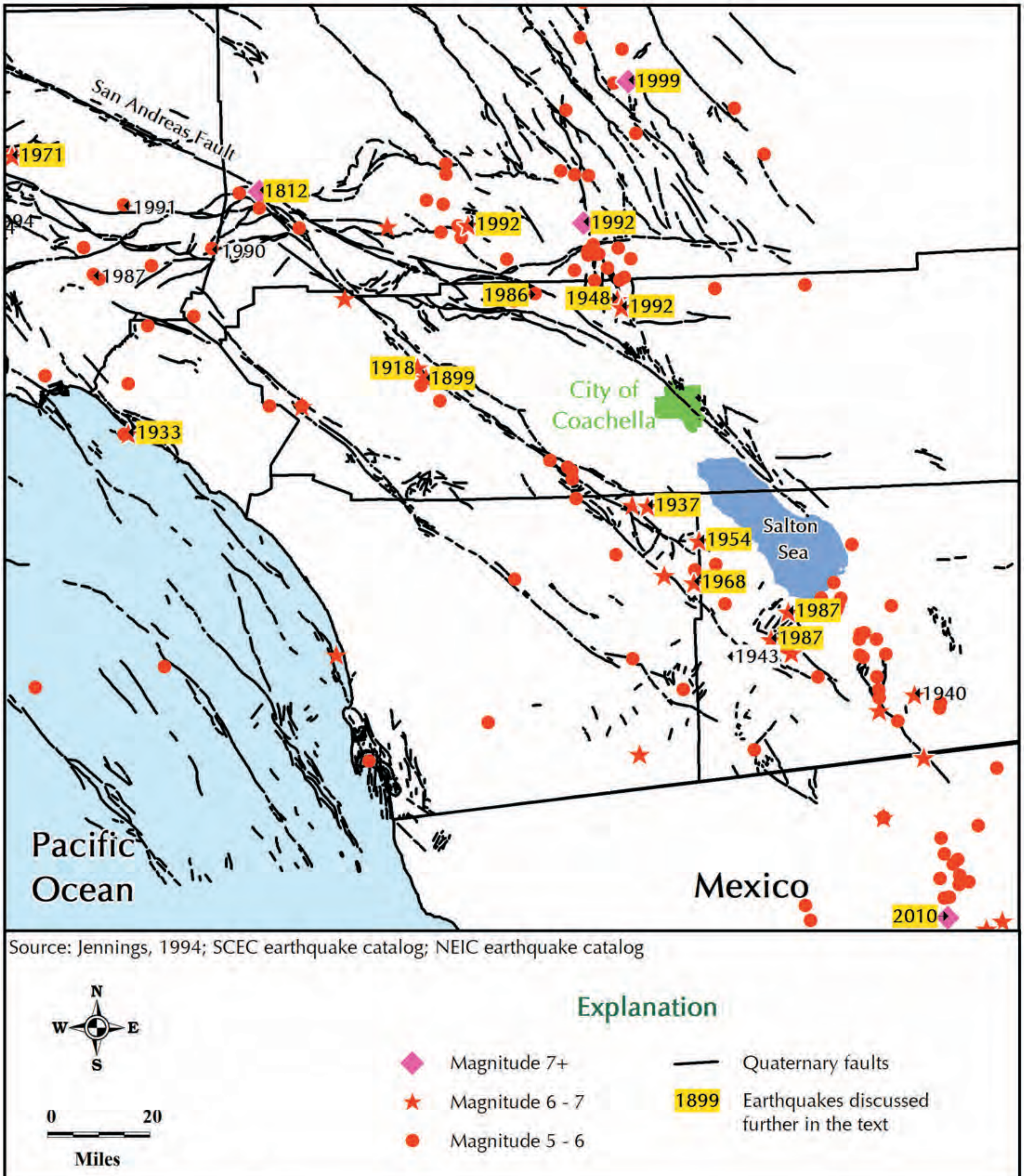
The California Environmental Quality Act (CEQA) was passed in 1970 to insure that local governmental agencies consider and review the environmental impacts of development projects within their jurisdictions. CEQA requires that an Environmental Impact Report (EIR) be prepared for projects that may have significant effects on the environment. EIRs are required to identify geologic and seismic hazards, and to recommend potential mitigation measures, thus giving the local agency the authority to regulate private development projects in the early stages of planning. The law requires that these documents be issued in draft form and made available at local libraries and City Hall for individuals and organizations to review and comment on. The comments are addressed in the final report submitted for approval or refusal by the Planning Commission and/or City Council.

1.3 Notable Past Earthquakes

Figure 1-2 shows the approximate epicenters of some of the historical earthquakes that have resulted in significant ground shaking in the southern California area, including Coachella. The most significant of these events, either because they were felt strongly in the area, or because they led to the passage of important legislation, are described below.

1.3.1 Wrightwood Earthquake of December 12, 1812

This large earthquake occurred on December 8, 1812 and was felt throughout southern California. Based on accounts of damage recorded at missions in the earthquake-affected area, an estimated magnitude of 7.5 has been calculated for the event (Toppozada et al., 1981). Subsurface investigations and tree ring studies show that the earthquake likely ruptured the Mojave Section of the San Andreas fault near Wrightwood, and may have been accompanied by



Earth Consultants International

Project Number: 3106/3218
Date: 2014

Notable Regional Earthquakes

Figure 1-2

a significant surface rupture between Cajon Pass and Tejon Pass (Jacoby, Sheppard and Sieh, 1988; www.scecdc.scec.org/quakedex.html). The worst damage caused by the earthquake occurred significantly west of the San Andreas fault at San Juan Capistrano Mission, where the roof of the church collapsed, killing 40 people. The earthquake also damaged walls and destroyed statues at San Gabriel Mission, and is thought to have triggered an earthquake thirteen days later that damaged several missions in the Santa Barbara area (Deng and Sykes, 1996). Strong aftershocks that occurred for several days after the main earthquake collapsed many buildings that had been damaged by the main shock.

1.3.2 San Jacinto Earthquake of 1899

This earthquake occurred at 4:25 in the morning on Christmas Day, in 1899. The main shock is estimated to have had a magnitude of 6.5. Several smaller aftershocks followed the main shock, and in the town of San Jacinto, as many as thirty smaller tremors were felt throughout the day. The epicenter of this earthquake is not well located, but damage patterns suggest the location shown on Figure 1-2, near the town of San Jacinto, with the causative fault most likely being the San Jacinto fault. Both the towns of San Jacinto and Hemet reported extensive damage, with nearly all brick buildings either badly damaged or destroyed. Six people were killed in the Soboba Indian Reservation as a result of falling adobe walls. In Riverside, chimneys toppled and walls cracked (Claypole, 1900). The main earthquake was felt over a broad area that included San Diego to the southwest, Needles to the northeast, and Arizona to the east. No surface rupture was reported, but several large "sinks" or subsidence areas were reported about 10 miles to the southeast of San Jacinto.

1.3.3 San Jacinto Earthquake of 1918

This magnitude 6.8 earthquake occurred on April 21, 1918 at 2:32 P.M. Pacific Standard Time (PST), near the town of San Jacinto. The earthquake caused extensive damage to the business districts of San Jacinto and Hemet, where many masonry structures collapsed, but because it occurred on a Sunday, when these businesses were closed, the number of fatalities and injuries was low. Several people were injured, but only one death was reported. Minor damage as a result of this earthquake was reported outside the San Jacinto area, and the earthquake was felt as far away as Taft (west of Bakersfield), Seligman (Arizona), and Baja California.

Strong shaking cracked the ground, concrete roads, and concrete irrigation canals, but none of the cracks are thought to have been caused directly by surface fault rupture. The shaking also triggered several landslides in mountain areas. The road from Hemet to Idyllwild was blocked in several places where huge boulders rolled down slopes. Two men in an automobile were reportedly swept off a road by a landslide, and would have rolled several hundred feet down a hillside had they not been stopped by a large tree. Two miners were trapped in a mine near Winchester, but they were eventually rescued, uninjured. The earthquake apparently caused changes in the flow rates and temperatures of several springs. Sand craters (due most likely to liquefaction) were reported on one farm, and an area near Blackburn Ranch "sunk" approximately three feet (one meter) during the quake (/www.scecdc.scec.org/quakedex.html).

1.3.4 Long Beach Earthquake of 1933

The M_w 6.4 Long Beach earthquake occurred on March 10, at 5:54 P.M. PST, following a strong foreshock the day before. The earthquake killed 115 people and caused $40 to 50 million in property damage (www.scecdc.scec.org/quakedex.html). The earthquake ruptured the Newport-Inglewood fault, and shaking was felt from the San Joaquin Valley to Northern Baja California (Mexico). Although its epicenter was located at the boundary between Huntington Beach and Newport Beach, the tremor was called "the Long Beach earthquake" because the worst damage was focused in the city of Long Beach. Although this earthquake occurred far away from the Coachella area and was probably not felt here, it is discussed in this report because it led to code changes that apply to all of California. Specifically, the regional significance of this earthquake is that damage to school buildings was especially severe, which led to the passage of the Field and Riley Acts by the State legislature. The Field Act regulates school construction and the Riley Act regulates the construction of buildings larger than two-family dwellings.

1.3.5 San Jacinto Fault Earthquake of 1937

This magnitude 6.0 earthquake occurred on March 25, 1937 at 8:49 AM PST, just after the advent of modern seismology, and as a result, it is one of the first earthquakes for which both an epicentral location and numerical magnitude value (using the then newly developed Richter scale) were determined. The event is known as the Terwilliger Valley earthquake, although this is actually a misnomer, since its epicenter is almost 19 miles (30 km) to the east-southeast of Terwilleger Valley. The earthquake caused very little damage given that the epicentral area was (and still is) sparsely populated. Nevertheless, a few chimneys were toppled, plaster cracked, and windows broke in structures located relatively near the epicenter (Wood, 1937). "It was recognized at the time, however, that the quake could have easily caused the kind of damage seen in Santa Barbara in 1925 or in Long Beach in 1933, had it been located in a densely populated area, being nearly the same magnitude as those destructive quakes" (http://www.data.scec.org/chrono_index/sanj37.html).

1.3.6 Desert Hot Springs Earthquake of 1948

This magnitude 6.0 earthquake struck on December 4, 1948 at 3:43 P.M. PST. The fault involved is believed to be the South Branch of the San Andreas (or Banning fault, depending on nomenclature used). The Desert Hot Springs earthquake of 1948 not only was felt over a large area (as far away as central Arizona, parts of Mexico, Santa Catalina Island, and Bakersfield), but also caused notable damage in regions far from the epicenter. In the Los Angeles area, a 5,800-gallon water tank split open, water pipes were broken at UCLA and in Pasadena, and plaster cracked and fell from many buildings. In San Diego, a water main broke. In Escondido and Corona, walls were cracked. The administration building of Elsinore High School was permanently closed due to the damage it sustained, as was a building at the Emory School in Palm City. Closer to the epicenter, landslides and ground cracks were reported, and a road leading to the Morongo Indian Reservation was badly damaged (Louderback, 1949). In Palm Springs, the city hit hardest by the quake, thousands of dollars of merchandise was thrown from shelves and destroyed. Part of a furniture store collapsed. Two people were injured when the shaking induced a crowd to flee a movie theater in panic. Numerous other instances of minor structural damage were reported. Fortunately, despite the damage brought on by this earthquake, no lives were lost.

1.3.7 San Jacinto Fault Earthquake of 1954

This magnitude 6.4 earthquake struck on March 19, 1954 at 1:54 A.M. PST. Magistrale et al. (1989) suggest that the Clark fault of the San Jacinto Fault Zone was involved. The 1954 San Jacinto fault earthquake, sometimes referred to as the Arroyo Salada earthquake, caused minor damage over a wide area of southern California, cracking plaster walls as far away as San Diego, and knocking plaster from the ceiling at the Los Angeles City Hall. In Palm Springs, a water pipe was broken, and the walls of several swimming pools were cracked. Part of San Bernardino experienced a temporary blackout when power lines snapped in the shaking. Indio and Coachella also experienced minor damage. The shock was felt as far away as Ventura County, Baja California, and Las Vegas (Louderback, 1954).

1.3.8 Borrego Mountain Earthquake of 1968

This magnitude 6.5 earthquake struck on April 8, 1968 at 6:29 P.M. It resulted in about 18 miles of surface rupture along the Coyote Creek fault (a branch of the San Jacinto Fault Zone), and triggered slip was observed on fault systems up to 40 miles away. When the Borrego Mountain earthquake struck, it was the largest and most damaging quake to hit southern California since the Kern County earthquake of 1952. It was felt as far away as Las Vegas, Fresno, and even Yosemite Valley. The quake caused damage across most of southern California – power lines were severed in San Diego County, plaster cracked in Los Angeles, and the Queen Mary, in dry-dock at Long Beach, rocked back and forth on its keel blocks for 5 minutes. A few ceilings collapsed at various places in the Imperial Valley. Close to the epicenter, the quake caused landslides, hurling large boulders downslope, damaging campers' vehicles at Anza-Borrego Desert State Park, and caused minor surface rupture, cracking Highway 78 at Ocotillo Wells (Lander, 1968).

The event apparently caused small displacements along the Superstition Hills fault (2.2 cm), Imperial fault (1.2 cm), and the Banning-Mission Creek fault (0.9 cm), 28, 43.5, and 31 miles (45, 70, and 50 km), respectively, from the epicenter. These fresh breaks and displacements were not noticed immediately after the mainshock, but no other significant events occurred within the interim that could have caused them. These are probably among the first noted instances of triggered slip, and they proved to be some of the most intriguing features of the Borrego Mountain earthquake.

1.3.9 San Fernando (Sylmar) Earthquake of 1971

This magnitude 6.6 earthquake occurred on the San Fernando Fault Zone, the westernmost segment of the Sierra Madre fault, on February 9, 1971, at 6:00 A.M. The surface rupture caused by this earthquake was nearly 12 miles long, and occurred in the Sylmar-San Fernando area. The maximum slip measured at the surface was nearly six feet. The earthquake caused over $500 million in property damage and 65 deaths. Most of the deaths occurred when the Veteran's Administration Hospital collapsed. Several other hospitals, including the Olive View Community Hospital in Sylmar suffered severe damage. Newly constructed freeway overpasses also collapsed, in damage scenes similar to those that occurred 23 years later in the 1994 Northridge earthquake. Loss of life could have been much greater had the earthquake struck at the busier time of the day. As with the Long Beach earthquake, legislation was passed in response to the damage caused by the 1971 earthquake. In this case, the building codes were strengthened and the Alquist-Priolo Special Studies Zones Act (now call the Earthquake Fault Zoning Act, see Section 1.2.1) was passed in 1972.

1.3.10 North Palm Springs Earthquake of 1986

This magnitude 5.6 earthquake occurred on July 8, 1986 at 2:21 A.M. PDT, along either the Banning fault or the Garnet Hill fault. The epicenter was about 6 miles northwest of Palm Springs, and about 31 miles from Coachella. The North Palm Springs earthquake was responsible for at least 29 injuries and the destruction or damage of 51 homes in the Palm Springs-Morongo Valley area. It also triggered landslides in the region. Damage caused by this quake was estimated at over $4 million. Ground cracking was observed along the Banning, Mission Creek, and Garnet Hill faults, but these cracks were due to shaking, not surface rupture (Person, 1986). Most of the ground fractures occurred on the northern side of the fault, between Whitewater Canyon on the west, and Highway 62 on the east. Fractures varied from single, discontinuous breaks less than 1 mm wide, to extensively fractured zones 30 to 40 m (100 to 120 feet) wide (Morton et al., 1989).

1.3.11 Elmore Ranch and Superstition Hills Earthquakes of 1987

The magnitude 6.2 Elmore Ranch earthquake struck on November 23, 1987 at 5:54 P.M. PST. This earthquake resulted in left-lateral strike-slip motion along the Elmore Ranch and associated faults, and appears to have triggered a larger earthquake the next morning on the right-lateral Superstition Hills fault, which is perpendicular to the Elmore Ranch system (Hudnut et al., 1989). A maximum surface offset of 12.5 centimeters was reported, and the faults where surface rupture was observed included the Elmore Ranch (main, west, and east branches), Lone Tree, and Kane Spring (main and east branches). The magnitude 6.6 Superstition Hills earthquake occurred the morning of November 24, at 6:16 A.M. PST, near the Salton Sea. A maximum surface offset of about 50 cm (20 inches) was observed on the Superstition Hills fault within 24 hours of the earthquake. However, during the next several months, the offset was observed to have increased to nearly 1 meter (3 ft), and triggered slip was observed on the Imperial, San Andreas, and Coyote Creek faults (Sharp et al., 1989).

1.3.12 Joshua Tree Earthquake of 1992

This magnitude 6.1 earthquake struck on April 22, 1992 at 9:50 P.M. PST, approximately 21 miles north of Coachella. This event resulted from right-lateral strike-slip faulting and was preceded by a magnitude 4.6 foreshock. The earthquake sequence raised some alarms due to the San Andreas fault's proximity; scientists assigned the San Andreas fault a 5 to 25 percent chance of generating an even larger earthquake within three days. Although an earthquake on the San Andreas fault did not materialize, the Landers earthquake occurred roughly two months and 6,000 aftershocks later, showing that the concern caused by the Joshua Tree earthquake was at least partially warranted (http://www.data.scec.org/chrono_index/joshuatr.html). There was no surface rupture associated with the Joshua Tree event, but aftershocks of the quake suggested that the fault that slipped was a north- to northwest-trending, right-lateral strike-slip fault at least 15 km long (Jones et al., 1995). Based on these data, researchers suggest that the Eureka Peak fault may have been the fault responsible for this earthquake.

Damage caused by the Joshua Tree earthquake was slight to moderate in the communities of Joshua Tree, Yucca Valley, Desert Hot Springs, Palm Springs, and Twentynine Palms. Thirty-two people were treated for minor injuries. Though somewhat forgotten in the wake of the Landers earthquake, the Joshua Tree quake was a significant event on its own, and was felt as far away as San Diego, Santa Barbara, Las Vegas, Nevada, and even Phoenix, Arizona (Person, 1992).

1.3.13 Landers Earthquake of 1992

On the morning of June 28, 1992, most people in southern California were awakened at 4:57 by the largest earthquake to strike California in 40 years. Named "Landers" after the small desert community near its epicenter, the earthquake had a magnitude of 7.3. The power of the earthquake was illustrated by the length of the ground rupture it left behind. More than 50 miles of surface rupture associated with five or more faults occurred as a result of this earthquake. The earthquake ruptured five separate faults: Johnson Valley, Landers, Homestead Valley, Emerson, and Camp Rock faults (Sieh et al., 1993). Other nearby faults also experienced triggered slip and minor surface rupture. The average right-lateral strike-slip displacement was about 10 to 15 feet, but a maximum of up to 18 feet was observed. Centered in the Mojave Desert approximately 120 miles from Los Angeles and 39 miles from Coachella, the earthquake caused relatively little damage for its size (Brewer, 1992). It released about four times as much energy as the very destructive 1989 Loma Prieta earthquake in the San Francisco area, but fortunately, it did not claim as many lives (one child died in Yucca Valley when bricks from the collapsed chimney fell into the room where he was sleeping).

1.3.14 Big Bear Earthquake of 1992

This magnitude 6.4 earthquake struck a little more than three hours after the Landers earthquake on June 28, 1992, at 8:05:30 A.M. PDT. This earthquake is technically considered an aftershock of the Landers earthquake (indeed, the largest aftershock), although the Big Bear earthquake occurred over 20 miles west of the Landers rupture, on a fault with a different orientation and sense of slip than those involved in the main shock. From its aftershocks, the causative fault was determined to be a northeast-trending left-lateral fault. This orientation and slip are considered "conjugate" to the faults that slipped in the Landers rupture. The Big Bear earthquake did not break the ground surface, and, in fact, no surface trace of a fault with the proper orientation has been found in the area.

The Big Bear earthquake caused a substantial amount of damage in the Big Bear area, but fortunately, it claimed no lives. However, landslides triggered by the quake blocked roads in that mountainous area, aggravating the clean-up and rebuilding process (www.scecdc.scec.org/ quakedex.html).

1.3.15 Hector Mine Earthquake of 1999

Southern California's most recent large earthquake was a widely felt magnitude 7.1. It occurred on October 18, 1999, in a remote region of the Mojave Desert, 47 miles east-southeast of Barstow, and more than 60 miles from Coachella. Modified Mercalli Intensities of VI (Table 1-1) were reported by two individuals in the Coachella area (http://earthquake.usgs.gov/ earthquakes/dyfi/events/ci/hectormi/us/index.html). The Hector Mine earthquake is not considered an aftershock of the M 7.3 Landers earthquake of 1992, although Hector Mine occurred on similar, north-northwest trending strike-slip faults within the Eastern Mojave Shear Zone. Geologists documented a 25-mile (40-km) long surface rupture and a maximum right-lateral strike-slip offset of about 16 feet on the Lavic Lake fault.

1.3.16 Baja California Earthquake of 2010

A magnitude 7.2 earthquake that occurred just south of the U.S. / Mexico border on Easter Sunday, April 4, 2010, at 3:40:42 PM PDT, was felt throughout Mexico, southern California, Arizona, and Nevada. Researchers who reviewed the seismograph data found that here were two sub-events: first a magnitude 6 earthquake that ruptured an 18-km section of the Pescadores fault, followed, about 15 seconds later, by a larger event on the Borrego fault. Both of these faults are part of the Laguna Salada fault system, which is the southern extension of the Elsinore fault. The total length of the zone of surface rupture is approximately 120 km (75 miles), extending across several faults, some unknown prior to the earthquake. Maximum surface fault rupture of about 4.3 m (14 feet) of predominantly right-lateral displacement was measured on the Pescadores fault; both right-lateral strike-slip and down-to-the-east vertical displacements were observed along the zone of fault rupture.

Surface rupture continued northward to just past the border into California. The main earthquake caused triggered slip of up to a few centimeters on several faults in the Salton Sea area, and as far north as the Mecca Hills, about 8 miles to the southeast of Coachella (Weldon, 2010; Wei et al., 2011). Secondary effects, including liquefaction, rockfalls and shattering were reported along a wide area in the El Centro and Brawley region, and westward toward San Diego. A peak instrumental ground acceleration of 1.1g was recorded at the Salton Sea. Similar or stronger shaking may have occurred closer to the epicenter, but given the lack of instrumentation in that area, went unrecorded. Based on observations reported by at least 30 residents, shaking in Coachella as a result of this earthquake was moderate, in the Modified Mercalli intensity V range (http://earthquake.usgs.gov/earthquakes/dyfi/events/ci/14607652/

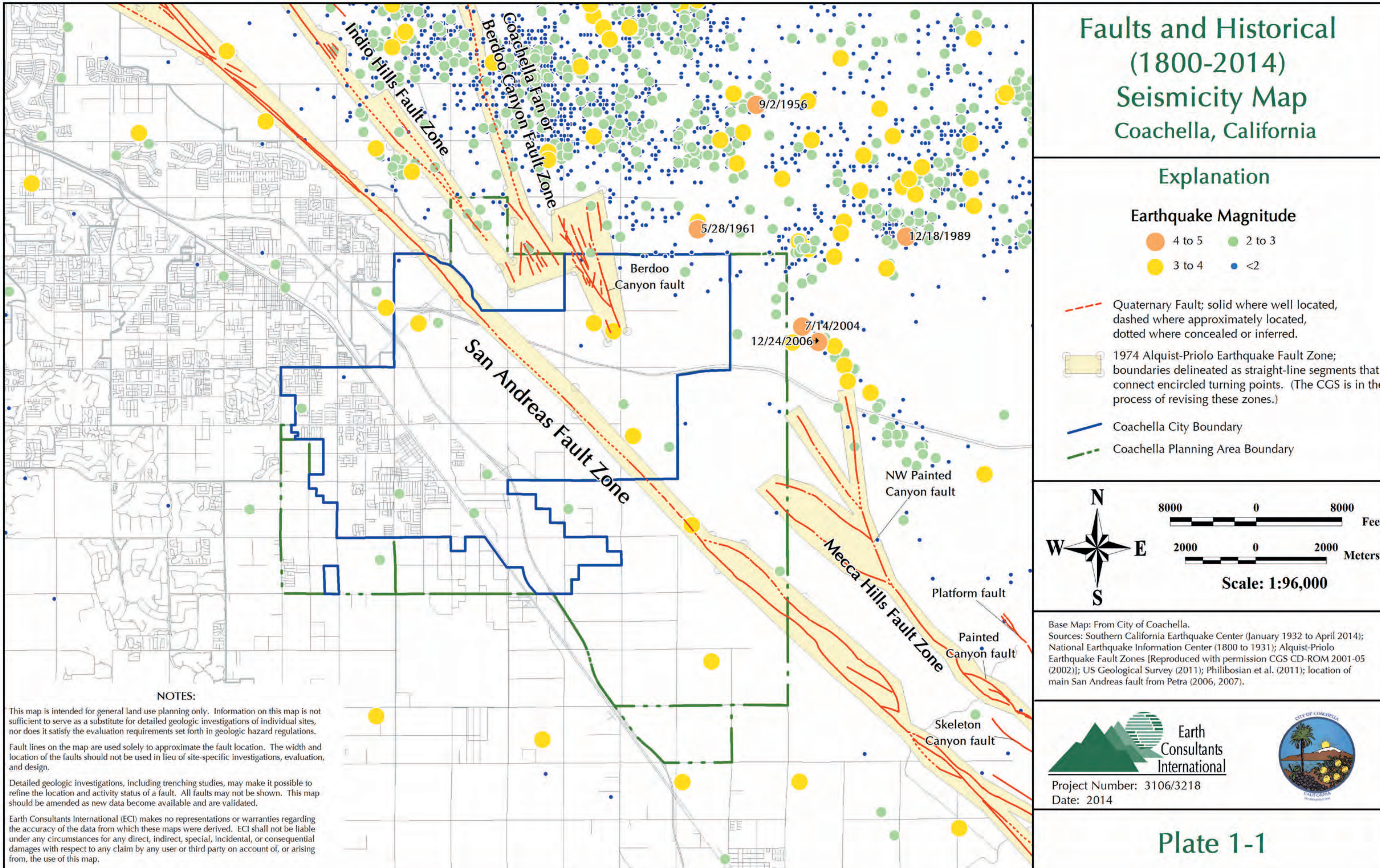
us/index.html). By November 2010, more than 10,000 aftershocks had been recorded (Hauksson et al., 2010). Many of the aftershocks occurred along the Elsinore, San Jacinto, and the southern extension of the San Andreas fault through the Brawley area. The largest aftershock was a magnitude 5.7 on June 14, 2010 that occurred just north of the International Border, about 5 miles from Ocotillo.

In addition to the earthquakes described above, hundreds of small earthquakes have occurred and will continue to occur in the immediate vicinity of Coachella. Plate 1-1 shows the epicentral locations of earthquakes in and around the city that were instrumentally detected between 1932 and April 2014, and those estimated to have occurred in the area between about 1800 and 1932. Earthquakes that occurred prior to 1932 are only approximately located because prior to that year there were no instruments available to measure the location and magnitude of an earthquake. The map shows that only a few magnitude 4 and smaller earthquakes have occurred in the Coachella General Plan area proper. Significant seismicity occurs to the east and northeast, along the San Andreas Fault Zone, and farther east, in the Mojave or Eastern California Shear Zone. The largest of these, in the magnitude 4 to 5 range, have all occurred to the east and northeast of the Coachella General Plan study area (see Plate 1-1), and although most likely associated with the San Andreas fault, are not directly linked with known mapped traces of the fault. The historical earthquake distribution shown on Plate 1-1 illustrates the concept that the southern San Andreas fault is locked, and presumed to be accumulating strain that will eventually be unleashed in a large-magnitude surfacing-rupturing earthquake.

1.4 Seismic Ground Shaking

Strong ground shaking causes the vast majority of earthquake damage. As mentioned previously, when a fault breaks in the subsurface, the seismic energy released by the earthquake radiates away from the hypocenter (the focus or section of the fault plane that first ruptures) in waves that are felt at the surface as shaking. In general, the bigger and closer the earthquake, the more damage it may cause. However, other effects discussed below are also important. Earthquakes are typically classified by the amount of damage reported, or by how strong and how far the shaking was felt. An early measure of earthquake size still used today is the seismic intensity scale, which is a qualitative assessment of an earthquake's effects at a given location. The most commonly used measure of seismic intensity is called the ***Modified Mercalli Intensity*** (MMI) scale, which has 12 damage levels (see Table 1-1). Although it has limited scientific application, intensity is intuitively clear and quick to determine. Keep in mind, however, that earthquake damage depends on the characteristics of human-made structures, and the complex interaction between the ground motions and the built environment. Governing factors include a building's height, construction, and stiffness, which determine the structure's resonant period; the underlying soil's strength and resonant period; and the periods of the incoming seismic waves. Other factors include architectural design, condition, and age of the structures.

Scientists used to measure the amplitude of ground motion, as recorded by an instrument a given distance from the epicenter, to report the size of an earthquake (such as the now outdated Richter magnitude). Seismologists have determined that the most meaningful factor in determining the size of an earthquake is the amount of energy released when a fault ruptures. This measure is called the ***seismic moment*** (abbreviated M_w), and most moderate to large earthquakes today are reported using moment magnitude. Both traditional magnitude scales and seismic moment scales are logarithmic. Thus, each one-point increase in magnitude represents a ten-fold increase in amplitude of the waves as measured at a specific location, and a 32-fold increase in energy. That is, a magnitude 7 earthquake produces 100 times (10 x 10) the ground motion amplitude of a magnitude 5 earthquake. Similarly, a moment magnitude 7 earthquake releases approximately 1,000 times more energy (32 x 32) than a moment magnitude 5 earthquake.



Faults and Historical (1800-2014) Seismicity Map
Coachella, California
Indio Hills Fault Zone
Coachella Fan or Berdoo Canyon Fault Zone
9/2/1956
5/28/1961
12/18/1989
Berdoo Canyon fault
7/14/2004
12/24/2006
San Andreas Fault Zone
NW Painted Canyon fault
Mecca Hills Fault Zone
Platform fault
Painted Canyon fault
Skeleton Canyon fault
Explanation
Earthquake Magnitude
4 to 5
2 to 3
3 to 4
<2
Quaternary Fault; solid where well located, dashed where approximately located, dotted where concealed or inferred.
1974 Alquist-Priolo Earthquake Fault Zone; boundaries delineated as straight-line segments that connect encircled turning points. (The CGS is in the process of revising these zones.)
Coachella City Boundary
Coachella Planning Area Boundary
N
W
E
S
8000 0 8000 Feet
2000 0 2000 Meters
Scale: 1:96,000
Base Map: From City of Coachella.
Sources: Southern California Earthquake Center (January 1932 to April 2014); National Earthquake Information Center (1800 to 1931); Alquist-Priolo Earthquake Fault Zones [Reproduced with permission CGS CD-ROM 2001-05 (2002)]; US Geological Survey (2011); Philibosian et al. (2011); location of main San Andreas fault from Petra (2006, 2007).
Earth Consultants International
Project Number: 3106/3218
Date: 2014
CITY OF COACHELLA
CALIFORNIA
Plate 1-1
NOTES:
This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.
Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.
Detailed geologic investigations, including trenching studies, may make it possible to refine the location and activity status of a fault. All faults may not be shown. This map should be amended as new data become available and are validated.
Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.

An important point to remember is that any given earthquake will have one moment and, in principle, one magnitude, although there are several methods of calculating magnitude, which give slightly different results. However, one earthquake will produce many levels of intensity because intensity effects vary with the location and the perceptions of the observer.

Another measure of the size and felt effects of an earthquake at a given location is ground acceleration. Acceleration is a measure of the forces released by the earthquake that result in the shaking of the ground we associate with earth tremors. Acceleration is scaled using as a reference the **acceleration due to gravity**, **g**, defined as the acceleration at which an object falls if released at rest in a vacuum. Horizontal ground acceleration is frequently responsible for widespread damage to structures, so structural engineers use estimates of horizontal ground acceleration that a building may be expected to experience during its lifetime to design the building. To make these estimates, it is important to know a fault's style of movement (i.e., is it dip-slip or strike-slip), total displacement, slip rate, and the age of its most recent activity. These values allow an estimation of how often a fault produces damaging earthquakes, and how big an earthquake should be expected the next time the fault ruptures. Full characterization of shaking potential also requires estimates of peak (maximum) ground displacement and velocity, the duration of strong shaking, and the periods (lengths) of waves that will control each of these factors at a given location.

In general, the degree of shaking can depend upon:

- **Source effects**. These include earthquake size, location, and distance. In addition, the exact way that rocks move along the fault can influence shaking. For example, the 1995, M_W 6.9 Kobe, Japan earthquake was not much bigger than the 1994, M_W 6.7 Northridge, California earthquake, but the city of Kobe suffered much worse damage. This is in part because during the Kobe earthquake, the fault's orientation and movement directed seismic waves into the city, whereas during the Northridge earthquake, the fault's motion directed waves away from populous areas.

- **Path effects**. Seismic waves change direction as they travel through the Earth's contrasting layers, just as light bounces (reflects) and bends (refracts) as it moves from air to water. Sometimes seismic energy gets focused in one location and causes damage in unexpected areas. Focusing of the seismic waves during the 1989 M_W 7.1 Loma Prieta earthquake caused damage in San Francisco's Marina district, some 62 miles (100 km) distant from the rupturing fault.

- **Site effects**. Seismic waves slow down in the loose sediments and weathered rock at the Earth's surface. As they slow, their energy converts from speed to amplitude, which heightens shaking. This is similar to the behavior of ocean waves – as the waves slow down near shore, their crests grow higher. The Marina District of San Francisco also serves as an example of site effects. Earthquake motions were greatly amplified in the deep, sediment-filled basin underlying the District compared to the surrounding bedrock areas. Seismic waves can get trapped at the surface and reverberate (resonate). Whether resonance will occur depends on the period (the length) of the incoming waves. Waves, soils and buildings all have resonant periods. When these coincide, tremendous damage can occur.

[Waves repeat their motions with varying frequencies. Slow-to-repeat waves are called long-period waves. Quick-to-repeat waves are called short-period waves. Long-period seismic waves, which are created by large earthquakes, are most likely to reverberate and cause damage in long-period structures, like bridges and high-rise buildings that respond to long-period waves. Shorter-period seismic waves, which tend to die out quickly, will most often cause damage in areas relatively close to the rupturing fault, and they will cause most damage to shorter-period structures such as one- to three-story buildings. Very short-period waves are most likely to cause near-fault, interior damage, such as to equipment.]

Table 1-1: Abridged Modified Mercalli Intensity Scale

Intensity Value and Description		Average Peak Velocity (cm/sec)	Average Peak Acceleration (g = gravity)
I.	Not felt except by very few under especially favorable circumstances (I Rossi-Forel scale). Damage potential: None.	<0.1	<0.0017
II.	Felt only by a few persons at rest, especially on upper floors of high-rise buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale). Damage potential: None.	0.1 – 1.1	0.0017 – 0.014
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people did not recognize it as an earthquake. Standing automobiles may have rocked slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale). Damage potential: None.		
IV.	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made creaking sound. Sensation like a heavy truck striking building. Standing automobiles rocked noticeably. (IV to V Rossi-Forel scale). Damage potential: None. Perceived shaking: Light.	1.1 – 3.4	0.014 - 0.039
V.	Felt by nearly everyone; many awakened. Some dishes, windows, and so on broken; plaster cracked in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may have stopped. (V to VI Rossi-Forel scale). Damage potential: Very light. Perceived shaking: Moderate.	3.4 – 8.1	0.039-0.092
VI.	Felt by all; many frightened and ran outdoors. Some heavy furniture moved, few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale). Damage potential: Light. Perceived shaking: Strong.	8.1 - 16	0.092 -0.18
VII.	Everybody ran outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (VIII Rossi-Forel scale). Damage potential: Moderate. Perceived shaking: Very strong.	16 - 31	0.18 - 0.34
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (VIII+ to IX Rossi-Forel scale). Damage potential: Moderate to heavy. Perceived shaking: Severe.	31 - 60	0.34 - 0.65
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel scale). Damage potential: Heavy. Perceived shaking: Violent.	60 - 116	0.65 – 1.24
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (X Rossi-Forel scale). Damage potential: Very heavy. Perceived shaking: Extreme.	> 116	> 1.24
XI.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.		
XII.	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.		

Modified from Bolt (1999); Wald et al. (1999).

Seismic shaking has the potential to impact the Coachella area, given that the city is bisected by the most significant seismic source (fault) in southern California, the San Andreas, and not too distant from several other faults. In order to provide a better understanding of the shaking hazard posed by those faults near the General Plan area, we conducted a deterministic seismic hazard analysis for a central point in the city (City Hall) and several other randomly selected points in the General Plan area using the software program EQFAULT by Blake (2000). This analysis estimates the Peak Horizontal Ground Accelerations (PHGA) that could be expected at these locations due to earthquakes occurring on any of the known active or potentially active faults within about 62 miles (100 km). The fault database (including fault locations and earthquake magnitudes of the maximum magnitude earthquakes for each fault) used to conduct these seismic shaking analyses is that used by the California Geological Survey (CGS) and the U.S. Geological Survey (USGS) for the National Seismic Hazard Maps (Petersen et al., 1996; Cao et al., 2003). However, as described further in the text, recent paleoseismic studies suggest that some of these faults may actually generate even larger earthquakes than those used in the analysis. Where appropriate, this is discussed further below.

PHGA depends on the size of the earthquake (which is dependent on the rupturing fault's dimensions), the proximity of the rupturing fault to the study site, and local soil conditions. Effects of soil conditions are estimated by use of an attenuation relationship derived empirically from an analysis of recordings of earthquake shaking in similar soils during earthquakes of various sizes and distances. Given that most of the developed portions of Coachella are underlain by alluvial sediments, we used alluvium for most of the deterministic analyses conducted for this study, and the attenuation relationships of Campbell and Bozorgnia (2000, 2003, revised, alluvium), and Boore et al. (1997; with NEHRP soil type D). The ground motions presented here are the ranges of the acceleration values calculated using these two attenuation equations.

Based on the ground shaking analyses described above, those faults that can cause peak horizontal ground accelerations of about 0.1g or greater (Modified Mercalli Intensities greater than VII) in the Coachella area are listed in Table 1-2. For maps showing most of these faults, refer to Figure 1-1 and Plate 1-2. Those faults included in Table 1-2 that could have the greatest impact on the Coachella area, or that are thought to have a higher probability of causing an earthquake, are described in more detail in the following pages. The deterministic analyses indicate that the San Andreas fault has the potential to generate very strong to moderate ground shaking in Coachella, with PGHA (median) of between about 0.5g and 1.05g (between 0.73g and 1.76g at the median plus 1 sigma standard deviation level). Shaking at these levels can cause significant damage to older structures, and moderate to significant damage to newer buildings constructed in accordance with the latest building code provisions. Other faults that may generate moderate to strong shaking in the study area include the San Jacinto, Burnt Mountain and Eureka Peak faults.

Table 1-2 shows:

- The approximate distance, in miles and kilometers, between the fault and various points in the Coachella area, given as a range. Since these measurements are based on specific, but randomly selected points in the study area; other points in the city could be closer or farther away from the faults than the distances provided herein;
- The maximum magnitude earthquake (M_{max}) each fault is estimated capable of generating;
- The range in peak ground horizontal accelerations (PGHA), provided both for the median (50^{th} percentile) and median plus 1 sigma standard deviation (84^{th} percentile), or intensity of ground motion, expressed as a fraction of the acceleration of gravity (g), that could be experienced in different areas of Coachella if the M_{max} occurs on the faults listed; and

- The range in Modified Mercalli seismic Intensity (MMI) values estimated for the Coachella area.

Table 1-2: Estimated Horizontal Peak Ground Accelerations and Seismic Intensities in the Coachella General Plan Area

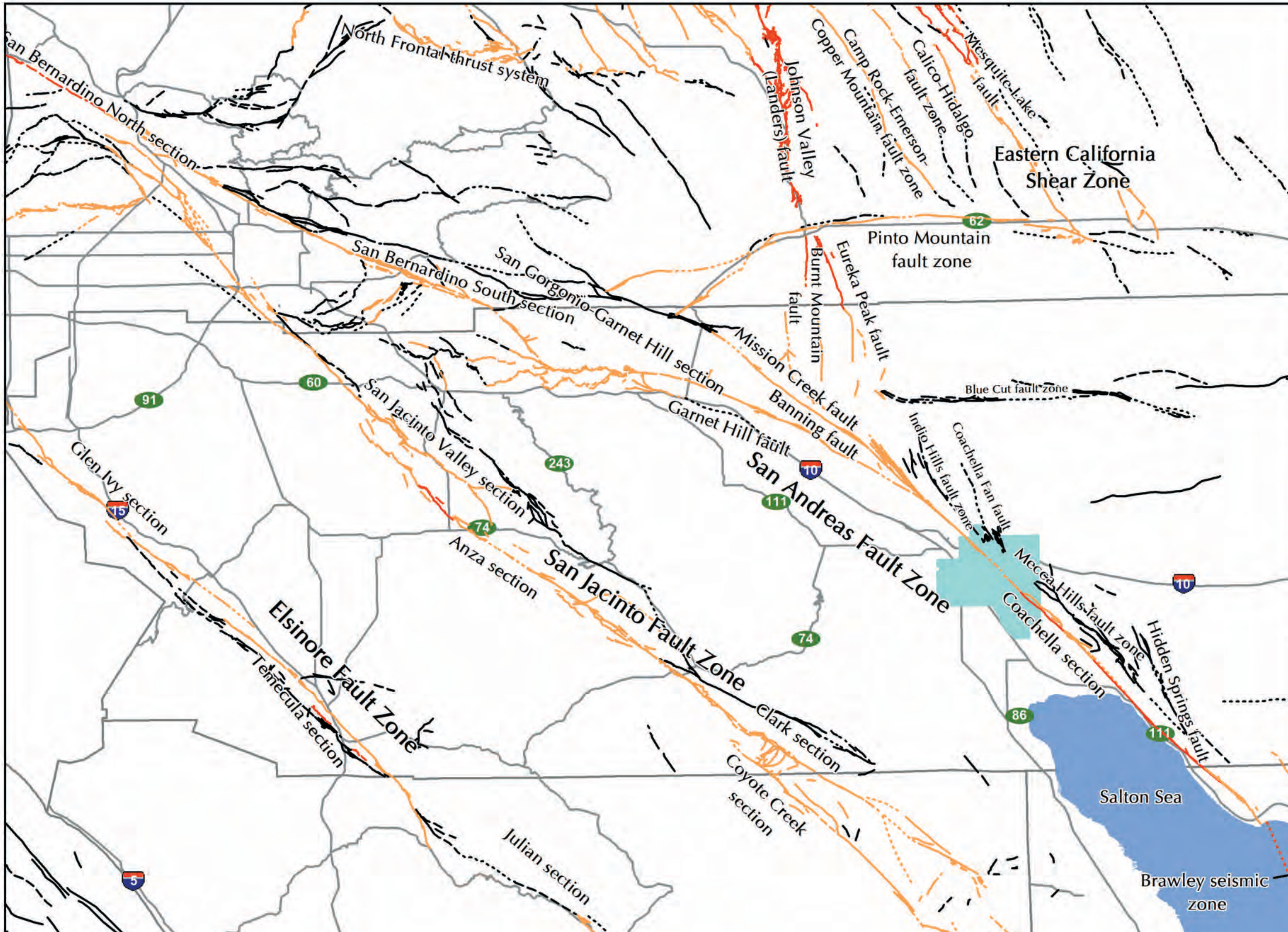
Fault or Fault Segment	Approx. Distance to Coachella (mi)	Approx. Distance to Coachella (km)	Magnitude of M_{max}	PGHA (g) from M_{max} (median, median + 1 sigma)	MMI from M_{max}
San Andreas fault (entire Southern)	0 – 6	0 – 10	8.0	1.05 – 0.5, 1.76 – 0.73	XII - X
San Andreas (Coachella segment)	0 – 6	0 – 10	7.2	0.69 – 0.42 1.15 – 0.63	XII - X
San Andreas (Coachella + San Bernardino)	0 – 6	0 – 10	7.7	0.89 – 0.47, 1.50 – 0.70	XII - X
San Andreas (San Bernardino)	21 – 29	34 – 46	7.5	0.20 –0.10, 0.31 –0.13	IX - VII
San Jacinto (Anza)	19 – 26	30 – 42	7.2	0.18 – 0.10, 0.27 – 0.15	IX – VII
Pisgah – Bullion Mtn. – Mesquite Lake	30 – 37	48 – 60	7.3	0.14 – 0.07, 0.23 – 0.12	IX - VI
Pinto Mountain	28 – 35	45 – 57	7.2	0.11 – 0.06, 0.22 – 0.11	IX – VI
Landers (Landers-like earthquake)	32 – 40	51 – 65	7.3	0.12 – 0.05, 0.21 – 0.09	VIII - VI
Burnt Mountain	18 – 26	29 – 42	6.5	0.12 – 0.05, 0.20 – 0.09	VIII - VI
Eureka Peak	18 – 26	29 – 42	6.4	0.12 – 0.05, 0.20 – 0.08	VIII - VI
San Jacinto (Clark)	21 – 28	33 – 45	6.6	0.10 – 0.05, 0.17 – 0.09	VIII – VI
Calico – Hidalgo	43 – 51	70 – 81	7.3	0.10 – 0.04, 0.17 – 0.07	VIII - V
Lenwood – Lockhart – Old Woman Springs	50 - 58	81 – 93	7.5	0.10 – 0.04, 0.17 – 0.06	VIII - V
North Frontal Fault (East)	39 – 47	63 – 75	6.7	0.10 – 0.03, 0.16 – 0.04	VIII - V
North Frontal Fault (West)	53 – 60	85 – 96	7.2	0.10 – 0.02, 0.17 – 0.04	VIII - IV

Abbreviations used in Table 1-2:
mi – miles; **km** – kilometer; **M_{max}** – maximum magnitude earthquake; **PGHA** – peak ground horizontal acceleration as a percentage of **g**, the acceleration of gravity; **MMI** – Modified Mercalli Intensity.

Several other faults have the potential to generate moderate seismic shaking in Coachella, with peak ground accelerations in the 0.02 to 0.07 range (median) and 0.03 to 0.14 range (median plus 1 sigma), with Modified Mercalli intensities in the III to VIII range. Faults that would generate these levels of shaking include: Elsinore (Julian segment), San Jacinto (San Jacinto Valley and Borrego segments), Helendale-South Lockhart, Brawley Seismic Zone, Elmore Ranch and Earthquake Valley.

Active and Potentially Active Faults

Within about 50 miles of Coachella, California



NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites,nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.

Detailed geologic investigations, including trenching studies, may make it possible to refine the location and activity status of a fault. All faults may not be shown. This map should be amended as new data become available and are validated.

Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.

Explanation

Fault; solid where location known, dashed where approximate, dotted where concealed. Color indicates age of movement on fault.

Age of last fault displacement.

- Fault Showing Evidence of Historic Rupture (Active).
- Fault Showing Evidence of Holocene Rupture (Active).
- Fault Showing Evidence of Quaternary and Late Quaternary Rupture (Potentially Active).
- Coachella General Plan Area

N S W E

50000 0 50000 Feet

15000 0 15000 Meters

Scale: 1:600,000

Base Map: From the City of Coachella.
Sources: U.S. Geological Survey and California Geological Survey, 2010, Quaternary fault and fold database for the United States, accessed June 2011, from USGS web site: http//earthquakes.usgs.gov/regional/qfaults/.

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Plate 1-2

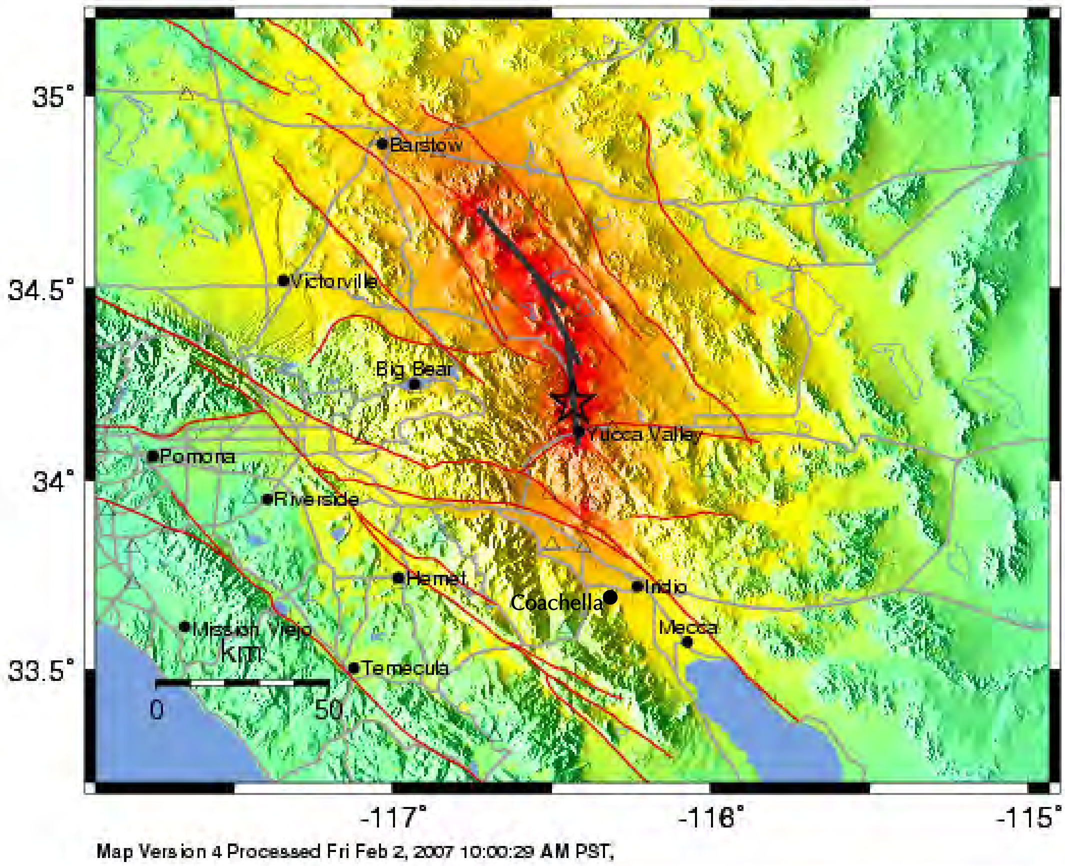
The peak ground horizontal accelerations and intensities summarized in Table 1-2 are shown from largest to lowest for each fault; these should be considered as general values, since different regions of the Coachella General Plan area are expected to feel and respond to each earthquake differently in response to site-specific conditions. As mentioned before, peak ground accelerations and seismic intensity values decrease with increasing distance away from the causative fault. However, local site conditions, such as reflection off the hard rock forming the mountains in the region, can amplify the seismic waves generated by an earthquake, resulting in localized higher accelerations than those listed here. The PHGA analyses conducted for this study provide a general indication of relative earthquake risk throughout the Coachella General Plan area. For individual projects however, site-specific analyses that consider the precise distance from a given site to the various faults in the region, as well as the local near-surface soil types, should be conducted. The faults listed in Table 1-2 are discussed further in the following sections.

The ground motions presented in Table 1-2 are based on the largest earthquake that each fault, or fault segment, is believed capable of generating, referred to as the ***maximum magnitude earthquake*** (M_{max} – as assigned by the California Geological Survey, although some researchers believe some of these faults can generate even larger events). This deterministic approach is useful to study the effects of a particular earthquake on a building or community. However, since many potential earthquake sources can shake the region, it is also important to consider the overall likelihood of damage from a plausible suite of earthquakes. This approach is called probabilistic seismic hazard analysis (PSHA), and typically considers the likelihood of exceeding a certain level of damaging ground motion that could be produced by any or all faults within a given radius of the project site, or in this case, the city, during a given timeframe. Most seismic hazard analyses consider a distance of 100 km (62 miles), but this is arbitrary. PSHA has been utilized by the U.S. Geological Survey to produce national seismic hazard maps such as those used by the Uniform Building Code (ICBO, 1997), the International Building Code (ICC, 2012) and the California Building Code (CBSC, 2013).

We ran the interactive ground motion module from the California Geological Survey (http://www.consrv.ca.gov/CGS/rghm/pshamap/pshamap.asp) and that by the U.S. Geological Survey (http://earthquake.usgs.gov/research/hazmaps/design/) to estimate the ground motions that have a 10 percent and 2 percent probability, respectively, of being exceeded in 50 years in the vicinity of City Hall. [Seismic design parameters in the 2013 California Building Code are based on the maximum considered earthquake, with a ground motion that has a 2 percent probability of being exceeded in 50 years and a recurrence interval of about 2,500 years.] For Coachella, the estimated level of ground motion that has a 10 percent probability of being exceeded in 50 years near City Hall is about 0.67g. The level of ground motion with a 2 percent probability of being exceeded in 50 years is about 1.13g. The ground motions at a site near the northeast corner of the city with a 10 percent and 2 percent probability of being exceeded in 50 years are 0.74g and 1.24g, respectively. This is the area of the city closest to the San Andreas fault, the principal source responsible for these levels of shaking, and a fault that has a high probability of rupturing in the next 30 years. These levels of shaking are in the high to very high range even for southern California, and can be expected to cause moderate to heavy damage, particularly to older and poorly constructed buildings.

Regardless of which fault causes a damaging earthquake, there will always be ***aftershocks***. By definition, these are smaller earthquakes that occur close in time and space to the ***mainshock*** (the biggest earthquake of the sequence). These smaller earthquakes occur as the Earth adjusts to the regional stress changes created by the mainshock. As the size of the mainshock increases, there typically is a corresponding increase in the number of aftershocks, the size of the aftershocks, and the size of the area in which they might occur. On average, the largest aftershock will be 1.2 magnitude units less than the mainshock. Thus, a M_W 6.9 earthquake will tend to produce aftershocks up to M_W 5.7 in size. This is an average, and there are many cases where the biggest aftershock is larger than the average predicts. The key point is this: any major earthquake will produce aftershocks large enough to cause additional damage, especially to already weakened structures. Consequently, post-disaster response planning must take damaging aftershocks into account.

Figure 1-3: Modified Mercalli Intensity ShakeMap for the June 28, 1992 Landers Earthquake



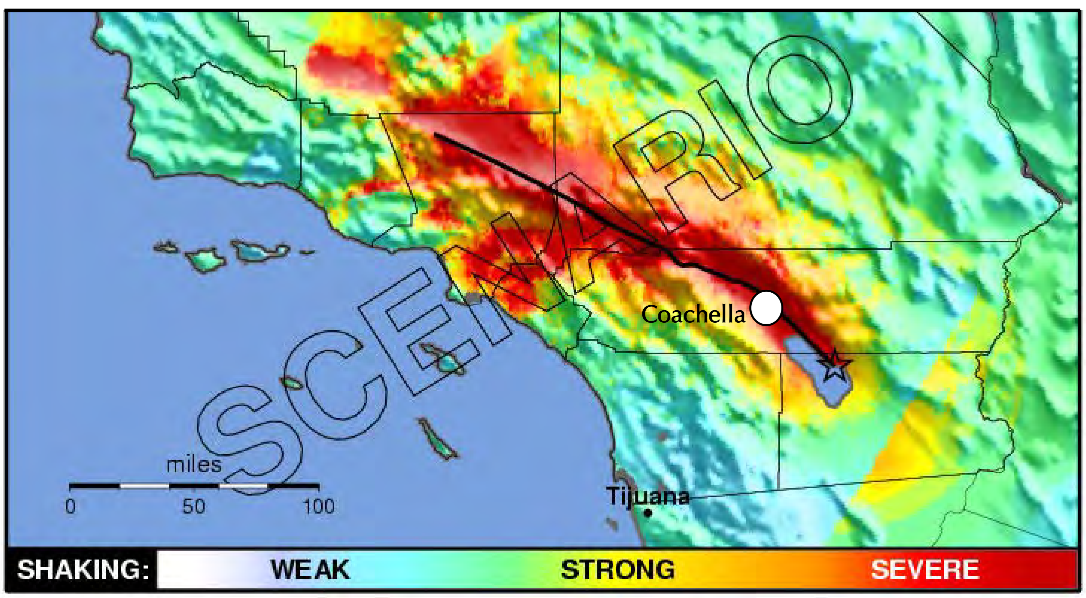
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: http://earthquake.usgs.gov/earthquakes/shakemap/sc/shake/Landers/

Another way to communicate the seismic shaking hazard is with the use of ShakeMaps. A ShakeMap is a representation of the various levels of ground shaking throughout the region where an earthquake occurs. ShakeMaps are compiled from the California Integrated Seismic Network (CISN) – a network of seismic recording instruments placed throughout the state – and are automatically generated following moderate to large earthquakes. Preliminary real-time maps are posted on the Internet, often minutes after the earthquake occurred (http://earthquake.usgs.gov/eqcenter/shakemap/), giving disaster response personnel an immediate picture of where most damage likely occurred. Although several shaking parameters can be illustrated on ShakeMaps, such as peak acceleration or velocity, most people can relate more easily to maps illustrating the *intensity* of ground shaking. Scientists have compared actual instrumental ground motion recordings to observed Modified Mercalli Intensities from recent California earthquakes to estimate shaking intensities; this allows them to estimate and develop shaking intensity distribution maps immediately following an earthquake. Figure 1-3 shows the ShakeMap generated by the U.S. Geological Survey for the 1992 Landers earthquake. Notice the strong level of shaking reported for the Coachella Valley area, including the city of Coachella.

ShakeMaps can also be used for planning and emergency preparedness by creating hypothetical earthquake scenarios. These scenarios are not predictions – knowing when or how large an earthquake will be in advance is still not possible. However, using realistic assumptions about the size and location of a future earthquake, we can make predictions of its effects, and use this information for loss estimations and emergency response planning. Figure 1-4 is an Intensity ShakeMap for the hypothetical magnitude 7.8 "ShakeOut" earthquake scenario that involves rupture of the entire southern San Andreas fault, from the Salton Sea northward to Lake Hughes, in northern Los Angeles County. The San Andreas fault would rupture through the city of Coachella, resulting in severe shaking and surface fault rupture in the region. We used the ShakeOut scenario in the loss estimation analyses presented in Section 1.9 of this report.

Figure 1-4: ShakeMap for a Magnitude 7.8 Earthquake Scenario (the ShakeOut Scenario) on the Southern San Andreas Fault



Source: http://earthquake.usgs.gov/eqcenter/shakemap/sc/shake/ShakeOut2_full_se/#Decorated

1.4.1 San Andreas Fault Zone

The San Andreas fault is the principal boundary between the Pacific and North American plates. The fault extends nearly 1,300 km (800 miles), from near Cape Mendocino in northern California to the Salton Sea region in southern California. This fault is considered the "Master Fault" in southern California because it has relatively frequent, large earthquakes and controls the seismic hazards of the area. Many refer to an earthquake on the San Andreas fault as "The Big One," and for many parts of southern California, including Coachella, this designation is indeed true. Other areas are actually at greater risk from other faults. Nevertheless, the San Andreas fault should be considered in all seismic hazard assessment studies in southern California given its high probability of causing an earthquake in the near future. In 2007-2008, a group of scientists referred to as the 2007 Working Group on California Earthquake Probabilities (WGCEP, 2008) calculated that the southern San Andreas fault had a 59 percent probability of causing an earthquake of at least magnitude 6.7 in the next 30 years. That probability increases with each passing year without an earthquake.

Large faults, such as the San Andreas, are often divided into segments and sections. The sections are typically based on physical characteristics along the fault, particularly changes in dip and/or strike, and style of faulting. Each fault section is assumed to have a characteristic slip rate (rate of movement averaged over time), recurrence interval (time between moderate to large earthquakes), and displacement (amount of offset during an earthquake). Historical records and studies of prehistoric earthquakes show it is possible for more than one section to rupture during a large quake or for ruptures to overlap into adjacent sections. For example, the last major earthquake on the southern portion of the San Andreas fault (and the largest earthquake reported in California) was the 1857 Fort Tejon (magnitude 8) event. The 1857 earthquake ruptured the Cholame, Carrizo, Big Bend, and Mojave North and Mojave South sections of the fault, resulting in displacements of as much as 27 feet (9 meters) along the rupture zone. There are data that suggest that these sections and portions of sections, which are combined into a fault segment, tend to rupture together time and time again in what is referred to as a "characteristic earthquake."

The definition and naming of the various sections, segments, fault strands and fault splays have varied over time, the result of many investigators working on different aspects and parts of the fault zone, and the recent efforts to compile these data into a unified model. In this report, the fault nomenclature used follows that defined by the 2007 Working Group on California Earthquake Probabilities (WGCEP, 2008). The southern and central San Andreas fault is now divided into ten sections named, from north to south, Parkfield, Cholame, Carrizo, Big Bend, Mojave North, Mojave South, San Bernardino North, San Bernardino South, San Gorgonio-Garnet Hill, and Coachella (WGCEP, 2008). The southernmost sections are discussed further below, starting with the Coachella section, as this is the section that extends through the Coachella General Plan area.

The **Coachella section** comprises the relatively straight, predominantly right-lateral strike slip fault that extends from Bombay Beach in the Salton Sea northward to the Biskra Palms area north of Indio, a distance of about 42 miles. The Coachella section is the only section of the southern San Andreas that has not produced a major earthquake in historic times (Sieh and Williams, 1990; Fumal et al., 2002; Philibosian et al., 2011). Paleoseismic studies indicate that the last surface-rupturing earthquake on this segment occurred more than 320 years ago, around A.D 1680 (Sieh and Williams, 1990) or A.D. 1690 (Philibosian et al., 2011).

At least five detailed studies have been conducted along the Coachella section of the fault from Indio southward, in addition to dozens of site-specific fault investigations conducted in response to zoning of the fault under the Alquist-Priolo Earthquake Fault Zoning Act (see Section 1.5). The detailed studies include the Indio site investigated by Sieh (1986), the Coachella site by Philibosian et al. (2011), the Stone Ring Gullies site of Shifflett et al. (2002), the Ferrum site (Sieh and Williams, 1990), and the Salt Creek site (Sieh and Williams, 1990; Williams, 2009). The two studies of most relevance to the Coachella General Plan area are those by Sieh and Williams (1990), and Philibosian et al. (2011).

At the Indio site just north of the city of Coachella, the stratigraphy and fault relations exposed in the trenches allowed Sieh (1986) and Sieh and Williams (1990) to interpret at least four surface-rupturing earthquakes on this section of the fault between A.D. 1000 and A.D. 1700. The most recent earthquake was dated, based on radiocarbon dating of stream and lake deposits exposed in the trenches, at between A.D. 1640 and A.D. 1720, with a preferred date of A.D. 1680. Three previous earthquakes occurred at about A.D. 1450 (±150 years), A.D. 1300 (±90 years), and A.D. 1020 (±20 years). Using these data, the Working Group on California Earthquake Probabilities (1995) calculated an average recurrence interval of 220 ±13 years for this section of the San Andreas fault. More recently, the 2007 Working Group (WGCEP, 2008) calculated an average recurrence interval of 246 years that includes the open interval since the most recent earthquake in about A.D. 1680 (that is, the time period between 1680 and 2006, when the calculation was made). With each passing year without an earthquake on this section of the fault, the average recurrence interval increases a bit.

At the Coachella site, located to the southwest of the intersection of Dillon Road and Avenue 44 in the city of Coachella, Philibosian et al. (2011) exposed evidence for five, and possibly as many as seven or eight, surface-rupturing earthquakes between A.D. 800 and the present. The most recent event (MRE) is dated at between A.D. 1657 and A.D. 1713, with a preferred date of A.D. 1690 (to the nearest decade). Preferred dates (also to the nearest decade) for previous earthquakes include A.D. 1630, A.D. 1420, A.D. 1300, A.D. 1140, A.D. 990, and A.D. 930. Using only the closed earthquake intervals, that is, the time bracketed in between two known earthquakes, the average recurrence interval for this section of the San Andreas fault based on the data collected at the Coachella site is between about 116 and 202 years. If the current open interval of about 320 years, since the last known earthquake, is included in the calculations, the average recurrence interval increases to between 150 and 221 years.

Although this fault section has not had a historical earthquake, portions of it are shown as having historical slip on Plate 1-2 because creep at rates of between about 1 and 4 mm/yr has been measured on it. This creep is the result of both continuous slip and slip triggered by earthquakes (Louie et al., 1985; Sieh and Williams, 1990; Lyons and Sandwell, 2003). Earthquakes that are known to have resulted in triggered slip on the southern San Andreas fault include the 1968 Borrego Mountain and 1979 Imperial Valley earthquakes (Clark, 1984, referencing Allen et al., 1972 and Sieh, 1982; Williams et al., 1986), the 1987 Elmore Ranch-Superstition Hills sequence (Sharp et al., 1989), the 1992 Joshua Tree-Landers-Big Bear sequence (Bodin et al., 1994; Lyons and Sandwell, 2003), and the 2010 El Mayor-Cucapah earthquake (Weldon, 2010; Wei et al., 2011; http://cires.colorado.edu/~bilham/LagunaSalada4April2010/Baja4April.html). This is only a small amount of the overall late Quaternary slip rate that has been calculated for the Coachella section of the fault, estimated at about 30 mm/yr at the Indio site (Sieh, 1986). More recently, the 2007 Working Group on California Earthquake Probabilities assigned the Coachella section a slip rate of 20 ±3 mm/yr, (although in some alternate models they use a slip rate as low as 16 ±3 mm/yr and as high as 24 ±3 mm/yr). The small amount of aseismic creep is not sufficient to release all of the strain that has accumulated on this fault section since its last surface-rupturing earthquake at about A.D. 1680. It is for this reason that this section of the fault is considered to have a high probability of rupturing in the next 30 years.

The **San Gorgonio-Garnet Hill section** is about 41 miles long, and extends westerly from just north of Indio, through the San Gorgonio Pass, to just south of Burro Flats. From south to north, this section is comprised of two main branches (the Banning fault on the south, and the Mission Creek fault on the north), in addition to several other faults including the Garnet Hill fault. At its western end, the Garnet Hill fault merges with the San Gorgonio Pass fault. Unlike the Coachella section to the south, this section is very complex, being mostly oblique strike-slip, with a major thrust component of movement (Yule and Sieh, 2003).

The *Banning fault* is an older, right-lateral strike-slip structure dating back to latest Miocene time (about 4 or 5 to 7.5 million years ago), when it served as an ancestral strand of the San Andreas fault (Matti and Morton, 1993). Based on geologic and geomorphologic characteristics, as well as the fault's tectonic history during the last two million years, Matti et al. (1992) have divided the Banning fault into three segments. Its western segment, extending from the San Jacinto fault southeastward to the Calimesa area, is considered not active because it does not break Quaternary alluvium and has no surface expression (the location of the fault has been inferred from gravity data and other indirect geologic evidence). The central segment, which extends from Calimesa to Cottonwood Canyon, for the most part also does not affect Quaternary deposits, and has been overprinted by reverse and thrust faults that are probably related to development of the San Gorgonio Pass Fault Zone. There is, however, a 2-mile long section of the central Banning fault, with thrust-type motion, that offsets young alluvium in Millard Canyon. Therefore, the fault is active in that area (Yule and Sieh, 2003). The easternmost portion of the ancestral Banning fault, from Cottonwood Canyon to its junction with the Coachella section of the fault near the Indio Hills, has been reactivated during Quaternary time, and has many geomorphic characteristics of youthful strike-slip activity.

