HYDROGEOLOGIC CONDITIONS FOR DEVELOPMENT OF THE MAXIMUM RECOVERY PLAN FOR THE KERN WATER BANK AUTHORITY

Revised Report

prepared for
Kern Water Bank Authority
Cawelo, California

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EXECUTIVE SUMMARY

The major conclusions from this evaluation are as follows:

1. It is estimated that at least about 720,000 acre-feet of water could be recharged in the KWBA basins before groundwater levels became so shallow as to reduce infiltration rates. Once groundwater levels reach the basin bottoms, infiltration rates are expected to decrease to about one half of the previous values. This is because the hydraulic gradients and transmissivity for the saturated alluvium become the controlling factors. These factors control the amount of lateral groundwater outflow away from the recharge facilities (and thus the infiltration rate) that is possible. The annual recharge would decrease to about 100,000 acre-feet under this condition. Over a five-year period, starting with relatively deep water levels, over 920,000 acre-feet of water could be recharged.

2. Drawdown calculations indicate that at a recovery rate of 200,000 acre-feet per year essentially all of the recharged water could be recovered over a five-year period, assuming that pumping starts when water levels are shallow (i.e. less than about 50 feet deep). This would result in a water level about 250 feet deep. If water levels are at an intermediate level (about 120 feet deep) when recovery pumpage commences, about 500,000 acre-feet of water could be recovered over a five-year period. About 200,000 acre-feet per year could be recovered for one and a half years and about 60,000 acre-feet per year for the remaining three and a half years. The water level would then be about 250 feet deep. An initial recovery rate of 300,000 acre-feet per year could be maintained for about two years, assuming that pumping starts when water levels are shallow. Thereafter, about 130,000 acre-feet per could be recovered each year for the rest of the five-year period.

3. Potential impacts of the project include: 1) water-level rises in shallow groundwater areas, 2) water-level declines during recovery well pumpage, 3) land surface subsidence, 4) migration of poor quality groundwater, and 5) reduction in natural river recharge. Relocating the proposed recovery well sites that are distant from the recharge basins to the central areas of these basins would help mitigate many of the impacts. Also, drawdown impacts on other wells could be minimized by intentionally pumping more groundwater directly out of the upper layer, thus minimizing the effects of pumping the deeper confined groundwater. The most significant potential groundwater quality problems north of the Kern River are DBCP, nitrate, and possibly EDB and uranium in some areas. The most significant potential groundwater quality problems south of the Kern River are arsenic, fluoride, and uranium. These problems can be avoided by conducting suitable water sampling programs for the recovery wells, and intentionally avoiding pumping in these areas. Land surface subsidence is being monitored, and results to date indicate that this should not be a significant problem. Potential adverse impacts can be mitigated through conducting appropriate monitoring and developing mitigating measures, as set forth in the Memorandum of Understanding.

Following is a summary of information used in developing these conclusions:

1. Three major layers in the subsurface have been delineated, extending from the land surface to a depth of 300 feet, from 300 to 500 feet, and from 500 to 700 feet. Most of the existing recovery wells tap all three layers, and are generally perforated from about 200 to 700 feet in depth.

2. During recharge episodes, a recharge ridge forms beneath the Kern River, and a recharge mound forms beneath the KWBA recharge basins. The direction of groundwater flow northwest of the river

is to the north or northwest. The direction of groundwater flow southeast of the river is to the southeast. Such flow directions are shown on the Spring 1997 water-level elevation map. Conversely, following periods of no recharge (i.e. Spring 1993), the regional direction of groundwater flow throughout the area is toward the northwest.

3. Beneath the recharge basins, the water level can be less than 50 feet deep at the end of recharge episodes. In this case, the upper layer is mostly saturated. Conversely, at the end of extended recovery well pumping episodes, the water level can be more than 200 feet deep, and at least about two-thirds of the upper layer is above the water level.

4. Information on aquifer characteristics can be used to estimate water-level changes due to future recharge and recovery operations. The most important of these characteristics are transmissivity and storage coefficient.. Because the water level in the upper layer can vary substantially, the saturated thickness and transmissivity of this layer also vary substantially. For example, much higher values are present at the end of recharge episodes, compared to at the end of recovery episodes. The upper layer acts as an unconfined aquifer, whereas the lower two layers act as a leaky or semi-confined aquifer. Values for the aquifer characteristics were developed from aquifer tests, past groundwater model calibration, and from water-level rises observed during large-scale recharge in 1995-96. The model-derived values were found valid in many cases, and in others were revised to reflect more up-to-date information. The upper layer contains the coarsest and most permeable deposits. Near the toe of the Kern River Fan, near Interstate 5, finer grained deposits predominate. This is the area of lowest transmissivity in the study area. The highest total transmissivity (of all layers) is generally highest

beneath the J and M-series basins.

5. During the 1995-96 recharge episode, when about 385,000 acre-feet of water were recharged in the KWBA recharge basins, the water level rose an average of about 110 feet. The water-level rises associated with this recharge were used to project conditions during periods of significant recharge.

HYDROGEOLOGIC CONDITIONS FOR DEVELOPMENT OF THE MAXIMUM RECOVERY PLAN FOR THE KERN WATER BANK AUTHORITY

INTRODUCTION

The Kern Water Bank Authority (KWBA) is developing a Maximum Recovery Plan for its Kern Fan water banking project. This project has about 3,000 acres of developed recharge basins. Most of the basins are north of the Kern River, south of Stockdale Highway, and southwest of the Southern Pacific Railroad Tracks. These basins are grouped (from east to west) into the following series: R, E, S, C, N, M, and W (Figure 1). In addition, 317 acres of basins (J-series) are located south of the Kern River in Sections 17, 19, and 20 of T30S/R26E. Recharge has been undertaken using these basins since 1995. Another 2,900 acres of basins are proposed to be routinely used. The purpose of this report is to develop the hydrogeologic information necessary for the Maximum Recovery Plan. Included are the determination of the storage capacity for the Kern Water Bank, recommendations for the spacing of recovery wells, and determination of the annual recovery capacity.

There are several other recharge and/or water-banking projects in the vicinity whose activities may impact the Kern Fan Water Bank. These include the City of Bakersfield 2,800-acre project along the Kern River, part of which is located between the R and J-series basins. The North Pioneer Project is located north of the COB project and east of the R-series basins. The South Pioneer Project is located south of the COB project and east of the J-series basins. The Rosedale-Rio Bravo Storage District recharge project is partly located north of the northernmost basins in the project (E, S, and N-series). The Buena Vista Water Storage District/West Kern Water District spreading facilities are relocated

