2. GEOLOGY AND HYDROGEOLOGY

2.1 Geologic Setting

The Chino Basin was formed as a result of tectonic activity along major fault zones. It is part of a larger, broad, alluvial-filled valley located between the San Gabriel/San Bernardino Mountains to the north (Transverse Ranges) and the elevated Perris Block/San Jacinto Mountains to the south (Peninsular Ranges). The Santa Ana River is the main tributary draining the valley and, hence, the valley is commonly referred to as the Upper Santa Ana Valley. Chino Basin is located in the western portion of this valley as shown on Figure 2-1.

The major faults in the Chino Basin area – the Cucamonga Fault Zone, the Rialto-Colton Fault, the Red Hill Fault, the San Jose Fault, and the Chino Fault – are at least in part responsible for the uplift of the surrounding mountains and the depression of Chino Basin. The bottom of the basin – the effective base of the freshwater aquifer – consists of impermeable sedimentary and igneous bedrock formations that are exposed at the surface in the surrounding mountains and hills. Sediments eroded from the surrounding mountains have filled Chino Basin to provide the reservoirs for groundwater. In the deepest portions of Chino Basin, these sediments are greater than 1,000 ft thick.

The major faults also are significant in that they are known barriers to groundwater flow within the aquifer sediments and, hence, define some of the external boundaries of the basin by influencing the magnitude and direction of groundwater flow. The location of the major faults and their spatial relation to Chino Basin are shown in Figure 2-1. These faults, their effects on groundwater movement, and the hydrogeology of the general Chino Basin area have been documented by various entities and authors (Eckis, 1934; Gleason, 1947; Burnham, 1953; MacRostie and Dolcini, 1959; Dutcher & Garrett, 1963; Gosling, 1966; DWR, 1970; Woolfenden and Kadhim, 1997).

2.2 Stratigraphy

In this report, the stratigraphy of Chino Basin is divided into two natural divisions: (1) the pervious formations that comprise the groundwater reservoirs are termed the *water-bearing sediments* and (2) the less pervious formations that enclose the groundwater reservoirs are termed the *consolidated bedrock*. The consolidated bedrock is further differentiated as (a) metamorphic and igneous rocks of the basement complex, overlain in places by (b) consolidated sedimentary rocks. The water-bearing sediments overlie the consolidated bedrock, with the bedrock formations coming to the surface in the surrounding hills and highlands. Below, these geologic formations are described in stratigraphic order, the oldest formations first.

{It should be noted that the terms used throughout this report to describe bedrock, such as "consolidated," "non-water-bearing," and "impermeable," are used in a relative sense. The water content and permeability of these bedrock formations, in fact, is not zero. However, the primary point is that the permeability of the geologic formations in the areas flanking the basin is much less than the aquifers in the groundwater basin.}

2.2.1 Consolidated Bedrock

The *consolidated bedrock* formations of the Chino Basin area include the basement complex that is comprised of crystalline igneous and metamorphic rocks of pre-Tertiary age, the marine sedimentary and volcanic strata of late Cretaceous to late Tertiary age, and the continental deposits of late Pliocene to middle-Pleistocene age. Figure 2-2 shows the surface outcrops of the consolidate bedrock formations that surround Chino Basin. Note that the basement complex is the exposed bedrock north and southeast of the Chino Basin. Consolidated sedimentary rocks are the exposed bedrock west of Chino Basin.

The bedrock formations also occur at depth, underlying the water-bearing sediments of Chino Basin. Pervious strata or fracture zones in the bedrock formations may yield water to wells locally; however, the storage capacity is typically inadequate for sustained production. Figure 2-2 shows the contact between the bedrock formations and the water-bearing sediments as equal elevation contour lines – referred to herein as the base of the freshwater aquifer. The contours were originally generated by DWR (1970) and modified based on work performed for this study. Note that the base of the freshwater aquifer forms an irregular bowl-shaped depression, with its deepest areas located in the central portions of Chino Basin.

Eckis (1934) speculated that the contact between the consolidated bedrock and the water-bearing sediments is unconformable, as indicated by an ever-present weathered zone in the consolidated bedrock directly underlying the contact with the water-bearing sediments. This observed relationship suggests that the consolidated bedrock in the Chino Basin area was undergoing erosion prior to deposition of the water-bearing sediments.

Well boreholes have penetrated the various bedrock formations in Chino Basin. Figure 2-2 shows the locations of these boreholes, and the type of bedrock penetrated. Much like the bedrock surface exposures that surround Chino Basin, the basement complex is typically the bedrock formation first penetrated on the east side of Chino Basin, and sedimentary rocks are typically the bedrock formations first penetrated on the west side of Chino Basin. The nature of the buried contact between the basement complex and the sedimentary bedrock is largely unknown, but is likely an angular unconformity or a fault contact, and strikes north-south through the central portions of Chino Basin.

The general character of the consolidated bedrock formations is known from drillers' logs and surface outcrops, and is described below.