The *Mission Creek fault* has right-lateral strike-slip motion along most of its trace, but gradually evolves into thrust-type motion at its western end. Some researchers have suggested this fault is either an older strand of the San Andreas, that is less active than other strands, or is no longer active (Matti et al., 1992; Yule and Sieh, 2003). This is most likely true for the northern end of the fault, but trenching near its southern end, at Thousand Palms Oasis, has shown that at this site, the fault has experienced four and probably five surface-rupturing earthquakes in the past about 1,200 years (Fumal et al., 2002). The most recent earthquake on this strand is most likely the same A.D. 1680 event reported by Sieh (1986) and Sieh and Williams (1990) at the Indio site. Comparison of data obtained at this site with data from the Indio site to the south, and the Wrightwood site about 75 miles (120 km) to the northwest, suggests that the southernmost 125 miles (200 km) of the San Andreas fault rupture together in large earthquakes (Fumal et al. 2002; Fumal, Rymer and Seitz, 2002).

The *Garnet Hill fault* parallels the trend of the Banning fault, extending from a few miles west of Whitewater south to Thousand Palms, where the fault trace dies out. The fault is primarily a right-lateral strike-slip fault along most of its trace, but splays into a series of oblique reverse faults at its western end. Based on seismological data, Yule and Sieh (2003) conclude that the Garnet Hill fault and the Banning fault merge at a depth of about 5 km, and that the single fault plane below this depth was the source of the 1986 North Palm Springs earthquake. They further suggest that the Garnet Hill fault merges with the San Gorgonio Pass Fault Zone to carry slip between the disconnected segments of the San Andreas fault, thus making the Banning-Garnet Hill-San Gorgonio Pass system a significant seismic source in the region.

The *San Gorgonio Pass Fault Zone* consists of a series of north-dipping reverse and thrust faults linked by strike-slip tear faults, giving its surface trace an irregular, saw-tooth appearance (Yule and Sieh, 2003). This zone begins near Cottonwood Canyon and extends westward to the Calimesa area. Faults within this east-west trending zone have thrust ancient crystalline rock southward over younger sedimentary rock and alluvial sediments. These faults formed during the Pleistocene in response to compression created by the bend and the step-over in the trace of the San Andreas fault; activity of some of these faults has continued into the Holocene, as indicated by many youthful scarps that are present in young alluvium (Matti et al., 1992; Yule and Sieh, 2003).

The San Gorgonio-Garnet Hill section is thought to have last ruptured in 1812, although additional studies need to be conducted to confirm this (Yule et al., 2006; Dawson et al., 2008). Paleoseismic data also suggest that the Coachella, San Gorgonio-Garnet Hill, and San Bernardino sections ruptured simultaneously in earthquakes that occurred around A.D. 1500, and possibly A.D. 1680 (Dawson et al., 2008, summarizing data by Fumal et al., 2002, Yule et al., 2006, and McGill et al., 2002). Investigators suggest that some of the strain is also being transferred northward onto the faults in the Indio Hills and probably the Eastern California Shear Zone. The 2007 WGCEP (2008) assigned a slip rate of 10±6 mm/yr to the San Gorgonio-Garnet Hill section.

Rupture of the Coachella and San Gorgonio-Garnet Hill fault segments in a magnitude 7.2 earthquake is estimated capable of generating peak ground accelerations in Coachella of about 0.4g to 1.2g. If the Coachella, San Gorgonio-Garnet Hill and San Bernardino (South and North) sections rupture together in a magnitude 7.7 earthquake, Coachella would experience peak ground accelerations of between 0.5g and 1.5g. These are strong to very strong ground motions.

The **San Bernardino (South and North) segments** combined are about 43 miles (70 km) long and extend from the Burro Flats area northward to approximately Cajon Pass. These faults, like the Coachella section, appear to be nearly vertical, with a predominant strike-slip in motion. Slip rate on the San Andreas fault in this area decreases southward. At the north end of the San Bernardino North segment, in the area of Cajon Pass and Pittman Canyon, the fault has a slip rate of 22±6 mm/yr. To the south, some of the slip is being transferred to the San Jacinto fault through the Crafton Hills fault and related structures, so that slip on the San Bernardino South segment is estimated at 16±6 mm/yr (WGCEP, 2008). Both segments appear to have last ruptured in 1812. If both sections rupture together in the future, the resultant magnitude 7.5 earthquake could cause peak ground accelerations in Coachella of between 0.10g and 0.31g. If, as discussed above, the San Bernardino sections rupture in conjunction with the Mojave, San Gorgonio Pass-Garnet Hill and/or Coachella sections, higher ground motions would be expected in the region.

1.4.2 San Jacinto Fault Zone

The San Jacinto Fault Zone consists of a series of closely spaced faults that form the western margin of the San Jacinto Mountains. The zone is about 280 km (175 miles) in length and extends from its junction with the San Andreas fault in San Bernardino, southeasterly toward the Brawley area, where it continues south of the international border as the Imperial fault. The San Jacinto fault has historically produced more large earthquakes than any other fault in southern California, although none of these earthquakes has been as large as the 1857 and 1906 earthquakes on the San Andreas fault. The two most-recent surface-rupturing earthquakes on the San Jacinto fault were the April 9, 1968, M_w 6.5 on the Coyote Creek section (Jennings, 1994), and the 1987 event on the Superstition Hills section. Offset across the fault traces is predominantly right-lateral strike-slip, similar to the San Andreas fault, although Brown (1990) has suggested that vertical motion contributes up to 10 percent of the net slip.

The San Jacinto Fault Zone has been divided into eight sections. From north to south these include the San Bernardino Valley, San Jacinto Valley, Anza, Coyote Creek, Clark, Borrego, Superstition Mountain, and Superstition Hills sections. Fault slip rates on the various sections of the San Jacinto fault are less well constrained than for the San Andreas fault, but the data available suggest right-lateral slip rates of 6 to 18 (±4 to 6) mm/yr for the northern and central sections of the fault and slip rates of 4 to 5 (±2 to 6) mm/yr for the Coyote Creek and other sections to the south (WGCEP, 2008). This amounts to between about 8 and 36 percent of the total slip on the San Andreas fault system. The Working Group on California Earthquake Probabilities (1995) gave the San Bernardino and San Jacinto Valley segments a 37 percent and 43 percent probability, respectively, of rupturing sometime between 1994 and 2024. These probabilities were reduced somewhat by the WGCEP (2008), to an average of 31 percent for all segments of the San Jacinto fault. The segments of the San Jacinto fault closest to Coachella include the Anza, Clark, and Coyote Creek. These sections are discussed further below.

The **Anza section** of the fault has been studied extensively at Hog Lake, where at least 16 past earthquakes have been resolved from the faulted stratigraphy (WGCEP, 2008 based on data provided by T. Rockwell). The data indicate an average recurrence interval of 238 years for this section, with the most recent earthquake having occurred between about A.D. 1775 and A.D. 1805. This fault section has a slip rate of about 18 (±6) mm/yr. A M_w 7.2 earthquake on this segment would generate peak ground accelerations in the Coachella area of between about 0.10g and 0.27g.

The next sections to the south, the **Clark** and **Coyote Creek**, are sub-parallel to each other, with the Clark section on the east, closer to Coachella. Each section is about 15 miles (24 km) long. There are no paleoseismic data for these sections, so fault parameters, such as slip rate and recurrence interval, are not well defined. Using geodetic data, and assuming that the slip rate from the Anza section to the north is being transferred southward and is being distributed (partitioned) between the two sections, the WGCEP (2008) assigned a slip rate of 14 (±6) mm/yr to the Clark section, and a rate of 4 (±6) mm/yr to the Coyote Creek section. A M_w 6.6 earthquake on either of these sections of the San Jacinto fault would generate peak ground accelerations in Coachella of between about 0.05g and 0.17g.

1.4.3 Pisgah – Bullion Mountain – Mesquite Lake Fault Zone

The Pisgah fault is a 34-km- (21-mile-) long, right-lateral strike-slip fault that experienced triggered slip in 1992 as a result of shaking from the Landers earthquake. The fault is thought to have moved in the past about 11,000 years (during the Holocene, which makes it an active fault), but the interval between surface-rupturing earthquakes on this fault is unknown. The zone is thought to slip at a rate of about 0.8 mm/yr, but geologic studies need to be conducted to confirm these estimates. If only the Pisgah fault ruptured in an earthquake, the resulting event would have a magnitude M_w between 6.0 and 7.0. However, the Pisgah fault may also rupture together with the 55-km- (34-mile-) long Bullion fault to the south, and the 40-km- (22-mile-) long Mesquite Lake fault farther south. The Bullion fault last ruptured on October 16, 1999 during the M_w 7.1 Hector Mine earthquake. Prior to that, both the Bullion and Mesquite Lake faults appear to have ruptured during a large earthquake in the mid to late Holocene (Madden et al., 2006).

Recent studies of the Mesquite Lake fault have shown that this fault has had three large surface-rupturing earthquakes in the past about 10,200 years, each creating an apparent vertical offset of between 1.0 and 1.2 meters, suggesting similar-sized earthquakes. The trenching data indicate this fault has a horizontal slip rate of between 0.7 and 0.9 mm/yr, consistent with the slip rates estimated for several other faults in the Mojave Desert. The paleoseismic data also seem to suggest that earthquakes on this fault occur in clusters, separated by seismically quiet periods that last several thousands of years, and that seismic activity in the shear zone alternates between the eastern and western faults in the region (Madden et al., 2006).

A magnitude 7.3 earthquake is estimated if all three fault segments – the Pisgah, Bullion Mountain and Mesquite Lake – ruptured together. An earthquake of that size on these faults would generate peak horizontal ground accelerations in the Coachella area of about 0.07g to 0.23g, with Modified Mercalli intensities of VI to IX.

1.4.4 Pinto Mountain Fault

The Pinto Mountain fault is a prominent left-lateral strike-slip fault that bounds the north side of the Little San Bernardino Mountains, about 28 miles north-northwest of the city of Coachella at its closest approach. The fault is at least 45 miles (73 km) long, and possibly as much as 56 miles (90 km). Relatively recent studies show that this fault has ruptured repeatedly in the past 14,000 years, with at least four events within the past about 9,400 years (Cadena et al., 2004). The fault is therefore active under the provisions of the Alquist-Priolo Act. Current estimates on its rate of slip suggest a rate of between 1.1 and 2.3 mm/yr. Additional studies should refine those estimates further. A magnitude 7.2 earthquake on this fault could generate peak horizontal ground acceleration in Coachella of about 0.06g to 0.22g. Such an earthquake would cause damage in Coachella typical of Modified Mercalli intensities between VI and IX. An even larger, magnitude 7.5, earthquake on the Pinto Mountain fault would generate stronger ground shaking in the Coachella area.

1.4.5 Landers (or Kickapoo) Fault

The Landers fault was the name given to the group of faults that ruptured during the 1992 Landers earthquake, including the Homestead Valley, Kickapoo, and Johnson Valley faults, and segments of the Burnt Mountain and Eureka Peak faults. Now, the name Landers is used to refer to the Kickapoo fault. The interval between major ruptures on these faults is uncertain, but is probably in the thousands of years, which is why these faults were unknown or poorly known prior to 1992. In 1992, however, some of these faults experienced significant lateral displacements – the Kickapoo fault moved laterally nearly 9.5 feet (3 meters) (Sieh et al., 1993). Individually, these faults could rupture in smaller earthquakes, but their combined lengths allowed for the magnitude 7.3 earthquake that shook southern California on the morning of June 28, 1992. Ground shaking in the Coachella area due to a Landers-type earthquake on these faults would cause horizontal ground accelerations of between 0.05g and 0.21g, with Modified Mercalli intensities in the VI to VIII range.

1.4.6 Burnt Mountain Fault

Like several other Mojave (or Eastern California) Shear Zone faults, the Burnt Mountain fault was unknown prior to late June 1992, when a 3.1-mile- (5 km) length of this fault ruptured at the ground surface, probably during a large aftershock of the Landers earthquake, experiencing about 2.4 inches (6 cm) of right-lateral offset. Geologists later mapped the area and determined that the Burnt Mountain fault has a total length of about 13 miles (21 km). Given its overall length (Wesnousky, 1986), this fault is thought capable of producing a magnitude 6.0 to 6.5 earthquake. The Burnt Mountain fault is at its closest approach about 18 miles to the north of Coachella. An estimated M_w 6.5 earthquake on this fault could generate horizontal ground accelerations in the Coachella area of between about 0.05g and 0.20g, with the higher accelerations occurring in the northern portions of the city, closest to the fault. The level of damage anticipated would be consistent with Modified Mercalli intensities of between VI and VIII.

1.4.7 Eureka Peak Fault

The Eureka Peak fault is a right-lateral strike-slip fault about 12.5 to 15 miles (20 to 25 km) in length that last ruptured, together with other faults, during the 1992 Landers earthquake. Only about 6 miles (10 km) of the fault ruptured at that time, but this allowed geologists to discover the fault and map its full length. Maximum offset on this fault in 1992 was 8-1/4 inches (21 cm); geologists think that this slip occurred in two separate but closely spaced events, plus some afterslip. The first rupture is thought to have occurred about 30 seconds after the Landers mainshock, whereas the second rupture episode was probably as a result of a magnitude 5.6 aftershock that occurred less than three minutes after the mainshock. Researchers have also suggested that the Joshua Tree earthquake of April 22, 1992 was caused by this fault (Jones et al., 1995). The Southern California Earthquake Center estimates that the Eureka Peak fault is capable of generating earthquakes of moment magnitude between 5.5 and 6.8. An average M_w 6.4 earthquake on this fault is estimated capable of generating horizontal peak ground accelerations in Coachella of between 0.05g and 0.20g.

1.4.8 Calico – West Calico - Hidalgo Fault Zone

The Calico fault is a 55-km (34 mile) long, right-lateral strike-slip structure that exhibited triggered slip during the 1992 Landers earthquake and was the source of a M_L 5.3 earthquake that shook the eastern California area on March 18, 1997. The 1997 earthquake is considered the last large aftershock of the 1992 Landers earthquake, and its epicenter was on the northern section of the fault, about 12 miles east-northeast of Barstow, near the Calico Mountains.

The Calico fault is the longest and fastest-slipping of the faults in the Eastern California Shear Zone, with slip rate estimated at between 1.0 and 2.6 mm/yr. The recurrence interval between earthquakes on this fault is estimated at about 1,500 years (http://www.scecdc.scec.org/fault_index/), although researchers have suggested that in this portion of the southern California fault system, earthquakes recur in clusters, with long periods of inactivity in between (Rockwell et al., 2000). Geologists are currently conducting paleoseismic studies of the Calico fault in an effort to better understand its past earthquake history and test the strength of the earthquake clustering hypothesis (Oskin et al., 2007).

Based on its length, the Calico fault is thought capable of generating an M_w 6.5 to 7.1 earthquake; however, the Calico fault is essentially continuous with the West Calico and Hidalgo faults to the south, and all three of these faults could rupture at the same time, potentially producing a larger magnitude earthquake. The 40-km (25 miles) long Hidalgo fault is thought to have a slower slip rate of only about 0.5 mm/yr, and its earthquake history is unknown. Alone, the Hidalgo fault is thought capable of generating an M_w 6.4 to 7.1 earthquake. For the purposes of this study, and in conformance with the California Geological Survey's fault parameters table (Cao et al., 2003), these faults are assumed to break concurrently in an M_w 7.3 earthquake. Such an event would produce peak horizontal ground accelerations in the Coachella area of between about 0.04g and 0.17g, with Modified Mercalli intensities in the V to VIII range.

1.4.9 Lenwood – Lockhart – Old Woman Springs Faults

Another of the Eastern California Shear Zone faults, the Lenwood fault is a right-lateral strike slip fault approximately 47 miles (75 km) long with a slip rate of about 0.8 mm/year. Trenching studies have shown that the fault has ruptured at least three times in the Holocene, roughly 200-400, 5,000-6,000, and 8,300 years ago, for a recurrence between major surface ruptures of 4,000 to 5,000 years. Prior to the 1992 Landers earthquake, when the fault experienced triggered slip near its southeast end, aseismic creep on this fault had been recorded but not verified (http://www.scecdc.scec.org/fault_index/).

The Lockhart fault, located north of the Lenwood fault, is a right-lateral strike-slip fault approximately 44 miles (70 km) long. The North Lockhart fault – a segment that shows no evidence of Holocene activity – adds 6 miles (10 km) to the length above. The interval between major surface-rupturing earthquakes on the Lockhart fault is estimated at between 3,000 and 5,000 years (Jennings, 1994), with the central portion of the fault having ruptured during the Holocene, and segments both to the north and south believed to have last ruptured in the Quaternary (http://www.data.scec.org/fault_index/lockhart.html).

The Old Woman Springs segment is the main trace of a complex system of faulting at the junction between the Eastern segment of the North Frontal Fault Zone and the Lenwood fault. The Old Woman Springs trace is about 6 miles (10 km) long and exhibits right-lateral strike-slip movement with some vertical slip. The fault is thought to have last moved in the Holocene (http://www.scecdc.scec.org/fault_index/), and is therefore considered active.

Although the Lenwood and Lockhart faults form an essentially continuous, 150-km- (90-mile-) long system, there is no evidence that both of these faults have ruptured together in the past. Nevertheless, such an event might be possible, as evidenced by rupture of five separate fault segments during the Landers earthquake. For the purposes of this study, these faults, together with the Old Woman Springs fault, are assumed to rupture together in a magnitude 7.5 maximum magnitude earthquake. Such an event would generate peak ground accelerations in Coachella of between about 0.04g and 0.17g, with Modified Mercalli Intensities in the V to VIII range. If only one of these faults ruptures in an earthquake, the smaller magnitude event would cause lesser ground motions in Coachella than those reported above.

1.4.10 North Frontal Fault

This south-dipping, partially blind reverse fault zone along the eastern flank of the San Bernardino Mountains consists of several fault splays that have a combined total length of approximately 65 km (40 miles). Several of the fault splays interact with other nearby faults; the most significant of these is the Helendale fault, which seems to right-laterally offset the North Frontal Fault Zone, dividing it into two main segments (referred to as the East and West segments; Meisling, 1984; Bryant, 1986).

The North Frontal fault is thought to have moved in the past 10,000 years, making it an active fault. However, the fault has not been studied in detail, and its recurrence interval, slip rate and other fault parameters are not well understood, although a slip rate of about 0.5 mm/yr is attributed to it. Furthermore, movement on this fault is thought to be responsible for an average uplift rate of about 1 mm/yr of the San Bernardino Mountains. Based on its length, the East segment of the North Frontal Fault Zone is thought capable of generating a maximum magnitude 6.7 earthquake. An earthquake of that size on this fault would be felt in Coachella with peak ground accelerations of between about 0.03g and 0.16g, resulting in Modified Mercalli intensities as high as VIII. If the more distant West segment of the North Frontal Fault Zone ruptured in a 7.2 earthquake, the Coachella area would experience ground shaking of about 0.02g to 0.17g, with Modified Mercalli intensities in the IV to VIII range.

1.4.11 Elsinore Fault Zone

The Elsinore fault is a major right-lateral strike-slip fault that extends from northern Baja California to the Los Angeles Basin, a distance of approximately 306 km (190 miles) (Treiman, 1998). As part of the San Andreas fault system in southern California, the Elsinore fault accommodates about 10 percent of the motion between the Pacific and North American plates (WGCEP, 1995), with a slip of about 5 mm/yr (Bergmann et al., 1993; Millman and Rockwell, 1986; Vaughan and Rockwell, 1986). The 2007 Working Group on California Earthquake Probabilities (WGCEP, 2008) assigned the Elsinore fault an 11 percent probability of rupturing in a M>6.7 earthquake in the next 30 years.

The fault is divided, from south to north into the Laguna Salada, Coyote Mountain, Julian, Temecula, Glen Ivy, and Whittier sections (WGCEP, 2008). The section closest to Coachella is the **Julian segment**, which at its nearest approach is about 42 miles to the west. The 42-mile (68-km) long Julian segment is the longest section of the Elsinore Fault Zone. Its north end is defined by a restraining bend, whereas at its south end, it steps across a 4- to 5-km wide area to the Coyote Mountain section. The most recent surface-rupturing earthquake on this section appears to have occurred about 1,500 years ago, and the penultimate event about 3,000 years ago. There are too few earthquakes resolved on this segment to calculate a recurrence interval. If the Julian segment of the Elsinore fault ruptured in a M 7.1 earthquake, peak ground motions of about 0.03g to 0.14g are anticipated in the Coachella area.

1.4.12 Blue Cut Fault

Although this fault is not included in the State's database of active faults thought capable of generating an earthquake (Cao et al., 2003), and is not identified by either the State or the U.S. Geological Survey as a recently active fault (see Plate 1-2), the Blue Cut fault does have geomorphic expression and thus, may be active. The fault has been the subject of only very limited studies (Hope, 1969a; Crippen and Spencer, 1984; Schell and Schell, 1994, Blythe et al., 2011) that have relied primarily on geomorphic interpretation of maps and aerial photographs, field mapping, and evaluation of fault scarp morphology. Exploratory trenches across the mapped trace of the fault have not, to our knowledge, ever been conducted, most likely because the fault is located in its entirety in the Joshua Tree National Park. The fault is reportedly about 80 km (50 miles) long (Schell and Schell, 1994) extending eastward from the San Bernardino Mountains to the Pinto Basin. The Blue Cut fault is similar in orientation and style to several other east- to northeast-trending, left-lateral faults, including the Pinto Mountain and Garlock faults to the north, that have accommodated (and are accommodating) significant clockwise rotation in the Mojave Desert (Blythe et al., 2011). The fault may be the source of large (M7 to M7.25) but infrequent earthquakes, with a recurrence interval in the tens of thousands of years (Schell and Schell, 1994).

Ground motions in Coachella as a result of an earthquake on the Blue Cut fault were not estimated. However, given that the fault is less than 20 km (12 miles) from Coachella, if the fault ruptures generating a moderate (>M6.5) to large (>M7) earthquake, shaking in Coachella will be strong to very strong, with Modified Mercalli intensities in the VIII to XI range.

1.5 Surface Fault Rupture

1.5.1 Definitions

Primary fault rupture refers to fissuring and displacement of the ground surface along a fault that breaks in an earthquake. Primary fault rupture is rarely confined to a simple line along the fault trace. As the rupture reaches the ground surface, it commonly spreads out into complex fault patterns of secondary faulting and ground deformation. In the 1992 Landers earthquake, the zone of deformation around the main trace was locally hundreds of feet wide (Lazarte et al., 1994). Surface displacement and distortion associated with secondary faulting and deformation can be relatively minor or can be large enough to cause significant damage to structures.

Primary ground rupture due to fault movement typically results in a relatively small percentage of the total damage in an earthquake, yet being too close to a rupturing fault can result in extensive damage. It is difficult and generally costly to safely reduce the effects of this hazard through building and foundation design. Therefore, the preferred, and traditional mitigation measure for this hazard is to avoid active faults by setting structures back from the fault zone. In California, application of this measure is subject to requirements of the Alquist-Priolo Earthquake Fault Zoning Act and guidelines prepared by the California Geological Survey – previously known as the California Division of Mines and Geology (CGS Note 42 by Hart and Bryant, 2007). The final approval of a fault setback lies with the local reviewing agency.

Secondary fault rupture refers to ground surface displacements along faults other than the main traces of active regional faults. Secondary ground deformation includes fracturing, shattering, warping, tilting, uplift and/or subsidence. Unlike the regional faults, most subsidiary faults are not deeply rooted in the Earth's crust and are not capable of producing damaging earthquakes on their own. Movement along these faults generally occurs in response to movement on a nearby regional fault. Yet, the zone of secondary faulting can be quite large, even in a moderate-sized earthquake. For instance, in the 1971 San Fernando earthquake, movement along subsidiary faults occurred as much as 2 km from the main trace (Ziony and Yerkes, 1985). Triggered slip as a result of a regionally large earthquake can also occur in faults many kilometers away from the causative fault. For example, as a result of the 1992 Landers earthquake, triggered surface slips were documented in the Coachella Valley area (Rymer, 2000). Similarly, following the 1999 Hector Mine earthquake, triggered surface slips were recorded in the Salton Trough (Rymer et al., 2002; Meltzner et al., 2006). More recently, as a result of the April 4, 2010 Sierra El Mayor-Cucapah earthquake in Baja California, triggered slip was reported on the San Andreas, Superstition Hills, Imperial and Brawley fault zones (Weldon, 2010, http://response.scec.org/node/273; Wei et al., 2011).

Faults have formed over millions of years, usually in response to regional stresses. Shifts in these stress regimes do occur over millennia. As a result, some faults change in character. For example, a thrust fault in a compressional environment may become a strike-slip fault in a transpressive (oblique compressional) environment. Other faults may be abandoned altogether, and previously not active faults may be reactivated. Consequently, the State of California, under the guidelines of the Alquist-Priolo Earthquake Fault Zoning Act of 1972 (Hart and Bryant, 1999, 2007), classifies faults according to the following criteria:

- ***Active***: faults showing proven displacement of the ground surface within about the past about 11,000 years (within the Holocene Epoch), that are thought capable of producing earthquakes;

- ***Potentially Active***: faults showing evidence of movement within the past 1.6 million years, but that have not been shown conclusively whether or not they have moved in the past 11,000 years; and

- ***Not active***: faults that have conclusively NOT moved in the past about 11,000 years.

The Alquist-Priolo classification is used primarily for residential subdivisions. Different definitions of activity are used by other agencies or organizations depending on the type of facility being planned or developed. For example, longer periods of inactivity are generally required for dams or nuclear power plants. Faults that have ruptured historically form an important subset of active faults. In California, that generally means faults that have ruptured since 1769, when the Spanish first arrived and settled in the area. However, since many parts of the State were not settled until well into the middle of the 1800s, some historical earthquakes most likely went un-noticed and therefore unreported.

The underlying assumption in this classification system is that if a fault has not ruptured in the past about 11,000 years, it is not likely to be the source of a damaging earthquake in the future. In reality, however, most potentially active faults have been insufficiently studied to determine their hazard level. For example, some of the faults that ruptured in the 1992 Landers and 1999 Hector Mine earthquakes were previously thought to be not active, as they appeared to have not moved in at least 11,000 years. Also, although simple in theory, the evidence necessary to determine whether a fault has or has not moved during the past 11,000 years can be difficult to obtain.

In most cases, it is impractical to reduce the damage potential of surface fault rupture by engineering design, and most regulatory agencies, following the position of the California Geological Survey, currently do not allow engineering design for habitable structures (although this is being reconsidered for "minor" faults at this time). Therefore, the most often-used mitigation measure is to simply avoid placing structures on or near active fault traces. The Alquist-Priolo Earthquake Fault Zoning Act requires that geologic investigations, which generally include fault trenching or some other method of subsurface analysis, be performed if conventional structures designed for human occupancy are proposed within a fault zone. These studies must evaluate whether or not an active segment of a fault extends across the area of proposed development following the guidelines for evaluating the hazard of fault rupture presented in Note 49, a publication by the CGS that is available on the worldwide web at http://www.consrv.ca.gov/CGS/rghm/ap/index.htm.

Based on the results of these geologic studies, appropriate structural setbacks are recommended to prevent the siting of the proposed structures directly on top or within a certain distance from the fault. A common misperception regarding setbacks is that they are always 50 feet from the active fault trace. In actuality, as part of a geologic investigation, the project geologist is required to characterize the ground deformation associated with an active fault. Based on these studies, specific setbacks are recommended. If a fault trace is narrow, with little or no associated ground deformation, a setback distance less than 50 feet could be recommended. Conversely, if the fault zone is wide, with multiple splays, or is poorly defined, a setback distance greater than 50 feet may be warranted.

1.5.2 Faults in the Coachella Area

The main fault zoned by the State of California under the criteria of the Alquist-Priolo Act in the Coachella General Plan area is the San Andreas fault. The fault zone extends in a southeasterly direction across the east-central portion of Coachella and the planning area to the southeast of the city (see Plate 1-1). Three other fault zones, referred to from north to south, as the Indio Hills, Berdoo Canyon (also called Coachella Fan), and Mecca Hills fault zones have also been zoned in the area, with portions of those fault zones extending into the City of Coachella General Plan area (Plate 1-1). These fault zones are discussed further below.

The official Alquist-Priolo Earthquake Fault Zone maps that cover the Coachella General Plan area, namely the Indio and Thermal Canyon quadrangles, both date from July 1, 1974, and as such, are part of the first group of maps released by the State. These first maps were based almost exclusively on mapping conducted by previous investigators, with little independent analysis and interpretation conducted by staff from the Fault Evaluation and Zoning Program

(Hart and Bryant, 1999; 2007). As indicated in the bottom-right corner of the Alquist-Priolo maps, the fault data were compiled from mapping conducted by Ware (1958), Popenoe (1959) and Hope (1969b).

These first maps also zoned both active and potentially active faults, with potentially active faults being those that show evidence of displacement in the past 1.6 million years (during the Quaternary). Maps issued after 1977 zoned only those faults that met the criteria of "sufficiently active" and "well-defined" discussed in Section 1.2.1. Between 1976 and 2007, 161 revised maps were issued, with the revisions generally based on the findings of field studies conducted in response to the first official maps. No revised maps have been issued for the Coachella area; however, as of the writing of this report, the maps that cover the Coachella General Plan area are being updated by the California Geological Survey (William Bryant, personal communication, July 2011; Jerome Treiman, personal communication, 2014), to reflect the findings of several trenching studies that have been conducted in the area in the past about 15 years. The preliminary revised maps have not yet been released for review and comment, but are expected to be released before the end of 2014 (Jerome Treiman, personal communication, March 2014). As a result, the boundaries of the Alquist-Priolo Fault Zones shown on Plate 1-1 are those in the original, and still official maps of 1974, and this figure will have to be replaced once the final new Alquist-Priolo maps are issued. The location of the San Andreas fault shown on Plate 1-1, however, has been modified from that shown on the official 1974 maps, as described further in the section below.

1.5.2.1 San Andreas Fault

The San Andreas fault, as the master fault in California, was one of the first structures mapped and zoned by the State Geologist after the Alquist-Priolo Earthquake Fault Zoning Act was signed into law on December 22 1972, with an effective date of March 7, 1973. As mentioned above, the fault was zoned based on mapping done in the 1950s and 1960s, with no independent review by the staff from the California Division of Mines and Geology (now the California Geological Survey). Studies to determine the location of a fault typically involve review of aerial photographs, field mapping, and fault trenching. A significant portion of the San Andreas Fault Zone in the Coachella area underlies the Coachella Canal and/or East Side Dike. Construction of these projects, which were completed in the late 1940s, before the geologic maps of the San Andreas fault used by the State to zone the fault were prepared, obscured many of the landscape features that would help to better define the location of the fault through this area. Tilling, road construction and other practices associated with farming in some areas south of the canal have also destroyed landforms typically associated with faults. As a result, most geological researchers have used pre-1940s aerial photographs of the region to estimate the fault's location, and while these efforts yielded reasonably correct results, the actual fault location, geometry, width of the zone, and recency of activity of the various fault strands are best determined from fault trenching studies. Furthermore, although regional maps of the San Andreas Fault Zone (see Plate 1-2) suggest that the section of the fault that extends through the Coachella General Plan area is simple, consisting of one or two relatively straight traces, the fault zone is locally complex, both at the regional and site-specific scales.

Site-specific complexities have become apparent in those areas where fault trenching studies have been conducted. In the area of Indio where Sieh (1986) and Sieh and Williams (1990) did their studies, the San Andreas fault consists of four strands in a zone at least 164 feet (50 m) wide, with the northeastern fault strand accounting for about 90 percent of the total displacement that has occurred along this portion of the fault zone in the past about 1,000 years. At the site studied by Philibosian et al. (2011), south of Avenue 44 and west of Dillon Road, the main fault zone is approximately 245 feet (75 meters) wide, but the entire width of the deformation zone may be in the thousands of feet. The researchers indicate that additional secondary faults to the northeast, under Avenue 44 and the Coachella Canal, are possible although unlikely, whereas other secondary faults and fractures have been mapped more than 400 feet to the southwest of the main fault at this property and in the parcel immediately to the southeast by other investigators (Medall, Aragon, Worswick and Associates, 1981). Unlike the Indio locality, at this site the southern fault trace investigated by Philibosian et al. (2011) appears to be the main fault based on its lateral continuity across the property, although the trenches excavated at this site were not optimal to address this issue. Locally, in the central portion of the Coachella site, the faults form a zone of depression or basin where a thick section of sediment has accumulated.

In addition to the studies mentioned above, several site-specific fault investigations that included trenching to locate the active traces of the fault have been conducted as part of the requirements to develop properties within an Alquist-Priolo Earthquake Fault Zone. These studies have also shown that the fault is a zone generally hundreds of feet wide, with the main faults oriented about 40 to 50 degrees to the west of north, consistent with the overall regional trend of the San Andreas fault, whereas the secondary faults tend to trend more northerly. These secondary faults, which tend to be a few hundred feet in length occur both to the south and north of the main fault traces. Most of these studies have shown that along a large portion of the fault zone in the Coachella area, the main traces of the San Andreas fault are not located where shown on the 1974 State maps: In the northern portion of the city, where Philibosian et al. (2011) conducted their study, the main fault is about 175 to 300 feet north of where previously mapped, whereas in the central and southern portions of the city, between about Avenues 46 and 50, the fault is about 500 to 650 feet to the southwest of where shown on the 1974 State maps. A revised location for the main fault zone in the Coachella General Plan area, based mostly on work by Petra Geotechnical Inc. (2006, 2007b, 2007c) is shown on Plate 1-1. This plate will have to be updated once the California Geological Survey releases the official revised maps for this area.

In the southern portion of the Coachella General Plan area, the San Andreas fault leaves the alluviated valley and extends through the southwestern portion of the Mecca Hills. In this area the fault zone is 65 to 165 feet (20 to 50 meters) wide, and is "clearly marked on the surface by a nearly straight . . . zone of red brown gouge and crushed rock (Sylvester and Damte, 1999). This section of the fault, from the south side of Thermal Canyon southward, has experienced slip triggered by distant earthquakes, including the 1968 Borrego Springs and 1979 Imperial Valley (Clark, 1984; Williams et al., 1988), 1986 Palm Springs (Williams et al., 1988), 1992 Landers (Rymer, 2000), and 2010 El Mayor-Cucapah (Weldon, 2010, http://response.scec.org/node/273; Wei et al., 2011).

As mentioned previously, the section of the San Andreas fault that extends through the Coachella General Plan area has not ruptured in an earthquake during historic times. At a rate of about 25 mm/yr, the fault has accumulated over the last approximately 320 years sufficient strain to slip more than 26 feet (8 meters) the next time it ruptures. In the ShakeOut scenario (Jones et al., 2008), fault slip in the Coachella area as a result of an earthquake on this segment of the fault is estimated at between 22 and 26 feet (6.7 and 8 meters). This will have significant impacts on the lifelines and infrastructure of the region, including extensive damage to the Coachella Canal, which locally sits on top of the fault zone.

1.5.2.2 Indio Hills Fault Zones, Including Berdoo Canyon (Coachella Fan) Fault

Starting in 1976, the California Division of Mines and Geology (now the California Geological Survey) issued Fault Evaluation Reports (FERs) that describe the faults under study and the rationale for zoning or not zoning a specific trace or splay of a fault. Interestingly, FERs describing the faults zoned in the Alquist-Priolo maps for the Indio and Thermal Canyon quadrangles are not available, which suggests that there are no specific data that explain why sections of the faults in the Indio and Mecca Hills were included in the 1974 Official Alquist-Priolo Earthquake Fault Zone maps. However, given that these early maps included all Quaternary faults, this may be the reason why these faults were zoned at that time. In the U.S. Geological Survey database of "Quaternary faults and folds in the United States" (http://geohazards.usgs.gov/qfaults/map.php), these faults are shown as having moved in the past 130,000 years, but not in the Holocene.

Clark (1984) mapped dozens of relatively short (½- to ¼-mile long), northwest- to north-northwest-trending normal faults in the Indio Hills and Mecca Hills areas that reportedly offset Quaternary and younger alluvium. According to Clark, most of these faults appear to be directly related to movement on the San Andreas fault, and form elongated ridges and/or low hills that are parallel to the main San Andreas fault. In the Indio Hills especially, uplift is highest to the south, and decreases northward. Uplift seems to be the result of recurrent movement on these faults, as indicated by steeper, less weathered scarps near the base of the ridges, and older units being offset more than younger units. Extensive work has been done over the years in the Indio Hills to study the various strands of the San Andreas fault (Keller et al., 1982; Sieh, 1986; Sieh and Williams, 1990; van der Woerd et al., 2006; Behr et al., 2010; Fletcher et al., 2010), but no research projects have been conducted, to our knowledge, of these secondary faults east and north of the San Andreas fault. Recent studies conducted for feasibility and planning purposes, first steps in a development project, have included extensive trenching across many of these features, to evaluate whether or not they are related to faulting (Petra, 2007a). Several of these features have been determined to be faults, although whether they are the result of primary or secondary faulting, regional lateral spreading or earthquake-induced shallow landsliding, or some other process, is still being debated. Preliminary results have been submitted to the California Geological Survey (CGS) as part of the requirement that all investigations of a fault zoned under the Alquist-Priolo Act need to be filed with the CGS. The State Geologist is in the process of reviewing these findings as part of the State's efforts to review and update the current, official Alquist-Priolo Earthquake Fault Zone maps for this area.

1.5.2.3 Mecca Hills Fault Zones

The Mecca Hills, like the Indio Hills to the north and the Durmid Hill to the south, are transpressional features along the San Andreas fault that formed due to a slight deviation in the orientation of the San Andreas fault at these locations. Specifically, along most of its length in the Coachella Valley, the San Andreas fault is parallel to the vector of plate motion, but at these locations, the strike of the fault is about 5 to 7 degrees farther west (Bilham and Williams, 1985). This results in northwest-southeast compression, causing the sediments in these areas, over hundreds of thousands of years, to pop up. Some of the movement associated with this uplift is manifested in the extensive folding and tilting of the sedimentary rocks that form the hills, whereas in other areas, it is accommodated along faults.

In addition to the San Andreas fault, the Mecca Hills are cut by three other fault zones. From west to east, these are the Skeleton Canyon, Painted Canyon and Eagle Canyon faults. These faults form prominent narrow valleys that extend northerly across the hills, locally forcing right steps along some of the drainage courses. Farther east, forming the southeastern margin of the hills is the Hidden Springs fault. Only the northern, horse-tail-shaped end of the Painted Canyon fault, referred to as the NW Painted Canyon Fault Zone, extends into the Coachella General Plan area (see Plate 1-1), with the northern ends of these fault strands appearing to extend even farther north than shown on the Alquist-Priolo Earthquake Fault Zone map. The eastern-most of these faults appears to continue at least 1.45 miles north of the I-10, as indicated by a strong tonal lineament on aerial photographs of the area, in addition to a line of seismicity that includes two of the largest earthquakes recorded in the area (the 12/24/2006 and 7/14/2004 events identified in Plate 1-1). Trenching across these tonal lineaments has been conducted locally as part of the geotechnical feasibility studies for the Lomas del Sol (now La Entrada) project (Petra, 2007a); these studies have shown that both active and potentially active faults extend through these areas, with additional studies required to further define the lateral continuity, width, and activity of the faults. The California Geological Survey is reviewing these studies as part of the process to update the Alquist-Priolo Earthquake Fault Zone map for this area (William Bryant, personal communication, July 2011).

1.6 Ground Failure due to Earthquake Shaking

Various types of ground failure that are the result of earthquake shaking can cause substantial damage to the built environment. The most destructive of these failures include liquefaction and slope failure, but other tectonically induced forms of ground failure are also possible. These are described further below.

1.6.1 Liquefaction

Liquefaction is a geologic process that causes various types of ground failure. It typically occurs within the upper 50 feet of the surface, in saturated, loose, fine- to medium-grained sandy to silty soils in the presence of ground accelerations over 0.2g (Borchardt and Kennedy, 1979; Tinsley and Fumal, 1985). Earthquake shaking suddenly increases pressure in the water that fills the pores between soil grains, causing the soil to have a total or substantial loss of shear strength, and behave like a liquid or semi-viscous substance. This process can be observed at the beach by standing on the wet sand near the surf zone. Standing still, the sand will support our weight. However, if we tap the sand with our feet, water comes to the surface, the sand liquefies, and our feet sink.

Liquefaction can cause structural distress or failure due to ground settlement, a loss of bearing capacity in the foundation soils, and the buoyant rise of buried structures. That is, when soils liquefy, the structures built on them can sink, tilt, and suffer significant structural damage. In addition to loss of bearing strength, liquefaction-related effects include ground oscillations, lateral spreading and flow failures or slumping. The excess water pressure is relieved by the ejection of material upward through fissures and cracks; water or water-soil slurries may bubble onto the ground surface, resulting in features called "sand boils," "sand blows," "sand volcanoes," or "mud spouts." Seepage of water through cracks may also be observed.

The types of ground failure typically associated with liquefaction are explained below.

Lateral Spreading – Lateral displacement of surficial blocks of soil as the result of liquefaction in a subsurface layer is called lateral spreading. Even a very thin liquefied layer can act as a hazardous slip plane if it is continuous over a large enough area. Once liquefaction transforms the subsurface layer into a fluid-like mass, gravity plus inertial forces caused by the earthquake may move the mass down-slope towards a cut slope or free face (such as a river channel or a canal). Lateral spreading most commonly occurs on gentle slopes that range between 0.3 degrees and 3 degrees, and can displace the ground surface by several feet to tens of feet. Such movement damages pipelines, utilities, bridges, roads, and other structures. During the 1906 San Francisco earthquake, lateral spreads with displacements of only a few feet damaged every major pipeline in the area. Thus, liquefaction compromised San Francisco's ability to fight the fires that caused about 85 percent of the damage (Tinsley et al., 1985). Lateral spreading was also reported in and around the Port of Los Angeles during both the 1933 and 1994 earthquakes (Barrows, 1974; Stewart et al., 1994; Greenwood, 1998).

Flow Failure – The most catastrophic mode of ground failure caused by liquefaction is flow failure. Flow failure usually occurs on slopes greater than 3 degrees. Flows are principally liquefied soil or blocks of intact material riding on a liquefied subsurface. Displacements are often in the tens to hundreds of feet, but under favorable circumstances, soils can be displaced for tens of miles, at velocities of tens of miles per hour. For example, the extensive damage to Seward and Valdez, Alaska, during the 1964 Great Alaskan earthquake was caused by submarine flow failures (Tinsley et al., 1985).

Ground Oscillation – When liquefaction occurs at depth but the slope is too gentle to permit lateral displacement, the soil blocks that are not liquefied may separate from one another and oscillate on the liquefied zone. The resulting ground oscillation may be accompanied by the opening and closing of fissures (cracks) and sand boils, potentially damaging structures and underground utilities (Tinsley et al., 1985).

Loss of Bearing Strength – When a soil liquefies, loss of bearing strength may occur beneath a structure, possibly causing the building to settle and tip. If the structure is buoyant, it may float upward. During the 1964 Niigata, Japan earthquake, buried septic tanks rose as much as 3 feet, and structures in the Kwangishicho apartment complex tilted as much as 60 degrees (Tinsley et al., 1985).

Ground Lurching – Soft, saturated soils have been observed to move in a wave-like manner in response to intense seismic ground shaking, forming ridges or cracks on the ground surface. At present, the potential for ground lurching to occur at a given site can be predicted only generally. Areas underlain by thick accumulation of colluvium and alluvium appear to be the most susceptible to ground lurching. Under strong ground motion conditions, lurching can be expected in loose, cohesionless soils, or in clay-rich soils with high moisture content. In some cases, the deformation remains after the shaking stops (Barrows et al., 1994).

As indicated above, there are three general conditions that need to be met for liquefaction to occur. The first of these – ground shaking of relatively long duration – can be expected to occur in the Coachella area as a result of an earthquake on the San Andreas, San Jacinto, Mesquite Lake, Pinto Mountain, and some of the other active faults in the region. The second condition – geologically young, loose, unconsolidated sediments – occurs throughout the valley portions of the Coachella area, and in the canyons east of the San Andreas fault. Note the distribution of Quaternary river channel deposits (Qg), alluvial fan and stream deposits (Qa), and interbedded lake and distal fan deposits (Ql/Qa) in Plate 2-1a. All of these sediments are cohesionless and loose in the upper sections, and thus susceptible to liquefaction if the other two necessary conditions are present. The third condition – historically shallow groundwater within about 50 feet of the surface – has been reported throughout the western half of the General Plan area, in the valley portion of Coachella.

This shallow groundwater, which in a large portion of the region occurred at or within about 10 feet of the ground surface during the 1960s (California Department of Water Resources - DWR, 1964), is water semi-perched on top of a thick sequence of fine-grained silts and clays deposited when this area was covered by ancient Lake Cahuilla. Intense pumping for groundwater in response to the increase in population and agricultural development of the region has significantly reduced the groundwater levels in the deep aquifer, but the shallow, non-potable aquifer levels have remained relatively constant, at least into the 1990s or early 2000s. A review of several fault investigations (such as Sladden Engineering, 2006; Petra, 2006, 2007c), and groundwater monitoring studies conducted for properties where leaks of petroleum fuels from underground storage tanks have been reported (GeoTracker database – see Chapter 5; EAR, 2010; Frey Environmental, 2008, 2009, 2010; RM Environmental, 2001, 2011) show that in general, groundwater levels in the upper aquifer have dropped approximately 10 feet from the levels reported by the DWR in 1964, but are still within the 30- to 50-foot depths considered in liquefaction susceptibility analyses. Furthermore, increased urbanization, with the resultant typical increase in landscaping irrigation, especially if the tile drains now common in the agricultural areas have been removed during development, has the potential to raise the water levels in the shallow aquifer. A shallower regional groundwater table could also develop again in the future if water levels rise in response to decreased pumping of groundwater (due to increased use of imported water) and/or the groundwater recharge programs ongoing in the lower Whitewater River, and proposed in the city of Indio (MWH, 2011).

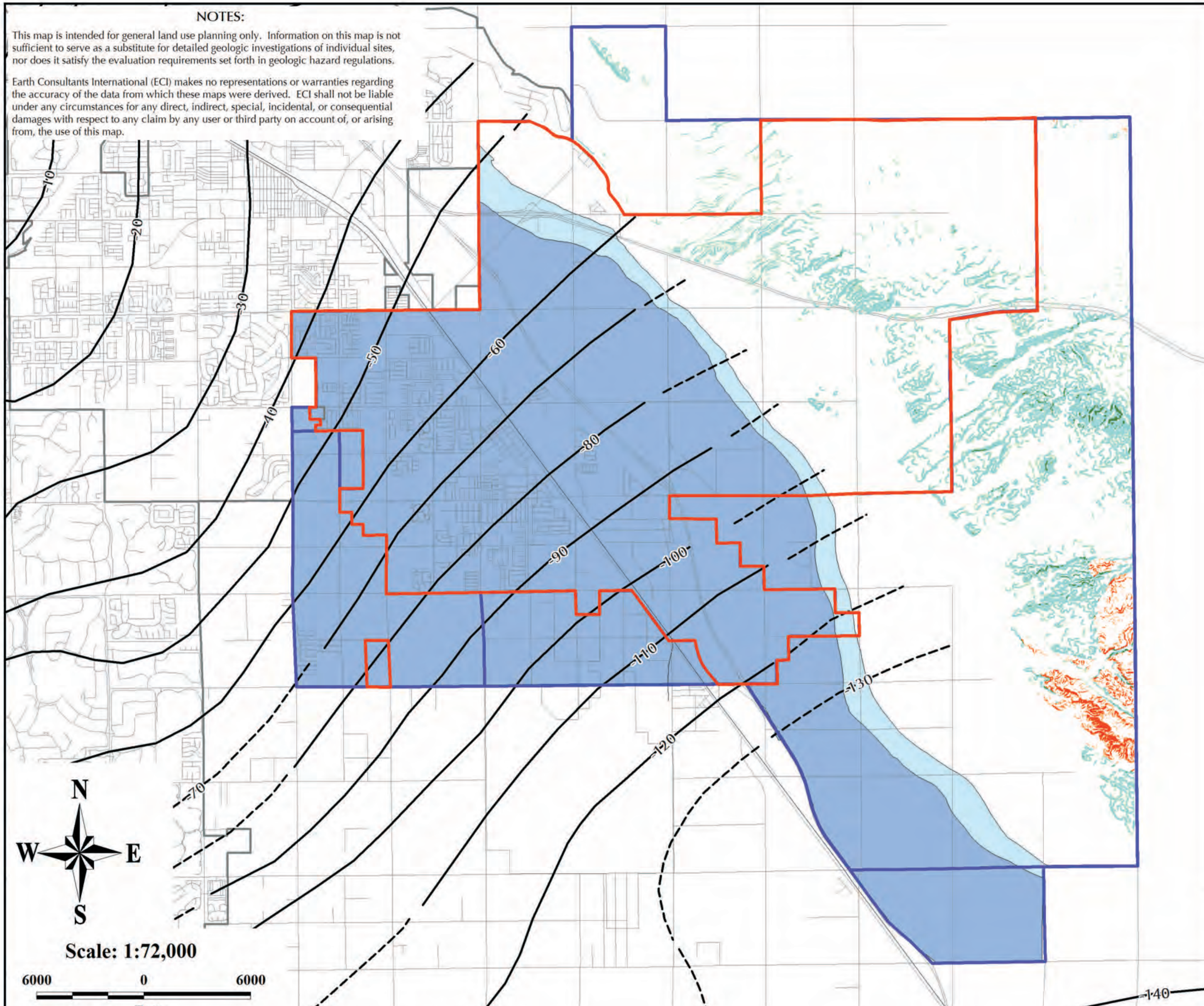
The areas of Coachella where young unconsolidated sediments and historically shallow groundwater conditions co-exist are shown on Plate 1-3 as susceptible to liquefaction. Areas where groundwater has been reported within 30 feet of the ground surface are shown as having a high susceptibility, whereas areas where groundwater has been reported at depths of between 30 and 50 feet are shown as having a moderate susceptibility. Geotechnical studies to evaluate the potential for liquefaction-induced differential settlement are recommended in these areas prior to development. Given that the groundwater levels in this area may fluctuate seasonally, the geotechnical analyses should use the shallowest groundwater levels reported in the area to calculate the anticipated settlement due to liquefaction. Areas immediately adjacent to the San Andreas fault, especially on the northeast side of the fault, may also be susceptible to liquefaction because the fault locally serves as a groundwater barrier, forcing water upward. Deformation features likely produced by liquefaction during past earthquakes have been observed in many of the trenches excavated to locate the San Andreas fault. These areas are not shown on Plate 1-3 because this condition does not necessarily occur along the entire length of the fault, and the scale of the map (Plate 1-3) does not permit a correct representation of the width of this zone. Nevertheless, geotechnical studies to evaluate the potential for liquefaction-induced differential settlement should be conducted if development is proposed immediately adjacent to the fault zone.

Absent an official map from the California Geological Survey, Plate 1-3 should be used as if it were the official map, and site-specific liquefaction susceptibility studies should be conducted in the mapped areas prior to any proposed development. In accordance with the Seismic Hazards Mapping Act (SHMA), all projects within a State-delineated Seismic Hazard Zone for liquefaction must be evaluated by a Certified Engineering Geologist and/or Registered Geotechnical Engineer (this is typically a civil engineer with training and experience in soil engineering). Most often however, it is appropriate for both the engineer and geologist to be involved in the evaluation, and in the implementation of the mitigation measures. Likewise, project review by the local agency must be performed by geologists and engineers with the same credentials and experience.

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.



Base Map: From the City of Coachella.

Sources: Groundwater levels from California Department of Water Resources (1964); geological data derived from Dibble (2008) and Rogers (1965) - See Plate 2-1a; California Geological Survey (2004, 2008); Keefer and Wilson (1989); recent groundwater information obtained from various sites in the GeoTracker database (http://geotracker.swrcb.ca.gov/), and from geotechnical and fault evaluation studies in the City of Coachella files. Slope gradients used in the slope instability analysis derived from the USGS 10m Digital Elevation Model.

Seismic Hazard Zones

Coachella, California

Explanation

Earthquake-Induced Slope Instability

Rock Falls Rock Slides	Areas underlain by bedrock where the local topographic, geological, and geotechnical conditions indicate a potential for permanent ground displacements, such that mitigation may be required. Refer to text for additional information.
Soil Falls Soil Slides Soil Slumps	Areas underlain by Holocene and Pleistocene sediments where the local topographic, geological, and geotechnical conditions indicate a potential for earthquake-induced soil block slides or soil slumps. Mitigation measures may be required if these areas are developed. Refer to text for additional information.

Liquefaction Susceptibility

High	Areas underlain by youthful, unconsolidated sediments, and where historically shallow groundwater, within 30 feet of the ground surface, has been reported. These conditions indicate a high potential for permanent ground displacements such that mitigation for liquefaction may be required.
Moderate	Areas underlain by youthful, unconsolidated sediments, and where historically shallow groundwater, 30 to 50 feet below the ground surface, has been reported. These conditions indicate a moderate potential for permanent ground displacements such that mitigation for liquefaction may be required.
(black line)	Historical groundwater elevation in feet relative to sea level (DWR, 1964). This shallow groundwater is generally perched above fine-grained sediments, and is for the most part not potable. Review of several geotechnical, geological and groundwater monitoring reports indicate that between 1990 and 2011, groundwater levels have dropped approximately 10 feet from the levels shown here.
(red line)	Coachella City Boundary
(blue line)	Coachella Planning Area Boundary

Note that shallow groundwater, within 30 feet of the ground surface, and unconsolidated sediments susceptible to liquefaction occur locally adjacent to the San Andreas fault, with shallower groundwater levels typically present on the east side of the fault zone. These zones are not shown on this map. Nevertheless, studies to evaluate the potential for liquefaction should be conducted on a site-specific basis in areas proposed for development adjacent to the fault zone.

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Plate 1-3

In order to assist project consultants and reviewers in the implementation of the SHMA, the State has published specific guidelines for evaluating and mitigating liquefaction (CDMG, 1997; CGS, 2008). Then, in 1999 a group sponsored by the Southern California Earthquake Center (SCEC, 1999) published recommended procedures for carrying out the California Geological Survey guidelines. In 2003, a consensus report that describes new criteria for the definition and study of the liquefaction resistance of soils was published by the Earthquake Engineering Research Center (Seed et al., 2003), and additional studies can be expected in this field. Consultants should review and apply the most recent, peer-reviewed guidelines for liquefaction study as applicable to the specific site being studied.

In general, a liquefaction study is designed to identify the depth, thickness, and lateral extent of any liquefiable layers that would affect the project site. An analysis is then performed to estimate the type and amount of ground deformation that might occur, given the seismic potential of the area. Mitigation measures generally fall in one of two categories: ground improvement or foundation design. Ground improvement includes such measures as removal and recompaction of low-density soils, removal of excess ground water, in-situ ground densification, and other types of ground improvement (such as grouting or surcharging). Special foundations that may be recommended range from deep piles to reinforcement of shallow foundations (such as post-tensioned slabs). Mitigation for lateral spreading may also include modification of the site geometry or inclusion of retaining structures. The types (or combinations of types) of mitigation depend on the site conditions and on the nature of the proposed project (CDMG, 1997; CGS, 2008). Given the benefits of the groundwater recharge programs that are ongoing and have been proposed in the lower Coachella Valley, mitigation measures to reduce the hazard of liquefaction in the Coachella General Plan area should emphasize the densification of the soils or other ground improvements, and the strengthening of the structural foundations, rather than the pumping of water to reduce the groundwater levels.

1.6.2 Earthquake-Induced Slope Failure

Strong ground motions can worsen existing unstable slope conditions. Seismically induced landslides can overrun structures, harm people or damage property, sever utility lines, and block roads, thereby hindering rescue operations after an earthquake. Over 11,000 landslides were mapped shortly after the 1994 Northridge earthquake, all within a 45-mile radius of the epicenter (Harp and Jibson, 1996). Although numerous types of earthquake-induced landslides have been identified, the most widespread type generally consists of shallow failures involving surficial soils and the uppermost weathered bedrock in moderate to steep hillside terrain (these are also called disrupted soil slides). Rockfalls and rock-slides on very steep slopes are also common. The 1989 Loma Prieta and 1994 Northridge earthquakes showed that reactivation of existing deep-seated landslides can also occur (Spittler et al., 1990; Barrows et al., 1995). One of the most impressive ancient landslides in the southern California region is the Martinez Mountain Landslide located immediately to the southwest of La Quinta. Some geologists have suggested that seismic shaking triggered this rock avalanche (Morton and Saddler, 1989).

A combination of geologic conditions leads to landslide vulnerability. These include high seismic potential; rapid uplift and erosion resulting in steep slopes and deeply incised canyons; highly fractured and folded rock; and rock with inherently weak components, such as silt or clay layers. Slope failures in soils can also occur, with slope angle, moisture content, and intensity of shaking being the most important triggers or components responsible for failure. The orientation of the slope with respect to the direction of the seismic waves (which can affect the shaking intensity) can also control the occurrence of landslides. Groundwater conditions at the time of the earthquake play an important role in the development of seismically induced slope failures. Thus, the 1906 San Francisco earthquake, which occurred in April after a winter of exceptionally heavy rainfall, produced over ten thousand slope failures (Wilson and Keefer, 1985), including some very large landslides and mudflows that killed several people. The 1989 Loma Prieta earthquake however, occurred in October, during the third year of a drought, and slope failures were limited primarily to rockfalls and reactivation of older landslides that were manifested as ground cracking in the scarp areas but with very little movement (Griggs et al., 1991).

Keefer and Wilson (1989) conducted a survey of the slope failures caused by over 40 earthquakes around the world and found that seismic shaking is one of the most important triggers of landslides in arid and semi-arid regions. Even in areas that receive very little precipitation, earthquakes larger than about magnitude 6 have caused hundreds to thousands of slope failures.

One of the most comprehensive and still widely used landslide classification schemes is that by Varnes (1978). His classification emphasizes the type of movement (falls, topples, rotational slides, translational slides, lateral spreads, flows, and combinations of the above), followed by the type of material involved (bedrock and engineering soils, with soils further divided into predominantly coarse-grained and predominantly fine-grained). Keefer (1984) and Wilson and Keefer (1985) used a modification of Varnes' (1978) scheme to classify earthquake-induced landslides. Their primary criteria include material, mechanism of movement and amount of internal disruption; secondary criteria include water content, velocity, depth, and geologic environment. Wilson and Keefer (1985) consider only two types of material – bedrock and soil, with soil comprising all uncemented or slightly cemented aggregate of mineral grains, including young sedimentary deposits, the regolith or weathered deposits that mantle bedrock, and man-made fill slopes. A review of their classification shows that earthquake-induced landslides that occur in rock and sedimentary deposits under dry conditions fall, with one exception, into their Category I landslides. The landslides in this category are all highly or very highly disrupted, having occurred rapidly or extremely rapidly. With the exception of rock avalanches, the materials involved are mostly shallow, generally less than 3 meters (10 feet) deep. The specific types of landslides in this category include rock falls, rock slides, rock avalanches, soil falls, and soil slides. These types of slope failures are described further in Table 1-3. The geologic and slope conditions commonly necessary for these failures to occur were used to evaluate the earthquake-induced slope instability potential in the Coachella General Plan and develop the potential earthquake-induced landslide zones shown on Plate 1-3.

The last type of slope failure included in Table 1-3, soil slumps, falls into Wilson and Keefer's (1985) Category II. This landslide category is characterized by relatively coherent slides that move slower than Category I slides, and are generally deep-seated. Soil slumps may occur in both dry and wet soil conditions. Although not shown on Plate 1-3, in the Coachella General Plan area earthquake-induced soil slumps may occur locally in man-made structures, including the embankment of the East Side dike (especially if retaining runoff water on its east side at the time of the earthquake), and in the walls of unlined or clay-lined reservoirs, ponds, and recharge basins. Soil slumps may also occur in the relatively gently sloped alluvial fans draining the Indio and Mecca Hills.

Table 1-3: Earthquake-Induced Slope Failures in Arid Environments

Landslide Type	Geologic Material. Environment	Minimum Slope (in degrees)	Velocity; Depth; Type of Movement	Potential Location in Coachella
Consolidated Bedrock (Igneous, Metamorphic and Sedimentary)				
Rock Falls	Weakly cemented, intensely fractured or weathered; with conspicuous planes of weakness dipping out of slope; precariously perched boulders. Common near ridge crests and on ledges; artificially cut slopes, and slopes undercut by active erosion.	34	Extremely rapid (>10 ft/sec); shallow (<10 ft deep); bouncing, falling and free-falling.	Locally in the Mecca Hills, where the Palm Spring Formation crops out in steep slopes, and in the northeast corner of the General Plan area, where plutonic rocks crop out.
Rock Slides	Weakly cemented, intensely fractured or weathered; conspicuous planes of weakness dipping out of slope, or boulders surrounded by weak matrix. Common in hillside flutes and channels, artificially cut slopes, and slopes undercut by active erosion.	25	Rapid to extremely rapid (>1 ft/sec); shallow (<10 ft deep); translational (planar or gently undulatory) sliding on basal shear surface, typically a pre-existing discontinuity such as bedding, joint, or fault.	Locally in the Mecca Hills, where beds of the Palm Spring Formation dip out of slope in canyon walls.
Rock Avalanches	Intensely fractured and exhibiting significant weathering, planes of weakness dipping out of slope, weak cementation, and/or evidence of previous landsliding. Generally restricted to slopes with more than 500 feet (150 m) of relief undercut by erosion.	25	Extremely rapid (>10 ft/sec); deep (>10 ft deep); complex, involves sliding and/or flow as a stream of rock fragments. May be accompanied by blast of air that can knock down trees and structures beyond the limits of the debris.	Rock avalanches may occur in the Little San Bernardino Mountains to the north and east of the Coachella General Plan area. The toe of the debris apron could impact the northeastern portion of the study area.
Unconsolidated and Weakly Consolidated Deposits (Older Alluvium, Alluvium, Colluvium, Soil, Artificial Fill)				
Soil Falls	Granular soils that are slightly cemented or contain clay binder. Generally common on bluffs and steep slopes such as stream banks, terrace faces, and artificially cut slopes.	34 – 40 (possible); >40 (more likely)	Extremely rapid to very slow (>1 ft/5 yr to >10 ft/sec); bouncing, falling, free falling.	May occur in steep slopes underlain by the Ocotillo Conglomerate, parallel or nearly parallel to slope faces.
Soil Slides	Holocene and Pleistocene loose, unsaturated sands, coarse-grained sediments, sensitive clays.	15	Moderate to rapid (>1 ft/sec); shallow (<10 ft deep); translational sliding on basal shear surface or zone of weakened sensitive clay.	May occur in the hillsides underlain by the Ocotillo Conglomerate.
Soil Slumps	Loose, dry to wet sand or silt; uncompacted or poorly compacted man-made fill consisting of sand, silt or clay; pre-existing soil slump deposits. Common on embankments built on soft, saturated materials; in hillside cut-and-fill areas; and on river floodplains.	10	Slow to rapid (> 5ft/year to < 1 ft/sec; deep (> 10 ft); sliding on basal shear surface with a component of headward rotation.	May occur along the East Side dike, especially if it is retaining water, and on the walls of partly filled reservoirs, ponds, and recharge basins. Also in the gentle slopes off the Indio and Mecca Hills, and the alluvial fans draining the hills.

Sources: Modified from Varnes (1978), Keefer (1984), Wilson and Keefer (1985) and CGS (2008).

The hills in the eastern section of the Coachella General Plan area have not been mapped within a State-delineated Seismic Hazard Zone for seismically induced landsliding because this mapping program has not yet been funded for Riverside County. Topographically, the eastern one-third to one-half of the Coachella General Plan area consists of gentle to steep hills, locally with steep canyon walls. Although the hills are for the most part currently undeveloped, sections of the I-10 freeway, the East Side dike, the Coachella Canal, and some roads at the foot of these hillsides are susceptible to earthquake-induced slope instability.

Rockfalls may happen suddenly and without warning, but are more likely to occur in response to earthquake-induced ground shaking, during periods of intense rainfall, or as a result of man's activities, such as grading and blasting. Wilson and Keefer (1985) reported that ground acceleration of at least 0.10g in steep terrain is necessary to induce earthquake-related rockfalls. Although exceeding this level of shaking does not guarantee that rockfalls will occur, this is certainly a concern in the Mecca Hills given the high ground accelerations anticipated in the area when the southern San Andreas fault ruptures next. Specifically, portions of the Mecca Hills in the southeasternmost section of the General Plan Area are underlain by bedrock assigned to the Palm Spring Formation. Faults, joints and fractures have formed several wedges of rock that are precariously attached to the slope faces; strong shaking during an earthquake is likely to topple these rocks posing a rockfall hazard to areas adjacent to and below these slopes. That this has happened in the past is evident, as large chunks of rock can be seen scattered around on the canyon floors. The 1992 Landers earthquake triggered several rock falls and rock slides in the Mecca Hills, including a large failure that blocked access to Red Canyon (Rymer, 2000). Given how the epicenter of the Landers earthquake occurred nearly 45 miles (72 km) from Red Canyon, it is clear that a near-source earthquake on the San Andreas fault would be particularly damaging to the rock faces in the Mecca Hills.

Rock falls and other types of bedrock landslides may also occur in the northeastern portion of the Coachella General Plan area, where plutonic rocks crop out. Steep relief to the north of the study area, in the Little San Bernardino Mountains, if combined with intensely jointed and fractured rock can result in rock falls, rock slides and rock avalanches. Rock avalanches are not likely to start within the General Plan area, but the toe of the disrupted material could encroach into the area's northeastern corner.

The hills north and northwest of the Mecca Hills are underlain by softer sediments assigned to the Ocotillo Formation (see Chapter 2 and Plate 2-1). These deposits form rounder slopes than the Palm Springs Formation in the Mecca Hills, but locally, especially along the canyon walls, these deposits form relatively steep to nearly vertical slopes that can fail in response to shaking during an earthquake. Different types of earthquake-induced slope failures can occur in this area, depending in great part on the angle of the slopes, as described in Table 1-3 and shown on Plate 1-3. Loose boulders left behind by erosion and removal of the surrounding matrix can also fail, bouncing, rolling and locally free falling. Areas directly downhill from these hillside regions are most vulnerable to the effects of slope failure. Existing slopes that are to remain adjacent to or within proposed developments should be evaluated for the geologic conditions mentioned above (also refer to Section 2.3.1 in Chapter 2). For suspect slopes, appropriate geotechnical investigation and slope stability analyses should be performed for both static and dynamic (earthquake) conditions. Protection from rockfalls or surficial slides can often be achieved by protective devices such as barriers, retaining structures, catchment areas, or a combination of the above. The runout area of the slide at the base of the slope, and the potential bouncing of rocks must also be considered. If it is not feasible to mitigate the unstable slope conditions, building setbacks should be imposed.

In accordance with the SHMA, all development projects within a State-delineated Seismic Hazard Zone for seismically induced landsliding must be evaluated and reviewed by State-licensed engineering geologists and/or geotechnical engineers (for landslide investigation and analysis, this typically requires both). In order to assist in the implementation of the SHMA, the State has published specific guidelines for evaluating and mitigating seismically induced landslides (CDMG, 1997; CGS, 2008). The Southern California Earthquake Center (SCEC, 2002) sponsored the publication of the "Recommended Procedures for Implementation of DMG Special Publication 117." The steep slope areas identified in Plates 1-3 and 2-2 should be evaluated following these procedures if development near these slopes is proposed.

