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 (upward flowing sediment). These can potentially damage structures and underground utilities.

Loss of Bearing Strength: When a soil loses strength and 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°.

Research into liquefaction in past earthquakes has linked liquefaction to certain hydrologic and geologic settings. Water-saturated, cohesionless, granular materials at depths of less than 50 feet are prone to liquefaction. To identify an area having significant potential for liquefaction, a liquefaction susceptibility map and a liquefaction opportunity map must be developed. The former depicts areas where the geology and hydrology are favorable for liquefaction. The latter summarizes information about the potential for strong earthquake shaking. When considered together, the two maps determine the liquefaction potential- the relative likelihood that an earthquake will cause liquefaction in an area.

1.6.2 Guidelines for Delineating Liquefaction Hazard Zones

In 1997 and 1998, the California Division of Mines and Geology (1997 and 1998) developed guidelines for delineating, evaluating, and mitigating seismic hazards in California. In 1999, a Southern California Earthquake Center sponsored group published "Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigating Liquefaction in California". The SCEC (1999) publication was a result of requests from city and county Building Officials for assistance in the development of procedures to implement the Seismic Hazards Mapping Act (see Section 1.1.3) for projects requiring their review. The guidelines in assessing liquefaction potential for this study are based on DMG (1997 and 1998), as well as SCEC (1999), and are summarized below:

Liquefaction Mapping Criteria: Liquefaction Hazard Zones are areas meeting one or more of the following criteria:

- Areas known to have experienced liquefaction during historic earthquakes. Field studies following past earthquakes indicate liquefaction tends to recur at many sites during successive earthquakes (Youd, 1984). There are many published accounts of liquefaction occurrences. Areas so delineated should be included in the Liquefaction Hazard Zones.

- All areas of uncompacted fills containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated. In some areas there has been a practice of creating useable land by dumping artificial fill on tidal flats or in large deep ravines. Standard geologic criteria are of little use in characterizing soils within these fills which are less homogeneous than natural deposits. For example, there is no reason to assume lateral stratification in these fills and the validity of extrapolating subsurface data is questionable. Evidence for filling can be found by examining maps showing old shorelines, by comparing old and modern topographic maps, by studying logs of boreholes, and by obtaining reports or original plans of specific projects involving reclaimed land.

- Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable. The vast majority of liquefaction hazard areas are underlain by recently deposited sand and/or silty sand. These deposits are not randomly distributed, but occur within a narrow range of sedimentary and hydrologic environments.

Geologic criteria for assessing these environments are commonly used to define bounds of susceptibility zones derived from other criteria, such as geotechnical analysis (Youd, 1991). Groundwater data should be compiled from well logs and geotechnical borings. Analysis of aerial photographs of various vintages may reveal zones of flooding, sediment accumulation, or evidence of historic liquefaction. Quaternary geology should be mapped and age estimates assigned based on ages reported in the literature, stratigraphic relationships and soil profile descriptions. In many areas of Holocene and Pleistocene deposition, geotechnical and hydrologic data are compiled. Geotechnical investigation reports with Standard Penetration Test (SPT) and/or Cone Penetration Test (CPT) and grain size distribution data can be used for liquefaction resistance evaluations.

For sand and silty sand, there are currently two reliable, in-situ (in place) approaches for quantitative evaluation of the soil's resistance to cyclic pore pressure generation and/or liquefaction. These are: (1) correlations and analyses based on in-situ Standard Penetration Test (SPT) (ASTM D1586) (ASTM, 1990) data, and (2) correlations and analyses based on in-situ Cone Penetration Test (CPT) (ASTM D3441) (ASTM, 1990) data.

Seed and others (1971, 1983, 1985), provide guidelines for performing "standardized" SPT, and also provide correlations for conversion of penetration resistance obtained using most of the common alternate combinations of equipment and procedures in order to develop equivalent "standardized" penetration resistance-- (N1)60. This "standardized" penetration resistance can then be used as a basis for evaluation of liquefaction resistance.

Cone penetration test (CPT) tip resistance (qc) may also be used as a basis for evaluation of liquefaction resistance, either by direct empirical comparison between qc-values to "equivalent" SPT resistance or by use of correlations between (N1)60 data and case histories of seismic performance (Robertson, et al., 1985; Seed and De Alba, 1986).

Some gravelly soils are also potentially vulnerable to liquefaction. The best available technique for quantitative evaluation of the liquefaction resistance of this type of deposit involves correlation and analysis based on in-situ penetration resistance measured using the very large scale Becker Hammer system (Harder, 1988).

The correlations of Seed et al. (1985), and the (N1)60 data can be used to assess liquefaction susceptibility. Since geotechnical analyses are usually made using limited available data, the susceptibility zones should be delineated by use of geologic criteria. Geologic cross sections, tied to boreholes and/or trenches, should be constructed for correlation purposes. The units characterized by geotechnical analyses are correlated with surface and subsurface units and extrapolated for the mapping project.

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes with LQ-Zones (potential liquefaction zones defined by the State Geologist under the Seismic Hazards Mapping Act that require site-specific geotechnical investigation for liquefaction hazards) will be that level defined by M_w 7.5-weighted peak ground acceleration (PGA) for UBC SD (stiff soil) soil conditions with a 10% probability of exceedance over a 50-year period.

Liquefaction mapping criteria in areas where geotechnical data are insufficient: In areas of limited or no geotechnical data, susceptibility zones are identified by geologic criteria as follows:

- Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

- Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

- Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Based on probabilistic mapping described earlier, only the easternmost portion of the County (Blythe region) has acceleration values below the criteria thresholds (Table 1-6).

Application of these criteria allows compilation of hazard maps that are useful for preliminary evaluations, general land-use planning and delineation of special studies zones where site-specific studies may be required before major development is approved (Youd, 1991). In developing a liquefaction hazard map for Riverside County, the Quaternary geology is taken from existing maps (Geologic Map for Riverside County, California), and described in detail within Chapter 2-Geologic Hazards of this Technical Background Report. Hydrologic data are compiled (Ground Water Contour Map for Riverside County, California; Plate 1-4), as described below.

1.6.2.1 Geographic Information System Coverage of Shallow Ground Water for Riverside County (Plate 1-4)

Coverage Description: Depth to Groundwater in Riverside County
Coverage distribution file name: gwcntrs.e00; gwwells.e00
Coverage Area: Riverside County
Source: Earth Consultants International
Accuracy: Only areas where groundwater exists within the upper 200 feet were mapped.

Groundwater was mapped using data from the Regional Water Quality board, Santa Ana Watershed Project Authority (SAWPA), and U.S. Geological Survey reports on groundwater within Riverside County. The groundwater is reported as the highest recorded elevation. Groundwater is only mapped in areas where sufficient data were available. There may be areas of perched water that have not been mapped throughout the county. Contours were created based on data collected from the various water districts through Santa Ana Watershed Project Authority. Reports located at the Regional Water Quality board were used to augment the data collected from the various water districts. All data were analyzed for highest historical recorded elevation. These data should be considered for regional analysis only.