available it is possible that this zone can be further subdivided into distinct aquifers. For example, Norfleet (2004) split the lower aquifer zone in the Amador Sub-basin into the "Gray," "Purple," and "Red" sequences. In future geologic and modeling studies, Zone 7 will likely extend the Norfleet sequence boundaries beyond the Norfleet study area.

In general, multiple aquifers are recognized in the alluvium of the Livermore Valley. As shown in Figure 3.4, a cross section of the basin from west to east, the water bearing alluvium increases in thickness from east to west across the basin and thins both north and south at its boundaries. Cross section SP to SP' (Figure 3.5) also shows a thickening of sediments from north to south to the central portion of the groundwater basin and then a thinning from the center towards the south. Although the upper aquifer zone appears to be very thick and continuous through the Central Amador Sub-basin, the water bearing units within the lower aquifer zone are often discontinuous and inter connected. The more recent geologic logging and monitoring of multilevel monitoring wells are allowing better understanding of the hydrostratigraphic units within the recent alluvium.

3.4.3 *Subsurface Inflow into the Main Basin*

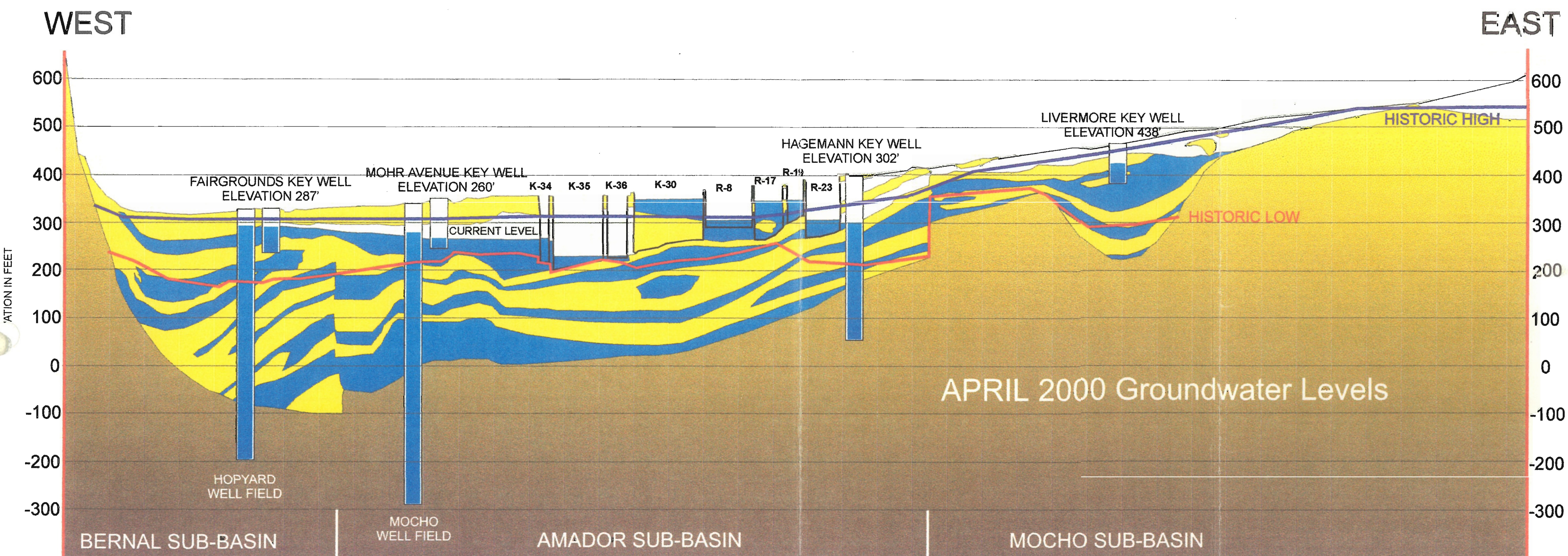
The existence of groundwater barriers along the edges and within the basin continues to be confirmed by the groundwater level measurements, investigations by Zone 7, and other investigations. In 1974 these groundwater barriers were generally interpreted as fault related. However, some may be the result of hydrostratigraphic boundaries and not fault related.

South of the basin, groundwater from the Livermore Formation is believed to move along the strike of the beds to the northwest and enter the Main Basin at the southern portions of the Bernal and Amador sub-basins. North of the basin, the near-vertical structural dip of the Tassajara and Green Valley formations is believed to prevent the commingling of waters among these formations and the alluvium, essentially cutting this water off from the groundwater basin (DWR, 1966, 1974, Zone 7 files).

The outer boundaries of the Main Basin have been divided into 10 regions of interest with respect to groundwater connectivity (Figure 3.6). Region 1, followed by regions 2 and 7, contribute the greatest amounts of subsurface inflow to the Main Basin through the shallow aquifers (Upper Zone). Subsurface inflow from the deeper aquifers (Lower Zone) is considered negligible as shown in Table 3.1.

