Black Lake Canyon Geologic,
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BLACK LAKE CANYON

GEOLOGIC AND HYDROLOGIC

STUDY

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CHIPPING GEOLOGICAL
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Geology, Groundwater
and Environmental Studies

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EXECUTIVE SUMMARY

Black Lake Canyon is located on the Nipomo Mesa in southern San Luis Obispo County. It is designated a Sensitive Resource Area as it contains wetlands and rare and uncommon plants and animals. This study, funded by the Land Conservancy of San Luis Obispo County through a grant from the California Coastal Conservancy, was conducted to better understand the geology and hydrology of the canyon, and to examine certain management options within the canyon relative to the wetlands.

The geology of the canyon is dominated by older dune sands that overlie sand, clays and gravels of the Paso Robles Formation. The canyon lies within the 'Nipomo Mesa hydrologic area', a sub basin of the larger Santa Maria ground water basin.

Earlier studies in the 1970's by the Department of Water Resources indicated that the Nipomo Mesa was in a state of overdraft. A later 1987 study by the consultant company LFM concluded that portions of the Nipomo Mesa were experiencing continuing drawdowns of the water table, but the area as a whole was maintaining or gaining ground water in storage. These earlier studies also concluded that there are two aquifers in the vicinity of Black Lake Canyon area; a shallow aquifer which supplies the lakes in the upper canyon, and a deeper aquifer that is the source of most well water.

In this study, well level data collected by the San Luis Obispo County Engineering Department since 1970 was analyzed. Maps have been constructed in the ground water piezomentric surface for certain years, and the then compared to estimate changes between those years. The water tables around Black Lake Canyon were shown to be declining at an average rate of 0.37 feet per year since 1975. This agrees with the LFM study for the lower Black Lake Canyon area.

The subsurface and surface geology of the canyon is described from surface mapping and from domestic drillers' well logs. The longitudinal profile of the canyon floor is unusual and strongly suggests that the canyon formed from the seepage of ground water. The upper part of the canyon is underlain by clay-bearing sediments that support a perched aquifer. This aquifer supplies the ponds in the upper canyon, and water levels appear to be rising due to increased local recharge from changed land use. The zone of wetland vegetation is increasing in area around the ponds. There is currently a ground water surplus in the shallow aquifer of the upper canyon, but the amount of extractable water that would allow the ponds to sustain is not known. The lower aquifer in the upper canyon is locally severely overdrafted to the south of the canyon, but this appears to have no direct effect on the canyon.

The canyon floor cuts through the clays as it descends westward through the central and lower reaches of the canyon, and the upper, perched aquifer is not present. The water table in the lower canyon has been lowered considerably below the canyon floor since the 1970's, and springs which supported peat bogs have dried up. Water entering the lower canyon may percolate through the floor of the canyon, where wetlands are drying up. Vegetation is changing from marsh to willow woodland. The current ground water deficit in the lower canyon can be attributed to regional overuse, and may not be easily reversed. There is insufficient data to isolate any individual wells that could be contributing significantly to the wetland degradation. The water losses to the lower canyon might be mitigated through enhanced surface runoff into the canyon, where it could be stored in a pond for slow release through seepage.

A simplistic model is developed to show that typical water use on the existing array of domestic wells was likely to be the cause of the current water table decline. The model shows that, with current well use, the water table use is only slightly in deficit, and that conservation could reverse the trend. However, expected development growth in the area will overwhelm any conservation savings.

The habitat requirements of rare and uncommon plants and animals within the canyon wetlands are considered, and management options are discussed relative to enhancing their populations. Currently many species appear to be confined to the lower canyon, and some may have their populations enhanced by introduction to the ponds of the upper canyon. Although very few of the rare plant, Marsh sandwort, survive today, it is not known if they occupy the optimal habitat for the plant, or if the plant could be established elsewhere in the canyon.

Wetlands in the upper canyon could be enhanced by excavating below the water table, by importing waste water, and by a controlled redirection of surface runoff to the canyon. Wetlands in the lower canyon would benefit from the addition of extra water. Dams in the lower canyon could retard water outlow but would damage the riparian plant community. Blockage of a drainage ditch along the axis of the canyon could be an effective measure. More detailed information is needed on the geohydrology of the lower canyon before any proposed modifications are implemented.

The removal of eucalyptus trees has been suggested by others as a way of conserving water. There may be some water savings if upland trees were replaced by chaparral or grassland, but little or none if replaced by other genera of trees such as Coast Live Oak. A review of literature on the species, mainly from Australian and Indian research, indicates that the tree's reputation as a heavy water user in upland areas is probably unwarranted. Trees that root close to the water table may be heavy water users. Although data gathered in India and Australia might not be applicable to California, it was used in a simple, quantitative model of the effects that removing eucalyptus would have on the water budget in the canyon. This model indicates that the removal of trees from the floor of the canyon could save significant amounts of water.

ACKNOWLEDGMENTS

David Chipping wishes to acknowledge the following people and organizations who contributed information, advice, criticism, and insight to this project:

Ray Belknap of The Land Conservancy of San Luis Obispo, Nancy Warner of The Nature Conservancy, Deb Hillyard of the California Department of Fish and Game, Dr. V.L. Holland and Dr. David Keil of California Polytechnic State University, Mr. Bill Deneen and Mrs. Kathleen Goddard Jones of the San Luis Obispo Chapter of the California Native Plant Society, San Luis Obispo County Engineering Department, the residents and landowners of Black Lake Canyon, and Linda Chipping.

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INTRODUCTION

Black Lake Canyon is located on the Nipomo Mesa of San Luis Obispo County (Figure 1). The canyon extends from Highway 1 east to the vicinity of Pomeroy Road for a distance of about four miles. The elevation of the canyon floor increases from 40 feet to 360 feet and the elevation of the canyon rim rises from 80 feet to 400 feet between these two points. The canyon contains wetlands throughout the year, harboring a number of rare plants and wide variety of animal species. It has been designated a Sensitive Resource Area by San Luis Obispo County. In recent years, the area surrounding the canyon has been under pressure of development, with a significant deterioration in the quality and extent of the wetlands. This study, funded by the Land Conservancy of San Luis Obispo County through a grant from the California Coastal Conservancy, was conducted to better understand the geology and hydrology of the canyon, and to examine certain management options within the canyon in terms of their effects on the wetlands. This includes the effects of removing eucalyptus trees.

GENERAL GEOLOGY AND SOILS OF THE NIPOMO MESA

GEOLOGIC UNITS

The Nipomo Mesa lies above a portion of the Santa Maria ground water basin. Studies of the basin include those of Worts (1951), Miller and Evenson (1966), California Department of Water Resources (DWR) (1958, 1970, 1979), and the Morro Group (1990).

The geology of the Santa Maria ground water basin consists of a thick wedge of Tertiary sediments, the bulk of which lie to the south of the Nipomo Mesa. At the southern edge of the mesa, the Tertiary water bearing rocks are about 800 feet thick. Underlying the mesa surface is approximately 100 feet of older dune sand of Upper Pleistocene age, and below this is several hundred feet of gravels, sands, and clays of the Paso Robles Formation. The general dip of the sediments is toward west to southwest toward the ocean at a few degrees. Toward the eastern edge of the mesa the sediments thin out and wedge out against rocks of either the Cretaceous Franciscan Formation, or poorly known Pliocene or Miocene marine strata.

Geologic cross sections are included from past studies . Figures 2A, 2B, 2C and 2D are reproduced from the Morro Group (1990) and were taken from the 1958 DWR study. Figure 2A is an east-west section that shows the eastward thinning of sediments. Figures 2B and 2C show two generally north-south sections, with Figure 2B's section crossing Black Lake Canyon near Highway 1, and Figure 2C's section crossing just above Zenon Road. The sections may be located through Figure 2D. Note that these cross sections have very little lithological well control geologic cross sections through the mesa.

Figure 3 is an east-west cross section from DWR (1979), showing the westward dip of the sediments and a division of the Paso Robles Formation into an 'upper' and 'lower' aquifer system. The cross section appears to have been constructed more as a conceptual tool than as a true interpretation from well logs. The positioning of the 'upper' and 'lower' aquifer systems and the clay and sand beds is probably inaccurate. The 'upper' aquifer of this cross section is not the perched aquifer of the upper canyon discussed in this report, but a subdivision of the 'main' production 'lower' aquifer of this report.

The Morro Group (1990) combined earlier works and their own studies into two cross sections that crossed Black Lake Canyon. These interpret the Paso Robles Formation to be exposed at the bottom of the upper canyon, placing the boundary with the Older Dune Sand higher in the geologic column than the DWR had in its studies. Figure 4A shows the cross sections, and Figure 4B shows their location.

Geological maps recognize a unit, designated as Younger Dune Sands, that are found near Black Lake, lying above the similarly designated Older Dune Sands in the area west of Highway 1. The Younger Dune Sands do not play a significant role in the hydrology of Black Lake Canyon, and will not be discussed relative to the ground water basin hydrology.

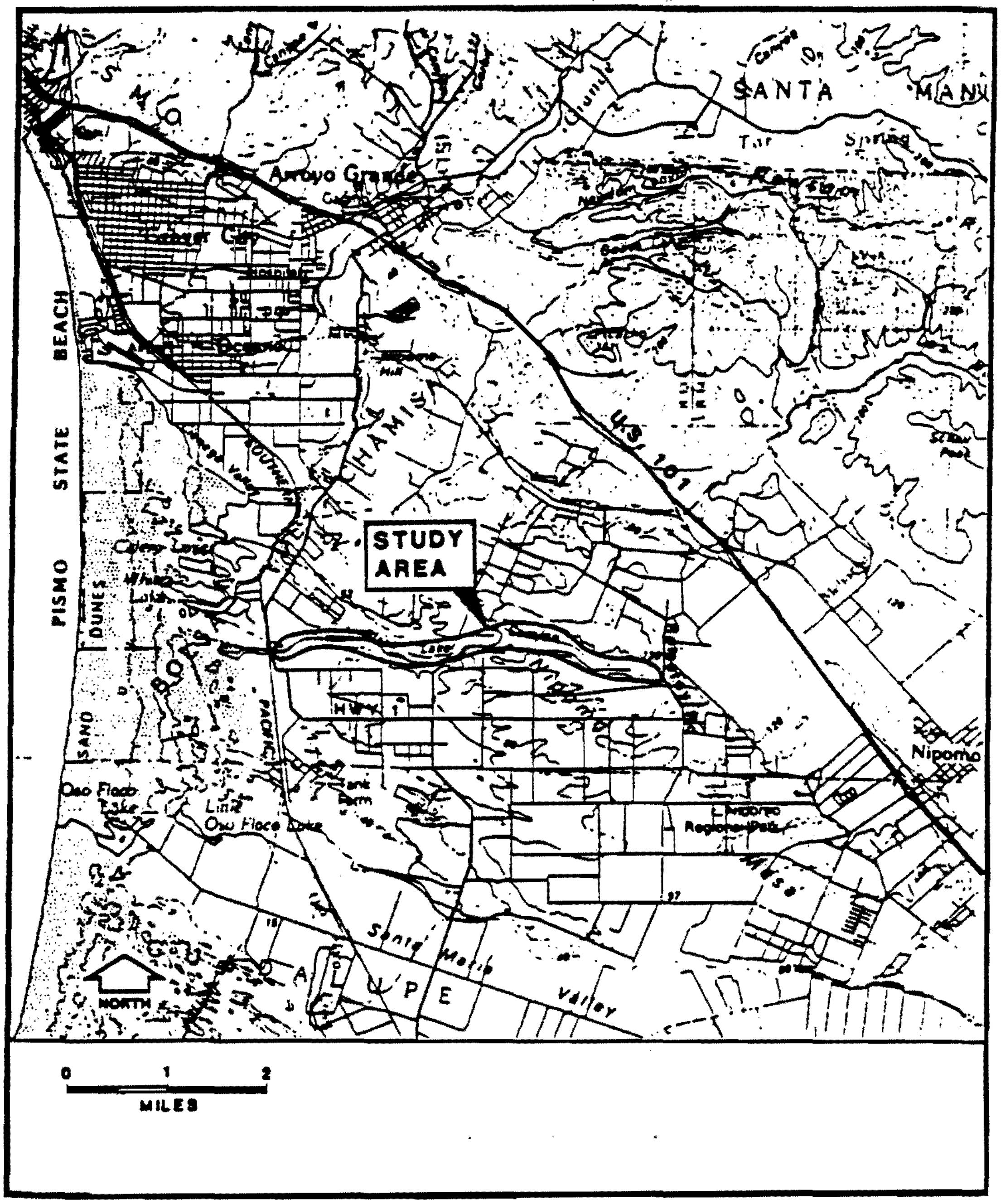


FIGURE 1 Location of Black Lake Canyon (source: McClelland, 1988).

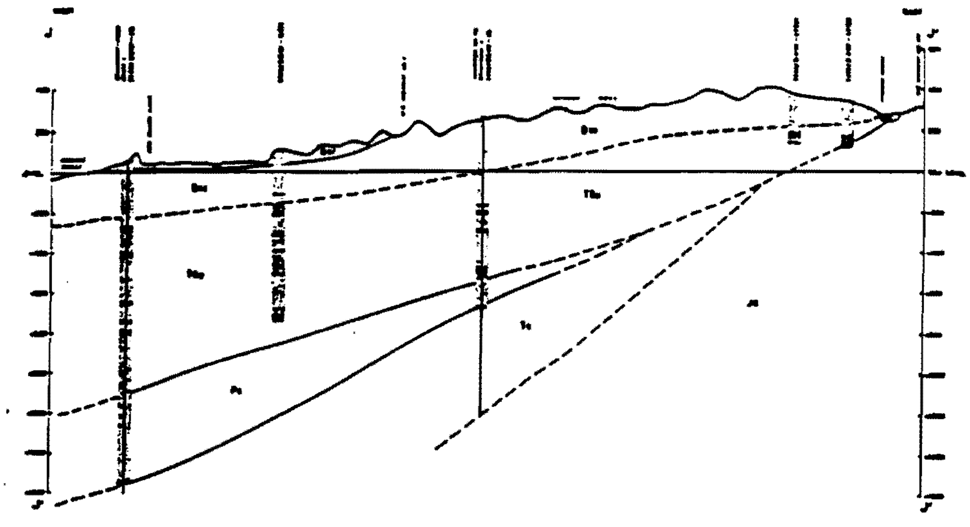


FIGURE 2A East-West Geological Cross Section, (source: DWR, 1958). For cross section location see Figure 2D.

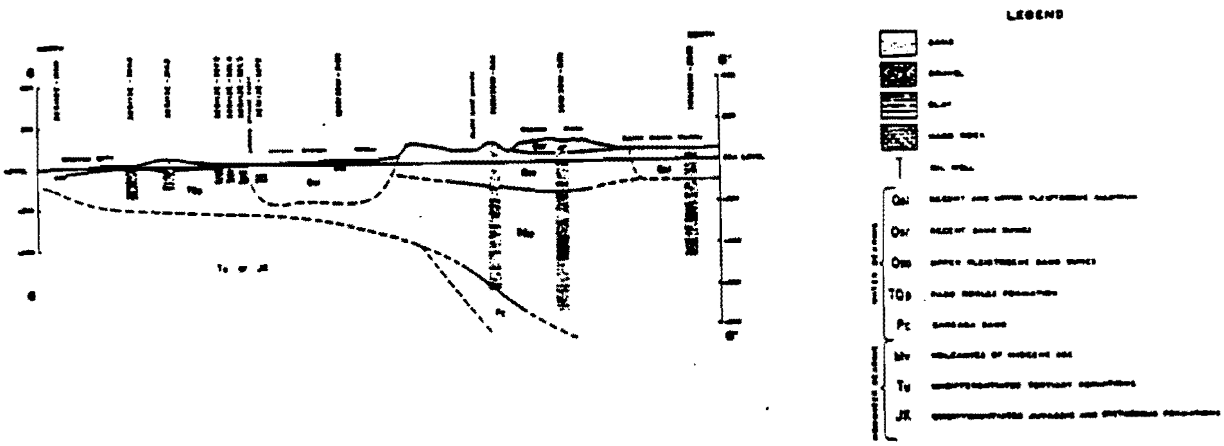


FIGURE 2B. North-South Geological Cross Section near Highway 1 (source: DWR, 1958). For cross section location see Figure 2D.

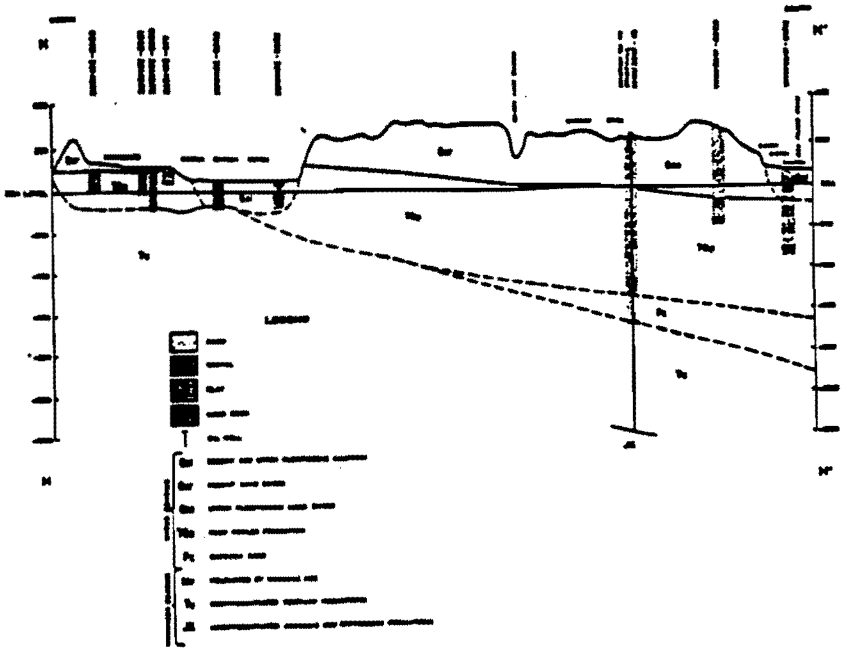


FIGURE 2C North-South Geological Cross Section near Zenon Road, (from DWR, 1958)
For Cross Section Location see Figure 2D

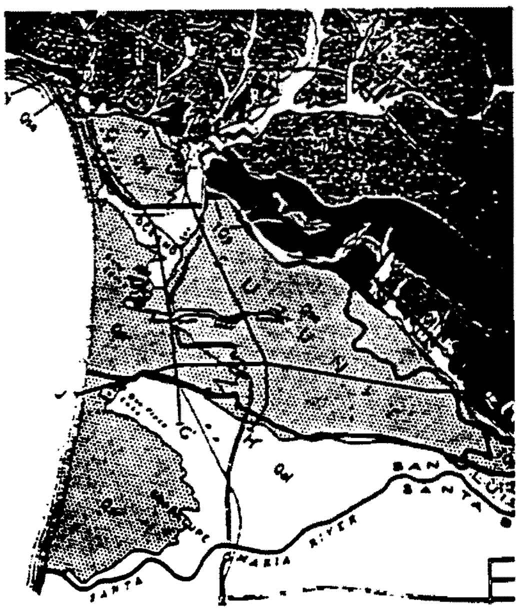


FIGURE 2D Cross Section Locations for Figures 2A-2C, (from DWR ,1958)

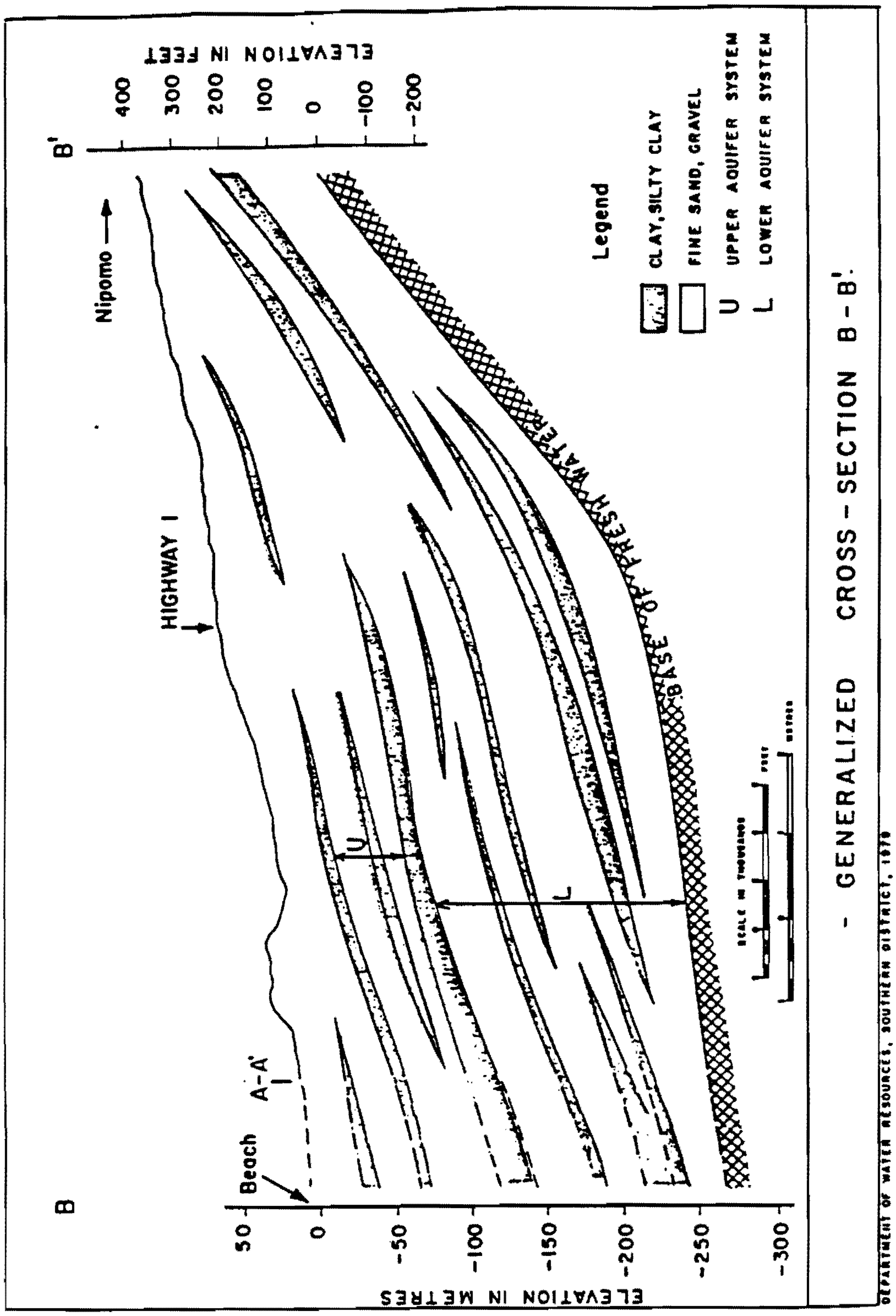


FIGURE 3 Generalized East-West Cross Section, (source DWR, 1979).

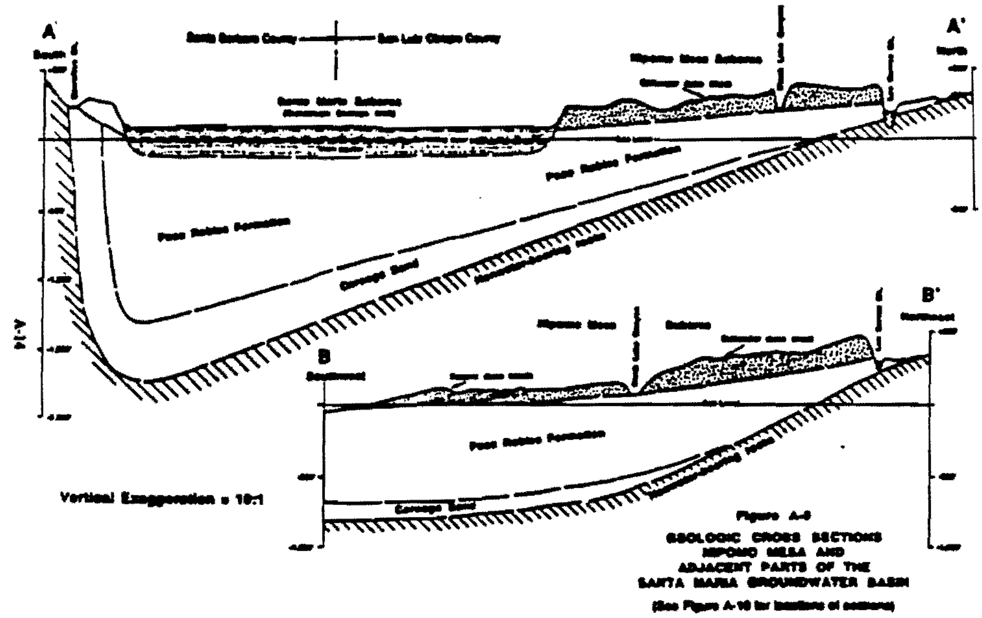


FIGURE 4A . Geologic Cross sections (source: The Morro Group, 1990)

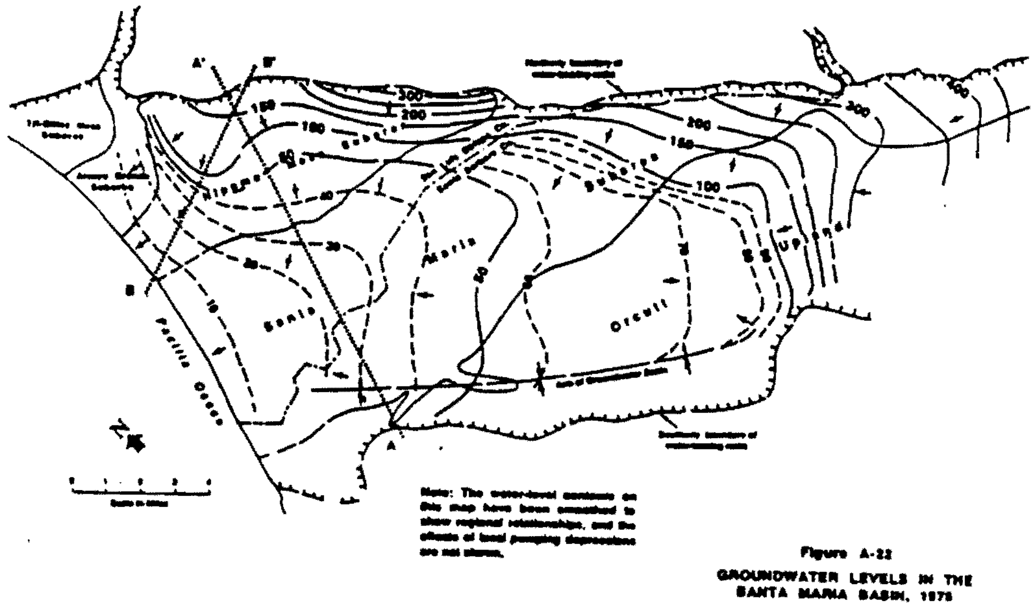


FIGURE 4B. Geologic Cross Section Locations (source: The Morro Group, 1990)

SOILS

Soils units mapped by the Soil Conservation Service (1984) within and around the central and western portions of the canyon consist of mapping units #184 and #185. A portion of Sheet 18 of that study is shown in Figure 5. The brief descriptions of the two units are:

> 184: Oceano Sand (0 to 9 Percent Slope): Very deep, excessively drained, nearly level to moderately sloping soil on stabilized sand dunes. The natural vegetation is mainly brush, annual grasses, and scattered hardwoods. High permeability. Runoff, slow-medium. Erosion hazard, slight to moderate. Crops must be irrigated, preferably by drip or sprinkler methods. Maintaining a good vegetative cover at all times protects the soil from erosion. The classification of this soil type is IV-i(14) irrigated.
>
> 185: Oceano Sand (9 to 30 Percent Slope): Very deep, excessively drained, strongly sloping to moderately steep soil on established sand dunes. The natural vegetation is mainly brush, annual grasses, and scattered hardwoods. High permeability. Runoff, medium-rapid. Erosion hazard, moderate to high. Maintaining a good plant cover at all times protects the soil from erosion. The classification of this soil type is IVe(14) non-irrigated.

