# APPENDIX G
# GEOLOGY AND SOILS/HAZARDS

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# METHODS AND INTRODUCTION

## Scope

The scope of this opportunities and constraints analysis investigation is outlined in the Wilson Geosciences Inc. proposal dated February 26, 2000 and appended to the March 14, 2000 Subcontractor Authorization for Professional Services from Michael Brandman Associates. The scope elements are related to Subarea 2 for the City of Chino Sphere of Influence General Plan. These elements are:

- Gather, review, evaluate and analyze readily available data and maps for the subject area that deal with geology, soils and seismicity.
- Prepare this technical report establishing conditions in Subarea 2, describing potential affects on development and illustrating possible opportunities and constraints to land use alternatives.
- Prepare a geologic map and a geologic hazards map as adjuncts to the report.

## Data Sources

Primary data sources are listed in the References Cited section of this report. Data from state and Federal agencies provide the main source of geologic unit mapping (Cox and Morton, 1978; Weber, 1977; Fife, et al, 1976), soils (considered by Cox and Morton, 1978 from Soil Conservation Service, 1971), fault (Cox and Morton, 1978; Weber, 1977; Fife, et al, 1976; Jennings, 1994) and seismicity information (Blake, 1989). Regional planning and EIR studies provided supplementary data, and the topographic maps provided slope information. The Chino Basin Watermaster (1999) provided a groundwater elevation contour map.

Geologic hazards categories (fault rupture, ground shaking, liquefaction, foundation suitability, and slope stability) and constraints classifications were developed based on commonly used criteria. These criteria are discussed in the section on constraints and opportunities.

## Organization

Following the introduction, the existing geologic, seismic and soils conditions are presented. These conditions are then analyzed and discussed in the context of opportunities and constraints that may impact future development. This discussion relies on a map of the geologic units and faults (Plate 1), and a map of the associated geologic hazards (Plate 2). Last, the summary provides a means of evaluating possible land use alternatives.

# EXISTING GEOLOGIC CONDITIONS

## Geology

One hundred percent of Subarea 2 is underlain by Pleistocene and Holocene (recent) alluvial deposits. Only a small area of bedrock is exposed just west of the western boundary (Cox and Morton, 1978).

### Surficial Geologic Units

The surface geology of Subarea 2 has been mapped in greatest detail by Cox and Morton (1978). They identified four distinct geologic units, two are recent (Holocene; < 12,000 years old) alluvium and two are late Pleistocene (>12,000 years old) in age. Weber's mapping (1977) is different than that of Cox and Morton (1978), however the geologic conditions of the basin area were not the main focus of Weber's study, which was oriented more toward fault identification than to mapping of surficial deposits. This is why the Cox and Morton mapping was used for this study. Very approximate estimates of the areal coverage of each unit are given below.

## Medium-Grained Holocene Alluvium (Qhm)

The youngest surficial unit is a medium-grained Holocene alluvium (map symbol Qhm) present in the alluvial stream valleys that trend northeast-southwest to northwest-southeast (mainly in the southern one-half of the subarea) and as an alluvial fan deposit in the far northeast corner of the subarea (Plate 1). These are unconsolidated deposits of fine-to-coarse-grained sand with interbeds of gravel and silt. As such these sand deposits are moderately to highly permeable and subject to erosion.

Qhm covers roughly 30 percent of the subarea. The edges of the Qhm deposits merge with and overlie the older fine-grained Holocene alluvium (Qhf), described below, in the northeast corner of the subarea. Qhm in the alluvial valleys overlies the much older fine- and medium-grained Pleistocene alluvium (Qpf and Qpm), which together make up nearly one-half of the subarea. Engineering characteristics of the Qhm unit are expected to be variable, but generally will require precautions. It is expected that the materials will be relatively porous, compressible, and subject to consolidation under structural loads. Erosion potential should be moderate to high. Foundation and backfill suitability should be satisfactory with proper over-excavation and compaction.

## Fine-Grained Holocene Alluvium (Qhf)

Qhf is the third most abundant geologic unit within the subarea (~25%). It underlies roughly the northern one-half of the subarea (Plate 1) and is present along the east and southeast edges of the subarea. Deposition was in a low energy possibly restricted basin-type environment. The fine-grained Qhf overlaps the older Pleistocene (Qpf and Qpm) alluvium deposited from the north, and rests against the bedrock along the western boundary of the subarea.

The fine-grained Holocene alluvium consists of clay and silty clay materials that contain interbeds of sand and variable quantities of organic material. This lithology makes the alluvium only moderately permeable to impermeable, and moderately to slightly erodible. Engineering characteristics of the Qhf will require precautions with regard to porosity, compressibility, and long-term consolidation under structural loads, particularly where organic deposits are present as interbeds, or dispersed within the silt and clay layers. Foundation and backfill suitability can be improved by implementing proper design recommendations.

## Medium-Grained Late Pleistocene Alluvium (Qpm)

This Pleistocene alluvium (Qpm) is the least abundant of the four surficial units, covering about 15 percent of the subarea distributed primarily in the southeast corner. It represents deposition in a river and alluvial fan environment with the probable sediment sources to the north and northeast.

Qpm consists of fine- to coarse-grained sand that is weakly to moderately consolidated. Engineering properties will be variable but generally superior to the younger units. Qpm will be porous, moderately permeable, slightly compressible, and subject to some consolidation under structural loads. Erosion potential should be moderate in fresh exposures. Foundation and backfill suitability should be high with proper preparation and compaction.