1.6.3 Seismically Induced Settlement

Under certain conditions, strong ground shaking can cause the densification of soils, resulting in local or regional settlement of the ground surface. During strong shaking, soil grains become more tightly packed due to the collapse of voids and pore spaces, resulting in a reduction of the thickness of the soil column. This type of ground failure typically occurs in loose granular, cohesionless soils, and can occur in either wet or dry conditions. Unconsolidated young alluvial deposits are especially susceptible to this hazard. Artificial fills may also experience seismically induced settlement. Damage to structures typically occurs as a result of local differential settlements. Regional settlement can damage pipelines by changing the flow gradient on water and sewer lines, for example. As shown in Plate 2-1a, the valley portion of Coachella is underlain by young, unconsolidated alluvial and lacustrine sediments, locally mantled with wind deposits (map symbols Qg, and Ql/Qa). These sediments are susceptible to seismically induced settlement.

Mitigation measures for seismically induced settlement are similar to those used for liquefaction. Recommendations are provided by the project's geologist and soil engineer, following a detailed geotechnical investigation of the site. Overexcavation and recompaction is the most commonly used method to densify soft soils susceptible to settlement. Deeper overexcavation below final grades, especially at cut/fill, fill/natural or alluvium/bedrock contacts may be recommended to provide a more uniform subgrade. Overexcavation should also be performed so that large differences in fill thickness are not present across individual lots. In some cases, specially designed deep foundations, strengthened foundations, and/or fill compaction to a minimum standard that is higher than that required by the UBC may be recommended.

1.6.4 Deformation of Sidehill Fills

Sidehill fills are artificial fill wedges typically constructed on natural slopes to create roadways or level building pads. Deformation of sidehill fills was noted in earlier earthquakes, but this phenomenon was particularly widespread during the 1994 Northridge earthquake. Older, poorly engineered road fills were most commonly affected, but in localized areas, building pads of all ages experienced deformation. The deformation was usually manifested as ground cracks at the cut/fill contacts, differential settlement in the fill wedge, and bulging of the slope face. The amount of displacement on the pads was generally about three inches or less, but this resulted in minor to severe property damage (Stewart et al., 1995). This phenomenon was most common in relatively thin fills (about 27 feet or less) placed near the tops or noses of narrow ridges (Barrows et al., 1995).

This hazard could occur locally in the hillsides on the eastern portion of the Coachella General Plan region, such as along portions of the I-10 freeway where fills were placed on the outside of a cut to create a wider cut for the road embankment. With increased development of the hillsides in this area, this hazard may become more common, as building pads built on the sides of a slope are particularly vulnerable to deformation as a result of ground shaking.

Hillside grading designs are typically conducted during site-specific geotechnical investigations to determine if there is a potential for this hazard. There are currently no proven engineering standards for mitigating sidehill fill deformation, consequently current published research on this topic should be reviewed by project consultants at the time of their investigation. It is thought that the effects of this hazard on structures may be reduced by the use of post-tensioned foundations, deeper overexcavation below finish grades, deeper overexcavation on cut/fill transitions, and/or higher fill compaction criteria.

1.6.5 Ridgetop Fissuring and Shattering

Linear, fault-like fissures occurred on ridge crests in a relatively concentrated area of rugged terrain in the Santa Cruz Mountains during the 1989 Loma Prieta earthquake. Shattering of the surface soils on the crests of steep, narrow ridgelines occurred locally in the 1971 San Fernando earthquake, but was widespread in the 1994 Northridge earthquake. Ridgetop shattering (which leaves the surface looking as if it was plowed) by the Northridge earthquake was observed as far as 22 miles away from the epicenter. In the Sherman Oaks area, severe damage occurred locally to structures located at the tops of relatively high (greater than 100 feet), narrow (typically less than 300 feet wide) ridges flanked by slopes steeper than about 2.5:1 (horizontal:vertical). It is generally accepted that ridgetop fissuring and shattering is a result of intense amplification or focusing of seismic energy due to local topographic effects (Barrows et al., 1995).

Ridgetop shattering is likely to occur locally in the Indio and Mecca Hills, and in the Little San Bernardino Mountains within and bordering, respectively, the Coachella General Plan area during a strong earthquake on the San Andreas, Burnt Mountain or Pinto Mountain faults. Given that there is currently no significant development on these ridgelines, damage to structures as a result of this hazard in the Coachella area is at this time low to none. If, and when development starts to encroach onto the hillside areas, the potential for ridgetop shattering will increase, unless mitigation measures to reduce this hazard are implemented in the design and construction of the proposed structures.

Projects located or proposed in steep hillside areas should be evaluated for this hazard by a Certified Engineering Geologist. Given that it is difficult to predict exactly where this hazard may occur, avoidance of development along the tops of steep, narrow ridgelines is probably the best mitigation measure. Recontouring of the topography to reduce the conditions conducive to ridgetop amplification, along with overexcavation below finish grades to remove and recompact weak, fractured bedrock is thought to reduce this hazard to an acceptable level. Post-tensioned slab foundations that can accommodate some minor movements and differential settlement can also help reduce the impacts of this hazard.

1.7 Other Potential Seismic Hazards

1.7.1 Seiches

A seiche is defined as a standing wave oscillation in an enclosed or semi-enclosed, shallow to moderately shallow water body or basin. Seiches continue (in a pendulum fashion) after the cessation of the originating force, which can be tidal action, wind action, or a seismic event. Reservoirs, lakes, ponds, swimming pools and other enclosed bodies of water are subject to these potentially damaging oscillations (sloshing). Whether or not seismically induced seiches develop in a water body is dependent upon specific earthquake parameters (e.g., frequency of the seismic waves, distance and direction from the epicenter), as well as site-specific design of the enclosed bodies of water, and is thus difficult to predict. Whether an earthquake will create seiches depends upon a number of earthquake-specific parameters, including the earthquake location (a distant earthquake is more likely to generate a seiche than a local earthquake), the style of fault rupture (e.g., dip-slip or strike-slip), and on the configuration (length, width and depth) of the water basin.

Amplitudes of seiche waves associated with earthquake ground motion are typically less than 0.5 m (1.6 feet high), although some have exceeded 2 m (6.6 ft). A seiche in Hebgen Reservoir, caused by an earthquake in 1959 near Yellowstone National Park, repeatedly overtopped the dam, causing considerable damage to the dam and its spillway (Stermitz, 1964). The 1964 Alaska earthquake produced seiche waves 0.3 m (1 ft) high in the Grand Coulee Dam reservoir, and seiches of similar magnitude were reported in fourteen bodies of water in the state of Washington (McGarr and Vorhis, 1968). Seiches in pools and ponds as a result of the 2010 Baja California earthquake were reported and often captured on video in southern California and Arizona, and the Chile earthquake of February 27, 2010 reportedly caused a 0.5-foot-high seiche 4,700 miles away, in Lake Pontchartrain, New Orleans.

Given that there are several lakes, ponds, and reservoirs in and around Coachella, seiches as a result of ground shaking can be expected to occur in the study area. The amplitude of the seiche waves that could occur in these water bodies cannot be predicted given that several parameters combine to form these waves, although, given the relatively shallow depth of these bodies of water, the seiches are anticipated to be relatively minor. Nevertheless, property owners down-gradient from ponds, lakes and pools that could seiche during an earthquake should be aware of the potential hazard to their property should any of these bodies of water lose substantial amounts of water during an earthquake. Water in swimming pools is known to slosh during earthquakes, but in most cases, the sloshing does not lead to significant damage.

Damage as a result of sloshing of water inside water reservoirs is discussed further in the Flood Hazards Chapter (Chapter 3). Site-specific design elements, such as baffles, to reduce the potential for seiches are warranted in tanks and in open reservoirs or ponds where overflow or failure of the structure may cause damage to nearby properties. Damage to water tanks iduring earthquakes, such as the 1992 Landers-Big Bear sequence and the 1994 Northridge, resulted from seiching. As a result of those earthquakes, the American Water Works Association (AWWA) developed Standards for Design of Steel Water Tanks (D-100) that provide revised criteria for seismic design (Lund, 1994).

1.7.2 Tsunami

A tsunami is a sea wave caused by any large-scale disturbance of the ocean floor that occurs in a short period of time and causes a sudden displacement of water. The most frequent causes of tsunamis are shallow underwater earthquakes and submarine landslides, but tsunamis can also be caused by underwater volcanic explosions, oceanic meteor impacts, and even underwater nuclear explosions. Tsunamis can travel across an entire ocean basin, or they can be local. Tsunamis are characterized by their length, speed, low period, and low observable amplitude: the waves can be up to 200 km (125 mi) long from one crest to the next, they travel in the deep ocean at speeds of up to 950 km/hr (600 mi/hr), and have periods of between 5 minutes and up to a few hours (with most tsunami periods ranging between 10 and 60 minutes). Their height in the open ocean is very small, a few meters at most, so they pass under ships and boats undetected (Garrison, 2002), but may pile up to heights of 30 m (100 ft) or more on entering shallow water along an exposed coast, where they can cause substantial damage. The highest elevation that the water reaches as it runs up on the land is referred to as wave runup, uprush, or inundation height (McCulloch, 1985; Synolakis et al., 2002). Inundation refers to the horizontal distance that a tsunami wave penetrates inland (Synolakis et al., 2002).

Because of the substantial increase in population in the last century and extensive development along the world's coastlines, a large percentage of the Earth's inhabitants live near the ocean. As a result, the risk of loss of life and property damage due to tsunami has increased substantially. Between 1992 and 2002, tsunamis were responsible for over 4,000 human deaths worldwide (Synolakis et al., 2002). Then, on December 26, 2004, a magnitude 9.3 earthquake off the northwest coast of Sumatra, Indonesia caused tsunamis in the Indian Ocean that resulted in more than 184,000 confirmed fatalities in the region, with another nearly 170,000 missing, and presumed killed, in Indonesia alone. The earthquake and resulting tsunamis also displaced nearly 1.7 million people in ten countries in South Asia and East Africa, making it the most devastating natural event in recorded history, and increasing overnight the worldwide awareness of tsunamis as a potentially devastating natural hazard. Hundreds of tourists that did not know about evacuating to higher ground were killed by the tsunamis. More recent devastating tsunamis include the September 29, 2009 earthquake and tsunami sequence in Samoa that killed 189 people, the February 27, 2010 earthquake and tsunami in Chile, and the March 11, 2011 Tohoku-oki earthquake and tsunami in Sendai, Japan.

Given Coachella's inland location, the tsunami hazard in the city is nil.

1.8 Vulnerability of Structures to Earthquake Damage

Although it is not possible to prevent earthquakes from occurring, their destructive effects can be minimized, especially since most of the loss of life and injuries due to an earthquake are related to the collapse of hazardous buildings and structures. [FEMA (1985) defines a hazardous building as "any inadequately earthquake resistant building, located in a seismically active area, that presents a potential for life loss or serious injury when a damaging earthquake occurs."] Therefore, the vulnerability of a community to earthquake damage can be reduced with a comprehensive hazard mitigation program that includes the identification and mapping of hazards, prudent planning and enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures.

As discussed previously, building codes have generally been made more stringent following damaging earthquakes. To mitigate for seismic shaking in new construction, recent building codes use amplification factors to account for the impacts that soft sediments and proximity to earthquake sources have on ground motion. Three main effects are considered: (1) soft soils, (2) proximity to earthquake sources (referred to as near-source factors), and (3) the seismic characteristics of the nearby earthquake sources (seismic source type). Each of these effects is discussed further below.

Soft-Soil Effects. The soft soil amplification factors were developed from observations made after the 1985 Mexico City, 1989 Loma Prieta and other earthquakes that showed the amplifying impact that underlying soil materials have on ground shaking. The ground-shaking basis for code design includes six soil types based on the average soil properties for the top 100 feet of the soil profile (see Table 1-4).

Youthful, unconsolidated alluvial sediments classified as site class type F soils may underlie those portions of the Coachella General Plan area that are susceptible to liquefaction (refer to Plate 1-3). The lacustrine (lake) deposits (Ql/Qa sediments on Plate 2-1a) may locally contain clay layers thick enough to be described as site class E or F. Site-specific studies need to be conducted in these areas to determine the soil class type that best fits the site conditions. Similarly, areas along the eastern edge of the valley underlain by youthful, unconsolidated sediments, but where groundwater is too deep for liquefaction, may fall under either site class E or D (compare Plates 2-1a and 1-3). The alluvial fan sediments at the base of the hillsides, in the eastern half of the General Plan area, both immediately west of and to the east of the San Andreas fault are best represented by site class D, except in the narrow canyons where these deposits are most likely less than 100 feet thick, and underlain by sediments assigned to the Ocotillo Conglomerate. Site class C may be most appropriate for these areas. Site-specific studies designed to characterize the shear wave velocity and undrained shear strength of the soil column would be necessary if these fans are to be developed. The areas underlain by the Ocotillo Conglomerate are best represented by site class C. The areas underlain by bedrock assigned to the Palm Spring Formation, in the southeastern portion of the General Plan area, most likely fall in site class B, unless deeply weathered.

Table 1-4: Site Class Definitions (Based on Soil Profile Types)
(from Chapter 20, ASCE Standard 7.10)

Site Class	Soil Profile Name/ Generic Description	Average Soil Properties for the Upper 100 Feet		
		Shear Wave Velocity (feet/second)	Standard Penetration Resistance (blows/foot)	Undrained Shear Strength (psf)
A	Hard Rock	>5,000	N/A	N/A
B	Rock	2,500 to 5,000	N/A	N/A
C	Very dense soil and soft rock	1,200 to 2,500	>50	>2,000
D	Stiff soil profile	600 to 1,200	15 to 50	1,000 to 2,000
E	Soft soil profile	<600	<15	<1,000
E	Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index PI > 20 2. Moisture Content ≥ 40%, and 3. Undrained shear strength < 500 psf			
F	Any profile containing soil having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays, where the thickness of this section is more than 10 feet. 3. Very high plasticity clays (more than 25 feet of clay with plasticity index PI > 75). 4. Very thick soft/medium stiff clays (thickness of the soil > 120 feet) and undrained shear strength < 1000 psf.			

From Table 20.3-1 of the American Society of Civil Engineers, Standard 7-10
psf = pounds per square foot

Near- Source Factors – The Coachella area is subject to near-source design factors given that the San Andreas fault extends across the city, and is located within 15 km of all locations in the city (see Table 1-2 and Plates 1-1 and 1-2). These parameters, which first appeared in the 1997 Uniform Building Code (UBC), address the proximity of potential earthquake sources (faults) to the site. These factors were present in earlier versions of the UBC for implementation into the design of seismically isolated structures, but are now included for all structures. The adoption into the 1997 code of all buildings in UBC seismic zone 4 was the result of observations of intense ground shaking at levels higher than expected near the fault ruptures at Northridge in 1994, and again one year later, in Kobe, Japan. The 1997 UBC also included a near-source factor that accounts for directivity of fault rupture. The direction of fault rupture was observed to play a significant role in distribution of ground shaking at Northridge and Kobe. For Northridge, much of the earthquake energy was released into the sparsely populated mountains north of the San Fernando Valley, while at Kobe, the rupture direction was aimed at the city and was a contributing factor in the extensive damage. However, the rupture direction of a given source cannot be predicted, and as a result, the UBC required a general increase in estimating ground shaking of about 20 percent to account for directivity. These factors are now included in the seismic maps provided in the CBC, and do not need to be calculated separately.

Seismic Source Type – Near-source factors considered in the seismic maps provided in the CBC also include a classification of seismic sources based on slip rate and maximum magnitude potential. Essentially, some faults like the San Andreas fault, are highly active and have a high rate of slip. This type of faults is weighted more in the calculations of ground motion for a given area, given that they are more likely to generate a high magnitude earthquake.

Building damage is commonly classified as either structural or non-structural. Structural damage impairs the building's support. This includes any vertical and lateral force-resisting systems, such as frames, walls, and columns. Non-structural damage does not affect the integrity of the structural support system, but includes such things as broken windows, collapsed or rotated chimneys, unbraced parapets that fall into the street, and fallen ceilings.

During an earthquake, buildings get thrown from side to side and up and down. Given the same acceleration, heavier buildings are subjected to higher forces than lightweight buildings. Damage occurs when structural members are overloaded, or when differential movements between different parts of the structure strain the structural components. Larger earthquakes and longer shaking duration tend to damage structures more. The level of damage can be predicted only in general terms, since no two buildings undergo the exact same motions, even in the same earthquake. Past earthquakes have shown, however, that some types of buildings are far more likely to fail than others. This section assesses the general earthquake vulnerability of structures and facilities common in the southern California area, including in Coachella. This analysis is based on past earthquake performance of similar types of buildings in the U.S. The effects of design earthquakes on particular structures within Coachella are beyond the scope of this study.

1.8.1 Unreinforced Masonry Buildings

Unreinforced masonry buildings (URMs) are prone to failure due to inadequate anchorage of the masonry walls to the roof and floor diaphragms, lack of steel reinforcing, the limited strength and ductility of the building materials, and sometimes, poor construction workmanship. Furthermore, as these buildings age, the bricks and mortar tend to deteriorate, making the buildings even weaker. As a result, the State Legislature passed Senate Bill 547, addressing the identification and seismic upgrade of URMs.

In response to the URM Law, all cities and counties in what the Building Code in effect at the time referred as Seismic Zone 4 were to conduct an inventory of their URMs, establish an URM loss-reduction program, and report their progress to the State by 1990. The Seismic Safety Commission has conducted updates to this inventory, more recently in 2003 and 2006.

In 2000, the City of Coachella reported to the Seismic Safety Commission that their original survey showed 14 URMs in the city, but 13 of those had been reinforced (based on a physical review of the buildings using metal detectors). The remaining URM was destroyed in a fire in 1994 (Seismic Safety Commission, 2000). Accordingly, there are no URMs in Coachella. The same information is given in the 2003 and 2006 reports on the "Status of the Unreinforced Masonry Law" by the Seismic Safety Commission.

In 2007, the City retained D.M. Buchanan and Associates Inc. to conduct a City-wide survey of all masonry structures (L. Lopez, Acting Developing Services Director, written communication, 2012). The survey was prepared for the City's Building Official in response to Ordinance 985 entitled *An Ordinance of the City Council of the City of Coachella, California, adding Chapter 15.66 Seismic Hazard Mitigation to Title 15, Buildings and Construction of the Coachella Municipal Code*. This survey, performed on November 1st through 6th of 2007, identified 110 masonry structures in the City, and their ancillary features and associated facilities. Of these, a total of 55 structures were actually studied. The objectives of the study were as follows:

1. Identify whether the surveyed structure has bearing walls sufficiently reinforced with steel to comply with the City's Ordinance which specifies that the walls must have not less than 50 percent of the 1988 Uniform Building Code (UBC) requirement.
2. Identify whether the roof assembly of the structure is securely attached to the bearing walls with a positive "roof to wall" connection.

Per the 1988 UBC code, steel reinforcement for a single-story structure located in Seismic Zone 4 and subjected to 80 miles per hour (mph) winds with a Class "C" exposure generally equates to a requirement of No. 4 bars spaced 24 inches apart, center to center. All structures were considered as separate entities and did not have the benefit of the shielding that could be provided by other structures since these surrounding buildings could be removed at some time and fully expose the structure being studied. The study identified the following twelve commercial structures in the City which are lacking bearing wall steel reinforcement adequate to comply with the City's Ordinance (see Table 1-5). An additional 31 structures were identified as not having a positive roof-to-wall connection.

Table 1-5: Commercial Structures in the City of Coachella Lacking Adequate Bearing Wall Steel Reinforcement

Address	Size of Structure	Approximate Age
52-717 Harrison	43' x 64' = 2,752 SF	44 Years
53-015 Harrison	45' x 26' = 1,170 SF	74 Years
53-175 Harrison	30' x 72.5' = 2,175 SF	84 Years
53-225 Harrison	48' x 47' = 2,256 SF	84 Years
48-487 Grapefruit Blvd	Varies = 200 SF	64 Years
85-963 Grapefruit Blvd	62' x 100' = 6,200 SF	74 Years
1510 and 1530 Sixth Street	50' x 65' = 3,250 SF	84 Years
1586 and 1590 Sixth Street	50' x 70' = 3,500 SF	74 Years
1612 Sixth Street	25' x 40' = 1,000 SF	79 Years
1615 Sixth Street	17' x 31' = 527 SF	74 Years
1632 Sixth Street	70' wide with various length depths = 4,200 SF	79 Years
1694 Sixth Street	50' x 70' = 3,500 x 2 = 7,000 SF	74 Years

Source: Buchanan and Associates, Inc., 2008.

1.8.2 Soft-Story Buildings

Of particular concern are soft-story buildings (buildings with a story, generally the first floor, lacking adequate strength or toughness due to too few shear walls). Residential units above glass-fronted stores, and buildings perched atop parking garages are common examples of soft-story buildings. Many multi-unit residential units built in the 1960s and 1970s are of the "tuck-under parking" type, with open areas at ground level and only thin columns carrying the gravity loads (Graf and Seligson, 2011). Collapse of a soft story and "pancaking" of the remaining stories killed 16 people at the Northridge Meadows apartments during the 1994 Northridge earthquake (EERI, 1995). There are many other cases of soft-story collapses in past earthquakes. In response, the State encourages the identification and mitigation of seismic hazards associated with these types of potentially hazardous buildings, and others such as pre-1971 concrete tilt-ups, mobile homes, and pre-1940 homes. There are several techniques that can be used to seismically strengthen buildings with soft-story construction. Some of these include adding shear walls or steel moment-frames to the entrance openings, and increasing or strengthening the shear walls in the first story. The City of Coachella should consider conducting an inventory of their soft-stories, and encouraging the structural retrofit of these structures so that they not collapse during an earthquake.

1.8.3 Wood-Frame Structures

The loss estimations conducted for this study (see Section 1.9) indicates that about 86 percent of wood-frame structures in Coachella are expected to experience slight to complete damage as a result of ground shaking caused by a M7.8 earthquake on the San Andreas fault, with about 30 percent experiencing moderate to complete damage. A smaller earthquake resulting from rupture of only the Coachella section of the San Andreas fault is anticipated to cause at least slight damage to about 60 percent of the wood-frame structures in the Coachella area.

Structural damage to wood-frame structures often results from an inadequate connection between the superstructure and the foundation. These buildings may slide off their foundations, with consequent damage to plumbing and electrical connections. Unreinforced masonry chimneys may also collapse. These types of damage are generally not life threatening, although they may be costly to repair. Wood frame buildings with stud walls generally perform well during an earthquake, unless they have no foundation or have a weak foundation constructed of unreinforced masonry or poorly reinforced concrete. In these cases, damage is generally limited to cracking of the stucco, which dissipates much of the earthquake's induced energy. The collapse of wood frame structures, if it happens, generally does not generate heavy debris, but rather, the wood and plaster debris can be cut or broken into smaller pieces by hand-held equipment and removed by hand in order to reach victims (FEMA, 1985).

1.8.4 Pre-Cast Concrete Structures

Partial or total collapse of buildings where the floors, walls and roofs fail as large intact units, such as large pre-cast concrete panels, cause the greatest loss of life and difficulty in victim rescue and extrication (FEMA, 1985). These types of buildings are common not only in southern California, but abroad. Casualties as a result of collapse of these structures in past earthquakes, including Mexico (1985), Armenia (1988), Nicaragua (1972), El Salvador (1986 and 2001), the Philippines (1990), Turkey (1999), China (2008) and Haiti (2010) add to hundreds of thousands. In southern California, many of the parking structures that failed during the 1994 Northridge earthquake, such as the Cal-State Northridge and City of Glendale Civic Center parking structures, consisted of pre-cast concrete components (EERI, 1995).

Collapse of this type of structure generates heavy debris, and removal of this debris requires the use of heavy mechanical equipment. Consequently, the location and extrication of victims trapped under the rubble is generally a slow and dangerous process. Extrication of trapped victims within the first 24 hours after the earthquake becomes critical for survival. In most instances, however, post-earthquake planning fails to quickly procure the equipment needed to move heavy debris. The establishment of Heavy Urban Search and Rescue teams, as recommended by FEMA (1985), has improved victim extrication and survivability. Buildings that are more likely to fail and generate heavy debris need to be identified, so that appropriate mitigation and planning procedures are defined prior to an earthquake.

1.8.5 Tilt-up Buildings

Tilt-up buildings have concrete wall panels, often cast on the ground, or fabricated off-site and trucked in, which are then tilted upward into their final position. Connections and anchors have pulled out of walls during earthquakes, causing the floors or roofs to collapse. A high rate of failure was observed for this type of construction in the 1971 San Fernando and 1987 Whittier Narrows earthquakes. Tilt-up buildings can also generate heavy debris.

1.8.6 Reinforced Concrete Frame Buildings

Reinforced concrete structures in southern California typically house offices, hotels, and mixed industrial, commercial, or retail occupancies. Reinforced concrete frame buildings, with or without reinforced infill walls, display low ductility. Earthquakes may cause shear failure (if there are large tie spacings in columns, or insufficient shear strength), column failure (due to inadequate rebar splices, inadequate reinforcing of beam-column joints, or insufficient tie anchorage), hinge deformation (due to lack of continuous beam reinforcement), and non-structural damage (due to the relatively low stiffness of the frame). A common type of failure observed following the Northridge earthquake was confined column collapse (EERI, 1995), where infilling between columns confined the length of the columns that could move laterally in the earthquake.

Older reinforced concrete buildings, dating to before 1980, are reportedly approximately nine times more likely to collapse than more modern, code-conforming reinforced concrete frame buildings and other types of structures built in conformance with the newer seismic-resistant building codes (Liet et al., 2011, as reported in Lynch et al., 2011).

1.8.7 Multi-Story Steel Frame Buildings

Multi-story steel frame buildings generally have concrete floor slabs. However, these buildings are less likely to collapse than concrete structures. Common damage to these types of buildings is generally non-structural, including collapsed exterior curtain wall (cladding), and damage to interior partitions and equipment. Overall, modern steel frame buildings have been expected to perform well in earthquakes, but the 1994 Northridge earthquake broke many welds in these buildings, a previously unanticipated problem.

Older, pre-1945 steel frame structures may have unreinforced masonry such as bricks, clay tiles and terra cotta tiles as cladding or infilling. Cladding in newer buildings may be glass, infill panels or pre-cast panels that may fail and generate a band of debris around the building exterior (with considerable threat to pedestrians in the streets below). Structural damage may occur if the structural members are subject to plastic deformation, which can cause permanent displacements. If some walls fail while others remain intact, torsion or soft-story problems may result.

1.8.8 Mobile (Manufactured) Homes

Mobile homes are prefabricated housing units that are placed on isolated piers, jackstands, or masonry block foundations (usually without any positive anchorage). Floors and roofs of mobile homes are usually plywood, and outside surfaces are covered with sheet metal. Mobile homes typically do not perform well in earthquakes. Severe damage occurs when they fall off their supports, severing utility lines and piercing the floor with jackstands. The results of the loss estimation analyses indicate that 100 percent of the mobile homes in Coachella area are likely to experience moderate to complete damage as a result of an M7.8 earthquake on the San Andreas fault, and nearly 98 percent will experience moderate to complete damage as a result of a M7.1 earthquake on the same fault. This suggests tat inspection and seismic strengthening as needed of the manufactured homes in the area can help to reduce the seismic losses in the city.

1.8.9 Combination Types

Buildings are often a combination of steel, concrete, reinforced masonry and wood, with different structural systems on different floors or different sections of the building. Combination types that are potentially hazardous include: concrete frame buildings without special reinforcing, precast concrete and precast-composite buildings, steel frame or concrete frame buildings with unreinforced masonry walls, reinforced concrete wall buildings with no special detailing or reinforcement, large capacity buildings with long-span roof structures (such as theaters and auditoriums), large un-engineered wood-frame buildings, buildings with inadequately anchored exterior cladding and glazing, and buildings with poorly anchored parapets and appendages (FEMA, 1985). Additional types of potentially hazardous buildings may be recognized after future earthquakes.

In addition to building types, there are other factors associated with the design and construction of the buildings that also have an impact on the structures' vulnerability to strong ground shaking. Some of these conditions are discussed below:

Building Shape – A building's vertical and/or horizontal shape can also be important in determining its seismic vulnerability. Simple, symmetric buildings generally perform better than non-symmetric buildings. During an earthquake, non-symmetric buildings tend to twist, as well as shake. Wings on a building tend to act independently during an earthquake, resulting in differential movements and cracking. The geometry of the lateral load-resisting systems also matters. For example, buildings with one or two walls made mostly of glass, while the remaining walls are made of concrete or brick, are at risk. Asymmetry in the placement of bracing systems that provide a building with earthquake resistance can result in twisting or differential motions.

Pounding – Site-related seismic hazards may include the potential for neighboring buildings to "pound," or for one building to collapse onto a neighbor. Pounding occurs when there is little clearance between adjacent buildings, and the buildings "pound" against each other as they deflect during an earthquake. The effects of pounding can be especially damaging if the floors of the buildings are at different elevations, so that, for example, the floor of one building hits a supporting column of the other. Damage to a supporting column can result in partial or total building collapse.

1.9 Earthquake Scenarios and Loss Estimations

HazUS-MH™ is a standardized methodology for earthquake loss estimation based on a geographic information system (GIS). [HazUS-MH stands for Hazards United States – Multi-hazard.] A project of the National Institute of Building Sciences, funded by the Federal Emergency Management Agency (FEMA), HazUS is considered a powerful advance in mitigation strategies. The HazUS project developed guidelines and procedures to make standardized earthquake loss estimates at a regional scale (also flood and hurricane loss estimates; see Chapter 3, Section 3.3 for the flood losses estimated for Coachella). With standardization, estimates can be compared from region to region. HazUS is designed for use by state, regional and local governments in planning for earthquake loss mitigation, and emergency preparedness, response and recovery. HazUS addresses nearly all aspects of the built environment, and many different types of losses. The methodology has been tested against the experience of several past earthquakes, and against the judgment of experts. Subject to several limitations noted below, HazUS can produce results that are valid for the intended purposes.

Loss estimation is an invaluable tool, but it must be used with discretion. Loss estimation analyzes casualties, damage and economic loss in great detail. It produces seemingly precise numbers that can be easily misinterpreted. Loss estimation results, for example, may cite 454 left homeless by a scenario earthquake. This is best interpreted by its magnitude. That is, an event that leaves 400 people homeless is clearly more manageable than an event that results in 4,000 homeless people; and an event that leaves 40,000 homeless will most likely overwhelm the region's resources. However, another loss estimation analysis that predicts 500, or even 600, people homeless should be considered equivalent to the 454 result. Because HazUS results make use of a great number of parameters and data of varying accuracy and completeness, it is not possible to assign quantitative error bars. Although the numbers should not be taken at face value, they are not rounded or edited because detailed evaluation of individual components of the disaster can help mitigation agencies ensure that they have considered all important variables.

The more community-specific the data that are input to HazUS, the more reliable the loss estimation. HazUS provides defaults for all required information. These are based on best-available scientific, engineering, census and economic knowledge. The loss estimations in this report were tailored to the Coachella General Plan area by including the Riverside County HazUS data obtained as part of a project that developed a detailed inventory of structures and essential facilities for Riverside, San Bernardino and Orange counties (H. Seligson and MMI Engineering, 2008). The revised inventory includes structure-specific information, including structural type, age and thus seismic design level (e.g., high, moderate, low, or pre-code), height, occupancy, and building replacement cost, among other variables, as provided by the owners of the structures (although in a few cases, thee building characteristics were inferred by the authors of the 2008 study). The HazUS analyses presented here also considered the soil types that underlie the study area, including their liquefaction susceptibility, and modifications to the population count, as described further below.

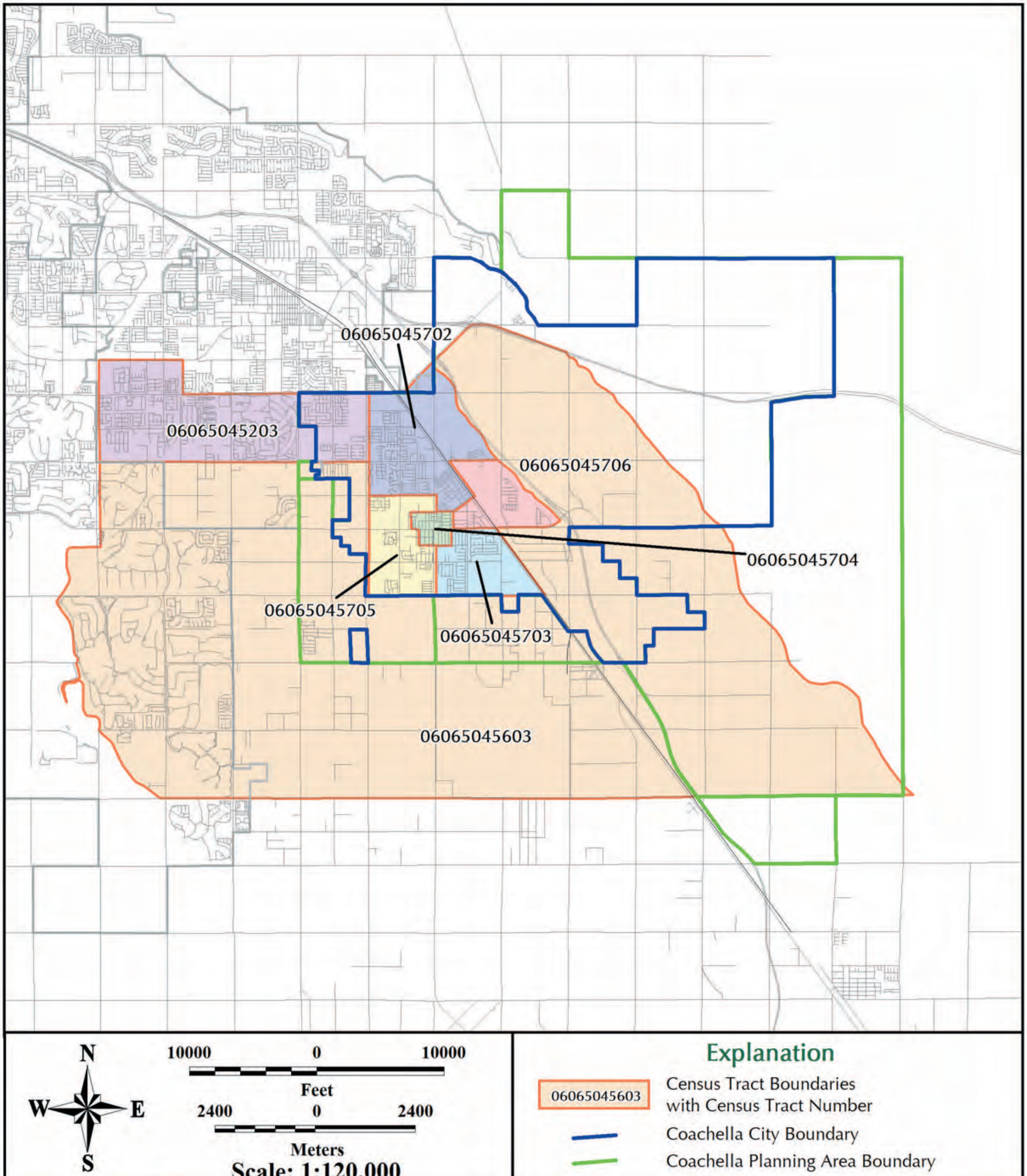
HazUS relies on census data, which are reported by geographical areas or tracts. Unfortunately, census tracts often do not correlate well with city boundaries, especially in areas with low population densities. This is certainly the case for Coachella, where seven census tracts cover most, but not all of the General Plan area, and one of the census tracts considered also includes a large portion of the city of La Quinta to the west. The total area covered by these census tracts is 62.5 square miles (see Figure 1-5). Population counts were modified from those provided in the HazUS database (that date to the census of 2000) to incorporate the 2010 Census Data where available, and thus model the population increase that this area has experienced in the last decade. When the HazUS analyses for this study were conducted in July 2011, the U.S. Census Bureau had released population data for four of the seven census tracts considered (census tracts ending in 703, 704, 705 and 706, see Figure 1-5). These four tracks are entirely within the Coachella General Plan study area, and thus, the 2010 population numbers for these tracts were replaced in the HazUS database. The population counts from 2000 were kept for two of the remaining three census tracts (203 and 603) because a review of historical Google Earth images showed that those portions of the census tracts within Coachella saw very little growth between 2000 and 2010. The population in census tract 702 was increased from the 2000 number to account for new housing developed in 2009. The total population used in the analyses is 43,716 people, a number that correlates closely with the 2010 population counts issued by the U.S. Census Bureau for Coachella (40,704) and the Vista Santa Rosa area (2,926). Thus, although the area considered in the analyses extends beyond Coachella and includes a large portion of La Quinta, the population counts used in the final analyses best represent the population estimates for the Coachella General Plan area only. Other aspects of the database, such as the critical facilities, were also modified to represent only the Coachella General Plan area. This is discussed further where appropriate.

As useful as HazUS can be, the loss estimation methodology has some inherent uncertainties. These arise, in part, from incomplete scientific knowledge concerning earthquakes and their effect upon buildings and facilities, and from the approximations and simplifications necessary for comprehensive analyses. Users should be aware of the following specific limitations:

- HazUS is driven by statistics, and thus is most accurate when applied to a region, or a class of buildings or facilities. It is least accurate when considering a particular site, building or facility.
- Losses estimated for lifelines may be less than losses estimated for the general building stock.
- Losses from smaller (less than M 6) earthquakes may be overestimated.
- Pilot and calibration studies have not yet provided an adequate test concerning the possible extent and effects of landsliding.
- The indirect economic loss module is still experimental. While output from pilot studies has generally been credible, this module requires further testing.
- The databases that HazUS draws from to make its estimates are often incomplete or as mentioned above, either do not match the boundaries of the desired study area, or are no longer representative of current conditions. In the case of Coachella, and as explained above, we made adjustments to the population counts in the HazUS database to approximate the current population numbers.

Essential facilities and lifeline inventory are located by latitude and longitude. However, the HazUS inventory data for lifelines and utilities were developed at a national level and where specific data are lacking, statistical estimations are utilized. Particulars about the site-specific inventory data used in the models are discussed further in the paragraphs below. Other site-specific data used include soil types. The user then defines the earthquake scenario to be modeled, including the magnitude of the earthquake, and the location of the epicenter. Once all these data are input, the software calculates the loss estimates for each scenario (see Figure 1-6).

The loss estimates include physical damage to buildings of different construction and occupancy types, damage to essential facilities and lifelines, number of after-earthquake fires and damage due to fires following the earthquake (included in Chapter 4). The model also estimates the direct economic and social losses, including casualties and fatalities for three different times of the day, the number of people left homeless and number of people that will require shelter, number of hospital beds available, and the economic losses due to damage to the places of businesses, loss of inventory, and (to some degree) loss of jobs. The indirect economic losses component is still experimental; the calculations in the software are checked against actual past earthquakes, such as the 1989 Loma Prieta and 1994 Northridge earthquakes, but indirect losses are hard to measure, and it typically takes years before these monetary losses can be quantified with any degree of accuracy.

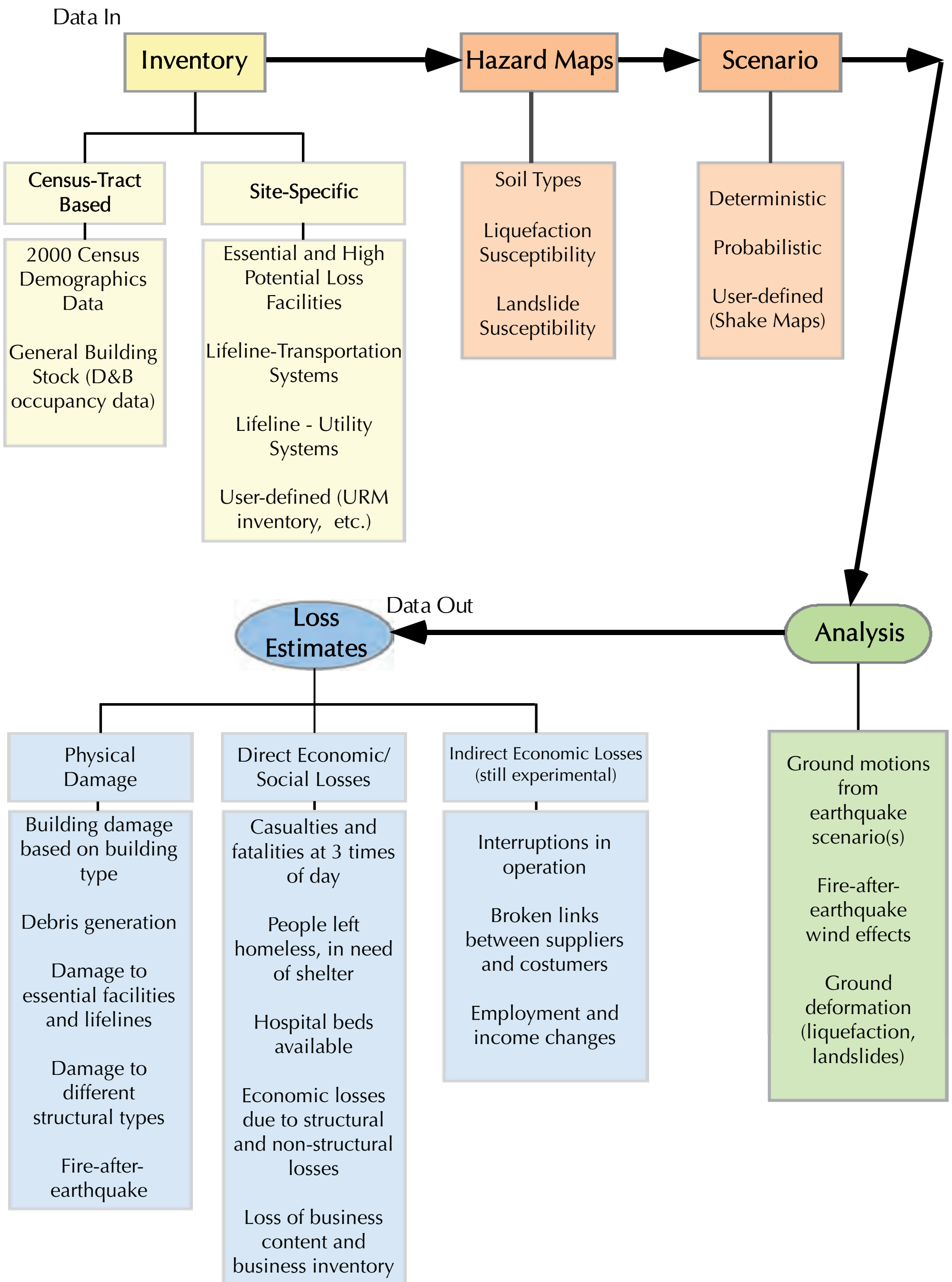


Earth Consultants International

Project Number: 3106/3218
Date: 2014

Census Tracts Used in the HazUS Analyses

Figure 1-5



Earth Consultants International

Project Number: 3106/3218
Date: 2014

Generalized Flow Chart Summarizing the HazUS Methodology

Figure 1-6

Two earthquake scenarios were modeled: an earthquake on the southern San Andreas fault rupturing the Mojave South, San Bernardino (North and South), San Gorgonio-Garnet Hill and Coachella sections of the fault (the ShakeOut scenario prepared by the U.S. Geological Survey in the fall of 2008 – see the ShakeMap for this scenario in Figure 1-4), and an earthquake on the Coachella section of the San Andreas fault only, which is the section of the San Andreas fault that extends across the city of Coachella. Specifics about these earthquake-producing fault sections and segments were provided in Section 1.4.1 above, and in Table 1-6 below. The following sections describe the losses anticipated in Coachella due to the two earthquake scenarios modeled.

Table 1-6: HazUS Earthquake Scenarios for the City of Coachella

Fault Source	Magnitude	Description
Southern San Andreas Fault	7.8	A large earthquake that ruptures a 300-km stretch of the southern San Andreas fault, from Bombay Beach to Lake Hugues, using the U.S. Geological Survey's ShakeOut scenario (Jones et al., 2008). This hypothetical earthquake is scientifically realistic; the mean probability of a M7.75 or greater earthquake occurring on the southern San Andreas fault in the next 30 years is 16 percent (Field et al., 2009).
Coachella Valley section of San Andreas Fault	7.1	Lower risk but high probability earthquake event. The Coachella section of the fault has not ruptured since about 1680, and is thus considered to have a high probability of rupturing in the next 30 years. The Coachella section of the fault extends across the city of Coachella and the Coachella General Plan study area.

The results indicate that of the two earthquake scenarios modeled for Coachella, the M_w 7.8 earthquake on the San Andreas fault, given the more intense ground shaking, will cause more damage in the study area. For most of southern California, an earthquake on the San Andreas fault is not the worst-case scenario, as there are often other faults much closer that have the potential to be equally or more damaging. However, the San Andreas fault is the worst-case scenario for Coachella and other communities in the Coachella and Imperial valleys – the fault's location and high probability of rupturing in the next 30 years resolve into a high probability, high risk seismic source for this region. However, the M7.8 ShakeOut scenario is not the worst-case event; the San Andreas fault could rupture in a M8.0 earthquake. The M7.8 ShakeOut scenario is considered realistic and plausible (Perry, Jones and Cox, 2011).

1.9.1 Building Damage

HazUS provides damage data for buildings based on these structural types:

- Concrete
- Manufactured Housing (Trailers and Mobile Homes)
- Precast Concrete
- Reinforced Masonry Bearing Walls
- Steel
- Unreinforced Masonry Bearing Walls
- Wood Frame

and based on these occupancy (usage) classifications:

- Agricultural
- Commercial
- Education
- Government
- Industrial
- Other Residential
- Religion
- Single Family

Loss estimation for the general building stock is averaged for each census tract. Building damage classifications range from slight to complete. As an example, the building damage classification for light, wood frame buildings, the most numerous building type in the city, is provided below.

- Slight Structural Damage: Small cracks in the plaster or gypsum-board at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.
- Moderate Structural Damage: Large cracks in the plaster or gypsum-board at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
- Extensive Structural Damage: Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of "room-over-garage" or other "soft-story" configurations; small foundation cracks.
- Complete Structural Damage: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off their foundations; or develop large foundation cracks.

The HazUS database includes nearly 16,000 buildings in the region, with a total building replacement value (excluding contents) of $3,743 million (2006 dollars). Approximately 90 percent of the buildings considered in the analysis (and 86 percent of the building value) are associated with residential housing. In terms of building construction types found in the region, wood-frame construction makes up approximately 76 percent of the building inventory, and manufactured housing comprises almost another 16 percent. The remaining about 8 percent is distributed between the other general building types.

Estimates of building damage are provided for "High," "Moderate" and "Low" seismic design criteria. Buildings of newer construction (e.g., post-1973) are best designated by "high." Buildings built after 1940, but before 1973, are best represented by "moderate" criteria. If built before about 1940 (i.e., before significant seismic codes were implemented), "low" is most appropriate. The building inventory for the seven census tracts considered indicates that about 1.2 percent of the housing units were built before 1939. About 22 percent of the building units were built between 1940 and 1969, and nearly 64 percent of the units were built after 1980. The remaining units (about 14 percent) were built in the decade between 1970 and 1979.

Therefore, nearly two-thirds of the housing stock in Coachella can be described as in the "high" category for seismic design criteria. However, structural engineers point out that buildings constructed before building codes were upgraded following the 1994 Northridge earthquake have significant deficiencies that could result in higher-than-expected levels of damage. Specifically, in the 1980s, low-rise wood-frame construction relied on stucco and gypsum wallboard for shear resistance, but these materials were observed to perform poorly during the Northridge earthquake. As a result, the newer building codes reduced the shear forces permitted in these materials, and promoted an increase reliance on plywood-sheathed shear panels instead (Graf, 2008; Graf and Seligson, 2011).

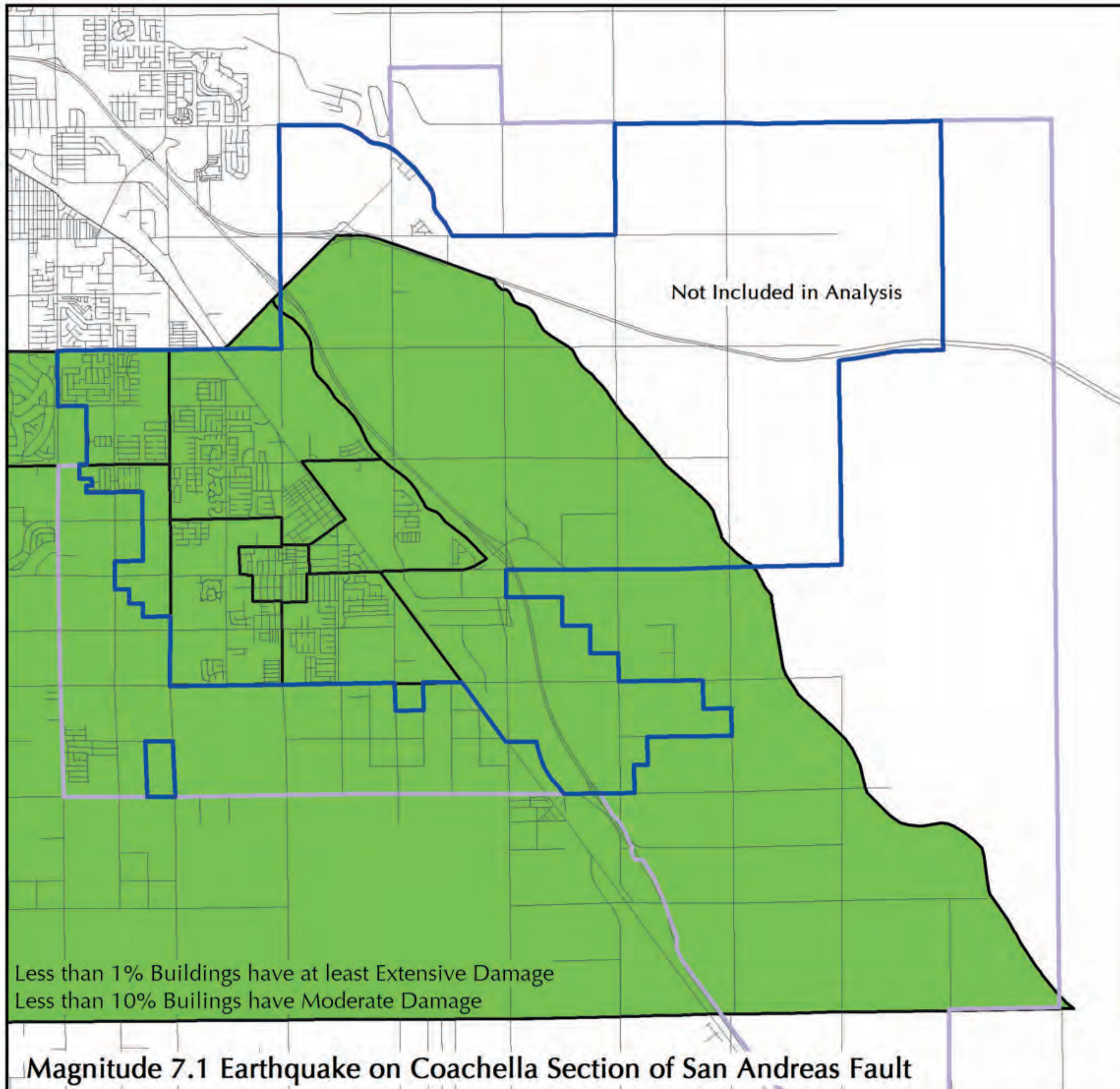
The HazUS models estimate that between 7,259 and 3,891 buildings in the Coachella HazUS study area will be at least moderately damaged by the earthquake scenarios presented herein, with the higher number representative of damage as a result of a M7.8 earthquake on the entire southern San Andreas fault, and the lower number representing damage as a result of a M7.1 earthquake on the Coachella section of the San Andreas fault only. These figures represent about 45 percent and 24 percent, respectively, of the total number of buildings in the region considered in the analysis. Table 1-7 summarizes the expected damage to buildings by general occupancy type, whereas Table 1-8 summarizes the expected damage to buildings in the region, classified by construction type.

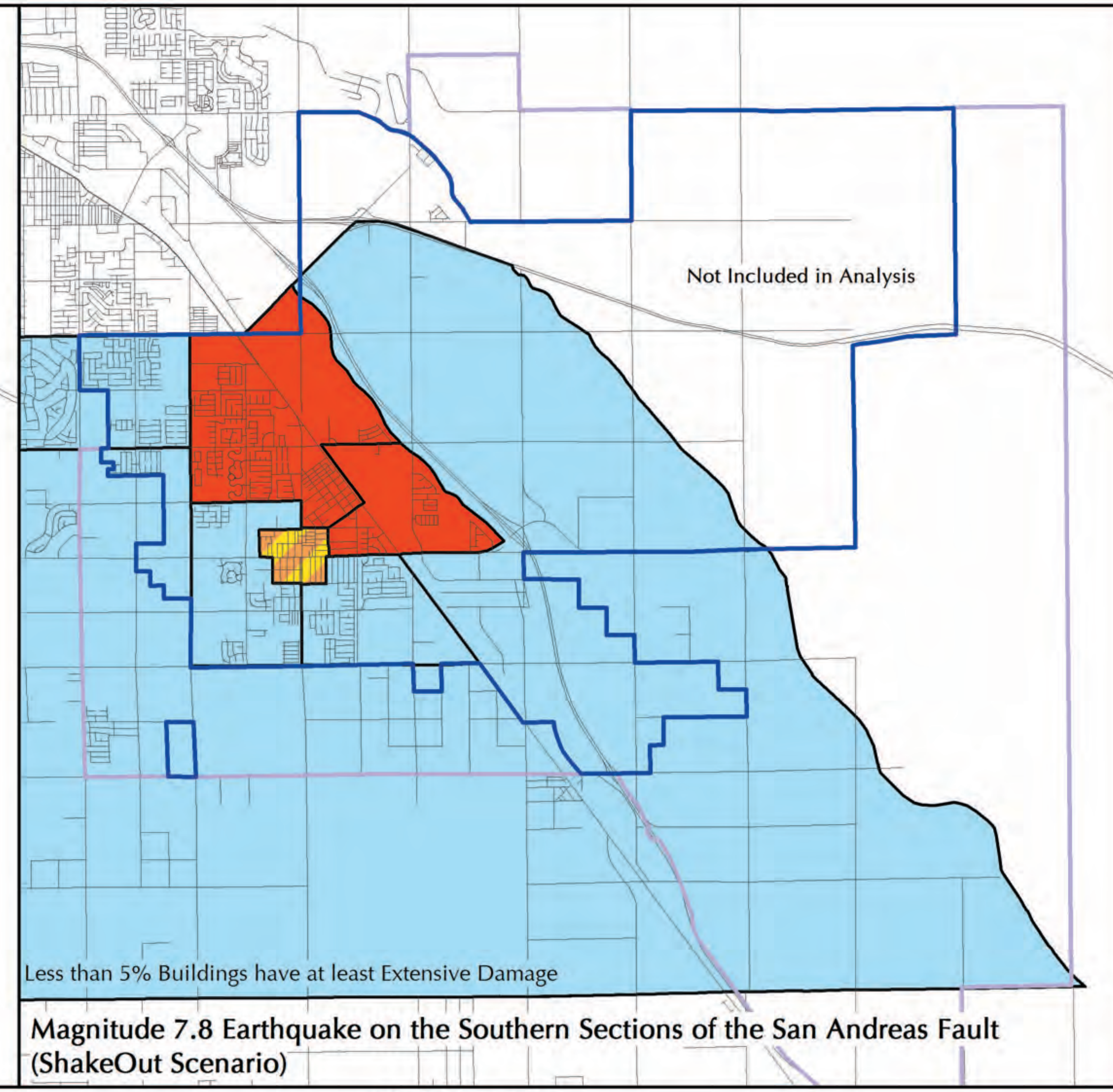
Table 1-7: Number of Buildings* Damaged, by Occupancy Type

Scenario	Occupancy Type	Slight	Moderate	Extensive	Complete	Total
San Andreas ShakeOut	Agriculture	203	136	67	185	591
	Commercial	49	69	74	195	387
	Education	106	90	40	96	332
	Government	2	1	1	4	8
	Industrial	10	18	18	47	93
	Other Residential	212	81	113	2,486	2,892
	Religion	5	4	3	10	22
	Single Family	6,444	3,303	187	31	9,965
	Total	**7,031**	**3,702**	**503**	**3,054**	**14,290**
San Andreas Coachella	Agriculture	244	155	64	17	480
	Commercial	126	125	56	11	318
	Education	139	74	29	5	247
	Government	3	2	1	0	6
	Industrial	29	32	15	4	80
	Other Residential	265	1,027	1,283	226	2,801
	Religion	8	6	3	1	18
	Single Family	6,111	750	5	0	6,866
	Total	**6,925**	**2,171**	**1,456**	**264**	**10,816**

* Based on a total of 15,998 buildings in the region.

As a percentage of the building damage by occupancy type, the model estimates that more than 90 percent of the residential structures other than single-family homes (i.e., multi-family residential buildings, including duplexes, condominiums and apartments) will suffer at least moderate damage from a M7.8 earthquake on the San Andreas fault. The distribution and severity of the damage to residential structures by census tract as a result of the two





Source: Federal Emergency Management Agency, HAZUS 2.1 v 12.2.0

N
W E
S

7000 0 7000 14000

Feet

Scale: 1:84,000

EXPLANATION

Building Damage

- 50-70% Buildings have at least Moderate Damage
- 30-50% Buildings have at least Moderate Damage
- 50-70% Buildings have Slight to No Damage
- 70-90% Buildings have Slight to No Damage
- Greater than 90% Buildings have Slight to No Damage
- Coachella City Boundary
- Coachella Planning Area Boundary

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Residential Building Damage

(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-4

earthquake scenarios is illustrated in Plate 1-4. Note that less than 10 percent of the residential structures in the city are expected to experience more than slight damage as a result of a M7.1 earthquake. A M7.8 event, on the other hand, will significantly impact certain sections of the city, with 50 to 70 percent of the residential structures (including multi-residential and manufactured homes) in some of the central census tracts experiencing at least moderate damage. In other portions of the city where newer residential tracts are located, HazUS estimates that between 10 and 30 percent of the residential buildings will experience at last slight damage.

Nearly 87 percent of the industrial structures, 59 percent of the agricultural, and 84 percent of the commercial structures in the Coachella General Plan area will be at least moderately damaged by a M7.8 earthquake on the San Andreas fault. Similarly, nearly 62 percent of the education buildings, 67 percent of the government buildings, and 74 percent of the religion buildings will suffer at least moderate damage. A smaller M7.1 earthquake on the Coachella Valley segment of the San Andreas fault is expected to cause at least moderate damage to nearly 86 percent of the residential structures other than single-family, and at least moderate damage to about 53, 36 and 48 percent of the industrial, agricultural, and commercial structures, respectively, in the study area. The M7.1 Coachella Valley segment earthquake scenario is also anticipated to cause at least moderate damage to about 30 percent of the educational buildings and nearly 38 percent of the government buildings in the region.

Table 1-8: Number of Buildings* Damaged, by Construction Type

Scenario	Structure Type	Slight	Moderate	Extensive	Complete	Total
San Andreas ShakeOut	Wood	6,868	3,431	168	41	10,508
	Steel	35	66	55	223	379
	Concrete	37	22	30	105	194
	Precast	24	58	46	64	192
	Reinforced Masonry	67	123	106	173	469
	Manufactured Housing	0	2	98	2,448	2,548
	Total	**7,031**	**3,702**	**503**	**3,054**	**14,290**
San Andreas Coachella	Wood	6,476	790	11	1	7,278
	Steel	93	146	70	20	329
	Concrete	75	51	24	7	157
	Precast	67	77	19	4	167
	Reinforced Masonry	152	126	55	8	341
	Manufactured Housing	62	981	1,277	224	2,544
	Total	**6,925**	**2,171**	**1,456**	**264**	**10,816**

* Based on a total of 15,998 buildings in the region.

Although wood-frame buildings comprise the largest number of buildings in the area, and therefore one would expect that most of the buildings damaged would be wood-frame structures, the data show that the building type that will suffer the most damage is manufactured housing. In fact, wood-frame buildings, as a group, are expected to perform relatively well during an earthquake. Case in point, the ShakeOut earthquake on the San Andreas fault is anticipated to cause at least moderate damage to 3,640 wood-frame buildings, comprising about 30 percent of the total number of wood-frame buildings in the region, and to 2,548 manufactured homes, equal to 100 percent of the total number of manufactured homes in the study area. Similarly, a smaller but significant M7.1 earthquake on the Coachella Valley segment of the San Andreas fault is expected to cause at least moderate damage to less than 7 percent of the wood-frame buildings, but to nearly 98 percent of the manufactured homes in the region. The other building types in Coachella, by construction type, that are anticipated to suffer at least moderate damage as a result of a M7.8 earthquake on the San Andreas fault include steel (89 percent will be at least moderately damaged), precast (85 percent), concrete (77 percent), and reinforced masonry (79 percent). An earthquake on only the Coachella Valley segment of the San Andreas fault is anticipated to cause at least moderate damage to 61 percent of the steel buildings in Coachella, 50 percent of the precast buildings, 40 percent of the concrete buildings, and 37 percent of the reinforced masonry buildings.

1.9.2 Casualties

Casualties are estimated based on the observation that there is a strong correlation between building damage (both structural and non-structural) and the number and severity of casualties. In smaller earthquakes, non-structural damage, (such as toppled bookshelves and broken windows) is typically responsible for most of the casualties. In severe earthquakes where there is a large number of collapses and partial collapses, there is a proportionately larger number of fatalities. Data regarding earthquake-related injuries are, however, not of the best quality, nor are they available for all building types. Available data often have insufficient information about the type of structure in which the casualties occurred and the casualty-generating mechanism. HazUS casualty estimates are based on the injury classification scale described in Table 1-9.

Table 1-9: Injury Classification Scale

Injury Severity Level	Injury Description
Severity 1	Injuries requiring basic medical aid without requiring hospitalization.
Severity 2	Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life-threatening status.
Severity 3	Injuries which pose an immediate life-threatening condition if not treated adequately and expeditiously. The majority of these injuries are the result of structural collapse and subsequent entrapment or impairment of the occupants.
Severity 4	Instantaneously killed or mortally injured.

In addition, HazUS produces casualty estimates for three times of day:

- Earthquake striking at 2:00 A.M. (population at home)
- Earthquake striking at 2:00 P.M. (population at work/school)
- Earthquake striking at 5:00 P.M. (commute time).

Table 1-10 provides a summary of the casualties estimated for the earthquake scenarios considered. The analysis indicates that the worst time for a San Andreas fault earthquake to occur in Coachella is during maximum educational, industrial and commercial occupancy loads, such as at 2 o'clock in the afternoon. An M7.8 earthquake on the San Andreas fault sometime during the day is anticipated to cause hundreds of Level 1 and Level 2 injuries, most likely related to people trying to run outside and in the process bumping into overturned furniture, being hit by objects falling off shelves in stores and offices, and by falling debris resulting from the structural damage to primarily commercial and educational buildings.

Table 1-10: Estimated Casualties*

Type and Time of Scenario			Level 1: Medical treatment without hospitalization	Level 2: Hospitalization but not life threatening	Level 3: Hospitalization and life threatening	Level 4: Fatalities due to scenario event
San Andreas Fault ShakeOut Scenario	2A.M. (max. residential occupancy)	Commercial	2	1	0	0
		Commuting	0	0	0	0
		Educational	0	0	0	0
		Hotels	1	0	0	0
		Industrial	1	1	0	0
		Other Res. Residential	189	51	4	8
		Single-Family	53	9	1	2
		Total	**246**	**61**	**6**	**10**
	2 P.M. (max educational, industrial, and commercial)	Commercial	172	56	10	19
		Commuting	1	1	2	0
		Educational	96	32	6	11
		Hotels	0	0	0	0
		Industrial	1	3	1	1
		Other Residential	40	11	1	2
		Single-Family	12	2	0	0
		Total	**332**	**105**	**19**	**33**
	5 P.M. (peak commute time)	Commercial	182	59	10	20
		Commuting	6	7	12	2
		Educational	5	2	0	1
		Hotels	0	0	0	0
		Industrial	7	2	0	1
		Other Residential	68	18	2	3
		Single-Family	20	3	0	1
		Total	**288**	**92**	**25**	**27**
San Jacinto Fault	2A.M. (max. residential occupancy)	Commercial	0	0	0	0
		Commuting	0	0	0	0
		Educational	0	0	0	0
		Hotels	0	0	0	0
		Industrial	0	0	0	0
		Other Residential	38	7	0	1
		Single-Family	14	1	0	0
		Total	**53**	**8**	**1**	**1**
	2 P.M. (max educational, industrial, and commercial)	Commercial	19	4	1	1
		Commuting	0	0	0	0
		Educational	10	2	0	1
		Hotels	0	0	0	0
		Industrial	1	0	0	0
		Other Residential	8	1	0	0
		Single-Family	3	0	0	0
		Total	**42**	**9**	**1**	**2**
	5 P.M. (peak commute) time)	Commercial	20	5	1	1
		Commuting	1	2	3	1
		Educational	1	0	0	0
		Hotels	0	0	0	0
		Industrial	1	0	0	0
		Other Residential	14	3	0	0
		Single-Family	5	0	0	0
		Total	**41**	**9**	**4**	**2**

*Based on a population base of 43,716

Dozens of Level 3 and Level 4 casualties are anticipated as a result of damage to primarily commercial structures, followed by educational structures. Significant damage to steel, concrete, and reinforced masonry structures, construction types typically used in non-residential applications, appears to control the anticipated injury severity levels and counts, as extensive damage to these types of buildings generates heavy debris that can result in significant numbers of trauma cases. Damage to residential structures, typically of wood-frame construction, result in mostly Level 1 and Level 2 injuries. For these same reasons, an earthquake occurring during maximum residential occupancy loads, such as at 2 o'clock in the morning, results in the least number of Level 3 and 4 casualties, with most injuries classified as Level 1 and Level 2.

Many injuries are also anticipated to occur if the San Andreas fault ShakeOut earthquake occurs during maximum commuting hours, such as at 5 o'clock in the evening, with similar numbers expected if the earthquake occurs between about 7 and 9 o'clock in the morning, or between 4 and 6 o'clock in the evening. Most of the casualties at this time are the result of damage to commercial and educational facilities, and damage to residential structures that are occupied at that time by people who have returned home from work or school. A relatively low number of the casualties at this hour are the result of traffic accidents due to drivers losing control of their vehicles, vehicle crashes due to stoplight (electric) failures, and the collapse of bridges and broken roadways (Shoaf, 2008).

A smaller M7.1 earthquake on the Coachella Valley segment of the San Andreas fault through the city of Coachella is anticipated to cause a relatively similar number of casualties in the Coachella area regardless of the time of day when the earthquake occurs. Most injuries will be classified as Level 1 or 2, with damage to commercial, educational and other residential structures controlling the number of casualties anticipated if the earthquake occurs during the day, and damage to residential structures controlling the number and type of injuries that are expected if the earthquake occurs at night.