The oak woodland on the south side of the eastern end of the canyon is mapped as unit # 223.

> 223: Xerothents, Escarpments (20 to 50 Percent Slope): Slopes range on average of about 40 percent. The soils are fairly well stabilized. The vegetative cover is annual grasses and shrubs. When the soil surface is bare, runoff is rapid, and the hazard of erosion is high. Erosion can be controlled by maintaining adequate plant cover on the soil surface. Some areas could be used for grazing if managed to protect the soil from excessive erosion. The classification of this soil type is VIIe(15) non-irrigated.

The SCS orthophoto map for the Black Lake Canyon area is shown as Figure 5, with the soil units delineated by number.

FIGURE 5 Soil Map For The Black Lake Canyon Area. (source: Soil Conservation Service, 1984).

PREVIOUS GEOHYDROLOGIC ANALYSES OF THE NIPOMO MESA

WATER STORAGE IN THE NIPOMO MESA HYDROLOGIC AREA

In 1979, the California Department of Water Resources (DWR) conducted a study of the ground water in the Arroyo Grande area and defined a "Nipomo Mesa hydrologic area" of 21,000 acres. This included essentially all of the lands west of Highway 101 between the Santa Barbara County Line and the valley of Arroyo Grande Creek. The study concluded that the sub basin of the larger Santa Maria ground water basin had an net inflow or recharge of 4,800 acre feet per year (afy) and a net outflow or extraction of 6,250 afy. DWR defined a 14% specific yield (volume of extractable water as a percentage of aquifer volume) for Nipomo Mesa sediments. The above-sea-level ground water storage changed from 194,000 acre feet in 1967 to 172,000 acre feet in 1975, a decline of 22,000 acre feet.

The DWR (1979) also showed a 3 meter (9.84 feet) cone of depression had developed in the water table at the lower end of Black Lake Canyon. The depression had been 1.5 meters in 1965 (DWR, 1979). This cone of depression may have been due to either wells on the floor of the canyon, or possibly to wells to the northwest at the base of the escarpment that defines the edge of the Arroyo Grande flood plain.

In an 1966 study by Miller and Evenson, the "hydrologic area" was not as rigorously defined, and the surface area for the basin, at 10,500 acres, is smaller than that used by the 1979 DWR investigation. They stated that ground water storage in the Nipomo Mesa dropped from 250,000 acre feet to 160,000 acre feet between the years 1918 to 1950, and to 140,000 acre feet by 1959. Although the area used in their calculations is poorly defined toward the north, it is clear that the section of the basin chosen for their analysis was in long term overdraft. They cite the specific yield of the aquifer to be 15%.

The Santa Barbara Water Agency (1977) used similar geographical boundaries to those of the Miller and Evenson study, and showed the Nipomo Mesa portion of the basin holding steady at 140,000 acre feet in 1975.

In 1987 the consultant company LFM made a thorough analysis of well level records throughout the entire Nipomo mesa, using a methodology similar to that used in this study. Using a 14% specific yield for the sediments, and a calculated sub basin area of 19,990 acres (similar to that of the 1979 DWR study), LFM calculated that between 1975 and 1985 there was a annual storage gain of 1,185 afy throughout the sub basin. LFM note that this apparent gain took place during a period when the basin was receiving above average rainfall. Storage appears to be concentrated along the edge of the Santa Maria River and to a lesser extent near the community of Los Berros. LFM shows areas along the Santa Maria River are gaining the most, and areas around Black Lake Canyon are losing large amounts of storage (Figure 6 and Table 1). However LFM calculated a water balance for the year 1987 that showed the Nipomo sub basin to have a 4,200 afy deficit for the year. Using a slightly different water balance model, San Luis Obispo County Planning Department (1987) calculated an identical 4,200 afy overdraft for 1987.

The 1979 DWR study showed well 11/35-11J1 in the upper canyon dropping from 109 feet above sea level in 1962 to 72 feet in 1974, with a minimum elevation of 60 feet above sea level in 1971-1972. Well 11/35-7R1, located at the north end of the Union Oil Refinery, was monitored between the years 1953-1967. That well's data, first reported by the DWR in 1970, shows the well to be 880 feet deep, and perforated from 280 feet to 800 feet. Well levels dropped from 40 feet above sea level to about 20 feet above sea level between 1953 and 1967. The 1979 DWR study showed the same well in 1973 recovered to 20 feet above sea level from a low of 5 feet above sea level in 1971. These wells were important to the decision made by the Department of Water Resources that the area was in a state of overdraft.

AQUIFER STRUCTURE OF BLACK LAKE CANYON

McClelland Engineers (1988) conclude that there are two aquifers in the canyon, and this is supported by the geologic cross sections of this report. McClelland Engineers conclude, based on earlier work, that there is an "Upper Aquifer" that extends to a depth of 55 feet below the floor of the upper canyon, and that ground water flow in this aquifer is westward at a gradient of 50 feet per mile. They note that some well logs show dry units of the Paso Robles Formation below the base of the upper aquifer, and that there is a "Lower Aquifer" at a depth of about 200 feet below the canyon floor. The hydraulic gradient in the lower aquifer is stated as being about 10 feet per mile toward the southwest. Envicom (1985) reported a 175 feet difference between the static water levels in the lower and upper aquifers in the upper part of the canyon, and a 75 feet difference in the lower canyon. The implication that the "upper" and "lower" aquifers are totally separated by an aquiclude may not be correct for the lower canyon (an aquiclude is a geologic horizon through which water either cannot flow, or flows very, very slowly), where the drying of the wetlands is not compatible with the observed increase in water entering the upper part of the canyon. It is therefore likely that the base of the upper aquifer is 'leaky' at the lower end of the canyon, and that regional drawdown of the principal aquifer, the lower, has resulted in greater infiltration through the leaky floor of the canyon. Also, there has been recent and relatively intensive development south of the western end of the canyon, and some of these wells may utilize waters derived from the upper aquifer. It is clear from the peat beds that are now desiccated and abandoned on the flanks of the canyon that there was once effluent water entering the canyon from at least the north side. The south edge of the marsh above the highway bridge was not visited during this study.

TABLE 1 . Changes in Groundwater Storage for Numbered Partitions of the Nipomo Mesa Sub basin (LFM, 1987) . Refer to Figure 6 for locations of partitions)

Map Ref. (Figure 6)	Average Change (ft.)	Area (acres)	Specific Yield (%~	Net Change (AFY)
1	2.8	1570	14	640
2	-2.1	660	14	-195
3	6.1	710	14	610
4	29	650	14	2650
5	11.9	1660	14	2780
6	26.4	650	14	2400
7	-9.3	900	14	-1170
8	2	2150	14	620
9	-5.7	3140	14	-2500
10	-0.4	1950	14	-110
11	-7.7	1180	14	-1270
12	-8.3	1520	14	-1760
13	-37.2	550	14	-2870
14	-6.4	120	14	-110
15	7.2	1250	14	1180
16	2.4	1350	14	450
	Totals:	19990		1185

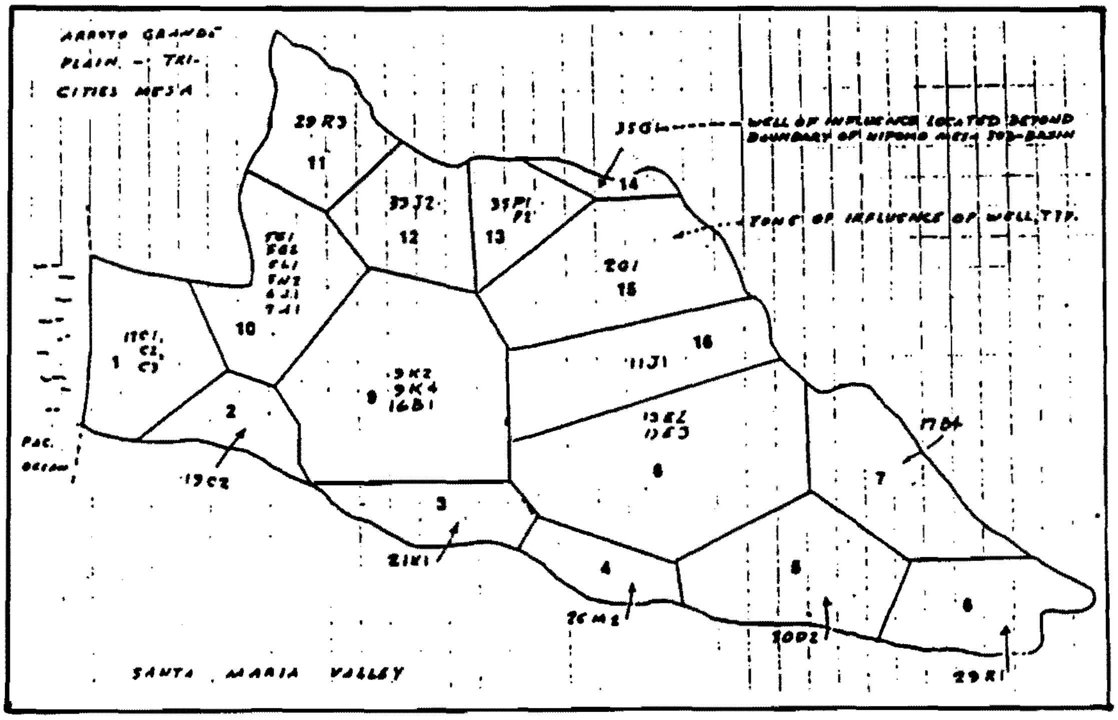


FIGURE 6 Basin Storage Areas used by LFM for storage computation (see Table 1).

CURRENT GEOHYDROLOGIC INVESTIGATION

ANALYSIS OF WELL RECORDS

For this study the group of wells monitored by San Luis Obispo County were used in the analysis. Data was collected from the early 1970's to the present time. The San Luis Obispo County Engineering Department measures well levels in the spring and fall, recording the water level as distance from the well head. The methodology for this current study is similar to that of the 1987 LFM study. This is essentially the same data set that was available for the 1987 LFM study.

For further analysis the data was converted to elevation of the well water surface above sea level, since the well head elevation was recorded in most cases. No attempt was made to validate the recorded elevations of the well heads, which are rumored to be inaccurate in some cases. The analysis should therefore be used with some caution. The wells are identified by well number and are shown in Figure 7. The changes in height above sea level of water in these wells are shown in Appendix A.

Use Of Well Level Data Collected During Spring Season

In comparing the well levels from one year to the next, great differences can exist due to the character of the well use. Well use is commonly highest during the summer when irrigation use is greatest. There are greater differences in the relative water depth in the fall than in the summer due to the variability of use and conditions prevailing just before the well level is read. Well levels are usually more consistent in the spring, and for this reason only spring readings were used in this analysis. In cases where the well reader noted either that the well pump was running or had been running very recently, the data was not used because it reflects the pumping drawdown rather than the water table level. It is possible that some of the data in the set falls into this category, but was unknowingly included.

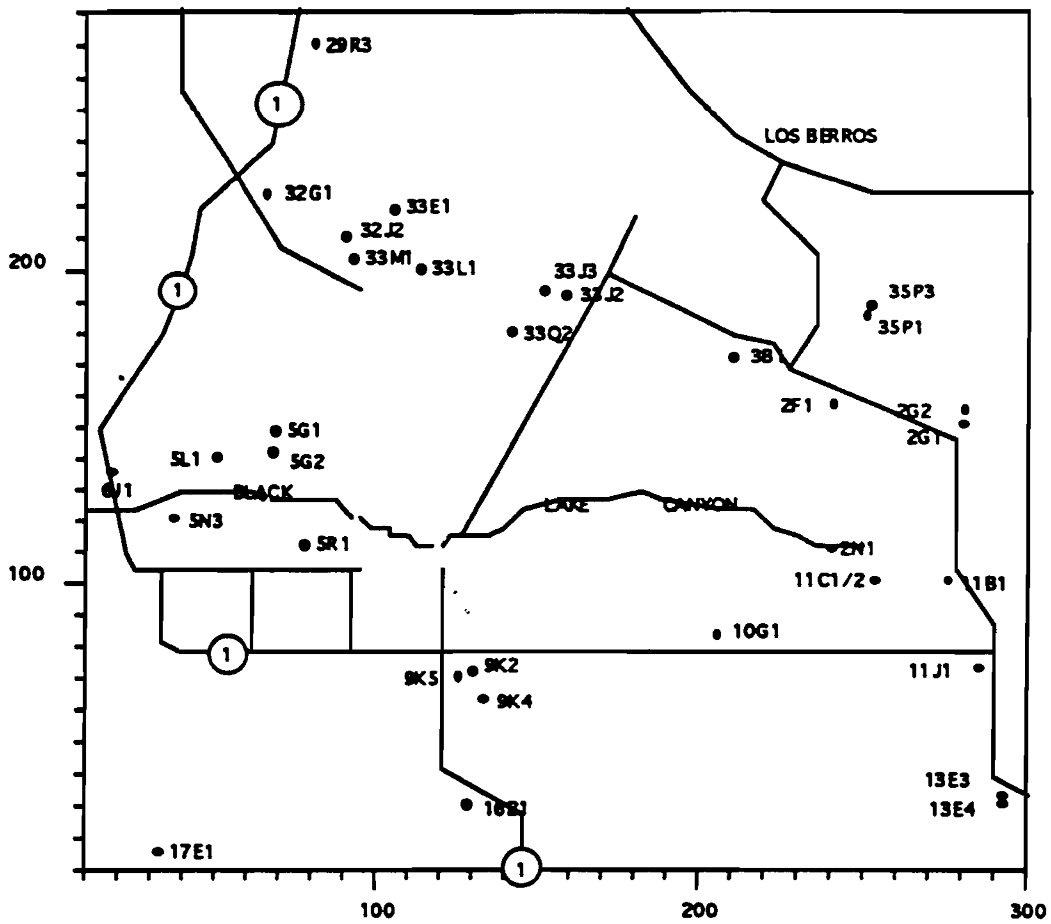


FIGURE 7 Wells Monitored by San Luis Obispo County and Used in This Analysis

<u>Development Of Piezometric Surface Maps</u>

The data collected from the well readings was entered into a three dimensional contouring program. An X- Y- grid was placed over the map of the well locations, and their coordinates entered into a spreadsheet. The spring water level relative to sea level was entered as the Z- coordinate, and the data then contoured using the graphing software MacGRIDZO™. Water level maps for the area of the mesa surrounding Black Lake Canyon are shown for each of the years 1975, 1980, 1985, 1990, and 1993 (Figures 8,9,10,11 and 12).

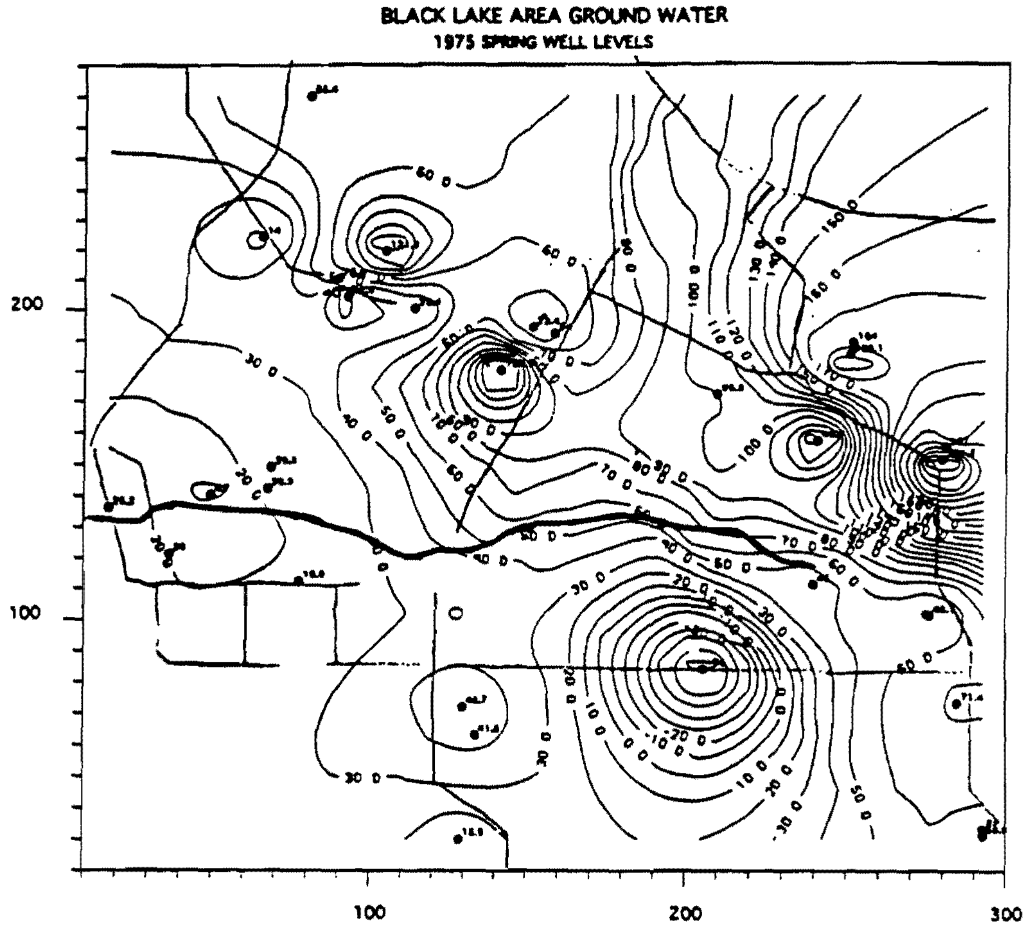


FIGURE 8 Piezometric surface computed from wells monitored by San Luis Obispo County in 1975

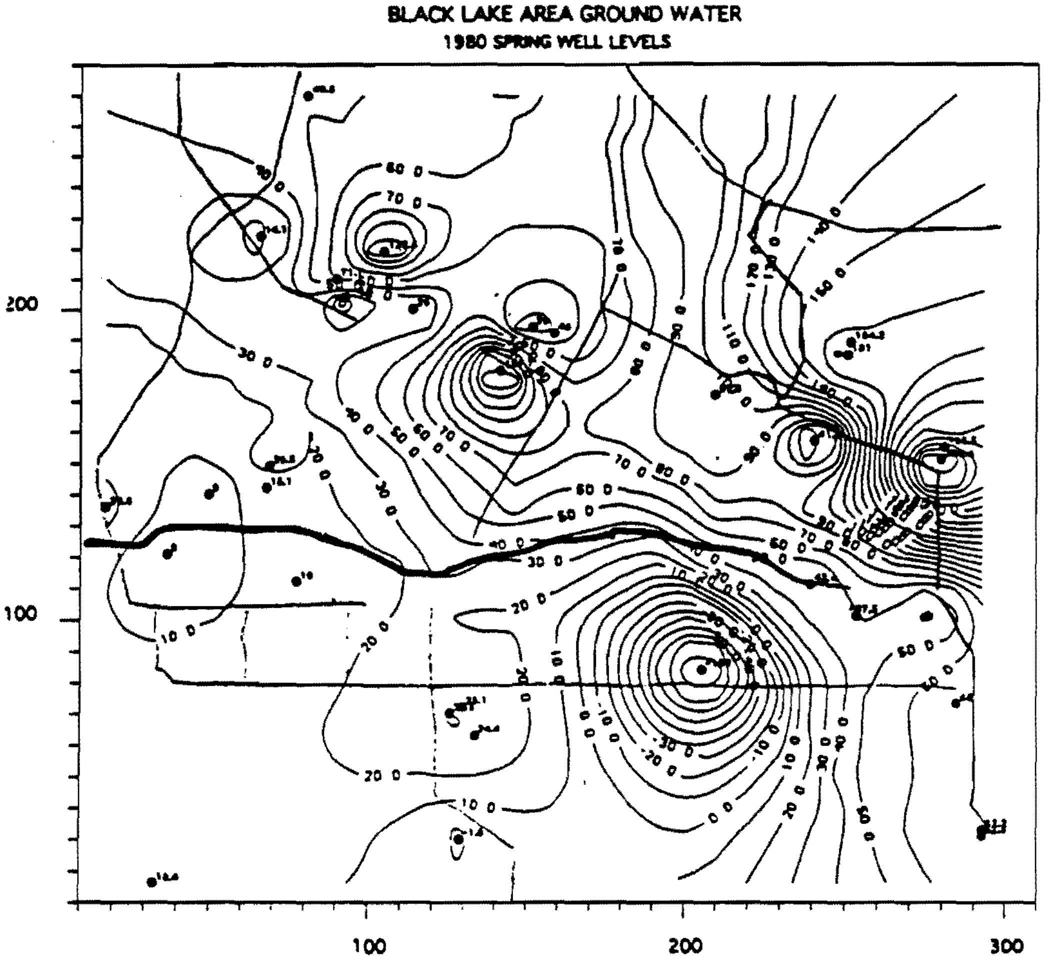


FIGURE 9 Piezometric surface computed from wells monitored by San Luis Obispo County in 1980

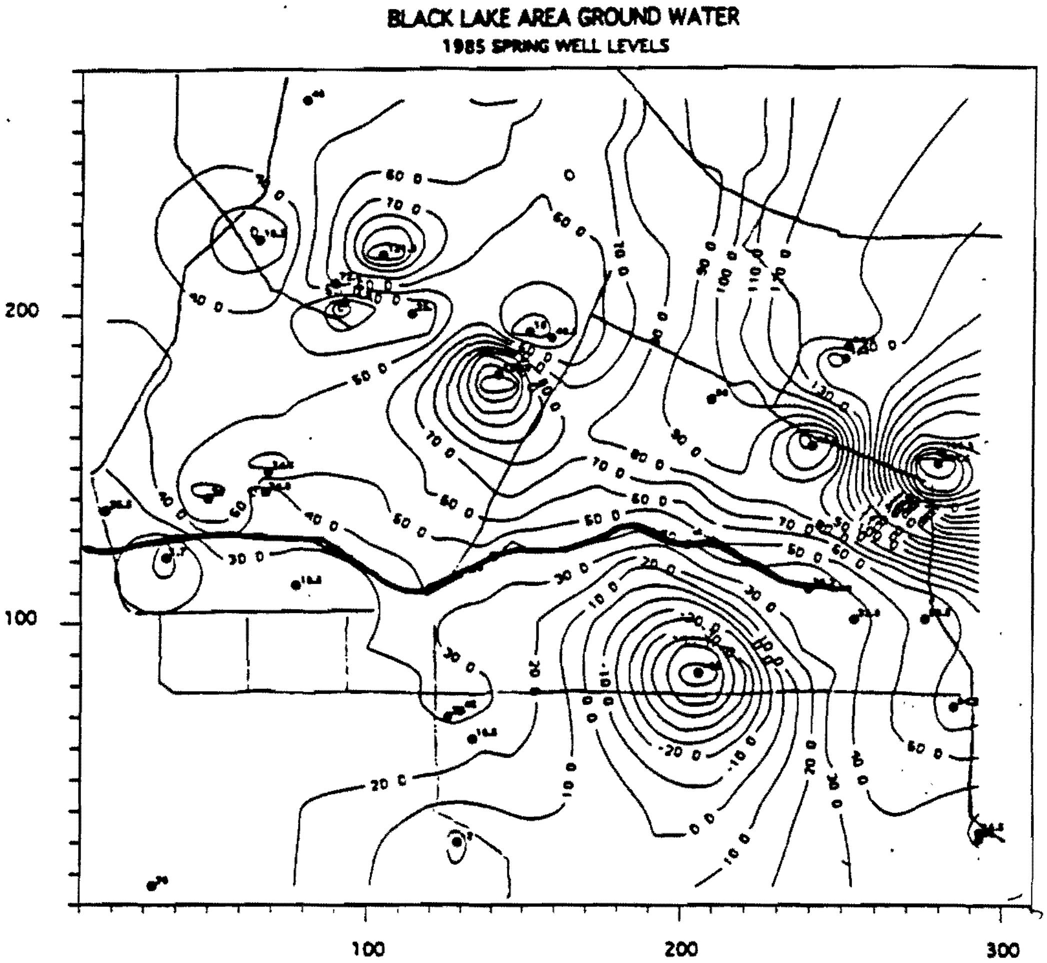


FIGURE 10 Piezometric surface computed from wells monitored by San Luis Obispo County in 1985