Fine-Grained Late Pleistocene Alluvium (Qpf)

Qpf is the oldest surficial unit exposed in the subarea and is the most wide spread (along with Qhm), occupying about 30% the subarea within the south-central portion and the far west edge. Similar to the Qhf, the Qpf was deposited in a low energy restricted basin-type environment.

The composition of the Qpf deposits is clay and silty clay. Engineering properties of the Qpf should be similar, or somewhat superior, to the Qhf due to the similar lithology and depositional history. Therefore, the materials have properties that will require precautions, including proper engineering and geologic investigation, and implementation of report recommendations.

### Bedrock Formation

Bedrock is not exposed in the subarea, but is found along the extreme south-western edge of the subarea at the lower portion of the Chino Hills. These Tertiary rocks may be found in the relatively shallow subsurface within adjacent portions of the subarea.

The bedrock is part of an undivided sequence in Cox and Morton (1978), but is mapped in the same area by Weber (1977) as the Puente Formation bedrock consisting of sandstone, conglomerate, siltstone, and as shale of the Sycamore Canyon Member (Fife, et al, 1976). The properties of the bedrock materials should be generally suitable for engineering purposes, (i.e., foundations, backfill), when standard engineering geologic and soils engineering investigation recommendations have been implemented.

## Faulting

Faults are the planes along which earthquakes occur. In cases where earthquakes are large enough, or shallow enough, ground rupture can occur along the fault plane where it intersects the earth's surface. Both earthquake shaking (discussed in the Seismicity section below) and fault rupture must be considered for Subarea 2. Active (Holocene offset) and potentially active (Pleistocene) faults (as defined by the State Division of Mines and Geology) must be considered as potential sources for fault rupture. In general, the younger the last movement on a fault, the higher the potential for future movement on that fault

### Central Avenue Fault

Numerous faults exist in the vicinity of Chino that can cause severe seismic shaking. The potentially active Central Avenue fault (Fife, et al, 1986; Jennings, 1994) trends northwest-southeast and is mapped just north of the subarea projecting toward its southwestern corner. It trends from Pomona (I-10) northwest-southeast on the east side of, and sub parallel to, Central Avenue terminating just south of Kimball Avenue within subarea 1 (Plate 1). Montgomery Watson (1993) show the Central Avenue fault as a groundwater barrier located more to the northeast, extending through subarea 2 from near Johnson Avenue and Chino-Corona Road to near where Mill Creek intersects the San Bernardino-Riverside County line. This is discussed as an unnamed groundwater barrier below.

The Central Avenue fault is sub parallel to the Chino fault, which lies to the west within and near the base of the Chino Hills. Both faults are interpreted to extend from the area of the north end of the Elsinore fault zone at the point where the Whittier fault branches to the west-northwest toward the Whittier Narrows. There is evidence of Holocene faulting on both the North Elsinore and Whittier fault zones (Jennings, 1992; Weber, 1977).

The Central Avenue fault is mapped as concealed (Fife, et al, 1976, including Morton, 1974) that indicates it is not exposed at the surface. However, the Morton (1974) map indicates that the fault appears to offset the water-bearing alluvium (late Pleistocene-Holocene age). The fault was originally recognized because it forms a groundwater barrier apparently due to this offset. Hayes Associates (1992) reports that the trace of the Central Avenue fault was trenched to a depth of 13 feet at the Majestic Spectrum project several miles north-northeast of Subarea 2 and no evidence of offset was found. Hayes Associates reports that there was no evidence to suggest Holocene activity.

No scientific or development-related studies within Subarea 2 are known to have defined Holocene activity on the Central Avenue fault. Wilson Geosciences (1995) identified several factors that suggest at least a possibility that the Central Avenue fault may have offset near surface (Holocene?) deposits. The linearity of Chino Creek is still evident within Subarea 2 along the trend seen in Subarea 1. The unusual morphology of the drainages entering Chino Creek from the north and east suggests possible local tectonic influences.

## Other Possible Late Quaternary or Younger Faults

An unnamed fault was mapped by Weber (1977) southeast of the Subarea to the County line, which can be projected northwesterly into Subarea 2 on a trend subparallel to the Central Avenue and Chino faults. Weber indicates that this fault offsets late Pleistocene medium-grained alluvium (Qpm) on the terrace along the south side of the Santa Ana River south of Subarea 2. A straight-line extension of this fault to the northwest would not directly connect with the Central Avenue fault. Based on data presently available, it is believed that the unnamed fault projects to the east of the Central Avenue fault.

Weber (1977) recognizes other aerial photo lineaments (although he does not show them on his map) on the northeast side of the Chino-Corona Basin that could be within Subarea 2. These lineaments are both northwest and north-northeast trending according to Weber, although they are not shown as faults on his map. He concludes that the lineaments are associated with linear gullies and closed depressions, and only a few were verified tentatively as faults by field mapping. Weber makes no determination as to the origin of these “unverified” features, but concludes that they are not apparently associated with "a strong, through going fault zone with late Quaternary displacement."

Similarly, northeast trending (approximately north 55-65 degrees east) and northwest trending (north 40-55 degrees west) lineaments were observed on topographic maps evaluated for this study. The long northwest trending lineament identified in Subarea 1 is subparallel to the Chino-Central Avenue fault trends and enters Subarea 2 at Chino-Corona Road east of Pioneer Avenue. Its southeast extension is questionable beyond about 1000 feet. To the east there are three other lineaments with similar trends, the longest of which lies approximately 4000 feet to the east of the projected trace of the Central Avenue fault (Plate 1) where it enters Subarea 2 at Pine and Euclid Avenues. Its trace is moderately well distinguished by apparent stream channel deflections/terminations and relatively abrupt changes in topography (Plate 1). This lineament appears to be truncated by a primary, north 55 degrees east trending feature. The significance of these northwest trending lineaments is not known at this time.

