4. CONCEPTUAL MODEL

The purpose of building a conceptual model is to simplify the modeling problem and organize the associated field data so that the system can be analyzed (Anderson and Woessner, 1992). The groundwater system is too complicated to simulate directly; therefore, it must be simplified as much as possible and yet retain enough complexity for the model to adequately reproduce the real system's behavior. Long-term regional groundwater flow and quality projections require the determination of hydrologic components and definition of the horizontal and vertical flow regimes within the system.

There are four elements in the building of the conceptual model:

- definition of the model domain and hydrostratigraphic units;
- specification of the boundary conditions;
- preparation of a hydrologic budget; and
- definition of flow systems.

4.1 Model Domain and Hydrostratigraphic Units

The model domain consists of the Chino and Temescal groundwater basins. The adjacent groundwater basins contribute some groundwater inflow to the Chino and Temescal basins. Figure 2-1 shows the location of the Chino Basin and adjacent groundwater basins.

A hydrostratigraphic unit is part of formation or group of formations that can be grouped into aquifers and associated confining layers. The hydrostratigraphic units described in Section 2, and shown in Figures 2-7 through 2-14, were used to define the three major water bearing units in the conceptual model, and are referred to herein as Layers 1, 2, and 3. The spatial extent of each layer is shown in Figures 2-15 to 2-17 for layers 1 to 3, respectively.

4.2 Specification of Boundary Conditions

Numerical models require the specification of boundary conditions for each time step of the simulation; for example, groundwater elevation and/or flux along the boundary of the model. In addition, there are internal boundaries such as groundwater barriers and streams that groundwater can either discharge to or be recharged from.

4.2.1 External Boundaries

The external boundaries of the model are all defined as constant flux boundaries and are either set to zero or to positive values. Figure 4-1 shows the boundary of the model area and identifies the various boundary flow areas that were assumed in the model.

4.2.2 Internal Boundaries

There are two faults within the model domain that have been considered potential barriers to groundwater flow – the Central Avenue Fault and Barrier J. These faults are not included as barriers in the current implementation of the model; however, they may be included in subsequent refinements to the model.

The Santa Ana River and some of its tributaries in the southern part of Chino Basin form an internal boundary where groundwater can either discharge to surface water or surface water can recharge groundwater. The Santa Ana River and its tributaries that need to be simulated dynamically with the groundwater flow system are shown in Figure 4-1. The tributaries include Chino, Mill, Day, San Sevaine, and Temescal Creeks, as well as a few smaller drainages. The streambed or stream flow elevation in the stream system acts as a fixed or nearly-fixed boundary elevation and can have a strong influence on groundwater elevations in the area of the stream system.

4.3 Preparation of Hydrologic Budget

Preparing the hydrologic budget consists of estimating the magnitude and location of the major recharges to and discharges from (collectively referred to herein as hydrologic components) the model domain. The hydrologic components are the forcing functions in the model; that is, they are the major cause of change in groundwater elevation, contaminant occurrence and movement, and groundwater discharge to surface water. WEI used specialized modeling tools and other means to develop the hydrologic components. Some of these components were refined during calibration – the final calibration values are included in this discussion. The hydrologic budget terms are geographically characterized by the management zones that have been defined in the proposed 2003 Water Quality Control Plan for the Santa Ana Watershed (hereafter the 2003 Basin Plan). The proposed 2003 Basin Plan will likely be approved in October 2003 about the time this report is finalized. This convention was adopted to facilitate review of this document consistent with management activities that are contained in the 2003 Basin Plan and specifically to the concept of *hydraulic control* that is discussed later in *Section 7 Dry-Year Yield Program Impacts*. Figure 4-2 shows the management zones delineated in the 2003 Basin Plan. These management zones are:

- Chino North MZ
- Chino East MZ
- Chino South MZ
- Prado Basin (PBMZ)
- Temescal MZ

The Chino North MZ includes most of Watermaster's Management Zones 1, 2, and 3. The Chino East MZ is identical to Watermaster's Management Zone 4. Chino South MZ consists of the eastern majority of Watermaster's Management Zone 5. The PBMZ consists of the southern ends of Watermaster's Management Zones 1, 2, and 3, the western end of Watermaster's Management Zone 5 and a portion of the Temescal Basin. The PBMZ generally consists of the area below elevation 566 mean sea level (MSL) and corresponds to the maximum pool level of Prado reservoir.

4.3.1 Recharge Components

4.3.1.1 Subsurface Inflow

Figure 4-1 shows the locations of defined boundary segments that are assumed to have subsurface inflow. The assumed boundary inflow areas, their initial values, the source of the initial values, and the values derived in calibration are listed in Table 4-1. Initial estimates of boundary flow were developed from previous modeling investigations (CDM, 1984; Montgomery Watson, 1993). Subsurface inflow is assumed constant over time for each segment and with about 18,600 acre feet per year (acre-ft/yr) in the Chino management zones and about 2,500 acre-ft/yr in the Temescal MZ for a total of about 21,100 acre-ft/yr for the model area. Subsurface inflow was assumed constant over the calibration period because groundwater levels across the boundaries do not change rapidly and these inflows are not great in magnitude compared with the groundwater flow systems to which they contribute.