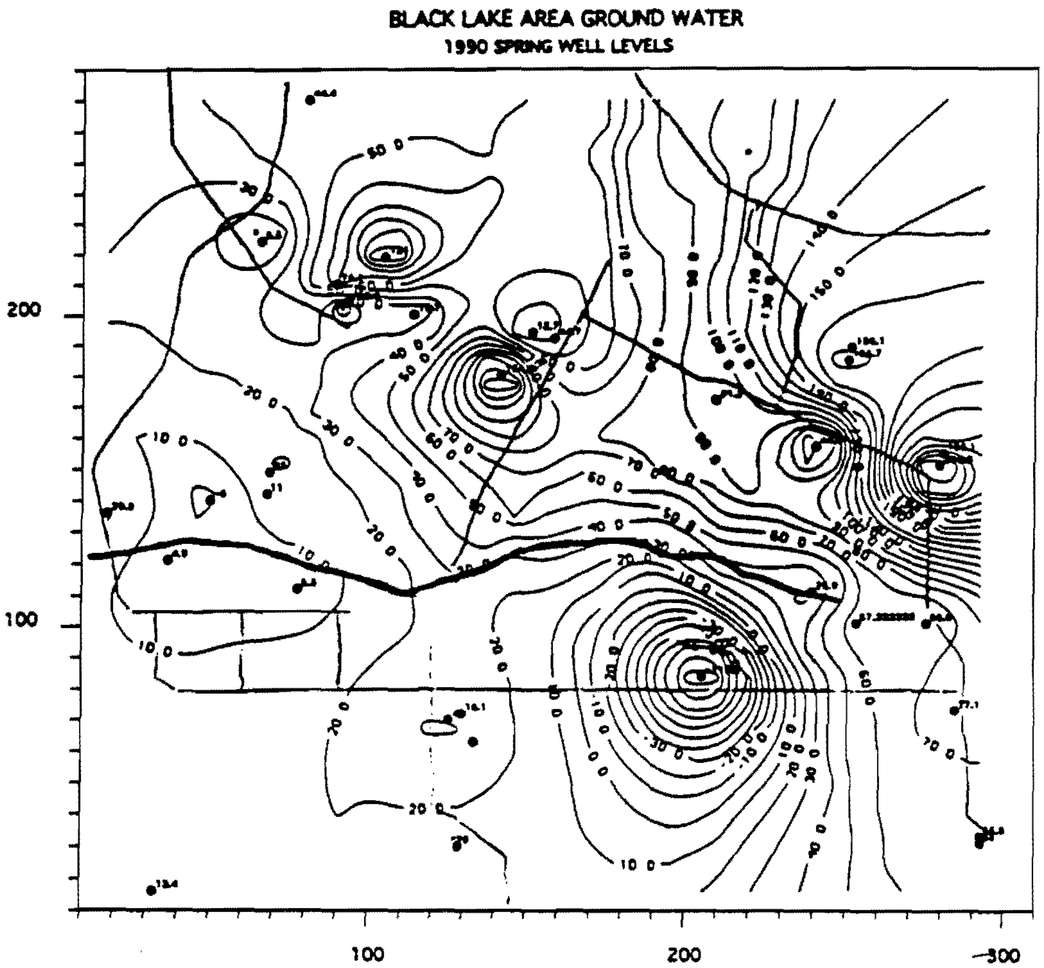


FIGURE 11 Piezometric surface computed from wells monitored by San Luis Obispo County in 1990

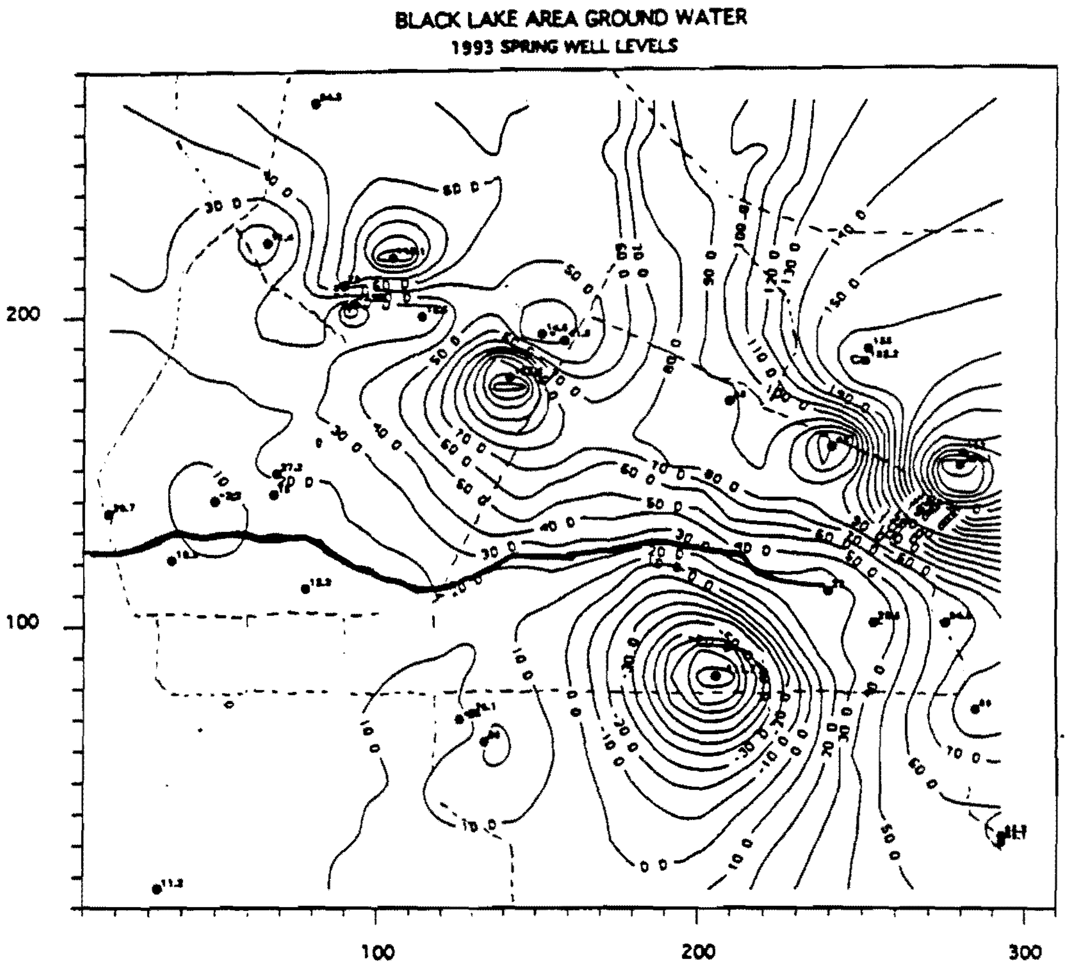


FIGURE 12 Piezometric surface computed from wells monitored by San Luis Obispo County in 1993

Data From Individual Wells

The spring season well levels from 1975 through 1992 for each of the wells in the county data set, together with the x- and y- coordinates of the well on the contour mapping grid are presented in Table 2. The water level history for each well is plotted and presented in Appendix A. Missing or suspect data is not shown. These wells are analyzed via the contour mapping process, and their locations are indicated on the contour plots. Some of the wells show changes that are hard to explain and may be an artifact of errors made during the well level measuring process.

Maps Of Piezometric Change and Computed Annual Rate of Water Table Change

The water table contour maps for the years 1975, 1980, 1990, and 1993 are compared to each other . This enables the water level differences to be calculated, and from this data contour maps are constructed of the values of those differences. The contour maps allow an observer to identify areas around the canyon where there are major changes in the piezometric water table surface. Differences were computed using the GridMath™ component on MacGRIDZO™. The well data for these comparisons is presented in Table 3.

The contour map of the differences between the 1975 and 1993 spring season water levels is shown in Figure 13. It shows that the water table has dropped 5 to 10 feet at the western end of Black Lake Canyon, and dropped about 40 feet at the eastern end of the canyon. (Data from wells 1 to 2 miles to the northeast of the east end of the canyon show some contradictory data, as in 11/35-2G1 (4.6 feet gain) and 11/35-2G2 (5.0 feet loss), and 12/35-35P1 (37.9 feet loss) and 12/35-35P3 (1 foot gain). In an analysis of the 30 wells in the data set, the average change per well was a loss of 6.6 feet, or an average sub basin drop of 0.37 feet/year.

The contour map of the differences between the 1985 and 1993 spring season water levels is shown in Figure 14. Analysis shows the average water table drop over this period to be 4.38 feet, and the rate of drop to be 0.55 feet/year. Continuous declines are seen throughout the immediate Black Lake Canyon area, but water level increases occur south of Los Berros and west of Nipomo.

Table 2

1975-1993 Spring Well Levels Monitored by San Luis Obispo County
Corrected to Elevation Above Sea Level.

well number	x	y	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
12/35-29R3	81	270	55.4	48.6	49.5	58	54.2	49.8	56.5	53	46	44	48	51.1	49.8	34.7	45.7	44.4	43.4	69.79	54.3
12/35-32G1	66	224	14	14.4	6.4	17.5	17.4	14.1	16.9	17.7	18.4		16.3	18.6	16.9	14.6	9.5	6.5	7.5	10.3	11.4
12/35-32J2	90	210	74.4	69.9	74	73	69.4	71.7	71	69.9	68.2		72.8	74.6	74.8	77.3	77.5	78.1	77.6	76.35	75
12/35-33M1	93	204	-8.6	-16.6	-7.4	-1.1	-7.1	-4.3	-2.1	-1.1	-4.7		-4.2	-1.7	-4.8	-7.8	-12.4	-12.9	-21.7	-4.5	-12.9
12/35-33E1	105	219	121.9	122.1	122.2	122.1	122.2	122.5	120.3	121.7	121.6		121.3	122.1	122.3	119.6	121.4	121	121.3	119.6	119.1
12/35-33L1	114	200	25.4	33.6	21.5	24.5	25.7	26	25.6	21.7	22.23		25.1	25.7	25	17	21	18.7	19.1	9.6	16.5
12/35-33Q2	142	180	159.7	160.3	158.7	159	158.5	157.7	152	157	156.4		156.8	156.5	154.3	155.5	155.8	154.6	154.1	153.7	152.4
12/35-33J3	152	194	23.4	23.4	17.1	22.5	22.3	20	23.4	20.5	25	21	18	23.6	23.3	21.1	23.3	15.7	6.95	6.1	14.6
12/35-33J2	159	192	54	51	48	48.5	48.8	48	45.5	49	46.65	48.2	48.8	51	50.4	43.4	46.4	44.7	42.2	41.4	41.9
11/35-3B1	210	172	99.8	99.2	98.7	97.5	97.4	97.6	94.8	96.6	97.1	98	98	42.8	97.5	96.5	94.9	91.2	90.1	89.45	88
11/35-2G2	281	155	167	170.1	149.7	167.2	169.8	165.5	166.4	165.3	166.1	172.7	166.3	166.1	163.4	163.9	158.1	159.1	160.7	161.7	162
11/35-2G1	280	151	301.5	302.2	302.1	302.8	302.7	303.4	304.2	304.4	305	305.2	307.5	309.6	310	310.5	310.6	310.3	309.4	307.75	306.1
11/35-2F1	241	157	46.7	47	44.3	45.4	44.8	41.5	45	44.13	45	45	46.4	47.2	46.3	48.5	45.4	44.3	45.9	46.6	45
12/35-35P3	252	189	154	154	154	154	154	154.2	154.8	156.6	157.6	157.4	156.4	159.3	160.9	158.8	154.6	156.1	155.9	155.5	155
12/35-35P1	251	185	220.1	213.4	199.7	196.6	186.6	181	184	180	176.9	180	184	191.8	192.4	174	183.1	186.7	186.1	168.5	182.2
11/35-5G1	69	149	29.8	25.4	21.1	30.9	32.5	26.5	30.7	33.2	32	25.9	24.7	36.1	35.6	29.2	28.2	25	28.9	26.5	27.2
11/35-5G2	68	142	20.9	13.5	11.4	22.4	23.2	15.1	10.5	22.3	19.4	17.3	24.6	27	22.1	19.4	15	11	14.1	15.4	15
11/35-5L1	50	140	4.7	-0.5	-5.7	-3.1	7.7	0	5.5	7	9.2	3.3	1.25	13	13.1	6.7	-0.9	-6	8	-2.5	-2.2
11/35-6J1	18	136	25.2	23.6	21.8	22.9	24.4	23.8	24.6	24.8	23.1	24.15	25.5	27.7	26.1	24.6	21.9	20.8	21.1	20.4	20.7
11/35-5R1	78	112	19.9	11.1	5.5	18.4	17.7	10	16.7	18.2	23.5	12.6	18.5	24.2	22.1	17.4	10.5	6.8	13.2	11.1	12.3
11/35-5N2	37	121	20	12.1	1	18.1	8.7	0	16.3	-1	9.2	-0.35	1.7	17.3	21.5	9.1	0.5	4.9	-2.5	2.4	10.8
11/35-17E1	33	16						18.4	20	22	26	27.7	26	23.2	20	16	13	13.4	8	10	11.2
11/35-16B1	129	30	15.9	-1.5	-10.5	5	18	-1.6	0	19.5	8.3	12.55	-2	28.8	20.9						
11/35-9K4	134	63	41.6	30.1	25.5	41	37.6	24.4	31.3	38.6	38.7	21.55	16.5	49	45.8	39.1	27.5	20	40.1	24.7	30
11/35-9K5	126	70						34.5	26.83	32.8	27	27	27	27	25.63	23.5	32	22.67	20	28	-16
11/35-9K2	130	72	48.7	38.9	35.8	49.8	46.7	28.1	35.4	46.9	41.8	39	45	51.4	46.3	48.1	37.4	16.1	32	16.5	26.1
11/35-10G1	206	84	-76	-80.1	-74	-102	-103	-103	-104.3	-94.43	-88.2	-98.7	-80	-67	-80	-103.2	-101.7	-110.2	-116.5	-116.83	-111.7
11/35-13E2	293	31	60.9	38.4	60	66.8	67.2	62.8	54.5	68.6	69.2	51.9	56	61.7	52.5	49.2	46.1	68	67.9	66.9	49.1
11/35-13E3	293	33	58	50.3	65.1	72	70.6	62.2	54.75	62.9	68.7	51	61.8	64.9	59.4	52.9	47	65.8	65.7	63	65.3
11/35-11J1	285	73	71.4	68.9	68.3	67.8	68.5	65	63	61	59	59.1	64.2	70.6	73.9	75.3	77.9	77.1	80.6	83.9	89
11/35-2N1	240	111	45	41	39.2	36.4	37.8	42.4	33.05	34.1	33	24.47	30.3	31.9	29	29.2	26.6	25.9	25.9	24.9	22
11/35-11C2	254	101											33.8	39.9	30.1	27.1	35.6	31.9	30.5	30.8	28.8
11/35-11B1	276	101	48.1	45	44	41.3	39.2	37.5	39.2	38.5	37.3	44.1	54.7	62.2	62.2	63	60.9	60.6	59.4	52.4	64.8

wrong el.?

Table 3 Differences between Spring Well Levels in 1993, and Those of the Years 1975, 1980, 1985, and 1993 (units are feet).

	1993-1975	1993-1980	1993-1985	1993-1990
12/35-29R3	-1.1	4.5	6.3	9.9
12/35-32G1	-2.6	-2.7	-4.9	4.9
12/35-32J2	0.6	3.3	2.2	-3.1
12/35-33M1	-4.3	-8.6	-8.7	0
12/35-33E1	-2.8	-3.4	-2.2	-1.9
12/35-33L1	-8.9	-9.5	-8.6	-2.2
12/35-33Q2	-7.3	-5.3	-4.4	-2.2
12/35-33J3	-8.8	-5.4	-3.4	-1.1
12/35-33J2	-12.1	-6.1	-6.9	-2.8
11/35-3B1	-11.8	-9.6	-10	-3.2
11/35-2G2	-5	-3.5	-4.3	2.9
11/35-2G1	4.6	2.7	-1.4	-4.2
11/35-2F1	-1.7	3.5	-1.4	0.7
12/35-35P3	1	0.8	-1.4	-1.1
12/35-35P1	-37.9	1.2	-1.8	-4.5
11/35-5G1	-2.6	0.7	2.5	2.2
11/35-5G2	-5.9	-0.1	-9.6	4
11/35-5L1	-6.9	-2.2	-3.45	3.8
11/35-6J1	-4.5	-3.1	-4.8	-0.1
11/35-5R1	-7.6	2.3	-6.2	5.5
11/35-5N2	-9.2	10.8	9.1	5.9
11/35-17E1		-7.2	-14.8	-2.2
11/35-16B1				
11/35-9K4	-11.6	5.6	13.5	10
11/35-9K5		-50.5	-43	-38.67
11/35-9K2	-22.6	-2	-18.9	10
11/35-10G1	-35.7	-8.7	-31.7	-1.5
11/35-13E2	-11.8	-13.7	-6.9	-18.9
11/35-13E3	7.3	3.1	3.5	-0.5
11/35-11J1	17.6	24	24.8	11.9
11/35-2N1	-23	-20.4	-8.3	-3.9
11/35-11C2			-5	-3.1
11/35-11B1	16.7	27.3	10.1	4.2
Average Change	-6.59666667	-2.32903226	-4.3765625	-0.6021875
Av.Yearly Change	-0.36648148	-0.17915633	-0.54707031	-0.20072917

The contour map (Figure 15) of the 1990 and 1993 spring season water level differences shows a 2 foot gain in the western lower portion of Black Lake Canyon, but continued drops in the central and eastern portions of the canyon. Analysis of the entire well set shows an average water table drop of 0.6 feet, or 0.2 feet/year. The lower canyon gain may be the infilling of the bottom of a deep cone of depression developed during the drought, and may be due to regional smoothing of the water table rather than an indication that local withdrawals are less then the local safe yield.

For a few wells used in each of the water level change computations, it was necessary to extrapolate the water level data from the levels measured in other years. The data had either not been collected or is considered unreliable from the well log field information at the County Engineering Department. A notation such as "well pumped within half hour" or similar language indicated that at the time of measurement the well level probably did not represent the water table. It is likely some measurements are suspect because the well reader may not have been aware of recent pumping, either in the well being measured or in nearby wells that were not part of the data set. Extrapolated well levels were used in some cases in order to construct the contour plots of the water table elevations.

In spite of the limitations of this form of analysis, it is clear that the water table in the Black Lake Canyon area has been dropping at a rate of about 1 foot every three to five years. The portion of the ground water basin surrounding the canyon is in a general state of overdraft.

Do the Piezometric Surface Elevations on the Contour Maps Mix Water Tables?

The contour maps created for any particular year is based solely on the well water levels as reported from the County. Thus it is possible that some wells tap into different aquifers, and that the contour elevations do not reflect the piezometric surface of a single aquifer. The cone of depression south of the east end of the canyon may therefore represent a different water table than that of the surrounding wells. However, the maps of the piezometric surface differences that follow accurately show changed conditions within the sub basin as a whole.

BLACK LAKE AREA GROUND WATER
1975 TO 1993 SPRING WELL LEVEL CHANGES

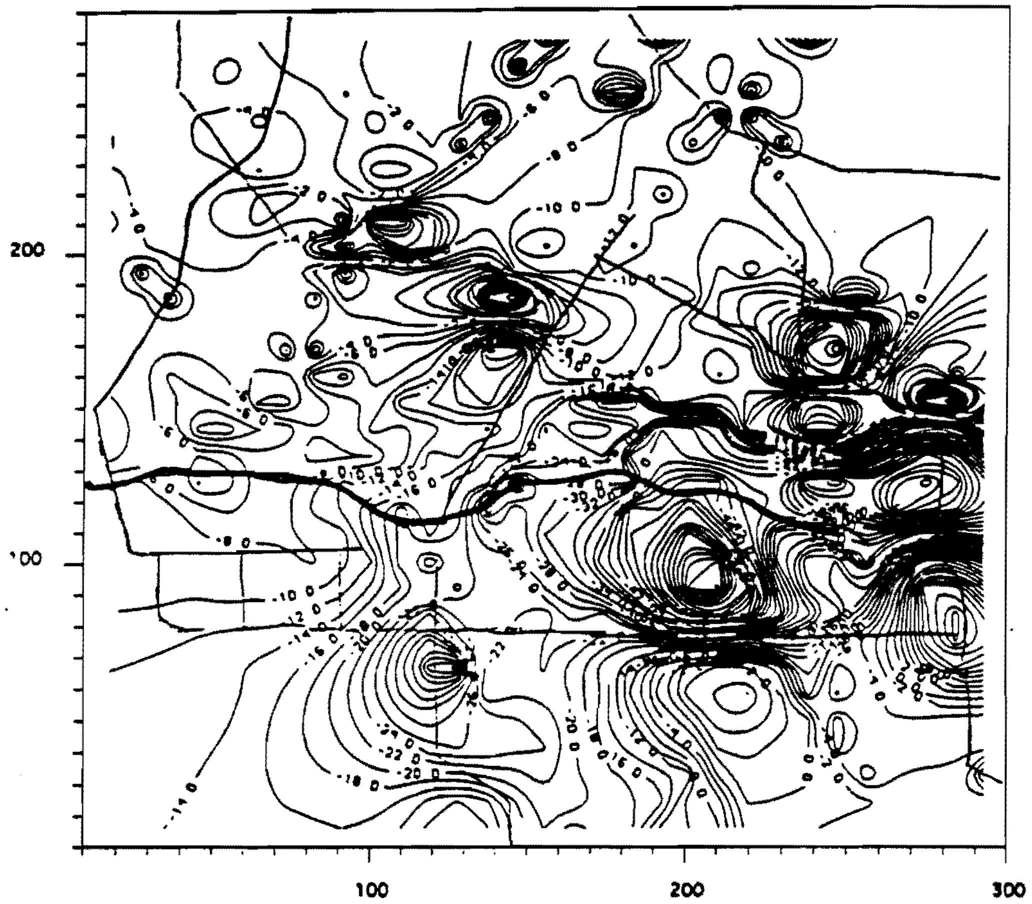


FIGURE 13 Computed Water Table Differences Between 1975 and 1993. (Negative values indicate a falling level.)

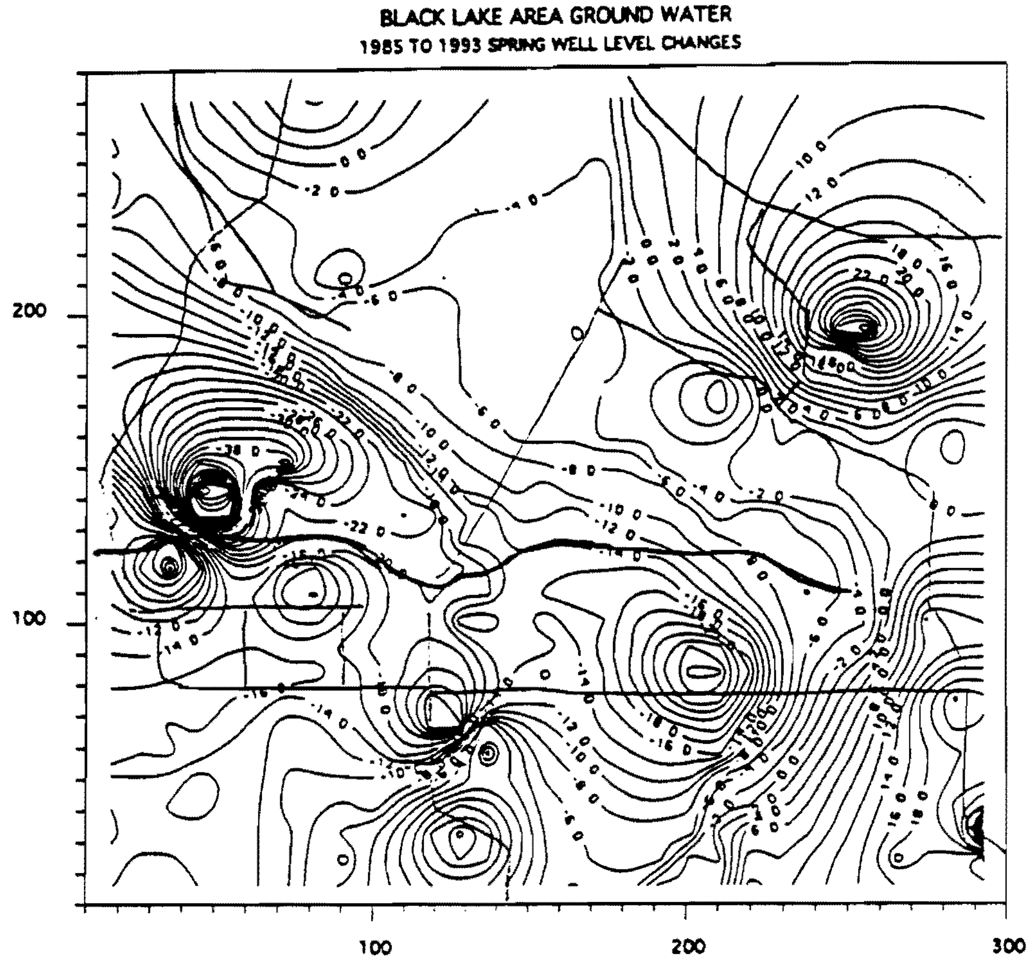


FIGURE 14 Computed Water Table Differences Between 1985 and 1993. (Negative values indicate a falling level)

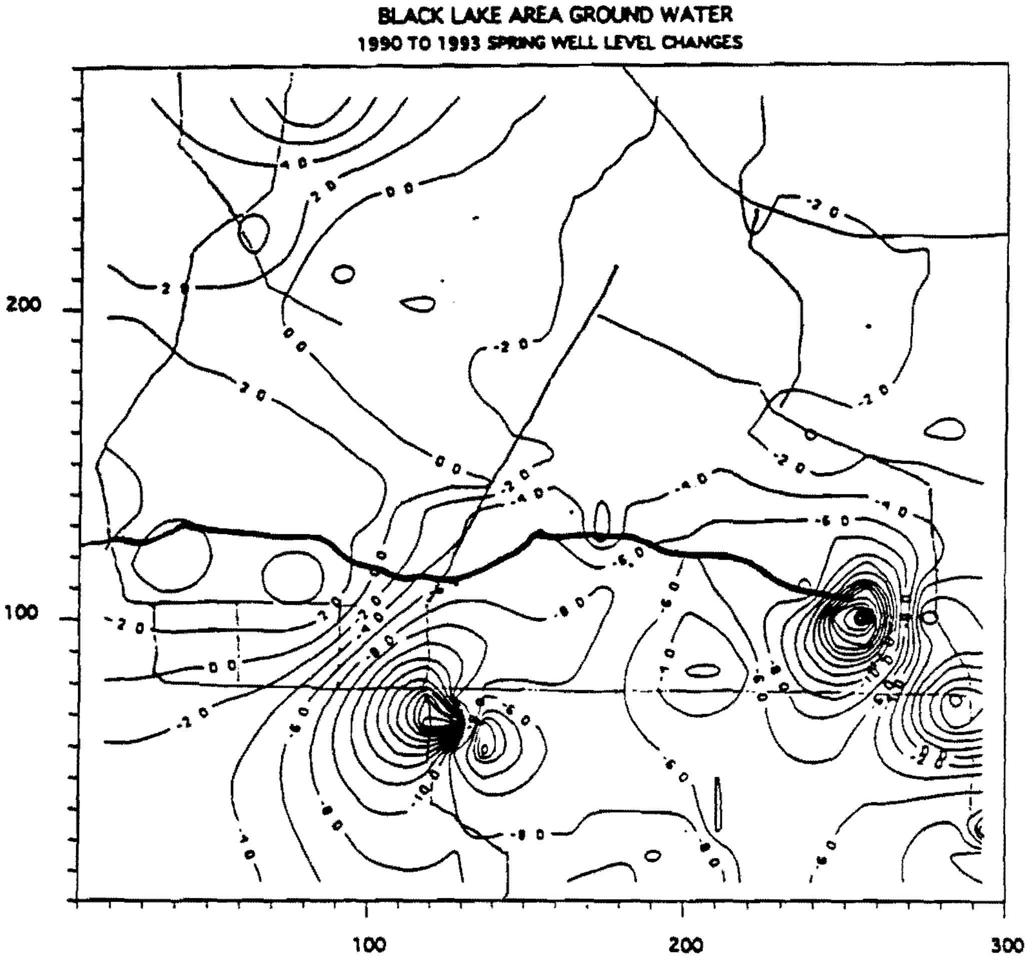


FIGURE 15 Computed Water Table Differences Between 1990 and 1993. (Negative values indicate a falling level)

Comparison of Findings to Those of the LFM (1987) Study

The 1987 LFM study showed that between 1975 and 1987 water storage in the entire Nipomo Mesa subarea of the Santa Maria basin had an average overall increase in storage of 1,185 acre feet per year. Their methodology is similar to that used for this current study. LFM divided the sub basin into Blocks, each of which was represented by one or several county-monitored wells. The well levels were then interpreted as representing the water level changes within the block, from which the storage change was computed. Compared to this study, LFM's study extended a few more miles to the south to include wells bordering the Santa Maria River flood plain. LFM showed that all of the wells adjacent to the flood plain showed significant gains, probably due to the year-round irrigation made possible by Twitchell Reservoir. LFM also recognized the gain in well levels just west of Nipomo, and the continued losses in ground water storage from the Black Lake Canyon area, both of which are evident in the current study. The positions of the Blocks and storage changes from the LFM study are shown in Figure 6 and Table 1 of this document.