Because of their geometric relationship to the Chino-Central Avenue faults they must be considered tectonic in origin, but their history of movement is unknown.

Four northeast trending sets of lineaments were observed based on topographic map and surface water features. Three such subparallel lineaments are associated with linear sections of the Mill Creek drainage in the south one-half of the Subarea 2. The lineaments are spaced about 1500 to 2000 feet apart and, while their continuity appears disrupted by northwest trending structure, are continuous across Subarea 2. The northernmost of the three lineaments trends roughly north 55 degrees east and enters the area from the east just north of Heilman Avenue and Chino-Corona Road. This location is nearly coincident with the southern extent of the artesian water area mapped in the early 1900s. All three features control the location of linear sections of Mill Creek that are connected by sharp 90 degree bends. These bends are nearly parallel with the northwest lineaments discussed above. The fourth northeast trending lineament crosses the subarea nearly coincident with Pine Avenue trending from north 70 to 85 degrees east. This feature bounds the southerly edge of a line of three prominent swamp/bog areas mapped in the late 1890s and forms apparent stream channel deflections and terminations.

The northeast trending lineaments trend subparallel to the reach of the adjacent Santa Ana River, and to buried faults in the northern San Gabriel-Pomona Valley and western San Bernardino Valley, namely the San Jose, Walnut Creek, Red Hill-Etiwanda, an inferred fault near Fontana, and so-called groundwater Barrier "J". All of the above named faults are considered potentially active (Jennings, 1994).

This study is not considered an exhaustive look at the possible relationships of topographic lineaments to the faulting, surficial geology and geomorphology of Subarea 2 and the surrounding areas. Analysis of vintage topographic maps, aerial photos, available imagery, and field mapping are required to provide definitive results. Observations suggest that there may be reasons to conclude that there has been late Pleistocene, and possible Holocene activity (faulting, uplift, and/or folding), associated with the lineaments and groundwater barriers described.

## Seismicity

Numerous regional and local faults are capable of producing severe earthquakes, those of Richter magnitude (M) of 6.0 or greater. An analysis of all such potential earthquake producing faults was performed considering faults within a radius of 50 miles from the Pine and Grove Avenues. Table 1 (Blake, 1989 and updates) shows the faults, their maximum potential earthquakes, the likely maximum Modified Mercalli Intensity (MMI) and peak horizontal ground acceleration (PGA) on the west side of the subarea.

The Chino, Whittier-North Elsinore, and Sierra Madre-San Fernando faults have the potential to generate the highest subarea accelerations. For the maximum probable earthquake (MPE), that is the 100-year event normally considered in design of non-critical structures, the range in value for these faults is about 0.23 to 0.29 g (g = the unit force of gravity). Maximum "credible" earthquake (MCE) events must be considered in the design of certain critical or important facilities (e.g. hospitals, dams, class III landfills). For these faults the MCE should yield an estimated peak horizontal acceleration in the range of 0.31 to 0.59 g. It should be noted that other attenuation and uncertainty relationships could provide other acceleration and intensity values. The selected relationship provides a close match when compared to observed values from the Northridge earthquake.

TABLE 1 - Deterministic Site Parameters far Earthquakes Associated With Active Faults Located Within Approximately 50 Miles of the Site Area

| ABBREVIATED FAULT NAME | APPROXIMATE DISTANCE (miles) | MAXIMUM CREDIBLE EVENT | | | MAXIMUM PROBABLE EVENT | | |
|---|---|---|---|---|---|---|---|
| | | Magnitude | Peak Acceleration | MMI Intensity | Magnitude | Peak Acceleration | MMI Intensity |
| Chino | 3 | 7.00 | 0.59 | X | 5.40 | 0.29 | IX |
| Whittier - North Elsinore | 6 | 7.10 | 0.39 | X | 6.00 | 0.23 | IX |
| San Jose | 10 | 6.7 | 0.23 | IX | 5.00 | 0.06 | VI |
| Sierra Madre - San Fernando | 13 | 7.30 | 0.31 | IX | 6.30 | 0.17 | VIII |
| Cucamonga | 14 | 6.90 | 0.22 | IX | 6.10 | 0.13 | VIII |
| Elsinore | 14 | 7.50 | 0.29 | IX | 6.60 | 0.16 | VIII |
| Glen Helen Lytle Creek Claremont | 19 | 7.00 | 0.15 | VIII | 6.70 | 0.12 | VII |
| Clamshell-Sawpit | 23 | 6.60 | 0.10 | VII | 4.90 | 0.03 | V |
| San Andreas (San Bernardino Mountains) | 23 | 8.00 | 0.26 | IX | 6.70 | 0.10 | VII |
| San Gorgonio Banning | 23 | 7.50 | 0.19 | VIII | 6.60 | 0.10 | VII |
| San Andreas (Mojave Segment) | 24 | 8.0 | 0.25 | IX | 7.40 | 0.16 | VIII |
| North Frontal Fault Zone (San Bernardino Mountains) | 25 | 7.70 | 0.19 | VIII | 6.00 | 0.05 | VI |
| Raymond | 26 | 7.50 | 0.16 | VIII | 4.90 | 0.02 | IV |
| Elysian Park Seismic Zone | 29 | 7.10 | 0.11 | VII | 5.80 | 0.04 | V |
| Compton-Los Alamitos | 30 | 7.20 | 0.17 | VIII | 5.80 | 0.06 | VI |
| Newport-Inglewood Offshore Zone of Deformation | 30 | 7.10 | 0.10 | VII | 5.90 | 0.04 | V |
| San Gabriel | 31 | 7.40 | 0.12 | VII | 5.60 | 0.03 | V |
| Verdugo | 32 | 6.70 | 0.07 | VI | 5.20 | 0.02 | IV |
| Newport-Inglewood North | 33 | 6.70 | 0.06 | VI | 4.20 | 0.01 | II |
| Casa Loma Clark (San Jacinto) | 35 | 7.00 | 0.08 | VII | 7.00 | 0.08 | VII |
| Santa Monica-Hollywood | 37 | 7.00 | 0.07 | VI | 5.80 | 0.03 | V |
| Wilshire Arch | 37 | 5.70 | 0.04 | V | 5.00 | 0.02 | IV |
| Palos Verdes-Coronado Banks - Agua Blanca | 38 | 7.20 | 0.08 | VII | 6.20 | 0.03 | V |
| Santa Monica Mountains Thrust | 38 | 7.20 | 0.12 | VII | 6.30 | 0.06 | VI |
| Hot Springs Buck Ridge (San Jacinto) | 42 | 7.00 | 0.06 | VI | 6.10 | 0.03 | V |
| Coronado Bank-Agua Blanca | 46 | 7.50 | 0.08 | VII | 6.70 | 0.04 | V |

