Resource Capacity Study

Water Supply in the Nipomo Mesa Area

November, 2004

Includes revisions
directed by the Planning Commission
at the September 23 public hearing
and revisions directed by the
Board of Supervisors at the
November 2, 2004 public hearing.
(See new map on page 9 and
additions to text on page 21.)

San Luis Obispo County
Department of Planning and Building

Resource Capacity Study

Water Supply in the Nipomo Mesa Area

1. INTRODUCTION / BACKGROUND

Nipomo Mesa Water Studies. The Nipomo Mesa area has been the subject of several groundwater studies since 1958, the year when the California Department of Water Resources (DWR) "San Luis Obispo County Investigation" was published. This report identified the Nipomo Mesa as one of two groundwater basins in the Arroyo Grande Subunit. For the Nipomo Mesa "basin", the report estimated that a safe yield of about 2,500 acre-feet per season could be achieved by lowering the water table to make room for the capture of additional natural recharge, by removal of extensive groves of eucalyptus trees and by reducing subsurface outflow.

The 1958 study was followed by several additional groundwater studies, some commissioned by the County and some included as components of environmental impact reports associated with proposals for new development. Some of these studies have concluded that groundwater extraction in the Nipomo Mesa area has exceeded, is now exceeding, or will soon exceed the safe yield of that portion of the basin. Others have said that, since there is no evidence of overdraft, demand remains within the estimated safe yield. Of the most recent studies, the 1996 Woodlands Environmental Impact Report (EIR) concluded that the basin was not in overdraft. A groundwater study of the Arroyo Grande – Nipomo Mesa area by DWR, begun in 1993 and completed in 2002, has been difficult to interpret because it seems to be internally inconsistent. The study's narrative states that the area is not in overdraft, yet the data in the study indicate the opposite. Meanwhile, the judge in the Santa Maria groundwater basin litigation has determined that the overall basin is not presently and has not historically been in a state of hydrologic overdraft and that evidence had not been presented to indicate overdraft in the Nipomo Mesa area of the basin.

In 2003, the county asked S.S. Papadopulos and Associates, Environmental and Water-Resource Consultants (SSPA), to review the data and analysis of the 2002 DWR study and other studies of groundwater in the Nipomo Mesa area, to note consistencies and inconsistencies among the studies, and to provide additional analysis as needed to enhance understanding of the studies. SSPA was not asked to conduct any primary data collection nor to perform parallel water level analyses or construct separate water budgets for the basin or sub-basins.

The Resource Management System. The county's Resource Management System (RMS) is a mechanism for ensuring a balance between land development and the resources necessary to sustain such development. When a resource deficiency becomes apparent, efforts are made to determine how the resource capacity might be expanded, whether conservation measures could be introduced to extend the availability of unused capacity, or whether development should be limited or redirected

to areas with remaining resource capacity. The RMS is designed to avoid adverse impacts from depletion of a resource.

The RMS describes a resource in terms of its "level of severity", based on the rate of depletion and an estimate of the remaining capacity, if any. In response to a staff recommended level of severity, the Board of Supervisors may direct that a Resource Capacity Study be conducted to provide additional details which would allow the Board to certify a level of severity and adopt whatever measures are needed to eliminate or reduce the potential for undesirable consequences.

Several studies of the Nipomo Mesa area in the 70s and 80s suggested the possibility of groundwater overdraft. Based on these studies, Level of Severity 2 was recommended in the 1990 Annual Resource Summary Report and, in 1993, the county commissioned the DWR to conduct an update of its 1979 study of the Arroyo Grande–Nipomo Mesa area. The Board of Supervisors directed staff to conduct a resource capacity study for water supply in the Nipomo Mesa area, to be based on the DWR update, when it was completed, leading to certification of a level of severity and adoption of appropriate mitigation measures. As indicated above, the update was completed in 2002. By the time of it's release, the Woodlands EIR had been certified and litigation was also underway to determine water rights in the Santa Maria basin. Because of contradictory conclusions among the various studies, the County retained SSPA to provide clarification.

This document is the Resource Capacity Study for Water Supply in the Nipomo Mesa Area. It is organized in the following manner:

1. **Introduction / background**
2. **Summary of the SSPA study**
3. **Discussion**
    a. **Safe yield**
    b. **Methods for estimating safe yield**
    c. **DWR conclusions**
    d. **Overdraft.**
4. **Estimate of projected growth**
5. **Summary of water supply and demand**
6. **Measures to increase supply**
7. **Measures to extend resource capacity**
8. **Recommended Level of Severity**
9. **Recommended actions**
10. **Appendix A: Building Permits, Subdivision Status, General Plan Amendments**
11. **Appendix B: "Water – In Short Supply"**
12. **Appendix C: SSPA study**

2. SUMMARY OF THE NIPOMO MESA GROUNDWATER RESOURCE CAPACITY STUDY, S.S. Papadopulos & Associates, Inc.

The complete study is included in Appendix C.

Support for DWR supply and demand estimates. Review of the DWR study and water studies conducted for Nipomo area EIRs indicates that the DWR study presents a generally accurate portrayal of groundwater supply and demand for that portion of the Santa Maria groundwater basin located north of the Santa Maria River and for the Nipomo Mesa Hydrologic Study Area (HSA). (A map of the Nipomo Mesa HSA may be found on page 7. A map showing the extent of the entire basin is included as Figure 1 in appendix C, the SSPA study.) Because of limitations inherent in the computer models used in some of the EIR studies, these studies tend to overestimate the sustainable yield of the groundwater basin and underestimate future groundwater declines and potential for seawater intrusion. The SSPA study explains why some reports by other investigators do not agree that the Nipomo Mesa area is in overdraft:

1. They may focus on the impact of a specific project without accounting for the cumulative impacts of projected development elsewhere in the region;
2. They may not consider the probability of prolonged periods with less than average rainfall;
3. They may overestimate transmissivity of the aquifer along the coastal margin, resulting in an underestimate of water level decline and the potential for seawater intrusion;
4. They may not have fully accounted for the change in discharge from evapotranspiration due to removal of eucalyptus trees.

"Overdraft" for Nipomo Mesa. Since current and projected pumping beneath Nipomo Mesa exceeds inflow (average annual natural recharge plus subsurface inflow), the Nipomo Mesa portion of the Santa Maria Groundwater Basin is currently in overdraft. Projections of future demand indicate increasing overdraft.

Although the DWR report "refrained from concluding that the basin or the Nipomo Mesa area of the basin was currently in overdraft", it included several warnings that overdraft was likely if existing trends were to continue. The statement in the DWR report that the groundwater basin within San Luis Obispo County is currently not in overdraft because of *"consistent subsurface outflow to the ocean and no evidence of sea water intrusion"* is inconsistent with DWRs definition of overdraft. DWR defines overdraft*as "the condition of a groundwater basin or subbasin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years, during which water supply conditions approximate average conditions."*

The DWR report appears to be internally inconsistent. The report's data clearly indicate an increasing water budget deficit for the Nipomo Mesa area, and existing conditions correspond to the DWR's own definition of overdraft. The SSPA study supports the

methodology and findings of the DWR report, except for the inconsistent conclusion about overdraft.

The aquifer's response to pumping. The SSPA study emphasizes that water moves slowly through an aquifer. An aquifer's recharge and discharge characteristics adjust slowly in response to an increase in pumping. Adverse impacts from overdraft may not become apparent for many decades following the onset of overdraft conditions. This explains how an overdraft condition can exist now, without evidence of seawater intrusion. For example, the consequences of heavy pumping in the 1960s and 1970s may still result in seawater intrusion in the future, even though there is currently no such evidence.

Potential consequences of continued overdraft. The DWR analyses, projections and water budget estimates clearly indicate that groundwater pumping in the Nipomo Mesa area is in excess of the dependable yield and that overdraft conditions have existed historically and are expected in the future. Increasing overdraft will lead to a condition, by 2025, where estimated outflow exceeds estimated inflow by at least 20 percent. To balance the assumed increases in pumping, sub-surface inflow from the Santa Maria Valley, which includes agricultural return flow, will increase, raising water quality issues; outflow to the ocean will decrease, increasing the potential for salt-water intrusion of the aquifer; discharge of groundwater to the coastal lakes will diminish, threatening the viability of those ecosystems; as storage is depleted, production capacity of some wells will be reduced and energy costs for pumping will increase.

Onset of adverse impacts is uncertain. Reliable prediction of when seawater intrusion will significantly impact the quality of water pumped from wells near the coastal margin is presently impossible. However, an expanded data base could increase the level of confidence in the ability of groundwater models to assess the possible progression of seawater intrusion.

RMS Level of Severity 3 recommended. SSP&A's findings indicate that a Level of Severity 3 is the appropriate Resource Management System severity level for groundwater beneath the Nipomo Mesa area. It is recommended that Level of Severity 3 be certified for the Nipomo Mesa area and that measures be implemented to lessen the adverse impacts of future development. Management response to these findings could include increased use of recycled water, importation of supplemental water, implementation of additional conservation measures and appropriate limits on development.

3. DISCUSSION

What is the "safe yield" of a groundwater basin?

Safe yield is the amount of naturally occurring ground water that can be withdrawn from an aquifer on a sustained basis, economically and legally, without impairing the native ground-water quality or creating an undesirable effect such as environmental damage

(C. W. Fetter, Applied Hydrogeology, Third Edition, 1994). "Undesirable effects" frequently cited as consequences of exceeding safe yield include:

Reductions in streamflow; reductions in lake levels
Drying of wetlands
Subsidence of the land surface
Degradation of water quality
In coastal locations, seawater intrusion into the aquifer's fresh water in storage
Lowering water levels leading to increase in pumping cost

What methods are used to estimate the safe yield of a groundwater basin?

Water level analysis. Groundwater levels in wells fluctuate over time representing the continuous adjustment of groundwater in storage to changes in recharge and discharge. Fluctuation of water levels is caused by several factors, including pumpage, recharge from direct precipitation and streamflow, infiltration of applied water and subsurface inflows and outflows. Water level analysis is based on empirical measurement of water levels in both production wells and monitoring wells. Levels in individual wells are compared to levels in other wells throughout an aquifer to create a contour map showing elevations of the groundwater surface. Contour maps are useful for estimating the direction and rate of flow of groundwater within an aquifer. They are also used for estimating the amount of groundwater in storage. Observation of water levels over time can illuminate trends with implications about the long-term prospects for the basin. Because annual recharge from precipitation is highly variable, long-term analysis of water level trends must include representative periods of above average and below average rainfall. Determination of trends is based on a period of observation that is not biased by an unusually dry or wet year or series of years.

Water budget analysis. Compilation of a water budget provides an estimate of each source of recharge and discharge to and from an aquifer. Estimates are based on a combination of empirical observation (rainfall data, stream flows, core samples, chemical analysis, well levels) and inference using logical assumptions. Water budgets are prepared to enable an understanding of the ways in which the groundwater basin adjusts to changes in recharge and discharge.

Since natural recharge from precipitation cannot be increased, an increase in discharge (pumping) can only be offset by an equivalent decrease in other forms of discharge (i.e., outflow to the ocean, to streamflow, to evapotranspiration, transfer from storage) and/or by supplemental recharge (imported water, control of recharge by dams). "Dynamic equilibrium" is the process by which an aquifer adjusts to a change in recharge or discharge. The most common change we have to deal with is increased pumping. Depending on the transmissivity and storativity of the aquifer, achievement of a new equilibrium may not take place for decades following an increase in pumping. Equilibrium is achieved when the water removed by pumping is replaced by water that would otherwise have been discharged via ocean outflow or other sub-surface outflow such as outflow to a local stream or lake or to evapotranspiration The cause and effect relationship between pumping and changes in various forms of discharge is not always appreciated, because pumping happens at the turn of a switch while the discharge

adjustments take place over a very long time. During the lengthy period of adjustment, a year or two of above average rainfall can temporarily reduce the size of pumping cones of depression and raise water levels in wells, giving a false impression that additional pumping can take place without a significant impact on the aquifer.

What does SSP&A conclude about the basin based on water level and water budget analysis?

DWR water level analysis.

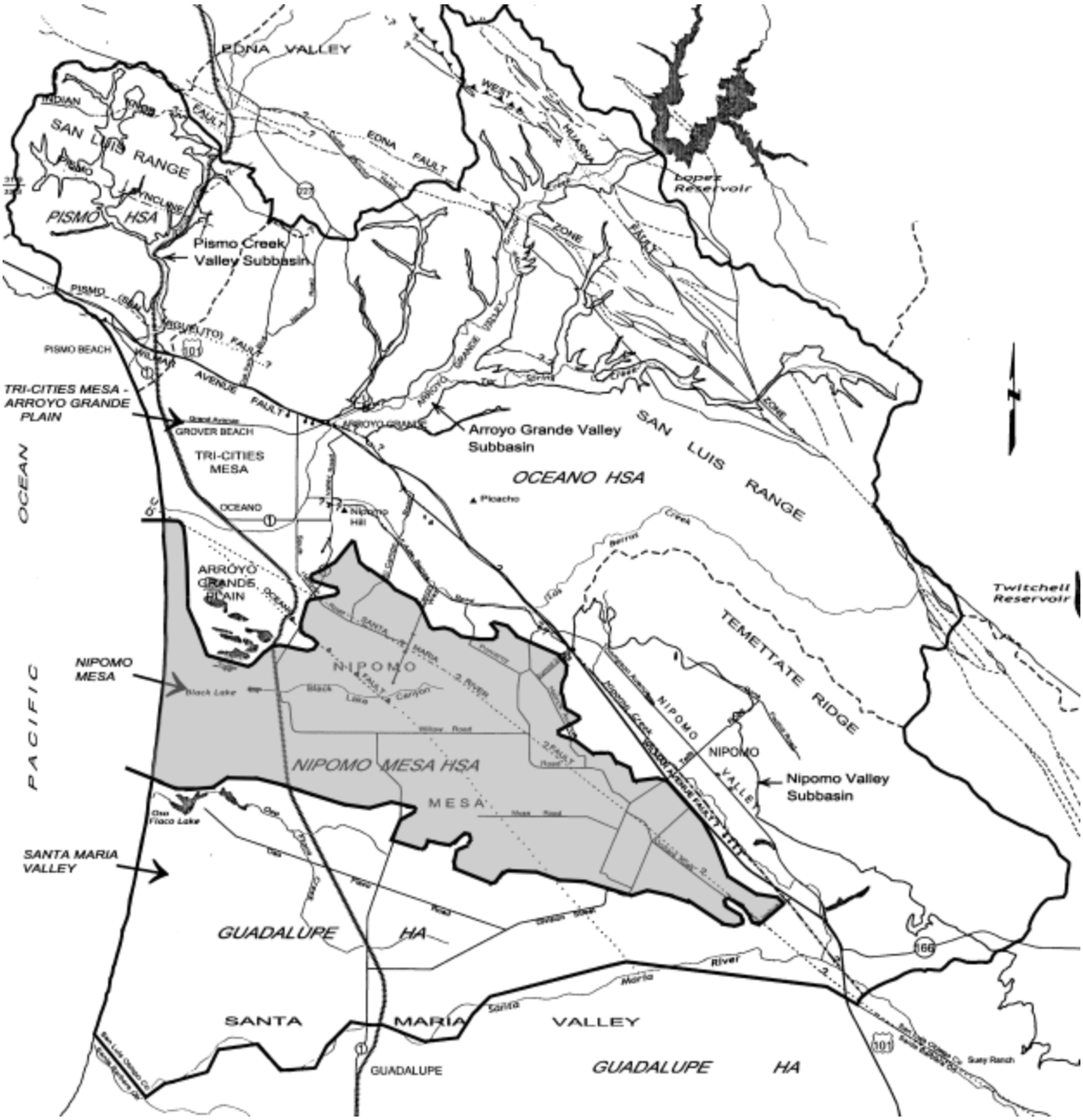
Declining trends in groundwater levels in parts of the Nipomo Mesa area from 1975 to 1995 are associated with increased pumping to serve the increase in development in that area. If these declines in groundwater levels continue in the future and expand to additional parts of the basin, the groundwater resources of the basin could be threatened by seawater intrusion. In other parts of the Mesa, alternating periods of decline and recovery indicate that recharge is balancing discharge over the long term.

DWR water budget analysis.

DWR conducted a separate water budget analysis for the entire study area north of the Santa Maria River and each of three sub-areas. The DWR map on page 7 shows the DWR study area and the extent of each of these sub-areas. In general, urban extractions are expected to increase, with agricultural extractions remaining relatively stable. In wet years, inflow from stream infiltration and/or deep percolation of precipitation helps to compensate for inflow deficiencies in dry years. However, over the long term, under conditions of average precipitation, outflow exceeds inflow, with accompanying reductions in the amount of groundwater in storage and reductions in subsurface outflow, including outflow to the ocean.

For the Tri-Cities Mesa – Arroyo Grande Plain, DWR notes that the projected loss of groundwater in storage due to the inflow/outflow imbalance will likely be offset by reduction in outflow to the ocean (DWR, p. 152). The report cautions that if subsurface outflow to the ocean is insufficient, sea water intrusion of the basin could occur. Likewise, for the Nipomo Mesa area, the projected loss of groundwater in storage is also likely to result in reduced outflow to the ocean. Since, in this portion of the basin, outflow to the ocean is only about seven percent of total outflow, potential seawater intrusion is a greater concern (DWR, p.153). SSPA notes (p.22) that because outflow to the ocean is a relatively small proportion of total inflow, it is vulnerable to small proportional increases in groundwater withdrawal from Nipomo Mesa, or reductions in inflow, for example, a prolonged period of low rainfall or increased pumping in Santa Maria Valley.

Results of these analyses are summarized in Table 6 on page 13.



Adapted from Plate ES1 (DWR 2002) – Arroyo Grande – Nipomo Mesa Study Area

What is overdraft? How can the apparent disagreement among experts regarding overdraft be understood?

The answer may be as simple as the fact that different definitions of overdraft are referenced by different experts. For example, the DWR defines overdraft as *"The condition of a groundwater basin or subbasin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years, during which water supply conditions approximate average conditions."*

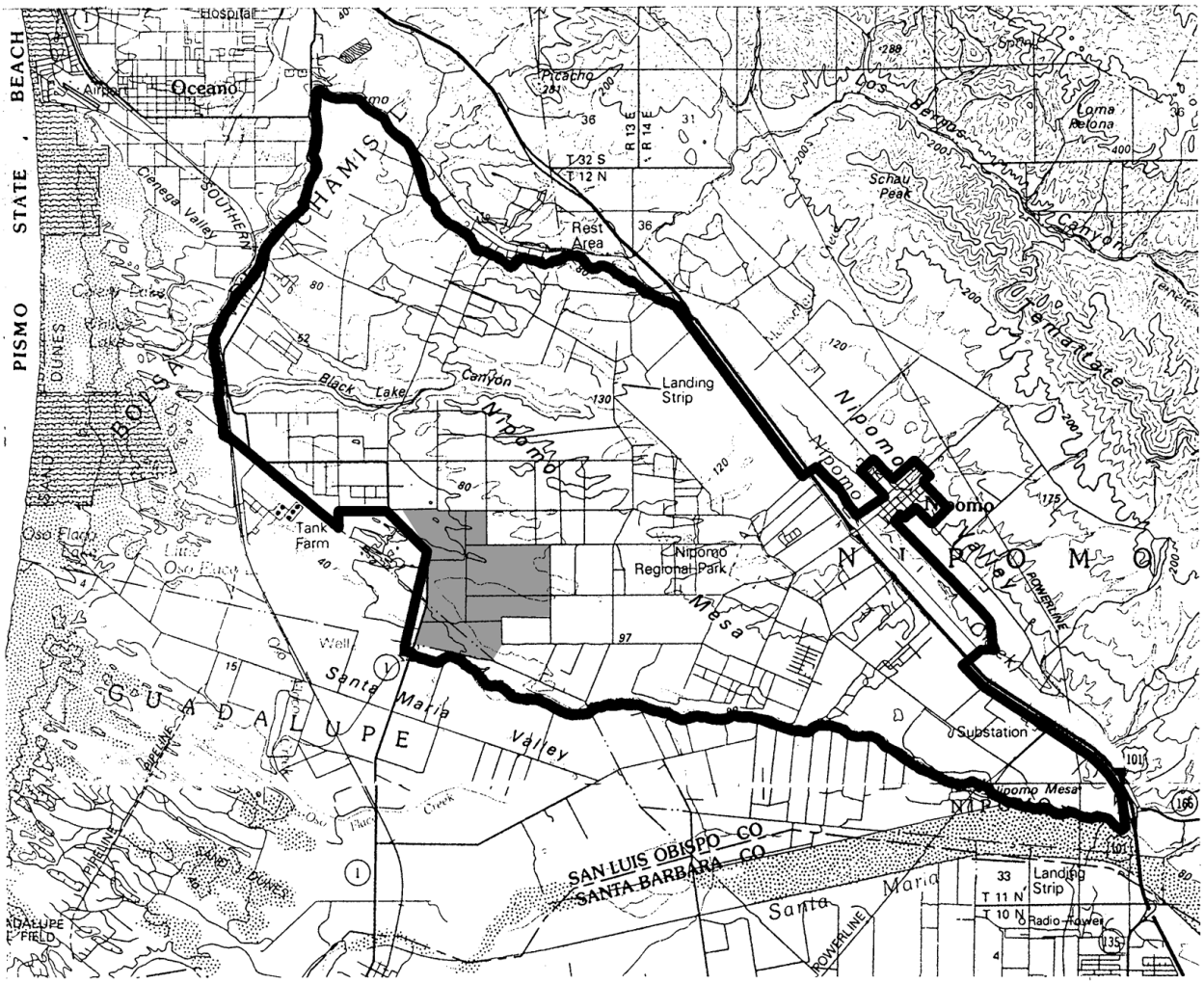
The judge in the Santa Maria groundwater litigation includes evidence of an adverse consequence in his definition of overdraft: *"The law defines 'overdraft' as extractions in excess of the safe yield of water from the aquifer, which over time will lead to a depletion of the water supply within a groundwater basin as manifested by permanent lowering of the water table." " … overdraft can be determined … by evidence of observed physical conditions in the Basin, such as declining underground water levels, seawater intrusion, declining water quality, or land subsidence over time .. "*

The review by S.S. Papadopulos accepts the DWR definition because the county's Resource Management System is designed to avoid adverse impacts from depletion of a resource. DWR says that overdraft exists when pumping exceeds recharge over a period of years, etc. without requiring a manifestation of adverse impacts. In fact, the DWR data, as interpreted by SSP&A, indicate that overdraft conditions have existed in the Nipomo Mesa area since about 1980. In contrast, the court's definition of overdraft says that an adverse impact must already be evident. Thus, the court did not find overdraft based on documentation submitted by the litigants.

In addition, differences between the DWR study and other studies regarding a finding of overdraft may be partially reconciled by adjusting some assumptions of the other studies to increase their ability to provide an accurate estimate of current and projected conditions. Adjustments could include the transmissivity of the aquifer, reduction of the amount of recharge assumed to be contributed by Twitchell Reservoir, a full accounting of the cumulative impact of new development, and fully incorporating in groundwater models the effect of removing eucalyptus trees with the attendant reduction in discharge due to evapotranspiration.

4. ESTIMATE OF PROJECTED GROWTH

The DWR 2002 study used historical population data and projections provided in 1996 by the State Department of Finance. For this Resource Capacity Study, projections are based on inspection of aerial photographs, reports of water service connections from NCSD and Cal Cities Water Company, and projected growth continuing at 2.3 percent per year, the maximum allowed by the county's Growth Management Ordinance since 2000. At that rate of growth, some sub-areas will reach buildout before 2020: Nipomo (Cal Cities) (2013); Black Lake (2009); Callender-Garrett (2009); Palo Mesa (2013). Projections include no increase in dwelling units after buildout is achieved.



2.3% Growth Area (adapted from Figure 1, Growth Management Ordinance, Title 26)
Note: Woodlands Specific Plan Area (shaded area) is not part of the Nipomo Mesa Water Conservation Area nor the 2.3% Growth Area.

Table 1. Existing and Projected Dwelling Units, Nipomo Mesa HSA
Projections based on annual increase of 2.3 percent

Sub-area	2003	2010	2020	Buildout (2)
Nipomo (NCSD) (1)	2830	3318	4165	5878
Nipomo (Cal Cities)	1444	1693	1800	1800
Summit Station (NCSD) (1)	122	135	150	160
Black Lake (NCSD) (1)	491	559	559	559
Callendar-Garrett	218	250	250	250
Palo Mesa	917	1075	1150	1150
Woodlands	0	825	1320	1320
Rural area of Nipomo Mesa	670	785	986	2260
Total	6692	8640	10380	13377

Notes: (1) Based on June, 2004 urban and village reserve lines and NCSD service areas. (2) Buildout data from South County Area Plan

Existing population and population projections in Table 2, below, are based on the number of persons per dwelling unit from the 2000 U.S. Census. Population for the urban community of Nipomo is based on 3.13 persons per unit. All other sub-areas are based on 2.61 persons per unit, the average for the unincorporated area of the county. A five percent vacancy rate is assumed for all sub-areas.

Table 2. Existing and Projected Population, Nipomo Mesa HSA

Sub-area	2003	2010	2020	Buildout
Nipomo (NCSD)	8415	9866	12385	17478
Nipomo (Cal Cities)	4294	5034	5352	5352
Summit Station (NCSD)	302	335	372	397
Black Lake (NCSD)	1217	1386	1386	1386
Callendar-Garrett	540	620	620	620
Palo Mesa	2274	2665	2851	2851
Woodlands	0	2046	3273	3273
Rural area of Nipomo Mesa	1661	1946	2445	5604
Total	18703	23898	28684	36961

5. SUMMARY OF WATER SUPPLY AND DEMAND

Water Supply and Demand, DWR 2002

In the 2002 DWR study, the water supply is expressed in terms of the dependable yield for the main Santa Maria Basin within San Luis Obispo County and for each of several divisions of the main basin. DWR defines dependable yield as " … the average quantity of water that can be withdrawn from the basin over a period of time (during which water supply conditions approximate average conditions) without resulting in adverse effects … ". The "average conditions" referenced parenthetically by DWR are primarily the average annual precipitation, the assumption being that each year receives no more nor less than the average. In fact, some years will receive greater rainfall than the average and some will receive less. Following wet years, water levels will rise; following dry years, levels will fall. However, over the long term, the average precipitation provides the appropriate benchmark.

DWR provides the following estimates of dependable yield (given as a range) for the main Santa Maria groundwater basin:

Tri-Cities Mesa – Arroyo Grande Plain	4,000 afy to 5,600 afy
Nipomo Mesa	4,800 afy to 6,000 afy
Santa Maria Valley	11,100 afy to 13,000 afy
Main Santa Maria Basin in SLO County	19,900 afy to 24,600 afy

The following tables compare the estimated dependable yield to the estimated extractions for the base period, and for 2010 and 2020. The low end of the range is identified as the worst case and the high end of the range is identified as the best case. Projected deficits are highlighted with bold type and shading.

Table 3. Comparison of Dependable Yield and Extractions – Base Period
Source: DWR 2002, Tables 24, 25, 26, 27 and 29
(Acre-feet per year)

	Tri-Cities Mesa		Nipomo Mesa		S. Maria Valley		Main Basin	
Dependable Yield	4000	5600	4800	6000	11100	13000	19900	24600
Urban Extractions	2300		3400		500		6200	
Ag Extractions	1500		1900		12300		15700	
Other Extractions	100		1000		100		1200	
Total Extractions	3900		6300		12900		23100	
Surplus / **Deficit**	+100	+1700	**-1500**	**-300**	**-1800**	+100	**-3200**	+1500

Table 4. Comparison of Dependable Yield and Extractions – 2010

Source: DWR 2002, Tables 24, 25, 26, 27 and 29
(Acre-feet per year)

	Tri-Cities Mesa		Nipomo Mesa		S. Maria Valley		Main Basin	
Dependable Yield	4000	5600	4800	6000	11100	13000	19900	24600
Urban Extractions	3400		5200		700		9300	
Ag Extractions	900		1600		10100		12600	
Other Extractions	100		1000		100		1200	
Total Extractions	4400		7800		10900		23100	
Surplus / **Deficit**	**-400**	+1200	**-3000**	**-1800**	+200	+2100	**-3200**	+1500

Table 5. Comparison of Dependable Yield and Extractions – 2020

Source: DWR 2002, Tables 24, 25, 26, 27 and 29
(Acre-feet per year)

	Tri-Cities Mesa		Nipomo Mesa		S. Maria Valley		Main Basin	
Dependable Yield	4000	5600	4800	6000	11100	13000	19900	24600
Urban Extractions	4400		6600		900		11900	
Ag Extractions	900		1600		10700		13200	
Other Extractions	100		1000		100		1200	
Total Extractions	5400		9200		11700		26300	
Surplus / **Deficit**	**-1400**	+200	**-4400**	**-3200**	**-600**	+1300	**-6400**	**-1700**

This comparison of dependable yield and extractions indicates that for the worst case scenario, representing the lowest estimate of dependable yield, dependable yield is exceeded in the base period for the Nipomo Mesa, the Santa Maria Valley and the Main Basin. For 2010, dependable yield is exceeded in the Tri-Cities Mesa, Nipomo Mesa and the Main Basin. Dependable yield is not exceeded in the Santa Maria Valley due to reduced agricultural extractions. For 2020, extractions in all sub-areas and the Main Basin exceed the dependable yield.

For the best case scenario, representing the highest estimate of dependable yield, the estimate for the Nipomo Mesa indicates a deficit in the base period. For the Nipomo Mesa, the deficit increases to 2010. In 2020, the Nipomo Mesa deficit increases again, and a deficit is also indicated for the Main Basin.

DWR 2002 also compares total outflow to total inflow, indicating growing deficits from the base period through 2020.

Table 6. Inflow, Outflow, Surplus/Deficit (1,000s of acre feet per year)
Source: DWR 2002, Tables 24, 25, 26 and 27

Sub-area	Base Period (1984 thru 1995)			2010	2020
	Inflow	Outflow	Surplus/Deficit	Surplus/Deficit	Surplus/Deficit
Main Basin	29200	33100	**- 3900**	**- 4700**	**- 7100**
Tri-Cities/A.G.Plain	7200	7100	+ 100	**- 500**	**- 1300**
Nipomo Mesa	6800	8200	**- 1400**	**- 2400**	**- 3800**
Santa Maria Valley	18800	21400	**- 2600**	**- 1800**	**- 2000**

Trends in water demand, Master Water Plan Update, 2003

Water demand for the Nipomo Mesa has also been estimated by the County's Master Water Plan Update. These estimates generally coincide with the DWR estimates for the Nipomo Mesa and the Santa Maria Valley.

Table 7. Water Demand, Water Planning Area 6
Master Water Plan Update, 2003
Acre feet per year

Demand Sector	Nipomo Mesa		Nipomo Valley		Santa Maria River Valley		Suey Creek		Total WPA6	
	2002	Buildout	2002	Buildout	2002	Buildout	2002	Buildout	2002	Buildout
Urban	3900	7340	3	320	0	0	0	0	3900	7670
Ag	2990	1900	4220	4120	12130	11740	3200	6420	22540	24180
Rural	2420	3350	490	730	140	220	30	50	3080	4350
Env	Black Lake, Coastal Lakes, Oso Flaco Lakes (No estimate)									
Total	9310	12590	4713	5170	12270	11960	3230	6470	29520	36200

The following table, Table 8, is an expanded version of the Nipomo Mesa portion of the 2003 WPA6 table, above. In this table, urban extractions are broken out into sub-categories representing the major water-using entities on the mesa. Demand for 2003 reflects the actual demand as reported by NCSD and Cal Cities, and estimated demand for communities and rural areas not served by these purveyors, based on the number of residential units existing in 2003 and estimates of demand per unit. Golf courses are listed as a separate component of rural demand. Agricultural demand is based on estimates of the Master Water Plan Update, as modified through the deliberations of the Nipomo Water Forum.

Table 8. Existing and Projected Extractions, Nipomo Mesa
(Acre-feet per year, no additional conservation)

	Afy/DU	2003	2010	2020	Buildout
Nipomo (NCSD)	0.68	1924	2256	2832	3997
Nipomo (Cal Cities)	0.92	1328	1558	1656	1656
Summit Station (NCSD)	1.5	183	203	225	240
Black Lake (NCSD)	0.78	383	436	436	436
Callender-Garrett	0.50	109	125	125	125
Palo Mesa	0.78	715	839	897	897
Woodlands	0.64	0	528	845	845
Rural (Residential)	1.0	670	785	986	2260
Rural (Golf Courses)		300	700	700	700
Total Non-AG		5612	7430	8700	11156
Agriculture (1)		2990	2590	1900	1900
Total		8602	10020	10600	13056
Dependable Yield		6000	6000	6000	6000
Surplus <Deficit>		<2602>	<4020>	<4600>	<7056>

Notes: (1) MWP shows WPA6 ag demand for 2020 = 23,860 to 31,770 afy. The 2003 MWP update shows demand reduced to a range between 19,260 and 28,450 afy, based on reduction in acreage from 1630 acres in 2002 to 980 acres in 2020. The lower end of the range is used in this table. Ag extractions are reduced accordingly. Buildout extractions for Nipomo (NCSD) and Rural (Residential) are based on dwelling unit buildout estimates from the South County Area Plan. For Nipomo (NCSD), buildout assumes redevelopment of under-built parcels to their full entitlement according to existing land use categories.

Conclusion Regarding Water Demand for Nipomo Mesa

DWR 2002 estimates that in 2020, the Nipomo Mesa will have urban extractions of about 6600 acre-feet per year (DWR, 2002, Table 5). The Master Water Plan Update estimates urban and rural non-agricultural extractions of about 10970 afy for the Nipomo Mesa at buildout (Table 1, page WPA6-2). The estimates of urban extractions in Table 8, above are generally consistent with the DWR and Master Water Plan estimates. The comprehensive compilation of extractions in Table 8, including projected agricultural extractions, indicates total extractions of about 8600 in 2003, increasing to 10020 in 2010, 10600 in 2020 and 13056 at buildout.

In order to maintain the sustainability of the groundwater supply, total extractions would have to become stabilized at 6000 afy. Sustainability can be achieved through some combination of conservation and supply augmentation so that urban extractions do not exceed 3400 afy or that they increase by no more than the addition of supplemental water to the Nipomo Mesa portion of the basin. To address fully the projected deficits, a combination of conservation and additional supply totaling 4020 afy should be in place by 2010 and a combination equaling 4600 afy should be on line by 2020. For example, without any supplemental water, conservation would be the only mechanism for

achieving sustainability. In 2010, 7430 afy is projected to be extracted for urban use to meet demand. However, if per capita water use could be reduced by 35 percent, the population served could increase by over 50 percent with no corresponding increase in extractions. For the projected 2020 demand of 8700 afy to be reduced to 4490 afy to maintain sustainability, per capita water use would need to be reduced by about 48 percent. It is theoretically possible that full implementation of an array of conservation programs could produce a savings of up to 40 percent, as estimated by the Pacific Institute (see discussion in section 6). However, it is more likely that some increment of additional supply, in combination with conservation, will be required.

6. MEASURES TO INCREASE SUPPLY

Water suppliers in the Nipomo Mesa area include the Nipomo Community Services District (NCSD), California Cities Water Company, Rural Water Company, at least 20 small private water companies, the Woodlands development and numerous private wells serving individual parcels. For future development outside the boundaries of the major suppliers, groundwater will continue to be the only source of supply. Operators of larger systems – NCSD, Cal Cities and, possibly, the Woodlands – have the financial means to consider the acquisition of supplemental water supplies.

In 2001, the Nipomo Community Services District retained Kennedy/Jenks consultants to evaluate various water supply alternatives. This report considered the following alternatives:

Table 9. Water Supply Alternatives, NCSD
From Table 4-1, Kennedy/Jenks Consultants

Supply Source	AFY	$/AFY	Reliability	Complexity
State Water Project (SLO County, Oceano), Nipomo turnout	350	$1000	Medium	High
State Water Project (Santa Barbara County, Solvang)	700	$2400	Medium	High
Intertie with City of Santa Maria	3000	$1200	High	Low
Desal water from City of Santa Barbara	3000	$1100	Medium	High
New groundwater well on Tosco property	1200	?	High	Low
Desal Tosco blowdown water	360	$3000	High	Low
Desal seawater	3000	$4000	High	Medium
Reclaimed water from SSLOCSD	3625	$8300	High	Low
Reclaimed water from NCSD Southland wastewater plant	300	?	High	None
Oil field process water, Price Canyon	800	?	High	Medium
Hard rock drilling	500	$1000	High	Low
Conservation	200	?	Medium	Low
Ocean transport using water bags	?	?	Medium	Low

From this list, the five most promising alternatives were ranked in the following order of priority for further investigation, evaluation and possible implementation:

1. Water conservation (500-1000 afy)

2. Intertie with the City of Santa Maria (2000-3000 afy)
3. Desal process water and groundwater exchange with Tosco Refinery (1300 afy)
4. Recycled water / groundwater exchange with agricultural users (500-1000 afy)
5. Hard rock drilling (500-1000 afy)

7. MEASURES TO EXTEND RESOURCE CAPACITY

Conservation

Indoor residential water use. A recent publication by the Pacific Institute (1) estimates that indoor residential water use can be reduced by about 40 percent. Reductions could be achieved by replacement of toilets, shower heads, clothes washers and dishwashers and repairing leaks. Conversion to low water-use fixtures will occur gradually over the long term. It can also be accelerated through pro-active programs involving public education, the offer of financial incentives and the adoption by water purveyors of steeply-tiered rate structures that reward conservation and penalize unreasonable water use. The Pacific Institute suggests the following rate structure:

Table 10. Recommended Tiered Rate Structure
Pacific Institute

Tier	Water Use (as percent of base allocation)	Price per Unit Used in Each Tier
Low Volume Discount	0-40%	Base Rate
Conservation Base Rate	41-100%	Base Rate
Inefficient	101-150%	2x Base Rate
Excessive	151-200%	4x Base Rate
Wasteful	201% and above	8x Base Rate

Outdoor residential water use. Outdoor residential water use can also be reduced through the implementation of conservation measures. The Pacific Institute identifies a variety of such measures, ranging from relatively simple and inexpensive practices such as maintaining a proper irrigation schedule to more demanding practices such as retrofitting an irrigation system with new efficiency components or changing landscape design. Some of the possibilities are included in the following table. It is estimated that application of these measures could reduce outdoor residential water use by 25 to 40 percent.

Excerpts from a recent article about water conservation are included in appendix B.

(1) *Waste Not, Want Not: The Potential for Water Conservation in California*, Pacific Institute, November, 2003. The Pacific Institute for Studies in Development , Environment and Security is an independent, nonprofit organization that provides research and policy analysis on issues at the intersection of sustainable development, environmental protection, and international security. More information can be found at www.pacinst.org.

Table 11.
Outdoor Residential Water Conservation Methods
Pacific Institute, 2003

Management Practices
Irrigation scheduling
Turf maintenance, irrigation system maintenance
Composting
Hardware Improvements
Soil moisture sensors
Auto rain shut off devices
Drip/bubbler irrigation
Landscape Design
Turf reduction
Choice of plants/xeriscape
Policies
Ascending block rate structure
Public education
Rebates, loans

Effect of water conservation on total demand for the Nipomo Mesa HSA. Is water conservation, by itself, sufficient to lower demand to a sustainable level? Probably not. Research conducted by the Pacific Institute suggests that an aggressive water conservation effort can reduce demand by about 40 percent. The NCSD's Urban Water Management Plan assumes that conservation will reduce demand by 15 percent. In the following table, various water conservation factors are applied to the non-agricultural water demand from Table 8, to determine if supplemental water would also be needed to reduce total demand to the level of dependable yield.

Table 12. Need for Supplemental Water
@ Various Levels of Non-Agricultural Water Conservation,
Nipomo Mesa HSA (1)

Conservation Factor	2003	2010	2020	Buildout
0%	2210 afy	3870 afy	4600 afy	7050 afy
15%	1370 afy	2720 afy	3230 afy	5320 afy
30%	530 afy	1570 afy	1870 afy	3590 afy
40%	0 afy	800 afy	960 afy	2430 afy

(1) Need for supplemental water calculated as follows:
Non-ag demand from Table 8 x (1.0 – conservation factor) – sustainable demand – reduction in ag demand = need for supplemental water.

8. RECOMMENDED LEVEL OF SEVERITY

The county General Plan's *Framework for Planning* contains a discussion of the objectives, procedures and criteria for levels of severity of the Resource Management System. Regarding water resources, the RMS indicates that *"Level of Severity III exists when water demand equals the available resource; the amount of consumption has reached the dependable supply of the resource. A Level III may also exist if the time required to correct the problem is longer than the time available before the dependable supply is reached*." (page 3-19). Table F (page 3-18) summarizes levels of severity for water supply:

Table F
RESOURCE DEFICIENCY CRITERIA FOR LEVELS OF SEVERITY

Level I	Level II	Level III
Projected consumption estimated to exceed dependable supply within 9 years	7 year lead time to develop supplementary water for delivery to users	Resource is being used at or beyond its estimated dependable supply or will deplete dependable supply before new supplies can be developed

This Resource Capacity Study confirms that, for the Nipomo Mesa area, demand presently equals or exceeds the dependable yield. Therefore, Level of Severity III is recommended for the water resources of the Nipomo Mesa area. For other portions of the basin, demand may equal or exceed the dependable yield by 2010 before a supplemental water supply can reasonably be expected to be secured. Level of Severity II is recommended for the balance of the basin within San Luis Obispo County.

9. RECOMMENDED ACTIONS

The Resource Management System includes three "action requirements" that accompany a Level of Severity III determination:

If Level III is found to exist, the board shall make formal findings to that effect, citing the basis for the findings, and shall:

1. *Institute appropriate measures (including capital programs) to correct the critical resource deficiency, or at least restore Level II so that severe restrictions will be unnecessary.*
2. *Adopt growth management or other urgency measures to initiate whatever restrictions are necessary to minimize or halt further resource depletion.*
3. *Enact a moratorium on land development, or other appropriate measures, in the area that is affected by the resource problem until such time that the project provides additional resource capacity to support such development.*

For the Nipomo Mesa area, the following measures are recommended for implementation:

1. Measures to correct the resource deficiency.

   The county can initiate measures that involve the land use and building permitting process. However, since the county is not a water purveyor in the Nipomo Mesa area, some of these measures will need to be undertaken by the NCSD, Cal Cities Water Company and other community water systems, acting separately or as part of a coordinated effort.

Measures to be undertaken by the county:

- Implement an improved well-monitoring program for the Nipomo Mesa area.
- Undertake a comprehensive water quality assessment and develop a water quality monitoring program for the Nipomo Mesa area.
- Require landscape plans for new development that include minimal turf areas, low water use plant materials and drip irrigation systems with automatic controllers and auto rain shut-off devices. To accomplish this measure, planning area standards should be adopted to broaden the application of low-water use landscape requirements in the urban and rural areas of the Nipomo Mesa. The County's landscape standards require submission of a landscape plan with applications for most types of land use permit approval, with certain exceptions. Landscape plans include the location and extent of permeable and impervious landscape materials, plant materials selected from an approved plant list, turf area not to exceed 20% of site area for parcels less than 1 acre or 20% of landscaped area for parcels on one acre or larger, and an irrigation plan indicating the method for achieving low volume, high efficiency irrigation. For the Nipomo Mesa area, standards should be added that would require landscape plans for home-owner installed landscapes as well as developer-installed landscapes and also to reduce the minimum size for exception from ordinance provisions from 2,500 square feet of irrigated area to 1,500 square feet. For development in rural areas, a standard should be added that would require a landscape plan for lot sizes up to five acres rather than two acres, as is currently required.
- Monitor water use per dwelling unit for NCSD, Cal Cities and Woodlands annually to determine progress toward achievement of conservation goals. Progress will be demonstrated by reducing or maintaining water use per dwelling unit according to the following schedule:

Table 13. Schedule for Reducing Water Use
(Acre-feet per year per dwelling unit.
Includes water used by non-residential accounts.)