Estimates of future inflow are based on currently planned development and assume that the potentiometric surface of the Main Basin will be drawn down to accommodate the added demand. Future TDS was taken from the technical memorandum, *Phase 4 Groundwater Modeling: Salt Management Plan Simulations* (CH2MHill, 1999). Scenario 1A, which examined the base case

LIVERMORE-AMADOR VALLEY GROUNDWATER BASIN
EAST-WEST CROSS-SECTION



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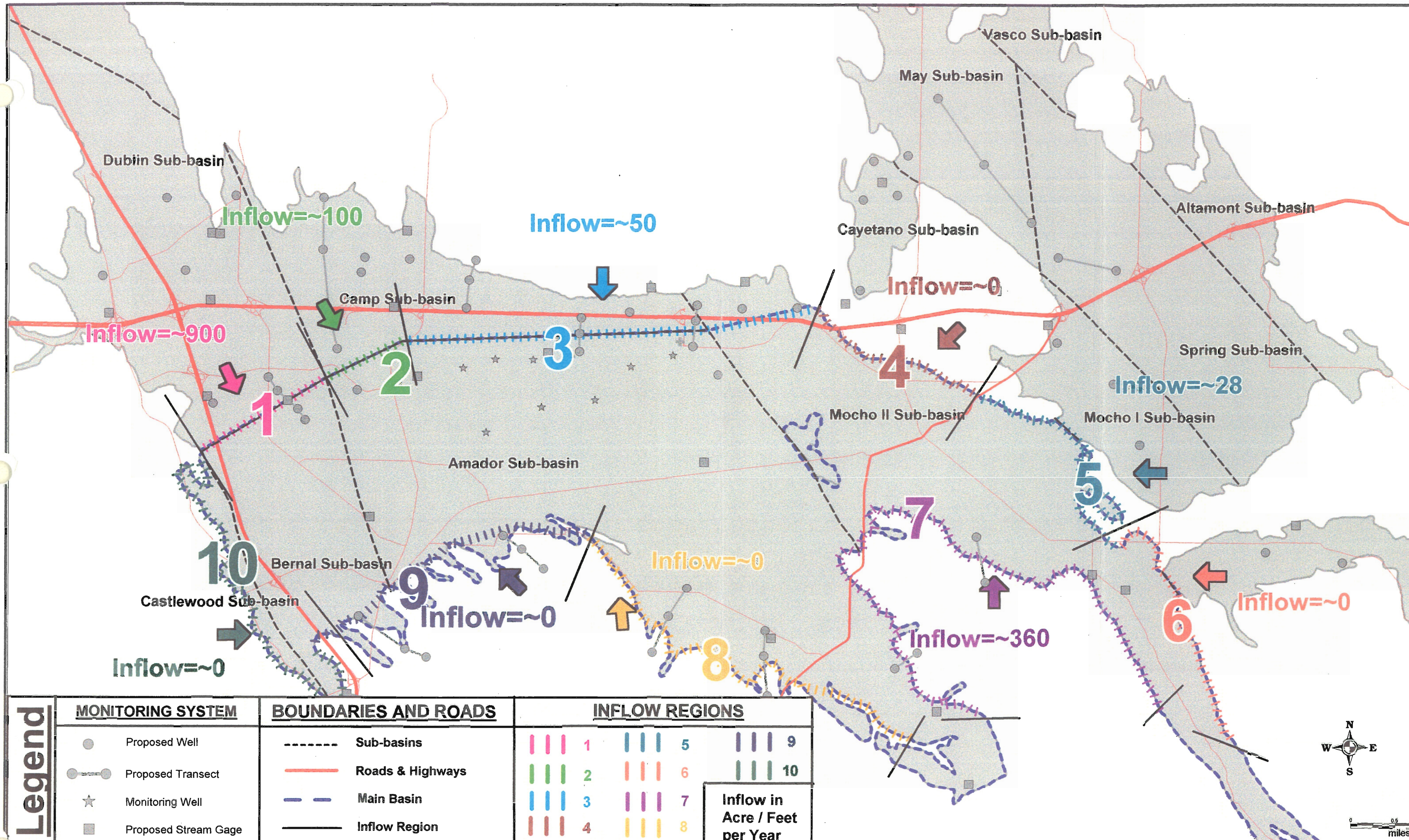
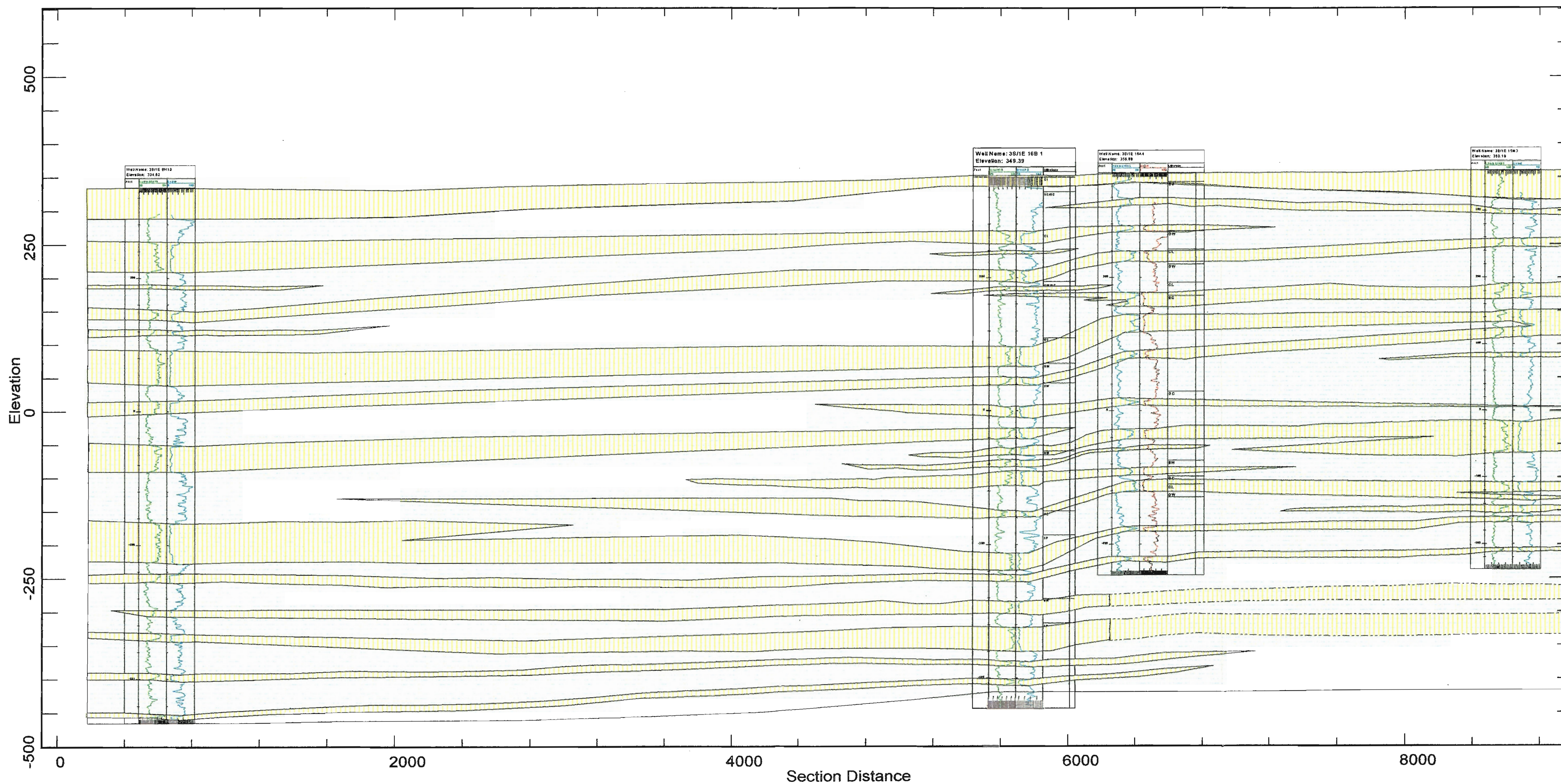
Water Resources Engineering
Salt Management Plan
Figure 3.4: East-West Cross Section