Notes: The maximum credible event is the largest estimated earthquake magnitude (Richter scale thought to be possible associated with a given fault or fault zone The maximum probable event is the largest estimated earthquake magnitude likely to occur in a 100-year period associated with a given fault or fault zone Peak acceleration is the estimated peak horizontal ground acceleration in percent gravity abbreviated g) using the attenuation relationship of Campbell and Bozorgnia (1994) with an uncertainty of mean + 1-sigma The intensity is the estimated Modified Mercalli Intensity (MMI) at the site which represents an empirical measure of physical damage to structures and of disturbance to the earth's surface as a result of various magnitude earthquakes at various site distances.

More distant faults are capable of larger earthquakes with a higher probability of occurrence. The two San Andreas fault segments (Table 1) can be expected to generate the MCE events approximately every 150 to
200 years. These events would yield a peak horizontal ground acceleration of approximately 0.25 g. While occurrence is considered about as likely as the MPE, these are appropriate design values for important facilities. Because the earthquake waves would have a longer period, these values should be considered particularly applicable to structures with a similar fundamental period.

Fife, et al (1976) evaluated the potential ground shaking severity in the area of Prado Dam from large earthquakes on several near and distant faults. They concluded that accelerations (assumed to be peak horizontal on the buried bedrock) would be in the range of approximately of 0.45 to 0.6 g within Subarea 2 (Plate 2). They also discuss site response due to the presence of a thick section of non-bedrock (alluvium; Plate 1). In general, they recommend that the design of important structures consider the site response spectra (acceleration, velocity and displacement) using standard techniques. The values in Table 1 (Blake, 1989, using Campbell and Bozorgnia, 1994) are for a soil (non-bedrock) site therefore provides some idea of an average condition for this one component.

## Soils and Slope

Soils consist of four associations that correspond well to the areal distribution of underlying geologic units. Cox and Morton (1976) considered the soil units when devising the geologic map of surficial deposits. These four associations (and their map symbols) are:

1. Foster-Grangeville (Fp-Gw; on Recent alluvial fans)
2. Tujunga-Delhi (TD-Dg/AR; on Recent alluvial fans)
3. Merrill-Chino (MB-CE); on Older alluvial fans and terraces), and
4. Placentia (Py/BC; on Older alluvial fans)

The soils overlying the Recent alluvial deposits (1 and 2 above) make up roughly 45% of the soils and are about evenly distributed by area. The Foster-Grangeville (Hayes Associates, 1992) is a deep, permeable soil with no development of a profile, and was formed from unconsolidated materials. Slopes range from 0-9%, particles are more generally granular, runoff is slow and depths reach 60 inches. Tujunga-Delhi soils extend to depths of 60 inches or more, are very permeable, loose and unconsolidated, and subject to wind erosion if unprotected. These soils generally correspond with surficial geologic units Qhm and Qpm in the southeast along the Santa Ana River.

Soils overlying the Older alluvial deposits (3 and 4 above) make up roughly 55% of the soils and are about evenly distributed by area. Merrill-Chino and Placentia soils are silty and sandy loam overlying clay loam with slopes of 0-9%, and depths of over 60 inches. These soils are moderately erodible, well drained, and have a low to moderate permeability, and are associated with the surficial geologic units Qhf and Qpf.

The geotechnical engineering properties of the soils in the subarea are not well known from specific geotechnical studies. One study obtained for the Chino Airport area (predominantly Merrill-Chino association and surficial unit Qhf) indicates fine- to medium-grained soils consisting of a sand, silt, and clay mixture. Encountered soils were classified as expansive, having a uniform permeability, being easily rippable, and having moderate erosion potential (RMA, 1989). For planning purposes, the agriculture related descriptions suffice to determine that there are conditions of concern for development, but that no highly unusual hazardous conditions exist.

Average surface slope across the subarea ranges between about 0.5 to 1.0 % on the primary geomorphic surface to the north. Slopes from this primary surface into the primary drainages average about 2 to 3 %. Locally slopes range up to 10 % or along the edges of some gullies. The incised Chino Creek and the larger flood plain have slopes in the range of 0.5 to 0.6 % along the flow line. Fife, et al (1976; Morton, 1974) analyzed the slope stability and found that the areas between the drainages and the flat valley surface to be of low relief and generally devoid of landslides. With standard geotechnical investigations and adherence to UBC requirements there is generally a low potential for instability. Surface slopes of greater than 10% have a moderate risk of surficial slope failures involving any of the above named soil units.