LFM's analysis Block 9 (Table 1 and Figure 6) showed a storage deficit of 2,500 acre feet per year in an area just south of the central portion of the canyon. LFM's Block 10, at the western end and to the north of the canyon, showed a 110 acre feet per year loss. Blocks 15 and 16, located respectively northeast and southeast of the eastern end of the canyon, both showed storage gains, which is consistent with observations of the size of ponds at the eastern end of the canyon. (Land Conservancy of San Luis Obispo County 1992).

In this current study, the average water level drops are computed to be at a rate of 1 foot every three to five years, or about 4 inches/ year. If the sediments have an assumed 15% specific yield, and the losses are applied to the sub basin's 21,000 acres, then a 945 acre feet per year deficit occurs. LFM's analysis by Block appears to find a different result, with an overall increase in storage if the wells near the Santa Maria River are included. However, LFM also performed a mass balance analysis of the sub basin for the year 1987 which yielded a much larger deficit of 4,200 acre feet per year. This current study compares the water tables between the years 1993 and 1985, and computed an annual average water table drop of 6 inches/year, which yields a deficit of 1,575 acre feet per year.

It appears that LFM's conclusion that there had been no significant long term ground water storage reduction in the Nipomo mesa is strongly biased by the rise in water tables along the Santa Maria River, and may be therefore be somewhat optimistic relative to the central and northern areas. The conclusion appears to be partly refuted by LFM's mass balance calculations. If the remainder of the mesa is examined in the absence of the wells close to the river, the storage is in deficit, and this is particularly evident in the vicinity of Black Lake Canyon.

SURFACE GEOLOGIC AND HYDROLOGIC FIELD SURVEY OF THE CANYON

A thorough geologic analysis of the floor and sides of Black Lake Canyon was made as part of this current study. The entire central and eastern portions of the canyon are underlain by the Older Dune Sand geologic unit, except for a portion of the north side just east of the Highway 1 bridge, where Younger Dune Sand forms the canyon side. The Older Dune Sands appear to have been reworked in some places by running water. It contains a much larger proportion of finer sand and silt-sized particles than does the Younger Dune Sand. In most locations, the fine grained fraction of the Older Dune Sand is composed of reddish silts, but at the eastern end of the canyon several horizons contain fines that are gray in color which may be derived from diatomaceous shales to the east. The gray coloration may indicate a transition to the underlying Paso Robles Formation, although dune sand dominates the unit.

East of the pipeline suspension bridge in the middle part of the canyon, the sediments containing the lighter colored fine grained fractions (silt and clay) are found around the elevation of the canyon floor, and appear to act as either an aquiclude or aquitard. On the south side of the eastern third of the canyon, the soils are mapped as 'xerorthents', which are described as 'loams' rather than the 'Oceano sand' soil of the rest of the canyon. The fines in the soil are derived from the weathering of the parent fines-rich Older Dune Sand, or from units transitional to the Paso Robles Formation. Loams, which contain a higher fine grained fraction, would have a lower permeability than sands. The lower permeability of the finer- grained Older Dune Sand and associated soil results in the formation of an aquiclude that supports a perched aquifer in the eastern half of the canyon. West of the pipeline crossing, the sediments containing gray silt and clay fractions are exposed on the sides of the canyon above the floor of the canyon, and can be seen in the sides of the hill north and northwest of the northern pipeline bridge anchor point.

The bedding within the complex of dune sands dips to the west and southwest, but the dip is slightly lesser than the slope of the canyon axis as it drops toward the west. The gradient of the canyon floor is relatively low where it is underlain by the beds containing the light colored fines, but it steepens in the central part of the canyon as the creek cuts into beds below the layer of the aquitard, allowing the waters of the canyon are able to infiltrate below the canyon floor.

The general shape of the canyon is unusual. Figure 16 illustrates the complex shape of the Black Lake Canyon longitudinal profile. In general the longitudinal profiles of erosional gullies and canyons tend to steepen rather than flatten at the upstream end. However, in cases where mass wasting is taking place due to water saturation in unconsolidated sediments, the longitudinal profile can be very flat. The profile of upper Black Lake Canyon is consistent with the hypothesis that ground water emerges into the head of the developing canyon from a perched aquifer above the fines-dominated sands, and once caused the sides and rear of the canyon to slurry into the stream. This process may have taken place when the climate was considerably wetter than now, and the present rate of discharge into the canyon is insufficient to generate the canyon's geomorphology. There is no contributory surface stream to the east of the canyon that can serve as an agent of 'normal' canyon cutting. Ground water and its associated mass wasting appear to be a reasonable hypothesis for the formation of the canyon. The perched aquifer is not utilized in the immediate vicinity of the canyon, and is supplemented by recharge from recent new development such as the Black Lake Golf Course's irrigation.

The absence of light colored fines probably plays a major roll in the hydrology of the lower portion of the canyon between the the Highway 1 bridge and the pipeline, as the perched water table is no longer supported. On the basis of the studies that show a falling water table, and the peat-rich sediments which occur along the edges of the floor of the canyon, it is likely that effluent ground water flowed from the canyon sides and maintained a permanent wetland across the the lower portion of the canyon. This water was presumably derived from the main water table, generally unconfined or semi-confined in this location, that still serves as the source of most domestic water in the area. Wells near the upper canyon also tapped into this water table, rather than the perched aquifer supplying water to the upper part of the canyon. This water table would have been locally higher than the floor of the canyon, which probably controlled the level by acting as a large scale drain.

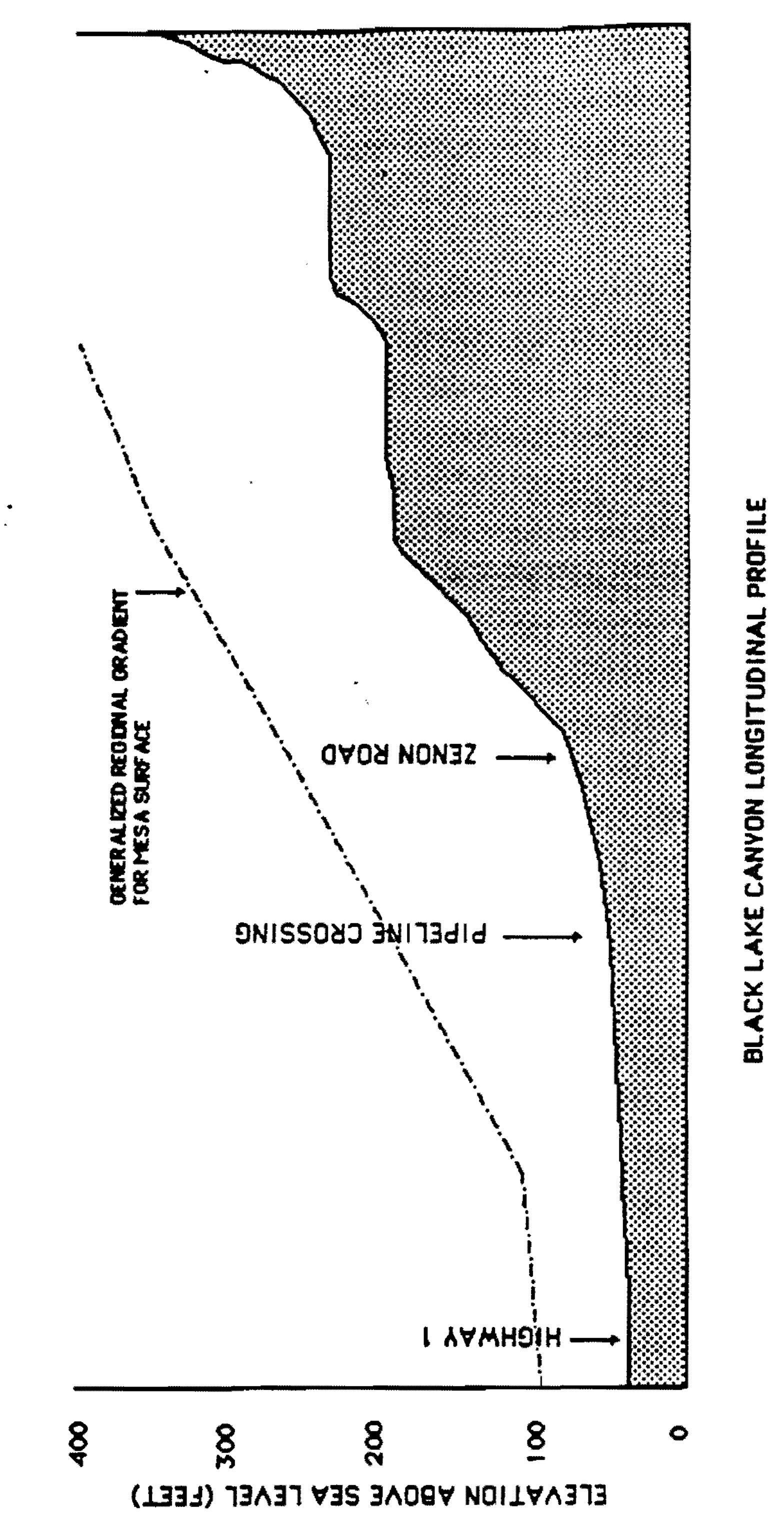


Figure 16 Longitudinal profile of Black Lake Canyon

The main water table has been drawn down and is now well below the floor of the lower portion of the canyon. The dessicated peats, which are well developed in the half mile of canyon east of the highway bridge, are several feet above the present level of the stream. Similar peats occur near Vandenberg Air Force Base, in Barka Slough, and are known to have been supported by effluent ground water. Over pumping of aquifers dewatered the peats in Barca Slough, which have developed very deep and wide contraction cracks due to shrinkage as they dried. The dried and cracked Black Lake Canyon peats also support the hypothesis that permanent dewatering has taken place. The peats consisted of a mat of water saturated vegetation growing on a mat of the carbonized residue of former generations of plants. If effluent ground water can sustain a year round wetland through seepage, and can do so for hundreds or even thousands of years, the peat deposits can become very thick.

It is likely that much of the water that once supported peat bog wetlands in the lower portion of the canyon came from the canyon sides and not from upstream. The peat wetlands in the lower canyon would have required year round water flow, needed to support the plant growth in the peat bogs. The lowered water table would also increase the degree to which the creek would recharge the aquifer. A stream flow from the upper canyon that might have kept the lower canyon wet is now partly lost to recharge the ground water. Ephemeral flow from winter rains is probably insufficient to maintain bog wetlands, although it is important in the maintenance of the canyon and the flushing of sediments from the canyon.

SUBSURFACE GEOLOGY OF BLACK LAKE CANYON FROM WELL LOG ANALYSIS

There are no previous detailed studies of the canyon subsurface geology, although in some earlier studies a few well logs and well standing-water levels were interpreted to show two aquifers existed. A geologic cross section drawn by the California Department of Water Resources (Figure 3), shows lenses of sands and clays in the aquifer dipping seaward parallel to that of the mesa surface slope. However, this does not appear to be based on an analysis of subsurface geology from a large number of wells, and seems to be a 'most likely' sketch based on a couple of well logs.

The present study made use of the set of drillers' logs held by the San Luis Obispo County Engineering Department. When a water well is drilled, the driller maintains a log describing the sediments recovered and the depths at which they occurred. The position of the well is identified by an address or location marked on a sketch map. Sometimes the location map is highly generalized, and the well's position cannot be easily pinpointed on the map.

The data derived from drillers' logs is sometimes misleading and frequently difficult to interpret, and therefore is not always useful. Logs vary in the degree of detail, the terminology used to describe rock types, and the amount of information provided on the geohydrology, such as the depth at which water was first encountered. Some logs could not be used simply because of the driller's recording methodology. However, if logs from a sufficient number of well drillers are used, commonalties emerge that are useful in relating the log to those of its neighbors. The majority made a contribution to the overall picture of the subsurface.

The issue of privacy is also associated with the use of driller's logs, because well logs are not open to public view. Consequently, the details of each log and its exact location have been omitted from this document. A map is provided showing the general positions of the wells with usable well logs is shown in figure 17.

Canyon Cross Sections Compiled From Well Logs

The drillers' well logs have been translated into two cross sections of the canyon area: (1) a parallel of the canyon on the south side, and (2) a parallel of the canyon on the north side. The wells adjacent to, but not exactly on, the line of the intended cross sections were projected onto the cross section along a line drawn at 90 degrees to the section line. Thus wells from the line of the section, the north side, and the south side may be drawn together on the section line by projection as if they were juxtaposed. The section represents an averaging of the subsurface geology for about 0.25 mile on either side of the section. When combined with the geologic variability of the well logs themselves, the sections become an abstraction of the real geology. However the sections prove useful in understanding the hydrology of the canyon.

Figure 18 shows a vertical stratigraphic section that was constructed along the line of Willow Road from Highway 1 to the eastern end of the canyon. Clays are well developed at the elevation of the upper canyon floor, but thin out and disappear in the mid-canyon. It is evident that a perched aquifer could be supported in the upper canyon by the clay. The geology below the clay has a greater affinity to Paso Robles Formation than Older Dune

Sand, and contains both gray and brown clays and gravels. Older Dune Sands do not extend much below the base of the canyon floor along most of its length, although some wells at the western end indicate a much sandier facies within the Paso Roble Formation than is seen at the eastern end.

Figure 18 shows clay in the subsurface at the western end of the canyon, with the top of the clay at about 50-55 feet above sea level in the vicinity of Highway 1. The uppermost clay is interbedded with thin sands, occurs at an elevation slightly above the level of the floor of the canyon, and extends downward in some wells to about 20 feet above sea level. This clay could have played an important role in sustaining the ground water effluence to the peat bogs. Clays are less evident in well logs about one mile upstream of the Highway 1 bridge, and this area might be the region where ground water descends to deeper levels. All of the clay, sand, and gravel units within the Paso Robles Formation appear from the well logs to be broadly lenticular in shape. This suggests that several perched aquifers could coexist above a main aquifer that is only semi-confined by the overlying clays. Some wells at the eastern end of the canyon penetrate the base of the Paso Robles Formation, reaching blue colored marine clays bearing sea shells at a depth of 50 to 100 feet below sea level.

Figure 19 presents a stratigraphic section on the north side of the canyon. The section line starts almost due east of the eastern termination of the canyon at Pomeroy Road. It extends northwest at a bearing of 295 degrees, with a western termination on Highway 1 near Halcyon Road. The geology is very similar to that shown in Figure 18. In the upper canyon , the clay that probably supports the perched aquifer shows the same stratigraphic features as it does in the southern section. At the western end of the section, clays are present at a similar position, and clays are again seen to be discontinuous in the middle section of the canyon.

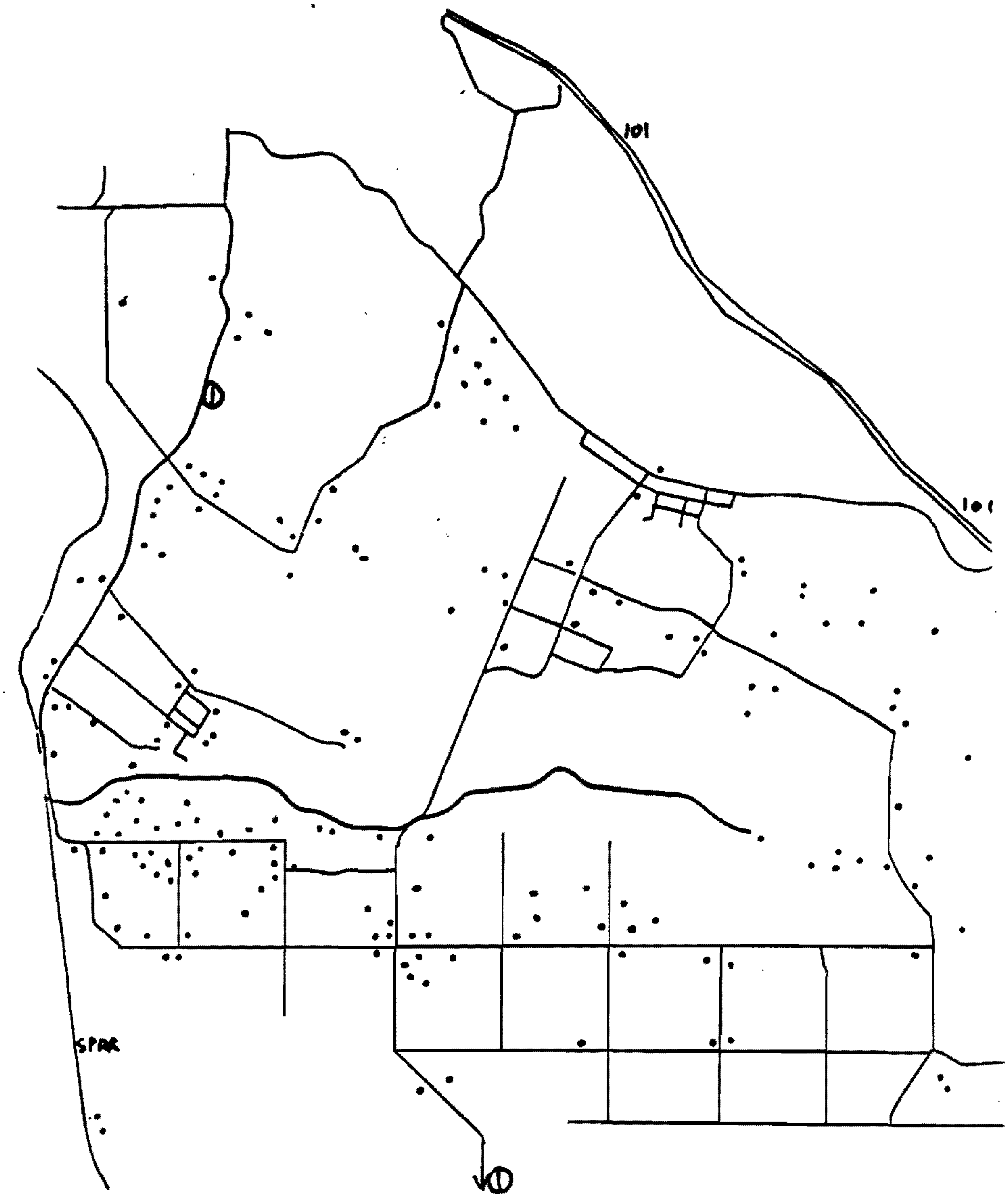
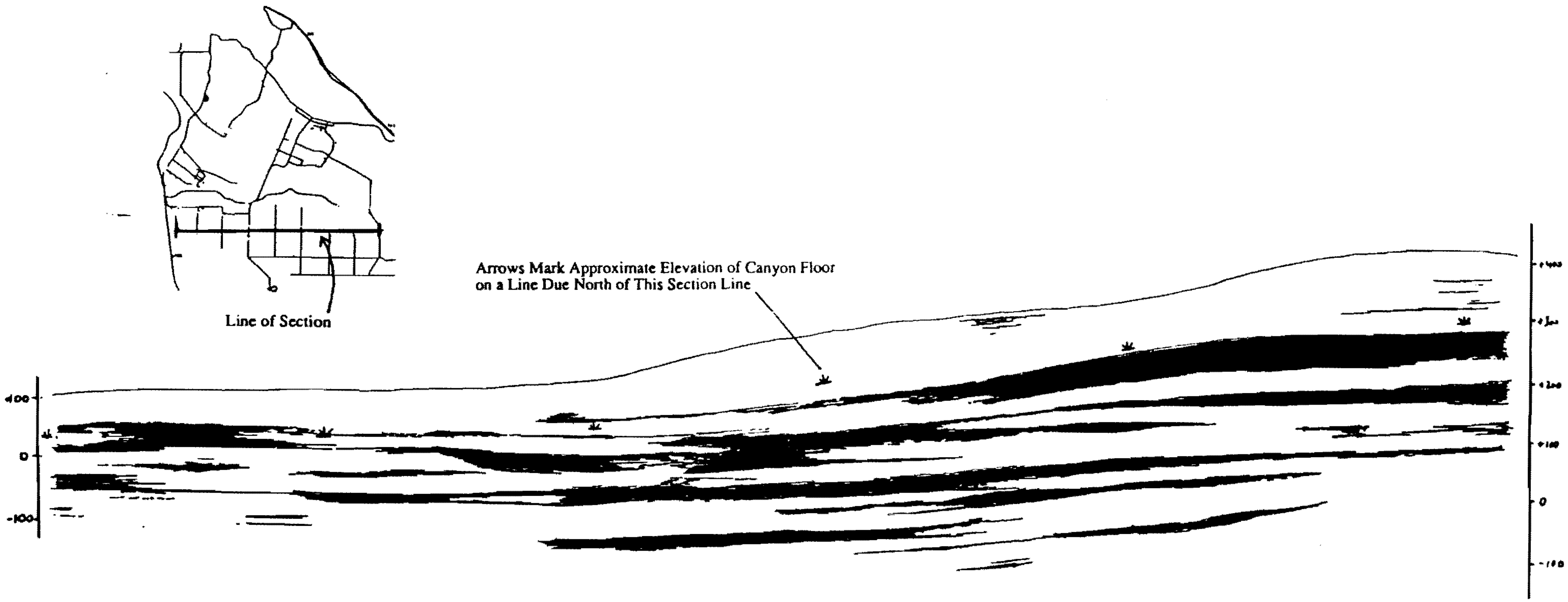


FIGURE 17 Approximate Positions of Wells With Usable Well Logs



Black Zones on Cross Section are Dominated by Clays

Vertical Scale Shows Elevation Above Sea Level

FIGURE 18 Geologic Cross Section Along an East-West Line on the South Side of the Canyon

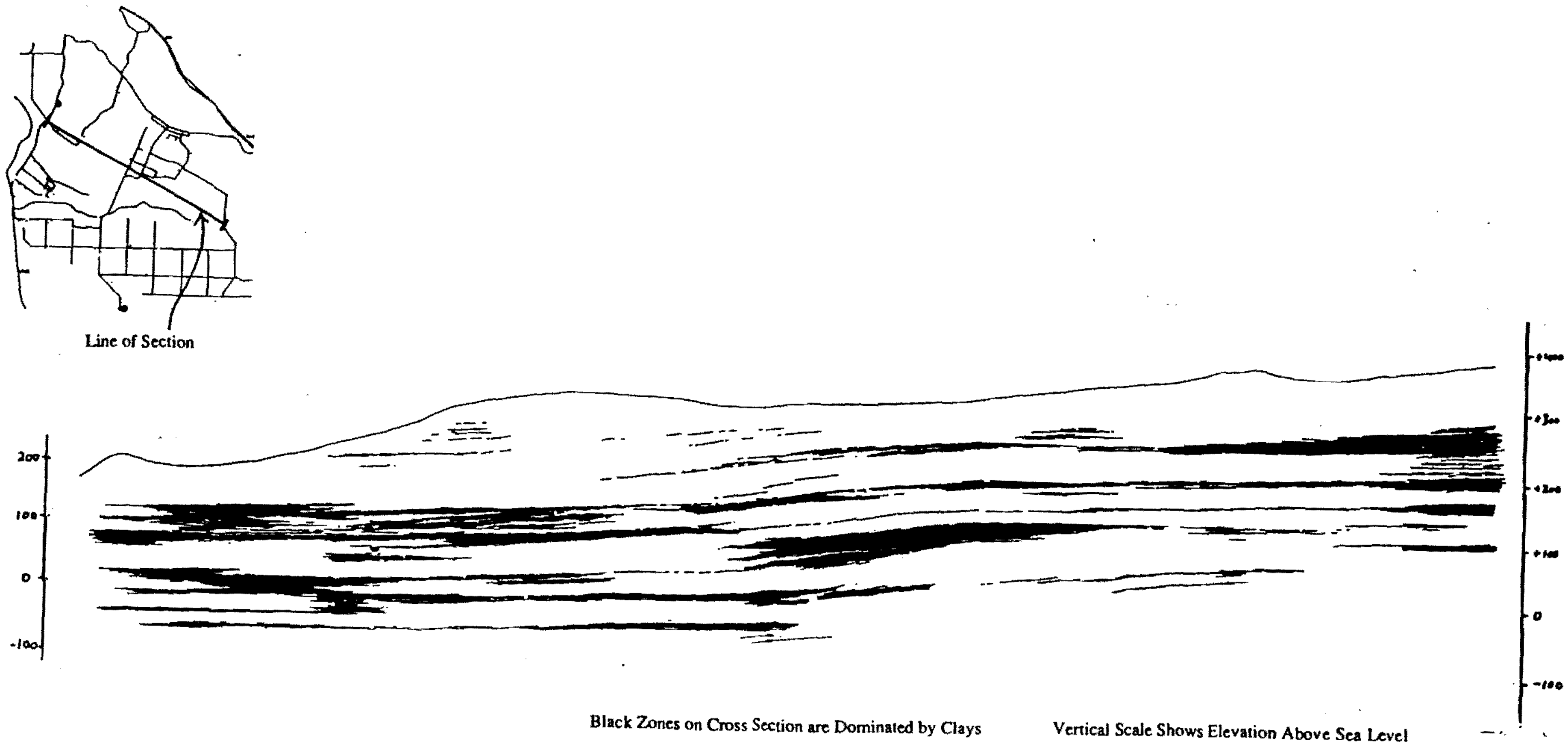


FIGURE 19 Geologic Cross Section Along an Northwest-Southeast Line on the North Side of the Canyon

GEOHYDROLOGY OF THE MARSHES AND PONDS

Upper Canyon Changes Evident From Aerial Photographs

Aerial photographs of Black Lake Canyon owned by the Land Conservancy of San Luis Obispo show changes in the vegetation cover over the last decade. The water level in the ponds east of Zenon Road/Guadaloupe Road has risen. Between 1981 and 1991, the area of wetland vegetation increased four or five fold, despite a severe drought in the latter part of the decade. The Land Conservancy speculates that the wetland increase is due to irrigation return water from the golf course and avocado orchards surrounding the east end of the canyon. However, the cause of the water level increase may be associated with a general rise in water levels to the east of Nipomo. The cause is likely attributable to the extraction of deeper waters by domestic and agricultural wells which then recharge a perched water table in the vicinity of the canyon.