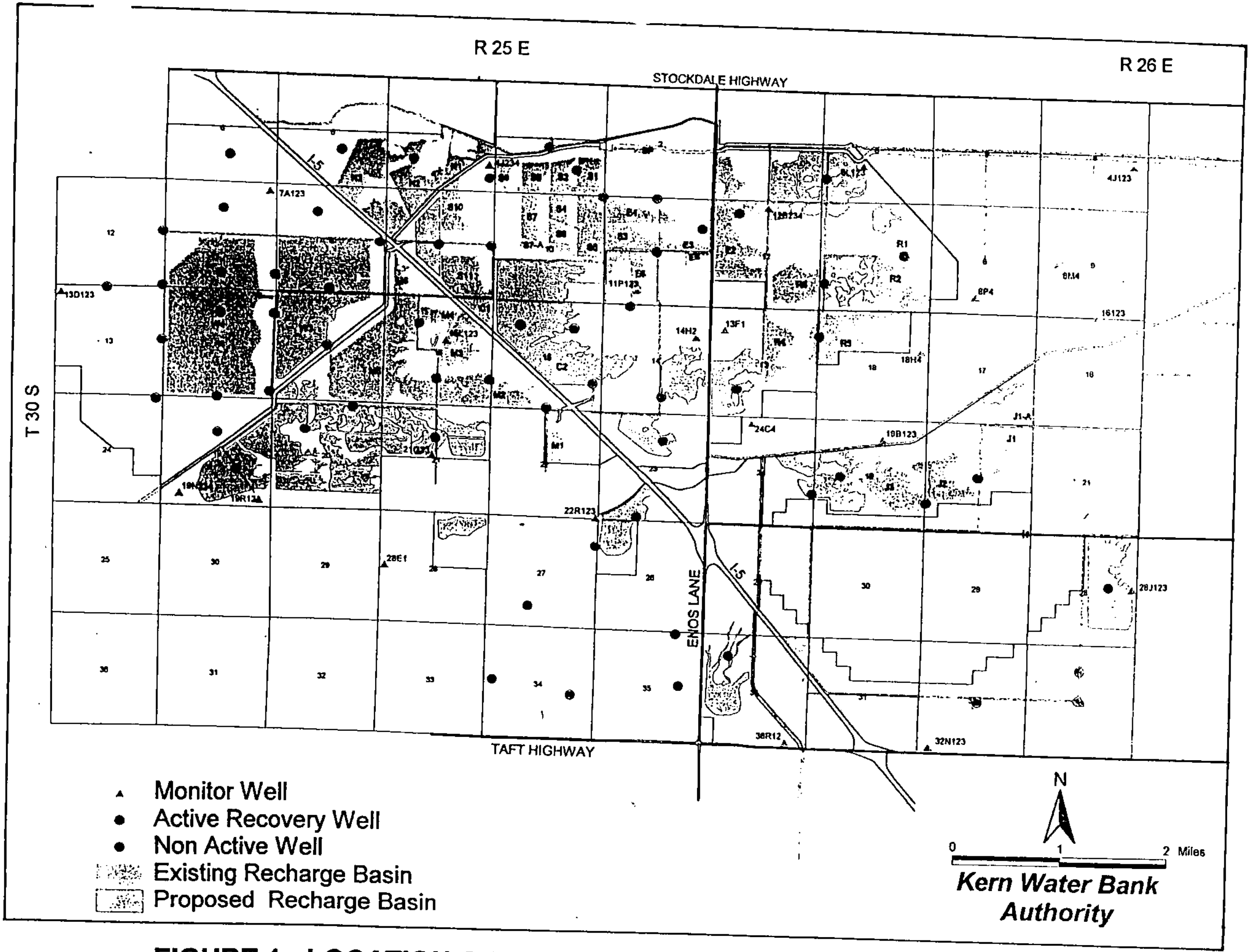


FIGURE 1 - LOCATION OF RECHARGE AND RECOVERY FACILITIES

primarily west of I-5 along the Kern River Bypass, the intertie, and the Main and Outlet Canals. This area is primarily south of the M and W-series basins.

SUBSURFACE GEOLOGIC CONDITIONS

Three major subsurface geologic units have been delineated in the area, based on past hydrogeologic evaluations of the Kern Fan. The Kern County Water Agency (KCWA) and California Department of Water Resources (DWR) installed a number of multiple completion monitor wells in the Kern Fan. Geophysical and geologic logs for these wells provide the foundation upon which subsurface geologic units are grouped. Wilson (1993) presented a number of subsurface geologic cross sections through the Kern Fan. The uppermost layer is generally coarser grained than the two underlying layers, and in the Kern Water Bank Area generally extends from the land surface to a depth of about 300 feet. The middle layer extends for 300 to 500 feet and the lower layer from 500 to 700 feet in depth. During drought and extended recovery periods, the upper two-thirds or more of the upper layer can be above the water level. Conversely, during pre-pumping conditions (i.e. the early 1900's) and during maximum recharge conditions, the upper layer is almost entirely saturated.

A number of fine-grained strata are indicated to be present at most wells, however geologic correlations indicate these are not usually laterally extensive. Water-level measurements indicate that during recharge and recovery periods, these strata function in a limited sense as confining beds. However, water levels at various depths quickly equilibrate during non-recharge and non-recovery periods. Thus these beds restrict the vertical flow of groundwater, but do not prevent it.

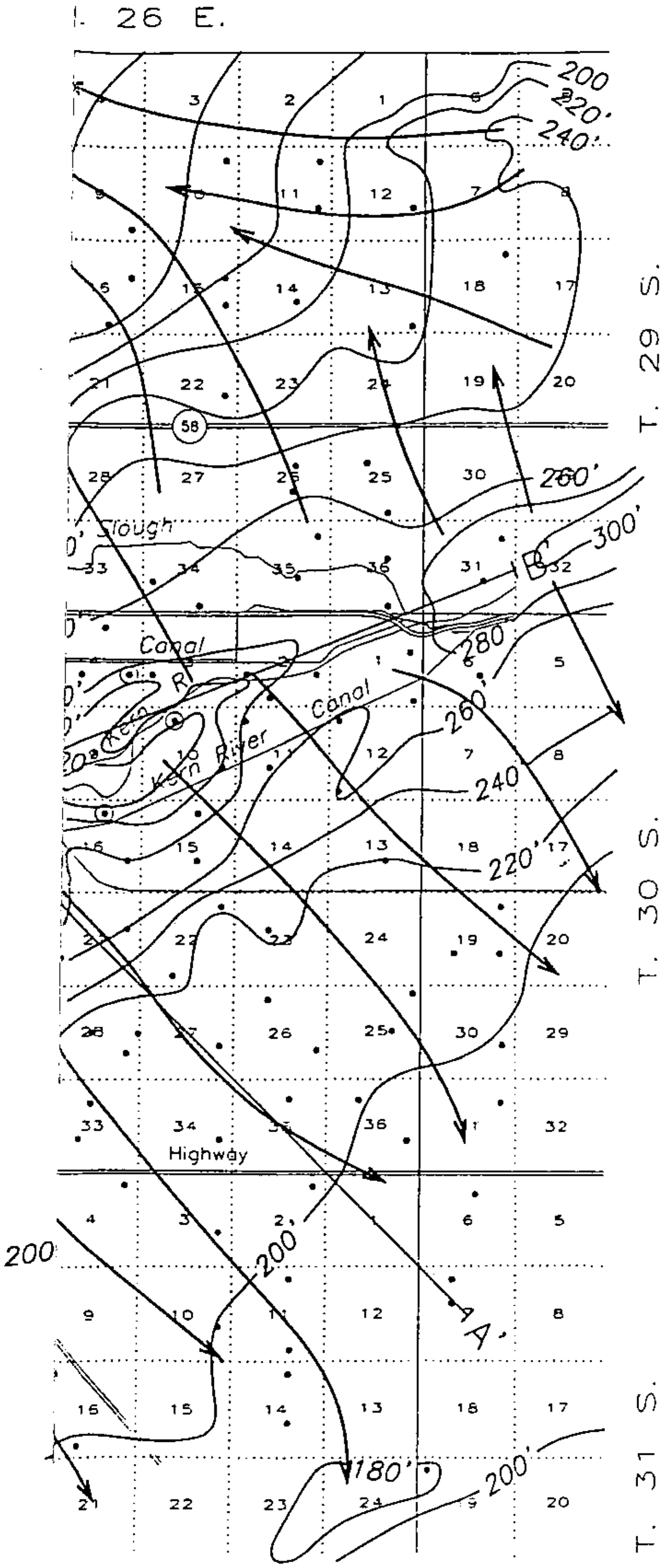
WATER LEVELS

The KCWA prepares annual water-level maps of the Kern Fan, based on water-level measurements in an extensive number of wells. Two triennial reports on the Kern Fan groundwater monitoring program have also been prepared for the period 1991-96. These reports contain annual depth to water and water-level elevation maps, water-level change maps (from year to year), and representative water-level hydrographs. Measurements for some of these monitor wells extend back to 1988. In addition to these maps, Spring 1997 water-level maps and a Spring 1996-1997 water-level change map are now available, and selected water-level hydrographs were updated through Summer 1997 for this evaluation.

Direction of Groundwater Flow

Flowlines, indicating the lateral direction of groundwater flow, have been added to the more recent water-level maps. Because of the extensive intentional recharge activities on the Kern Fan during 1995-96, when about one million acre-feet of water were recharged, the contour map for Spring 1997 (Figure 2) shows a substantial influence due to this recharge. At this time, depth to water was less than 40 feet beneath much of the COB 2,800-acre area and less than 60 feet beneath much of the part of the Kern Water Bank project area east of I-5. There was a noticeable recharge ridge beneath the Kern River, extending from the Berrenda Mesa project to near the west edge of the COB project. Groundwater flowed away from this ridge, both to the northwest and southeast. The Spring 1997 water-level elevation map shows a substantial recharge mound beneath the Kern Water Bank project, from which groundwater flowed to the north, west, and southwest. The average water-level slope on the edges of the recharge ridge and mound has been about 50 feet per mile.

One of the most important uses of the water-level maps is that they indicate in which lateral direction the recharged water can move. For example, recharged water from the R-series ponds cannot



Elevations – Spring 1997

T. Haslebacner, 4/97
Flowlines by K. Schmidt

move to the east because of the North Pioneer project, or to the south because of the COB project. Darcy's Law can be used, in conjunction with water-level slopes and aquifer characteristics, to estimate the amounts of lateral flow of groundwater away from the various recharge sites. As long as water levels in the shallow completion monitor wells are more than about 10 feet deep directly beneath the infiltration basins, shallow groundwater does not hinder the infiltration rates. However, once the water level is shallower (i.e. near the pond bottoms), the transmissivity of the aquifer, which controls the lateral flow of the recharged water, may constrain infiltration rates. This will occur if the un-hindered infiltration rates (i.e those with deeper water levels) would have exceeded the rate of lateral flow of the recharged water.