Subsurface inflow from one management zone to an adjacent management zone does occur and is computed by the 2003 Watermaster Model.

4.3.1.2 Streambed Recharge

Streambed recharge occurs in unlined stream channels and in flood control and water recharge basins. Most of the major stream channels in the Chino Basin are concrete-lined as of March 2003. In the case of future projections, all of the stream channels will be concrete-lined. Figure 4-2 shows the location of flood control and recharge basins, and major stream channels.

WEI used the Wasteload Allocation Model (WLAM) developed by WEI (2002) to estimate the storm water recharge in stream channels and in flood control and recharge basins. The WLAM was developed from the Chino Basin Watermaster Recharge Model, which was also developed by WEI (Wildermuth, 1998; WEI, 2001). The WLAM contains two modules – RUNOFF and ROUTER. RUNOFF estimates daily runoff from discrete drainage areas. ROUTER routes runoff from each drainage area through the drainage system and calculates, among many things, discharge and recharge in channels and in flood control and recharge basins. The drainage areas within the Chino Basin are shown in Figure 4-3. Other important data used in the WLAM include precipitation data, Soil Conservation Service (SCS) hydrologic soil types, land use, and physical properties of the drainage system (channel geometry, slope, lining, *etc.*). Figures 4-3 through 4-5 show the location of precipitation stations used herein, the spatial distribution of hydrologic soil types, and the 1993 land uses that were used in this analysis. The reader is referred to *TIN/TDS Study – Phase 2B of the Santa Ana Watershed, Wasteload Allocation Investigation, Final Technical Memorandum* (WEI, 2002) for a discussion of the capabilities, conceptual design, data, and an example application of the WLAM. Table 4-2 lists the time history of storm water recharge in stream channels and in flood control and recharge basins. Over the period 1988/1989 through 2000/2001, about 5,600 acre-ft of storm water recharged the Chino Basin through recharge basins and about 2,800 acre-ft of storm water recharged the unlined channels in Etiwanda and San Sevaine Creeks upstream of channel improvements.

4.3.1.3 Deep Percolation of Precipitation and Applied Water

WEI estimated the deep percolation of precipitation and applied water together. Deep percolation of precipitation and applied water was assumed to occur when soil moisture exceeded field capacity for the soil. Field capacity is the maximum volume of water that can be stored in the soil zone against the force of gravity. Soil moisture volume in excess of field capacity is assumed to percolate beyond the root zone and migrate through the vadose zone to the saturated zone. A soil moisture accounting module (SOILH2O) was developed and incorporated into the WLAM model structure. The WLAM Runoff module computes the volume of precipitation that infiltrates the soil. The SOILH2O module combines the volume of precipitation that infiltrates the soil with the volume of applied (irrigation) water. Soil moisture is modeled as follows:

$$SM_{t+1} = SM_t + I_{t\ to\ t+1} - E_{t\ to\ t+1}$$

If $SM_{t+1} < FC$ $\quad DP_{t\ to\ t+1} = 0$

If $SM_{t+1} > FC$ $\quad DP_{t\ to\ t+1} = SM_{t+1} - FC$ and

$SM_{t+1} = FC$

where:

SM_t is the soil moisture at the time t
$I_{t\ to\ t+1}$ is the infiltration from precipitation and applied water that occurs between time t to t+1
$E_{t\ to\ t+1}$ is the evapotranspiration that occurs between
$DP_{t\ to\ t+1}$ is the deep percolation of precipitation and applied water
FC is field capacity

Applied water for urban areas was estimated from reports, prepared by IEUA, that show the volume of water produced by each water purveyor in their service area and the volume of sewage produced by each purveyor. The difference was assumed to be equal to applied water. This information was estimated for the Three Valleys Municipal Water District (TVMWD) and the Western Municipal Water District (WMWD) service areas. Evapotranspiration was estimated for various vegetation types based on unit water use rates and California Irrigation Management Information System (CIMIS) data. Table 4-3 lists the time history of deep percolation of precipitation and applied water by 2003 Basin Plan management zone that were used in the 2003 Watermaster Model.

4.3.1.4 Supplemental Water Recharge

Supplemental water is recharged in the Chino Basin by the Chino Basin Watermaster pursuant to the 1978 Chino Basin Judgment and the 2000 Peace Agreement. Table 4-4 lists the annual time history of supplemental water recharge by the Chino Basin Watermaster. All supplemental water recharge done by Watermaster occurs in the Chino North MZ in the Montclair, San Sevaine and Etiwanda recharge basins. IEUA has recharged about 500 acre-ft/yr of recycled water in the Ely Basin since 1999/2000.