1.9.3 Damage to Critical and Essential Facilities

HazUS breaks critical facilities into two groups: (1) essential facilities, and (2) high potential loss (HPL) facilities. Essential facilities are those parts of a community's infrastructure that must remain operational after an earthquake. Buildings that house essential services include hospitals, emergency operation centers, fire and police stations, schools, and communication centers. HPL or high-risk facilities are those that if severely damaged, may result in a disaster far beyond the facilities themselves. Examples include power plants, dams and flood control structures, and industrial plants that use or store explosives, extremely hazardous materials or petroleum products in large quantities.

Other critical facilities not considered in the HazUS analysis but that should be considered in both emergency preparedness and emergency response operations given their potential impact on the community include: (1) High-occupancy facilities, such as large assembly facilities, and large multi-family residential complexes because of the potential for a large number of casualties or crowd-control problems; (2) dependent care facilities, such as preschools, schools, rehabilitation centers, prisons, group care homes, nursing homes, and other facilities that house populations with special evacuation considerations; and (3) economic facilities, such as banks, archiving and vital, record-keeping facilities, and large industrial or commercial centers, that should remain operational to avoid severe economic impacts.

There are no hospitals in the Coachella General Plan area. The three closest hospitals to the study area include: 1) JFK Memorial Hospital in Indio, 2) Eisenhower Medical Center in Rancho

Mirage, and 3) Desert Regional Medical Center in Palm Springs. The following table summarizes information about these hospitals, including their expected functionality immediately following the two earthquake scenarios considered for this study.

Table 1-11: Hospitals Near the Coachella General Plan Area

Hospital Name	Address, Distance from Coachella	Bed Capacity	Expected Functionality after Earthquakes
JFK Memorial Hospital	47111 Monroe Street, Indio, CA 92201; approximately 1.1 miles NW of Coachella, 4 miles from downtown Coachella	158 beds	Expected to experience moderate to complete damage as a result of a M7.8 earthquake; expected to be non-functional immediately after and for at least one month after a M7.8 earthquake on the San Andreas fault; only about 30 percent functional after 90 days. Approximately 12 percent functional immediately after and for 3 days following a M7.1 earthquake; about 38 percent functional after day 7; over 80 percent functional after day 30.
Eisenhower Medical Center	39000 Bob Hope Drive, Rancho Mirage, CA 92270; approximately 12 miles to the NW of Coachella; and 15 miles from downtown	313 beds	Several hospital buildings are expected to experience moderate to extensive damage as a result of a M7.8 earthquake on the San Andreas. Only about 17 percent functional on the first 3 days; about 30 percent functional after day 7; only 50 percent functional after day 90. Only 30 percent functional after day 3 following a M7.1 earthquake; nearly 60 percent functional after day 7; nearly 90 percent functional after day 30.
Desert Regional Medical Center	1150 N. Indian Canyon Road, Palm Springs, CA 92262 approximately 22 miles from downtown Coachella	367 beds	Expected to be non-functional immediately after and for at least 2 weeks following a M7.8 earthquake on the San Andreas fault; approximately 36 percent functional after day 30, and about 60 percent functional after day 90. Only about 20 percent functional immediately after a M7.1 earthquake; about 56 percent functional after day 7; about 95 percent functional at day 90.

Hospitals lose functionality as a result of both structural and non-structural damage. Even if the hospital buildings perform well, equipment failures can result in a lack of primary and/or secondary emergency power. Rupture of water lines, and shearing of fire sprinkler heads can result in significant water damage. This is what happened at the Olive View Medical Center in Sylmar as a result of the 1994 Northridge earthquake, requiring the evacuation of 300 patients, and the performance of health care functions in the parking lot for about 30 hours (Pickett, 2008). The M7.8 ShakeOut scenario is expected to cause an immediate interruption of commercial electrical power (Pickett, 2008). As a result, all hospitals in the region should have emergency generators that would kick in automatically upon loss of commercial power, with automatic transfer switches that make the transition from the commercial power to the emergency power sources. All three hospitals near Coachella are expected to be impacted by the extensive damage to the external supply of potable water, which in this region could take months to be repaired. The external waste water system is also expected to be damaged

extensively. The ShakeOut scenario is also expected to result in an immediate interruption of commercial telecommunication systems, which would impact the hospitals directly. Internal communications within the hospitals may also be impaired as a result of structural damage, power losses, and water damage that would cause the circuit breakers to be tripped open.
Given that all three hospitals in the region are anticipated to be non-functional immediately following a M7.8 earthquake on the San Andreas fault (see Tables 1-9 and 1-10), and that hundreds of people in the region are expected to require medical attention (Table 1-10), alternate medical providers both within and outside the community should be identified. Possible sources of care for Level 1 and 2 casualties include urgent care and out-patient medical facilities, and private doctors' offices. Severely hurt patients may have to be airlifted to other hospitals in southern California or Arizona. It is also important to mention that access to hospitals in communities east of the San Andreas fault could be difficult because the fault is anticipated to rupture the roads that cross it, including the I-10 freeway just north of Coachella.

Other critical facilities in the HazUS database for Coachella include 366 school buildings, three fire stations, two police stations, and one emergency operations center. The expected damage to these essential facilities is summarized in Table 1-12, below. High potential loss facilities in the area include three dams, three hazardous materials sites, zero military installations, and zero nuclear power plants. None of the dams are considered "high hazard."

Table 1-12: Expected Damage to Essential Facilities

Scenario	Classification	Total #	# Facilities		
			At Least Moderate Damage >50%	Complete Damage >50%	With Functionality >50% on Day 1
San Andreas Fault - ShakeOut	Hospitals	3	3	1	0
	Schools	364	221	52	0
	EOCs	1	1	0	0
	Fire Stations	3	0	0	1
	Police Stations	2	0	0	0
San Andreas Fault - Coachella	Hospitals	3	1	0	0
	Schools	364	67	0	11
	EOCs	1	0	0	1
	Fire Stations	3	0	0	3
	Police Stations	2	0	0	2

According to the earthquake scenario results, the M7.8 San Andreas fault event will cause at least moderate damage to 221 school buildings, with 52 school buildings displaying complete damage to more than 50 percent of their structure. None of the school buildings are expected to be more than 50 percent functional on the day after the earthquake. By comparison, the smaller M7.1 earthquake scenario is estimated to cause at least moderate damage to 67 of the school buildings in the HazUS study area, but none of the buildings will experience damage to more than 50 percent of the structure. However, only eleven school buildings are expected to be more than 50 percent functional the day after the earthquake. This lack of functionality is most likely the result of non-structural failures, such as toppled unanchored bookshelves, or overturned computer equipment.

The three fire stations considered in the analysis include the station in Coachella proper, the station at the Thermal airport, and the station in La Quinta. The station in La Quinta was included to obtain data on its anticipated performance given that the station in Coachella was expected to suffer significant damage, and as a result, other stations in the area would likely be asked to step in and provide emergency response services to both the community they are located in and to Coachella. The analysis results indicate that only one of the three fire stations, and neither of the police stations or the City's EOC is expected to be more 50 percent functional on the day after a M7.8 earthquake on the southern Andreas fault. In comparison, all three fire stations, the two police stations and the City's EOC are expected to be more than 50 percent functional on the day after a M7.1 earthquake on the Coachella Valley segment of the San Andreas fault, except for the limitations imposed by the lack of water and electric power discussed in Section 1.9.6.

1.9.4 Economic Losses

HazUS estimates structural and non-structural repair costs caused by building damage and the associated loss of building contents and business inventory. Building damage can cause additional losses by restricting the building's ability to function properly. Thus, business interruption and rental income losses are estimated. HazUS divides building losses into two categories: (1) direct building losses and (2) business interruption losses. Direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. Business interruption losses are associated with inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the earthquake.

Earthquakes may produce indirect economic losses in sectors that do not sustain direct damage. All businesses are forward-linked (if they rely on regional customers to purchase their output) or backward-linked (if they rely on regional suppliers to provide their inputs) and are thus potentially vulnerable to interruptions in their operation. Note that indirect losses are not confined to immediate customers or suppliers of damaged enterprises. All of the successive rounds of customers of customers, and suppliers of suppliers are affected. In this way, even limited physical earthquake damage causes a chain reaction, or ripple effect, that is transmitted throughout the regional economy.

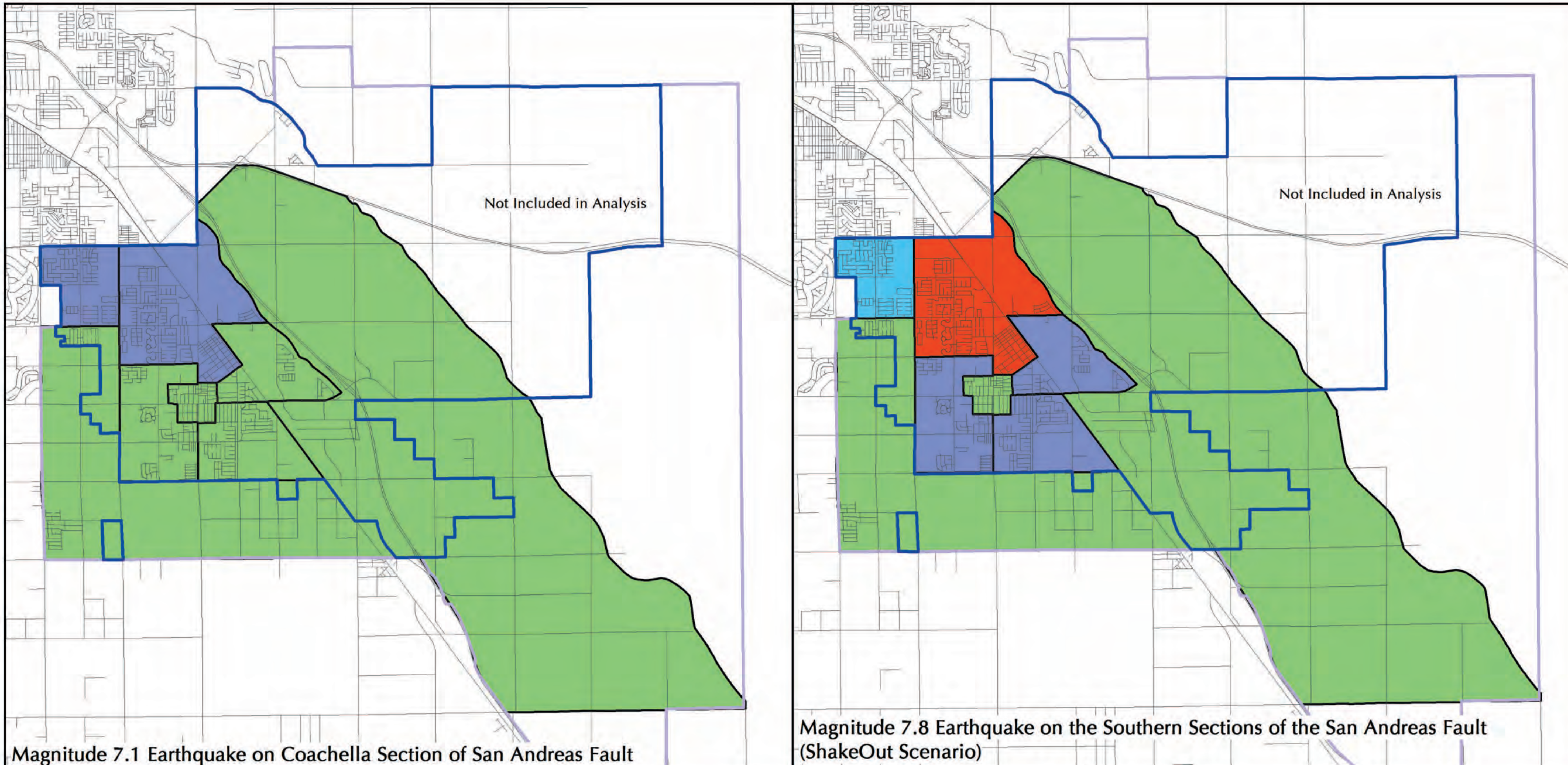
The model estimates that total economic losses in the Coachella area will range from slightly less than $301 million for a M7.1 earthquake on the Coachella Valley segment of the San Andreas fault to slightly more than $1,091 million for a M7.8 earthquake on the San Andreas fault. These figures include building-, transportation-, and lifeline-related losses based on the region's available inventory. Business-related losses include direct building losses (capital stock losses such as structural and non-structural damage, and damage to contents and inventory), and business interruption losses (loss of income from wages, rental properties, relocation expenses, and capital related). Building-related losses estimated for the two earthquake scenarios are summarized in Table 1-13 below. Transportation and utility lifeline losses are summarized in the following sections.

Direct building losses, excluding damage to contents and inventory, are estimated to account for about 65 percent and 66 percent of the building-related economic losses in the city of Coachella as a result of a M7.8 and M7.1 earthquake on the San Andreas fault, respectively. The loss analysis shows that residential occupancies would suffer the most, with a substantial amount of the property damage due to non-structural losses; that is, cosmetic damage to a structure that does not result in the collapse of the structure, and is repairable. This is essentially what building codes are designed to do. Business interruption losses would account for about 16 percent of the losses in the region as a result of either of the two earthquake scenarios.

Table 1-13: Building-Related Economic Losses (in millions of $) Estimated as a Result of Two Earthquake Scenarios

Scenario	Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
San Andreas ShakeOut	Income Losses	Wage	0.00	2.32	22.05	0.63	2.14	27.14
		Capital-Related	0.00	1.01	24.48	0.38	1.31	27.17
		Rental	5.35	9.97	9.73	0.14	0.60	25.79
		Relocation	20.86	15.45	13.36	0.62	8.76	59.05
		SubTotal	26.21	28.76	69.61	1.77	12.81	139.15
	Capital Stock Losses	Structural	28.67	28.91	25.31	3.41	33.17	119.46
		Non-Structural	163.86	115.22	93.34	14.59	65.26	452.26
		Content	63.78	27.83	42.24	8.91	24.02	166.79
		Inventory	0.00	0.00	1.01	2.08	3.02	6.11
		SubTotal	256.31	171.96	161.89	29.00	125.46	744.62
	Total		**282.52**	**200.72**	**231.50**	**30.77**	**138.27**	**883.77**
San Andreas Coachella	Income Losses	Wage	0.00	0.61	6.21	0.19	0.62	7.63
		Capital-Related	0.00	0.27	6.81	0.11	0.30	7.49
		Rental	1.44	2.81	2.98	0.05	0.17	7.46
		Relocation	4.72	6.59	4.19	0.27	2.84	18.60
		SubTotal	6.16	10.27	20.18	0.63	3.94	41.17
	Capital Stock Losses	Structural	11.66	7.92	5.62	0.92	9.13	35.26
		Non-Structural	71.82	31.30	16.20	2.64	13.83	135.79
		Content	27.83	5.65	6.53	1.57	5.21	46.78
		Inventory	0.00	0.00	0.17	0.36	0.69	1.22
		SubTotal	111.31	44.87	28.52	5.49	28.86	219.05
	Total		**117.47**	**55.14**	**48.70**	**6.12**	**32.80**	**260.22**

The distribution of economic losses to buildings of different types in the city of Coachella by census tract as a result of the two earthquake scenarios considered are illustrated in Plates 1-5 (Residential), 1-6 (Commercial and Industrial), and 1-7 (Schools). All of these graphics show that a M7.8 earthquake on the entire southern section of the San Andreas fault will be significantly more damaging to Coachella than a M7.1 earthquake on only the Coachella segment of the fault. Furthermore, Plate 1-5 shows that the largest economic losses to residential buildings can be expected in the older, more-densely occupied sections of the city, where there is a higher concentration of pre-1980s structures. Economic losses associated with the damage to commercial and industrial facilities (Plate 1-6) are partly constrained by the age and density of these types of structures in the city (like the residential stock described above), but are also dictated by the location of these facilities relative to the San Andreas fault. Thus, given that there are many industrial facilities along the eastern portion of the city, adjacent to the fault, the census tract where these facilities are located shows significant economic losses, especially as a result of the M7.8 earthquake scenario. Similarly, the losses estimated for school buildings (Plate 1-7) are defined in great part by the age of the structures, and the schools' locations relative to the San Andreas fault. The highest losses anticipated as a result of damage to school buildings are expected in the center of the city, where the oldest schools are located, seconded by the losses in the census tract closest to the San Andreas fault.



Source: Federal Emergency Management Agency, HAZUS 2.1 v.12.2.0

Based on 2000 real estate values, not adjusted for inflation

N W E S

7000 0 7000 14000

Feet

Scale: 1:84,000

EXPLANATION

Economic Loss by Census Tract
(in Millions of Dollars)

- 60 - 70
- 50 - 60
- 40 - 50
- 30 - 40
- 20 - 30
- 10 - 20
- 0 - 10
- Coachella City Boundary
- Coachella Planning Area Boundary

Earth Consultants International

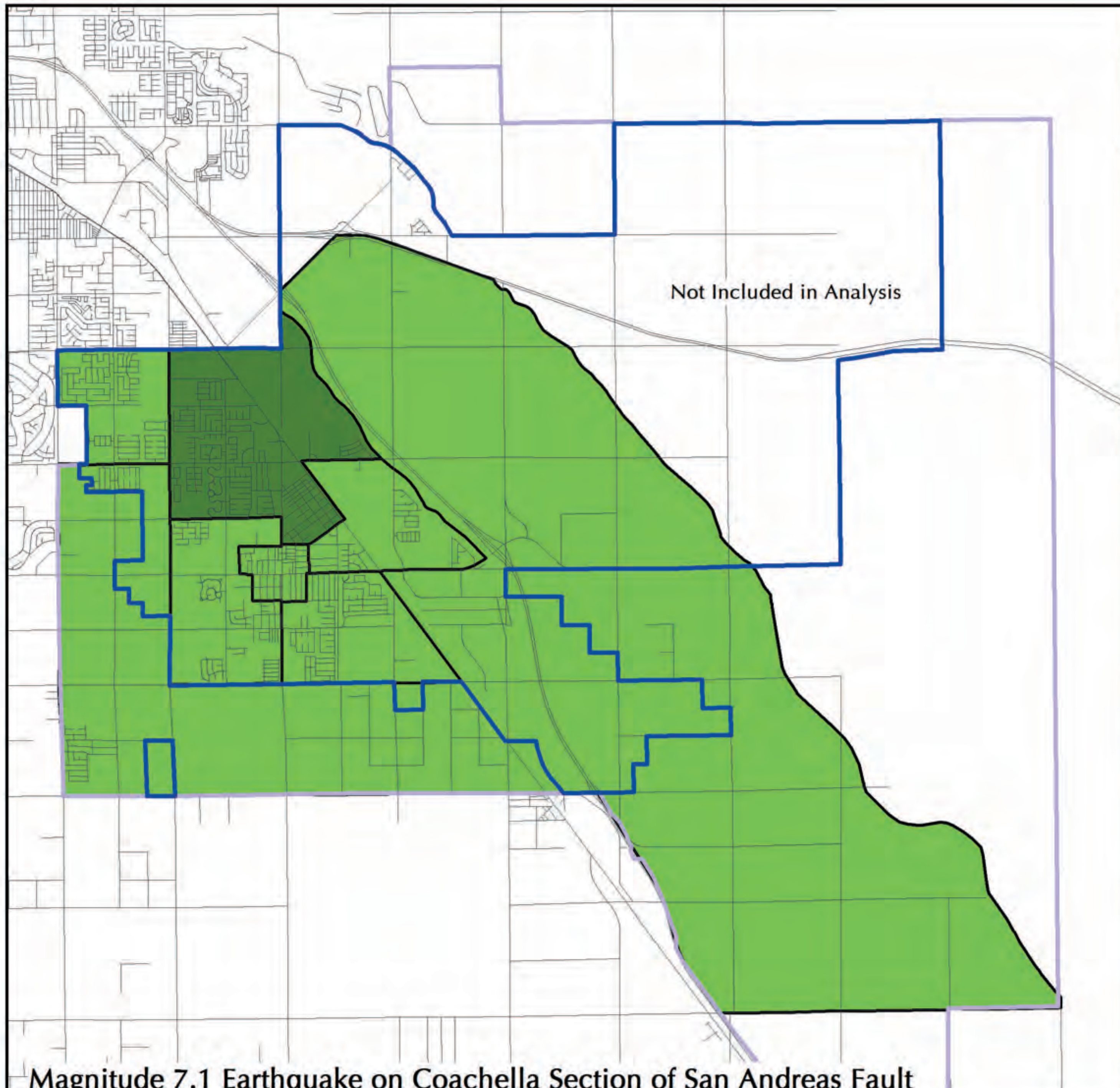
Project Number: 3106/3218
Date: 2014

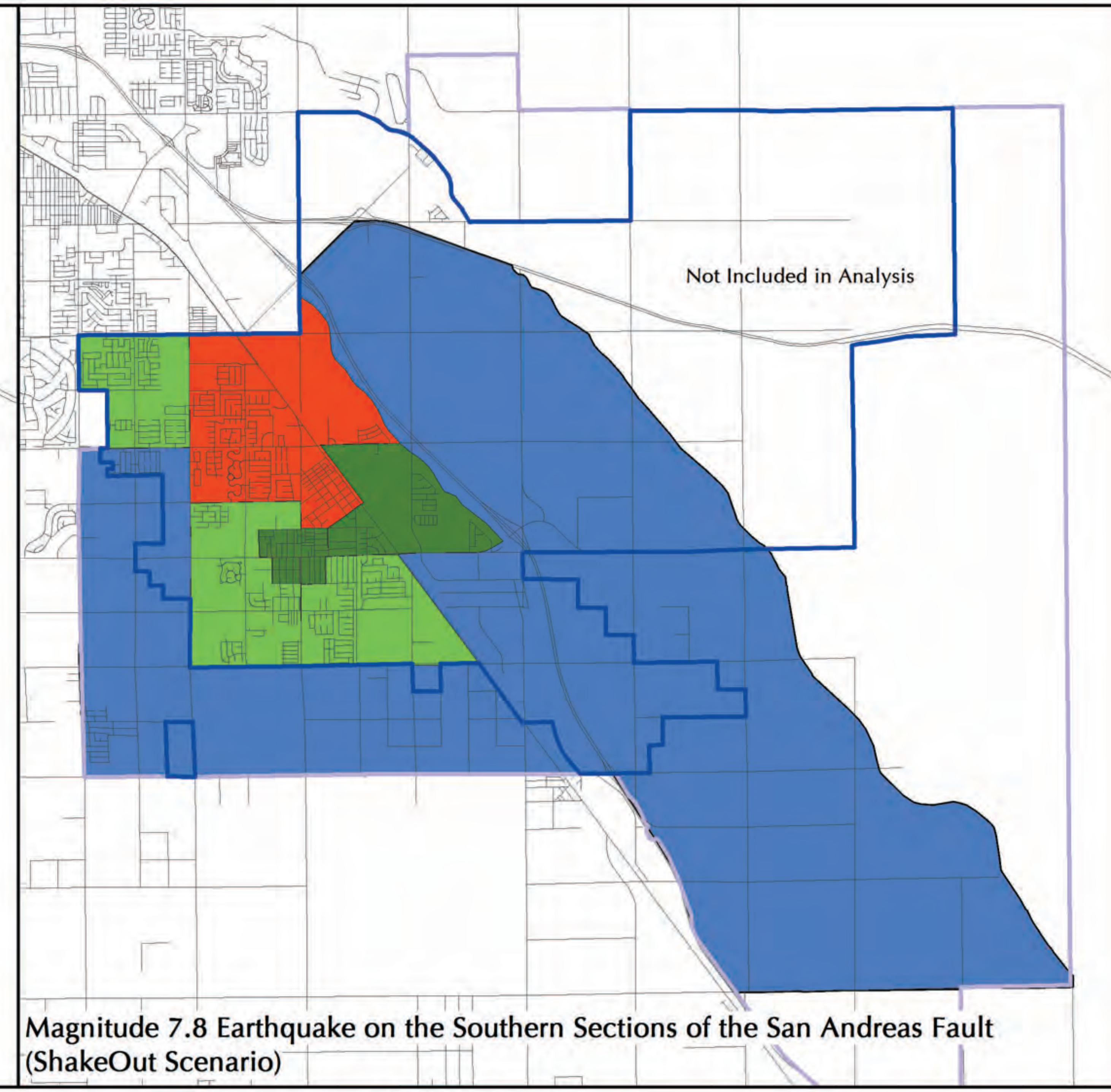
Economic Losses due to Residential Building Damage

(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-5





Source: Federal Emergency Management Agency, HAZUS 2.1 v 12.2.0

N
W E
S

7000 0 7000 14000
Feet
Scale: 1:84,000

EXPLANATION
Economic Loss by Census Tract
(in Millions of Dollars)

80 - 90
70 - 80
60 - 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
0 - 10

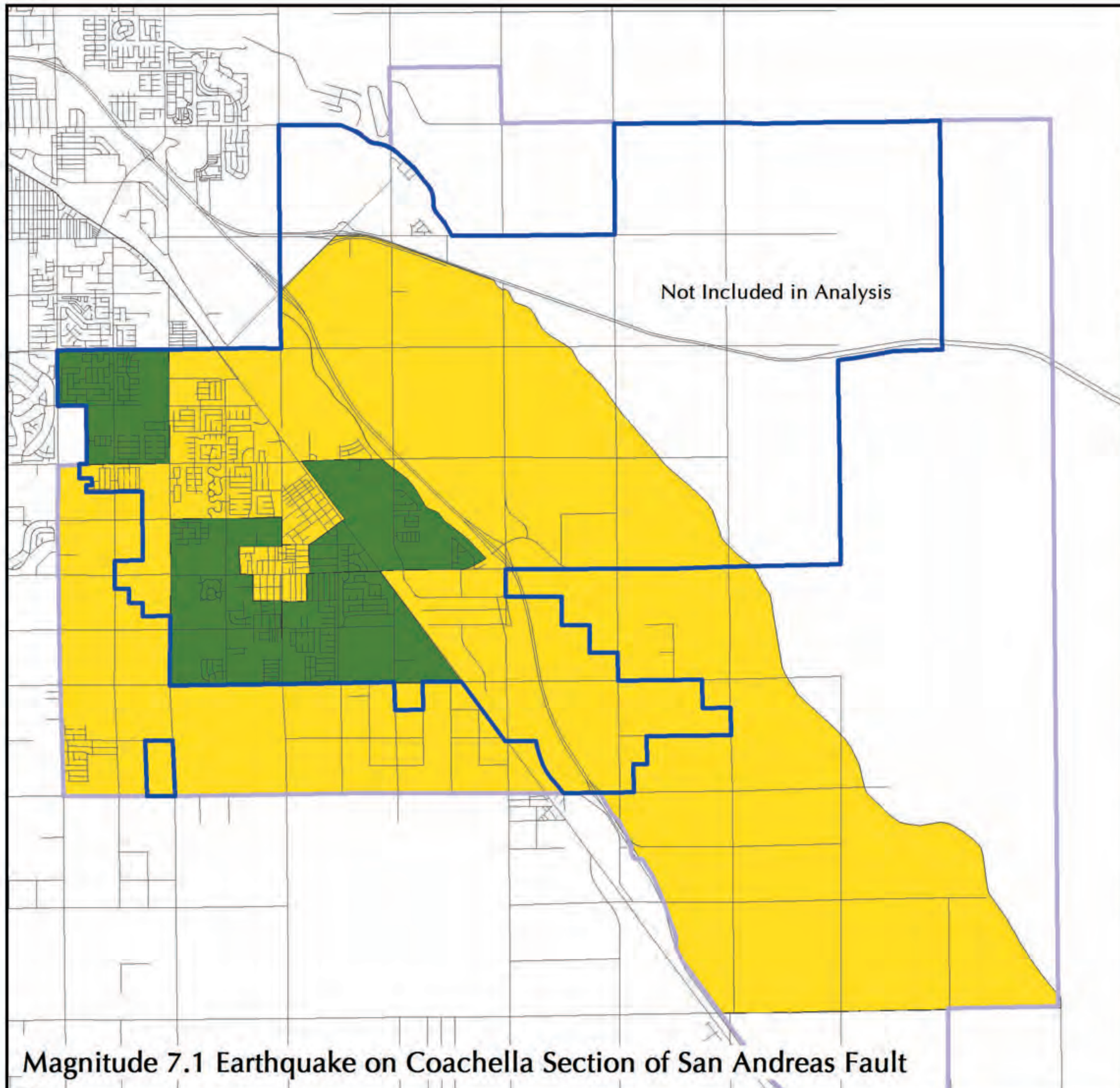
Coachella City Boundary
Coachella Planning Area Boundary

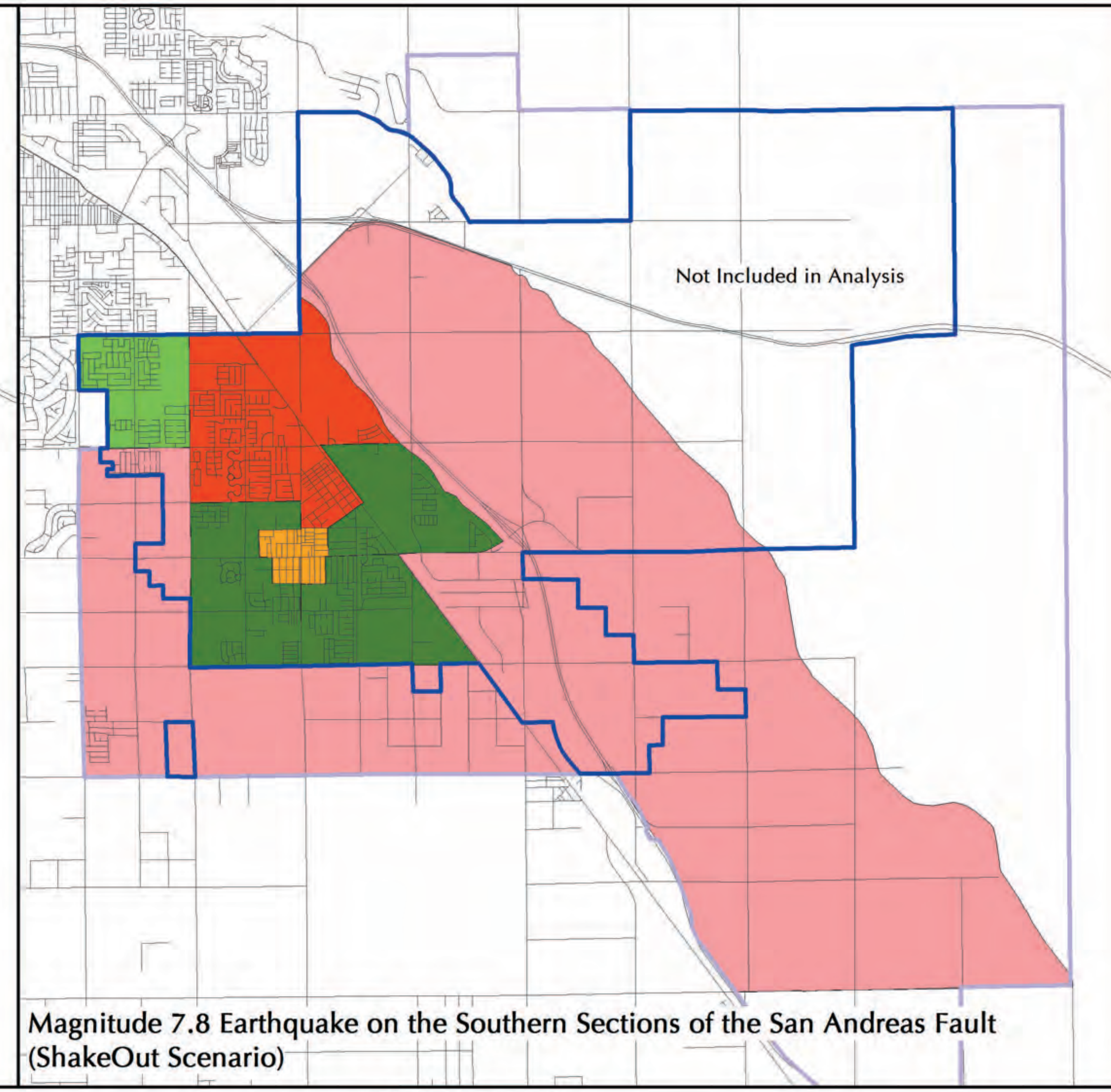
Earth Consultants International

Project Number: 3106/3218
Date: 2014

Commercial and Industrial Loss
(Based on Two Earthquake Scenarios)
Coachella, California

Plate
1-6





Sources: Federal Emergency Management Agency, HAZUS 2.1

N W E S

7000 0 7000 14000

Feet

Scale: 1:84,000

EXPLANATION

Economic Loss by Census Tract (in Millions of Dollars)

- 15 - 20
- 10 - 15
- 5-10
- 1 - 5
- 0.5 - 1
- 0 - 0.5

- Coachella City Boundary
- Coachella Planning Area Boundary

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Economic Loss due to School Damage

(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-7

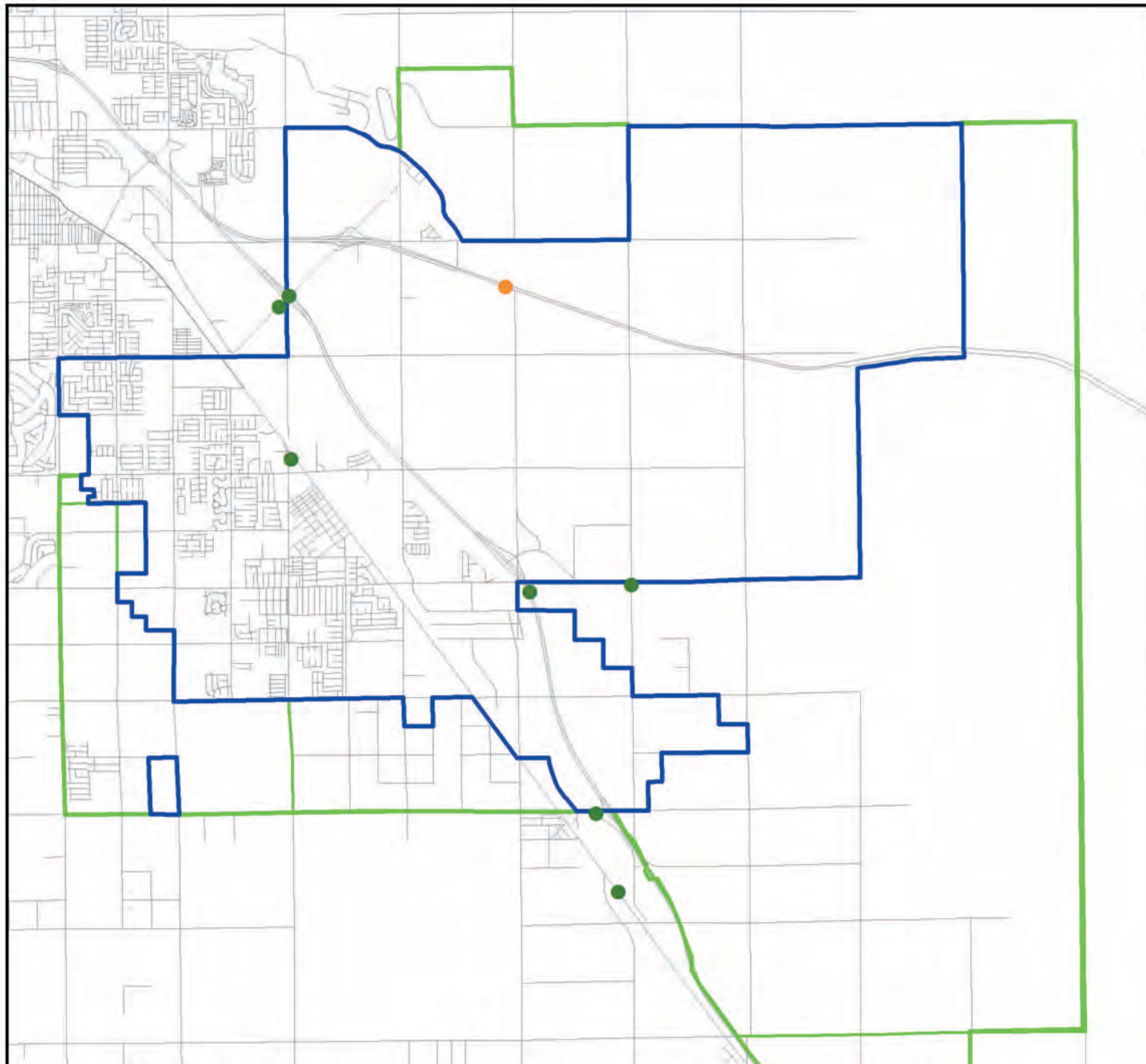
1.9.5 Transportation Damage

Lifelines are those services that are critical to the health, safety and functioning of the community. They are particularly essential for emergency response and recovery after an earthquake. Furthermore, certain critical facilities designed to remain functional during and immediately after an earthquake may be able to provide only limited services if the lifelines they depend on are disrupted. Lifeline systems include transportation and utilities. Transportation systems are discussed in more detail in the following paragraphs, whereas utility lifelines are discussed further in the next section.

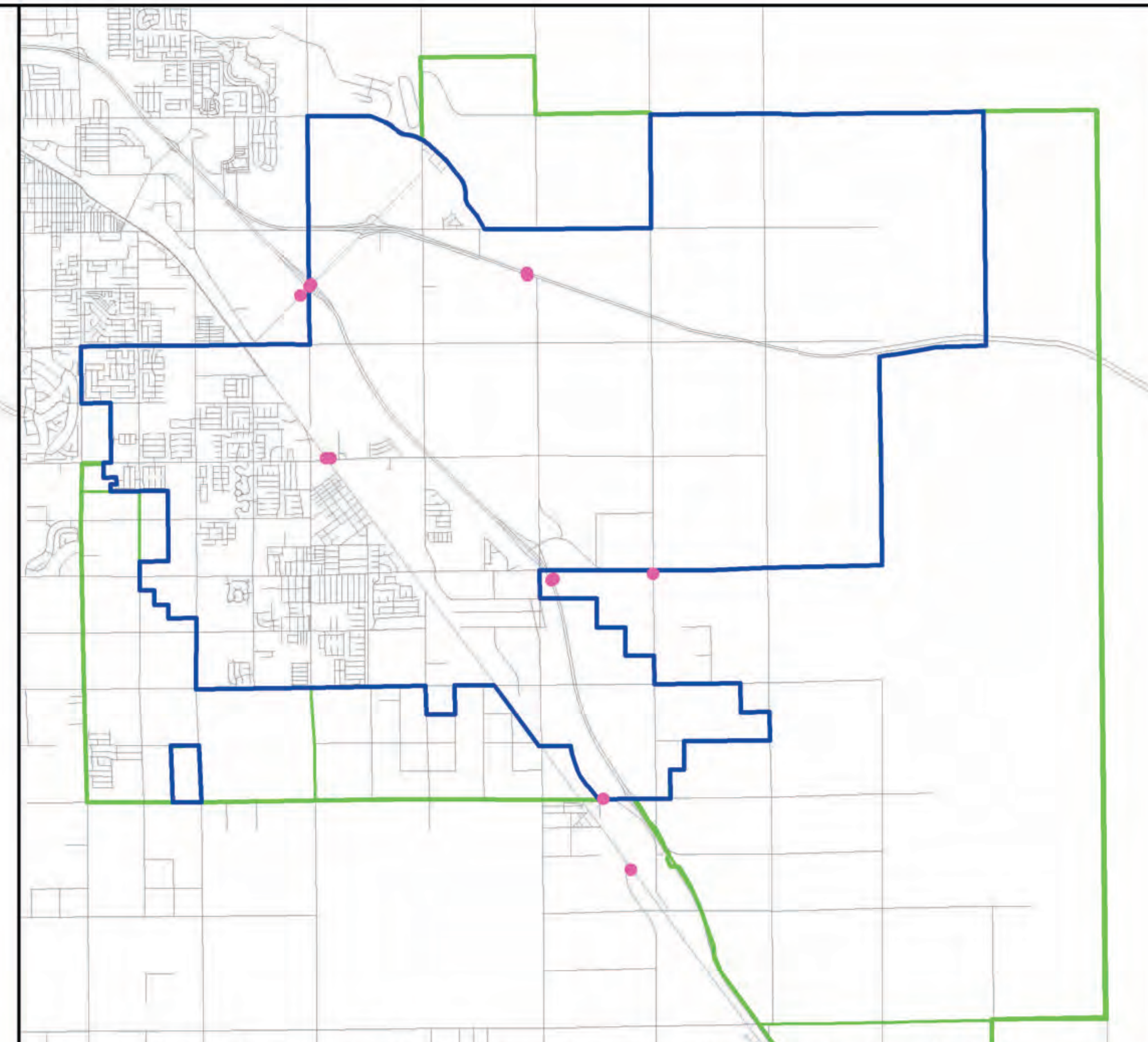
HazUS divides the transportation system into seven components: highways, railways, light rail, bus, ferry, ports, and airports. Only highways, railways, and airports are relevant to the area covered in the analysis for Coachella. The replacement value for the transportation and utility lifeline systems combined in the study area is estimated at over $658 million, with the highway segments ($332.4 million) and airport runways ($73.3 million) accounting for most of this value. The HazUS inventory for the study region includes over 103 kilometers (64 miles) of highways and 21 bridges.

Table 1-14 provides damage and loss estimates for specific components of the transportation system within the study area. The results of this analysis suggest that the transportation system in Coachella will be impacted by a M7.8 earthquake on the San Andreas fault, with more than 80 percent of the bridges in the highway system at least moderately damaged and nearly 50 percent completely damaged. Only one third of the bridges are expected to be more than 50 percent functional one week after the earthquake. A M7.1 earthquake on the Coachella segment of the San Andreas fault is not expected to cause at least moderate damage to any of the bridges in the study area, and 20 of the 21 bridges considered are expected to be more than 50 percent functional on the day after the earthquake. Damage to the bridges in the study region as a result of the two earthquake scenarios considered is illustrated in Plate 1-8.

It is important to mention that given that the study area considered in the HazUS analyses does not include the section of the General Plan area immediately adjacent to and to the east of the San Andreas fault, including where the I-10 freeway extends across the fault zone, the damage to the transportation system is under-represented in the loss estimates presented above. Rupture of the San Andreas fault as a result of either earthquake scenario will involve rupture of the ground surface and ground deformation due to both liquefaction and slope failure, in addition to damage due to shaking. Surface fault rupture will damage most, if not all, of the road segments and bridges that extend across the fault. Treiman et al. (2008) estimate that the ShakeOut scenario will laterally offset the I-10 freeway where it crosses the San Andrea fault in Coachella about 4 meters (13 feet) immediately upon the earthquake occurring, with an additional 2.7 meters (9 feet) possible as afterslip in the weeks to months following the earthquake. The afterslip displacement is anticipated to interfere with recovery efforts. Real et al. (2008) calculated approximately 3 meters (9.8 feet) of lateral spreading at the I-10 / Dillon Road crossing. This amount of lateral spreading has the potential to severely impact the bridge and other infrastructure, such as fiber optic cables, that cross this area. As the I-10 freeway continues east through the hills in the eastern portion of the General Plan area, earthquake-induced soil slides and soil slumps (see Plate 1-3) have the potential to block sections of the freeway, which in turn could impede assistance efforts from communities and states to the east.



Magnitude 7.1 Earthquake on Coachella Section of San Andreas Fault



Magnitude 7.8 Earthquake the Southern Sections of the San Andreas Fault (ShakeOut Scenario)

Source: Federal Emergency Management Agency, HAZUS 2.1 v12.2.0

N W E S

7000 0 7000 14000

Feet

Scale: 1:84,000

EXPLANATION

Bridge Damage

- >50% probability damage exceeds extensive
- >50% probability damage exceeds moderate
- >50% probability damage is slight to none

- Coachella City Boundary
- Coachella Planning Area Boundary

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Highway Bridge Damage

(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-8

The facilities at the Thermal Airport are also expected to be at least moderately damaged by a M7.8 earthquake on the San Andreas fault. As a result, the airport facility is not expected to be more than 50 percent functional on the day after the earthquake, although it should be by day 7. A smaller but significant M7.1 earthquake is not anticipated to cause at least moderate damage at the airport, and as a result, it should be more than 50 percent functional the day after the earthquake.

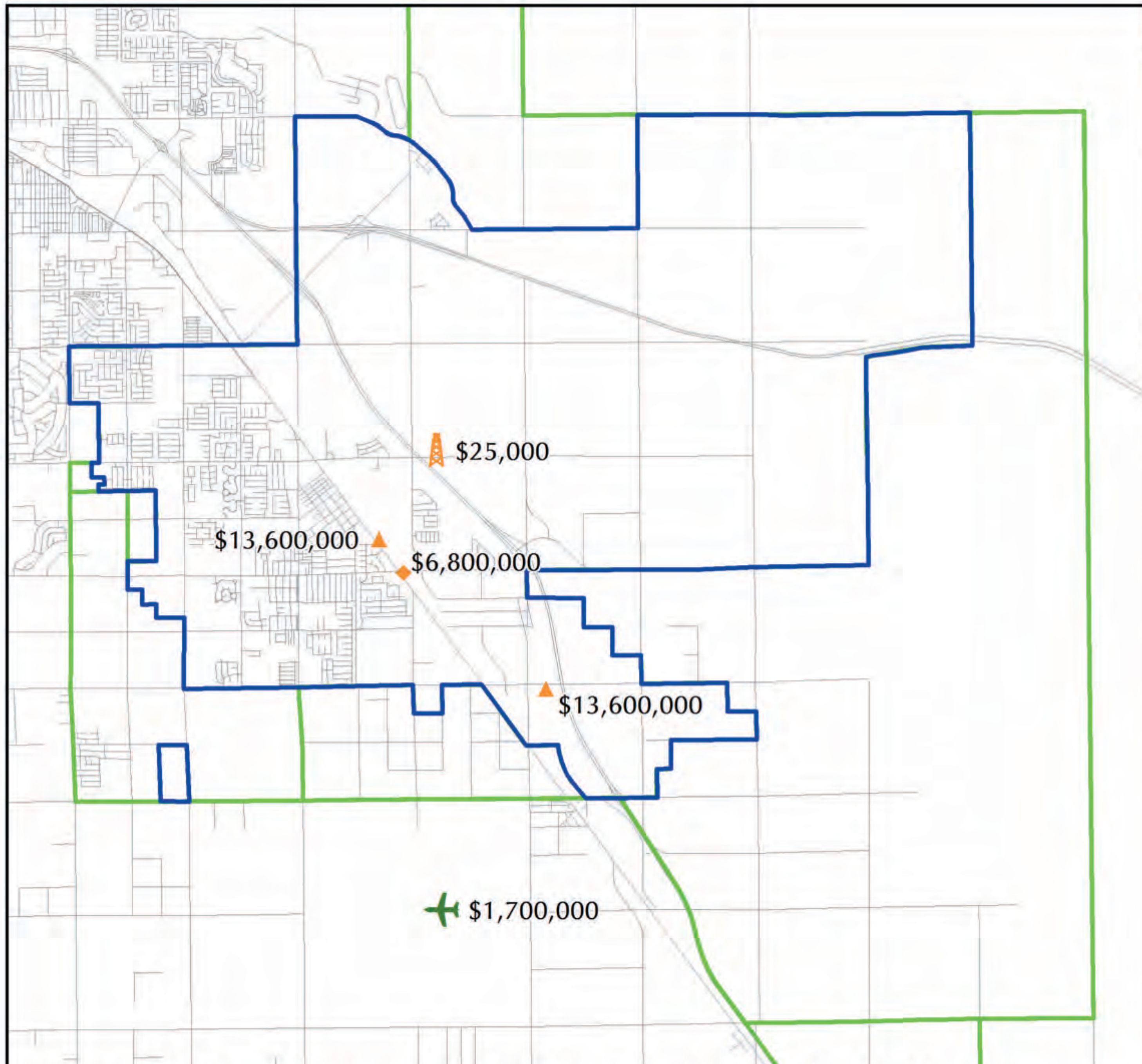
Economic losses to the transportation system as a result of the ShakeOut scenario are estimated at about $13.8 million in the area modeled for the HazUS scenario. Given the extensive damage anticipated just east of the HazUS model area, in the area where the San Andreas fault extends through the Coachella General Plan, total losses to the transportation system are anticipated to be significantly larger. The model estimates losses of about $4.7 million to the transportation system due to a M7.1 earthquake on the Coachella section of the fault (for a quick snapshot of the economic losses to the transportation and utility systems as a result of the earthquake scenarios considered, refer to Plate 1-9). As with the ShakeOut scenario, this estimate is for west Coachella, and does not include damages to the roads and bridges that cross the San Andreas fault, nor damages to the roads and bridges east of the fault, in the hillside areas where earthquake-induced slope instability is a concern.

Additional damage to the transportation system not accounted for by the model may be the result of strong ground shaking. Past earthquakes have shown that ground shaking can cause deformation to the ground surface, with resultant damage to the roadways, but this effect is not modeled effectively.

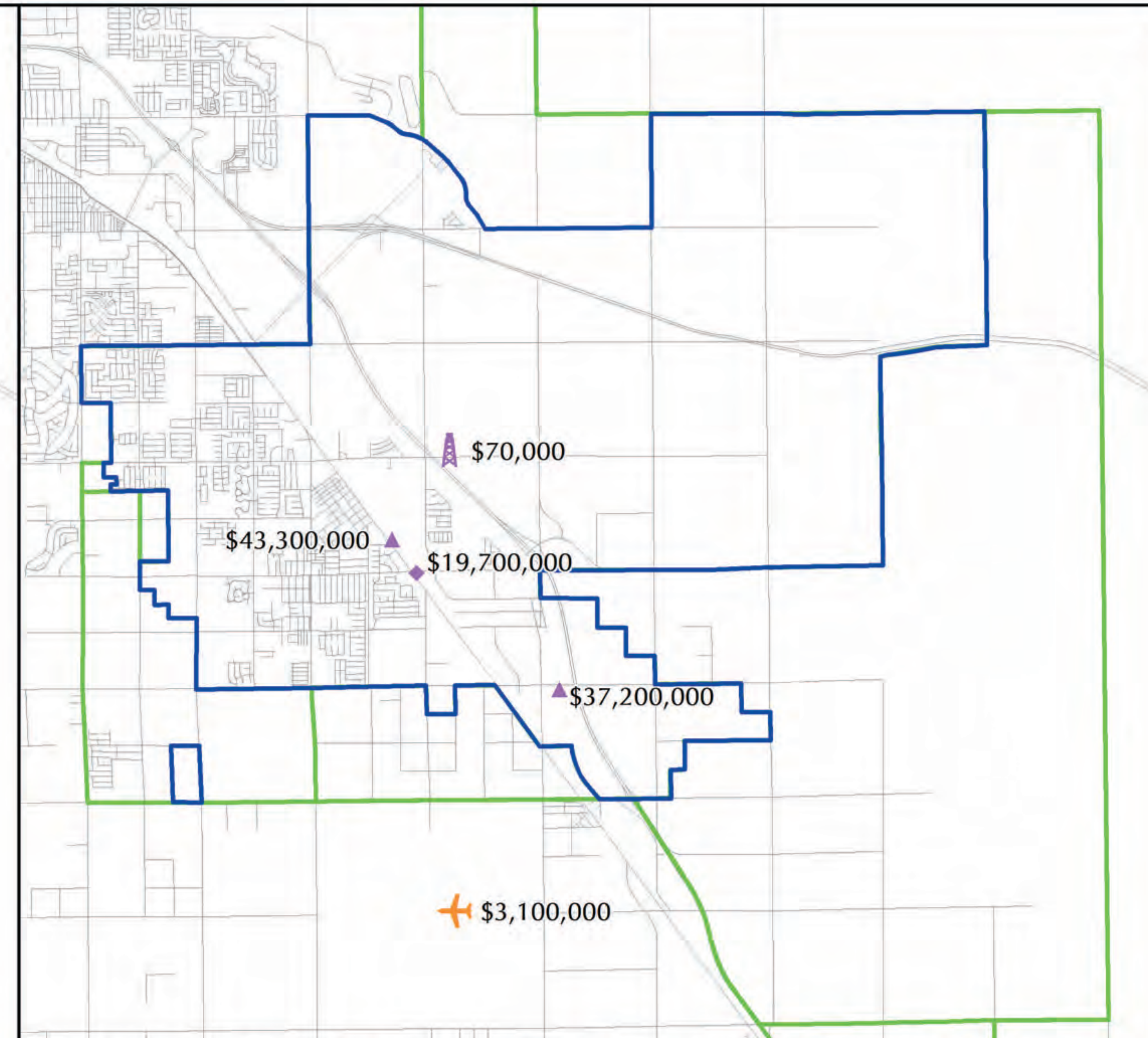
Table 1-14: Transportation System – Expected Damage and Economic Losses

Scenario	System	Component	Locations/ Segments	With at Least Moderate Damage	With Complete Damage	Functionality >50%		Economic Loss (Millions $)
						After Day 1	*After Day 7*	
San Andreas	Highway	Segments	4	0	0	4	4	0.00
		Bridges	21	17	10	4	7	10.71
	Railways	Segments	6	0	0	6	6	0.00
	Airport	Facilities	1	1	0	0	1	3.10
		Runways	2	0	0	2	2	0.00
San Andreas Coachella	Highway	Segments	4	0	0	4	4	0.00
		Bridges	21	0	0	20	21	3.03
	Railways	Segments	6	0	0	6	6	0.00
	Airport	Facilities	1	0	0	1	1	1.71
		Runways	2	0	0	2	2	0.00

It is also important to remember that the transportation system will be significantly impacted in areas outside of Coachella, such as along the San Gorgonio Pass, due to surface fault rupture, landsliding, liquefaction or other types of seismically induced ground deformation, which could directly and indirectly have an impact on Coachella's residents, both in the short-term and long-term. For example, disrupted roadways are likely to make it very difficult, if not impossible, for commuters outside of the Coachella Valley to return home immediately following the earthquake, as well as hindering evacuation efforts. This will also impact disaster response and recovery, hindering the effective transport of injured individuals to medical facilities outside of



Magnitude 7.1 Earthquake on Coachella Section of San Andreas Fault



Magnitude 7.8 Earthquake on the Southern Sections of the San Andreas Fault (ShakeOut Scenario)

Source: Federal Emergency Management Agency, HAZUS 2.1 v12.2.0

N W E S

7000 0 7000 14000

Feet

Scale: 1:84,000

EXPLANATION

Damage (Labeled with Economic Loss in Dollars)

- Airport
- Radio Tower
- ◆ Potable Water System Facility
- ▲ Waste Water Facility
- >50% probability damage exceeds extensive
- >50% probability damage exceeds moderate
- >50% probability damage is slight to none

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Utility and Communication Facilities Damage and Economic Loss

(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-9

the damaged area, in the delivery of water, food, and supplies to the earthquake-damaged areas. In the long-term, damage to the transportation system may impact the recovery of those businesses that rely on products shipped on these transportation systems. The HazUS model anticipates that the railway system in the study area will not suffer significant damage, but the railroad tracks have the potential to be damaged by liquefaction-induced lateral spreading both in the Coachella General Plan area (see Plate 1-3) and elsewhere along the Coachella and Imperial valleys. The railroad tracks also extend across the trace of the San Andreas fault both to the north and south of the Coachella area (for a more detailed discussion of the potential damage to the railroad system, refer to Chapter 5, Section 5.6).

1.9.6 Utility Systems Damage

Utility lifelines include potable water, wastewater, natural gas, crude and refined oil, electric power, and communications. The improved performance of lifelines in the 1994 Northridge earthquake relative to the 1971 San Fernando earthquake, shows that the seismic codes that were upgraded and implemented after 1971 have been effective. Nevertheless, the impact of the Northridge earthquake on lifeline systems was widespread and illustrated the continued need to study earthquake impacts, upgrade substandard elements in the systems, provide redundancies, improve emergency response plans, and provide adequate planning, budgeting and financing for seismic safety. Water supply facilities, such as dams, reservoirs, pumping stations, water treatment plants, and distribution lines are especially critical after an earthquake, not only for drinking water, but to fight fires. Possible failure of dams and above-ground water storage tanks as a result of an earthquake is discussed further in Chapter 3.

If site-specific lifeline utility data are not provided for these analyses, HazUS performs a statistical calculation based on the population served to develop an estimate of the total length of pipelines that comprise the potable water, natural gas, wastewater and oil systems. From this inventory, the model then calculates the expected number of leaks and breaks in these systems. The replacement value for the utility lifeline system in the Coachella study area is estimated at $109.9 million.

Table 1-15 summarizes the expected damage to the potable water, waste water, and natural gas systems in Coachella as a result of two different earthquake scenarios on the San Andreas fault. The models suggest that the potable water, waste water and natural gas systems in Coachella will experience extensive damage as a result of an M7.8 earthquake on the San Andreas fault, and moderate damage as a result of a smaller M7.1 event. The San Andreas ShakeOut earthquake scenario is expected to cause thousands of leaks and breaks in these systems. Where potable water lines extend across leach fields or occupy the same trench as sewer lines, breaks in these lines could result in contamination of the potable water supply. The potable water system in particular is estimated to be so extensively damaged that the community is anticipated to be without piped-in potable water for a minimum of three months (see Table 1-16). Given these results, Coachella residents should be strongly encouraged to store at least a seven-day supply of drinking water for the entire household (including pets), allowing families to be self-sufficient immediately following the earthquake, and giving the City and the Coachella Valley Water District some time to organize and develop alternate methods of water delivery to their residents and customers.

Table 1-15: Expected Utility System Pipeline Damage

Scenario	System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks	Economic Loss ($Millions)
San Andreas ShakeOut	Potable Water	516	19,038	4,759	105.33
	Waste Water	310	15,057	3,764	148.23
	Natural Gas	206	16,096	4,024	72.43
San Andreas Coachella	Potable Water	516	396	99	8.57
	Waste Water	310	313	78	28.55
	Natural Gas	206	335	84	1.51

Table 1-16 shows the expected performance of the potable water, and electric power systems using empirical relationships based on the number of households served in the area. As briefly discussed above, and according to the models, a M7.8 earthquake on the San Andreas fault is expected to have a significant negative impact on both the potable water and electric power services – essentially all households in the Coachella study area are expected to have no potable water for at least 90 days (3 months) following the earthquake, and possibly even longer. The number of pipe breaks is expected to be such that the entire water system is going to have to be recreated. Given that the M7.8 ShakeOut scenario is going to impact a very large area, "there will not be enough pipe and connectors or trained manpower to repair all the breaks quickly. The worst hit areas may not have water in the taps for 6 months" (Jones et al., 2008).

Thousands of households are also expected to be without electric power following the earthquake, but repairs to this system are expected to occur more quickly. According to the model, nearly 7,400 households are expected to be without power on the first day after the earthquake, and by day 7, 2,600 households would still be without power. With very few exceptions, all households are expected to have electric power by day 90. Economic losses associated with the expected damage to utilities in the area resulting from the two earthquake scenarios are summarized in Plate 1-9.

Table 1-16: Expected Performance of Potable Water and Electric Power Services

Scenario	Utility	Number of Households without Service*				
		Day 1	Day 3	Day 7	Day 30	Day 90
San Andreas ShakeOut	Potable Water	9,190	9,190	9,190	9,190	9,190
	Electric Power	7,393	5,153	2,559	610	9
San Andreas Coachella	Potable Water	6,105	1,696	0	0	0
	Electric Power	0	0	0	0	0

*Based on Total Number of Households = 9,190

The smaller M7.1 earthquake scenario on the San Andreas fault is anticipated to leave more than 6,100 households without water for 24 hours, and nearly 1,700 households would have no water after three days. However, all households are anticipated to have water a week after the earthquake. This smaller earthquake is not expected to cause a loss in electric power in the region.

1.9.7 Shelter Needs

Earthquakes can cause loss of function or habitability of buildings that contain housing. Displaced households may need alternative short-term shelter, provided by family, friends, temporary rentals, or public shelters established by the City, County or by relief organizations such as the Red Cross. Long-term alternative housing may require import of mobile homes, occupancy of vacant units, net emigration from the impacted area, or, eventually, the repair or reconstruction of new public and private housing. The number of people seeking short-term public shelter is of most concern to emergency response organizations. The longer-term impacts on the housing stock are of great concern to local governments, such as cities and counties.

HazUS estimates that about 281 households in Coachella will be displaced due to the M7.8 San Andreas fault earthquake modeled for this study, and that about 558 people will seek temporary shelter in public shelters (see Table 1-17 below). Considering that the region is anticipated to be without piped-in potable water for more than three months, the displaced households number for the ShakeOut scenario given below may be significantly underestimated. A smaller M7.1 earthquake is anticipated to displace about 52 households, with approximately 103 people seeking temporary cover in public shelters. In both scenarios, those people displaced that do not seek short-term shelter in public facilities are expected to find alternate temporary housing with family or friends.

The actual number of people seeking shelter may also be larger than the estimates given because of the fairly large percentage of Hispanics or Latinos in the General Plan area. Past history has shown that Hispanics, especially those of Mexican and Central American ancestry, generally prefer to camp out in parks and other open spaces rather than return to their house soon after an earthquake, even if their house appears to be undamaged. This was observed in the greater Los Angeles area following the 1994 Northridge earthquake, as well as other previous earthquakes in California, such as the 1987 Whittier Narrows and 1989 Loma Prieta earthquakes (Tierney, 1994; Tierney, 1995; Andrews, 1995).

Table 1-17: Estimated Shelter Requirements

Scenario	Displaced Households	People Needing Short-Term Shelter
San Andreas – ShakeOut	281	558
San Andreas – Coachella	52	103

1.9.8 Debris Generation

HazUS estimates the amount of debris that will be generated by the scenario earthquakes. The model breaks the debris into two general categories: 1) brick/wood, and 2) concrete/steel. The distinction is made because of the different types of equipment required to handle the debris. The M7.8 San Andreas earthquake is estimated to generate a total of 350,000 tons of debris, with brick/wood amounting to about 34 percent (119,000 tons) of this total. Removing this debris would require approximately 14,000 truckloads (at 25 tons/truckload). The model estimates that the M7.1 earthquake on the San Andreas fault will generate 37,800 tons of brick and wood, and 52,200 tons of concrete and steel, for a total of 90,000 tons of debris. If the debris tonnage is converted to an estimated number of truckloads, it would require approximately 3,600 truckloads to remove the debris generated by this earthquake.

Table 1-18: Debris Generation (in Thousands of Tons)

Scenario	Brick, Wood & Others	Concrete & Steel	Total
San Andreas-Shakeout	119	231	350
San Andreas – Coachella	37.8	52.2	90

1.10 Summary and Recommendations

Since it is not possible to prevent an earthquake from occurring, local governments, emergency relief organizations, and residents are advised to take action and develop and implement policies and programs aimed at reducing the effects of earthquakes. Individuals should also exercise prudent planning to provide for themselves and their families in the aftermath of an earthquake. This is particularly important in the Coachella Valley area, and other areas immediately adjacent to or bisected by the southern San Andreas fault.

Earthquake Sources and Design Earthquake Scenarios:

- The San Andreas fault is the most significant seismic source in the Coachella General Plan area. The fault extends across the city, intersecting the region's infrastructure, which in this area includes the Interstate 10 freeway, the Coachella Canal, and several significant oil and gas pipelines and fiber optic cables. The section of the fault that extends across the city, referred to as the Coachella section, last ruptured about 320 to 330 years ago (around A.D. 1680), and is estimated to have a 59 percent probability of causing an earthquake of at least magnitude 6.7 in the next 30 years. Therefore, all development in the Coachella General Plan area should be designed to withstand strong ground shaking.

- A number of historic earthquakes have caused moderate ground shaking in Coachella. Moderate to strong ground shaking due to future earthquakes on regional sources, including other sections of the San Andreas fault, should be expected and designed for.

- Geologists, seismologists, engineers and urban planners typically use maximum magnitude and maximum probable earthquakes to evaluate the seismic hazard of a region, the assumption being that if we plan for the worst-case scenario, smaller earthquakes that are more likely to occur can be dealt with more effectively.

- The San Andreas and San Jacinto faults have the potential to generate earthquakes that would be felt strongly in the Coachella region. Unfortunately, we cannot predict when a fault will break causing an earthquake, but we can anticipate the size of the resulting earthquake and estimate the level of damage that the earthquake would generate in the region. The southern section of the San Andreas fault closest to Coachella is thought capable of generating a M7.8 to 8.0 earthquake. Individual segments of this section of the fault could generate M7.2 to M7.5 earthquakes. Similarly, the sections of the San Jacinto fault closest to Coachella are thought capable of generating earthquakes of M6.6 to M7.2. Most other faults within 100 km (62 miles) of the city can generate earthquakes as large or larger than the M_w 6.7 Northridge earthquake, the single most-expensive earthquake yet to impact the United States.

- The loss estimation analyses conducted for this study indicate that the San Andreas fault will generate be the worst-case earthquake for Coachella. A M7.8 earthquake, which is not the largest the fault is capable of generating, would result in significant damage in the city, with economic losses estimated at more than $884 million. A smaller M7.1 earthquake on the Coachella section of the fault zone is anticipated to cause more than $260 million in damages in the Coachella General Plan area. The San Jacinto fault is not expected to cause as much damage in the General Plan area because the maximum magnitude earthquake that it is capable of generating is significantly smaller, and it is also farther away.

Fault Rupture and Secondary Earthquake Effects:

- The main strands of the San Andreas fault extend in a southwesterly direction through the Coachella General Plan area. When this fault ruptures next, large displacements in the order of 20 feet or more could be expected locally. Any improvement that straddles the fault zone can be expected to be significantly impacted.

- The California Geological Survey (CGS) has not conducted mapping in the Coachella area under the Seismic Hazards Mapping Act. This report presents a liquefaction susceptibility map that was prepared using a similar method used by the California Geological Survey (CGS). Shallow ground water levels (less than 30 feet from the ground surface) have been reported historically in the western part of the General Plan area. Although the groundwater levels have dropped recently as a result of increased pumping of the underlying aquifers, increased recharge of the basin could result in a rise in the water levels to past historical highs. Trenches excavated in the region as part of fault investigations have exposed evidence for past liquefaction events in the area, indicating that if shallow groundwater is present, these deposits could liquefy again. Studies in accordance with the guidelines prepared by the CGS should be conducted in those areas identified as susceptible to liquefaction, at least until sufficient studies have conclusively shown whether or not the sediments are indeed susceptible to liquefaction.

- Soil slides and soil slumps may occur in the hillside areas in the eastern and northeastern portions of the Coachella General Plan area.

- Precariously perched rocks are common on the hillsides in the northeastern and southeastern portions of the Coachella General Plan area. Earthquake-induced ground shaking could dislodge some of these rocks, posing a rockfall hazard to areas adjacent to and below these slopes.

- Those areas of Coachella underlain by youthful unconsolidated alluvial sediments may be susceptible to seismically induced settlement. Geotechnical studies to evaluate this potential hazard should be conducted in areas underlain by Holocene sediments where developments are proposed. If the sediments are found to be susceptible to this hazard, mitigation measures designed to reduce settlement should be incorporated into the design.

