municipal pumpage increased from the deep due to drought conditions, and both aquifers declined from 1984 through 1992.

The upper aquifer levels declined to lower elevations than in the deep aquifer. This happened because of deeper mining (but still within the upper aquifer) and hence increased pumpage from the upper aquifer at this location. The groundwater flow around these wells seemed to be from the deep to the upper aquifer during that period. It can be concluded that there is linkage between the two aquifers and that whenever there is sufficient gradient, groundwater flows and there is mixing between the upper and deep aquifer.

Mocho-II Sub-basin upper and deep aquifer mixing - Figure 3.11 presents groundwater level data for two wells in the Mocho II Sub-basin for the period 1975-99. The figure shows the groundwater levels in the Livermore Key well as representative of the upper aquifer and well 3S/2E 8p1 as representative of the deep aquifer. The major groundwater pumpage from this sub-basin is the municipal pumpage by CWS. It does not change significantly for the most part with either dry or wet conditions. During 1991-92, CWS pumped more than their GPQ. This increased pumpage lowered the deep groundwater levels during that period. As the upper aquifer levels recovered during the subsequent wet years, the deep aquifer levels followed higher. This indicates groundwater movement from the upper to the deep aquifer.

In summary, it can be concluded from the water level monitoring data and groundwater model simulations that there is inter and intra aquifer mixing, the extent of which varies with location and time. During prolonged droughts when the deep aquifer is pumped heavily, the upper aquifer water and salts move to the deep aquifer. The increased pumpage during these dry years increases the vertical hydraulic gradient and the horizontal gradient towards the pumping centers. The increased groundwater level potential gradient during drought years thereby increases the mixing in the main groundwater basin.

3.5 Vadose Zone Attenuation

Attenuation is a natural process whereby a material is reduced in amount, force, or severity. Attenuation may occur by various methods including dilution, dispersion, absorption, biodegradation, volatilization, and/or chemical reactions with soil particles. The vadose zone of soil is that area where the soil is mainly void of water. This region is also called the unsaturated zone or zone of aeration and generally represents the soil layers which lie above a water table or saturated zone, where present.

Evaluation of vadose zone attenuation within a groundwater basin poses various problems with respect to modeling. Example sites must be chosen carefully to insure that they represent the overall groundwater basin vadose zone. The general thickness of the vadose zone at these sites must be established for both wet and dry