The City of Corona discharged almost all of its recycled water to ponds located in the Temescal MZ and the PBMZ. Half of the water was assumed to be recharged in the Temescal MZ and half of the water assumed to be recharged in the PBMZ. Table 4-4 lists the annual time history of recycled water recharge by the City of Corona.

4.3.2 Discharge

4.3.2.1 Subsurface Outflow

The only places where subsurface outflow could occur in the Chino Basin are to the Temescal Basin and underflow at Prado dam. Historical groundwater levels in Temescal Basin have caused groundwater outflow into the Chino Basin. However, it is theoretically possible for groundwater levels in the Temescal Basin to drop to levels where small amounts of groundwater outflow from Chino to Temescal Basin could occur. The Army Corps of Engineers constructed a grout curtain under Prado dam. As such, the subsurface outflow from Chino Basin at Prado dam is assumed negligible. Subsurface outflow out of the model domain area was assumed to be zero. Subsurface outflow from one management zone to an adjacent management zone does occur and is computed by the 2003 Watermaster Model.

4.3.2.2 Rising Groundwater

Rising groundwater can occur in the Santa Ana River and its tributaries in the Southern Chino Basin when the piezometric level of groundwater under the river exceeds the elevation of the streambed. Rising groundwater varies seasonally being greater in the winter and less in the summer. Rising groundwater cannot be directly measured from existing monitoring programs. The available data consist of surface water discharge monitoring stations at the MWD Crossing, just below Prado Dam, and the following tributaries: Chino Creek, Cucamonga Creek, and Temescal Creek. Other measured non-tributary discharges include recycled water discharges from the Cities of Corona and Riverside, the IEUA, and Western Riverside Regional, and occasionally Arlington Desalter discharge and State Project water discharges to San Antonio Creek in Upland. Between the MWD Crossing and Prado Dam, there are no measurements of surface water discharge that can be used to define reaches of rising groundwater or streambed recharge. The great stands of riparian vegetation in along the Santa Ana River and the Prado Reservoir area are likely to contribute to the seasonal variation of base flow in the Santa Ana River and may impact rising groundwater in the Prado Reservoir area. Rising groundwater estimates were made during model calibration.

4.3.2.3 Evapotranspiration by Riparian Vegetation

WEI performed a literature review of a select group of studies, conducted elsewhere in the southwestern United States, to develop annual water use rates for riparian vegetation. These studies were identified and reviewed by the USGS in *Riparian Vegetation and its Water Use During 1995 along the Mojave River, Southern California* (Lines and Bilhorn, 1996). The USGS developed estimates of riparian water use in the Mojave area by transferring estimates of riparian water use from other areas in the southwestern United States based on climatic factors. In a similar way, the Mojave estimates were transferred to the Chino Basin area. WEI collected reference evapotranspiration data from CIMIS for the Mojave area (Barstow and Victorville) and for the upper Santa Ana watershed (UC Riverside, Claremont, and Pomona). The reference evapotranspiration at the UC Riverside station was compared to the reference evapotranspiration at the Barstow and Victorville CIMIS stations and found to be about 83 percent of, or about 17 percent less than, the Mojave area reference evapotranspiration. Table 4-5a contains estimates of annual unit riparian water use for the Santa Ana River and tributaries in the Chino Basin area. A value of 41 inches per year of consumptive use (corresponding to cottonwoods, willows, and baccharis at 71 to 100 percent areal density) was assumed to apply to all riparian vegetation in the model area.

There is great variation in riparian water demand throughout the year, with demands being the greatest in July and August and the least in January and February. The monthly distribution of riparian water demand was estimated from *Bulletin 50, Use of Water by Native Vegetation* (Department of Public Works, Division of Water Resources, State of California 1942). Table 4-5b shows the monthly distribution for tules and willows from *Bulletin 50*, their combined average monthly evapotranspiration, and monthly distribution as a percentage of annual water use. The annual values listed in Table 4-5a were distributed monthly based on the monthly distribution shown in Table 4-5b. Figure 4-7 shows the areal extent of riparian vegetation in the Chino Basin based on digital air-photos taken in February 2002. Riparian vegetation covers approximately 6467 acres in the Chino South, Prado Basin, and Temescal MZs. The water demand by riparian vegetation in this area was initially estimated to be about 22,000 acre-ft/yr and was assumed constant over the period 1989/1990 through 2000/2001.