## Groundwater

The southern Chino Basin area has a relatively shallow water table due to the large drainage area feeding the Santa Ana River, and to the natural restriction at Corona and the Santa Ana Canyon. The natural damming affect of the Chino Hills and Santa Ana Mountains is due to the movement and uplift along the Chino-North Elsinore fault zone. The Chino Basin has both water-bearing and non water-bearing rocks. The water-bearing units are the Holocene and Pleistocene-age deposits described above. These sediments vary in thickness from less than 300 feet and to slightly more than 800 feet within Subarea 2 (Plate 1). The greater thickness (650-800 feet) occurs along a north-south axis through the center of the subarea. Lesser thickness is found along the western edge (300-400 feet).

Regional groundwater elevations (Chino Basin Watermaster, 1997) at the northeast corner of the subarea vary from about 550 to 560 feet. The southern one-half of the subarea has water elevations of 500 feet or less. These elevations represent depths of approximately 100 feet in the northeast and less than 30 feet in the south. These depths will likely vary somewhat by season, but in general they should be within a range of about $\pm$ 5 to 10 feet. Fife, et al (1976) indicate that the northern two-thirds of Subarea 2 lies within what was an important zone of artesian ground water in the early 1900s. Recharge from the north replenished the aquifer under the lower permeability confining layer(s). The confining layer is not entirely impermeable, allowing upward flow into perched zones at shallower depths.

In the late 1800s there were marshes and bogs (surface water) present along the southwest and southeast portions of the subarea now occupied by alluvial drainages (Chino and Mill Creeks). This indicates that the groundwater was at the surface, or at zero depth. These marshes correspond roughly to the boundaries of the Qhm deposits in this area (Plate 1). There are also five isolated swamp/bog areas in the north one-half of the subarea, three along the north side of Pine Avenue, one southeast of the Kimball and Euclid Avenue intersection, and one just north of the intersection of Kimball and Grove Avenues. It is unlikely that the water levels in the late 1800s would recur on a broad scale. It is possible that in local areas water may be perched at levels much shallower than 100 feet; this likelihood is much higher south of Pine Street.

Carson and Matti (1982) prepared a map showing the minimum depth to water during the period 1973-1979 for the upper Santa Ana River Valley. They show contours within Subarea 2 that indicate that the range in minimum depth to water was less than 30 feet deep to greater than 100 feet deep (Plate 1). They used very few wells for control points and the contours are considered approximate. Variations in precipitation and well pumping since 1979 would indicate that these depths are not likely to be the same today. No direct comparison to the 1997 Chino Watermaster data was possible since their contours are elevation rather than depth. Comparisons at selected points using the surface elevation USGS contours indicates that the water level may have been slightly shallower in 1997 in the north one-half of the subarea than in 1973-1979. Data points are too sparse to compare the south one-half of the subarea. However, relatively shallow groundwater depths may be encountered in the future if similar rainfall and water use conditions prevail.

## Subsidence

Subsidence is the gradual downward settling of the land surface with little or no horizontal movement. A principal cause can be the removal of large volumes of water from subsurface formations that are confined groundwater aquifers. Groundwater withdrawal has been going on in the Chino Basin for approximately 100 years. The presence of thick, poorly consolidated sediments, as exist in the Chino-Prado Basin area, increase the possibility of subsidence. Although no documentation of subsidence was found for Subarea 2, there are reports (Morton, 1974; Fife, et al, 1976; Harding Lawson Associates, 1991; Kleinfelder, 1993, 1996a, 1996b) of a nearly north-south trending set of ground fissures immediately north of the California Institution for Men at Chino. These reports document active subsidence 3 to 4 miles northwest of Subarea 2.

Morton (Wilson Geosciences, 1995) suggested that he has observed other such features in this general area of the Chino Basin that are likely attributable to subsidence. Kleinfelder (1993) used available leveling survey data to define a subsidence trough trending north to northwest in the area of Central Avenue between Chino Avenue and Eucalyptus Avenue. They concluded that the subsidence had occurred over a much broader area and wad no localized at the ground fissures. The observed fissures were parallel to the trough of maximum subsidence and about 1000 to 1200 feet to the east. This indicates that tensional forces parallel to but outside the zone of maximum subsidence generated the ground fissures.

Beneath the ground fissures appear as infilled, steep-sided gullies up to several feet wide at the surface and narrowing to an inch or less at depth of 10 to 25 feet. The infilled soil is typically loose with very poor engineering properties. Little differential vertical movement is usually present due to the tensional nature of the stresses.

Based on the data cited above the following conclusions can be drawn:

1. Subsidence is ongoing and will continue even if water levels are allowed to increase.
2. Ground fissures were difficult to detect using poor quality, small-scale aerial photographs.
3. Existing 1987 to present leveling survey data is very useful in defining subsidence areas.
4. The physical properties of material in fissure "trenches" can have adverse impacts on structures if fissures are undetected.
5. Large regional earthquakes and/or prolonged heavy rainfall may accelerate subsidence, surface material settlement, and fissure propagation.