2.2.1.1 Basement Complex

The basement complex consists of deformed and re-crystallized metamorphic rocks that have been invaded and displaced in places by huge masses of granitic and related igneous rocks. The intrusive granitic rocks, which make up most of the basement complex, were emplaced about 110 million years ago in the late Middle Cretaceous (Larsen, 1958). These rocks were subsequently uplifted and exposed by erosion, as presently seen in the San Gabriel Mountains and in the uplands of the Perris block (Jurupa Mountains and La Sierra Hills). They have been the major source of detritus to the younger sedimentary formations, in particular, to the water-bearing sediments of Chino Basin.

2.2.1.2 Undifferentiated Pre-Pliocene Formations

Outcropping along the western margin of Chino Basin (in the Chino and Puente Hills) are consolidated sedimentary and volcanic rocks that unconformably overlie the basement complex. They consist of well-stratified marine sandstones, conglomerates, and shales, and interlayered lava flows that range in age from late Cretaceous to Miocene. According to Durham and Yerkes (1965), this sequence reaches a total stratigraphic thickness of more than 24,000 feet in the Puente Hills and is down-warped more than 8,000 feet below sea level in the Prado Dam area. Wherever mapped, these strata are folded and faulted and in most places dip from 20 to 60 degrees.

2.2.1.3 Plio-Pleistocene Formations

Overlying the older consolidated bedrock formations is a thick series of semi-consolidated clays, sands, and gravels of marine and non-marine origin. These sediments have been named the Fernando Group (Eckis, 1934), and outcrop in two general locations of the study area: the Chino Hills on the western margin of Chino Basin and in the San Timoteo Badlands southeast of Chino Basin. In surface outcrop, the entire Group is mapped as consolidated bedrock for this study, and is likely the first bedrock penetrated in southwest Chino Basin. However, the upper portion of the Fernando Group is more permeable than the lower portion, and thus represents in the subsurface, a gradual transition from the non-water-bearing consolidated rocks to the water-bearing sediments. Furthermore, the upper Fernando sediments are similar in texture and composition to the overlying water-bearing sediments, which complicates the distinction between the formations from borehole data.

2.2.2 Water-Bearing Sediments

Beginning in the Pleistocene and continuing to the present, an intense episode of faulting depressed the Chino Basin area and uplifted the surrounding mountains and hills. Detritus eroded from the mountains were transported and deposited in Chino Basin atop the consolidated sedimentary and crystalline bedrock as interbedded, discontinuous layers of gravel, sand, silt, and clay to form the *water-bearing sediments*.

The water-bearing sediments can be differentiated into the Older Alluvium of Pleistocene age and Younger Alluvium of Holocene age. The general character of these formations is known from driller's logs and surface outcrops, and is described below.

2.2.2.1 Older Alluvium

The Older Alluvium varies in thickness from about 200 feet thick near the southwestern end of Chino Basin to over 1,100 feet thick southwest of Fontana, and averages about 500 feet throughout Chino Basin. It is commonly distinguishable in surface outcrop by its red-brown or brick-red color, and is generally more weathered than the overlying Younger Alluvium. Pumping capacities of wells completed in the Older Alluvium range between 500 and 1,500 gallons per minute (gpm). Capacities exceeding 1,000 gpm are common, with some modern production wells test-pumped at over 4,000 gpm (*e.g.*, Ontario Wells 30 and 31 in southeastern Ontario). In the southern part of Chino Basin where sediments tend to be more clayey, wells generally yield 100 to 1,000 gpm.

2.2.2.2 Younger Alluvium

The Younger Alluvium occupies streambeds, washes, and other areas of recent sedimentation. Oxidized particles tend to be flushed out of the sediments during transport, and the Younger Alluvium is commonly light yellow, brown, or gray. It consists of rounded fragments derived from erosion of bedrock, from reworked Older Alluvium, and from the mechanical breakdown of larger fragments within the Younger Alluvium itself. The Younger Alluvium varies in thickness from over 100 feet near the mountains to a just few feet south of Interstate 10, and generally covers most of the northern half of Chino Basin in undisturbed areas. The Younger Alluvium is not saturated and thus does not yield water directly to wells. Water percolates readily in the Younger Alluvium and most of the large spreading basins are located in the Younger Alluvium.

2.3 Groundwater Occurrence and Movement

The physical nature of the groundwater reservoirs of Chino Basin is describe below with regard to basin boundaries, recharge, groundwater flow, discharge, distinct aquifer systems, hydrostratigraphy, aquifer properties, and internal faults.

2.3.1 Chino Basin Boundaries

The physical boundaries of the Chino Basin are shown on Figure 2-1 and include:

- **Red Hill Fault to the north.** The Red Hill Fault is a recently active fault evidenced by recognizable fault scarps such as Red Hill at the extreme southern extent of the fault near Foothill Boulevard. The fault is a known barrier to groundwater flow and groundwater elevation differences on the order of several hundred feet on opposite sides of the fault are typical (Eckis, 1934; DWR, 1970). Groundwater seeps across the Red Hill Fault as underflow from the Cucamonga Basin to the Chino Basin, especially during periods of high groundwater elevations within the Cucamonga Basin.
- **San Jose Fault to the northwest.** The San Jose Fault is known as an effective barrier to groundwater flow with groundwater elevation differences on the order of several hundred feet on opposite sides of the fault (Eckis, 1934; DWR, 1970). Groundwater seeps across the San Jose Fault as underflow from the Claremont and Pomona basins to the Chino Basin, especially during periods of high groundwater elevations within the Pomona and Claremont Heights basins.
- **Groundwater divide to the west.** A natural groundwater divide near Pomona separates the Chino Basin from the Spadra Basin in the west. The divide, which extends from the eastern tip of the San Jose Hills southward to the Puente Hills, is produced by groundwater seepage from the Pomona Basin across the southern portion of the San Jose Fault (Eckis, 1934).
- **Puente Hills/Chino Hills to the southwest.** The Chino Fault extends from the northwest to the southeast along the western boundary of the Chino Basin. It is, in part, responsible for uplift of the Puente Hills and Chino Hills, which form a continuous belt of low hills west of the fault. The Chino and Puente Hills, primarily composed of consolidated sedimentary rocks, form an impermeable barrier to groundwater flow.
- **Flow system boundary with Temescal basin to the south.** Comparison of groundwater elevation contour maps over time suggests a consistent distinction between flow systems within the lower Chino Basin and Temescal Basin. As groundwater within Chino Basin flows southwest into the Prado Basin area, it converges with groundwater flowing northwest out of the Temescal Valley (Temescal Basin). These groundwaters commingle and flow southwest toward Prado Dam and can rise to become surface water in Prado Basin. This area of convergence of Chino and Temescal groundwaters is indistinct and probably varies with changes in climate and production patterns. As a result, the boundary that separates Chino Basin from Temescal Basin was drawn along the legal boundary of the Chino Basin (Chino Basin Municipal Water District v. City of Chino *et al.*, San Bernardino Superior Court, No. 164327).
- **La Sierra Hills to the south.** The La Sierra Hills outcrop south of the Santa Ana River and are primarily composed of impermeable bedrock and form a barrier to groundwater flow between the Chino Basin and the Arlington and Riverside basins.
- **Shallow bedrock at the Riverside Narrows to the southeast.** Between the communities of Pedley and Rubidoux, the impermeable bedrock that outcrops on either side of the Santa Ana River narrows considerably. In addition, the alluvial thickness underlying the Santa Ana River thins to approximately 100 feet or less (*i.e.*, shallow bedrock). This area of narrow and shallow bedrock along the Santa Ana River is commonly referred to as the Riverside Narrows. Groundwater upgradient of the Riverside

Narrows within the Riverside basins is forced to the surface to become rising water within the Santa Ana River (Eckis, 1934). Downstream of the Riverside Narrows, the bedrock configuration widens and deepens, and surface water within the Santa Ana River can infiltrate to become groundwater in Chino Basin.

- **Jurupa Mountains and Pedley Hills to the southeast.** The Jurupa Mountains and Pedley Hills are primarily composed of impermeable bedrock and form a barrier to groundwater flow that separates the Chino Basin from the Riverside basins.
- **Bloomington Divide to the east.** A flattened mound of groundwater exists beneath the Bloomington area as a likely result of groundwater flow from the Rialto-Colton basin through a gap in the Rialto-Colton Fault north of Slover Mountain (Dutcher and Moyle, 1963; Gosling, 1966; DWR, 1970). This mound of groundwater extends from the gap in the Rialto-Colton Fault to the southwest towards the northeast tip of the Jurupa Mountains. Groundwater to the northwest of this divide recharges the Chino Basin and flows westward staying north of the Jurupa Mountains. Groundwater southeast of the divide recharges the Riverside basins and flows southwest towards the Santa Ana River.
- **Rialto-Colton Fault to the northeast.** The Rialto-Colton Fault separates the Rialto-Colton Basin from the Chino and Riverside basins. The fault is a known barrier to groundwater flow along much of its length – especially in its northern reaches (south of Barrier J) where groundwater elevations can be hundreds of feet higher within the Rialto-Colton Basin (Dutcher and Garrett, 1963; DWR, 1970; Woolfenden and Kadhim, 1997). The disparity in groundwater elevations across the fault decreases to the south. To the north of Slover Mountain, a gap in the Rialto-Colton Fault exists. Groundwater within the Rialto-Colton Basin passes through this gap to form a broad groundwater mound (divide) in the vicinity of Bloomington and, hence, is called the Bloomington Divide (Dutcher and Moyle, 1963; Gosling, 1966; DWR, 1970).
- **Extension of the Rialto-Colton Fault north of Barrier J.** Little well data exist to support the extension of the Rialto-Colton Fault north of Barrier J (although hydraulic gradients are steep through this area). Groundwater flowing south out of Lytle Creek Canyon, in part, is deflected by Barrier J and likely flows across the extension of the Rialto-Colton Fault north of Barrier J and into the Chino Basin.

2.3.2 Groundwater Recharge, Flow, and Discharge

Predominant recharge to the groundwater reservoirs of Chino Basin is from percolation of direct precipitation and infiltration of stream flow within tributaries exiting the surrounding mountains and hills and within the Santa Ana River. The following is a list of all potential sources of recharge in Chino Basin:

- Infiltration of flow (and, locally, imported water) within unlined stream channels overlying the basin.
- Infiltration of storm water flow and municipal wastewater discharges within the channel of the Santa Ana River.
- Underflow from the saturated sediments and fractures within the bounding mountains and hills.
- Artificial recharge at spreading grounds of storm water, imported water, and recycled water.
- Underflow from seepage across the bounding faults, including the Red Hill Fault (from Cucamonga Basin), the San Jose Fault (from the Claremont Heights and Pomona basins), and the Rialto-Colton Fault (from the Rialto-Colton Basin).
- Intermittent underflow from the Temescal Basin.
- Deep percolation of precipitation and returns from use.