Water-Level Changes

Hydrographs for the monitor wells and selected other wells with long-term records are provided in Appendix A. Representative hydrographs for a cluster monitor well in the KWBA project area are provided in Figure 3. Figure 4 is an example of a long-term hydrograph for a well in the area. Long-term water-level hydrographs indicate a depth to water ranging from about 10 to 20 feet in the area in the late 1930's and 1940's. Water levels declined after the 1940's, at rates averaging about five feet per year through the late 1970's. Water levels then rose through 1987, also at rates averaging about five feet per year. The period for 1978 to 1987 was a wet hydrologic period and some intentional recharge projects had commenced on the fan by that period. Water levels then declined from 1987 to 1992 during the recent drought. The deepest water levels in the Kern Water Bank project area were generally during Summer 1992. Depth to water in the deep completion monitor wells ranged from about 190 to 215 feet at that time. Rates of water-level decline averaged about 13 feet per year beneath the KWBA project area during 1988-92.

During 1995-96, there were substantial water-level rises due to large-scale intentional recharge

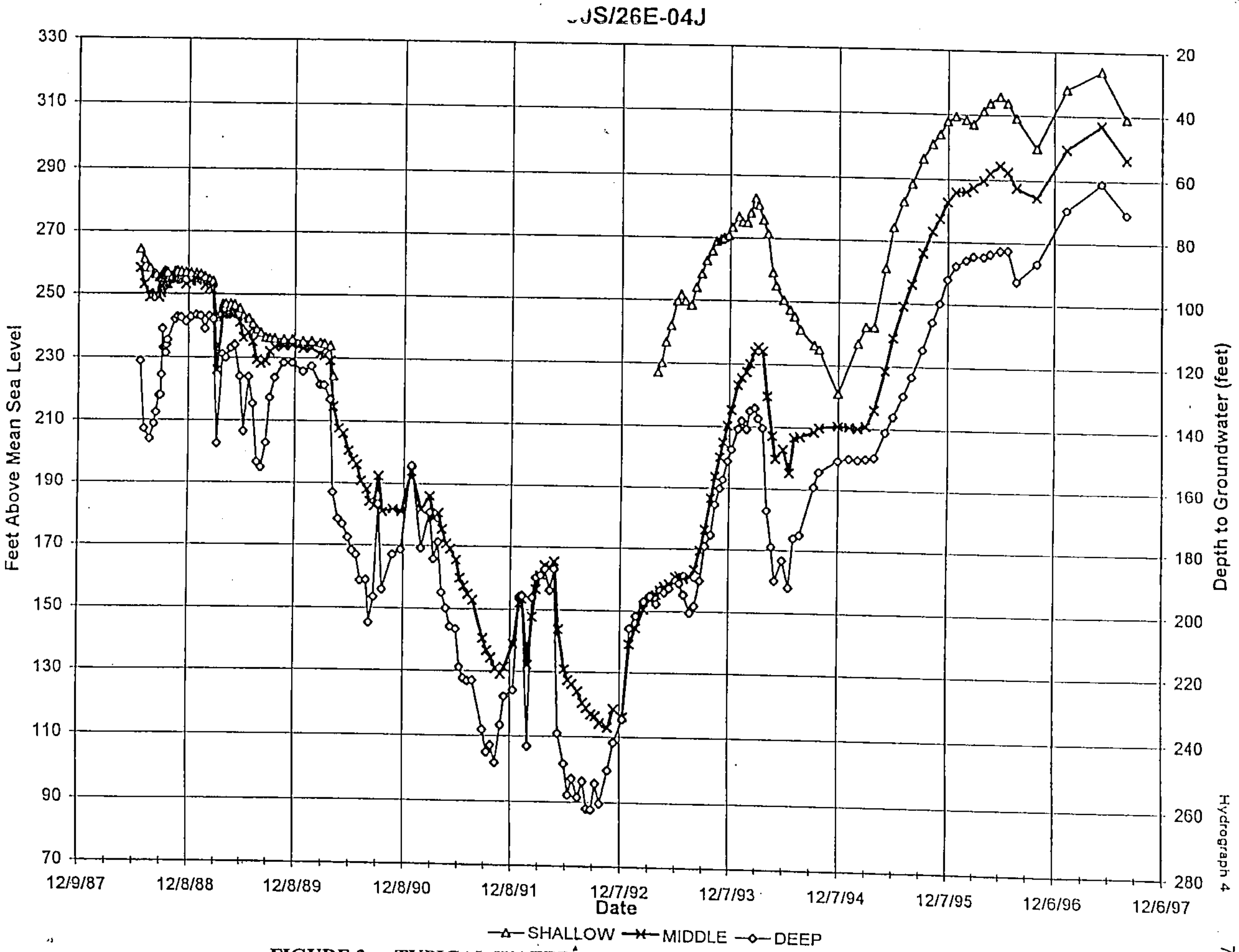


FIGURE 3 – TYPICAL WATER LEVEL HYDROGRAPHS FOR CLUSTER MONITOR WELL

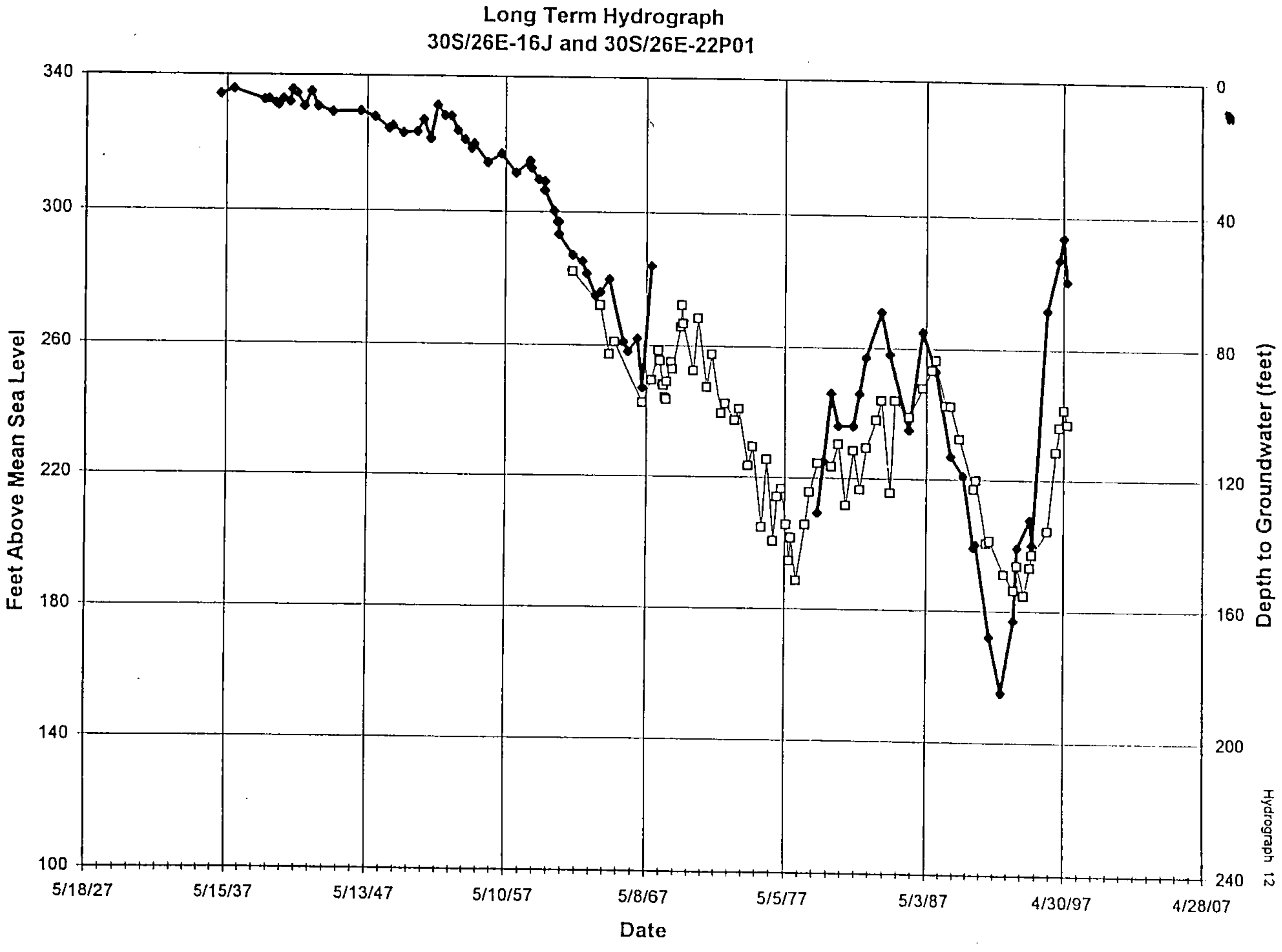


FIGURE 4 – LONG-TERM WATER-LEVEL HYDROGRAPHS

in the KWBA area. About 385,000 acre-feet of water were recharged in this area, most of which was in the last half of 1995 and the first half of 1996. Water-level rises in the shallow completion wells in the KWBA project area averaged 55 feet during 1996. Once intentional recharge stopped in 1996, water levels in these wells fell at rates averaging about 30 feet per year.

