THREE-DIMENSIONAL GROUNDWATER FLOW MODEL USE AND APPLICATION - BISHOP BASIN, OWENS VALLEY, CALIFORNIA

by

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ABSTRACT

Groundwater models used appropriately, are useful tools in water management decisions. For this study, input parameter sensitivity was analyzed for a three-dimensional groundwater model which depicted effects of pumping and varying recharge on water levels in northern Owens Valley. Sensitivity analysis determined that transmissivity, total recharge, and increases in stream and canal recharge significantly affected results in the Bishop Basin model. Vertical conductance, changes in evapotranspiration, flowing well production, and added precipitation were insensitive parameters. Groundwater pumping affected water levels in both confined and unconfined aquifers in the vicinity of production wells and, to a lesser extent, in areas away from well fields. Water level recovery occurred with above-normal runoff, but remained depressed with insufficient recharge to the groundwater system.

CHAPTER 1

INTRODUCTION

Groundwater models have become increasingly important as tools in water management decisions. A model represents a valuable tool for analyzing groundwater flow if the limitations of the modeling approach are adequately and accurately stated. The predictive accuracy of models does not necessarily represent their primary value. Rather, they provide a means to quantitatively assess the area of interest and improve understanding of factors that control groundwater movement. In many cases, a relatively simple groundwater modeling effort demonstrates the need for more detailed or comprehensive analysis.

Detailed, three-dimensional modeling is generally appropriate for regional analyses. This approach is usually implemented with the use of numerical models where aquifer heterogeneity can be incorporated in the input parameters. Success of this approach, however, is still directly linked to accuracy of the conceptual model of the real system, and accuracy of the input parameters.

Background

Three-dimensional groundwater models have been developed by the U.S. Geological Survey (USGS) (Danskin, 1988), Inyo County Water Department (Hutchison and Radell, 1988 and Hutchison, 1988), and Los Angeles Department of Water and Power (LADWP or City) (LADWP, 1988) for the Owens Valley located in east-central California (Figure 1.1). The need for these and other models developed for the area have come about in response to events of the past and present.

The water resources of the Owens Valley have been a subject of conflict for nearly 90 years. Although today, differences are handled by negotiation or through the courts rather than with dynamite, feelings of bitterness, hostility, and frustration remain. What began as an issue of loss of irrigation water due to surface diversions turned into an issue of loss of an unique environment due to groundwater pumping. The entire history or parts thereof are reported, among others, by Kahrl (1974), Nadeau (1982), Smith (1978), Risner (1986), and Hoffman (1981). A general overview is provided in this section.

Many events took place in the early years that set the stage for the ensuing and long-lasting water conflict. In 1903, the Owens Valley was recommended for a federal irrigation project by the newly-founded U.S. Reclamation Service. Enthusiastic valley residents had eagerly turned over their water storage rights for the irrigation project which was eventually abandoned in favor of transporting water to Los Angeles. The abandonment came about through a series of what was later perceived by valley residents as

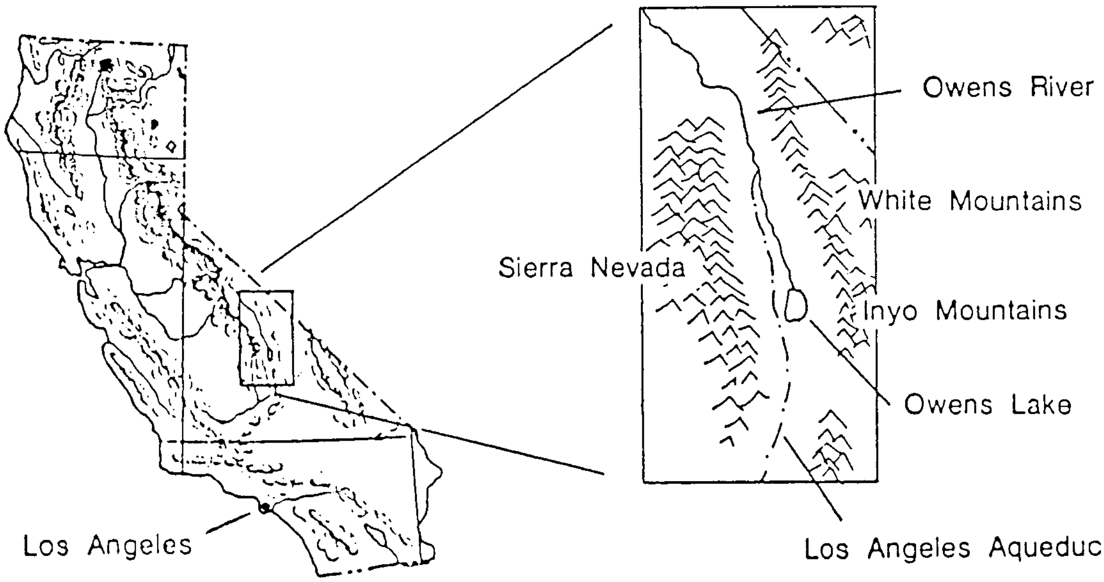


Figure 1.1. Owens Valley Location.

sneaky and underhanded tactics by the city of Los Angeles and agents of the Reclamation Service. The entire plan was kept quiet by Los Angeles officials and members of a land syndicate with interests in the San Fernando Valley until the Los Angeles Times breached the secrecy and released the story in 1905. The Los Angeles headline read, "Titanic Project to Give the City a River" while the city's plans were reported in the Inyo Register as "Los Angeles Plots Destruction, Would Take Owens River, Lay Lands Waste, Ruin People, Homes, and Communities" (Kahrl, 1982).

Now that the story was out, the problem that faced the City was money. A great deal was needed to finance the project and could not possibly come from private sources. In 1907, Los Angeles voters approved a $23 million bond for aqueduct construction. Approval of the bond was brought about by fabrication of a drought by Los Angeles officials and tales of impending doom. The 233-mile aqueduct which flowed entirely by gravity was completed in November, 1913.

In 1921, the City, realizing it needed upstream water rights, secretly hired a local valley resident to secure options on two major irrigation ditches. In retaliation, valley men dynamited the aqueduct near the town of Lone Pine. The ensuing decade was filled with such incidents and, at one point, valley residents seized the aqueduct and turned all the water onto the valley floor for five days.

Valley residents held their hope in the Watterson brothers. They owned the valley banks and had offered financial support and leadership in dealings with Los Angeles. At one point, the bankers found themselves over-extended and sought support from outside banks. A bank examiner, perhaps tipped off by the City, was alerted to this situation. He conducted an investigation and found the banks short of over $2 million (Nadeau, 1974). The fall of valley banks and imprisonment of the bank owners in 1927, brought financial ruin to many Owens Valley farmers, ranchers, and business men. The City bought remaining land, including town properties, and a period of unsettled peace began in the Owens Valley. Except for the Hillside Decree of 1940, a court decision that prohibited groundwater export from the Bishop area, all was quiet in the Owens Valley until the announcement of a second aqueduct in 1963.

The second aqueduct was completed in 1970, and approximately doubled the City's exporting capacity. This additional water came from increased diversions in the Mono Basin, increased surface water diversions in the Owens Valley (made available by the retirement of City-owned irrigated lands), and increased groundwater pumping in Owens Valley.

Soon after completion of the second aqueduct, valley residents perceived significant damage to phreatophytic vegetation on the valley floor. They noticed too, that springs and artesian wells had either reduced flows or entirely stopped flowing. In an effort to limit LADWP's impact on the environment, Inyo County filed suit against the City over expanded groundwater pumping. They claimed that an Environmental Impact Report (EIR) was required under mandates of the California Environmental Quality Act (CEQA).

Trial court originally ruled in favor of Los Angeles on the theory that the second aqueduct was already in place and operating prior to enacting CEQA. Inyo County petitioned the Third District Court of Appeal in 1973. The judge upheld the County's demand for an EIR on increased pumping since that, in itself, was a "project" by CEQA definitions.

Three years later, in 1976, LADWP completed the EIR. The project was described as "increased pumping for in-valley use". It did not include increased pumping or surface water diversions for export to Los Angeles. The County challenged adequacy of that report and sought to restrain pumping rates. Subsequently, the court ordered an average annual pumping limit of 149.56 cubic feet per second (cfs) until an "adequate" EIR could be written and approved by the court.

During 1977, California experienced the worst drought of the state's history. The court, at request of the City, allowed pumping at a maximum of 315 cfs until March 1978, with provision that Los Angeles pass a mandatory conservation ordinance. In addition to this ordinance for Los Angeles, LADWP installed water meters in Owens Valley towns and charged then-current Los Angeles water rates. Further, they cut off water to valley ranchers. Later the same year, LADWP petitioned the California Supreme Court to review the previous Court of Appeal decisions. The Supreme Court unanimously denied all petitions.

A second EIR was completed in 1979, but was rejected by the court in 1981. Court decision stated that LADWP failed to include changes in surface water practices after 1970, as part of the project description.

Meanwhile, in 1980, Inyo County voters passed a Groundwater Ordinance which intended to regulate the pumping in the Valley through a groundwater management plan and permit procedure. It also created the Inyo County Water Department and Inyo County Water Commission. LADWP filed suit against the County claiming that the ordinance was unconstitutional and pre-empted by state law. The trial court ruled in favor of the City in 1983.

In an effort to work together to meet the needs of both City and County, LADWP and Inyo County adopted a Memorandum of Understanding in 1982. This document stated the intent of both sides to cooperate as well as the desire of each to have a comprehensive study of Owens Valley made by USGS. In

1983, an interim 5-year agreement was reached. Major points of the agreement were:

(1) joint management of the Owens Valley through a negotiated annual pumping program;

(2) establishment of enhancement/mitigation projects in compensation for past problems;

(3) undertake vegetation and groundwater studies as a basis for environmental agreement; and

(4) lower town water rates and maintain in-valley water uses.

Currently, negotiations are underway for a long term groundwater management plan. It is necessary to complete a preliminary agreement at the latest by April 1, 1989, to allow preparation of an EIR which was ordered submitted to the court by June 30, 1990.

If there is preliminary agreement, the parties will jointly prepare an EIR on the management plan. Then, the EIR, upon approval by both parties, will be submitted to the Third District Court of Appeal. At that time, all pending litigation will be terminated or permanently suspended.

If there is no agreement, LADWP will begin preparing an EIR on increased water-gathering practices conducted since completion of the second aqueduct. The EIR must be submitted to the court by June 30, 1990, or, according to the order, groundwater pumping will be limited to 89 cfs.

Also, any litigation that has been "on hold" will be resumed.

Purpose and Scope

As part of the interim agreement, groundwater models were developed for the Owens Valley by USGS, LADWP, and Inyo County. The models were intended to obtain a better understanding of the groundwater system and eventually to predict areas where pumping may impact the vegetation reliant upon groundwater. This study is a continuation of the modeling project undertaken by Inyo County Water Department. The purpose of this study is two-fold: (1) to evaluate sensitivity of the model developed by Inyo County Water Department for the northern half of Owens Valley, and (2) to use this calibrated model to separately evaluate the effects of pumping, low runoff or drought conditions, as well as, a combination of the two. Information on geology, hydrology, and developed model is included to provide a complete understanding of this project.

Relation to Other Investigations

The geology and hydrology of Owens Valley have been studied extensively since the early 1900's. Many researchers have defined the geologic structures and processes associated with their development. Seismic and gravity profiles have been used to determine stratigraphy and depth to crystalline bedrock. A detailed description of the geology of Owens Valley has been presented by Pakiser et al. (1964) and Hollett et al. (1989).

Of particular interest to this study are hydrologic investigations of both past and present. C.H. Lee (1912) did preliminary investigations of water resources in southern Owens Valley and made estimates of recharge to the groundwater. LADWP, in their subsequent studies, used estimates of recharge based on Lee's findings. LADWP presented a detailed water budget in their Water Resources Management Plan (1972). They reiterated this budget in their final Environmental Impact Reports (1976 and 1979).

Griepentrog and Groeneveld (1981) developed a comprehensive groundwater management plan for the Owens Valley including a valleywide water budget. Hutchison presented an analysis of Owens Valley pumping (1986a), updated versions of valley water budgets (1986b), estimated base flow of Owens River (1986c), and completed aquifer test analyses in the Big Pine area (1986d). Most recently, Danskin (1988) and Hollett et al. (1989) described detailed water budgets for Owens Valley and Danskin (1988) presented a simulated steady-state budget for water years 1935-1970.

Groundwater models were developed for Owens Valley by USGS, Inyo County, and Los Angeles (Danskin, 1988; Hutchison and Radell, 1988; Hutchison, 1988; LADWP, 1988). A report comparing and contrasting input and output parameters of four preliminary models was prepared by Radell and Hutchison (1988).

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

Physiography

The study area is coincident with the Bishop Basin as described by Hollett et al. (1989). It is located in northern Inyo County in east-central California (Figure 1.1), approximately 250 miles north of Los Angeles. The study area is contained in the Mount Tom, Bishop, Big Pine, and Waucoba Mountain quadrangles of the U.S. Geological Survey 15-minute topographic series.

The model area covers approximately 465 square miles and extends from the Inyo-Mono county line, just north of Bishop, to Tinemaha Reservoir (Figure 2.1). Located within the model area are the towns of Laws, Bishop, and Big Pine and includes the Laws, Bishop, and Big Pine well fields (Figure 2.2).

The Bishop Basin study area is bordered on the east by the Inyo-White Mountains and on the west by the Sierra Nevada. Crests of these ranges vary from 10,000-14,000 feet. The valley floor slopes (with an average slope of 8-10 feet per mile) from the Volcanic Tablelands north of Bishop, southeast to Tinemaha Reservoir.

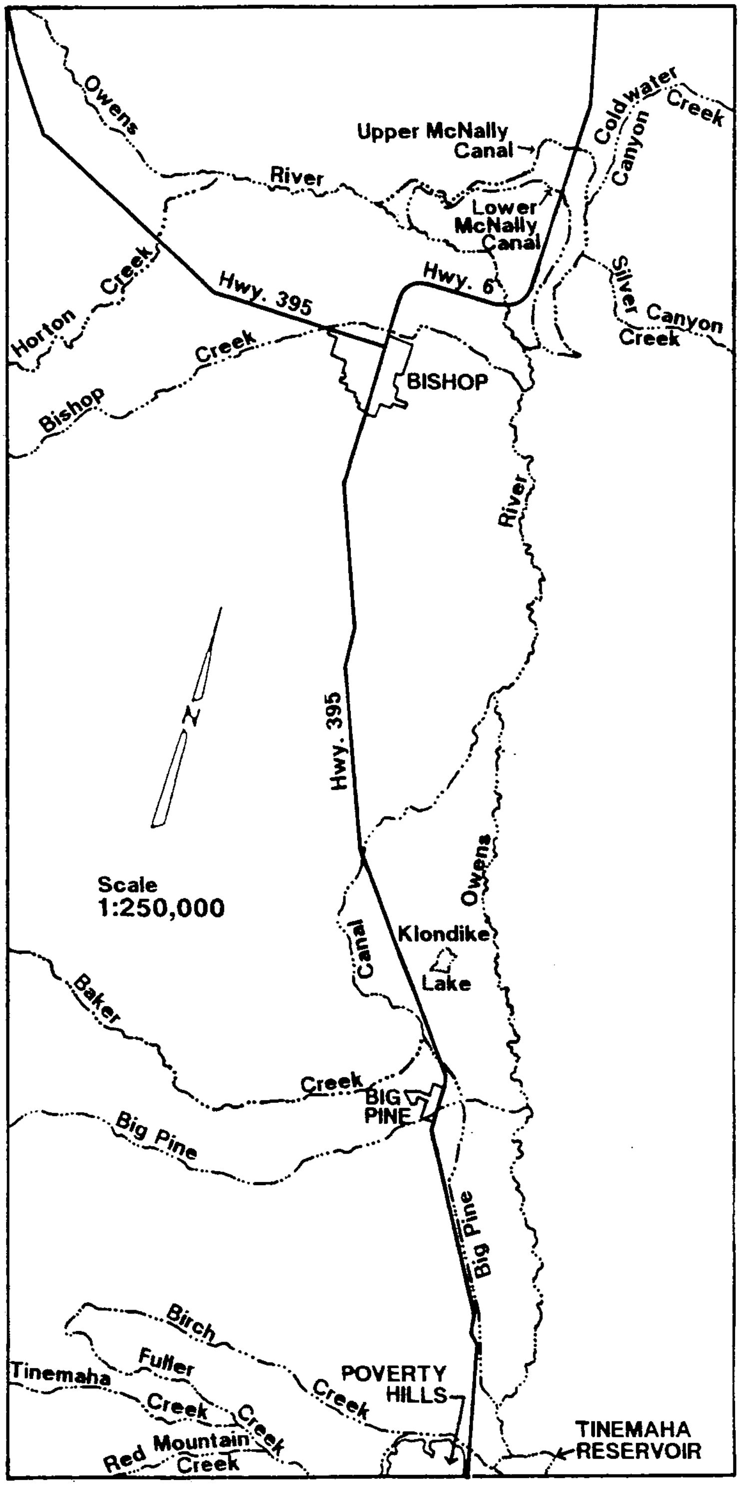


Figure 2.1. Bishop Basin Area Map.
(from Hutchison, 1988)

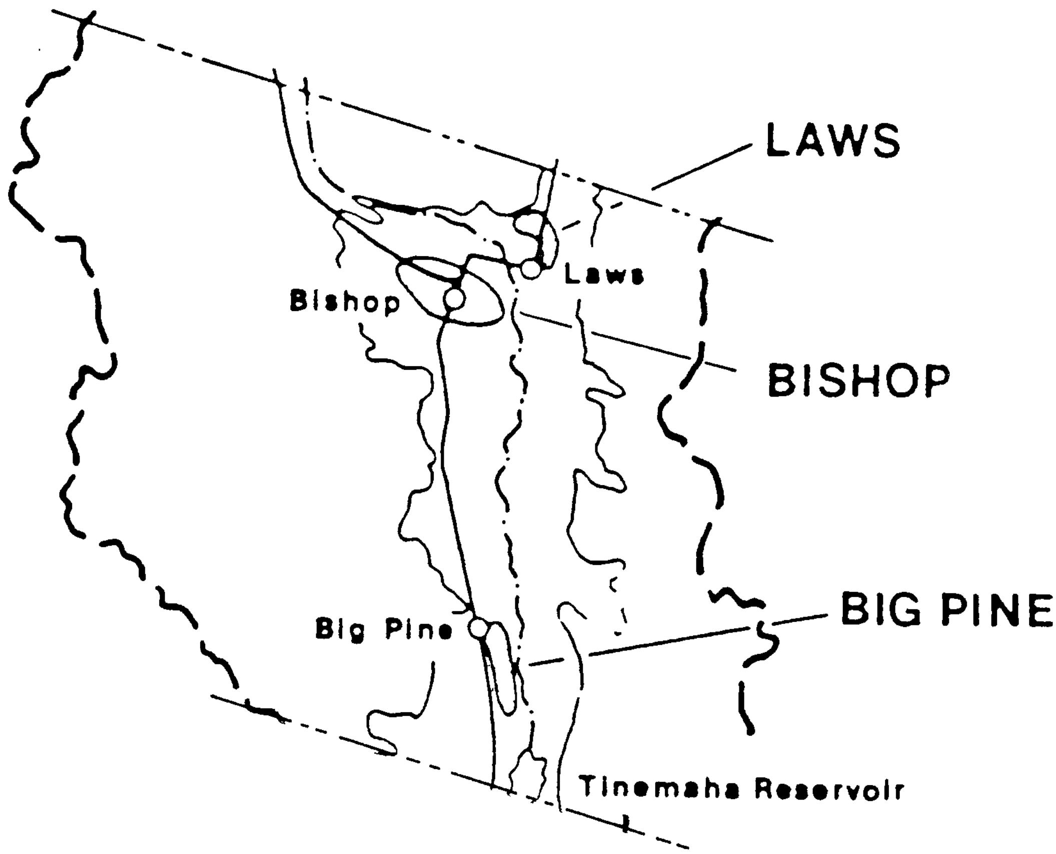


Figure 2.2. Bishop Basin Well Field Location Map. (modified from LADWP, 1972)

Climate

The Sierra Nevada Mountain range greatly influences climate of the study area. Precipitation occurs as both rain and snow, falling predominately from moisture-laden air crossing the valley from west to east. Precipitation varies considerably from mountain slopes to the valley floor and from year to year. Average annual precipitation at Sabrina Lake, located west of Bishop at an altitude of 9,132 feet, is 17.2 inches. Annual precipitation at the LADWP equipment yard in Bishop varies from 0.63 to 21.04 inches, and averages 6.58 inches for the period of record (Figure 2.3). Approximately 60-80 percent of precipitation occurs from October to April. Temperature ranges from less that 0°F in the winter to more than 100°F in the summer.

Land Use and Water Demand

There are two major land owners in the study area: LADWP and the U.S. Government. In general, the U.S. Forest Service manages mountain slopes, Bureau of Land Management controls alluvial fans, and Los Angeles owns most of the valley floor. There is very little private land owned outside of Bishop and Big Pine. At the present time, the major industry in the area is tourism.

Primary uses of water in the study area are: (1) export to Los Angeles, and (2) irrigation of land leased

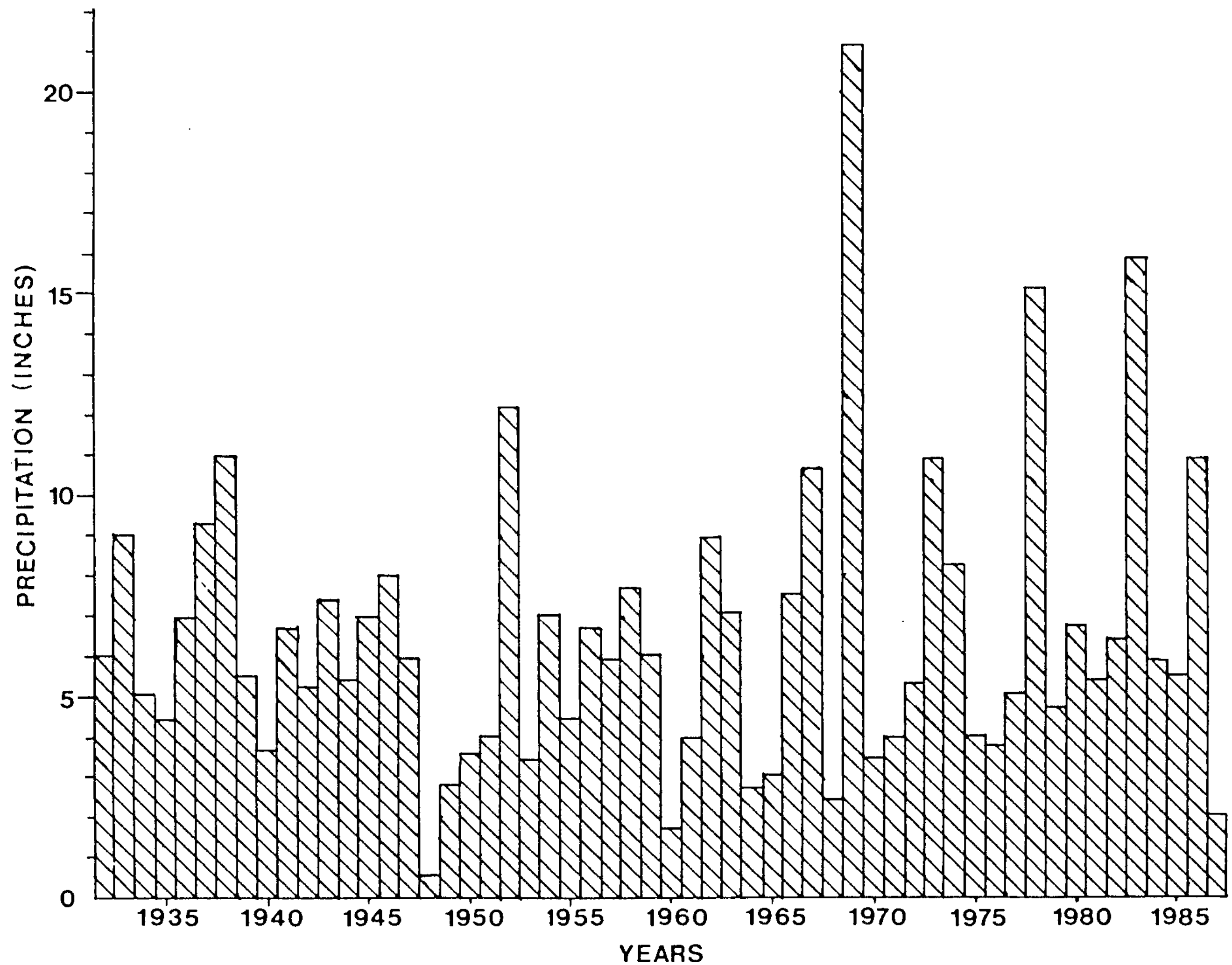


Figure 2.3. Rainfall Record for Bishop Yard.

from LADWP. Surface water diverts into irrigation canals for use within the area and excess water is allowed to flow to the Owens River. The river later diverts into the Los Angeles Aqueduct (LAA). In all but the wettest years, pumped groundwater supplements flow to the LAA.

CHAPTER 3

GEOLOGY

Owens Valley is a deep alluvial basin on the western edge of the Basin and Range Province. Formation of this valley, a down-dropped block or graben, began with faulting along the base of the Inyo-White and Sierra Nevada Mountain ranges (Pakiser et al., 1964). Erosion along uprising mountains widened the valley and filled the deepening trough with alluvial deposits. Large alluvial fans developed on the flanks of the Sierra Nevada.

Major streams through the valley reworked alluvial material and redeposited it as moderately well-sorted layers of silt, sand, and gravel (Danskin, 1988). Historic blockages of the valley's surface outflow resulted in deposition of extensive clay and silt layers. Exposed volcanic material evidenced past volcanic activity. Alluvial material buried much of the tuff, cinders, and lava flows.

Over time the valley underwent complex faulting and today shows evidence of rotation and structural warping (Pakiser et al., 1964). As a result, alluvial deposit thickness ranges from about 4,000 feet near Bishop to less than 3,000 feet at Tinemaha Reservoir (Danskin, 1988).

The northern boundary of Bishop Basin is the Volcanic Tableland, composed of nearly horizontal layers of ash and tuff. Beneath this layer of tuff, the valley splits and connects both to Round Valley, northwest of Bishop, and to Chalfant Valley, northeast of Bishop. Groundwater inflow is expected from these areas. The southern limit of the Bishop Basin is marked by an inferred normal fault that crosses the valley in a northwest-southeast direction across the north side of Poverty Hills (Hollett et al., 1989).

The geologic history in the study area is complex and many areas with similar geologic characteristics have been identified. Despite the complexity, two major categories exist: (1) bedrock and (2) valley fill.

Bedrock

Bedrock of the study area is primarily pre-Quaternary granitic, sedimentary, and metamorphic rock. Volcanic bedrock is also present in the study area. Correlation of bedrock making up the core of the Inyo-White and Sierra Mountain ranges implies that granitic rock extends across the graben beneath the valley fill (Ross, 1962). Hydraulic conductivity and porosity are low except along weathered fractures and joint intersections. Many experts consider the bedrock of the study area impermeable, except in localized areas where it may produce some water to wells or recharge small amounts to the valley fill.

Metamorphic and sedimentary rocks are present in mountain ranges of the study area. The metamorphics are dense and have low porosity. Secondary porosity is evident in areas of shearing but, due to limited contact with the valley fill, there is little chance of recharge in the metamorphic rocks (Hollett et al., 1989). Sedimentary rocks in Bishop Basin are fractured and may contain localized, but not dependable, water supplies.

The Bishop Tuff is a welded ash flow that forms bedrock in the area of the Volcanic Tableland, north of Bishop. The tuff is described as being comprised of differing textures in which porosity decreases with depth beneath the unit.

Bedrock is exposed in Bishop Basin at three locations: (1) Volcanic Tablelands on the northern boundary of the study area, (2) Tungsten Hills near Bishop, and (3) Poverty Hills near Tinemaha Reservoir (Figure 2.1).

Valley Fill

The valley fill is a heterogeneous mixture of unconsolidated to moderately consolidated gravel, sand, silt, and clay deposited in varying sequences. Each sequence has unique hydrologic characteristics and may consist of alluvial fan deposits, stream channel deposits, lakebed deposits, and volcanic deposits.

Alluvial fans on the east side of Bishop Basin are small and poorly developed. This is attributed to low precipitation and runoff in the Inyo-White Mountains. In contrast, fans on the western side of the valley are large and well developed by 12 major streams flowing from the Sierra Nevada. Estimates of alluvial fan thickness range from a few feet at the heads of the fans to more than 1,000 feet at the toes (Danskin, 1988). Fan material is poorly sorted and ranges in size from clay to boulders more than six feet in diameter. Clay layers are absent except near the toes of the fans.

Fill materials in the middle of the valley are primarily stream channel deposits. These materials are reworked alluvial fan material, floodplain material from the Owens River, and lakebed deposits. An ancient lake which extended north from the present location of Tinemaha Reservoir, marks the source of lakebed deposits (Hollett et al., 1989). Stream channel deposits consist of coarser materials close to the alluvial fans and progressively finer materials toward the middle of the valley. Well logs indicate clay layers from 5-25 feet thick. Many are lacking in lateral continuity, but areas around Big Pine and Bishop have extensive areas of blue-green clay associated with a lacustrine environment.

Volcanic deposits in Bishop Basin consist of cinder cones and basaltic lava flows. Some deposits are visible at the surface, but extensive areas are buried by alluvial material.

CHAPTER 4

HYDROLOGY

Owens River and tributary streams have been diverted and used for irrigation since the 1800's. Agricultural activities were greatly increased in the 1870's and many more canals and ditches were constructed to convey the water. Today the canals and ditches are intermittently used for flood control, irrigation, and spreading water for groundwater recharge. All surface water, except for limited in-valley uses is diverted into the Los Angeles Aqueduct (LAA), south of Tinemaha Reservoir, for export to Los Angeles.

Groundwater is used as a supplemental source of water for the LAA. Prior to 1970, however, groundwater was pumped when there was not sufficient surface water to fill the aqueduct. After 1970, upon completion of a second aqueduct, pumping demand was increased. Other groundwater uses include public supply, irrigation, fish hatchery use, and enhancement-mitigation projects. In general, annual runoff and annual pumping are inversely related (Figure 4.1).