In general, groundwater flow mimics surface drainage patterns: from the forebay areas of high elevation (areas in the north and east flanking the San Gabriel and Jurupa Mountains) towards areas of discharge near the Santa Ana River within Prado Flood Control Basin. Figure 2-3 is a groundwater elevation contour map for Fall 2000 that shows this general groundwater flow pattern (perpendicular to the contours). Comparing this contour map to groundwater elevation contour maps from other periods shows similar flow paths, indicating consistent flow systems within Chino Basin (WEI, 2000).

While considered one basin from geologic and legal perspectives, the Chino Basin can be hydrologically subdivided into at least five flow systems that act as separate and distinct hydrologic units. Each flow system can be considered a *management zone*. Each management zone has a unique hydrology, and water resource management activities that occur in one management zone have limited impact on the other management zones.

Figure 2-3 shows the location of the five management zones in Chino Basin that were developed during the TIN/TDS Study (WEI, 2000) of which the Watermaster, the Chino Basin Water Conservation District (CBWCD), and the Inland Empire Utilities Agency (IEUA) were study participants. Nearing the southwestern (lowest) portion of Chino Basin, these flows systems become less distinct as all groundwater flow within Chino Basin converges and rises beneath Prado Basin. In detail, groundwater discharge throughout Chino Basin primarily occurs via:

- Groundwater production.
- Rising water within Prado Basin (and potentially other locations along the Santa Ana River depending on climate and season).
- Evapotranspiration within Prado Basin (and potentially other locations along the Santa Ana River depending on climate and season) where groundwater is near or at the ground surface.
- Intermittent underflow to the Temescal Basin.

2.3.3 Aquifer Systems

The saturated sediments within Chino Basin comprise one groundwater reservoir, but the reservoir can be sub-divided into distinct aquifer systems based on the physical and hydraulic characteristics of the aquifer system sediments and the contained groundwater. These aquifer systems include a *shallow aquifer system* and at least one *deep aquifer system*.

The sediments that comprise the shallow aquifer system are saturated in the southern portion of Chino Basin, but are unsaturated in the northern forebay regions where they provide a thick vadose zone for percolating groundwater (see Figure 2-3). The sediments that comprise the deep aquifer system are always at least partially saturated, but pinch out near bedrock outcrops and in the southern-most portion of Chino Basin. Section 2.3.4 describes and illustrates the detailed configurations of the shallow and deep aquifer systems.

The shallow aquifer system is generally characterized by unconfined to semi-confined groundwater conditions, high permeability within its sand and gravel units, and high concentrations of dissolved solids and nitrate. The deep aquifer system is generally characterized by confined groundwater conditions, lower permeability within its sand and gravel units, and lower concentrations of dissolved solids and nitrate. Where both aquifer systems are present and saturated, hydraulic head tends to be higher in the shallow aquifer system, indicating a downward vertical hydraulic gradient.

To illustrate the above generalizations, Figure 2-4 shows the location of Well 1A and Well 1B owned by the City of Chino Hills. These two wells are physically located within 30 feet of each other on the west side of Chino Basin, but their non-pumping water-level time histories are dramatically different. Figure 2-5 is a water-level time history of Well 1A (perforated within the shallow aquifer system), which maintains a relatively stable water level that fluctuates annually by about 20 feet (and a maximum of about 50 feet), probably in response to seasonal production and recharge. Comparatively, Well 1B (perforated within the deep aquifer system) displays a wildly fluctuating piezometric level that can vary seasonally by as much as 250 feet. The water level fluctuations observed in the deep aquifer system are typical of confined groundwater conditions where relatively small changes in storage can generate large changes in piezometric levels. Invariably, piezometric head is lower in the deep well (1B).

Wells 1A and 1B also display significant differences in water quality. Nitrate concentrations in 1A and 1B averaged 7 mg/L and 1 mg/L, respectively from 1997 to 2002. Total dissolved solids concentrations in 1A and 1B averaged 288 mg/L and 175 mg/L, respectively from 1997 to 2002. Arsenic concentrations are relatively high in the deep aquifer system (average of 66 ug/L in Well 1B from 1997 to 2002 compared to non-detectable in Well 1A). Similar water quality disparities have been noted between deep and shallow groundwater in the area of the Chino-1 Desalter well field (see Figure 2-4) and its eastward expansion currently under construction (Fox, 1990; GSS, 2001; Dennis Williams, GSS, pers. comm., 2003).