Earthquake Hazard Reduction:

- Most of the loss of life and injuries that occur during an earthquake are related to the collapse of hazardous buildings and structures, or from non-structural components, including contents, in those buildings. The HazUS analyses conducted for this study indicate that more than 74 percent of the residential structures other than single-family homes (that is, multi-family residential buildings, including duplexes, condominiums and apartments) will suffer at least moderate damage as a result of an earthquake on the San Andreas fault. Nearly 59 percent of the industrial structures, 58 percent of the agricultural, and 54 percent of commercial structures are also expected to be at least moderately damaged by a San Andreas fault earthquake. Similarly, about 50 percent of the education, government and religion buildings in the study area will suffer at least moderate damage. Nearly 95 percent of the manufactured homes in the area will be damaged.

- The HazUS results indicate that the worst time for an earthquake to occur on the San Andreas fault is during the day, during maximum education, commercial and industrial laods. Because many of the buildings damaged generate heavy debris, an earthquake during the day is anticipated to generate dozens of Level 3 and 4 injuries, in addition to hundreds of Level 1 and 2 injuries.

- The regional hospitals are not expected to be functional immediately following an earthquake on the San Andreas fault, and able to meet the demand for medical care in the aftermath of a San Andreas earthquake in the area. Emergency management personnel and planners need to develop a contingency plan that provides for medical care at facilities other than the local hospitals, in addition to agreements with hospitals outside of the region that can provide assistance with Level 3 and 4 casualties. Given the extensive damage anticipated to the transportation system, most victims that need to be transported elsewhere for treatment will have to be airlifted out of the area.

- The inventory and retrofit of potentially hazardous structures, such as pre-1952 wood-frame buildings, concrete tilt-ups, pre 1971- reinforced masonry, soft-story buildings and especially mobile homes, are recommended.

- The best mitigation technique in earthquake hazard reduction is the constant improvement of building codes with the incorporation of the lessons learned from past earthquakes. This is especially true in areas not yet completely developed. In addition, current building codes should be adopted for re-development projects that involve more than 50 percent of the original cost of the structure. Current building codes incorporate two significant changes that impact the city of Coachella. First, there is recognition that soil types can have a significant impact on the amplification of seismic waves, and second, the proximity of earthquake sources will result in high ground motions and directivity effects. However, for those areas of Coachella already developed, and given that building codes are generally not retroactive, the adoption of the most recent building code is not going to improve the existing building stock, unless actions are taken to retrofit the existing structures. Retrofitting existing structures to the most current building code is in most cases cost-prohibitive and not practicable. However, specific retrofitting actions, even if not to the latest code, that are known to improve the seismic performance of structures should be attempted.

- While the earthquake hazard mitigation improvements associated with the latest building code address new construction, the retrofit and strengthening of existing structures requires the adoption of ordinances. The City of Coachella should consider the implementation of a mandatory ordinance aimed at retrofitting older wood-frame residential buildings that are not tied-down to their foundations, pre-cast concrete buildings, steel-frame buildings, soft-story structures, and manufactured housing. Although retrofitted buildings may still incur severe damage during an earthquake, their mitigation results in a substantial reduction of casualties by preventing collapse.

- Adoption of new building codes does not mitigate local secondary earthquake hazards such as liquefaction and ground failure. Therefore, these issues are best mitigated at the local level.

Avoiding areas susceptible to earthquake-induced liquefaction or settlement is generally not feasible. The best alternative for the City is to require "special studies" within these zones for new construction, as well as for significant redevelopment, and require implementation of the engineering recommendations for mitigation.

- Effective management of seismic hazards in Coachella includes technical review of consulting reports submitted to the City by licensed engineering geologists and/or civil engineers having competence in the evaluation and mitigation of seismic hazards (CCR Title 14, Section 3724). Because of the interrelated nature of geology, seismology, and engineering, most projects will benefit from review by both the geologist and civil engineer. The California Geological Survey has published guidelines to assist reviewers in evaluating site-investigation reports (CDMG, 1997; CGS, 2008).

- The HazUS analyses suggest that the potable water, wastewater and electric systems in Coachella will be extensively damaged by an earthquake on the San Andreas fault, with thousands of leaks and breaks anticipated in the potable water system. Hardest hit areas may be without water at the tap for up to six months. The City and its lifeline service providers should consider retrofitting the older pipelines in these systems, to reduce the number of potential breaks as a result of corrosion and age, in addition to developing plans to truck in water that is delivered directly to the City residents. Residents of the Coachella area should be encouraged to store at least a 7-day supply of water for all family members, including pets, so that they can be self-sufficient immediately following the earthquake, until the City can arrange for water to be trucked in.

CHAPTER 2: GEOLOGIC HAZARDS

Geologic hazards are generally defined as surficial earth processes that have the potential to cause loss or harm to the community or the environment. The basic elements involved in the assessment of geologic hazards are: 1) underlying geology (including soil types, rock types, groundwater, and zones of weakness like faults, fractures, and bedding); 2) topography; 3) climate; and 4) land use. The geology and types of geologic hazards affecting the City of Coachella General Plan area are discussed in the following sections.

2.1 Physiographic and Geologic Setting

Southern California is divided into distinct geomorphic provinces, that is, regions having their own unique physical characteristics formed by geologic, topographic, and climatic processes. The Coachella General Plan area is located at the boundary of two very distinct provinces. The valley portion of Coachella is part of the Colorado Desert Province, a low-lying basin (up to 240 feet below sea level) that stretches from the San Gorgonio Pass to the Mexican border. In contrast, the northeast corner of the General Plan area reaches up to the base of the Little San Bernardino Mountains, a moderately high range that is the southernmost extension of the Transverse Ranges Province. This province is a region whose characteristic features are a series of generally east-west trending ranges that include the San Gabriel and San Bernardino Mountains. These ranges are called "transverse" because they lie at an oblique angle to the prominent northwesterly structural grain of the southern California landscape, a trend that is aligned with the San Andreas fault. The Transverse Ranges are being intensely compressed by active tectonic forces, therefore they are some of the fastest rising (and fastest eroding) mountains in the world. The boundary of these two provinces is defined by the San Andreas fault, a wide zone of multiple fault strands that also forms the eastern boundary of the basin. Movement along the fault zone has led to the rise of a string of low hills, including those in the northeastern part of the General Plan area.

Elevations across the valley floor, within the General Plan area, range from sea level at the northern end, to about 160 feet below sea level at the southeastern corner, near the community of Thermal. The highest point in the General Plan area is within the northernmost extension of the Mecca Hills, at an elevation of about 1,400 feet above sea level.

The largest drainage in the region, the Whitewater River, crosses the west-central part of the city. The river intermittently drains the surrounding highlands, as well as the Coachella Valley. Streambeds in the surrounding mountains are dry most of the year, and have significant flow only during and immediately after storms, when they carry large amounts of runoff for short periods of time. The Coachella Branch of the All-American Canal (also known as the Coachella Canal) crosses, in a northwesterly direction, the east-central part of the General Plan area, transporting water from the Colorado River to Lake Cahuilla, a man-made storage reservoir located in the city of La Quinta.

Geologically speaking, the valley portion of Coachella is situated at the edge of a broad structural depression known as the Salton Trough. Over the last million years or so, the tectonically subsiding trough has filled with a thick sequence of sediments that now forms the nearly flat valley floor. Although the trough is physically continuous from the San Gorgonio Pass to the Gulf of California, early settlers in the area gave different names to the northern and southern portions: The portion north of the Salton Sea is known as the Coachella Valley or Indio region, and the portion south of the Salton Sea is known as the Imperial Valley.

The sedimentary sequence infilling the trough records the geologic history of the Coachella area. For instance, the Imperial Formation, a geologic unit exposed in Garnet Hill to the north, but occurring predominantly at depth in the valley, is of marine origin, indicating the trough was inundated by sea water in latest Miocene to late Pliocene time (about 6 to 2 million years ago). In the last two million years, these marine sediments were in turn buried by a thick sequence of terrestrial sediments shed from the adjacent highlands. At about the same time, the Colorado River was building its delta at the Gulf of California, effectively forming a dam by depositing sediment at the mouth of the river and turning the trough into a closed basin. The presence of interlayered lakebed sediments in the valley's stratigraphic sequence indicates the basin was periodically inundated with fresh water derived from the Colorado River as it migrated back and forth across its delta. Ancient Lake Cahuilla, the last, and possibly one of the largest of the ancient lakes to occupy the basin, completely evaporated about 400 years ago when the Colorado River again changed course and flowed directly into the Gulf of California. The size of ancient Lake Cahuilla is estimated at over 2,000 square miles, covering most of the basin, including the valley portion of Coachella's General Plan area. In fact, the lake's paleo-shoreline transects the General Plan area, near the base of the hills. The Salton Sea, which formed in 1905 when water from the Colorado River was unintentionally diverted to the basin by man, is considerably smaller by comparison.

The physical features described above reflect geologic and climatic processes that have affected this region in the last few million years. The physiographic and geologic histories of the Coachella area are important in that they control to a great extent the geologic hazards, as well as the natural resources, within the city. For example, wind-blown sand erosion poses a significant hazard in the Coachella Valley due to funneling of fierce winds through the steep mountain passes. Regional tectonic subsidence of the valley floor, concurrent with uplift of the adjacent mountains, is responsible to a great extent for the rapid deposition of poorly consolidated alluvium that is susceptible to consolidation and/or collapse. On the other hand, the deep alluvium-filled basin, which is bounded by relatively impermeable rock and faults, provides a natural underground reservoir (aquifer) for groundwater, the area's primary source of drinking water.

The Coachella General Plan area is located within a region that is changing rapidly. In fact, this region, which includes San Bernardino and Riverside counties, has the fastest-growing population in all of California. Most of Coachella's valley area is currently developed for growing crops; business districts and densely populated neighborhoods are located almost entirely west of the Whitewater River. The hills in the northeastern part of the area are currently undeveloped. Proposed development is expanding eastward however, and will eventually reach into both the agricultural and hillside areas.

2.2 Earth Units and Their Engineering Properties

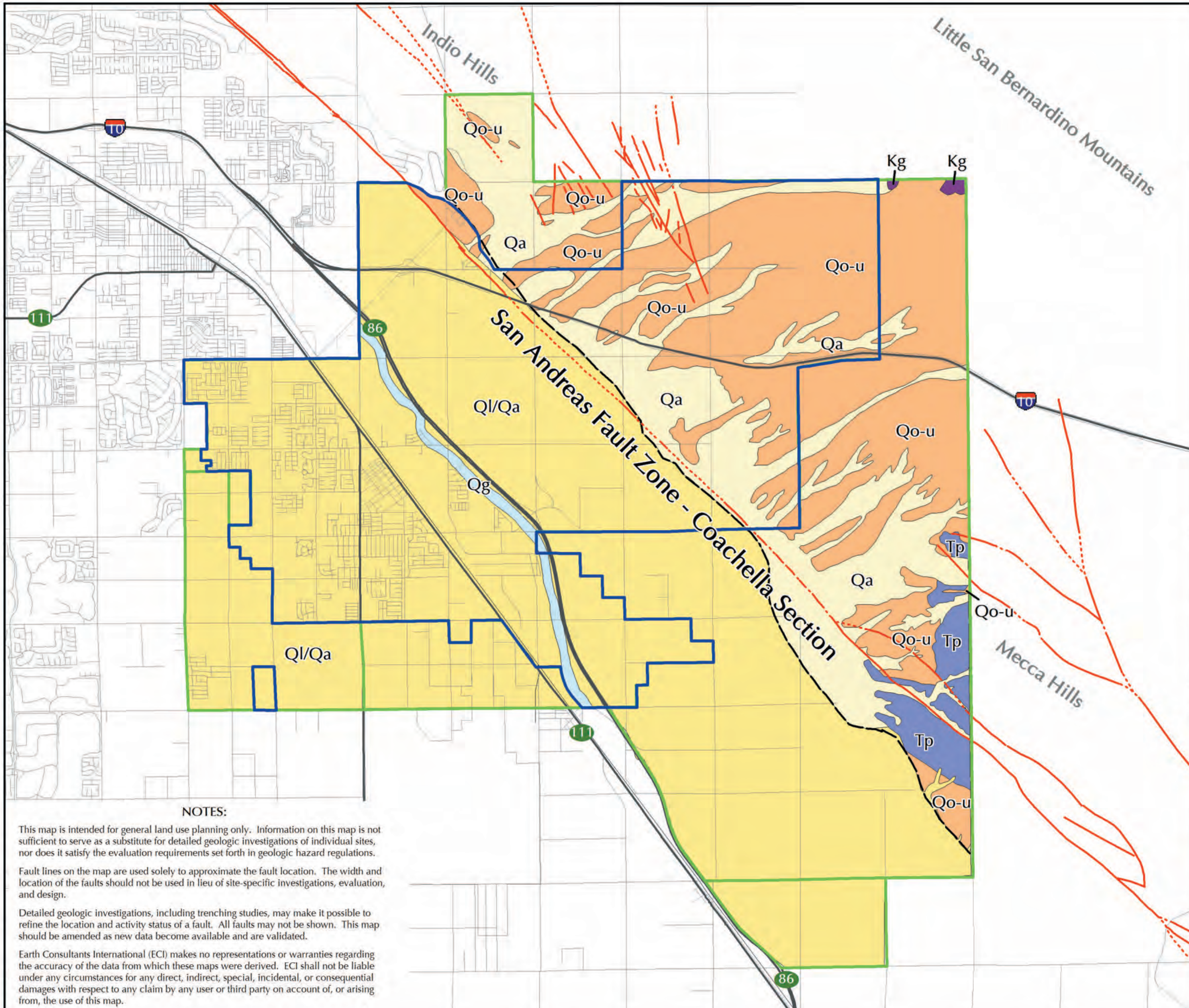
The general distribution of geologic units that are exposed at the surface is shown on the Geologic Map (Plate 2-1a, b). This map is a modified version of that published by Dibblee (2008) and Rogers (1965). The general physical and engineering characteristics of each unit are discussed in the following sections, and summarized on Table 2-1.

2.2.1 River Channel Deposits (map symbol: Qg)

This unit comprises unconsolidated alluvium recently deposited by the Whitewater River. Consisting of crudely bedded sand, silt, gravel, boulders, and debris deposited by floodwaters, these sediments are highly susceptible to erosion, reworking, and burial by future flooding. Construction is generally not allowed in regulated flood control channels, nevertheless roadways, bridges, or pipelines may need to cross these areas out of necessity.

Geologic Map

Coachella, California



Symbols

- Fault; solid where location known, dashed where approximate, dotted where concealed. (For more information refer to Plates 1-1 and 1-2)
- Approximate location of eastern shoreline of ancient Lake Cahuilla
- Geologic Contact
- Coachella City Boundary
- Coachella Planning Area Boundary

For Geologic Unit Descriptions See Plate 2-1b

N W E S

Scale: 1:72,000

6000 0 6000 Feet

2000 0 2000 Meters

Base Map: From City of Coachella.
Sources: Modified from Dibblee (2008) and Rogers (1965, reprinted 1992); faults from Quaternary fault and fold database for the United States, accessed April 2010, from USGS web site: http//earthquakes.usgs.gov/regional/qfaults; location of main San Andreas fault from Petra (2006-2007).

Earth Consultants International

Project Number: 3106/3218
Date: 2014

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.

Detailed geologic investigations, including trenching studies, may make it possible to refine the location and activity status of a fault. All faults may not be shown. This map should be amended as new data become available and are validated.

Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.

Plate 2-1a

Geologic Unit Descriptions

Surficial Sediments

Qg	River Channel Deposits: Sand, gravel, and boulders within the modern Whitewater River channel (Holocene)
Ql/Qa	Lake and Distal Fan Deposits: Fine-grained sand, silt, and clay of the valley floor (Holocene)
Qa	Alluvial Fan and Stream Deposits: Sand, silt, and gravel filling active drainages within the Indio and Mecca Hills, and forming gently sloping fans at the valley margin (Holocene)

Upper Ocotillo Conglomerate

Qo-u	Upper Ocotillo Conglomerate: Sand, gravel, and boulders, gray, widely exposed in the Indio and Mecca Hills (late Pleistocene to early Holocene)

Palm Spring Formation

Tp	Palm Spring Formation: Arkosic sandstone, light pinkish-gray, with interbedded siltstone and red clays, exposed in southeastern part of the Planning Area, in the Mecca Hills (Pliocene)

Crystalline Rocks

Kg	Plutonic rocks of variable composition, including quartz monzonite and quartz diorite, exposed in the Little San Bernardino Mountains (Cretaceous)

River sediments are highly compressible, so bridge supports and roadway embankments need to extend through the unconsolidated sediments, onto firm ground. Foundation elements, roadways, and culverts placed in the river will be susceptible to scour from floodwaters or to damage from boulders carried by fast-moving waters.

2.2.2 Lake and Distal Fan Deposits (map symbol: Ql/Qa)

Unconsolidated sediments forming the upper part of the valley fill consist predominantly of variable mixtures of fine-grained sand, silt, and clay. Lenses of medium- to coarse-grained sand and gravels occur locally. These sediments were derived intermittently from prehistoric lakes that once occupied the valley floor, from fine-grained sediments that washed down from the mountains, and from periodic flooding of the Whitewater River before it was confined to its man-made channel. Wind-blown sand also occurs intermittently. The uppermost layers of the valley fill are Holocene in age (deposited in the last 11,000 years).

From an engineering perspective, these deposits are compressible in the upper few feet and will erode easily if subjected to concentrated water flow. Permeability is high except where interbedded silt or clay layers retard the downward percolation of water; in fact, shallow clay layers have created local perched water conditions in areas that are heavily irrigated. The potential for expansive soils is generally low, except where lake deposits of silt and clay are within or just below the depth of structural foundation elements. These deposits are suitable for fill materials, however clay-rich sediments should not be placed in foundation areas if possible.

Figure 2-1: Geologic Units in the Coachella Area. The sands in the foreground are alluvial deposits reworked by the wind; the hills in the middle are comprised of the Upper Ocotillo Conglomerate, whereas the mountains in the far distance consist of crystalline rocks.

2.2.3 Alluvial Fan and Stream Deposits (map symbol: Qa)

This unit consists of young (Holocene-aged) crudely bedded silt, sand, and gravel deposited in active drainages within the adjacent low hills, eventually spreading out as a series of small, coalescing fans at the valley margin. The fan surfaces are relatively smooth and support a network of shallow, ephemeral streams. Towards the valley, these deposits become increasingly finer grained, transitioning into the alluvial and lakebed sediments forming the valley floor.

How and where these deposits were laid down have a significant bearing on the engineering properties of these materials. Young near-surface alluvium often has organic debris, and is typically deposited rapidly by flash floods. As a result, the engineering issues affecting these geologically young deposits are: 1) compressibility, which occurs when additional loads are applied, and 2) collapse (hydroconsolidation) upon introduction of irrigation water if the deposit is dry. Being unconsolidated, the young alluvium is also highly susceptible to erosion. Alluvial deposits also have moderate to high permeability. Alluvial sediments are suitable for use as fill once the organic materials and oversized rocks are removed; however, they typically require the addition of water to achieve compaction. Stability of manufactured slopes is generally good, provided the slope is protected from erosion.

2.2.4 Upper Ocotillo Conglomerate (map symbol: Qo-u)

The Ocotillo Conglomerate is present both northeast and southwest of the San Andreas fault. In the valley, southwest of the fault, it is part of the thick sequence of sediments filling the Salton Trough. Beneath Coachella, Ocotillo sediments overlie older marine and non-marine deposits, and are buried beneath the younger fan and lake deposits described above. Because of its stratigraphic position, this formation is considered to be late Pleistocene to early Holocene in age (Popenoe, 1959). This unit is considerably thicker in the basin (Dibblee, 1954), where it is the primary water-bearing formation (aquifer) beneath Coachella, supplying domestic water to the area (California Department of Water Resources, 1964). Northeast of the San Andreas fault, this unit has been tectonically uplifted relative to the valley and is widely exposed in Coachella's hills, where it forms a relatively smooth surface that has been incised to various degrees by numerous streams conveying storm water from the Little San Bernardino Mountains to the valley.

The upper portion of the Ocotillo Conglomerate, namely that part of the formation exposed in the low hills in eastern Coachella, has been described as a weakly consolidated, light tan to grayish, crudely bedded, coarse sand, gravel, and boulder deposit (Proctor, 1968; Dibblee 1954 and 2008). The unit represents an older alluvial fan built with detritus shed from the nearby mountains. Bedding in the formation dips gently southwestward, generally about 3 to 10 degrees. Steep dips, reversed dips, and localized folding are present where active fault traces traverse the hills.

General engineering characteristics of the Ocotillo Conglomerate include erosion susceptibility, compressibility, and collapse upon the addition of landscape water if the unit is very dry. Boulders can also be a hindrance to earthwork or foundation construction. Positive aspects are good permeability, low expansion potential, and generally good stability in engineered slopes due to the lack of well-developed bedding or weak clay beds. These sediments are suitable for fill materials, provided boulders are removed or placed in deeper fills as directed by a geotechnical engineer. Boulders should not be placed near finished grades.

2.2.5 Palm Spring Formation (map symbol: Tp)

In the valley, alluvial and lacustrine (lake) deposits of the Palm Spring Formation are buried beneath the Ocotillo Conglomerate and are estimated to be over 5,000 feet thick (California Department of Water Resources, 1964). This unit is exposed however, in the Mecca Hills, where it has been elevated by the San Andreas fault. In contrast to the Ocotillo Conglomerate, hills underlain by the Palm Spring Formation have been eroded into a rugged badlands topography, displaying serrated ridges and deeply incised drainages. This unit is moderately lithified and is finer-grained than the Ocotillo Conglomerate, consisting primarily of light pinkish gray arkosic (quartz-rich) sandstone and pebbly sandstone, with a lesser amount of siltstone and red clay interbeds. Sandstone beds are commonly thick and internally massive. Based on fossil correlations, this formation is estimated to be Pliocene (2.6 to 5.3 million years old) in age (Dibblee, 1954; Popenoe, 1959). This unit has been severely deformed by faults of the San Andreas system, resulting in intense folding, shearing, and slippage along weak, clayey bedding planes (Sylvester and Damte, 1999). Erosion of the Palm Spring Formation in the Mecca Hills has made it a popular location for viewing exposures of the San Andreas fault.

Because the unit is moderately lithified, compressibility and collapsibility are generally not a concern. The unit is not water-bearing (California Department of Water Resources, 1964), therefore permeability is likely to be poor overall. Its expansion potential will be highly variable, ranging from low in sandy zones to moderately high in siltstone and clays. Slope stability is also variable, but due to the intense deformation, presence of clay-rich beds, shearing, faulting, and highly variable bedding orientations, the potential for localized slope failures in manufactured slopes is high, and would most likely require remedial grading. This unit is suitable for fill materials, although mixing sand and clay can be difficult from an earthwork-construction point of view.

2.2.6 Crystalline Rocks (map symbol: Kg)

The oldest geologic unit in the Coachella area consists of very hard, crystalline rock that forms the surrounding mountains and the bottom of the basin. Rock classifications are based primarily on genesis, texture, and mineral composition. Because crystalline rocks are usually highly variable in texture and mineralogy, often grading from one type to another, the units are typically named by the dominant rock type. Based on genesis alone, rocks underlying Coachella are plutonic, meaning that the rocks crystallized from the molten state deep within the Earth's crust. Plutonic rocks generally have large grains that can easily be seen without magnification, and often have a spotted appearance. The rock forming the mountains east of Coachella is light-colored and has a mineral assemblage that most closely aligns with quartz monzonite or quartz diorite (Dibblee, 2008). Most of this rock crystallized from a magma that was emplaced over 65 million years ago (Cretaceous age).

Outcrops of crystalline rock are rare in the General Plan area, occurring only in the northeast corner, at the base of the Little San Bernardino Mountains. Adjacent to the mountains it is most likely present in the shallow subsurface, buried by variable thicknesses of alluvium. In the valley, the crystalline rocks are deeply buried below the thousands-of-feet thick sequence of sediments.

Crystalline rock is very hard where not highly weathered, cannot be excavated easily, and in some cases must be blasted. It is typically non-water bearing and has low to moderately low permeability, except where joints and fractures provide avenues for water to move in and around the rock mass. Crystalline rocks provide strong foundation support and are generally non-expansive. Slope stability is generally good, however these rocks contain fractures and cooling joints that may locally serve as planes of weakness along which slope instability can occur. Very steep roadcuts are most vulnerable to this type of failure.

2.3 Geologic Hazards in the Coachella Area

2.3.1 Landslides and Slope Instability

Developments that encroach upon the edge of natural slopes may be impacted by slope failures. Even if a slope failure does not reach the adjacent property, the visual impact will generally cause alarm to homeowners. Although slope failures tend to affect a relatively small area (as compared to an earthquake or major flood), and are generally a problem for only a short period of time, the dollar losses can be high. Homeowner's insurance policies typically do not cover land slippage, and this can add to the anguish of the affected property owners.

A significant portion of the General Plan area encompasses the northern extension of the Mecca Hills, and the northeastern corner reaches up to the base of the Little San Bernardino Mountains. Hillside areas within and adjacent to Coachella are currently uninhabited, however future land uses identified for these areas include low density residential development. Consequently, slope stability remains a potential hazard.

2.3.1.1 *Types of Slope Failures*

Slope failures occur in a variety of forms, and there is usually a distinction made between **gross failures** (sometimes also referred to as "global" failures) and **surficial failures**. Gross failures include deep-seated or relatively thick slide masses, such as landslides, whereas surficial failures can range from minor soil slips to destructive mud or debris flows. Failures can occur on natural or man-made slopes. Most failures of man-made slopes occur on older slopes built at slope gradients steeper than those allowed by today's grading codes. Although infrequent, failures can also occur on newer, graded slopes, generally due to poor engineering or poor construction. Furthermore, slope failures often occur as elements of interrelated natural hazards in which one event triggers a secondary event, such as earthquake-induced landsliding, fire-flood sequences, and storm-induced mudflows.

Gross Failures

Landslides are movements of relatively large landmasses, either as nearly intact bedrock blocks, or as jumbled mixes of bedrock blocks, fragments, debris, and soils. Landslide materials are commonly porous and very weathered in the upper portions and along the margins of the slide. They may also have open fractures and joints. The head of the slide may have a graben (pull-apart area) that has been filled with soil, and bedrock blocks and fragments.

The potential for slope failure is dependent on many factors and their interrelationships. Some of the most important factors include slope height, slope steepness, shear strength and orientation of weak layers in the underlying geologic unit, as well as pore-water pressures. Joints and shears, which weaken the rock fabric, allow water to infiltrate the rock mass. This in turn results in increased and deeper weathering of the rock, increased pore pressures, increased plasticity of weak clays that may be present in the rock, and increased weight of the landmass. Geotechnical engineers combine these factors in calculations to determine if a slope meets a minimum standard of safety. The generally accepted standard is a factor of safety of 1.5 or greater (where 1.0 is equilibrium, and less than 1.0 is failure). Natural slopes, graded slopes, or graded/natural slope combinations must meet these minimum engineering standards where they have the potential to impact planned homes, subdivisions, or other types of developments.

Table 2-1: Engineering Characteristics of the Geologic Units that Crop Out in the Coachella General Plan Area
(Refer to Plate 2-1 for the areal distribution of these units in the study area)

Geologic Unit / Engineering Characteristics	River Channel Deposits (Qg)	Distal Fan and Lake Deposits (Ql/Qa)	Alluvial Fan and Stream Deposits (Qa)	Upper Ocotillo Conglomerate (Qo-u)	Palm Spring Formation (Tp)	Crystalline Rocks (Kg)
Compressibility	Highly compressible.	Compressible in the upper few feet. Collapse may be a concern locally.	High in stream channels; moderate to high on alluvial fans, especially near the ground surface. If dry may be subject to collapse upon the addition of irrigation water.	Compressible in the upper few feet.	Generally not compressible or collapsible.	Not compressible or collapsible.
Expansion Potential	Low.	Low to moderately high, depending on the amount of silts and clays at or just below foundation grades.	Low.	Low.	Highly variable; low to moderately high.	Low.
Slope Stability	Poor.	Good for manufactured slopes.	Good, except where natural slopes are oversteepened by stream erosion. Moderate to good in cut slopes on alluvial fans. Surficial instability could contribute to debris flows.	Good except where natural slopes are oversteepened by stream erosion. Good in cut slopes except where fault deformation is present. Surficial instability could contribute to debris flows.	Moderate to poor. Cut slopes will likely need remedial grading. Surficial instability may contribute to debris flows.	Good.
Erosion / Sedimentation Potential	Very high.	Moderate to high when subjected to concentrated water flow.	High.	High, especially if subjected to concentrated water flow.	Moderate. More erosion-resistant than the younger units, but still susceptible if subjected to concentrated water flow.	Very low.
Permeability	High.	High, except where silt and clay-rich layers retard the downward percolation of water.	Moderate to high.	High.	Low.	Low.
Ease of Excavation	Easy.	Easy.	Easy.	Easy.	Easy.	Difficult to very difficult where unweathered. May require blasting.
Suitability of Fill	Generally good after organics, debris, and oversize rocks are removed.	Good, however, rich-clay soils should not be placed near foundation elements.	Good, provided vegetation and oversized rocks are removed.	Good, provided that vegetation and oversized rocks are removed.	Good, however, mixing sands and clays may be difficult. Clay-rich fill should not be placed at or near foundation elements.	Good for weathered, decomposed rock. Poor for unweathered rock.

Slopes adjacent to areas where the risk of economic losses from landsliding is small, such as parks and roadways, are sometimes allowed a lesser factor of safety, at the discretion of the local reviewing agency.

The geologic units in the Coachella General Plan area are generally resistant to landsliding and no existing landslides have been mapped here. Nevertheless, grading cuts in the Palm Spring Formation could result in localized slope failures due to tectonic deformation and the presence of weak, clay beds. The Ocotillo Conglomerate, which is more widespread in the hillside areas, is generally more stable in a gross sense, but more susceptible to erosion. All hillside areas are susceptible in various degrees to surficial failures, some of which may result in debris flows.

Surficial Failures

Surficial failures are too small to map at the scale used in Plate 2-1, however they may be present locally in hillside areas, typically occurring in drainage swales, and in accumulated sediments near the base of steep slopes. Surficial failures, predominantly soil slips, occur throughout mountainous areas during winters of particularly heavy and/or prolonged rainfall. The types of surficial instability most likely to occur in the Coachella area are described below.

Soil slip failures are generated by strong winter storms, and are widespread in mountainous areas, particularly after winters with prolonged and/or heavy rainfall. Failures occur on canyon sideslopes, and in soils that have accumulated in swales, gullies and ravines. Slope steepness has a strong influence on the development of soil slips, with most slips occurring on slopes having gradients between about 27 and 56 degrees (Campbell, 1975).

Slopes within this range of gradients are present in the higher hills and mountains within and above the Coachella General Plan area (see Plate 2-2).

Debris flows are the most dangerous and destructive of all types of slope failure. A debris flow (also called mudflow, mudslide, and debris avalanche) is a rapidly moving slurry of water, mud, rock, vegetation and debris. Larger debris flows are capable of moving trees, large boulders, and even cars. This type of failure is especially dangerous as it can move at speeds as fast as 40 feet per second, is capable of crushing buildings, and can strike with very little warning. As with soil slips, the development of debris flows is strongly tied to exceptional storms with periods of prolonged rainfall. Failure typically occurs during an intense rainfall event, following saturation of the soil by previous rains.

A debris flow most commonly originates as a soil slip in the rounded, soil-filled “hollow” at the head of a drainage swale or ravine. The rigid soil mass is deformed into a viscous fluid that moves down the drainage, incorporating into the flow additional soil and vegetation scoured from the channel. Debris flows also occur on canyon walls, often in soil-filled swales that do not have topographic expression. The velocity of the flow depends on the viscosity, slope gradient, height of the slope, roughness and gradient of the channel, and the baffling effects of vegetation. Even relatively small amounts of debris can cause damage from inundation and/or as a result of crashing into a structure (Ellen and Fleming, 1987; Reneau and Dietrich, 1987). Recognition of this hazard led FEMA to modify its National Flood Insurance Program to include inundation by "mudslides."

Watersheds that have been recently burned typically yield greater amounts of soil and debris than those that have not burned. Erosion rates during the first year after a fire are estimated to be 15 to 35 times greater than normal and peak discharge rates range from two to 35 times higher. These rates drop abruptly in the second year, and return to normal after about five years (Tan, 1998). In addition, debris flows in burned areas can develop in response to small storms and do not require a long period of antecedent rainfall. These kinds of flows are common in small gullies and ravines during the first rains after a burn, and can become catastrophic when a severe burn is followed by an intense storm season (Wells, 1987). An example is the debris flows that impacted several communities at the base of the portion of the Los Angeles National Forest that burned during the Station Fire of August and September 2009. The debris flows, which occurred in February 2010, following several intense rainstorms, severely damaged more than 40 homes and many cars were swept by the mud- and debris-laden water.

Within the Coachella General Plan area, locations that are most susceptible to debris flows are those properties at the base of moderate to steep slopes, or at the mouths of small to large natural drainage channels.

2.3.1.2 *Mitigation of Slope Instability in Future Development*

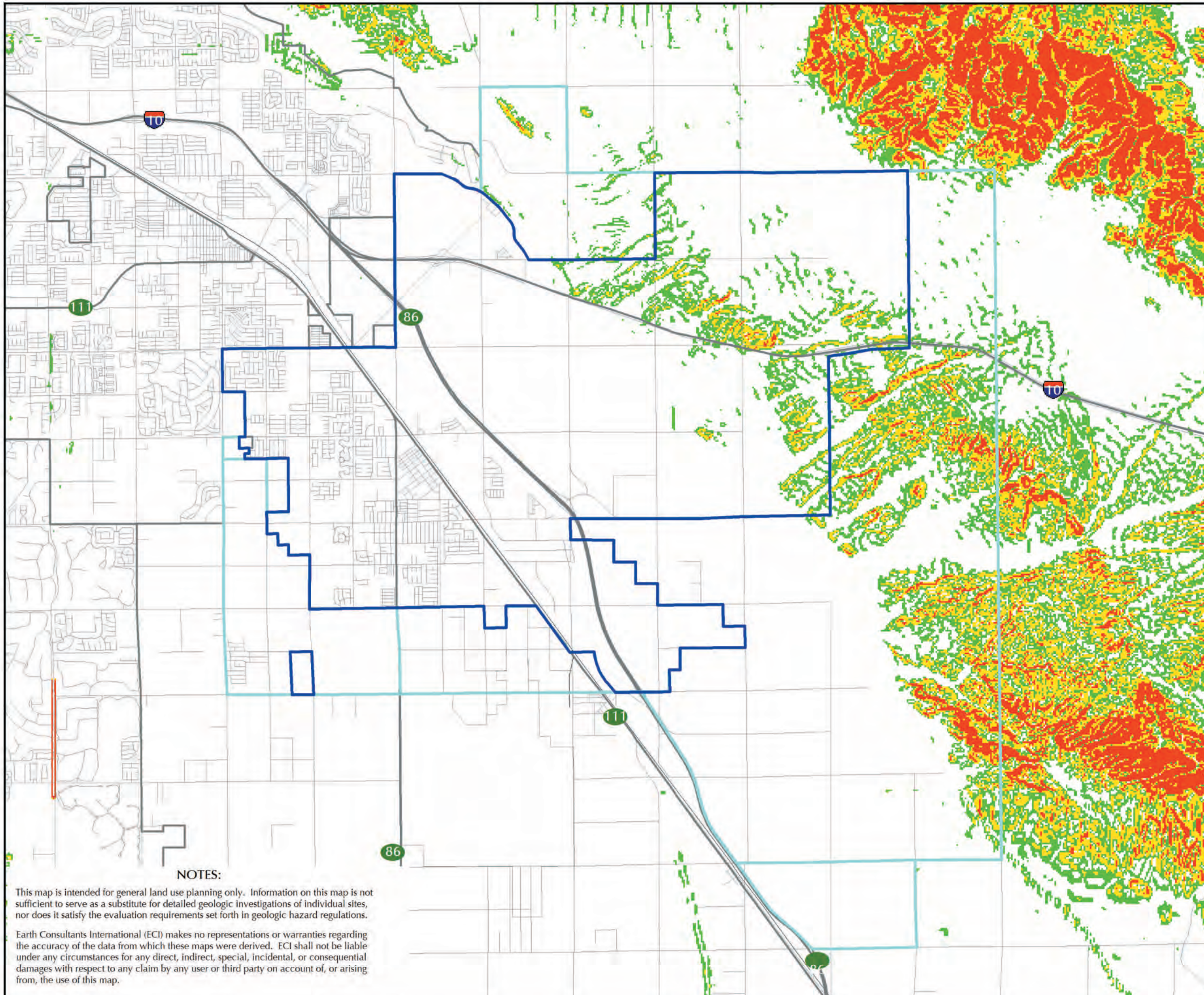
Careful land management in hillside areas can reduce the risk of economic and social losses from slope failures. This generally includes land use zoning to restrict development in unstable areas, grading codes for earthwork construction, geologic and soil engineering investigation and review, construction of drainage structures, and if warranted, placement of warning systems. Other important factors are risk assessments (including susceptibility maps), a concerned local government, and an educated public.

The City of Coachella has developed a comprehensive Hillside Conservation & Development Ordinance, which is currently in the draft stage. The ordinance would establish an overlay district with the intent to: 1) protect the health and safety of the public; 2) protect and preserve existing landforms, drainage patterns, natural ridgelines and rock outcrops, scenic vistas, native vegetation, and wildlife habitat; 3) discourage mass grading and terracing; 4) encourage design that blends with the natural terrain; and 5) mitigate seismic hazards, slope instability, erosion, and sedimentation by requiring geotechnical reports, and where necessary, engineered drainage and flood control facilities. The draft ordinance also considers other issues related to hillside development, such as open space, archeological resources, and fire protection.

Within the city of Coachella, the hillsides are zoned largely as low density residential, with smaller areas dedicated to open space (generally watercourses, either natural or manmade) and commercial development. The draft ordinance would generally restrict development, allowing only trails and access roads, on slopes steeper than a 20-percent gradient (a 20-percent slope is slightly steeper than 11 degrees). For alluvial fans flatter than 20 percent, permitted uses include golf courses, parks, and certain other recreational facilities; water wells, pump stations, and water tanks; substations, transmission lines, antennas, and trails. Alluvial fans may be developed for other uses if flood protection is provided. Single-family residential and commercial developments, along with associated facilities, are permitted on hillside slopes flatter than 20 percent. All hillside development is subject to various regulations and guidelines, as well as planning and engineering reviews by the City.

Slope Distribution Map

Coachella, California



NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.

Explanation

Slope (in Percent Grade)

- 0 to 10
- 10 to 20
- 20 to 36
- 37 and greater

- Coachella City Boundary
- Coachella Planning Area Boundary

N E S W

Scale: 1:72,000

6000 0 6000
Feet

2000 0 2000
Meters

Base Map: From the City of Coachella.
Source: Derived from USGS 30m Digital Elevation Model.

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Plate 2-2

For the unincorporated portions of the General Plan area, Riverside County Ordinances provide similar standards and guidelines for growth and development, in addition to providing a basis for county-wide planning and construction of public facilities such as drainage control. The ordinances address zoning, permitting, grading, and investigation requirements for areas subject to potential geologic problems, including slope instability.

Soils and geology reports for hillside areas, which are required by both the City and the County, should include a geotechnical evaluation of any slope that may impact the future use of the property, as well as any impact to adjacent properties. This includes existing slopes that are to remain natural, and any proposed graded slopes. This type of investigation typically includes borings and/or test pits to collect geologic data and soil samples, laboratory testing of soil samples to determine soil strength parameters, and engineering calculations. Numerous soil-engineering methods are available for stabilizing slopes that pose a threat to development. These methods include designed buttresses (replacing the weak portion of the slope with engineered fill); reducing the height of the slope; designing the slope at a flatter gradient; and adding reinforcements to fill slopes such as soil cement or layers of geogrid (a tough polymeric net-like material that is placed between the horizontal layers of fill). Most slope stabilization methods include a subdrain system to prevent excessive ground water (typically landscape water) from building up within the slope area. If it is not feasible to mitigate the slope stability hazard, building setbacks are typically imposed.

For debris flows, assessment of this hazard for individual sites should focus on structures located or planned in vulnerable positions. This generally includes canyon areas; at the toes of steep, natural slopes; and at the mouth of small to large drainage channels. Mitigation of soil slips and debris flows is usually directed at containment (debris basins), or diversion (impact walls, deflection walls, diversion channels, and debris fences). A system of baffles may be added upstream to slow the velocity of a potential debris flow. Other methods may include avoidance by restricting habitable structures to areas outside of the potential debris flow path.

Temporary slope stability is also a concern, especially where earthwork construction is taking place next to existing improvements. Temporary slopes are those made for slope stabilization backcuts, fill keys, alluvial removals, retaining walls, and underground utility lines. The risk of slope failure is higher in temporary slopes because they are generally cut at a much steeper gradient. In general, temporary slopes should not be cut steeper than 1:1 (horizontal:vertical, equal to 45 degrees), and depending on actual field conditions, flatter gradients or shoring may be necessary. The potential for slope failure can also be reduced by cutting and filling large excavations in segments, and by not leaving temporary excavations open for long periods of time. The stability of large temporary slopes should be geotechnically analyzed prior to construction, and mitigation measures provided as needed.

The City can further reduce slope instability losses in developed hillsides by:

- Encouraging homeowners to install landscaping consisting primarily of drought-resistant, preferably native vegetation that helps stabilize the hillsides;
- Providing public education on slope stability, including the importance of rodent control, maintaining drainage devices, and avoiding heavy irrigation.

2.3.2 Compressible Soils

Compressible soils are typically geologically young, unconsolidated sediments of low density that may compress under the weight of proposed fill embankments and structures. The settlement potential and the rate of settlement in these sediments can vary greatly, depending on the soil characteristics (texture and grain size), natural moisture and density, thickness of the compressible layer(s), the weight of the proposed load, the rate at which the load is applied, and drainage.

In the Coachella General Plan area, compressible soils are most likely to occur in the valley and within drainage channels in the hills, where unconsolidated sediments are present (see Plate 2-1). This generally includes the modern floodplain and prehistoric lake deposits and the surface of young alluvial fan sediments. Compressible soils are also present in hillside areas, within canyon bottoms, swales, and at the base of natural slopes. Although the older sedimentary deposits forming the hills are relatively dense, the upper few feet, which are commonly weathered and/or disturbed, are typically compressible.

2.3.2.1 *Mitigation of Compressible Soils*

When development is planned within areas that contain potentially compressible soils, a geotechnical analysis is required to confirm whether or not this hazard is present. The analysis should consider the characteristics of the soil column in that specific area, and also the load of any proposed fills and structures that are planned, the type of structure (i.e. a road, pipeline, or building), and the local groundwater conditions. At a minimum, the removal and recompaction of the near-surface soils is required. Deeper removals may be needed for heavier loads, or for structures that are sensitive to minor settlement. Based on location-specific data and analyses, partial removal and recompaction of the compressible soils is sometimes performed, followed by settlement monitoring for a number of months after additional fill has been placed, but before buildings or infrastructure are constructed. Similar methods are used for deep fills. In cases where it is not feasible to remove the compressible soils, buildings can be supported on especially engineered foundations that may include deep caissons or piles.

2.3.3 Collapsible Soils

Hydroconsolidation or soil collapse typically occurs in recently deposited sediments that accumulated in an arid or semi-arid environment. Sediments prone to collapse are commonly associated with alluvial fan and debris flow sediments deposited during flash floods. These deposits are typically dry and contain minute pores and voids. The soil particles may be partially supported by clay, silt or carbonate bonds. When saturated, collapsible soils undergo a rearrangement of their grains and a loss of cementation, resulting in substantial and rapid settlement under relatively light loads. An increase in surface water infiltration, such as from irrigation, or a rise in the groundwater table, combined with the weight of a building or structure, can initiate rapid settlement and cause foundations and walls to crack. Typically, differential settlement of structures occurs when landscaping is heavily irrigated in close proximity to the structures' foundations.

Granular alluvial sediments in the Coachella General Plan area that are very dry may be susceptible to this hazard due to their rapid deposition in the desert environment. Collapsible soils do not appear to be widespread in the planning area, but most likely do occur in localized areas. Consequently, geotechnical studies for future projects in areas underlain at shallow depth by susceptible geologic units should include testing for this potential hazard.

2.3.3.1 *Mitigation of Collapsible Soils*

The potential for soils to collapse should be evaluated on a routine, site-specific basis as part of the geotechnical studies for development. If the soils are determined to be collapsible, the hazard can be mitigated by several different measures or combination of measures, including excavation and recompaction, or in-place pre-saturation and pre-loading of the susceptible soils to induce collapse prior to construction. After construction, infiltration of water into the subsurface soils should be minimized by proper surface drainage design, which directs excess runoff to catch basins and storm drains.

2.3.4 Expansive Soils

Fine-grained soils, such as silts and clays, may contain variable amounts of expansive clay minerals. These minerals can undergo significant volumetric changes as a result of changes in moisture content. The upward pressures induced by the swelling of expansive soils can have significant harmful effects upon structures and other surface improvements.

The valley portion of the Coachella General Plan area is underlain by sediments that are composed of fine-grained sand interlayered with very fine-grained lakebed deposits (silts and clays). Consequently, after site grading, the expansion characteristics of the soils at finish grade can be highly variable. In the hillsides, expansion potential within the Palm Spring Formation could range from very low (sandstone layers) to moderate or high (siltstone and clay layers). If pedogenic soil profiles have developed on older alluvial fan deposits (Ocotillo Conglomerate) as a result of weathering, these may be clay-rich and would probably fall in the moderately expansive range.

The rock that forms the hills and mountains generally has low expansion characteristics, however sheared zones within the rock may contain clays with expansive minerals.

In some cases, engineered fills may be expansive and cause damage to improvements if such soils are incorporated into the fill near the finished surface.

2.3.4.1 *Mitigation of Expansive Soils*

The best defense against this hazard in new developments is to avoid placing expansive soils near the surface. If this is unavoidable, building areas with expansive soils are typically "presaturated" to a moisture content and depth specified by the soil engineer, thereby "pre-swelling" the soil prior to constructing the structural foundation or hardscape. This method is often used in conjunction with stronger foundations that can resist small ground movements without cracking. Good surface drainage control is essential for all types of improvements, both new and old. Property owners should be educated about the importance of maintaining relatively constant moisture levels in their landscaping. Excessive watering, or alternating wetting and drying, can result in distress to improvements and structures.

2.3.5 Corrosive Soils

Corrosive soils can, over time, cause extensive damage to buried metallic objects, commonly impacting such things as buried pipelines (such as water mains), and even affecting steel elements within foundations. The electrochemical and bacteriological processes that take place between the soil and the buried structure are complex and depend on a number of factors involving the structure type and certain soil characteristics. For instance, the type, grade, length, and size of the piping, as well as the materials used in the pipe connections, may control the electrochemical reactions that will take place between the pipes and the surrounding soil, and different soils may react differently. For soils, the most common factor used in identifying the potential for corrosion is electrical resistivity. Soils with low resistivity are especially susceptible to corrosion reactions. Other soil characteristics that increase the risk of corrosion to metals are low pH (acidic soils), wet soils, high chloride levels, low oxygen levels, and the presence of certain bacteria.

Soils with high concentrations of soluble sulfates are not directly corrosive to metals, however the presence of sulfate-reducing bacteria in the soil may cause sulfates to convert to sulfides, which are compounds that do increase the risk for corrosion. If the concentration of soluble sulfates is high enough, the soil will be corrosive to concrete.

Several consulting reports for projects in the valley area have indicated, based on laboratory testing, that the near-surface soils are moderately corrosive to metals, but not to concrete. Nevertheless, soils with high sulfate concentration are known to exist in the area. Consequently laboratory testing should be done where structures that will be in contact with the soil are planned. The City's Standard Specifications and Procedures require corrosion testing for all ductile iron and steel pipelines.

2.3.5.1 *Mitigation of Corrosive Soils*

Corrosion testing is an important part of geotechnical investigations. Onsite soils, as well as any imported soils, are typically tested in the laboratory for resistivity, pH, chloride, and sulfates. For treatment of high sulfate content, special cement mixes and specified water contents are typically used for concrete that will be in contact with the soil. For corrosion of metals, there are a number of procedures that can be used to protect the structure, including cathodic protection, coatings such as paint or tar, or wrapping with protective materials. As mentioned above, the corrosion processes are complex; consequently, the site-specific recommendations must be provided by an engineer who is a corrosion specialist.

2.3.6 Ground Subsidence

Ground subsidence is the gradual settling or sinking of the ground surface with little or no horizontal movement. Most ground subsidence is man-induced. In the areas of California where ground subsidence has been reported (such as the San Joaquin Valley, Coachella Valley, and the Long Beach-Wilmington area), this phenomenon is most commonly associated with the extraction of fluids (water and/or petroleum) from sediments below the surface. Less commonly, ground subsidence can also occur as a response to natural forces such as earthquake movements. Earthquakes have caused abrupt regional elevation changes in excess of one foot across faults. For instance, the Imperial Valley earthquake of 1979 resulted in ground subsidence of approximately 15 inches on the east side of the Imperial fault (Sharp and Lienkaemper, 1982).

Ground-surface effects related to regional subsidence can include earth fissures, sinkholes or depressions, and disruption of surface drainage. Damage is generally restricted to structures sensitive to slight changes in elevations, such as canals, levees, underground pipelines, and drainage courses; however, significant subsidence can result in damage to wells, buildings, roads, railroads, and other improvements. Subsidence due to the overdraft of groundwater supplies can also result in the permanent loss of aquifer storage capacity. Subsidence has largely been brought under control in affected areas by careful management of local water supplies, including reducing pumping of local wells, importing water, and providing artificial recharge (Johnson, 1998; Stewart et al., 1998).

The Coachella Valley is filled with as much as 14,000 feet of sediments, with the upper 2,000 feet defined as water-bearing deposits. As discussed before, this area is tectonically active, and regional subsidence over the last several millions of years is responsible for the great thickness of alluvial deposits forming the valley floor. Nevertheless, the rate of subsidence in some areas appears to have accelerated recently, at rates too great to be accounted for solely by tectonics. Increased groundwater pumping coincident with these rapid rates of subsidence suggests that groundwater extraction is causing the subsidence that has been reported locally in the Coachella Valley. Recognizing that significant subsidence in the area could pose a major environmental constraint, several agencies (including the U.S. Geological Survey and the Coachella Valley Water District) are currently devoting resources to the study and mitigation of this potential hazard.

Regional subsidence related to groundwater withdrawal was first suspected in the Coachella Valley when ground fissuring developed suddenly in the city of La Quinta in 1948. The fissures occurred after nearly 30 years of intense groundwater pumping for agricultural, municipal and domestic purposes. Water levels declined as much as 50 feet between the early 1920s and the late 1940s, before imported water from the Colorado River became the area's main water source. Once surface water from the Coachella Canal was introduced in 1949, pumping of ground water decreased, and between 1950 and the 1970s, groundwater levels actually recovered throughout most of the valley. Some of the basin recharge was also attributed to leakage from unlined water canals. Since the late 1970s, however, the demand for water has exceeded the deliveries of imported surface water, and groundwater levels have again declined as a result of increased pumping. By 1996, water levels in some wells had dropped 50 to 100 feet, to all-time historical lows.

Recognizing that these observed declines in water level had the potential to induce new or renewed land subsidence in the area, the U.S. Geological Survey established in 1996 a precise geodetic network to monitor land subsidence in the lower Coachella Valley. This network of monuments extended from the Salton Sea on the south to just northwest of Indio (Ikehara et al., 1997). The study compared elevation measurements made in 1996 using Geographic Positioning System (GPS) technology with elevation survey data collected by several agencies over several years, dating back to 1936. Because the methods and geographic scales used varied from agency to agency, there are substantial error bars on the results, but the data indicate that between 1936 and 1996, the lower Coachella Valley subsided by as much as 0.5±0.3 feet (Ikehara et al., 1997; Sneed et al., 2001).

Where data were available, historical subsidence was plotted over time and compared to water level changes in nearby wells. In general, subsidence occurred during periods of water level decline, and rebound occurred during intervening periods of water level recovery. Since the timing of the subsidence measurements corresponds with water level declines, land subsidence appears to be occurring in response to groundwater pumping. Water levels began declining below their previously recorded low levels in the early 1990s. Researchers believe that most of the subsidence measured in 1996 had probably just occurred in the last few years prior to the survey. Rapid rates of subsidence over a relatively short period of time are suggested by a study conducted in 1998, when 14 of the 17 original monuments were re-surveyed. The measurements indicate that between 1996 and 1998, vertical changes (subsidence) in the land surface elevation of between 0.04 and 0.22 feet (±0.13 feet) occurred locally.

Since a large portion of the Coachella Valley was not covered in the first study, new technology referred to as Interferometric Synthetic Aperture Radar (InSAR) was used to extend the study area northwesterly, to the Palm Springs/Palm Desert area. InSAR uses differences in reflected radar signals acquired at different times to measure ground-surface deformations. [This method has been used successfully in the last few years to study changes in the land and built environment resulting from earthquakes, volcanic activity, and even warfare]. The InSAR-generated maps reviewed by Sneed et al. (2001) show three areas that appear to have subsided between May 7, 1996 and September 30, 1998: in the Rancho Mirage/Palm Desert area, in the Indian Wells area, and southeast of the modern Lake Cahuilla. The Rancho Mirage/Palm Desert area that appears to have subsided extends from about Country Club Drive on the north, to Fred Waring Drive on the south, and between Highway 111 and the San Jacinto Mountains on the west, to Portola Avenue on the east. Subsidence of as much as 0.23 feet was measured in the southwestern portion of this area. The subsidence area in Rancho Mirage/Palm Desert coincides with an area of substantial groundwater development, where more than 70 production wells produced about 170,000 acre-feet of water during the 1996-98 period (Sneed et al., 2001).

The results of a third study were released in 2002, covering the period between 1998 and 2000. During this time, four additional GPS stations were placed in the valley (including one in the Rancho Mirage/Palm Desert area). Four InSAR images (two pairs) were combined to evaluate ground elevation changes between two time periods as follows: 1) June 1998 to June 1999, and 2) November 1999 to October 2000. The InSAR data indicate that subsidence was still occurring in the three areas previously identified, plus in a new area near La Quinta. The Rancho Mirage/Palm Desert subsidence area (with a 0.2-foot drop in the surface elevation during this time period) coincides with or is near areas where groundwater levels have again declined, in some cases to new lows from their recorded histories (Sneed et al., 2002). The U.S. Geological Survey team recommended that monitoring for subsidence be continued in the area. However, given that the rates of subsidence appear to be small compared to the GPS measurement error, the team indicated that GPS surveys need not be conducted on an annual basis.

The most current study released by the U.S. Geological Survey reports that subsidence rates have increased two to four times since the year 2000 in Palm Desert, Indian Wells, and La Quinta. Water levels in wells within or near the subsiding areas fluctuated seasonally but declined overall between 1996 and 2005. In fact, some of the 2005 water levels measurements were the lowest in the wells' recorded histories. The report concluded that due to the localized character of the subsidence, as well as the coincident areas of declining water levels and subsidence, some aquifer compaction may be taking place. Although the relationship between subsidence and groundwater pumping is complex and more data are needed, the researchers suggest that pumping is the most likely cause (Sneed and Brandt, 2007). The report also suggests improvements for future monitoring that could be used to develop groundwater models that would assist the Coachella Valley Water District in balancing groundwater withdrawal with land subsidence.

Permanent (irreversible) subsidence can occur if ground water is removed from clay and silt layers in the underlying aquifers. This phenomenon has heavily impacted the Antelope Valley, where surface fissures or cracks in the land surface have been reported. The cracks, which have measured as much as 1,300 feet long, 6 feet wide, and 13 feet deep, have caused substantial damage to runways, roads, wells, pipelines, and other structures. With the exception of the cracks observed in the La Quinta area in 1948, no cracks or fissures have been reported in the Coachella Valley. There is however, the potential for fissuring to develop if subsidence as a result of groundwater pumping continues or increases in the area. It is not clear why ground fissures developed in the La Quinta area, but the area where they developed, near the intersection of Avenue 52 and Adams Street, is near the margin of the Coachella Valley, at the base of the Santa Rosa Mountains. While subsidence typically occurs throughout an overdrafted valley, differential displacement and fissures are generally manifested at or near the valley margin. Therefore, if subsidence continues in the lower Coachella Valley, damage to structures as a result of regional subsidence would be expected to be greatest along the edges of the valley, next to the mountains.

There are at least four geodetic monuments (flat metal disks that are anchored to the ground or to a structure) in the Coachella General Plan area that are part of the GPS station network used in the U.S. Geological Survey studies. These four monuments have recorded subsidence ranging from about 0.3 feet to 1 foot between 1996 and 2005. InSAR data for the Indio-Coachella area indicated the land surface elevation changes were rising or stable. However, because InSAR measurements are relative, Sneed and Brandt (2007) suggest this could indicate the Indio-Coachella area is not rising, but is subsiding at a slower rate than nearby areas, such as La Quinta.

2.3.6.1 *Mitigation of Ground Subsidence*

Prevention of subsidence requires a regional approach to groundwater conservation and recharge. Conservation efforts will be more than offset by the rapid growth of the region and the heavy water requirements of golf courses (±8 acre-feet per acre per year) unless water consumption is diligently managed. Some measures that are typically implemented to manage subsidence include:

- Increased use of reclaimed water, storm water, or imported water;
- Implementation of artificial recharge programs (this is already being done, with percolation ponds near Palm Springs, recharge ponds near Desert Hot Springs, and the Levy Groundwater Replenishment Facility in La Quinta);
- Determination of the safe yields of the local groundwater basins, so that available supplies can be balanced with extraction;
- Continued cooperative efforts with the U.S. Geological Survey to monitor groundwater levels and subsidence;
- Protection of groundwater quality;
- Reduction of long-term water demand with specific programs of water conservation;
- Acquisition of additional imported water supplies; and
- Increased public education to encourage (or if necessary, enforce) water conservation.

The Coachella Valley Water District (CVWD) has already implemented most of the actions mentioned above and continues to expand those activities related to water supply, including the goals of developing a shared water resources database with other water agencies, cities, and tribes; developing or updating groundwater and water quality models; and monitoring water demands and the effectiveness of conservation programs (MWH, 2010 and 2011). Current CVWD programs also include the artificial recharge with water from the Colorado River Aqueduct, utilization of canal and recycled water for the irrigation of agricultural fields and golf courses, the requirement that water-efficient plumbing be used in new construction, and the use of more efficient irrigation practices, especially for high quantity users such as farmers, golf courses, and large developments. The goal is to reduce water consumption in the valley even with the expected population increase. In 2003, the Coachella Valley Water District adopted a landscape model ordinance that calls for the use of water-efficient vegetation in new and remodeled landscaping.

The City of Coachella provides potable water to the City, all of which is provided by City-owned wells, reservoirs, and distribution system. Unincorporated areas are serviced by the Coachella Valley Water District (CVWD). The underlying aquifer, known as the lower Whitewater River Sub-basin, is shared with the CVWD, the City of Indio, local tribes, and numerous private well owners. In order to meet future demands without increasing depletion of the aquifer, the City is researching additional water sources, including a water treatment plant for Coachella Canal water, exchange programs with other agencies in the valley, and the feasibility of developing the infrastructure for recycled water use. The City has also adopted conservation programs and incentives including a requirement for the use of drought-resistant landscaping and highly efficient irrigation systems, offering water audits, encouraging plumbing retrofits, and providing public education (TKE Engineering & Planning, 2011). In addition, the City has prohibitions against wasting water, and can apply specific limitations on water usage during a water shortage emergency (Coachella Municipal Code, Chapter 13.04).

2.3.7 Erosion

Erosion, runoff, and sedimentation are influenced by several factors, including climate, topography, soil and rock types, and vegetation. The topographic relief between the valley and the adjacent mountains makes erosion and sedimentation an important issue for Coachella. The fractured condition of the bedrock forming the mountains, combined with rapid geologic uplift and infrequent but powerful storms, leads to high erosion rates. Further, erosion can increase significantly when mountain slopes are denuded by wildfires. Winter storms that follow a season of mountain wildfires can transport great volumes of sediment onto the low-lying areas below.

Natural erosion processes, even on more consolidated sediments, are often accelerated through man's activities – whether they be agricultural or land development. Grading increases the potential for erosion and sedimentation by removing protective vegetation, altering natural drainage patterns, compacting the soil, and constructing cut and fill slopes that may be more susceptible to erosion than natural slopes. Developments also reduce the surface area available for infiltration, leading to increased flooding and sedimentation downstream of the project.

In the Coachella General Plan area, the unconsolidated sediments in the canyon bottoms and valley floor, as well as the granular semi-consolidated sediments forming the hills, are generally the most susceptible to erosion.

2.3.7.1 *Mitigation of Erosion*

Erosion will have an impact on those portions of Coachella located above and below natural and man-made slopes. Hilltop homes or structures above natural slopes should not be permitted at the head of steep drainage channels or gullies without protective measures against headward erosion of the gully. Structures placed near the base of slopes or near the mouths of small canyons, swales, washes, and gullies will need protection from sedimentation. Developments in the valley that are adjacent to natural drainage channels should be adequately set back from eroding channel banks. Alternatively, modification of the channel to reduce erosion should be included in the project design. Although development is generally not present and not permitted within canyons and major drainage channels, roadways and utility lines, out of necessity, must sometimes cross these areas and will need protection from erosion and sedimentation.

Mitigation of erosion and sedimentation typically includes structures to slow down stream velocity, such as check dams and drop structures, devices to collect and channel the flow, catchment basins, and elevating structures above the toes of the slopes. Diversion dikes, interceptor ditches, swales, and slope down-drains are commonly lined with asphalt or concrete, however ditches can also be lined with gravel, rock, decorative stone, or grass.

There are many options for protecting manufactured slopes from erosion, such as terracing slopes to minimize the velocity attained by runoff, the addition of berms and v-ditches, and installing adequate storm drain systems. Other measures include establishing protective vegetation, and placing mulches, rock facings (either cemented on non-cemented), gabions (rock-filled galvanized wire cages), or building blocks with open spaces for plantings on the slope face. All slopes within developed areas should be protected from concentrated water flow over the tops of the slopes by the use of berms or walls. All ridge-top building pads should be engineered to direct drainage away from slopes.

Temporary erosion control measures must be provided during the construction phase of a development, as required by local building codes and ordinances, as well as State and Federal stormwater pollution regulations. In addition, permanent erosion control and clean water runoff measures are required for new developments. These measures might include desilting basins, percolation areas to cleanse runoff from the development, proper care of drainage control devices, appropriate irrigation practices, and rodent control. Erosion control devices should be field-checked following periods of heavy rainfall to assure they are performing as designed and have not become blocked by debris.

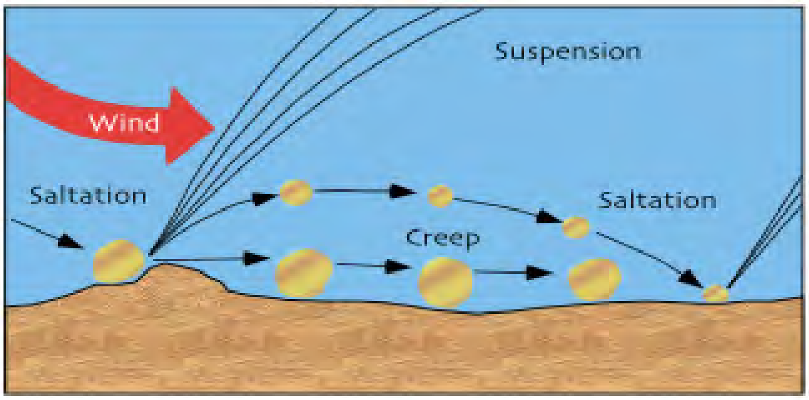
Both the City of Coachella and the County of Riverside require plans be developed for both temporary and permanent erosion control in new projects. Construction must comply with the project's Storm Water Pollution Prevention Plan and Best Management Practices, which are part of the site's grading plans (see Chapter 5, Section 5.2.1). The goal is to minimize or restrict the release of runoff and sediment from the site, as well as debris or potential pollutants.

2.3.8 Wind-Blown Sand

Wind erosion is a serious environmental problem attracting the attention of many across the globe. It is a common phenomenon occurring mostly in flat, bare areas; dry, sandy soils; or anywhere the soil is loose, dry, and finely granulated. Wind erosion damages land and natural vegetation by removing soil from one place and depositing it in another. It causes soil loss, dryness and deterioration of soil structure, nutrient and productivity losses, air pollution, and sediment transport and deposition.

Soil movement is initiated as a result of wind forces exerted against the surface of the ground. For each specific soil type and surface condition, there is a minimum velocity required to move soil particles. This is called the threshold velocity. Once this velocity is reached, the quantity of soil moved is dependent upon the particle size, the cloddiness of the particles, and the wind velocity itself. Suspension, saltation, and surface creep are the three types of soil movement that occur during wind erosion (Figure 2-2). While soil can be blown away at virtually any height, the majority (over 93 percent) of soil movement takes place at or within one meter (3 feet) of the ground surface.

Figure 2-2: Wind-Induced Soil Movement



Wind-induced soil movement is initiated as a result of wind forces exerted against the surface of the ground, and includes suspension, saltation, and surface creep.
Soil can be blown high into the atmosphere; however, most soil movement takes place at or within one meter of the ground surface.

According to El-Aghel (1984), five physical factors determine the distribution and intensity of the wind-blown sand hazard in the Coachella Valley:

- **Orientation of hill and mountain masses**: The major mountain masses bordering the valley have their long axes aligned in a northwest-southeast direction. As a result, these mountains offer little resistance to the free flow of air down the long axis of the Coachella Valley. The narrow San Gorgonio Pass accelerates the wind and improves its ability to pick-up and transport sand.

- **Nature of the bedrock**: The granitic rock that comprises the local mountains readily weathers to grain size categories that are easily transported by wind.

- **Location of the Whitewater River floodplain**: The Whitewater River is the main stream feeding the upper Coachella Valley, and the floodplain is located at the eastern end of San Gorgonio Pass, precisely where wind velocities are the greatest. The river drains much of the adjacent parts of the San Bernardino Mountains, and is the primary source of sand and gravel in the area. During flood events, large quantities of sand and gravel are deposited on the Whitewater floodplain. Studies have shown that increases in the amount of wind-blown sand are related to episodic flooding of the Whitewater River (Sharp, 1964, 1980). For example, a 15-fold increase in wind erosion rates has been noted following heavy flood events (Sharp, 1980). Flood events generally change the character of the Whitewater River drainage from a stony to a sandy appearance. Yet, within a few months of the flooding event, the drainage bottom typically returns to a predominantly stony appearance, as the finer-grained sand is removed from the streambed by the wind, depositing it elsewhere on the valley floor where it becomes a nuisance. Plate 2-3 shows those areas underlain by sediments susceptible to erosion as a result of the strong winds that physically assault the valley portion of the Coachella General Plan area.

- **Slope of the valley floor**: From the summit of the San Gorgonio Pass, at an elevation of about 1,300 feet, to the Salton Sea, with elevations below sea level, the valley floor slopes without interruption, thereby allowing air to move unhindered down the long axis of the Coachella Valley. The region of greatest blow-sand activity is located down the central axis of the valley, in a region that stretches from eastern Palm Springs to La Quinta and Coachella.

- **Climate:** The Coachella Valley is a hot dry desert with sparse, widely spaced vegetation. As a result, surficial materials are exposed to wind activity. The precipitation in the adjacent mountains is often short and intense, leading to torrential run-off and considerable detritus deposition on the valley floor.