McClelland Engineers (1988) stated the easternmost ponds in the canyon "previously supported a higher water level". Similar comments were made about a pond at the Zenon Road crossing and the dammed basin immediately downstream of that pond. No supportive documentation was presented to explain the statement, and no mention was made about the bands of dead riparian vegetation or of other indicators of the supposed water table drop. The "higher water tables" may refer to those required for the erosion of the canyon itself in the geologic past, and not levels of the recent historic past.

Lower Canyon Changes Evident From Aerial Photographs

The lower part of the canyon has also experienced changes in vegetative cover. Aerial photographs taken in 1949 and 1956 of the canyon just east of the Highway 1 bridge were compared to modern conditions by the Land Conservancy. In 1949, the floor of the canyon was covered by freshwater marsh and peat bog vegetation. Very few willows or other trees were present except as fringe along the edges of the canyon floor. By 1956, willows were expanding from the sides onto the floor, and were also becoming extensive along the drainage channel on the canyon axis. The drainage channel may have played a role in the vegetative changes. By allowing more efficient drainage of the former peat bogs, the water table would be lowered sufficiently to expose areas of drier land. Willows could then become established. Between 1949 and 1956, there is evidence of extensive eucalyptus removal on the north side of the canyon. The eucalyptus plantation was apparently replaced by pasture. Conventional wisdom suggests that this would increase ground water recharge rather than decrease it, especially since area residential construction was little negligible at the time. Thus, if the willow invasion indicates a drying of the former marsh, the effect appears to result from regional water table changes rather than a localized effect. By 1956, the willow invasion appeared to be greater in the vicinity of the present pipeline crossing site. At the present time, willows cover all of the former lower canyon flood plain with the exception of a few small rush and sedge patches in the marsh close to the Highway 1 bridge. Today, the remains of some of the former bogs can be found today as cracked and desiccated peat beds well above the creek's present water level.

It was previously noted that for the years 1965 and 1975 the California Department of Water Resources (1979) had demonstrated a cone of depression in the water table at the lower end of the canyon. It is not certain that this was caused by pumping from the canyon itself, although the photographs provide weak supportive evidence for this. In the 1960s there were wells on the floor of the canyon, but the surrounding land does not appear to be irrigated. The 1956 photograph furnishes one possible indicator that these wells were at least partly responsible for the drying of this portion of the canyon. It shows a significant darkening of the wetland vegetation adjacent to wells located on the north side of the creek, close to the termination of Fowler Lane. This could indicate the drying effect of a sustained, but very local, cone of depression around the wells, but cannot by known for sure. The darkening may have been due to vegetative changes induced by some other disturbance.

Changes in Levels For Wells Near The Upper Canyon

The vegetation and water table changes shown in the upper portions of the canyon could be induced by a rise in the regional water table of approximately 2 to 4 feet. The easternmost ponds are not supplied by surface flow. They are not connected by a running stream and there is no indication of enhanced lateral flow from the sides of the canyon. The water appears to have simply risen 'in place'. The records of wells to the northeast and southeast of the canyon's eastern termination tend to support this possibility.

The LFM (1987) study shows a long term rise in monitored well water levels near the head of the canyon. The current study shows well 11/35-2G1, northeast of the head of the canyon, to have risen 2.7 feet between 1980 and 1993, and 4.6 feet between 1975 and 1993, although the well dropped 4.2 feet between 1990 and 1993. Well 11/35-11J1, southeast of the eastern end of the canyon, rose 17.6 feet between 1975 and 1993, and 24 feet between 1980 and 1993, but only 11.9 feet between 1990 and 1993. These water table changes are summarized in Table 4.

TABLE 4

Changes by Time Periods in Well Levels
Located Near the Eastern End Of Canyon

Well & Location	1975 to 1993	1980 to 1993	1990-1993
11/35-2G1 Northeast of east end of canyon	4.6 feet rise	2.7 feet rise	4.2 feet fall
11/35-11J1 Southeast of east end of canyon	17.6 feet rise	24 feet rise	11.9 feet rise

Well 11/35-11J1 did not experience any fall during the drought, strongly suggesting it is recharged by other than rainfall. A hypothesis may be that the local 'production aquifer' serving well 11/35-11J1 has a rising water table, although it does not necessarily mean that that aquifer is recharging the ponds. It is more likely that the ponds are supplied by a separate perched aquifer that is located much higher than the main production aquifer. Based on the well record, it is probable that well 11/35-2G1 does tap into this shallower perched aquifer and reflects its long term rise. It is equally likely that 11/35-11J1 reflects conditions in the main production aquifer. Both wells indicate a local ground water surplus in the immediate area. Local observers report, but have not quantified, small drops in the water levels of some of the ponds in the last couple of years. This may reflect the recent drop in the 11/35-2G1 well level. Field observations made during this study could not verify the short term drop.

HYDROLOGIC IMPLICATIONS OF DEVELOPMENT NEAR THE CANYON

Upper Canyon

The above analysis strongly suggests that east of the upper canyon there is a general rise in water tables and a current ground water surplus, at least in normal rainfall years. The average rainfall at Nipomo was 19.7 inches from 1975-1985, and 16.16 inches for the period from 1921-1988. There may be an exploitable surplus for use, but it is not known at this time if the current exploitation rates will be sustainable. However, the development of the Black Lake Canyon area is both recent and relatively intense.

A persistent cone of depression can be seen in the piezometric surface plots (Figures 8 to 12), located south of the canyon's east end in the general location of the Black Lake Canyon development. As earlier noted, it is not possible to tell if the well generating the cone is in the same or different aquifer from the surrounding wells, and therefore the piezometric surface contour maps may not reflect real conditions. However, the bottom of the apparent cone is below sea level, and probably deepening with time, suggesting that there is local overdraft. If the plots reflect real conditions, the cone is drawing deeper ground water southward from the Los Berros area. The 1975 contour plot (Figure 8) shows the cone of depression was present in 1975, and since that time there has been no deleterious effect on the lakes in the upper canyon. Therefore, the potential for overdraft-induced problems may be confined to a deeper production aquifer. It is possible that new development and more wells in the upper canyon area will increase the cone of depression's size and depth, and possibly push the aquifer into a locally dangerous set of overdraft conditions. The 1979 DWR study did not show the presence of the cone of depression. The reasons may that their analysis of the data differed significantly from that used in this report or that the key well was not used in their study.

With certain qualifying criteria, development in the upper canyon should not affect the water table or the ponds on the floor of the canyon. Wells should not exploit the perched aquifer and should be perforated only into the lower production aquifer. A shallow irrigation well in the canyon, intercepting the water table that supports the ponds, could impact their levels. All wells should avoid casing perforations for 100 feet below the elevation of the canyon floor.

If wells are placed on the canyon floor or close to the canyon rim, and tap into the shallower perched aquifer, it is likely that wetlands on the canyon floor will be affected, and those nearest the well will be affected first. The logs for wells surrounding the canyon indicate that the upper perched aquifer is generally not utilized. The current surplus of water in this aquifer could be reversed if usage were to increase. Similarly, changes in irrigation practice and septic tank recharge could also affect this aquifer.

Lower Canyon

The impacts of development on the lower part of the canyon are more complicated. Vegetative changes occured at the same time that DWR (1979) mapped a cone of depression, and showed the cone increasing in size. The base of the cone about 20 feet above sea level in 1965, but only about 10 feet above sea level in 1975. The cone of depression continues to grow and currently its apex is located just below sea level. This can be seen in the ground water contour maps (Figures 13,14, & 15) that show computed differences in water level. These show that the water table near Highway 1 has fallen another 6 to 8 feet between 1975 and 1993. Water tables in 1993 were locally below that of sea level Any additional development in the area that utilizes the same aquifer is likely to aggravate the size and depth of the cone of depression. This is the same lower aquifer used for production at the upper end of the canyon. The perched 'upper' aquifer is not present in the lower portion of the canyon.

The historical data suggests that although the amount of water entering the upper canyon appears to be increasing, the lower canyon is drying out, and that the mass balance of water in the canyon is in deficit. It might be expected that through-flow from the upper canyon into the lower canyon would also increase. However, that is not the case. Explanations for this could be (1) other inflows to the canyon are being reduced, (2) extractions from the canyon have increased, or (3) both of the above. Evidence of a reduced inflow is provided by the dessicated peats on the north side of the canyon. These are above the level of the creek, and were presumably supported by lateral seepage from the side of the canyon. Additionally, a decline in the regional water table may have increased the rate of percolation through the canyon floor.

With one exception, it is unlikely that the current hydrologic trends could be altered by changing the management of the lands within the lower canyon. If there are shallow wells extracting from the perched water table, their production may cause much of the problem. Well logs show the majority of wells in the area are perforated into the Paso Robles Formation, and not into the overlying Older Dune Sands from which the lateral flow into the canyon was once supplied. It is possible that some wells receive, or received, water from the shallow zone. This could have been from (1) deliberate perforation into the zone, (2) from infiltration down the well casing through gravel packing or (3) from corroded casings. If these wells could be identified and modified to utilize only the deeper aquifer, they would improve the mass balance and possibly even remove the deficit. However, there is no way to quantify the degree to which the shallow ground water is exploited without performing an inspection of each well in the area. Even if it can be proven to exist, correction of the well loss impacts to the canyon floor may not be sufficient to counter the general lowering of the water table and its impacts. Switching more production to the lower aquifer would aggravate its cone of depression, which is dangerously deep and close to sea level, and which could eventually lead to sea water intrusion. A thorough analysis of the impact of shallow zone water extraction on the lower canyon wetlands would require a denser grid of observation wells than currently exists through the San Luis Obispo County Engineering Department monitoring program.

<u>Validation Of Regional Drawdown Rates Using A Simple Regional Extraction Model</u>

A model has been constructed for this study in an attempt to examine the cumulative impact of individual wells on the piezometric surface of the lower canyon. Recent aerial photographs provided by the Land Conservancy of San Luis Obispo were used to identify probable well sites. These sites were entered into a geographic coordinate system, and each site was then 'pumped' within the model to observe the resultant drawdown of the piezometric surface.

The model contains some very broad assumptions of water use from individual wells and of aquifer characteristics. These assumptions are (1) gross water extraction from each well is equivalent to typical family use of 1 acre-foor per year; (2) the net extraction is only 25% of gross, due to recharge from septic tanks, irrigation return flow etc.; and (3) the aquifer properties lie between a transmissibility of 1,200 - 50,000 gallons per day per foot (gpd/ft) and a storage coefficient of 0.1 - 0.18. An aquifer thickness of 200 feet was assumed on the basis of the geologic cross sections, although this is possibly inaccurate. The resultant drawdowns were computed using the Drawdown module of MacGRIDZO™. Annual drawdowns were highest at the greatest concentrations of wells, located just south of the western end of the canyon. They are illustrated in Figures 20 - 25, which shows drawdowns resulting from all the wells operating under the assumptions described above, for different combinations of transmissivity and storage coefficient for the aquifer.

In Figure 26 the maximum drawdown values derived from the six drawdown contour figures are graphed against possible values of aquifer transmissivity for two values of storage coefficient. The results indicate that annual drawdown could be 1-4 feet, given the range of assumptions described above.

The crude model does not consider lateral inflow or outflow from beyond the area, or the infiltration of water from the upper aquifer, except for the allowance of 75% return flow. The assumption of 75% return flow from 1 acre foot per well gross extraction is the weakest part of the model, as there has been no research to validate the number. The ground water contour maps suggest a long term drop in well levels of about 5 inches/year, suggesting the model is innacurate because (1) much higher transmissibility values occur in the aquifer, (2) net extraction is smaller than the 0.25 acre-feet/year per well used in the model, (3) lateral inflows from other areas are an important factor, or (4) some mix of factors. If it is assumed that lateral inflows and ouflows are identical, the 5 inch per year long term drawdown could be caused by extraction deficits of 0.1 to 0.2 acre-feet/year, given that there is no hydrologic evidence for very high aquifer transmissivity values.

<u>Aquifer Storage Mass Balance Considerations</u>

For a simple mass balance calculation of the inflows and ouflows from the aquifer, the lateral inflow and ouflow components are unknown. The calculation therefore is limited to pumped extractions and infiltrated returns from irrigation and domestic use.

The Morro Group (1990) calculated rainfall infiltration to be 28.4% of rainfall, based on the high efficiency of the dune sands to accept water and to the lack of surface runoff from the mesa surface. If 28.4 % of the average 19.2 inches of rainfall (for the years 1975-1985) infiltrated, it would be equivalent to 0.45 acre-foot of recharge.

For domestic water use on the Central Coast, 30% is used outdoors, and 70% used indoors, and 90% of the water used indoors could be expected to recharge the ground water if septic tanks are used (California Department of Water Resources, 1983). Thus 0.63 acre-foot of every extracted acre foot would return to the ground water. This implies that net extraction is 0.37 acre-foot per year which, when combined with the 0.45 acre feet of rain recharge, would produce a net gain of 0.12 acre foot. However, it is likely that some of the wells would be irrigation wells which, if irrigation efficiency was high, would return very little to the ground water, and which could be expected to subtract from the

0.12 acre foot of gain. Large scale irrigation projects were not evident in the aerial photographs, but lots were large and the ratio of water used in the house to that used on the land would probably be somewhat smaller than the average numbers given by California Department of Water Resources, (1983).

However, for the Black Lake Canyon area, this infiltration would be primarily to the perched aquifers, and may not reach the production aquifer. The computer model assumed that the partial isolation of the aquifer from the surface reduces recharge to 75% of the extracted volume.

The model and mass balance calculations imply, but not prove, that relatively small amounts of conservation and recharge enhancement could reverse the water table decline at this time. It is clear that, under these circumstances, any differential between lateral inflow and outflow will be critical for accurate mass balance calculation. Regretably, the difference between the inflow and ouflow components in mass balance equations are usually calculated from differences between vertical withdrawals and recharges, and observed changes in storage.

While conservation could reverse or slow the apparent local overdraft, the development of the Nipomo Mesa is accelerating, and it is likely that any conservation savings will be overwhelmed by increased overall demand. McClelland Engineers (1988) noted that maximum buildout under proposed standards for the Black Lake Canyon Sensitive Resource Area could result in a net groundwater consumption increase of 82.12 acre feet per year. Net increase in demand is calculated from the gross demand after an allowance is made for return to the aquifer of waste and irrigation water infiltration.

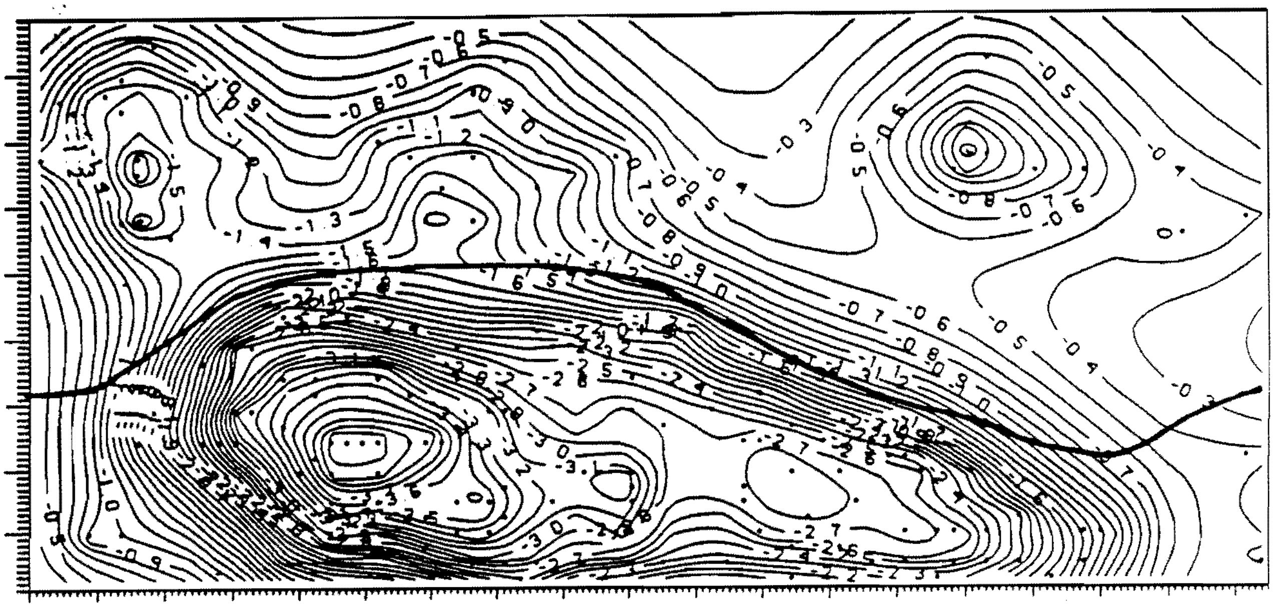


FIGURE 20 Drawdown Values For Transmissivity Of 1,200 gpd/ft, a Storage Coefficient of 0.1, and net extraction of 0.25 acre feet per well. Line shows Black Lake Canyon from Highway 1 to Zenon Road

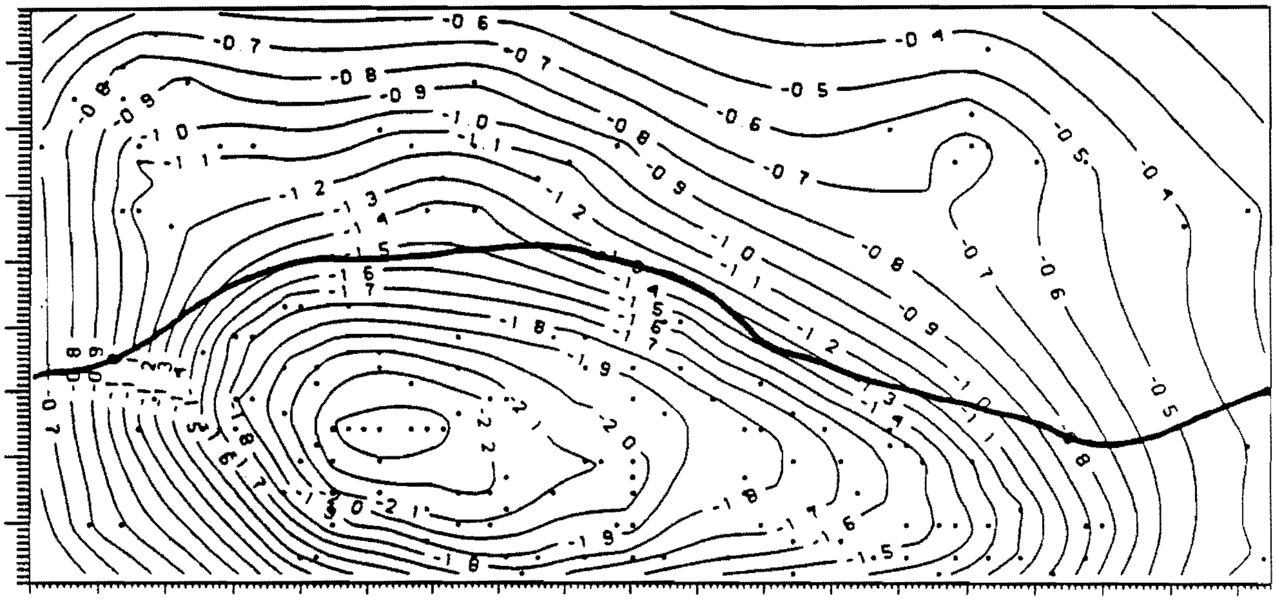


FIGURE 21 Drawdown Values For Transmissivity Of 5,000 gpd/ft, a Storage Coefficient of 0.1, and net extraction of 0.25 acre feet per well. Line shows Black Lake Canyon from Highway 1 to Zenon Road

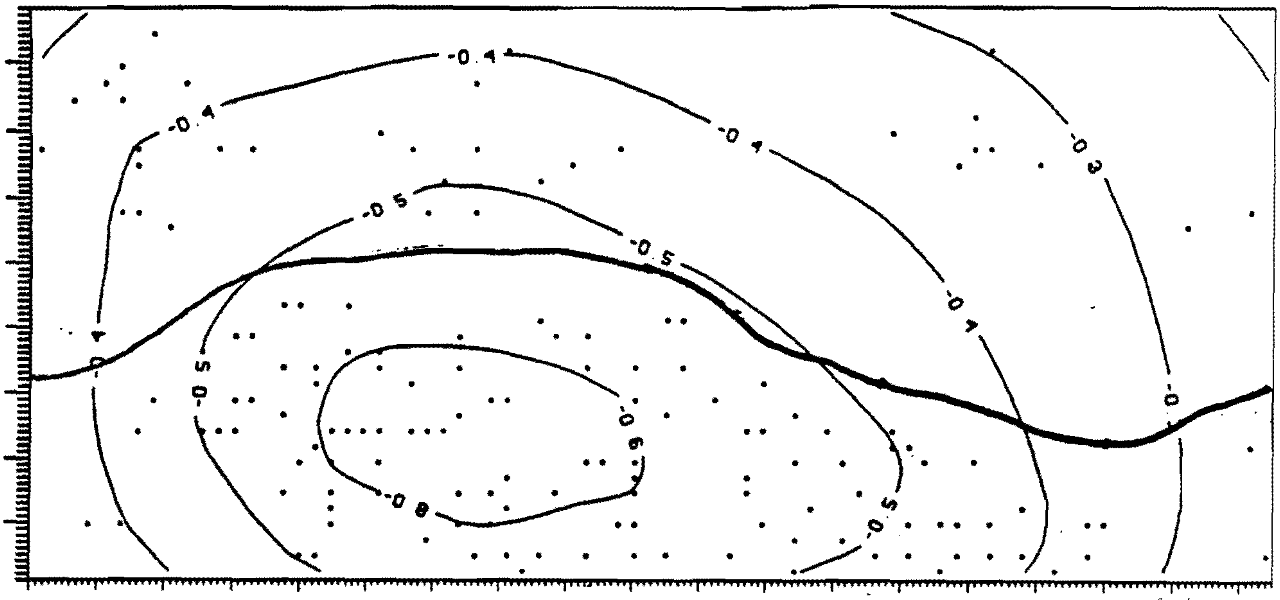


FIGURE 22 Drawdown Values For Transmissivity Of 50,000 gpd/ft, a Storage Coefficient of 0.1, and net extraction of 0.25 acre feet per well. Line shows Black Lake Canyon from Highway 1 to Zenon Road

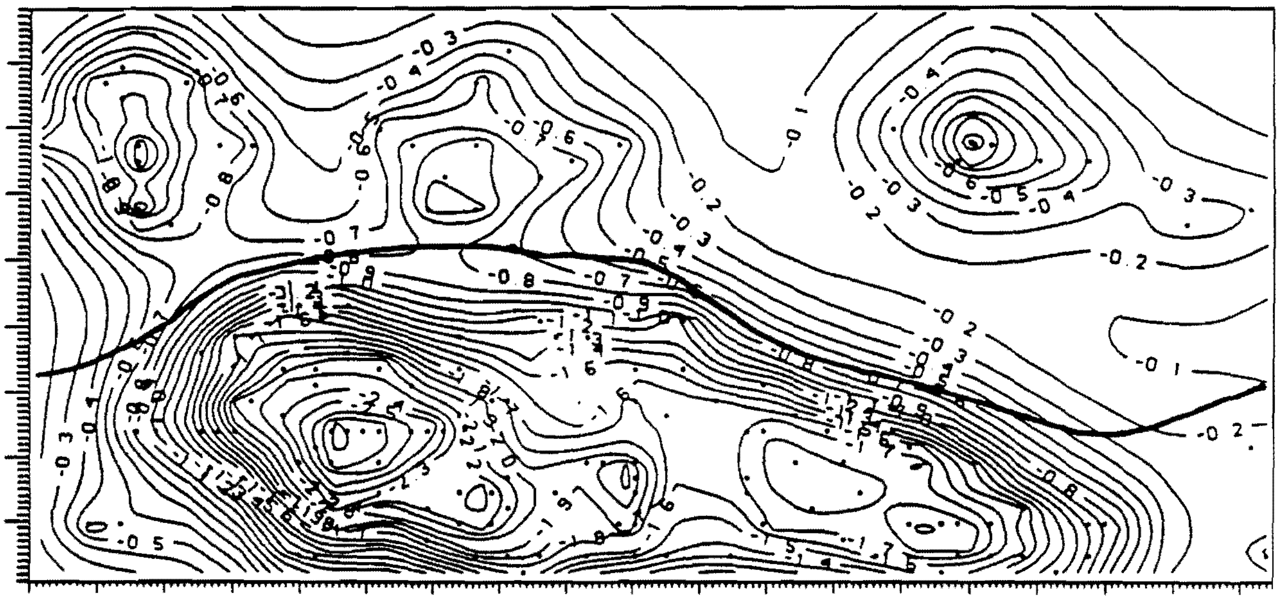


FIGURE 23 Drawdown Values For Transmissivity Of 1,200 gpd/ft, a Storage Coefficient of 0.18, and net extraction of 0.25 acre feet per well. Line shows Black Lake Canyon from Highway 1 to Zenon Road

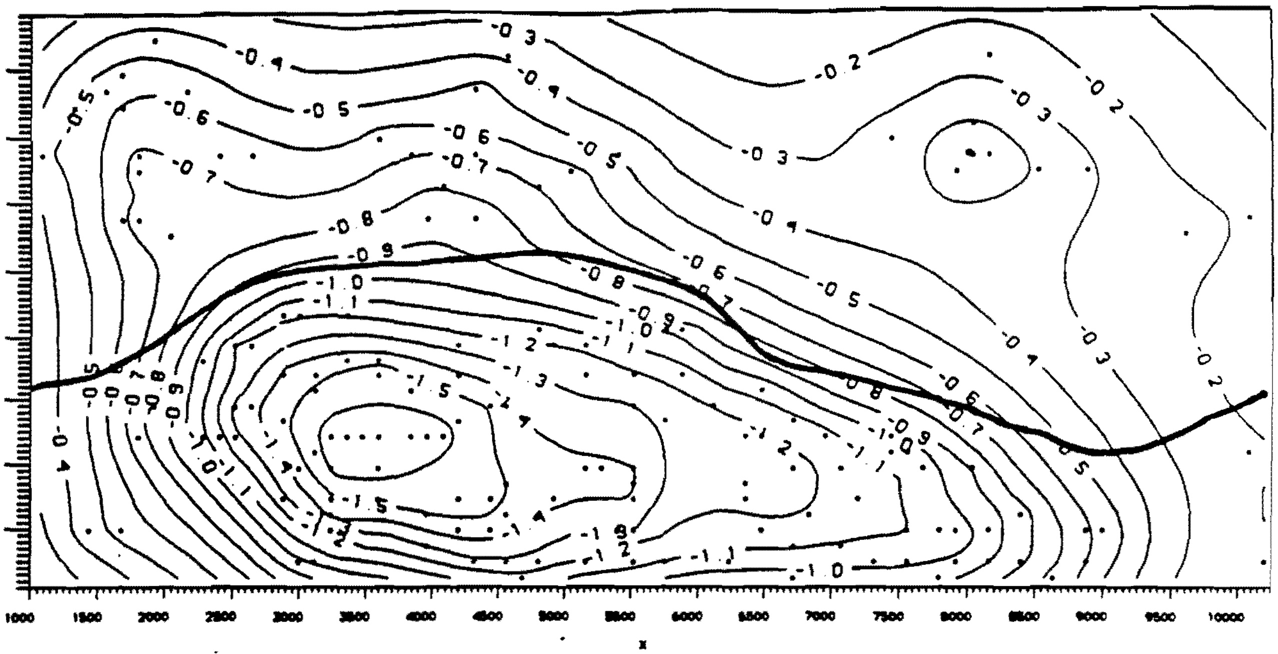


FIGURE 24 Drawdown Values For Transmissivity Of 5,000 gpd/ft , a Storage Coefficient of 0.18, and net extraction of 0.25 acre feet per well. Line shows Black Lake Canyon from Highway 1 to Zenon Road