Also shown in Figure 2-4 – near Wells 1A and 1B – is Chino Basin Watermaster's recently constructed Ayala Park Extensometer facility. At this facility are 11 piezometers with screens of 5-20 feet in length that were completed at various depths that range from 139 to 1,229 feet below ground surface (ft bgs). Slug tests were performed at a number of these piezometers to, among other objectives, determine the permeabilities of the sediments at various depths within the total aquifer-system. In general, the piezometers in the shallow aquifer-system (less than about 350 ft bgs) display relatively high hydraulic conductivities of 20 to 27 ft/day. The piezometers within the deep aquifer-system display relatively low hydraulic conductivities of 1.6 to 0.5 ft/day. A notable exception is a piezometer completed in a gravelly sand in the uppermost portion of the deep aquifer-system (438 to 448 ft bgs) that displays a relatively high hydraulic conductivity of 48 ft/day, indicating the existence of some higher permeability zones within the deep aquifer-system.

The distinction between aquifer systems is most pronounced within the west-southwest portions of Chino Basin. This is likely because of the relative abundance of fine-grained sediments in the southwest (multiple layers of clays and silts). Groundwater flowing from high-elevation forebay areas in the north and east becomes confined beneath these fine-grained sediments in the west-southwest, which effectively isolate the shallow aquifer system from the deep aquifer system(s).

The three-dimensional extent of these fine-grained sedimentary units and their effectiveness as confining layers has never been mapped in detail across Chino Basin. However, the following data, shown on Figure 2-4, can be used to estimate the lateral extent of these units:

- Historical flowing-artesian conditions were mapped in the early 1900s in the southwest portion of Chino Basin (Mendenhall, 1905, 1908; Fife *et al.*, 1976), which indicates the existence of confining layers in these areas.
- Remote sensing studies were conducted to analyze land subsidence in Chino Basin (Peltzer, 1999a, 1999b). These studies employed Synthetic Aperture Radar Interferometry (InSAR), which utilizes radar imagery from an Earth-orbiting spacecraft to map ground surface deformation. InSAR has indicated the occurrence of persistent subsidence across the western portion of Chino Basin from 1992

to 2000 – likely due to the compaction of fine-grained sediments as a result of lower pore pressures within the aquifer system (WEI, 2002). The southern extent of persistent subsidence is currently unknown because InSAR data is difficult to obtain in areas of agricultural land uses, but may extend southward to encompass the historical artesian area.

North and east of these areas, the distinction between aquifer systems is less pronounced because:

- the fine-grained layers in the west-southwest thin and/or pinch-out to the north and east, and
- much of the shallow aquifer system is unsaturated in the forebay regions of Chino Basin.

Geologic descriptions from driller's logs in Chino Basin confirm the predominance of fine-grained sediments in the west-southwest portion of Chino Basin, and the predominance of coarser-grained sediments in the north and east portions of Chino Basin. These observations are described and illustrated in more detail in the following two sections (2.3.4 – Hydrostratigraphy and 2.3.5 – Aquifer Properties).

2.3.4 Hydrostratigraphy

As described in Section 2.2.2, the water-bearing sediments of Chino Basin are composed of interbedded, discontinuous layers of gravel, sand, silt, and clay. These layers and their geometries are too numerous and complex to characterized on a basin-wide scale. A simplified geologic model is needed to characterize the three-dimensional distribution of the water-bearing sediments and their hydrogeologic properties for input to a numerical groundwater flow model.

In order to develop this conceptual model, 10 hydrogeologic cross-sections were constructed across Chino Basin. The plan-view locations of eight cross-sections are shown in Figure 2-6 and the profile-view cross-sections are shown in Figures 2-7 through 2-14. Plotted on these cross-sections are selected well and borehole data, including borehole lithology, short-normal resistivity logs, well casing perforations, and water levels.

Through analyses of these cross-sections and other hydrogeologic data, the water-bearing sediments were grouped into three hydrostratigraphic units (layers):

- *Layer 1* consists of the upper 200-300 feet of sediments, and is generally representative of the shallow aquifer-system (see Section 2.3.3). Layer 1 sediments are typically coarse-grained (sand and gravel layers) and, where saturated, transmit large quantities of groundwater to wells due to high hydraulic conductivities. On the west side of Chino Basin, Layer 1 sediments are composed of a greater fraction of finer-grained sediments (silt and clay layers), especially in the uppermost 100 feet.
- *Layer 2* consists of 200-500 feet of sediments underlying Layer 1, and is representative of the upper portion of the deep aquifer system (see Section 2.3.3). On the west side of Chino Basin, Layer 2 sediments are primarily fine-grained (silt and clay layers) with few interbedded sand and gravel layers. Layer 2 sediments become increasingly coarse-grained in the northern and eastern portions of Chino Basin, and as a result, the distinction between Layer 1 and Layer 2 sediments becomes less pronounced.
- *Layer 3* consists of 100-500 feet of sediments underlying Layer 2, and is representative of the lower portion of the deep aquifer system (see Section 2.3.3). The distribution of Layer 3 sediments is limited to the deepest (central) portions of Chino Basin, with "pinch-out" toward the basin margins. Layer 3 sediments are typically coarse-grained (sand and gravel layers), but due to their greater age, consolidation, and state of weathering, these sediments have lower permeability than the coarse-

grained sediments of Layer 1 and 2. Layer 3 sediments, in places, may include the upper portion of the continental deposits of the Fernando Group.