CDM 7/3/2000
Fig3-4EWxsec.cdr



ZONE 7 WATER AGENCY 5997 PARKSIDE DRIVE PLEASANTON, CA. 94588	DRAWN BY: C MAHONEY	SCALE: 1" = 1 mile	WATER RESOURCES ENGINEERING SALT MANAGEMENT PLAN
	DESIGNED BY: C MAHONEY	DATE: 3 JULY 2000	**Figure 3.6:**
	CHECKED BY: D LUNN	REVISED BY:	**Hydrologic Regions of Inflow**
	APPROVED:	FILE: h:\SMP\Fig3-6.WOR	



	Sand/Gravel Unit
	Clay Unit

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Salt Management Plan
Figure 3.5: SP - SP' Cross Section

Vertical Exaggeration: 5

H:\Viewlog\SPX_Section.map

Nov. 1, 2000

scenario with no recycled water injection, was used to represent future impact conditions. This scenario examined TDS at 50 years from the initial condition of October 1995.

Table 3-1
Subsurface Inflow and TDS with Respect to Urban Development
Inflow (Acre Feet per Year) and TDS (mg/L)

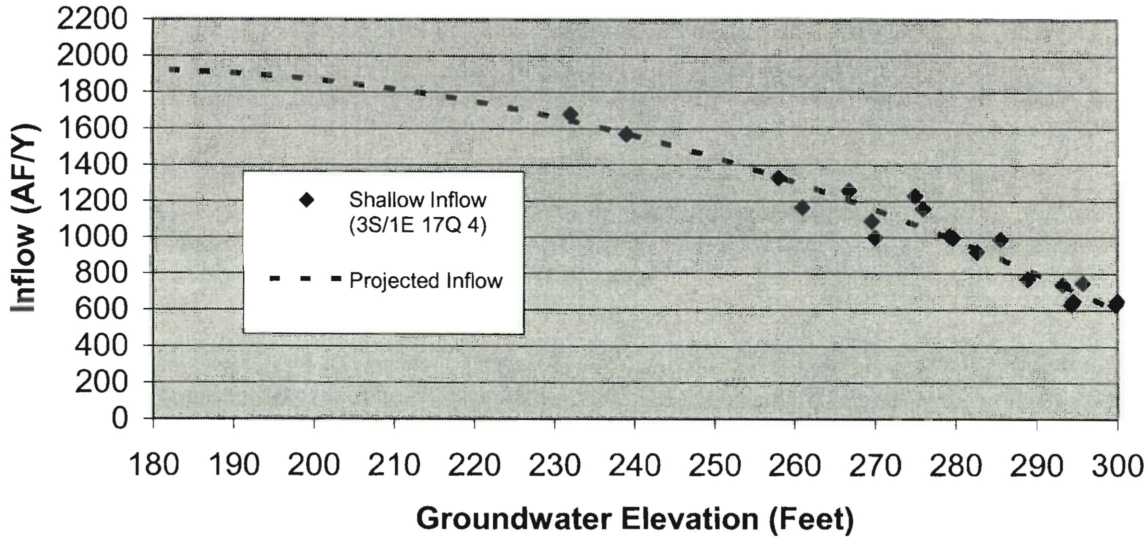
Inflow Region	Upper Zone afy		Lower Zone afy		Upper Zone Mg/L		Lower Zone mg/L	
	Current Inflow	Future Inflow	Current Inflow	Future Inflow	Current TDS	Future TDS	Current TDS	Future TDS
1	900	950	<50	<50	900	1000	400	850
2	100	200	<10	<20	1000	1000	400	950
3	50	100	<5	<10	850	1000	450	850
4	N	N	N	N	750	800	450	800
5	28	U	N	U	650	700	500	700
6	N	N	N	N	700	750	450	700
7	360	360	N	N	450	450	450	450
8	N	N	N	N	450	400	450	350
9	N	N	N	N	500	700	450	650
10	N	N	N	N	600	900	500	800
Total Inflow	1438	1610	<65	<65				