Service District	2003	2010 15%	2020 30%
NCSD, Town Division	0.68	0.58	0.48
NCSD, Black Lake Division	0.78	0.66	0.55
Cal Cities	0.92	0.78	0.64
Woodlands (From EIR)	0.64	0.64	0.64

Measures to be undertaken by water purveyors:

- Adopt an array of conservation measures that will achieve an overall reduction of 15% by 2010 and 30% by 2020, compared to 2003 consumption. Such conservation measures may include:
  - Mandatory retrofit of toilets, showerheads and faucets with low-water-use fixtures upon change of use, expansion of use or change of ownership of any residential or non-residential structure in the district service area.
  - Provision of incentives for voluntary retrofit.
  - Adoption of an effective ascending block rate pricing structure consistent with Pacific Institute recommendations.
  - Adoption of an ordinance prohibiting wasteful outdoor water use.
  - Provision of leak detection assistance to customers.
  - An on-going leak detection program for the delivery system.
  - On-going customer education programs, including provision of water conservation information to applicants for new service, water bills comparing current use to historical use and average use for comparable accounts, advertising using newspapers, tv and radio, public school education programs and landscape water-use audits for customers.
  - Provision of incentives for installation of low-water-use appliances such as clothes washers and dishwashers and automatic shut-off devices.
  - Provision of incentives for conversion to low-water-use landscaping.
- Increase the use of reclaimed water from wastewater treatment plants and other sources.
- Secure supplemental water supplies in sufficient quantity, when combined with conservation measures, to meet demand at the 2010, 2020, 2030 and buildout milestones, while limiting non-agricultural groundwater extractions to no more than 3,400 afy.

2. Growth Management measures

In accordance with the provisions of the county's Growth Management Ordinance, the Nipomo Mesa area is currently subject to a local growth limit of 2.3 percent. This limit

should be retained while conservation programs and efforts to secure supplemental water are implemented. Meanwhile, water use per residential connection for the major water purveyors should be monitored to determine the effectiveness of their water conservation efforts. If the use rate does not begin to trend downward toward achievement of conservation objectives, consideration should be given to adoption of a lower growth limit. (A reduction in water use of 2.5% per year would lead to achievement of 15% conservation by 2010.) The annual hearing on the Growth Management Ordinance should include a report on Nipomo Mesa water use trends. Progress toward acquisition of supplemental water should also be monitored to determine the appropriateness of a lower growth limit.

Consideration should be given to progressive decreases in the growth limit if progress toward conservation goals is insufficient. For example, the growth limit might be reduced by 0.4% for the year following a year in which additional water conservation of 2.5% is not achieved. In the absence of adequate conservation, the growth limit would decrease to 1.9% in 2005, to 1.5%, 1.1%, 0.7%, 0.3% in years 2006 through 2009 and would decrease to 0% in 2010. It would be possible to apply these factors throughout the Mesa or only within water districts that do not achieve conservation objectives.

Growth limits do not apply within the Woodlands Specific Plan area. The Board of Supervisors has approved a phasing program for the Woodlands that is independent of the 2.3% growth limit for the balance of the Nipomo Mesa. The Woodlands is the only project that has proved its 20 year water supply, namely, dependable safe yield under the new State water law. The Board of Supervisors certified the Woodlands' verification and, in fact, was further validated by the recent court decisions in the Santa Maria water litigation. In view of the years of work, including planning, analysis, Board findings and court decisions, any changes to the level of severity for the Nipomo Mesa, either now or in the future, should not apply to The Woodlands' Village.

3. Land Development measures

- Adopt a planning area standard for the Nipomo Mesa to require requests for **General Plan Amendments and land divisions** to either demonstrate that no increase in water use would result from the proposed development, or to provide supplemental water to offset any projected increase.
- **Building Permits** should be issued only if the construction documents include indoor and outdoor water conservation measures.

A summary of these recommendations may be found on the following page.

Information about completed building permits, subdivision activity and general plan amendments in the South County Planning Area is provided in Appendix A.

Summary of Recommendations

	Corrective Measures	Responsible Entity
1	Improved well-monitoring program	County
2	Water quality assessment and monitoring program	County
3	Expand application of landscape standards	County
4	Monitor progress toward conservation objectives	County
5	Implement conservation programs	Purveyors
6	Increase use of reclaimed water	Purveyors
7	Secure supplemental water	Purveyors

	Growth Management Measures	
8	Retain 2.3% growth limit for Nipomo Mesa	County
9	Reduce growth rate for insufficient conservation	County

	Land Development Measures	
10	GPAs required to demonstrate no increase in water use and/or provide supplemental water	County
11	Land divisions required to demonstrate no increase in water use and/or provide supplemental water	County
12	Building permits issued only if indoor and outdoor water conservation measures are included	County

Appendix A

Completed Building Permit History; Subdivision Status; General Plan Amendments

Completed Building Permits by Year, Nipomo Mesa										
	1994	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Nipomo	112	111	58	72	101	126	117	109	113	94
Los Berros	2	0	0	0	3	1	4	1	0	0
Callender Garrett	0	0	1	3	5	5	3	4	21	14
Palo Mesa	6	4	7	14	5	10	23	72	121	39
Black Lake	0	0	0	0	0	36	60	4	1	0
Balance of Mesa (1)	30	21	27	33	41	36	21	33	29	22
Total Mesa	150	136	93	122	155	214	228	223	285	169
Total Units @ year end	4719	4855	4948	5070	5225	5439	5667	5890	6175	6344
2.3% limit for new units (Limit in Nipomo Mesa area initiated in 2000)							125	130	142	146
Rural South County	40	49	46	52	63	45	24	47	41	32
South County Total	160	164	112	141	177	223	231	237	297	179

Note (1) "Balance of Mesa" is an estimated portion of the "Rural South County" number.

Status of Subdivision Activity in South County Planning Area
August, 2004

Status	Maps with less than 20 lots		Maps with 20 or more lots		Building permits applied for	Estimated water demand per lot	Estimated total water demand
	Maps	Lots	Maps	Lots			
Received, no action	29	124	4	125	-	0.9 afy	224 afy
Hearing scheduled	1	5	-	-	-	0.9 afy	5 afy
Approved, not recorded	46	187	7	237	-	0.9 afy	382 afy
Recorded	73	394	6	327	68	0.9 afy	649 afy
Total	149	710	17	689	68		1260 afy

(1) Estimated water demand represents a rough average of water use for the range of locations and water use estimates from Table 8, page 13.

1399 total lots less 68 already with building permits equals 1331 lots available for development. This represents about nine years of completed building permits at the rate of 2.3% per year currently allowed by the Growth Management Ordinance.

Status of General Plan Amendments in South County Planning Area
August, 2004

File #	Request	Status	Comment	Est. Change in Water Demand
G020020	CS to IND	Authorized	EIR in preparation	probably negligible
G030009	AG to RR	Authorized	Initial study in preparation	not significant
G990013	AG to CR	Authorized	Initial study not yet begun – waiting for project description from applicant	unknown
G990027	RL to RS/CS	Authorized	On hold, new owner	unknown
G980008	Amend standards	Authorized	Summit Station. Hrg scheduled Dec 4	+ 111 afy
G030011	AG to RSF/RMF	Received	Not yet authorized. Includes 265 residential units	+ 170 afy

Status: "Authorized" means that the Board of Supervisors has directed staff to prepare the request for a public hearing to determine if the general plan amendment should be approved. "Received" means that the request has been submitted to staff, but further processing has not yet been authorized by the Board of Supervisors.

11. Appendix B

Water – in Short Supply
Rebecca Bryant, excerpted from *Urban Land*, July 2003

Rober Hirsch of the USGS pinpoints the weakest links in the overall water supply system in the U.S.: *first*, overall capacity and *second*, ecological fragility. "Aquatic ecosystems are showing signs of stress because of the timing and rate of water extraction from groundwater and rivers."

Cities and regions that populate the American coast, including San Diego, Santa Barbara, and the San Francisco Bay Area, are all facing critical water shortages. Many of these rely heavily on groundwater. As pumps reach deeper and deeper into underground reservoirs, they draw in saline water. The solution, Hirsch says, is to search further inland for wells or river sources – or turn to desalination. The plunging cost of reverse osmosis, the escalating cost of developing freshwater sources, and the unreliability of those sources during periods of drought are favorably reconfiguring the economics of seawater desalination. In 2003, Tampa Bay (Florida) Water activated a 25 million-gallon-per-day desal plant that produces water at a cost of $2 per 1,000 gallons ($650 per acre-foot). San Diego County Water Authority is planning a 50 mgpd facility.

Groundwater-dependent cities throughout the desert regions of the western states have been dipping deeper and deeper to pump groundwater reservoirs at greater and greater expense, while also coping with saltwater intrusion. Through higher water prices, xeriscaping, the use of low-flow appliances, and the purchase of surface water rights from farmers, desert communities are managing, sometimes just barely, to avert crisis.

Aquifer storage and recovery are another possibility for both coastal and desert cities. Water extracted from streams during periods of abundant flow or from the outflow pipe of water treatment facilities is pumped into wells or spread over land and allowed to infiltrate. Since 1987, all developments in Scottsdale, Arizona, have paid a water resources acquisition fee. A state-of-the-art water campus treats waste water to irrigation standards for golf courses. When irrigation demand drops, water is purified to drinking water standards and pumped underground.

Water utilities try to plan for future needs by forecasting supply and demand, then developing strategies to meet their internally established reliability criteria. When shortages become apparent, the provider trys to adapt. The traditional approach was dams, pipelines, new wells, desal plants and water reclamation. Now, conservation is generally seen as the first line of defense against shortages.

In New Mexico, the developer of a master-planned community worked with local officials throughout the planning process to develop a comprehensive water plan. At the

homesite scale, low-flow appliances were installed, swimming pools were prohibited, xeriscaping was encouraged and irrigated areas were limited to 1,000 square feet. Actual consumption in 2001 averaged 58,600 gallons per unit per year, compared to 70,000 gallons in a typical municipal system. In 2002, with water restrictions and surcharges in place, use dropped to 48,900 gallons per unit. Beginning in 2003, each new home was equipped with a cistern to store rain water for future landscape irrigation. This was expected to reduce consumption further, to about 29,300 gallons per unit per year.

A Los Angeles-based nonprofit group retrofitted an existing home with a cistern, water retention grading, vegetated swales to slow the flow of stormwater and filter pollutants, sunken gardens to hold rainwater until it could infiltrate the soil, redirected downspouts, and a drywell at the base of the driveway that captured runoff in a box of sand and crushed rock. In a public demonstration, a local fire department dumped two tons of water (about 500 gallons) on the roof; all of it remained on site.

Catching rainwater as close as possible to its point of origin with low-tech, decentralized, on-site techniques is a strategy that saves money, replenishes groundwater, reduces pollutants and creates an urban environment with more green space, native landscaping, and trees.

12. Appendix C

Nipomo Mesa Groundwater Resource Capacity Study, San Luis Obispo County, California, S.S. Papadopulos & Associates, Inc., San Francisco, CA, March, 2004

Nipomo Mesa Groundwater Resource Capacity Study, San Luis Obispo County, California

S.S. PAPADOPULOS & ASSOCIATES, INC.
San Francisco, California

March 2004

116 New Montgomery Street, Suite 900, San Francisco, CA 94105-3692 - (415) 896-9000

Nipomo Mesa Groundwater Resource Capacity Study, San Luis Obispo County, California

Prepared For:

San Luis Obispo County

Prepared By:

S.S. PAPADOPULOS & ASSOCIATES, INC.
San Francisco, California

March 2004

116 New Montgomery Street, Suite 900, San Francisco, CA 94105-3692 - (415) 896-9000

Table of Contents

Figures

Appendices

Executive Summary

The Department of Water Resources (DWR) analyses, water budget estimates, and projections indicate that groundwater pumping in the Nipomo Mesa area is in excess of the dependable yield. Since current and projected pumping beneath Nipomo Mesa exceeds inflow (natural recharge plus subsurface inflow), the Nipomo Mesa portion of the Santa Maria Groundwater Basin is currently in overdraft and projections of future demand indicate increasing overdraft. Some studies conducted for Nipomo Area Environmental Impact Reports have overestimated the sustainable yield of groundwater and underestimated future groundwater declines and potential for seawater intrusion.

DWR defines overdraft *as "the condition of a groundwater basin or subbasin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years, during which water supply conditions approximate average conditions."* The statement in the DWR report that the groundwater basin within San Luis Obispo County is currently not in overdraft because of *"consistent subsurface outflow to ocean and no evidence of sea water intrusion"* is inconsistent with DWR's definition of overdraft.

DWR's findings for groundwater beneath the Nipomo Mesa Area are consistent with the County's Resource Management System Water Supply Criterion, Level of Severity III-- existing demand equals or exceeds the dependable supply.

Although existing and projected future water demand at Nipomo Mesa exceeds sustainable groundwater supply based on local water balance analyses, associated potential impact such as seawater intrusion of the aquifer system is not an imminent threat. Hydraulic analyses indicate that a time lag of many decades is likely before heavy groundwater pumping a few miles from the coast results in evidence of seawater intrusion near the coastline.

Declines of 40 to 60 feet in groundwater levels in Santa Maria River Valley occurred between the mid 1940s and late 1960s. Although increased pumping with agricultural development contributed to the drop in groundwater levels, the most important factor appears to be a decrease in recharge due to a prolonged period from 1945 to 1970 with less than average rainfall.

Analysis of historical rainfall data indicate a 30% likelihood that another 10-year period will occur within the next 100 years with annual rainfall nearly 2 inches below average. This would result in major declines in groundwater levels in the Santa Maria River Valley and Nipomo Mesa accompanied by reduced production capability from many wells, increased energy costs for pumping, and increased risk of seawater intrusion of the aquifers near the coastal margin.

Management response to these findings could include increased use of recycled water, increased importation of supplemental water, implementation of additional conservation measures, and appropriate limits on development.

Section 1
Introduction and Background

Increase in population and development of the Nipomo Mesa area of southern San Luis County (Figures 1 and 2) has led to concern by the County about limitations of groundwater supply on which the area is dependent. A 1979 study by the State of California Department of Water Resources (DWR) entitled *Ground Water in the Arroyo Grande Area*, reported that groundwater levels were declining in all parts of the study area as a consequence of groundwater pumping. In 1993, the DWR began a renewed and expanded study of water resources of the area. The results of the DWR study are presented in a 2002 report entitled *Water Resources of the Arroyo Grande – Nipomo Mesa Area*, which is referred to herein as the 2002 DWR Report.

Work by DWR presented in 2002 report was conducted over a period of several years, and during this time several water resource evaluations were also conducted by consulting firms, some on behalf of developers and some for environmental impact reports (EIRs). The DWR report is a voluminous document and valuable compilation of data, however the basis for some of the conclusions and implications regarding sustainable groundwater pumping beneath Nipomo Mesa remain unclear. Moreover, fundamental differences exist between some of the interpretations and conclusions presented in the 1979 and 2002 DWR reports and water resource assessments by consultants.

1.1 Objective and Scope

In June 2003, the County retained S.S. Papadopulos & Associates, Inc. (SSP&A) to conduct a resource capacity study of the Nipomo Mesa area. The objective of the study and this report is to distill relevant information from the DWR report and other water resource assessments of the Nipomo Mesa and vicinity, present an assessment of groundwater resources of the Nipomo Mesa, make recommendations for managing the groundwater resources including appropriate level of severity of depletion of the groundwater resource as part of the County's Resource Management System. In addition to the 2002 DWR Report, SSP&A reviewed numerous documents that pertain to water resources of the Nipomo Mesa and vicinity. A list of references is provided at the end of this report.

1.2 Acknowledgements

John Hand, Senior Planner was the primary contact for the County. John was helpful throughout the project and his comments on preliminary drafts improved this report. Cynthia Koontz, Christine Ferrara, and Frank Honeycutt with the County Public Works Department provided data and contact information. Cynthia Koontz also wrote a useful summary review of the DWR report.

Lew Rosenberg and Martin Feeney shared ideas on hydrogeology of the area. Tim Cleath and Spencer Harris shared data and provided electronic copies of some of their model figures. Dennis Gibbs and Rob Almy at the Santa Barbara County Water Agency, Meryll Gonzalez, Gerhardt Hubner, and Harvey Packard at the RWQCB, and Jodi Isaacs with the Dunes Center helped by sharing information and providing contacts. Don Eley who is the geological coordinator at Unocal Guadalupe Oil Field and Kristine Schroeder with LFR Levine-Fricke provided copies of reports and data on remediation of the Guadalupe Oil Field.

Section 2
Santa Maria Groundwater Basin and Vicinity

2.1 Geology

Nipomo Mesa overlies the northwestern portion of and is contiguous with the Santa Maria Groundwater Basin (Figures 1). The Santa Maria Groundwater Basin is the upper, relatively recent and water-bearing portion of the Santa Maria Geologic Depositional Basin, which includes older Tertiary age consolidated rocks. The aquifer system in the basin consists of unconsolidated Plio-Pleistocene alluvial deposits including gravel, sand, silt and clay with total thickness ranging from 200 to nearly 3,000 feet. The underlying consolidated rocks typically yield relatively insignificant quantities of water to wells. Jurassic and Cretaceous age basement complex rocks of the Franciscan and Knoxville Formations unconformably underlie the Tertiary and Quaternary rocks.

The unconsolidated alluvial deposits in the Santa Maria Groundwater Basin comprising the aquifer system include the Careaga Sand, the Paso Robles Formation, the Orcutt Formation, Quaternary Alluvium, and river channel deposits, sediment, terrace deposits and wind-blown dune sands at or near the surface. Figure 3 depicts conceptual geologic cross-sections and stratigraphy of the primary aquifer system of the Santa Maria Groundwater Basin (Morro Group, 1990). Offsets of the basement rocks and aquifer units by faults, which are not represented in these simplistic cross-sections (Figure 3), are represented on geologic cross-sections prepared by DWR (2002). The DWR 2002 report discusses significant differences in water levels on opposite sides of the estimated trace of the Santa Maria River Fault, suggesting that the fault is to some degree a hydraulic barrier along the eastern margin of Nipomo Mesa. The DWR cross-sections are included in Appendix A, which provides a more detailed discussion of the geology of the Santa Maria Geologic basin.

2.2 Aquifer Characteristics

This summary of aquifer characteristics of the Santa Maria Groundwater Basin is based on a review of several sources of information including the DWR 2002 report, a report on a groundwater flow model and assessment of Santa Maria River Valley groundwater yield (Luhdorff & Scalmanini, 2000), a number of reports regarding development of the

Nipomo Mesa Areas (e.g. Cleath and Associates, 1996a, 1998; ESA 1998). Many of these references rely heavily on estimates of aquifer properties reported by Worts (1951). Estimates of hydraulic conductivity are based on specific capacity values from driller's pumping tests, and aquifer testing conducted on a few wells.

The Santa Maria Groundwater Basin includes the Careaga Sand, Paso Robles Formation, Orcutt Formation, terrace deposits, Quaternary Alluvium, river channel deposits, and dune sand. The Aquifers are generally confined in the western portion of the basin. Focus is on the Paso Robles Formation and Quaternary Alluvium, which are the most important aquifers in the Santa Maria River Valley and Nipomo Mesa areas.

The Paso Robles Formation is the thickest and most extensive aquifer in the basin. The report by Luhdorff and Scalmanini (2000) includes a map with hydraulic conductivity (K) values for the Paso Robles Formation at 20 locations. In the Sisquoc plain, Orcutt Upland, and central Santa Maria River Valley, K ranges from 100 to 400 gpd/ft^2 (13 to 52 ft/d). Values are lower in the western portion of the Santa Maria River Valley and beneath Nipomo Mesa where the reported values range from 15 to 110 gpd/ft^2 (2 to 15 ft/d). The wells are typically screened over hundreds of feet of the Paso Robles Fm, so these values represent bulk averages for the formation.

The Quaternary Alluvium is the most permeable aquifer, although few testing data seem to be available to estimate hydraulic conductivity. Luhdorff & Scalmanini show seven locations with estimates of hydraulic conductivities. As for the Paso Robles Formation, data indicate that the hydraulic conductivity of the Alluvium generally decreases to the west. Values of 4500 gpd/ft2 (600 ft/d) are typical in the Sisquoc plain, while 2000 gpd/ft2 (265 ft/d) is typical for the lower portion of the alluvium near Guadalupe. Typical thickness for the Quaternary Alluvium in the Santa Maria River Valley is 100 to 200 feet. Near Guadalupe the upper portion of the alluvium is generally fine-grained and acts as a hydraulic confining layer above the lower alluvium and Paso Robles Fm.

Luhdorff & Scalmanini (2000) report specific yield values in the range of 8 to 13 percent, and assume a reasonable value of storativity of 0.0001 for portions of the aquifers system under confined conditions.

2.3 Historical Precipitation Record

DWR compiled and analyzed long-term precipitation records from 36 stations in San Luis Obispo and Santa Barbara Counties (DWR, 2002) and constructed a map showing contours of equal mean annual precipitation based on records from 1870 to 1995. The DWR rainfall map is included as Figure 4. The long-term average annual rainfall in the northern portion of the Santa Maria Groundwater Basin is approximately 14 inches. The majority of rainfall occurs between November and April. Figure 5 shows historical rainfall records for Santa Maria, Nipomo Mesa, and San Luis Obispo.

Cumulative departure curves are useful for evaluating long-term rainfall trends. Figure 6 shows graphs prepared by DWR of cumulative departure from mean precipitation for three stations: (1) California Polytechnic University, San Luis Obispo, (2) Nipomo, and (3) Santa Maria. As indicated on the graphs, long-term downward sloping trends correspond to prolonged periods of less than average rainfall, and upward sloping trends correspond to prolonged periods of more than average rainfall. Based on the cumulative departure curve for San Luis Obispo rainfall, the DWR report identified three wet-dry cycles of precipitation: 1884-1900, 1901-1934, and 1935-1966. In addition, a fourth wet-dry cycle appears to have begun in 1967. Similar cycles are evident on cumulative departure curves for Nipomo and Santa Maria.

Based on the long-term rainfall data, DWR chose 1984-1995 as the base hydrologic period, which is intended to be representative of long-term conditions and encompass dry, wet, and average years of rainfall. This twelve-year period included the most recent pair of dry and wet trends and begins and ends with a series of wet years. In addition, data are available for the 1984-1995, and the period reflects recent conditions.

2.4 Watersheds and surface water

Most of the Santa Maria Groundwater Basin is within the Santa Maria River Watershed, which extends eastward into the coastal range region and covers nearly 1.2 million acres. The California Rivers Assessment (CARA) program[1] divides the Santa Maria River Watershed into two sub-basins: the Cuyama Basin, which is the upper portion of the watershed, and the Santa Maria, which is the lower portion of the watershed. Figure 7 provides maps showing the extent of each.

The Santa Maria portion of the watershed, which includes the Sisquoc and Santa Maria Rivers, covers an area of 453,777 acres (1,836 sq km) and the average annual precipitation (weighted by area) is 19.7 inches. The Cuyama portion of the watershed covers an area of 732,147 acres (2,963 sq km) and average precipitation is 16.3 inches per year. Average precipitation for these watersheds is greater than that for the northwestern portion of the Santa Maria Groundwater Basin because the watershed boundaries extend further inland and include highlands, which receive the most precipitation.

The Santa Maria River begins at the confluence of the Cuyama and Sisquoc Rivers near the town of Garey and it forms the border between Santa Barbara and San Luis Obispo Counties. The Santa Maria River Valley is the major surface water drainage of the Santa Maria River Watershed and a major source of recharge to the aquifers beneath the valley. The Santa Maria River Channel meanders westward some 20 miles over extensive

[1] The California Rivers Assessment (CARA) program is a computer-based data management system designed to give resource managers, policy-makers, landowners, scientists and interested citizens rapid access to essential information and tools with which to make sound decisions about the conservation and use of California's rivers. The website (http://endeavor.des.ucdavis.edu/newcara/) and program is managed by the Information Center for the Environment at UC Davis.

permeable alluvial deposits with high infiltration potential on its way to the Pacific Ocean. Flow of water in the Santa Maria River Channel is intermittent, occurring only during periods of high seasonal runoff.

The flows of the Sisquoc River and its tributary creeks have been unimpaired throughout the historical period of record, and stream gauging data for the Sisquoc River near Garey are available since 1942. The Cuyama River, which drains a portion of the Sierra Madre Mountains, has been controlled since 1959 by Twitchell Dam (Figure 1).

The Bureau of Reclamation (BOR) constructed Twitchell Dam during the period from July 1956 to October 1958. BOR reports a total storage capacity behind the dam of 224,300 acre-feet (http://www.usbr.gov/dataweb/html/santamaria.html). The Dam is on the Cuyama River about 6 miles upstream from its junction with the Sisquoc River.

After construction, BOR transferred operations to the Santa Barbara County Water Agency. Currently, the Santa Maria River Valley Water Conservation District physically operates the reservoir. Floodwaters of the Cuyama River stored behind the dam are released from the dam as quickly as they can be percolated into the Santa Maria River Valley ground-water basin. An important objective of the operation of the dam is to attempt to prevent salt-water intrusion into the aquifers of the Santa Maria River Valley by helping to increase recharge to groundwater and to maintain outflow to the ocean (http://www.usbr.gov/dataweb/html/santamaria.html).

When the Sisquoc and Santa Maria Rivers are no longer flowing from natural run-off, available water from Twitchell Reservoir is slowly released and allowed to seep into the ground as it flows towards the ocean. Because water is released from the dam nearly continuously, Twitchell Reservoir is empty much of the time. The discharge rate is controlled, typically at 12,500 cubic feet per second (cfs). At this flow rate water rarely flows past Bonita School Road crossing, nearly 20 miles from the dam and 3.3 miles east of Guadalupe. Even prior to construction of the dam, water flowed in the river all the way to the mouth at the Pacific Ocean only during extended periods of high runoff.

Water nearly always flows in the last few miles of the Santa Maria River bed downstream of Guadalupe. USGS topographic maps (Guadalupe, Point Sal 1:24,000, and Santa Maria 1:100,000 quadrangles) depict a dry Santa Maria River bed in the vicinity of Guadalupe, but flowing water in the last 4 miles of the river, beginning 1.5 miles downstream of Guadalupe. This is likely a consequence of groundwater discharge to the river near the sea. This portion of the Santa Maria River is a gaining river—it functions as a drain for groundwater in the shallow aquifers in this region. The hydraulic gradient is upward from the deeper confined aquifers to the shallow aquifers so upward leakage of groundwater contributes to the shallow aquifers in this area. Irrigation return flows also contribute water to the river. In addition, small but essentially year-round flow from Orcutt Solomon Creek joins the Santa Maria River at the confluence approximately 1.2 miles upstream from the sea (phone conversation with Dunes Program Manager, http://www.dunescollaborative.org/index.html).

2.5 Santa Maria River Valley

Gauging data for the Santa Maria River near Guadalupe are available since 1941. During the period from 1941 to 1959, before the construction of Twitchell Dam, the number of days per year that the Santa Maria River near Guadalupe flowed was generally decreasing from an average of 30 days in 1941 to less than 10 days in 1959. As a consequence of management of Cuyama River flows after construction of Twitchell, the 1960 to 1987 record at Guadalupe shows a stabilized trend with an average of 10 days per year with water flowing in the River. This is a consequence of management of flows with the Twitchell Dam.

Major declines in groundwater levels in Santa Maria River Valley wells and decrease of the groundwater hydraulic gradient toward the ocean occurred between the mid 1940s and late 1960s. Drops in water level of 40 to 60 feet were common in wells during this period (e.g. DWR, 2002; Luhdorff & Scalmanini, 2000). Total dissolved solids (TDS) in groundwater east of Guadalupe was less than 1000 mg/l in the 1930s, but increased to greater than 3000 mg/l by 1975 (Santa Barbara County Water Agency, 1996, 1999). Increasing groundwater pumping and possible surface water diversions to support flourishing agricultural development in Santa Maria River Valley contributed to the drop in groundwater levels, decrease in flows in the Santa Maria River, and increase in TDS in groundwater. However, the most important factor appears to be a decrease in recharge due to a prolonged period from 1945 to 1970 with less than average rainfall. Graphs of cumulative departure from mean precipitation (Figure 6) illustrate this period of low rainfall.

Substantial recovery of groundwater levels in the Santa Maria River Valley occurred in the 1970s and 1980s. Management of Cuyama River floodwater flows by Twitchell Dam began in 1959 and is credited with increasing recharge to the Santa Maria River Valley and helping to arrest the decline in groundwater levels. Reported estimates of supplemental recharge since construction of the dam range from 20,000 acre-feet per year (AF/Y) (Dames and Moore, 1991) to 38,000 AF/Y (Luhdorff & Scalmanini, 2000). However, these estimates of supplemental recharge are much too large relative to the Cuyama River Flows. Supplemental recharge due to control of storm water flows cannot exceed the total average flow below the dam, and is likely a relatively small portion of the total average flow. Available gauging data for Cuyama River below Twitchell Dam indicate average annual flow in the range of 35,000 to 39,500 AF/Y.

Prior to, as well as after construction of Twitchell Dam, most of the water in the Santa Maria river infiltrated the Santa Maria Valley prior to reaching the mouth at the Pacific Ocean. River water flowed all the way to the Ocean only during extended periods of high runoff. Even prior to the construction of the dam, this occurred on average only several days per year. Based on comparison of Santa Maria River flow records before and after construction of the dam, we estimate that management of Cuyama River discharge at

Twitchell dam[2] enhances average recharge to the Santa Maria River Valley aquifers by no more than 10,000 to 15,000 acre-feet per year. As is discussed in Section 3.4.1 below, the data indicate that long-term variation of rainfall has had much more influence groundwater levels in Santa Maria than Twitchell Dam.

Luhdorff & Scalmanini (2000) report that hydrographs records for the period from the early 1980s to late 1990s show successive periods of decline and recovery that are not consistent with perennial overdraft[3]. Reported estimates of the annual yield of the basin include 120,000 AF (SB Co, 1996, 2000, 2002; Ahlroth, 1995), and 124,000 during the period 1968-1989, which Luhdorff & Scalmanini (2000) report as the approximate sustainable perennial yield[4]. Based on estimates by Luhdorff & Scalmanini (Figures 4-10, 4-12, Luhdorff & Scalmanini, 2000), average demand (groundwater pumping) in the Santa Maria River Valley was 96,200 AF/Y during the period from 1945 to 1970, and 140,000 AF/Y in 2000.

Water balance evaluations for Santa Maria Groundwater Basin using hydrologic conditions based on 45-year period from 1935 to 1979 are reported to indicate average annual deficits of 6,000 AF for historical water demand conditions, and 20,000 AF for water demands projected into the future from the late 1990s (Santa Barbara County, 1992, 1994, 1996, 2000, 2002). However, this estimated deficit is reduced by importation of water to Santa Barbara County beginning in 1996 from the State Water Project (SWP). Santa Barbara County estimated that 12,000 AF of SWP water were imported to the Santa Maria Groundwater Basin in 1999. This reduces the estimated deficit from 20,000 to 8,000 AF/Y. And if we assume that recharge enhancement by Twitchell Dam of 10,000 AF/Y

[2] During the period from 1959 to 1983 reported average annual flow in the Cuyama River below Twitchell Dam flow of the Cuyama River is 35,372 AF/Y (pgs E5-E6, DWR, 2002). Our calculation of average flow based on monthly USGS gauge data for a similar time period is 54.4 cfs or 39,456 AF/Y.

[3] *Groundwater Overdraft* is defined in the glossaries to the California Water Plan Update and California's Groundwater Bulletin 118 – 2003 Update (DWR 1998; DWR 2003) as "the condition of a groundwater basin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years during which water supply conditions approximate average conditions." However, the DWR Nipomo Mesa Report and in the text of the Bulletin 118 – 2003 Update (DWR, 2002; pg 154, DWR 2003), also define groundwater overdraft as a condition of a groundwater *subbasin*. *Perennial Overdraft* is sustained overdraft over a long period of time.

[4] *Perennial Yield* is defined in the glossary to the California Water Plan Update (DWR, 1998) as the "maximum quantity of water that can be annually withdrawn from a groundwater basin over a long period of time (during which water supply conditions approximate average conditions) without developing an overdraft condition." We consider *sustainable yield*, *sustainable perennial yield*, *perennial yield*, and *dependable yield* to be equivalent terms. In the glossary to the 2002 Nipomo Mesa report, DWR defines *dependable yield* as the "average quantity of water that can be extracted from an aquifer or groundwater basin over a period of time (during which water supply conditions approximate average conditions) without resulting in adverse effects such as subsidence, sea water intrusion, permanently lowered groundwater levels, or degradation of quality. If water management in the basin changes, the perennial yield of the basin may change." *Safe yield* also directly implies consideration of negative consequences and is defined in the 2003 update to Bulletin 118 (pg 99, DWR, 2003) as "the amount of groundwater that can be continuously withdrawn from a basin without adverse impact." Some papers that address a common misconception that safe yield is equivalent to the rate of natural recharge are provided in Appendix B.

directly contributes to yield, then the estimated deficit is erased and instead there is a surplus of 2,000 AF/Y. Table 1 summarizes estimates of yield and demand for year 2000 in Santa Maria Valley.

Clearly, these estimates of a yield, demand, and supplemental yield due to enhanced recharge are not precise numbers. Their accuracies are influenced by many uncertain assumptions. Moreover, the recharge enhancement provided by management of flood water discharge from Twitchell Dam may diminish in the future due to depletion of Cuyama river flows by groundwater pumping in Cuyama Valley (DWR, 2003) and decrease in storage capacity with accumulation of sediment in Twitchell Reservoir (e.g. SAIC et al., 2003). Without the assumed 10,000 AF/Y of enhanced recharge, the estimated projected deficit was 8,000 AF/Y, which is only 6.5% of Lurdorff & Scalmanini's estimate of sustainable perennial yield. In other words, the water balance deficit may be a small fraction of the sustainable yield for *average* rainfall conditions.

Table 1
Reported Estimates of Annual Groundwater Yield, Demand, and Deficit in Year 2000
Santa Maria River Valley

Perennial Yield (AF/Y)	Recharge Enhancment (AF/Y)	SWP Supplement (AF/Y)	Demand in Year 2000 (AF/Y)	Deficit in Year 2000 (AF/Y)
120,000	10,000	12,000	140,000	-2,000 (surplus)

2.5.1 Prolonged Period of Low Rainfall Results in Overdraft

Regardless of details about basin yield and deficits, the data show that a major decline of groundwater levels (drops of 40 to 60 feet) occurred as a consequence of reduced recharge from the river to the Santa Maria River Valley due to a prolonged period from 1945 to 1970 with less than average precipitation. The average annual rainfall during this 25-year period was 2.11 inches (16%) less than the average (13.60 inches) over the entire historical record (1886-2003). Many hydrographs from wells in the Santa Maria River Valley show that major decline in water levels occurred in the first five or ten years during this 25-year period. Based on the 177-year precipitation record for Santa Maria, we have evaluated the probability of prolonged periods with less than average rainfall in the future, which would again result in major decline of groundwater levels in Santa Maria River Valley.

We calculated sliding window averages (moving average) from Santa Maria precipitation record for a 10-year window. Statistical evaluation of this data set provides a basis for estimating probability of future conditions that would result in a major decline in groundwater levels in Santa Maria River Valley, such as occurred during the period from the 1940s to late 1960s. Figure 8 provides graphic illustration of the data and the statistical summary for 10-year moving average data set. The data indicate that the chance is approximately 30% in the next 100 years that a 10-year period will occur with average annual rainfall nearly 2 inches below average, which would result in a major decline in groundwater in the Santa Maria River Valley.

Moreover, this analysis likely underestimates chances of conditions in the future that would result in a major decline of groundwater levels in the Santa Maria River Valley because current and future water demand is greater than average demand during the historical overdraft period upon which this analysis is based. In addition, future contributions to Santa Maria Groundwater Basin from the Cuyama River may decrease as increasing demands deplete water resources in Cuyama Valley, which has been reported to be in a condition of critical groundwater overdraft[5] (e.g. pg 98, DWR, 2003, and Cuyama Valley Study[6]).

For the period from 1895 to 1947, the average annual natural runoff in the Santa Maria River system was estimated at 90,900 AF (pg 49 and Appendix E, DWR, 2002)[7]. Gauging data for the Santa Maria River near Guadalupe recorded since 1941 indicate a much lower average annual flow of 21,700 AF. Moreover, for the period from 1941 to 1987, the majority of time, flow is zero at Guadalupe. Flow exceeding 1 cubic foot per second (cfs) at Guadalupe only occurs an average of 21 days each year (Figure 9). DWR attributes the decrease in average flow in the Santa Maria River to impoundment of runoff at Twitchell Reservoir and presumably increased recharge with controlled releases.

The record from 1941 to 1959, which is before the construction of Twitchell Dam, the number of days per year that the Santa Maria River near Guadalupe flowed was generally decreasing. A trend line fitted to the data drops from an average of 30 days in 1941 to less than 10 days in 1959. Increasing groundwater pumping near the river due to agricultural development in Santa Maria River Valley likely contributed to this trend. The post-Twitchell Dam record, 1960 to 1987, shows a stabilized trend with an average of 10 days per year with water flowing in the River (Figure 9). This is a consequence of management of flows with the Twitchell Dam. Average annual flow data for this gauging station show the same trends (http://water.usgs.gov/cgi-bin/wuhuc?huc=18060008).

---

[5] Definition of *Critical Overdraft* (pg 98, DWR, 2003): "A basin is subject to critical conditions of overdraft when continuation of present water management practices would probably result in significant adverse overdraft-related environmental, social, or economic impacts."

[6] Cuyama Valley Irrigation Water Management & Groundwater Study conducted by researchers at the UC Davis Information Center for the Environment for the USDA - Natural Resources Conservation Service in cooperation with the Cachuma Resource Conservation District: http://endeavor.des.ucdavis.edu/nrpi/NRPIDescription.asp?ProjectPK=4988

[7] Original data source: California State Water Resources Board, Bulletin 1, 1951.

The amount of additional recharge provided to the Santa Maria River Valley by management of Cuyama River flows by Twitchell Dam appears to have been overestimated. In addition, both overdraft in Cuyama Basin (e.g. pg 98, DWR, 2003) and decrease in the capacity of Twitchell reservoir caused by accumulation of sediment (SAIC et al., 2003) will reduce the additional recharge to Santa Maria River Valley in the future. Importation of State Water to Santa Maria River Valley has helped avoid overdraft conditions, however, the data indicate that a series of several years with less than average rainfall would lead to significant decline in groundwater levels in the Santa Maria River Valley and accompanying reduced production capability from many wells, increased energy costs for pumping, and increased risk of seawater intrusion of the aquifers near the coastal margin.

2.6 Groundwater Quality

Total dissolved solids (TDS) in groundwater generally increase from east to west. TDS east of Guadalupe <1000 mg/l in the 1930s, but increased to >3000 mg/l by 1975. In the vicinity of Santa Maria and Guadalupe, the basin is classified as vulnerable to nitrate contamination, and in places, concentrations of nitrate have increased from <30 mg/l in 1950s to over 100 mg/l in the 1990s (Santa Barbara County, 1996, 1999). The Careaga Sand, which is the basal member of the system of alluvial aquifers in the basin, is generally considered to have poor water quality (e.g. Dames and Moore, 1991).

2.7 Groundwater Levels and Flow Directions

The California Department of Water Resources began monitoring groundwater levels in some wells in the Santa Maria Groundwater Basin in the 1930s. Most of the available water level data are from pumping wells and usually it is not known if the wells are pumping or idle, or how long pumping was curtailed before making a water level measurement. As a consequence the water level data are of limited value. However, particularly for wells with long records, the general trends can be useful and informative.

Profiles along the Santa Maria River of historical groundwater levels show that major decline of groundwater levels occurred as a result of expansion of irrigated agriculture in the 1920s and 1930s. Prior to the beginning of heavy pumping for irrigation, confined hydraulic groundwater head elevations were 50 to 75 feet higher within a few miles of the coast (e.g. Morro Group, 1996). Over the years, the transition between unconfined and confined conditions has generally migrated westward toward the coast. This means that water levels have dropped below confining intervals (aquitards) so the water is no longer under confined (pressure) conditions. Prior to the decline in water levels, groundwater discharged to the Santa Maria River near the coast, but as hydraulic head in the aquifer dropped contribution near the coast of groundwater to baseflow of the Santa Maria River decreased and the potential for seawater intrusion of the aquifers increased.

General groundwater flow in Santa Maria basin is east to west, from the Sisquoc area toward the ocean. As a consequence of agricultural demands on groundwater in the Santa Maria River Valley, the hydraulic gradient flattened considerably beneath the central and western portions of the basin between the mid-1940s and mid-1960s. Luhdorff & Scalmanini report that since the mid-1960s the flattening of the hydraulic gradient in the SMV has fluctuated and the portion of the Santa Maria Valley along the upper reach of Santa Maria river shows influence of increased recharge due to management of flows by Twitchell Dam.

Section 3
Nipomo Mesa

3.1 Geology and Hydrogeology

A mantle of late Pleistocene eolian (wind-blown) dune sands underlies the elevated area, known as Nipomo Mesa. The dune deposits were once much more extensive, but most were eroded away during the last ice age by the ancestral Arroyo Grande Creek, Los Berros Creek, and Santa Maria River. Today the Nipomo Mesa older dune sands is a triangular lobe more than 4 miles wide on the coastal side and extending inland more than 12 miles just east of Hwy 101. Lithologic logs of water wells indicate that the Nipomo Mesa dune sands are 150 to 250 feet thick. The Nipomo Mesa dune sands are very porous and permeable, and very little runoff leaves the Mesa. DWR (2002) reports that little runoff occurs from the bluffs at the margins of Nipomo Mesa, but that increased development has resulted in some increase in runoff from the mesa to the adjacent Arroyo Grande Plain and Santa Maria River Valley.

Groundwater in the dune sands is of relatively minor significance for water supply and the primary aquifer is the underlying Paso Robles Formation where groundwater is in hydraulic continuity with the Santa Maria groundwater basin (e.g. Morro Group, 1996; Cleath and Associates, 1996a, 1998; ESA 1998; DWR, 2000). Hydraulic conductivity of Paso Robles Formation is generally lower beneath Nipomo Mesa and in the western portion of the Santa Maria River Valley relative to the eastern portion; reported values range from 15 to 110 gpd/ft2 (2 to 15 ft/d) (e.g. Luhdorff & Scalmanini, 2002, Morro Group, 1996, Cleath and Associates 1996a).

The dune sands locally contain clay layers on which groundwater is perched. In addition, fine-grained layers in the upper portion of the Paso Robles Formation beneath dune sands are reported to function as a perching layer (Morro Group, 1996). Some of the shallow groundwater that percolates downward within the permeable Nipomo Mesa dune sands is diverted laterally along these low-permeablity layers and discharges into Black Lake Canyon and supports Black Lake and the other systems of coastal drainages and lakes west of Nipomo Mesa including the creek in Cienega Valley, Celery Lakes, White Lake, Little Oso Flaco Lake and the creek along the southwest margin of Nipomo Mesa.

The majority of water demands in the Nipomo Mesa area are supplied with groundwater because there are no significant creeks or rivers. As a consequence DWR (2002) reports that the main source of recharge is percolation of rainfall. However, subsurface inflow from Santa Maria River Valley is also an important component of the groundwater balance of the Nipomo Mesa area.

The amount of recharge to groundwater from precipitation on the Mesa is controversial, and estimates vary wildly—from zero to 100 percent. Cleath and Associates (1996a) estimated that 25% of rainfall on Nipomo Mesa percolates to groundwater, which equates to 5625 AF/Y of recharge over an area of 18,000 acres. However, Cleath and Associates (1997) subsequently advocated that extensive groves of eucalyptus trees intercept essentially all rainfall and prevent any recharge to groundwater for portions of Nipomo Mesa. Removal of gum trees and engineering of suburban runoff should locally increase recharge, but may not make significant difference to recharge to main aquifers on scale of the Nipomo Mesa.

3.2 Groundwater Levels and Flow Directions

Interpretation of groundwater flow directions from groundwater contour maps for the Nipomo Mesa is difficult because in some cases data is included from wells, which are screened within perched groundwater in the dunes, and little information regarding pumping status for wells is available. In addition, groundwater levels are discontinuous across the Santa Maria River Fault, which functions as a partial hydraulic barrier along the northeast margin of the Nipomo Mesa (e.g. Luhdorff & Scalmanini, 2000). In the early 1970s, some groundwater contour maps depicted a general groundwater mound beneath Nipomo Mesa with flow to the south to Santa Maria River Valley, to the northwest toward Arroyo Grande Valley, and to the west toward the sea. In general, however, most groundwater contour maps show westward flow toward the sea.