AQUIFER CHARACTERISTICS

Knowledge of aquifer characteristics is essential in order to determine: 1) water-level rises (mounding) due to recharge, and 2) water-level declines during recovery. The most important of these characteristics are: 1) hydraulic conductivity, 2) transmissivity, and 3) storage coefficient (specific yield for an unconfined aquifer). Information on aquifer characteristics is ideally obtained from suitable aquifer tests. In the absence of such tests, specific capacity values (pumping rate divided by drawdown) can be used to estimate the aquifer transmissivity. A substantial effort was undertaken as part of this evaluation to compile the available data, and develop new data, on the aquifer characteristics in the Kern Water Bank area.

Specific Capacities

Information is available on specific capacities for 15 wells in the Kern Water Bank area in 1986. Most of these wells were perforated for about 200 to 700 feet in depth. Specific capacities averaged about 80 gpm per foot in the N and S-series basin areas, and averaged about 50 to 55 gpm in the C and M-series basin areas. The static water levels in the supply wells at the time of the tests were about 120 to 130 feet deep. Specific capacities are available for the wells that were used in 1992 for the La Hacienda program. The average specific capacity was about 70 gpm per foot. The static water levels in the supply wells averaged about 190 feet at the time.

Information is also available on specific capacities for five KCWA recovery wells in Sections

3 and 4 of T30S/R26E in 1989. The static water level was about 100 to 105 feet at the time of the tests. Specific capacities ranged from 102 to 120 gpm per foot and averaged 120 gpm per foot. Most of the wells tested were perforated from about 180 to 650 feet in depth. Information is available for eight KCWA recovery wells in Sections 4, 5, and 9, T30S/R26E in 1991. Specific capacities ranged from about 40 to 130 gpm per foot and averaged 80 gpm per foot. The static water level ranged from about 160 to 190 feet at the time. Information is available for the two Olcese W.D. wells in section 24, T30S/R25E in 1991. The static level was about 160 feet at the time. Specific capacities for these wells ranged from 34 to 54 gpm per foot and averaged 44 gpm per foot. The latter two wells are near the toe of the Kern River alluvial fan, where fine grained deposits are predominant.

Aquifer Tests

The most important aquifer tests considered applicable to this evaluation are: 1) the KCWA five-well test in Summer 1987, and 2) the La Hacienda pumping in 1992. The five-well test was conducted in and adjacent to the eastern part of the COB 2,800-acre area, between the Cross Valley Canal and the Kern River. KCWA recovery wells were pumped and other recovery wells and monitor wells were used as observations wells. The recovery wells tested were perforated from about 180 to 690 feet in depth. The static water levels in the shallow completion monitor wells at the time were about 70 to 75 feet deep. Pumping was for about three days. The most meaningful transmissivity values were obtained from measurements in other recovery wells. Theis plots (log-log) indicate a transmissivity of 227,000 gpd per foot, whereas modified Jacob (semilog) plots indicate an average transmissivity of 267,000 gpd per foot. Because of the relatively shallow groundwater, these values represent the combined transmissivity of about three -fourths of the upper layer and all of the lower two layers. Confined values (i.e. 0.001 to 0.0001) were found for the storage coefficient, but these are not considered valid for long-term pumping (i.e. months or years).

Later long-term tests in this area in 1990-91 provided more information on the nature of the lower two layers. These data generally indicated that either one unconfined aquifer could be assumed with a storage coefficient of about 0.01 to 0.02, or the two deep (below 500 feet) layers could be considered a leaky aquifer, with a storage coefficient of about 0.0002 to 0.0007 and a vertical hydraulic conductivity of 0.01 to 0.02 gpd per square foot for the over-lying confining bed.

The La Hacienda Project pumping in 1992 generally comprised several weeks of pumping from nine wells in July and about one month of pumping from six wells in October - November. The average static water level in these wells was about 190 feet deep at the time. Transmissivities were determined from recovery measurements, and ranged from 42,000 to 108,000 gpd per foot and averaged 66,000 gpd per foot. These wells were located in the C, M, N, and W-series basin areas, near or west of I-5. Because of the relatively deep water levels at the time, the transmissivities are highly influenced by values for the lower two layers, as the about two-thirds of the upper layer was above the water level at the time.

Water-level declines in the Kern Water Bank project area associated with the late 1994 - early 1995 pumpage were also evaluated. Most of the pumped wells were in or near the M and W-series basins. A total of about 12,500 acre-feet was pumped over a period of about four months. Drawdown measurements in the deep completion wells at T30 S/R25E-4J and 16L indicated a transmissivity of 166,000 gpd per foot and a storage coefficient of 0.02. Static water levels in these wells were about 170 to 180 feet deep prior to pumping.

DWR Model Generated Values

Schwartz (1995) reported on the development and calibration of the Kern Fan groundwater model. Essentially three layers, corresponding to those previously described, were modeled. The upper layer, extending from the land surface to a depth of about 300 feet was modeled as an unconfined aquifer. The initial transmissivity and specific yield values were estimated primarily based on the texture of the alluvial deposits, as indicated by numerous logs. The model was calibrated through the drought cycle, and prior to the large-scale 1995-96 intentional recharge on the Kern Fan. Calibration during drought periods provided some indication of the storage coefficients of the lower two zones, which were indicated to be confined or semi-confined.

Figure 9 of that report provides calibrated values of specific yield for the upper layer at various nodes in the model. Figure 10 provides calibrated hydraulic conductivity values for the upper layer. However, better values can now be developed in some parts of the Kern Water Bank area by utilizing the results of monitoring during the 1995-96 recharge. Transmissivity of the upper layer is determined by multiplying the hydraulic conductivity times the saturated thickness. Obviously, when water levels are shallow, the transmissivity of this generally permeable layer is high. Conversely, when water levels are low, the transmissivity is much lower. Figures 12 and 13 provide calibrated storage coefficients and transmissivities for the middle layer. Figures 15 and 16 provide calibrated storage coefficients and transmissivities for the deepest layer. Values of aquifer characteristics derived from groundwater modeling are provided in Appendix B.

Information from 1995-96 Recharge

The results of the aquifer tests previously described generally confirm the model derived values of transmissivity for the lower two layers. For the upper layer, water-level rises associated with the 1995-96 recharge were carefully evaluated, as these provide some of the best indications yet available for transmissivity of the upper layer in the Kern Water Bank project area. For the N and S-series basins, the water-level rise in Well T30S/R25E-4J was used. Bouwer (1978) provided the appropriate equations for evaluating mounding. Calculations indicated a transmissivity of 144,000 gpd per foot for a final water-level depth of about 50 feet, or an average hydraulic conductivity of 580 gpd per square foot for the upper layer. This value was used for the N and S-series basins, as opposed to model derived values, which were lower. For the E-series basins, the water-level rise for Well T30S/R25E-11P was used. In this case, a transmissivity of 107,000 gpd per foot was determined, for a final water-level depth of about 50 feet. An average hydraulic conductivity of 430 gpd per square foot was obtained. In this case, the model-derived value for the upper layer was confirmed. For the M-series basins, the water-level rise for Well T30S/R25E-16L was evaluated. In this case a transmissivity of 520,000 gpd per foot and hydraulic conductivity of 2,080 gpd per square foot were determined for a final water-level depth of about 50 feet. These values also generally confirmed the model-generated values in this area.

Values of these modified model-derived parameters were compiled and tabulated for each series of recharge basins, and the major intervening areas. Two conditions were then evaluated. For shallow groundwater levels, a depth to water of ten feet was used (Table 1). Figure 5 shows the transmissivities for each layer in the various ponds and intervening area for the shallow water-level situation. The total transmissivity for the J-series basins was reduced to 400,000 gpd per foot, to provide data more consistent with the results of aquifer tests. For deep groundwater levels, a depth to water of 230 feet was used for the upper layer, thus assuming an average of only 70 feet of saturation (Table 2). Figure 6 shows the transmissivities for each layer in the various recharge basins and intervening areas for the deep water-level situation.

Results for the composited recharge basin areas north of the Kern River (including the intervening areas) indicate the following. For the shallow water-level condition, the average transmissivity is 230,000 gpd per foot, and for the deep water level condition, the average transmissivity is 90,000 gpd per foot. For the J-series basins, south of the river, the average transmissivity is 310,000 gpd per foot for the shallow water-level condition, and 130,000 gpd per foot for the deep water-level condition.