The top and bottom elevations of the three layers were brought into a Geographic Information System (GIS) as point values. These elevation values were then used as input to create a series of grids that represent the three-dimensional conceptual model of the water-bearing sediments of Chino Basin.

2.3.5 Aquifer Properties

The aquifer properties of critical importance for this study are effective porosity (specific yield) and hydraulic conductivity.

2.3.5.1 Effective Porosity

The effective porosity of the water-bearing sediments in Chino Basin was estimated through the analysis of lithologic descriptions from driller's logs. Watermaster maintains a library of driller's logs of all known well boreholes that have been drilled in Chino Basin. The lithologic descriptions from the driller's logs were input into a relational database along with corresponding US Geological Survey (USGS) estimates of effective porosity by sediment type (Johnson, 1967).

Effective porosity was averaged at each borehole for each layer. These values were plotted and gridded using a Kriging method within the ArcGIS Spatial Analyst extension for each layer, and are shown in Figures 2-15 through 2-17.

Figure 2-15 displays average effective porosity for Layer 1. Average effective porosities are highest, ranging up to 20 percent, in the northern (Upland) and eastern (Fontana) portions of Chino. A belt of similarly high effective porosity runs north of and parallels the Santa Ana River near Norco. This belt may represent coarse-grained sediments deposited by an ancestral Santa Ana River. Average effective porosities are lowest, ranging down to 6 percent, on the west side of Chino Basin (Pomona and Chino). This area of relatively low effective porosity overlaps the historical artesian area, and may represent fine-grained sediments that historically acted as confining layers.

Figure 2-16 displays average effective porosity for Layer 2. As with Layer 1, average effective porosities are highest, ranging up to 20 percent, in the northern (Upland) and eastern (Fontana) portions of Chino Basin. A belt of similarly high effective porosity runs north of the Jurupa Mountains from Fontana to Norco. As with Layer 1, this belt may represent coarse-grained sediments deposited by an ancestral Santa Ana River. Average effective porosities are lowest, ranging down to 3 percent, on the west side of Chino Basin (Pomona, Chino, and west Ontario). This area of relatively low effective porosity overlaps the historical artesian area and the area of historical subsidence as indicated by InSAR, and may represent fine-grained sediments that have experienced compaction due to reduced pore pressures.

Figure 2-17 displays average effective porosity for Layer 3. Again, the primary observation is coarser-grained sediments comprising the east side of Chino Basin, and finer-grained sediments comprising the west side.

2.3.5.2 Hydraulic Conductivity

The hydraulic conductivity of water-bearing sediments is a measure of its capacity to transmit water. Generally, sands and gravels have high hydraulic conductivities while clays and silts have low hydraulic conductivities. Since the effective porosity figures (Figure 2-15 through 2-17) were created from lithologic descriptions of well bore cuttings, they also qualitatively indicate the distribution of hydraulic conductivity of the water-bearing sediments. On average, hydraulic conductivities are highest in the northern (Upland) and eastern (Fontana) portions of Chino Basin. A belt of similarly high hydraulic conductivity runs north of the Jurupa Mountains from Fontana to Norco. Average hydraulic conductivities are lowest on the west side of Chino Basin (Pomona, Chino, and west Ontario). Generally, hydraulic conductivities decrease with depth because deeper sediments typically have experienced a greater degree of secondary alteration (*e.g.* weathering of feldspars to clay minerals, cementation of pore space, *et cetera*). Sections 6 and 7 will discuss and illustrate the distribution of hydraulic conductivity in Chino Basin in more detail.

2.3.6 Internal Faults

- Barrier “J” - Barrier "J" appears to be a significant impediment to groundwater flow in the Rialto Basin. However, there is no conclusive evidence that Barrier "J" acts as barrier in the Chino Basin. The displacement in the effective base of the aquifer in the Chino Basin and barrier effects in Rialto Basin suggest potential for Barrier "J" to be a groundwater barrier in the Chino Basin.
- Central Avenue Fault - The effect of the Central Avenue fault on groundwater flow is unknown. The sediments west of the fault are generally finer than the sediments east of the fault and it unclear if the relatively poor production capabilities of the area west of the fault are the result of marginal aquifer properties, the Central Avenue fault acting as a hydrologic barrier, or both.

2.4 Groundwater Levels

2.4.1 Groundwater Level Monitoring

Various entities have collected groundwater-level data in the past. Municipal and agricultural water supply entities have historically collected groundwater-level data in programs that range from irregular, study-oriented measurements to long-term periodic measurements. Groundwater-level measurements were made for specific investigations such as various California Department of Water Resources (DWR) studies, the 1969 Judgment on the Santa Ana River (Orange County Water District *vs.* City of Chino *et al.*), and the Chino Basin Judgment (Chino Basin Municipal Water District vs. City of Chino *et al.*). The spatial extent and temporal history of groundwater-level measurements south of State Route 60 have, until recently, always been less than north of State Route 60. The DWR and the San Bernardino County Flood Control District (SBCFCD) were very active in collecting groundwater-level measurements in the Chino Basin prior to the settlement of the Chino Basin adjudication. After the Judgment was entered in 1978, the water level monitoring south of State Route 60 stopped almost completely except for the cities of Chino, Chino Hills, and the Jurupa Community Services District (JCSD). Most of the pre-1978 measurements were digitized by the DWR.