Figure 3.10

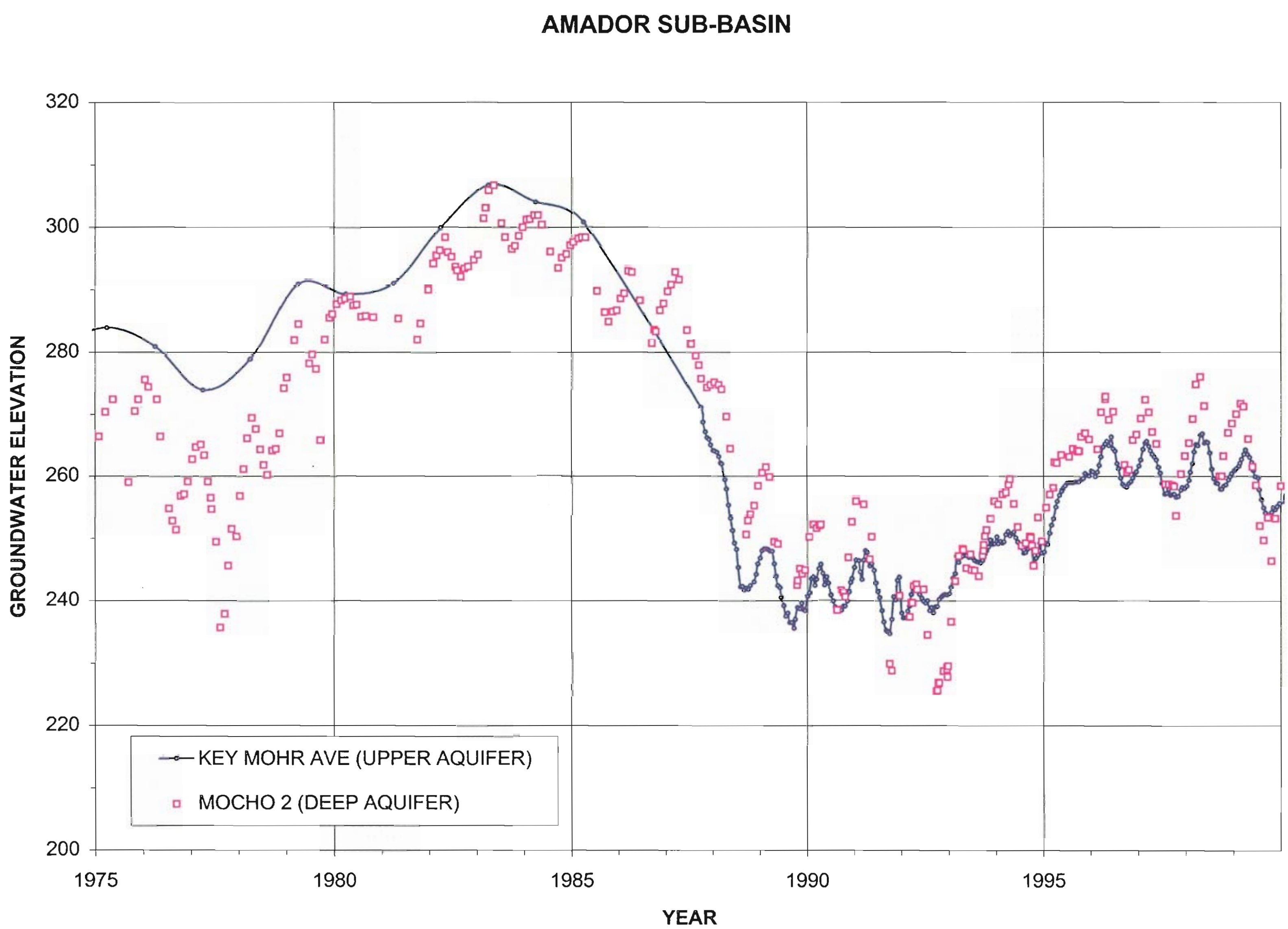
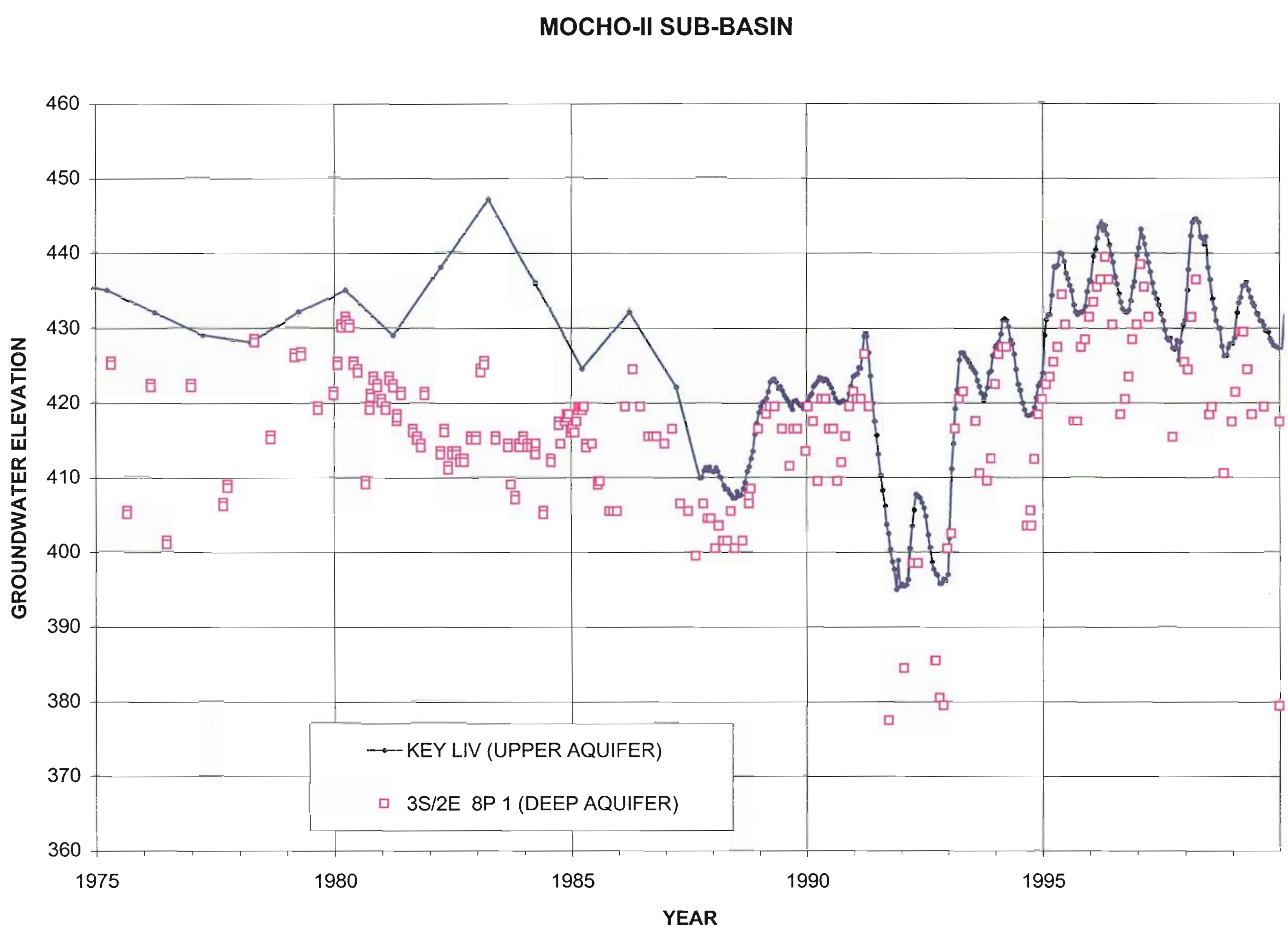