DWR (2002) presented contour maps of groundwater levels for Spring 1975, 1985, 1995 and 2000, included herein as Figures 10 to 13. These contour maps show that marked depressions associated with heavy pumping beneath parts of Nipomo Mesa have a significant influence on local groundwater flow directions. Based on our review of available water level from specific wells, the 1995 DWR contour map (Figure 12) appears to underestimate the depth and extent of a significant groundwater depression beneath Nipomo Mesa. Static water levels recorded in four wells installed in 1993 and 1994 for the Woodlands project over an area of approximately 4 square miles, are 6 to 31 feet lower (average 14 feet lower) than water levels indicated by the DWR water level contour map for 1995. These water level data are posted on Figure 12.

The County measures water levels twice a year in approximately 85 wells in the San Luis Obispo County portion of the Santa Maria Basin and recently completed compiling historical data and upgrading the database of groundwater elevations. Hydrographs, which depict water level elevation versus time, are provided in Appendix C for 20 wells in the

Nipomo Mesa Area. A line fitted to the entire data record is included on each hydrograph to show general trend in water level over the entire period of record. An overall decreasing trend in water level prevails.

Most wells on Nipomo Mesa with water level elevations greater than 100 feet are likely completed within or across intervals of shallow perched groundwater in the dune deposits. Such wells are not representative of the regional water level in the underlying Paso Robles Formation, which is the primary aquifer.

Based on the County water level database, several of the Nipomo Mesa wells have water levels below 10 feet MSL and a few have water levels below sea level even for non-pumping conditions. Note also, that in most cases the water levels are recorded for non-pumping conditions, and the pumping levels are generally several tens of feet lower.

3.3 Groundwater Budget and Change in Storage

DWR (2002) evaluated groundwater deficits and surpluses beneath the Nipomo Mesa for the period from 1975 to 1995 using both the specific yield-change in water level method and estimates of difference between inflow and outflow (water budget). Cumulative loss of groundwater storage over the twenty years is 7,000 AF using the change in water level method, and 11,000 AF using the water budget method. For a similar time period, 1976 to 1992, Cleath and Associates (1996a) estimated that volume of Nipomo Mesa groundwater in storage above sea level decreased from 55,200 to 49,200 AF, a net deficit of 6,000 AF, which is similar to the estimated deficits reported by DWR. Note however, that the Addendum to the DWR 2002 report includes an update using data for 2000, and as a consequence of rise in water levels between 1995 and 2000, the DWR analysis indicates zero net change in groundwater storage beneath Nipomo Mesa for the 25-year period from 1975 to 2000.

Based on the data and calculations for the period from 1975 to 1995, DWR (2002) estimated that dependable groundwater yield beneath Nipomo Mesa is in the range of 4,800 to 5,000 AF/Y. DWR also reported that projected groundwater demand for the Nipomo Mesa area exceeds the estimated dependable yield by approximately 50% in 2010, and 80% in 2020. As consequence of an expected decline in water levels, the hydraulic gradient would increase toward Nipomo Mesa from Santa Maria River Valley and the rate of groundwater influx would increase. However, DWR cautioned that increased groundwater flow from Santa Maria River Valley "might not be a desirable long-term solution to meet the water supply needs of the Nipomo Mesa."

Water budget estimates reported by DWR (Table 26, 2002) indicate that subsurface influx of groundwater to Nipomo Mesa from the Santa Maria River Valley accounts for about 35% of the total inflow of water for Nipomo Mesa (including rainfall). Groundwater modeling by Cleath and Associates (1996a) of increased pumping associated with Nipomo Mesa development projects indicates that approximately half of the increased groundwater

extraction at Nipomo Mesa comes from Santa Maria River Valley and ultimately recharge from the Santa Maria River. A more detailed discussion and analysis of the water budget estimated by DWR for Nipomo Mesa follows.

3.4 Estimates of Groundwater Demand and Capacity

DWR (2002) reported annual estimates of water budget for Nipomo Mesa for the period from 1975 to 1995, and for future years 2010 and 2020. Estimated components of inflow include

- deep percolation of precipitation;
- urban return;
- agricultural return;
- other return (zero for Nipomo Mesa);
- recharge of recycled water;
- subsurface inflow from Santa Maria River Valley and Nipomo Valley.

Estimated components of outflow include

- urban, agricultural, and other groundwater extraction;
- subsurface outflow to Tri-Cities Mesa – Arroyo Grande Plain; and
- subsurface outflow to the Ocean

Chapter 7 in the DWR report includes a discussion of each of these water budget components, and DWR Table 26 lists the annual values for each component for the period from 1975 to 1995, as well as for 2010, and 2020. Figure 14 illustrates the average contribution of each of the inflow and outflow components for DWR's Nipomo Mesa water budget estimates. DWR selected water years 1984 to 1995 as the base period for their evaluation. This period encompassed the most recent pair of wet and dry trends.

Figure 15-A shows DWR's estimated annual values for total inflow and outflow for Nipomo Mesa for the 20-year period from 1975 to 1995 and projected estimates for years 2010 and 2020. Average annual inflow during the study base period (1984-1995) is also shown on the graph (Figure 15-A). This graph shows that DWR's estimates of total outflow have exceeded average inflow since 1980 with an apparent increase in deficit with time.

Figure 15-B is a graph showing more detail of the DWR (2002) water budget annual estimates (see also Figure 14). The annual value of deep percolation component of inflow varies greatly because it is a function of rainfall. Components of inflow other than deep percolation (60 percent of which is groundwater inflow from Santa Maria River Valley) are more stable and show two nearly flat trends during the 20-year period of analysis: (1) 1975 to 1985 and (2) 1986 to 1995. We have fitted a line through these data and the DWR estimates for 2010 and 2020. This suggests a 1000 AF per decade increase (12.5 percent) in inflow to groundwater beneath Nipomo Mesa other than deep percolation of rainfall and accounts for increase subsurface inflow in response to increasing hydraulic gradient toward Nipomo Mesa with increases in pumping.

Figure 15-B also shows a trend line fitted to the 20-year period of outflow values to provide an estimate of outflow rates in the future. The trend increases at a rate of 1.2% per year. DWR's estimated values of outflow for years 2010 and 2020 are close to this projected trend. Also shown on Figure 15-B (open diamond symbols) are estimates of Nipomo Mesa water demand for years 2002 and 2020 from the County Master Water Plan Update (January, 2003) discussed in Section 3.5 below. These two demand estimates by the County (9.2 AF/yr in 2002 and 12.6 AF/yr in 2020) equate to an increase of 1.75% per year. The filled diamond symbols at 2002 and 2020 are the County's Nipomo Mesa Demand estimates with the DWR estimates of subsurface outflow added (Table 26, DWR, 2002).

We used trends and averages of the DWR water budget components to project two ranges of estimated inflow to Nipomo Mesa. These and the projected outflow are shown on Figure 15-C. One inflow range is constant with time. The lower value (6,800 AF/yr) is based on the DWR average inflow estimate for their base period: 1984-1995 (Table 26, DWR, 2002). The upper value (7,800 AF/yr) is based on average deep percolation for the 20-year period from 1975-1995, which is greater than the DWR base period (1984-1995), and average inflow (excluding deep percolation of rainfall), during the period from 1986 to 1995 (Table 26, DWR, 2002), which is the higher other inflow plateau shown on Figure 15-B.

The other inflow range shown on Figure 15-C increases with time. The rate of increase is based on the trend line fitted to the DWR estimates of components of inflow, not including deep percolation, for the period 1975-1995 and including the estimated values for years 2010 and 2020. This trend line and the data are shown on Figure 15-B. Addition of the average value of deep percolation for the DWR base period (1984-1995) gives the bottom of the increasing inflow range. And, addition of the average value of deep percolation for the 20-year period (1975-1995) gives the top of this increasing inflow range.

This analysis of the DWR water budget estimates for Nipomo Mesa shows outflow outpacing inflow even if we account for estimated increasing influx of groundwater from Santa Maria River Valley due to increasing pumping beneath Nipomo Mesa. By year 2025, estimated outflow exceeds the highest of a range of inflow estimates by 20 percent (Figure 15-C)—substantial overdraft and mining of groundwater in storage, and accompanying reduced production capability from many wells, increased energy costs for pumping, reduction of groundwater discharge to the coastal drainages and lakes west of Nipomo Mesa, and increased risk of seawater intrusion of the aquifers near the coastal margin.

3.5 Nipomo Water-Planning Area

The first phase of the San Luis Obispo County's Master Water Plan Update defined twelve Water Planning Areas (WPA) that are based on geography and land use (EDAW

and Boyle, 1998). The County addresses water supply and demand separately for each WPA. The Nipomo Area (WPA 6), which is one of six coastal water-planning areas in the County, includes the southern portion of the County. To better address specific water needs, the second phase of the Master Water Plan Update divided WPA 6 into four geographic water-demand sub-regions: Nipomo Mesa, Nipomo Valley, which is east of Hwy 101, the Suey Creek Area, which is further southeast, and the portion of the Santa Maria River Valley in San Luis County (north of the Santa Maria River). Figure 2 illustrates the subareas of WPA6.

Nipomo Community Services District (NCSD) and the Southern California Water Company (SCWC) are the primary municipal water purveyors in WPA 6. In addition there are approximately 25 private water purveyors that pump groundwater beneath WPA 6. In addition, there are hundreds of private domestic wells.

Estimates by the County (January 2003a) of current and projected water demand for the Nipomo Mesa sub region of WP6 (Figure 2) are summarized in the table below. Estimates of urban demand provided by the table only include water provided to customers serviced by NCSD and SCWC. These estimates are based on NCSD and SCWC records and projections.

Table 2
Summary of Estimates by the County of Water Demand for Nipomo Mesa

Category of Demand	Year 2002 (1000 af/yr)	Projected Demand Year 2020 or Build Out (1000 af/yr)
Urban	3.9	7.34
Agricultural	2.9	1.9
Rural	2.42	3.35
Environmental	0	0
Total	9.22	12.59

Considerable effort by the County and consultants went into the estimates of agricultural demand, which is also called Gross Irrigated Water Requirements (GIWRs) in the County Master Water Plan Update document. The estimates incorporate assessment of acreages of various crop types, evapotranspiration, effective rainfall, frost protection, leaching requirements, and irrigation efficiency. In the 2003 Update for WPA 6 (San Luis Obispo County, 2003a), the County reported a range of agricultural demand: 2,400 to 3,580 AF in 2002, and 1,440 to 2,280 AF in 2020. The average of each range is provided in Table 1 above.

Rural water demand includes rural dwelling units, schools, churches, and some commercial and industrial facilities, irrigation water for the Black Lake and Cypress Ridge golf courses, and the proposed Woodlands Development. It includes water provided by purveyors other than NCSD or SCWC as well as private domestic wells.

Because most private wells are not metered, rural water demand was estimated by number of dwelling units (DU) and parcel size. Duty factors were 0.5 AF/DU/YR for homes on less than one acre, 1.5 for homes on more than an acre, and 2 AF/ACRE/YR for golf courses. The County used estimates of 1550 dwelling units in 2002, and 2,300 at build-out.

Environmental demands include conditions on water right permits and licenses and associated orders by the State Water Resources Control Board, California Fish and Game, and other regulatory agencies. No current environmental demands are in place, and the County assumed none for 2020. However, the possibility exists that future environmental demands for Nipomo Mesa could be put in place to help ensure minimum discharges to Black Lake Canyon and the lakes and coastal watersheds west of the mesa.

3.6 Groundwater Modeling to Assess Impact of Development

Despite concern that recent and proposed residential developments of the Nipomo Mesa may accelerate the depletion of groundwater storage and degrade the quality of groundwater near the coast by inducing salt-water intrusion, some hydrogeologic evaluation and groundwater modeling reports (e.g. Cleath and Associates, 1996a, 1997; 1998; ESA 1998) assert that the impact of additional pumping for proposed development is insignificant. However, for several reasons some of the model results may underestimate the future groundwater declines and overestimate sustainable yield:

- Typically, the model runs to estimate potential future impact of a project were conducted by adding increased pumping associated with a proposed development, but the rest of the pumping assigned in the model remained constant for model simulations, 48-years into the future. This does not account for cumulative impact of projected increased future groundwater demand for other portions of Nipomo Mesa and the Santa Maria River Valley and underestimates future water budget deficits.

- No model simulations are presented with long periods with less than average rainfall.

- After the Woodlands model was developed, information became available indicating that Eucalyptus Globulus trees have dense mat of shallow roots that store excess water and use 80-90 % of rainfall. Since the majority of 863 acres of these trees would be removed for the development project, the model runs to estimate potential impact to groundwater were revised to reflect increased recharge of rainfall to groundwater after removal of the eucalyptus trees. However, apparently the base case model was not revised using reduced recharge before removal of the trees. This revision would likely require recalibration and local reduction of hydraulic conductivity resulting in increased groundwater drawdown associated with additional pumping.

- The model may not adequately account for interception and diversion of infiltrating water by low-permeable intervals within both the Nipomo Mesa dunes and upper portion of the Paso Robles Formation. Consequently the model may overestimate recharge to the main aquifer beneath Nipomo Mesa.

Hydraulic conductivity values assigned in the Cleath and Associates model (Cleath and Associates, 1996a, 1997; 1998; ESA 1998) along the coastal margin and along the Santa Maria River are significantly higher than available estimates from pumping tests and higher than values assigned to the Santa Maria Basin model (Luhdorff & Scalmanini, 2000). Particularly high values are assigned in the vicinity of Black Lake and the northwest corner of the model domain. The resulting model transmissivity (hydraulic conductivity times aquifer thickness) near the coast west of Nipomo Mesa is 9 times higher than in the Santa Maria Basin Model and 19 times higher than values used by DWR for water balance calculations. As a consequence, the model groundwater discharge rates to the sea may be as much as ten times too high and the decreases in groundwater levels toward the coast due to increases in pumping beneath Nipomo Mesa, perhaps ten times too low.

3.7 Sea Water Intrusion

The aquifer system of Nipomo Mesa and the Santa Maria Groundwater Basin is hydraulically continuous offshore beneath the ocean. In a typical coastal aquifer, freshwater discharges from the seafloor to a point where the interface between freshwater and saltwater intersects the seafloor. The interface slants inland and downward and its geometry is controlled by density differences, hydraulic gradient within the freshwater portion of the aquifer, and distribution of hydraulic conductivity of the aquifer system. Figure 16 shows a conceptual model of a freshwater-saltwater interface for an idealized homogeneous coastal aquifer.

3.7.1 Idealized Freshwater/Saltwater Interface

Assuming steady-state horizontal flow in the freshwater (brackish) region and no flow in the saltwater region, the estimated depth below sea level of a sharp freshwater-saltwater interface in a confined aquifer can be calculated with the following equation (p. 385, Bear, 1979):

$$h_s = [P_f / (P_s - P_f)] h_f$$

where h_s is the depth to the interface below sea level, P_f is the density of the freshwater, P_s is the density of the seawater, and h_f is the freshwater head. For density values of 1 g/cc for fresh water and 1.025 for seawater the equation is:

$$h_s = [1/ (1.025-1)] h_f = 40 h_f$$

For a typical hydraulic gradient of 0.00143 between the Nipomo Mesa and the coastline we calculate saltwater interface in an idealized homogeneous aquifer as shown on Figure 17. If the depth of the freshwater/saltwater interface is known near the coastline, Figure 17 provides insight to the hypothetical distance offshore of the freshwater/saltwater groundwater interface. Reports of poor groundwater quality in the Careaga Sands at depths greater than 700 feet near the coast (e.g. Dames and Moore, 1991) would suggest that the offshore interface might intersect the seafloor at a distance on the order of 12,000 feet.

3.7.2 Coastal Margin Monitoring Wells

In the 1960s and 70s, a total of seven monitoring wells were installed near the coast to monitor hydraulic head, water quality, and test for evidence of salt water intrusion, and provide an early warning if saltwater intrusion reaches the coastline. Figure 18 shows the location of the coastal margin monitoring wells that serve as sentries for salt-water intrusion. Most of these monitoring wells consist of several piezometers screened at different depths.

Water samples collected twice per year from these wells show no clear evidence of salt-water intrusion. Generally the hydraulic gradient has remained westward near the coast. However, concern regarding potential for salt-water intrusion is based on interpretation that the Careaga Sand is exposed on the sea floor several miles west of the coastline, and there are no known barriers to salt water intrusion.

With the exception of a couple of the shallow screens, which either have poor seals between the surface or intercepted local perched brackish water, chloride concentrations in all of the piezometers are well below the MCL of 250 mg/l for chloride in drinking water, which is nearly two orders of magnitude less than the concentration of chloride in sea water (20,000 mg/l).

The two highest concentrations of chloride in deep piezometers are 95 mg/l at a depth of 720-730 in monitoring well 11N/36W-12C, which is on the coastline west of Black Lake, and 125 mg/l at depth of 535-545 in MW 12N/36W-36L, which is a couple of miles further north. These relatively elevated chloride levels might be indicative of shoreward advancement of the seawater interface. Approximately 2.5 miles inland, groundwater levels in production well 11N35W20E001S, which is southwest of Nipomo Mesa, were pumped down to 40 feet below sea level in the 1940s to 1950s, and down to 80 feet below sea level for several years in the early 1970s (Figure 19). Potential seawater intrusion as a consequence of this pumping may occur beneath the coastline several decades after this pumping. Groundwater modeling discussed below helps to assess likely lag-times between inland pumping and potential seawater intrusion of the aquifer.

3.7.3 Modeling to Evaluate Potential Salt Water Intrusion

We developed groundwater flow and chemical transport models for use as tools to help evaluate potential seawater intrusion. Specifically, the models were used to evaluate time lapse between heavy inland pumping and changes in aquifer hydraulic head, groundwater discharge, and increases in groundwater salinity in the aquifer beneath the coastal margin. Summary descriptions of the model designs are provided in Appendix D.

Results of a simplistic MODFLOW/MT3D (McDonald and Harbaugh, 1988; Zheng, 1990, 1999) flow and transport model show a lag time of many decades between the onset of pumping 15,000 feet inland and increase in chloride concentration in groundwater beneath the coastal margin even when pumping only lasts for 5 years (Figure 20). For this model, however, the initial position of the freshwater/saltwater interface is assumed to be

coincident with the sea floor. If the interface were further inland, the increase in salinity would occur more rapidly.

A second set of models was run using SEAWAT (Guo and Langevin, 2002), which is a specialized version of MODFLOW/MT3D that also accounts for variable fluid density. Appendix D provides a summary of the SEAWAT modeling. Model inflow includes constant head at upland margin and uniform recharge of 4 inches per year (25% of average rainfall).

First, the model was run without any pumping to achieve an equilibrium position for the saltwater-freshwater interface. Then a range of pumping rates were simulated at a distance of 15,000 feet inland using the non-pumping equilibrium initial condition for each case. Figure 21 shows a series of cross-sections of a coastal margin aquifer that illustrate the model equilibrium salinity distribution for a range of pumping rates. These model results show significant saltwater intrusion when the pumping rate exceeds 60% of the total inflow.

Figure 22 shows model increase with time of salinity in groundwater for a range of depths at distance of 3000 feet from the coastline as a consequence of pumping 15,000 feet inland at 70 percent of the total inflow. The model pumping well is screened between 100 and 600 feet below the static water table.

The models are simplistic tools and do not account for heterogeneity of hydraulic conductivity in the aquifer system that we know occurs. Relatively high permeability preferential pathways could exist within the aquifer and result in saltwater intrusion occurring more quickly than the models suggest. On the other hand, the two-dimensional cross-section nature of the modeling overestimates the response beneath the coastline to inland pumping because the model design does not allow for any groundwater inflow from the north or south. This is equivalent to assuming that uniform pumping occurs all along the coast and no groundwater flow occurs parallel to the coastline.

The model results are not intended to represent reality, or to predict the future, but they help evaluate time frame and sensitivity with depth for potential increases in salinity associated with seawater intrusion. For example, the models results suggest that drawdown of water levels to 80 feet below sea level due to heavy pumping a few miles inland 30 years ago, may still result in saltwater intrusion in the future. The modeling also suggests that pumping rates less than 50 percent of the total inflow (from percolation and subsurface flow) may not lead to significant degradation of groundwater quality in the coastal aquifer, but that pumping rates exceeding 50 percent of the total inflow may. In addition, pumping can induce upward flow of saline groundwater at depth.

Section 4
Conclusions and Recommendations

Evaluation of long historical records of groundwater levels and rainfall in the Santa Maria River Valley indicates that a 25-year period (1945-1970) with 2 inches less than average annual rainfall resulted in major decline of groundwater levels in the Santa Maria River Valley. Based on the 117-year rainfall record, the probability is approximately 30 percent that a 10-year period with 2 inches less than average annual rainfall will occur in the one hundred years resulting in major decline in groundwater levels again in the Santa Maria River Valley. Because of increased groundwater demand compared to the period from 1945 to 1970, the depletion of groundwater storage and resulting problems would likely be greater than before.

The aquifer system beneath Nipomo Mesa is contiguous with the Santa Maria River Valley and groundwater flow from the Santa Maria River Valley toward Nipomo Mesa constitutes a significant portion of the inflow to the Nipomo Mesa groundwater budget (including rainfall). Reported estimates of the contribution from Santa Maria River Valley range from approximately 35 percent (DWR, 2002) to 50 percent (Cleath & Associates, 1996a). A major decline of groundwater levels in the Santa Maria River Valley would decrease subsurface inflow to the Nipomo Mesa area.

Estimates by DWR (2002) of water budget deficits for the Nipomo Mesa Area during the period from 1975 to 1995 appear to be reasonable and agree well with a deficit estimated for a similar time period by Cleath and Associates (1996a). While modeling by Cleath and Associates (1996a, 1997, 1998, 2001) may provide reasonable assessments of future additional impact to groundwater by a development project, some of the model simulations do not provide realistic estimates of future groundwater conditions because the future simulations have neither provision for increased demand elsewhere in the basin, nor prolonged periods with less than average rainfall. Assigned transmissivity along the coastal margin in the Cleath and Associates model appears to be substantially too high and likely results in underestimates of water level decline near the coast and potential for saltwater intrusion. Decrease of transmissivities assigned to the model near the coast, incorporation in the model of projected general increases in demand for other portions of the groundwater basin in addition to specific proposed projects, and simulations designed to evaluate the effect of a series of several years with less than average rainfall would help to improve the model as a tool to assess the groundwater resource capacity of Nipomo Mesa.

Although the highly permeable dune deposits of Nipomo Mesa facilitates a high rate of infiltration of rainfall on the Mesa, fine-grained intervals within the dunes and in the upper portion of the Paso Robles Formation intercept a portion of the deep percolating water. This perched groundwater flows along these low-permeablity layers and discharges into Black Lake Canyon and the other systems of coastal drainages and lakes west of Nipomo Mesa. Groundwater modeling and water budget calculations that neglect discharge of the

perched shallow groundwater likely overestimate recharge rates to the main aquifer beneath Nipomo Mesa.

The DWR 2002 report "*refrains from finding that the Santa Maria Groudwater Basin within San Luis Obispo County is currently in overdraft because of consistent subsurface outflow to the ocean and no evidence of sea water intrusion*" (pg 155, DWR, 2002). This statement by DWR is inconsistent with their definition of overdraft (e.g. pg 154 DWR 2002): "*the condition of a groundwater basin or subbasin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years, during which water supply conditions approximate average conditions*." Based on this definition, since current and projected pumping beneath Nipomo Mesa exceeds inflow (recharge plus subsurface inflow), the Nipomo Mesa portion of the Santa Maria Groundwater Basin is currently in overdraft and projections indicate increasing overdraft.

By year 2025, projection of outflow exceeds the highest of a range of inflow estimates by 20 percent. This substantial overdraft and mining of groundwater in storage, will likely be accompanied by reduced production capability from many wells, increased energy costs for pumping, reduction of groundwater discharge to the coastal drainages and lakes west of Nipomo Mesa, and increased risk of seawater intrusion of the aquifers near the coastal margin.

DWR's (2002) reported finding of *"consistent subsurface outflow to the ocean and no evidence of sea water intrusion"* does not preclude the existence of overdraft conditions. DWR's definition of overdraft, which is provided two paragraphs above, is simply that pumping exceeds recharge over a period of years with approximately average conditions. Indeed it is possible for consistent subsurface outflow to the ocean to persist for decades despite concurrent overdraft conditions in an inland portion of the same groundwater basin. In addition, although we agree that seawater intrusion is not yet evident based on data from the coastal monitoring wells, the basis for consistent subsurface outflow from the aquifers to the ocean is tenuous. The DWR's water budget analysis for the Nipomo Mesa area (Table 26, DWR 2002) indicates that for both the base study period (1984-1995) and for 2020 projections the best estimate of subsurface outflow to the ocean is in the range of only 8 to 9 percent of the total inflow including recharge from average rainfall. This indicates that consistent subsurface outflow to the ocean from the aquifers beneath the Nipomo Mesa Area is vulnerable to small proportional increases in groundwater withdrawal from Nipomo Mesa, or reductions in inflow, for example a prolonged period of low rainfall or increased pumping in Santa Maria Valley.

DWR's (2002) conclusions for the Nipomo Mesa area study seem to confuse assessment of water resource capacity and manifestation of exceeding dependable yield. The DWR analyses, projections, and water budget estimates clearly indicate that groundwater pumping in the Nipomo Mesa area is in excess of the dependable yield and that overdraft conditions have existed and are expected in the future. Our analyses indicate that as a consequence of the buffering effect of depletion of groundwater in storage and slow rates

of groundwater flow in the aquifers, a lag time of several decades is expected before overdraft conditions are manifested as seawater intrusion in the aquifers near the coast. Reduction of groundwater discharge to coastal drainages and lakes west of Nipomo Mesa is likely to be a relatively rapid consequence of continued overdraft conditions beneath the Nipomo Mesa.

The County's Resource Management System (RMS) defines three categories of levels of severity when water supply is exceeded by demand[8]. Based on a January 2000 draft version of the DWR report on the water resources of the Nipomo Area (DWR, 2002), the County General Plan recommended a Water Supply Level of Severity of II for the Nipomo Mesa Sub-Unit of the Santa Maria Groundwater Basin.

Analysis of the groundwater budget estimates reported by DWR (2002) for Nipomo Mesa shows outflow outpacing inflow (including estimates of recharge from average rainfall) since 1980. Projections to year 2025 show an increasing deficit, even when accounting for increasing influx of groundwater from Santa Maria River Valley due to increasing pumping beneath Nipomo Mesa. By year 2025, the estimated outflow exceeds even the highest of a range of inflow estimates by 20 percent. Thus, DWR's findings are consistent with a Level of Severity III RMS Water Supply Criterion for groundwater beneath the Nipomo Mesa Area.

Although existing and projected future water demand at Nipomo Mesa exceeds sustainable groundwater supply based on local water balance analyses, associated potential impact such as seawater intrusion of the aquifer system is not an imminent threat.

Reliable prediction of when seawater intrusion will significantly impact quality of water pumped from wells near the coastal margin is impossible. Important unknowns include

- historical and current location of the interface between freshwater and seawater in the aquifers offshore,
- when did/will the seawater intrusion clock start ticking? 1940s, 1970s, 2000?
- offshore aquifer geometry and degree of hydraulic connection between aquifers and the sea,
- high permeability preferential pathways for sea water intrusion such as faults or ancient river channel deposits.

Groundwater models cannot serve as crystal balls, but when designed as tools to assess implications of reasonable possibilities they are useful to evaluate alternatives for groundwater management and potential timing of seawater intrusion. A groundwater model developed as a resource management tool could also be used to assess possible progression of seawater intrusion.

[8] County RMS water supply levels of severity:
I projected demand over the next nine years equals or exceeds estimated dependable supply.
II projected demand over the next seven years equals or exceeds estimated dependable supply.
III existing demand equals or exceeds the dependable supply.

Estimates of hydraulic gradient and changes in groundwater storage using water level contour maps by DWR (2002) are difficult to evaluate because the data points on which the contours are based are not included and the screen intervals and pumping status of the wells is not provided. Recent completion of work by the County on compiling historical data and upgrading the database of groundwater elevations will facilitate routine evaluation of hydraulic gradients and change in groundwater storage. Collaboration with Santa Barbara County to collect semi-annual water level data and produce annual monitoring reports is recommended to improve understanding to Santa Maria Groundwater Basin as a whole.

Continued efforts on Nipomo Mesa to increase the use of recycled water, such as for the irrigation of golf courses, will help to lessen impact of development on the rate of depletion of groundwater resources. Opportunities for conjunctive use of surface water and groundwater on the Nipomo Mesa are limited and expensive because of the lack of significant surface water on the Mesa and the distance and lift that would be required to pipe water in from outside the Mesa. Management of floodwater discharge from Cuyama River to the Santa Maria River with Twitchell dam has provided some enhancement of recharge to the aquifers of the Santa Maria River Valley. However, since water in the Santa Maria River nearly always infiltrates the subsurface before reaching the coast, there is little opportunity for additional enhancement of recharge along the river without an additional source of water. Basin management planning should also account for likely future decrease in recharge enhancement provided by flood water management at Twitchell Dam due to depletion of Cuyama river flows by heavy groundwater pumping in Cuyama Valley (DWR, 2003) and decrease in storage capacity with accumulation of sediment in Twitchell Reservoir (e.g. SAIC et al., 2003).

Importation of water to Santa Barbara County from the State Water Project (SWP) began in 1996; approximately 12,000 AF of SWP water were provided to the Santa Maria Groundwater Basin in 1999. Continued supply of SWP to the Santa Maria River Valley is important to help offset groundwater supply deficits for portions of both Santa Barbara and San Luis Counties. Perhaps the two Counties can work together to increase the SWP allotment to the Santa Maria River Valley. Desalinization of seawater is also an option for supplementary water supply for Nipomo Mesa, but is generally considered a very expensive, last resort option.

Water conservation measures and appropriate limits on development of the coastal communities are perhaps the most practical approaches for preventing sustained depletion of groundwater resources of Nipomo Mesa and the Santa Maria Groundwater Basin as a whole.

Section 5
References

Alley, W.M., T. Reilly, O.L. Franke, 1999, Sustainability of Ground-Water Resources, U.S. Geological Survey Circular 1186, 79 pgs.

Arthur D. Little et al., 1998, Guadalupe Oil Field Remediation and Abandonment Project, Final Environmental Impact Report, prepared for SLO County Dept of Planning and Building, March 1998.

Bredehoeft, J., S.S. Papadopulos, and H.H. Cooper Jr., 1982, The Water Budget Myth, *in* Scientific Basis of Water Resource Management, Studies in Geophysics, 51-57, Washington DC: National Academy Press.

Bredehoeft, J., 1997, Safe yield and the water budget myth: Ground Water, v. 35, no. 6, p. 929.

Bredehoeft, J., 2002, The Water Budget Myth Revisited: Why Hydrogeologists Model: Ground Water, v. 40, no. 4, p. 340-345.

California Department of Water Resources, 1970, Sea-Water Intrusion: Pismo–Guadalupe Area: Bulletin No. 63-3, 76 p.

California Department of Water Resources, 1979, Ground Water in the Arroyo Grande Area: Southern District Report, June 1979.

California Department of Water Resources, 1998, California Water Plan Update: Bulletin 160-98.

California Department of Water Resources, 2000, Water Resources of the Arroyo Grande-Nipomo Mesa Area, Revised Final Draft, January 2000.

California Department of Water Resources, 2002, Water Resources of the Arroyo Grande-Nipomo Mesa Area; Southern District Report.

California Department of Water Resources, 2003, California's Groundwater, Bulletin 118, Update 2003, October 2003, 246 p.

California Regional Water Quality Control Board, Central Coast Ambient Monitoring Program (CCAMP), regionally scaled water quality monitoring and assessment program, http://www.ccamp.org/ccamp/ccamp.htm

Chipping Geological Services, 1994, Black Lake Canyon Geologic and Hydrologic Study, Draft: Los Osos, California.

Cleath & Associates, 1994, Well Construction Report for the Woodlands :Project, *prepared for* Hanson Properties West, Inc., September 1994.

Cleath & Associates, 1995, Ground Water Supply Management for Bartleson Development Plan, Project, *prepared for* Stuart Bartleson, July 1995.

Cleath & Associates, 1996a, Water Resources Management Study for The Woodlands, *prepared for* USI Properties, Inc., April 1996.

Cleath & Associates, 1996b, Status of the Santa Maria Ground Water Basin, *prepared for* USI Properties, Inc., April 1996.

Cleath & Associates, 1997, Water Resources Management Study addendum for the Woodlands, *prepared for* USI Properties, Inc., September 1997.

Cleath & Associates, 1998, Modeling Data and information for the Woodlands Project, Woodlands Specific Plan EIR: San Luis Obispo, California, *prepared for* San Luis Obispo County, June 9, 1998.

Cleath & Associates, 2001, Ground water impact of the 180 units of development projects identified by the County of San Luis Obispo on Nipomo Mesa, *prepared for* PH Properties, Inc., April 17, 2001.

Cleath & Associates, 2003, Water and Wastewater impacts analysis for Summit Station Area Land Use Ordinance Amendment, prepared for EMC Planning Group, Inc., October, 2003.

Dames &Moore, 1991, Draft Program Environmental Impact Report, Groundwater Resources Section, Conservation Element, Santa Barbara County Comprehensive Plan, October, 1991.

EDAW and Boyle Engineering, 1998, Master Water Plan Update, San Luis Obispo County, Phase I; August 1998.

Envicom Corporation, 1982, Development Constraints Analysis, Black Lake Gold Course, San Luis Obispo County, California: Calabasas, California, *prepared for* San Luis Obispo County.

Envicom Corporation, 1982, Final Environmental Impact Report, Black Lake Specific Plan, *prepared for* San Luis Obispo County, December 3, 1982.

Envicom Corporation, 1985, Final Environmental Impact Report, Bjerre General Plan Amendment.

Environmental Science Associates, 1996, Final Woodlands Specific Plan, Baseline Environmental Assessment and Constraints Analysis: Los Angeles, California.

Environmental Science Associates, 1998, Woodlands Specific Plan, Supplemental Environmental Impact Report: Los Angeles, California, *prepared for* the San Luis

Obispo County Department of Planning & Building, September 1998 (Also separate appendices volume).

Environmental Science Associates, 2001, Woodlands Specific Plan, Supplemental Environmental Impact Report: Los Angeles, California, *prepared for* the San Luis Obispo County Department of Planning & Building.

Guo, W. and C. D. Langevin, 2002, User's Guide to SEAWAT: A Computer Program for Simulation of Three-Dimensional Variable-Density Ground-Water Flow, Techniques of Water-Resources Investigations of the US Geological Survey, Book 6, Chapter A7,

Heath, R.C., 1989, Basic Ground-Water Hydrology, *USGS Water Supply Paper 2220*, 84 p.

Hughes, 1977, Evaluation of GW Quality in the Santa Maria Valley, Califorinia, US Geological Survey Water Resources Investigation 76-128. 70 p.

James M. Montgomery Consulting Engineers, Inc., 1982, Ground Water Availability for the Proposed Black Lake gold Course Development Project: Pasadena, California, *prepared for* Plaza Builders, Incorporated.

Lawrance, Fisk, & McFarland, Inc., 1987, Final Report Water, Wastewater and Drainage Studies, Nipomo Mesa Planning Study, *prepared for* RRM Design Group, August 1987.

Lipinski, P., 1985, Comparison of two Methods for Estimating Ground-Water Recharge in 1978-80, Santa Maria Valley, California: U.S. Geological Survey Water-Resources Investigations Report 85-4129, *prepared in* cooperation with the Santa Barbara County Water Agency, 17 p.

Luhdorff & Scalmanini, 2000, Development of a Numerical Ground-Water Flow Model and Assessment of Ground-Water Basin Yield, Santa Maria Valley Ground-Water Basin, *prepared for* Santa Maria Valley Water Conservation District, March, 2000.

Mann, J.F., Jr., 1961, Factors affecting the safe yield of ground-water basins: Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, v. 87, no. IR3, p. 63-69.

McClelland Engineers, 1987, Supplement and Final Environmental Impact Report, Guadalupe Abalone Culture Facility, *prepared for* San Luis Obispo County Environmental Coordinator, July 1987.

McDonald, M.G. and A.W. Harbaugh, 1988, A Modular Three-Dimensional Finite Difference Ground-Water Flow Model, *Techniques of Water-Resources Investigations,* 06-A1, U.S. Geological Survey, 576 p.

Miller, G.A., and Evenson, R.E., 1966, Utilization of Ground Water in the Santa Maria Valley Area, California: U.S. Geological Survey Water-Supply Paper 1819-A, 24 p.

The Morro Group, 1990, Appendix A, review of groundwater conditions in the northern Santa Maria Basin and scenarios for the evaluation of impacts of development on the water resources of Nipomo Mesa: *in* The Morro Group, 1991, Final Environmental Impact Report, South County Area Plan Inland Portion: *prepared for* the Office of the Environmental Coordinator, County of San Luis Obispo, p. A1-A59.

The Morro Group, 1991, Final Environmental Impact Report, South County Area Plan Inland Portion, *prepared for* Office of the Environmental Coordinator, County of San Luis Obispo, May 1991.

The Morro Group, 1996a, Environmental Assessment of Water Resources Availability, Bartleson Development Plan, *prepared for* County of San Luis Obispo, Department of Planning and Building, January 1996.

The Morro Group, 1996b, Final Environmental Impact Report, Cypress Ridge Tract Map and Development Plan: *prepared for* the Office of the Environmental Coordinator, San Luis Obispo County, August, 1996.

Nipomo Community Services District, 1995, A Groundwater Management Plan for the Nipomo Mesa (AB 3030): draft.

Nipomo Community Services District, 2003, Urban Water Management Plan: draft.

Santa Barbara County Water Agency, 1994, Santa Maria Valley Water Resources Report, 114 p.

Santa Barbara County Water Agency, 1996, Draft Groundwater Resources Report, *prepared by* Naftaly et al., *for* Santa Barbara County Water Agency, March 1996.

Santa Barbara County Water Agency, 1996, Santa Barbara County 1996 Groundwater Resources Report, August 1996.

Santa Barbara County Water Agency, 1999, Santa Barbara County 1999 Groundwater Resources Report, (incomplete portion of report).

Santa Barbara County Water Agency, 2000, Groundwater Report, *prepared by* Gibbs et al. for Santa Barbara County, February 2001.

San Luis Obispo County, 2003a, Water Planning Area 6 – Nipomo Mesa, County Master Water Plan Update – Phase II, January 2003.

San Luis Obispo County, 2003b, Review/Summary of "Water Resources of the Arroyo Grande – Nipomo Mesa": 2002 Report by DWR, Memorandum to Central File 900.50.01 by Cynthia Koontz, Public Works Department, August 5, 2003.

Science Applications International Corp (SAIC) et al., 2003, Santa Maria River Estuary Enhancement and Management Plan, prepared for The Dunes Center, The State Coastal

Conservancy, and the Central Coast RWQCB, October 2003, Proposed Final, http://www.dunescenter.org/research.html

Shipsey & Seitz, Inc., 2002a, Letter to County Planning Commissioners, re PH Property Development Plan S9901187U/T Tract 2341, Date of Hearing: October 24, 2002.

Shipsey & Seitz, Inc., 2002b, Letter to County Board of Supervisors re Woodlands Project, Verification of Water Supply Pursuant to Government Code 66473.7, Mitigation Measure 4.1-6A (Retrofitting), Date of Hearing: December 17, 2002.

Sophocleous, M., 1997, Managing water resources systems: why "safe yield" is not sustainable: Ground Water, v. 35, no. 4, p. 561.

Sophocleous, M., 2000, From safe yield to sustainable development of water resources: the Kansas experience: Journal of Hydrology, v. 235, pp 27-43.

Thomasson, H.G., Jr., 1951, Surface-water resources: *in* Worts, G.F., 1951, Geology and Ground-Water Resources of the Santa Maria Valley Area, California: U.S. Geological Survey Water-Supply Paper 1464, p. 207-223.

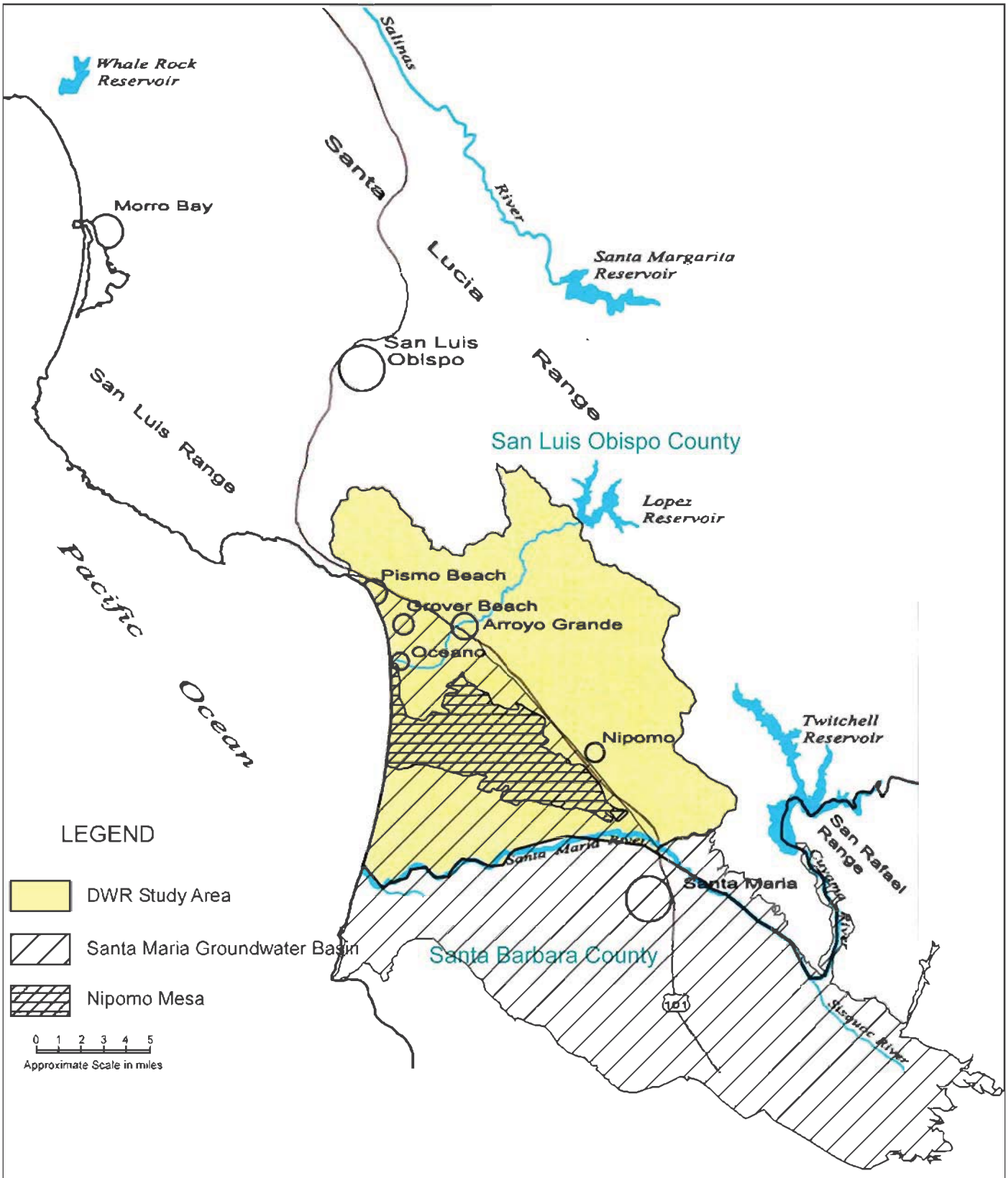
Valentine, D.W., Densmore, J.N., Galloway, D.L., and Amelung, F., 2001, Use of InSAR to Identify Land-Surface Displacements Caused by Aquifer-System Compaction in the Paso Robles Area, San Luis Obispo County, California, March to August 1997, U.S. Geological Survey Open-File Report 00-447, 11 p.

Worts, G.F., 1951, Geology and Ground-Water Resources of the Santa Maria Valley Area, California: U.S. Geological Survey Water-Supply Paper 1000, 169 p.

Yates, E.B., and J.H. Wiese, 1988, Hydrogeology and Water Resources of the Los Osos Valley Ground-water Basin, San Luis Obispo County, California: U.S. Geological Survey Water Resources Investigations Report 88-4081.

Zheng, C., 1990, MT3D, A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems, Report to the U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma.