Notes:

TDS = Total dissolved solids
N = Negligible inflow
U = Unknown at this time
AFY = acre-feet per year

In Figure 3.7, inflow from the "Fairgrounds Key" Well, currently designated as 3S/1E 17Q 4, is shown at observed groundwater elevations. These data represent calculated inflows from 1974 through 1994 into the northwestern boundary of the Main Basin as associated with the observed groundwater elevation. The projected linear curve represents the average inflow that may be expected at any given groundwater elevation. As the basin approaches the historic low elevation of 180 feet below ground surface (e.g., following a seven-year drought), the relative rate of subsurface inflow decreases. At some elevation below 180 feet, inflow is projected to stabilize at about 1,900 AF/year.

Figure 3-7: Trends in Shallow Aquifer Inflow



Region 1 is the boundary between the Dublin Sub-basin and the Main Basin. The boundary is the Parks Fault, which creates a vertical zone of very low permeability at about a 100-foot depth. Subsurface groundwater inflow is precluded below this depth, therefore, subsurface inflow occurs mainly in the shallower portion over this boundary. Subsurface flow across this Region 1 boundary accounts for the majority of groundwater flow into the Main Basin. Subsurface flow from the Dublin Sub-basin into the Main Basin is calculated from groundwater gradients every year. The average calculated flow is approximately 900 acre-feet per year with a TDS of about 900 mg/L and it moves from northwest to southeast.

Region 2 is the western boundary between the Camp Sub-basin and the Main Basin. This boundary is made up of the eastern extension of the Parks Fault and a low permeability boundary of alluvial deposits interfingering with the less permeable alluvial deposits eroded from the Tassajara Formation. North of the boundary, all subsurface flow is in the upper aquifer. The Tassajara Formation precludes deep formation subsurface inflow from entering into the Main Basin. This inflow is computed each year from groundwater gradients and averages about 100 acre-feet. The100 AF/year of subsurface inflow moves in the upper aquifer alluvial materials that overlie the Livermore and Tassajara formations and crosses the Amador Sub-basin boundary flowing south. Again, inflow from the deeper aquifers in considered to be minor.

Region 3 represents the eastern boundary between the Camp Sub-basin and the Main Basin and the western portion of the Cayetano Sub-basin and the Main

Basin. Again the lower aquifer groundwater from the northern portion of this sub-basin is precluded from flow into the Main Basin. Shallow subsurface inflow in this region is moving south to southwest and is estimated to be approximately 50 AF/year or less.

Region 4 is the boundary between the eastern portion of the Cayetano Sub-basin and the Main Basin. The Cayetano Sub-basin is underlain by the Tassajara Formation, which has little to no hydraulic connectivity with the overlying alluvial deposits and the Main Basin, and contains water of a sodium bicarbonate character. The volume of subsurface flow is assumed to be insignificant and travels southwest. Minor flows rise into the creek and are counted in the Arroyo Las Positas stream recharge calculations.

Region 5 is the northern boundary between the Mocho I Sub-basin and the Main Basin, or more specifically the Mocho II Sub-basin. Subsurface flow is limited to the upper aquifer. Gradients in this area are very flat and often flow to the East. Zone 7 estimates no flow across this gap and others have estimated 28 AF/Y.

Region 6 represents the contribution of Dry Creek to the Main Basin. Only small quantities of surface water flow through this creek due to agricultural applications. It is unknown how much of the surface flow recharges the groundwater and moves as subsurface flow. Subsurface flow moves in a western direction across this boundary and is assumed to be insignificant.

Region 7 is the boundary between the Main Basin and the less permeable Livermore Formation uplands located between the upper reaches of Arroyo Mocho and Arroyo del Valle. Groundwater quality in this area ranges from a sodium chloride to a sodium bicarbonate water type. Subsurface flow exits in this region through a storm drain on the northeastern side of the boundary and moves in a north to northwest direction to the Arroyo Mocho. Discharge from this drain is estimated to be approximately 360 AF/year but with a fairly low TDS of 450 mg/L. It recharges the groundwater via the Arroyo Mocho and is included in Arroyo Mocho recharge calculations.

Region 8 is the boundary between the Main Basin and the less permeable Livermore Formation uplands located west of the Arroyo del Valle. Water here is considered to be of a sodium bicarbonate character. Subsurface flow in this region is moving northwest and is assumed to be insignificant. This is based on well yields and observations of dry summer creek beds.

Region 9 is the boundary between the Main Basin and southwestern most area of less permeable Livermore Formation uplands. Water in this region is of sodium bicarbonate character. The Livermore Formation in this area is striking northwest/southeast and is dipping northeast toward the Main Basin. Subsurface flow in this region is moving northwest along strike and is assumed to be insignificant. This is based on field observations at dry creeks and from limited well observation within the uplands.

Region 10 is the boundary between the Castle Sub-basin and the Main Basin. The boundary is the west branch of Calaveras Fault. Formations west of the fault are water bearing.