AMADOR SUB-BASIN
GROUNDWATER ELEVATION
320
300
280
260
240
220
200
1975
1980
1985
1990
1995
YEAR
KEY MOHR AVE (UPPER AQUIFER)
MOCHO 2 (DEEP AQUIFER)

Figure 3.11



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water years. The material makeup of the vadose zone soil must be established for these sites and can be ascertained from geologic logs of wells. Intermittent layers of sands, gravels, silts, and clays must be taken into account in the calibration of the model along with variation in potentiometric surfaces through time and differences in hydraulic conductivities. Input data for a model also needs to take into account land use, surface cover, annual rainfall, and applied water quality. Values must be estimated where field data is lacking, which increases the margin of error.

In 1996, Zone 7 contracted with Todd Engineers to undertake a vadose zone attenuation modeling demonstration for selected sites to define the accumulation of salts, represented by TDS, under predetermined conditions (Todd, 1996). The preliminary model results from this demonstration project were inconclusive, reaffirming the complexity and level of effort and data required to construct a representative vadose model for the Livermore-Amador Valley groundwater basin. The results did provide evidence that regardless of where water is applied in the Main Basin and regardless of the total dissolved solids (TDS) concentrations in the applied water, the results would be very similar across the basin. This showed that vadose zone attenuation in the Livermore Valley did not appear to be a function of TDS or soil type.