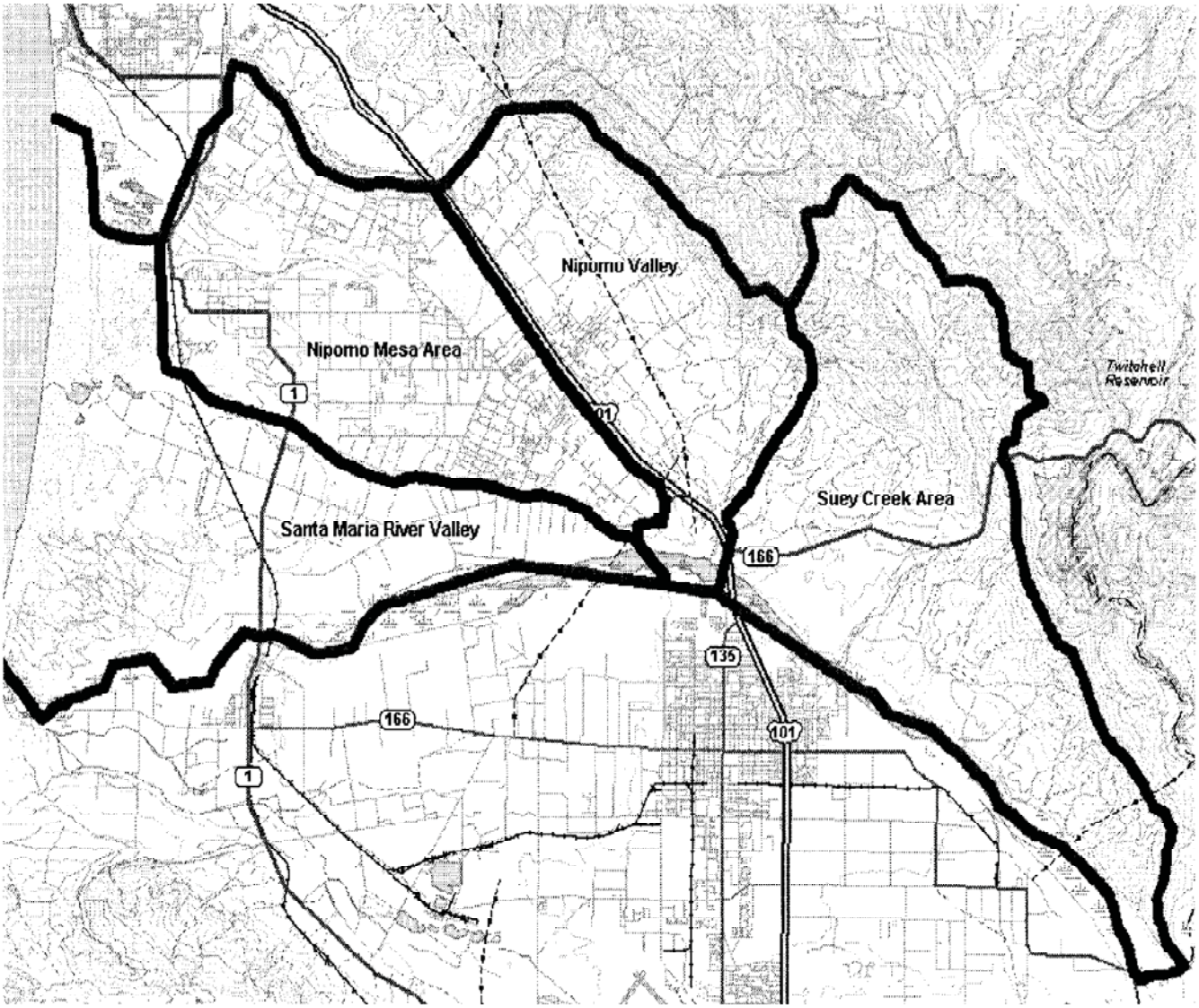
Zheng, C., 1999, MT3D^{99}, User's Guide, S.S. Papadopulos & Associates, Inc., Bethesda, Maryland.



Adapted from Figure 1 and Plate 1. DWR, 2002.

SITE LOCATION MAP
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 1

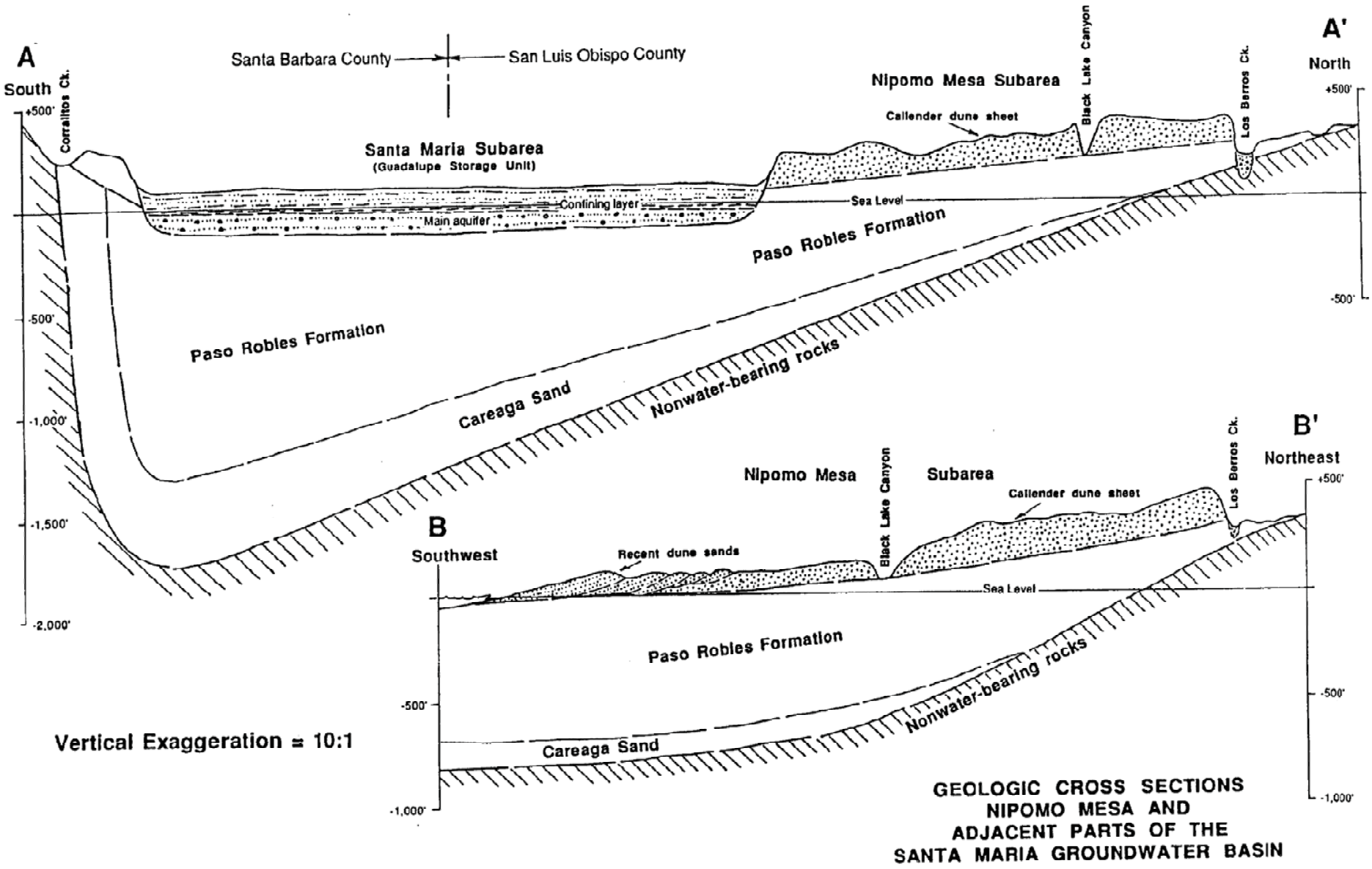


Adapted from San Luis Obispo County Master Water Plan Update, Phase II, January 2003

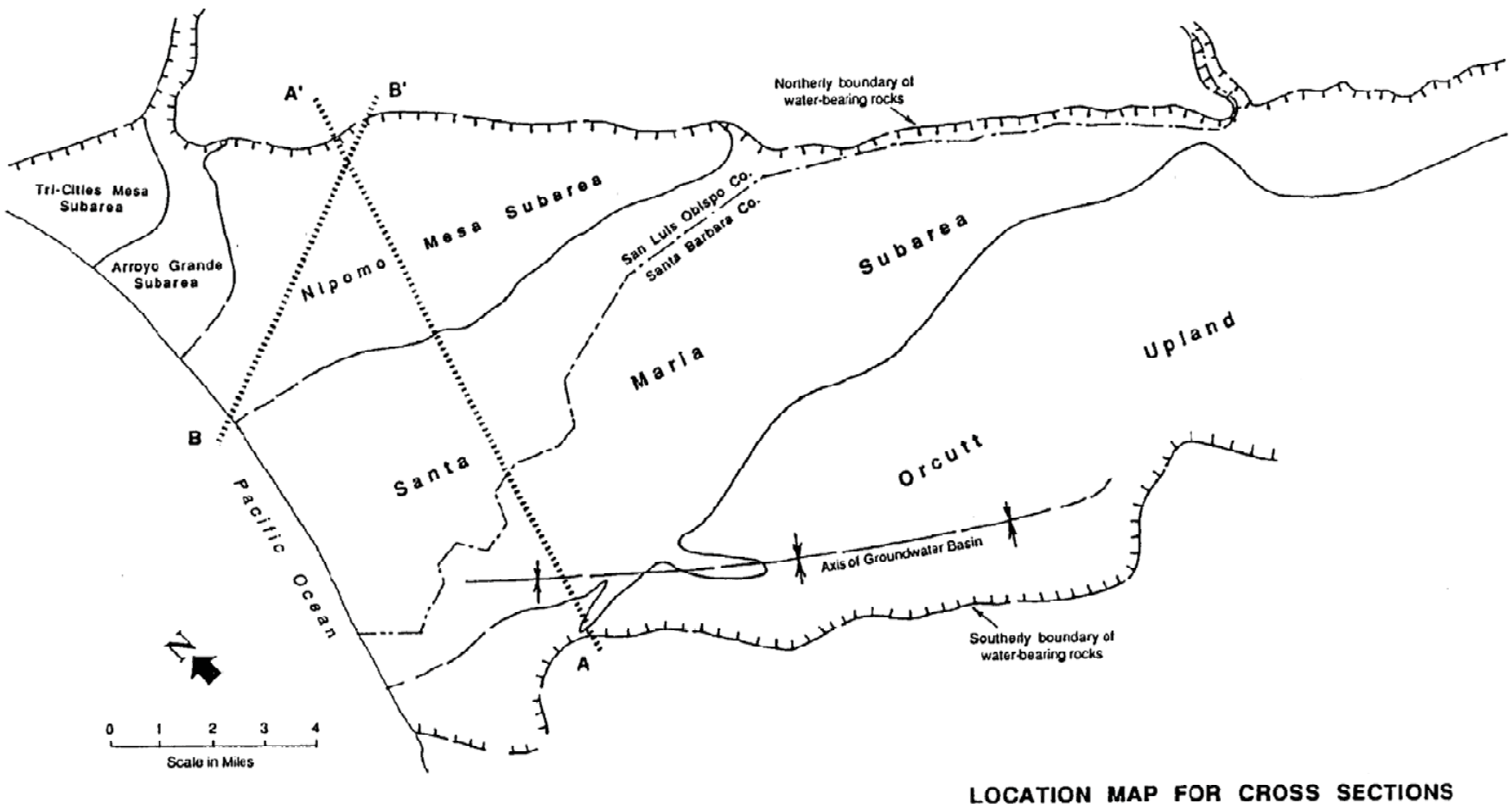
$\Sigma^2\Pi$

NIPOMO WATER PLANNING AREA (WPA6) AND SUBAREAS
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 2



**GEOLOGIC CROSS SECTIONS
NIPOMO MESA AND
ADJACENT PARTS OF THE
SANTA MARIA GROUNDWATER BASIN**

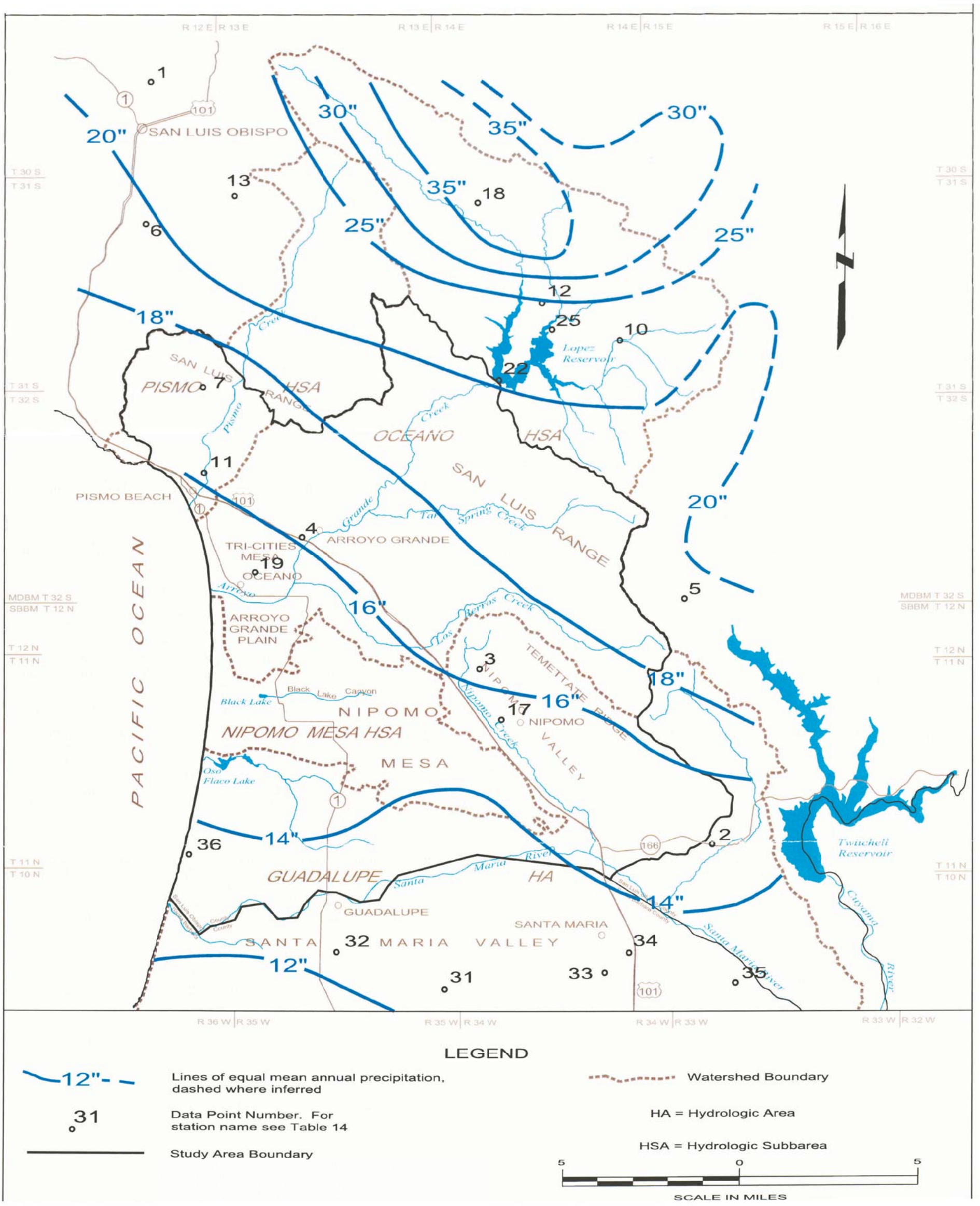


LOCATION MAP FOR CROSS SECTIONS

Adapted from Figures A-9 and A-10, Morro Group (July 1990)

CONCEPTUAL GEOLOGIC CROSS-SECTIONS
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 3



LEGEND

12" — Lines of equal mean annual precipitation, dashed where inferred

31 — Data Point Number. For station name see Table 14

Study Area Boundary

Watershed Boundary

HA = Hydrologic Area

HSA = Hydrologic Subbarea

5 0 5

SCALE IN MILES

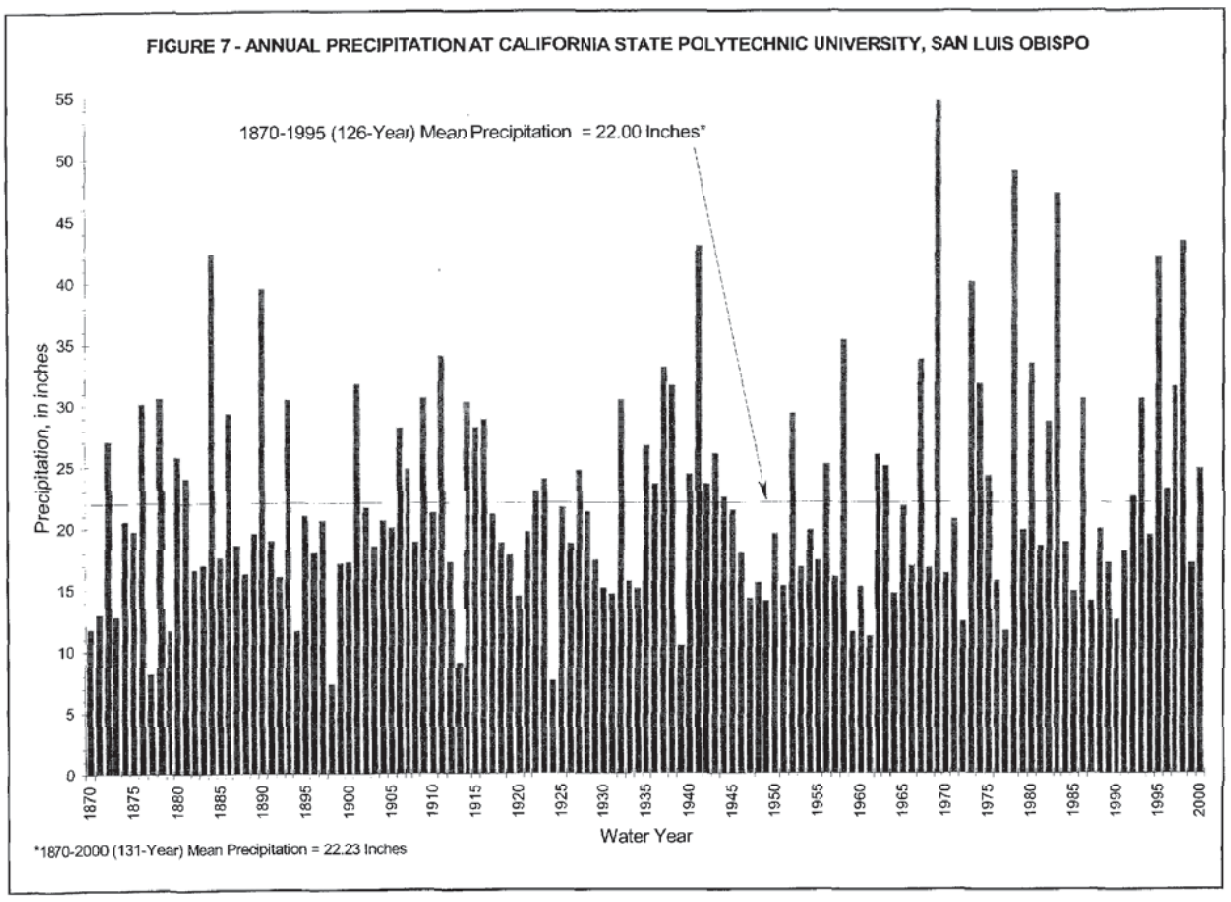
Adapted from Plate 8. DWR, 2002.

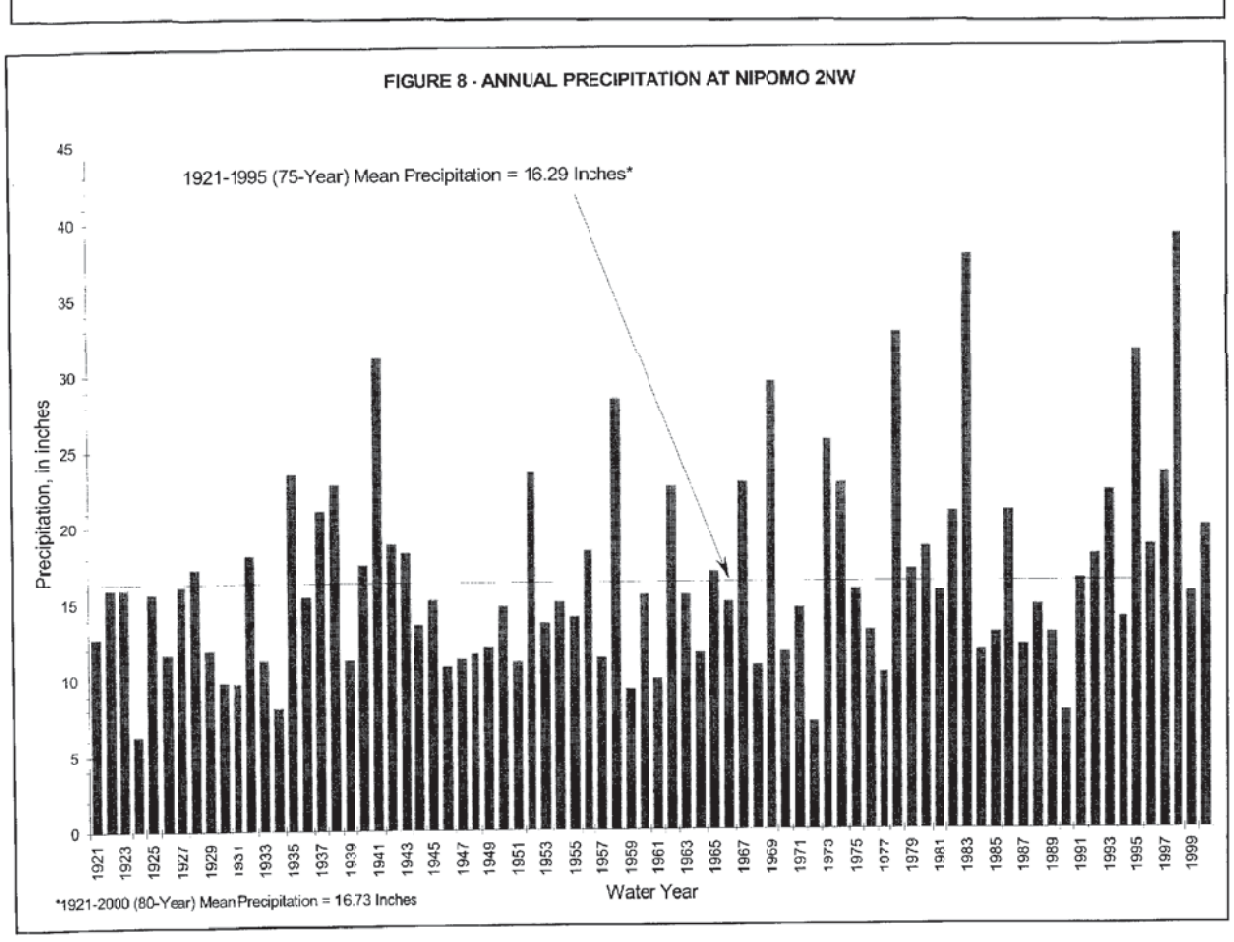
CONTOUR MAP OF EQUAL MEAN ANNUAL PRECIPITATION

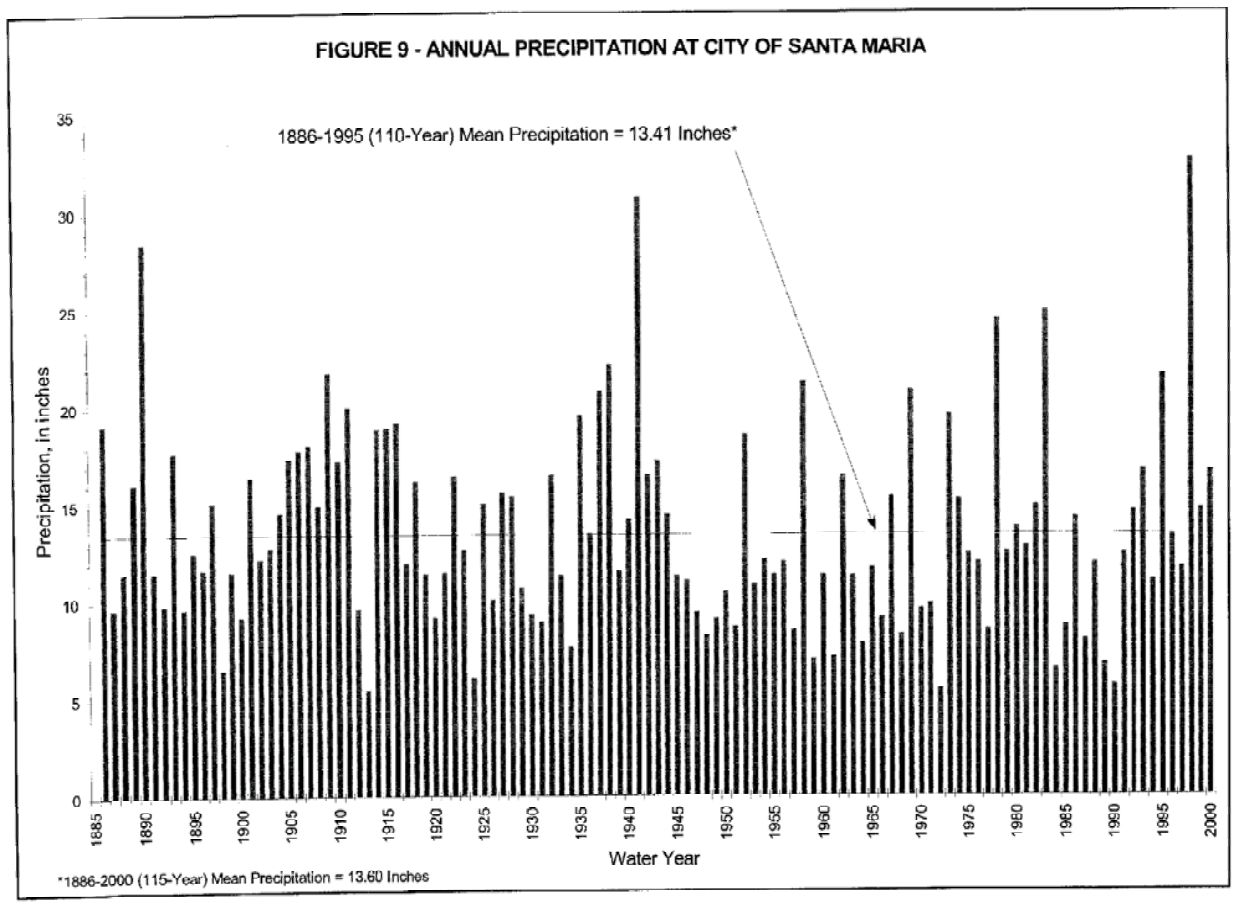
Nipomo Mesa Water Resource Capacity Study

San Luis Obispo County, California

Figure 4



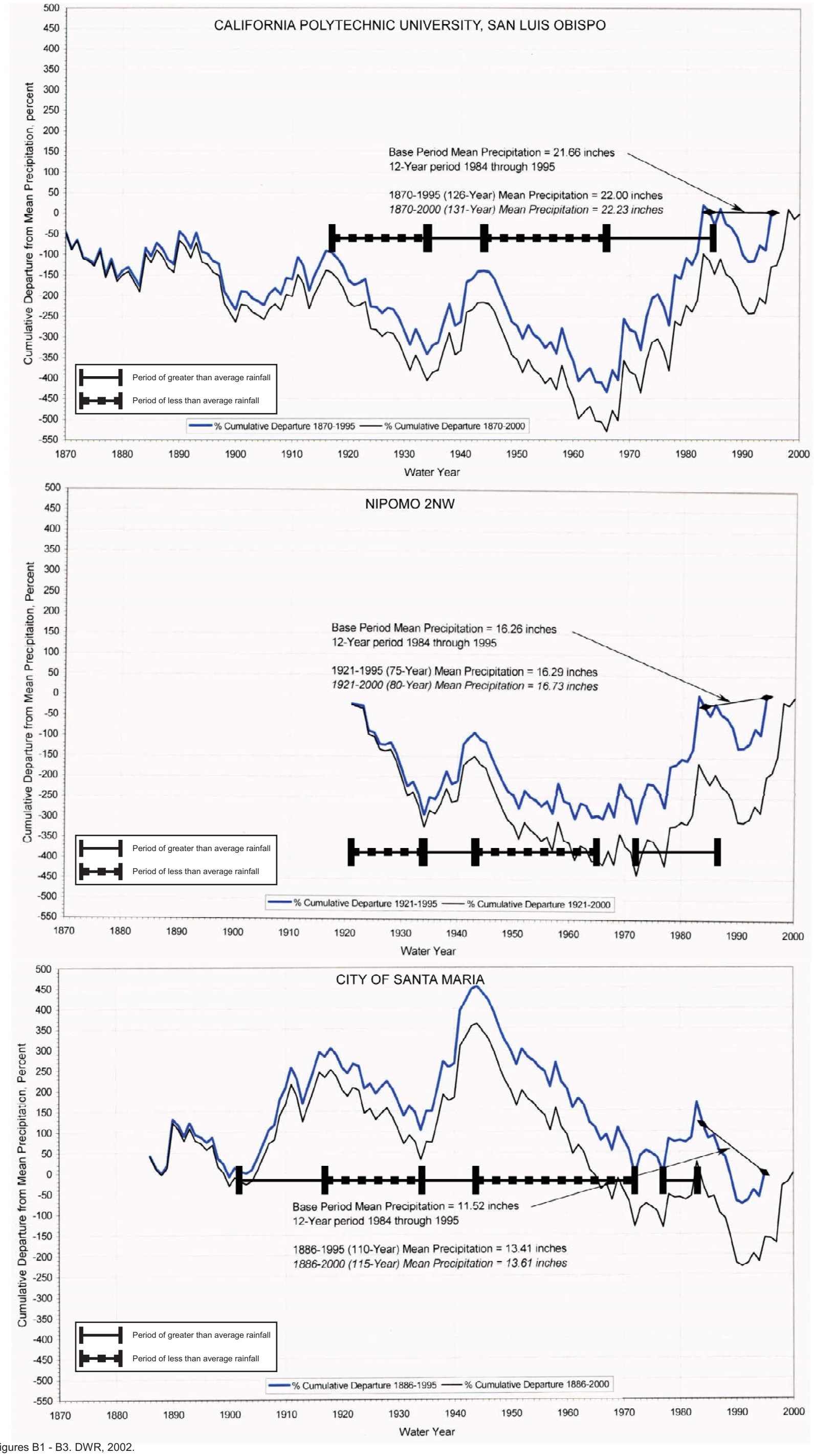




Adapted from Figures 7-9. DWR, 2002.

RAINFALL RECORDS (DWR, 2002)
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

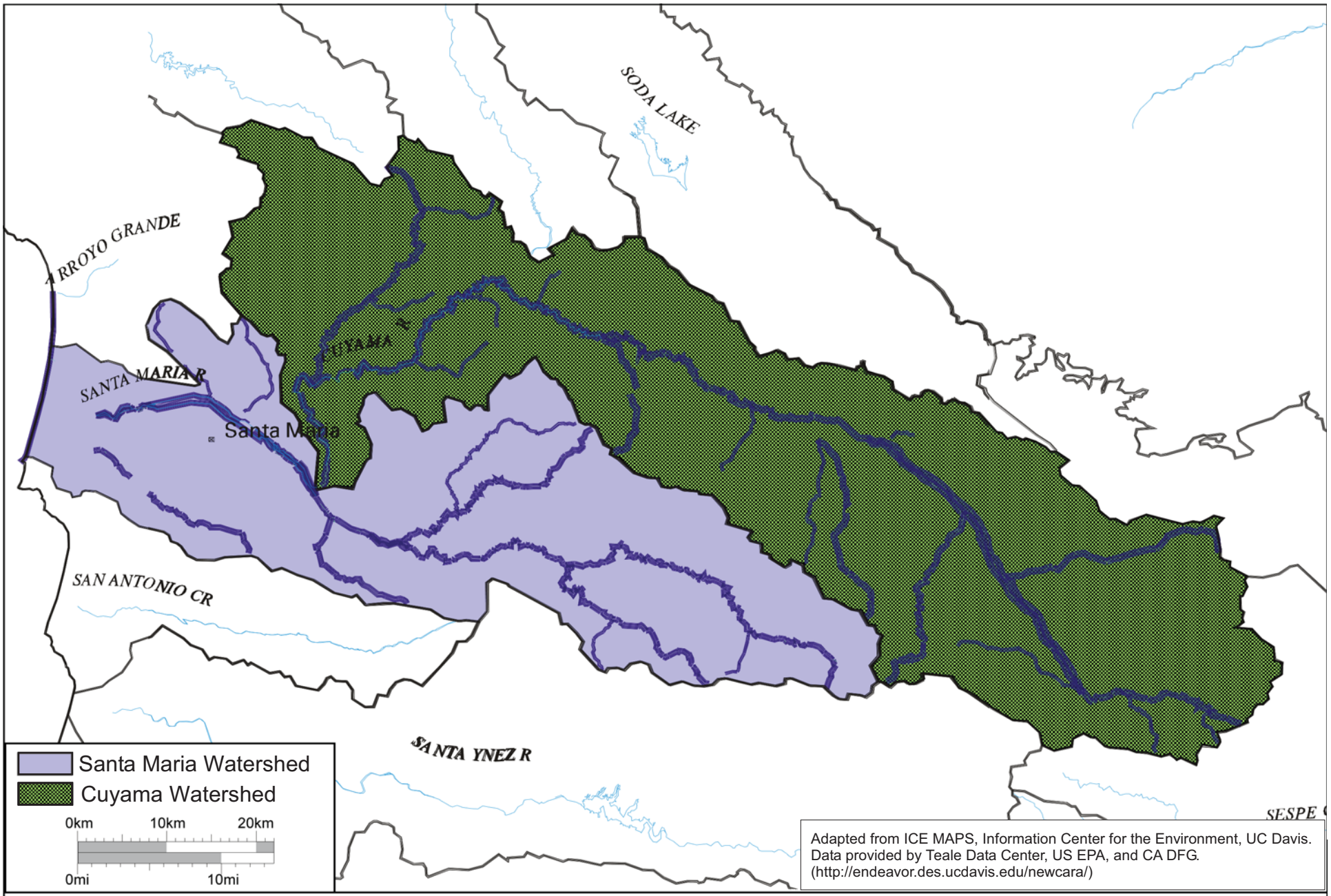
Figure 5



Adapted from Figures B1 - B3. DWR, 2002.

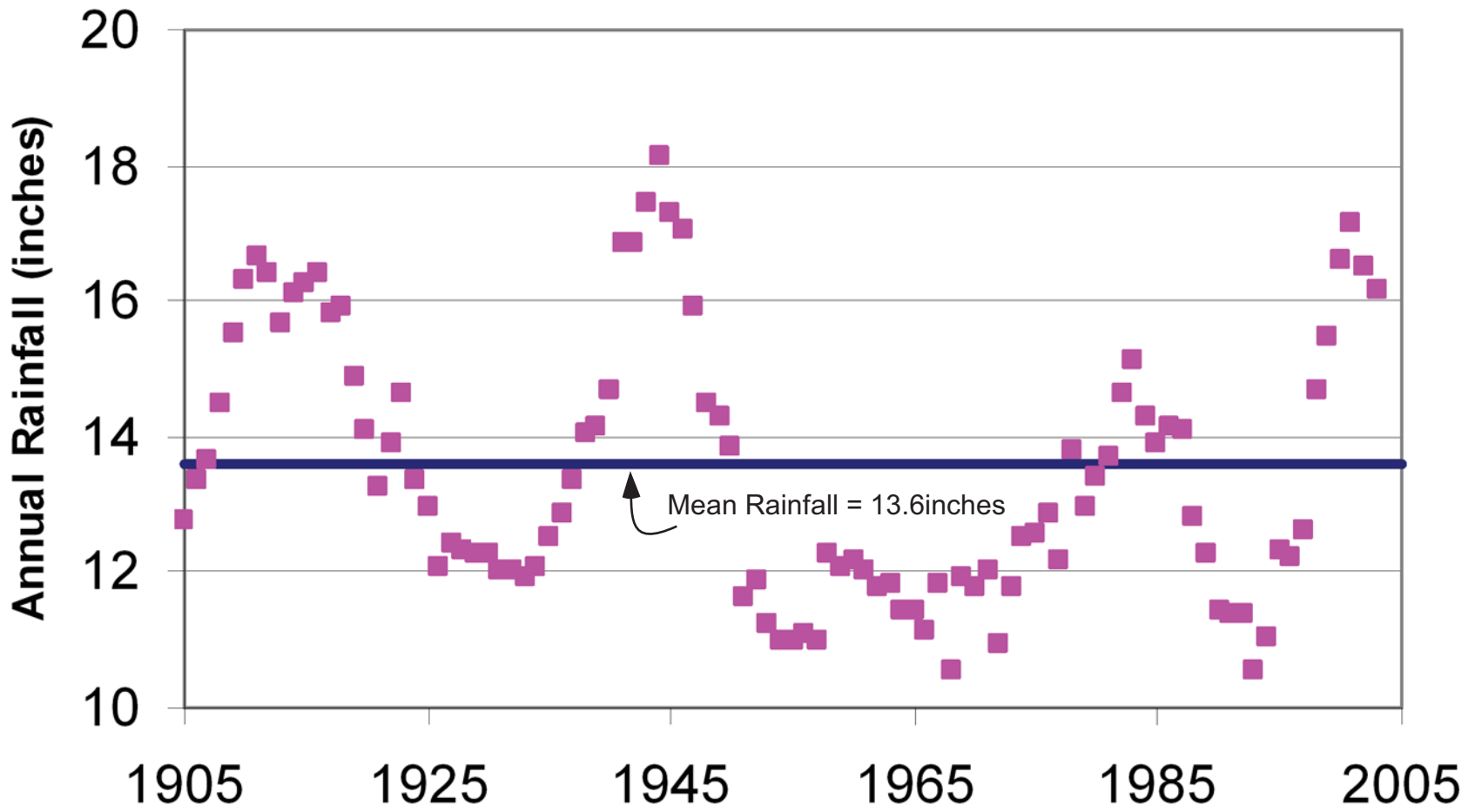
CUMULATIVE DEPARTURE FROM MEAN PRECIPITATION
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 6



SANTA MARIA AND CUYAMA WATERSHEDS
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

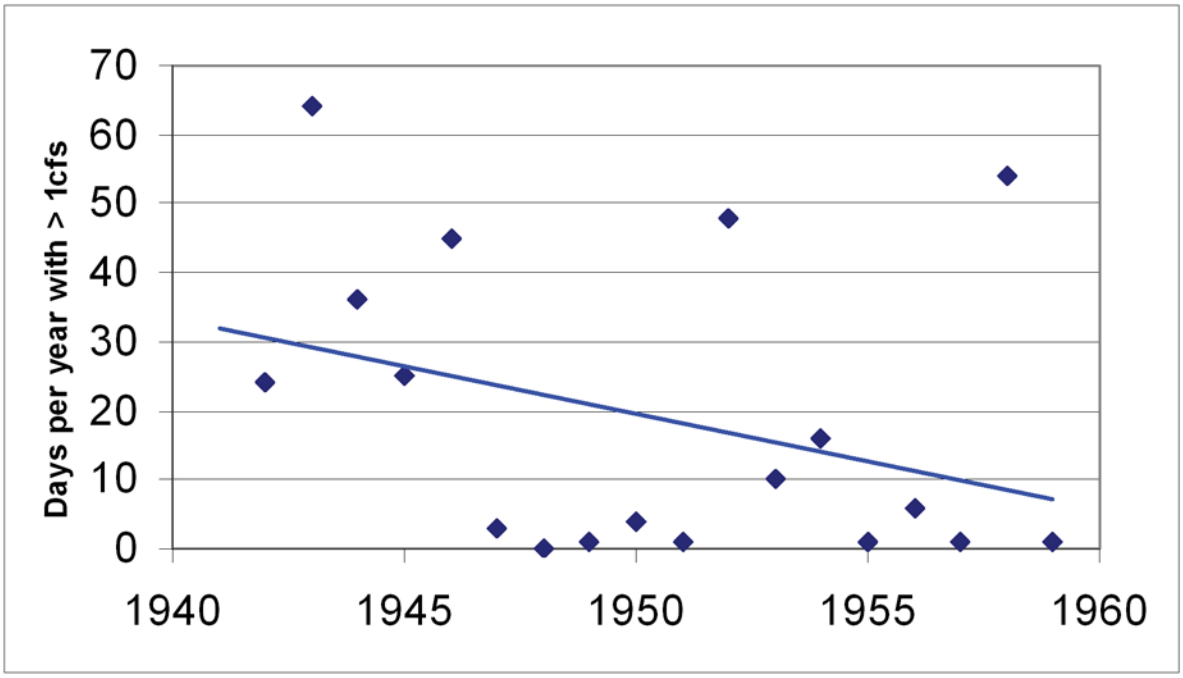
Figure 7



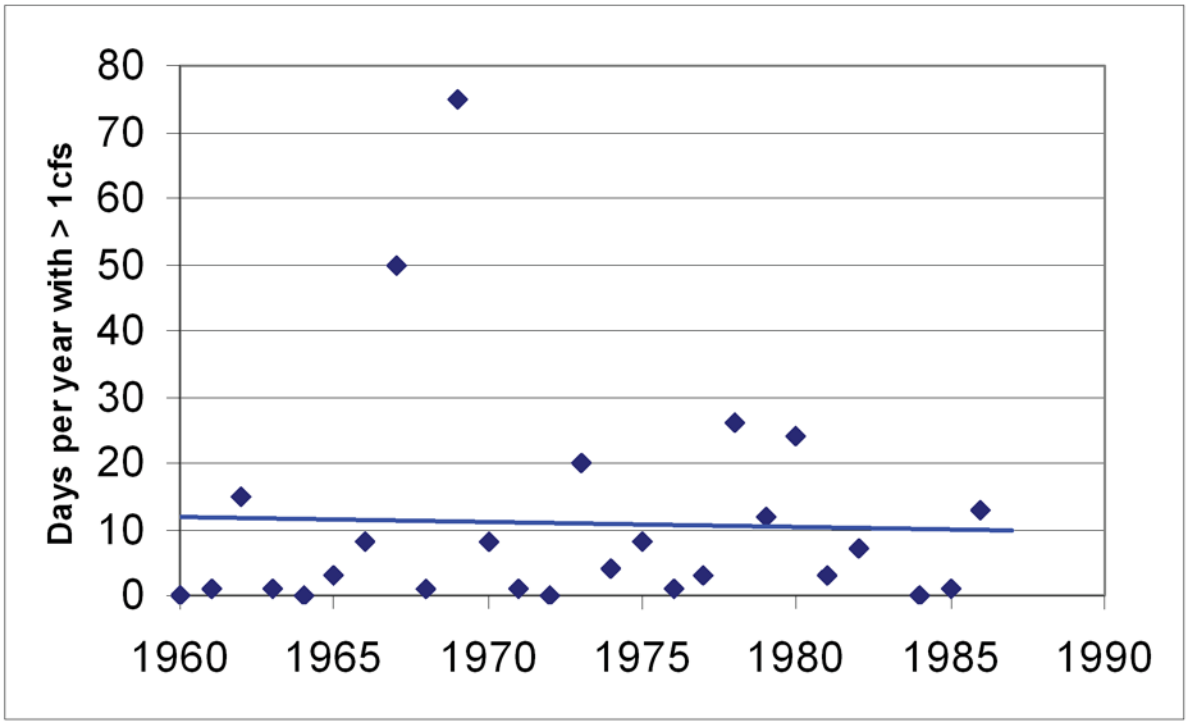
10-YEAR SLIDING WINDOW AVERAGE ANNUAL RAINFALL AT SANTA MARIA
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 8

Pre-Twitchell Dam



Post-Twitchell Dam



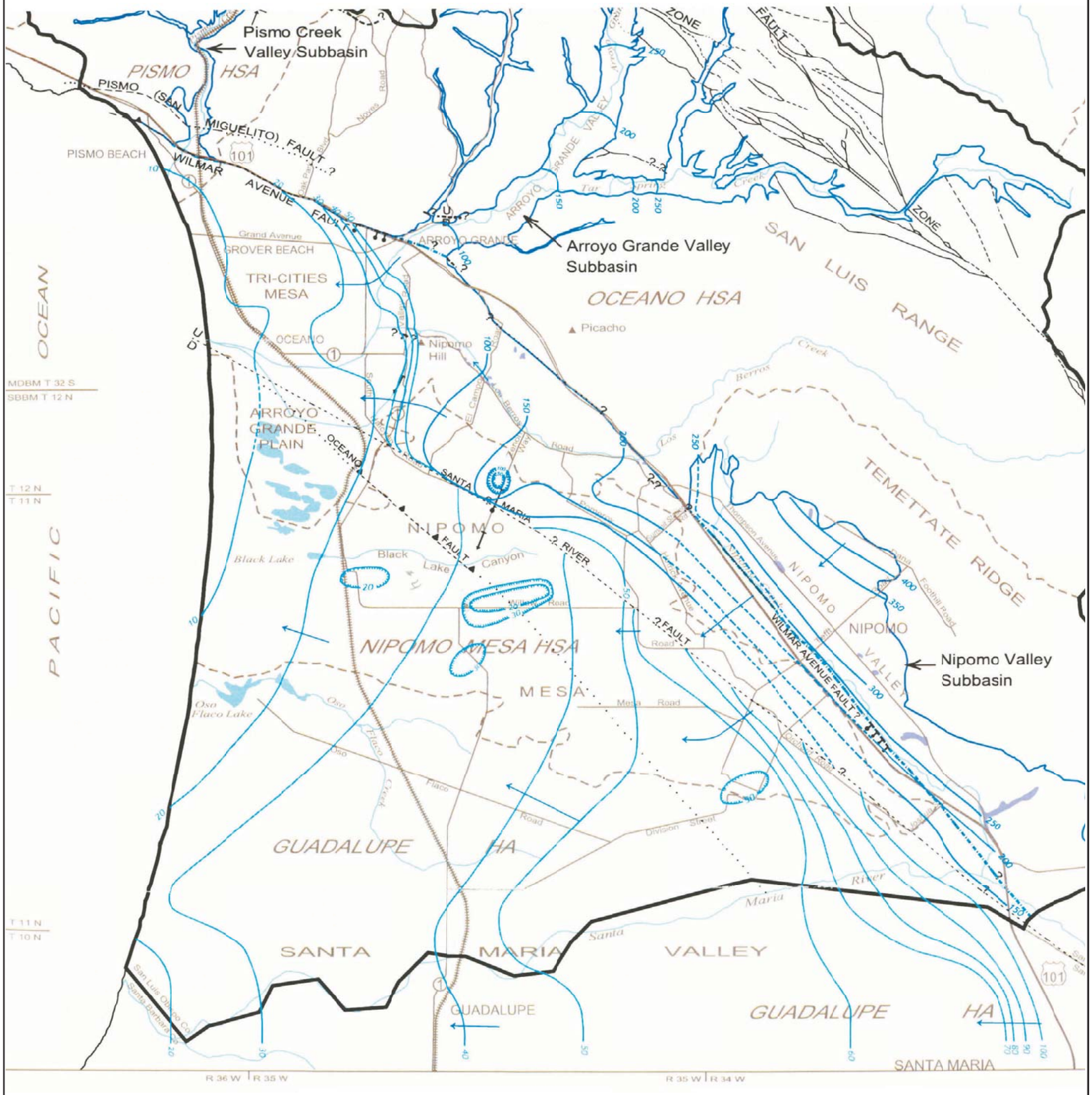
Notes:

1. Values exceeding the mean plus two standard deviations are considered outliers and were removed.
2. Pre-Twitchell Dam dataset illustrates decreasing trend in number of days per year that the Santa Maria River near Guadalupe was flowing.
3. Post-Twitchell Dam dataset shows a stabilized trend with an average of 10 days per year with water flowing in the River. This is a consequence of management of flows with the Twitchell Dam.