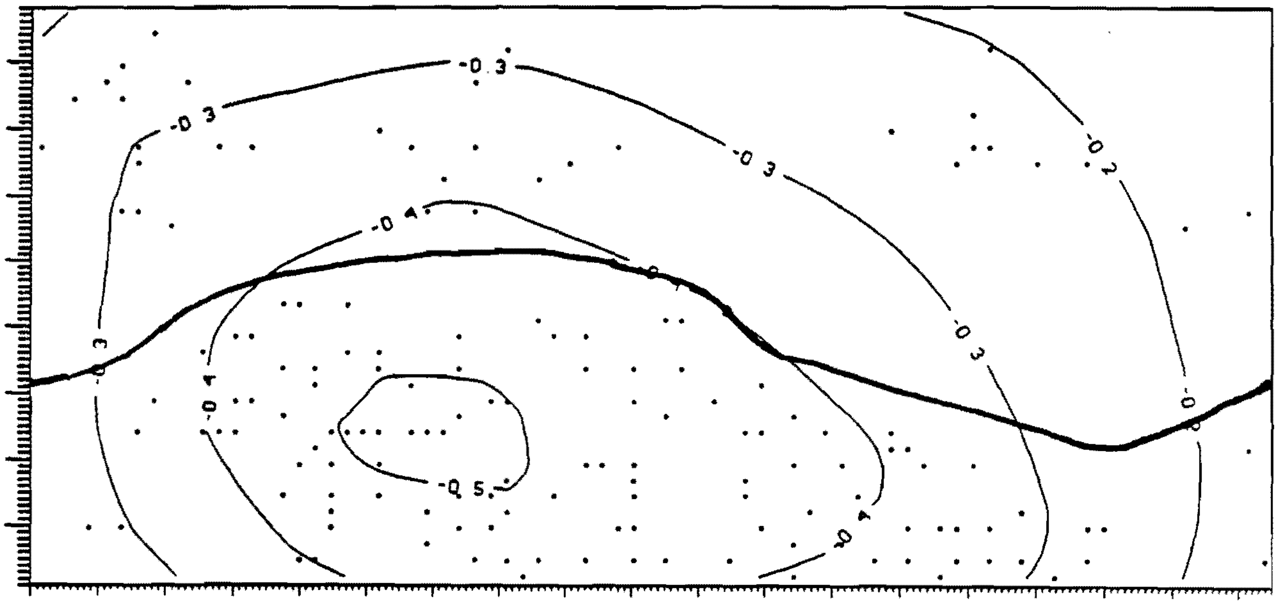


FIGURE 25 Drawdown Values For Transmissivity Of 50,000 gpd/ft , a Storage Coefficient of 0.18, and net extraction of 0.25 acre feet per well. Line shows Black Lake Canyon from Highway 1 to Zenon Road

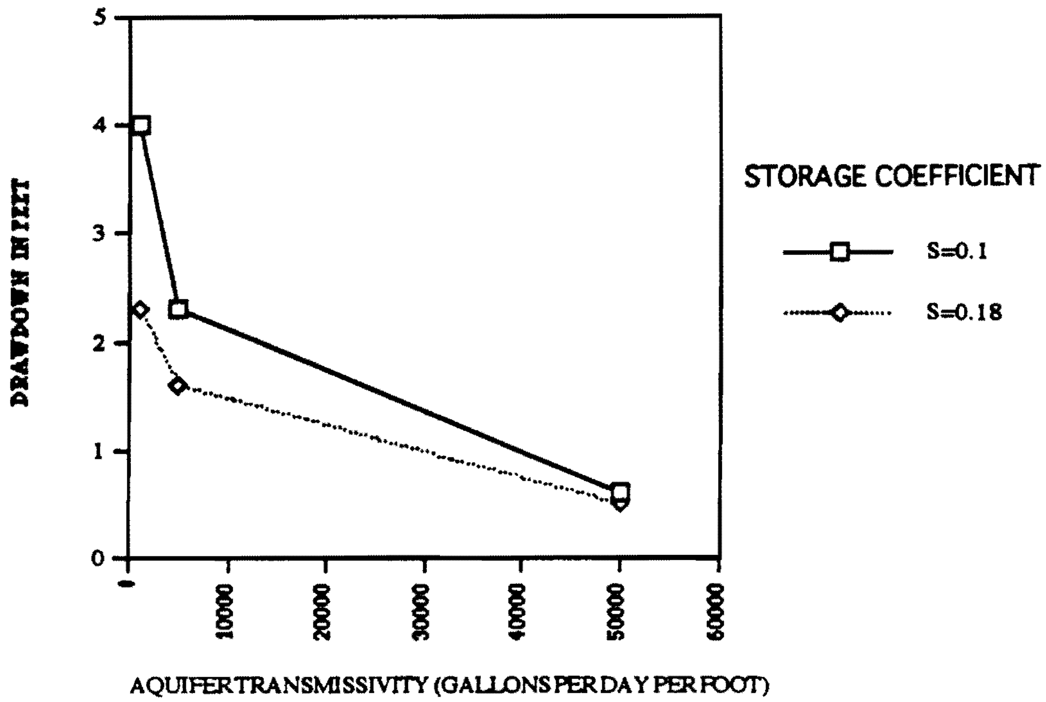


Figure 26 Annual Water Table Drawdowns (Feet) Measured Against Aquifer Transmissivity Resulting From 0.25 Acre-Feet/Year Net Extraction Per Identified Well In The Black Lake Canyon Area, And Given For Two Storage Coefficient Values.

EXISTING WETLAND HABITAT

PLANTS LISTED UNDER THE ENDANGERED SPECIES ACTS

The two plant species of greatest concern are obligate wetland plants Arenaria paludicola ("Marsh sandwort") and Rorippa gambelii ("Gambel's water cress").

Arenaria paludicola represents the last known population of this obligate wetland plant in the United States, although it once ranged through coastal regions of the Pacific Northwest and California. The legal status of the plant is Endangered under both the State and Federal Endangered Species Acts. The population appears to be represented by two plants (Anuja Parikh, personal communication, July 1994). The plant previously occurred at Black Lake, Jack Lake and Oso Flaco Lake, all of which are moderate sized, water-table supported, open water lakes in close proximity to the coast. The remaining habitat of the marsh sandwort differs from that of the coastal dune lakes where it once existed. The sites in Black Lake Canyon are surrounded by eucalyptus forest and more heavily shaded. There is little eucalyptus at the dune lakes. Willow is present at the site, but it is generally less vigorous and the canopy more open than the willow woodland near the dunes, due most probably to light competition from the taller eucalyptus.

Rorippa gambelii was once distributed in a number of wetlands from San Diego County to San Luis Obispo County, but is now restricted to San Luis Obispo County in Black Lake Canyon and Oso Flaco Lake. The Gambell's water cress grows in the conditions more similar to the coastal dune lakes; it lies in wetlands higher on the canyon that are not surrounded by eucalyptus. The legal status of the plant is Threatened under the California Endangered Species Act and Endangered under the Federal Endangered Species Act.

The Land Conservancy of San Luis Obispo County (1992) describes the plants as 'narrow endemics', in that they both require water saturated dune sands as habitat. They have also noted the deterioration and change of wetlands in the lower portion of the canyon. The areas of open water and open bog have both been reduced, with open waters being converted to bog, and a faster conversion of bog to willow woodland.

Little is known about the acidity and shading tolerances that are optimal for either of the plants, and the current habitats may not necessarily be ideal for either of the plants. There is a reasonable probability that the current location of the marsh sandwort is not ideal, because of the environment by eucalyptus. If the plants are to expand their ranges into other parts of the canyon, they might have to occupy somewhat different wetland types..Factors as water chemistry, shading, wetland hydraulics, tannin levels, acidity and competition within its ecological niche must be considered in defining suitable habitat beyond the simple presence of a wetland.

From the general scarcity of both plants, it is apparent that they do not have the characteristics of 'weedy' species, and have not been successful at maintaining or expanding habitat. It would appear that the wetlands in the upper canyon would offer suitable habitat for both plants, but the micro habitat requirements may be wrong. What role does the sand substrate play in sandwort regeneration? Does bare sand have to be present, as might be found around dune bounded lakes? Would bare sand be found, and would it persist, in upper Black Lake Canyon? Is the dissolved oxygen level of the water important, and should any part of the wetland be anaerobic? What is the predation pressure from rodents, or the competition stress from other species? To what degree do decomposing mulches need to be present.

Abrams (1944) described the marsh sandwort habitat as "swamps". His plant description strongly suggests that the plant spreads vegetatively, stating that the stems are "elongate, weak, and flaccid....procumbent, rooting at the nodes." A key habitat requirement may be the available room for a plant to grow to a critical size, and a mechanism/agent that breaks off stems for them to re-root elsewhere. A local biologist has propagated cuttings of the plant with ease (personal communication). If this is a prime plant dispersal method, then available habitat in Black Lake Canyon may not be re-pioneered by the plant unless it is physically moved. The Jepson Manual, (Hickman J.C. ed.,1993) describes marsh sandwort habitat as "boggy meadows and marshes", suggesting more open conditions than the presently occupied habitat. Such conditions exist in the upper canyon, and in a few diminishing wetlands near the Highway 1 bridge. In the upper canyon, the availability of suitable seed or plant stem propagating mechanisms and the adverse plant competition is unknown. The bogs and wetlands of the lower canyon will probably support the plant, since the existing populations are already in the lower canyon.

The expansion of the water cress habitat may require a somewhat more energetic hydrology in the wetland. It is possible that The Jepson Manual habitat description (Hickman J.C. ed.,1993) of marshes, stream banks, and lake margins reflects the manner of plant dispersion. Seeds and broken stems may float to new habitat along a bank or shoreline. All of the wetlands in the upper canyon may be suitable habitat, provided they remained as wetlands and their water levels did not fluctuate to any great degree. Under existing conditions, the upper canyon wetlands are either increasing in size or remaining stable. The wetlands in the lower canyon may also be utilized, although they seem less stable and their long term future is in doubt.

PLANT SPECIES OF LIMITED DISTRIBUTION

The wetlands of Black Lake Canyon support a number of plants that, while not protected by the Federal or California Endangered Species Acts, are considered of sufficient rareity to be addressed in the California Environmental Quality Act environmental impact assessment process as 'plants of limited distribution'. This means they are either at the limit of their geographic range or have a limited total range, and that losses of a few plants could represent a substantial loss of the entire population.

The Land Conservancy of San Luis Obispo (1992) lists the following as plant species of limited distribution in the wetlands. Two duckweeds Wolffia columbiana ("Water-meal") and Wolfiella lingulata ("Mud-midget"), are present in the still waters of at least four ponds throughout the canyon. Their population would be enhanced by expanding the areas of still water. Ribes divaricatum var. pubiflorum (Straggly gooseberry") is found in the damp soils surrounding several of the ponds. Other wetland dependent plant species include Stachys chamissonis ("Hedge nettle"), Athyrium felix-femina ("Lady fern"), Calamagrostis nutkaensis ("Pacific reedgrass"), Carex cusickii ("Sedge"), Cicuta douglasii ("Water hemlock"), Cladium californicum ("California sawgrass"), Habenaria dilitata var leucostachys ("White Rein orchid"), Nuphar luteum ssp. polysephalum ("Yellow pond lily") and Rumex occidentalis var. fensestratus ("Western dock"). The largest variety and concentrations of these species are found in the lower part of the canyon (McClelland Engineers ,1988). .If many of the plants are dependent on a combination of wetland and peat substrate found over most of the present lower canyon wetlands, enhancement of the aquatic habitat of upper canyon ponds that lack peat may not necessarily benefit these species. Further degradation of the lower canyon wetlands has the potential to threaten the habitat of each of these plants and their continued existence.

FEDERAL CANDIDATE ANIMAL SPECIES

Rana aurora draytoni ("Red-legged Frog"), is one of the fastest disappearing amphibians in the western states. It is a Category 1 federal candidate species for listing as Endangered or Threatened, and a California Department of Fish and Game'Species of Special Concern'. Its habitat includes marshes, slow moving riparian areas with nearly continual water supply, ponds and reservoirs near woodlands and grasslands, Stebbins (1985). Although it was observed by McClelland Engineers in 1988, they suggested it could be present. Any enhancement of the ponds would benefit the frog.

Southwestern Pond Turtle ("Clemmys marmorata ssp. pallida") is also a Category 1 federal candidate species for listing as Endangered or Threatened, and a California Department of Fish and Game Species of Special Concern . The turtle was seen in the McClelland Engineers 1988 survey. It would benefit from any expansion of the wetlands, as its habitat is ponds, marshes, rivers, and streams.

POTENTIAL FOR WETLAND HABITAT ENHANCEMENT

The minimum requirements for the sandwort and the water cress seem to be water and sand, combined as a shallow water body, bog or marsh. This condition would have to persist throughout the year for a perennial plant such as the sandwort, which would die if the soil dried. Similarly, the habitat of an emergent obligate wetland plant would be destroyed if the water became too deep. Therefore the minimum requirements might be restated as a stable water level and sand. The existing wetlands in the upper canyon offer apparently suitable habitat for both plants. Water levels have generally been rising slowly, and there is no indication that they will not continue either to rise slowly or remain stable. Increased development near the east end of the canyon will increase waste water infiltration, which could raise levels in the perched aquifer while drawing down the main production aquifer. If water levels continue to rise, the amount of habitat will increase, although the degree to which it will be an optimal habitat for either of the plants is unknown.

For the gooseberry the requirements are somewhat similar. It appears to grow in damp sands under shaded conditions. Therefore, a raised water table, an enhanced willow woodland and enhanced riparian live oak woodland could result in a habitat increase.

For the duckweeds and animals the habitat requirements are enhanced by the presence of more water on the canyon floor, but are not dependent on the presence of sand.

MITIGATION FOR WATER DEFICITS IN THE CANYON

As noted in the previous sections, there is a deficit in the water balance in the lower part of the canyon, but an apparent surplus of water in the upper canyon. Additional water extractions from the perched aquifer in the upper canyon may result in a reduced growth of the wetlands there, and possibly a reduction of the throughflow into the lower canyon, thereby aggravating problems in the lower canyon. Significantly higher extractions from the upper canyon perched aquifer may have local or more widespread effects on the hydrology of the upper canyon, especially if a sustained cone of depression developed about the point(s) of extraction. Water extractions from the lower canyon will aggravate an already apparent deficit, further degrading the wetlands.

The following mitigations are suggested for increases in water demand, and, if demand remains constant, as ways to increase wetland area in the upper and middle portions of the canyon. These are: 1) excavation of new wetland areas, 2) enhanced waste water recharge to the canyon, and 3) enhanced surface runoff to the canyon. For the lower canyon, any enhancements of flow from the upper canyon will be beneficial. For the lower canyon mitigation could include earthwork.

It has also been suggested that eucalyptus removal could improve the water balance in the canyon (Land Conservancy, 1992). Since removal has already commenced within the canyon, it will be discussed in a later section.

EXCAVATION OF NEW WETLAND AREAS

A great opportunity to enhance the wetlands exists in the upper canyon while there is a continued increase in the upper aquifer level. Observation of the ponds shows slow flow from the east to the west end. The presumption is that the water table surface slopes gently westward just below the valley floor, with underflows subparallelling the floor. Excavation of the valley floor to the water table should produce ponds similar to those east of Zenon Road. The water table depth between the existing ponds, and the annual water table fluctuations that might affect the pond levels, could be calibrated by installing small bore piezometers along the axis of the canyon.

WASTE WATER RECHARGE

If waste water is imported to the canyon from other areas and water extraction from the perched aquifer is not increased, the recharge mound at the point of delivery could raise the local water table and the size of the nearby ponds. The down valley subsurface flow would increase, and all of the wetlands in the upper and middle portions of the canyon would increase in size. Adverse environmental effects on the plant life in the ponds might occur due to the nutrient increase. The pond ecosystems could be seriously harmed by massive algal growth. Both nitrate and phosphate nutrient loading of the waters could be expected. Clean waste water recharge has an advantage of being a year round source that could maintain a relatively constant water table.

A possible complication of interaction between a wastewater recharge cone and a cone of depression about the extraction well site could arise if waste water recharge is introduced to offset extractions from new wells on the canyon floor. Detailed hydrologic modelling would be required to ensure that extraction wells locations do not drawdown the ponds, and recharge points designed to maintain a down-canyon subsurface underflow along the axis of the canyon. The hydrology could probably be managed to benefit the wetlands, although possibly requiring a fairly complicated water distribution system.

Currently the Nipomo Community Services District sewer system is an important existing recharge source for the ground water system on the Nipomo Mesa (Morro Group 1990), and there is competition of the recycled water. Net gains in the water table near Nipomo may come from this recharge source, and any partial redirection to Black Lake Canyon may have a deleterious effect on the water table around Nipomo.

A small amount of recharged water, if supplied to the lower part of the canyon, may rectify the mass balance problem. It may also serve as an ultimate recharge source to the lower aquifer, which has developed a cone of depression in the area. Without more detailed knowledge of the mass balance in the lower canyon, which cannot be calculated until the underflow and surface flow volumes are known, it is impossible to predict how much waste water would be needed. The wetlands themselves would act as an efficient waste water cleaner prior to its recharge to the lower aquifer. The lower part of the canyon could serve as an integral part of the regional water management system. Conflicts with existing production wells may arise if waste water is applied close to those wells.

ENHANCED SURFACE RUNOFF

The sandy surface of the mesa generally lacks drainage courses, and has a number of wind formed deflation hollows that serve as closed catchments. Therefore rainfall runoff flows to the catchments and recharges the shallowest part of the aquifer. Rainfall is an important source of the water in the perched aquifer in the canyon. As development increases, so do impermeable surfaces and a larger proportion of the surface flow reaches the closed catchments. This would tend to increase the infiltration and decrease evapotranspiration losses. There is no advantage in re-routing street runoff from nearby developments to the canyon floor, as the water in the catchments would contribute to the perched aquifer. This would be expensive, and there is a risk of playing a zero-sum-game by moving the point of shallow water recharge from one place to another.

However, if water is collected from impermeable surfaces more distant from the canyon and then transported to the canyon, it could build a transient groundwater mound below the canyon that would not otherwise be present, and have a positive effect by slowly releasing water down-canyon.

Water could also be stored in a leaky pond constructed on the canyon floor at an elevation higher and 'upstream' of the highest of the natural wetlands. Leakiness is achieved by constructing the bed of the pond with a certain permeablity. The leaky pond would recharge the shallow aquifer slowly enough to maintain a fairly constant subsurface flow throughout the year.

It must be emphatically stated that runoff cannot simply be dumped onto the floor of the canyon in uncontrolled flow. Discharge into the canyon would tend to be very flashy, generating episodic flows along the axis of the canyon that could cause erosion and sedimentation in the soft sandy sediments. Flashy, uneven discharge would also create an unstable water table elevation, potentially damaging wetlands that tend to experience relatively constant water levels. A storage pond would be required to damp out high peak discharges.

EARTHWORK IN THE LOWER CANYON

In the lower canyon, habitat enhancement is dependent on a complicated water balance of inflows and outflows. As noted above, the historical data suggests that the canyon is drying out, and experiencing a mass balance deficit. This deficit is linked to water use well beyond the edge of the canyon, and may not be reversed unless local use of well water is curtailed. As there is no current substitute for local use of this water, this part of the water balance equation cannot be addressed except by conservation and the restriction of new demand. However, better knowledge of the morphology of the aquifers and perched water tables below the canyon might provide a solution by allowing withdrawals to be optimized relative to drawdowns on the canyon floor.

The mass balance could be improved if the downstream losses toward Black Lake were slowed. This would be dependent on restricting surface and subsurface flow across the Highway 1- Southern Pacific barrier. It is likely this barrier is already holding back some water, as is evidenced by the last remaining lily pond just above the barrier. Some subsurface compaction and restriction of underflow has undoubtedly taken place due to the compactive load of the Highway 1 fill.

Mass balance in the former bogs of the lower canyon might be altered if barriers to flow were to be constructed across the valley, although not if the current mass balance deficits are due to leakage from the stream bed. Water tables throughout the lower canyon have to be raised considerably to restore the bogs. This could possibly be accomplished by a series of low dams extending across the canyon, forming the floor of the canyon into a series of low terraces. Unfortunately, if dams are constructed on a leaky canyon floor, a cycle of periodic inundation and dessication might be more damaging to wetlands than the current relatively constant water table. In addition, the construction of the dams would damage the existing wetlands.

Earthwork does not have to be a cross-canyon dam. The 1949 aerial photograph shows that a drainage ditch had been cut along the axis of the canyon. It is possible that ditch precipitated the drying of the peat bogs, as was its intent, and that the dessication had only affecting the upstream part of the channel in 1949. Thus if the ditch was blocked by a series of low, bank-to-bank berms that did not extend beyond its banks, the wetlands might be restored. Blockage of the ditch could be achieved more cheaply than constructing a dam, although it would require destruction of wetland vegetation during construction.

HYDROLOGIC IMPACTS OF EUCALYPTUS

Very little research on the water uptake or hydrologic impacts of eucalytpus has been taken place within the United States, where research has focused on forestry and biomass accumulation issues. The 1993 Conference Proceedings on Eucalyptus in California, edited by R.B. Standiford and F.T. Ledig contain no hydrologic presentations. Aware of the increased use of eucalyptus as a commercial wood around the world, and the gap between scientific research and apparent folklore on water uptake, Calder (1992) performed a world-wide literature search. He found that eucalyptus' reputation for using copious amounts of water is unjustified. However, it is difficult to extrapolate from the small amount of quantitative research performed around the world on Eucalyptus globulus ("Blue Gum") to Black Lake Canyon, where it is the dominant eucalyptus species.

Hydrologic impacts manifest themselves through changes in the net evaporation of the site. Evaporative losses can be divided into interception and transpiration components. Interception describes that portion of rainfall that fails to reach the ground due to the presence of the tree, such as the water caught on the leaves and bark. Transpiration is the evaporative moisture loss that occurs from the leaf and bark surfaces of the tree as it pulls moisture from the root zone. Studies on evaporative losses have sometimes concentrated on the transpiration and sometimes on the interception and runoff characteristics, but rarely on both at the same time. Scientific methodologies varied, as do the conclusions drawn from the experiments.

For an effective application of the worldwide data to the Black Lake Canyon site, key factors that need to be considered and included are the: (1) relative density and health of the trees, (2) effects of competition from other species, (3) degree of root growth inhibition developed by the soil and rock under the trees, (4) average and maximum / minimum temperature distribution, (5) humidity, (6) the wind strength, (7) amount of fog and fog drip, (8) relative effects of leaf mulches on the forest floor, (9) annual water table fluctuations and depths, and (10) rainfall distribution characteristics.

E. globulus itself can provide some information through consideration of its native habitat requirements in Australia. Turnbull and Pryor (1978) find that the annual rainfall must be higher than 500 millimeters (19 inches), and is usually between 600-1,100 millimeters; the climate free of frost, and the soils moderately fertile loams, or heavier soils that are well drained but contain adequate moisture. The species does not tolerate poorly drained sites or severe drought, especially in shallow soils. Thus, the normal rain percolation into the Nipomo Mesa sands should provide sufficient water to sustain the tree. The climate is well suited to the tree, even though it is at the lower range of necessary rainfall. The tree does not need a high weter table to survive.

RAINFALL INTERCEPTION

Calder's 1992 review of the literature shows that E. globulus intercepted 22% of an annual 1150mm (45 inches) rainfall in Nilgiri, India (Samraj et. al. 1982). This would compare with a Pinus radiata (Monterey Pine) interception of 25% in a Victoria, Australia plantation with 1200 mm (47 inches) rainfall (Feller, 1981). Greenwood (1992) claims Blue Gum has a 21% interception in an area with total annual evaporation of 2690 mm (106 inches).

Calder (1992) concludes that eucalyptus species have relatively low canopy capacities, and intercept less rainfall than most forest tree genera. He also concludes that interception by E. globulus is greater than that of shorter vegetation.

The removal of E. globulus from Black Lake Canyon may result in more water reaching the ground if the tree was replaced with low brush. If it is replaced with another tree such as Quercus agrifolia (Coast Live Oak), it is likely that about the same, or possibly less, water would reach the ground. Oak has a large leaf canopy area, and the leaves may not shed drops of water as easily as the down-pointing eucalyptus leaves. Eucalyptus leaves are also oily, and would bead water more easily than oak.

TRANSPIRATION

For E. globulus in Western Australia, Greenwood et. al (1985) found the combined transpiration and interception moisture total from two sites was 2700 mm (106 inches) and 2200 mm (87 inches), in an area with 680 mm (27 inches) annual rainfall. The trees rooted to 6 meters, and were extracting from the ground water. Comparing this to data from India, where trees were found to intercept about 25 % of the rainfall, the intercepted component of these totals would only be about 6.5 inches, implying that purely transpiration losses were between 81 -100 inches. However, Greenwood and Beresford (1979) found that there was considerable variation in the water uptake of the same eucalyptus species at different sites. Poore and Fries (1985) show that different species of eucalyptus transpire 1.5-6.0 mm per day in the field, or 20-40 liters per day per tree.

It is difficult to export these findings of high water loss to the local situation because of the limited number of factors evaluated which influence the evaporation process. If transpirative losses of 100 inches of water took place at Black Lake Canyon, that would be four times higher than precipitation, and would support the hypothesis that the trees have an important impact on the water table.

The Indian data from derived from research in the Nilgiri Hills of southern India, where winters are relatively dry and cold but above frezing, and very wet, but summers are wet and moderately hot. This climate is very different from that of Black Lake Canyon.

Respiration in E. globulus was measured at 8.5 microlitres CO_2 per 100 milligrams wet weight per hour, which is about the same as that of oak (Spector, 1956, p.265). Calder concluded that transpiration is likely to be the same as for other tree genera except for those that have little stomatal control (this apparently does not include E. globulus). Those species of the genus Eucalyptus that have little stomatal control may be the species that have caused the entire genera to be considered 'water pumps' and 'marsh reclaimers'. Thus the data suggests that, even though E. globulus may have a significant effect on the water table, the effects would be very similar for other tree species such as oak. The intercellular space for E. globulus leaves is 30% by volume, about the same as for sycamore but higher than that of oak (24%). (Spector, 1956, p.145). The ratio of the internal leaf surface area to the external leaf surface area is fairly high at 31:1 (Spector, 1956, p.146)

Stomatal control in E. globulus can limit summer transpiration. Pereira et al (1986, 1987) found that leaf area photosynthesis varied with the season. The amount of change for E. globulus in Portugal was 100 milligrams CO_2 per square decimetre per day in the rainy winter to 10 milligrams CO_2 per square decimetre per day in the rain-free summer. The tree was capable of controlling its transpiration when there was a 'vapor pressure deficit' (during the low humidity summer).