A literature search was also undertaken to determine if there were similar groundwater basins that had successfully created an attenuation model and ranges of attenuation found. Most notably among these were papers by Aulenbach, et.al. (1974); Bouwer, H. (1974); Rice, et.al. (1989); Runnells, D.D. (1976); Saffigna and Keeney (1977); and Tedaldi and Loehr (1992).

Aulenbach, et.al. (1974) found that the release of treated effluent into a filtration system of natural delta sands did not appreciably reduce the amount of phosphates, nitrates, and chlorides, even at a 10-foot depth. Bouwer (1974) noted that, in arid regions, salt concentrations increase as the percolate from irrigation water passes through the root zone and deeper. Rice, et.al. (1989) states that about 25% of the irrigation water applied to arid soils results in the deep percolation that recharges groundwater. They further noted that, if artificial recharge processes were undertaken in these areas, salt loading could be "very significant."

Runnells (1976) discussed the potential to use the vadose zone to attenuate certain chemicals by evaluating the soil type and adding certain amendments such as pH buffering or oxidation agents. Saffigna and Keeney (1977) found that the application of irrigation water was increasing the nitrate and chloride concentrations in the groundwater of the sand plains of central Wisconsin. Tedaldi and Loehr (1992) theorized that the dissolution of naturally occurring minerals could be a significant contributor to the amount of salts in groundwater.

A literature search and vadose zone modeling conducted for the Chino Basin indicated that 70 to 80% of the applied salt mass would reach the groundwater. The remaining mass was believed to be locked in the vadose zone as immobile mass. The fate of the immobile mass was unclear particularly under conditions such as if groundwater levels were to rise and saturate the vadose zone.

Zone 7's limited vadose attenuation literature review and preliminary modeling investigation confirmed the complexity of the issue and the likely high costs of attempting to more rigorously quantify site specific attenuation percentages. Zone 7 water quality and salt mass balance results also generally supported an assumption of minimal attenuation

Given these results and recommendations from the GMAC and TAG, a policy decision was made that instead of spending significant amounts of money on vadose zone modeling, the money should be spent on fixing the salt loading problem. It was further decided to use zero salt attenuation as a conservative management policy decision. However, several salt management strategies were evaluated (Chapter IX) that did include assumptions of 15 and 30% attenuation to determine how sensitive the results and conclusions were to the zero attenuation assumption.

3.6 Hydrogeologic Information Collection

There have been over 5,000 wells, and countless soil borings drilled in the Livermore Groundwater Basin. The record goes back approximately 110 years to the late 1800s. Basin geology, water levels, water quality, aquifer properties, and boundary conditions have been compiled, studied, and reported by the USGS, California Department of Water Resources, and Zone 7 Water Agency since the 1950's (Williams, 1912, CDWR, 1955, 1960, 1963, 1974; Zone 7 annual monitoring reports, Sorenson et al, 1985; Dibblee, 1980; Sylvester, 1983).

Zone 7 has been collecting precipitation, surface water and groundwater level, and water quality data since 1978. Currently, a network of 23 surface water gauging sites, 11 climatological stations and approximately 200 wells are monitored by Zone 7 for the purpose of groundwater management; i.e., water inventory and quality. Included in the monitoring well network are several multi-level piezometers or well clusters. Water level measurements are periodically made and water quality samples are collected annually from these wells/piezometers to evaluate vertical gradients and flow components.

Municipal water supply well data, such as production histories, water quality, and production logs are shared between local agencies and local water purveyors. Additionally through its Groundwater Protection Ordinance program (GPO), Zone 7 receives well location, well log, and pump test (when performed) information for all new wells drilled in the Zone 7 Service area from the permittees. These data are all cataloged and archived in Zone 7's historic databases.