Subsidence has been associated with the San Jacinto fault near San Jacinto causing surface displacements along pre-existing fault planes (Fife, et al, 1976). It is not known if Chino Basin subsidence features are associated with faults. Some of the topographic map and aerial photographic lineaments discussed in the Faulting section may be a result of subsidence and may represent zones where ground fissure should be expected. These features are roughly parallel to the alluvial thickness contours, and shallow groundwater contours, each of which would be expected to control subsidence fissure location and orientation to some degree. Without a study using several data sets (i.e., aerial photographs, leveling surveys, topography, groundwater elevations, alluvial thickness) it will be very difficult to predict the most likely locations for ground fissure zones in Subarea 2.

## GEOLOGIC HAZARDS, CONSTRAINTS, AND OPPORTUNITIES SUMMARY

There is a range of potentially hazardous geologic conditions within the overall setting described above. For purposes of this analysis, this potential range is defined as either a concern or a constraint. A concern is defined as a geologic condition raising environmental issues that necessitate resolution through the standard study process. Constraints are defined as conditions raising environmental land use and design issues that are usually not easily mitigated, and may require avoidance, preservation, buffers/setbacks, relocation or other special mitigation. Opportunities for development are greatest in areas lacking concerns or constraints.

Two maps (Plates 1 and 2) are provided with this report. Plate 1 is a geologic map of Subarea 2 showing the geologic, seismic, soils, and groundwater conditions in the subarea. Plate 2 is a map of potential geologic hazards showing the location and extent of areas that may be adversely impacted by certain of the geologic, seismic, soils, and groundwater conditions sufficiently to be considered constraints.

The following section briefly describes the nature of the concerns and constraints, as well as the potential affects that may be important to land use decisions.

### Geology

#### Constraints

There are no known physical geologic characteristics of mapped surficial geologic units that rise to the level of significance of a constraint.

#### Concerns

There are several geologic concerns related to the mapped geologic units that must be further evaluated and resolved during project-specific siting and design studies. These include:

- Slope Instability
- Unsuitable Engineering Characteristics
- Unique Geologic Formations

#### Slope Instability

Morton (1974, in Fife, et al, 1976) classifies the geologic units in the Subarea relative to their potential for slope instability. Morton (1974) rates these materials as either Class I (Qhf) or II-a (Qhm and Qpf). Class I materials on the valley floor are generally devoid of landslides and therefore have a very low potential for slope instability. Class II-a materials are in the low relief areas, again generally devoid of landslides. Natural slope instability in Class II generally will be limited to surficial failures in the Qhf, Qhm and Qpf on slopes greater than 10%.

Slope stability evaluations must consider the affects of construction on both natural slopes and newly created cut slopes. These evaluations will be required for new development within the subarea. Design and construction mitigation measures (e.g., retaining walls, reduce slope angles, earth buttress) in conformance with City of Chino and UBC (1997) standards must be employed to prevent slope instability.

### Unsuitable Engineering Characteristics

The clayey nature of the Qhf and Qpf make these materials susceptible to high expansion coefficients and long-term consolidation that require standard mitigations (e.g., reinforced foundations, proper surface drainage, removal and replacement of expansive soils) to prevent adverse affects on foundations and overlying structures.

All geologic units are susceptible to erosion with the Qhm most susceptible and Qpf the least. Standard mitigation measures (e.g., using non-erosive drainage devices and providing proper vegetation cover) must be employed in the design and construction stages to prevent severe erosion.

Chemical reactivity of the materials with concrete and utilities will require assessment. Standard techniques are available to prevent adverse reactions that would be deleterious to performance of man-made materials.

### Unique Geologic Formations

Geologic formations can be unique if their outcrop pattern, stratigraphic significance or fossil content is sufficiently unusual relative to other geologic deposits in the nearby region. Such a case may qualify the formation for scientific or academic study to obtain information/data that cannot otherwise readily obtained.

The late Pleistocene (Qpf and Qpm) deposits are clay, silty clay, silt, and sand deposited in restricted basin and riverine environments; these have a fairly limited distribution in the region. This makes the deposits very unique in the San Bernardino-Inland Empire area due to the vertebrate fossil content that is unusual and rare. Abundant vertebrate fossils are known from prior study in the area by the San Bernardino County Museum (Wilson Geosciences Inc., 1995). The relative abundance and rarity of the fossils in this restricted area make identification and future study very important, in particular relative similar restricted fauna in the Domenigoni Valley area being affected by the MWD water storage project. In the Chino Basin area these fossils are often found within five feet of the surface, placing them within the depth range of normal construction. Development (e.g., grading, trenching, drilling, mapping) will lead to opportunities for study that may not otherwise be possible. Standard mitigation measures for identification and salvage of fossil specimens must be a part of project development in the subarea.

## Faulting

### Constraints

It is not known with confidence that the surface trace (location) of the Central Avenue fault continues into Subarea 2. The potential for its existence along the Chino Creek trend should be taken into account in conjunction with future studies for habitable structures, and critical, or important facilities in Subarea 1. Only if it is determined that the potentially active Central Avenue fault offsets either Holocene nor Pleistocene deposits would it remain a concern that would require study on a case by case basis. Such studies may or may not lead to actions, such as avoidance/setbacks. If future work indicates a possibility of Holocene or late Pleistocene activity along the Central Avenue fault, the fault would subject to a minimum 25 foot setbacks with greater setbacks possible. Fault activity can be addressed on a site-specific basis with aerial photographic analysis and possibly subsurface trenching, drilling, and/or geophysics; trenching may be particularly appropriate where late Pleistocene deposits are exposed near the surface.

### Concerns

Other possible fault or fold related features observed on topographic maps are presently of unknown significance. Features trending parallel, or nearly so, to the Central Avenue and Chino fault trends (generally northwest) should be viewed as having similar, but less significant, characteristics as the Central Avenue fault. Features that are oriented generally perpendicular to this trend and subparallel to the San Jose-Walnut Creek faults should be considered as possible locations for ground movement.