Surface Water

Surface water features present in the study area include the Owens River, tributary streams, canals, and

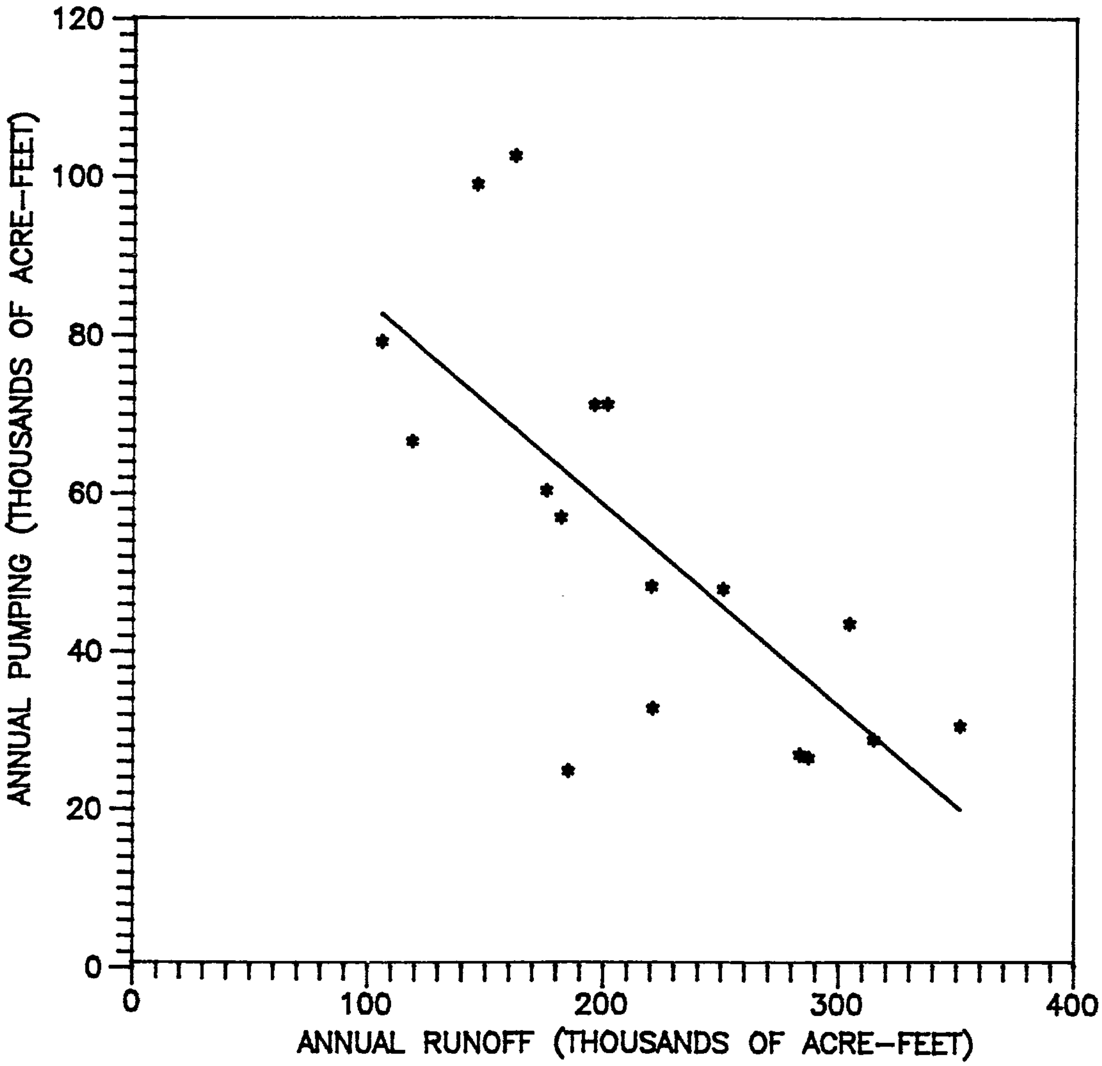


Figure 4.1. Annual Runoff vs. Annual Pumping for Owens Valley.

Tinemaha Reservoir. The water is primarily used for irrigation and for export to Los Angeles.

Flow in the Owens River is measured as it is released from Pleasant Valley Reservoir, located just north of the study area, and at Tinemaha Reservoir. Of 14 tributary streams in the study area, Bishop and Big Pine Creeks contribute the most inflow (Table 4.1). Small hydroelectric development exists on both creeks. LADWP maintains several gauging stations along surface water courses. Complete records are available from 1935 to the present. The river, tributary streams, and most of the canals are unlined and serve as sources of groundwater recharge.

Groundwater

Occurrence

Groundwater in the study area occurs in the valley fill under both confined and unconfined conditions, conceptually shown in Figure 4.2. Within alluvial fans the aquifer system is unconfined due to absence of a confining layer. Towards the middle of the valley, clay layers are present, which create confined conditions. These two aquifers are hydrologically connected, and, under non-pumping conditions, flow through the confining layer is from the confined to the unconfined zone.

Table 4.1. Average Streamflow - Water Years 1935-81.
(from Rogers and others, 1987)

Tributary Streams	Average Flow (Acre-feet/yr)
Horton Creek	6,855
McGee, Birch, and Coyote Creeks	11,143
Bishop Creek	65,387
Rawson Creek	1,332
Coldwater Canyon Creek	718
Silver Canyon Creek	1,227
Fish Slough	5,440
Baker Creek	6,043
Big Pine Creek	30,541
Birch Creek	5,373
Tinemaha Creek	5,544
Red Mountain Creek	3,826

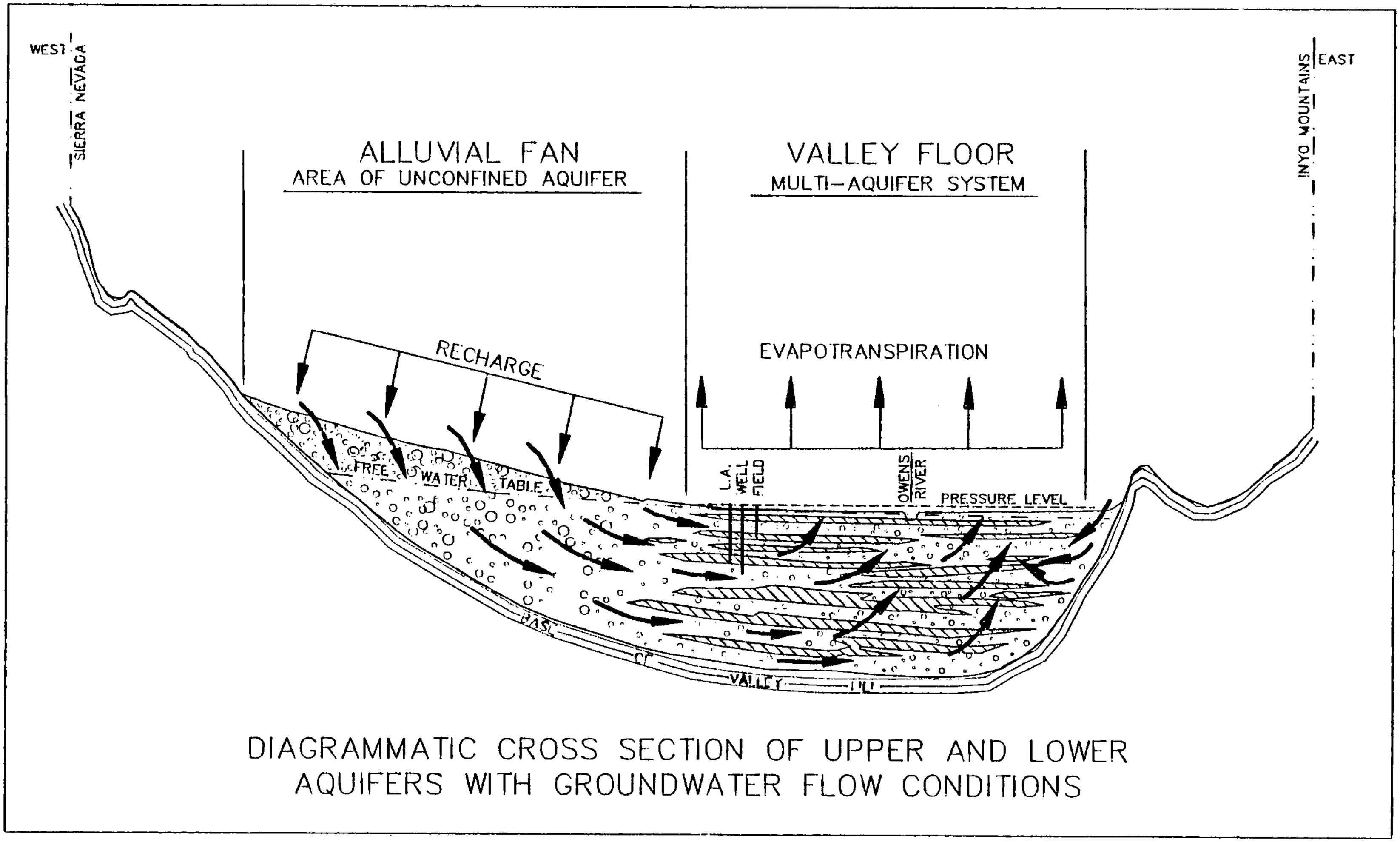


Figure 4.2. Conceptual Owens Valley Hydrologic System.

There are nine flowing wells in the study area and one spring, named Fish Springs. Historically, Fish Springs flowed at approximately 22 cfs; however, since 1970, when pumping increased dramatically for hatchery use, Fish Springs ceased to flow (Figure 4.3). One study measured a direct and immediate effect on the quantity of spring flow when nearby deep wells were pumped (LADWP, 1979).

Hydraulic Characteristics

Hydraulic characteristics of the groundwater system affect the ability of an aquifer to transmit and store water. Therefore, hydraulic conductivity, transmissivity, storage coefficient, and vertical hydraulic conductivity have been estimated for the area from aquifer test and geophysical data.

Hollett et al. (1989) report horizontal hydraulic conductivity ranging from 1.0-1,500 ft/day in alluvial fans to 900-21,000 ft/day in the Big Pine volcanic field. Danskin (1988) reports transmissivity ranging from 4,000-70,000 ft^2/day in alluvial fans to more than 1,300,000 ft^2/day in volcanic deposits near Big Pine. Hutchison's (1986d) analysis yields transmissivity values of 9,000-12,600 ft^2/day in the alluvial aquifer near Big Pine.

Specific yield ranges from <0.01 in the fluvial-lacustrine clays to 0.30 in sands and gravels of alluvial

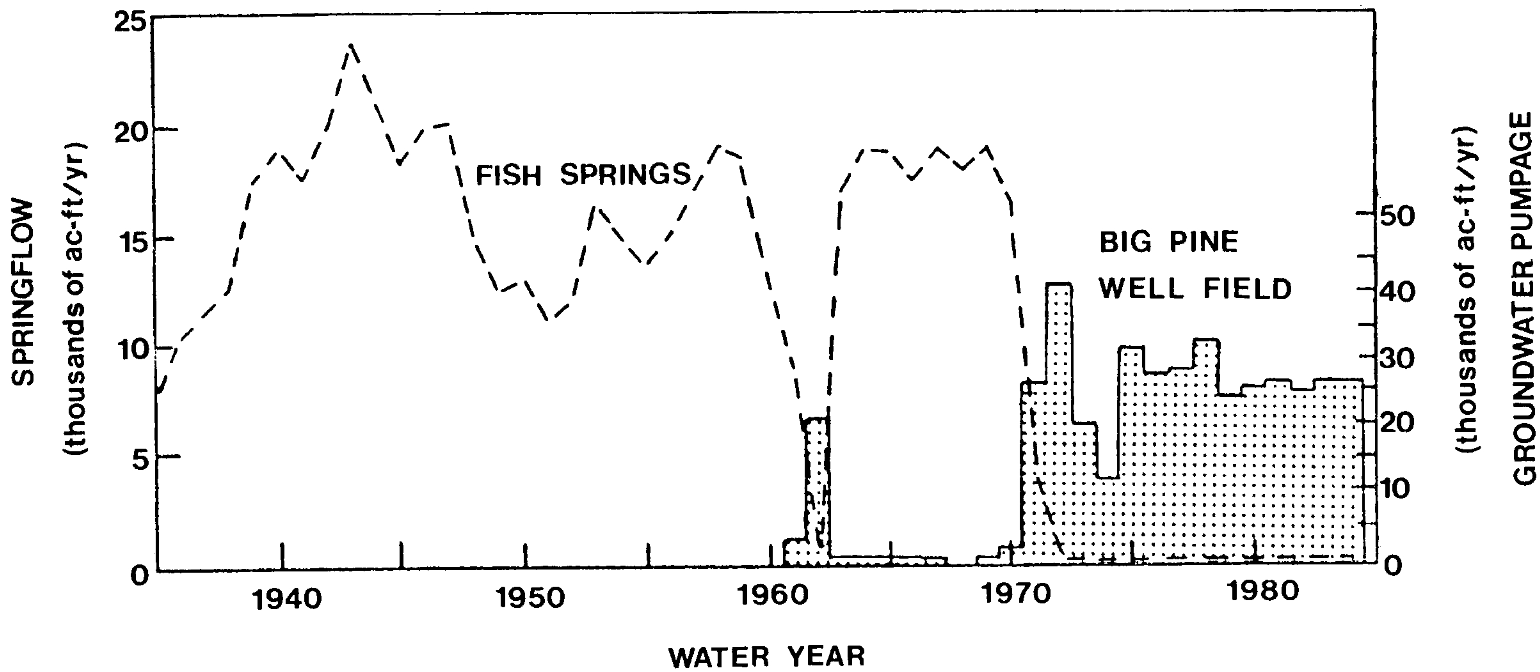


Figure 4.3. Fish Springs Flow and Big Pine Well Field Pumping. (from Rogers and other, 1987)

fans (Hollett et al., 1989). Hutchison (1986d) reports storage coefficients ranging from 2.4×10^{-4} to 5.5×10^{-4} in alluvial material near Big Pine.

Hutchison (1986d) used the Hantush method for leaky aquifers to estimate vertical hydraulic conductivity. Based on a fifty foot confining layer, as evidenced by well logs, he reports vertical hydraulic conductivity as 1.38×10^{-2} ft/day.

Groundwater Recharge

Sources of recharge to the groundwater system include infiltration from stream channels, canals, irrigated and urban areas, and groundwater spreading areas. Water is released onto the valley floor by LADWP from streams and canals when runoff is substantially above-normal and is greater than the capacity of the aqueduct. Water is also supplied by LADWP to irrigated leases. A 5 acre-foot/acre duty is applied and approximately 21 percent is considered to become recharge. Recharge from these two sources is limited and localized. Subsurface inflow is another source of water to the groundwater system. Some estimates of recharge include precipitation on the valley fill; however, significant recharge to the groundwater system from precipitation is unlikely. Mann (1976) reports that recharge may only occur when annual precipitation is greater that 8 inches. This accounts for the difference in groundwater budgets developed for Owens Valley by LADWP (1978) and Hutchison (1986b). Evapotranspiration was the residual term in the LADWP budget, while Hutchison calculated recharge as the residual. Time periods differed slightly in the two estimates. LADWP used a base period of 1935-1966, and a second period, 1971-1986. Hutchison used two time periods as well, 1945-1969 and 1971-1986. These budgets are presented in Table 4.2.

Groundwater Discharge

Groundwater is discharged from the system by phreatophytic plants on the valley floor, springs, flowing wells, groundwater outflow, baseflow to the river, and pumped wells. Pumping, which became a significant factor after 1970, upon completion of the second aqueduct, currently accounts for approximately 50 percent of the outflow from the system (Hollett et al., 1989). Estimated outflow is presented in Table 4.2.

Some wells are developed in both the unconfined and confined aquifers, though many older wells are screened from top to bottom. Water is withdrawn from both zones in the older wells, although not uniformly. The current trend is to replace wells that are fully screened with wells screened only in the confined zone. Although the two aquifers are

Table 4.2. Summary of Groundwater Budgets. (Acre-feet/year)

	LADWP (1978) 1935-66	LADWP (1978) 1971-86	Hutchison (1986) 1945-69	Hutchison (1986) 1971-86
INFLOW				
1. Deep Percolation				
Precip. on Valley Fill	94,120	94,120	n/a	n/a
Runoff	184,620	159,280	117,425	144,090
Transit Loss	n/a	n/a	0	1,618
Pumping Loss	n/a	n/a	282	1,369
Aqueduct Releases	n/a	n/a	347	552
2. Subsurface Inflow	25,340	25,340	25,340	25,340
3. Owens River & Aqueduct Transit Losses	0	7,240	n/a	n/a
4. Artificial Recharge	n/a	n/a	0	8,544
5. TOTAL INFLOW	304,080	285,980	143,394	181,513
OUTFLOW				
1. Well Production				
LADWP wells	7,240	112,220	10,063	91,729
Private wells	3,620	3,620	3,500	3,500
2. Subsurface Outflow	10,860	10,860	10,860	10,860
3. Evapotranspiration	238,920	137,560	75,691	60,000
4. Flowing Groundwater	43,440	21,720	42,376	15,424
5. Transit Gain	n/a	n/a	904	0
6. TOTAL OUTFLOW	304,080	285,980	143,394	181,513

n/a - not listed as item in budget

hydrologically connected, pumping from the confined zone may delay or buffer the effect on the overlying water table.

There are a total 322 LADWP wells in the Bishop Basin study area, 68 of which are pump-equipped (Hutchison, 1988). Total pumping capacity is 202.3 cfs. Numerous private wells in the study area pump less than a total of 3,500 acre-feet/year (Table 4.2).

Water Quality

Quality of the surface and groundwater in the Bishop Basin is good to excellent. Most of the water is calcium bicarbonate in character. Total dissolved solids range from 50 to 200 ppm for surface water, and from 70 to 300 ppm for groundwater (LADWP, 1972). No comprehensive evaluation of groundwater quality has been conducted.

CHAPTER 5

DESCRIPTION OF MODEL

Inyo County Water Department developed a three-dimensional groundwater flow model for the northern half of the Owens Valley (Bishop Basin model) to better understand the overall groundwater system. Stages of development of this model included conceptualization, identification of boundary conditions, steady-state and transient calibration, and sensitivity analysis. Verification is the final step in any modeling effort and takes place at some point in the future to test the model's predictive accuracy. The model is currently being used to determine potential areas of drawdown due the effect of pumping and drought as part of an effort to develop effective management and monitoring programs. The model is described in detail by Hutchison and Radell (1988) and Hutchison (1988). An overview of these reports is presented in this chapter.

Conceptual Model

The basis for any groundwater modeling effort is development of a conceptual model of groundwater flow. This model is then tested by use of a numerical model. The conceptual model describes the inflow/outflow regime and boundary conditions of the groundwater system. For the Bishop Basin model, the general direction of groundwater flow is north to south. Groundwater inflow is expected from Chalfant and Round Valleys into the model area, and subsequently flows out around the eastern portion of Poverty Hills (Figure 2.1).

One of the most significant components of total recharge in the model area occurs as percolation of streamflow crossing alluvial fans. Due to this large influx, groundwater flow in the alluvial fan area has a strong west to east component. Outflow is largely from evapotranspiration from phreatophytic vegetation on the valley floor, groundwater pumping, flowing groundwater (springs and flowing wells), and baseflow to the Owens River.

The groundwater system is a two layer system. A zone of lower hydraulic conductivity separates an unconfined aquifer from an underlying confined aquifer system.

Numerical Model

Translating the conceptual model into a quantitative model requires assumptions. The foremost among these is the method of mathematically describing groundwater flow through porous media. Three-dimensional movement of groundwater through porous earth material may be described by the partial-differential equation:

$$\frac{\delta}{\delta x}(Kxx\,\frac{\delta h}{\delta x})+\frac{\delta}{\delta y}(Kyy\,\frac{\delta h}{\delta y})+\frac{\delta}{\delta z}(Kzz\,\frac{\delta h}{\delta z})-W=Ss\,\frac{\delta h}{\delta t}$$

where

x, y, & z are cartesian coordinates aligned along the principal axis of hydraulic conductivity K_{xx}, K_{yy}, & K_{zz};

h is the potentiometric head;

W is a volumetric flux per unit volume and represents sources and/or sinks of water;

S_s is the specific storage of the porous media; and

t is time.

For this analysis, the partial-differential equation is solved using the finite-difference method with the USGS Modular Model (McDonald and Harbaugh, 1983). Key assumptions in this approach are related to discretization of space and time. The flow system is subdivided into cells and all hydraulic properties are assumed uniform over the extent of a given cell. The pre-conditioned conjugate gradient method (Kuiper, 1987) is used by the computer program that solves the finite-difference equations for head in each cell.

The Bishop Basin model is divided into a grid having 162 rows, 80 columns, and 2 layers (Figure 5.1, pocket). This grid is uniform and each cell is 1,000 feet on a side. Each of the 25,920 cells is designated as active, inactive, or having a constant head (Figure 5.2). Transmissivity, storage coefficient, and vertical conductance distributions are presented in Figures 5.3 through 5.7.

The groundwater system in the Bishop Basin is modeled as a two layer system. Model layer 1 is unconfined and model layer 2 is confined. Transmissivity is referred to in model layer 1 due to an assumption made when translating the conceptual model to the numerical model. It is assumed that the drawdown in model layer 1 will be small in comparison to total aquifer thickness and that the error in this assumption will be less than if a bottom aquifer elevation is chosen for each model node.

Boundary and Initial Conditions

Defining the boundary conditions for the numerical model are of critical importance for an accurate solution. Boundary conditions are developed from both the conceptual model for groundwater flow and assumptions in translating the conceptual model to the numerical model. Mathematically, the boundary conditions include the geometry of the boundary and the values of the dependent variable or its derivative

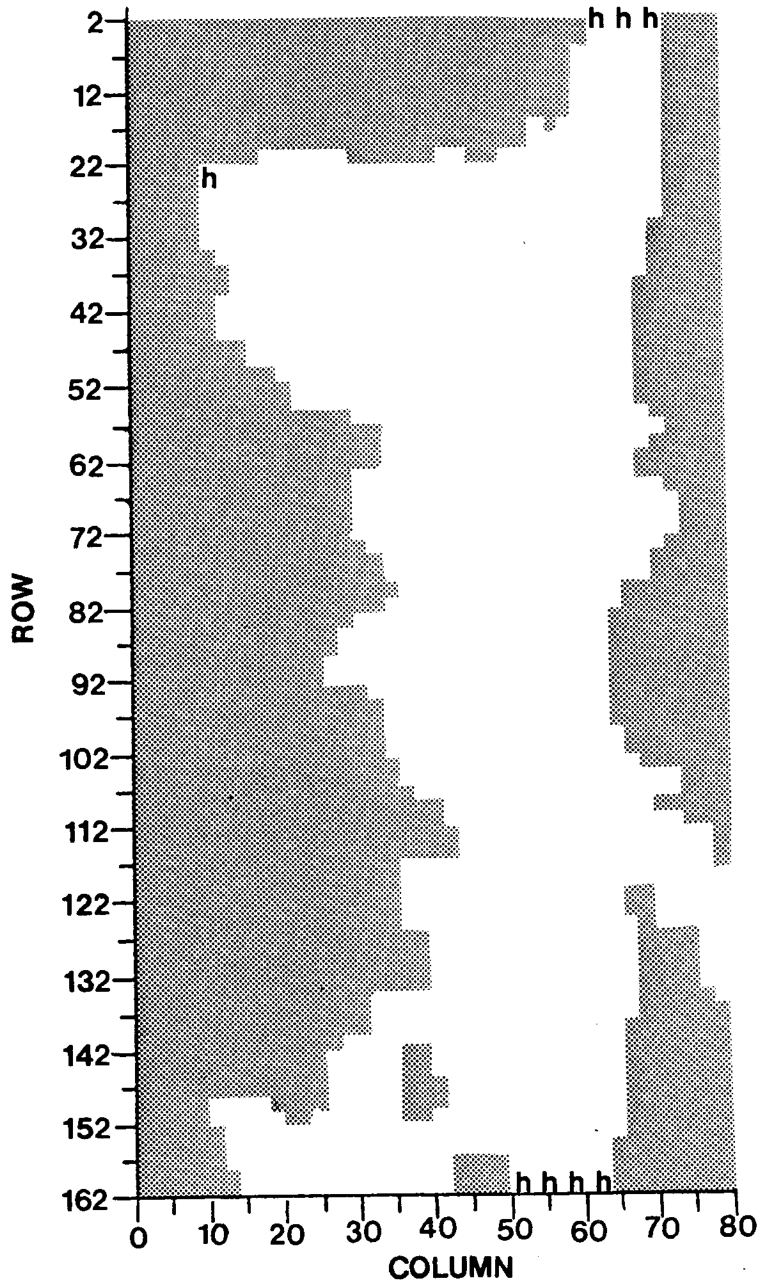


Figure 5.2. Model Cell Designation Map. Shaded Areas are No Flow Boundaries, h = constant head boundary.