$\Sigma^2\Pi$

SANTA MARIA RIVER FLOW RATE NEAR GUADALUPE
NUMBER OF DAYS PER YEAR WITH FLOWS EXCEEDING 1 CFS (1941-1987)
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 9



LEGEND

- 10 — Lines of equal elevation of groundwater in feet above mean sea level, contour interval 10 feet, dashed where inferred, hachures indicate depression
- 100 — Lines of equal elevation of groundwater in feet above mean sea level, contour interval 50 feet, dashed where inferred, hachures indicate depression
- Direction of groundwater flow
- Study Area Boundary
- Groundwater Basin Boundary
- Groundwater Subbasin Boundary
- Hydrologic Area (HA) and Subarea (HSA) Boundaries
- Bedrock Outcrop Within Groundwater Basin
- Fault, dashed where approximately located, queried where inferred, dotted where concealed
- Thrust Fault, dashed where approximately located, saw-teeth on upper plate, dip of fault plane between 30 and 80 degrees
- Buried bedrock step of uncertain origin, ball on lower side
- Buried monocline, arrow showing direction and width of downwarp
- Syncline, showing trace of axial surface, dashed where approximately located, dotted where concealed

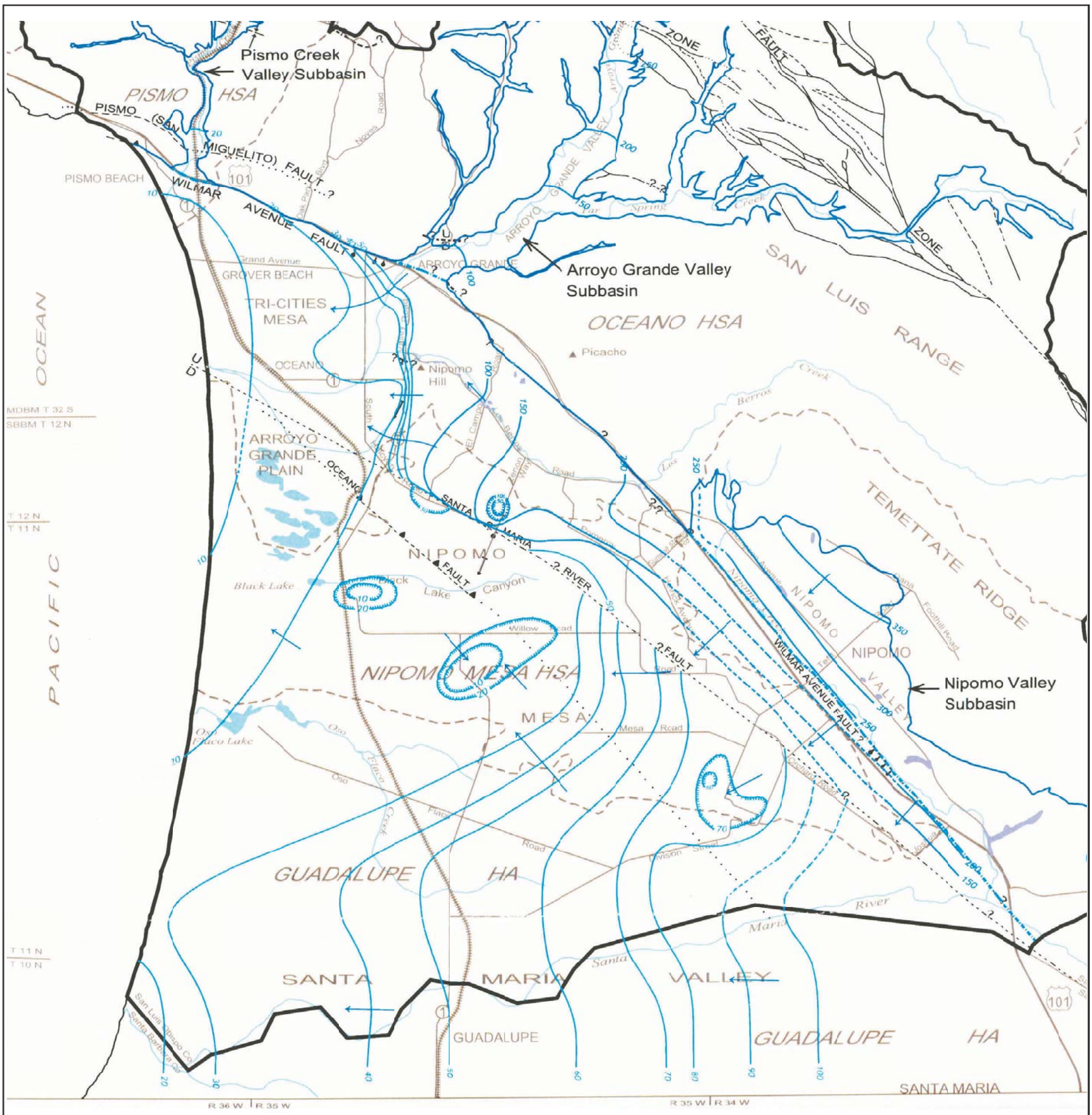
1 0 1

Approximate Scale in Miles

Adapted from Plate 12, DWR, 2002

SPRING 1975 GROUNDWATER ELEVATION CONTOURS (DWR, 2002)
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

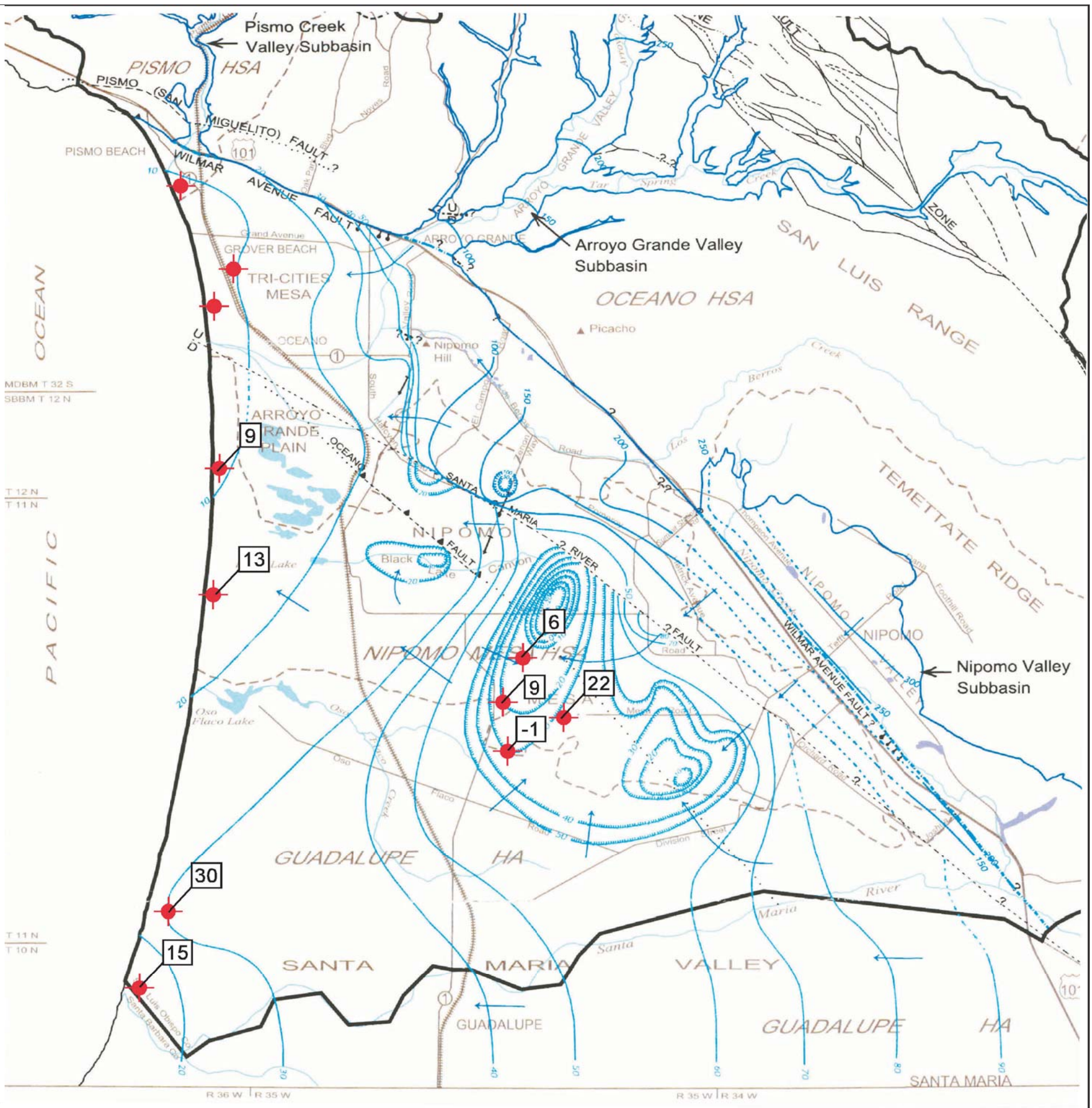
Figure 10



Adapted from Plate 13, DWR, 2002

SPRING 1985 GROUNDWATER ELEVATION CONTOURS (DWR, 2002)
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 11



LEGEND

10 — Lines of equal elevation of groundwater in feet above mean sea level, contour interval 10 feet, dashed where inferred, hachures indicate depression

100 — Lines of equal elevation of groundwater in feet above mean sea level, contour interval 50 feet, dashed where inferred, hachures indicate depression

Direction of groundwater flow

22 — Well location and elevation of groundwater in feet above mean sea level.

Available static water level data are posted for coastal monitoring wells and newly installed production wells for the Woodlands Development (Aug 1993 & Jun-Jul 1994).

Study Area Boundary

Groundwater Basin Boundary

Groundwater Subbasin Boundary

Hydrologic Area (HA) and Subarea (HSA) Boundaries

Bedrock Outcrop Within Groundwater Basin

1 0 1

Approximate Scale in Miles

?...? Fault, dashed where approximately located, queried where inferred, dotted where concealed

Thrust Fault, dashed where approximately located, saw-teeth on upper plate, dip of fault plane between 30 and 80 degrees

Buried bedrock step of uncertain origin, ball on lower side

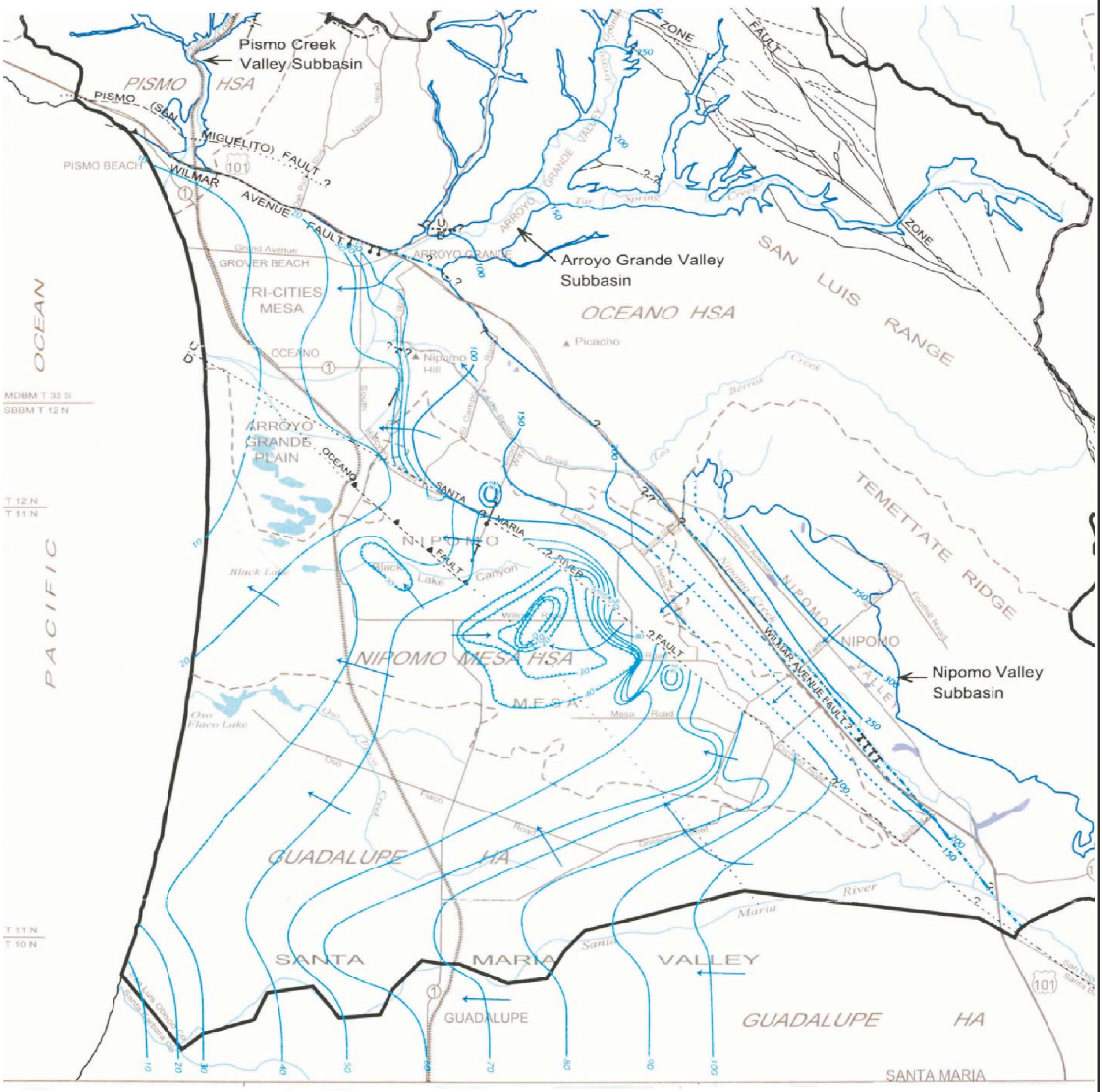
Buried monocline, arrow showing direction and width of downwarp

Syncline, showing trace of axial surface, dashed where approximately located, dotted where concealed

Adapted from Plate 14, DWR, 2002

SPRING 1995 GROUNDWATER ELEVATION CONTOURS (DWR, 2002) AND WATER LEVEL DATA FROM SPECIFIC WELL LOCATIONS
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 12



LEGEND

10 — Lines of equal elevation of groundwater in feet above mean sea level, contour interval 10 feet, dashed where inferred, hachures indicate depression

100 — Lines of equal elevation of groundwater in feet above mean sea level, contour interval 50 feet, dashed where inferred, hachures indicate depression

Direction of groundwater flow

Study Area Boundary

Groundwater Basin Boundary

Groundwater Subbasin Boundary

Hydrologic Area (HA) and Subarea (HSA) Boundaries

Bedrock Outcrop Within Groundwater Basin

Fault, dashed where approximately located, queried where inferred, dotted where concealed

Thrust Fault, dashed where approximately located, saw-teeth on upper plate, dip of fault plane between 30 and 80 degrees

Buried bedrock step of uncertain origin, ball on lower side

Buried monocline, arrow showing direction and width of downwarp

Syncline, showing trace of axial surface, dashed where approximately located, dotted where concealed

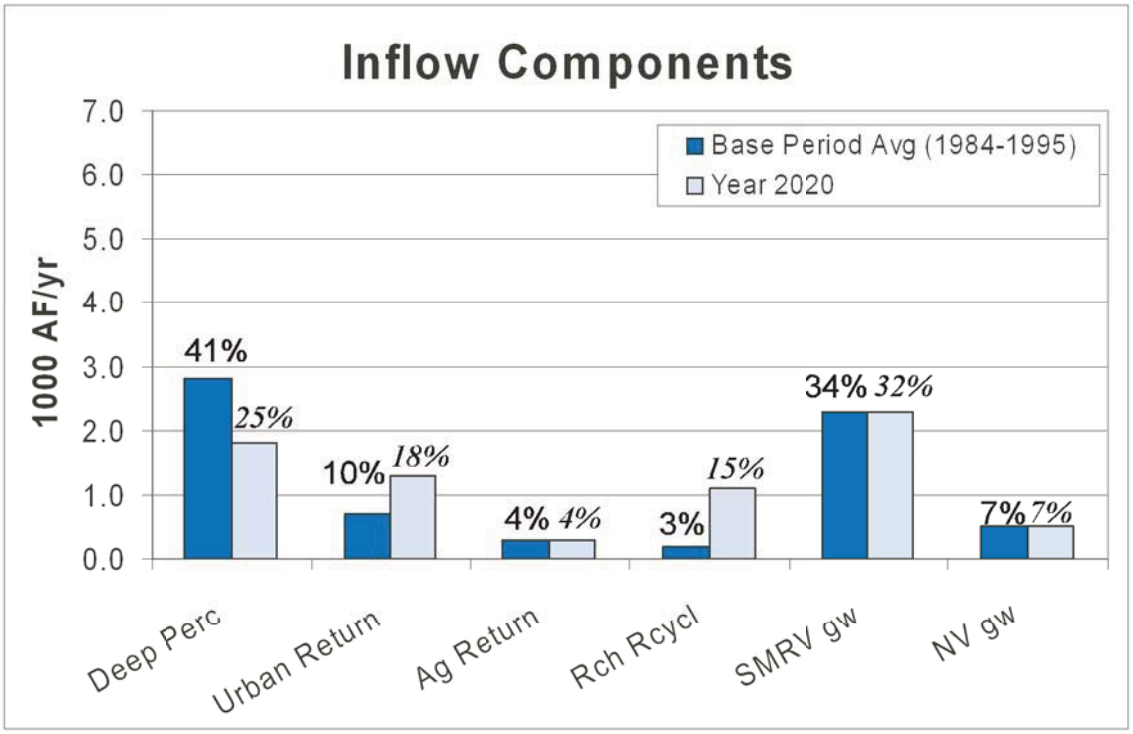
1 0 1

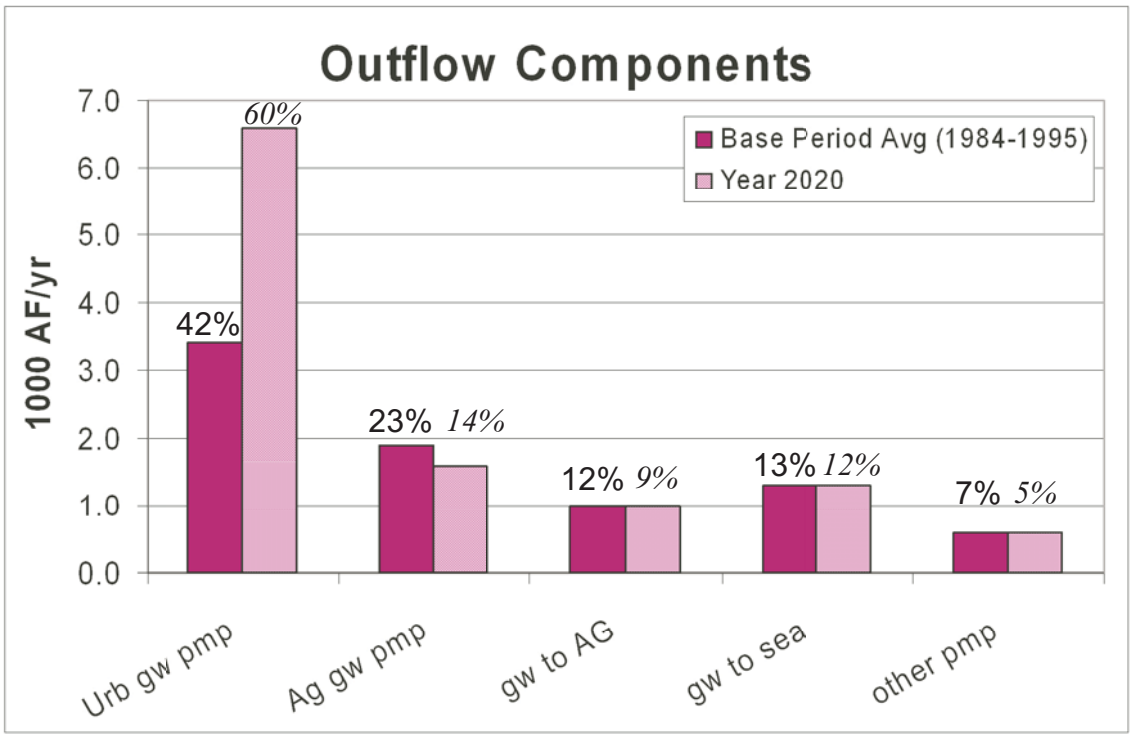
Approximate Scale in Miles

Adapted from Plate A1, DWR, 2002

SPRING 2000 GROUNDWATER ELEVATION CONTOURS (DWR, 2002)
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 13





Data Source: Table 26 (DWR, 2002)

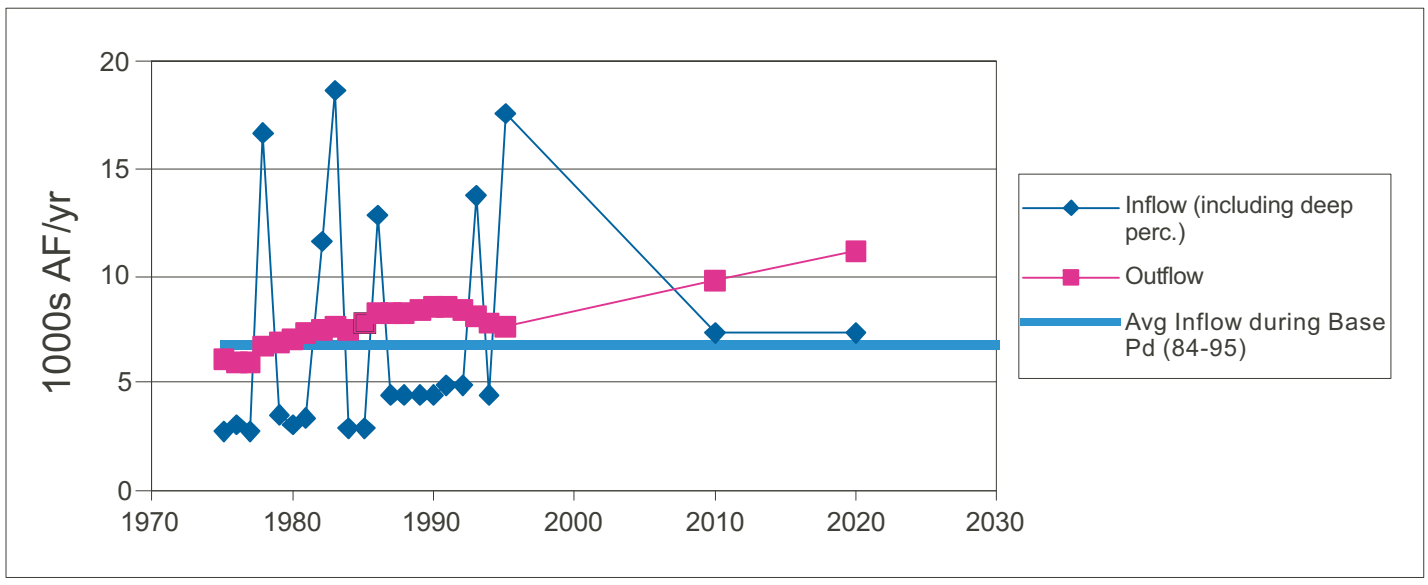
Inflow Components: Deep percolation of precipitation; Urban Return; Ag Return; Recharge of Recycled Water; Groundwater flow from Santa Maria River Valley; Groundwater Flow from Nipomo Valley

Outflow Components: Groundwater pumping for Urban Use; Groundwater pumping for Ag Use; Flow of groundwater to Tri-Cities Mesa - Arroyo Grande Plain; Flow of groundwater to Sea, Other pumping

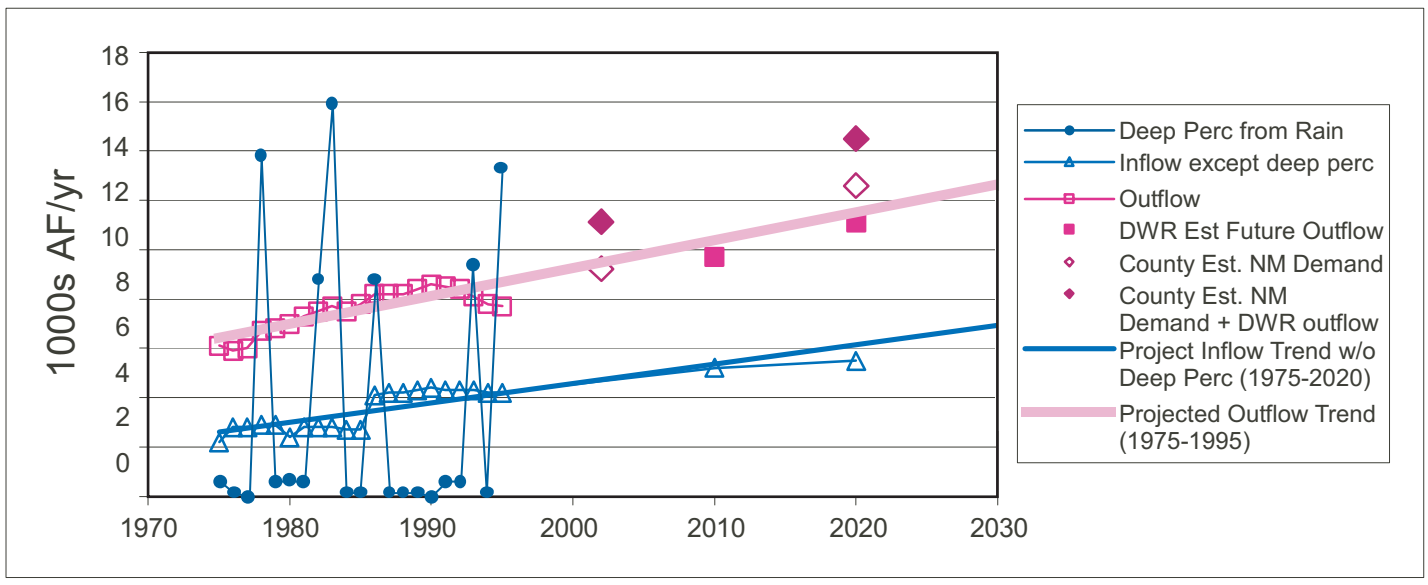
ESTIMATES BY DWR OF WATER BUDGET COMPONENTS FOR NIPOMO MESA
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 14

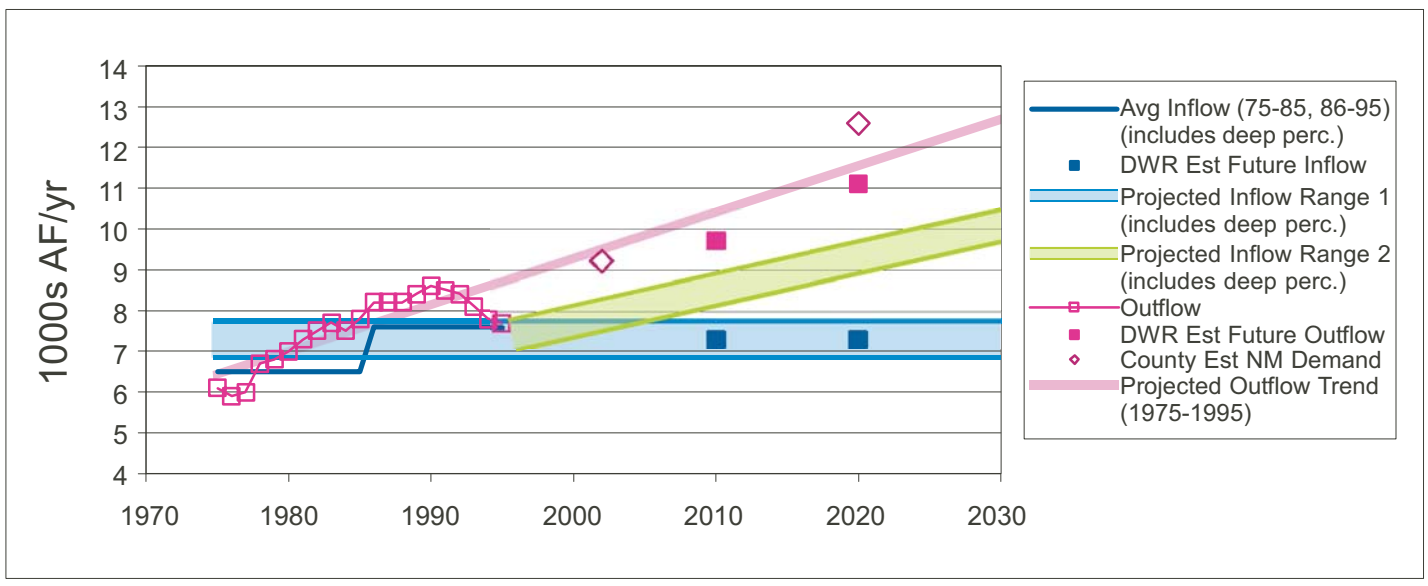
A.



B.



C.



Notes:

Graph A shows estimates by DWR (2002) of annual values for total inflow and outflow for Nipomo Mesa for the 20-year period from 1975 to 1995 and projected estimates for years 2010 and 2020. Inflow includes deep percolation of rainfall, which is the reason for the large variation. Average annual inflow during the study base period (1984-1995) is also shown. This graph shows that DWR's estimates of total outflow have exceeded average inflow since 1980 with an apparent increase in deficit with time.

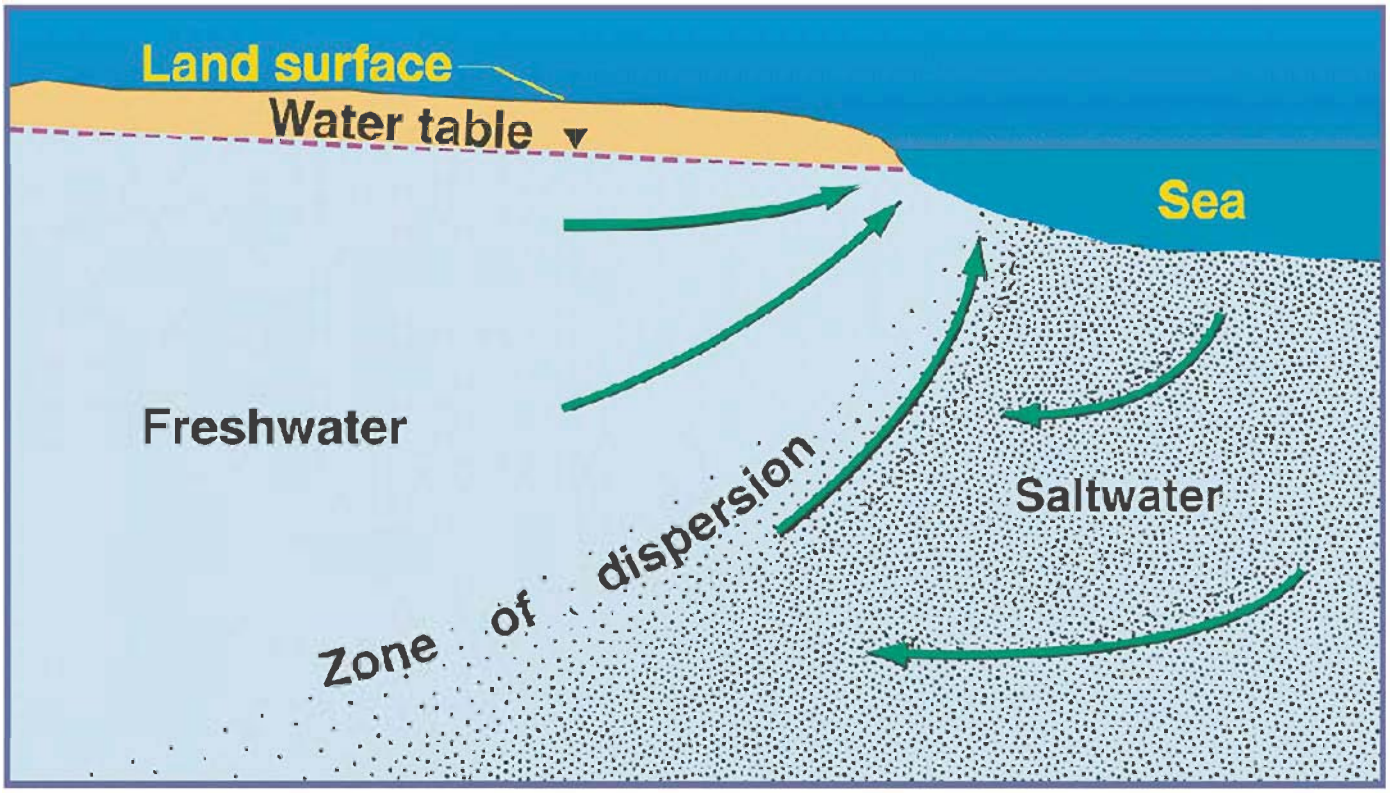
Graph B provides details for the components of the annual water budget annual by DWR (2002). Components of inflow other than deep percolation, 60 percent of which is groundwater inflow from Santa Maria River Valley, are more stable and show two nearly flat trends during the 20-year period of analysis: 1975 to 1985 and 1986 to 1995. We fitted a line through these data and the DWR inflow estimates for 2010 and 2020, which account for more subsurface inflow in response to greater hydraulic gradient toward Nipomo Mesa with increases in pumping.

Graph B also shows a trend line fitted to the 20-year period of outflow values to provide an estimate of outflow rates in the future. DWR's estimated values of outflow for years 2010 and 2020 are close to this projected trend. The open diamond symbols are estimates of Nipomo Mesa water demand for years 2002 and 2020 from the County Master Water Plan Update (January, 2003). The filled diamond symbols at 2002 and 2020 are Nipomo Mesa demand estimates by the County with the DWR estimates subsurface outflow added (Table 26, DWR, 2002).

Graph C shows projected outflow and two ranges of estimated inflow to Nipomo Mesa based on DWR water budget components. One inflow range is constant with time. The other inflow range increases with time as a consequence of increase in rate of groundwater flow from Santa Maria Valley to Nipomo Mesa estimated by DWR (2002). Additional explanation is provided in the text of Section 4.4 to this report.