Wind and wind-blown sand pose an environmental, often destructive, hazard throughout the Coachella Valley, including the city of Coachella. To measure the effects of the high winds that blow through the valley, in the late 1970s, Caltech investigators conducted several tests near Garnet Hill. The researchers stocked sample plots with 2- to 3-inch-thick lucite rods, common bricks, hard crystalline rock, and gypsum-cement cubes. Then they measured, over several years, the effects of the wind on these artifacts. As a result of wind erosion, one lucite rod was severed, and many samples were eroded up to several centimeters per year. It is no wonder, therefore, that buildings, fences, roads, crops, trees and shrubs can all be damaged by abrasive blowing soil. In some areas, wind-blown sand has actually forced the abandonment of dwellings and subdivided tracts in the central Coachella Valley (Sharp, 1980). Utility poles in the area are frequently armored with sheet metal around the base to help reduce wind erosion. Wind-blown sand has repeatedly caused the closure of roads, costing cities thousands of dollars in cleanup.

The presence of dust particles in the air is also the source of several major health problems. Atmospheric dust causes respiratory discomfort, and may carry pathogens that cause eye infections and skin disorders. Dust storms reduce highway- and air-traffic visibility. Since high winds blow down the axis of the Coachella Valley, the recreational and resort communities that first developed in the Coachella Valley were generally located in areas sheltered from these winds, tucked in coves at the base of the mountains. However, as the area has grown, development has spread into the central axis of the valley and into the high-wind areas. Rapid development of the Coachella Valley is in part responsible for changes in land use, such as removing native vegetation and building roads and other types of infrastructure, that have led to increases in wind-blown sand across the valley floor (grading a site for development results in loose soil that can be readily picked up and transported down-wind). Recreational land-uses, especially use of off-road vehicles, can also accelerate erosion in the area.

Most of the Coachella General Plan area is within the active wind erosion zone. The area is also underlain by highly erodible sediments (see Plates 2-1 and 2-3).

2.3.8.1 *Mitigation of Wind-Blown Sand*

Mitigation measures that have been used and are used in the area include hedges and other barriers to wind. Increased development in the valley has had the positive side-effect of reducing the local sand available to be picked up and transported by the wind. This is due to the increasing amount of hardscape (homes, asphalt, and concrete) and vegetation (such as golf courses and ornamental plants) covering the soil and isolating it from the wind.

During grading and construction, however there is the potential for increased amounts of soils available for transport. Therefore, water is typically sprayed at construction sites to reduce dust in the air. On very windy days earthwork construction may be curtailed altogether.

2.4 Summary

The Coachella General Plan area is highly diverse geologically. This diversity is strongly related to the youthful (in geologic terms) seismic setting of the surrounding region, which includes tectonic subsidence of the Coachella Valley and the ongoing uplift of the surrounding mountains. This, along with the effects of climate, has resulted in a landscape that is complex in geologic processes and hazards. As Coachella's population grows in the next decades, new development will be needed to meet the demand for homes. When meeting this demand, it is imperative to manage land uses in a responsible way, as development disrupts natural processes, often leading to negative impacts on the environment as well as on the development and adjacent projects. The impacts of land development can be minimized, however, if both site-specific and regional planning elements are recognized and considered, the projects incorporate knowledge gained from scientific research in developing and implementing a design appropriate to the area, and protective measures are constructed and maintained for the lifetime of the projects.

The surrounding mountains not only form a dramatic backdrop to the city, but also greatly influence the area's climate, geology, and hydrology. These elements combine in various ways to create geologic hazards, as well as benefits to the community. Hazards that have the greatest impact on the General Plan area are summarized below.

Slope instability will be a potential hazard when development encroaches into the hills in the northeastern part of the General Plan area. The geologic unit forming most of the hills is generally resistant to large-scale landsliding, so future slope failures are more likely to consist of surficial failures and erosion of sandy geologic materials. Such failures typically occur during exceptional and/or prolonged rainfall, and may manifest as mud or debris flows. Larger slope failures could occur in the small portion of the hills underlain by the Palm Spring Formation due to the presence of clay beds and deformation by the San Andreas fault. Cut slopes in this area will most likely need remedial grading to meet minimum engineering requirements.

Potentially compressible and/or collapsible soils underlie a significant part of the valley and canyons, typically where geologically young sediments have been deposited, such as young alluvial fans, washes, and canyon bottoms. These are generally sediments of low density with variable amounts of organic materials. Under the added weight of fill embankments or buildings, these sediments can settle, causing distress to improvements. Construction in these areas will require some removal and recompaction of the near surface soils, based on soil engineering testing.

Some of the geologic units, primarily in that portion of the valley that was once occupied by ancient Lake Cahuilla, have fine-grained components that are likely to be moderately to highly expansive. These materials may be present at the surface or may be exposed by grading activities. Man-made fills can also be expansive, depending on the soils used to construct them.

Sediments in the valley areas may be corrosive to metallic objects, such as pipelines, that are in contact with the soil. All soils should be tested for corrosion potential, with mitigation measures developed by a corrosion engineer where needed.

Regional ground subsidence from groundwater withdrawal is a hazard that can be reduced or prevented by aggressive water management, the use of recycled water, the continued development of new water sources, continuing public education, the widespread use of drought-tolerant plants in landscaping, and the implementation and enforcement of stringent water conservation measures, especially during droughts. Coachella should also require new subdivisions or commercial developments to install infrastructure for water recycling, so that these sites can be connected to recycled water mains as they become available. With the expected increase in population, water shortage is one of the most serious challenges ahead. Overdraft of the aquifer underlying Coachella could result in permanent ground subsidence, with resultant negative impact on the area's environmental quality.

Because of the topographic relief in and around Coachella, erosion and sedimentation are inherently significant elements of the natural setting. Land development can have adverse impacts on these elements by altering the natural processes, topography, and protective vegetation, in addition to reducing the area of natural infiltration. This in turn can lead to damage from increased flooding, erosion, and sedimentation in other areas, typically downstream. Erosion and sedimentation are also important considerations on a site-specific basis, with respect to developments adjacent to slopes and drainage channels. These issues are not only critical during the design of a project, but also during construction and during the long-term maintenance of the developed site.

Like most of the valley, damage from strong winds and blowing sand is a hazard to Coachella. Increased development and irrigation in the Coachella Valley has alleviated the hazard of blowing sand somewhat, however many sand sources are still available, including sediments in the Whitewater River channel.

Losses resulting from geologic hazards are generally not covered by insurance policies, causing additional hardship on property owners. The potential for damage can be greatly reduced by:

- Strict adherence to grading ordinances – many of which have been developed as a result of past disasters;
- Sound land planning and project design that avoids severely hazardous areas;
- Detailed, site-specific geotechnical investigations, followed by geotechnical oversight during grading and during construction of foundations and underground infrastructure;
- Effective geotechnical and design review of projects performed by qualified, California-registered engineering geologists, soil (geotechnical) engineers, and design engineers; and
- Public education that focuses on reducing losses from geologic hazards, including the importance of proper irrigation and landscaping practices, in addition to the care and maintenance of slopes and drainage devices.

CHAPTER 3: FLOOD HAZARDS

Floods are natural and recurring events that only become hazardous when man encroaches onto floodplains, modifying the landscape and building structures in the areas meant to convey excess water during floods. Unfortunately, floodplains have been alluring to populations for millennia, since they provide level ground and fertile soils suitable for agriculture, as well as access to water supplies and transportation routes. Notwithstanding, these benefits come with a price – flooding is one of the most destructive natural hazards in the world, responsible for more deaths per year than any other geologic hazard. Furthermore, average annual flood losses (in dollars) have increased steadily over the last decades as development in floodplains has expanded.

The city of Coachella and surrounding areas are, like most of southern California, subject to unpredictable seasonal rainfall. Most years, the winter rains are barely sufficient to turn the hills and mountains green for a few weeks, but every few years the region is subjected to periods of intense and sustained precipitation that results in flooding. Historic flood events that occurred in southern California have resulted in an increased awareness of the potential for public and private losses as a result of this hazard, particularly in the highly urbanized parts of floodplains and alluvial fans. As the population grows, there is an increased pressure to build on flood-prone areas, and in areas upstream of previously developed land. With increased development also comes an increase in impervious surfaces, such as asphalt. Water that used to be absorbed into the ground becomes runoff to downstream areas. If drainage channels that convey storm waters are not designed or improved to carry these increased flows, areas that have not flooded in the past may be subject to flooding in the future. This is especially true for developments on alluvial fans and downstream from natural drainages that have the potential to convey mudflows.

3.1 Storm Flooding

3.1.1 Hydrologic Setting

The Coachella General Plan area straddles the eastern margin of the Salton Trough (also known as the Salton Sink and Coachella Valley), an arid, low-lying valley with hot summers, cool winters, and infrequent, but potentially violent rainstorms. The valley is a broad, gently sloping basin shaped by a combination of sediments deposited by flash flooding on alluvial fans emerging from canyons in nearby mountains; by past flooding of the valley's main watercourse, the Whitewater River; and by sediments deposited in prehistoric lakes that once occupied the area. The portion of the valley encompassed by the city of Coachella is still largely agricultural. Except for widely scattered farm structures, most of the existing development is within the central and western parts of the city. The northeastern part of Coachella occupies low hills that are still undeveloped, except for localized farming, aggregate mining operations, and a landfill. Several large projects, along with associated infrastructure, have been proposed for both the valley and hillside areas.

There are two distinct flood sources in the Coachella Valley: 1) the Whitewater River and its tributaries upstream from the valley, and 2) the streams entering the valley from mountain ranges flanking the northeast and southwest sides of the valley. The Whitewater River, with a watershed of more than 1,000 square miles, is the most significant drainage course in the area. Collecting runoff from the precipitous slopes and steep canyons of the San Bernardino and San Jacinto Mountains, the river emerges from the mountains near the southern entrance to the San Gorgonio Pass, where it joins and captures the San Gorgonio River, and near Palm Springs, Taquitz Creek. In recent historical times, during flood stage, the river flowed on the southwestern side of the valley above Point Happy (near the intersection of Highway 111 and Washington Street in La Quinta). At this point the main channel crossed to the other (easterly) side of the valley, where it was less well-defined, and bifurcated, with one channel carrying floodwaters down the center of the valley, and a more pronounced channel that followed, somewhat, its current route to the Salton Sea (Coachella Valley County Water District[1], 1967). Today the river follows its historical path through the northern part of the valley where it is surrounded by dense development, including some areas where the riverbed itself is developed as golf courses. The southern part of the river, below Point Happy, is now confined to the man-made Coachella Valley Stormwater Channel and is largely surrounded by undeveloped land or agricultural fields.

The Coachella Valley is flanked by mountains and hills drained by steep canyons and washes, including the San Jacinto and Santa Rosa Mountains to the west, and the Little San Bernardino Mountains, as well as the Indio and Mecca Hills, to the north and east. When a storm arrives, normally dry, rocky canyons and arroyos can quickly become dangerous torrents of water, sand, mud, and rocks, capable of transporting boulders, trees, and even cars. Drainage channels in the mountains are deeply incised; however, when they reach the valley floor they loose their definition and sediment-laden water spills out onto braided ephemeral stream channels and as sheet flow. Light or moderate rainfall is usually absorbed on the alluvial fans and the valley floor, but strong storms, especially if combined with snowmelt, can produce flows that eventually reach the Whitewater River and the Salton Sea. Numerous large drainages from the nearby Little San Bernardino Mountains flow toward Coachella; the most significant of these in terms of flood hazard are Fargo Canyon and Thermal Canyon. The region currently has facilities in place that have greatly reduced the potential for flooding from these sources in the valley portion of Coachella.

3.1.2 Weather and Climate

Southern California owes its agreeable climate of generally mild winters and warm, dry summers to a semi-permanent high-pressure area located over the eastern Pacific Ocean, which deflects storms to the north. During the winter months, this high pressure area breaks down, allowing the jet stream to move storms along a more southerly track.

In spite of southern California's reputation for a mild Mediterranean climate, there are varied and distinct climatic zones in close proximity that are controlled by terrain and altitude. The local mountain ranges, including the San Bernardino, San Jacinto, and Santa Rosa Mountains, have a powerful effect on the climatic conditions in this region. Capturing precipitation from strong Pacific storms that pass through, the mountains separate the semi-arid environment to the west from the dry, desert regions to the east. Most precipitation occurs in the winter months, between November and April. However, high-intensity, short-duration tropical thunderstorms emanating from the south are common during the summer and fall, typically occurring July through September. Often accompanied by strong winds, these powerful storms frequently result in localized damage to roadways, power poles, trees, and structures. These storms are highly localized, drenching one area with several inches of rain in a short period of time, while leaving nearby areas completely dry.

The mountains receive significantly more precipitation than the adjacent lowlands. Consequently, mountain thunderstorms can inundate the adjacent valleys with floodwaters, mud, and debris, even if no rain actually falls on the valley. The average yearly precipitation in the Coachella area is a little more than 3 inches (see Table 3-1), whereas more than 25 inches (average) of precipitation fall annually in the San Jacinto Mountains (Table 3-2).

[1] The Coachella Valley County Water District was established in 1918. In 1979, the word "County" was dropped from its name.

Table 3-1: Average Annual Rainfall* by Month for the Coachella Area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Inches	0.6	0.5	0.3	0.1	0.1	0.0	0.1	0.3	0.3	0.2	0.3	0.5	**3.3**

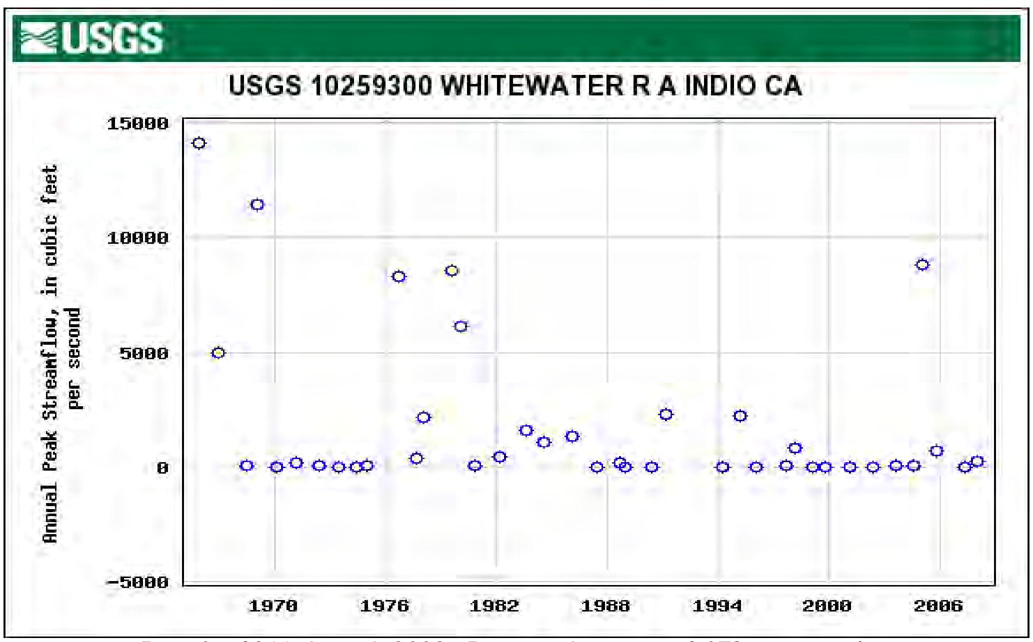
Source: Global Historical Climatology Network; http://www.worldclimate.com/
Data based on 1314 months between 1877 and 1989
Weather Station location: Indio, California, about 33.70° N and 116.30° W
Weather Station elevation: About 9 feet above mean sea level
*Average rainfall = Mean monthly precipitation, including rain, snow, hail, etc.

Table 3-2: Average Annual Rainfall* by Month for the San Jacinto Mountains

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Inches	6.0	4.7	3.9	1.5	0.3	0.0	0.5	1.2	0.8	0.6	3.3	2.7	**25.3**

Source: NCDC Cooperative Stations; http://www.worldclimate.com/
Data based on 8 complete years between 1965 and 1978
Weather Station location: Mount San Jacinto, California, about 33.80°N and 116.63°W
Weather Station elevation: About 8,425 feet above mean sea level
*Average rainfall = Mean monthly precipitation, including rain, snow, hail, etc.

Figure 3-1: Peak Annual Streamflow Values for Gage Station USGS 10259300 Located on the Whitewater River in Indio, Near Coachella



Data for 1966 through 2008. Drainage basin size: 1,073 square miles.

Not only does rainfall in southern California vary from one location to the next, often within short distances, it is also extremely variable from year to year, with periods of drought alternating with periods of flooding. For instance, annual rainfall totals are illustrated in the peak streamflow graph for a gage on the Whitewater River (see Figure 3-1). This gage, located at the Southern Pacific Railroad Crossing in Indio, has recorded the extreme fluctuations in stream discharge that occurred in the area over a 42-year period (1966-2008) that, given its location, best represents the conditions that have occurred and can occur in Coachella. With peaks typically at or near zero cubic feet per second (cfs) for most years, peak flows reached more than 10,000 cfs on November 22, 1965 and on January 25, 1969. Floodwaters at these rates move at high velocities, with the potential to do considerable damage. Other relatively high peak flows were reported in 1976, 1980, and 2005.

Both winter storms and late summer monsoons can impact the Coachella area, as described further below, in the following paragraphs.

Winter Storms. Winter storms are characterized by heavy and sometimes prolonged precipitation over a large area. These storms usually occur between November and April, and are responsible for most of the precipitation recorded in southern California. This is illustrated by the data presented above in Tables 3-1 and 3-2. The storms originate over the Pacific Ocean and move eastward. Mountain ranges, such as the San Bernardino and San Jacinto Mountains, form a rain shadow, slowing down or stopping the eastward movement of this moisture. A significant portion of the moisture is dropped on the mountains as snow. If large storms are coupled with snowmelt from the local mountains, large peak discharges can be expected in the main watersheds at the base of the mountains.

Some of the severe winter storm seasons that have historically impacted the southern California area have been related to El Niño events. El Niño is the name given to a phenomenon that originates every few years, typically in December or early January, in the southern Pacific, off the western coast of South America, but whose impacts are felt worldwide. Briefly, warmer than usual waters in the southern Pacific are statistically linked with increased rainfall in both the southeastern and southwestern United States, droughts in Australia, western Africa and Indonesia, reduced number of hurricanes in the Atlantic Ocean, and increased number of hurricanes in the Eastern Pacific. Two of the largest and most intense El Niño events on record occurred during the 1982-83 and 1997-98 water years. [A water year is the 12-month period from October 1 through September 30 of the second year. Often a water year is identified only by the calendar year in which it ends, rather than by giving the two years, as above.] These are also two of the worst storm seasons reported in southern California in recent decades.

More recently, the severe storms of December 2004 and January 2005 have been blamed on a different climatic condition, one where the sub-tropical jet stream carries moisture-laden air directly from the tropics to the west coast of California. Because it passes over the Hawaiian Islands, it is commonly referred to as the "Pineapple Express." In December 2004, as this condition was developing, the northern jet stream shifted towards the California coast allowing storms from the north to tap into the deep tropical moisture, dramatically increasing the rainfall in southern California (NOAA, 2005a). Powerful winter storms during February 2005, however, have been attributed to a weak but persistent El Niño condition, combined with an atmospheric condition that blocked or slowed the normal eastward movement of the storms (NOAA, 2005b). These events combined to give the region record-breaking rainfall in the 2005 water year, in addition to spawning numerous waterspouts and small tornadoes.

Monsoon Storms. Typically developing in late summer to fall, these storms are usually most prevalent in the higher mountains and the deserts, but can also move into nearby valleys. They develop when moist, unstable air moves into our area from Mexico through Arizona (Mexican monsoons), from the Sea of Cortez (Gulf Surge), or at times from tropical storms or hurricanes that reach Baja California. Once the monsoonal moisture enters California and flows up steep mountain slopes, explosive thunderstorms can develop. Although these high-intensity, short-duration storms typically impact relatively small areas, they often release torrential rainfall that causes flash flooding and mudslides. Frequently packing lightning, hail, very strong wind gusts, and even small tornadoes, thunderstorms cause power outages and damage to people and property. Such storms have impacted Coachella and the surrounding area in the past.

The ARkStorm. Much research in the last decade has focused on the study of a meteorological phenomenon called the Atmospheric River (AR). ARs are narrow streams of water vapor transported in the lower atmosphere that are probably responsible for most of the large storms on the west coast of the U.S. Typically packing high wind speeds, ARs are no more than 400 to 500 kilometers wide, but are thousands of kilometers long, sometimes extending across whole ocean basins. When ARs traveling across the Pacific Ocean collide with the mountain ranges in the west coast, the vapor is forced upwards, where it condenses and rains out, leading to significant flooding (Ralph and Dettinger, 2011).

The U.S. Geological Survey's Multi Hazards Demonstration Project (MHDP) has been combining various science disciplines to test and improve the resiliency of communities to natural disasters. By developing a disaster scenario (such as the 2008 ShakeOut Earthquake Scenario discussed in Chapter 1) scientists, engineers, and other experts are engaging emergency planners, first responders, businesses, universities, insurance companies, government agencies and the public in preparing for a major natural disaster. The second major project of the MHDP is a catastrophic winter storm scenario consisting of a hypothetical (but not unrealistic) Pacific storm striking the west coast of California, similar in intensity to the 1861-1862 series of storms that resulted in state-wide flooding that left the central coast impassible, the capital underwater for three months, and the State bankrupt. Named the ARkStorm (for Atmospheric River 1,000), the impacts of such a storm today are expected to overwhelm the State's flood protection system, which is normally designed to control the 100- to 200-year storm runoff. Property damages and business disruptions from the ARkStorm are estimated to be on the order of $725 billion, nearly three times the loss expected for the hypothetical southern California earthquake (Porter et al., 2011). The USGS report indicates an ARkStorm is not only plausible, but probable, and may not be a worst case. The geological record suggests that six megastorms may have occurred in California in the past 1800 years – all more severe than the 1862 event. The products of the ARkStorm Scenario are intended to be used by emergency planners, policymakers and other to review disaster preparedness, conduct risk assessments and disaster drills, explore ways to adequately fund response and recovery, plan future hazards mapping, and educate the public.

Although ARkStorm flooding in the Coachella Valley is predicted to be less severe than in southern California coastal areas, Coachella would be impacted by both deep-seated and shallow, surficial landsliding in the local hills and mountains. Much of the damage in Coachella would likely be from alluvial fan flooding and debris flows. Additional information on this megastorm scenario can be obtained from http://pubs.usgs.gov/of/2010/1312/.

3.1.3 Past Flooding

Because of the arid climate and the generally dry local washes, Coachella residents might be surprised to learn that desert alluvial fans and valleys are the sites of infrequent but catastrophic flooding. Flood hazards in the Coachella area can be classified into two general categories: 1) flash flooding down natural or man-made channels, and 2) sheet flooding across the valley floor.

Flash floods are short in duration, but have high peak volumes and high velocities. This type of flooding occurs in response to the local geology and geography, and the built environment (man-made structures). The local mountains are steep and consist of rock types that are fairly impervious to water. Consequently, little precipitation infiltrates the ground. When a major storm moves in, water collects rapidly and runs off quickly, making a steep, rapid descent from the mountains into natural or modified channels within the foothill and valley areas. Because of the steep terrain and the constant shedding of debris from the mountain slopes (primarily as dry ravel and rock falls), flood flows often carry large amounts of mud, sand, and rock fragments. Sheet flow occurs when the capacities of the existing channels (either natural or man-made) are exceeded or when channels become blocked by debris or structures, causing water to flow into adjacent areas.

Using historical records dating back to 1769, the U.S. Army Corp of Engineers determined that there were relatively large flood events in the Whitewater River basin in 1825, 1833, 1840, 1850, 1859, 1862, 1867, 1876, 1884, 1886, and 1891. Damaging floods also occurred in January 1916, December 1921, April 1926, February 1927, February 1937, March 1938, and December 1940. More recently, substantial floods occurred in November 1965, December 1966, January 1969, February 1969, and September 1976. The maximum flood of record in the lower Coachella Valley occurred in 1965. FEMA (2008a) reports that the most extensive flood damage occurs on alluvial fans between the base of the mountains and the Whitewater River – the portion of Coachella that is still mainly agricultural, but where several large residential developments have been proposed.

3.1.4 National Flood Insurance Program (NFIP)

Because floods are the leading cause of natural disaster losses in the United States, the nation invests significant resources to reduce the risk of flooding. Floods can be widespread and cause catastrophic losses, therefore insurance companies generally consider flood hazards too costly to insure (National Research Council, 2009). In order to manage the increasing flood losses, the Federal Emergency Management Agency (FEMA) was mandated by the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 to evaluate flood hazards and provide affordable flood insurance to residents in communities that regulate future floodplain development. To that end, FEMA created **Flood Insurance Rate Maps (FIRMS)** for the purpose of setting flood insurance premiums and for regulating the elevations and flood proofing of structures in mapped flood zones.

The NFIP is required to offer federally subsidized flood insurance to property owners in those communities that adopt and enforce floodplain management ordinances that meet minimum criteria established by FEMA. Floodplain management may include such measures as requirements for zoning, subdivisions, and building construction, as well as special-purpose floodplain ordinances. The National Flood Insurance Reform Act of 1994 further strengthened the NFIP by providing a grant program for State and community flood mitigation projects. The act also established the **Community Rating System (CRS)**, a system for crediting communities that implement measures to protect the natural and beneficial functions of their floodplains, and managing their erosion hazard.

The City of Coachella has participated as a regular member in the NFIP since 1980 (Community ID No. 060249#), and the required floodplain regulations are set forth in Chapter 15.56 of the Coachella Municipal Code. Coachella's most current effective FIRM maps are dated August 2008 (four community panels), however maps and flood elevations are amended periodically to reflect future changes. For unincorporated areas, the County of Riverside has participated as a regular member in the NFIP since 1980 (Community ID No. 060245#).

Because Coachella and Riverside County are participating members of the NFIP, flood insurance is available to any property owner in the General Plan area. In fact, to secure financing to buy, build, or improve structures in a Special Flood Hazard Zone (SFHZ – see definition below), property owners are required to purchase flood insurance. Lending institutions that are federally regulated or federally insured must determine if the structure is located in a SFHZ and must provide written notice requiring flood insurance.

FEMA recommends that most property owners, whether residential or commercial, purchase and keep flood insurance, even if they are not located in a mapped flood hazard zone. Keep in mind that approximately 20 to 25 percent of all flood claims occur outside of mapped high flood risk areas, and typical homeowner or business insurance policies do not cover flooding. Residents or business owners that rent property can also purchase coverage for the contents of their homes or business inventories. In low to moderate risk areas, property owners should ask their insurance agents if they are eligible for the FEMA Preferred Risk Policy, which provides inexpensive flood insurance protection. Insured property owners can be reimbursed for all covered losses, even if the flood-impacted zone is not officially declared a Federal disaster area. Residents should also be aware that localized flooding could be caused by a temporary situation, such as a storm drain inlet or culvert that becomes blocked by debris during a storm. Hillside areas are generally outside of the FEMA-mapped flood zones, however these areas can be vulnerable to mudslides, which are also covered under flood insurance.

FEMA also recommends that residents do not forgo purchasing insurance, assuming instead Federal disaster assistance will pay for flood damage. In order to receive assistance, a community must first be declared a Federal disaster area, and these declarations are issued in less than 50 percent of flood events. Remember also that Federal assistance is usually in the form of a loan, which must be repaid with interest. Furthermore, if uninsured property owners do receive Federal assistance, they must purchase flood insurance to remain eligible for future disaster relief.

3.1.5 FEMA Flood Zone Mapping

Flood risk information presented on FIRMs is based on historic, meteorological, hydrologic, and hydraulic data, as well as topographic surveys, open-space conditions, flood-control works, and existing development. Rainfall-runoff and hydraulic models are utilized by the FIRM program to analyze flood potential, adequacy of flood protective measures, surface-water and groundwater interchange characteristics, and the variable efficiency of mobile (sand bed) flood channels. For riverine flooding, the extent of potential flooding is predicted from statistical analyses and hydrologic models that rely heavily on data from U.S. Geological Survey stream gages and land surface topography.

Some FEMA flood map features that are relevant to the residents of Coachella are:

Flood Insurance Study (FIS). To prepare FIRMs that illustrate the extent of flood hazards in a flood-prone community, FEMA conducts engineering studies referred to as Flood Insurance Studies. The General Plan area is included in the FIS for Riverside County; the most recent version is dated August 2008. This document includes community descriptions, flooding sources (including the Whitewater River), information on historical flooding, existing flood protection measures, hydrologic and hydraulic analyses, and definition of potential flood areas.

Special Flood Hazard Area (SFHA). Using information gathered in FIS studies, FEMA engineers and cartographers delineate Special Flood Hazard Areas on FIRMs. SFHAs are those areas subject to a high risk of inundation by a "base flood" which FEMA sets as a 100-year flood. As mentioned above, SFHAs are regulated zones, requiring the mandatory purchase of flood insurance. They are also subject to special standards and regulations that apply to new construction, and in some cases, existing buildings. Floodplain regulations required by the NFIP apply only to properties located in a SHFA. However, these are minimum requirements, and local jurisdictions may regulate areas outside of the SHFAs, based on knowledge specific to their area.

Base Flood. The base flood, also called the **100-year flood,** is defined by looking at the long-term average period between floods of a certain size, and identifying the size of a flood that has a 1 percent chance of occurring during any given year. This base flood has a 26 percent chance of occurring during a 30-year period, the length of most home mortgages. However, a recurrence interval such as "100 years" represents only the long-term average period between floods of a specific magnitude; rare floods can in fact occur at much shorter intervals or even within the same year.

The base flood is a regulatory standard used by the National Flood Insurance Program (NFIP) as the basis for insurance requirements nationwide. The Flood Disaster Protection Act requires owners of all structures in identified SFHAs to purchase and maintain flood insurance as a condition of receiving Federal or federally related financial assistance, such as mortgage loans from federally insured lending institutions.

The base flood is also used by Federal agencies, as well as most County and State agencies, to administer floodplain management programs. The goals of floodplain management are to reduce losses caused by floods, while preserving and restoring the natural and beneficial value of the floodplain.

Base Flood Elevation (BFE). This is the calculated elevation of the water surface during a base flood event. The BFE is important because it is the regulatory standard used for the elevation or flood-proofing of structures. Further, the height of the first floor elevation above the BFE determines the amount of the flood insurance premium. BFEs are shown on FIRMs for those flooding sources that have been analyzed using detailed methods. BFEs on FIRM maps have been rounded to whole-foot elevations and are intended for use in flood insurance rating purposes only. Data in the FIS should be utilized for construction and floodplain management as well.

Floodway. The basis of floodplain management is the concept of the "floodway." FEMA defines this as the channel of a river or other watercourse, and the adjacent land areas that must be kept free of encroachment in order to discharge the base flood without cumulatively increasing the water surface elevation more than a certain height. The intention is not to preclude development, but to assist communities in managing sound development in areas of potential flooding. The community is responsible for prohibiting encroachments into the floodway unless it is demonstrated by detailed hydrologic and hydraulic analyses that the proposed development will not increase the flood levels downstream.

Mapped flood areas outside of the 100-year flood zone. FIRMs in the Coachella area also show the estimated limits of areas with moderate to low risk of flooding. The flood having a 0.2 percent annual chance of occurring (also called the 500-year flood) is usually the basis for these categories, with moderate risk defined as the zone between the limits of the 100-year and 500-year floods, and low risk defined as the area outside of the 500-year flood limits. These zones may also include areas where the base flood is less than one foot deep, or where the drainage basin is small (less than one square mile), or areas that are protected from the base flood by levees. Flood insurance is available for properties in these zones, but is not mandated by the NFIP.

Letter of Map Revision (LOMR). A Letter of Map Revision is a modification to the FIRM or floodway boundaries, generally based on physical changes that affect the hydraulic or hydrologic characteristics of the flood source (usually as a result of development or new flood control facilities). The letter is typically accompanied by an annotated copy of the portion of the map that has been revised. Modifications to the FIRM maps are usually made in response to an agency supplying new hydraulic data that show that the flooding hazard in a specific area has changed or has been abated.

In addition to their original purpose of setting insurance rates and regulating flood hazards, FIRMs are now widely used by local and regional planners for other purposes, including land-use planning, emergency preparedness and response, natural resource management, and risk assessment. However, it should be noted there are many uncertainties inherent in the establishment of FEMA flood zones (Larson, 2009). Given the importance of these maps, some of the limitations that communities should be aware of are discussed below:

- It is important to realize that FIRMs only identify potential flood areas based on the conditions at the time of the study, and do not consider the impacts of future changes in the area. Conditions that affect the maps and decisions made on their basis may include changes in corporate boundaries, changes in population, man-made and natural changes to the landscape, removal of vegetation, changes to hydrologic systems, construction of flood control facilities, and potential climate changes. These changes in the environment may increase or reduce the area susceptible to flooding.
- The level of detail studied and presented on the maps, as well as the boundaries of the area studied, depend on the type of flood hazard, the funding available, and the risk of flood damage at the time of the analysis. For instance, areas studied by approximate methods do not provide BFEs on the map, and some study areas are limited in extent.
- The maps do not necessarily identify all areas of flooding. For instance, drainages of small size, areas of localized ponding during storms, or areas where drainages are restricted by temporary or permanent structures may not be shown.
- The analytical process relies on many assumptions and incomplete data. Data used to construct the maps may be too old, incomplete, interpolated, and/or inaccurate. For instance, in relatively flat floodplains, such as Coachella, small elevation errors in the topography can result in large errors in flood zone boundaries.
- One major drawback is the very short time period for which we have meteorological records. Research on some parts of southern California has shown slight climate fluctuations between wet and dry cycles have occurred since the late 1800s (Hereford and Longpre, 2009). Future global climate change is still intensely debated, but many scientists now believe even slight global warming could bring an increase in precipitation overall, although the specific effects on the Coachella region are not known.

- Long-term changes in the watershed or floodplain, primarily from man's encroachment, are even harder to predict. Even flood-control structures, such as berms and levees, can increase the flood risk to other areas. The design of high-density developments often requires taking drainages that used to be spread over a wide area and constricting them into narrow channels, thereby increasing the velocity and erosive power of the flow, and perhaps leading to overtopping. Consequently, there are clearly limitations in using hydrologic calculations based on past, imperfect records to predict the future.
- Larson (2009) also argues that the process of placing a line on a map (flood zone boundaries) conveys a sense of certainty about the risk to the public and policy makers that does not exist.

Flood Map Modernization Program. Because many flood maps and related products were outdated, FEMA started its Map Modernization Program in 2003 to reduce reliance on paper maps and transition to digital processes for distributing and reading flood maps. The program also includes collecting new flood data for unmapped areas. Based on funding limitations and feedback from stakeholders, FEMA changed its goals midway through the program. Rather than try to create digitized flood maps for the entire nation, it was decided to improve the accuracy of the newly updated maps by establishing two criteria: 1) a floodway boundary standard that would insure flood maps match the topographic data used (although use of the standard itself does not validate the accuracy of the topographic data); and 2) guidelines for determining whether an existing flood study is adequate for current use or if an updated study is needed. The adjusted goal was to have 65 percent of the continental U.S. land area and 92 percent of the population covered by digital maps by 2008 (National Research Council, 2009).

Risk MAP Program. With the Risk MAP Program approved in March 2009, FEMA is moving from simply portraying flood hazard zones on maps to more accurately communicating and assessing risk to the local community. Building on the digitized maps, FEMA developed a five-year plan to fill in data gaps, increase public awareness, increase their outreach on flood risks, support state and local agencies in risk-based mitigation planning, and provide an enhanced digital platform that improves communication and sharing of risk data. In 2011, FEMA started a multi-year project to improve their guidelines and standards for flood risk analysis and mapping, the goal being to bring better overall consistency, clarity, and efficiency to the mapping process. The result of this work was publication of a compendium document covering all standards applicable to the Risk MAP program (FEMA, 2013a). FEMA plans to issue updates to their mapping policies on a semi-annual basis (FEMA, 2014).

New Levee Analysis. FEMA considers accredited levees (levees that meet the requirements of Title 44, Chapter 1, Section 65.10 of the Code of Federal Regulations) to be those that protect the surrounding area from the 100-year flood. FEMA recently joined with the U.S. Army Corps of Engineers and engineering experts to review different technical approaches for analysis and modeling of flood hazards in the vicinity of levees, in order to more precisely identify SFHAs. Consequently, approval of non-accredited or provisionally accredited levees was put on hold, including those within Coachella, while the new methods of analysis were developed. In 2013, FEMA published a document outlining the new procedures for analyzing and mapping flood hazards on the landward side of non-accredited levees. The new methodology provides a more refined approach to mapping, based on recent advances in data collection, as well as hydrologic and hydraulic modeling (FEMA, 2013b).

3.1.6 Flood Zone Mapping in Coachella

As part of the National Flood Insurance Program, the potential for flooding in portions of the Coachella General Plan area has been analyzed through the Flood Insurance Study for Riverside County (FEMA, 2008a). The potential flood zones mapped by FEMA are published in Flood Insurance Rate Maps that were updated in 2008. The current FEMA flood zones for the General Plan area are illustrated on Plate 3-1. According to the FIRMs, the Coachellla Valley Stormwater Channel (Whitewater River) is the only part of the General Plan area that is classified as a 100-year flood zone.

Nevertheless, FEMA studies indicate a large part of the valley area still has a low to moderate risk of flooding. This could occur during an event stronger than the 100-year storm, may include areas that could be flooded with average depths of less than one foot during the 100-year storm, or problem areas too small to map. Other parts of Coachella are shown as outside of the 500-year flood zone. It should be noted that the eastern half of the General Plan area has not been studied by FEMA, and the flood hazard there, for insurance purposes, is undetermined.

In order to identify flood hazard areas in California that have not been mapped under the NFIP, the California Department of Water Resources (DWR) has initiated a program to provide communities and residents with information on potential flood hazard areas that are not currently regulated floodplains. The maps identify 100-year flood hazard areas by approximate means, without specific depths or other flood hazard data. The DWR mapping indicates portions of the area between the base of the mountains and the Coachella Canal are subject to flooding (shown on Plate 3-1). A berm (Eastside Dike) protecting the canal from hillside runoff also provides protection to valley properties west of the canal. The DWR mapping is broad-based and very general, consequently it should be used as a starting point by local agencies for mandating more detailed studies when and where developments are proposed.

3.1.7 Existing Flood Protection Measures

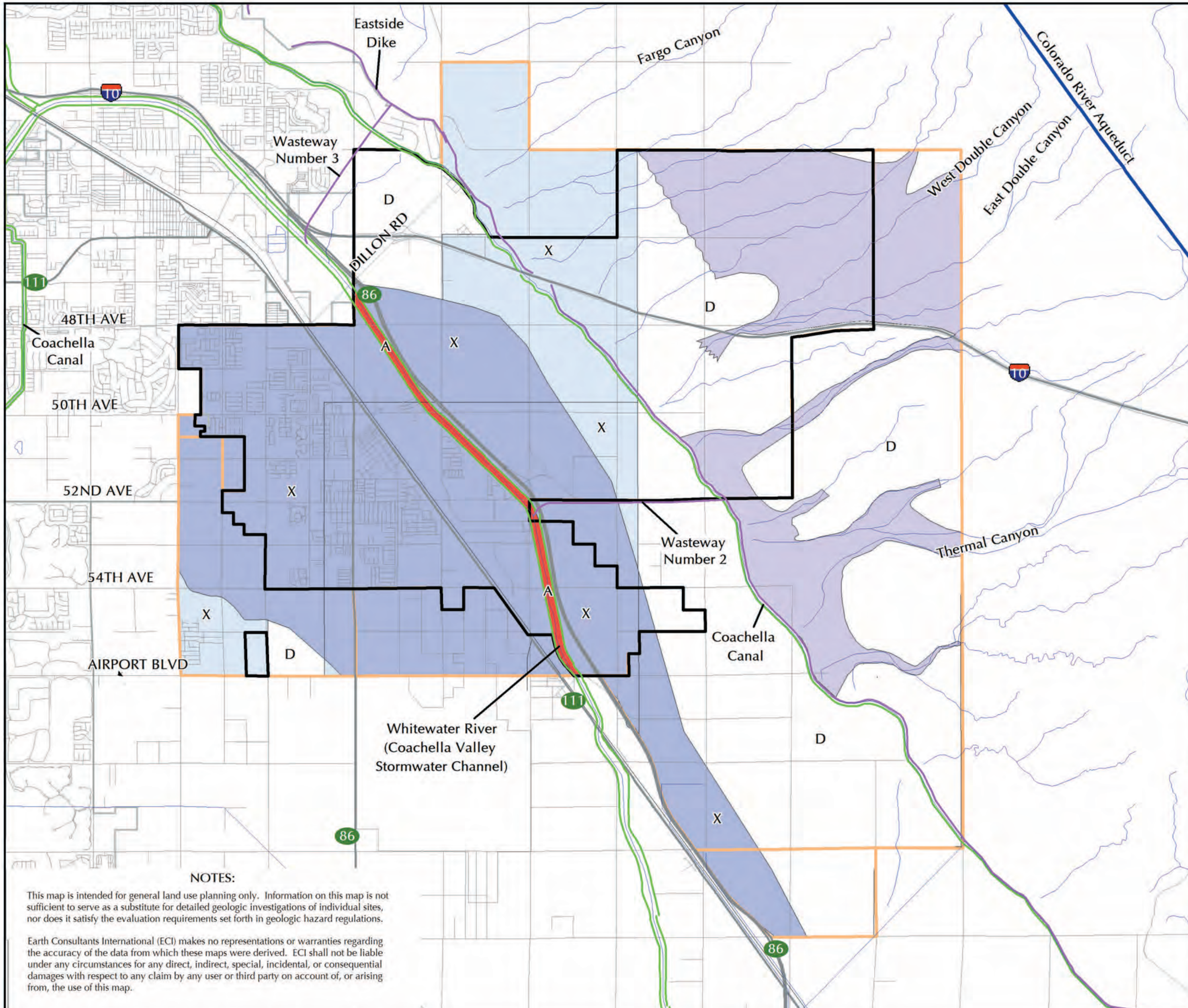
Coachella flood control facilities fall into two categories:

1. Regional facilities that convey runoff from the mountains to the Whitewater River. The river (also known as the Coachella Valley Stormwater Channel) and its major tributary facilities are maintained by the Coachella Valley Water District (CVWD). However, bridges, culverts, and low-flow crossings across the Coachella Valley Stormwater Channel are maintained by the cities and Riverside County.
2. Local facilities that collect runoff from streets and properties, and direct it to the regional channels and basins. These are usually maintained by the City within the incorporated area, or Riverside County in unincorporated areas.

Flood control facilities in the Coachella area are briefly described below and major regional structures are identified on Plate 3-1.

Coachella Valley Stormwater Channel: The Whitewater River is the principal drainage course through Coachella Valley, collecting runoff from the surrounding mountain ranges. It is typically dry, but flows southeasterly through the valley when carrying water. Approximately 25 miles of the Whitewater River, from Point Happy in La Quinta to the Salton Sea, is a man-made channel that roughly follows the recent historical path of the natural drainage. The channel is known throughout the valley as the Coachella Valley Stormwater Channel (in some publications it is referred to as the Whitewater River Storm Channel).

Flood Hazard Map
Coachella, California



Explanation

FEMA Flood Insurance Rate Zones

High Risk Areas

- A — Zone that corresponds to the 100-year flood areas, as determined by approximate methods. Because detailed hydraulic analyses were not performed, no base flood elevations or depths are shown. Flood insurance is mandatory.

Moderate and Low Risk Areas

- X — Zone that corresponds to areas of 500-year flood; areas of 100-year flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 100-year flood. No base flood elevations or depths are shown. Flood insurance is available but not required.
- X — Zone that corresponds to areas outside of the 500-year flood. No base flood elevations or depths are shown. Flood insurance is available but not required.

Undetermined Risk Areas

- D — Zone that corresponds to unstudied areas where flood hazards are undetermined, but flooding is possible. Flood insurance is available but not required.

DWR Awareness Floodplain Mapping

- Area that corresponds to the 100-year flood hazard, as determined using approximate assessment procedures. These floodplains are shown simply as flood-prone areas without specific depths.

- Levee or Dike
- East Side Dike and Wasteways
- Drainage Course
- Coachella City Boundary
- Coachella Planning Area Boundary

* For elevations or depths see original FEMA Flood Insurance Rate Maps available at the City, County, or www.fema.gov.

N S W E

Scale: 1:72,000

6000 0 6000 **Feet**

2000 0 2000 **Meters**

Base Map: City of Coachella
Sources: California Department of Water Resources (2006) and Federal Emergency Management Agency, Riverside County, Flood Insurance Rate Maps (Panel Numbers: 06065C2254G, 06065C2260G, 06065C2262G, 06065C2270G).

Earth Consultants International

CITY OF COACHELLA CALIFORNIA

Project Number: 3106/3218
Date: 2014

Plate 3-1

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.

In addition to its main purpose of collecting stormwater, the Coachella Valley Stormwater Channel also receives treated wastewater and agricultural runoff. The channel is mostly unlined with an average cross-section width of about 260 feet, however within the General Plan area, the southwestern slope of the channel is lined with reinforced concrete from the City of La Quinta south to Avenue 54. The concrete slope protection is designed to contain the 100-year storm with three feet of freeboard (FEMA standard) and the Standard Project Flood (CVWD standard) with one foot of freeboard. The northeastern bank of the channel, from the Monroe Street crossing to the Salton Sea is not lined.

FEMA (2008a) indicates there is a potential for a major breakout of the Whitewater River during a 100-year storm at the bend in the river between Jefferson Street and Miles Avenue (within the city of Indio), where the man-made channel deviates from the natural watercourse. FEMA attributes this to the lack of sufficient channel capacity at that point and the erodibility of the levee at the bend. A breakout would result in a 50 percent loss of channel capacity and send floodwaters throughout the cities of Indio and Coachella.

Figure 3-2: Coachella Valley Stormwater Channel.
The Whitewater River's course through Coachella is confined to this broad, soft-bottom channel. The western bank of the channel is reinforced with concrete north of Avenue 54. This view, looking north from Avenue 50, shows the sand levees along the channel and concrete facing on the western bank.

Levees constructed of large sandpiles with no reinforcement occur along both sides of the channel (see Plate 3-1). The levees are easily eroded and require periodic maintenance. According to the most recent (August 2008b) FIRMs, and the CVWD, the levees along the Whitewater River that protect Coachella from the 100-year flood are currently not accredited. Detailed hydraulic analyses, based on the new FEMA procedures, were performed by the CVWD for the reach extending from the Monroe Street bridge (in the city of Indio) to the Salton Sea. The result of these analyses indicated areas adjacent to channel, from just north of Airport Boulevard (Avenue 56) to the south, are susceptible to inundation from a levee breach or overtopping during a 100-year flood event. The CVWD is currently working with FEMA and the local impacted communities, forming a Local Levee Partnership Team. These efforts should allow channel improvements to move forward, ultimately resulting in the revision of FEMA maps (T. Demissie, Associate Engineer with the CVWD, personal communication via email, 2014).

FEMA points out that because these structures are potentially at risk of overtopping or failure, citizens, community officials, builders, insurance agents, lenders, and others need to understand the risk to life and property posed to land near to, but behind these levees. This is a risk that even the best flood control system cannot completely eliminate. Communities traversed by these flood-protection facilities are well-served by having evacuation plans in place, and property owners adjacent to these structures are encouraged to purchase flood insurance.

Eastside Dike: The Bureau of Reclamation constructed the Eastside Dike in the 1940s to protect the Coachella Canal by detaining runoff from the Mecca Hills, Indio Hills, and Little San Bernardino Mountains, and diverting it to the Coachella Valley Stormwater Channel (thereby protecting the valley area as well). North of Interstate 10, the earthen dike is located northeast of the canal, where it forms a detention basin with a capacity of 21,000 acre-feet. South of Interstate 10, the dike lies adjacent to the east side of the canal, forming a detention basin with a capacity of 18,000 acre-feet (Coachella Valley County Water District, 1967). In the city of Coachella area, two inlet structures allow water detained behind the dike to reach the Stormwater Channel via open, concrete-lined diversion channels. One of the channels is located at the northern edge of the General Plan area (Wasteway No. 3, see Plate 3-1), and one is present in the central part of the area, running parallel to Avenue 52 (Wasteway No. 2). The Eastside Dike and its diversion channels are maintained by the Coachella Valley Water District. The District is currently implementing plans to repair the wasteway channels in order to facilitate the flow of stormwater impounded behind the dike during floods, and to provide a way to drain the Coachella Canal during an emergency.

Agricultural Tile Drain System: Tile drain installations in the Coachella Valley were started in 1949 in order to lower the high water table created by the heavy application of irrigation water, and to drain the agricultural fields of excess water with high salt concentrations. The drain lines commonly consist of clay or concrete pipes surrounded by gravelly sand or pea gravel, and are laid out in a grid pattern, with spacing dependent on soil type, orientation of row crops, and locations of collector lines (Halsey and Marsh, 1967). The effectiveness of some drains has declined with age, resulting in crop damage. Today there are miles of tile drains on valley farms which are connected to an extensive collection system installed and maintained by the Coachella Valley Water District. Water from the drains is released into the Coachella Valley Stormwater Channel. Although their primary purpose is to lower the artificially high water table and remove salts in the water, the drains also capture some surface runoff. When future developments are planned in these agricultural areas, the drains need to be removed from the project area, while maintaining the integrity of the outfall system for the remaining farms. New drainage systems may need to be added. The CVWD will consider use of the existing drains for urban drainage if:

- The surface and subsurface drainage facilities can physically handle the new urban runoff;
- The area is incorporated into the National Pollutant Discharge Elimination System permit and Waste Discharge Requirements for the discharge of stormwater in the Whitewater River Watershed (known as the MS4 Permit);
- The project is annexed into a future district(s) for recovery of capital and operation/maintenance costs associated with the new urban drainage system.

Figure 3-3: Coachella Canal and Eastside Dike.
The Eastside Dike, the earthen berm shown in the upper left corner of the photo, protects the Coachella Canal from stormwater flowing out of the nearby hills and mountains.

Local Structures: Although the Coachella Valley Water District has as a goal to safely convey floodwaters from the mountains across the valley to the Salton Sea, rain that falls directly on incorporated or unincorporated areas is the responsibility of the local cities or the county. Currently, there is not a permanent, interconnected flood control system in the area, nor does the City or County have a comprehensive master drainage plan. Most stormwater passes through Coachella as surface flow, as there are very few underground structures (such as storm drains) and existing local structures are not tied to the Coachella Valley Stormwater Channel. As a consequence, the city experiences localized, periodic flooding of downtown streets. Furthermore, streets in the older parts of the city have very slow drainage, which occasionally results in runoff water ponding at some locations for days after a storm.

3.1.8 Future Flood Protection

Improvement and additions to regional structures are the responsibility of the CVWD. In addition to improvements to the Coachella Valley Stormwater Channel and levees, the CVWD is currently preparing a Stormwater Master Plan for the Eastern Coachella Valley, a document that will address regional flooding and valley floor drainage. This study should help identify areas subject to flooding, both within and upstream of the city of Coachella that are not currently shown on the FEMA maps.

The City of Coachella is also currently working on a Storm Drain Master Plan that will identify areas of poor drainage. The Plan will guide the future development of structures that will help mitigate local flooding problems.

Developers of new construction projects are responsible for the planning, design, and construction of local flood control facilities, as determined by development agreements. Flood control guidelines and requirements for new construction in the City of Coachella are spelled out in the City's Municipal Code, Title 15, Chapter 15.56, and in the City's Standard Specifications and Standard Drawings. Design of flood control structures is based on the Riverside County Flood Control Manual and hydrology reports must be prepared in accordance with requirements of the Riverside County Flood Control District.

As new developments are considered, it is important that hydrologic studies be conducted to assess the impact that increased development may have on the existing development down gradient. These studies should quantify the effects of increased runoff and alterations to natural stream courses. Such constraints should be identified and analyzed during the earliest stages of planning. If any deficiencies are identified, the project proponent needs to prove that these can be mitigated to a satisfactory level prior to proceeding forward with the project, in accordance with California Environmental Quality Act (CEQA) guidelines. Mitigation measures typically include flood-control devices such as catch basins, storm drain pipelines, culverts, detention basins, dry wells, desilting basins, and velocity reducers, in addition to debris basins for protection from mud and debris flows below hillside areas.

In general, existing tributary drainages must be able to flow around or through a newly developed site without adversely impacting adjacent or downstream properties. Further, all runoff within a developed site must be contained within the property. This usually requires the construction of shallow retention basins and dry wells. Drainage on the project site should be designed to flow toward low-lying permeable areas for infiltration. New developments must also consider and make provisions for any disruptions to the extensive network of agricultural tile drains.

Hydrology studies and proposed flood control measures are reviewed by the City, the CVWD, and the Riverside County Flood Control District. In order to achieve effective flood control for the City and its neighbors, all agencies must be involved in the planning and approval of mitigation measures, to assure compatibility.

Across the United States, substantial changes in the philosophy, methodology and mitigation of flood hazards are currently in the works. For example:

- Some researchers have questioned whether or not the current methodology for evaluating average flood recurrence intervals is still valid, since we are presently experiencing a different, warmer and wetter climate. Even small changes in climate can cause large changes in flood magnitude (Gosnold et al., 2000).
- Flood control in undeveloped areas should not occur at the expense of environmental degradation. Certain aspects of flooding are beneficial and are an important component of the natural processes that affect regions far from the particular area of interest. For instance, lining major channels with concrete reduces the area of recharge to the underlying groundwater table. Thus there is a move to leave nature in charge of flood control. The advantages include lower cost, preservation of wildlife habitats and improved recreation potential.
- Floodway management design in land development projects can also include areas where stream courses are left natural or as developed open space, such as parks or golf courses. Where flood control structures are unavoidable, they are often designed with a softer appearance that blends in with the surrounding environment.
- Environmental legislation is increasingly coming in conflict with flood control programs. Under the authority of the Federal Clean Water Act and the Federal Endangered

Species Act, development and maintenance of flood control facilities has been complicated by the regulatory activities of several Federal agencies including the U.S. Army Corps of Engineers, the Environmental Protection Agency, and the U.S. Fish and Wildlife Service. For instance, FEMA requires that the County and incorporated cities therein maintain the carrying capacity of all flood control facilities and floodways. However, this requirement can conflict with mandates from the U.S. Fish and Wildlife Service regarding maintaining the habitat of endangered or threatened species. Furthermore, the permitting process required by the Federal agencies is lengthy, and can last several months to years. Yet, if the floodways are not cleared of vegetation and other obstructing debris in a timely manner, future flooding of adjacent areas could develop.

As the population of Coachella grows, the consequences of flooding are likely to increase. In light of the uncertainties with respect to estimating floods, land use planning in the City and the General Plan area in general could benefit from additional mapping in undeveloped areas, a conservative approach to permitting, and a strong adherence to an area-wide, long-term vision for flood safety as individual projects are considered.

3.1.9 Flood Protection Measures for Property Owners

As discussed above, flooding remains a risk locally, especially in areas of future development where adequate mapping of the flood hazard is incomplete. Mitigation measures that can reduce the flood hazard are discussed below.

At the Community Level:

- Continue the enforcement of the County's provisions for flood hazard reduction, tract drainage, and storm water management (Ordinance Nos. 458, 460, and 754) and the City's flood hazard and floodplain regulations (Municipal Code Chapter 15.56). These regulations include construction standards that address the major causes of flood damage – i.e., structures that are not adequately elevated, flood-proofed, or otherwise protected from flooding. The regulations apply to new construction or substantial improvements, and include provisions for anchoring, placement of utilities, elevating the lowest floors, flood-resistant materials, and other methods to minimize damage.
- Map flood problem areas too small or currently outside of FEMA mapped areas.
- Because most of the General Plan area is still undeveloped or used as farmland, there is an opportunity to develop a comprehensive outline for drainage that would then be used as a guideline as the City is built out in the future.
- FEMA recommends that communities be proactive in protecting lives and preventing property damage in areas with provisional structures (such as levees and dikes), due to the risk of overtopping or failure of these structures. This might include having evacuation plans in place and encouraging residents and businesses to buy flood insurance.
- Encourage residents to purchase flood insurance for areas outside of the 100-year flood zone.
- Develop methods to conduct real-time storm warnings and evacuations if necessary.
- Continue to educate the public on the risks of flooding, including the uncertainties inherent in flood hazard zoning.
- Establish easements for entrenched flow paths.
- Create flood overlays for zoning and land use maps.

- Create an atmosphere of working with nature and the natural processes inherent to the semi-arid environment characteristic of this area.

For Property Owners:

- Elevate new homes on pads, foundations, or piers in flood-prone areas.
- Orient new homes and pads to provide minimum obstruction to the direction of flow, and do not force flows onto adjacent properties.
- Try to accommodate natural flows rather than restricting them.
- Any grading to direct flow around a home or structure should include directing it back to its natural path downstream.
- Protect foundations or piers from erosion and scour.
- Numerous methods are available for flood protection – which methods are most appropriate for an individual lot should be based on the local conditions surrounding and upstream from the lot.
- Some lots may require special engineering studies to determine the extent of the hazard and to design appropriate mitigation.

FEMA has identified several flood protection measures that can be implemented by property owners to reduce flood damage. These include: installing waterproof veneers on the exterior walls of buildings; putting seals on all openings, including doors, to prevent the entry of water; raising electrical components above the anticipated water level; and installing backflow valves that prevent sewage from backing up into the house through the drainpipes. Obviously, these changes vary in complexity and cost, and some need to be carried out only by a professional licensed contractor. For additional information and ideas, refer to the FEMA web page at www.fema.gov (and links therein such as http://www.fema.gov/small-business-toolkit/protect-your-property-or-business-disaster). Structural modifications require a permit from the City or County Building Departments. Refer to them for advice regarding whether or not flood protection measures would be appropriate for your property.

3.1.10 Bridge Scour and Flood Channel Crossings

Nationwide, several catastrophic collapses of highway and railroad bridges due to scouring and a subsequent loss of support of foundations have occurred. This has led to a nationwide inventory and evaluation of bridges (Richardson and others, 1993). Scour at highway bridges involves sediment-transport and erosion processes that cause streambed material to be removed from the bridge vicinity. Scour is generally separated into components of pier scour, abutment scour, and contraction scour. Pier scour occurs when flow impinges against the upstream side of the pier, forcing the flow in a downward direction and causing scour of the streambed adjacent to the pier. Abutment scour happens when flow impinges against the abutment, causing the flow to change direction and mix with adjacent main-channel flow, resulting in scouring forces near the abutment toe. Contraction scour occurs when flood flow is forced back through a narrower opening at the bridge, where an increase in velocity can produce scour. Total scour for a particular site is the combined effects of each component. While different materials scour at different rates, the ultimate scour attained for different materials is similar and depends mainly on the duration of peak streamflow acting on the material (Lagasse and others, 1991). Scour can occur within the main channel, on the floodplain, or both. California's seismic retrofit program of bridges includes underpinning of foundations that is expected to help reduce the vulnerability to undermining of the foundations by scour..

Figure 3-4: Bridge Crossing the Coachella Valley Stormwater Channel (Whitewater River) at Dillon Road

Dillon Road, Avenue 50, Avenue 52, and Airport Boulevard (Avenue 56) are Coachella's only crossings of the Coachella Valley Stormwater Channel. Except for Avenue 50, these crossings consist of bridges over the channel. The roadway for Avenue 50 dips into the channel and is impassable when the channel is flooded. Highway 111 (Grapefruit Boulevard) and the Southern Pacific Railroad tracks cross the channel just south of Coachella. In December 1966, one of the most damaging storms on record hit the valley. Although water remained within the channel banks, the channel bed from Airport Road south to Avenue 60 was scoured so deeply it caused damage to the Airport Road bridge, threatened the stability of Highway 111, and exposed about three feet of the pile footing under the railroad bridge piers (Coachella Valley County Water District, 1967). Again, in January-February of 1969, a series of strong storms damaged roads, storm channel crossings and railroad bridges. The rail bridge and Highway 111 bridge south of Thermal were washed out, as was the Airport Road bridge just east of Thermal. In fact, between Palm Springs and the Salton Sea, the only usable crossings remaining were the Highway 86 (Indio Boulevard) bridge and the rail crossing west of Indio. It is thus very important that these crossings continue to be inspected by the City's Public Works Department, during and after flooding, for obstructions and potential scour damage.

The city's current Capital Improvement Program includes a new bridge which will replace the dry weather crossing at Avenue 50. This will allow another safe crossing of the channel during storms.

Figure 3-5: Proposed Location of New Bridge.
The city of Coachella is currently planning a bridge for the Avenue 50 dry-weather crossing.

3.2 Seismically Induced Inundation

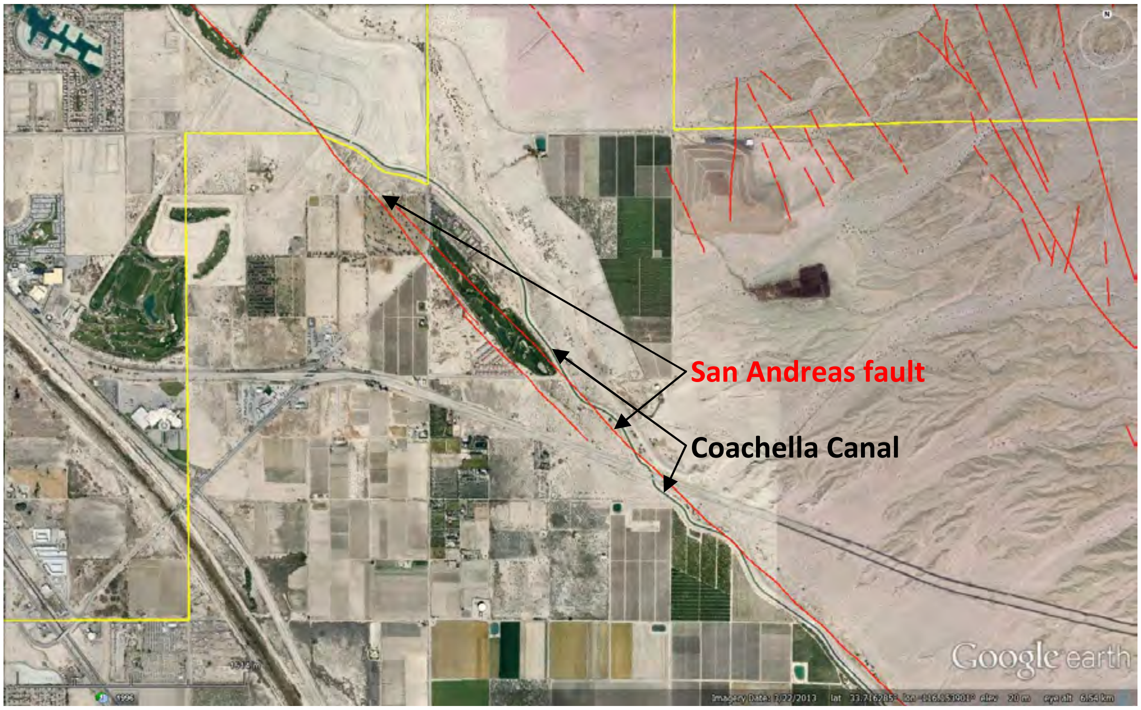
3.2 1 Dam or Levee Failure

Seismically induced inundation refers to flooding that results when water retention structures, such as dams, fail due to an earthquake. Statutes governing dam safety are defined in Division 3 of the California State Water Code (California Department of Water Resources, 1986). These statutes empower the California Division of Safety of Dams to monitor the structural safety of dams that are greater than 25 feet in height or have more than 50 acre-feet of storage capacity. A review of records maintained by the California Office of Emergency Services indicates that there are no existing dams with the potential to inundate Coachella.

Nevertheless, there are water-retaining structures in Coachella not under the jurisdiction of the California Division of Safety of Dams. Local flooding associated with failure of the Coachella Canal, the Eastside Dike, or the Coachella Valley Stormwater Channel levees, remains a risk for the people of Coachella. The channel's levee system and/or the canal could be impacted by a severe earthquake, with the potential for the foundation soils to fail as a result of lateral spreading (see Chapter 1, Section 1.6). Liquefaction and lateral spreading damaged Imperial Valley canals during earthquakes in 1979 and 1987, and more recently, as a result of the Easter Sunday (Sierra El Mayor-Cucapah) earthquake of 2010. Field reconnaissance of the Imperial Valley canal following the 2010 earthquake showed that there was significant slumping and lateral spreading along the canals, although none of them failed, and there were no reports of flooding as a result of slumping of the canal levees. However, these damages were the result of an earthquake many miles to the south, with the damage the result of shaking-induced lateral spreading, and not the result of surface fault rupture.

Within the City, the Coachella Canal is especially vulnerable to primary fault rupture, as its alignment nearly coincides with the trace of the San Andreas fault – a condition considerably more severe than a high-angle fault crossing (see Figure 3-6 and Chapter 1, Section 1.5). The 2008 USGS ShakeOut Scenario estimates that rupture by offset of the canal would likely occur in at least three places, resulting in flooding of valley areas to the southwest. Immediate offset could be on the order of 7.2 to 15.7 feet (2.2 to 4.8 meters), with an additional afterslip of 5.9 to 10.8 feet (1.8 to 3.2 meters), which is likely to hamper repairs of the damaged canal (Jones et al., 2008).

Figure 3-6: Crossings of the Coachella Canal by the San Andreas Fault.
Faults in red. Compare this Figure with Plate 1-2.



In anticipation of a major earthquake, the Coachella Valley Water District has a comprehensive Emergency Response Plan in place that includes the canal system. They have also participated in Shakeout drills that include simulated earthquake damage and practiced response to a break in the canal. The only structures within the canal system that are seismically designed are the siphon under-crossings. Additional information regarding the potential impacts to the potable water system as a result of an earthquake on the San Andreas fault is provided in Chapter 1, Section 1.9.6.

Other regional aqueducts that deliver imported water to many parts of southern California, including the Colorado River Aqueduct, are likely to suffer extensive damage if a major earthquake occurs on either the San Andreas fault or other nearby active faults. Repairs to these aqueducts could take weeks to months (Toppozada et al., 1993; Jones et al., 2008).

The canal and Eastside Dike diversion channels in the city are also subject to seiches (sloshing of water back and forth) during an earthquake, which in itself can damage containment structures such as levees and berms.

3.2.2 Inundation From Above-Ground Storage Tanks

Seismically induced inundation can also occur if strong ground shaking causes structural damage to above-ground water tanks. If a tank is not adequately braced and baffled, sloshing water can lift a water tank off its foundation, splitting the shell, damaging the roof, and bulging the bottom of the tank (causing what is referred to as "elephant's foot") (EERI, 1992). Movement can also shear off the pipes leading to the tank, releasing water through the broken connections. These types of damage were reported as a result of the 1992 Landers, 1992 Big Bear, 1994 Northridge, and 2010 Sierra El Mayor-Cucapah (Baja California) earthquakes. The Northridge earthquake alone rendered about 40 steel tanks non-functional (EERI, 1995), including a tank in the Santa Clarita area that failed and inundated several houses below. As a result of lessons learned from the 1992 and 1994 earthquakes, revised standards for design of steel water tanks were adopted in 1994 (Lund, 1994). The revised tank design includes flexible joints at the inlet/outlet connections to accommodate movement in any direction.