Table 3.1 shows that future development is not anticipated to result in any significant changes to the quantity or quality of subsurface inflow to the Main Basin. Region 1, the largest contributing area, is only expected to increase in flow from 900 to 950 AF/year and the TDS is only projected to increase from 900 to 1000 mg/L. Total inflow would increase from 1438 to 1610 AF/year (+215 AF/year). Areas in the lower zone showing moderate TDS increases are also areas with negligible inflow.

3.4.4 Main Basin Groundwater Mixing and Movement

Groundwater always moves from areas of high groundwater level potential (high groundwater level elevation) towards area of low potential. Recharge in an area raises the groundwater level elevation and discharge from an area lowers the groundwater level elevation. The difference in groundwater level potential per unit distance between two points is called groundwater level gradient. Therefore, groundwater always moves from areas of artificial and natural recharge towards areas of artificial and natural discharge or withdrawal. In general, recharge and discharge areas in the same aquifer create intra-aquifer (horizontal) movement and in different aquifers create inter-aquifer (vertical) movement.

The main groundwater basin is a multi-layered system having an upper unconfined aquifer overlaying a sequence of semi-confined aquifers. In general groundwater in both the upper and lower aquifer zones generally follows a westerly flow pattern, along the structural central axis of the valley, towards municipal or gravel mining company groundwater pumping wells in the western portion of the basin.

The groundwater movement and mixing in the Main Basin is very dependent on the location and magnitude of recharges into and discharge from the basin. Stream recharge, ASR injection, rainfall recharge, applied water recharge and subsurface inflow are the main sources of recharge. The main demand components (pumpage or discharge components) are municipal pumpage, agricultural pumpage, gravel mining water use and groundwater basin outflow. The average annual Main Basin recharge and pumpage is about 20,000 AF.

Groundwater monitoring data, and results from the Zone 7 numerical groundwater model for the Main Basin, indicate that the extent of mixing in the Main Basin varies considerably from location to location. The groundwater model animations help visualize the groundwater movement in the basin. Bernal, Amador and

Mocho II are the three main sub-basins of the Main Basin. The groundwater exchange between these sub-basins also varies with the extent of groundwater elevation gradient changes.

The Main Basin is made up of the Castle, Amador, Bernal, and the Mocho II sub-basins overlain by recent alluvium. The Mocho Sub-basin has been divided into two distinct areas, Mocho I and Mocho II distinguished by a change in aquifer characteristics from a sodium bicarbonate (Mocho I) to a magnesium bicarbonate water type (Mocho II) and by the presence of the less permeable Livermore Formation extending from both north and south into the middle of the sub-basin. The Main Basin is bounded:

- On the north primarily by the Parks Boundary and by a lack of hydraulic continuity with the Livermore and Tassajara formations,
- On the west by the Calaveras Fault,
- On the south primarily by thinning of the recent alluvium and contact with the Livermore Formation, and
- On the east by the divide between the Mocho I and II sub-basins.

Amador Sub-basin - The Amador Sub-basin is located in the west central portion of the groundwater basin and is bounded to the:

- West by the Pleasanton Fault,
- East by the Livermore Fault,
- North by a permeability barrier of inter-fingering of alluvial deposits. Historically this boundary was thought to also include a fault called the Parks Fault, however there has not been any direct evidence of this fault. It is possible that this barrier is caused by permeability change between younger and older alluvium. Herein this boundary is called the Parks Boundary, and
- South by the drainage divide and partly by contact with non-water bearing formations.

This sub-basin is host to the majority of high production wells and has both unconfined and confined aquifers. Well production in this sub-basin ranges from 42 to 2,820 gallons per minute (gpm) and specific capacities of 1.1 to 217 gpm per foot of drawdown (CDWR, 1974). Waters from this sub-basin are of good to excellent quality, characterized by sodium bicarbonate, magnesium bicarbonate, and calcium bicarbonate with few instances of elevated levels of boron and nitrate.

In this sub-basin the maximum thickness of the Quaternary alluvium was previously thought to be approximately 500 feet. However, Norfleet (2004) did not find any evidence for the bottom of the alluvium at over 800 feet below ground surface. The alluvium is believed to lie unconformably over the Livermore Formation.

Bernal Sub-basin - The Bernal Sub-basin is located in the southwestern portion of the groundwater basin and is bounded to the west by branches of the Calaveras Fault, to the east by the Pleasanton Fault, to the north by the Parks Fault, and to the south by contact with non-water bearing formations and partly by contact with the Verona Fault. Both unconfined and confined aquifers exist in the water bearing sediments. Waters from this sub-basin are of fair to excellent quality. However, much of the upper aquifer water has high TDS exceeding 600 mg/l. The water from the northern and southern portions of the sub-basin are of a sodium bicarbonate nature, while the central portion is of the magnesium bicarbonate type and the western and south-central portion is of a calcium bicarbonate character.

The Bernal Sub-basin is the point of convergence for all of the major streams that drain the Livermore Valley. The Arroyo de la Laguna subsequently drains the sub-basin. Like the surface water, the groundwater also historically converges in this sub-basin, which allows for the mixing of the dominant cations of sodium, magnesium, and calcium. The Quaternary alluvium is estimated to have a thickness of at least 400 feet in this sub-basin and conformably overlies the Livermore Formation. Well production in this sub-basin ranges up to 3,500 gpm and specific capacities range from 3 to 260 gpm per foot of drawdown.

Mocho I/II Sub-basin - The Mocho Sub-basin is located in the east central portion of the groundwater basin and is bounded to the west by the Livermore Fault, to the east by the Tesla Fault, to the north by the Tassajara Formation that is not hydraulically connected to the sub-basin, and to the south by the Livermore Uplands and contact with non-water bearing marine formations. Both unconfined and confined aquifers exist in the water bearing sediments. Waters from this sub-basin are of fair to excellent quality sodium bicarbonate (Mocho I) and magnesium bicarbonate character (Mocho II) with some instances of elevated boron and sodium ions.