TABLE 1 - TRANSMISSIVITY VALUES FOR LAYERS WHEN WATER LEVELS ARE SHALLOW

Area	Layer 1			Layer 2	Layer 3	Total
	K (gpd/ft²)	m (ft)	T (gpd/ft)	Transmissivity (gpd/ft)		
C	300	290	87,000	3,000	3,000	93,000
E	400	290	116,000	39,000	12,000	167,000
J	1,300	290	387,000	4,000	9,000	400,000
M	2,100	290	609,000	28,000	5,000	642,000
N	600	290	174,000	27,000	3,000	204,000
R	200	290	58,000	4,000	11,000	73,000
S	600	290	174,000	45,000	7,000	226,000
W	500	290	145,000	52,000	15,000	212,000
Area 1	1,000	290	290,000	52,000	22,000	364,000
Area 2	400	290	116,000	7,000	3,000	126,000
Area 3	300	290	87,000	5,000	37,000	129,000
Area 4	400	290	116,000	700	700	117,000
2800 Acres	800	290	232,000	2,000	22,000	256,000

For shallow water levels, the depth to water in the upper layer (Layer 1) assumed to be ten feet deep. Some values are taken from DWR groundwater model calibration and others have been modified. K is hydraulic conductivity, m is saturated thickness, and T is transmissivity.

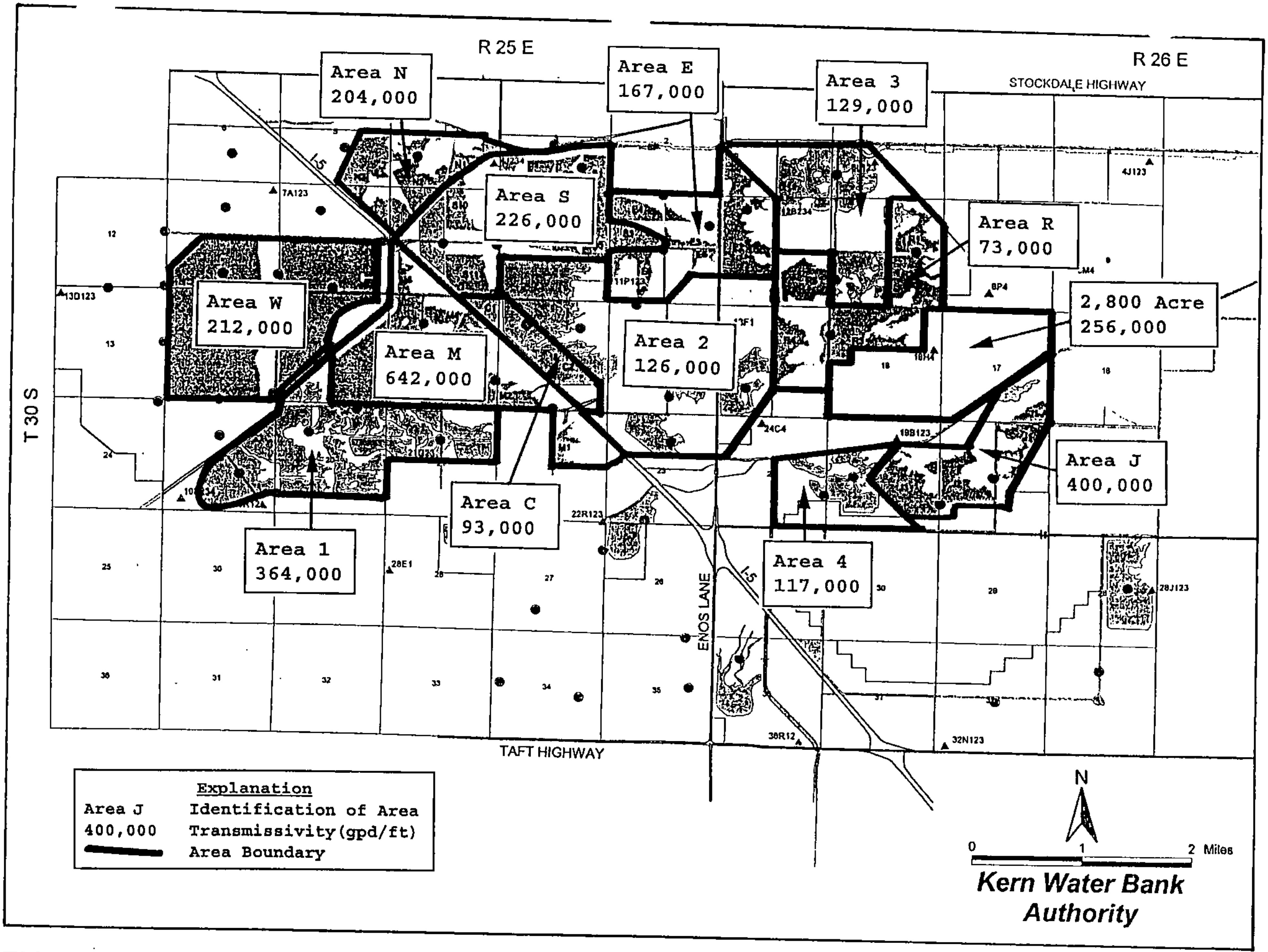


FIGURE 5 - DISTRIBUTION OF TRANSMISSIVITY FOR SHALLOW GROUNDWATER LEVELS

TABLE 2 - TRANSMISSIVITY VALUES FOR LAYERS WHEN WATER LEVELS ARE DEEP

	Layer 1			Layer 2	Layer 3	Total
Area	K (gpd/ft^2)	m (ft)	T (gpd/ft)	Transmissivity (gpd/ft)		
C	300	70	21,000	3,000	3,000	27,000
E	400	70	28,000	39,000	12,000	79,000
J	1,300	70	91,000	4,000	9,000	104,000
M	2,100	70	147,000	28,000	5,000	180,000
N	600	70	42,000	27,000	3,000	72,000
R	200	70	14,000	4,000	11,000	29,000
S	600	70	42,000	45,000	7,000	94,000
W	500	70	35,000	52,000	15,000	102,000
Area 1	1,000	70	70,000	52,000	22,000	144,000
Area 2	400	70	28,000	7,000	3,000	38,000
Area 3	300	70	21,000	5,000	37,000	63,000
Area 4	400	70	28,000	700	700	29,000
2800 Acres	800	70	56,000	2,000	22,000	80,000

For deep water levels, the depth to water in the upper layer (layer 1) is assumed to be 230 feet deep. Some values are taken from the DWR groundwater model calibration and others have been modified. K is hydraulic conductivity, m is saturated thickness, and T is transmissivity.