The City of Coachella has three above-ground water reservoirs in the General Plan area. The newest tank, located at Well 18, is the only one constructed to current seismic standards. All tanks have isolation valves. The only above-ground reservoir in the Coachella General Plan area owned by the Coachella Valley Water District is located in their Coachella yard. It is an older tank that has not been retrofitted. The District is currently evaluating whether to upgrade or demolish the facility.

Figure 3-7: View of One of the Above-ground Water Tanks in the Coachella General Plan Area

Table 3-3: Above-ground Water Tanks Owned by the City of Coachella Water Department

Reservoir	Type	Year Built	Capacity (millions of gallons)	Seismic Upgrades	Containment/ Diversion Structures
Dillon	Steel	1971	1.5	No	No
Mecca	Steel	1987	3.0	No	No
Well 18	Steel	2007	5.0	Yes	No

Water lost from tanks during an earthquake can affect not only structures down slope from the tanks, but can significantly reduce the water resources available to suppress earthquake-induced fires. Damaged tanks and water mains can also limit the amount of water available to residents. Similar damage can be expected to the groundwater wells in the region, further limiting the water available to the community after an earthquake. Therefore, it is of paramount importance that the water storage tanks in the area retain their structural integrity during an earthquake, so water demands after an earthquake can be met. In addition to evaluating and retrofitting water reservoirs to meet current standards, this also requires that the tanks be kept at or near full capacity at all times.

3.3 Loss Estimation Analyses Using HazUS

HazUS is a regional multi-hazard loss estimation model developed by FEMA and the National Institute of Building Sciences. The primary purpose of HazUS is to provide a methodology and software application to develop multi-hazard losses at a regional scale. Local, state and regional officials can use these loss estimates to evaluate the area's vulnerability to multi-hazards and prepare for emergency response and recovery. Additional information regarding HazUS, including its uses and limitations, is provided in Chapter 1, Section 1.9. Unlike the earthquake analyses, where HazUS uses census tracts as the smallest areal unit of study, for flood analyses, HazUS uses census blocks. The geographical size of the region analyzed is nearly 62.5 square miles (see Figure 1-6); this region contains 521 census blocks (in 7 census tracts).

The flood analysis was conducted using a digital version of the 500-year flood zone shown on the Flood Insurance Rate Map presented on Plate 3-1 as a "user-supplied hazard" that was converted to a HazUS compatible format. We used HazUS to generate building stock and essential facility loss estimates for a 0.2 percent annual chance flood event (500-year flood) on the Whitewater River, with average water depths of 1 foot. The 500-year flood was chosen because the 100-year flood event would be mostly confined to the channel of the Whitewater River, whereas the 500-year flood event, while a lot less likely, would impact a significant part of the community. The results of the analysis are presented in the sections below.

The HazUS analysis conducted for Coachella uses the enhanced building stock data and essential facilities compiled for Riverside County by MMI Engineering and ABSG Consulting Inc. for the Riverside County Essential Facilities Risk Assessment (RCEFRA) Project (MAP IX – Mainland, 2009). The enhanced data used include parcel data for single-family homes, apartment and condominiums, hotels/motels and agricultural properties that replace the basic, "out-of-the-box" default inventory provided with HazUS. Parcel data for mobile homes obtained for the RCEFRA project was used to supplement the HazUS default inventory. Essential facility data were provided by the facilities themselves. Use of these data is expected to yield more accurate results than the default data, however, the numbers generated should still be considered generalized and used with caution. The results do provide an estimate of the risk, and this information can be used to develop realistic disaster mitigation plans, hazard mitigation grant applications, and to design emergency response exercises (MAP IX – Mainland, 2009).

3.3.1 Building-Related Losses

There are an estimated 9,000 households in this region, and 16,000 buildings with a total replacement value, excluding contents, of $3,743 million (in 2006 dollars). More than 90 percent of the buildings, and 85.6 percent of the building value, is associated with residential housing. The building exposure by occupancy type for the scenario considered is summarized in Table 3-4, and the expected building damage, by both occupancy and building type, is presented in Tables 3-5 and 3-6, respectively. The damage is measured as a percent of the replacement cost. Specifically, if the damage amounts to between 1 and 10 percent of the replacement cost, the damage is considered slight, whereas 11 to 50 percent damage is considered moderate. If a building suffers damage exceeding 50 percent of its replacement cost, it is considered substantially damaged. These buildings would be considered unsafe for continued occupancy and would be "red-tagged."

Table 3-4: Building Exposure by Occupancy Type for the Flood Scenario

Scenario	Whitewater River (500-Year Flood)	
Occupancy	**Exposure ($1,000)**	**Percent of Total**
Residential	1,142,490	78.0
Commercial	130,798	8.9
Industrial	21,961	1.5
Agricultural	71,367	4.9
Religion	9,254	0.6
Government	2,463	0.2
Education	86,275	5.9
Total	**1,464,608**	**100**

Tables 3-5 and 3-6 show that a 500-year flood in the Whitewater River is not anticipated to completely destroy any buildings in Coachella. However, the 500-year flood is anticipated to cause minor to moderate damage to nearly 2,360 residential structures in the region, with nearly 1,500 of these experiencing about 20 to 30 percent damage, and 283 structures experiencing more than 40 percent damage. The 2,348 damaged structures amount to more than 37 percent of the total number of buildings considered in the scenario. A comparison of Tables 3-5 and 3-6 shows that the residential structures anticipated to experience the most damage are all manufactured housing (i.e., mobile homes).

Table 3-5: Expected Building Damage by Occupancy Type

Flood Scenario	Occupancy	1-10 Count	11-20 Count	21-30 Count	31-40 Count	41-50 Count	Substantially Count
500-Year Flood Whitewater River	Agriculture	211	0	0	0	0	0
	Commercial	120	57	0	0	0	0
	Education	145	0	0	0	0	0
	Government	5	0	0	0	0	0
	Industrial	6	3	27	0	0	0
	Religion	11	0	0	0	0	0
	Residential	98	529	1,449	0	283	0
	Total	**596**	**589**	**1,476**	**0**	**283**	**0**

Table 3-6: Expected Building Damage by Building Type

Scenario	Building Type	1-10 Count	11-20 Count	21-30 Count	31-40 Count	41-50 Count	Substantially Count
500-Year Flood Whitewater River	Concrete	113	5	0	0	0	0
	Manufactured Housing	0	0	0	0	283	0
	Masonry	104	8	8	0	0	0
	Steel	108	0	0	0	0	0
	Wood	222	537	1,422	0	0	0

Building-related losses are broken into two categories: direct building losses and business interruption losses. Direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. Business interruption losses are the losses associated with the inability to operate a business because of the damage sustained during the flood. This includes loss of income for business owners, and loss of wages for employees of facilities impacted by the flood. Business interruption losses also include temporary living expenses and relocation expenses for those people displaced from their homes because of the flood.

Table 3-7: Building-Related Losses (in Millions of Dollars) as a Result of the Flood Scenario

Flood Scenario	Category	Area	Residential	Commercial	Industrial	Others	Total
500-Year Flood Whitewater River	Building Loss	Building	73.0	10.52	2.87	6.10	92.49
		Content	41.81	27.23	4.59	16.24	89.87
		Inventory	0.00	0.63	1.14	1.53	3.30
		Subtotal	114.81	38.37	8.60	23.88	185.66
	Business Interruption	Income	0.01	0.26	0.00	0.14	0.40
		Relocation	0.57	0.07	0.00	0.05	0.69
		Rental Income	0.16	0.04	0.00	0.00	0.20
		Wage	0.03	0.23	0.00	0.39	0.65
		Subtotal	0.76	38.97	0.00	0.57	1.93
	Totals		**115.57**	**38.97**	**8.60**	**24.45**	**187.59**

The HazUS analysis estimates that the 500-year flood event in the Whitewater River will generate $187.59 million in building-related losses in the Coachella General Plan area, with approximately 1 percent of this figure related to business interruption. The total economic loss represents 12.8 percent of the total replacement value of the buildings considered in the analysis. Residential occupancies make up 61.6 percent of the total loss. Table 3-7 shows the estimated building-related losses by categories that this flood event is estimated to generate in the study area.

3.3.2 Debris Generation

HazUS estimates the amount of debris that will be generated by a given flood. The model breaks debris into three general categories:

1. finishes (dry wall, insulation, etc.),
2. structural (wood, brick, etc.), and
3. foundation (concrete slab, concrete block, rebar, etc.). These distinctions are made because of the different types of equipment required to handle the debris. The HazUS estimates of debris that will be generated by the flood scenario considered for this study are presented in Table 3-8.

The model estimates that a 500-year flood event in the Whitewater River will generate 18,266 tons of debris with 100 percent of that consisting of finishes (dry wall, insulation, and like materials). This amounts to approximately 731 truckloads (at 25 tons per truckload) needed to remove this debris from the study area.

Table 3-8: Debris Generated by Flood Scenarios (in Tons)

Flood Scenario	Category of Debris Generated			Truckloads Required to Clean Debris
	Finishes	Structural	Foundation	
500-Year Whitewater River	18,266	0	0	731

3.3.3 Shelter Needs

HazUS estimates the number of households expected to be displaced from their homes due to the flood and the associated potential evacuation. HazUS also estimates those displaced people that will require accommodations in temporary public shelters. The results of the HazUS analysis for the 500-year flood event modeled for this study are presented in Table 3-9.

Table 3-9: Shelter Requirements Due to Flooding Scenarios

Flood Scenario	# Households Displaced	# of People that will Look for Shelter in Public Shelters
500-Year Whitewater River	10,558	30,348

3.3.4 Expected Damage to Essential Facilities

Essential facilities in these scenarios include hospitals, fire stations, police stations, emergency operation centers, hospitals, and schools. The essential facilities in the study area considered in the analysis include zero (0) hospitals, three fire stations, 366 school buildings, two police stations and one emergency operation center. The Coachella Emergency Operations Center is located at 53-462 Enterprise Way, in a dedicated room on the second floor of the City's Corporate Yard facility.

The results presented in Table 3-10 show the number of essential facilities that will experience at least moderate damage as a result of the flooding scenario considered. The model suggests that one of the fire stations and the 2 police stations in the study area will experience at least moderate damage. Approximately 145 school buildings are also estimated to experience at least moderate damage. However, none of these damaged facilities are expected to experience loss of use.

Table 3-10: Estimated Damage to Essential Facilities as a Result of the 500-Year Flood Scenario

Flood Scenario	Classification		No. of Facilities		
		Total	At Least Moderate Damage	At Least Substantial Damage	Loss of Use
500-Year Whitewater River	Fire Stations	3	1	0	0
	Police Stations	2	2	0	0
	School Buildings	366	145	0	0
	Emergency Operations Center	1	0	0	0

3.4 Summary

The Coachella Valley Water District, the agency in charge of regional flood control, has been proactive is protecting the valley areas from the significant flooding that occurred in the last century. Further, based on new FEMA guidelines, the Coachella Valley Water District, impacted communities, and FEMA have formed a partnership with the goal of improving the regional flood hazard from the Coachella Valley Stormwater Channel and obtaining accreditation for the levees. In addition, the District is currently preparing a Stormwater Master Plan for the eastern Coachella Valley, and the City of Coachella is developing a Storm Drain Master Plan to identify local problem areas and plan future flood control projects.

Currently, except for the Coachella Valley Stormwater Channel, no parts of the General Plan area identified as within a FEMA Special Flood Hazard Zone, thereby mandating property owners to purchase flood insurance. Nevertheless, a number of flood risks remain:

- Large portions of the General Plan area have not been mapped by FEMA, consequently the flood hazard in these areas has not been identified and evaluated.
- A significant portion of Coachella is zoned by FEMA as having a moderate flood hazard, meaning this area may be flooded during a storm stronger than the 100-year event, or subject to shallow flooding during a 100-year storm.
- A low-probability but possible 500-year flood event is estimated to cause significant losses in the city, with approximately 37 percent of the buildings in the area at least moderately damaged. Given the large area within the 500-year flood, nearly 70 percent of the city's population may be temporarily displaced.
- Levees forming the Coachella Valley Stormwater Channel are not accredited by FEMA, indicating the impacts of levee failure or overtopping have not been mitigated.
- Areas within the city are subject to localized flooding, due most commonly to the lack of adequate storm drains or the lack of temporary retention facilities.
- Unpredictable local flooding can also occur during storms if catch basins or inlets are clogged with debris.
- The areas near the Coachella Valley Stormwater Channel and the Wasteway Channels could be inundated if the channels were breached (while containing water) during a severe earthquake.
- The Eastside Dike that protects the Coachella Canal also provides significant flood protection to Coachella's valley area. However, the hillside areas northeast of the dike are subject to flooding and debris flows.

- The valley area southwest of the Coachella Canal is at risk of inundation if the canal is offset by a major ground-rupturing earthquake on this section of the San Andreas fault. Areas around and downgradient of the older water tanks may also be at risk if the tanks or associated piping rupture during a strong earthquake.

For the reasons discussed above, FEMA encourages property owners outside of the Special Flood Hazard Areas to purchase flood insurance. Further, the City should have evacuation plans in place in the event of a levee or dike failure. This is especially important for critical facilities such as schools. This also true for facilities using, storing, or otherwise dealing with substantial quantities of onsite hazardous materials, unless all requirements for elevation, anchoring, and flood proofing have been met. Hazardous materials should always be stored in watertight containers that are not capable of floating.

Given the anticipated extensive damage to the regional potable water system (including aqueducts, water mains, and distribution lines) resulting from a large-magnitude earthquake on the San Andreas fault, it is very important that the water storage tanks in the area remain structurally sound, and that they be maintained as full of water as possible. Thus, even if the water distribution pipelines are damaged, the City would have access to stored water that can be distributed to the community using water trucks or other similar methods, at least until water can be imported while the pipelines are repaired.

The City should continue to require that future planning for new developments consider the impact on flooding potential, as well as the impact of flood control structures on the environment, both locally and regionally. Flood control should not be introduced in the undeveloped areas at the expense of environmental degradation. Land development planning should continue to consider leaving watercourses natural wherever possible, or continuing to develop them as parks, nature trails, golf courses or other types of recreation areas that can withstand inundation.

CHAPTER 4: FIRE HAZARDS

4.1 Vegetation Fires

Wildfires are a significant hazard throughout the United States, and especially in the West, where they occur often. Large areas of southern California are particularly susceptible to wildfire due to the region's weather, topography and native vegetation. The typically mild, wet winters characteristic of our Mediterranean climate result in an annual growth of grasses and plants that dry out during the hot summer months. This dry vegetation provides fuel for wildfires in the autumn. Although wildfires are often considered highly disruptive and even dangerous, the fact is that wildland fires are a necessary part of the natural ecosystem of many parts of southern California, and have been part of the natural environment for millennia. Many of the native plants require periodic burning to germinate and recycle nutrients that enrich the soils. Native Americans took advantage of this, and used fire extensively to control their environment by enhancing feed for wildlife, decreasing insects and pests that impact wild foods, increasing the abundance and density of edible tubers, greens and other useful plants, and clearing underbrush to ease travel and provide increased visibility (Anderson, 2006).

Wildfires become a hazard when they extend out of control into developed areas, with a resultant loss of property, and sometimes, unfortunately, loss of life. The wildfire risk in the United States has increased in the last few decades with the increasing encroachment of residences and other structures into the wildland environment, and the increasing number of people living and playing in wildland areas. The National Interagency Fire Center estimates that approximately 15 percent of all wildland fires in the United States are started by lightning strikes, with humans causing the rest. The most common human causes of wildfires are arson, sparks from brush-clearing equipment and vehicles, improperly maintained campfires, improperly disposed cigarettes, and children playing with matches.

As the 2003, 2006, 2007, 2009, and May 2014 fires in southern California have shown, the containment of wildfires that consume thousands to hundreds of thousands of acres of vegetated property require the participation of a multi-jurisdictional emergency response effort, with hundreds to thousands of people at or near the fire lines combating the flames, clearing brush ahead of the fire to establish defensible zones, and assisting evacuees (Figures 4-1 and 4-2). Under the right wind conditions, multiple ignitions can develop as a result of the wind transport of burning cinders (called **brands**) over distances of a mile or more. Wildfires in those areas where the wildland approaches or interfaces with the urban environment (referred to as the **urban-wildland interface** area or **UWI** area) can be particularly dangerous and complex, posing a severe threat to public and firefighter safety, and potentially causing devastating losses of life and property. This is because when a wildland fire encroaches onto the built environment, ignited structures can then sustain and transmit the fire from one building to the next. It has become increasingly clear that continuous planning, preparedness, and education are required to reduce the fire hazard and limit the destruction caused by fires. These mitigation measures are discussed in this document.

Wildland fires usually last a few hours to days, but their effects can last much longer, especially in the case of intense fires that develop in areas where large amounts of dry, combustible vegetation have been allowed to accumulate. If wildland fires are followed by a period of intense rainfall, debris flows emanating from the recently burned hillsides can develop. Studies (Cannon, 2001) suggest that in addition to rainfall and slope steepness, other factors that contribute to the formation of post-fire debris flows include the underlying rock or sediment type, the shape of the drainage basin, and the presence or absence of water-repellant soils (during a fire, the organic material in the soil may be burned off or decompose into water-repellent substances that prevents water from percolating into the soil.) Flood control facilities may be severely taxed by the increased flow from the denuded hillsides and the resulting debris that washes down. If this debris overwhelms the flood control structures, widespread damage can ensue in areas down gradient from the failed structures. As an example, in San Bernardino County 16 people died as a result of debris flows during the 2004 storms that followed the 2003 fire season. During the storms of 2010, the Los Angeles County Public Works Department and several cities had crews around the clock cleaning out the debris basins between the mountains and the communities at the foot of the 250-square-mile area that burned during the Station Fire. These efforts helped significantly in reducing the hazard of mudflows, although unfortunately nearly 50 homes were still seriously damaged in the communities of La Crescenta, La Canada Flintridge, and Acton.

Other effects of wildfires are economical and social. Homeowners who lose their house to a wildfire may take years to recover financially and emotionally. Recreational areas that have been affected may be forced to close or operate at a reduced scale. In addition, buildings destroyed by fire are usually eligible for re-assessment, which reduces income to local governments from property taxes. The impact of wildland fire on plant communities is generally beneficial, although it often takes time for plant communities to re-establish themselves. If a grassland area has been burned, it will re-sprout the following spring. Chaparral plant communities will take three to five years. Oak woodland, if it has had most of the seedlings and saplings destroyed by fire, will require at least five to ten years for a new crop to start. Desert plants, like cacti, typically take more than a decade to recover after a fire.

Figure 4-1: View of the Cedar Fire of October 2003 Moving Down Oak Canyon, Toward the 52 Freeway, in San Diego County.

This fire burned more than 273,000 acres, destroyed 2,820 structures, damaged 63 others, and caused 15 fatalities. The fire was cased by a signal flare set off by a lost hunter. This is the largest fire by acreage burned in California since at least 1932, when reliable records were first kept.

Figure 4-2: View of a Backfire to the Station Fire Behind Homes in La Crescenta.
The Station Fire burned 160,557 acres, 209 structures and caused 2 deaths. It is considered the 10th largest California fire by acreage burned (http://cdfdata.fire.ca.gov/incidents/incidents_statsevents).
(Photograph by Jae C. Hong/AP Photo, taken on September 1, 2009).

4.1.1 Local Characteristics and History on Local Fires

The fire hazard of an area is typically based on the combined input of several parameters. These conditions include: 1) fuel loads – that is, the type of fuel or vegetation, and its density and continuity, 2) topography – elevation and slope, 3) weather, 4) wildfire history, 5) dwelling density, and 6) existing local mitigation measures that help reduce the area's fire hazard – such as fuel modification zones, fire-rated construction, fire hydrants, etc. The fuel loads, weather and wildfire history of the Coachella General Plan area are discussed further immediately below. Other aspects of the fire hazard equation, with emphasis on the fire risk areas mapped in the study region, and the fire suppression services available are discussed further in Sections 4.1.2 and 4.3, respectively.

4.1.1.1 Fuel Loads and Topography

Coachella is for the most part located in the Colorado Desert section of the Southeastern Deserts Bioregion (Brooks and Minnich, 2006). The Southeastern Deserts bioregion comprises about 27 percent of the land mass in California, and the Colorado Desert section comprises about 10 percent of that. The Deserts Bioregion is characterized by isolated mountain ranges separated by broad basins blanketed with alluvial fan, dune and playa deposits. This wide range in elevations and soil types results in a wide range of vegetation and fuel types. In its native state, the Colorado Desert section is characterized by low- to mid-size riparian vegetation, with desert scrub (including creosote bush scrub and desert saltbush scrub) being the predominant vegetation type (estimated at 57 percent by Brooks and Minnich, 2006). Barren areas, devoid of vegetation, are estimated to account for anywhere between about 40 percent and 90 percent of the acreage in this region (Brooks and Minnich, 2006; Crosswhite and Crosswhite, 1982). Unlike the primary vegetation types common in other bioregions of southern California, desert plants do not need fire to reproduce, and many of the native plants common to this area are highly susceptible to fire. Furthermore, native desert plant communities may take decades to re-establish after a fire, whereas non-native grasses are quick to invade burned areas, generally at the expense of the native plants.

In Coachella, however, most of the acreage within the Colorado Desert section is no longer in a natural state, as the native cover has been replaced by crops and urban development, or has been altered to varying degrees by road construction, introduction of invasive plant species, and other stressors. Pockets of native desert saltbush scrub, often intergrading with Sonoran creosote bush scrub have been reported along and to the west of the Coachella Canal. The saltbush scrub occurs in areas of moist, sandy loam soil with relatively high salinity, whereas the creosote bush scrub occurs on alluvial fans and low-gradient desert slopes, on coarse-grained, well-drained soils with lower salinity. Woody wetlands with denser stands of vegetation still occur primarily in the southern part of Coachella, just north of the Thermal airport (Bureau of Reclamation, 2006).

Figures 4-3a and 4-3b: Examples of Vegetation Cover in the Coachella Area.
Photo at left shows typical desert vegetation in the foreground, cultivated vegetation in the background. Photo at right shows dense stands of vegetation near the Whitewater River channel.

The hilly, far eastern section of the planning area, in the southeastern foothills of the San Bernardino Mountains, is placed by Keeley (2006) in a small outlier of the South Coast Bioregion. The South Coast Bioregion includes the highest peaks outside of the Sierra Nevada (the San Bernardino Mountains reach an elevation of more than 11,500 feet), although more than 50 percent of the area is at elevations below 1,600 feet. As with the deserts region, this range of elevations translates into a high diversity of vegetation types and fire regimes. In the Coachella area, vegetation series that have been reported along the Coachella Canal and in the hillsides to the east include tamarisk, catclaw acacia shrub, mesquite hummocks, and along the canyon bottoms and washes, Fremont cottonwood.

Mesquite hummocks, which are relatively large clumps of honey mesquite shrubs forming hummocks (hills) over sand fields and sand dunes, occur locally in the planning area, typically along or near the San Andreas fault (where not disturbed by the Coachella Canal) (Bureau of Reclamation, 2006). Furthermore, the San Andreas fault brings groundwater up to near the ground surface, forming isolated springs and seeps. These springs support stands of denser vegetation consisting of cottonwood and willows.

In southern California, the predominant vegetation types generally germinate after the first rains of spring, and dry up in the fall, when the weather is dry and hot. This dried-up vegetation provides fuel for wildfires (Photo 4-4). In the desert bioregion, the primary factor controlling fire occurrence and spread is fuel condition, especially fuel type and continuity. Since fuel continuity is generally low in the region, fires typically do not spread beyond their ignition points. In the currently developed portions of the City, vegetation fires are not considered a hazard given the low topographic relief and low fuel loads. In the areas developed as agricultural fields, the carefully maintained and regularly watered vegetation combine to mitigate the potential for wildfires. Vegetation fires in these areas are possible, typically the result of intentionally set brush and grass fires, but these tend to be small in area (typically less than one acre in size), and less intense in heat than dense brush and forest fires.

Figure 4-4: **Photo of a Wildfire in Thousand Palms**,
With Barren Areas Limiting the Fire Spread

Source: Photo of the Palm Fire of November 26, 2010, taken by Thousand Palms resident Mike Smith, from http://thousandpalms.kpsplocal2.com/content/palm-fire-90-contained-coachella-valley-preserve, article by Anne Hsu, Local 2 Mobile Journalist, dated Friday, November 26th, 2010, 10:33PM.

4.1.1.2 Weather

The Coachella General Plan area is arid. Annual temperatures in the Coachella Valley fluctuate significantly given the region's inland location, away from the stabilizing influence of the Pacific Ocean. Average minimum temperatures in the Indio-Coachella region, based on data collected at the Indio Fire Station for the 30 years between 1961 and 1990, range from 39.9 degrees Fahrenheit in January to 77.7 degrees in July; average maximum temperatures range from 71.8 degrees in January to 107.2 degrees in July (http://www.worldclimate.com/). Average annual precipitation in Coachella is a little over 3 inches (see Chapter 3, Section 3.1.2 for more details), with approximately 60 percent of the precipitation occurring in the winter months between November and February, and approximately 20 percent occurring in the late summer and early fall, between July and September. These summer storms typically approach from the south (from Mexico through Arizona, or from the Sea of Cortez or Baja California).

Both winter and summer thunderstorms that pass through southern California often include lightning. The deserts have the highest frequency of lighting than any other California bioregion. In the Colorado Desert, lightning averages 12 strikes per 100 square kilometers per year (based on Bureau of Land Management detection data by van Wagtendonk and Cayan, 2008, as reported in Brooks and Minnich, 2006). Most lightning in the desert occurs between July and September, and most occurs during daylight hours (Brooks and Minich, 2006). As discussed in the introduction, lightning is responsible for a significant percentage of the acreage burned by wildfires in the United States, although human-caused fires are far more common.

4.1.1.3 Wildfire History

According to data by the California Department of Forestry and Fire Protection (Cal Fire; http://frap.cdf.ca.gov/data/frapgismaps/download.asp), there have not been any large fires in the Coachella General Plan study area between 1900 and 2008. Three fires were mapped by CalFire to the south of Coachella, including a fire in 1981 that occurred approximately one mile south of the City limits, off Highway 86 (Harrison Street). The other two fires reported by CalFire south of the study area occurred in 1975 and 2008. This database, however, is incomplete, as the CalFire data typically do not include fires less than 10 acres in size. The National Oceanic and Aeronautic Agency (NOAA) maintains a database of wildland fires that, in the case of Riverside County, extends back to 1996 (in other areas, and for other hazards, the records may extend back to 1950). Several fires in the NOAA list are not in the CalFire database and vice-versa. Table 4-1 summarizes wildland fires reported in the Coachella Valley, including the city of Coachella, for the period between 1996 and January 2014, with data obtained both from the NOAA database and newspaper accounts.

Table 4-1: Wildland Fires Reported in the Coachella Valley and In and Near the City of Coachella, 1996 to January 2014

Date	Fire Description
January 21, 1999	Strong winds caused palm fronds to touch electrical power lines and ignite about 8 miles east-southeast of Mecca, near the intersection of Palm Island Drive and Highway 111. Wind gusts to 80 mph then fanned the flames into a 30-acre wildfire that affected the community of North Shore, destroying one house, a garage, small office building, one storage shed, two travel trailers, and eight vehicles. Several residents were evacuated and one family was left homeless. Property damage was estimated at $400k.
August 9, 1999	A wildfire was quickly spread by shifting winds, burning 10 acres about 2 miles north of the Thermal Airport (in **Coachella**). Flames approached within 2 feet of six homes but did not burn any structures.
September 8, 2000	A wildfire triggered by lightning started in the Santa Rosa Mountains, about 9 miles southwest of the Thermal Airport, and spread about 35 acres before it was fully contained. No property damage was reported.
June 17-18, 2001	A brush fire occurred along the Palm Springs Tramway Road that eventually burned 300 acres and forced temporary closure of the Aerial Tramway. Winds in the canyon of between 25 and 30 mpg during the night impeded the Fire Department's efforts to stop the blaze.
May 9, 2002	A brush fire consumed 35 acres about 2 miles north of **Coachella** before being contained. No structures were damaged, and no injuries were reported.

Date	Fire Description
June 1, 2002	Flames from a house fire about 2 miles northwest of the Palm Springs Airport were spread by wind to the surrounding brush, consuming a telephone pole. Property damage was estimated at $95K.
June 17, 2002	Gusty winds and 120 degree temperatures helped fuel a brush fire about 2 miles southwest of Desert Hot Springs that eventually consumed one house, several vehicles and numerous trees. Fur firefighters were treated for heat exhaustion, and another suffered a minor injury. Property damage was estimated at $300K.
June 25, 2002	A wildfire was reported in White Water, in the center divide of the I-10 freeway, with dense smoke affecting traffic. No property damage or injuries reported.
June 30, 2002	A vehicle fire was spread by winds, burning 10 acres of brush about 3 miles north of Palm Springs. Property damage was estimated at $20K.
June 26, 2003	A brush fire burned 324 acres, threatened 120 structures, and forced the evacuation of 300 residents from the Torres Martinez Indian Reservation in Mecca. Two firefighters were treated for smoke inhalation.
August 26-31, 2005	The Blaisdell (Canyon) Fire, as it was named, started as an out-of-control campfire in Blaisdell Canyon, on the north face of the San Jacinto Mountain. The fire raced up canyon, shutting down temporarily the Palm Springs Aerial Tramway. The fire burned 5,493 acres before it was extinguished. No property damage was reported.
April 3-5, 2009	A blaze started in the afternoon, south of Tramway Road, Palm Springs, and quickly spread due to the strong winds, burning 50 acres. The fire damaged two homes and forced mandatory evacuations for residents in the Racquet Club Road area west of Hwy. 111. At least two people suffered smoke inhalation. The Palm Springs Aerial Tramway was closed for the duration of the fire due to wind gusts up to 70 mph. $250k in property damage reported.
November 26-27, 2010	The Palm Fire occurred in the Coachella Valley Preserve near Thousand Palms. No structures were threatened and no injuries were reported. Most of the damage was confined to the Willis Grove, with the palm fronds and skirts of most trees impacted by the blaze. By the spring of 2011, most trees tops were showing new green growth.
September 24-26, 2011	The Windy Point Fire occurred in steep, rocky terrain west of the Palm Springs Tramway. State Highway 111 was closed in both directions while the blaze was fought. The fire burned 541 acres before being fully contained on the 26th. No structures were damaged or threatened, and there were no injuries reported.

Sources: NOAA, at http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms;
Los Angeles Times, and The Californian

The list presented above is undoubtedly incomplete, as it does not include small, vegetation/refuse fires. Data compiled by the National Fire Protection Agency (NFPA) show that many local fire department responses are for brush, grass and other miscellaneous fires. In fact, statistics from the NFPA for the years between 2004 and 2008 show that nationwide, brush, grass and forest fires account for about 23 percent of all fires reported to local fire departments. Nearly three-fourths of these fires burn less than one acre, and only 4 percent burn more than ten acres (Ahrens, 2010). About 20 percent of the vegetation fires reported are intentionally set, and another 15 percent start as refuse or debris disposal fires (both permitted and not permitted). Other leading causes of vegetation fires include hot embers or ashes (17 percent), high winds (13 percent), smoking materials (12 percent), playing with heat or fire sources such as matches (6 percent), fireworks (5 percent), electrical power or utility lines (4 percent), and lightning (4 percent) (Ahrens, 2010). For statistics regarding the types of incidents that the Riverside County Fire Department responded to between 2010 and 2013 in Coachella, refer to Table 4.2. Note that fires comprise less than 5 percent of the total yearly incident calls, with vegetation fires (presumably categorized under “Other Fires”) comprising an even smaller percentage.

Table 4-2: Statistics on Incident Types Responded to by the Fire Department in the City of Coachella for the Years 2010-2013

Year / Incident Type	2010	2011	2012	2013
Structure Fires	28	20	24	14
Other Fires	65	49	71	90
Ringing Alarms	118	133	147	160
Medical Incidents	1,523	1,485	1,608	1,682
Other Incidents	342	341	387	325
Total (within City Limits)	**2,076**	**2,028**	**2,237**	**2,271**

Source: Data provided by Battalion Chief De La Cruz, written communication on May 12, 2014.

4.1.2 Regulatory Context and Fire Risk Areas

Since the early 1970s, several fire hazard assessment and classification systems have been developed for the purpose of quantifying the severity of the fire hazard in a given area. Many of these are regulatory in that they were implemented as a result of legislation enacted either at the State or Federal level. Early systems characterized the fire hazard of an area based on a weighted factor that typically considered fuel, weather and topography. More recent systems rely on the use of Geographic Information System (GIS) technology to integrate the factors listed above to map the hazards, and to predict fire behavior and the impact on watersheds.

4.1.2.1 HUD Study System

In April 1973, the California Department of Forestry (CDF – now the California Department of Forestry and Fire Protection, also known as CalFire) published a study funded by the Department of Housing and Urban Development (HUD) under an agreement with the Governor's Office of Planning and Research (Helm et al., 1973). As is the case with several other more recent programs, the study was conducted in response to a disaster: during September and October 1970, 773 wildfires burned more than 580,000 acres of California land. The HUD mapping process relied on information obtained from U.S. Geological Survey (USGS) 15- and 7.5-minute quadrangle maps on fuel loading (vegetation type and density) and slope, and combined it with fire weather information (now available in real-time at http://gacc.nifc.gov/oscc/predictive/fuels_fire-danger/index.htm) to determine the **Fire Hazard Severity** of an area. This system was the basis for several subsequent studies and programs that have been conducted as a result of more recent legislation, as described further below.

4.1.2.2 California Department of Forestry and Fire Protection – State Responsibility Areas System

Legislative mandates passed in 1981 (Senate Bill 81, Ayala, 1981) and 1982 (Senate Bill 1916, Ayala, 1982) that became effective on July 1, 1986, required the CDF to develop and implement a system to rank fire hazards in California. Areas were rated as moderate, high or very high based primarily on fuel types. Thirteen different fuel types were considered using the 7.5-minute quadrangle maps by the USGS as base maps (Phillips, 1983). Areas identified as having a fire hazard were referred to as **State Responsibility Areas** (SRAs) (Public Resources Code Section 4125). These are non-federal and non-incorporated lands covered wholly or in part by timber, brush, undergrowth or grass, for which the State has the primary financial responsibility of preventing and suppressing fires. SRAs also do not exceed a housing density of 3 units per acre, and the land has watershed and/or range/forage value, effectively eliminating most desert lands from the SRA definition.

There are no State Responsibility Areas in the Coachella General Plan area. However, there are several areas in the Coachella General Plan study region that are classified as ***Federal Responsibility Areas (FRAs)*** *with a* ***moderate fire hazard*** *(CDF, 2007). A small section in the far northeastern corner of the planning area is considered to have a* ***high fire hazard*** *(see orange areas on Plate 4-1). Most of the eastern and northeastern portions of Coachella are mapped as Local Responsibility Areas (LRAs*), as described further below.

4.1.2.3 Bates Bill Process

The Bates Bill (Assembly Bill 337, September 29, 1992) was a direct result of the great loss of lives and homes in the Oakland Hills Tunnel Fire of 1991. Prior to the adoption of this bill, the authority to apply wildland fire safety regulations in areas outside State control varied from one jurisdiction to the next, depending on the regulations adopted by individual legislative bodies. The original intent of the bill was to create a single fire district to provide coordinated response to any future fires in the area; the final document developed fire safety regulations to be applied consistently throughout the State (Collins, 2000). As part of this effort, the California Department of Forestry and Fire Protection (CDF), in cooperation with local fire authorities, was tasked to evaluate the fire hazard **of Local Responsibility Areas** (**LRA**s) and identify **Very High Fire Hazard Severity Zones** (VHFHSZs) therein. To accomplish this, the CDF formed a working group comprised of state and local representatives that devised a point system that considers fuel (vegetation), slope, weather, and dwelling density. To qualify as a VHFHSZ, an area has to score ten or more points in the grading scale. Once the boundaries of a VHFHSZ have been delineated, the CDF notifies the local fire authorities that are responsible for fire prevention and suppression within that area. Since the State is not financially responsible for Local Responsibility Areas, local jurisdictions have final say regarding whether or not an area should be included in a VHFHSZ (Government Code Section 51178). Declaring an area a VHFHSZA means that the local fire department has to enforce the provisions of Section 4291 of the Public Resources Code. Local jurisdictions that do not follow the Bates system are required to follow at a minimum the model ordinance developed by the State Fire Marshal for mitigation purposes. The risk of fire in VHFHSZs needs to be addressed in the Safety Element of the General Plan (see section below entitled Senate Bill 1241, Kehoe Statutes of 2012).

The CDF (2008) recommended that the hillside areas in the eastern and northeastern portions of Coachella, which are ***Local Responsibility Areas****, be classified as having a* ***moderate fire hazard*** *(see pink areas on Plate 4-1). There are no very high fire hazard severity zones in the Coachella General Plan area. The developed areas in the valley floor are mapped as Non-Wldland or Urban Unzoned, and are considered to not have a wildland fire hazard.*

4.1.2.4 California Fire Plan

The 1996 California Fire Plan is a cooperative effort between the State Board of Forestry and Fire Protection and the CDF (California Board of Forestry, 1996). This system ranks the fire hazard of the wildland areas of the State using four main criteria: fuels, weather, assets at risk, and level of service (which is a measure of the fire department's success in initial-attack fire suppression). The California Fire Plan uses GIS-based data layers to conduct the initial evaluations, and local CDF Ranger Units are then tasked with field validation of the initial assessment. The final maps use a Fire Plan grid cell with an area of approximately 450 acres, which represents 1/81 of the area of a 7.5-minute quadrangle map (called Quad 81). The fire hazard of an individual cell is ranked as **moderate**, **high** or **very high**. The main objective of the California Fire Plan is to reduce total costs and losses from wildland fire in the State by protecting assets at risk before a fire occurs. To do so, the plan identifies prefire management

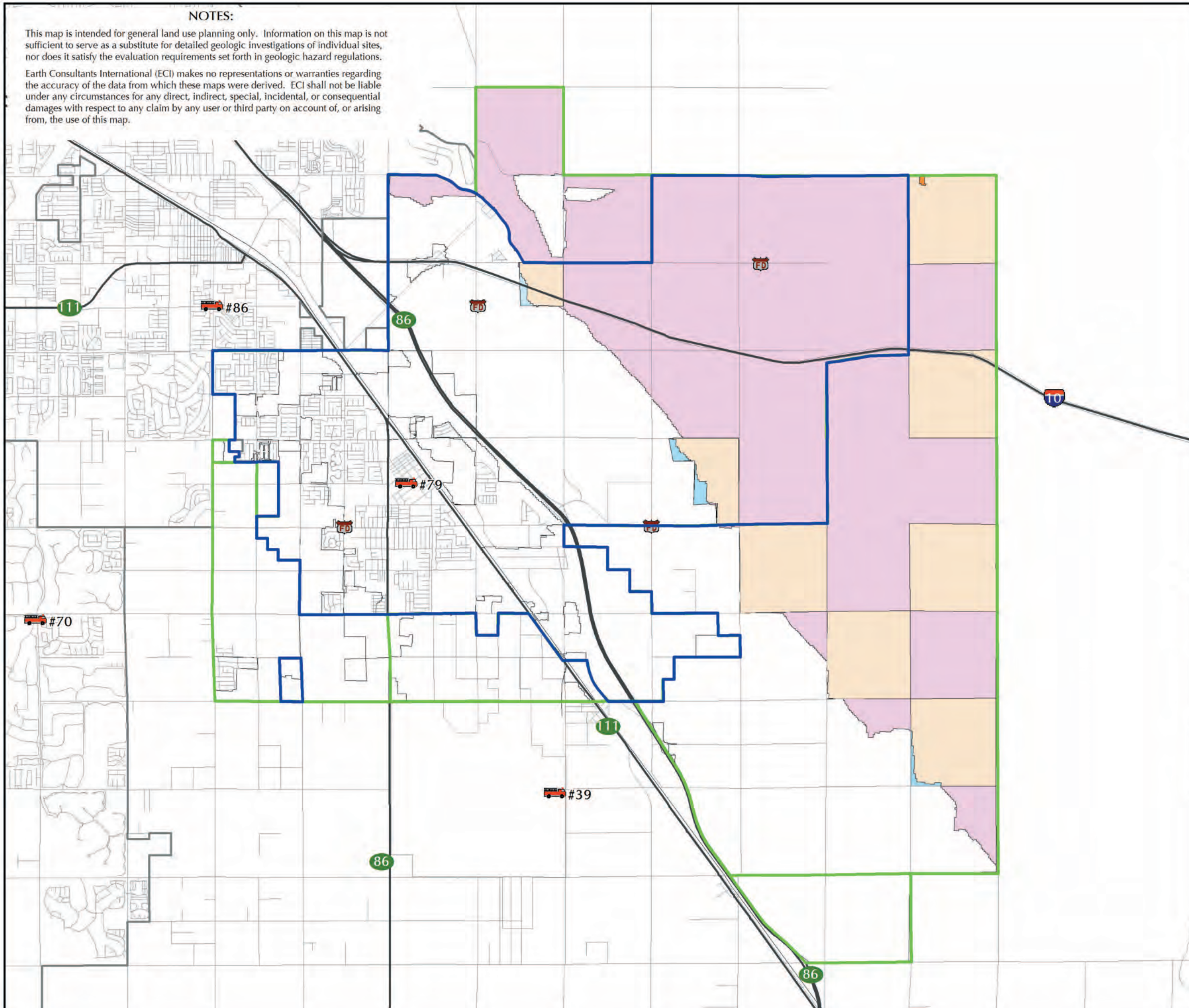
High Fire Hazard Areas

Coachella, California

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.



Explanation

Local Responsibility Area

- Moderate Fire Hazard Severity Zone
- Non-Wildland/Non-Urban or Urban Unzoned

Federal Responsibility Area

- High Fire Hazard Severity Zone
- Moderate Fire Hazard Severity Zone
- Non-Wildland/Non-Urban or Urban Unzoned

- Fire Station
- Approximate location of proposed or recommended new fire stations (City of Coachella Fire and Emergency Master Plan, 2007).
- Coachella City Boundary
- Coachella Planning Area Boundary

Possible future fire station in the McNaughton area not shown.

N W E S

Scale: 1:72,000

6000 0 6000 Feet

2000 0 2000 Meters

Base Map: City of Coachella.
Sources: Fire and Resource Assesment Program, California Department of Forestry and Fire Protection (2007&2013); Riverside County Fire Department (www.rvcfire.org/opencms/facilities/).

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Plate 4-1

prescriptions that can be implemented to reduce the risk, and analyzes policy issues and develops recommendations for changes in public policy. The most current California Fire Plan, as of the writing of this document, dates from 2010. For more information, including a digital copy of the entire 2010 Plan, go to http://cdfdata.fire.ca.gov/fire_er/fpp_planning_cafireplan.

Under the California Plan, most of the Coachella General Plan area east of the Coachella Canal, given the area's vegetation types and slope characteristics, is mapped as having a ***moderate fuel rank*** *and* ***potential fire behavior****, with isolated pockets of high fuel rank potential fire behavior (http://frap.cdf.ca.gov/data/frapgismaps/download.asp). The western and southwestern portions of the General Plan area are mapped as having non-wildland fuel.*

4.1.2.5 National Fire Plan

During the 2000 fire season, wildfires burned millions of acres of land throughout the United States, prompting politicians, fire managers and government agencies to re-think their approach to fire management. Under Presidential Executive Order, the Secretaries of Agriculture and the Interior were tasked with preparing a report that outlined recommendations to minimize both the long- and short-term impacts of wildfires with a broader effort and closer cooperation between agencies and fire programs. The resultant report, entitled the "National Fire Plan," has as its main purposes to protect communities and restore ecological health on Federal lands (http://www.forestsandrangelands.gov/NFP/index.shtml). The Plan outlines five key points: 1) firefighting, 2) rehabilitation and restoration, 3) hazardous fuel reduction, 4) community assistance, and 5) accountability. The Plan, which was first funded in 2001, commits to funding for a continued level of "Hazardous Fuel Reduction" and new funding for a "Community Assistance/Community Protection Initiative." The intent of the Community Assistance initiative is to provide communities that interface with federal lands an opportunity to get technical assistance and funding to reduce their threat of wildfires.

As part of the Community Assistance/Community Protection Initiative, the National Fire Plan funded a study to identify areas that are at high risk of damage from wildfire. Under this program, Federal fire managers authorized State foresters to determine which communities are at significant risk from wildland fire on Federal lands. In California, this task was undertaken by the California Fire Alliance (CFA), a cooperative group of State, Federal and local agencies, who in 2001 generated a list of communities at risk. Given California's extensive Urban-Wildland Interface (UWI), the list of communities extends beyond just those on Federal lands. In fact, as of 2014, the CFA has identified 1,289 fire-threatened communities in California, and *the City of Coachella* was, in 2001, placed on the list of Federally regulated ***Communities at Risk****, as the city is located adjacent to Federal lands with a fire threat that are Federally protected* (http://www.cafirealliance.org/communities_at_risk/). Communities can change their status on the Communities at Risk list, or they can request to be added to the list. Information on this program, including the Communities at Risk Application Form, is available from the worldwide web at http://www.cafirealliance.org/communities_at_risk/communities_at_risk_changestatus.

Under the auspices of the National Fire Plan, the CDF also produced a **Wildland Fire Threat Map**, released on October 20, 2005, that takes into account the combined effects of potential fire behavior (fuel rank) and expected fire frequency (fire rotation) from the past 50 years to create four threat classes for risk assessment. These threat classes are extreme, very high, high and moderate. Areas that do not support wildland fuels (such as open water, and agricultural lands) were not considered in the analysis. Most large urbanized areas receive a moderate fire threat classification to account for fires carried by ornamental vegetation and flammable structures. *The Fire Threat Map (available at http://www.frap.fire.ca.gov/data/frapgismaps/*

download.asp) shows that the developed areas of Coachella west of the Canal are included in the non-fuel fire threat classification, whereas the eastern and northeastern sections to the east of the Coachella Canal predominantly have a ***moderate fire threat****.* ***High fire threat areas*** *are shown locally in the northern and southeastern sections of the General Plan area.*

4.1.2.6 California Fire Alliance (CFA)

In addition to generating and updating the Communities at Risk list described above, the CFA funds a variety of projects designed to reduce the threat of wildfire before it happens. As part of this effort, the CFA encourages the development of Community Wildfire Protection Plans (CWPP), as defined by the Healthy Forest Restoration Act (HFRA) of 2003. CWPPs enable a community to plan how it will reduce its risk of wildfire by identifying strategic sites and methods for fuel reduction projects across the landscape and jurisdictional boundaries. Benefits of having a CWPP include National Fire Plan funding priority for projects identified in a CWPP. The USDA Forest Service and Bureau of Land Management can expedite the implementation of fuel treatments, identified in a CWPP, through alternative environmental compliance options offered under the HFRA. The CWPP must be agreed to by three entities: the local government, the local Fire Department, and the CDF. Communities developing CWPPs are encouraged to integrate their CWPP planning process into other planning processes, including the Safety Element of the General Plan (i.e., this document), Local Hazard Mitigation Plans, Flood Mitigation Plans, and other local hazard, evacuation and emergency plans. As of May 2014, *neither the City of Coachella, nor Riverside County, had a Community Wildfire Protection Plan on file with the California Department of Forestry and Fire Protection.*

4.1.2.7 Real-Estate Disclosure Requirements

California state law [Assembly Bill 6; Civil Code Section 1103(c)(6)] requires that fire hazard areas be disclosed in real estate transactions; that is, real-estate sellers are required to inform prospective buyers whether or not a property is located within a wildland area that could contain substantial fire risks and hazards, such as a State Responsibility Area.

Real-estate disclosure requirements are important because in California the average period of ownership for residences is only five years (Coleman, 1994). This turnover creates an information gap between the several generations of homeowners in fire hazard areas. Un-informed homeowners may attempt landscaping or modifications that could be a detriment to the fire-resistant qualities of their structure, with potentially negative consequences.

Although Federal, State and to some degree, local agencies have inventoried and classified the fire hazard of a given area, some users are in need of additional detail, or need to evaluate the fire conditions of an area at a specific time of the year, or under specific fuel loading and weather conditions. The tools below are not regulatory, but given that they are used by specific industry groups, or have applications that can be useful to an agency such as the local or County Department or the National Forest Service, they are described further.

4.1.2.8 FireLine System

The Insurance Services Office (ISO) developed a program used by the insurance industry to identify those areas where the potential loss due to wildfire is greatest (ISO, 1997). ISO retained Pacific Meridian Resources of Emeryville, California to develop the FireLine software, which uses satellite-imagery interpretation to evaluate the factors of fuel types, slope and roads (access) to develop the risk rating. Most insurance companies that provide insurance services to homeowners in California now use this system. This software is only available through ISO.

Updated versions of this system are being developed that include the factors of elevation, aspect, and relative slope position.

4.1.2.9 BEHAVE, FARSITE, FlamMap and Other Models

These are computer programs, typically PC-based, that can be used by fire managers to calculate potential fire behavior in a given area using GIS data inputs for terrain and fuels. The purpose of these models is to predict fire behavior. Data inputs that can be used in the analyses include elevation, slope, aspect, surface fuel, canopy cover, stand height, crown base height and crown bulk density.

The oldest of these models is the **BEHAVE** Fire Behavior Prediction and Fuel Modeling System (Burgan and Rothermel, 1984; Burgan, 1987; Andrews, 1986; Andrews and Chase, 1989; Andrews and Bradshaw, 1990) that has been used since 1984. A newer version of it is referred to as the BehavePlus Fire Modeling System (Andrews and Bevins, 1999). **BehavePlus** is a suite of fire behavior systems that includes FlamMap, FARSITE, and FSPro. Input to the BehavePlus model is supplied interactively by the user; typically users run several calculations to evaluate and compare the effects that a range of values will have on the results. Each run consists of a set of uniform conditions.

FARSITE (Finney, 1995, 1998) is a deterministic modeling system that calculates the growth and behavior of a wildfire as it spreads through variable fuel and terrain under changing weather conditions (http://www.firemodels.org/index.php/farsite-introduction). This software can be used to project the growth of ongoing wildfires and prescribed fires, and can be used as a planning tool for fire suppression and prevention, and fuel assessment.

FlamMap (Finney, 2006; Stratton, 2006) is a mapping and analysis system that can be used to model fire behavior across the landscape under constant weather and fuel moisture conditions. The system provides the spatial component to the software suite. Because the environmental conditions remain constant, the software cannot be used to simulate temporal variations in fire behavior. Given that fuel is a variable in the input data, this software is well-suited to run landscape-level comparisons to evaluate the effectiveness of different fuel treatments under varying topographic conditions.

FSPro is used to calculate the probability that fire will spread from a known perimeter or point, but it does not provide fire perimeters, nor does it provide a projection of fire size. This piece of software requires more computing power than that typically provided by a personal computer (http://www.firemodels.org/index.php/behaveplus-introduction/behaveplus-overview).

4.1.2.10 Disaster Mitigation Act of 2000

This Act requires local governments to prepare and adopt a Local Hazard Mitigation Plan that has been reviewed and approved by the State's Mitigation Officer (in California this agency is the California Emergency Management Agency – Cal-EMA) and the Federal Emergency Management Agency (FEMA), as a condition of receiving mitigation project assistance. These documents are to focus on pre-disaster planning and activities as a way to reduce response and post-disaster costs. Local Hazard Mitigation Plans should be consistent with the policies contained in the General Plan, especially the Safety Element. Wildfire mitigation programs discussed in these two documents should be consistent and integrated to ensure that the hazard of wildfire is addressed in an effective manner. *The City of Coachella is a participant member of the Riverside County Operational Area Multi-Jurisdictional Hazard Mitigation Plan (HMP) approved by FEMA in March 2005 and ongoing updates to that document.*

4.1.2.11 Senate Bill 1241 (2012 Kehoe Statutes)

To address the increasing issues at the wildland-urban interface, Senate Bill 1241 (Kehoe, Statutes of 2012) revised the Safety Element requirements for state responsibility areas and very high fire hazard severity zones (Government Code Sections 65302 and 65302.5). Specifically, SB 1241 requires cities revising their Housing Element of the General Plan on or after January 1, 2014, to also review and update their Safety Element to address the risk of fire in state responsibility areas and very high fire hazard severity zones. SB 1241 requires the Safety Element include the following:

1. Fire hazard severity zone maps available from the Department of Forestry and Fire Protection.
   a. Historical data on wildfires available from local agencies;
   b. Information about wildfire hazard areas that may be available from the United States Geological Survey;
   c. General location and distribution of existing and planned uses of land in very high hazard severity zones and in state responsibility areas, including structures, roads, utilities, and essential public facilities;
   d. Local, state and federal agencies with responsibility for fire protection, including special districts and local offices of emergency services.

2. A set of goals, policies, and objectives based on the information identified in subparagraph (1) regarding fire hazards for the protection of the community from the unreasonable risk of wildfire.

3. A set of feasible implementation measures designed to carry out the goals, policies, and objectives based on the information identified in subparagraph (2) including, but not limited to:
   a. Avoiding or minimizing the wildfire hazards associated with new uses of land;
   b. Locating, whenever feasible, new essential public facilities outside of high fire risk areas, including, but not limited to, hospitals and health care facilities, emergency shelters, emergency command centers, and emergency communication facilities, or identifying construction methods or other methods to minimize damage if these facilities are located in a state responsibility area or very high fire hazard severity zone;
   c. Designing adequate infrastructure if a new development is located in a state responsibility area or in a very high fire hazard severity zone, including safe access for emergency response vehicles, visible street signs, and water supplies for structural fire suppression;
   d. Working cooperatively with public agencies with responsibility for fire protection.

4. If a city or county has adopted a fire safety plan or document separate from the General Plan, an attachment of, or reference to a city or county's adopted fire safety plan or document that fulfills commensurate goals and objectives and contains information required pursuant to this paragraph.

SB 1241 also requires that the draft Element of or draft amendment to the Safety Element of a county or a city's General Plan be submitted to the State Board of Forestry and Fire Protection and to every local agency that provides fire protection to territory in the city or county at least 90 days prior to either: 1) the adoption or amendment to the Safety Element of its General Plan for each county that contains state responsibility areas; or 2) the adoption or amendment to the

Safety Element of its General Plan for each city or county that contains a very high fire hazard severity zone as defined pursuant to subdivision (b) of Section 51177.

There are no State Responsibility Areas and no very high fire hazard severity zones in the Coachella General Plan area. Thus, the provisions of SB 1241 do not apply to Coachella. However, this does not prevent the City from submitting a copy of this report to the Riverside County Fire Department and other agencies for informational purposes.

4.1.3 Fire Prevention and Suppression Programs and Regulations

There are several fire prevention and suppression programs that communities can implement to reduce their wildland fire hazard. Some of these programs aim to control the type, density and continuity of fuel (vegetation) available for a fire to burn; others are directed at the strengthening of structures to be more fire resistant. Given that the increase in catastrophic, human-caused wildland fires is associated with an increased number of people living and playing in wildland areas, limiting human-wildland interaction during periods of heightened fire risk can also help reduce the likelihood of human-caused fires in an area. Finally, the effective containment of a wildland fire before it impacts vulnerable structures is in great part the result of the suppression resources available to the agencies fighting the fire, and the fire department's accessibility to the impacted area. Some of these programs are described in more detail below.

4.1.3.1 Vegetation Management

Experience and research have shown that vegetation management is an effective means of reducing the wildland fire hazard. Therefore, in those areas identified as susceptible to wildland fire, land development is governed by special State, county and local codes, and property owners are required to follow maintenance guidelines aimed at reducing the amount and continuity of the fuel (vegetation) available.

Requirements for vegetation management at the urban-wildland interface (UWI) in California were revisited following the 1993 wildland fires that impacted large areas of Orange, Los Angeles and Ventura counties. The International Fire Code Institute formed a committee to develop a Wildland-Urban Interface Code under the direction of the California State Fire Marshal. The first draft of this code was published in October 1995. Then, in 2003, the International Fire Code Institute consolidated into the International Code Council. The International Code Council updates these documents every three years; the most recent Wildland-Urban Interface Code is the 2012 edition. The code contains provisions addressing fire spread, accessibility, defensible space, and water supply for buildings constructed near wildland areas. California incorporated the Wildland-Urban Interface Code into the California Building Standards Code, which incorporates the fire safety provisions of the California Fire Code and the California Building Code. The California Fire Code contains standards for building design, water supply and brush clearance.

Per the City of Coachella Municipal Code, Sections 3.08.070 and 3.08.080 - Uniform Fire Code and California Fire Code Violations, the Fire Chief shall have exclusive enforcement authority regarding any violation of the Uniform Fire Code and California Fire Code, respectively, unless otherwise provided in writing by the Fire Chief pursuant to the Uniform Fire Code and California Fire Code or any other applicable statutes, codes, rules and/or regulations.

Hazard reduction and **fuel modification** are the two methods that communities most often employ to reduce the risk of fire at the UWI. Both methodologies use the principle of reducing the amount of combustible fuel available, which reduces the amount of heat, associated flame lengths, and the intensity of the fire that would threaten adjacent structures. The purpose of these methods is to reduce the hazard of wildfire by establishing a **defensible space** around buildings or structures in the area. Defensible space is defined as an area, either natural or man-made, where plant materials and natural fuels have been treated, cleared, or modified to slow the rate and intensity of an advancing wildfire, and to create an area for firefighters to suppress the fire and save the structure. These standards require property owners in the UWI to conduct maintenance, modifying or removing non-fire-resistive vegetation around their structures to reduce the fire danger. This affects any person who owns, leases, controls, operates, or maintains a building or structure in, upon, or adjoining the UWI.

Since January 1, 2005, properties in California within a wildland fire hazard area are required to maintain a defensible space clearance around buildings and structures of 100 feet (Public Resources Code 4291), or to their property line, whichever is less. This requirement applies to any person who owns, leases, controls, operates, or maintains a building or structure in, upon, or adjoining a mountainous area, forest-covered land, brush-covered land, grass-covered land, or any land that is covered with flammable material, and located within a State Responsibility Area. While individual property owners are not required to clear beyond the 100-foot distance, or beyond their property line, groups of property owners are encouraged to extend clearances beyond the 100 -foot requirement to create community-wide defensible spaces (State Board of Forestry and Fire Protection, 2006).

Fuel or vegetation treatments often used include mechanical, chemical, biological and other forms of biomass removal (Greenlee and Sapsis, 1996) within a given distance from habitable structures. The intent of this hazard-reduction technique is to create a defensible space that slows the rate and intensity of the advancing fire, and provides an area at the urban-wildland interface where firefighters can set up to suppress the fire and save the threatened structures. **Hazard reduction** includes requirements for the maintenance of existing trees, shrubs, and ground cover within a setback zone, to reduce the amount of fuel on those sides of any structure that face the UWI. These requirements include: clearing all dead or dying foliage; planting fire-resistive vegetation; keeping clearances between tree stands, bushes and shrubs, and between trees and structures; irrigating ground covers, storing firewood and combustible materials away from habitable structures; using fire-resistant roofing and construction materials; cleaning vegetation debris from roofs and rain gutters; and using spark arresters on chimneys.

In some communities or developments adjacent to a wildland area, residents are required to comply with **fuel modification** requirements. A **fuel modification zone** is a ribbon of land surrounding a development within a fire hazardous area that is designed to diminish the intensity of a wildfire as it approaches the structures. Fuel modification includes both the thinning (reducing the amount) of combustible vegetation, and the removal and replacement of native vegetation with fire-resistive plant species. These modification zones may be owned by individual property owners or by homeowners' associations. Emphasis is placed on the space near structures that provides natural landscape compatibility with wildlife, water conservation and ecosystem health. Immediate benefits of this approach include improved aesthetics, increased health of large remaining trees and other valued plants, and enhanced wildlife habitat.

4.1.3.2 Notification and Abatement

City and county codes typically specify that property owners are required to mitigate the fire hazard in their properties by implementing vegetation management practices. *Coachella's Municipal Code, Title 3, has several provisions that address the maintenance and abatement of nuisances, including weeds, trees and shrubs with dead or fallen limbs or branches that pose a safety* *hazard, and the accumulation of dry or dead plant matter, combustible refuse or waste that comprise a fire hazard (see Chapter 3.10 of the Municipal Code).* If dry weeds, grass, brush, plant material, dead trees, or other hazardous vegetation are present in an improved or unimproved real property in the city, the Fire Chief has the authority to give the person or persons responsible for the violation(s) a Notice of Violation (Section 3.24.010 of the Coachella Municipal Code). Failure to comply with the notice of violation typically results in the issuance of a field citation, a notice of public nuisance or other such action. If the person responsible for the public nuisance conditions does not abate the hazard during the time period specified in the notice, the City may elect to perform the abatement work. In that case, the owner of record of the property is liable for all abatement costs incurred by the City, including administrative costs (Section 3.36.010). Weed abatement issues are handled by the Fire Department in conjunction with the City of Coachella Code Enforcement Office. Fire Department personnel provide fire safety presentations and prepare and distribute flyers providing information about fire safety, including weed abatement, at many school and city events.

The County of Riverside has similar provisions regarding the issue of weeds and other vegetation as a potential fire hazard that apply to the unincorporated regions of the Coachella General Plan area. In the County, the Fire Chief or his designated representative has the authority to give the property owner of record a Notice of Violation and Order to Abate the hazard. If the owner does not abate the fire hazard during the time period specified in the notice, typically 30 days, the County may take further action to reduce the hazard. The costs of notification and abatement are then charged to the property owner of record, and if not paid within 15 calendar days, the County has the option of making the outstanding costs a Special Assessment against the property, or authorizing the recordation of a Nuisance Abatement Lien against the subject property. Furthermore, a citation may be issued for non-compliance. For additional information refer to Riverside County Ordinance 695.4.

4.1.3.3 Building to Reduce the Fire Hazard

Building construction standards for such items as roof coverings, fire doors, and fire resistant materials help protect structures from external fires and contain internal fires for longer periods. The portion of a structure most susceptible to ignition from a wildland fire is its roof, which is exposed to burning cinders (or brands) generally carried by winds far in advance of the actual fire. Roofs can also be ignited by direct contact with burning trees and large shrubs (Fisher, 1995). The danger of combustible wood roofs, such as wooden shingles and shakes, has been known to fire fighting professionals since at least 1923, when California's first major urban fire disaster occurred in Berkeley. It was not until 1988, however, that California was able to pass legislation calling for, at a minimum, Class C roofing in fire hazard areas (Class C roof coverings are effective against light fire exposures; under such exposures roof coverings of this class are not readily flammable, afford a measurable degree of fire protection to the roof deck, do not slip from position, and do not produce flying brands). Then, in the early 1990s, there were several other major fires, including the Paint fire of 1990 in Santa Barbara, the 1991 Tunnel fire in Oakland/Berkeley, and the 1993 Laguna Beach fire, whose severe losses were attributed in great measure to the large percentage of combustible roofs in the affected areas. In 1994-1996, new roofing materials standards were approved by California for Very High Fire Hazard Severity Zones.

To help consumers determine the fire resistance of the roofing materials they may be considering, roofing materials are rated as to their fire resistance into three categories that are based on the results of test fire conditions that these materials are subjected to under rigorous laboratory conditions, in accordance with test method ASTM-E-108 developed by the American

Society of Testing Materials. The rating classification provides information regarding the capacity of the roofing material to resist a fire that develops outside the building on which the roofing material is installed (The Institute for Local Self Government, 1992). The ratings are as follows:

- **Class A**: Roof coverings that are effective against **severe** fire exposures. Under such exposures, roof coverings of this class are not readily flammable, afford a high degree of fire protection to the roof deck, do not slip from position; and do not produce flying brands.

- **Class B**: Roof coverings that are effective against moderate fire exposures. Under such exposures, roof coverings of this class are not readily flammable, afford a moderate degree of fire protection to the roof deck, do not slip from position, and do not produce flying brands.

- **Class C**: Roof coverings that are effective against light fire exposures. Under such exposures, roof coverings of this class: are not readily flammable, afford a measurable degree of fire protection to the roof deck, do not slip from position, and do not produce flying brands.

Roofing materials can also be:

- **Non-Combustible**: Roof made of non-combustible materials like metal. Although metal roofs don't burn, they are excellent heat conducts, and during an intense fire, heat can be conducted through the metal to the underlying, combustible materials.

- **Non-Rated**: Roof coverings have not been tested for protection against fire exposure. Under such exposures, non-rated roof coverings may be readily flammable; may offer little or no protection to the roof deck, allowing fire to penetrate into attic space and the entire building; and may pose a serious fire brand hazard, producing brands that could ignite other structures a considerable distance away.

The City of Coachella does not require a minimum fire-rated roof type, but it has adopted the 2013 California Building and Fire Codes, with some exceptions. The City implements Section 1505 (Table 1505.1) of the California Building Code, which provides minimum roof covering classifications for different types of construction. Furthermore, all new single family residential construction projects since 2005 have been and continue to be required to use concrete or clay tile roofing, in accordance with the City's Single Family Residential Design Guidelines (Luis Lopez, Development Services Director, City of Coachella, written communication, April 28, 2014). Concrete and clay tile roofing qualify as Class A roofing material under the Building Code, as defined above.

Attic ventilation openings are also a concern regarding the fire survivability of a structure. Attics require significant amounts of cross-ventilation to prevent the degradation of wood rafters and ceiling joists. This ventilation is typically provided by openings to the outside of the structure, but these opening can provide pathways for burning brands and flames to be deposited within the attic. To prevent this, it is important that all ventilation openings be properly screened.

Additional prevention measures that can be taken to reduce the potential for ignition of attic spaces is to "use non-combustible exterior siding materials and to site trees and shrubs far enough away from the walls of the house to prevent flame travel into the attic even if a tree or shrub does torch" (Fisher, 1995).

The type of exterior wall construction used can also help a structure survive a fire. Ideally, exterior walls should be made of non-combustible materials such as stucco or masonry. During a wildfire, the dangerous active burning at a given location typically lasts about 5 to 10 minutes (Fisher, 1995), so if the exterior walls are made of non-combustible or fire-resistant materials, the structure has a better chance of surviving. For the same reason, the type of windows used in a structure can also help reduce the potential for fire to impact a structure. Single-pane, annealed glass windows are known for not performing well during fires; thermal radiation and direct contact with flames cause these windows to break because the glass under the window frame is protected and remains cooler than the glass in the center of the window. This differential thermal expansion of the glass causes the window to break. Larger windows are more susceptible to fracturing when exposed to high heat than smaller windows. Multiple-pane windows, and tempered glass windows perform much better than single-pane windows, although they do cost more. Fisher (1995) indicates that in Australia, researchers have noticed that the use of metal screens helps protect windows from thermal radiation.