There is no doubt that E. globulus roots will find the water table within much of Black Lake Canyon. Giordano (1969) showed that in sandy soil, 7 year old E. globulus tree roots radiated 1 to 2 meters from the trunk at a depth of 1 meter, with tap roots reaching to 2 to 4 meters deep. Greenwood (1985) showed that in Australia the tree can root to 6 meters deep. The degree to which deep rooting takes place in Black Lake Canyon is not known. E. globulus also grows well in areas with no obvious high water table, such as the hills surrounding the Black Lake Canyon. It is also known to be very susceptible to wind blow-down in the Black Lake Canyon area due to weak root anchoring in a shallow root system.

SURFACE RUNOFF

Poore and Fries (1985) conclude from the literature that there is very little quantitative data on the effect of eucalyptus plantations on surface runoff. There is some weak evidence of increased runoff from eucalyptus stands compared to brushlands. They suggest that the cause of the increased runoff is the inhibition of the understory vegetation due to allelopathic effects from eucalyptus. Allelopathy is the influence, usually chemical, of one plant upon the growth and vigor of another. Eucalyptus produces volatile terpenes (oils) in its leaves that act to suppress competing species. The oils commonly give runoff a tea or tannin-like coloration. The possibility that an allelopathic effect is taking place at Black Lake Canyon is supported by the general lack of understory vegetation. The thick cover of eucalyptus leaves and bark on the forest floor may also repress understory growth, and thus allelopathic effects cannot not proven as impacting the canyon's hydrology. Poore and Fries (1985) performed paired-watershed studies that showed there is a higher peak flow and lower base flow in eucalyptus-forested watersheds compared to grass covered watersheds. This is an effect similar to that seen when the runoff coefficient is increased, implying that less water is held in the soils and more is immediately passed downslope as runoff in the eucalyptus forest compared to the grassland.. Any allelopathic effects and the thick plant debris on the forest floor would diminish if the eucalyptus is removed. As seen at other sites on the Nipomo Mesa, invasive plants such as <u>Ehrharta calycina</u> (African Veldt Grass) quickly occupy cleared sites, suggesting that allelopathic effects, if originally present, are also fast to decay.

Stein(1952) noted in association with <u>E. globulus</u>' inhibition of understory vegetation, there was increased runoff that contributed to soil erosion.

Chinnamani, Gupte, Rege, and Thomas, (1965) performed runoff studies under different forest covers in the Nilgiri watersheds of India. Growing in an area with 16% slope and 1,340 millimeters (53 inches) of annual rainfall, <u>E. globulus</u> plantations had 1% runoff after rains, but none occured from a cover of French Broom or grassland. Poore and Fries (1985) compared water table deficits in eucalyptus plantations to those of nearby grassland. Compared to crop or pasture with deficits that lowered streamflow and ground water recharge by about 70 millimeters/year (2.7 inches/year), the <u>Eucalyptus</u> deficits seem to be on the order of 250 millimeters/year (9.8 inches/year) in areas of deeper soils and higher rainfall. However the eucalyptus plantation deficits were similar to those of pine plantations. Catchment transpiration is 1,000 millimeters/year (39.3 inches/year) for annual rainfall >1,200 mm/yr.(>47.24 inches/year), and about 450 millimeters/year (17.7 inches/year) when the annual rainfall is 500 millimeters/year (19.7 inches/year). This is again about the same as that of pine forests. Clear cutting eucalyptus in high rainfall areas increased runoff by 400 millimeters/year (15.7 inches/year). It should be noted that the results of quantitative studies conducted in the Nilgiri hill station in monsoon-prone area of southern India probably cannot be replicated in California.

Thomas, Chandrasekhar, and Haldorai (1972), created a mathematical model to estimate of evapotranspiration by E. globulus from the Nilgiri watershed in India. Calder (1992) criticizes the model as flawed, simplistic and invalid , and it is not considered further in this study.

BIOMASS ACCUMULATION

Water uptake may be loosely associated with biomass accumulation. Beadle and Turnbull (1992) compared the growth rates of Eucalyptus in native forest and in plantation monocultures. E. globulus added between 42-98 cubic meters of dry weight per hectare in 5 years in Victoria and Tasmania. Maximum growth of wood biomass was in the 15th year at 55 cubic meters per hectare, but dropped to 15 cubic meters per hectare at a stand age of 45 years. Energy conversion was less than the rate for field crops, and about half of that of hybrid poplar. Cromer, Williams, and Tompkins, (1983), have shown that nitrogen and phosphorus stimulate growth in eucalyptus plantations. It is possible that, if water quality in Black Lake Canyon is degraded by septic tank effluent or fertilizers, the biomass accumulation and water uptake will increase.

CALCULATING THE EFFECTS OF REMOVING EUCALYPTUS

INTERCEPTION

On plant communities similar to those that could occupy Black Lake Canyon, Zinke (1967) showed that interception storage for each storm event was generally lower than that for Eucalyptus. Values were 0.5 to 1.5 millimeters for Baccharis; 2.0 millimeters for Ceanothus-Mountain Mahogony-Scrub Oak chaparral; 1.0 to 1.5 millimeters for annual grasses; 0.5 millimeters for mixed hardwoods; 0.3 to 0.1 millimeters for Monterey Pine; and 0.5 to 3.6 millimeters for a Monterey Pine forest floor (the forest age was 5 to 30 years, and the value does not represent the interception of the trees themselves). Multiplied by 10, the values would reflect the intercepted rainfall for a ten storm rainy season. Using a 1.0 millimeter per event interception value, then 10 millimeters (0.4 inches) would be intercepted during a 10 storm year in a plant community resembling the non-eucalyptus scrubs around Black Lake Canyon. This would be about 2.6% to 2.0% of the 381 mm (15 inch) to 483 mm (19 inch) rainfall. For Eucalyptus forest, interception has been calculated as between 11and 20% of rainfall. This would compare with a Monterey Pine interception of 25% in an area of 1200 millimeters (47 inches) rainfall (Feller, 1981).

Poore and Fries (1985) conclude that the interception of Eucalyptus plantations is about the same as for other trees. They showed that Eucalyptus intercepts between 11 and 20% of precipitation, less than pine but much more than low vegetation. Thus replacement of the existing Black Lake Canyon Eucalyptus forest with Quercus agrifolia (Coast Live Oak) should not have a major effect on the hydrology after the oak trees achieve about the same canopy cover. Runoff and water storage may increase while the replacement native flora is in a seral scrub stage.

FOG DRIP

Eucalyptus has the ability to collect precipitation in drifting mist. .If eucalyptus is replaced by oak, the evapotranspirative losses would be about the same, but fog drip would decrease. If the trees are replaced by chaparral, the interception of fog would decrease.

It has been suggested that decades of fog drip may cause some ecological problems relating to restoration. Del Moral and Muller (1970) ascribe the lack of understory in Eucalyptus plantations to allelopathy from phytotoxins transferred to the soil through fog drip. These chemicals may persist in the soil and inhibit restoration, but the rapid invasion of grasses into eucalyptus clear-cuts suggests that any allelopathic effect is short lived. Bara (1981) found that soils under a 100 year old E. globulus stand were not substantially different from those under a Quercus robur stand of unknown age, or from a 30-year old Pinus pinaster stand. Calder (1992) does not consider this study to be definitive.

If phyotoxins do suppress the woodland understory, a change from Eucalyptus to another genus would eventually result in an increase of understory plants. As a result, the long term interceptive losses from the understory would increase.

MULCH

In Black Lake Canyon Eucalyptus leaf mulches are thickly developed on the ground below the trees and must inhibit evaporative losses from the soil surface. If the trees are removed and replaced by oak, the effect of oak leaf mulch would probably be similar. Soil surface evaporation would increase if Eucalyptus is replaced by dune scrub. As the Eucalyptus mulches on cleared land will ultimately decompose or be removed by fire, the net evapotranspiration would also increase unless the replacement vegetation can maintain a similar soil cover. Oak may provide such a mulch, but dune scrubs produce very little detritus.

RUNOFF

The studies described above suggest that Eucalyptus actually increases watershed runoff relative to other vegetation. This runoff appears to be due to the lack of understory vegetation and therefore more flashy. Removal of Eucalyptus may slightly diminish peak runoff discharge, generating a slightly slower release of waters. This would be a short lived effect during storms, and would not contribute substantially to sustaining wetlands throughout the year. Based on field observations of erosional impacts in Black Lake Canyon among Eucalyptus woodland, dune scrub, and pasture, and the effect of ground mulch is considered, there does not appear to be any obvious difference in runoff characteristics.

CONCLUSIONS

Removal of Eucalyptus will at first slightly diminish surface runoff volumes entering the canyon, and may increase subsurface seepage into the canyon. This may result in a temporary rise in the local water table. This effect can be expected to diminish, possibly to vanish completely, as the forest is replaced by another kind, such as Coast Live Oak.

A THUMBNAIL HYDROLOGIC MODEL OF THE IMPACTS OF EUCALYPTUS REMOVAL

From the above discussion the following factors emerge as being pertinent to a hydrologic model: 1) Eucalyptus use more water when it is available, as in the case of a shallow water table, than when the water is harder to extract; 2) The interception of rain by the trees is insignificantly different from that of other vegetation, and can be discounted from a 'thumbnail' calculation; 3) The effects of leaf mulch on water retention, runoff values, and fog drip may be pertinent factors, but with no data available on their effects, they will also be discounted from the 'thumbnail' calculation; 4) Existing data is dominated by information from India and Australia, where climates differ from those of the Nipomo Mesa. An Indian tropical forest with rainfall similar to that of the Nipomo Mesa might offer the best comparative data, but would not be representative of a forest where the trees have 'wet feet', as in a riparian corridor. The Australian data addresses a 'wet feet' environment, but in a hotter climate than that of the Nipomo Mesa.

Thus for the 'thumbnail' calculation, two scenarios have been chosen; 1) riparian eucalyptus with 'wet feet' along the lower portions of the slopes and on the floor of the canyon, and 2) for 'dry feet' trees on the upper slopes of the canyon. Because the Australian 'wet feet' data was developed in a more extreme climate, the evapotranspirative losses were halved to 1,250 millimeters (49 inches). The Indian 'dry feet' data used an evapotranspiration of 450 millimeters (17.7 inches), which has been adopted in this model.

For all scenarios it is assumed that there is a 20% infiltration of rainfall to ground water during the year in all areas that have dune scrub rather than eucalyptus, and a 20 inch rainfall was assumed. The average rainfall at Nipomo was 19.7 inches from 1975 to 1985, and 16.16 inches for the period from 1921 to 1988. As Nipomo is on the leeward side of the mesa, and would not experience the orographic effects of the rising western slope, a higher value is assumed for the Black Lake Canyon.

The model assumes a simplified landscape with either eucalyptus or bare ground. All space with eucalyptus experiences a greatly reduced infiltration due to evapotranspiration, where the amount of water available at the ground surface for infiltration is the rainfall minus the evapotranspiration. However, only 20% of this available water actually infiltrates. All bare ground experiences a gross infiltration of 20% of the 20 inch rainfall, or 4 inches.

Thus for the 'wet feet' scenario, the rainfall of 20 inches is subtracted from the gross evapotranspirative loss of 49 inches to yield a net loss to the water table of 29 inches beneath eucalyptus. Bare ground has a 4 inch recharge to the water table.

For the 'dry feet' scenario the evapotranspirative loss in eucalyptus of 17.7 inches is less than the rainfall of 20 inches, creating 2.3 inches of water available for recharge at the surface. If 20% of this available water reaches the water table, the net gain is 0.46 inches. Bare ground has a 4 inch recharge to the water table.

Table 5 shows the amount of 'dry feet' eucalyptus cover as a percent of land area; the annual gain to the water table of 0.46 inches from land with eucalyptus; the bare ground infiltration of 20% of the rainfall of 20 inches ; the net gain to the water table; and the net recharge in acre feet per acre. Thus, with 20 inches of rainfall, 'dry feet' eucalyptus would allow a very small of water to infiltrate to the water table. Clear cutting eucalyptus would yield an extra 0.3 acre feet per acre of recharge.

Table 6 shows the 'wet feet' case, where an acre of eucalyptus removes 2.416 acre feet per acre from the water table. Clear cutting eucalyptus would yield an extra 2.75 acre feet per acre of recharge.

In Black Lake Canyon 'wet feet' trees could still extract water as high as 20 feet above the water table. However, large volume extractors would probably be closer to the water table. Presumably a large percentage of the trees at the Zenon Road crossing have 'wet feet', but the amount of water they extract could be very different from that removed by trees in India and Australia.

TABLE 5

Net Acre Feet Per Acre Water Table Recharge From Different Percentages of 'Dry Feet' Eucalyptus Cover

% Eucalyptus Cover	Net Infiltration from Eucalyptus (inches)	Net Infiltration from Bare Ground (inches)	Total Infiltration (inches)	Recharge in Acre Feet per Acre
100	0.46	0	0.46	0.038
90	0.414	0.4	0.81	0.067
80	0.368	0.8	1.17	0.097
70	0.322	1.2	1.52	0.126
60	0.276	1.6	1.88	0.156
50	0.23	2.0	2.23	0.185
40	0.184	2.4	2.58	0.215
30	0.138	2.8	2.94	0.244
20	0.092	3.2	3.29	0.274
10	0.046	3.6	3.65	0.303
0	0	4.0	4.0	0.333

TABLE 6

Net Acre Feet Per Acre Water Table Recharge Or Loss (-) From Different Percentages Of 'Wet Feet' Eucalyptus Cover

% Eucalyptus Cover	Net Transpiration loss from Eucalyptus (inches)	Net Infiltration from Bare Ground (inches)	Total Infiltration or Loss (-) (inches)	Recharge in Acre Feet per Acre
100	29	0	-29	-2.416
90	26.1	0.4	-25.7	-2.141
80	23.2	0.8	-22.4	-1.866
70	20.3	1.2	-19.1	-1.591
60	17.4	1.6	-15.8	-1.316
50	14.5	2	-12.5	-1.041
40	11.6	2.4	-9.2	-0.766
30	8.7	2.8	-5.9	-0.491
20	5.8	3.2	-2.6	-0.216
10	2.9	3.6	0.7	0.058
0	0	4	4	0.333

SUMMARY OF FINDINGS

1) The wetlands in the upper canyon are either stable or are increasing in size.

2) Wetlands in the lower canyon are drying up.

3) Dessicated peats indicate that the lower canyon once received lateral flow from the sides of the canyon, and it appears that regional lowering of the water table may be responsible for the drying of the wetlands

4) The geology of the upper canyon supports the theory that the upper canyon has a perched aquifer which has been receiving increased recharge in recent years

5) Plants threatened by the loss of wetlands in the lower canyon might be able to occupy wetlands in the upper canyon, although the latter lacks the peat soils of the lower canyon.

6) The regional water table utilized by most wells near the upper canyon is in a state of overdraft, and is below the perched aquifer..

7)The water tables around Black Lake Canyon were shown to be declining at an average rate of 0.37 feet per year since 1975.

8) Mass balance calculations suggest that, although the lower canyon is in overdraft, the annual deficit is small and could be reversed through conservation, but conservation will be insufficient to accomodate new growth without a return to overdraft conditions

9) Wetlands in the upper canyon could be increased by excavating into the water table, by recharging with waste water within the canyon, and by routing surface water to the canyon and releasing it slowly into the water table.

10) The water table in the lower canyon could be raised if flow through the canyon is slowed. Although dams may be damaging to the wetlands, elimination or blockage of the drainage ditch in the center of the canyon could be an effective measure.

11) More detailed hydrologic surveys of the lower canyon are needed, as the questions of the amount of leakage from the canyon floor and the relation of its waters to those of the regional aquifer have not been resolved.

12) There is not much information available on the effects of removing eucalyptus to conserve water. Data from India and Australia suggests that eucalyptus does not use any more water than other trees. There are water-saving advantages to removing eucalyptus trees in the riparian corridor, but very little to removing trees higher on the slopes around the canyon.

BIBLIOGRAPHY

Abrams, LeRoy. 1944. Illustrated Flora of the Pacific States, 4 volumes. Stanford University Press, Stanford, California.

Bara, T. S. 1981. Avance de los Resultados de los Effectos de Eucalypto Sobre la Composicion Granulometrica y Quimica del Suelo en Lourizan (Pontevedra). Departemento Forestal de Zonas Humedas. Pontevedra, Spain. 11p.

Beadle, C. L. and C. R. A.Turnbull. 1992. Comparative Growth Rates of Eucalyptus in Native Forest and in Plantation Monoculture. IN: Growth and Water Use of Forest Plantations. Edited by Calder, I. R.; Hall, R. L. and P. G. Adlard. John Wiley & Sons, New York. pp. 318-331.

Calder, I. R. 1992. Water Use of Eucalypts-A Review. IN: Growth and Water Use of Forest Plantations. Edited by Calder, I. R.; Hall, R. L. and P. G. Adlard. John Wiley & Sons, New York. pp. 167-179.

California Department of Water Resources. 1958. San Luis Obispo County Investigation: State Water Resources Board Bulletin 118.

California Department of Water Resources. 1970. Sea Water Intrusion: Pismo Guadalupe Area: California Department of Water Resources Bulletin 63-3.

California Department of Water Resources. 1979. Ground Water in the Arroyo Grande Area: Prepared by the Department of Water Resources for the County of San Luis Obispo, June 1979.

California Department of Water Resources. 1983. Urban Water Use in California: California Department of Water Resources Bulletin 166-3. pp. 239.

Chinnamani, S., Gupte, S. C., Rege, N. D. and P. K. Thomas. 1965. Run-off Studies Under Different Forest Covers in the Nilgiris. Indian Forester v.91, no.8, pp. 676-679.

Cromer, R. N., Williams, E. and D. Tompkins. 1983. Biomass and Nutrient Uptake in Fertilized E. globulus. Silviculture v.8, no.32, pp.672-674.

del Moral, R. and C. H. Muller. 1970. Fog Drip: A Mechanism for Toxic Transport from Eucalyptus globulus. Bulletin Torry Botanical Club v.96, no.4, pp. 467-475.

Envicom. 1985. Final Environmental Impact Report, Bjerre General Plan Amendment: Prepared for the Office of the Environmental Coordinator, County of San Luis Obispo.

Feller, M.C. 1981. Water Balances in *Eucalyptus regnans*, *E. obliqua* and *Pinus radiata* Forests in Victoria. Australian Forests v.44 (3), pp.153-161.

Greenwood, E. A. N. 1992. Water Use of Eucalypts-Measurement and Implications for Australia and India. IN: Growth and Water Use of Forest Plantations. Edited by Calder, I. R.; Hall, R. L. and P. G. Adlard. John Wiley & Sons, New York. pp. 298-300.

Giordano, E. 1969. Osservazioi Sull'apparanto Radicale Dell'Eucalyptus globulus Labill. Publicazioni del Centro di Sperimentazione Agricola e Forestale. v.10 pp.135-147.

Hickman, J. C. (ed.). 1993. The Jepson Manual - Higher Plants of California. University of California, Berkeley.

LFM. 1987. Water, Wastewater and Drainage Studies, Nipomo Mesa Planning Study: Prepared by Lawrence, Fisk, and McFarland, Inc., for RRM Design Group and Nipomo Mesa Technical Study Sponsors, August 24, 1987.

Land Conservancy of San Luis Obispo County. 1992. Black Lake Canyon Enhancement Plan: Prepared for The California Coastal Conservancy, June 1992.

McClelland Engineers. 1988. Draft Environmental Impact Report, Black Lake Canyon Planning Area Standards and Sensitive Resource Area Boundary General Plan Amendment: ED 85-155 (G820607:2); Prepared for the Office of the Environmental Coordinator, County of San Luis Obispo, July 1988.

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

Morro Group. 1990. South County Area Plan Draft Environmental Impact Report: Prepared for the Office of the Environmental Coordinator, County of San Luis Obispo, July 1990.

Poore, M. E. D. and C. Fries. 1985. The Ecological Effects of Eucalyptus: Forestry Paper 59, FAO, United Nations. 87p.

Santa Barbara County Water Agency. 1977. Adequacy of the Santa Maria Groundwater Basin.

San Luis Obispo County Planning Department. 1987. Hearing Draft for Circulation Element, Land Use Element, South County Planning Area.

Skinner, M. W. and Bruce M. Pavlic. 1994. Inventory of Rare and Engangered Vascular Plants of California. California Native Plant Society, Special Publication No. 1. Fifth Edition. Sacramento.

Spector, W.S. (ed.). 1956. Handbook of Biological Data. W.B.Saunders Co., 1956.

Standiford, R.B. and F.T. Ledig (coordinators). 1983. Proceedings of a Workshop on Eucalyptus in California: Pacific Southwest Forest and Range Experiment Station General Technical Report, PSW-69.

Stebbins, R. C. 1985. A Field Guide to Western Reptiles and Amphibians. Houghton Mifflin, Boston.

Stein, A.H. 1952. Nota Sobre los Resultados Obtenidos en Otros Paises en las Experiencias Acerca de la Influencia del Eucalyptus Sobre la Cubierta Forestal de las Hoyas Hidrograficas y Sobre el Mejoramiento del Suelo con su Aplicacion a la Misma Materia en Chile: Paper from "Mision Forestal de la FAO". No 9. Santiago de Chile.

Thomas, P. K., Chandrasekhar, K. and B. Haldorai. 1972. An Estimate of Evapotranspiration by Eucalyptus globulus from Nilgiris Watershed. Indian Forester v.98 no. 2 pp. 775-780.

APPENDIX A

INDIVIDUAL WELL RECORDS FROM THE SAN LUIS OBISPO COUNTY MONITORING PROGRAM

Well levels are recorded from 1975 to 1993. Although the county measured the wells twice a year, only measurements made in the spring have been graphed. The horizontal axis shows the year (the .3 indicates a spring reading), and the vertical axis the water level as feet above sea level. Each graph is identified by the well number. The well number contains the following information:

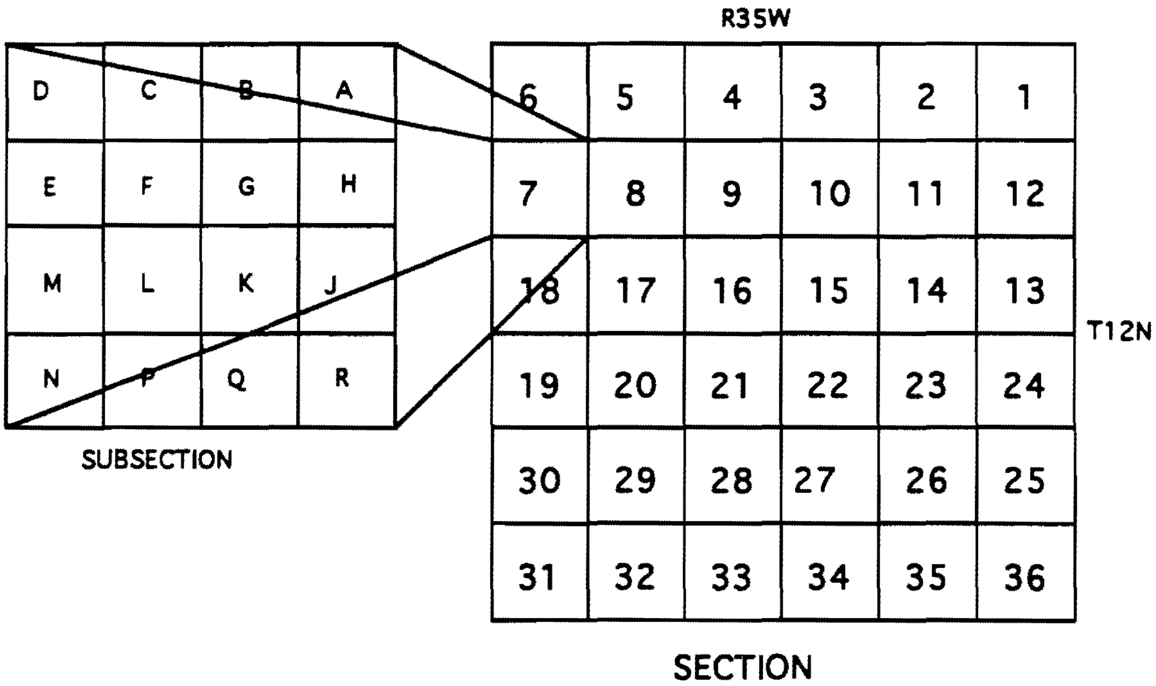
TOWNSHIP

SECTION

12/35-33Q2

SUBSECTION

RANGE

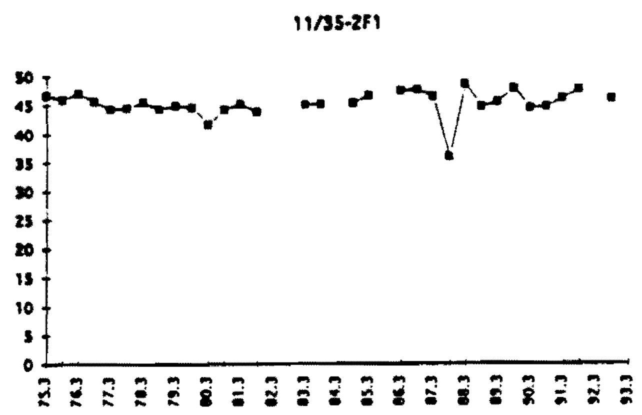


Turnbull, J. W., and L. D. Pryor. 1978. Choice of Species and Seed Source: Chapter 2 in Hillis W.E., and A.G. Brown, (editors), Eucalyptus for Wood Production: CSIRO, Adelaide, Australia.

United States Soil Conservation Service. 1984. Soil Survey of San Luis Obispo County, California - Coastal Part. U.S. Department of Agriculture Soil Conservation Service.