The recent alluvium ranges in thickness from approximately 10-50 feet thick in Mocho I and up to 150 feet thick in Mocho II. This alluvium overlies, both conformably and unconformably, the Livermore Formation. Mocho I and Mocho II appear to be hydraulically connected only in the shallow alluvial deposits. Well production in this sub-basin ranges up to 950 gpm with specific capacities of 2 to 50 gpm per foot of drawdown.

3.4.5 Horizontal Mixing and Movement (Intra-Aquifer Movement)

Groundwater level gradient and hydraulic conductivity are two essential parameters for characterizing groundwater movement in an aquifer. Hydraulic conductivity is an aquifer property and groundwater gradient is dependent on recharge/discharge locations.

Upper Aquifer - The upper aquifer in the Main Basin has generally good hydraulic conductivity. The presence of geologic faults in the Main Basin does not impede flow at shallow depths as compared to the higher impedance at deeper depths.

The main components of recharge for the upper aquifer are the areal recharge (rainfall and irrigation), stream recharge, fringe basin subsurface inflow and groundwater inflow from deep aquifers at some locations. The discharge components are dewatering by gravel mining, rising groundwater in Arroyo de la Laguna, and leakage to the deeper aquifer. Figure 3.8 presents the groundwater level contours for the upper and deep aquifers.

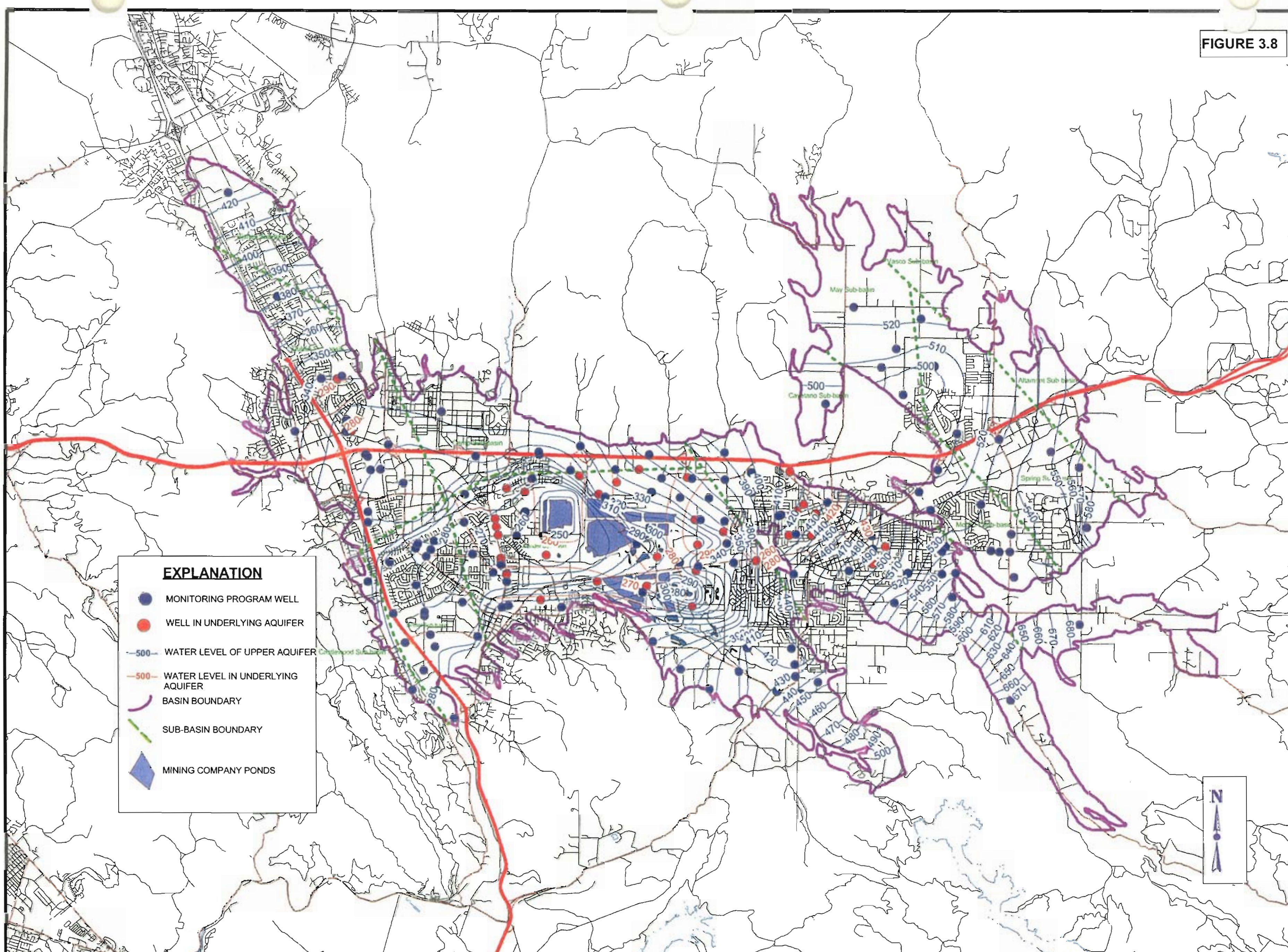
Areal recharge occurs over most of the Main Basin and in and of itself does not create any significant groundwater gradients in the upper aquifer. This is primarily why Main Basin areas in the upper aquifer that do not have any other major source of recharge or discharge other than areal recharge have very poor groundwater mixing and movement. For the Bernal Sub-basin upper aquifer, the recharge sources are areal recharge and subsurface inflow from the Dublin Sub-basin. The discharge components are the small amount of rising groundwater to Arroyo de la Laguna and leakage to the deeper aquifer.