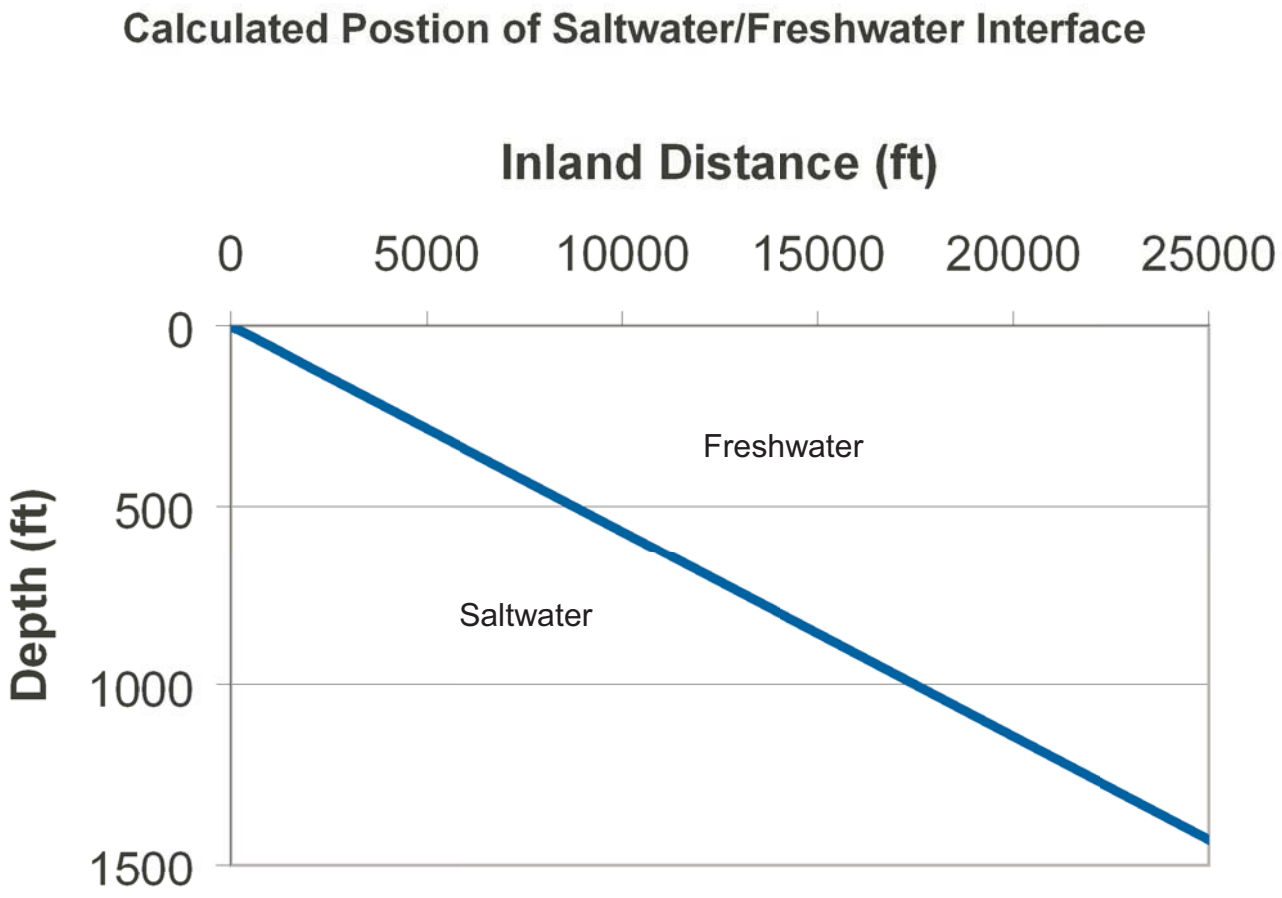
GRAPHIC ANALYSIS OF DWR NIPOMO MESA WATER BUDGET
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 15



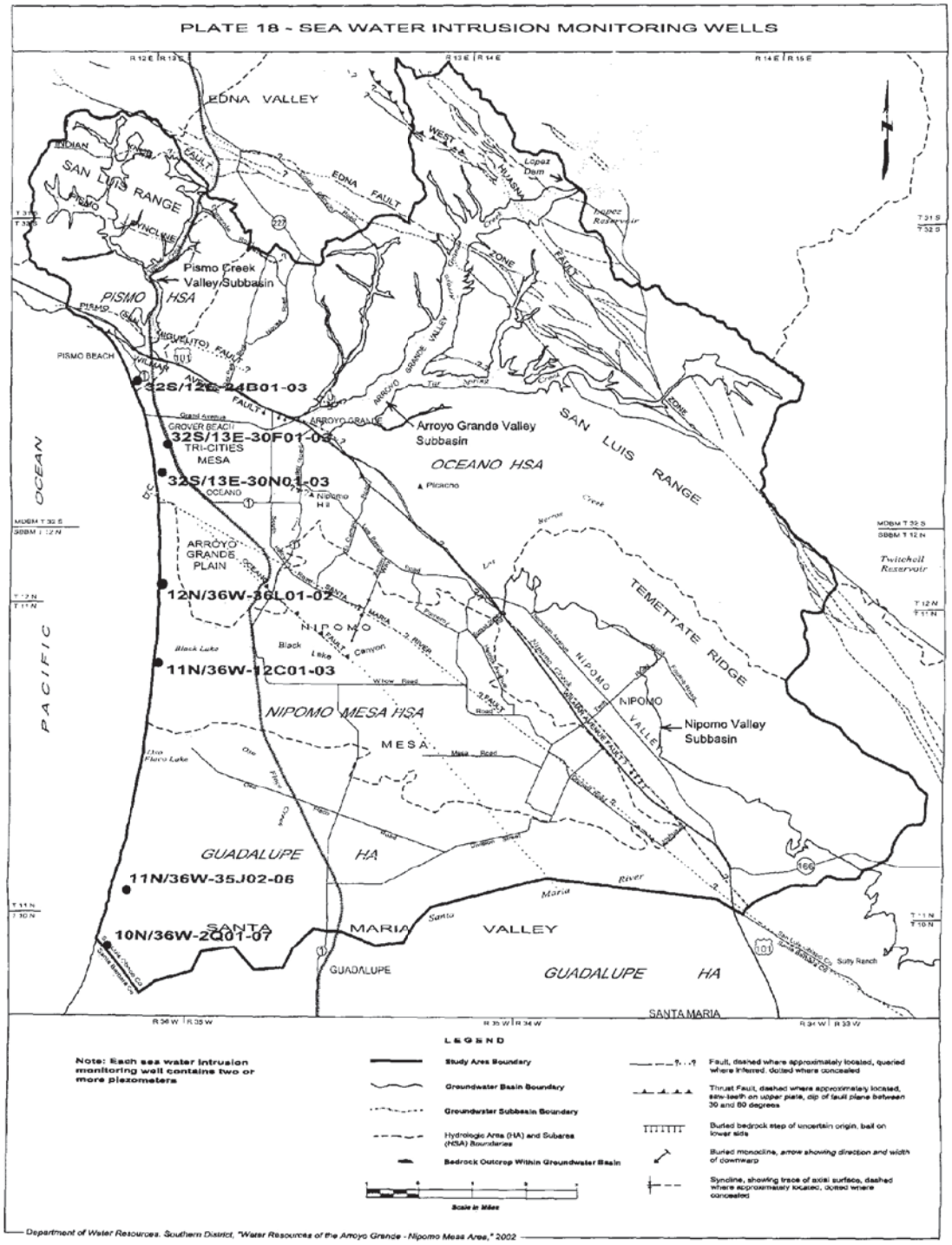
COASTAL AQUIFER CONCEPTUAL CROSS-SECTION
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 16



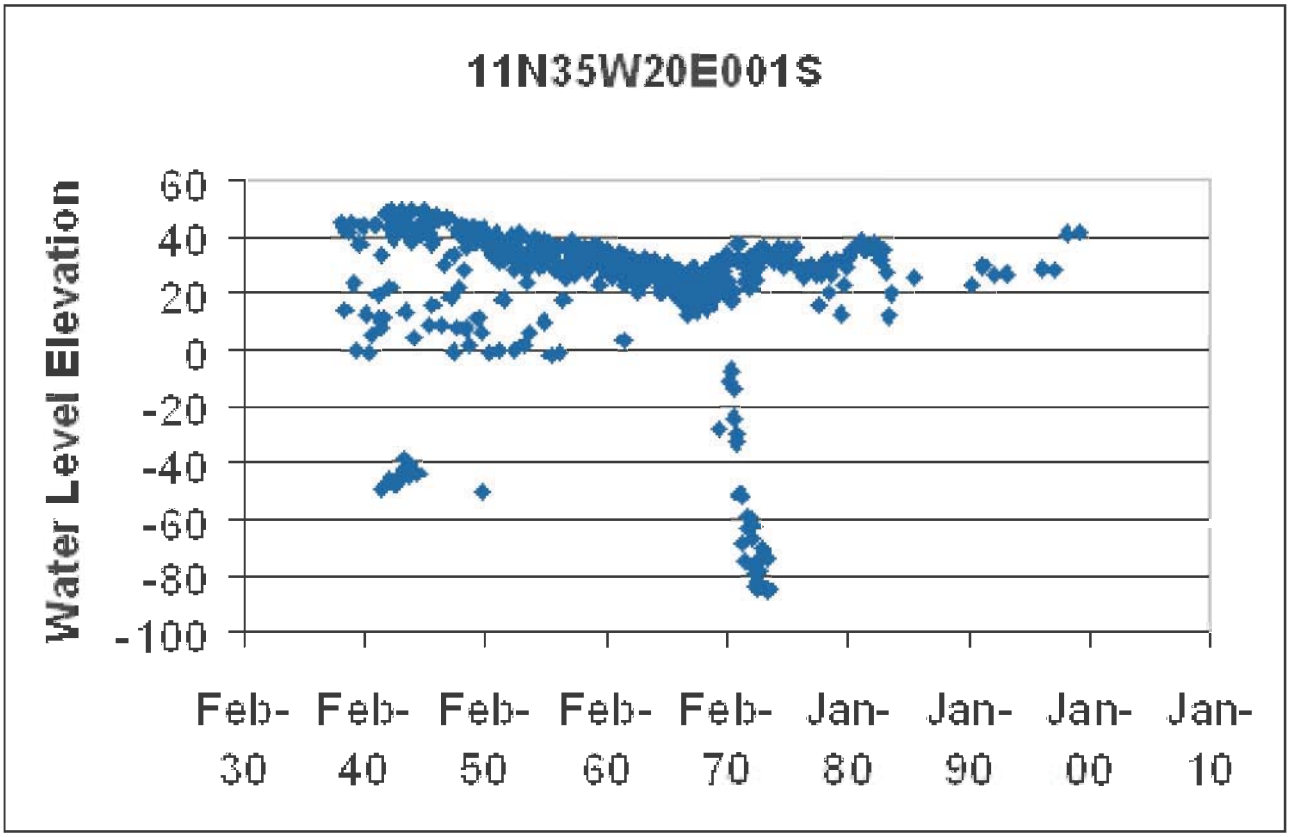
CALCULATED POSITION OF SALTWATER/FRESHWATER INTERFACE
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 17



SEA WATER INTRUSION MONITORING WELLS
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 18



Notes:

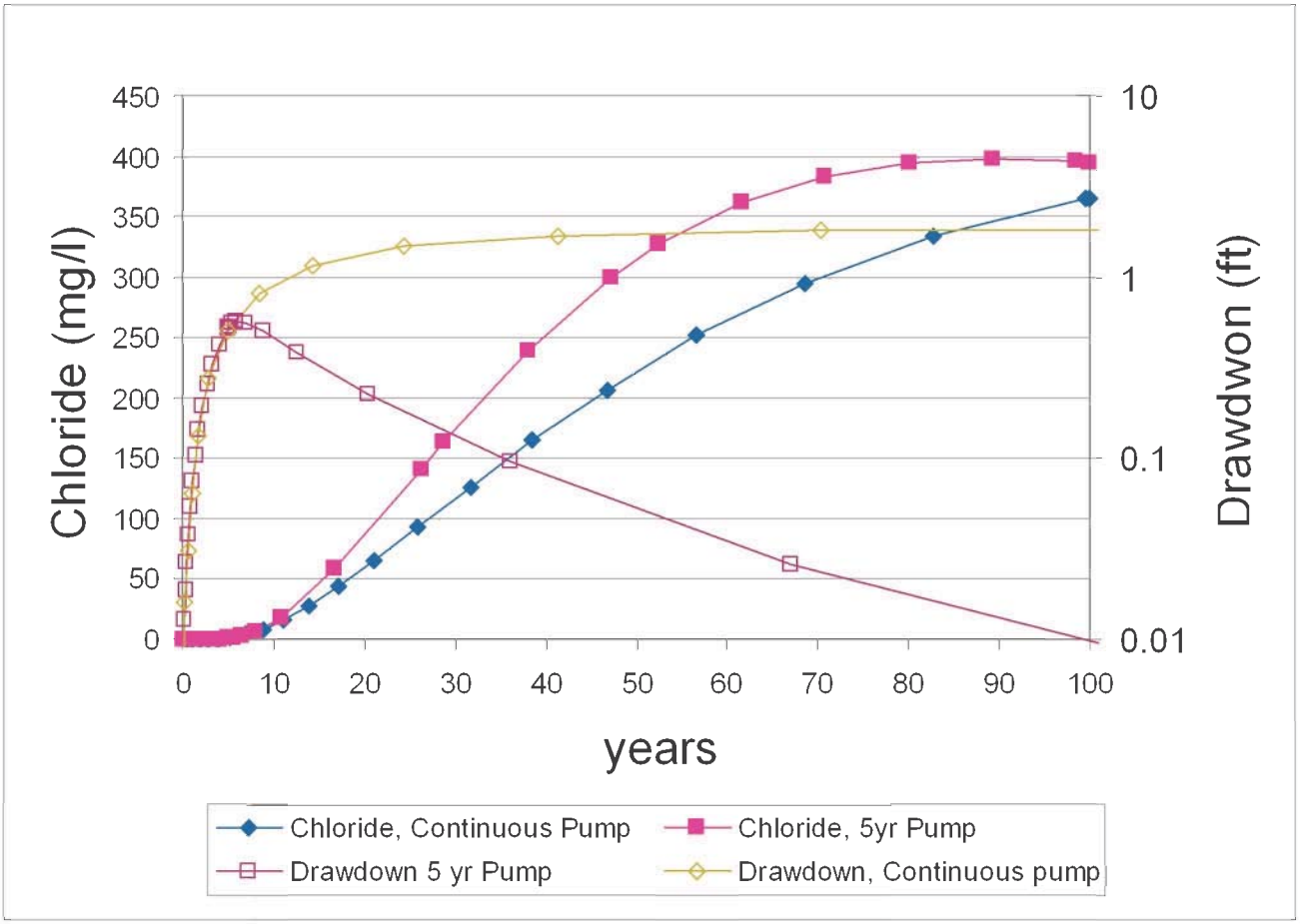
Data from DWR online database
http://wdl.water.ca.gov/gw/admin/main_menu_gw.asp

This well is southwest of Nipomo Mesa.

$\Sigma^2\Pi$

HYDROGRAPH SHOWING WATER LEVELS BELOW SEA LEVEL IN WELL SOUTHWEST OF NIPOMO MESA
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 19

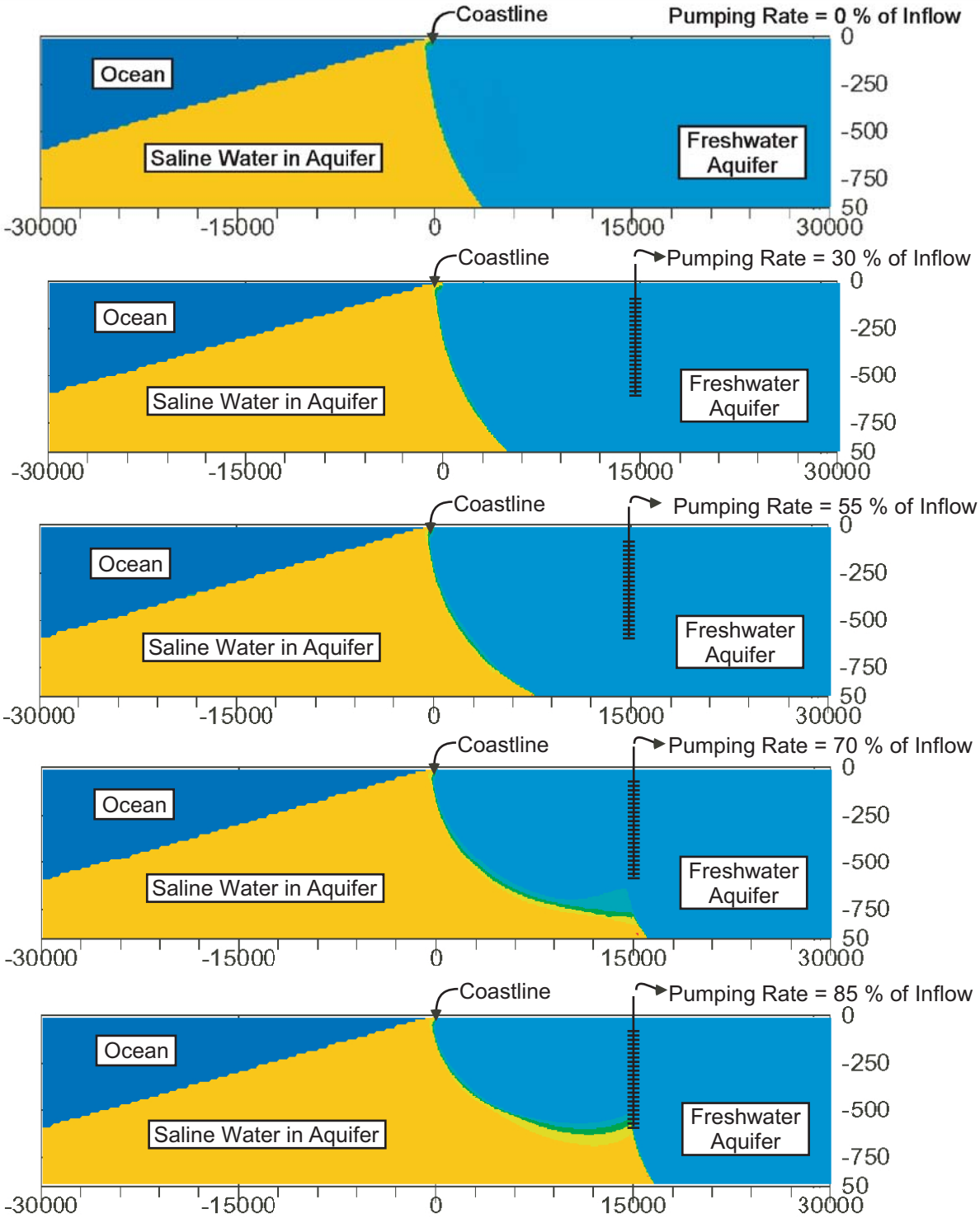


Notes:

1. Graph shows drawdown of hydraulic head in the aquifer and increase in chloride concentration for a point near the middle of the aquifer beneath the coastline.
2. Note that drawdown is logarithmic scale.
3. Pumping rate is equal to approximately 75% of groundwater discharge for non-pumping conditions.
4. Increase in chloride concentration occurs for several decades even when pumping only lasts for five years.
5. Aquifer storage coefficient 0.001

MODEL RESULTS SHOWING TIME LAG BENEATH COASTLINE IN RESPONSE TO PUMPING 15,000 FEET INLAND
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 20



Notes:

Series of images depict cross-section view of a coastal margin aquifer showing equilibrium salinity distribution for a range of pumping rates. Pumping is 15000 feet inland from the coastal margin.

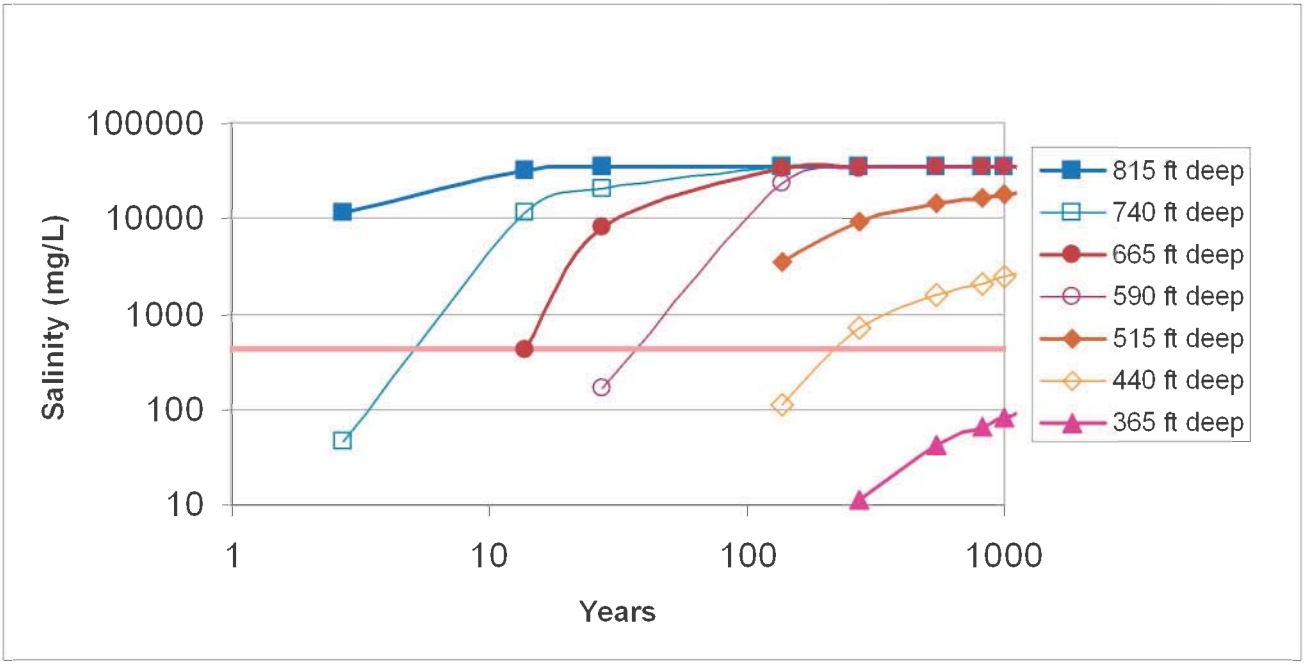
Model inflow includes constant head at upland margin and uniform recharge of 4 inches per year (25% of average rainfall). Summary description of the model is provided in Appendix B.

Uppermost image shows the equilibrium position of the saltwater/freshwater interface in the aquifer for the case without any pumping.

Model results suggest that saltwater intrusion becomes a likely problem when the pumping exceeds 50% of inflow.

MODELED SALINITY DISTRIBUTION FOR A RANGE OF PUMPING RATES
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 21



Notes:

Graph shows model increase in time of salinity in groundwater for a range of depths at distance of 3000 feet from the coastline.

Pumping well, which is 15,000 feet inland of the coastline, is screened between 100 and 600 feet bgs

Pumping rate is 70 percent of total inflow.

MODELED INCREASE IN SALINITY WITH TIME
3000 FEET INLAND IN RESPONSE TO PUMPING 15,000 FEET INLAND
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

Figure 22

Appendix A

Geology of Santa Maria Basin

Nipomo Mesa Groundwater Resource Capacity Study
San Luis Obispo County, California

Appendix A: Geology of Santa Maria Basin

The Santa Maria Geologic Basin was formed by right-lateral, strike-slip faulting and concurrent deposition of marine sediments in a subsiding fault bounded block during a period of several million years in middle of the Tertiary Period of geologic time. Continued faulting, but a change in tectonic regime in middle to late Tertiary time resulted in compression of the basin, which formed large-scale folding, such as the Santa Maria syncline. Late Tertiary to relatively recent west-northwest trending reverse and thrust faults, local folding, uplift, subsidence and tilting complicates the middle Tertiary geologic framework of the basin and crustal blocks. The Santa Maria Basin extends several miles offshore where it is bounded by the Hosgri fault zone.

The Santa Maria Groundwater Basin is the upper, relatively recent and most permeable portion of the Santa Maria Geologic Basin. The aquifer system in the basin consists of unconsolidated plio-pleistocene alluvial deposits including gravel, sand, silt and clay with total thickness ranging from 200 to nearly 3,000 feet. The underlying consolidated rocks typically yield relatively insignificant quantities of water to wells. Jurassic and Cretaceous age basement complex rocks of the Franciscan and Knoxville Formations unconformably underlie the Tertiary and Quaternary rocks. A generalized geologic map of the Nipomo Area and geologic cross sections from the DWR 2002 report are provided as Figures A1 to A4.

The unconsolidated alluvial deposits in the Santa Maria Groundwater Basin include the Careaga Sand, the Paso Robles Formation, the Orcutt Formation, Quaternary Alluvium, and river channel deposits, sediment, terrace deposits and wind-blown dune sands at or near the surface.

The Careaga Sand is a late Pliocene accumulation of shallow-water marine unconsolidated to well-consolidated, coarse- to fine-grained sediments with locally common sea shell fragments and sand dollar fossils. The majority of the Careaga consists of white to yellowish-brown, loosely consolidated, massive, fossiliferous, medium- to fine-grained sand with some silt. The Careaga Sand is identified as the lowermost fresh water bearing formation in the Santa Maria Groundwater Basin, but water quality in the Careaga Sand is typically poor. It is approximately 150 feet thick under Nipomo Mesa south of the Santa Maria River Fault and thickens toward the south to approximately 700 feet beneath the Santa Maria River.

The Plio-Pleistocene Paso Robles Formation overlies the Careaga Sand and comprises the majority of the alluvial basin fill deposits. Thickness of the Paso Robles Formation is approximately 200 feet at northwestern extent of the Santa Maria basin. The Paso Robles Formation thickens to the south and reaches a maximum of approximately 2000 feet near the syclinal axis of the basin beneath the town of Orcutt south of Santa Maria. It consists of unconsolidated to poorly consolidated heterogeneous alluvium deposited under a variety of conditions including fluvial, lagoonal, and nearshore marine. The Paso Robles Formation is highly variable in color and texture, ranging from gravel and clay, sand and clay, gravel and sand, silt and clay. Most of it is fluvial in origin and in most places correlation between individual beds is not possible.

The late Pleistocene Orcutt Formation, which also is primarily fluvial in origin, locally overlies the Paso Robles Formation. In the Orcutt Upland area it is ranges in thickness from 100 to 200 feet. Based on well logs the Orcutt is report to consist of an upper fine-grained sand member and a lower coarse-grained sand and gravel member. Both members of the Orcutt become finer

grained toward the coast. In most of the northern portion of the Santa Maria Groundwater Basin, the Orcutt may not be present, or has been eroded away.

Middle to late Pleistocene age alluvium, which is termed Older Alluvium by some, occurs unconformably on older rocks on the floor of Nipomo Valley. These Older Alluvium deposits are relatively minor in extent and thickness—typical thickness is 10 to 90 feet. Terrace deposits of similar age to the Older Alluvium are remnants of wave-cut platforms or older fluvial deposits, subsequently uplifted and preserved as terraces. The terrace deposits range in thickness from 1 to 15 feet and consist of reworked clasts of underlying formations. Marine terrace deposits are exposed along the coast at Pismo Beach and along the north side of Arroyo Grande Creek. The terrace deposits likely extend beneath the sand dune deposits in the Nipomo Mesa area.

Extensive deposits of Holocene Alluvium (Younger Alluvium), mainly of fluvial origin, comprise the majority of the Santa Maria Valley floor and are typically 100 to 200 feet thick. In Santa Maria Groundwater Basin, the younger alluvium overlies the Orcutt Formation if present, or the Paso Robles Formation throughout most of the northern portion of the basin. Although the 2002 DWR report treats the Holocene alluvium as single unit, sometimes it is divided into two members. The upper portion (member) becomes progressively finer-grained toward the coast with boulders gravel and sand in the Sisquoc Plain Area (upstream portion of the Santa Maria River), sand and gravel in the central and eastern Santa Maria Valley, sand with silt from SM to approximately halfway to Guadalupe, and clay with silt and minor sand westward. The lower portion (member) is mainly coarse-grained sand, gravel, cobbles and boulders with minor clay lenses near the coast. The Holocene Alluvium is approximately 130 feet thick near Hwy 101, and progressively thickens along the Santa Maria River toward the coast where it is approximately 230 feet thick.

The fine-grained facies of the upper portion of the Holocene Alluvium functions as a hydraulic confining layer above the underlying system of aquifers. Based on lithologic logs of well reports, clay beds within the Holocene alluvium range in thickness from 1 to 170 feet in the Santa Maria Plain. Cross sections in the 2002 DWR report show through-going clayey beds within the alluvium, however other reports conclude that the intervals of clay beds may not be continuous layers. In either case, it is apparent that intervals with high proportions of fine-grained material function as semi-confining units that limit the hydraulic connection between the upper portion of the Holocene Alluvium and system of aquifers below.

A mantle of late Pleistocene eolian (wind-blown) dune sands underlies the elevated area, known as Nipomo Mesa. In the 2002 DWR report these dune deposits are referred to as the Older Dunes as opposed to the Younger Dunes that are present along the coastal margin. The Holocene (older) dune deposits are reported to range in age from 40,000 to 120,000 years and were once much more extensive, but most were eroded away during the last ice age by the ancestral Arroyo Grande Creek, Los Berros Creek, and Santa Maria River. Today the Nipomo Mesa older dune sands is a triangular lobe more than 4 miles wide on the coastal side and extending inland more than 12 miles just east of Hwy 101. The dune sand consists of loosely to slightly compacted, massive but cross-bedded, coarse- to fine-grained, well-rounded quartoze sand. The older dune sands have a well-developed soil mantle and are stabilized by vegetation. Lithologic logs of water wells indicate that the Nipomo Mesa dune sands locally contain clay layers on which groundwater may be perched.

An extensive system of Holocene sand dunes occurs along a greater than 10-mile long section of the coastal margin from near just south of Pismo Beach to a couple of miles north of Point Sal.

These dunes are sometimes called the Nipomo Dunes, but are distinct from the older stabilized sand dune deposits that comprise Nipomo Mesa.

A minor alluvial deposit in Black Lake Canyon is the only alluvium in the Nipomo Mesa area.

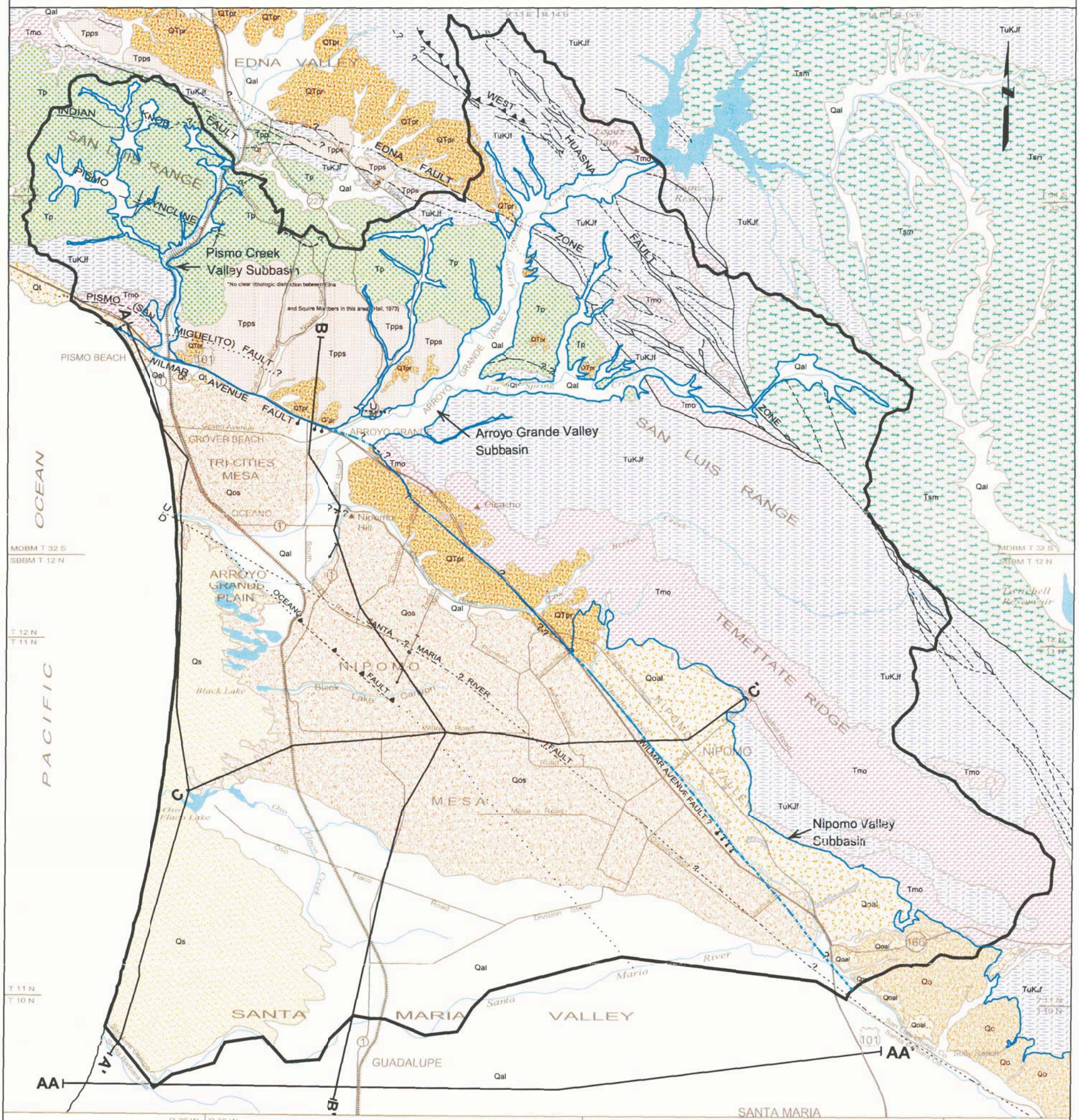
Faults

Faults in the vicinity can be grouped into two categories: (1) largely inactive, right-lateral, strike-slip faults, and (2) potentially active reverse and thrust faults. Both groups generally trend west-northwest. Several faults are concealed within the Santa Maria Basin and the location and associated displacements are estimated from well logs and extrapolation of observations were the faults are exposed at margins of the basin or detected by offshore geophysical exploration.

The Santa Maria and Bradley Canyon Faults are both northwest-trending concealed faults that cross the Santa Maria Valley. They are reported to be high-angle reverse faults the vertically offset the Paso Robles Formation and underlying rocks, but not overlying Orcutt Formation or Quaternary Alluvium. The Santa Maria River and Oceano faults are high-angle faults beneath the northern portion of the Santa Maria basin. They extend beneath in the Nipomo Mesa area in a northwestward direction toward Oceano. Both vertically offset Paso Robles Formation and older rocks, but apparently do not displace the overlying Alluvium or Older Dune Sands. However, the Santa Maria River Fault is also reported to have a significant strike-slip component of offset. DWR reported that the Santa Maria River and Oceano Faults merge near the coastline and then merge offshore with the Hosgri Fault zone. The maximum vertical offset on the Oceano Fault is reported to be 300 to 400 feet and offset on Santa Maria River Fault, the Santa Maria Fault, and Bradley Canyon is within the range of 80 to 150 feet (L&S, 2000). Decreasing vertical offset along Oceano Fault to the southeast is believed indicate that this fault dies out near the Santa Maria River.

The DWR 2002 report discusses significant differences in water levels on opposite sides of the estimated trace of the Santa Maria River Fault, suggesting that the fault is to some degree a hydraulic barrier. However, L&S (2000) report that based on their evaluation of water level data, these faults do not appear to influence groundwater flow within the Santa Maria Groundwater Basin.

PLATE 2 - GENERALIZED GEOLOGY OF THE ARROYO GRANDE - NIPOMO MESA AREA



LEGEND

- Study Area Boundary
- Groundwater Basin Boundary
- Groundwater Subbasin Boundary
- Bedrock Outcrop

Scale in Miles: 1 0 1 2 3

QUATERNARY – HOLOCENE	Qs	Dune Sands
	Qal	Alluvium
	Qos	Older Dune Sands
	Qoal/Qt	Older alluvium or Terrace Deposits
TERTIARY – PLEISTOCENE	Qo	Orcutt Formation
	QTpr	Paso Robles Formation
TERTIARY – PLIOCENE	Tpps/Tpc	Squire Member, Pismo Formation/ Careaga Formation
	Tp	Pismo Formation
	Tsm	Santa Margarita Formation
MIOCENE	Tmo	Obispo Formation
JURASSIC-CRETACEOUS and TERTIARY	TuKJf	Rocks include Miocene Monterey Formation, Cretaceous Serpentinite and ultrabasic rocks, and Jurassic Franciscan Complex

- Fault, dashed where approximately located, queried where inferred, dotted where concealed
- Thrust Fault, dashed where approximately located, saw-teeth on upper plate, dip of fault plane between 30 and 80 degrees
- Buried bedrock step of uncertain origin. Ball on lower side
- Buried monocline, arrow showing direction and width of downwarp
- Syncline, showing trace of axial surface, dashed where approximately located, dotted where concealed
- A — A' Line of Geologic Cross-Section
- AA — AA' Line of Section showing Water Level Profiles

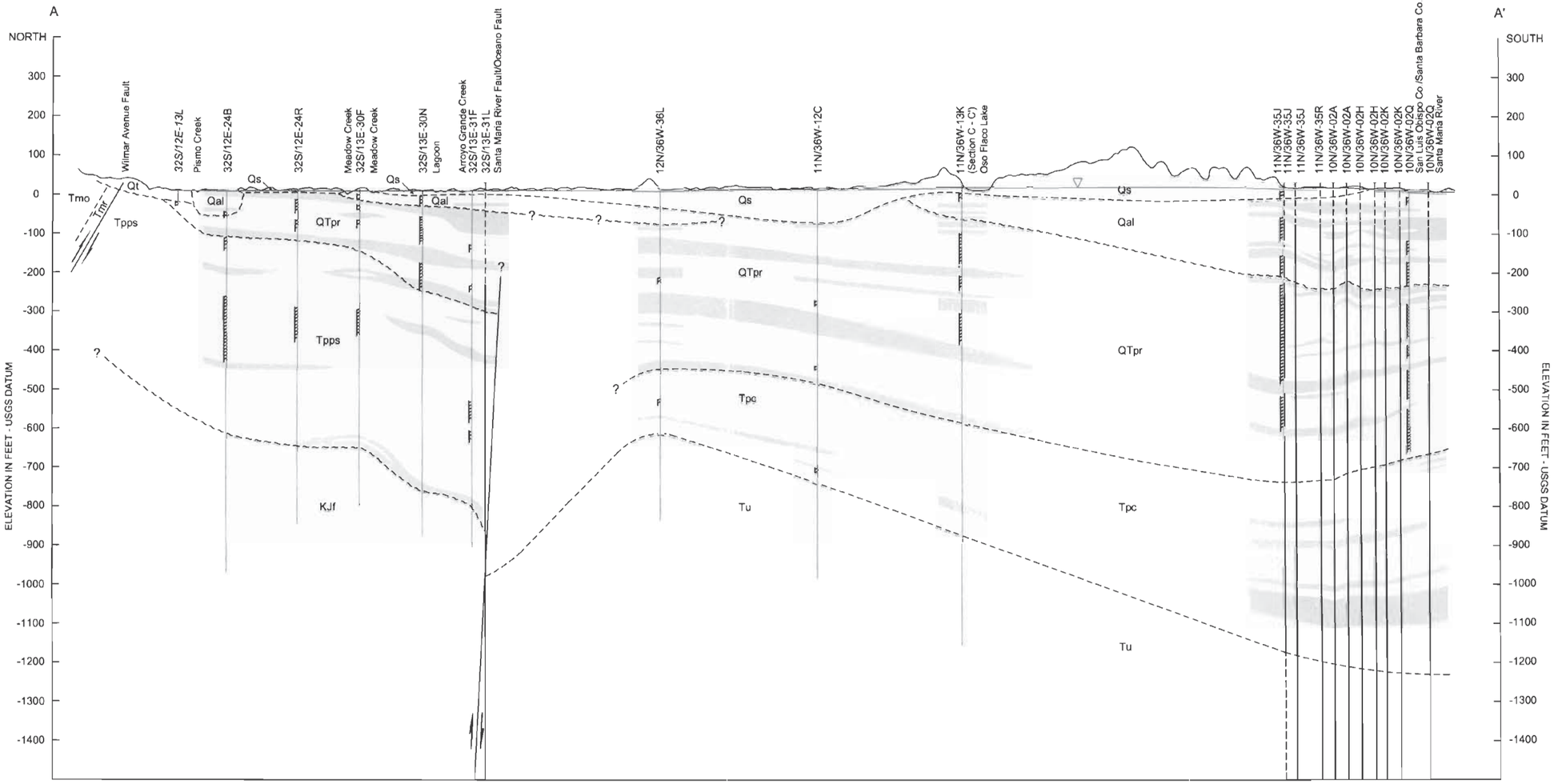
Note: Modified from Hall & Corbato, 1967; Hall, 1973, 1978, 1981; Buchanan-Banks, et al., 1978; Dibblee, 1989, 1994; and Hanson, et al., 1994.

Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

GENERALIZED GEOLOGY OF THE ARROYO GRANDE - NIPOMO MESA AREA (DWR, 2002)

SAN LUIS OBISPO, CAIFORNIA

Figure A-1



EXPLANATION

Formation and Symbol

Qs	Dune Sand
Qal	Alluvial Deposits
Qt	Terrace Deposits
QTpr	Paso Robles Formation
Tpc	Careaga Formation
Tpps	Squire Member, Pismo Formation
Tmo	Obispo Formation
Tmr	Rincon Formation
Tu	Undifferentiated Tertiary Deposits
KJf	Franciscan Complex

12N/36W-36L Water well with electric and geologic log

32S/12E-13L Water well with geologic log

10N/36W-02G Oil well with electric log, dashed above record

Hydrogeologic Unit

- Unconsolidated to weakly cemented clayey silt to silty clay with minor sand and gravel
- Unconsolidated to weakly cemented sand, gravel, silt, sandstone with minor clay and silty clay
- Bedrock

- Perforated interval
- Fault, arrows indicate relative vertical movement
- Unconformity
- Contact
- 1995 Groundwater Elevation

Note: References include: Department of Water Resources, 1970; Buchanan-Banks et al., 1978; Hall, 1981; Nitchman, 1988; Hanson et al., 1994; Lettis et al., 1994.

Location of geologic section shown on Plate 2

Vertical scale 20 times horizontal scale

Horizontal scale in feet

4000 0 4000

WATER RESOURCES OF THE
ARROYO GRANDE - NIPOMO MESA AREA

◇◇◇

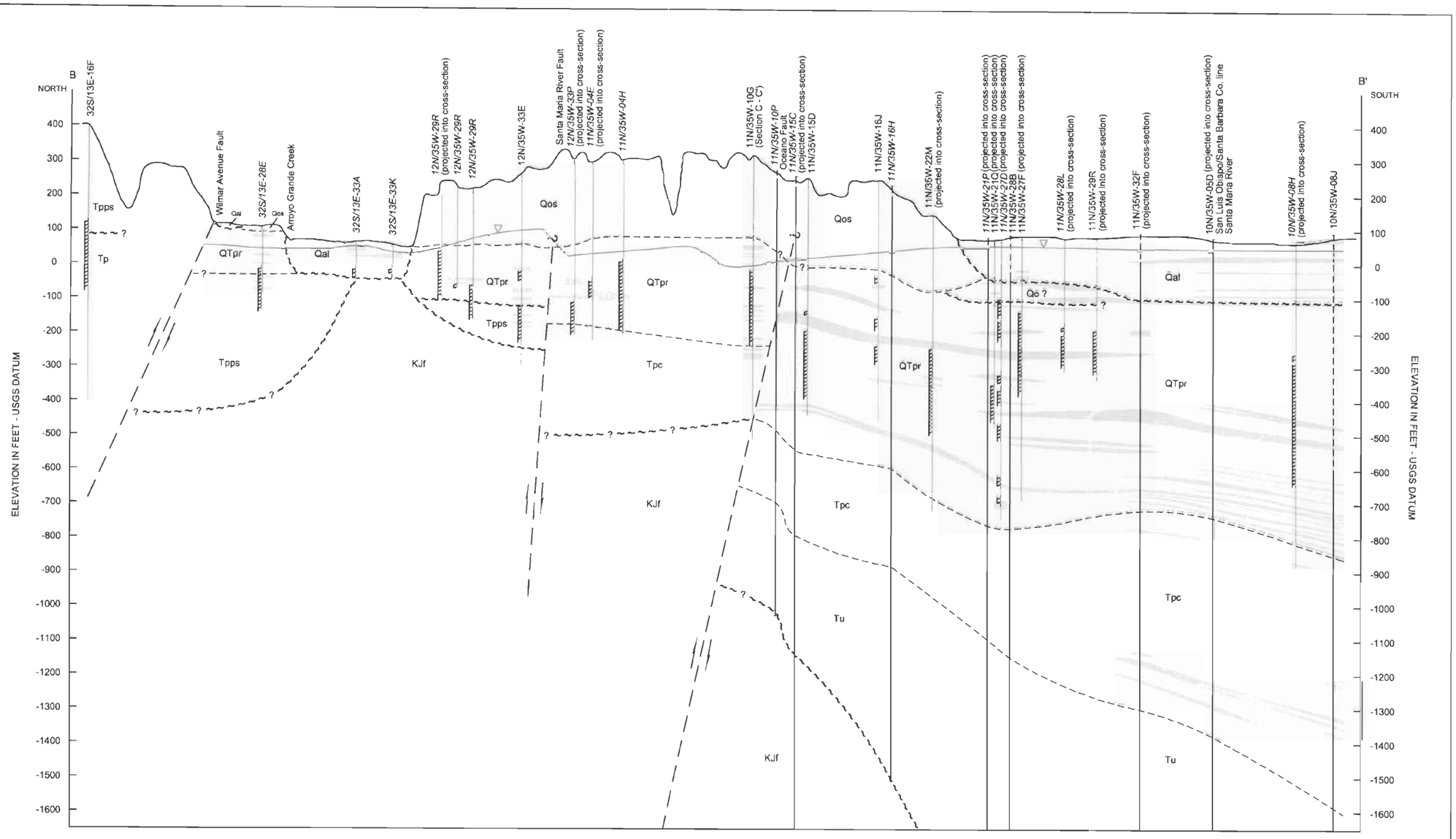
PLATE 3

GEOLOGIC SECTION A - A'

Department of Water Resources, Southern District, 2002

$\Sigma^2\Pi$

Figure A-2



EXPLANATION

Formation and Symbol

Qal	Alluvial Deposits
Qos	Older Dune Sand
Qo	Orcutt Formation
QTpr	Paso Robles Formation
Tpc	Careaga Formation
Tpps	Squire Member, Pismo Formation
Tp	Pismo Formation
Tu	Undifferentiated Tertiary Deposits
KJf	Franciscan Complex

12N/36W-36L Water well with electric and geologic log

32S/12E-13L Water well with geologic log

10N/36W-02G Oil well with electric log, dashed above record

11N/35W-10P Oil well with geologic log, dashed above record

Hydrogeologic Unit

Unconsolidated to weakly cemented clayey silt to silty clay with minor sand and gravel

Unconsolidated to weakly cemented sand, gravel, silt, sandstone with minor clay and silty clay

Bedrock

Perforated interval

Fault, arrows indicate relative vertical movement

Unconformity

Contact

1995 Groundwater Elevation

Note: References include: Department of Water Resources, 1970; Buchanan-Banks et al., 1978; Hall, 1981; Nitchman, 1988; Hanson et al., 1994; Lettis et al., 1994.