Watermaster conducted its first large-scale groundwater-level monitoring program for the Chino Basin in the spring of 1986. In 1989, Watermaster initiated a more regular monitoring program for Chino Basin with groundwater-level measurements obtained in 1990, and periodically thereafter through 1997.

Since 1998 and pursuant to implementation of the Optimum Basin Management Program (OBMP), Watermaster has developed and implemented three groundwater-level monitoring programs:

- Basin-wide;
- Chino-1 Desalter; and

- Chino-2 Desalter.

A fourth program is currently being implemented for Management Zone 1 to support subsidence and fissuring investigations.

These Watermaster programs typically rely on municipal producers and other government agencies to supply their groundwater-level measurements on a cooperative basis. Watermaster staff supplements these data with groundwater-level measurements collected by staff, primarily south of State Route 60. Chino Basin was initially canvassed for all wells capable of yielding a groundwater-level measurement, and these wells were included in at least one of the four groundwater-level monitoring programs. Measurement frequencies range from twice per year for the Basin-wide program, to twice a month for the Desalter programs. Water levels at some wells participating in the MZ-1 monitoring program are recorded by pressure transducers once every 15 minutes. Watermaster digitizes all of these recent measurements and has combined the measurements from all known sources into a relational database that is maintained at Watermaster's office.

2.4.2 Historical Groundwater Levels

This section describes the groundwater-level time histories in the Chino Basin by management zone and characterizes the differences between management zones. Figure 2-18 illustrates the location of wells whose groundwater-level time histories are discussed herein and the management zone boundaries. The wells were selected based on length of record, completeness of record, and geographical distribution. Wells discussed herein are identified by their owner and local name designation if a municipal well, and by state well location if a private well.

The behavior of groundwater levels at specific wells is compared to climate, to pre- and post-Judgment periods, and to other factors as appropriate. {Note: the short-term groundwater-level fluctuations shown in the following figures are caused by including static and dynamic observations in the groundwater-level time histories.}

For comparison to climate, the cumulative departure from mean precipitation (CDFM) is plotted on all water-level time history figures. Positive sloping lines on the CDFM curve imply wet years or wet periods. Negatively sloping lines imply dry years or dry periods. For example, the period between 1937 to 1944, 1978 to 1983, and 1993-1998 are wet periods, and are represented as positively sloping lines. The period 1945 through 1977 is a drought period and is represented as a negatively sloping line, punctuated with a few wet years (positively sloped in 1952, 1958, and 1969).

The implementation of the Chino Basin Judgment in 1978 is evident in most of the water-level time histories because it corresponded with (1) the management of groundwater production, (2) the initiation of groundwater replenishment with imported water, and (3) the reduction in pumping due to increased direct use of imported surface water.

- **Management Zone 1.** Upland-7, Monte Vista Water District well MVWD-4, and Pomona-6 (Figure 2-19) illustrate typical groundwater-level time histories in the northern half of Management Zone 1. Water levels in these wells followed the climatic trends very closely, with little or no lag in water-level response to major climatic changes. This quick response may be due to rapid infiltration through a thick coarse-grained vadose zone, changes in groundwater demand (pumping) because of surface water availability, or both. Prior to the Judgment (1978), these time histories show that the northern half of MZ-1 was experiencing overdraft, as water levels declined by as much as 200 feet from 1945 to 1977.

After the Judgment, water levels recovered in these wells, especially during the 1978 to 1983 wet period. Over the last 10 years (1992 to 2002), water levels were relatively stable with a slight decline in the most recent dry years (1998 to 2002).

Chino-4 illustrates a typical groundwater-level time histories in the southern half of MZ-1. Water levels in this well do not follow climatic trends closely, as shown by declining water levels during the relatively wet 1993 to 1998 period. This observation is likely due to the fine-grained texture of the aquifer-system sediments that inhibit rapid recharge to this area. During the last 10 years (1992 to 2002), water levels were relatively stable with a slight decline in the most recent dry years (1998 to 2002). Few wells in this region have water-level time histories that extend back prior to the Judgment (1978).

Not shown in Figure 2-19 are water-level time histories from wells in the southern half of MZ-1 that are perforated solely in the deep aquifer-system. Recall from Section 2.3.3 that two very distinct aquifer systems exist in this area. Chino Hills-1B is one of these deep aquifer-system wells, and its water-level time history is shown in Figure 2-5. During the last 10 years (1992 to 2002), water levels in the deep aquifer-system fluctuated seasonally by up to 250 feet, but stayed relatively stable within this range over the 10-year period. Most of these deep wells were drilled in 1990, so little water-level data exists prior to 1990 for the deep aquifer-system.