FIGURE 5.3

TRANSMISSIVITY DISTRIBUTION MODEL LAYER 1

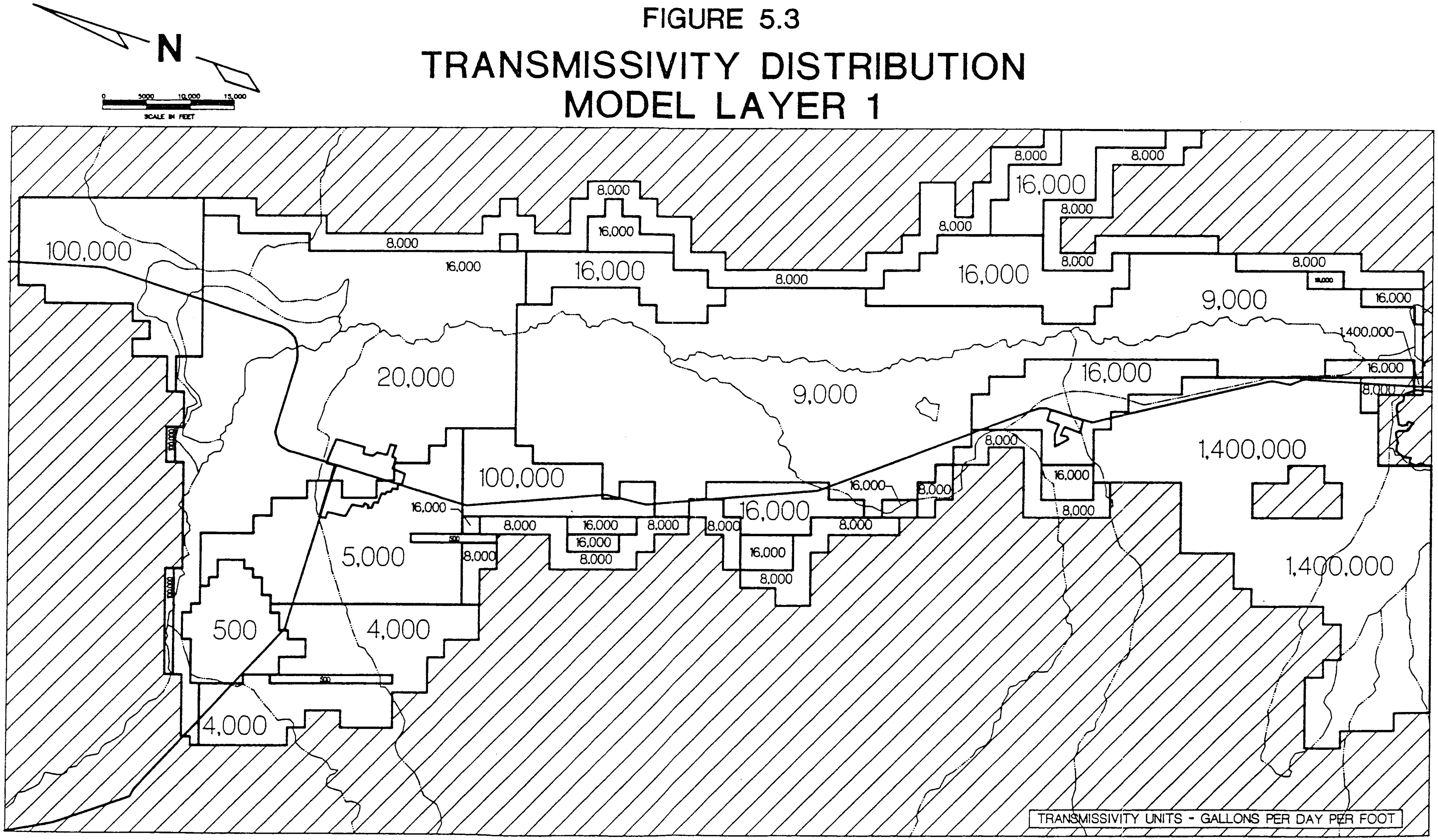


FIGURE 5.4
STORAGE COEFFICIENT DISTRIBUTION
MODEL LAYER 1

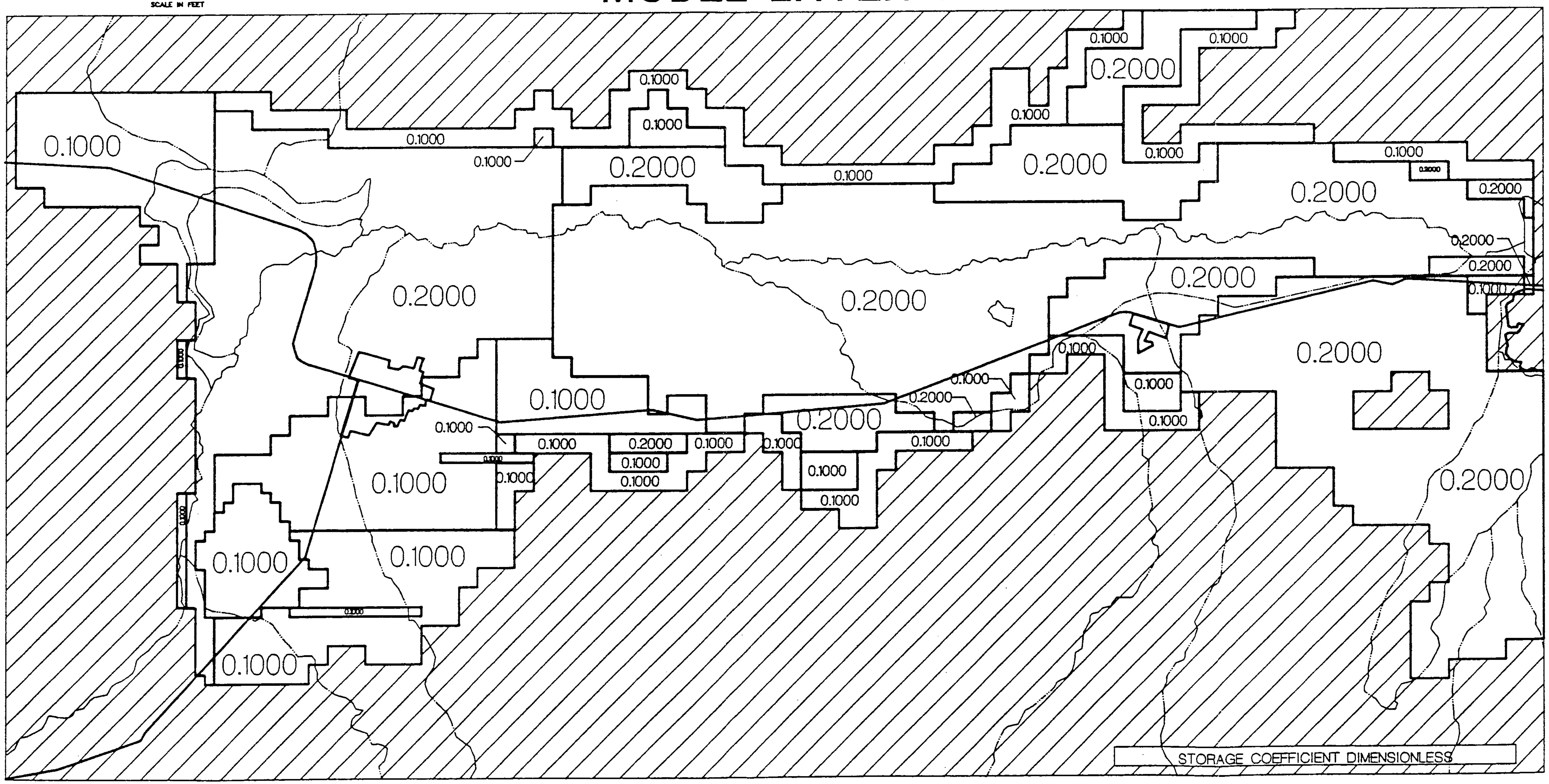


FIGURE 5.5

TRANSMISSIVITY DISTRIBUTION MODEL LAYER 2

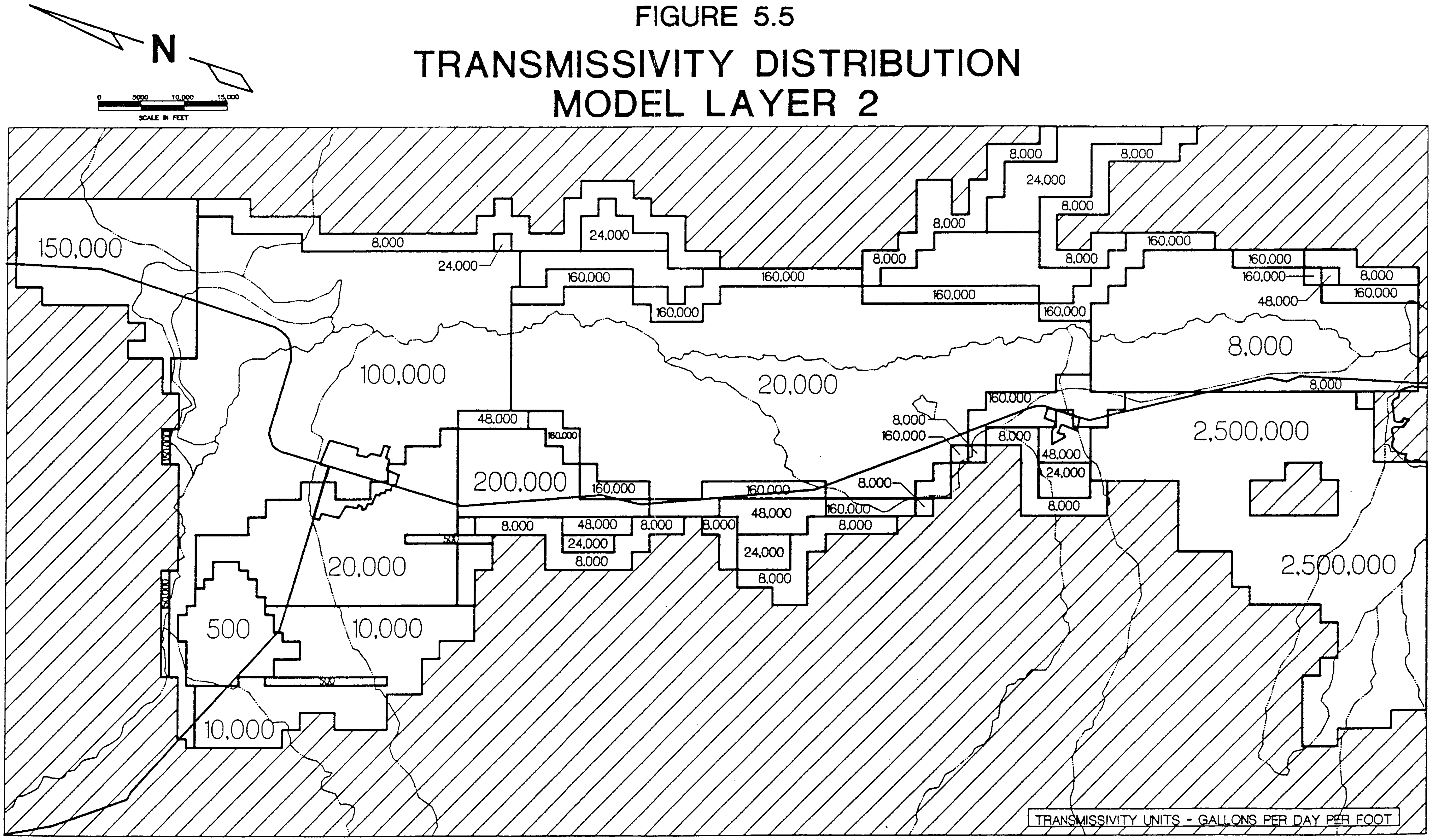


FIGURE 5.6

STORAGE COEFFICIENT DISTRIBUTION
MODEL LAYER 2

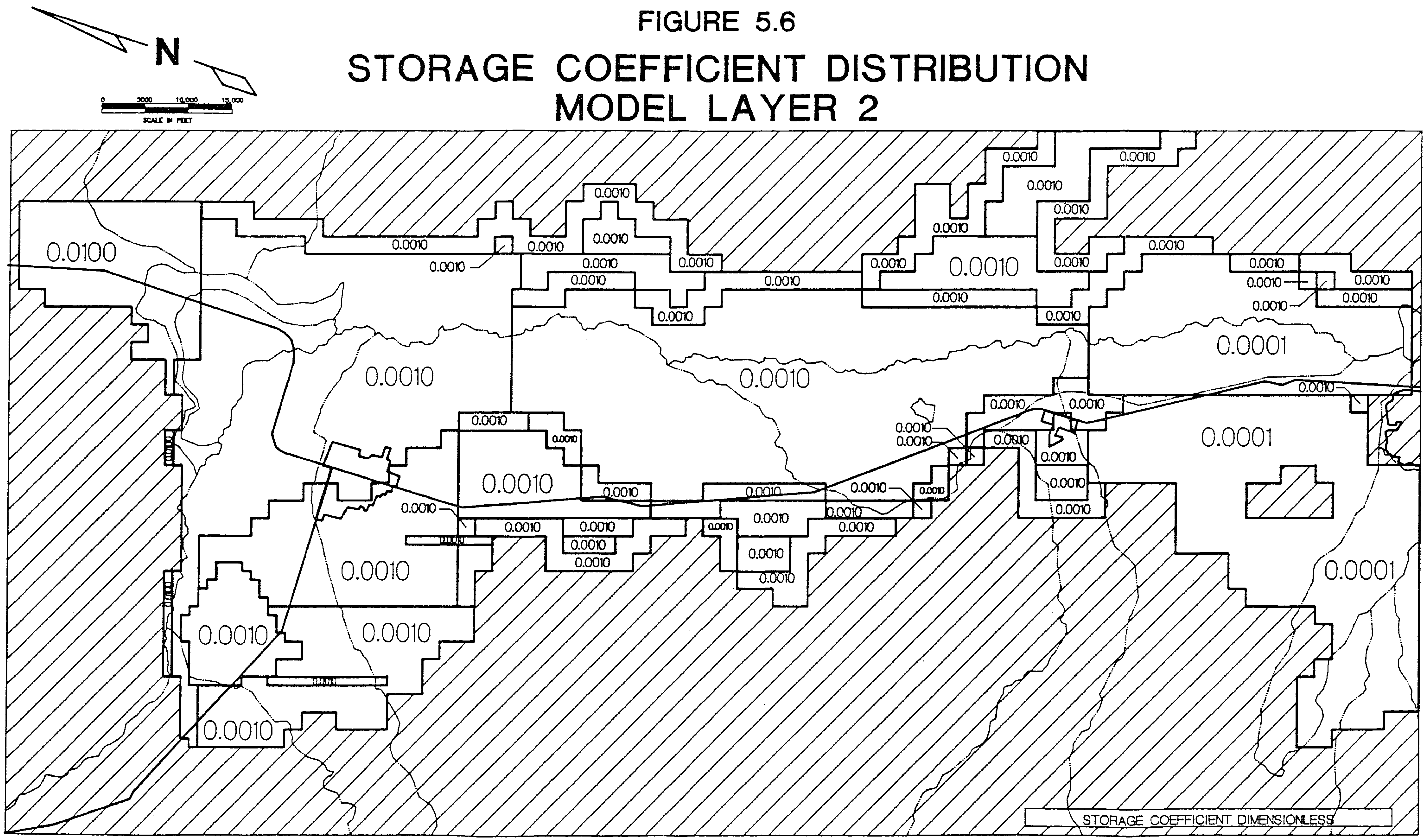
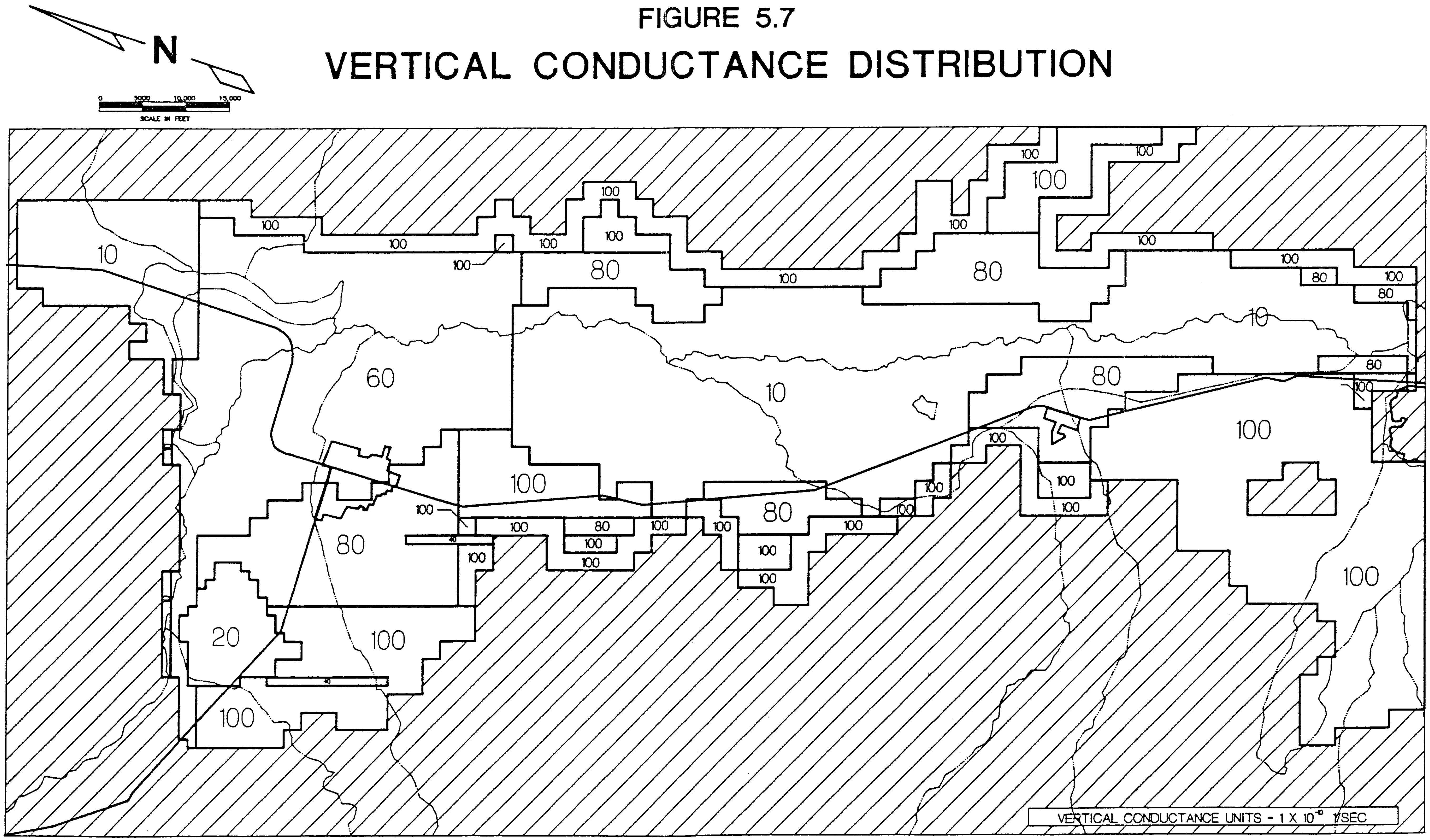


FIGURE 5.7
VERTICAL CONDUCTANCE DISTRIBUTION



normal to the boundary (Mercer and Faust, 1981). In physical terms, for groundwater applications, the boundary conditions are generally of three types; (1) specified head; (2) specified flux; or (3) head-dependent.

Groundwater inflow and outflow of the study area are analyzed as a combination of specified head and specified flux boundaries. Specified head boundaries explain where subsurface flow enters and exits the model area (Figure 5.2). Groundwater divides are assumed to exist north and south of the Bishop Basin model area. These divides are shifted as pumping and recharge stresses fluctuate, but do not cause significant changes in inflow/outflow regimes (Hutchison, 1988).

Simulating recharge and discharge from streamflow, precipitation, and evapotranspiration gives specified flux boundaries. Evapotranspiration may be better analyzed as a head dependent boundary, but no reliable functional relationship has ever existed (Hutchison, 1988). Distributed evapotranspiration data based on vegetation communities were gathered during concurrent vegetation studies undertaken jointly by Inyo County Water Department and LADWP and were used to develop the specified flux values for individual model cells. The recharge package for the groundwater model is generated in a pre-processing program. Input to the program includes stream recharge, canal recharge, spreading area recharge, recharge from return irrigation flows, and negative values representing evapotranspiration. These values are totaled and consideration is given to water retained in the soil and held over from season to season.

Discharge from flowing and pumped wells is simulated as specified flux boundaries (Figure 5.8). Historic records of well production and rates from flowing wells were used to develop average rates in six-month intervals.

The Owens River and Fish Springs are modeled as permeable boundaries (Figure 5.9). These head dependent boundaries are simulated using the river and drain packages, respectively. The initial condition at the start of a simulation is a head distribution throughout the model area. In transient analysis, the initial condition is the head distribution from the calibrated steady-state model.

Model Calibration

Steady-State Analysis

Steady-state analysis consisted of calibrating the model results to heads in 51 indicator wells from early 1984. High pumping was begun in 1970, and prior to that time, the groundwater system was considered to be in equilibrium. Heads in 1984 were used because prior to 1970, well data was limited. These hydrographs, available from

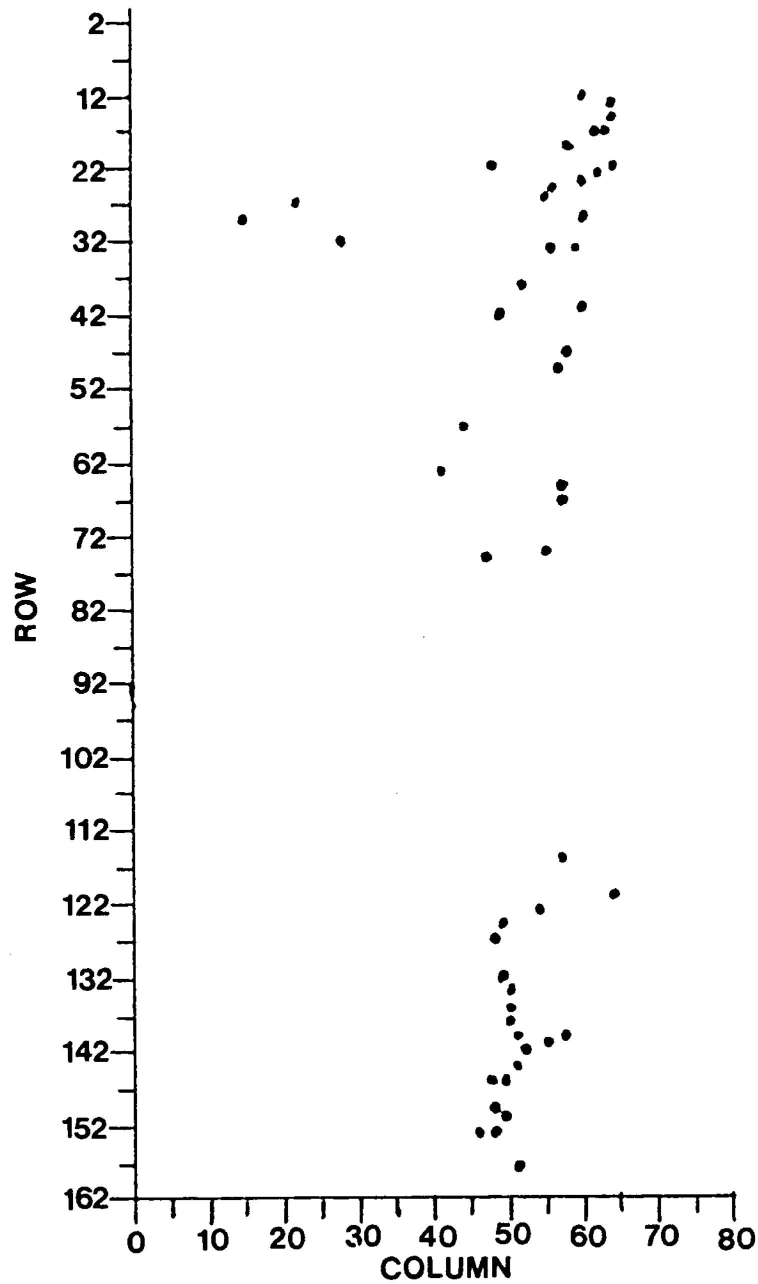


Figure 5.8. Specified Flux Boundaries - Well Locations.

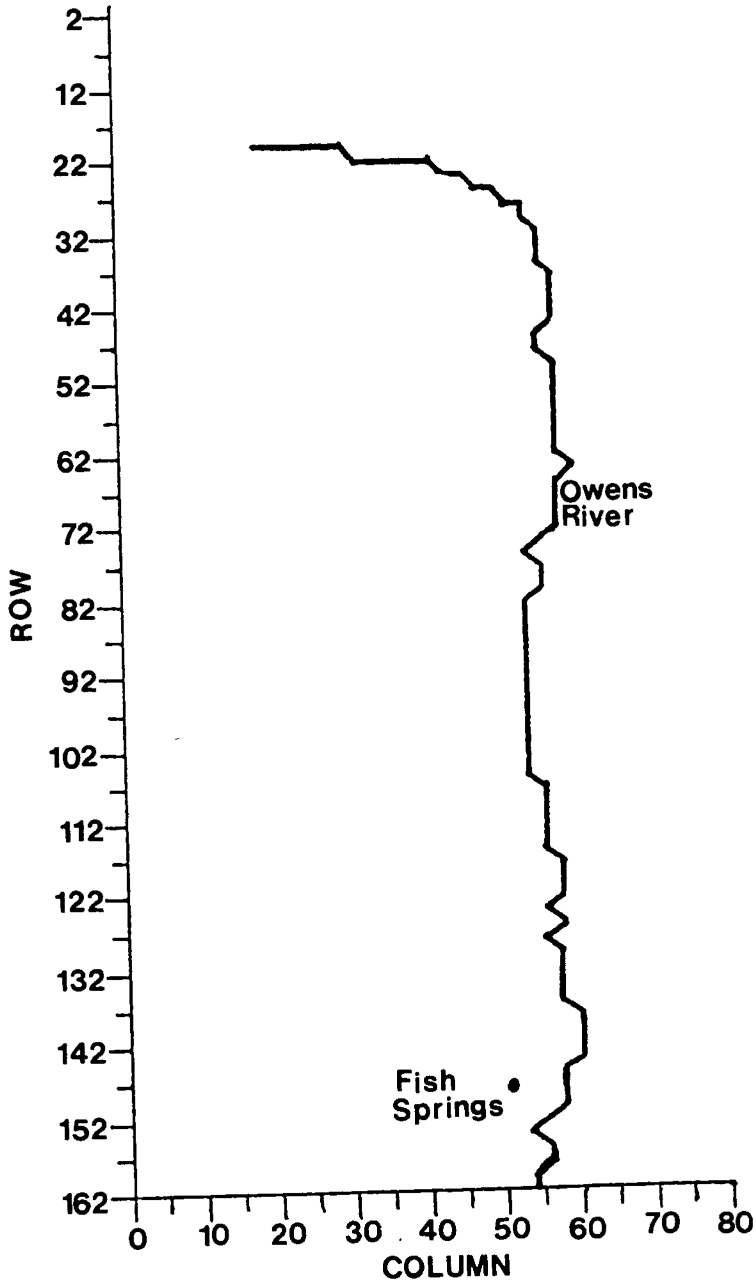


Figure 5.9. Head Dependent Boundaries - Owens River and Fish Springs.

before 1970-1984, had shown that heads in 1984, generally, were equivalent to the level prior to 1970. This was due to above-normal runoff years in the early 1980's. Therefore, an assumption was made that heads in 1984, were equivalent to heads in 1970, throughout the model area (Hutchison, 1988). An exception to that assumption was seen in the Big Pine volcanic area. Water levels had been generally 15 to 20 feet lower in 1984 than in 1970, due to continuous heavy pumping for the Fish Springs Hatchery. This exception was taken into account during model calibration. Results of the final calibration run for the model have compared favorably to actual heads in the indicator wells.

Of equal or greater importance, was the evaluation of contour maps of head (Figures 5.10 and 5.11). The simulated contour maps matched closely with previously drawn contour maps developed by LADWP (1976).

Transient Analysis

The transient simulation period was from April 1, 1970, to September 30, 1984, and was divided into 29 six-month stress periods. The 51 indicator wells used in the steady-state analysis also appeared in the transient analysis. Both simulated well hydrographs and head contour maps compared favorably with actual data.

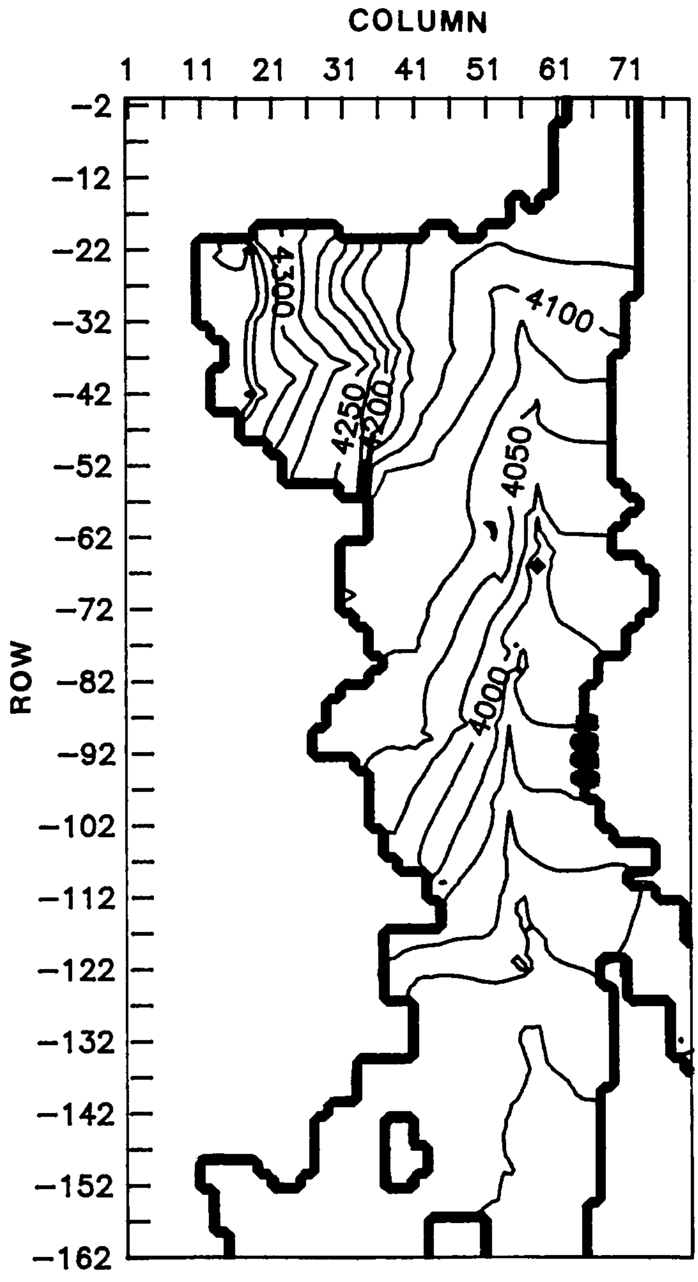


Figure 5.10. Water Level Contours - Model Layer 1.

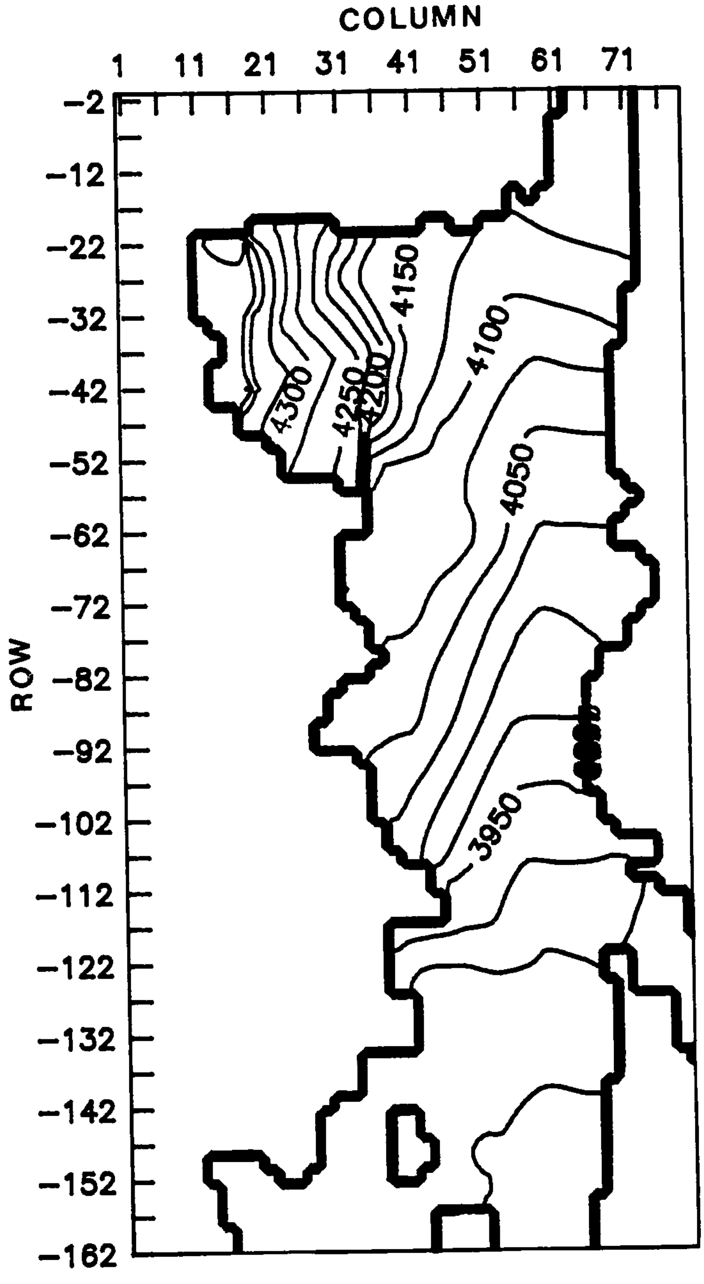


Figure 5.11. Water Level Contours - Model Layer 2.

CHAPTER 6

SENSITIVITY ANALYSIS

Sensitivity analysis determines how and to what degree each input variable affects the model solution. In distributed parameter modeling, input variables are specified for each model cell even though they may not be known for each cell. Therefore, some uncertainty is associated with model results. A sensitivity analysis determines which input parameters exert the most control over the model solution and may therefore, produce extensive errors. Results from sensitivity analyses can focus future studies to better determine sensitive parameters, and in doing so, improve the model solution. It is important to note that the sensitivity of each parameter is tested individually and does not address the additive effect of two or more parameters. This particular aspect is more easily handled through trial and error calibration of the model.

Analysis Description

Input parameters were varied a certain amount from values used in the calibrated steady-state simulation. Tested variables and a summary of the changes are presented in Table 6.1. Transmissivity, vertical conductance, and flowing well production were varied over two orders of

Table 6.1. Summary of Sensitivity Analysis Changes.

Parameter	Change
Transmissivity - Both Layers Transmissivity - Layer 1 Transmissivity - Layer 2 Vertical Conductance Flowing Wells Total Recharge	One order of magnitude above and below steady-state
Recharge from Precipitation	Addition of up to 15% of precipitation in areas above 5,000 feet
Canal Recharge Spreading Area Recharge Stream Recharge	Manipulation of recharge factors - multiplied by 0.2, 0.5, 2.0, and 5.0
Recharge from Changes in Evapotranspiration	From 80% to 120% of steady-state values

magnitude. This range encompassed reasonable variations in input parameters.

Since estimates of total recharge differed greatly, this parameter was varied over a wide span. Recharge factors for stream, canal, spreading area, and precipitation were manipulated over two orders of magnitude. These factors were estimates of the percentage of water that infiltrated and became recharged to the groundwater system. For example, streamflow was measured at the base of the mountains and then multiplied by a factor to get recharge from this source.

Stream, canal, and spreading area recharge were also varied individually through the use of the recharge factors. Variations ranged from 0.2-5.0 times the calibrated steady-state factors.

No recharge from precipitation was assumed in the Inyo County calibrated steady-state simulation. Recharge from precipitation is an input parameter in the LADWP groundwater model. Since it was (and is) a point of disagreement between LADWP and Inyo County, up to 15 percent of precipitation was added to recharge in areas with an elevation of 5,000 feet or greater. This corresponded to roughly 8 or more inches of annual precipitation, the amount predicted by Mann (1976) that was necessary for recharge to occur.

Evapotranspiration was varied from 80-120 percent of calibrated steady-state values. This input parameter was determined for each model node through concurrent vegetation studies. Valley vegetation was mapped by LADWP and evapotranspiration was measured for each vegetation type. Since evapotranspiration was well known, it was varied only slightly from the steady-state.

The model results were compared by means of the root-mean square error (RMSE) of the heads. A total of 48 wells were used in the analysis (13 wells in model layer 1 and 35 wells in model layer 2). Three layer 1 calibration wells were eliminated because they exhibited localized groundwater conditions and were not representative of regional conditions (Hutchison, personal communication, 1989). Root mean square error is calculated as follows:

$$RMSE_h = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left[\hat{h}_i - h_i \right]^2}$$

where

$RMSE_h$	is the root mean square error of the potentiometric head;
n	is the number of indicator wells;
$\hat{h}^i$	is the predicted head of the i^{th} indicator well;
h^i	is the actual head of the i^{th} indicator well.

Results and Discussion

Sensitivity analysis results were plotted on the same scale so that visual comparison is possible. Exceptions include recharge from precipitation and changes in evapotranspiration. The X-axis, or change factor, represents the sensitivity analysis parameter value divided by the steady-state parameter value. The Y-axis is the RMSE of the potentiometric heads. Data used to produce the graphs is presented in Appendix A.

Transmissivity

Transmissivity was varied in three ways: (1) layer 1 transmissivity changed only; (2) layer 2 transmissivity changed only; and (3) both layers 1 and 2 transmissivity changed. The results are presented in Figures 6.1, 6.2, and 6.3.

Heads in model layer 1 are little affected by the transmissivity changes in the separate layers or to increasing transmissivity in both model layers. They are, however, sensitive to decreasing transmissivity when the change occurs in both model layers.

Layer 2 heads are least sensitive to decreases in layer 1 transmissivity. They are sensitive to all other transmissivity changes.

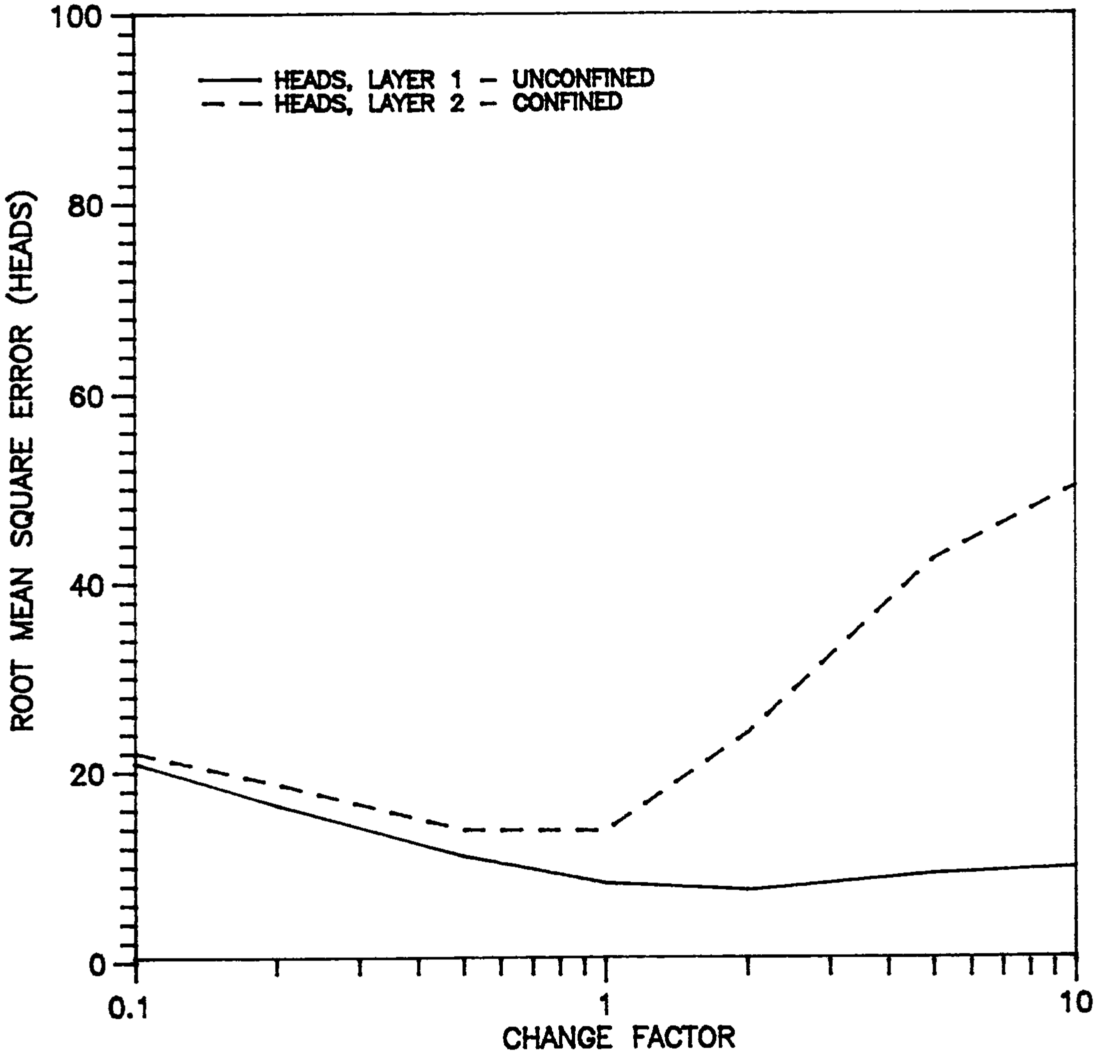


Figure 6.1. Sensitivity Analysis - Transmissivity Changed in Model Layer 1 Only.