Groundwater exchange between the Amador and Bernal sub-basins also occurs. There is a significant groundwater gradient from north to south in the northern portion of the Main Basin due to subsurface inflow from the Dublin Sub-basin recharging this area. The gradient can also be affected due to groundwater leakage to the deep aquifer occurring in the central portion of this sub-basin during drought years. There is also a mild groundwater gradient from the western and southern portions towards the center.

The stream recharge that occurs along the arroyos creates a higher groundwater potential along the arroyos. For the most part the groundwater flows away from the stream recharge areas. Groundwater de-watering by gravel mining companies in the Amador sub-basin creates groundwater gradients towards the central portion of the Main Basin. The groundwater level contours in Figure 3.8 indicate flow from the eastern part of the Main Basin towards the central part of the Main Basin. A part of the areal recharge and stream recharge that occurs in the Amador and Mocho II sub-basins moves towards the gravel mining areas and the remaining portion moves down to the deep aquifer.

Groundwater TDS in the upper aquifer at most locations is dependent upon the TDS of the locally recharged water. The groundwater TDS along the northern boundary of the Main Basin is high because of the high TDS subsurface inflow from the Dublin Sub-basin and high TDS recharge from Arroyo Las Positas. The groundwater TDS along Arroyo Mocho and Arroyo Valle is lower because of the lower TDS water recharged in those areas. The groundwater TDS in the shallow aquifer at locations where the recharge source is only areal recharge, and at

FIGURE 3.8



ZONE 7 WATER AGENCY 5997 PARKSIDE DRIVE PLEASANTON CA 94588	DRAWN BY: STEVEN J. ELLIS DESIGNED BY: STEVEN J. ELLIS CHECKED BY: APPROVED BY:	WATER RESOURCES ENGINEERING GROUNDWATER LEVEL CONTOURS FALL 1996	SCALE: 1" = 6000' (ON ORIGINAL) DATE: 10 JANUARY 1997 FILE NO.: B-342

locations not receiving any low TDS stream recharge, is high because of the high TDS of the areal recharge.

Although the TDS of rainfall recharge is insignificant, the TDS of recharge from irrigation is generally quite high. For example, if the irrigation water TDS is 300 mg/l, the irrigation water recharge (percolate) TDS could range from 1,200 mg/l to 3,000 mg/l depending upon the soil type. Typically 75-90% of the applied irrigation water evaporates and 10-25% recharges into the aquifer, along with 100% of the applied salts. This concentration process increases the TDS of recharge from irrigation by 4-10 times the TDS of irrigation water.

Deep Aquifer - The deep aquifer in the Main Basin is a sequence of semi-confined aquifers with good hydraulic conductivity. The presence of some geologic faults in the Main Basin impedes flow across the sub-basin boundaries at deeper depths.

The recharge components for the deep aquifer include groundwater leakage from the upper aquifer and treated surface water injection from the Hopyard well #6 (ASR well). As discussed in Section 3.3, subsurface inflow from the fringe basins through the deep aquifer is insignificant. Since the groundwater leakage from the upper aquifer is spread over the Main Basin, it does not create any significant potential gradient between two geographically separated points. The Hopyard #6 injection raises the groundwater potential in the Hopyard well field depending upon the injection amounts.

The discharge components from the deep aquifer include groundwater pumpage and leakage into the upper aquifer in the Amador Sub-basin due to upper aquifer dewatering near the gravel mining operations. The groundwater pumpage is the major reason for gradients between two geographically separated points in the deep aquifer in the Bernal and Mocho II sub-basins. Groundwater pumpage and leakage to the upper aquifer are the main reasons for gradients in the Amador Sub-basin.

The mixing in the deep aquifer appears to be primarily dependent upon the distribution and amount of groundwater pumpage from the aquifer. The groundwater model animations show how some of the stream recharge on Arroyo Valle leaks to the deeper aquifer and moves towards Pleasanton's municipal wells (Pleasanton #5, 6 & 8).

3.4.6 Vertical Mixing and Movement (Inter-Aquifer Movement)

The relatively low hydraulic conductivity of the aquitard layers impedes the vertical movement of groundwater between the upper and lower aquifers. The low conductivity of the aquitard is the major reason for the slower movement and reduced mixing that occurs between the upper and deep aquifers.

The location of the water sources and water sinks also controls the movement and mixing of groundwater in the Main Basin aquifers. Most of the vertical movement and mixing occurs by leakage through the aquitard separating the upper and lower aquifers. Some exchange also occurs by leakage due to geologic faults and wells screened in different aquifers.