The latest version of the California Building Code (2013) has specific construction requirements for new buildings located in any State Responsibility Areas, in Very High Fire Hazard Severity Zone in Local Responsibility Areas, and in any Wildland-Urban Interface Fire Area (Chapters 7A and 15 of Title 24, California Code of Regulations). The 2013 California Building Code also has specific fire-resistance-rated construction requirements for all types of construction, based on occupancy type and construction type. Although these conditions do not apply to the City of Coachella because there are no State Responsibility Areas, Very High Fire Hazard Severity Zones or Wildland-Urban Interface areas in Coachella, *the City has adopted and enforces the use of the 2013 California Building Code for all new construction.*

4.1.3.4 Restricted Public Access

In addition to the fire-susceptibility conditions described before, the wildfire susceptibility of an area changes throughout the year, and from year to year in response to local variations in precipitation, temperature, vegetation growth, and other conditions. To map these changes, the EROS Data Center (EDC) in Sioux Falls, South Dakota, has produced since the early 1990s weekly and biweekly maps for the 48 contiguous states and Alaska (available at http://edc.usgs.gov/). These maps, prepared under the Greenness Mapping Project, display plant growth and vigor, vegetation cover, and biomass production, using multi-spectral data from satellites of the National Oceanic and Atmospheric Administration (NOAA). The EDC also produces maps that relate vegetation conditions for the current two weeks to the average (normal) two-week conditions during the past seven years. EDC maps provide comprehensive growing season profiles for woodlands, rangelands, grasslands, and agricultural areas. With these maps, fire departments and land managers can assess the condition of all vegetation throughout the growing season, which improves planning for fire suppression, scheduling of prescribed burns, and study of long-term vegetation changes resulting from human or natural factors.

Another valuable fire management tool developed jointly by the U.S. Geological Survey and the U.S. Forest Service is the Fire Potential Index (FPI). The FPI characterizes relative fire potential for woodlands, rangelands, and grasslands, both at the regional and local scale. The index combines multi-spectral satellite data from NOAA with geographic information system (GIS) technology to generate 1-km resolution fire potential maps. Input data include the total amount of burnable plant material (fuel load) derived from vegetation maps, the water content of the dead vegetation, and the fraction of the total fuel load that is live vegetation. The proportion of living plants is derived from the greenness maps described above. Water content of dead vegetation is calculated from temperature, relative humidity, cloud cover, and precipitation. The FPI is updated daily to reflect changing weather conditions.

Local fire authorities can obtain data from either of the two sources above to better prepare for the fire season. When the fire danger is deemed to be of special concern, local authorities can rely on increased media coverage and public announcements to educate the local population about being fire safe. For example, to reduce the potential for wildfires during fire season, hazardous fire areas can be closed to public access during at least part of the year. Typically, the fire season in southern California begins in May and lasts until the first rains in November, but different counties or jurisdictions can opt to start the fire season earlier and end it later. With more site-specific data obtained from the FPI or Greenness Mapping Project, however, the fire hazard of an area can be assessed on a weekly or bi-weekly basis (for more information see http://edc.usgs.gov/greenness/index.html). These data can also be used to establish regional prevention priorities that can help reduce the risk of wildland fire ignition and spread, and help improve the allocation of suppression forces and resources, which can lead to faster control of fires in areas of high concern.

4.1.3.5 Fire Safety Education

Individuals can make an enormous contribution to fire hazard reduction if provided with the information and tools to do so. In addition to the specific code requirements and guidelines mentioned in the sections above regarding defensible space and appropriate landscaping and construction materials, homeowners can implement several measures to reduce their fire risk. Some of these measures are listed below:

- Do not mow or use gas-powered landscaping tools during the hottest time of the day.
- Use care when refueling garden equipment and maintain it regularly.
- Dispose of cuttings and debris promptly, according to local regulations.
- Store firewood away from structures.
- If an irrigation system is used, keep it well maintained.
- Store and use flammable liquids properly.
- Dispose of smoking materials carefully, such as in metal containers.
- Do not light fireworks.
- Become familiar with local regulations regarding vegetation clearings, disposal of debris, and fire safety requirements for equipment.
- Follow manufacturers' instructions when using fertilizers and pesticides.
- When building, selecting or maintaining a home, consider the slope of the terrain. Be sure to build on the most level portion of the lot since fire spreads rapidly on slopes, even minor ones.
- Watch out for construction on ridges, cliffs, or drainage embankments. Keep a single-story structure at least 30 feet away from the edge of a cliff or ridge; increase this distance if the structure exceeds one story.
- Use construction materials that are fire-resistant or non-combustible whenever possible.
- Install an approved automatic fire sprinkler system. The California Building Code has fire sprinkler requirements for new buildings according to occupancy and construction type, but all types of structures can benefit from having a fire sprinkler system installed. This is

particularly true of older construction.

- Driveways should provide easy access for fire engines. Driveways and access roads should be well maintained, clearly marked, and include ample turnaround space near houses.
- So that everyone has a way out, provide at least two ground level doors for safety exits and at least two means of escape (doors or windows) in each room.
- Keep gutters, eaves, and roofs clear of leaves and other debris.
- Occasionally inspect your home, looking for deterioration, such as breaks and spaces between roof tiles, warping wood, or cracks and crevices in the structure.
- If an all-wood fence is attached to your home, a masonry or metal protective barrier between the fence and house is recommended.
- Use non-flammable metal when constructing a trellis and cover it with high-moisture, non-flammable vegetation.
- Prevent combustible materials and debris from accumulating beneath patio decks or elevated porches. Screen, or box in, areas that lie below ground level with wire mesh.
- Make sure an elevated wooden deck is not located at the top of a hill where it will be in the direct line of a fire moving up slope.
- Install automatic seismic shut-off valves for the main gas line to your house. Information for approved devices, as well as installation procedures, is available from the Southern California Gas Company.

4.2 Structure Fires

Based on census data, in 2010 the city of Coachella has a population of about 40,700 (http://census.gov/). A large percentage of the housing stock in the city of Coachella area consists of single-family, detached structures, but approximately 25.75 percent of the housing stock in the city consists of apartments, condominiums, and other multi-occupancy structures. Multiple-family and multiple-occupancy units have special fire protection needs, including the requirement to have fire and life-safety systems in place, such as automatic fire sprinklers and smoke detectors, in conformance with the latest California Building and Fire Codes. Given that only since January 2011 has the State required one- and two-family dwellings and townhouses to be fitted with fire sprinklers, most of Coachella's residential stock is likely to be un-sprinklered.

In the United States, deaths from fires and burns are the third leading cause of fatal injury, and four out of five fire deaths in 2008 occurred in homes (Karter, 2009, as reported by the Center for Disease Control and Prevention at http://www.cdc.gov/HomeandRecreationalSafety/FirePrevention/fires-factsheet.html). Smoking is the leading cause of fire-related deaths, and cooking is the primary cause of residential fires (Ahrens, 2009a, as reported by the Center for Disease Control and Prevention). Although the number of fatalities and injuries caused by residential fires has declined in the last decades, residential fire-related deaths and injuries still pose a significant public health issue. The good news is that residential fire-related deaths and injuries can be prevented.

When a fire develops in a newer, single-family residential structure constructed of fire-resistant materials and with internal fire sprinklers, the fire can generally be contained to the room of origin, unless the building contents are highly flammable. In older residential areas where the building materials may not be fire-rated, and the structures are not fitted with fire sprinklers, there is a higher probability of a structural fire impacting adjacent rooms, and even adjacent structures, unless there is ample distance between structures, there are no strong winds, and the local fire department is able to respond quickly. Fire losses, as a percentage of the total area of the building, are thus potentially higher in older buildings not built with fire-resistant materials (such as gypsum wallboard) that help slow down the spread of fire from the ignition source to other rooms in the structure. Older structures are also less likely to have the redundant exits and window-height requirements that allow occupants to more easily evacuate the building if needed.

In high-density residential areas, especially in older neighborhoods, fire can easily spread from one structure or unit to the next, and the narrow spaces between structures and property lines provide limited room for emergency access, hindering fire suppression and evacuation efforts. Emergency access and exits may also be compromised if obstructions, such as bay windows and roof awnings, project into the setback between structures, or if non-structural items, such as garbage cans or sheds are stored in those areas. Newer multiple-family units typically meet special fire protection requirements, including automatic fire sprinklers and smoke detectors, and fire-resistant construction materials, in conformance with the more recent California Building and Fire Codes. These improvements help retard the spread of fire between dwelling units.

Post-fire forensic data show that fire safety in structures is controlled to a great degree by the contents in the structure: upholstered furniture, bedding, curtains, mattresses and floor coverings (such as carpets and rugs) allow for quick fire spread and fire growth, and ignition of these materials is responsible for more deaths and injuries than the collapse of structures due to fire (Canadian Wood Council, 2000). Most injuries or deaths due to fire are in fact the result of smoke or toxic fumes inhalation, and not burns (Hall, 2001), so smoke detectors and/or fire alarm systems, combined with window and door openings that allow the occupants to evacuate safely, are very important in managing the impact of a structure fire. Approximately 40% of the home fire deaths occur in homes without smoke alarms (Ahrens, 2009b as reported by the Center for Disease Control and Prevention).

Data provided by the Riverside County Fire Department (see Table 4-2 in Page 4-8) shows that between 2010 and 2013, only about 1 percent of the incident calls received by the Fire Department in the city of Coachella were for structure fires. Losses due to fires, as the data in Table 4-2 show, vary from year to year. The reality is that one fire incident in a high consequence structure (see below) could alter the yearly statistics significantly. Although mostly residential, some of the businesses and land-uses in and around Coachella could result in chemical fires. Issues associated with the storage, use and disposal of hazardous materials are discussed in more detail in Chapter 5, whereas a discussion of chemical fires is provided in Section 4.4 below. Finally, fires after earthquakes are a real concern in southern California, given the region's seismic potential. This is discussed further in Section 4.5.

4.2.1 Target Fire Hazards and Standards of Coverage

In order to quantify the structural fire risk in a community, it is necessary for the local fire departments to evaluate occupancies based upon their type, size, construction type, built-in protection (such as internal fire sprinkler systems) and risk (high-occupancy versus low-occupancy) to assess whether or not they are capable of controlling a fire in the occupancy types identified. Simply developing an inventory of the number of structures present within a fire station's response area is not sufficient, as those numbers do not convey all the information necessary to address the community's fire survivability. As mentioned above, in newer residential areas where construction includes fire-resistant materials and internal fire sprinklers, most structure fires can be confined to the building or property of origin. In older residential areas where the building materials may not be fire-rated, and the structures are not fitted with fire sprinklers, there is a higher probability of a structure fire impacting adjacent structures, unless there is ample distance between buildings, there are no strong winds, and the Fire Department is able to respond in a timely manner.

Fire departments quantify and classify structural fire risks to determine where a fire resulting in large losses of life or property is more likely to occur. The structures at risk are catalogued utilizing the following criteria:

- Their size, height, location and type of occupancy;
- The risk presented by the occupancy (probability of a fire and the consequence if one occurs);
- The unique hazards presented by the occupancy (such as the occupant load, the types of combustibles therein and any hazardous materials);
- Potential for loss of life;
- The presence of fire sprinklers and fire-resistant construction materials;
- Proximity to exposures;
- The estimated dollar value of the occupancy;
- The needed fire flow versus available fire flow; and
- The ability of the on-duty forces to control a fire therein.

These occupancies are called "Target Hazards." Target Hazards encompass all significant community structural fire risk inventories. Typically, fire departments identify the major target hazards and then perform intensive pre-fire planning, inspections and training to address the specific fire problems in that particular type of occupancy (for example, training to respond to fires in facilities that handle hazardous materials is significantly different than training to respond to a fire in a high-occupancy facility such as a mall, auditorium or night club). Typically, the most common target hazard due to its life-loss potential, 24-hour occupancy, risk, and frequency of events, is the residential occupancy. However, the consequences of residential fires can be high or low, depending on the age of the structure, location, size, and occupancy load, among other factors. Four classifications of risk are considered, as follows:

- **High Probability/High Consequences:** such as multi-family dwellings and residential buildings like apartments and condominiums, single-family residential homes in the older sections of the Town, hazardous materials occupancies, and large shopping stores and high-occupancy facilities like movie theaters, convention centers, and meeting halls.
- **Low Probability/High Consequences:** such as the medical offices, mid-size shopping centers, industrial occupancies, and large office complexes.
- **High Probability/Low Consequences:** such as older, detached single-family dwellings.
- **Low Probability/Low Consequences:** such as newer, detached single-family dwellings, and small office buildings.

The Fire Department (Battalion Chief De La Cruz, written communication, May 12, 2014) has indicated that the largest target hazards in Coachella include the local schools, large shopping centers, the Armtec Defense Products facility, bulk petroleum plants and a biodiesel manufacturing plant.

4.2.2 Regulatory Context

Effective fire protection cannot be accomplished solely through the acquisition of equipment, personnel and training. The area's infrastructure also must be considered, including adequacy of nearby water supplies, transport routes and access for fire equipment, addresses, and street signs, as well as maintenance.

The City of Coachella has adopted the 2013 California Fire Code as amended by the County

(Riverside County Ordinance No. 787.7), a modification of the International Fire Code. These provisions include sprinkler and fire hydrant requirements in new structures and remodels, road widths and configurations designed to accommodate the passage of fire trucks and engines, and requirements for minimum fire flow rates for water mains. The Riverside County Fire Department Chief is authorized and directed to enforce the provisions of the California Fire Code throughout the City. Coachella has also adopted the most recent (currently 2013) version of the California Building Code that includes sections on fire-resistant construction material requirements based on building use and occupancy. The construction requirements are a function of building size, purpose, type, materials, location, proximity to other structures, and the type of fire suppression systems installed.

Some of the more significant Fire Code items that help reduce the hazard of structural fire include requirements regarding fire-extinguishing systems such as automatic fire sprinklers. Fire sprinklers can help contain a fire that starts inside a structure from spreading to other nearby structures, and also help prevent total destruction of a building. The most recent version of the California Fire Code requires fire sprinklers in all new one- and two-family residential structures built after January 1, 2011.

Fire apparatus access to a burning structure is critical to the rapid containment of a fire. Given the size and weight configurations of fire engines, access roads need to comply with minimum width, maximum grade and surface requirements. Approved fire apparatus access roads need to be provided for every facility or building in the city. Fire apparatus roads need to extend to within 150 feet of all of the facility and all portions of the exterior walls of the first story of the building. In some areas, more than one road may be required if and when it is determined that access by a single road may be impaired by vehicle congestion, difficult terrain, weather conditions which could result in dangerous situations or other factors that could limit access. Furthermore, appropriate signage is important to identify the emergency access roads, and to identify the street number of a property, and the buildings therein.

Fire flow is the flow rate of water supply (measured in gallons per minute – gpm) available for fire fighting, measured at 20 pounds per square inch (psi; equal to 138 kPa) residual pressure. Available fire flow is the total water flow available at the fire hydrants, also measured in gallons per minute. The California Fire Code lists the minimum required fire-flow and flow duration for buildings of different floor areas and construction types; a reduction in required fire flow is allowed when the building is provided with an approved automatic sprinkler system. Fire flow requirements within commercial projects are based on square footage and type of construction of the structures. Minimum fire flow for any commercial structure is 1,500 gallons per minute (gpm) at a residual pressure of 20 psi, and can rise to 8,000 gpm, per Table A-III of the California Fire Code. For additional information regarding the required fire-flow for your building, contact the City's Building Department and the Riverside County Fire Department. The Fire Department conducts inspections of all public fire hydrants in Coachella to make sure that they are working properly at the appropriate flows for the area.

Emergency water storage is critical, especially when battling large structural fires or fires after earthquakes. During the 1993 Laguna Beach fire, water streams sprayed on burning houses sometimes fell to a trickle (Platte and Brazil, Los Angeles Times, 1993), primarily because of dwindling water pressure, inadequate pipeline connections and insufficient pumping capacity: most water reservoirs in Laguna Beach were located at lower elevations than the fire, and the water district could not supply water to the higher elevations as fast as the fire engines were using it.

Some, but not all of the above-ground storage tanks in the Coachella General Plan area are located at higher surface elevations than the neighborhoods that they serve. This allows for a gravity-fed mechanism for water distribution. However, regional gravity-fed water distribution systems can still be compromised, especially as a result of an earthquake. While the majority of pipeline failures during earthquakes occur due to fault rupture and lateral spreading, about 40 percent of the failures are due to wave propagation effects, such as amplification in sedimentary basins (O'Rourke and Liu, 1999). Studies conducted by Eguchi (1991) [as referenced in O'Rourke and Liu (1999)] indicate that damage to X-grade welded steel pipes as a result of wave propagation is typically an order of magnitude less than that for ductile iron pipes, and nearly two orders of magnitude less than that for welded steel gas-welded joint, concrete or asbestos cement pipes. Thus, municipalities that have an older utilities system that includes some of these more vulnerable pipe types should consider upgrading their systems to prevent significant pipeline failures during an earthquake.

Furthermore, as the City grows to the east, and onto higher elevations, the existing water storage tanks will not be able to provide water to all the new proposed structures, unless the water is pumped. During and after an earthquake, if there is loss of electric power with a resultant failure of the water pumps, and there are substantial breaks in the water mains due to surface fault rupture, other types of surface failure, and ground shaking, large portions of Coachella will be left without water for days or weeks. In fact, the HazUS analyses conducted for this study indicate that a M7.8 earthquake on the San Andreas fault is expected to have a significant negative impact on both the potable water and electric power services – essentially all households in the Coachella study area are expected to have no potable water for at least 90 days (3 months) following the earthquake, and possibly even longer. The number of pipe breaks is expected to be such that the entire water system is going to have to be recreated. Given that the M7.8 ShakeOut scenario is going to impact a very large area, "there will not be enough pipe and connectors or trained manpower to repair all the breaks quickly. The worst hit areas may not have water in the taps for 6 months" (Jones et al., 2008). The smaller M7.1 earthquake scenario on the San Andreas fault is anticipated to leave more than 6,100 households without water for 24 hours, and nearly 1,700 households would have no water after three days. However, all households are anticipated to have water a week after the earthquake.

Also important to consider is the fact that two of the three existing water reservoirs in Coachella do not have the seismic valves, flexible joints and other seismic upgrades that are now required in newer tanks (see Chapter 3, Section 3.2.2), based on lessons learned from the 1992 Landers and 1994 Northridge earthquakes. Damage to these tanks during an earthquake, in addition to leaking irrigation lines and open valves in damaged homes can reduce the amount of water available to fire fighters. A minimum seven-day emergency storage supply is recommended, especially in areas likely to be impacted by fires after earthquakes, due to the anticipated damage to the main water distribution system as a result of ground failure and/or weaknesses in the pipes due to corrosion or age.

4.3 Fire Suppression Services

Between 1946, when the City of Coachella was incorporated, and 1990, the City was served by its own fire department. In 1990, the City entered into a cooperative fire protection agreement with the Riverside County Fire Department (RCFD), and as result, since then, fire suppression and emergency services in the city of Coachella and in the Coachella General Plan area have been provided, and continue to be provided, by the RCFD with support, as needed, from the Coachella Volunteer Fire

Company (CVFC). The RCFD is in turn administered and operated by the California Department of Forestry and Fire Prevention under an agreement with the County of Riverside. The RCFD is a "full service" agency, providing all fire services including suppression, inspection and prevention, fire safety, hazardous materials response, urban search and rescue, and emergency medical (paramedic) response to citizens within its jurisdiction. The RCFD also monitors the fire hazard in the area, and has ongoing programs for public education, and the investigation and mitigation of hazardous situations.

Fire-fighting resources in Coachella and the immediate surrounding area include the fire stations listed in Table 4-3 and shown on Plate 4-1. The general telephone number for the Riverside County Fire Department, Battalion 6 Headquarters (Station 79 in Coachella) is **760-398-8895. For emergencies, dial 911.**

Table 4-3: Fire Stations In and Near Coachella

Station No.	Address
Station 79 - Coachella Battalion Headquarters.	1377 Sixth Street, Coachella, 92236
Station 86 – Indio	46-990 Jackson Street, Indio 92201
Station 87 - Indio	42-900 Golf Center, Indio 92201
Station 39 - Thermal	86-911 Avenue 58, Thermal 92274
Station 70 – La Quinta	54-001 Madison Street, La Quinta 92253

Fire Station 79 is currently the only fire station physically located in the city of Coachella. The station has been in operation at its current location since 1978, and is manned by 13 full-time fire-fighting personnel, plus one Office Assistant and one Battalion Chief, with a minimum of five firefighters on duty at all times (Battalion Chief De La Cruz, written communication, May 12, 2014). The full-time paid personnel operate the City's two Type 1 fire engines (one 1997 frontline and one 1994 back-up unit), one Paramedic Rescue Squad, and one Type-1 fire engine (1989) reserve unit. The frontline fire engine is staffed with a Fire Captain, a Fire Apparatus Engineer, and a Firefighter II. This unit is also a paramedic assessment unit, meaning that at least one of the above personnel is a certified paramedic. The Paramedic Rescue Squad is staffed with a Fire Apparatus Engineer and a Firefighter-II, of which one or both members are certified paramedics. For units and personnel available on a daily basis by Fire Station serving the Coachella region, refer to Table 4-4 below.

Table 4-4: Units and Personnel Available on a Daily Basis by Fire Station

Fire Station #, City	Units Available (Daily)				# of Personnel Available (Daily)
	Engines	Truck Company	Reserve Apparatus	Paramedic Ambulance	
#79, Coachella	1	No	1	1 Squad (non-transport)	5
#86, Indio	1	1	No	Yes	9
#87, Indio	1	No	Yes	No	3
#39, Thermal	1	No	No	No	3
#70, La Quinta	1	No	Yes	No	3

Source: Battalion Chief De La Cruz, written communication dated May 12, 2014.

Being a cooperative partner with the RCFD, the Coachella fire station receives supplemental assistance as needed for fire department resources from other RCFD stations in the region, with the responses handled as part of the regional and integrated fire protection system. The neighboring cities of La

Quinta and Indio are also part of the RCFD, and as such, stations from these cities provide emergency response as needed in Coachella and surrounding unincorporated areas. The fire stations in these cities include Fire Stations #86 and #87 in Indio, and Fire Station #70 in La Quinta (see Tables 4-3 and 4-4). The fire units from these cities, as well as the surrounding unincorporated communities, are not bound by city limits, boundaries or jurisdictions. As a result, the closest available fire unit(s) will respond to an emergency in any of these jurisdictions with no regard for city boundaries. Formal automatic and/or mutual aid agreements do not apply.

The Riverside County Fire Department (RCFD) has been in business for nearly 70 years (the first county-owned fire stations and engines were established in 1946), and includes city, county, state, and volunteer fire stations in its regional, integrated fire protection organization. The RCFD serves 16 of the 24 cities in the County of Riverside, in addition to one Community Services District. Funding for the RCFD is obtained from various sources, including the County's general fund, city general and benefit assessment funds, redevelopment money and other sources. RCFD's combined State, County, and contract cities budget is over $80 million. Volunteer firefighters, trained and available for emergencies, are paid for actual fire fighting services.

In addition, following the tragic Esperanza Fire that started on October 26, 2006 near Cabazon, the Riverside County Board of Supervisors created a Fire Hazard Reduction Task Force. This Task Force is tasked with reviewing and providing recommendations to reduce the fire hazards and clarify evacuation measures throughout the County.

4.3.1 Response Objectives and Statistics

The National Fire Protection Association (NFPA Standard 1710, 2010) recommends the following objectives for fire departments:

- An alarm answering time of not more than 15 seconds for at least 95 percent of the alarms received, and not more than 40 seconds for at least 99 percent of the alarms received;
- When the alarm is received at a public safety answering point (PSAP) and transferred to a secondary answering point (or communication center), the agency responsible for the PSAP should have an alarm transfer time of not more than 30 seconds for at least 95 percent of all alarms processed;
- The responding fire department should have an alarm processing time (the time interval from when the alarm is acknowledged at the communication center until response information begins to be transmitted via voice or electronic means to emergency response facilities and emergency response units) of not more than 60 seconds for at least 90 percent of the alarms, and not more than 90 seconds for at least 99 percent of the alarms;
- Turnout time for fire and special operations of 80 seconds, and turnout time for EMS response of 60 seconds;
- Travel time of 240 seconds or less for the arrival of the first arriving engine company at a fire suppression incident and 480 seconds or less travel time for the deployment of an initial full alarm assignment at a fire suppression incident;
- Travel time of 240 seconds or less for the arrival of a unit with first responder with automatic external defibrillator (AED) or higher level capability at an emergency medical incident;
- Travel time of 480 seconds or less for the arrival of an advanced life support unit at an emergency medical incident, where this service is provided by the fire department, provided

that a first responder with AED or basic life support unit arrived in 240 seconds or less travel time.

These time recommendations for fire suppression incidents are based on the demands created by a structure fire: It is critical to attempt to arrive and intervene at a fire scene prior to the fire spreading beyond the room of origin, and this typically occurs within 8 to 10 minutes after ignition. In reality however, response times are going to vary depending on the distance between the responding fire stations and the incident location, the setting (urban, rural or outlying), traffic density and patterns, and conditions specific to the area that may hamper fire response times.

The Coachella Fire Department reports that their response time to emergency calls within the city in 2013 averaged 3.6 minutes, and that in 83 percent of the time, on scene response took 5 minutes or less (De La Cruz, personal communication 2014). For statistics regarding fire department response times in the city of Coachella, refer to Table 4-5 below.

4.5: Fire Department Response Times Within Coachella City Limits

Year	2010	2011	2012	2013
Average Response Time (in Minutes)	3.6	3.6	3.7	3.6
% of Calls on Scene in Five Minutes or Less	84	84	82	83

Rapid growth and development can create traffic challenges that can have an impact on emergency response, including extended response times and service delays. Some of the highest daily traffic volumes in the Coachella Valley occur in the city of Coachella. In 2007, the section of Grapefruit Boulevard near Avenue 48 and Dillon Road serviced nearly 52,000 vehicles daily; similarly, the section of Grapefruit Boulevard north of Harrison Street serviced more than 43,000 vehicles daily. Heavy traffic congestion on these roads during peak commuting hours can impact the fire department's response time to an emergency in these areas.

The Union Pacific railroad and canal crossings are also limiting factors, obstructing traffic from the fire stations on the western portion of the Coachella Valley to the eastern sections of the city. The Riverside County Fire Department also reports that emergency response times in Coachella can be impacted by flooding as a result of heavy rains, and due to downed electrical lines and/or debris buildup along roadways during periods of high to strong winds. Other issues that can hamper response times include restricted access at gated communities (such as the Prado Tract at Avenue 50, between Van Buren and Frederick streets, and the Villas at Vineyards, at Dillon Road and Avenue 44), and medians on roads (such as Harrison Street).

Another potential issue that can impact emergency response is multiple emergency alarms. These do occur occasionally, and when this happens, and simultaneous or numerous calls are received, the Fire Department dispatches the next closest available resource to the new incident. Multiple alarm and/or large resource requests are handled through the fire department's 9-1-1 Emergency Command Center. The closest resources are dispatched to mitigate the emergencies, and the response can consist of as few as two fire units, or as many as twenty plus.

In addition to the response time, there is another component called "set up" time. This is the time it takes firefighters to get to the source of a fire and get ready to fight the fire. This may range from 2 minutes at a small house fire to 15 minutes or more at a large or multi-story occupancy, such as a large apartment complex, or a large school, such as Coachella Valley High School. Structure fire response requires numerous critical tasks to be performed simultaneously, and the number of firefighters required to perform the tasks varies based upon the risk.

Obviously, the number of firefighters needed at a maximum high-risk occupancy, such as a shopping mall or large industrial occupancy would be significantly higher than for a fire in a lower-risk occupancy. Given the large number of firefighters that are required to respond to a high-risk, high-consequence fire, Fire Departments routinely rely on stations from adjacent jurisdictions to address the fires suppression needs of their community. As mentioned before, given that Coachella is a cooperative partner with the Riverside County Fire Department, supplemental needs for emergency response resources are handled through the regional and integrated fire protection system, which does not rely on automatic and/or mutual aid agreements. If additional resources are needed due to the intensity or size of the fire, additional fire units from other jurisdictions and agencies may be requested to provide assistance.

The Riverside County Fire Department has established specific objectives (or goals) for Land Use/Fire Suppression in their area of coverage that specify the Department's response times, fire ground operations and fire station locations. These objectives are summarized in Table 4-6.

Table 4-6: Riverside County Fire Department
Land Use / Fire Suppression Objectives

Objectives	Heavy Urban	Urban	Rural	Outlying
Extinguishing agent applied to fires within listed minutes from dispatch	5 Response +3 Setup 8 Minutes	7 Response +3 Setup 10 Minutes	11 Response +3 Setup 14 Minutes	17 Response +3 Setup 20 Minutes
Full assignment in operation within listed minutes from dispatch	6 Response +4 Setup 10 Minutes	11 Response +4 Setup 15 Minutes	16 Response +4 Setup 20 Minutes	26 Response +4 Setup 30 Minutes
Suppression initiated within listed minutes of dispatch for 90 percent of all fires	Prior to flashover	8 Minutes	10 Minutes	15 Minutes
Fire station located within listed miles	1-1/2 miles	3 miles	5 miles	8 miles

The Insurance Services Office (ISO) provides rating and statistical information for the insurance industry in the United States. To do so, ISO evaluates a community's fire protection needs and services, and assigns each community evaluated a Public Protection Classification (PPC) rating. The rating is developed as a cumulative point system, based on the community's fire-suppression delivery system, including fire dispatch (operators, alarm dispatch circuits, telephone lines available), fire department (equipment available, personnel, training, distribution of companies, etc.), and water supply (adequacy, condition, number and installation of fire hydrants). Insurance rates are based upon this rating. The worst rating is a Class 10. The best is a Class 1.

The City of Coachella currently has a Class 4 ISO rating. As urban sprawl continues to increase in the Coachella Valley, this land development may have a cumulative adverse impact on the Fire Department's ability to provide an acceptable level of service, unless additional fire stations are built to provide the needed coverage. The increase in population and development is also anticipated to result in an increased number of emergency and public service calls. As development extends onto the east side of the Coachella Canal, both to the south and north of Interstate 10, at least one new fire station will be required in this area. It is also important to note that when the San Andreas fault breaks in the next earthquake, the surface fault displacements anticipated in the Coachella area will be large enough that vehicular traffic across the fault will be impossible immediately following the earthquake. Given that all of the fire stations are currently on the west side of the fault, emergency personnel from Coachella will not be able to access the eastern half of the Coachella General Plan until the roads crossing the San Andreas fault have been repaired.

The NFPA Fire Protection Handbook (Volume II, 20th Edition) provides guiding principles for the location of additional fire stations, including:

- Consideration of criteria established by the ISO regarding the distributions of fire companies within the community;
- Consideration of NFPA Standard 1710 guidelines with regards to response times, including that an engine company should respond within 240 seconds of travel time to fire incidents and emergency medical services, and within 640 seconds for a full first-alarm group in a minimum of 90 percent of annual incidents;
- Consideration of the proximity of travel time to other station protection zones for timely inclusion in the full first-alarm response group;
- Consideration of rapid and safe access to multi-directional major response routes;
- Consideration of appropriate locations given the land use issues in the surrounding environment;
- Consideration of utility availability, plot size, and surrounding traffic control issues; and
- Consideration of historical and projected call volume (response workload) in the area of concern using risk versus cost analysis.

Battalion Chief De La Cruz (written communication, May 12, 2014) further indicates that City's Planning Department staff should work in concert with the Strategic Planning Bureau of the Riverside County Fire Department to ensure that any proposed fire station locations meet the overall response time criteria and meet the goal of regional fire protection. A typical six-step process that can be used as a decision guide for placement of future fire stations includes:

1. Identify the geographic area of concern on a regional map;
2. Use response mapping computer software to locate a hypothetical station at or near the center of the geographic area or near a major response route;
3. Use a realistic safe response speed or appropriately varied response speeds to plot color-coded timed distances on all streets and roads emanating from the hypothetical station extending out to the response area boundary
4. Determine the number of responders and types of apparatus that would respond from that station for various types of calls and compare with the department standards of cover for that type of area and its hazards;
5. Evaluate the response time and resources that would be dispatched to fire and emergency medical service calls from other stations to make up the first alarm assignment "standards of cover" set by policy for that area; and
6. Adjust the hypothetical station location, if necessary while maintain the station location as close to the center of that geographic area as possible to maintain equity of response time.

4.3.2 Automatic and Mutual Aid Agreements

Fire-fighting agencies team up and work together during emergencies. These teaming arrangements are typically handled through automatic and mutual aid agreements, which obligate fire departments to help each other under pre-defined circumstances. **Automatic aid** agreements obligate the nearest fire company to respond to a fire regardless of the jurisdiction. **Mutual aid** agreements obligate fire department resources to respond outside of their district upon request for assistance.

The California Disaster and Civil Defense Master Mutual Aid Agreement (California Government Code Section 8555-8561) states: "Each party that is signatory to the agreement shall prepare operational plans to use within their jurisdiction, and outside their area." These plans include fire and non-fire emergencies related to natural, technological, and war contingencies. The State of California, all State agencies, all political subdivisions, and all fire districts signed this agreement in 1950.

Riverside County was one of the first counties in the State to endorse and support cooperative and integrated fire protection in support of greatest efficiency and economy. As early as 1906, the County authorized funds to augment the State's fire protection efforts. Since 1921 the County has appointed the California Department of Forestry Unit Chief as the County Fire Chief. It also has appropriated County funds to augment and improve the level of protection in 3,570,000 acres of local responsibility area, and to protect lives and structural property in the unincorporated areas of the County. The County also enhances the existing California Department of Forestry system that protects 1,070,000 acres of state responsibility area for year-round protection.

The County of Riverside contracts with the State of California for fire protection. Public Resources Cod 4142 affords legal authority for the California Department of Forestry and Fire Protection (CDF or CalFire) to enter into agreements with local government entities to provide fire protection services with the approval of the Department of General Services. By virtue of this authority, CalFire administers the Riverside County Fire Department. CalFire is primarily a wildland fire protection agency with the legal responsibility for protection of approximately 33 million acres of private and state lands in California. The Riverside Unit of CalFire provides direct protection for 1,070,000 acres of vegetation-covered wildlands designated by the State Board of Forestry as state responsibility areas (SRAs).

Numerous other agencies are available to assist the Riverside County Fire Department if needed. These include the Police Department and the California Highway Patrol, who, depending on the location of the incident, would provide support during evacuations and to discourage people from traveling to the incident area to observe Fire Department operations, as this can hinder fire suppression and emergency response efforts. Several State and Federal agencies have roles in fire hazard mitigation, response and recovery, depending on the type of incident and its location.

Other agencies that could provide assistance to the Riverside County Fire Department in the event of a significant fire include the Office of Emergency Services, Office of Aviation Services, National Weather Service, the Department of the Interior, and, in extreme cases, the Department of Defense. In forest and open areas, agencies that often assist with fire suppression include the National Park Service, U.S. Forest Service, National Association of State Foresters, Fish and Wildlife Service, and the Department of Agriculture. Private companies and individuals may also be asked to provide assistance in some cases.

4.3.3 Standardized Emergency Management System (SEMS) and National Incident Management System (NIMS)

The SEMS law refers to the Standardized Emergency Management System described by the Petris Bill (Senate Bill 1841; California Government Code Section 8607, made effective January 1, 1993) that was introduced by Senator Petris following the 1991 Oakland fires. The intent of the SEMS law is to improve the coordination of State and local emergency response in California. It requires all jurisdictions within the State of California to participate in the establishment of a standardized statewide emergency management system.

When a major incident occurs, the first few moments are absolutely critical in terms of reducing loss of life and property. First responders must be sufficiently trained to understand the nature and the gravity of the event to minimize the confusion that inevitably follows catastrophic situations. The first responder must then put into motion relevant mitigation plans to further reduce the potential for loss of lives and property damage, and to communicate with the public. According to the State's Standardized Emergency Management System, local agencies have primary authority regarding rescue and treatment of casualties, and making decisions regarding protective actions for the community. This on-scene authority rests with the local emergency services organization and the incident commander.

Depending on the type of incident, several different agencies and disciplines may be called in to assist with emergency response. Agencies and disciplines that can be expected to be part of an emergency response team include medical, health, fire and rescue, police, public works, and coroner. The challenge is to accomplish the work at hand in the most effective manner, maintaining open lines of communication between the different responding agencies to share and disseminate information, and to coordinate efforts.

Emergency response in every jurisdiction in the State of California is handled in accordance with SEMS, with individual City agencies and personnel taking on their responsibilities as defined by the City's Emergency Plan. This document describes the different levels of emergencies, the local emergency management organization, and the specific responsibilities of each participating agency, government office, and City staff.

The framework of the SEMS system is the following:

- Incident Command System – a standard response system for all hazards that is based on a concept originally developed in the 1970s for response to wildland fires;
- Multi-Agency Coordination System – coordinated effort between various agencies and disciplines, allowing for effective decision-making, sharing of resources, and prioritizing of incidents;
- Master Mutual Aid Agreement and related systems – agreement between cities, counties and the State to provide services, personnel and facilities when local resources are inadequate to handle and emergency;
- Operational Area Concept – coordination of resources and information at the county level, including political subdivisions within the county; and
- Operational Area Satellite Information System – a satellite-based communications system with a high-frequency radio backup that permits the transfer of information between agencies using the system.

The SEMS law requires the following:

- Jurisdictions must attend training sessions for the emergency management system;
- All agencies must use the system to be eligible for funding for response costs under disaster assistance programs; and
- All agencies must complete after-action reports within 120 days of each declared disaster.

The September 11, 2001 terrorist attacks, and later, the 2004 and 2005 hurricane seasons demonstrated the need for improve the country's emergency management, incident response capabilities and coordination processes. On February 28, 2003, the President issued Homeland Security Presidential Directive 5 (HSPD-5), and in response, on March 1, 2004, the Department of Homeland Security unveiled the basic framework guiding the development and administration of the **National Incident Management System** (**NIMS**). NIMS provides a nationwide template that is meant to enable Federal, State, tribal, and local governments, in addition to non-governmental organizations and the private sector, to work together to "prevent, protect against, respond to, recover from, and mitigate the effects of incidents, regardless of cause, size, location, or complexity." NIMS is a core set of doctrines, concepts, principles, terminology and organizational processes that enable effective, efficient and collaborative incident management. NIMS works hand in hand with the National Response Framework (NRF), which provides the structure and mechanisms for national-level policy for incident management.

NIMS is the following:

- A comprehensive, nationwide systematic approach to incident management, including the Incident Command System, Multiagency Coordination Systems, and Public Information;
- A set of preparedness concepts and principles for all hazards;
- Essential principles for a common operating picture and interoperability of communications and information management;
- Standardized resource management procedures that enable coordination among different jurisdictions and organizations;
- Scalable, so that it may be used for all incidents (from day-to-day to large-scale); and
- A dynamic system that promotes ongoing management and maintenance.

NIMS components include:

- Preparedness;
- Communications and Information Management;
- Resource Management;
- Command and Management; and
- Ongoing Management and Maintenance.

HSPD-5 requires all Federal departments and agencies to adopt NIMS and use it in all their individual incident management and activities. *Furthermore, the directive requires Federal departments and agencies to make adoption of NIMS by State, tribal and local (i.e., cities) organizations a condition for receiving Federal preparedness assistance.* Given that the basic framework for NIMS was put together in short order, it was understood that it would be a work in progress. In the years since 2004, the NIMS process has been reviewed continuously to incorporate best practices and lessons learned from recent incidents. In 2005, all state, local and tribal jurisdictions were to adopt NIMS for all Departments/Agencies, and were to revise and update their emergency operations plans, standard operating procedures, and standard operating guidelines to incorporate NIMS and National Response Framework components, principles and policies. In 2008, local jurisdictions were to use existing resources, such as programs, personnel and training facilities to coordinate and deliver NIMS training requirements. These training requirements are based on a group of training courses at different levels have been developed and that all appropriate emergency response personnel at all levels of government are required to take to satisfy the NIMS objectives. For the most recently published NIMS compliance metrics refer to the FEMA website at http://www.fema.gov/.

The Riverside County Fire Department has been NIMS-SIMS-ICS compliant since 2007, formalized by a Board of Supervisors Action.

Consistent with both SIMS and NIMS requirements, all firefighting personnel of the Riverside County Fire Department are required to train daily. Each employee trains either individually and/or in groups (such as engine company drills and multi-engine company drills), and participates in a formalized program of instruction (with a lesson plan, instructor, or instructional device) to acquire the skills and knowledge necessary to improve the employee's performance in his or her current position. The drills are held at the local fire station, local buildings or complexes, or at the Riverside County Fire Department's Roy Wilson Fire Training Center. In addition, the RCFD maintains an in-service training program that consists of monthly company drills, quarterly re-certification training, monthly emergency medical service skills labs, on-duty EMS skills proficiency verification, structured multi-company drills, on-line training delivery, spot drills, interagency drills, twelve hours of station-level training per month, quarterly truck/rescue drills, annual wildland preparedness drills, and company manipulative drills at both the Ben Clark (3423 Davis Avenue, Riverside) and Roy Wilson Desert (31920 Robert Road, Thousand Palms) Training Centers.

4.4 Chemical Fires

Chemical substances are often unstable under high temperatures. Other chemicals are reactive to water or oxygen, and can self-ignite if exposed to water or air. For example, sulfuric acid, one of the most abundant and widely distributed chemicals produced in the U.S., is highly reactive when exposed in its concentrated form to water. Other substances if mixed together can also generate a fire. Therefore, when dealing with chemical fires it is important to know what type of chemicals are present in the area and where they are being stored or used. It is also important to note that when dealing with chemical fires, time is critical: the longer chemicals are exposed to extreme heat, the more likely that they will react violently, increasing the severity of the fire. Fire fighters can better respond to a situation with the appropriate equipment if they have the information needed to make these decisions immediately available to them. This is what the business plans and the Material Safety Data Sheets (MSDS) discussed in Chapter 5 – Hazardous Materials Management – are intended to provide.

Firefighters recognize four main different types of fires:

- **Class A** fires involve ordinary materials like paper, lumber, cardboard, and some types of plastics.

- **Class B** fires involve flammable or combustible liquids such as gasoline, kerosene, and common organic solvents.
- **Class C** fires involve energized electrical equipment, such as appliances, switches, panel boxes, power tools, and hot plates. Water is a particularly dangerous extinguishing medium for class C fires because of the risk of electrical shock.
- **Class D** fires involve combustible metals, such as magnesium, titanium, potassium and sodium, as well as pyrophoric organometallic reagents such as alkyllithiums, Grignards and diethylzinc. These materials burn at high temperatures and will react violently with water, air, and/or other chemicals.

It is not uncommon for fires to be a combination of the types discussed above. Therefore, it is typically recommended that fire extinguishers obtained for household and office use have an ABC rating, which means that they have the capacity to fight Class A, B and C fires.

Common types of extinguishers include:

- **Water extinguishers**, which are suitable for class A (paper, etc.) fires, but not for class B, C and D fires, because the water can make the flames spread.
- **Dry chemical extinguishers**, which are useful for class ABC fires and are the best all-around choice. They have an advantage over CO_2 extinguishers because they leave a blanket of non-flammable material on the extinguished material that reduces the likelihood of re-ignition. There are two kinds of dry chemical extinguishers:
  - Type BC fire extinguishers contain sodium or potassium bicarbonate, and
  - Type ABC fire extinguishers that contain ammonium phosphate.
- **CO_2 (carbon dioxide) extinguishers** are for class B and C fires. They do not work very well on class A fires because the material usually re-ignites. CO_2 extinguishers have an advantage over dry chemical extinguishers in that they leave behind no harmful residue – a good choice for an electrical fire on a computer or other delicate instrument. Note that CO_2 is a bad choice for flammable metal fires such as Grignard reagents, alkyllithiums and sodium metal because CO_2 reacts with these materials. CO_2 extinguishers are not approved for class D fires.
- **Metal/Sand Extinguishers** are for flammable metals (class D fires) and work by simply smothering the fire.

Not only is it imperative to control chemical fires as soon as possible, but two main "by-products" of these types of fires require special attention, including special handling and evacuation procedures. These by-products include the "smoke plume" and water run-off from the fire-extinguishing process. The smoke plume has the potential to pose a severe hazard to those exposed to it: chemicals in the vapor phase can be mildly to extremely toxic if inhaled, depending on the chemicals involved. Smoke inhalation is a hazard in itself, but when chemicals are part of the smoke, it can have severe negative impacts on the health of those nearby, including fire-fighting personnel and individuals not evacuated in time to prevent them from inhaling the smoke. Soot from some types of fires can also cause chemical burns on skin. Therefore, depending on the types of chemicals involved in the fire, an evacuation of the immediate area and especially of those areas down-wind should be conducted.

If water is used to fight a fire, the runoff could include chemicals or substances that pose a hazard to the environment. Therefore, the runoff should be contained to prevent it from flowing into storm drains or leach fields. Containing the water runoff from a fire is difficult but possible, especially if the special equipment to do so is available.

4.5 Fires Following Earthquakes

Wildland fires are not a concern in the Coachella area, and thus are not the worst-case scenario for the community. History shows, however, that earthquake-induced fires have the potential to be the worst-case fire-suppression scenarios for a community because an earthquake typically causes multiple ignitions distributed over a broad geographic area, with the potential to severely tax the local fire suppression agencies. Furthermore, if fire fighters are involved with search and rescue operations, they are less available to fight fires. Fire suppression efforts can also be limited by a water distribution system that has been impaired by the earthquake. Thus, many factors affect the severity of fires following an earthquake, including ignition sources, types and density of fuel, weather conditions, functionality of the water systems, and the ability of firefighters to suppress the fires. The principal causes of earthquake-related fires are open flames, electrical malfunctions, gas leaks, and chemical spills. Downed power lines may ignite fires if the lines do not automatically de-energize. Unanchored gas heaters and water heaters are common problems, as these readily tip over during strong ground shaking (State law requires new and replaced gas-fired water heaters to be attached to a wall or other support).

The major urban conflagrations of yesteryear in major cities were often the result of closely built, congested areas of attached buildings with no fire sprinklers, no adequate fire separations, no Fire Code enforcement, and narrow streets. In the past, fire apparatus and water supplies were also inadequate in many large cities, and many fire departments were comprised of volunteers. Many of these conditions no longer apply to the cities of today. Nevertheless, major earthquakes can result in fires and the loss of water supply, as it occurred in San Francisco in 1906, and in Kobe, Japan in 1995. A large portion of the structural damage caused by the great San Francisco earthquake of 1906 was the result of fires rather than ground shaking.

The 1992 Landers earthquake caused two residential fires in Landers, most likely the result of propane gas leaks from overturned appliances; both structures burned down completely. In Yucca Valley, two mobile homes fell off their supports and ignited, also most likely as a result of severed propane gas lines or overturned gas appliances. One of these mobile homes was completely destroyed. Despite multiple breaks in the water distribution system, the San Bernardino County Fire Department reported sufficient water supply to fight these fires (EERI, 1992).

The moderately sized, M6.7 Northridge earthquake of 1994 caused 15,021 natural gas leaks that resulted in three street fires, 51 structure fires (23 of these caused total ruin) and the destruction, by fire, of 172 mobile homes. In one incident, the earthquake severed a 22-inch gas transmission line and a motorist ignited the gas while attempting to restart his stalled vehicle. Response to this fire was impeded by the earthquake's rupture of a water main; as a result, five nearby homes were destroyed. Elsewhere, one mobile home fire started when a ruptured transmission line was ignited by a downed power line. In many of the destroyed mobile homes, fires erupted when inadequate bracing allowed the houses to slip off their foundations, severing gas lines and igniting fires.

As the examples above indicate, fires following earthquakes can cause severe losses. In some instances, these losses can outweigh the losses from direct damage, such as the collapse of buildings and disruption of lifelines. This potential hazard is particularly applicable to the southern California area given its high seismic potential, and to the city of Coachella, given its location relative to the San Andreas fault, the most significant seismic source in southern California, with a high probability of rupturing in the near-future. A strong earthquake on this fault could trigger multiple fires and disrupt lifelines services (such as the water supply in the region (discussed in more detail in Section 4.2.2 above, and in Chapters 1 and 3).

Given that thousands of leaks and breaks in the natural gas system are expected in Coachella following an earthquake on the San Andreas fault (refer to Table 1-15 in Chapter 1), several fires following the earthquake can be expected. In support of this argument consider the following example from the Los Angeles area: In 1988 the California Division of Mines and Geology (now the California Geological Survey; Toppozada and others, 1988) published a study that identified projected damages in the Los Angeles area as a result of an earthquake on the Newport-Inglewood fault. The Newport-Inglewood earthquake scenario estimated that thousands of gas leaks would result from damage to pipelines, valves and service connections. This study prompted the Southern California Gas Company to start replacing their distribution pipelines with flexible plastic polyethylene pipe, and to develop ways to isolate and shut off sections of supply lines when breaks are severe. Nevertheless, as a result of the 1994 Northridge earthquake, which occurred on a buried thrust fault that did not cause surface fault rupture, the Southern California Gas Company reported 35 breaks in its natural gas transmission lines and 717 breaks in its distribution lines. About 74 percent of the leaks were corrosion related. There were 51 structure fires, and approximately 172 mobile homes were destroyed by fire. The structure fires were caused by overturned water heaters (20), other overturned or damaged gas appliances (8), broken interior gas lines (8), broken gas meter set assemblies (2), street fires due to breaks in gas mains (7), and other unknown causes (8). The mobile home fires were primarily the result of failure of the supports leading to breakage of the gas risers, and breakage of the interior gas lines due to overturned water heaters and other appliances (Savage, 1995).

A regional earthquake scenario that involves rupture of the entire southern section of the San Andreas fault was conducted in 2008 for the ShakeOut Scenario (Jones and others, 2008; Scawthorn, 2008). The scenario estimates that as a result of a magnitude 7.8 earthquake on the southern San Andreas, a total of 239 ignitions would occur in Riverside County. This estimate does not include ignitions that are suppressed by responding citizens. Of the estimated 239 ignitions that will require fire department response, 157 would develop into large fires, each requiring the response of more than one fire engine company. The estimated ultimate burnt area in the County would be equivalent to about 1,000 single-family dwellings (Scawthorn, 2008). Using the 1994 Northridge earthquake as proxy, about half of the ignitions are expected to be electric related, about a quarter would be gas related, and the rest would be the result of a variety of causes, including chemical reactions. Also based on the Northridge earthquake, about 70 percent of all ignitions will occur in residential structures. Although city-specific estimates were not computed as part of the ShakeOut scenario, the data clearly highlight the hazard associated with earthquake-induced fires. Response to these fires will be hindered by a damaged water distribution system, overwhelmed local fire department resources, overwhelmed 911 centers, and extremely delayed response from strike teams coming in from outlying areas due to damage to the transportation system and traffic disruption (Scawthorn, 2008).

The Riverside County Fire Department has policies specific to earthquake planning. Specifically, in the event of an earthquake, the Fire Captain first ensures that the personnel are accounted for and are safe, then fire department personnel conduct a facility damage assessment inspection, move the fire apparatus outside the fire station, and start a local area damage reconnaissance. The assessment considers a review and identification of target hazards, potential rescue hazards, road closures, utility failures, hazardous materials releases, and other life-safety concerns. If an earthquake is more severe, the local stations call for more resources as needed, including the activation of emergency operations centers, and the County's Office of Emergency Services. A number of fire engines in the County have the availability to draft water from alternate sources (such as swimming pools and ponds) to use for fire suppression, a capability of great value, especially if the water distribution system has been damaged and the Fire Department has to resort to alternative water sources to fight fires.

4.6 Summary and Recommended Programs

The Riverside County Department manages the fire hazard in the city of Coachella by providing fire prevention, suppression and public education programs. The City and the County have also invested and continue to invest on infrastructure and equipment that help the Fire Department be as responsive as possible. However, the coverage area is large, and land development and traffic congestion at times hinder the Fire Department's response time to emergency calls. Coachella's ISO rating of 4 could drop if the fire department does not keep pace with the level of development expected in the area.

Although very few historical wildland fires have been reported in the Coachella General Plan area, a few small vegetation fires do occur annually. The eastern and northeastern portions of the General Plan area are currently mapped as either Local Responsibility or Federal Responsibility areas, typically with a moderate fire hazard. A small area in the far northeastern portion of the General Plan area is mapped as having a high fire hazard. The boundaries of these regions are shown on Plate 4-1. Residents of and near these fire hazard areas should be encouraged to practice fire-safe procedures, including maintaining a fire-safe landscape, and keeping combustibles (such as fire wood) a safe distance away from all structures. Similarly, the County and City should continue to enforce the weed abatement and notification program, to reduce the potential for vegetation fires to occur in vacant or poorly maintained lots.

Fires in the Coachella General Plan area represent a very small percentage of the annual emergency calls that the Fire Department receives and responds to. However, fires can represent a large percent of the total annual losses. Therefore, programs that can be continued or implemented to reduce these losses should be encouraged.

Specifically the City and County:

- Should continue to regularly reevaluate specific fire hazard areas and adopt reasonable safety standards, covering such elements as adequacy of nearby water supplies, routes or throughways for fire equipment, clarity of addresses and street signs, and maintenance.
- Should encourage owners of non-sprinklered properties, especially high-occupancy structures, to retrofit their buildings and include internal fire sprinklers. The City may consider some form of financial assistance (such as low-interest or no-interest loans) to encourage property owners to do this as soon as possible.
- Should continue to conduct emergency response exercises, including mock earthquake-induced fire-scenario exercises to prepare for the multiple ignitions that an earthquake is expected to generate. Civilians should be encouraged to participate in these exercises as much as possible also, to empower neighborhoods to be self-reliant in the face of a natural or man-made disaster. These training sessions should use the adopted emergency management systems (SEMS and NIMS).
- Should continue to conduct regular assessments of the Fire Department's response objectives, to identify those areas that, because of increasing population, will require an increase in fire department presence. Specifically, as the city's population increases, additional fire stations will be required, their locations to be selected based on population demands. The City should continue to require that funding for the construction of these new fire stations be supported, at least in part, by the developers of the proposed large-scale master-planned communities. Fees that cover the purchasing of fire equipment and manning of these new fire stations should also be considered.
- Should consider siting and building additional above-ground storage tanks on the west side of the San Andreas fault, where most of the City's residents currently live. Furthermore, strengthening of the City's water distribution system should be considered a top priority to reduce the estimated damage caused by an earthquake on the San Andreas fault.

CHAPTER 5: HAZARDOUS MATERIALS MANAGEMENT

5.1 Setting and Definitions

A high standard of living has driven our increasing dependence on chemicals. Chemicals like hydrocarbon fuels, chlorine, pesticides and herbicides are used on a daily basis and in large quantities. In areas with an agricultural tradition, such as the Coachella Valley and the city of Coachella, pesticides, herbicides and fertilizers have been used and are being used extensively. Because of the high demand for these types of chemicals, their storage and transportation is necessary. Some industrial, commercial and manufacturing facilities also use hazardous materials, and releases of these compounds onto the environment, either intentionally or accidentally, even if it was years or decades ago, can still pose a threat to public health. Compounds that were used extensively decades ago, when regulations regarding the manufacture, use and storage of these substances were lax, have been found to be hazardous to human health and to the environment. In response to these concerns, which began in the late 1960s, dozens of Federal, State, and local regulations have been implemented to dictate the use, storage, transportation, handling and clean-up of hazardous materials and wastes. It is the aim of these regulations to minimize the risk of exposure to hazardous materials by the general public.

The United States Environmental Protection Agency (herein referred to as the EPA) has defined hazardous waste as substances that 1) may cause or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; 2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of or otherwise managed; and 3) whose characteristics can be measured by a standardized test or reasonably detected by generators of solid waste through their knowledge of their waste. Hazardous waste is also ignitable, corrosive, or reactive (explosive) (EPA 40 CFR 260.10). A material may also be classified as hazardous if it contains defined amounts of toxic chemicals. The EPA has developed a list of specific hazardous wastes that are in the forms of solids, semi-solids, liquids, and gases. Producers of such wastes include private businesses, and Federal, State, and local agencies.

The State of California further defines hazardous materials as substances that are toxic, ignitable or flammable, reactive, and/or corrosive. The State also defines an extremely hazardous material as a substance that shows high acute or chronic toxicity, carcinogenity, bioaccumulative properties, is persistent in the environment, or is water reactive (California Code of Regulations, Title 22).

5.2 Regulatory Context and Lists of Sites

Various Federal and State programs regulate the use, storage, and transportation of hazardous materials. These will be discussed in this section as they pertain to the Coachella area and the City's management of hazardous materials. The goal of the discussions presented herein is to provide information that can be used to reduce or mitigate the danger that hazardous substances may pose to Coachella's residents and visitors, both in normal, day-to-day conditions, and as a result of a regional disaster, such as an earthquake.

Several of the Federal and State programs are summarized in the subsections below.

5.2.1 Federal Clean Water Act (33 U.S.C. §1251 et seq., 1972) and California Water Code

"Out of sight, out of mind" has been the traditional approach to dealing with trash, sediment, fertilizer-laden irrigation water, used motor oil, unused paint and thinner, and other hazardous substances that people dump onto the ground, or into the sewer and storm drains. What we often forget is that substances dumped into the storm drain system can make their way into drainages, lakes, rivers, and eventually the ocean. Contaminants in these waterways can endanger aquatic organisms and wildlife dependent on these water sources, and can impact human health and the environment. Some substances dumped onto the ground can eventually make their way into the groundwater, with the potential for contamination of our drinking water resources.

In part to deal with these issues, the Federal government enacted the Clean Water Act in 1972. This Act establishes the framework by which discharges of pollutants into the waters of the United States are regulated, including the establishment of quality standards for surface waters. One of the earliest programs established under the Act was the National Pollutant Discharge Elimination System (NPDES) to control wastewater discharges from various industries and wastewater treatment plants known as a "point sources." A point source is defined by the EPA as a discrete, easily discernible source of pollution, such as a smokestack or sewer. Then, in 1987, the Water Quality Act amended the NPDES permit system to include "non-point source" (NPS) pollution. NPS pollution refers to the introduction of bacteria, sediment, oil and grease, heavy metals, pesticides, fertilizers and other chemicals from less well-defined sources into our rivers, lakes, bays and oceans. These pollutants are not released at one specific, identifiable point, but rather, from a number of points that are spread out and are thus difficult to identify and control. The pollutants are washed away from roadways, parking lots, yards, farms and other areas by rain and dry-weather urban runoff into the storm drain system, from where they are ultimately conveyed to the area's water bodies and the ocean. NPS pollution is now thought to account for most water quality problems in the United States. Therefore, strict enforcement of this program at the local level, with everybody doing his or her part to reduce NPS pollution, can make a significant difference.

The NPDES program is handled at the State-level by the California Water Resources Control Board (CWRCB, SWRCB or "the Board"), with regional offices of the Board overseeing implementation and enforcement of the program at the local level. NPDES permits are required by all municipalities that own or operate a municipal separate storm sewer system (MS4) that: a) serves a population greater than 100,000 (medium) or 250,000 (large); b) contributes to a violation of a Water Quality Standard, c) is a significant contributor of pollutants to waters of the U.S., or d) is owned and/or operated by a small municipality that is interrelated to a medium or large municipality.

Urban runoff from Coachella discharges into the Whitewater River watershed within the Colorado River Regional Board (Region 7) jurisdiction. The main office of Region 7 of the Water Quality Control Board is located at 73-720 Fred Waring Drive, Suite 100, Palm Desert, California 92260. Their general telephone number is (760) 346-7491. In accordance with the Clean Water Act, and the Porter-Cologne Water Quality Control Act (contained in Division 7 of the California Water Code), the CWRCB is responsible for the formulation and adoption of State policy for water quality control. This includes the development of water quality principles and guidelines for ground waters, surface waters and the use of reclaimed water; the formulation, adoption and periodic review and revision of water quality control plans; and the formulation and enforcement of waste discharge requirements (WDRs).

In 2013, the Colorado River Regional Water Quality Control Board (Regional Board) re-issued a municipal storm water NPDES permit to the County of Riverside and the Riverside County Flood Control and Water Conservation District (RCFCWCD) as Principal Permittees, and to the Coachella Valley Water District (CVWD) and incorporated cities of Riverside County within the Whitewater River Watershed as Co-Permitees. The incorporated cities that collectively are referred to as co-permitees include Banning, Cathedral City, Coachella, Desert Hot Springs, Indian Wells, Indio, La Quinta, Palm Desert, Palm Springs, and Rancho Mirage. On November 21, 2012, the joint group of permittees submitted NPDES Application No. CAS617002, a Report of Waste Discharge (RoWD) and a revised Whitewater River Region Storm Water Management Plan (SWMP) to renew their MS4 permit for the urbanized area of the Whitewater River Region (the Permit Area) within Riverside County. The updated Order (Urban Runoff Management Program Order No. R7-2008-0001, NPDES Permit No. CAS617002) was adopted on June 20, 2013, and will expire on June 19, 2018. A completed application for re-issuance of the order needs to be submitted no later than December 23, 2017.

Co-permittees, such as the City of Coachella, have certain responsibilities defined by the NPDES permit order and the region's Storm Water Management Plan (SWMP). Some of these responsibilities are summarized below (for the complete texts refer to the NPDES permit order and extensive resources provided by the Colorado River Basin RWCB for construction, industrial and municipal storm water programs available from http://www.waterboards.ca.gov/coloradoriver/water_issues/programs/stormwater/). Specifically, a permittee is required to:

1. Comply with the requirements of the MS4 permit within its jurisdictional boundaries.
2. Provide certification for all reports and other information requested by the Board as specified in Section 1.9 of the MS4 permit;
3. Annually review the Whitewater River region map to ensure that it encompasses urbanized areas within the permittee's jurisdiction. Any changes or errors in the map need to be submitted to the principal permittees as an amendment to the map.
4. Prepare in a timely manner and provide to the principal permittees all documents required by the MS4 permit.
5. Implement the Whitewater River Region Storm Water Management Plan (SWMP) to: a) reduce potential pollutants in urban runoff from commercial, industrial and residential areas, b) reduce potential pollutants in the urban runoff from land development and construction sites through the use of structural and non-structural best management practices, c) reduce potential pollutants in urban runoff from permittee's maintenance activities to the maximum extent practicable, d) eliminate illegal connections and illegal discharges to the maximum extent practicable, e) encourage spill prevention and containment, as well as provide appropriate spill response plan for permittees' maintenance facilities to the maximum extent practicable; f) increase public awareness to the maximum extent practicable, g) continue to provide MS4 permit compliance-related training for permittee's staff to the maximum extent practicable, and g) control increases in urban runoff flows within the permittee's jurisdictional boundaries to the maximum extent practicable so as not to cause erosion and sedimentation problems downstream.
6. Designate at least one representative to the Desert Task Force, who shall attend Desert Task Force meetings. The Principal Permittees shall be notified immediately of changes to the designated representative.
7. Establish and maintain adequate legal authority which authorizes or enables the permittee to implement and enforce, at a minimum, the following requirements: a) control through ordinance, permit, contract, order or similar means, the contribution of pollutants to the MS4 by urban runoff associated with industrial activity and the quality

of urban runoff discharged from sites of industrial activity, b) prohibit through ordinance, order or similar means, illegal discharges to the MS4 including, but not limited to discharges of wash water resulting from:

i) the hosing or cleaning of gas stations, auto repair garages or other types of automotive services facilities,

ii) the cleaning, repair, or maintenance of any types of equipment or machinery including motor vehicles, cement-related equipment, and port-a-potty servicing,

iii) mobile operations such as oily or greasy discharges from mobile automobile washing, and/or discharges from steam cleaning, power washing, carpet cleaning, etc.,

iv) runoff from material storage areas containing chemicals, fuels, grease, oil, or other hazardous materials, and

v) food-related wastes (such as grease, fish processing, and restaurant kitchen mat and trash bin wash water, etc.).

8. Control, through ordinance, order or similar means, the discharge to the MS4 of spills, dumping or disposal of materials other than urban runoff.
9. Control through interagency agreements among permittees the contribution of pollutants from one portion of the MS4 to another portion of the MS4.
10. Require compliance with conditions in its ordinances, permits, contracts or orders consistent with the enforcement and compliance strategy (Section 1.7) of the storm water management plan.
11. Carry out all inspection, surveillance, and monitoring of procedures necessary to determine compliance with MS4 permit conditions, including the prohibition on illegal discharges to the MS4.
12. Maintain in good working condition at all times the facilities that collect, transport and store urban runoff.

In addition to regulatory activities, and in compliance with the Whitewater River Region Storm Water Management Plan and the MS4 permit, permittees are required to implement public education and outreach programs to increase public awareness about controlling pollution associated with urban runoff. The Desert Task Force provides oversight and guidance for the implementation of the public education program in the Whitewater River Region, whereas the Riverside County Flood Control and Water Conservation District (District), as a Principal Permittee, is the administrator of the program, and is responsible for developing a consistent message about stormwater/urban runoff pollution prevention throughout the County. The cost-sharing program pools staff and resources to: 1) prepare informational materials that can be distributed to the public in general, at schools and businesses; 2) conduct workshops and community events where information on the NPDES program is provided to attendees; and 3) sponsor presentations to civic/rotary/group organizations to discuss the prevention of stormwater pollution. For additional information regarding this program, including scheduling of events, and downloadable materials, refer to http://www.floodcontrol.co.riverside.ca.us/stormwater/. Pamphlets with information regarding stormwater pollution, with emphasis on how to prevent it, and how to report an unauthorized release, are also available at Coachella's City Hall, at the front counter.

Specific programs that Co-permittees typically conduct in support of the NPDES program include:

- Regular maintenance of public rights of way, including street sweeping, litter collection, and storm drain facility maintenance to reduce the discharge of pollutants, including trash and debris, to their respective MS4 facilities;
- Documentation of the observations of field personnel of unauthorized dumping or spills to help locate the source of pollutants, using standardized reporting forms to document, track and report illicit connections / illegal discharge incidents,
- Maintenance of a database of investigations of illegal connections/illegal discharges;
- Provision, collection, and maintenance of litter receptacles in strategic public areas and during public events;
- Assessment and modification, if necessary, of existing field programs to detect and prevent dumping, or routine discharge of pollutants into MS4 facilities;
- Implementation and enforcement of leash laws and other pet laws (i.e., pet waste cleanup, no pets in public areas) in selected public-use areas;
- Adoption and enforcement of ordinances prohibiting the discharge of pollutants into the storm drain system;
- Plan review procedures to ensure that unauthorized connections to the storm sewer system are not made; and
- Public education efforts to inform residents about storm water quality. These efforts typically include publishing the City's annual water quality report describing the NPDES program and stormwater pollution prevention measures; stenciling of storm drains with warnings about the illegal dumping/discharge of substances; and organizing educational presentations at fairs and other public events, and for school programs.

The California Water Code states that anyone who is discharging or proposing to discharge wastewater onto land shall file a report with the Regional Board. After review, and following any necessary hearings, the Board may impose waste discharge requirements on that individual or facility. All dischargers, except from small, residential, on-site systems, are required to complete and submit to the Regional Board a Report of Waste Discharge. The appropriate forms, including descriptions and instructions for each, can be obtained online at http://www.waterboards.ca.gov/santaana/publications_forms/docs/form200.pdf.

The Regional Board also monitors development projects during the construction stage. Specifically, all dischargers whose projects will disturb one or more acres of soil, or whose projects are less than one acre in size but that are part of a larger development that in total will disturb one or more acres of land are required to obtain a General Permit for Discharges of Storm Water Associated with Construction Activity, under Construction General Permit Order 2009-0009-DWQ adopted on September 2, 2009, and amendments issued in Orders 2010-0014-DWQ and 2012-0006-DWQ. Construction activity includes clearing, grading and disturbances such as stockpiling or excavation. The Construction General Permit requires the development of a Storm Water Pollution Prevention Plan (SWPPP). For additional information regarding this program, copies of the appropriate forms, and specifics regarding the contents of a SWPPP, refer to http://www.waterboards.ca.gov/water_issues/programs/stormwater/constpermits.shtml.