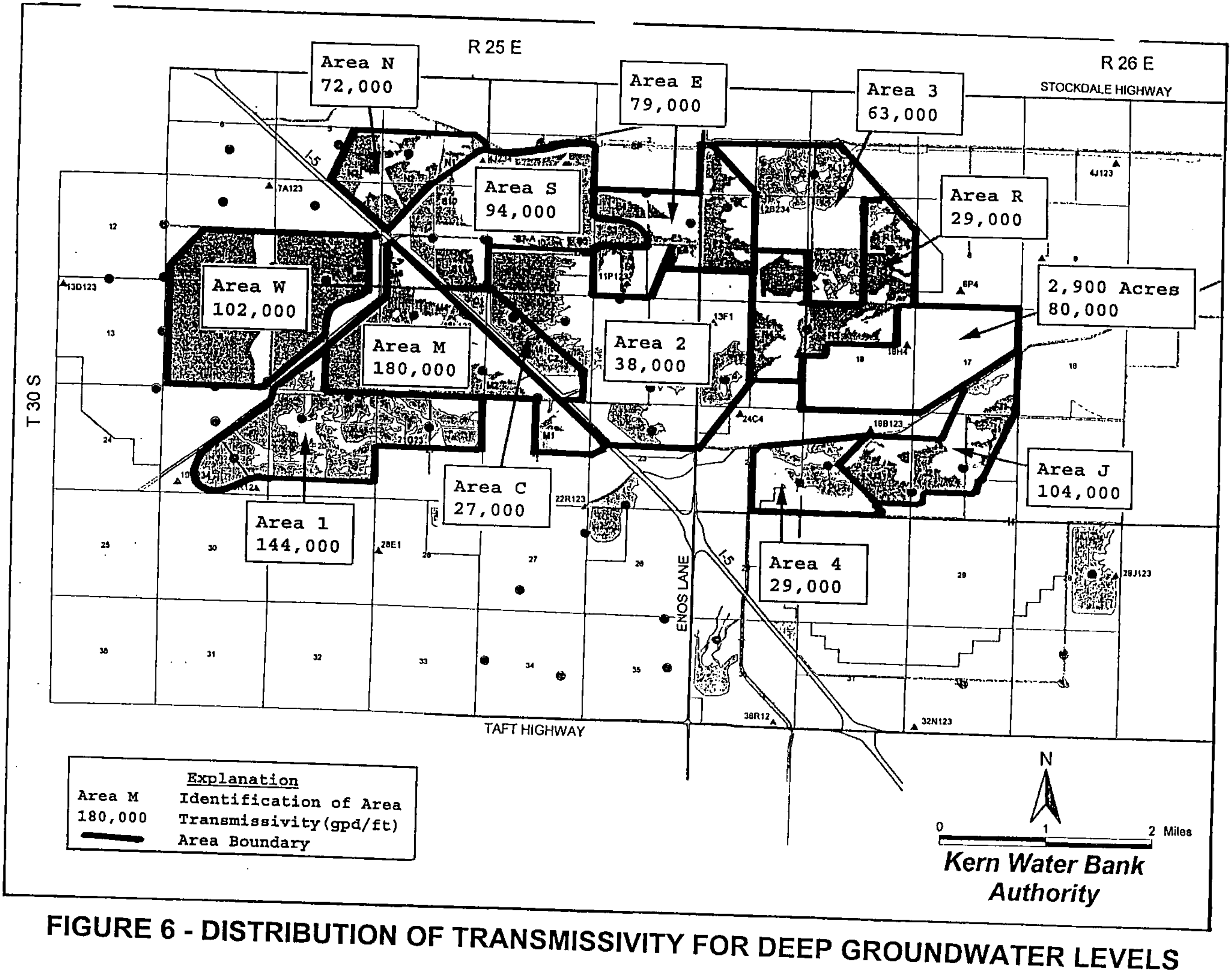


FIGURE 6 - DISTRIBUTION OF TRANSMISSIVITY FOR DEEP GROUNDWATER LEVELS

RECHARGE AND MOUND BUILDUP

Water-level rises during the 1995-96 recharge based on measurements in shallow completion monitor wells provide the best evidence of the actual mound buildup in the Kern Water Bank area. The estimated recharge (deliveries minus evapotranspiration) during 1995-96 in the Kern Water Bank area was 385,000 acre-feet. The water levels in the upper layer rose from an average of 180 feet deep prior to the start of the 1995 recharge to 70 feet deep in Spring 1997. This represents an average of 3,500 acre-feet of recharge per foot of water-level rise in the upper layer. Under deep water-level conditions, there will be 220 feet of storage space available in the upper layer. At this same rate of water-level rise, about 720,000 acre-feet could be recharged in the basins that were used during 1995-96 before water levels became so shallow (i.e. less than ten feet deep) as to reduce infiltration rates in the basins. If the rate of rise decreases as water levels rise at shallower depths, more water could be recharged before this point is reached.

Once water levels become shallow, the lateral groundwater outflow would control and possibly reduce the infiltration rates from the recharge basins. Darcy's Law can be used to determine this outflow. For the combined recharge basins and intervening areas north of the river, an outflow width of 10 miles (to the north, west, and southwest) would be expected. The average water-level slope would be 50 feet per mile at the edge of the recharge mound. Using an average transmissivity of 230,000 gpd per foot for these conditions, the lateral outflow from the combined north area would be about 128,000 acre-feet per year. For the J-series basins, an outflow width of two miles (to the southeast) would be expected. The average hydraulic gradient would be 40 feet per mile at the edge of the basins. Using an average transmissivity of 310,000 gpd per foot, the outflow would be 27,000 acre-feet per year. The total outflow from the basins and intervening areas north and south of the river would be about 155,000 acre-feet per year. Some of this outflow would comprise lateral flow of recharged water from the COB 2,800-acre area. This is presently estimated to be about 55,000 acre-feet per year. The residual of 100,000 acre feet per year is considered the sustainable infiltration rate for the KWBA basins, once groundwater levels reach near the bottom of the basins, and assuming no pond clogging beyond that previously experienced. This could result in an average decease in infiltration rates to about one-half of those observed in 1995-96 in the KWBA recharge basins. Starting with the water level in the upper layer at about 230 feet deep, an estimated 920,000 acre feet could be recharged in the KWBA basins over a five-year period.

Rates of water-level decline following the cessation of recharge are available following the cessation of recharge in mid-May 1997. Average rates of decline for shallow completion monitor wells in the KWBA project area averaged 2.5 feet per month, or about 30 feet per year. This indicates approximately how fast water levels will recede in the absence of recovery well pumping.

DRAWDOWN DUE TO RECOVERY WELL PUMPING

Recovery of 200,000 Acre-Feet Annually

Drawdowns were estimated for a recovery well pumpage rate of 200,000 acre-feet per year for two conditions. One was for when recovery pumping is started with shallow groundwater (i.e. ten feet deep). The second was at an intermediate depth water level (i.e. 120 feet deep). The drawdowns are different for the two conditions because of the different transmissivities there are applicable in each case for the upper layer. The Theis non-equilibrium formula was used to determine the drawdown after one year and five years of recovery pumping at this rate. For calculation purposes, ten wells were used, each pumping 12,000 gpm. Eight of the wells were located in the north area and two in the J-series basin area. The average transmissivities of 230,000 gpd per foot for the area north of the river and 310,000 gpd per foot for the area south of the river were used for the shallow groundwater level condition. The average transmissivities of 150,000 gpd per foot for the area north of the river and 220,000 gpd per foot for the area south of the river were used for the deep groundwater level condition. One of the biggest unknowns in estimating drawdowns in the future is the storage coefficient. Existing recovery wells are not perforated opposite the upper two-thirds of the shallow layer. Past pumping in the COB 2,800-area and the Kern Water Bank area indicate a value for the storage coefficient of 0.02, which is considered applicable for most of the existing recovery wells. With continued pumping (i.e. greater than six months), the storage coefficient is expected to gradually increase, to about 0.05, and to possibly as high as 0.10. However, as more of the permeable deposits of the upper unit are progressively dewatered , and more of the pumped water comes from deeper zones (i.e. after several years of pumping), this value could then decrease. Another complicating feature will be the interference between different banking projects. Only actual large-scale pumping and accompanying monitoring experience can exactly determine the applicable storage coefficient.

For purposes of this evaluation, a conservative storage coefficient of 0.02 was initially used to estimate drawdowns in wells tapping strata in the same depth interval as most of the recovery wells (i.e. about 200 to 700 feet). For these calculations, it is assumed that 80 percent of the KWBA recovery well pumping would come from north of the Kern River. For the recovery pumping initiating under the shallow water-level (i.e. 10 feet deep) condition, the estimated maximum drawdown in the deep layer would be about 160 feet after one year of pumping 200,000 acre-feet and about 250 feet after five years of pumping 200,000 acre-feet per year. This would mean that static water levels in the deep layers would average about 170 feet deep at the end of one year and 260 feet at the end of five years of recovery. The projected levels in the deep layer are expected to approximate those in most of the existing recovery wells. If each recovery well is assumed to pump 3,000 acre-feet per year, about 67 total recovery wells would be needed. There are now 30 existing recovery wells.

Water-level declines would be less in the upper layer because there is a higher transmissivity and storage coefficient. Past monitoring has indicated that water-level declines in the upper layer average slightly less than half of those in the deeper layers during pumping episodes for the existing recovery wells. Using this relation, the estimated maximum drawdown in the upper layer would be about 70 feet deep after one year of pumping (assuming similarly constructed wells to the existing ones are used) 200,000 acre-feet and about 115 feet after five years of pumping 200,000 acre-feet per year. This means that static water levels in the upper layer would average about 80 feet deep after one year and 125 feet after five years of pumping. Thus under the shallow water-level condition at the beginning of recovery well pumping, about sixty percent of the upper layer would still be saturated, even after five years of pumping. Drawdowns in the upper layer could be increased, if desired, by installing and pumping new recovery wells that tap all of the upper layer.

Under the intermediate water-level condition, prior to recovery well pumping, it is assumed that there would be about 500,000 acre-feet of groundwater in storage from previous banking operations. If recovery pumping were to commence with an average depth to water of about 120 feet (the intermediate condition), pumpage of 200,000 acre-feet per year doesn't appear possible with the assumed recovery well configuration after more that about a year and a half. This is because the estimated drawdown in the deep layer in the recovery well field north of the Kern River would be almost 200 feet after only one year of pumping, making the resulting static levels about 320 feet deep. The resulting drawdown in the upper layer would be about 90 feet, and the resulting static level about 210 feet. It is likely that recovery pumping rates of about 60,000 acre-feet per year could be maintained for the rest of the five-year period. This amount of pumpage could be provided by 20 recovery wells. Over five years, 500,000 acre-feet could be recovered, using the assumed recovery well configuration.