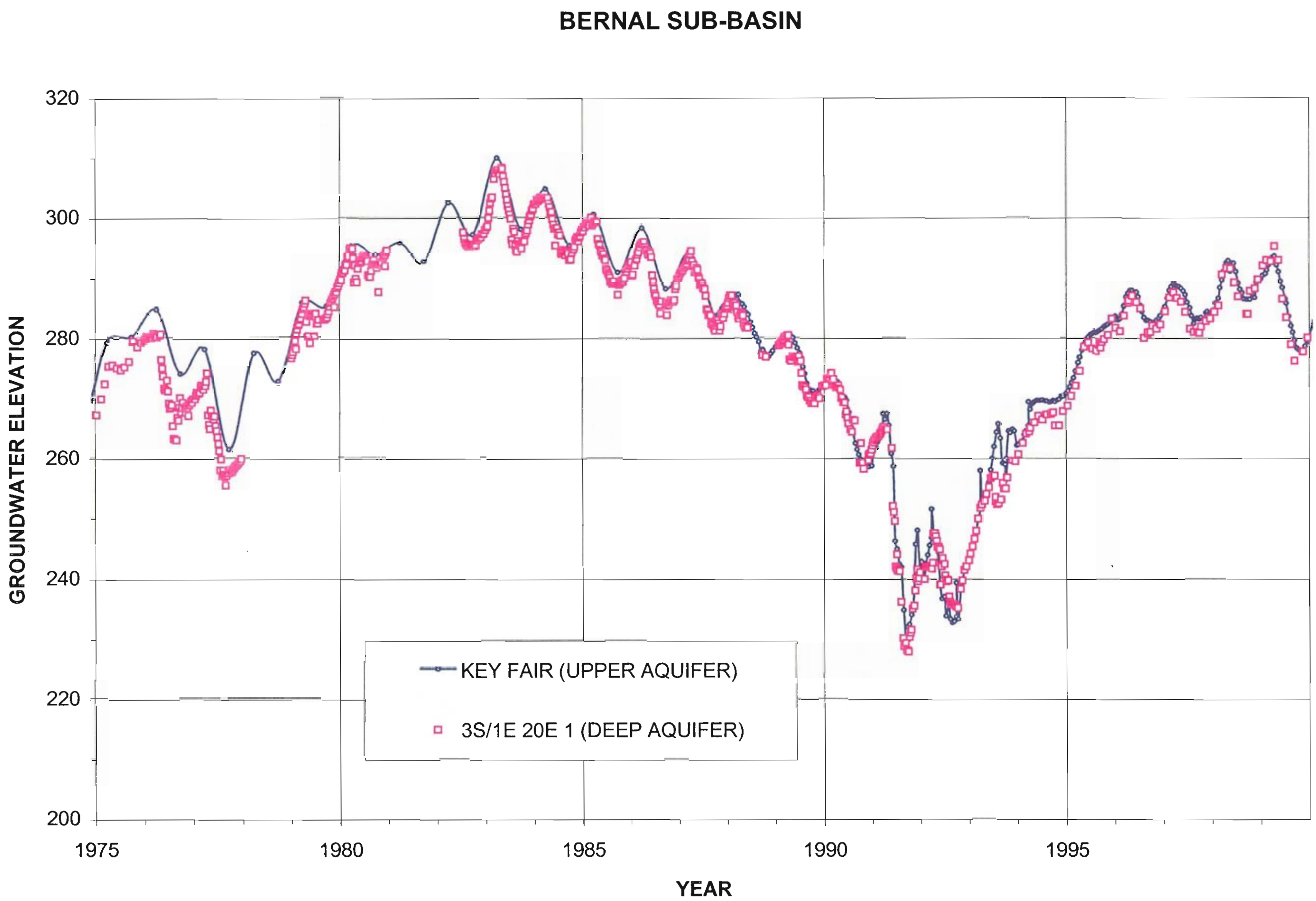
The exchange between the two aquifers, as indicated by the groundwater monitoring data, varies depending upon the thickness and permeability of the separating aquitard and the potential gradient. Even though the movement of water and salts from the upper aquifer to the lower aquifer is slow, it is still the major source of recharge to the lower aquifer. In the past, prior to injection (ASR) to the lower aquifer, the leakage from the upper aquifer was the only source of water and salts.

Water quality monitoring data and the groundwater model simulations indicate that the movement of salts from the upper aquifer to the lower aquifer is even slower due to the other transport mechanisms. This section describes the mixing processes occurring between the upper and deep aquifers within the Bernal, Amador and Mocho II sub-basins.

Bernal Sub-basin upper and deep aquifer mixing - Figure 3.9 presents the actual groundwater level data for two wells in the Bernal Sub-basin for the period 1975-99. The Fairgrounds Key well levels are representative of the upper aquifer and well 3S/1E 20E1 levels are representative of the deep aquifer. During drought conditions in 1976-77 and 1987-92, the deep aquifer groundwater levels declined due to increased municipal pumpage. The groundwater levels in the upper aquifer also declined with the decline in the upper aquifer tracking the decline in the deep aquifer. Since there was no significant increase in pumpage from the upper aquifer, this indicates that significant amounts of groundwater moved from the upper to the deep aquifer. Similarly, when the upper aquifer groundwater level recovered during wet years, the deep aquifer groundwater levels followed. From this figure and other groundwater level data, it can be concluded that there is significant linkage between the two aquifers. The increase in potential gradient due to wet or dry conditions increases the amount of groundwater mixing between the upper and deep aquifers in the Bernal Sub-basin.

Amador Sub-basin upper and deep aquifer mixing - Figure 3.10 presents groundwater level data for two wells in the Amador Sub-basin. The Mohr Avenue key well represents groundwater levels in the upper aquifer and the Mocho-II represents groundwater levels in the deep aquifer. During drought conditions in 1976-77, the groundwater level in both aquifers declined due to increased groundwater pumpage from the deep aquifer. The groundwater levels in the upper aquifer recovered during 1978-83 due to wet years, and the groundwater levels in the deep aquifer returned to even higher elevations than before the drought. Then, the gravel mining companies increased their pumpage from the upper aquifer,

Figure 3.9



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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