Location of geologic section shown on Plate 2

Vertical scale 20 times horizontal scale

Horizontal scale in feet

4000 0 4000

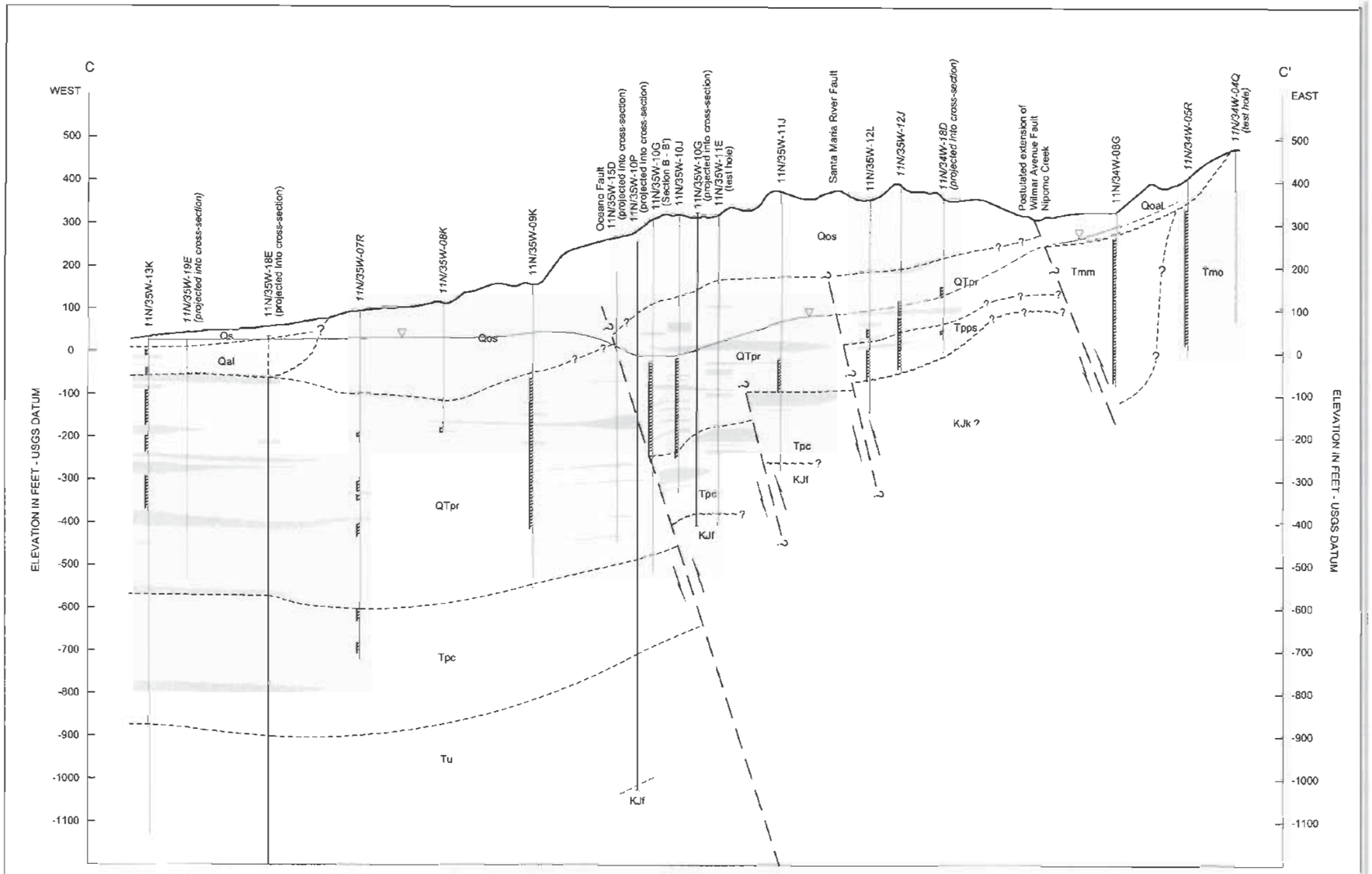
WATER RESOURCES OF THE
ARROYO GRANDE - NIPOMO MESA AREA

◇◇◇

PLATE 4

GEOLOGIC SECTION B - B'

Department of Water Resources, Southern District, 2002



EXPLANATION

Formation and Symbol

Qs	Dune Sand
Qal	Alluvial Deposits
Qos	Older Dune Sand
Qoal	Older Alluvial Deposits
QTpr	Paso Robles Formation
Tpc	Careaga Formation
Tpps	Squire Member, Pismo Formation
Tmm	Monterey Formation
Tmo	Obispo Formation
Tu	Undifferentiated Tertiary Deposits
KJk	Knoxville Formation
KJf	Franciscan Complex

12N/36W-36L — Water well with electric and geologic log

32S/12E-13L — Water well with geologic log

10N/36W-02G — Oil well with electric log, dashed above record

11N/35W-10P — Oil well with geologic log, dashed above record

Hydrogeologic Unit

- Unconsolidated to weakly cemented clayey silt to silty clay with minor sand and gravel
- Unconsolidated to weakly cemented sand, gravel, silt, sandstone with minor clay and silty clay
- Bedrock