Recovery of 300,000 Acre-Feet Annually

Drawdowns were estimated for a recovery well pumpage rate of 300,000 acre-feet per year, when recovery pumping is started with shallow groundwater (i.e. about ten feet deep). The same ten wells were used, except the pumping rate for each was assumed to be 18,000 gpm (for calculation purposes only). The average transmissivities of 230,000 gpd per foot for the area north of the river and 310,000 gpd per foot for the area south of the river were used. A storage coefficient of 0.02 was used. The estimated maximum drawdown in the deep layer would be about 225 feet after one year of pumping 300,000 acre-feet per year and more than 300 feet after two years of pumping 300,000 acre-feet per year. This would mean that static water levels in the deep layers would average about 235 feet deep at the end of one year and more than 300 feet at the end of two years of recovery. The projected levels in the deep layer are expected to approximate those in most of the existing recovery wells. If each recovery well is assumed to pump 3,000 acre-feet per year, about 100 total recovery wells would be needed. Because the upper layer would essentially be dewatered after about two years of pumping, the possible recovery rates would decline to about 130,000 acre-feet per year for the rest of the five-year period.

The deepest water levels that have been measured in the deep completion monitor wells were in Summer 1992, near the end of a prolonged drought. At the time, water levels ranged from about 170 to 260 feet deep in the Kern Water Bank project area, and averaged about 205 feet deep. Levels greater than 215 feet deep are indicated to have been for monitor wells relatively close to pumped wells.

LONG-TERM WATER-LEVEL TRENDS

The last triennial Kern Fan monitoring report includes long-term hydrographs for several wells. In general, these hydrographs indicate water level declines form 1950-77 ranging from about 4 to 6 feet per year. Between 1977 and 1987, water-levels rose from about 2 to 6 feet per year. A common trend for specific wells appeared to be similar rates of water-level decline and rise for these periods. From 1987 to 1992, water levels fell at rates ranging from 6 to 14 feet per year. This period coincided with a prolonged drought period. Using values through 1987, the average long-term rate of water-level decline in the area ranged from about 2 to 3 feet. This decline is assumed to be what would be occurring in the absence of the recharge and water banking projects that have been implemented since 1987, if other conditions remained the same.

POTENTIAL IMPACTS

Potential adverse impacts of the KWBA water banking project include:

1. Water-level rises in the area of shallow groundwater, due to recharge activities.
2. Reduction in natural river recharge that would otherwise have occurred.
3. Water-level declines during recovery well pumpage periods
4. Land surface subsidence associated with recovery well pumpage.
5. Migration of poor quality groundwater due to recharge and/or recovery well pumping.

A groundwater monitoring committee has been established as part of a Memorandum of Understanding (MOU) between the banking participants and adjoining entities. The purpose of the committee is to develop and implement a mutually acceptable monitoring program for the project, and to develop mitigation measures to minimize adverse impacts of the banking projects to the extent possible.

Water-Level Rises

Substantial water-level rises can occur beneath the recharge basins. However, monitoring data indicate relatively steep water-level gradients (i.e. about 50 feet per mile) away from the edges of the recharge basins. Because of this, shallow groundwater problems should be limited to the immediate proximity of the basins, except for already existing shallow groundwater areas. This potential problem could be mitigated by having appropriate setbacks of wetland areas from nearby lands, and operating with minimal water levels (i.e. 20 feet or so) where necessary. Also, monitoring of the shallow groundwater levels, such as in part of the Buena Vista WSD, should be continued and the results carefully interpreted, as the banking project proceeds.

Reduction in Natural Recharge

Because most of the KWBA recharge basins are not adjacent to the Kern River, shallow water levels beneath most of the basins should not reduce natural recharge. The closest basins to the river are the J3, R3, and M1 basins. Because of the relatively small acreage of these basins, overall impacts of changes in natural river recharge are expected to be small

Water-Level Declines

In general, the greatest concern about water-level declines will be in drought periods and during the later phases of recovery pumping episodes. In general, minimal drawdowns compared to background conditions will occur when recovery wells are used that are as close to the recharge basins as possible, as opposed to several miles away. Considering the hydraulic conductivities and water-level gradients expected, average lateral flow rates of the groundwater away from the basins are expected to usually range from about 500 to 1,000 feet per year. Thus as a general guideline, recovery wells should probably be spaced with about one mile or less of recharge basins. There are about 67 existing wells considered to be recovery wells, and 31 of these are considered active. There are another 63 proposed recovery wells. There are two areas where recovery wells have been proposed at some distance from KWBA recharge basins (Figure 7). The largest is in the area west of I-5 and south of the Kern River, where eight recovery wells have been proposed. However, there are few other water supply wells in this

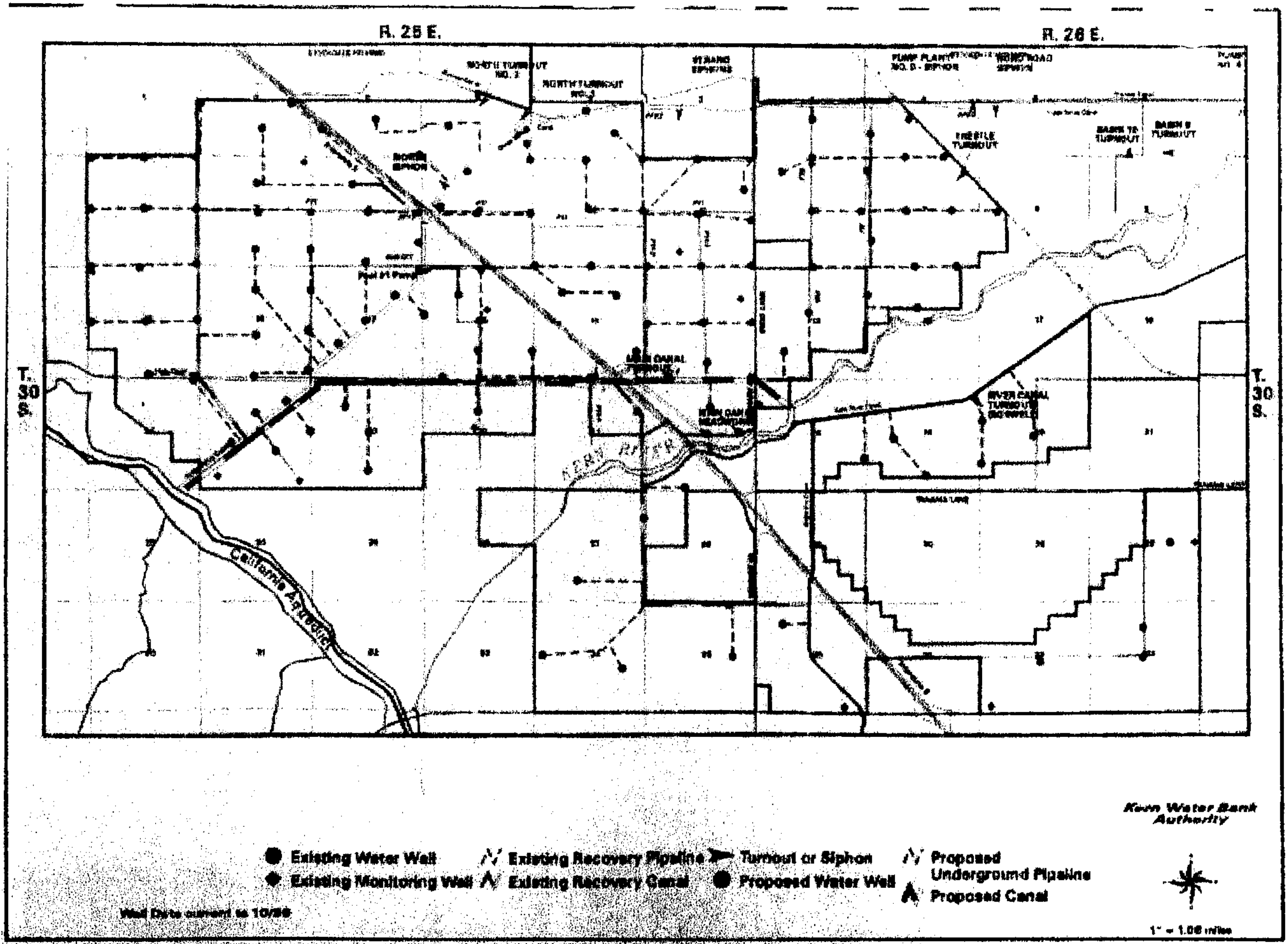


FIGURE 7 - LOCATION OF EXISTING AND PROPOSED RECOVERY WELLS

area. There are concerns in this area about poor quality groundwater, both in terms of the water pumped from recovery wells and potential enhanced lateral migration, if significant water-level declines are produced. These concerns could be addressed, if the sites would be moved to the E, J, R, S, N, and M-series basins. The second area is south and east of the Ten Section area, generally southeast of the J-series recharge basins, where four recovery wells have been proposed. However, operation of these wells would have minimal impacts because of the overall lack of water supply wells in this area.

A map should be prepared showing the locations and types of all water-supply wells within one mile of the proposed recovery wells. This information and well construction data could be used to evaluate the proposed locations and perforated intervals of new recovery wells before the locations are finalized.