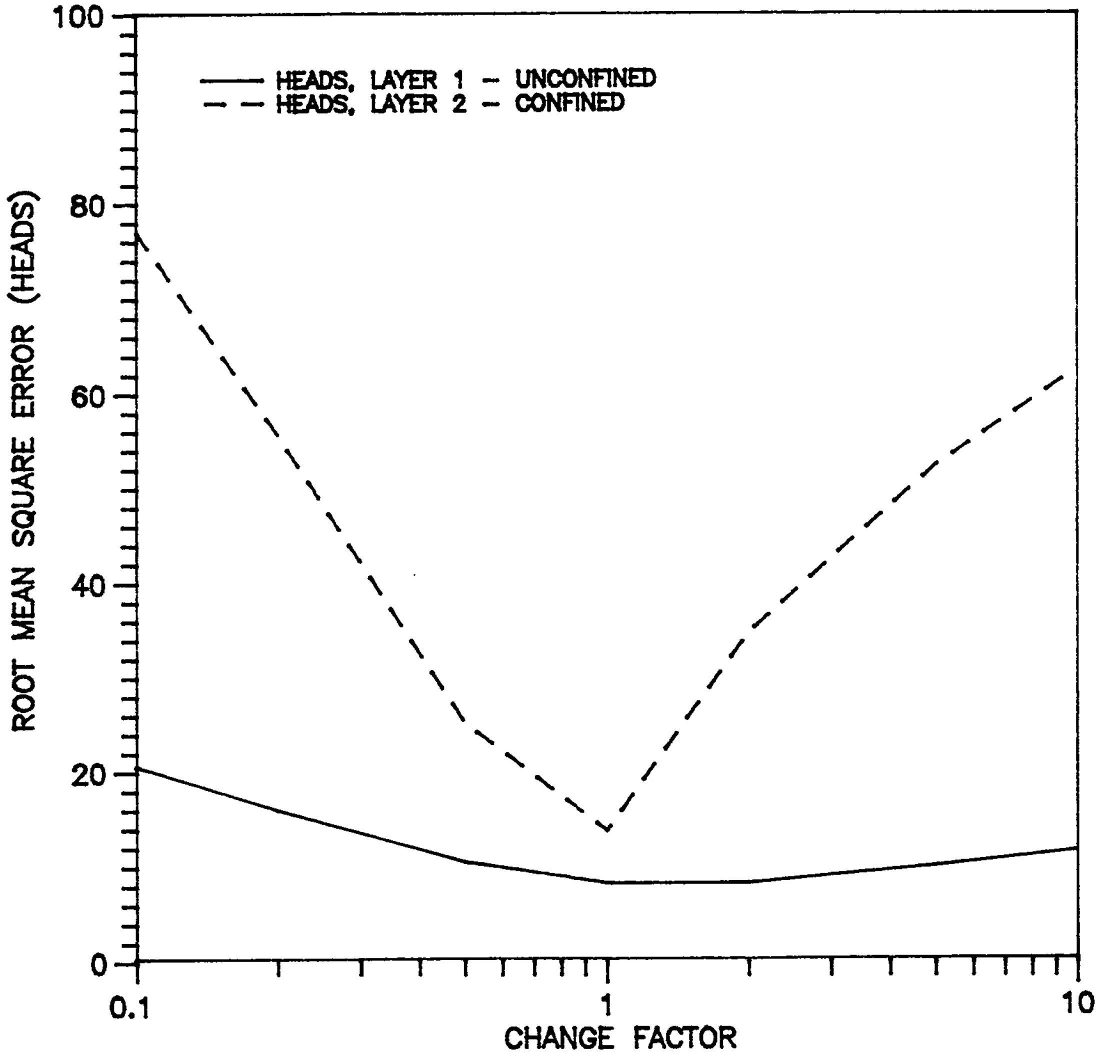


Figure 6.2. Sensitivity Analysis - Transmissivity Changed in Model Layer 2 Only.

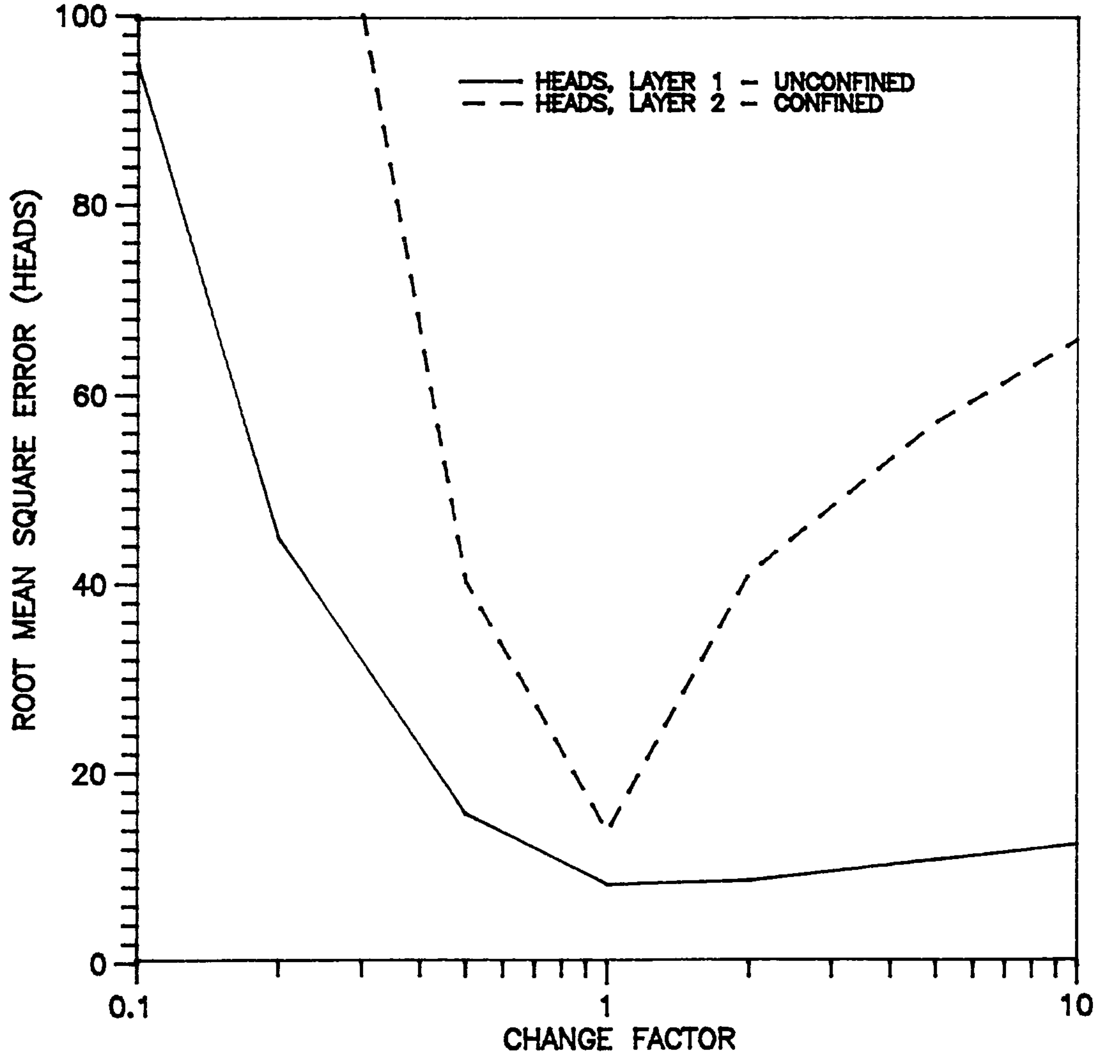


Figure 6.3. Sensitivity Analysis - Transmissivity Changed in Both Model Layers.

Heads in layer 2 are more sensitive to changes in transmissivity than those in layer 1. Transmissivity is generally higher in the confined zone (layer 2) and, therefore, an order of magnitude change may produce values that are not probable in nature. Lower transmissivity values of layer 1, when changed by an order of magnitude, result in smaller values. These changes cause less perturbation in head and therefore appear less sensitive.

Vertical Conductance

Potentiometric heads in both model layers are insensitive to changes in vertical conductance (Figure 6.4). Results of this analysis could be deceptive since vertical conductance is typically more important in transient simulations. Vertical conductance is a more significant factor when increased pumping stress creates a greater head difference between the confined and unconfined zones.

Flowing Wells (Steady-State Pumping)

Values used for the nine flowing wells in the study area were derived from monthly staff gage readings taken by LADWP. Heads in both layers are insensitive to decreasing flow values (Figure 6.5). The model is sensitive, however, to flow values above twice that of steady-state. Estimates used in steady-state simulation may be subject to

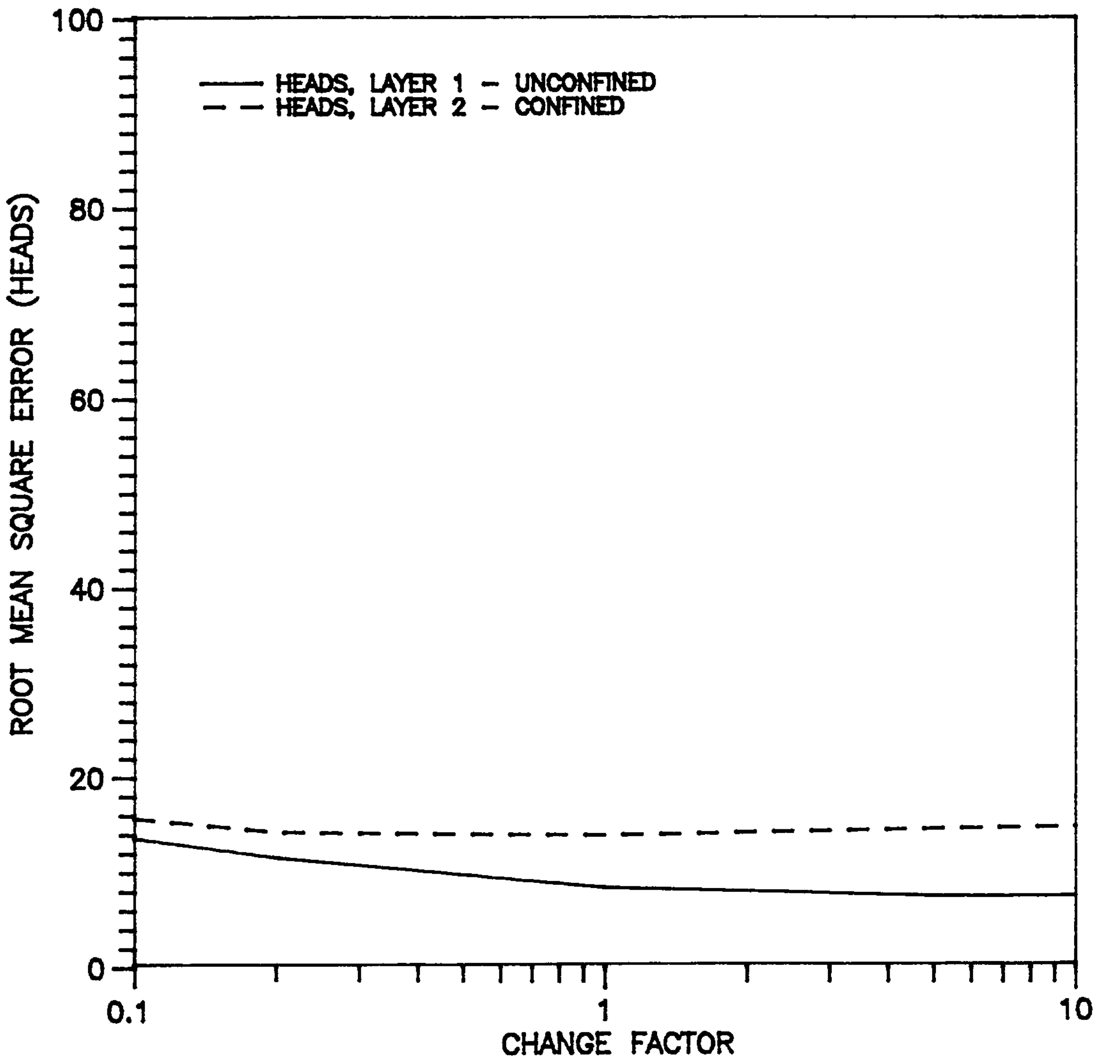


Figure 6.4. Sensitivity Analysis - Vertical Conductance.

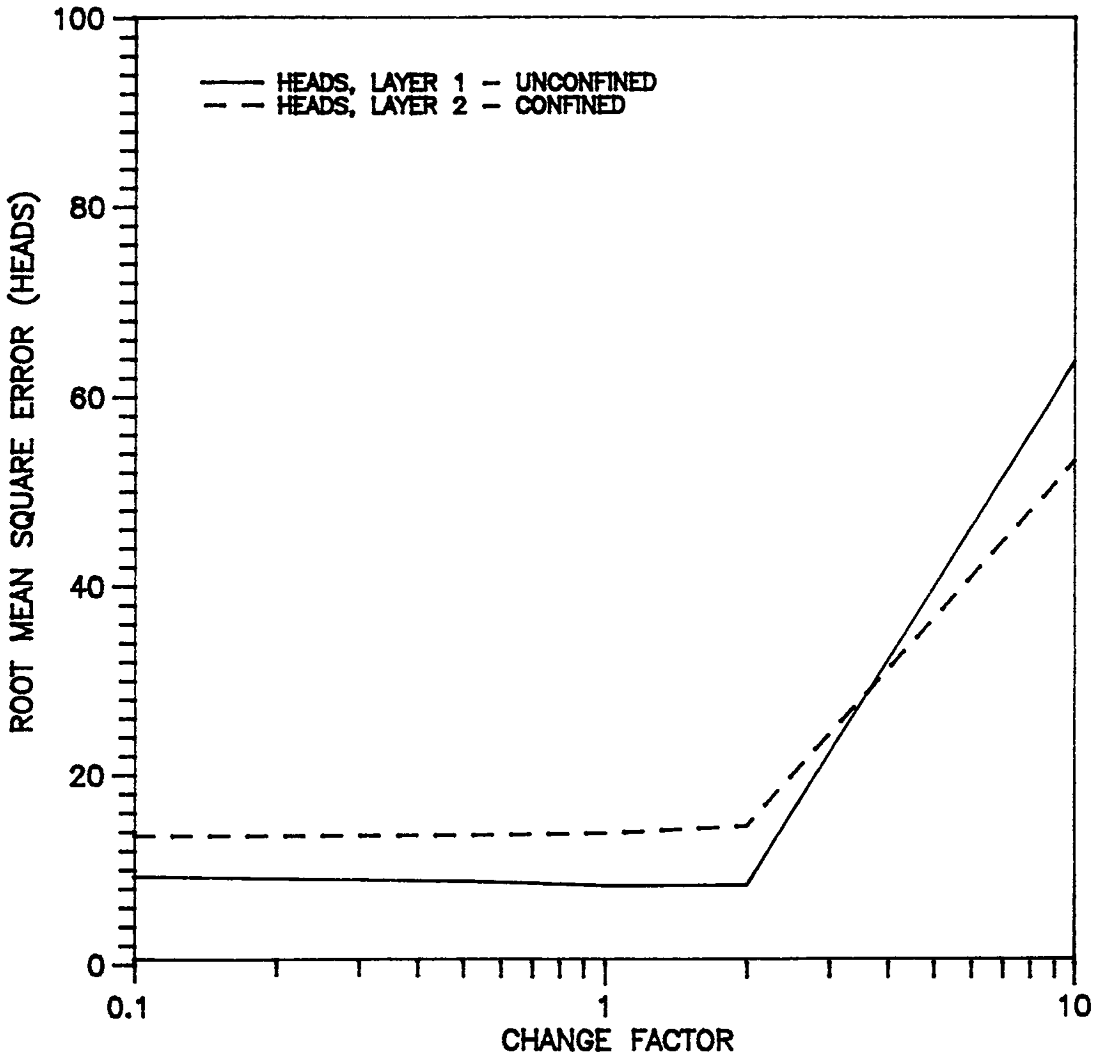


Figure 6.5. Sensitivity Analysis - Flowing Well Production.

measurement error, which analysis illustrates even significant error does not affect model results.

Total Recharge

Total recharge is a sensitive model parameter (Figure 6.6). Increases in total recharge affect model results significantly. Decreases also produce significant effects, but layer 1 head changes were less that those in layer 2.

Changes in total recharge by varying recharge factors over two orders of magnitude are found in Appendix A. For example, doubled recharge factors increase total recharge from 29,276 to 55,468 acre-feet, a change of 89.47 percent. Halving the factors decreases total recharge 13,095 acre-feet or 44.73 percent.

Recharge was expected to be a sensitive parameter in the simulated model. Increases or decreases in the inflow, without appreciably changing the outflow (evapotranspiration), will certainly affect potentiometric heads in both model layers.

Recharge Components

Components making up total recharge are stream recharge, canal recharge, spreading area recharge, recharge from precipitation, and change in evapotranspiration. Change in evapotranspiration is considered a recharge component because of how the recharge array is generated. More or

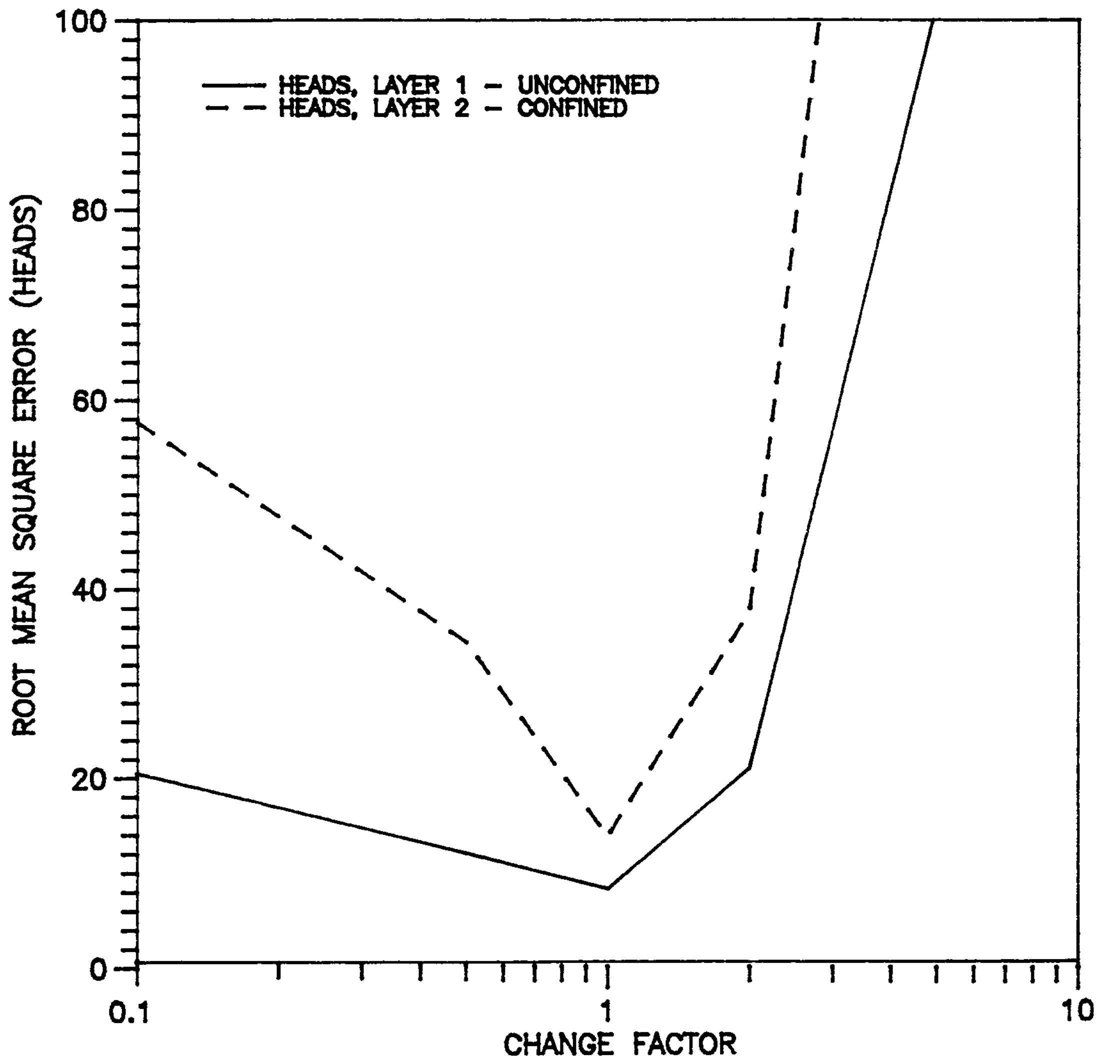


Figure 6.6. Sensitivity Analysis - Total Recharge.

less water is demanded from the groundwater system as evapotranspiration changes. Results of the sensitivity analysis for the recharge components are presented in Figures 6.7 through 6.11.

Heads in both model layers are sensitive to increases in stream and canal recharge. Decreasing stream recharge causes significant change in model layer 2 heads, whereas all other decreases in stream and canal recharge produce little change in head. The model is relatively insensitive to changes in spreading area recharge, addition of precipitation, and changes in evapotranspiration.

Relative location of wells used in the analysis and recharge areas is important when interpreting sensitivity analysis results. For example, effects of spreading area recharge may be localized and few, if any, indicator wells would be affected.

The observation that the model is sensitive to changes in total recharge but insensitive to changes in individual recharge components requires further interpretation. Changing individual parameter recharge does change the amount of recharge from that component, but affects the total amount of recharge very little. Changes in the total recharge for individual components are presented in Appendix A. These can be compared with values from the table for total recharge. For example, if spreading area recharge is

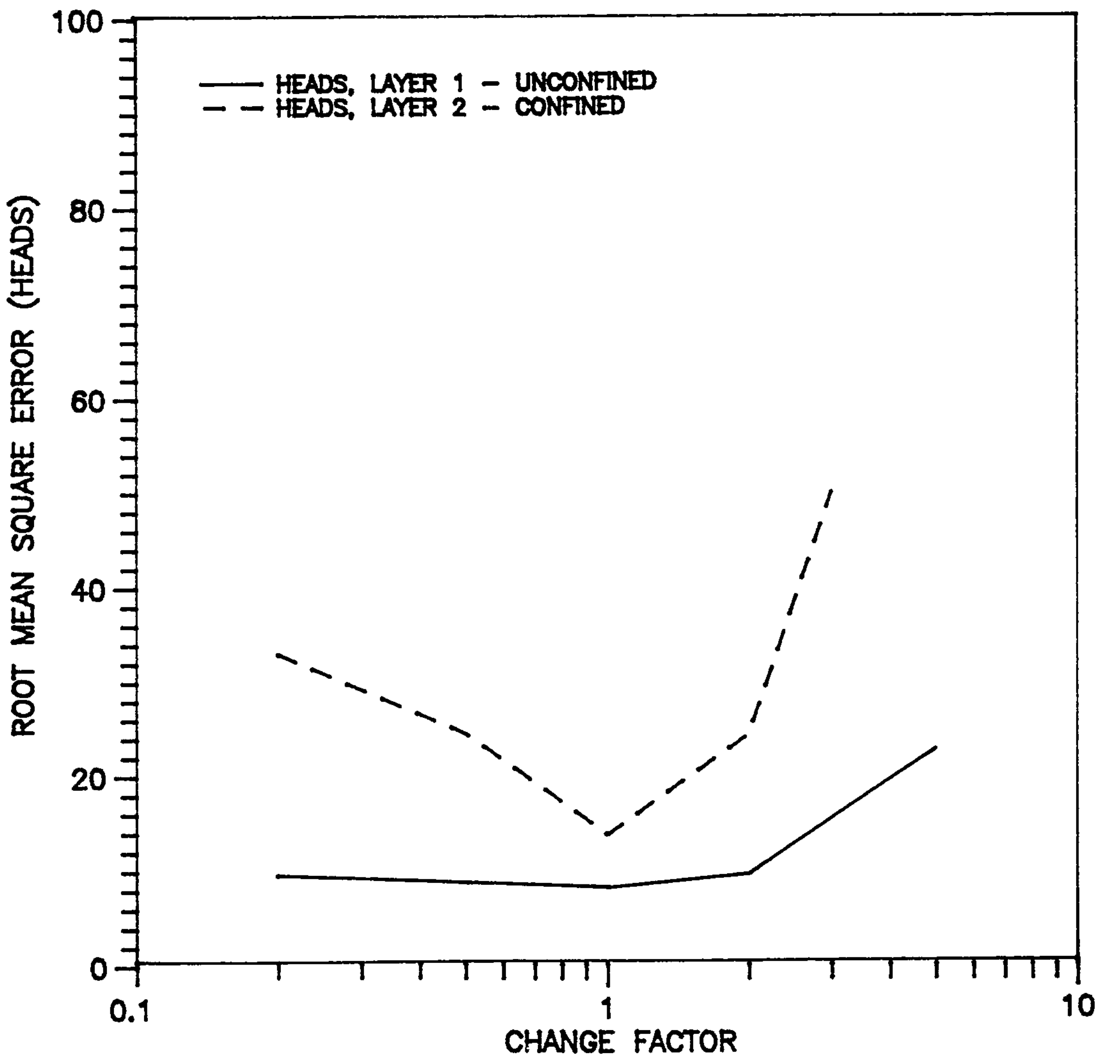


Figure 6.7. Sensitivity Analysis - Stream Recharge.

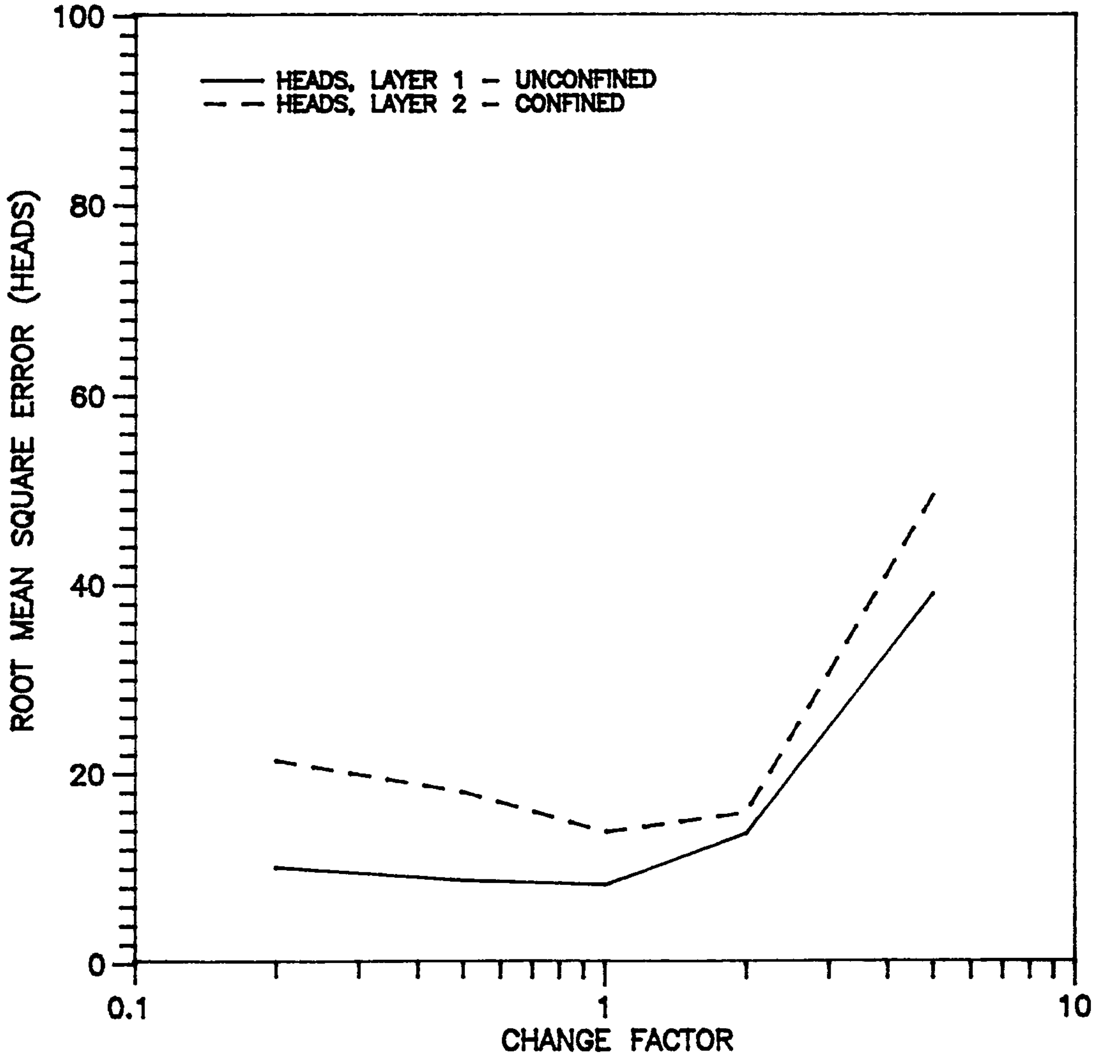


Figure 6.8. Sensitivity Analysis - Canal Recharge.