- **Management Zone 2.** Few wells exist in the northern forebay portions of MZ-2 in part because of great depths to groundwater. CCWD-CB4 and Ontario-7 (Figure 2-20) illustrate typical groundwater-level time histories in the central portion of Management Zone 2. Water levels in these wells followed the climatic trends, but with a significant lag in water-level response to major climatic changes (2 to 4 years). This lag in water-level response to climate is likely due to a thick vadose zone (300 to 400 feet) and the significant distance to the primary recharge areas in the north (5 to 8 miles to the San Sevaine and Etiwanda Spreading Grounds). Prior to the Judgment (1978), these time histories show that the central portion of MZ-2 was in overdraft as water levels declined by as much as 130 feet during the period of 1930 to 1977, with water levels showing little or no response to wet years until 1978. After the Judgment, water levels at these wells increased slightly (10 to 20 feet) until about 1990. This post-Judgment increase is probably due to the combination of 1978 to 1983 wet period, reduction in overdraft following the implementation of the Judgment, the start of artificial replenishment with imported water in the San Sevaine and Etiwanda basins, and the increased use of imported surface water. During the last 10 years (1992 to 2002), water levels declined slightly (10 to 20 feet), even during and after the 1993-1998 wet period.

  2S/7W-9M1 and 2S/7W-21C illustrate typical groundwater-level time histories for wells in the southern half of MZ-2. Prior to the Judgment (1978), and similar to the wells in the central portion of MZ-2, these time histories show that the southern half of MZ-2 was in overdraft as water levels declined by as much as 80 feet during the period of 1930 to 1974. Water levels showed little or no response to wet years. During the last 10 years (1992 to 2002), water levels declined by about 20 feet, with most of this decline occurring since 1999. This most recent decline in water levels may be in part related to the onset of pumping at the Chino Basin Desalter well field.

- **Management Zone 3.** Fontana Water Company wells FWC-FU28 and FWC-F3A (Figure 2-21) illustrate typical groundwater-level time histories in the upgradient eastern portion of Management Zone 3. Water levels in these wells followed the climatic trends, but with a significant lag in water-level response to major climatic changes (1 to 2 years). This lag in water-level response to climate is likely due to a thick vadose zone (~400 feet) and the absence of nearby sources of recharge. Prior to the Judgment (1978), these time histories show that the eastern portion of MZ-3 was in overdraft as water levels declined by as much as 70 feet during the period of 1930 to 1977, with water levels showing little or no response to wet years. After the Judgment, water levels at these wells increased slightly (20 to 30 feet) until about 1990. This post-Judgment increase was probably due to the combination of the 1978 to 1983 wet period, the reduction in overdraft following the implementation of the Judgment, and the increased use of imported surface water. During the last 10 years (1992 to 2002), water levels were relatively stable but have declined slightly (10 to 20 feet) since about 1998.

JCSD-18 and JCSD-19 illustrate typical groundwater-level time histories for wells in the central portion of MZ-3. Prior to the Judgment (1978), and similar to the wells in the upgradient eastern portion of MZ-3, these time histories show that the central portion of MZ-3 was in overdraft as water levels declined by as much as 75 feet during the period of 1930 to 1977. Water levels showed little or no response to wet years. During the last 10 years (1992 to 2002), water levels remained relatively stable.

2S/7W-34H1 and 2S/7W-27 illustrate typical groundwater-level time histories for wells in the downgradient southern portion of MZ-3. Water levels in these wells followed the climatic trends with little or no lag in water-level response to major climatic changes – possibly due to their close proximity to the Santa Ana River. Prior to the Judgment (1978), these time histories show that the southern portion of MZ-3 was in overdraft as water levels declined by about 20 feet during the period of 1930 to 1977. During the last 10 years (1992 to 2002), water levels have declined by about 10-30 feet, with most of this decline occurring since 1999. This most recent decline in water levels may be in part related to the onset of pumping at the Chino Basin Desalter well field.

- **Management Zone 4.** 2S/6W-16B2, 2S/6W-13B6 and 2S/6W-14C2 (Figure 2-22) illustrate typical groundwater-level time histories in Management Zone 4. Water levels in these wells followed the climatic trends with little or no lag in water-level response to major climatic changes. These rapid responses to climatic trends is likely because MZ-4 is within a narrow valley bounded by bedrock hills, and its primary source of recharge is percolation of precipitation and storm flow in unlined channels that exit the bounding hills. Prior to the Judgment (1978), these time histories show that MZ-4 was in slight overdraft as water levels declined by about 20 feet during the period of 1945 to 1977. After the Judgment, water levels at these wells increased slightly (~10 feet) and have remained relatively stable and have continued to follow precipitation trends closely.
- **Management Zone 5.** JCSD-Limonite1, SARWC-7, Norco-11, and 2S/7W-36A (Figure 2-23) illustrate typical groundwater-level time histories in Management Zone 5, which parallels the Santa Ana River in Chino Basin. Water levels in these wells followed the climatic trends with little or no lag in water-level response to major climatic changes. However, the magnitude of water-level responses to changes in climate and/or groundwater production is less in MZ-5 than at wells in other management zones – likely because the close proximity of the perennial Santa Ana River has a stabilizing effect on groundwater levels. Prior to the Judgment (1978), these time histories show that MZ-5 was in slight overdraft as water levels declined in some wells by about 25 feet during the period of 1953 to 1977. After the Judgment, water levels at these wells recovered to their 1953 levels during the 1978 to 1983 wet period. After the Judgment, water levels were relatively stable but have declined slightly (by 10 feet or less) since 2000.