Land Surface Subsidence

Compaction of fine-grained deposits associated with significant water-level declines has been demonstrated to cause subsidence of the land surface in alluvial deposits. The California Department of Water Resources has operated a compaction recorder adjacent to cluster monitor well T30S/R25E-16L since Fall 1994. It should be noted that subsurface geologic conditions at this site are not representative of most of the KWBA project area. A review of electric logs for Well 16L and numerous others in the project area indicates that finer-grained deposits are highly developed at this site. Figure 8 shows water-level and compaction hydrographs. Some compaction was recorded in late 1994 and early 1995, associated with the 1994 pumping episode. Continuous water-level records for the two deeper layers indicate that a water-level decline of about 30 feet produced a compaction of about 0.027 foot. The apparent compaction in late 1996 cannot be explained by pumping in the vicinity. In late 1995 and early 1996, an expansion occurred, associated with large-scale intentional recharge activities. By Spring 1996, an expansion of 0.042 foot had occurred. If comparable compaction rates occur in the

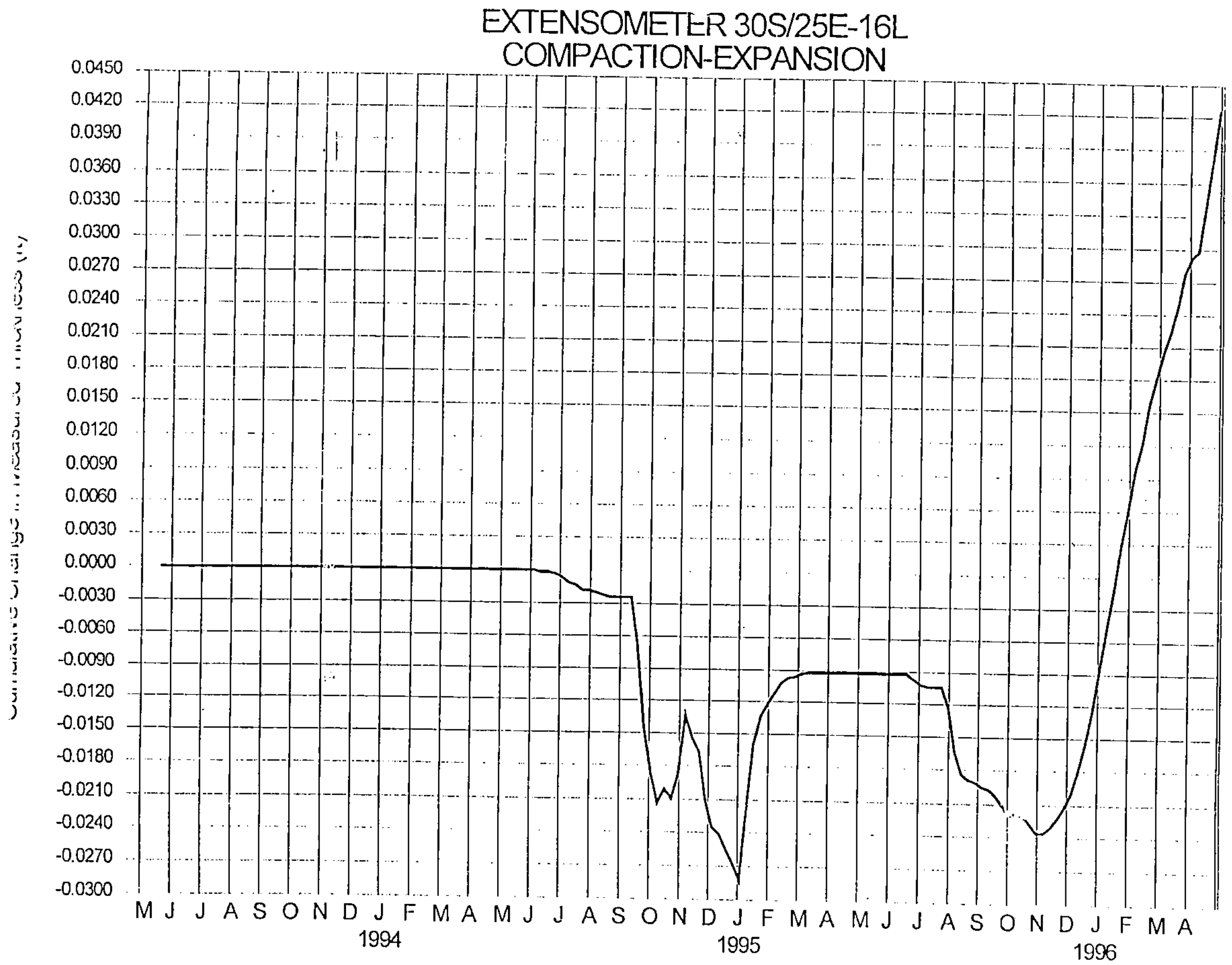


FIGURE 8 - COMPACTION AND WATER-LEVEL HYDROGRAPHS

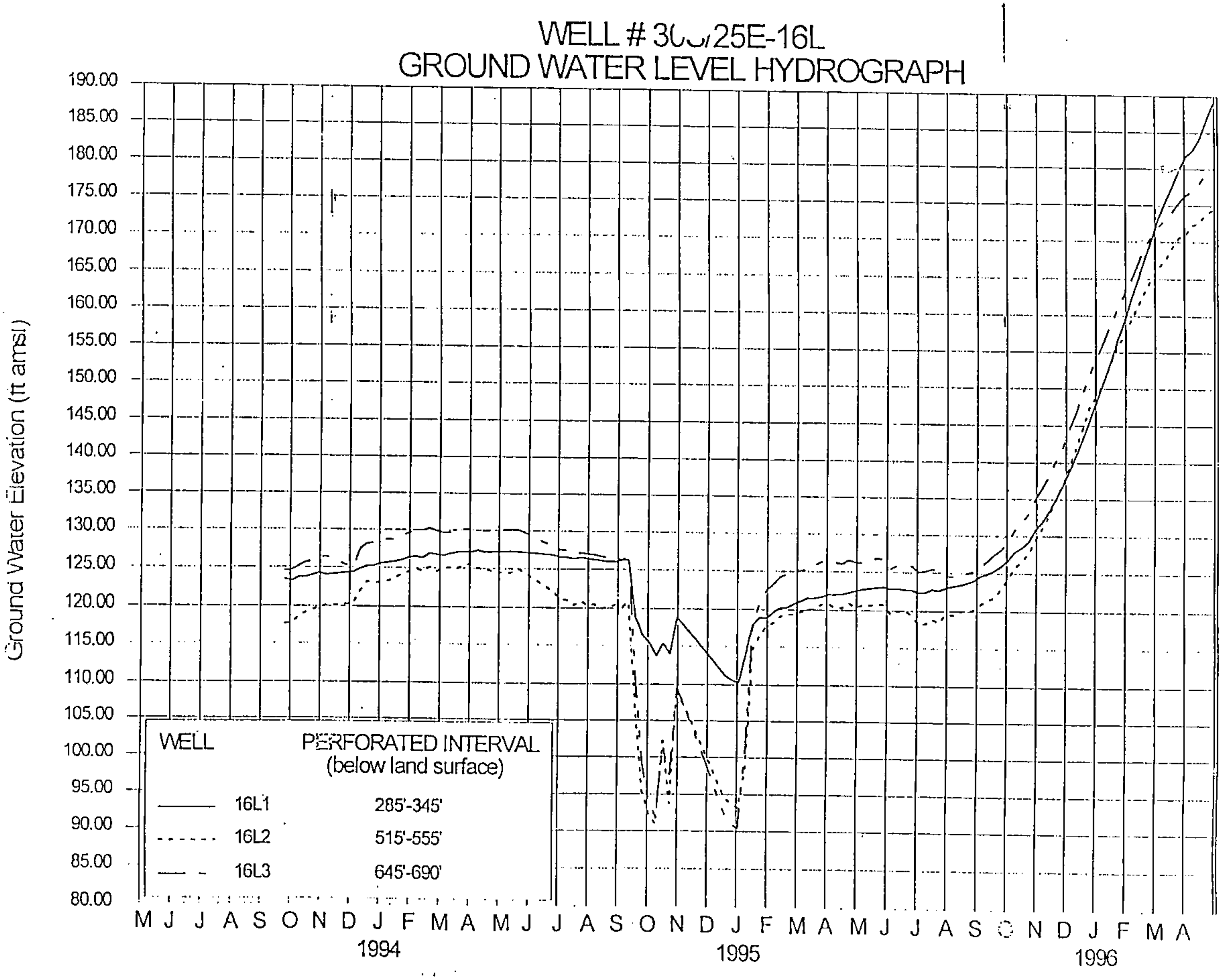


FIGURE 8 - COMPACTION AND WATER-LEVEL HYDROGRAPHS