It is recommended that a study program be initiated to determine the likelihood that these features are potentially significant structural features that be the source of a severe earthquake, or undergo ground surface rupture during a severe earthquake on the nearby Chino-North Elsinore fault system. Some level of overall assessment should be completed prior to the time of detailed specific planning for Subarea 2, and the results will dictate whether or not future constraints are necessary. This approach has been discussed with local experts in 1995 (Wilson Geosciences, 1995). The nature of the assessment recommended herein will allow the ground rupture potential to be evaluated prior to more detailed planning of habitable or critical structures, and major utilities in the area. The assessment would consist of detailed mapping from aerial photographs and topographic maps, and field checking to confirm where possible mapped features have significance to overall development plans. Selected subsurface investigations of significant features would be appropriate.

## Seismicity

### Constraints

<u>Severe Groundshaking</u>

Current Uniform Building Code Standards (ICBO, 1997) set a threshold for horizontal ground acceleration for design of non-critical residential structures, and some commercial and industrial facilities. Where this value has a high likelihood of being exceeded during the design life of planned structures (e.g., the MPE acceleration assumed to occur in a 100 year period), a constraint can be said to exist. This is the case for all of the subarea where the peak horizontal ground acceleration for the Maximum Probable Earthquake is approximately 0.5 to 0.6 g. Plate 2 indicates very approximately where the 0.5 g., 0.55 g., and 0.6 g. peak horizontal acceleration contours may be expected for a MPE on the nearby Chino fault.

Unusual mitigation measures will be required to compensate for these levels of acceleration, particularly for critical, important, or high occupancy facilities. This is especially true for this area due to the potential for site amplification of earthquake waves in thick alluvium, and due to high groundwater. With alluvial thickness in the range of 300 to 800 feet, the relative amplification and attenuation affects of nearby and distant earthquakes must be considered for major and important construction projects. Sufficient information exists to prepare generalized, subarea-wide ground response maps for the critical local and distant earthquakes. Site-specific data and analysis would still be required for major facilities.

<u>Liquefaction</u>

Liquefaction occurs when saturated, cohesionless (low relative density) materials (usually sand or silty sand) are transformed from a solid to a near liquid state due to the increase in pore-water pressure that can be caused by moderate to severe seismic ground shaking. The expected level of ground shaking in the subarea is above 0.5 g, high enough to initiate liquefaction. Two of the three key conditions that are conducive to liquefaction, shallow groundwater and cohesionless sands, are thought to be present within Subarea 2, however insufficient data exist to map either condition with precision. There is some potential for liquefaction where water is greater than about 50 feet deep, but the potential is higher with depths less than 50 feet (LP). Liquefaction potential is substantially higher where water is less than 30 feet deep (LH).

The areas of highest liquefaction potential are coincident with the Holocene deposits (Qhm and Qhf) in the lowest lying areas where surface water has been observed in the late 1880s, where water has been reported to be less than 30 feet deep, and in the major drainages (Plate 2). These areas are considered to have potential land use constraints due to liquefaction.

Liquefaction can cause overlying structures (e.g., bridges, buildings, storage tanks) to settle non-uniformly, and buried structures (e.g., fuel tanks, pipelines) to float. In either situation severe damage to the structure is highly likely. Estimates of liquefaction potential require specific data from geotechnical borings and groundwater level monitoring. It should be a priority to compile such data as it might exist in City, State, or County files, and to obtain new data so that a broad-area assessment is possible.

Other areas of Holocene deposits have minimal potential (LM) and areas underlain by Pleistocene deposits have a lower potential. Due to the lack of specific data, the geologic unit and depth to groundwater boundaries shown on Plate 1 should be considered approximate, and liquefaction assessments should be made for all important projects. The depth and intensity of study will naturally vary depending on the location, type, and importance of the project.

Lateral spreading landslides can occur on relatively shallow slopes due to liquefaction of shallow layers causing a loss of shear strength. Within the subarea, this is most likely adjacent to the drainages where slopes are steepest and water may be more likely to accumulate (the II-a slope areas in Plate 2). It is not possible to map specific areas based on the current data, although the steeper slopes and the area at the base of these slopes are the most susceptible.

Mitigation measures exist for development in liquefaction-prone areas. These include:

1. Excavation and removal or recompaction of liquefiable soils;
2. In-situ ground densification;
3. Ground modification and improvement;
4. Deep foundations;
5. Reinforced shallow foundations; and
6. Reinforced structures to resist deformation during liquefaction.

## Soils and Slope

### Constraints

There are no known soils engineering conditions that are so significant that they qualify as planning constraints.

### Concerns

Many of the soils in the subarea are susceptible to expansion, settlement and possibly hydroconsolidation. Data are insufficient to provide specific quantitative conditions by geologic or soil unit. Moderate to high expansion indices indicate that there is a substantial amount of clay in the soils and repeated episodes of wetting and drying will cause distress to structures in contact with such soils. Consolidation (and long-term settlement) is most prominent in clay-rich and silt-rich soils due to the loading pressure of man-made structures, including buildings or artificial fill. The added weight can collapse the internal void spaces in the soils causing the overlying structures to settle, and possible be damaged. This consolidation and settlement can be much more dramatic under severe seismic shaking (dynamic settlement). Hydroconsolidation will also lead to settlement, but includes the addition of water into the soil structure causing more rapid and more substantial settlements.