Recently, Zone 7 conducted a well siting study to evaluate several locations in the Main Basin as potential new production well sites. During the investigation, Zone 7 drilled and tested six sites, Sites 7, 8, 9, 11, 15, and Murrieta. Lithology and borehole geophysical logging and depth-specific water quality sampling were conducted at each site. At Sites 7, 9, 11 and 15, a second well was drilled for production testing purposes. Aquifer testing, production logging, and additional water quality sampling were conducted in these wells. The data and analyses are reported in individual site-specific reports written by Fugro West, Inc. (Fugro 1999a-e) and have been added to the appropriate Zone 7 databases. Similar testing was done by DSRSD and the City of Livermore at several locations for their proposed RO recycled water injection projects. Table 3.2 summarizes the aquifer property results from recent well siting investigations, as well as those from the recycled water project aquifer tests.

Table 3.2:
Summary of Recent Aquifer Test Results

Site No.	State Well No.	Ave. Transmissivity (gpd/ft)	Ave. Storage Coefficient
Site 7	3S/1E 8H 14	98,400	0.0022
Site 9			
Site 11	3S/1E 15M 4	54,300	0.0062
Site 15 (Hop 4)	3S/1E 17D 2	90,400	0.0007
Stoneridge	3S/1E 9B 1	280,500	0.00178
Mocho 1	3S/1E 9M 2	485,600	0.00031
Site 15 (Hop 9)			

Other recent data acquisitions include the collection of various geophysical log data for several private and public production or test wells that have been recently drilled in the valley. Zone 7 has encouraged, and in some instances provided for, the logging of several new key wells.

Zone 7 will continue to collect hydrogeologic data through its various monitoring and GPO programs. Zone 7 has scheduled the construction of several new production wells in the near future. As these wells are drilled and tested, Zone 7 will collect additional data from these locations. As other potential well sites are explored by Zone 7 as part of the Well Master Plan effort, staff will continue to collect lithologic, hydrologic, and geophysical data from these locations. An attempt will be made to fill in the areas where modern geophysical logs are sparse or lacking by continuing to encourage, and sometimes provide for the running of geophysical surveys in key new private wells and exploration borings as they are identified during the permitting process.

Several new monitoring wells are planned for the explicit purpose of salt impact monitoring (see Chapter 6, Salt Management Monitoring Plan). Besides providing additional water level, flow gradient and water quality data, they provide an opportunity to collect additional geological information such as: lithology, geologic heterogeneity, and aquifer thickness near the basin margins.

Lawrence Livermore National Laboratories (LLNL) has recently obtained a grant from the State Water Resources Agency to investigate the vulnerability of groundwater supplies throughout the state by age dating the water from several hundred production wells. Zone 7 and several other local groundwater producers may cooperate in this investigation. The results may be used to refine the current understanding of flow velocities and directions and aquifer mixing.

3.7 Groundwater Model

A groundwater model is a device that represents an approximation of a groundwater basin. Physical models such as laboratory sand tanks simulate groundwater flow directly. A mathematical groundwater model simulates groundwater flow indirectly by means of equations to represent the physical process that occur in the groundwater basin. A mathematical model can be solved analytically or numerically. Since analytical solutions are not suitable due to complexities in the groundwater flow modeling, numerical groundwater modeling is more often used for groundwater basin modeling.

Groundwater models are useful for predicting the consequences of a proposed groundwater basin management action. Groundwater models can also be used to learn about the controlling parameters in a site-specific setting such as establishing locations and characteristics of aquifer boundaries.

The original Main Basin groundwater model was developed by Zone 7 and the California Department of Water Resources (DWR) in the 1970's and is documented in DWR Bulletin 118-2. Davies (a Stanford graduate student) developed a groundwater model of the Amador Sub-basin in 1981. Danskin (another Stanford graduate student) extended this model into the Bernal Sub-basin in December 1985 and calibrated the model for average fluxes for the period 1977-1981. Although these models and the associated documentation provided some useful technical information, Zone 7 did not use them for basin management studies.

In 1996, Zone 7 staff retained consultant CH2M Hill to assist with the development of a groundwater flow and solute (salt) transport model for the main groundwater basin. The model was designed to be useable by Zone 7 staff for evaluating alternative Salt Management Plan (SMP) strategies (see Chapter X) and