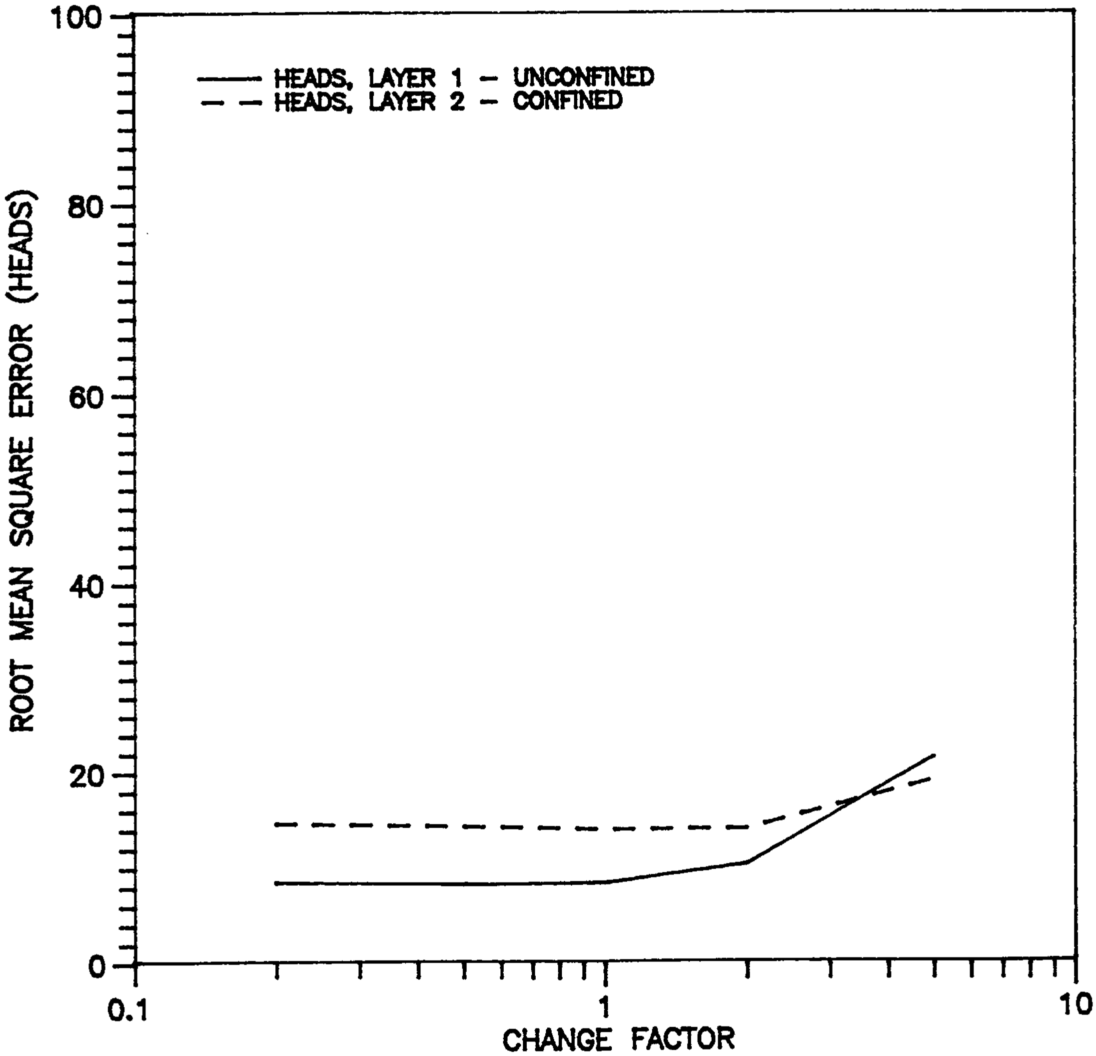


Figure 6.9. Sensitivity Analysis - Spreading Area Recharge.

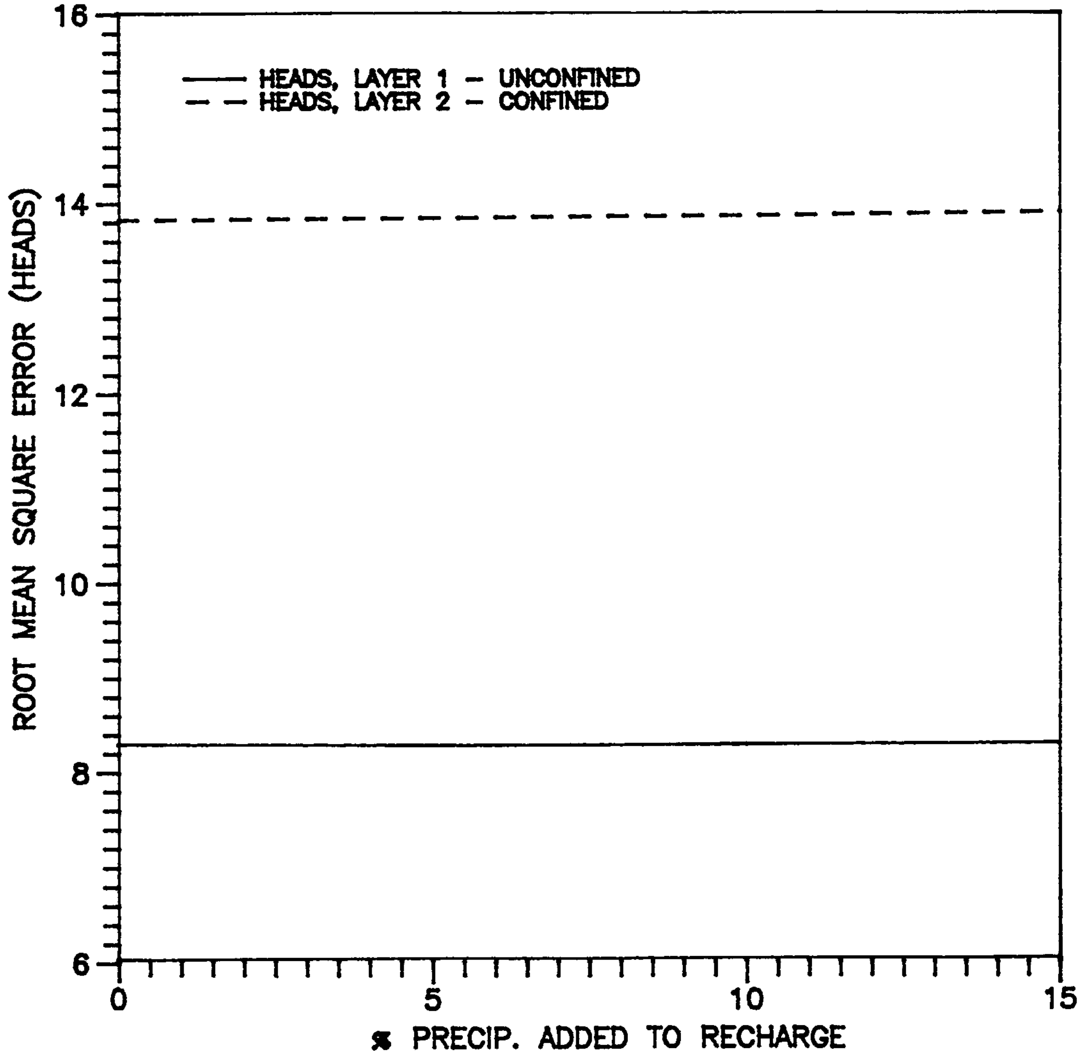


Figure 6.10. Sensitivity Analysis - Precipitation.

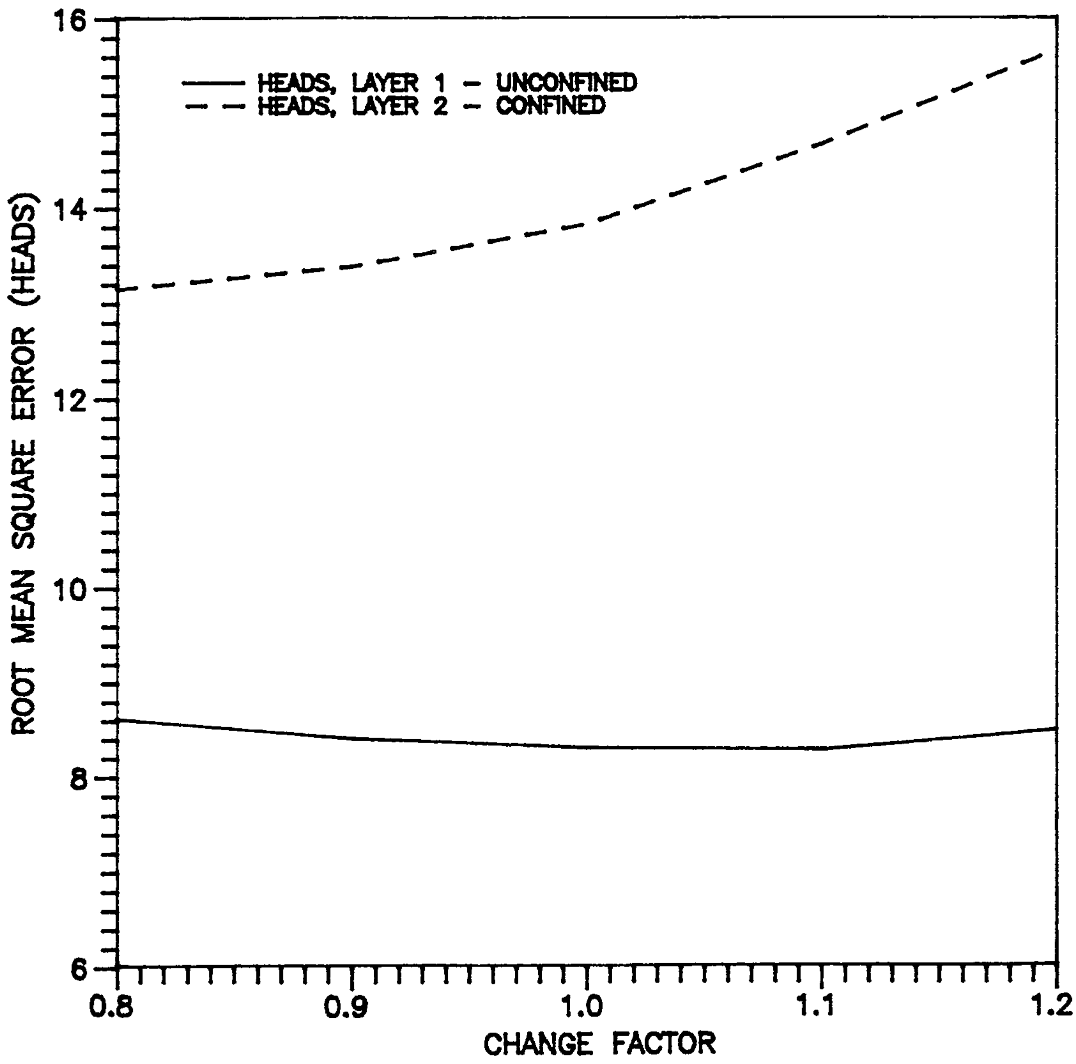


Figure 6.11. Sensitivity Analysis - Evapotranspiration.

doubled, the total recharge is increased by only 4,272 acre-feet or a 14.59 percent change. This corresponds with a total recharge change factor of 1.32.

CHAPTER 7

PREDICTIVE SIMULATION

Water level changes are often caused by a combination of events occurring at the same time. Determining the effect of these various components is difficult at best. Numerical models offer flexibility to analyze various pumping and recharge scenarios, separate simultaneous events, and analyze the resulting water level changes - a form of hydrograph analysis.

Analysis Description

In an effort to separate the water-level response due to low runoff from high pumping, three simulation runs were made:

(1) transient pumping and transient recharge (pumping and recharge that occurred during the transient simulation period, as reported by Hutchison and Radell (1988) and Hutchison (1988);

(2) steady-state pumping (flowing well production only, repeated for each stress period) and transient recharge; and

(3) transient pumping and steady state recharge (average annual recharge repeated for each stress period).

The first transient run simulated "true" conditions over the 29 stress periods. The simulated heads for the model area were compared to the actual heads in known wells to calibrate the transient model.

The second model run simulated what would have happened in the Bishop Basin had there been no groundwater pumping. It used the actual recharge file for the period based on historic data. It included only the production of flowing wells in the model area.

The final model run isolated the effect of pumping with no influence from wet or dry years. Actual pumping that occurred over the period was coupled with average annual recharge (repeated each stress period).

Results and Discussion

Simulated hydrographs for 48 indicator wells were produced for each model run. Results were plotted together for each well and are presented in Appendix B. Four representative hydrographs, two for each model layer, are discussed in detail in this section. In order to show the range of runoff variation, a summary is presented in Table 7.1.

Model Layer 1 - Unconfined

Observation Well 489T is located on the valley floor east of Bishop, away from well fields or any production

Table 7.1. Transient Simulation Runoff

Runoff Year	Percent of Normal
1970-71	92
1971-72	85
1972-73	74
1973-74	117
1974-75	112
1975-76	95
1976-77	62
1977-78	55
1978-79	150
1979-80	98
1980-81	147
1981-82	87
1982-83	162
1983-84	185
1984-85	118

wells. The simulated hydrographs are presented in Figure 7.1. Water level is only minimally affected by transient pumping when actual simulation runoff is used. A maximum difference of 3 feet is observed between the pumping and non-pumping hydrographs.

Effects on water level due to recharge are evident when comparing the hydrograph that uses actual recharge with the hydrograph that uses average annual recharge. Water level declines in the beginning of the simulation period and levels out with only slight increases in the 1980's when the benefit of above-normal runoff is removed.

Observation Well 425T is located directly down-gradient from a string of pumping wells in the Big Pine well field. Water level in this well is affected by transient pumping, or actual pumping that occurred during the simulation period (Figure 7.2). Differences between the transient pumping and steady state pumping hydrographs using transient recharge vary as much as 32 feet. Coupled with above-normal runoff, as in 1973-75 and again in the 1980's, is decreased pumping. Water level increases occur in the transient pumping-transient recharge hydrograph during these periods, but never recover to the level which occurred at the beginning of the simulation period.

The significance of recharge is also illustrated by simulated hydrographs of this well. Because pumping is

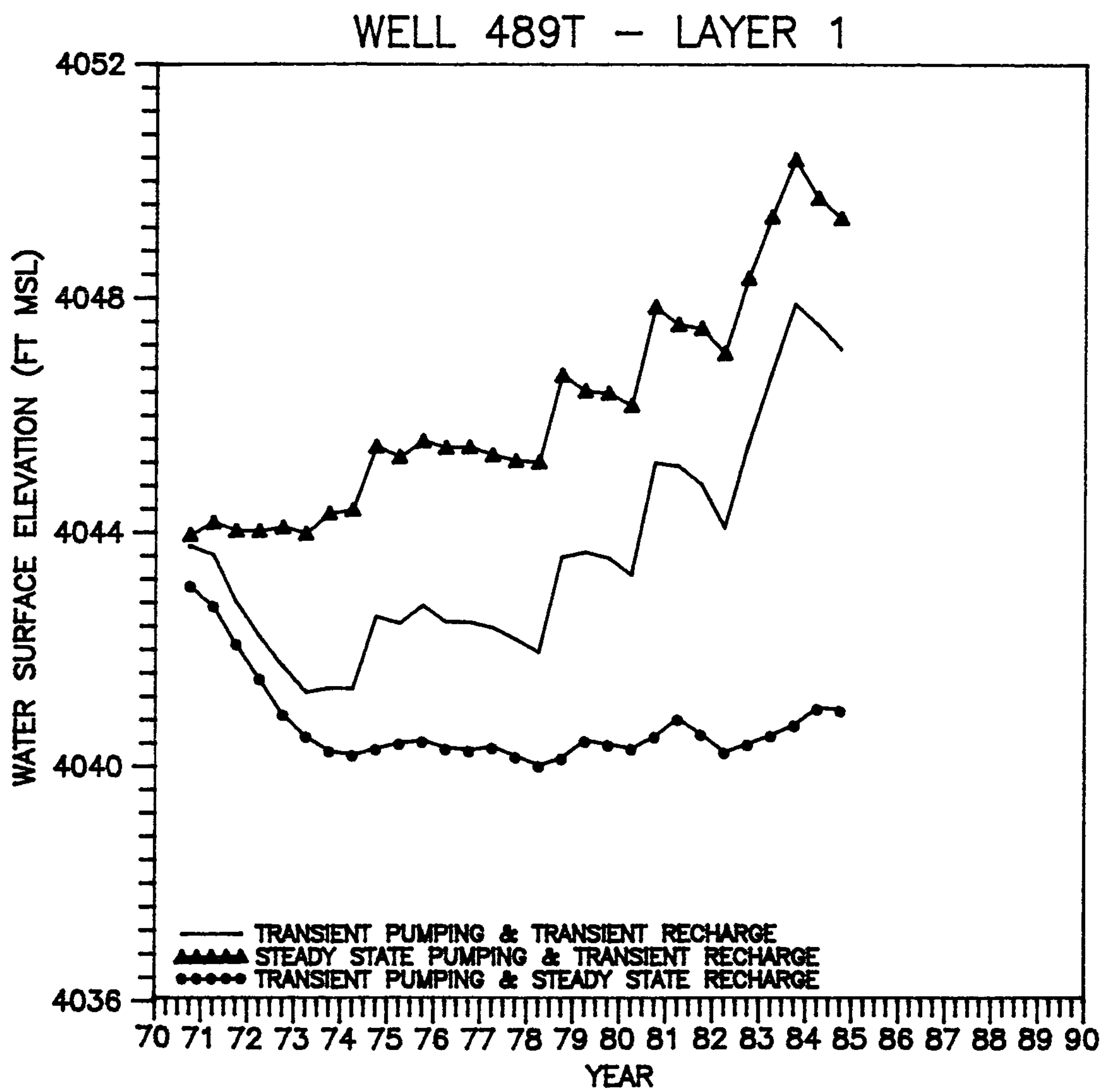


Figure 7.1. Simulated Hydrographs - Well 489T.

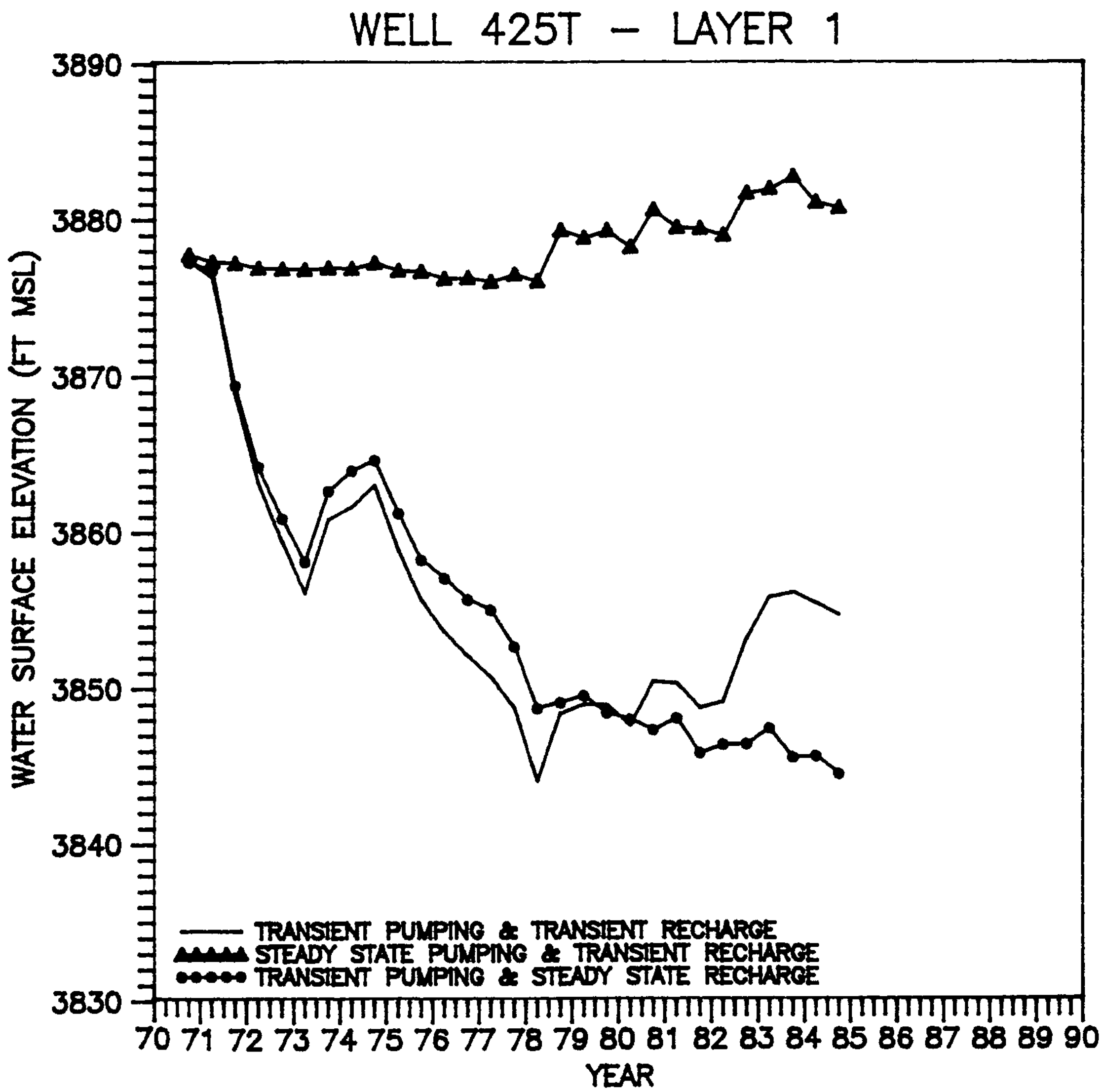


Figure 7.2. Simulated Hydrographs - Well 425T.

decreased in wet years, water level increased in 1973-75. The following three years had below-normal runoff resulting in increased pumping. Water level once again decreased. Even though pumping was reduced in the early 1980's, water level did not recover. Continued heavy pumping occurred for the nearby Fish Springs Hatchery and may have affected this observation well.

In general, water levels in the unconfined aquifer are affected by pumping in the confined aquifer when they are within or adjacent to well fields or pumping wells. Above-normal runoff is extremely important in water table recovery. Although water levels do not fully recover in wells affected by pumping, above-normal runoff years and the related reduction in pumping tend to buffer the effect on the water table.

Model layer 2 - Confined

Although there are both production and observation wells in the confined zone of the study area, to be consistent with the previous section, representative observation wells will be contrasted in this section as well.

Well 271 is located in the Laws well field. Several irrigation canals and groundwater spreading areas are situated nearby. The simulated hydrographs are presented in

Figure 7.3. The effects of pumping are evident when contrasting the two hydrographs depicting transient recharge. The transient pumping-transient recharge water level is always lower than that resulting from steady-state pumping and transient recharge, and may vary as much as 40 feet during periods of below-normal runoff. Above-normal runoff and the associated reduction in pumping, as well as contribution from the irrigation canals and groundwater spreading areas, have resulted in water level recovery. At the end of the simulation, following a series of wet years in the 1980's, the difference in water level between the pumping and non-pumping hydrographs was recorded as only 14 feet.

Once again, the hydrograph depicting average annual recharge illustrates the importance of above-normal recharge to the recovery of water levels. Some recovery is evident in the wet periods due to the reduction in pumping, but is never as great as shown in the hydrograph that incorporates actual recharge values.

Well 121 is located southeast of Bishop directly adjacent to the Owens River. It is an example of a well in the confined zone that is not affected by pumping. Simulated hydrographs are presented in Figure 7.4. Two factors contribute to this phenomena: no pumping wells are nearby and the river is a constant source of water. The

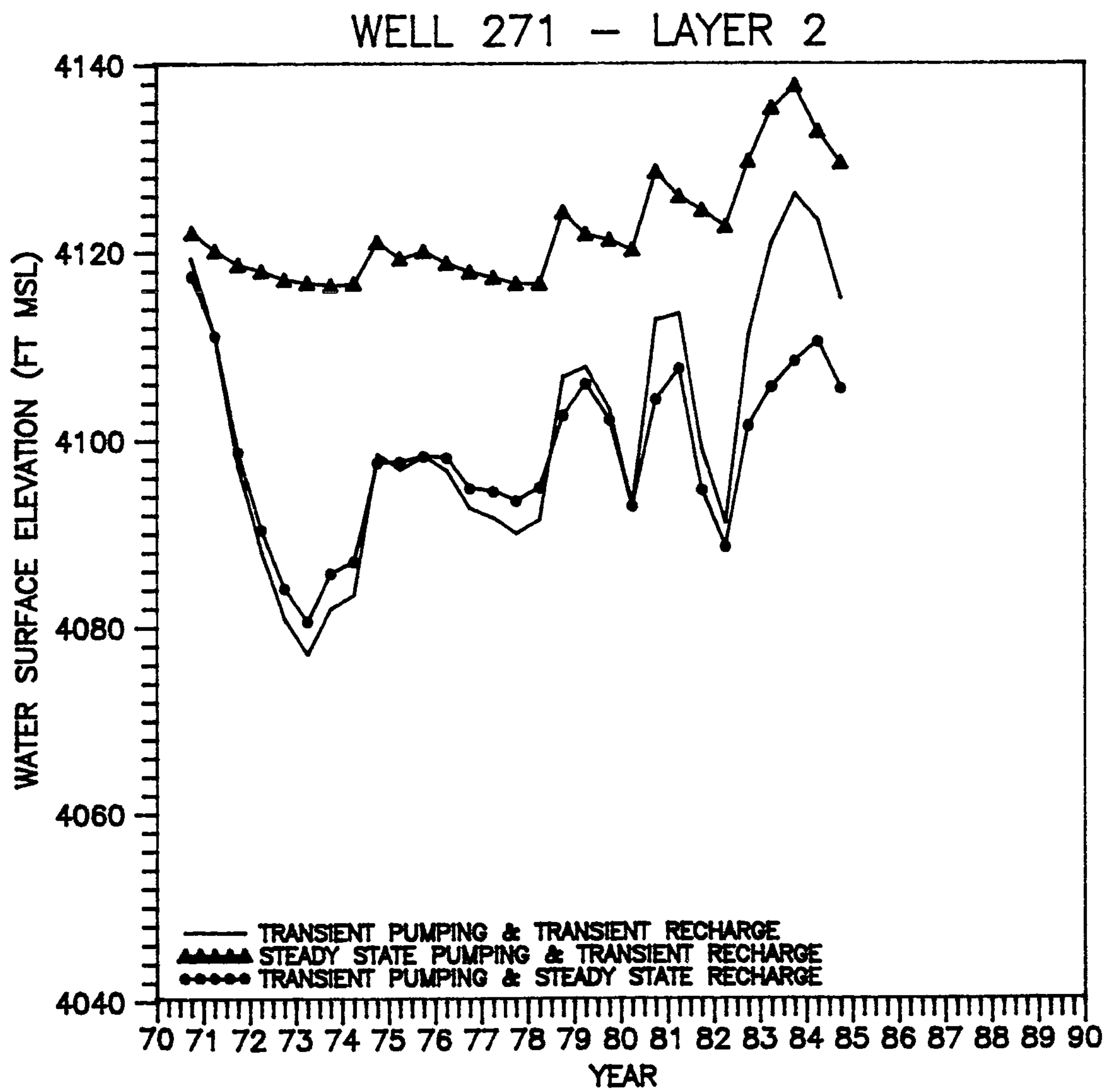


Figure 7.3. Simulated Hydrographs - Well 271.

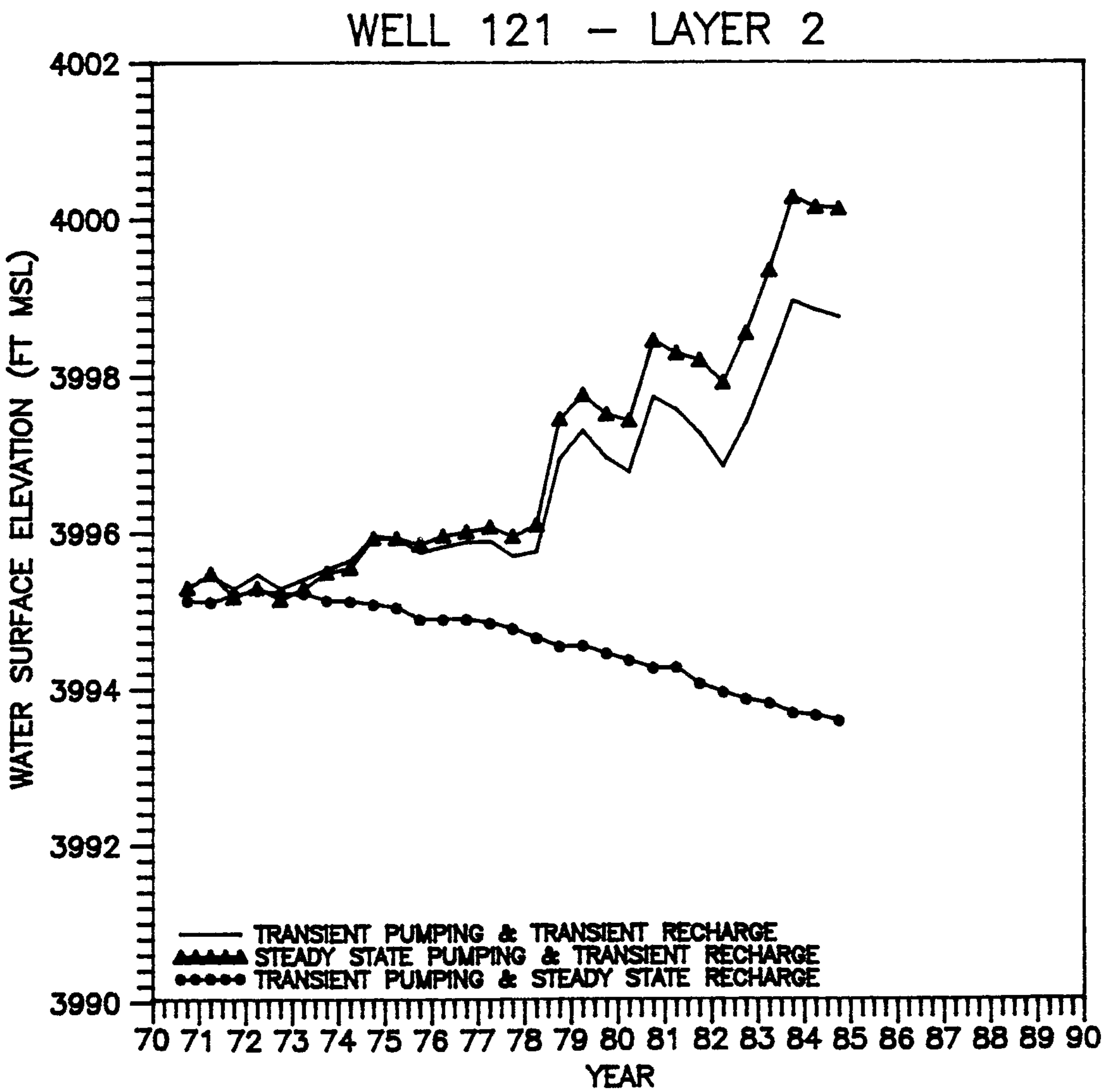


Figure 7.4. Simulated Hydrographs - Well 121.

resulting difference in water level due to pumping shown in Figure 7.4 is never greater than 1.25 feet, and in both cases water levels are higher at the end of the simulation than at the beginning.

Water level declines throughout the simulation in the steady-state recharge case. However, water level at the end of the simulation in only 5 feet lower than the level using transient recharge. This illustrates that the river is providing some recharge to the well.

Generally, pumping affects water levels in the confined zone. Wells located near the river, however, are not affected by pumping because water is supplied to these wells by the river. If recharge is held constant and there is high pumping, water levels in the entire area are drawn down over time while baseflow is reduced in the river.

Water levels recover in periods with above-normal runoff due to increased recharge, as well as reduced pumping. Recovery may be evident in some average annual recharge hydrographs and attributed to only the reduction in pumping.

Simulated Water Budgets

The simulated water budgets for the analysis are presented in Table 7.2. There is a net decrease in storage in both simulations that use transient pumping, however, the

Table 7.2. Summary of Simulated Groundwater Budgets. (Acre-feet/year)

	Steady-State	Transient Pumping & Transient Recharge	Steady-State Pumping & Transient Recharge	Transient Pumping & Steady-State Recharge
INFLOW				
Storage	0	22,383	9,842	16,682
Constant Head	2,830	6,006	2,637	6,281
Wells	0	0	0	0
Drains	0	0	0	0
Recharge	74,514	77,779	77,779	74,514
River Leakage	3,793	4,430	4,211	6,086
TOTAL	81,138	110,599	93,470	103,563
OUTFLOW				
Storage	0	20,392	17,182	5,810
Constant Head	2,188	755	2,349	644
Wells	6,796	47,620	6,796	47,620
Drains	14,252	813	14,914	793
Recharge	15,981	1,606	1,606	15,980
River Leakage	42,948	39,401	50,756	32,733
TOTAL	82,137	110,590	93,578	103,580

net decrease is less in the transient recharge case. The amount of water in storage increases in the simulation that uses steady-state pumping.

The two simulations that use transient pumping illustrate that when pumping occurs, heads are drawn down sufficiently to steepen the gradient and increase the amount of groundwater inflow into the model area. The amount of water leaving the area is decreased.