The concerns expressed for expansion, consolidation/settlement, and hydroconsolidation potential can be addressed through standard, comprehensive geotechnical and soils engineering investigation and analysis. Recommendations that are made in conjunction with such investigations should specify all necessary steps to be taken to mitigate the potential affects of these soils concerns.

## Groundwater

### Constraints

There are no known groundwater conditions (except as associated with liquefaction discussed above) that are significant enough to be classed as constraints.

### Concerns

Two potential concerns exist for the presence of shallow groundwater. These relate to 1) water seepage that may collect within, around or on a structure (e.g., foundations, slabs, cut/fill slopes, and utility trenches), and 2) water that may be intercepted in a deep excavation causing potential dewatering and safety problems. The first instance could cause damage and/or nuisance with regard to the long-term care and maintenance of facilities. The second instance could cause safety problems for workers, as well as the aforementioned problems.

Geologic, hydrologic, and soils engineering/geotechnical investigation and analysis can be performed to determine if shallow water may be present at a given site. Recommendations that are made in conjunction with such investigations should specify all necessary steps to be taken to mitigate the potential affects of these hydrologic and engineering concerns.

## Subsidence

### Constraints

Although nothing specific is known about the subsidence history of the subarea and its adjacent areas, the potential does appear to exist for subsidence induced ground fissures. At present it is considered a specific planning constraint. However, insufficient information exists to more fully define the constraint. At present it is assumed that it could occur almost anywhere, and the possible size and depths of fissures is similar to those documented near the California Institution for Men and Ayala Park.

### Concerns

Subsidence that is regional in nature (over several square miles) may have little or no affect on smaller structures. Effects to the ground surface (e.g., cracking, noticeable differential movement) and on larger, more continuous structures anchored to the ground may be much more noticeable depending on the magnitude of the subsidence. Evidence suggests that the artesian water area that encompasses the northern 60% of Subarea 2 has undergone and may be undergoing subsidence. Since little evidence has been developed to help determine the location and magnitude of subsidence, a constraint cannot be mapped at this time.

It is recommended that a stepwise program of data evaluation be conducted beginning with all existing leveling survey data to determine subsidence areas. This should allow zones of likely tensional stress to be identified. These results could be extended using local groundwater pumping histories, re-surveys in critical areas, reviewing records of past distress/repair of linear structures (roads, pipelines) crossing the basin. Combined with aerial photographic and topographic map analysis, high potential areas for subsidence in the areas of Subarea 2 could be defined above elevation 540 feet. Alternatively, tasks after the compilation of leveling survey data could be required for individual projects. Past reports have suggested mitigation measures to minimize the impacts of ground fissures on construction.

## Conclusions

There are four potential geologic constraints affecting land use and development in Subarea 2. These are ***fault rupture*** and ***severe groundshaking*** due to a local moderate to large earthquake, ***liquefaction (including lateral spread landslides)*** due to shallow groundwater and severe groundshaking from local and major regional faults, and *subsidence-induced ground fissures* due to groundwater withdrawal. These potential constraints are sufficiently significant that special studies, avoidance zones and above standard mitigations may be required. Due to the limited amount of specific data available for Subarea 2, there is uncertainty as to the extent and severity of these potential constraints. It is believed that sufficient information exists to apply these constraints for the purposes of land use planning.

Other geologic concerns are slope instability, unsuitable engineering properties of geologic units, and the existence of unique geologic/paleontologic resources in the late Pleistocene or Holocene units. These concerns are important, but can be addressed by standard mitigation measures that are instituted under normal building codes and environmental impacts report requirements.

Other faults and lineaments have been observed within the late Pleistocene sediments and coincident with topographic features. This indicates a level of concern that these features may:

- Serve as locations for ground rupture in a severe local earthquake on the Chino-Elsinore fault zone
- Be locations where severe ground shaking is more focused should a local moderate to severe earthquake occur under the basin, and
- Exhibit differential movement and ground fissures due to subsidence and groundwater withdrawal

The Subarea 2 portion of the Chino Basin has not been extensively studied for development and few geologic publications on the area have been issued for the past 18-20 years. During this time earthquake activity has become better understood relative to the location of exposed and buried (so-called "blind") earthquake faults. Additional analysis beyond the scope of this study will be needed to determine if tentatively defined northeast trending features are important in the planning of development in the Subarea 2 portion of the Chino Basin. Until such time as such studies can be performed, the City should consider these features in the planning process.

Liquefaction may be a concern in areas where it is not noted as a constraint, due to the unpredictability of shallow/perched groundwater conditions, and the location of low density sand and silt layers. This possibility should be considered for development that is susceptible to damage in a liquefaction event. There are engineering measures that can be applied to reduce or eliminate the impacts of liquefaction to engineered facilities.

Soils engineering and geotechnical conditions are not well studied in the subarea, however it is known that similar soils outside the subarea have potentially deleterious properties. These properties are considered to be within the range of conditions dealt with in a comprehensive soils engineering or geotechnical engineering investigation for construction of habitable or other important facilities.

Groundwater in the Chino Basin appears to lie at depths of about 100 feet at the northeast corner of the subarea and possibly less than 30 feet in the southern portions. The potential for perched water zones at very shallow levels also exists throughout the subarea. These occurrences can be dealt with in a comprehensive geotechnical engineering investigations that have subsurface borings to the depth of influence for the construction that is proposed. Standard mitigation measures (e.g., dewatering) exist to prevent adverse affects from shallow groundwater.

Subsidence appears to be a potential hazard for this portion of the basin, however little study has been done to determine potential locations or magnitudes of future subsidence. Some of the topographic lineaments mapped for this study may reflect past subsidence, but this is uncertain. This potential for subsidence should be considered for future development projects.

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