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

Zinke, P.J. 1967. Forest Interception Studies in the United States. IN: International Symposium on Forest Hydrology. Edited by W.E. Sopper and H.W. Lull. Peragmon Press, New York. pp. 137-162.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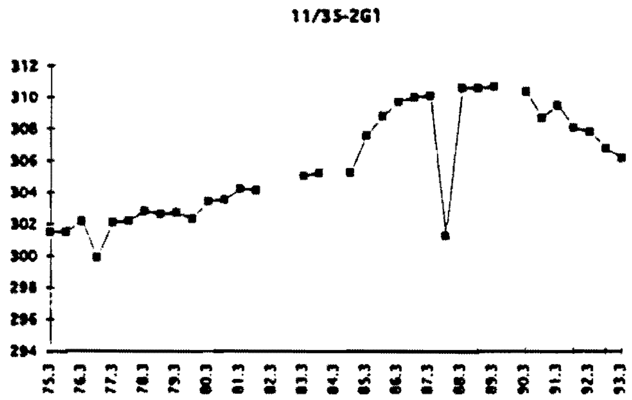
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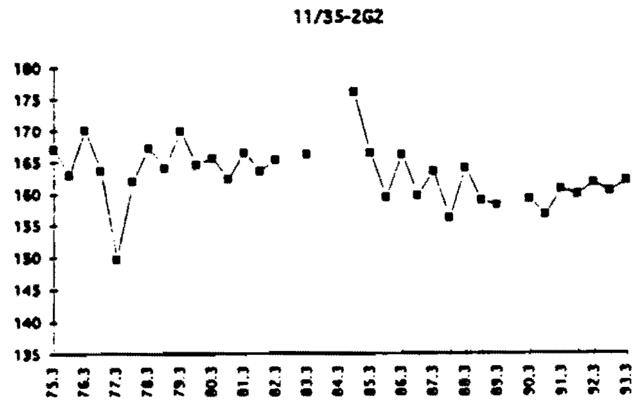
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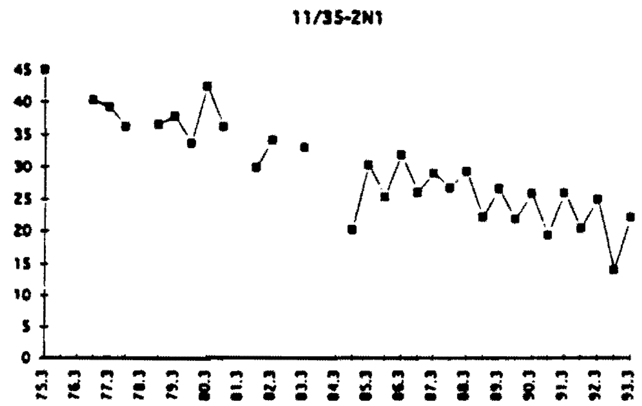
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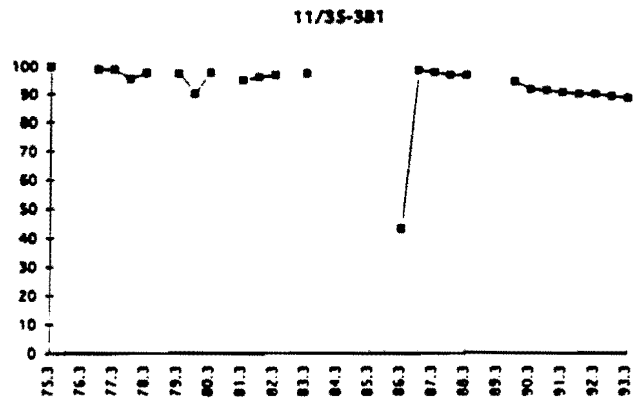
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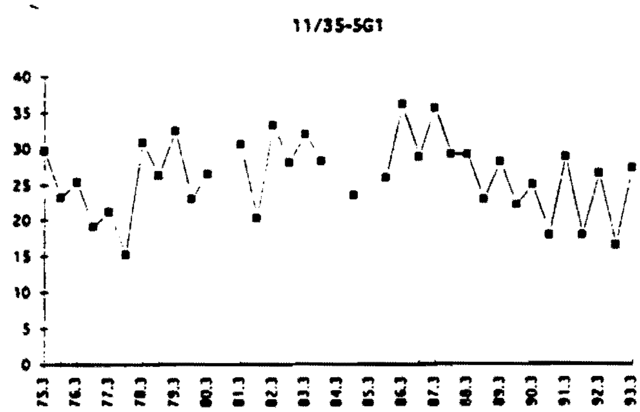
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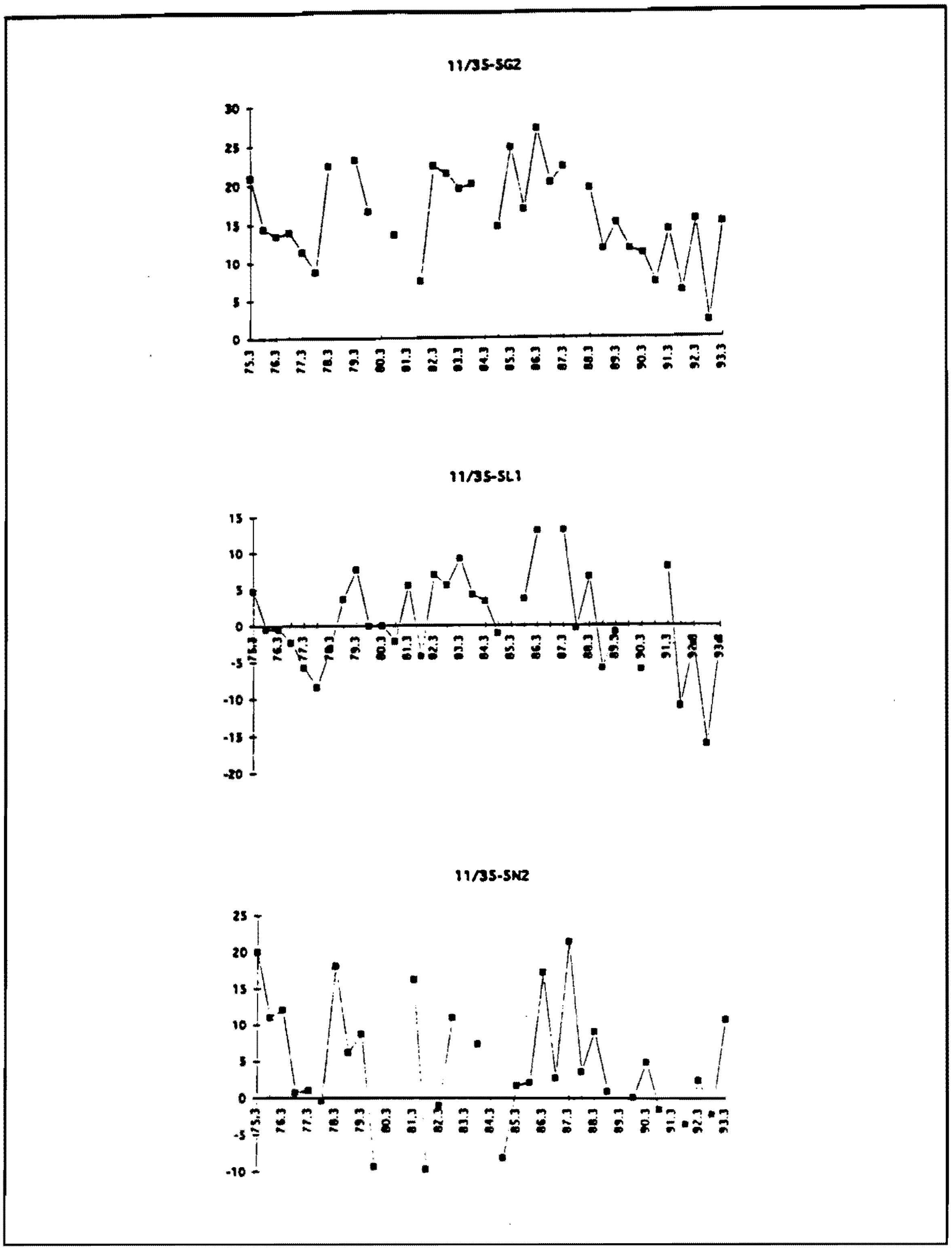
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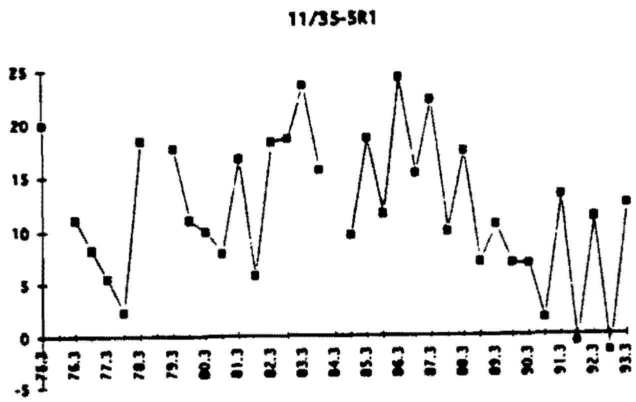
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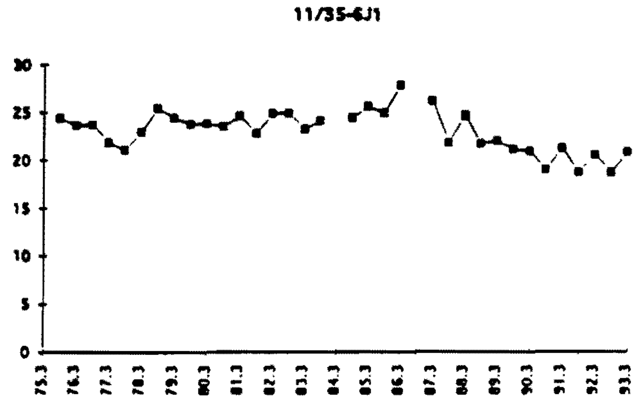
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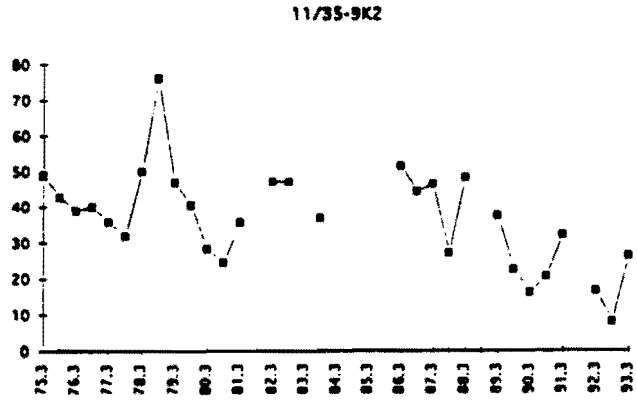
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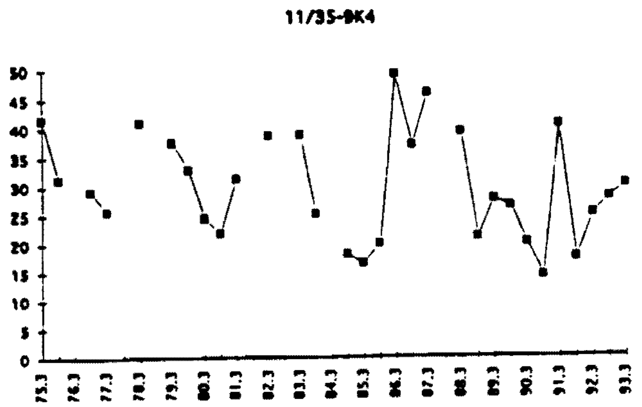
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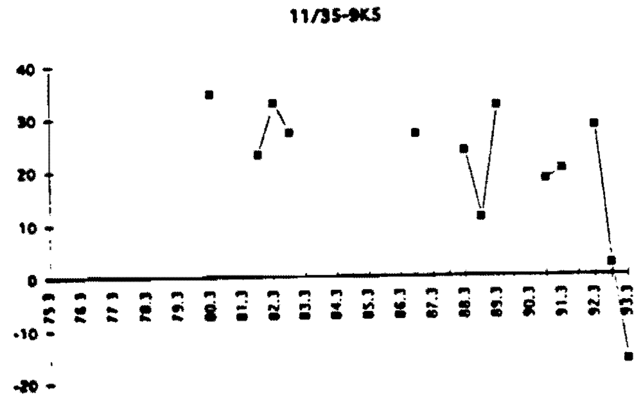
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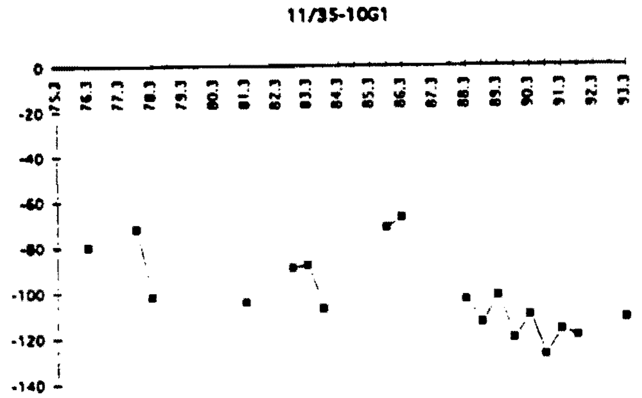
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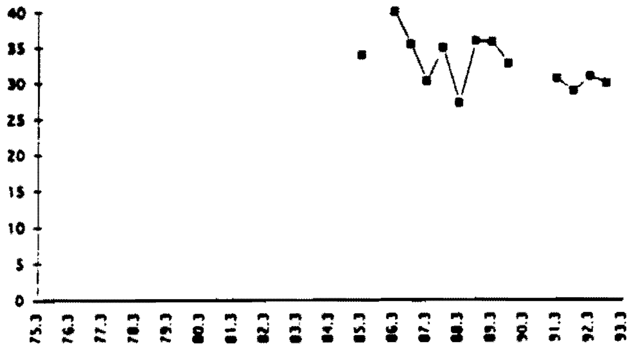

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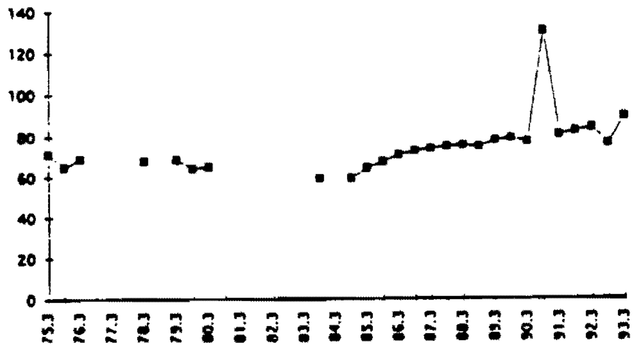

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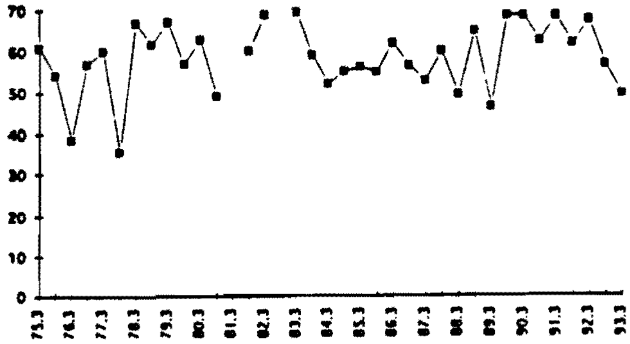

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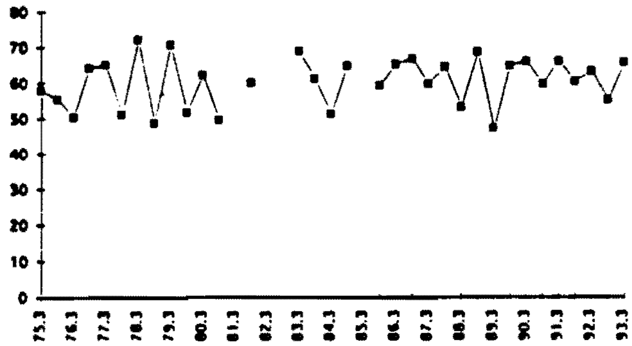

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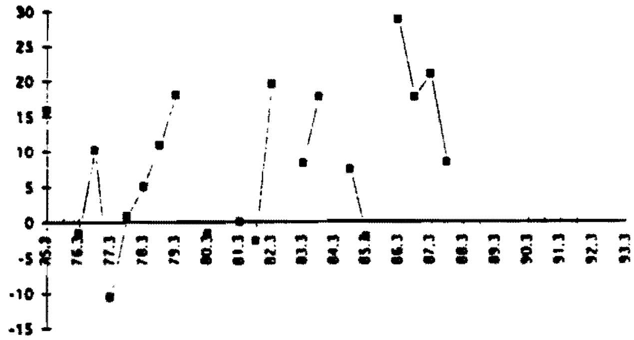

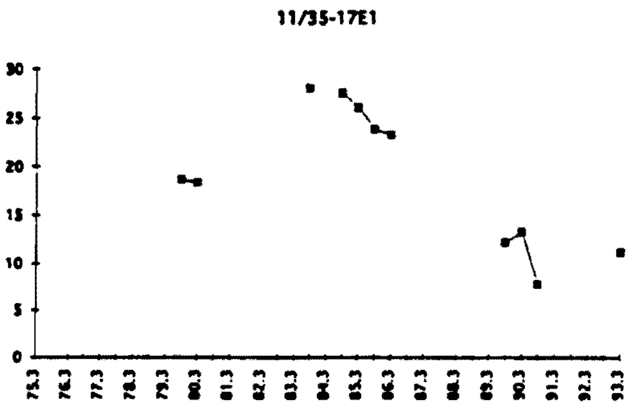
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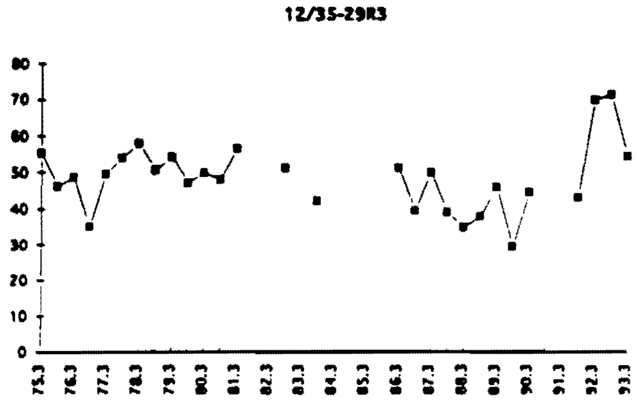
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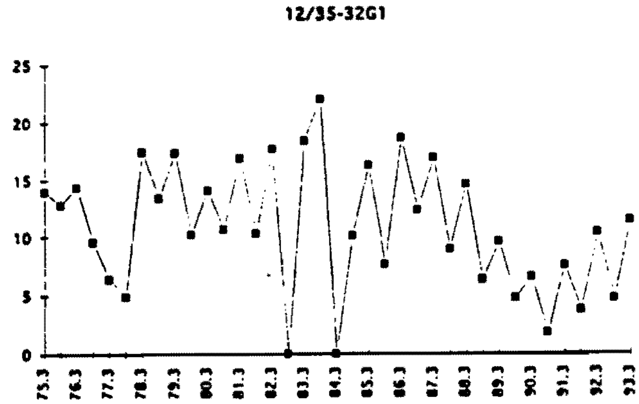
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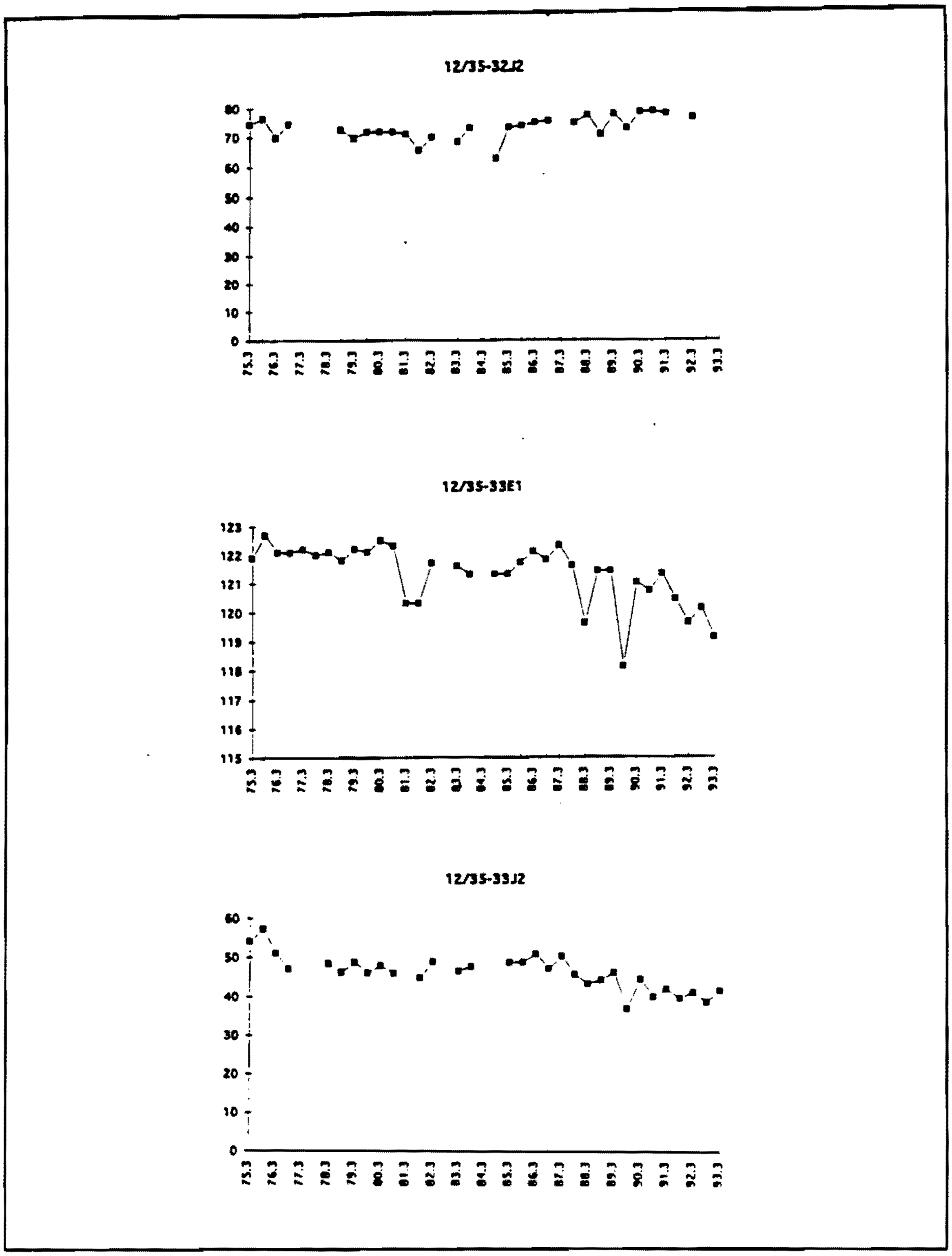
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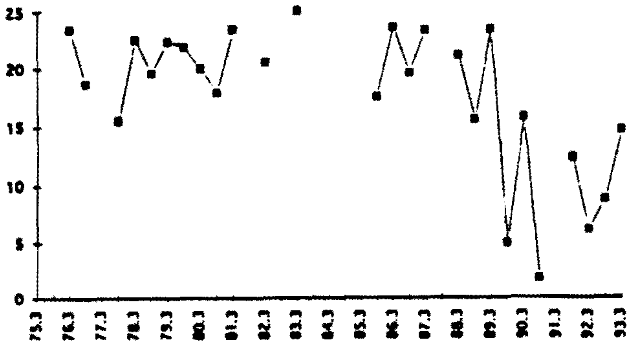

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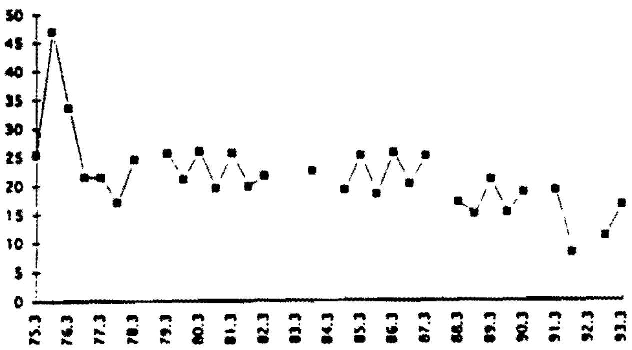

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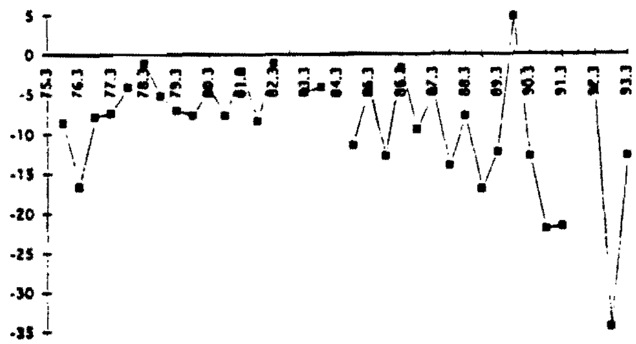

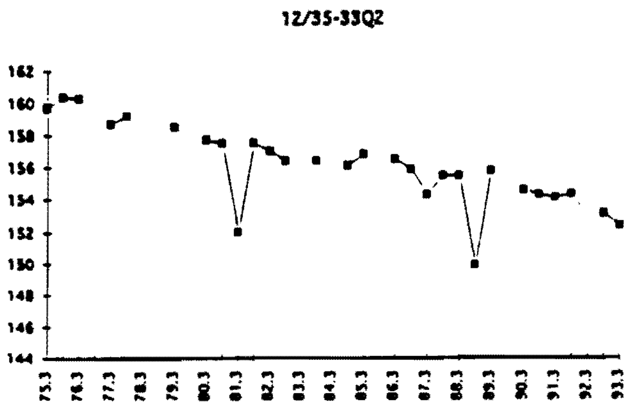
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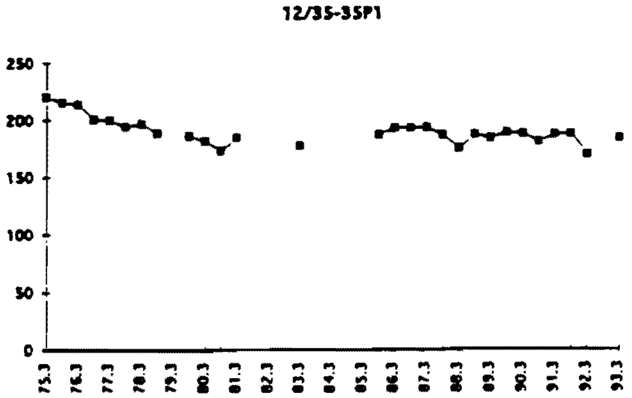
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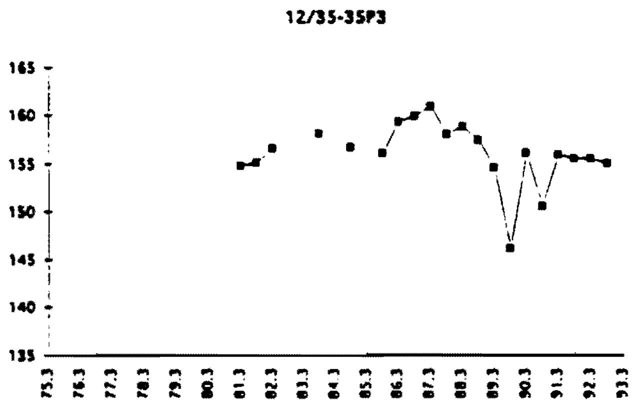
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