- Perforated interval
- Fault, arrows indicate relative vertical movement
- ~~~ Unconformity
- --- Contact
- 1995 Groundwater Elevation

Note: References include Department of Water Resources, 1970; Buchanan-Banks et al., 1976; Hall, 1981; Nitchman, 1988; Hanson et al., 1994; Lettis et al., 1994

Location of geologic section shown on Plate 2

Vertical scale 20 times horizontal scale

Horizontal scale in feet

4000 0 4000

WATER RESOURCES OF THE
ARROYO GRANDE - NIPOMO MESA AREA

◇ ◇ ◇

PLATE 5

GEOLOGIC SECTION C - C'

Department of Water Resources, Southern District, 2002

Figure A-4

Appendix B

Recharge Rate is Not Equivalent to Safe Yield

Nipomo Mesa Groundwater Resource Capacity Study
San Luis Obispo County, California

Collection of References:

Sophocleous, M., 1997, Managing water resources systems: why "safe yield" is not sustainable: Ground Water, v. 35, no. 4, p. 561.

Bredehoeft, J., 1997, Safe yield and the water budget myth: Ground Water, v. 35, no. 6, p. 929.

Bredehoeft, J., 2002, The Water Budget Myth Revisited: Why Hydrogeologists Model: Ground Water, v. 40, no. 4, p. 340-345.

EDITORIAL

MANAGING WATER RESOURCES SYSTEMS: WHY "SAFE YIELD" IS NOT SUSTAINABLE

by Marios Sophocleous[a]

Although major gaps in our understanding of soil and water ecosystems still exist, of more importance are the gaps between what is known and what is applied. One such gap is in the use of the concept of "safe yield" (SY) in ground-water management. Despite being repeatedly discredited in the literature, SY continues to be used as the basis of state and local water-management policies, leading to continued ground-water depletion, stream dewatering, and loss of wetland and riparian ecosystems.

Traditionally, "safe yield" has been defined as the attainment and maintenance of a long-term balance between the amount of ground water withdrawn annually and the annual amount of recharge. Thus, SY limits ground-water pumping to the amount that is replenished naturally. Unfortunately, this concept of SY ignores discharge from the system. Under natural or equilibrium conditions, recharge is balanced, in the long term, by discharge from the aquifer into a stream, spring, or seep. Consequently, if pumping equals recharge, eventually streams, marshes, and springs dry up. Continued pumping in excess of recharge also eventually depletes the aquifer. This has happened in various locations across the Great Plains. Maps comparing the perennial streams in Kansas in the 1960s to those of the 1990s show a marked decrease in miles of streamflow in the western third of the state. (For more information on SY, see the edited volume by Sophocleous, 1997, "Perspectives on Sustainable Development of Water Resources in Kansas," Kansas Geological Survey, Bulletin 239, in press.) Policymakers are primarily concerned about aquifer drawdown and surface-water depletion, both unrelated to the natural recharge rate. Despite its irrelevance, natural recharge is often used in ground-water policy to balance ground-water use under the banner of SY. Adopting such an attractive fallacy does not provide scientific credibility.

To better understand why "safe yield" is not sustainable yield, a review of hydrologic principles (concisely stated by Theis in 1940) is required. Under natural conditions, prior to development by wells, aquifers are in a state of approximate dynamic equilibrium: over hundreds of years, recharge equals discharge. Discharge from wells upsets this equilibrium by producing a loss from aquifer storage. A new state of dynamic equilibrium is reached only by an increase in recharge (induced recharge), a decrease in natural discharge, or a combination of the two. Initially, ground water pumped from the aquifer comes from storage, but ultimately it comes from induced recharge. The timing of this transition, which takes a long time by human standards, is a key factor in developing sustainable water-use policies. However, it is exceedingly difficult to distinguish between natural recharge and induced recharge to ascertain possible sustained yield. This is an area that needs further research. Calibrated stream-aquifer models could provide some answers in this regard.

The concept of sustainable yield has been around for many years, but a quantitative methodology for the estimation of such yield has not yet been perfected. A suitable hydrologic basis for determining the magnitude of possible development would be a quantification of the transition curve (from ground-water storage depletion to full reliance on induced recharge), coupled with a projected pattern of drawdown for the system under consideration. The level of ground-water development would be calculated using specified withdrawal rates, well-field locations, drawdown limits, and a defined planning horizon. Stream-aquifer models are capable of generating the transition curve for most situations.

Another problem with SY is that it has often been used as a single-product exploitation goal—the number of trees that can be cut, the number of fish that can be caught, the volume of water that can be pumped from the ground or river, year after year, without destroying the resource base. But experience has repeatedly shown that other resources inevitably depend on the exploited product. We can maximize our SY of water by drying up our streams, but when we do, we learn that the streams were more than just containers of usable water.

A better definition of SY would address the sustainability of the system—not just the trees, but the whole forest; not just the fish, but the marine food chain; not just the ground water, but the running streams, wetlands, and all the plants and animals that depend on it. Given the dynamic connectedness of a watershed, management activities can fragment the habitat "patches" if they are not planned and implemented from an ecosystem and watershed perspective. Such a holistic approach, however, is fraught with difficulty. We cannot use a natural system without altering it, and the more intensive and efficient the use, the greater the alteration.

Science will never know all there is to know. Rather than allowing the unknown or uncertain to paralyze us, we must apply the best of what we know today, and, at the same time, be flexible enough to allow for change and for what we do not yet know. Instead of determining a fixed sustainable yield, managers should recognize that yield varies over time as environmental conditions vary.

Our understanding of the basic principles of soil and water systems is fairly good, but our ability to use this knowledge to solve problems in complex local and cultural settings is relatively weak. Communication is vital. We need people who can transfer research findings to the field and who can also communicate water-users' needs to the researchers. Delivering a journal publication to a manager's desk is not sufficient to ensure that research results are quickly put into practice. I believe this breakdown in communication accounts for the persistence of such misguided concepts as SY in ground-water management today. Researchers increasingly must cross the boundaries of their individual disciplines, and they must look to their clients—the managers and water users—for help in defining a practical context for research. A strong public education program is also needed to improve understanding of the nature and complexity of ground-water resources and to emphasize how this understanding must form the basis for operating conditions and constraints. This is the only way to positively influence, for the long term, the attitudes of the various stakeholders involved.

[a]Senior Scientist, Kansas Geological Survey, The University of Kansas, 1930 Constant Ave., Lawrence, Kansas 66047-3726. The views expressed here are the author's and not necessarily those of the AGWSE, NGWA, and/or the Ground Water Publishing Company.

GROUND WATER

Editorial

Safe Yield and the Water Budget Myth

by John Bredehoeft[a]

The editorial by Marios Sophocleous in the July-August issue of *Ground Water* is an especially important one. I agree with Marios, the idea of safe yield as it is generally expressed in which the size of a development if it is less than or equal to the recharge is considered to be "safe" is fallacious. As Marios indicates, Theis pointed out the fallacy of this notion of "safe yield" in a 1940 paper entitled: *The source of water to wells: essential factors controlling the response of an aquifer to development (Civil Engineering*, p. 277–280)—every practitioner of ground water should go back and read this paper. Theis' 1940 principle is one of the least understood concepts in ground-water hydrology.

Hilton Cooper, Stavros Papodopulos, and I reiterated Theis' paradigm in a 1982 paper entitled: *The water-budget myth (Scientific Basis of Water Management, National Academy of Sciences Studies in Geophysics*, p. 51–57). At the time, Theis said to me that this paper eliminated the need for a paper he had been contemplating. Unfortunately, our 1982 paper was printed in an obscure publication; and yet it may be one of the more important papers we wrote.

I have some additional remarks to add to Marios Sophocleous' editorial. As Marios correctly indicated, Theis stated: "*A new state of dynamic equilibrium is reached only by an increase in recharge (induced recharge), a decrease in discharge, or a combination of the two.*" Cooper, Theis, and others had a name for the sum of increased recharge plus the decreased discharge—they refer to it as capture. In order for a development to reach a new equilibrium, the capture must ultimately equal the new stress on the system, the development. Capture is dynamic, and depends upon both the aquifer geometry and the parameters (permeability and specific storage) of the system. This is why both well response and aquifer system response are so much a part of ground-water hydrology.

In my experience, the recharge, and certainly the change in recharge due to a development (induced recharge) is difficult, if not impossible, to quantify. Usually the recharge is fixed by rainfall and does not change with development. Marios leaves an impression that the change in recharge (induced recharge) is where our focus as ground-water hydrologists should be. It is on this point that we may differ.

Commonly the virgin discharge is what changes and makes it possible to bring a ground water system into balance. Capture is a dynamic quantity that changes through time until the system reaches a new equilibrium. Usually this is what we attempt to quantify with flow models—we estimate the magnitude of the capture from the virgin (natural) discharge. It is usually much more important to focus on the discharge, and the change in discharge—the capture. Capture from the natural discharge is usually what determines the size of a sustainable development.

Pumping does not have to exceed the recharge for streams to be depleted. Pumping is an additional stress on the system. The water pumped will usually be supplied from both storage and from reduced natural discharge. We define equilibrium as a state in which there is no more change in ground-water storage with time—water levels are stable in time. If no new equilibrium can be reached, as Theis showed for the high plains aquifer of New Mexico, the aquifer will continue to be depleted. Once a new equilibrium is reached, the natural discharge is reduced by an amount equal to the development—capture equals development. This statement has nothing to do with recharge. Often streams are depleted long before the pumping reaches the magnitude of the recharge.

It is important that the profession understand the concept of safe yield. Sustainable ground-water developments have almost nothing to do with recharge; as Marios correctly states, it is irrelevant. However, I continue to hear my colleagues say they are studying the recharge in order to size a development—I heard this again last week. The water budget as it is usually applied to scale development is a myth—Theis said this in 1940. Yet the profession continues to perpetuate this wrong paradigm.

[a]Consultant, The Hydrodynamics Group, 234 Scenic Dr., La Honda, California 94020.

The views expressed here are the author's and not necessarily those of the AGWSE, NGWA, and/or the Ground Water Publishing Company.

ground water

Issue Paper/

The Water Budget Myth Revisited: Why Hydrogeologists Model

by John D. Bredehoeft[1]

Abstract/

Within the ground water community, the idea persists that if one can estimate the recharge to a ground water system, one then can determine the size of a sustainable development. Theis addressed this idea in 1940 and showed it to be wrong—yet the myth continues. The size of a sustainable ground water development usually depends on how much of the discharge from the system can be "captured" by the development. Capture is independent of the recharge; it depends on the dynamic response of the aquifer system to the development. Ground water models were created to study the response dynamics of ground water systems; it is one of the principal reasons hydrogeologists model.

Introduction

The idea persists within the ground water community that if one can determine the recharge to an aquifer system then one can determine the maximum magnitude of a sustainable development. One commonly hears the statement, "the pumping must not exceed the recharge (if the development is to be sustainable)."

The idea that the recharge (by which one usually means the virgin recharge before development) is important in determining the magnitude of sustainable development is a myth. A number of hydrogeologists have tried to debunk the myth, starting with Theis (1940) in a paper titled "The Source of Water Derived from Wells: Essential Factors Controlling the Response of an Aquifer to Development." Brown (1963) and Bredehoeft et al. (1982) wrote papers debunking the myth. Unfortunately, the message in Brown's paper was apparent only to those deeply schooled in ground water hydrology. The Bredehoeft et al. paper, while more readily understandable, was published in an obscure National Academy of Science publication that is out of print. At the time the Bredehoeft et al. paper was published, Theis congratulated the authors, commenting that he had intended to write another paper on the subject, but now he did not see the need. Needless to say, in spite of these efforts the myth goes on; it is so ingrained in the community's collective thinking that nothing seems to derail it.

[1]Principal, The Hydrodynamics Group, 127 Toyon Ln., Sausalito, CA 94965; jdbrede@aol.com

Received January 2002, accepted March 2002.

It is presumptuous and perhaps arrogant of me to imply that the entire community of ground water hydrologists does not understand the principles first set forth by Theis in 1940; clearly this is not the situation. There are good discussions in recent papers that indicate other hydrogeologists understand Theis' message. The 1999 USGS Circular 1186, *Sustainability of Ground-Water Resources* (Alley et al. 1999), states the ideas lucidly. Sophocleous and his colleagues at the Kansas Geological Survey have published extensively on the concept of ground water sustainability; Sophocleous (2000) presents a summary of his ideas that contain the essence of Theis' principles.

On the other hand, I do not find Theis' principles on sustainabilty expressed clearly in the texts on ground water. These ideas were taught to me, early in my career, by my mentors at the U.S. Geological Survey. Also I find in discussions with other ground water professionals that these ideas, even though they are 60 years old, are not clearly understood by many individuals. It is my purpose in this paper to address again the myth that recharge is all important in determining the size of a sustainable ground water development, and show that this idea has no basis in fact.

Analytical Methods in Hydrogeology

Before digital computer modeling codes, hydrogeologists used traditional analytical methods to assess the impacts of wells on ground water systems. The traditional method of analysis used is the principle of superposition. In this approach, one assumes that the hydraulic head (or the water table) before development resulted from the inputs and outputs (recharge and discharge) from the system. One

analyzes the impact of pumping independent of the initial (virgin) hydraulic head. The cone of depression is calculated as a function of time. This cone of depression is then superposed upon the existing hydraulic head (or water table). The resulting head after superposition is the solution to the development.

To make such a superposition calculation, one needs: (1) the transmissivity and storativity distribution within the aquifer, (2) the boundary conditions that will be reached by the cone of depression, and (3) the rate of pumping. Those trained in classical hydraulic theory are well aware of reflection boundaries and image wells to account for the boundary conditions.

Missing from the classical analysis is any mention of recharge. The recharge is taken into account by the initial hydraulic head (or the water table). The initial head is a solution to an initial boundary value problem that includes the recharge and discharge.

Prior to the widespread use of digital computer models most analyses in ground water flow were made using the principles of superposition. This was also the methodology used in the analog computer models of the 1950s, '60s, and '70s. With the advent of digital computer models, it became feasible to specify the varying distributions of recharge and discharge with the idea of solving for the virgin water table. The calculated water table can then be compared to the observed water table (or hydraulic head). To do such an analysis requires knowledge of the distribution of both the virgin rate of recharge and the virgin rate of discharge—in addition to the transmissivity distribution and the boundary conditions.

With an estimate of the rainfall, there is still no idea of how large the recharge is, except that it cannot exceed some unknown fraction of rainfall. The researcher may know the transmissivity of the aquifer at a few places and the aquifer discharge that makes up the baseflow of streams associated with the aquifer. Based on this set of limited information, a steady-state model analysis is made in an attempt to estimate the transmissivity of the aquifer. This is a common model analysis. In this context, knowledge of the virgin recharge is useful in estimating the transmissivity.

The recharge and the discharge are the inputs and outputs from a ground water system. Both quantities are important in understanding how a particular ground water system functions. However, it is not my purpose in this paper to discuss recharge or discharge. My focus is on how recharge and discharge enter into the determination of the sustainable yield of a ground water system.

In the classical analytical method, the important variables for determining the impacts of pumping are those that describe the dynamic response of the system—the distribution of aquifer diffusivity and the boundary conditions. This argument was the thrust of Brown's 1963 paper. The argument makes sense to one trained in classical analytical methods; it is more obscure to others. Brown's paper made almost no impact. I will attempt to further simplify the mathematical argument.

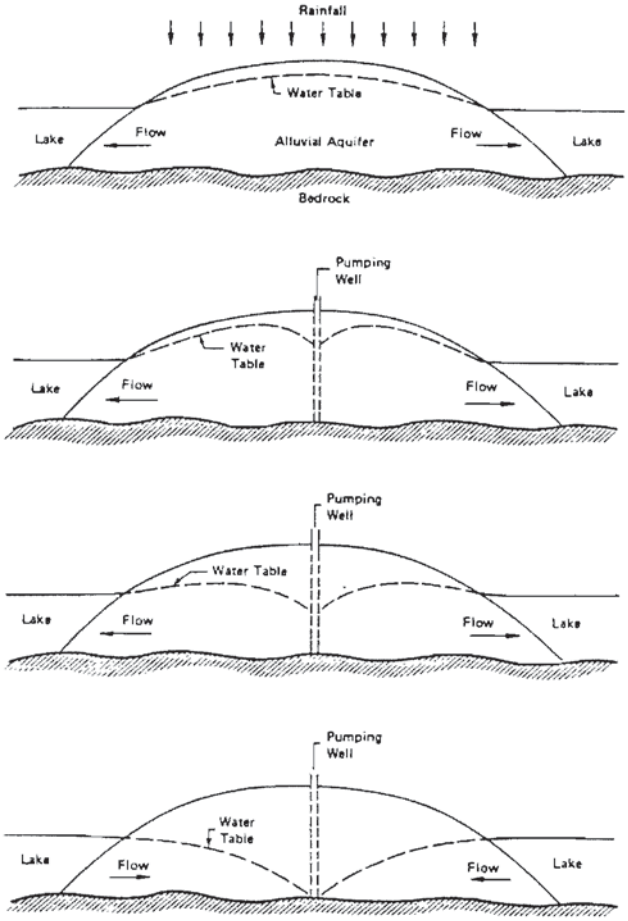


Figure 1. Schematic cross section of an aquifer situated on a circular island in a fresh water lake that is being developed by pumping. (Reprinted with permission from *Scientific Basis of Water-Resource Management*. Copyright 1982 by the National Academy of Sciences. Courtesy of the National Academy Press, Washington, D.C.)

The Water Budget

To illustrate the basic premise, I want to consider a simple aquifer system. A permeable alluvial aquifer underlies a circular island in a fresh water lake. Our intent is to develop a well on the island. The island aquifer is shown schematically in various stages of development in Figure 1.

Before development, recharge from rainfall creates a water table. The recharge over the island is balanced by discharge from the permeable aquifer directly to the lake (Figure 1—top cross section). We can write the following water balance for virgin conditions on our island:

$$R_0 = D_0 \qquad \text{or} \qquad R_0 - D_0 = 0$$

where R_0 is the virgin recharge (this is the recharge generally referred to in the myth), and D_0 is the virgin discharge. A water table develops on the island in response to the distribution of recharge and discharge and the transmissivity of the alluvial aquifer (Figure 1—top cross section).

The discharge to the lake can be obtained at any point along the shore by applying Darcy's law:

$$d = T\,(dh/dl)$$

where d is the discharge through the aquifer at any point along the shore; T is the transmissivity at the same point; and dh/dl is the gradient in the water table at that point. If

we integrate the point discharge along the entire shoreline of the island we obtain the total discharge from the island:

$$\int T\,(dh/dl)\,ds = D_0$$

We now go into the middle of the island, install a well and initiate pumping (Figure 1—second cross section). At any new time, we can write a new water balance for the island:

$$(R_0 + \Delta R_0) - (D_0 + \Delta D_0) - P + dV/dt = 0$$

where ΔR_0 is the change in the virgin rate of recharge caused by our pumping; ΔD_0 is the change in the virgin rate of discharge caused by the pumping; P is the rate of pumping; and dV/dt is the rate at which we are removing water from ground water storage on the island.

We know that the virgin rate of recharge, R_0, is equal to the virgin rate of discharge, D_0, so our water budget equation following the initiation of pumping reduces to

$$\Delta R_0 - \Delta D_0 - P + dV/dt = 0$$

or

$$\Delta R_0 - \Delta D_0 - P = dV/dt$$

For a sustainable development, we want the rate of water taken from storage to be zero; in other words, we define sustainability as

$$dV/dt = 0$$

Now our water budget for sustainable development is

$$\Delta R_0 - \Delta D_0 = P$$

We are now stating that, to reach a sustainable development, the pumping must be balanced by a change in the virgin rate of recharge, ΔR_0, and/or a change in the virgin rate of discharge, ΔD_0, caused by the pumping. Traditionally, the sum of the change in recharge and the change in discharge caused by the pumping, the quantity $(\Delta R_0 - \Delta D_0)$, is defined as the "capture" attributable to the pumping. To be a sustainable development, the rate of pumping must equal the rate of capture.

Notice that to determine sustainability we do not need to know the recharge. The recharge may be of interest, as are all the facets of the hydrologic budget, but it is not a determining factor in our analysis.

Recharge is often a function of external conditions—such as rainfall, vegetation, and soil permeability. In many, if not most, ground water situations, the rate of recharge cannot be impacted by the pumping; in other words, in terms of our water budget,

$$\Delta R_0 = 0$$

In most situations, sustainability of a ground water development occurs when the pumping captures an equal amount of virgin discharge:

$$P = \Delta D_0$$

Let's return to the island aquifer and see how the capture occurs conceptually. When we start to pump, a cone of depression is created. Figure 1 (second cross section) shows the cone of depression at an early stage in the development of our island aquifer. The natural discharge from the island does not start to change until the cone of depression changes the slope in the water table at the shore of the island; remember: Darcy's law controls the discharge at the shoreline. Until the slope of the water table at the shoreline is changed by the pumping, the natural discharge continues at its virgin rate. Until the point in time that the cone reaches the shore and changes the water table gradient significantly, all water pumped from the well is supplied totally from storage in the aquifer. In other words, the cone of depression must reach the shoreline before the natural discharge is impacted (Figure 1—third cross section). The rate at which the cone of depression develops, reaches the shoreline, and then changes the slope of the water table there depends on the dynamics of the aquifer system—transmissivity, storativity (or specific yield), and boundary conditions. The rate of capture in a ground water system is a problem in the dynamics of the system. Capture has nothing to do with the virgin rate of recharge; the recharge is irrelevant in determining the rate of capture.

Figure 1 (third cross section) shows the water table in our island aquifer at a point in time when the natural discharge is almost eliminated; the slope of the water table is almost flat at the shoreline. I deliberately created an aquifer system in which one can induce water to flow from the lake into the aquifer (Figure 1—fourth cross section). In this instance, the sustainable development can exceed the virgin recharge (or the virgin discharge). This again suggests that the recharge is not a relevant input in determining the magnitude of a sustainable development.

Often the geometry of the aquifer restricts the capture. For example, were the aquifer on the island to be thin, we might run out of water at the pump long before we could capture any fraction of the discharge. In this case all water pumped would come from storage. It would be "mined." In the island example, with a thin aquifer, the well could run dry before it could impact the discharge at the shoreline. Notice in Figure 1 (fourth cross section) that I have drawn the situation where the drawdown reached the bottom of the aquifer; the aquifer geometry and diffusivity limit the potential drawdown at the well. This again points out that the dynamic response of the aquifer system is all-important to determining the impacts of development. It is for these reasons that hydrogeologists are concerned with the dynamics of aquifer system response. Hydrogeologists model aquifers in an attempt to understand their dynamics.

Clearly, the circular island aquifer is a simple system. Even so, the principles explained in terms of this simple aquifer apply to all ground water systems. It is the dynamics of how capture takes place in an aquifer that ultimately determines how large a sustainable ground water development can be.

Water Law in the West

Nevada recognized in the early 1900s that the water supply for many of the valleys within the state would have

to come totally from local ground water. Enlightened individuals in Nevada decided to attempt to make the ground water supply within these valleys sustainable. The total discharge in many of the closed valleys in Nevada is by evaporation from the playas and from the transpiration (evapotranspiration [ET]) of phreatophytic plants that tap the water table. Nevada was willing to let the ground water pumping capture both the evaporation of ground water and the ground water that went to support the phreatophytic plants. This thinking led to the Nevada Doctrine that ground water pumping must not exceed the recharge. Perhaps the Nevada Doctrine perpetuates the myth. In reality the Nevada Doctrine is a roundabout statement that the development must not exceed the potential capture of ET (because as shown previously, the virgin ET is equal to the virgin rate of recharge).

As an aside, it has been difficult for the state engineer in Nevada to administer this doctrine in places of heavy urbanization such as Las Vegas, even though Nevada law codified the doctrine. The law also has been difficult to administer where discharge from a valley occurs as perennial streamflow (surface water) that is already appropriated.

The case of the perennial stream with an associated aquifer raises the problem of stream depletion, where pumping impacts streamflow that is appropriated by downstream users. Again, stream depletion is a dynamic ground water problem in capture—all the principles of the simple island example apply. Western water law recognizes the process of stream depletion with varying degrees of success—from zero to full recognition, depending upon the particular state.

Aquifer Dynamics and Models

Since the development of the Theis equation in 1935, hydrogeologists have been concerned with the dynamics of aquifer response to stress: pumping or recharge. Once Theis (1935) and later Jacob (1940) showed the analogy of ground water flow to heat flow, the ground water community has been busy solving the appropriate boundary value problems that describe various schemes of development. This endeavor has gone through several stages.

The 1940s and 1950s were a time during which the ground water profession was concerned with solving the problems of flow to a single well. Numerous solutions to the single well problem were produced. These solutions were used both to predict the response of the aquifer system and to estimate aquifer properties—transmissivity (or permeability) and storativity.

Hydrogeologists of that day saw the limitations in analyzing wells and sought a more robust methodology by which to analyze an entire aquifer, including complex boundary conditions and aquifer heterogeneity. The search led a group at the U.S. Geological Survey (USGS) to invent the analog model in the 1950s; the genius behind this development was Herb Skibitski, one of those individuals who rarely published. The new tool was the electric analog computer model of the aquifer. The model consisted of a finite-difference network of resistors and capacitors. In the analog computer, aquifer transmissivity is represented by the network of resistors; the storativity is represented by the network of capacitors. The resulting resistor-capacitor network is excited by electrical function generators that simulate pumping or other stresses. Voltage is equivalent to hydraulic head in the analog computer; electrical current is equivalent to the flow of water.

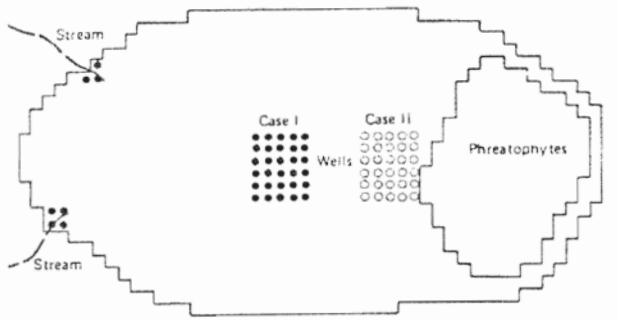


Figure 2. Plan view of a hypothetical closed basin aquifer that is being developed. (Reprinted with permission from *Scientific Basis of Water-Resource Management*. Copyright 1982 by the National Academy of Sciences. Courtesy of the National Academy Press, Washington, D.C.)

In reality, these were elegant finite-difference computer models of aquifer systems. By 1960, the USGS had a facility in Phoenix, Arizona, where analog models of aquifers were routinely built on a production basis. Some of these analog models had multiple aquifers; some had as many as 250,000 nodes. At the time, it was infeasible to solve the same problems with digital computers; the digital computers of the day were too small and too slow. However, by 1970 the power of digital computers increased to the point that digital aquifer models could begin to compete with the analog models. By 1980 digital computer models had replaced the analog models, even at the USGS. The models of the 1980s have now grown to include solute transport, pre- and postprocessors, and automatic parameter estimation. By far the vast majority of ground water flow problems are simulated using the USGS code MODFOW; there is a new version MODFLOW 2000.

The ground water model is a tool with which to investigate the dynamics of realistic aquifer systems. As suggested previously, it is only through the study and understanding of aquifer dynamics that one can determine the impact of an imposed stress on an aquifer system.

Dynamics of a Basin and Range Aquifer

To illustrate the dynamic response of aquifers, I will use closed basin aquifers such as those in the Basin and Range of Nevada as the prototypes. The aquifer geometry is illustrated in plan view in Figure 2. The basin is approximately 50 miles in length by 25 miles in width. At the upper end of the valley, two streams emerge from the nearby mountains and recharge the aquifer at an average combined rate of 100 cfs; approximately 70,000 acre-feet annually. At the lower end of the valley, an area of phreatophyte vegetation discharges ground water as ET at an average rate of 100 cfs. The system before development is in balance; 100 cfs is being recharged, and 100 cfs is being discharged by ET.

Table 1
Aquifer Properties for Our Hypothetical Basin and Range Aquifers

Basin size	50×25 miles (Figure 2)
Cell dimensions	1×1 mile
Hydraulic conductivity	0.0005 and 0.00025 ft/sec
Saturated thickness	2000 ft
transmissivity	1.0 and 0.5 ft^2/sec (approximately 90,000 and 40,000 ft^2/day—both highly transmissive)
Storage coefficient	0.1%–10% specific yield
Phreatophyte area	170 mi^2
Average consumption	100 cfs
Wellfield area	30 mi^2
Average pumping	100 cfs
Recharge	100 cfs

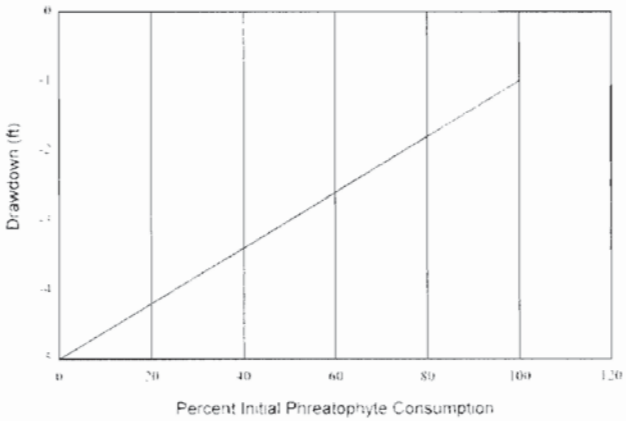


Figure 3. Linear function relating phreatophyte use to drawdown in the aquifer.

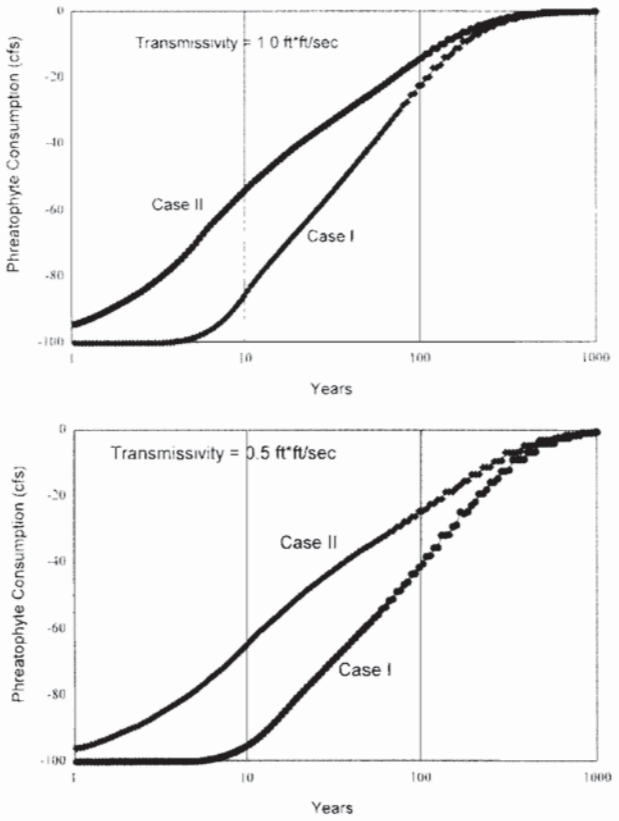


Figure 4. Plots of phreatophyte use vs. time.

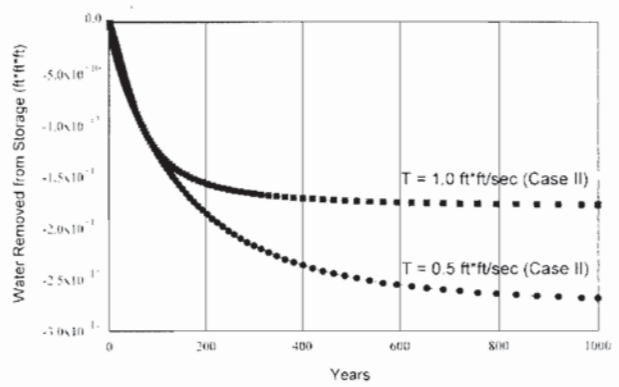


Figure 5. Plots of the change in storage vs. time.

To simulate a well development in this aquifer, I will make the size of the development equal to the recharge (and the discharge) 100 cfs. We consider two locations for our wellfield, shown as Case I and Case II in Figure 2. The Case II wellfield is closer to the area of phreatophyte vegetation. To simulate the system, we need aquifer properties; the aquifer properties are specified in Table 1.

In our hypothetical system, we will eliminate phreatophyte ground water consumption as the pumping lowers the water table in the area containing phreatopyhtes. I deliberately created a ground water system in which capture of ET can occur. A linear function is used to cut off the phreatophyte consumption. As the water table drops from 1 to 5 feet, we linearly reduce the phreatophyte use of ground water—the function is shown in Figure 3. The reduction in phreatophyte use does not start until the ground water declines 1 foot; by the time the water table drops 5 feet, the phreatophyte use is eliminated in that cell. The phreatophyte reduction function is applied cell by cell in the model.

For this system to reach a new state of sustainable yield, the phreatophyte consumption must be eliminated entirely. Using the model, we can examine the phreatophyte use as a function of time. Figure 4 is a plot of the phreatophyte use in our system versus time since pumping was initiated. I have considered two transmissivities for the hypothetical system (1.0 and 0.5 ft^2/sec); both are high transmissivities. In the higher transmissivity aquifer, the phreatophyte consumption is very small after 400 years; in other words, the system has reached a new steady state in approximately 400 years. The new steady state is a sustainable development. In the lower transmissivity case, it takes approximately 900 to 1000 years for the phreatophyte consumption to be become very small.

In both aquifers, the phreatophytes are impacted faster where the pumping is closer to the phreatopytes (Case II). The point of considering Cases I and II is to show that the location of the pumping makes a difference in the dynamic response of the system. Most individuals, even trained hydrogeologists, are surprised at how slowly a water-table ground water system, like both the two systems simulated, responds to development.

We can look at the output from the model another way by examining the total amount of water removed from storage in our aquifers (Figure 5). In the high transmissivity aquifer, the amount of water removed from storage stabilizes in ~400 to 500 years, indicating we have reached a new steady state. Figure 5 shows that something of the order of 10^{11} cubic feet (approximately 3 million acre-feet) of water has been permanently removed from storage as the system changed to reach this new steady-state condition. This illustrates the important point that water must be removed from storage to reach a new steady state (sustainable) condition. In the lower transmissivity aquifer, water is still being removed from storage at 1000 years, and we have not yet reached a new steady state. In the lower transmissivity aquifer, ~5.7 million acre-feet of water have been removed from storage in 1000 years of pumping. Figure 5 again illustrates how slowly a water table aquifer responds.

It is important to notice that, even though the two developments (Case I and Case II) are equal in size, the aquifer responds differently depending on where the developments are sited. This again emphasizes the importance of studying the dynamics of the aquifer response: the response is different depending on where the development is located.

This example of our rather simple basin and range aquifer illustrates the importance of understanding the dynamics of aquifer systems. Again, while this is a simple example, the principles illustrated apply to aquifers everywhere. It is the rate at which the phreatopyte consumption can be captured that determines how this system reaches sustainability; this is a dynamic process. Capture always entails the dynamics of the aquifer system.

Conclusions

The idea that knowing the recharge (by which one generally means the virgin rate of recharge) is important in determining the size of a sustainable ground water development is a myth. This idea has no basis in fact.

The important entity in determining how a ground water system reaches a new equilibrium is capture. How capture occurs in an aquifer system is a dynamic process. For this reason, hydrologists are occupied in studying aquifer dynamics. The principal tool for these investigations is the ground water model.

These ideas are not new; Theis spelled them out in 1940. Somehow the ground water community seems to lose sight of these fundamental principles.

References

Alley, W.M., T.E. Reilly, and O.L. Frank. 1999. Sustainability of ground-water resources. U.S. Geological Survey Circular 1186.

Bredehoeft, J.D., S.S. Papadopulos, and H.H. Cooper Jr. 1982. The water budget myth. In *Scientific Basis of Water Resource Management,* Studies in Geophysics, 51–57. Washington, D.C.: National Academy Press.

Brown, R.H. 1963. The cone of depression and the area of diversion around a discharging well in an infinite strip aquifer subject to uniform recharge. U.S. Geological Survey Water-Supply Paper 1545C.

Jacob, C.E. 1940. On the flow of water in an elastic artesian aquifer. *Transactions of American Geophysical Union,* part 2: 585–586.

Sophocleous, M. 2000. From safe yield to sustainable development of water resources: The Kansas experience. *Journal of Hydrology* 235, 27-43.

Theis, C.V. 1935. The relation between lowering the piezometric surface and the rate and duration of discharge of a well using ground water storage. *Transactions of American Geophysical Union,* 16th annual meeting, part 2, 519–524.

Theis, C.V. 1940. The source of water derived from wells: Essential factors controlling the response of an aquifer to development. *Civil Engineer* 10, 277-280.

Appendix

Conversion of Relevant Units—English versus Metric

1 foot	=	0.305 m
1 mile	=	1.61 km
1 square foot	=	0.0929 m^2
1 square mile	=	2.59 km^2
1 acre-foot	=	1234 m^3
1 cubic foot per second (cfs)	=	0.0283 m^3/sec

Appendix C

Hydrographs for Nipomo Mesa Area

Nipomo Mesa Groundwater Resource Capacity Study
San Luis Obispo County, California

The County's Santa Maria Basin Groundwater Monitoring Program Database is the source of data for the hydrographs.

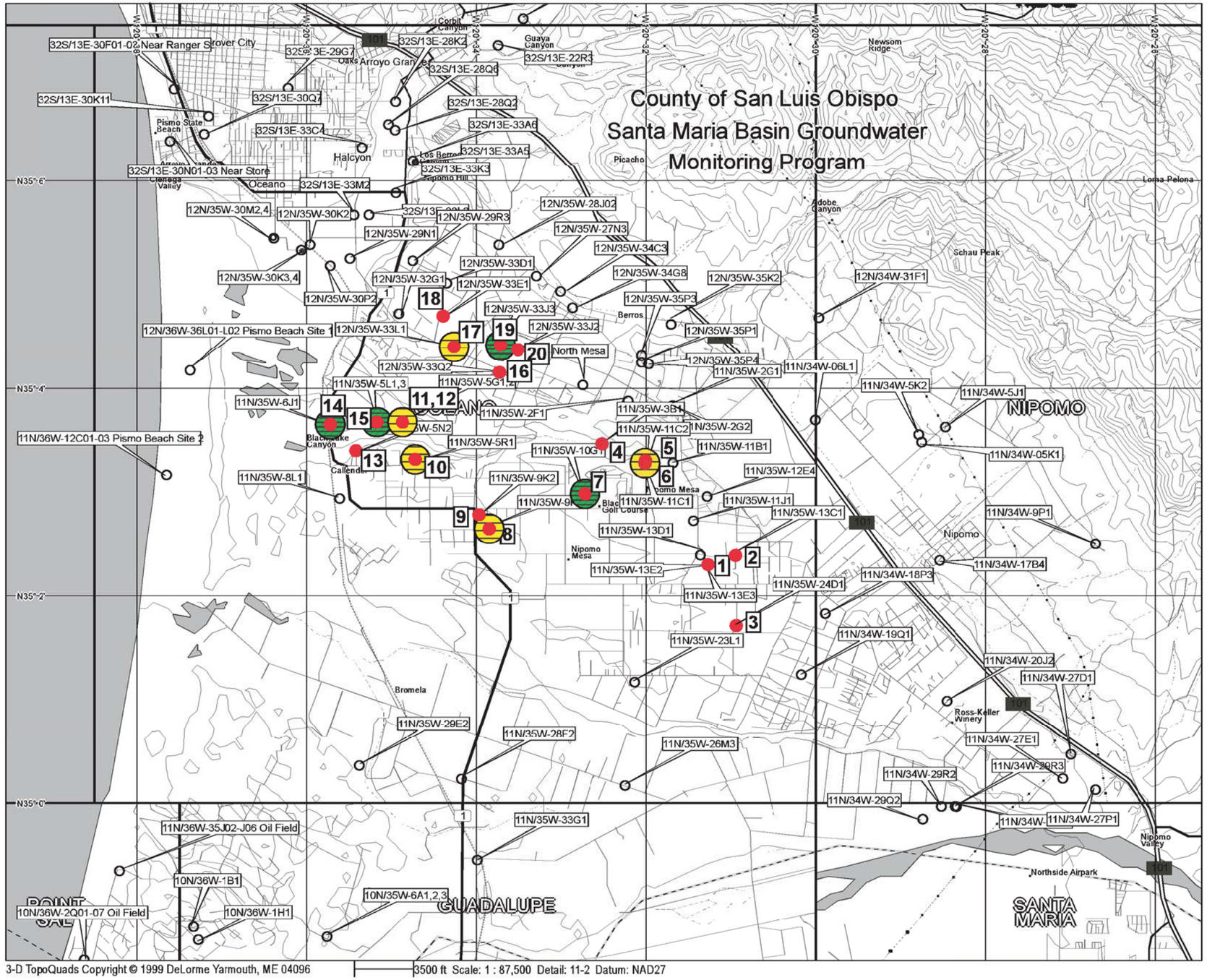
Legend:

- Hydrograph provided herein
- 0ft to 10 ft MSL
- Below sea level

Notes:

14) Non-pumping level -20 ft msl
Pumping level -30 ft msl

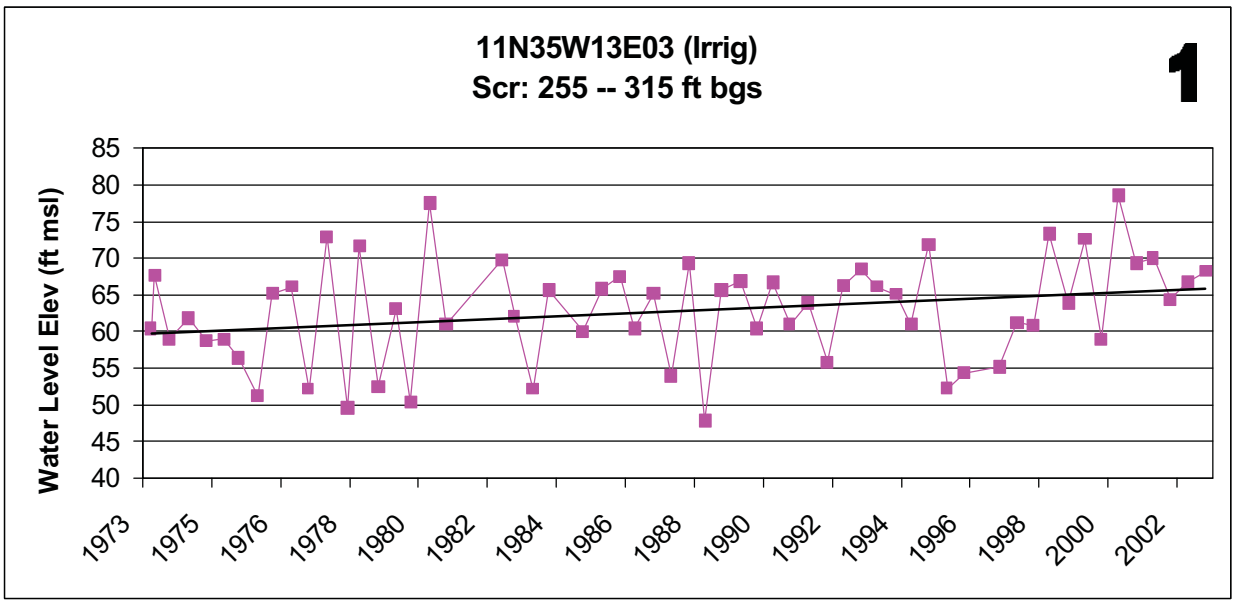
15) Non-pumping level -10 ft msl
Pumping level -40 ft msl

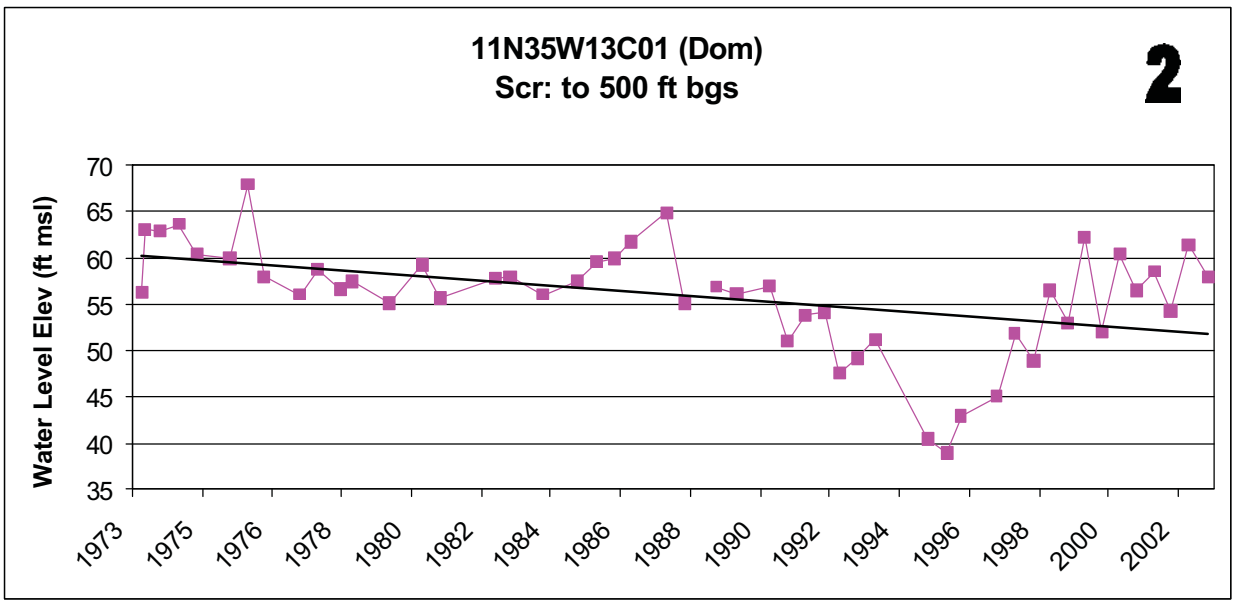


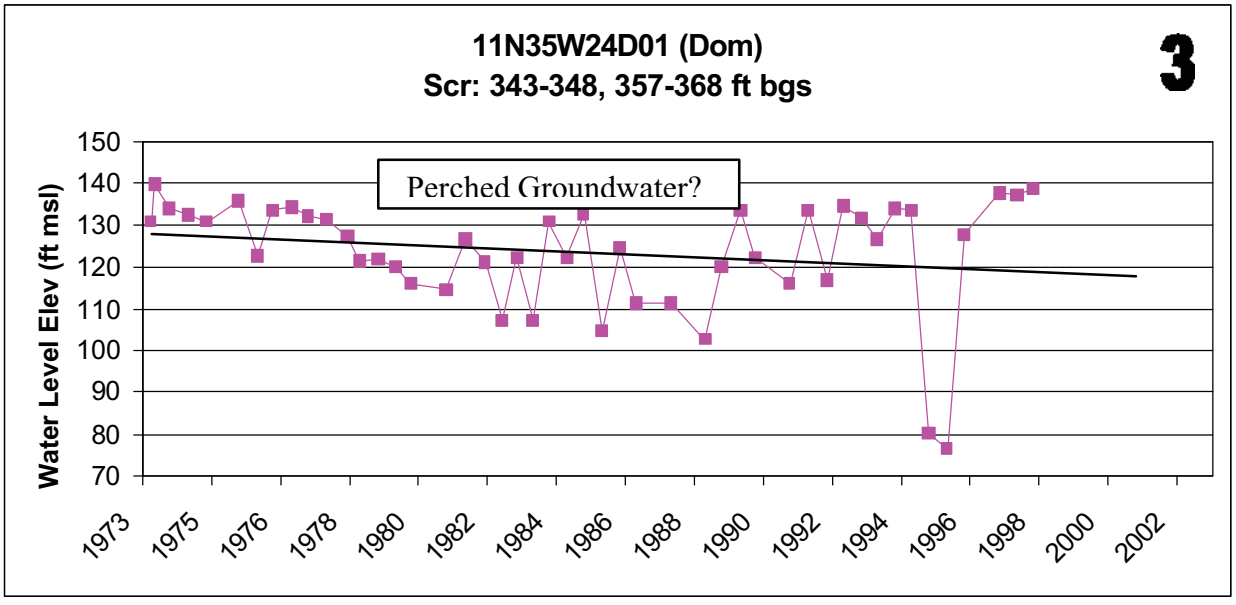
3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 — 3500 ft Scale: 1 : 87,500 Detail: 11-2 Datum: NAD27

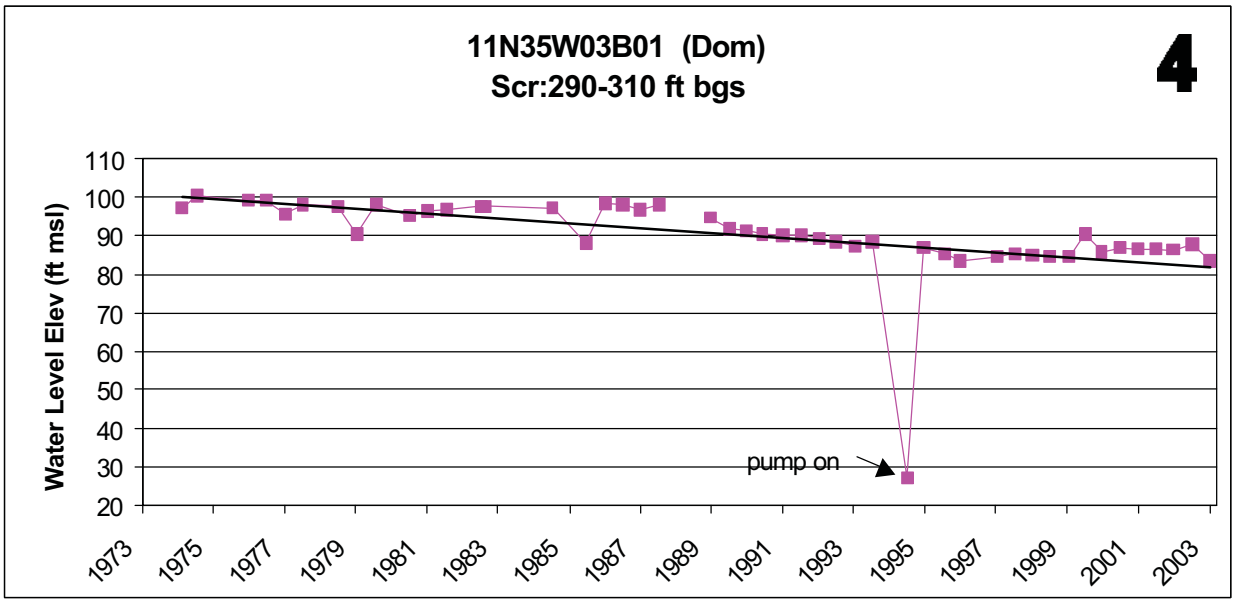
LOCATIONS OF SELECTED HYDROGRAPHS
COUNTY MONITORING WELL LOCATIONS
Nipomo Mesa Water Resource Capacity Study
San Luis Obispo County, California

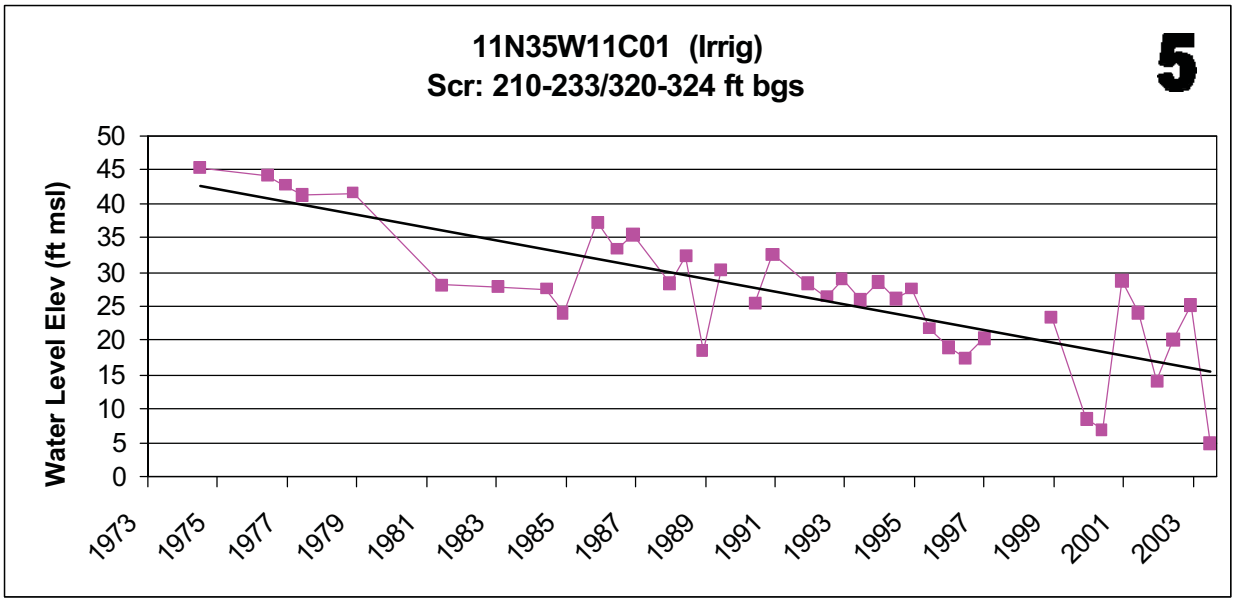
Figure C-1

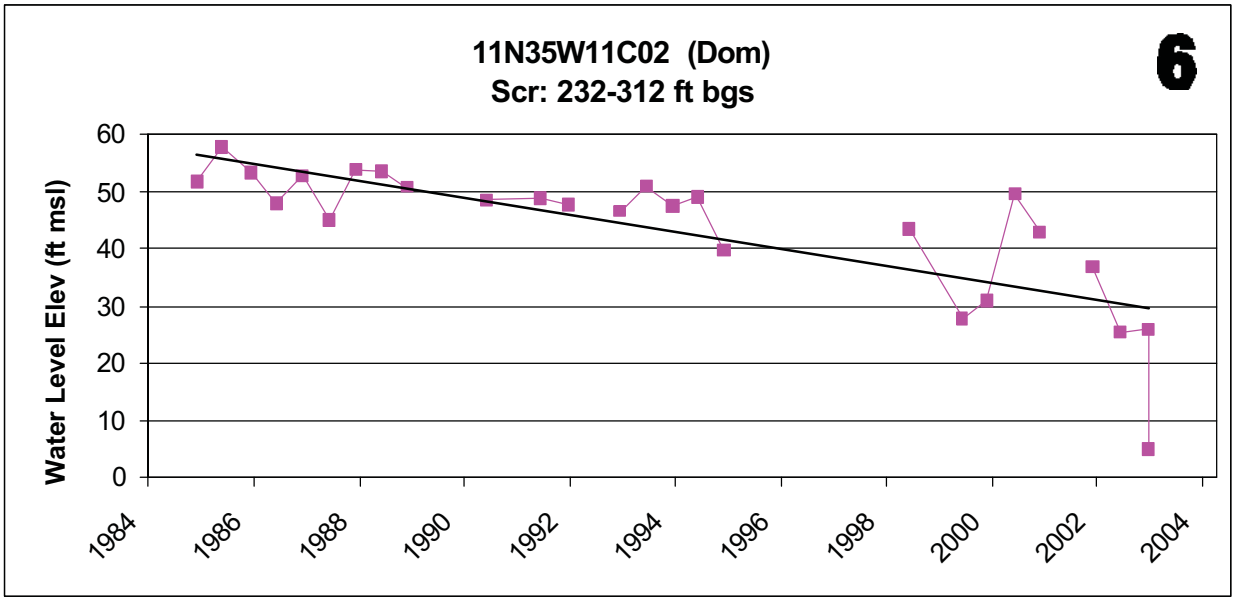

11N35W13E03 (Irrig)
Scr: 255 -- 315 ft bgs
1
Water Level Elev (ft msl)
85
80
75
70
65
60
55
50
45
40
1973
1975
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002


11N35W13C01 (Dom)
Scr: to 500 ft bgs
2
Water Level Elev (ft msl)
70
65
60
55
50
45
40
35
1973
1975
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002


11N35W24D01 (Dom)
Scr: 343-348, 357-368 ft bgs
3
Perched Groundwater?
Water Level Elev (ft msl)
150
140
130
120
110
100
90
80
70
1973
1975
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002

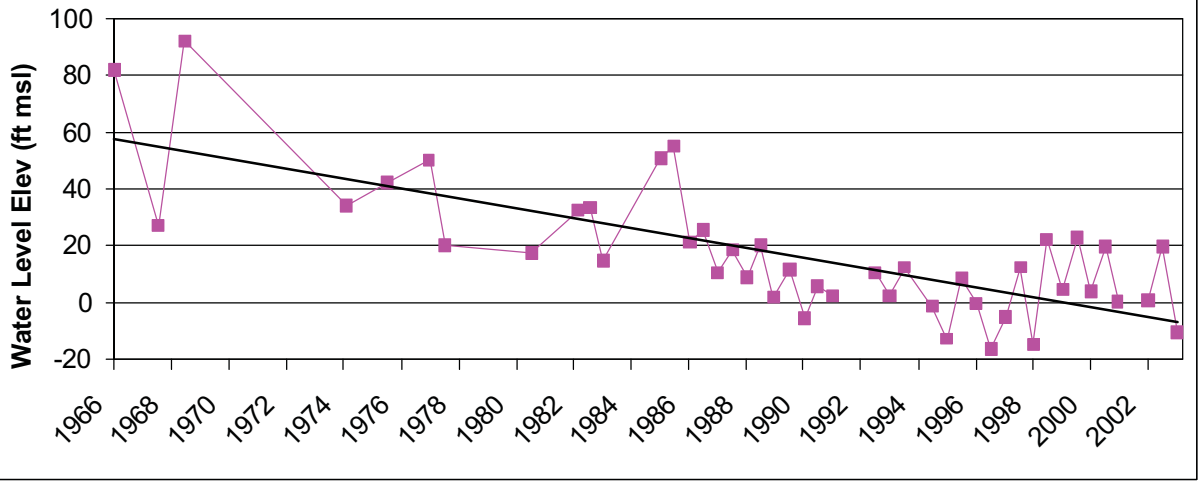

11N35W03B01 (Dom)
Scr:290-310 ft bgs
4
Water Level Elev (ft msl)
110
100
90
80
70
60
50
40
30
20
pump on
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003


11N35W11C01 (Irrig)
Scr: 210-233/320-324 ft bgs
5
Water Level Elev (ft msl)
50
45
40
35
30
25
20
15
10
5
0
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003


11N35W11C02 (Dom)
Scr: 232-312 ft bgs
6
Water Level Elev (ft msl)
60
50
40
30
20
10
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004

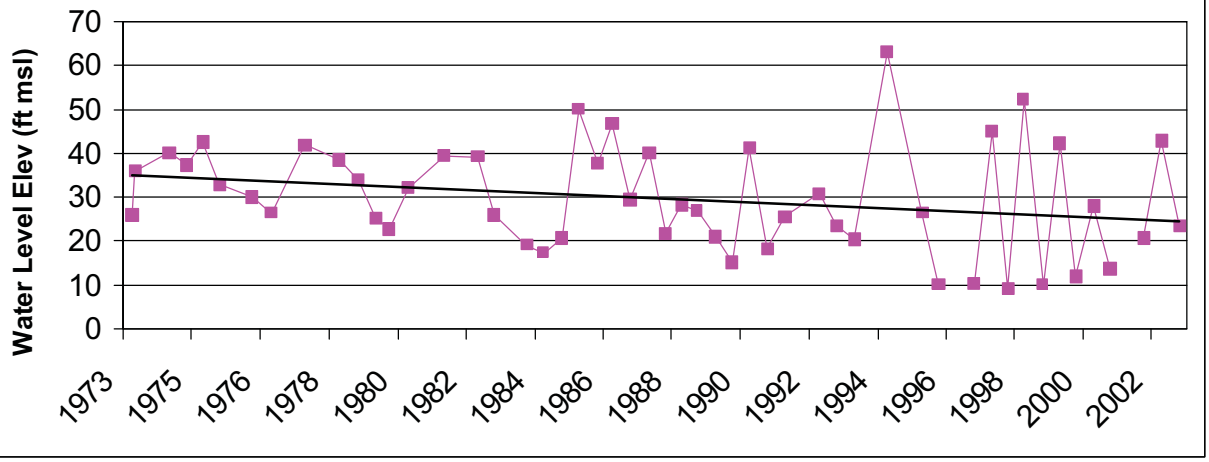
11N35W10G01 (Municipal)
Scr: 230 -- 498 ft bgs

7



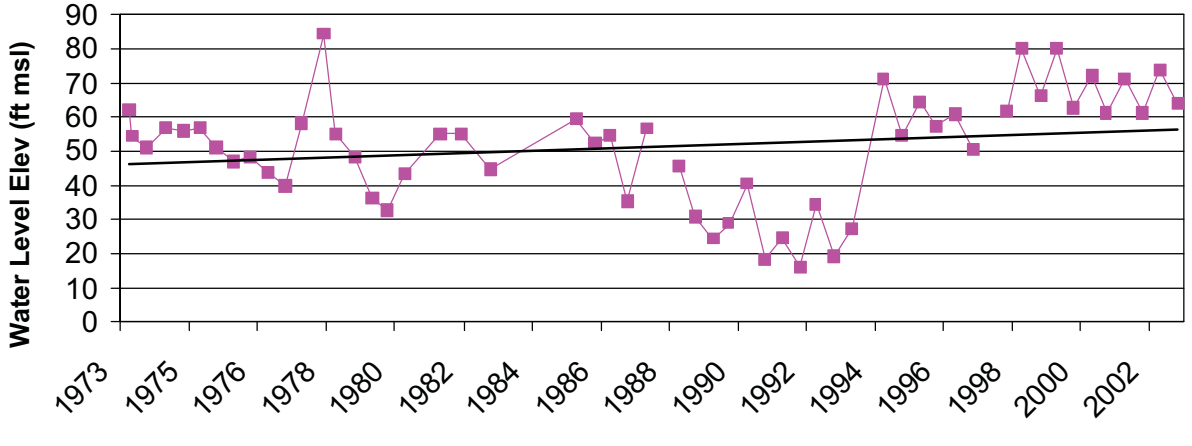
11N35W09K04 (Dom)
Scr: 274 ft bgs

8



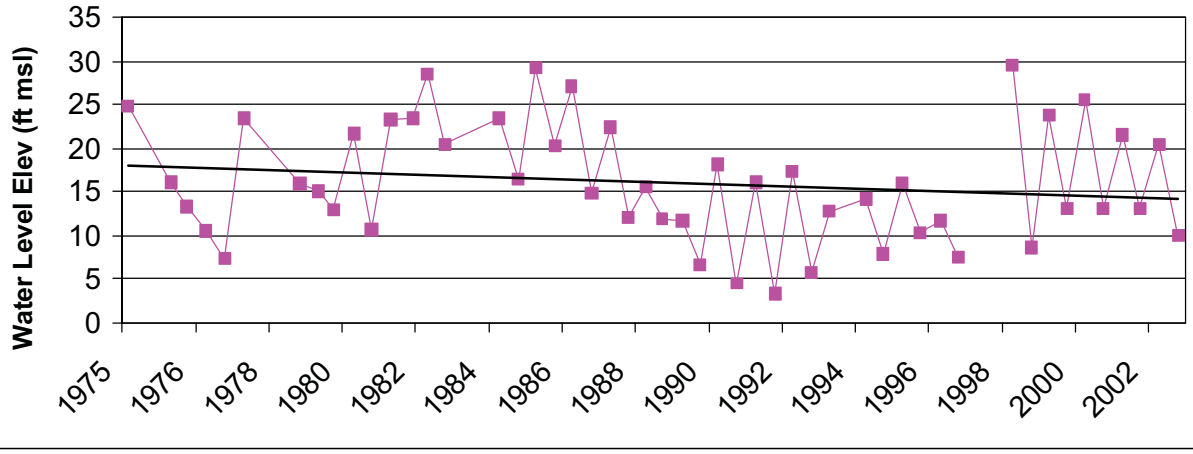
11N35W09K02 (Dom)
Scr: 356 ft ??

9



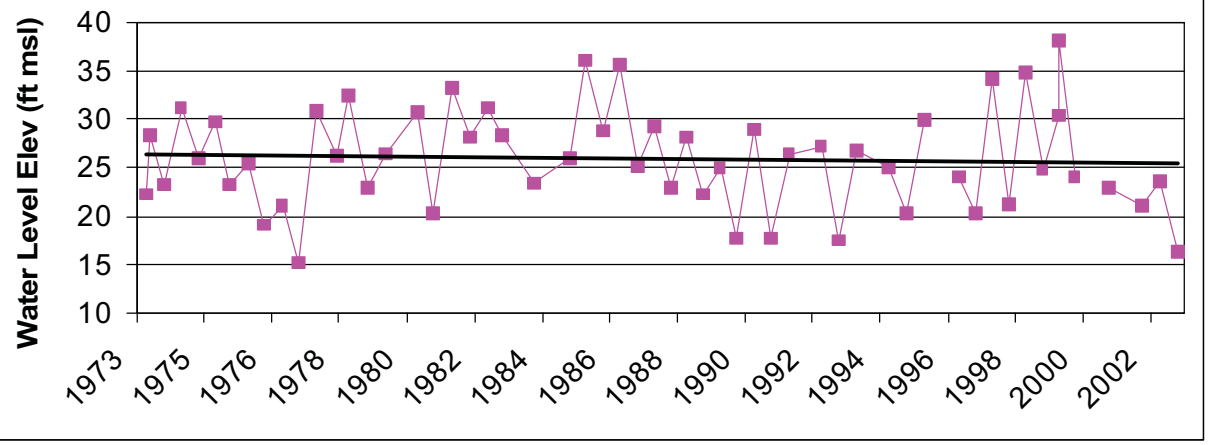
11N35W05R01 (Dom)
Scr: 220-240 ft bgs

10



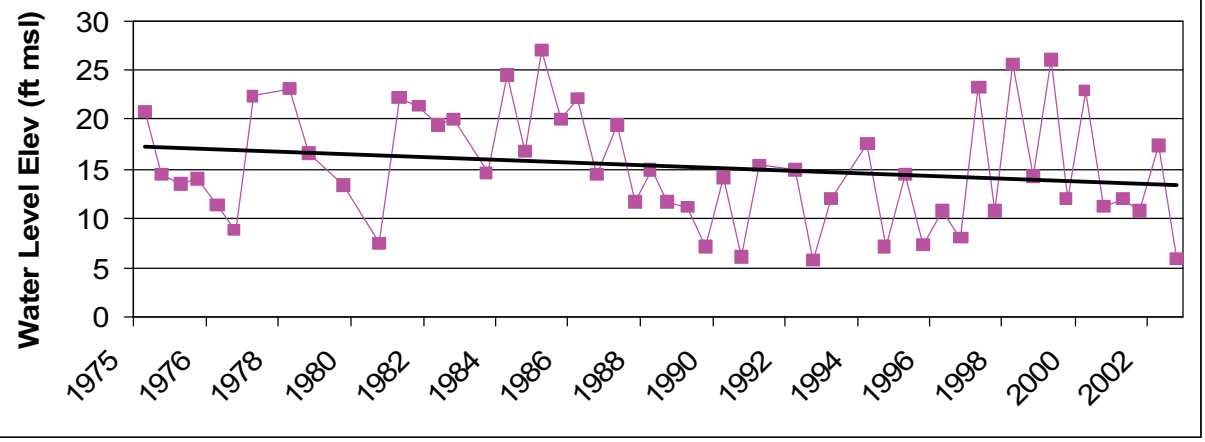
11N35W05G01 (Stock)
Scr 250-265, 165?

11



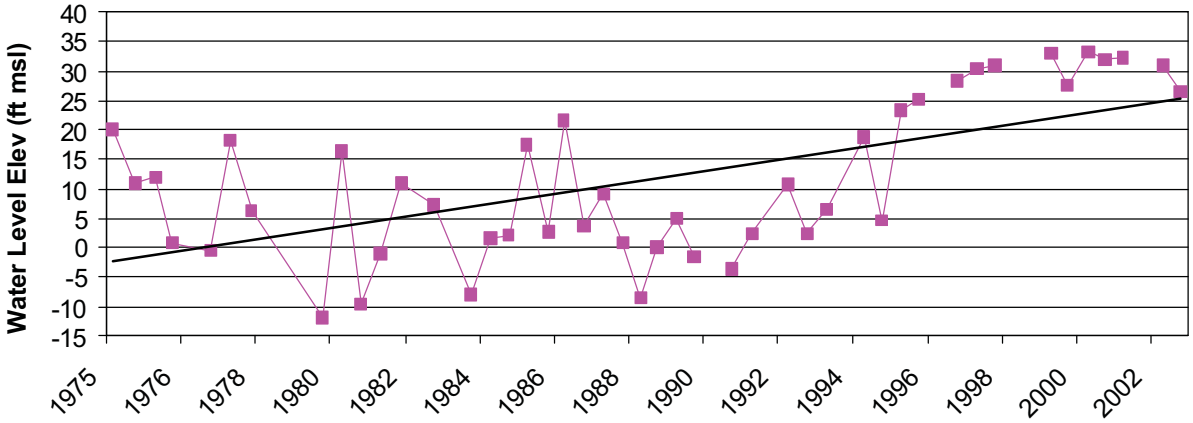
11N35W05G02 (Dom)
Scr 140+ ft bgs

12



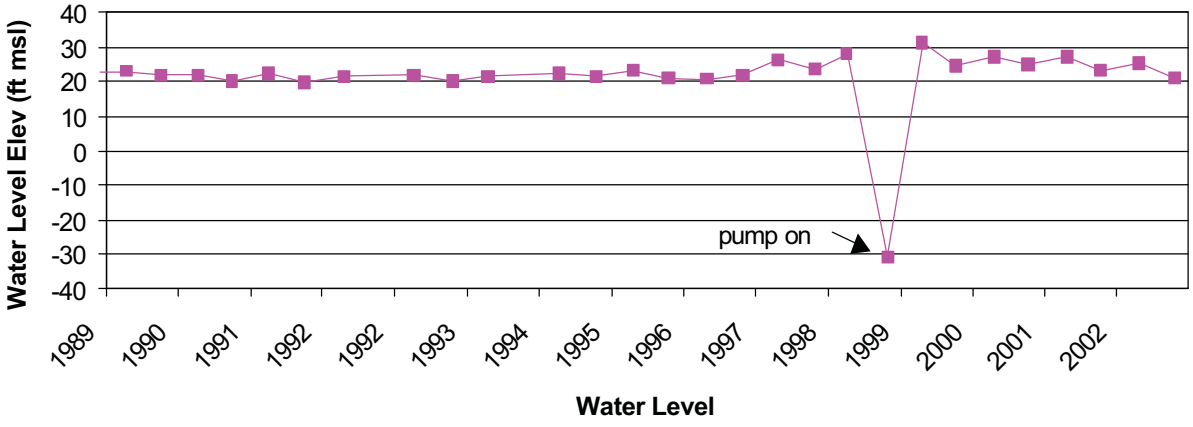
11N35W05N02 (Dom)
(Scr 258-278 ft bgs)

13



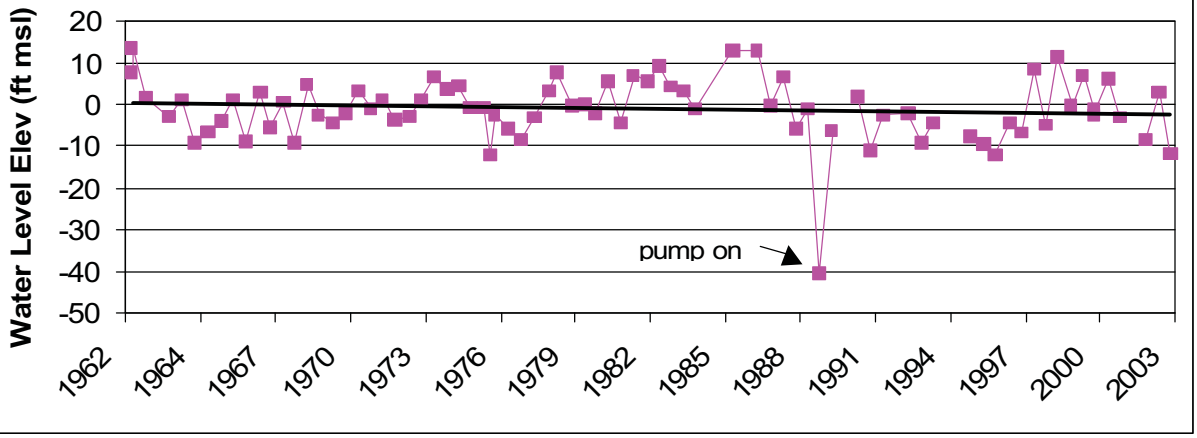
11N35W06J01 (Dom)
Scr ??

14



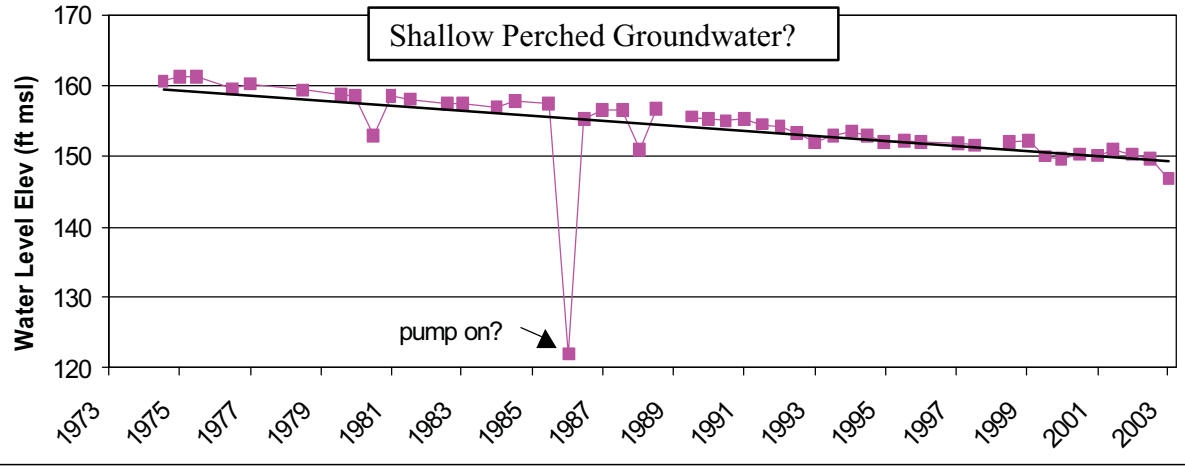
11N35W05L01 (Dom)
200 ft bgs, then clay

15



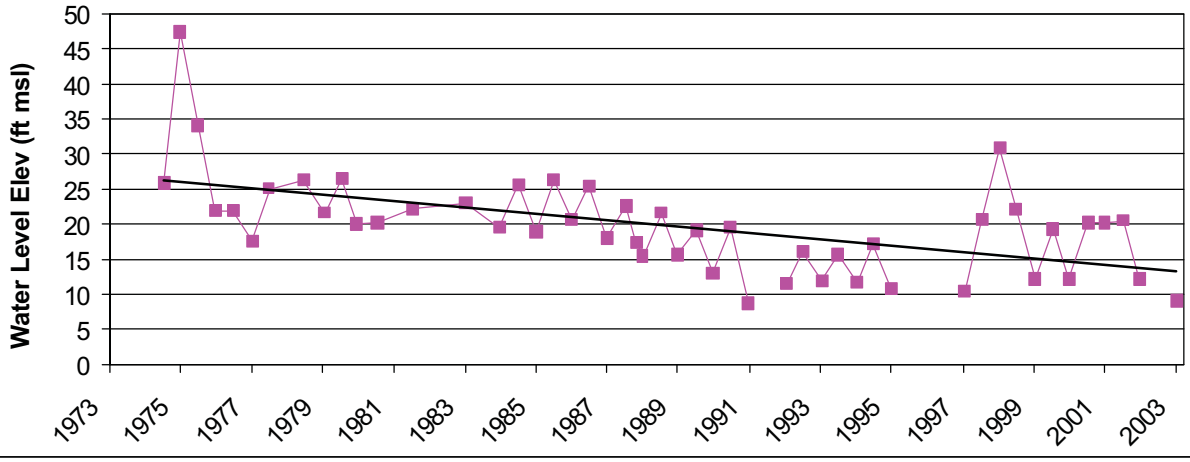
12N35W33Q02 (Dom)
Scr: ??

16



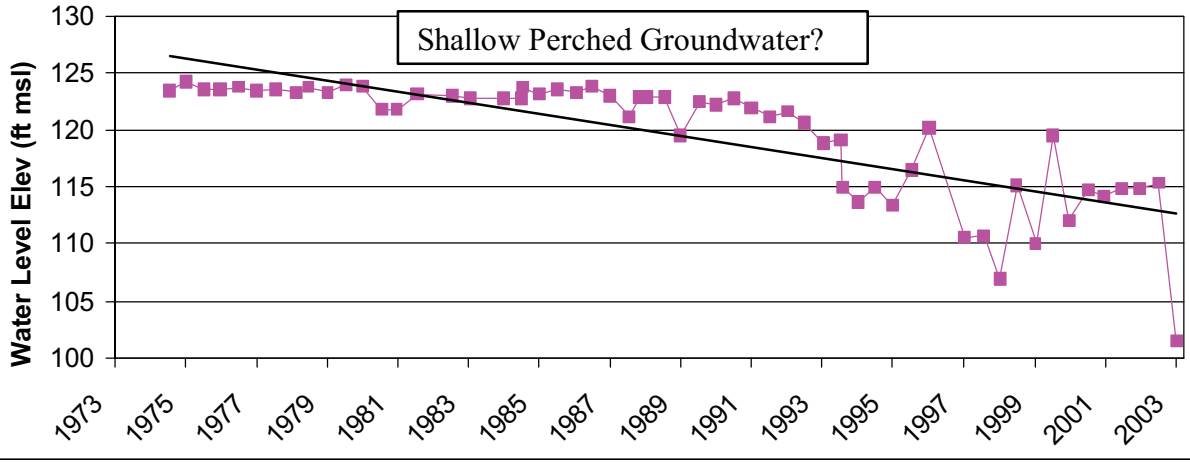
12N35W33L01 (Dom)
Scr: 300-380 ft bgs

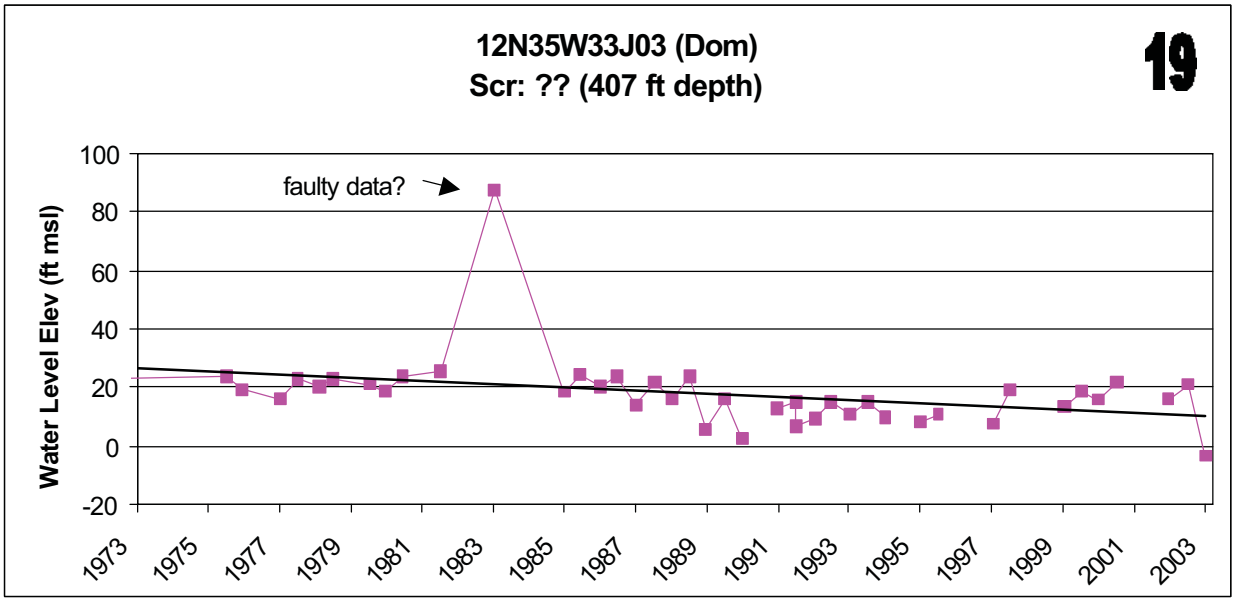
17

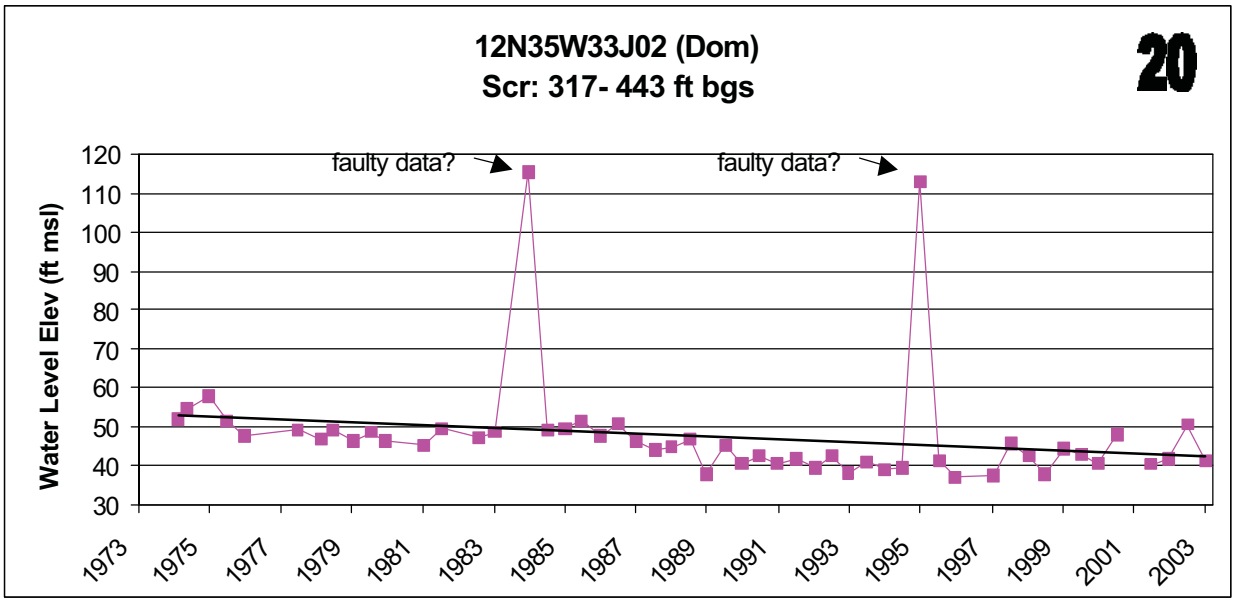


12N35W33E01 (Dom)
Scr: ??

18




12N35W33J03 (Dom)
Scr: ?? (407 ft depth)
19
faulty data?
Water Level Elev (ft msl)
100
80
60
40
20
0
-20
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003


12N35W33J02 (Dom)
Scr: 317- 443 ft bgs
20
faulty data?
faulty data?
Water Level Elev (ft msl)
120
110
100
90
80
70
60
50
40
30
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003

Appendix D

Summary Documentation of Modeling to Evaluate Saltwater Intrusion

Nipomo Mesa Groundwater Resource Capacity Study
San Luis Obispo County, California

Appendix D
Summary Description of Groundwater Models

MODLOW/MT3D Model

Modeling was conducted using MODFLOW (McDonald and Harbaugh, 1988) and MT3D (Zheng, 1990, 1999) to represent a cross-section of the coastal aquifer perpendicular coastal margin. The model cross-section is 80,000 feet long, 1000 feet deep, and consists of one row, forty 2000-foot-wide columns, and thirteen layers most of which are approximately 60 feet thick. The coastal margin is at the center of the model (40,000 feet), and the offshore slope of the model aquifer is based on bathymetric contours on the San Luis Obispo 1:100,000 USGS topographic map.

Constant head is specified at the upgradient margin and at the top layer offshore of the coastal margin to produce a horizontal hydraulic gradient of 0.00125. Uniform horizontal and vertical hydraulic conductivity of 10 and 1 ft/d, respectively, was assigned to the aquifer, and extremely high conductivity of 100,000 ft/d is assigned to the represent the sea. Aqufier storage and specific yield were assigned as 0.001 and 0.25, respectively. Initial concentration of 19,000 mg/l was specified for the sea, initial concentration of 0 mg/l was specified for the aquifer.

Pumping was simulated a distance of 15,000 feet inland of the coastal margin from a well screened from –100 to –800 ft MSL. Change in head and concentration was monitored in the middle portion of the aquifer beneath the coastal margin. Results are discussed in Section 5.3 of the report.

SEWAT Model

Modeling was also conducted using SEAWAT (Guo and Langevin, 2002), which is a specialized version of MODFLOW/MT3D that also accounts for variable fluid density. Model design and assigned properties are similar to the MODFLOW/MT3D model described above, except for the SEWAT model the discretization is much finer.

The model represents a cross-section of the aquifer system perpendicular to the coastline. It is 60,000 feet long and 900 ft deep and consists of 629 columns and 60 layers. The shoreline is at the center 30,000 ft from both ends of the model. The slope of the seafloor is based on bathymetric contours from the USGS San Luis topographic quadrangle.

Model inflow includes constant head at upland margin and uniform recharge of 4 inches per year (25% of average rainfall). Regional horizontal hydraulic gradient is approximately 0.00125. Horizontal and vertical hydraulic conductivity was assigned is 10 and 1 ft/day, respectively. Dispersivity is 50 feet.

First, the model was run without any pumping to achieve an equilibrium position for the saltwater-freshwater interface. Then pumping was assigned 15,000 from the inland from the shore at a depth interval between 100 ft to 600 ft below the water table. Increase in salinity with time a various depths 3000 feet inland of the coastline was evaluated in response to pumping 15,000 feet inland. Results are discussed in Section 5.3 of the report.