4.3.2.4 Pumping

Estimates of groundwater pumping were developed from the records of the Chino Basin Watermaster for the Chino Basin and from the non-verified pumping records compiled by WMWD for the Temescal Basin. Watermaster determined the physical location of wells in the Chino Basin using Global Positioning System (GPS) technology. The locations of wells in the Temescal Basin were digitized from well location maps prepared by WMWD and the City of Corona. Figure 4-8 shows the location of wells that have been active during the period of 1989/1990 to the present. The assignment of pumping to the various model layers is primarily based on well construction data. If well construction data were not available, pumping was assigned to model layers based on groundwater level and water quality data. Table 4-6 lists the annual groundwater pumping from the Chino and Temescal Basins for the period 1989/1990 through 2000/2001.

4.3.3 Balance of Recharge and Discharge

Tables 6-2a through 6-2e contain the recharge and discharge components and the balance for the period 1989/1990 through 2000/2001, which is the calibration period of the model. These tables are based on estimates of recharge and discharge that are the result of data collection and modeling and include the final calibration results. These tables will be discussed in Section 6.

4.4 Definition of Flow Systems

There are two flow system types that are interest in the evaluation of dry-year yield programs – the vadose zone and the saturated zone. Their importance is described below.

4.4.1 Vadose Zone

The vadose zone is the part of the aquifer that extends from the water table surface to the soil zone near the ground surface. In this zone, the void space contains water and gases; the movement of water is primarily vertical. In areas where the vadose zone is recharged by deep percolation of precipitation and applied water, the seepage rate through the vadose zone is very slow. In areas that receive large recharge volumes from recharge basins or streambed recharge, the seepage rate can be quite rapid as the vadose zone becomes locally saturated. Montgomery Watson estimated that the seepage rate was less than 10 ft/yr in areas where citrus was cultivated and recharge consisted of deep percolation of precipitation and applied water (JMM, 1989). By contrast the Montclair and San Sevaine recharge basins have recharged thousands of acre-ft per year of imported water over small areas where the underlying volume in the vadose zone is a fraction of the annual recharge – the implication being that the seepage rates are hundreds of feet per year when the rate of recharge is large.

In Section 2.5, it is reported that there is only a slight seasonal variation in groundwater levels in the Chino Basin and that there is a delayed response to a significant wet year or cumulative wet years. This occurs, in part, because the vadose zone is thick and acts like a regulating reservoir. The vadose zone smoothes out the variability of deep percolation of precipitation and applied water from extreme wet and dry periods. The hydraulic implications of the vadose zone for the dry-year yield program are that:

- increased recharge from the deep percolation of precipitation and applied water during wet years will not greatly increase groundwater levels when groundwater is *put* into the dry-year yield program account; and
- decreased recharge from the deep percolation of precipitation and applied water during dry years will not exacerbate groundwater levels when groundwater is produced from the dry-year yield program account.

In Section 3.3.5, the water quality implication of the vadose zone was discussed and it is stated that Watermaster considers that the proposed program to use 100,000 acre-ft of storage will not cause a significant release of contaminants to the saturated zone. Consequently, modeling of the vadose zone was not included in this investigation.

4.4.2 Saturated Zone

The saturated zone consists of the saturated part of the aquifer ranging from the water table to the effective base of the aquifer. In Section 2, there is considerable discussion on the occurrence and flow of groundwater in the saturated zone. Watermaster had divided the basin into five management zones that are based on the hydrology of the basin. These management zones are shown in Figure 2-3. For the remainder of this report we will use the management zone delineations in the 2003 Basin Plan. Most of the storage used in the dry-year yield program will occur in the Chino North MZ. The aquifer system in this management zone consists of three layers. In the northern parts of the Chino North MZ, the top layer (layer 1) is dry, and in some areas the top layer and middle layer (layer 2) are dry. Groundwater can flow vertically between layers in response to pressure gradients, which are caused mostly by pumping.

In the western part of the Chino Basin underlying the City of Chino and extending slightly north, east, and south of the city, there are several fine-grained layers that act as confining units. Layers 2 and 3 in this area have limited recharge and the area has been subject to subsidence and fissuring. East of this area, the aquifer materials become coarser, aquifers are readily recharged, and there has been little or no observed subsidence. Groundwater levels need to be managed very carefully in the City of Chino area to prevent additional subsidence and ground fissuring. There is greater flexibility in groundwater level management in the other areas of the basin.

There could be some outflow from Chino North and Chino South MZs to the PBMZ, and subsequently to the Santa Ana River or its tributaries. The Temescal MZ can also contribute outflow to the PBMZ, and subsequently to the Santa Ana River or its tributaries.

Given the above, the saturated zone must be represented in the model as a three-dimensional flow system to show the impacts of OBMP and related activities in the western Chino Basin. The groundwater system must be dynamically coupled to the overlying stream system in the southern part of Chino Basin to estimate the impacts of OBMP and related activities on groundwater discharge to the Santa Ana River and subsequent impacts on safe yield and downstream water quality.