The flow of Fish Springs (drain flow) is nearly zero and baseflow in the river is decreased in both transient pumping cases. In the steady-state pumping-transient recharge case, Fish Springs flow is slightly higher than steady-state and river baseflow actually increases significantly.

Comparison of the water budget values in the three predictive simulations further illustrate that pumping decreases spring flow and river baseflow. Without the benefit of above-normal runoff, these decreases are greater. This comparison also illustrates that net storage is decreased in the pumping simulations, as well as outflow from the study area. In the non-pumping simulation, river baseflow and storage increase.

CHAPTER 8

SUMMARY AND CONCLUSIONS

Groundwater models, if used appropriately, are useful tools in water management decisions. They can provide information for assessment on a regional basis and lead to more detailed and comprehensive studies.

Long-standing conflict over the export of Owens Valley water to Los Angeles has led to the development of three-dimensional groundwater models by USGS, Inyo County, and LADWP. This study focused on a sensitivity analysis of the Inyo County model and used this model to evaluate separately the effects of pumping and of low runoff, as well as the combination of the two.

Geologic formation of Owens Valley, a deep alluvial trough, has caused the existence of groundwater under both confined and unconfined conditions. The two zones are separated by clay layers of fluvial and lacustrine origin. Aquifers of the study area are primarily sand and gravel units, but localized volcanic aquifers exist. Surface water is used for irrigation and export to Los Angeles. Groundwater has supplemented these uses and supplied local communities and fish hatcheries. Amount of groundwater exported to Los Angeles was increased after 1970, upon completion of the second aqueduct.

Uncertainty is associated with any numerical model. Sensitivity analysis determines which input parameters exert the most control on the model results. Use of root mean square error evaluates the sensitivity of the Bishop Basin model in this study. The model results are most sensitive to changes in transmissivity when they occur in the two model layers, total recharge, and increases in stream and canal recharge. It is insensitive to changes in evapotranspiration, vertical conductance, flowing well production, and addition of recharge from precipitation.

Three simulations were made to evaluate the effects of pumping, low runoff or drought, and the combination of the two. Actual recharge that occurred during the transient simulation was coupled with actual pumping to simulate "true" conditions over the period. Actual recharge, together with only flowing well production, has simulated conditions without any groundwater pumping. Finally, to remove the effect of wet or dry years, average annual recharge and actual pumping were used.

These predictive simulations have illustrated that pumping from the confined zone affected water levels in both the confined and unconfined aquifers in the vicinity of production wells. Water levels were affected to a lesser extent by pumping in areas away from well fields. This is apparently due to capture of river baseflow and a resultant lowering of regional water levels. Water level recovery is most complete in above-normal runoff years, but remains depressed when there is not sufficient recharge to the groundwater system.

This study is part of the overall modeling effort of the Inyo County Water Department. The ultimate goal of the county is to protect the environment of Owens Valley. This is in direct conflict with the needs of the city of Los Angeles. Especially in this, the third dry year, settling differences and agreeing upon a management plan to best achieve the goals of both parties becomes almost impossible. Los Angeles has also developed groundwater models for Owens Valley and as in most dealings with the county, disagreements exist. Both Inyo County and LADWP have developed models separately but somewhat together. In this sense, they can be used as management tools if there is a long-term agreement. However, if there is no agreement, LADWP will use their model results in writing their "final" EIR. In that case, if Inyo County disagrees technically with LADWP's findings and predictions, they will use their model results to challenge the accuracy and adequacy of the EIR.

The water conflict in Owens Valley has been long-standing and emotional. Even if there is technical agreement on how the valley should be managed to best meet the needs of both parties, politics may reign. Some people in the valley feel that Inyo County should go to court and may the best man win (and of course, the county is the best man). Others feel that if there is an agreement, Los Angeles will continue to fund research and provide enhancement/mitigation projects for the valley. Just as there is uncertainty in model results, there is uncertainty as to the outcome of the negotiations.

Water has been and always will be a hot topic and supply problems will only get worse as long as major cities continue to grow. Inyo County and the Owens Valley have provided examples to other California counties, states, and even Japan on how to handle (or not to handle) water export issues. Many await the outcome of the agreement negotiations to know how to proceed with their exporting endeavors.

APPENDIX A

RMSE DATA

Transmissivity.
(Layer 1 changed)

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)
.1	20.97	22.06
.2	16.50	18.77
.5	11.13	13.94
1.0	8.29	13.82
2.0	7.53	24.11
5.0	9.27	42.50
10.0	9.92	50.23

Transmissivity.
(Layer 2 changed)

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)
.1	20.59	76.96
.2	16.00	55.68
.5	10.52	25.19
1.0	8.29	13.82
2.0	8.31	34.80
5.0	10.10	52.49
10.0	11.72	62.74

Transmissivity.
(Both layers changed)

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)
.1	94.88	333.43
.2	44.82	149.36
.5	15.66	40.20
1.0	8.29	13.82
2.0	8.69	41.11
5.0	10.85	57.08
10.0	12.49	65.83

Vertical Conductance.

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)
.1	13.48	15.59
.5	11.47	14.18
1.0	8.29	13.82
2.0	7.39	14.55
10.0	7.41	14.78

Flowing Wells.

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)
.1	9.27	13.56
.5	8.75	13.62
1.0	8.29	13.82
2.0	8.36	14.61
10.0	63.69	53.18

Total Recharge.

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)	Total Recharge (Acre-ft)	Change in Total Recharge from Steady-State (Acre-ft)	Percent Change
.1	20.43	57.60	5,704	-23,572	80.52
.5	12.05	34.42	16,181	-13,095	44.73
1.0	8.29	13.82	29,276	0	0.00
2.0	20.96	37.62	55,468	+26,192	89.47
10.0	165.35	345.60	264,999	+235,723	805.17

Stream Recharge.

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)	Change in Total Recharge from Steady-State (Acre-ft)	Percent Change
.2	9.66	33.02	-7,939	27.12
.5	8.84	24.56	-4,984	17.02
1.0	8.29	13.82	0	0.00
2.0	9.73	24.45	+9,925	33.90
5.0	22.81	83.76	+39,700	135.61

Canal Recharge.

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)	Change in Total Recharge from Steady-State (Acre-ft)	Percent Change
.2	10.14	21.36	-8,226	28.10
.5	8.72	18.02	-5,320	18.17
1.0	8.29	13.82	0	0.00
2.0	13.67	15.88	+10,245	34.99
5.0	39.02	49.51	+40,980	139.98

Spreading Area Recharge.

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)	Change in Total Recharge from Steady-State (Acre-ft)	Percent Change
.2	8.32	14.49	-3,417	11.67
.5	8.10	14.15	-2,143	7.32
1.0	8.29	13.82	0	0.00
2.0	10.25	13.95	+4,272	14.59
5.0	21.44	19.11	+17,087	58.36

Recharge from Precipitation.

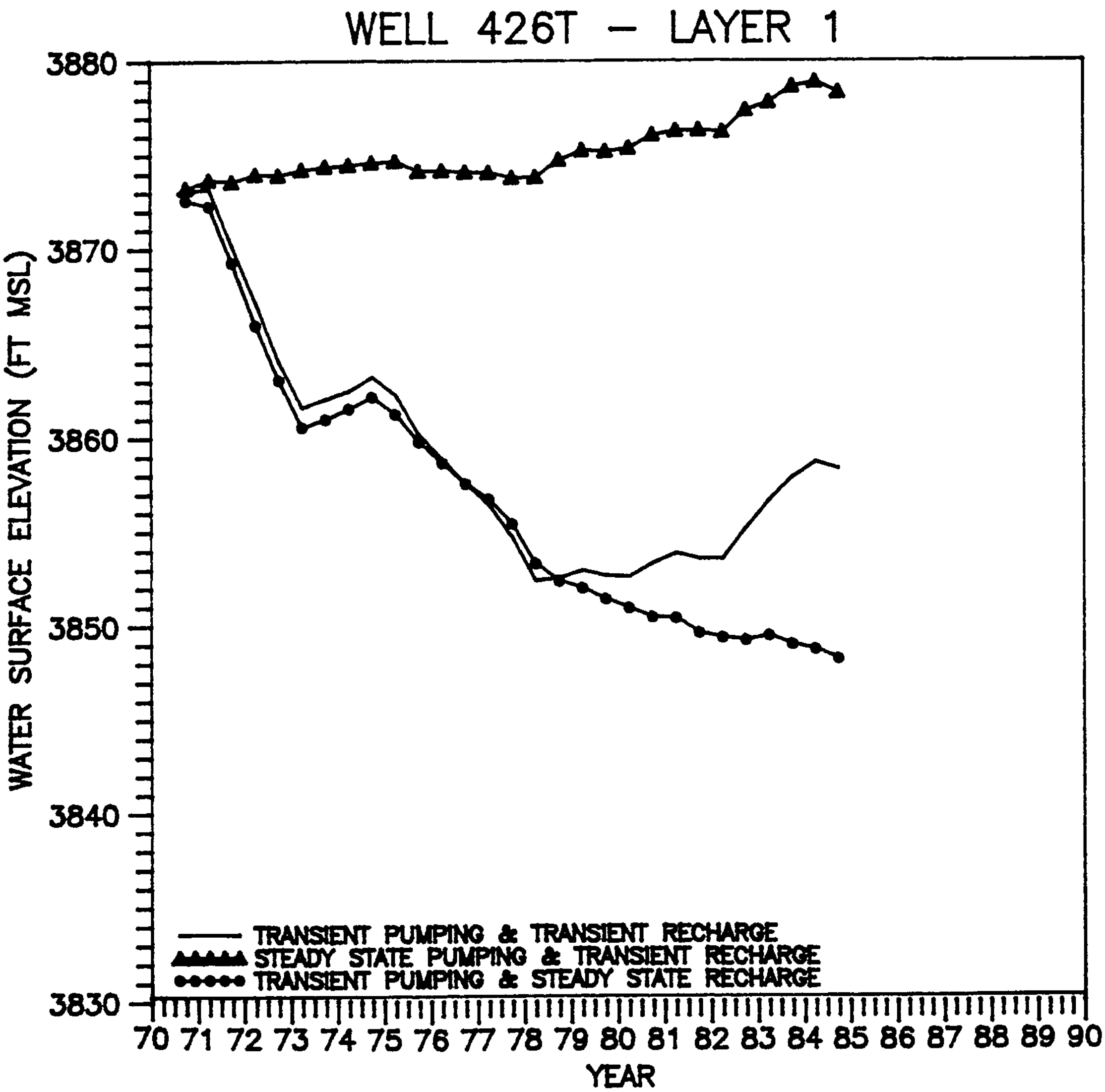
Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)	Change in Total Recharge from Steady-State (Acre-ft)	Percent Change
0	8.29	13.82	0	0.00
5	8.27	13.84	+249	0.85
10	8.28	13.86	+497	1.70
15	8.29	13.90	+746	2.55

Recharge from Changes in Evapotranspiration (ET).

Change Factor	RMSE Layer 1 (Heads)	RMSE Layer 2 (Heads)	Change in Total Recharge from Steady-State (Acre-ft)	Percent Change
0.8	8.60	13.14	+3,357	11.47
0.9	8.39	13.39	+1,760	6.01
1.0	8.29	13.82	0	0.00
1.1	8.27	14.67	-1,976	6.75
1.2	8.48	15.67	-4,157	14.20

APPENDIX B

SIMULATED HYDROGRAPHS FOR INDICATOR WELLS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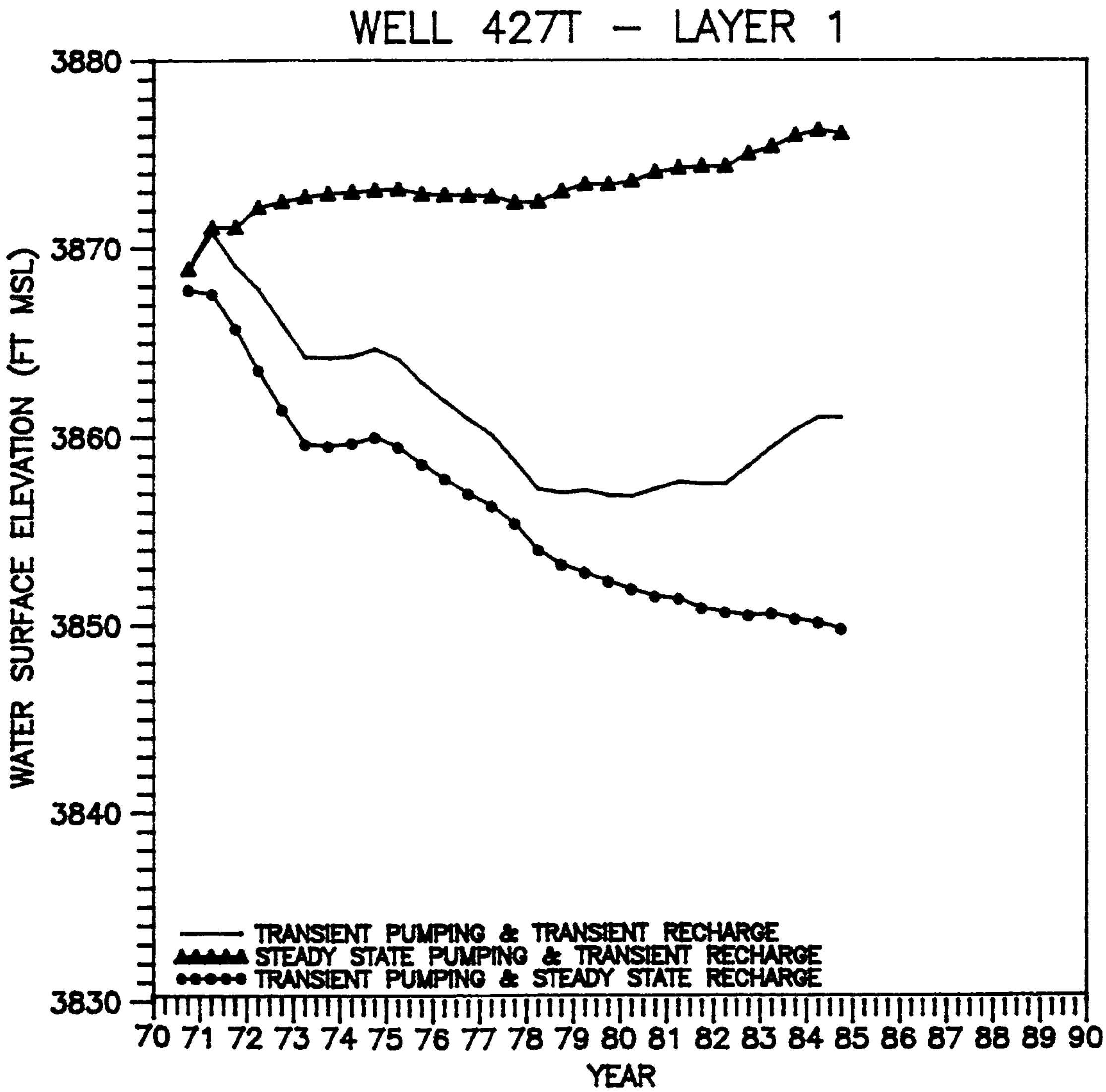
3880
3870
3860
3850
3840
3830
WATER SURFACE ELEVATION (FT MSL)
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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3870
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3850
3840
3830
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YEAR
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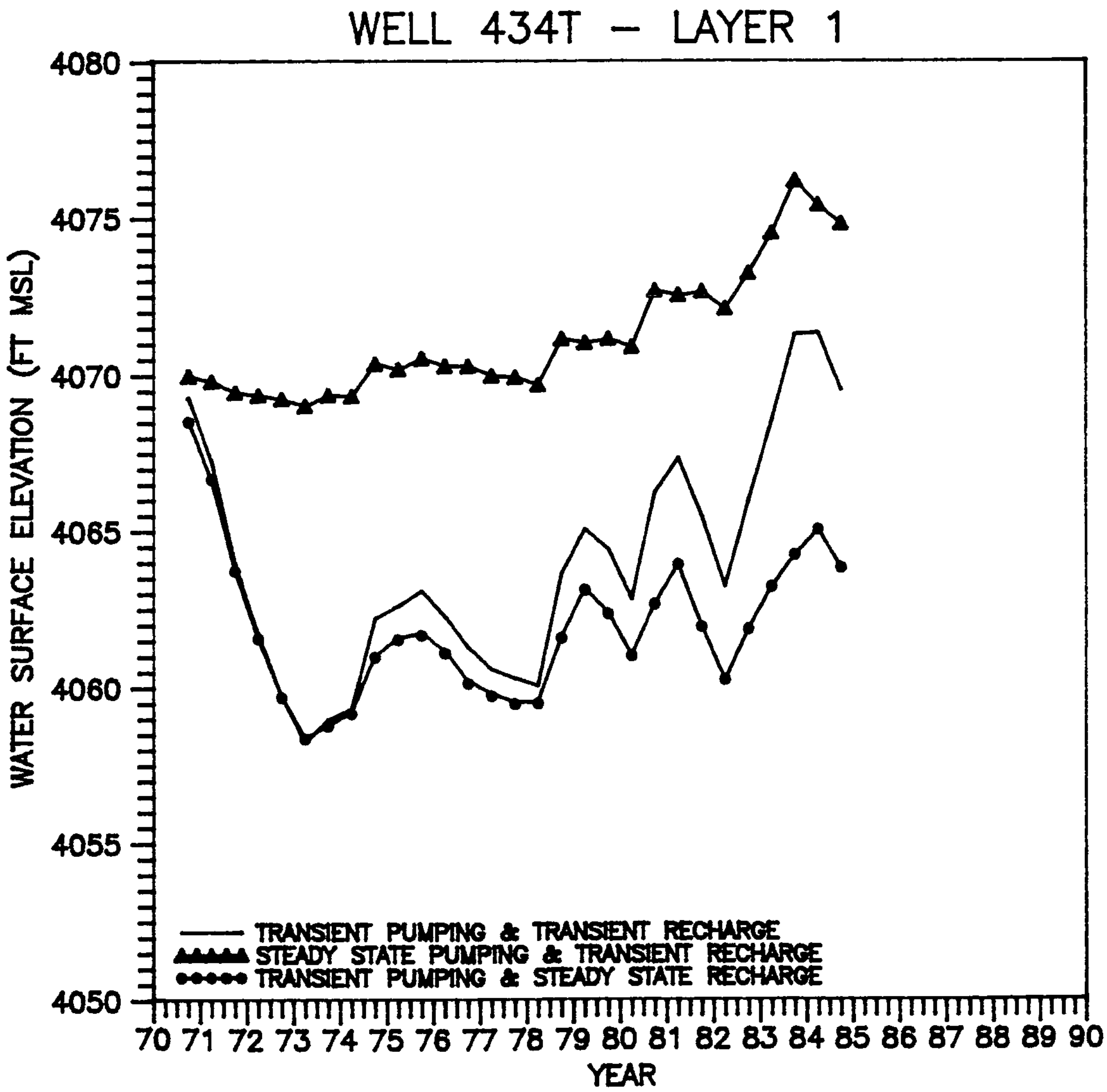
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE



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4075
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4065
4060
4055
4050
WATER SURFACE ELEVATION (FT MSL)
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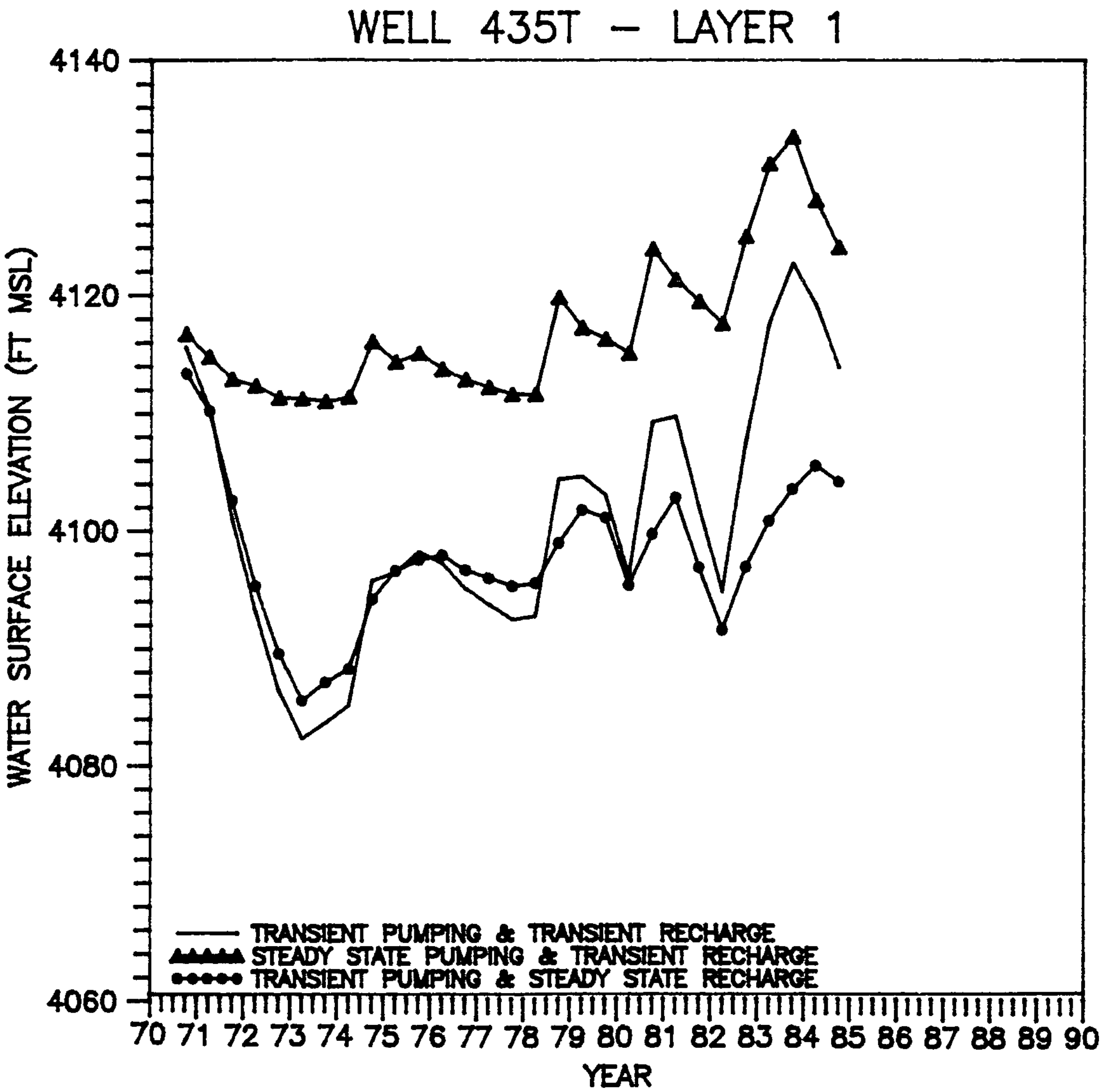
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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4120
4100
4080
4060
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YEAR
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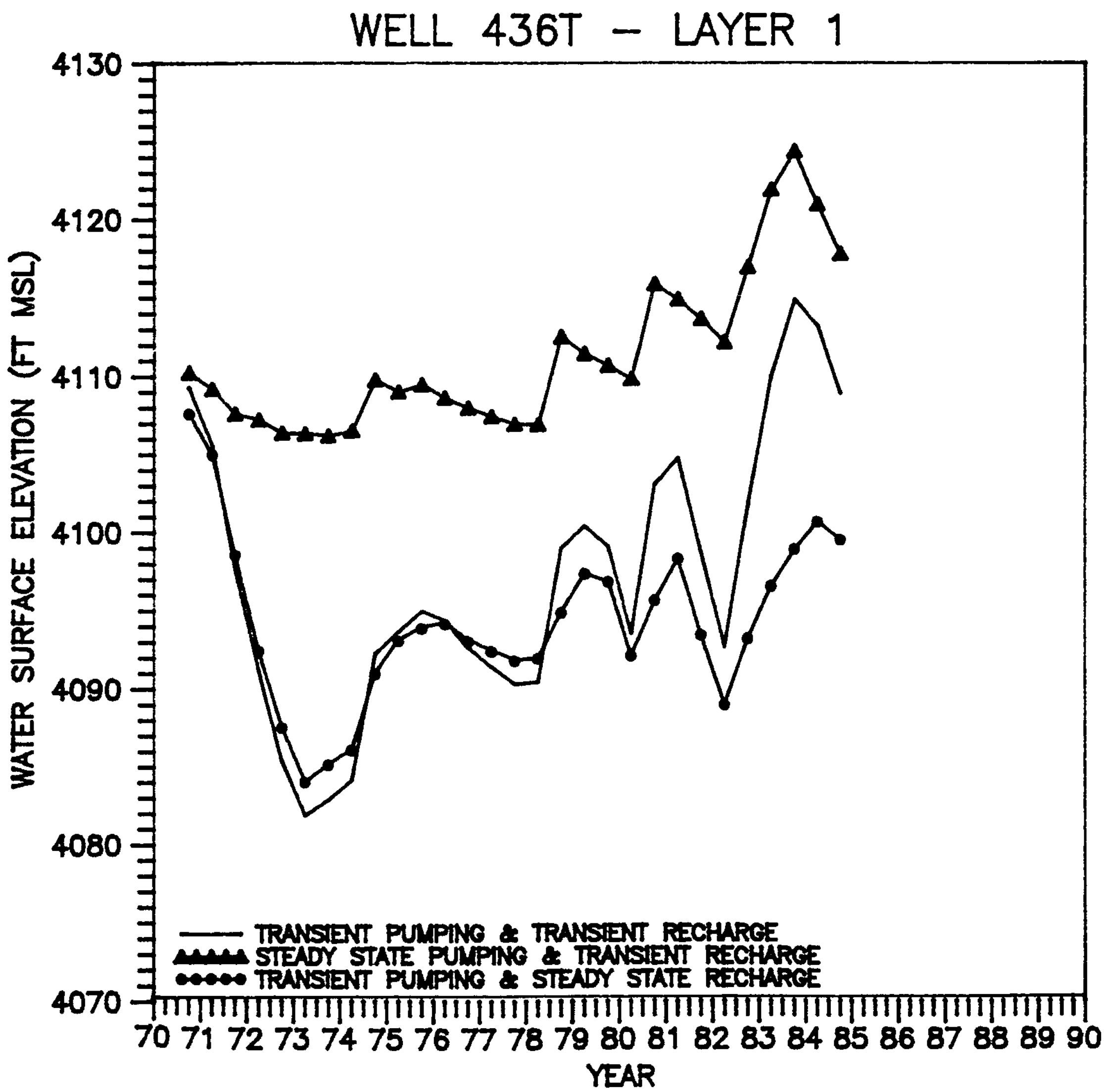
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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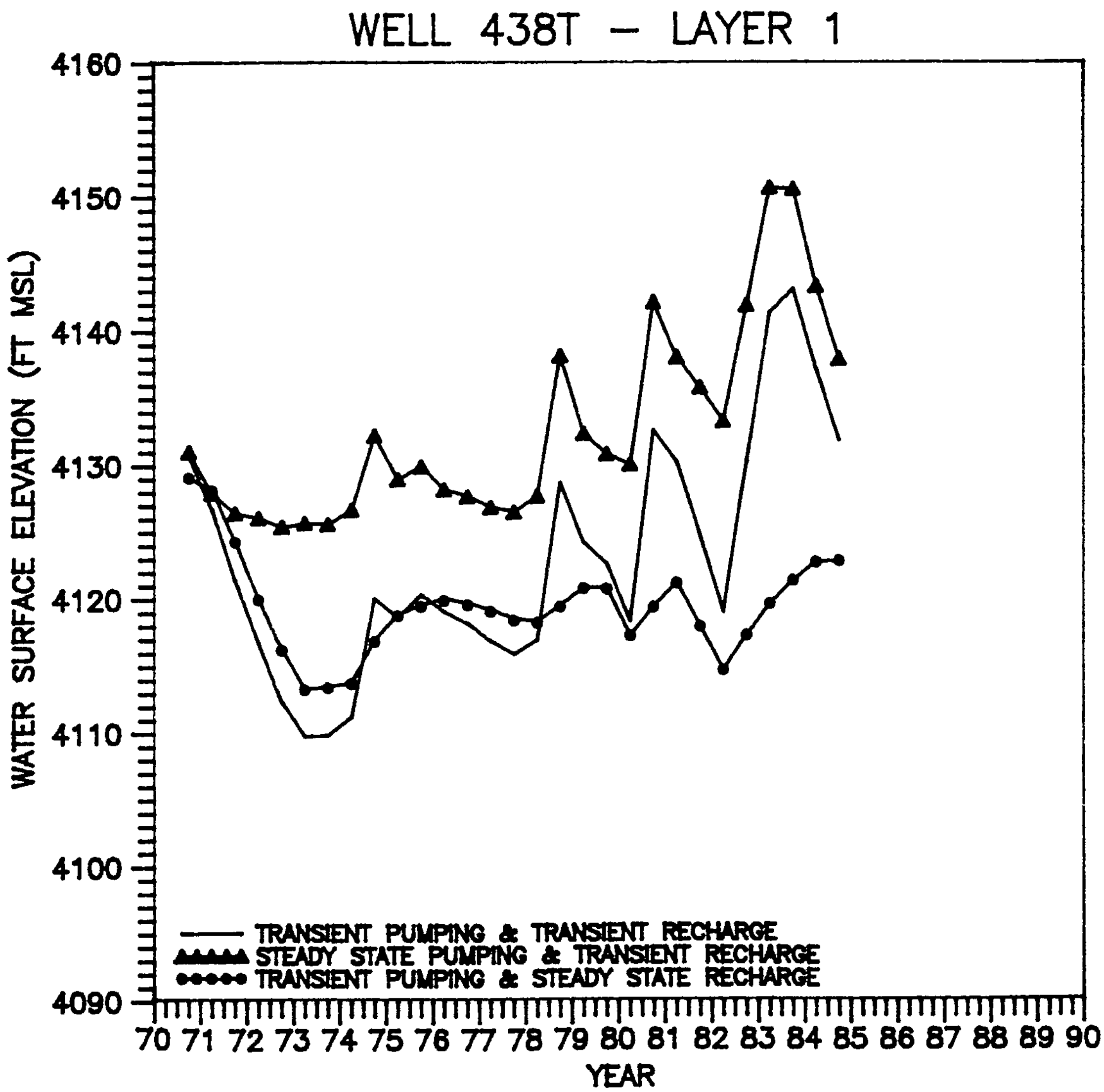
4120
4110
4100
4090
4080
4070
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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WATER SURFACE ELEVATION (FT MSL)
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4150
4140
4130
4120
4110
4100
4090
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
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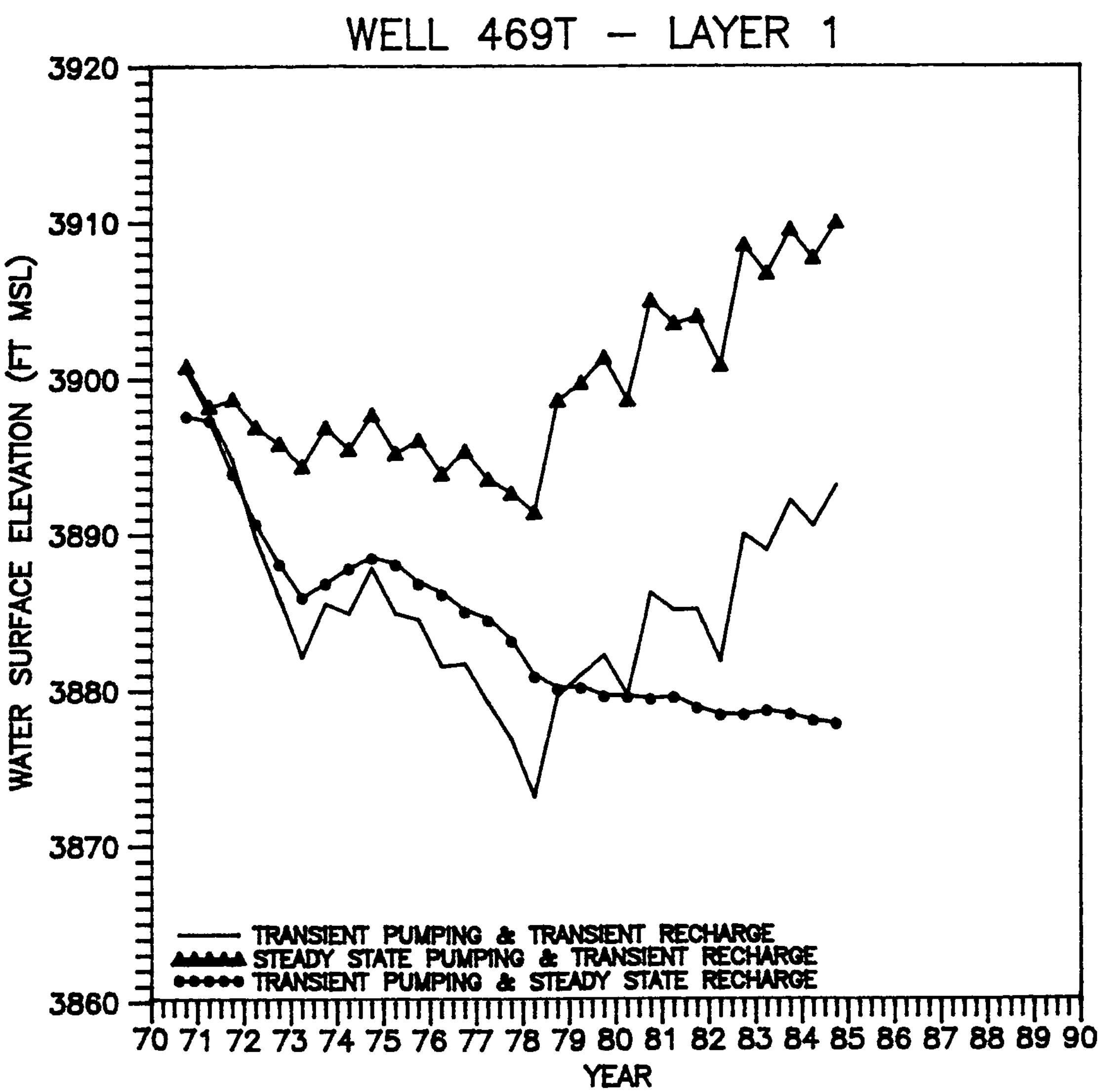
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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3910
3900
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3860
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YEAR
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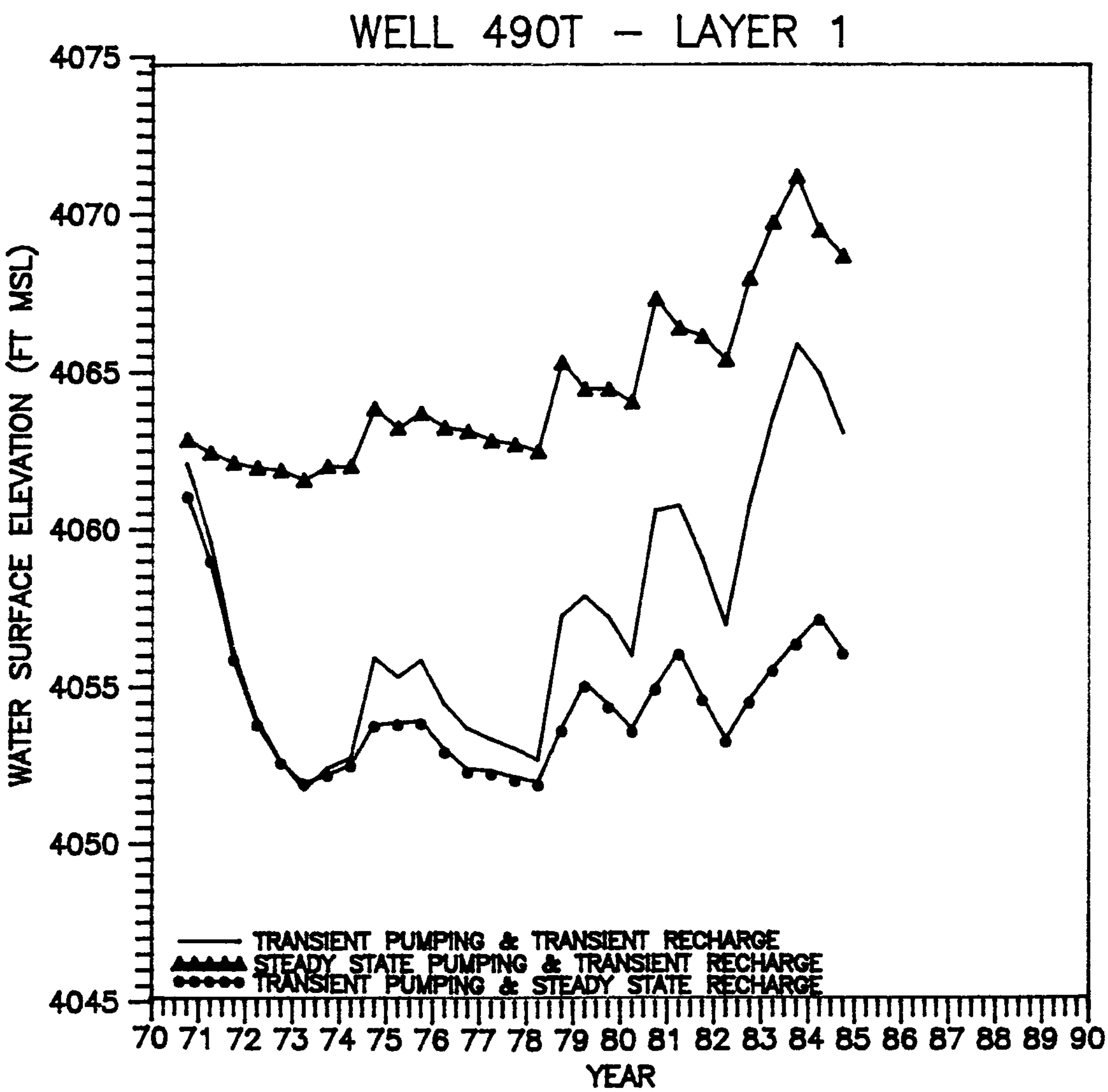
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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4055
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STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
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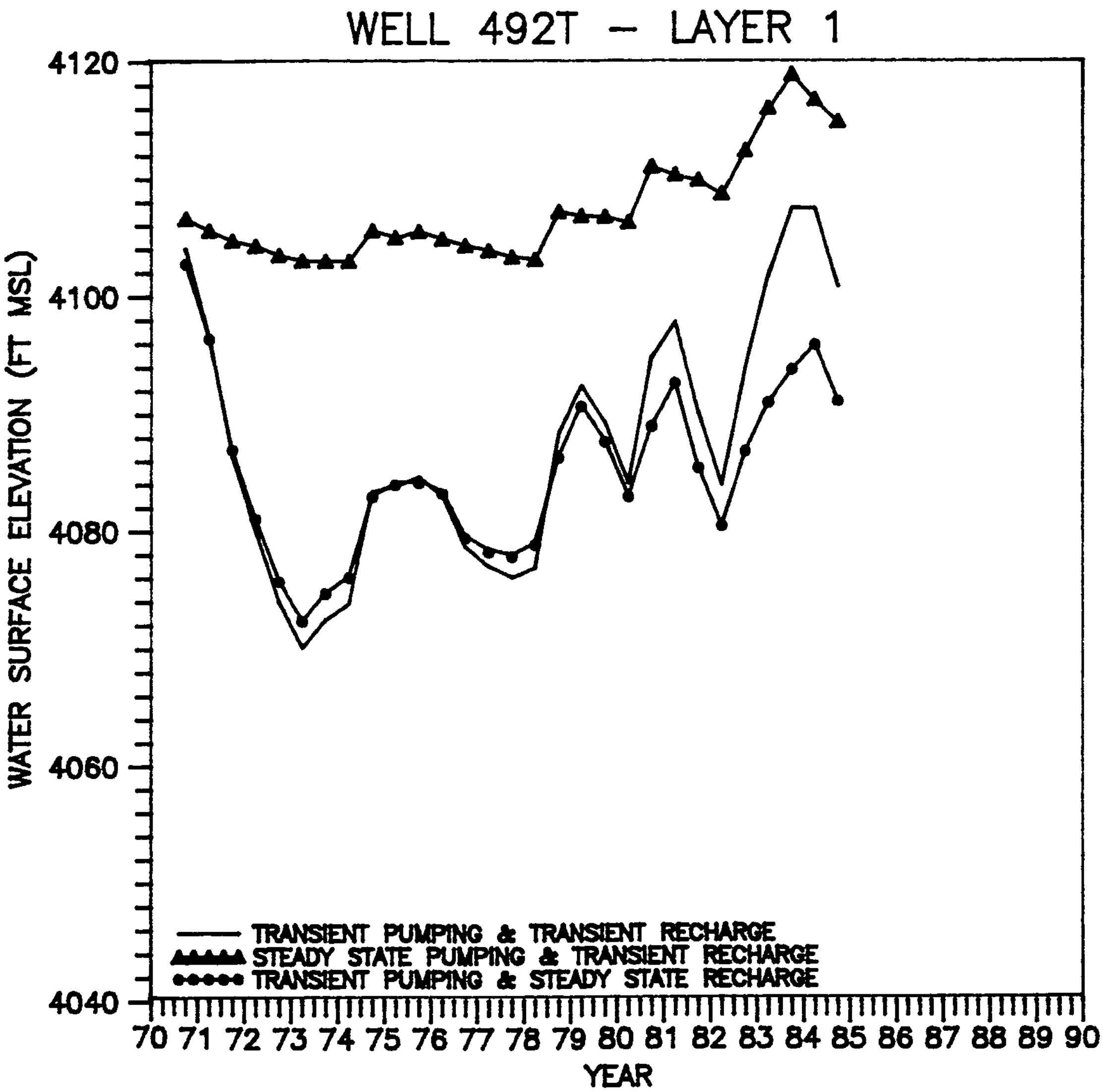
YEAR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4080
4060
4040
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
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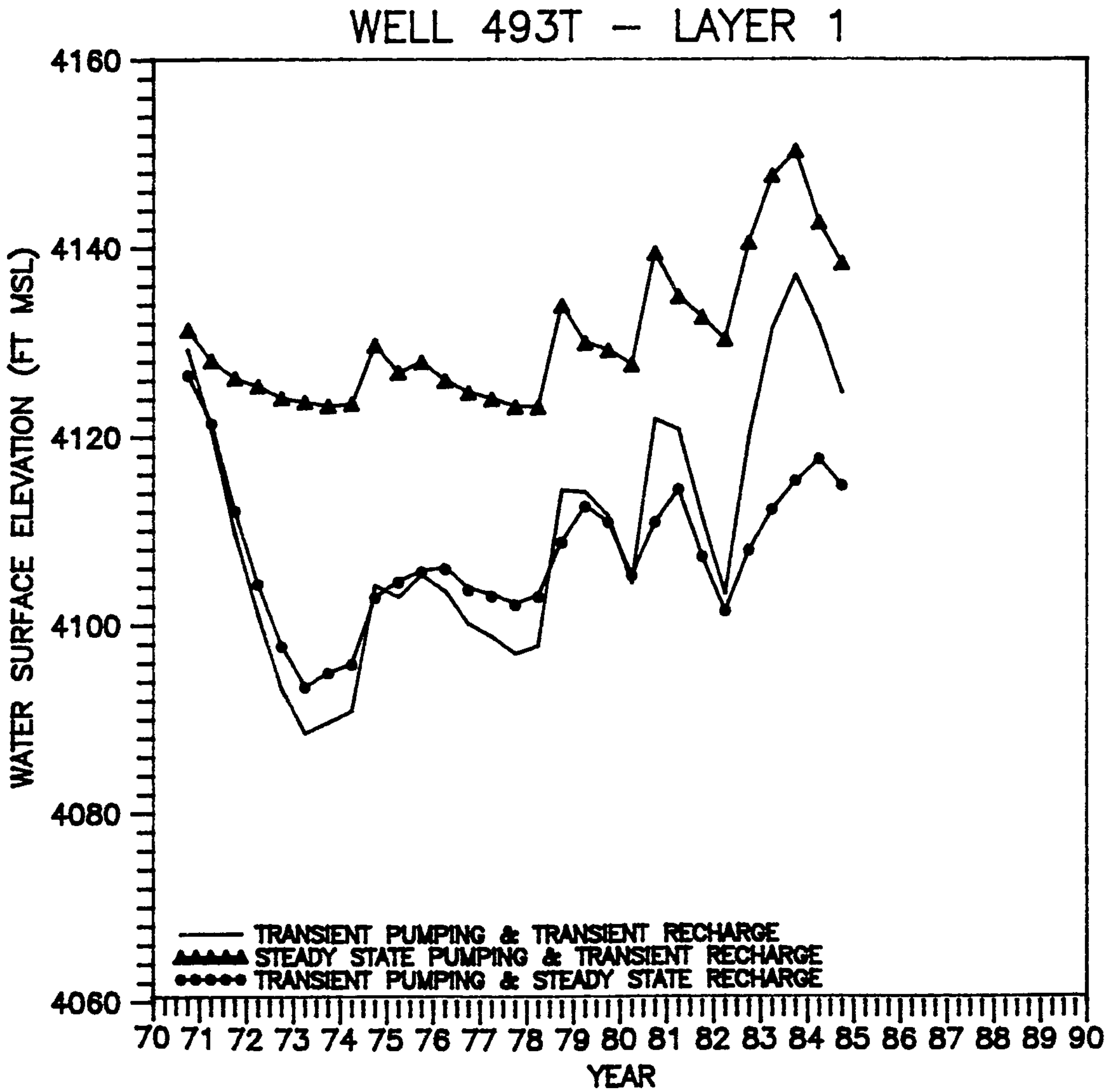
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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4100
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WATER SURFACE ELEVATION (FT MSL)
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TRANSIENT PUMPING & STEADY STATE RECHARGE
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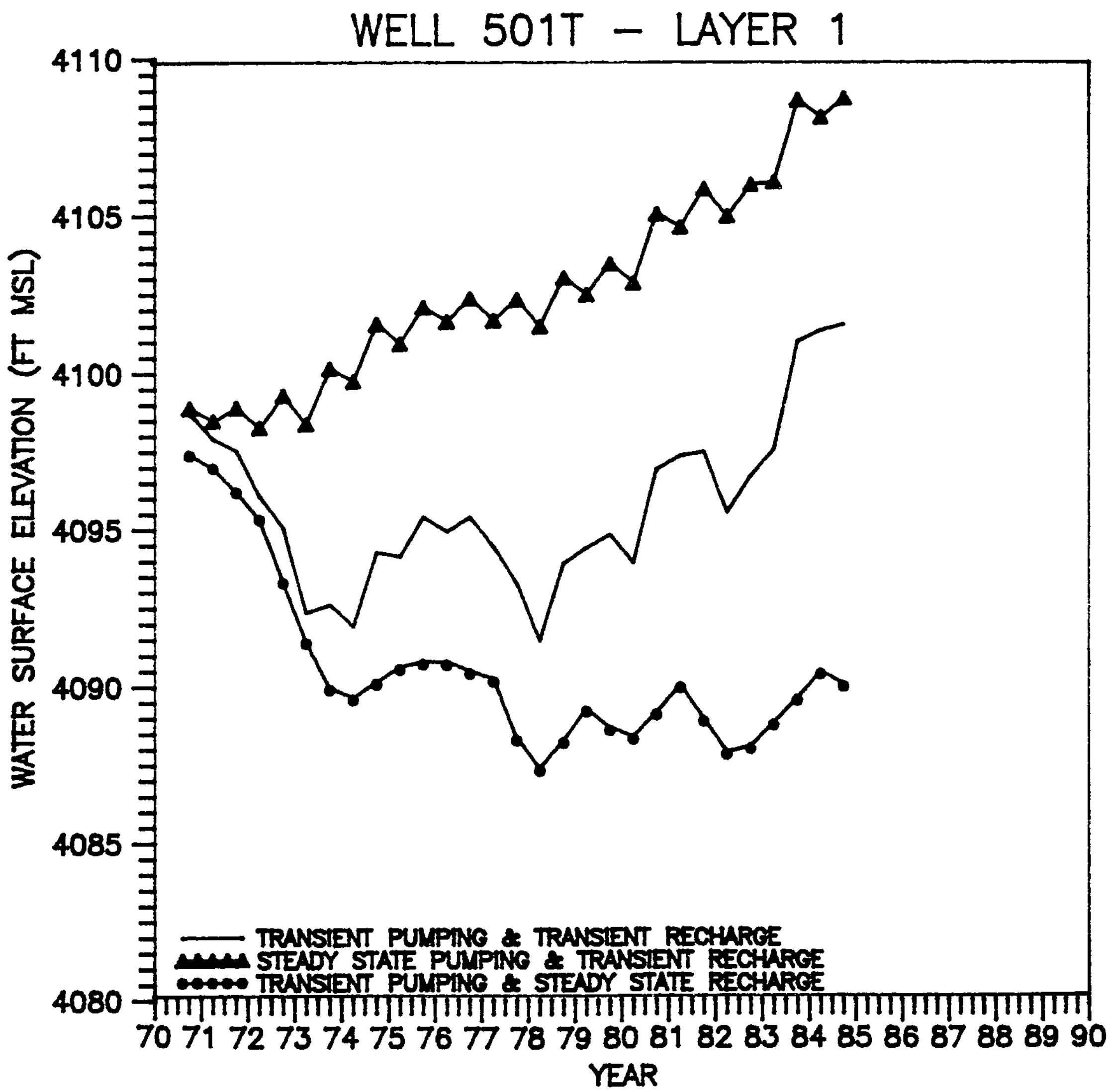
YEAR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4105
4100
4095
4090
4085
4080
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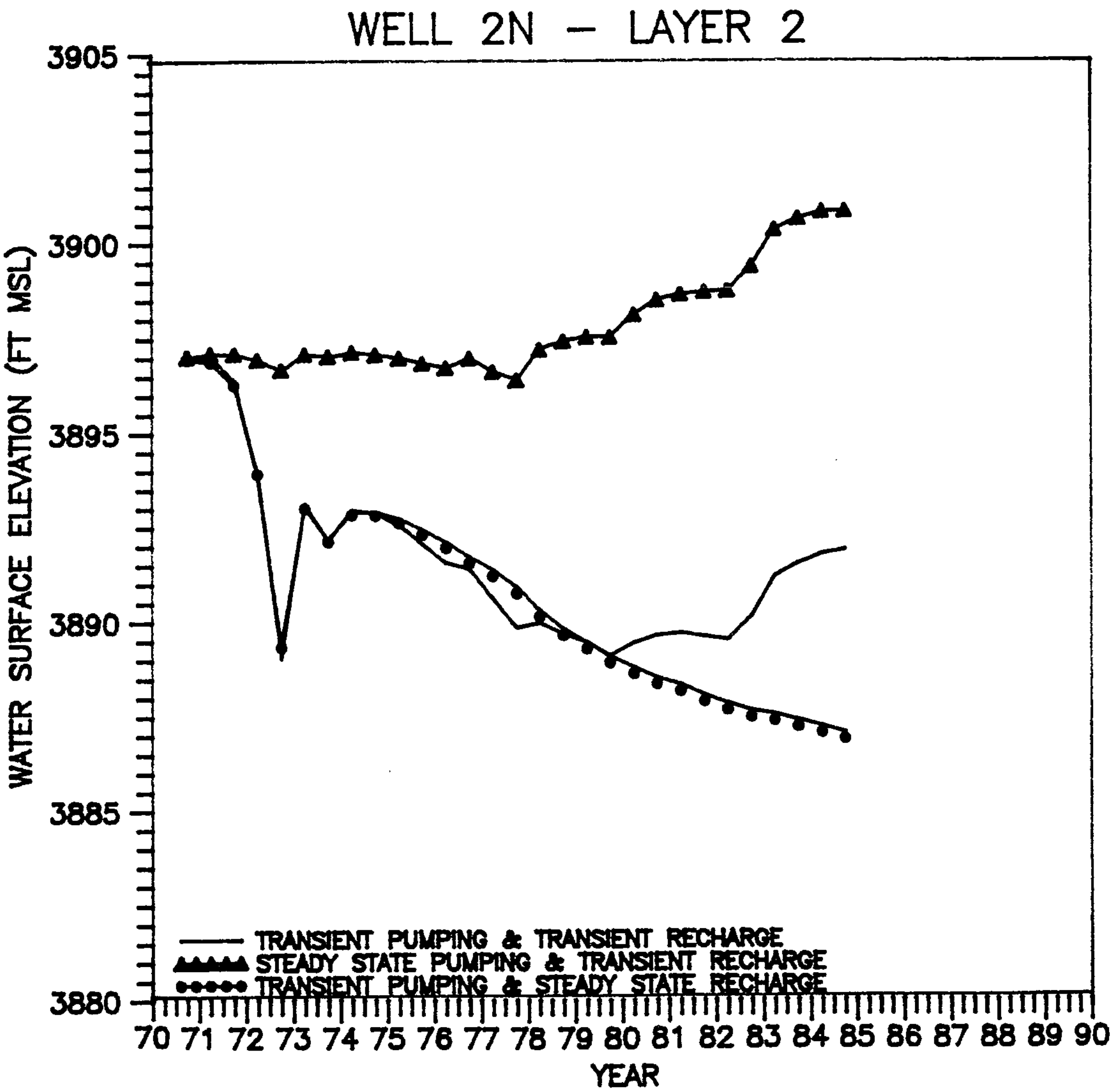
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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3905
3900
3895
3890
3885
3880
WATER SURFACE ELEVATION (FT MSL)
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YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
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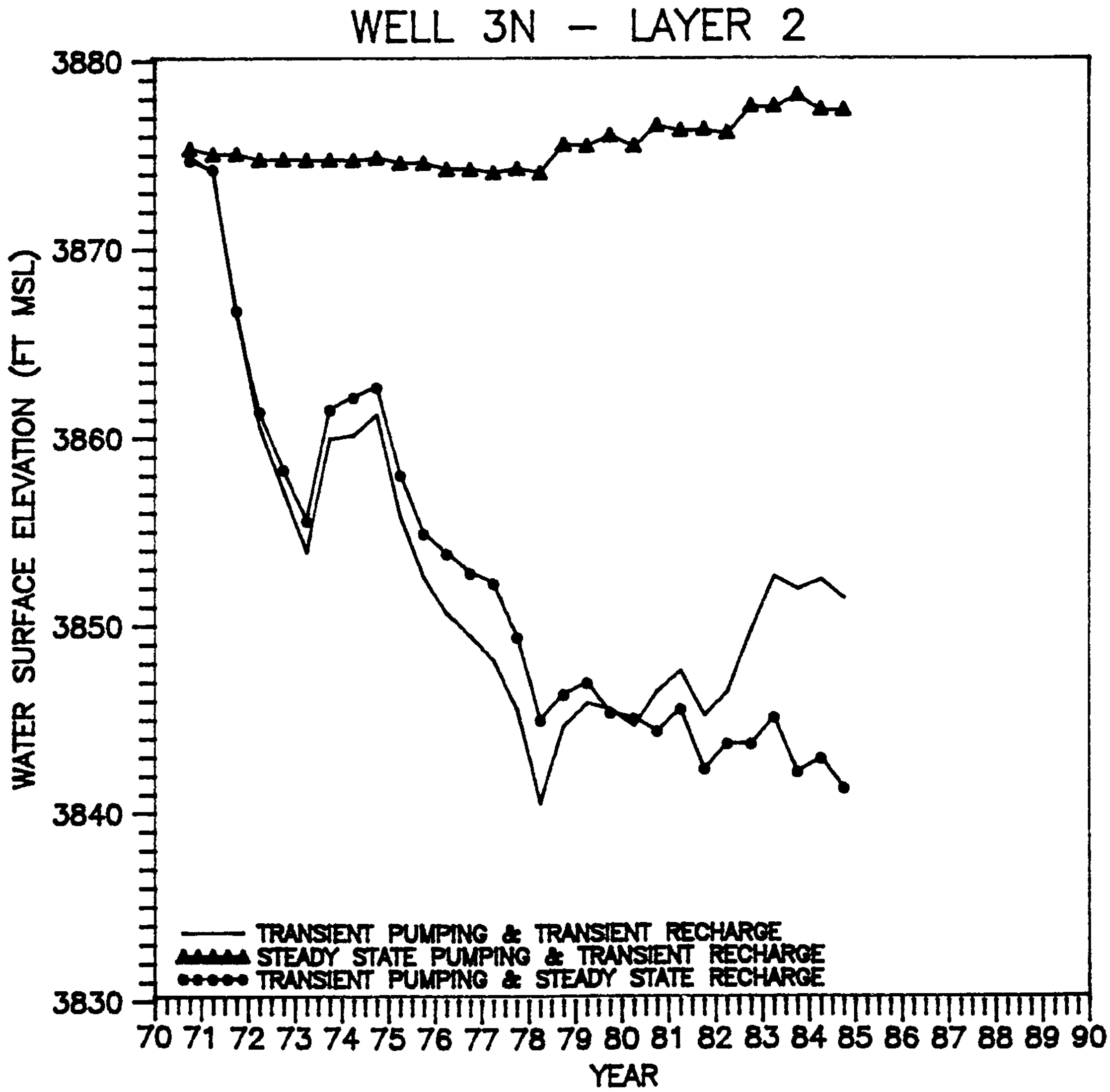
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WATER SURFACE ELEVATION (FT MSL)
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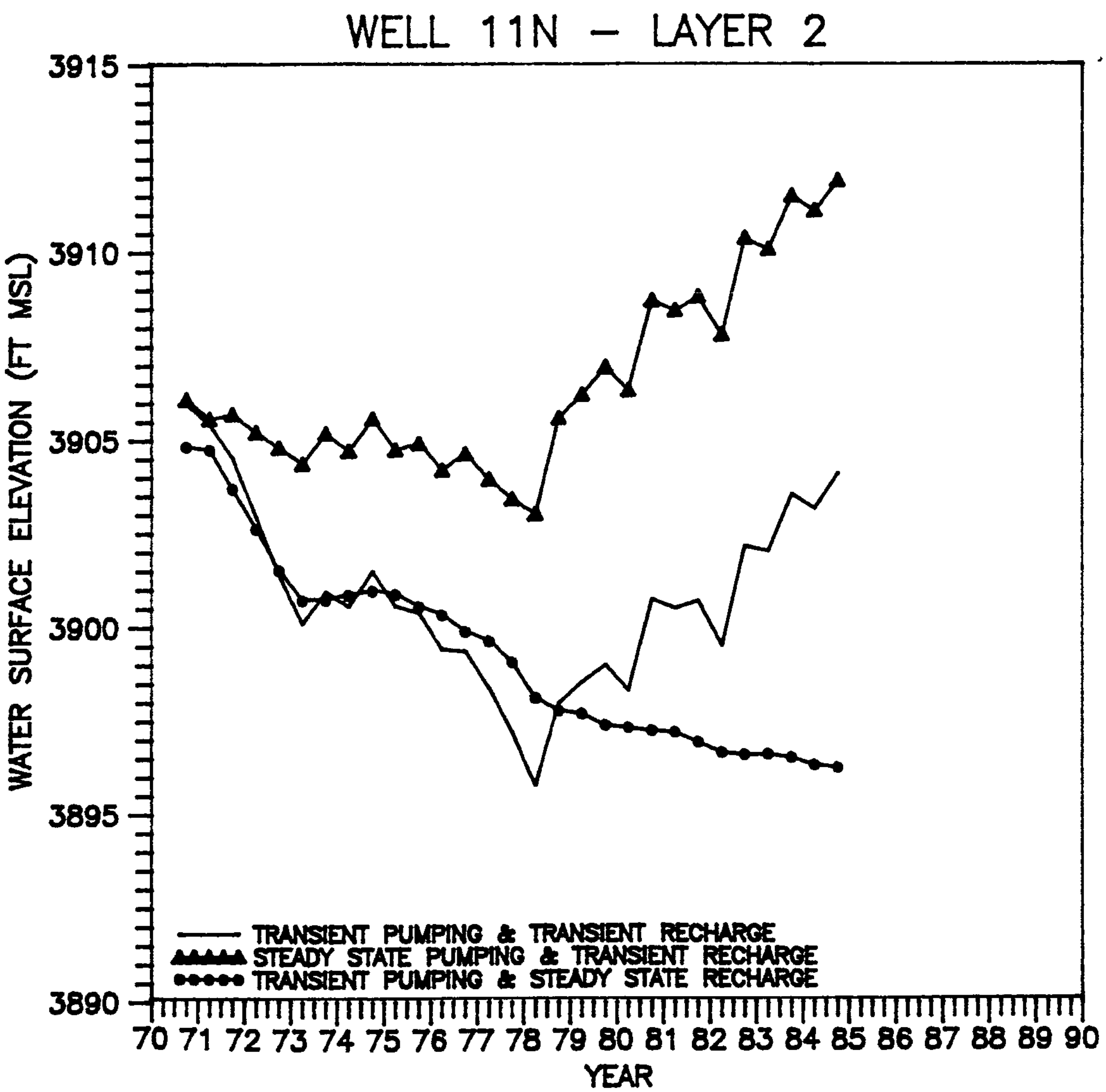
3870
3860
3850
3840
3830
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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3910
3905
3900
3895
3890
WATER SURFACE ELEVATION (FT MSL)
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YEAR
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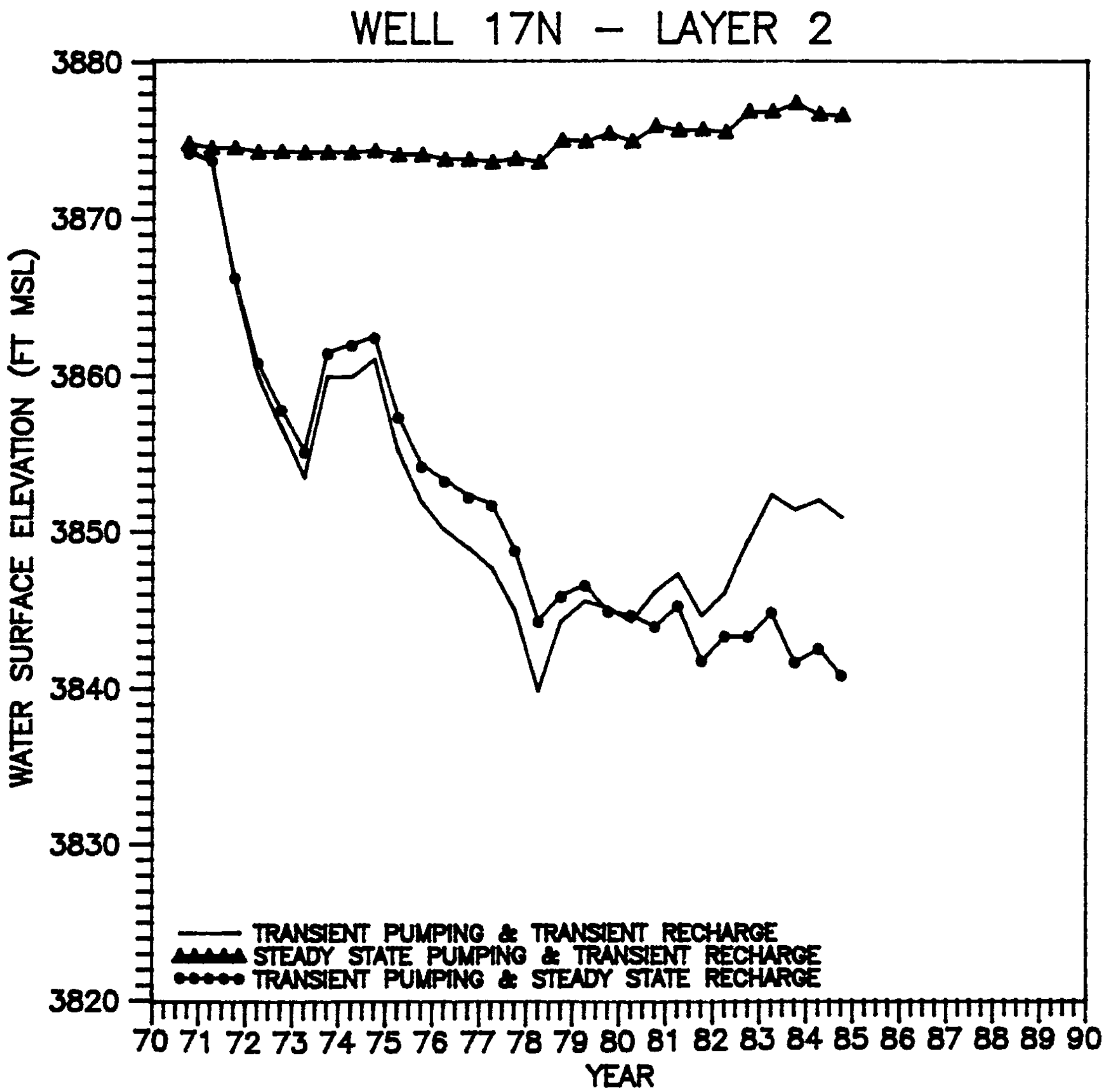
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE



WELL 17N - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
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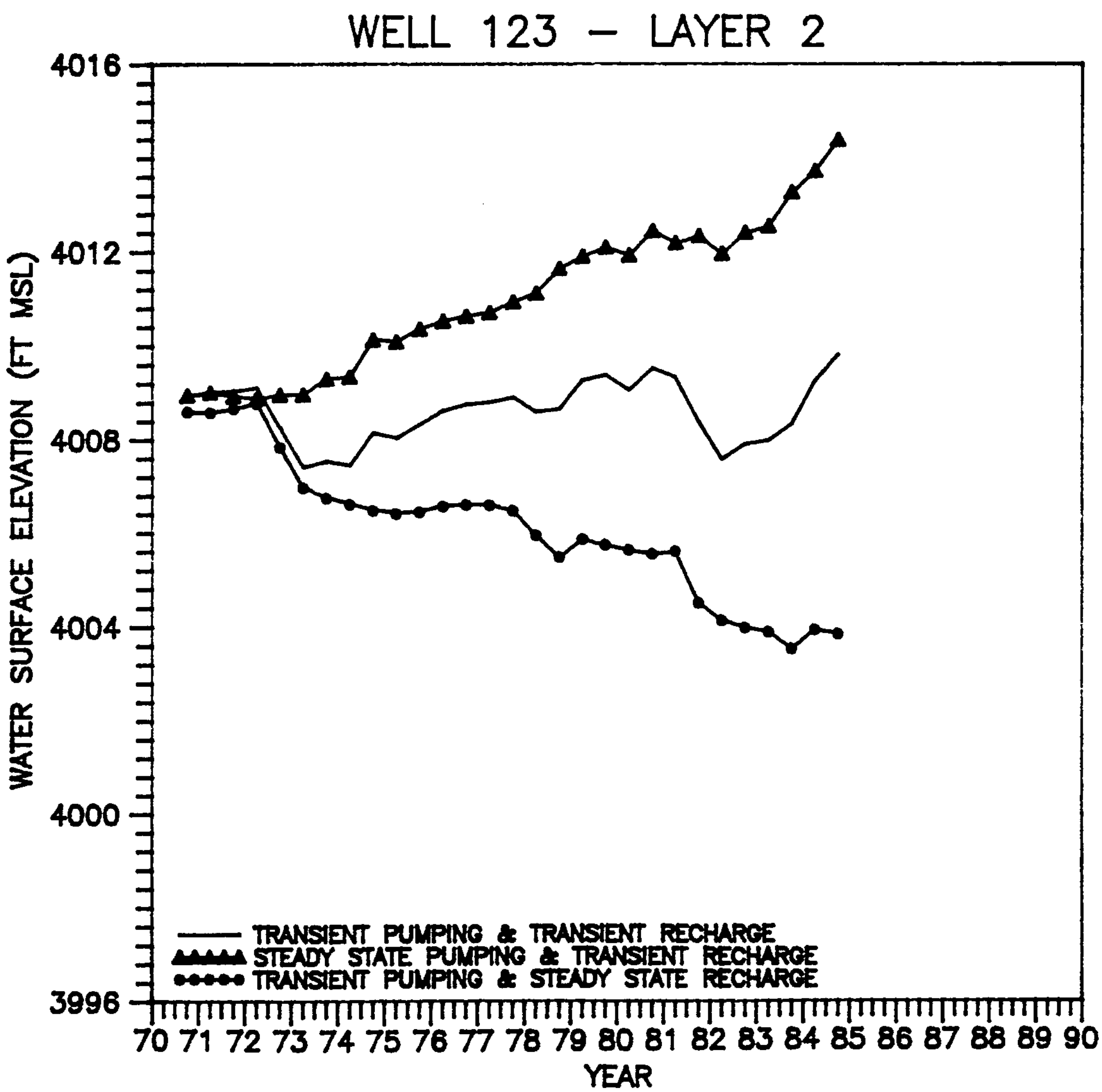
3870
3860
3850
3840
3830
3820
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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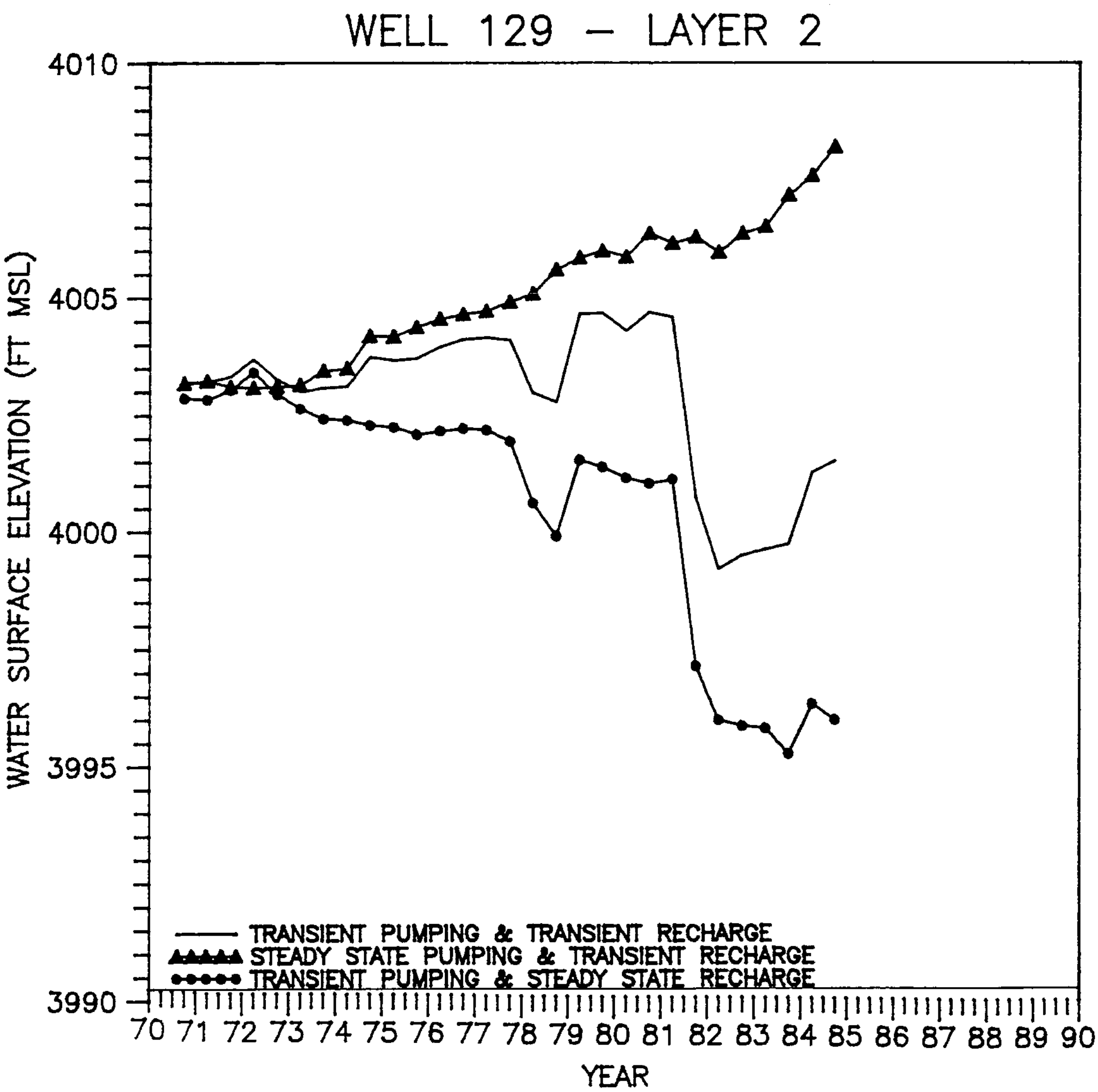
4016
4012
4008
4004
4000
3996
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE


WELL 129 - LAYER 2
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4005
4000
3995
3990
WATER SURFACE ELEVATION (FT MSL)
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STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
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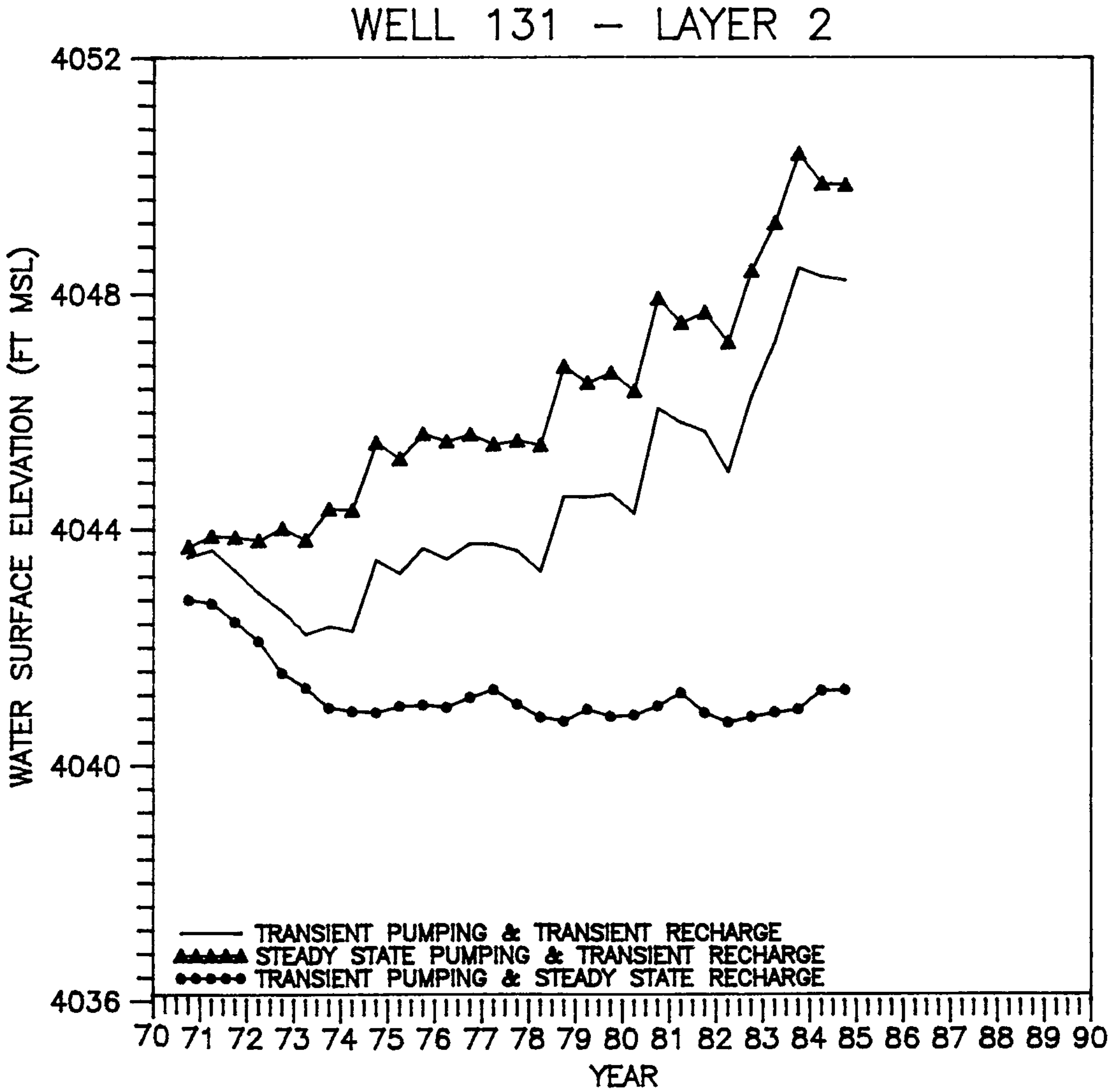
YEAR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TRANSIENT PUMPING & STEADY STATE RECHARGE
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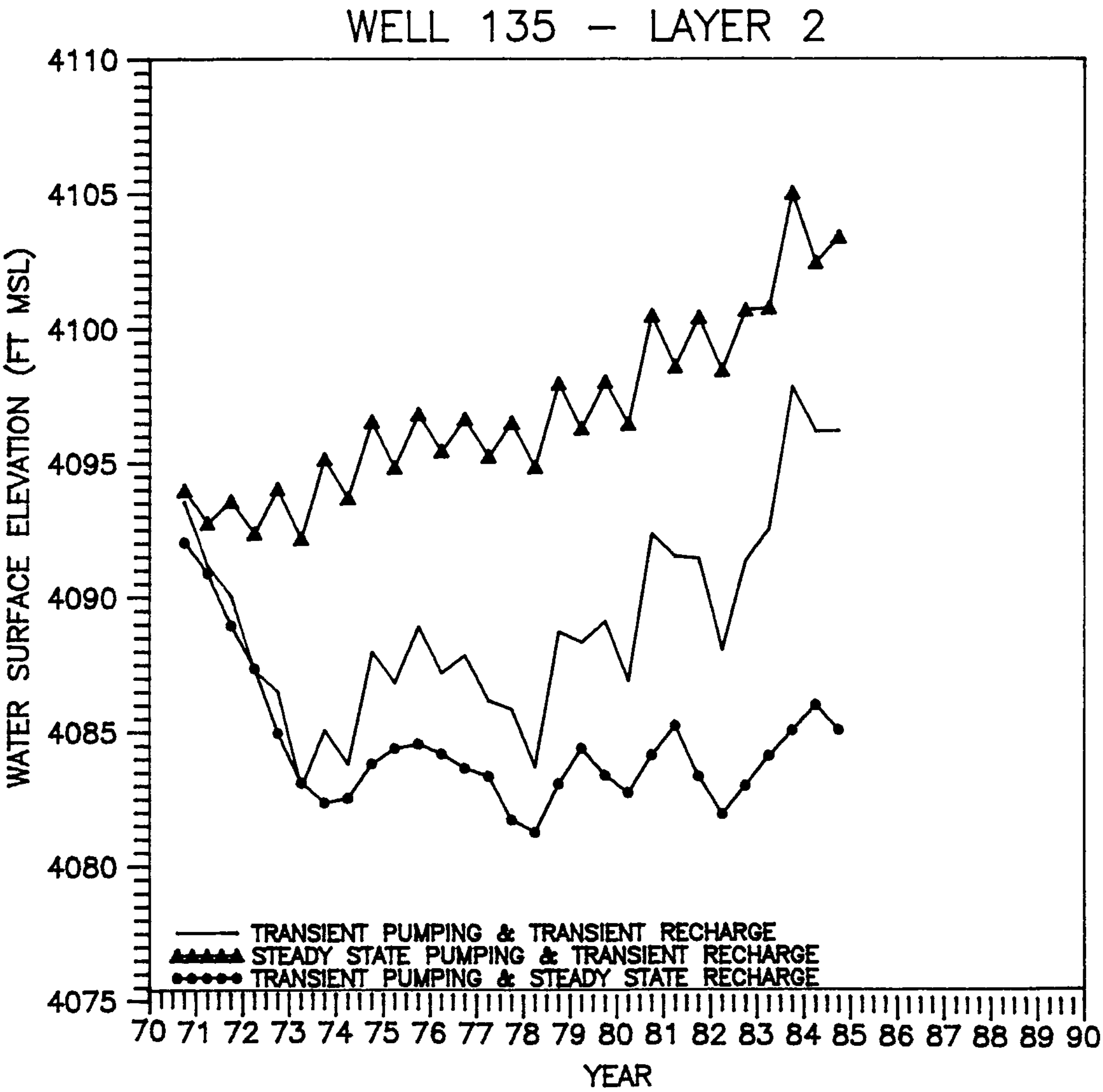
YEAR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WATER SURFACE ELEVATION (FT MSL)
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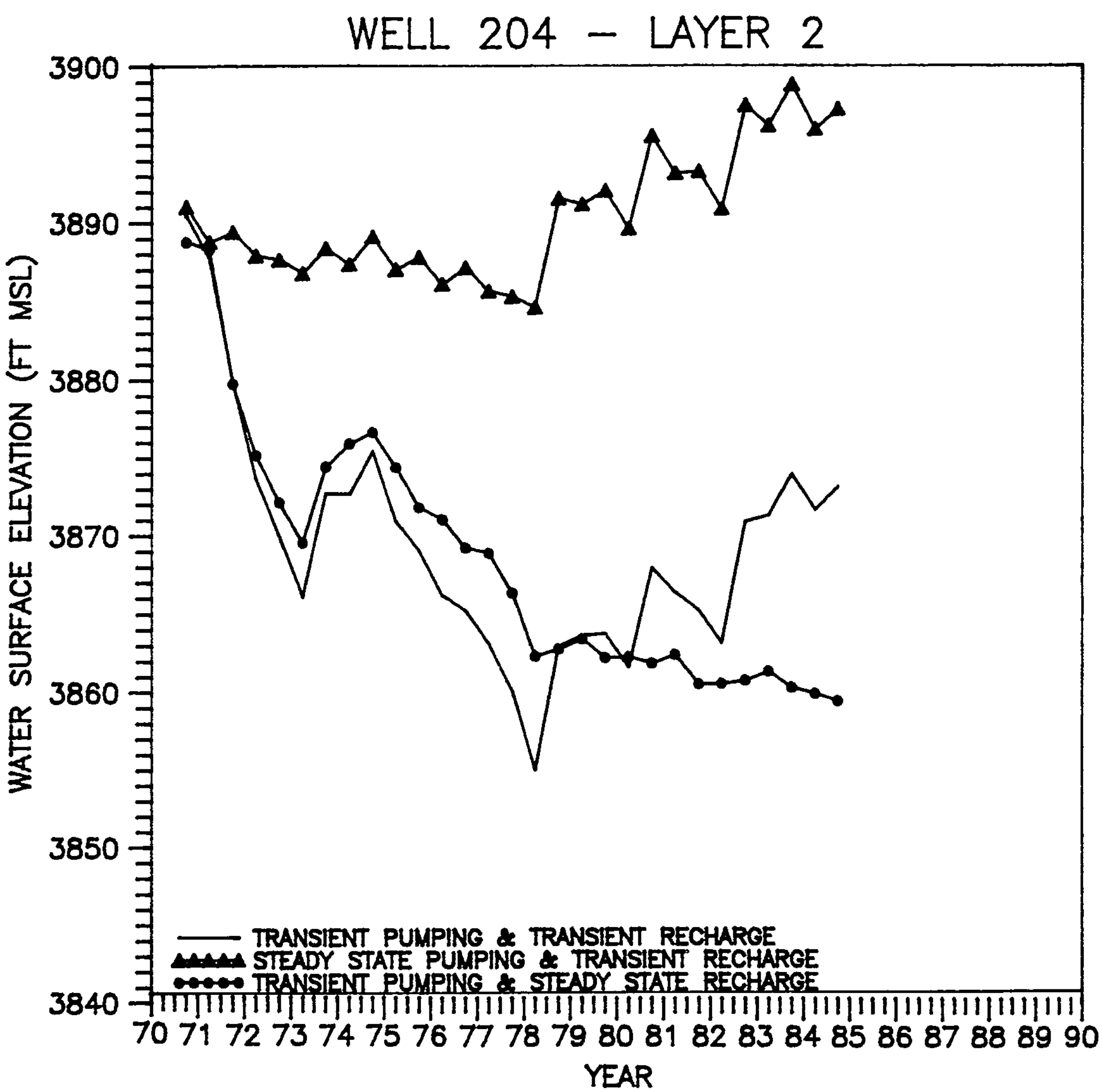
4105
4100
4095
4090
4085
4080
4075
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE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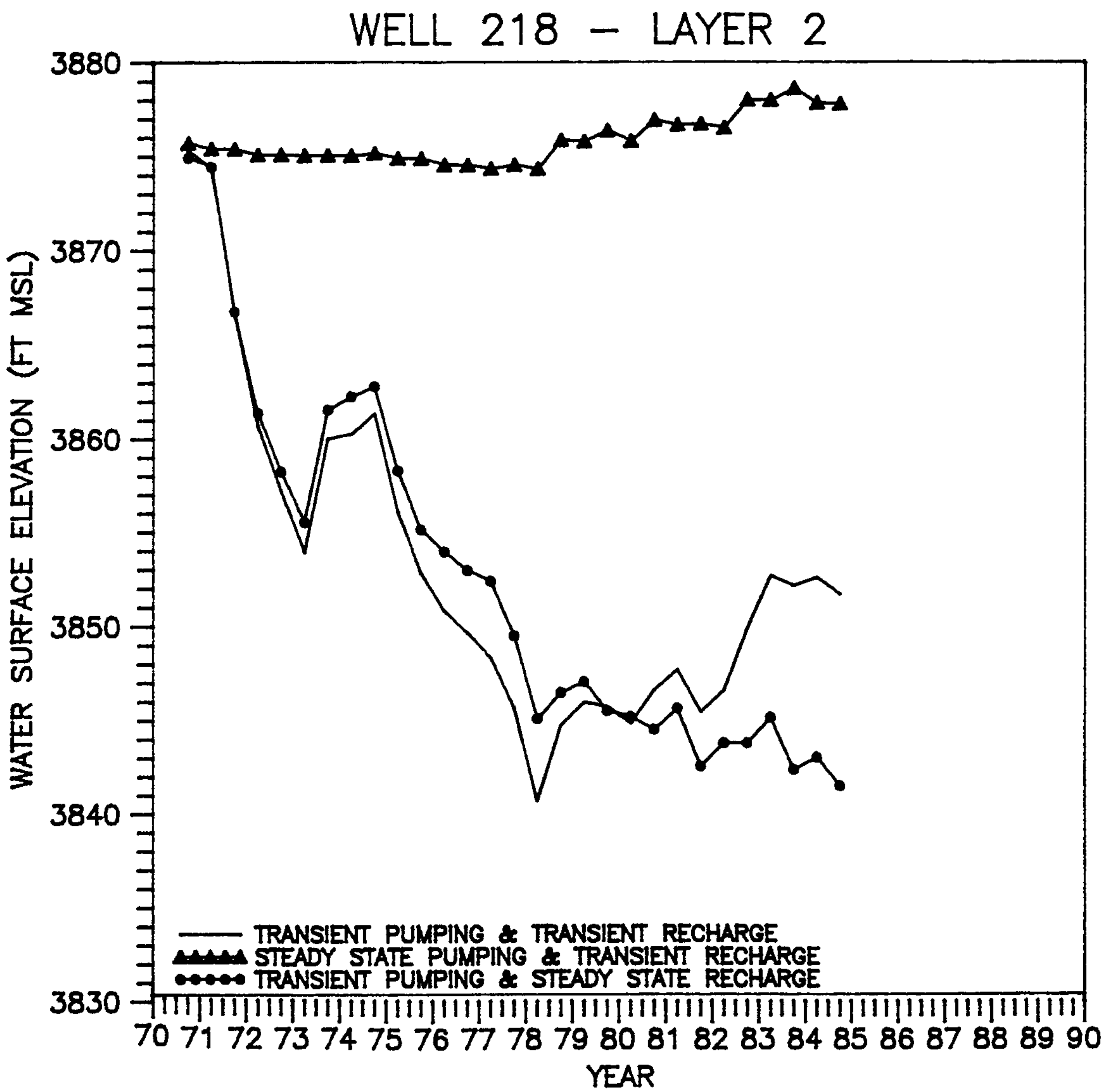
3900
3890
3880
3870
3860
3850
3840
WATER SURFACE ELEVATION (FT MSL)
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR


WELL 218 - LAYER 2
3880
3870
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WATER SURFACE ELEVATION (FT MSL)
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
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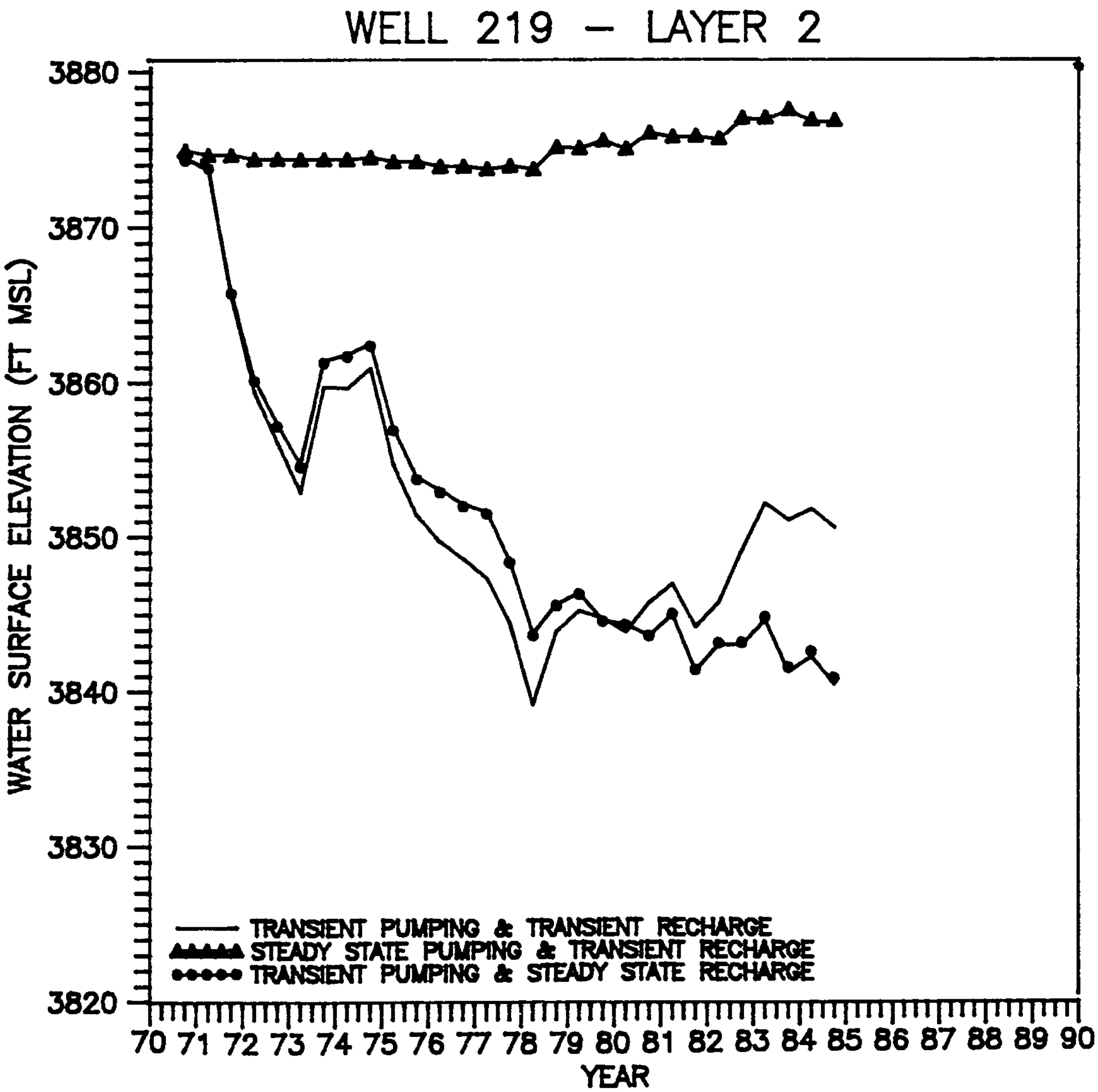
YEAR


WELL 219 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
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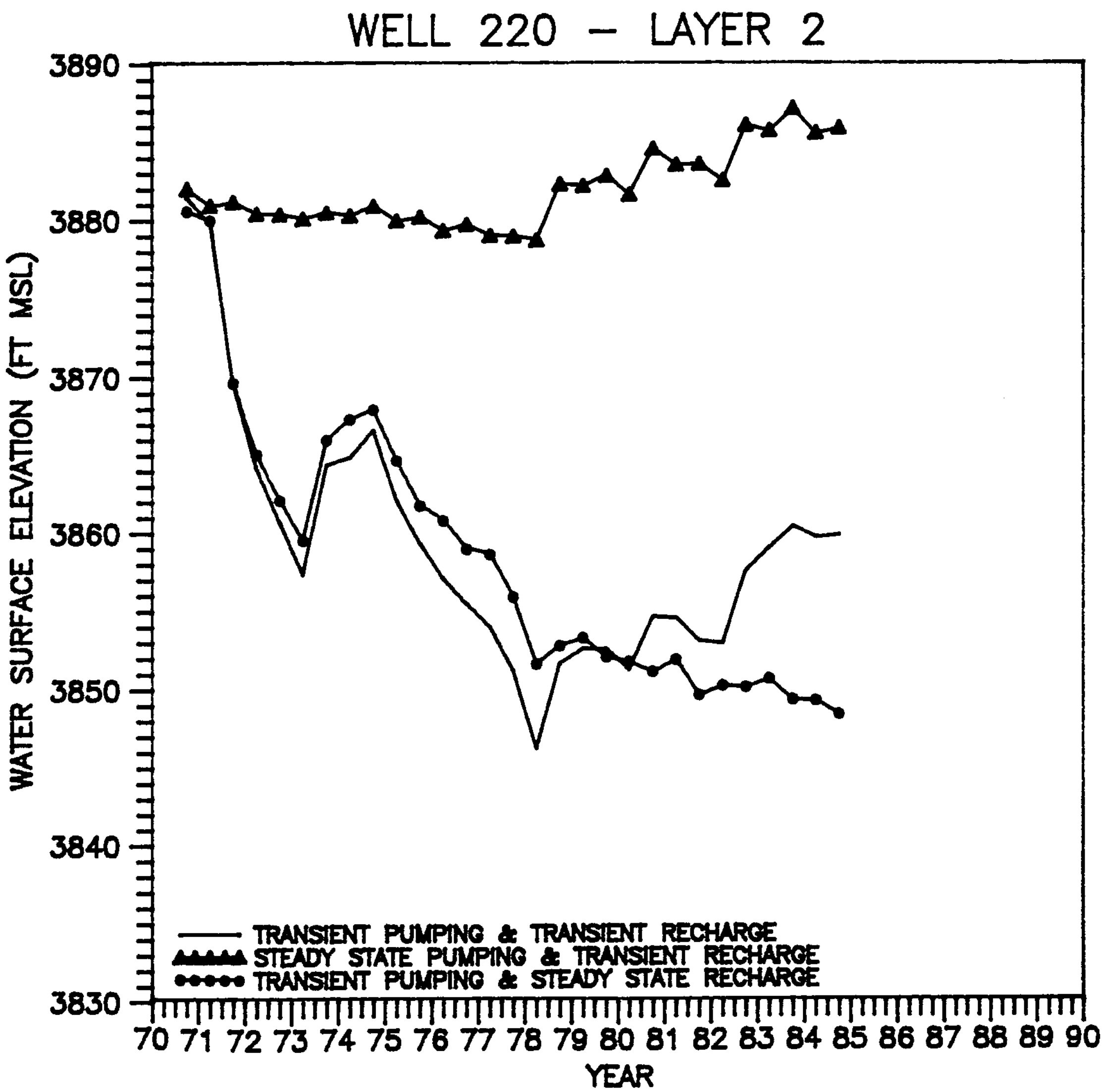
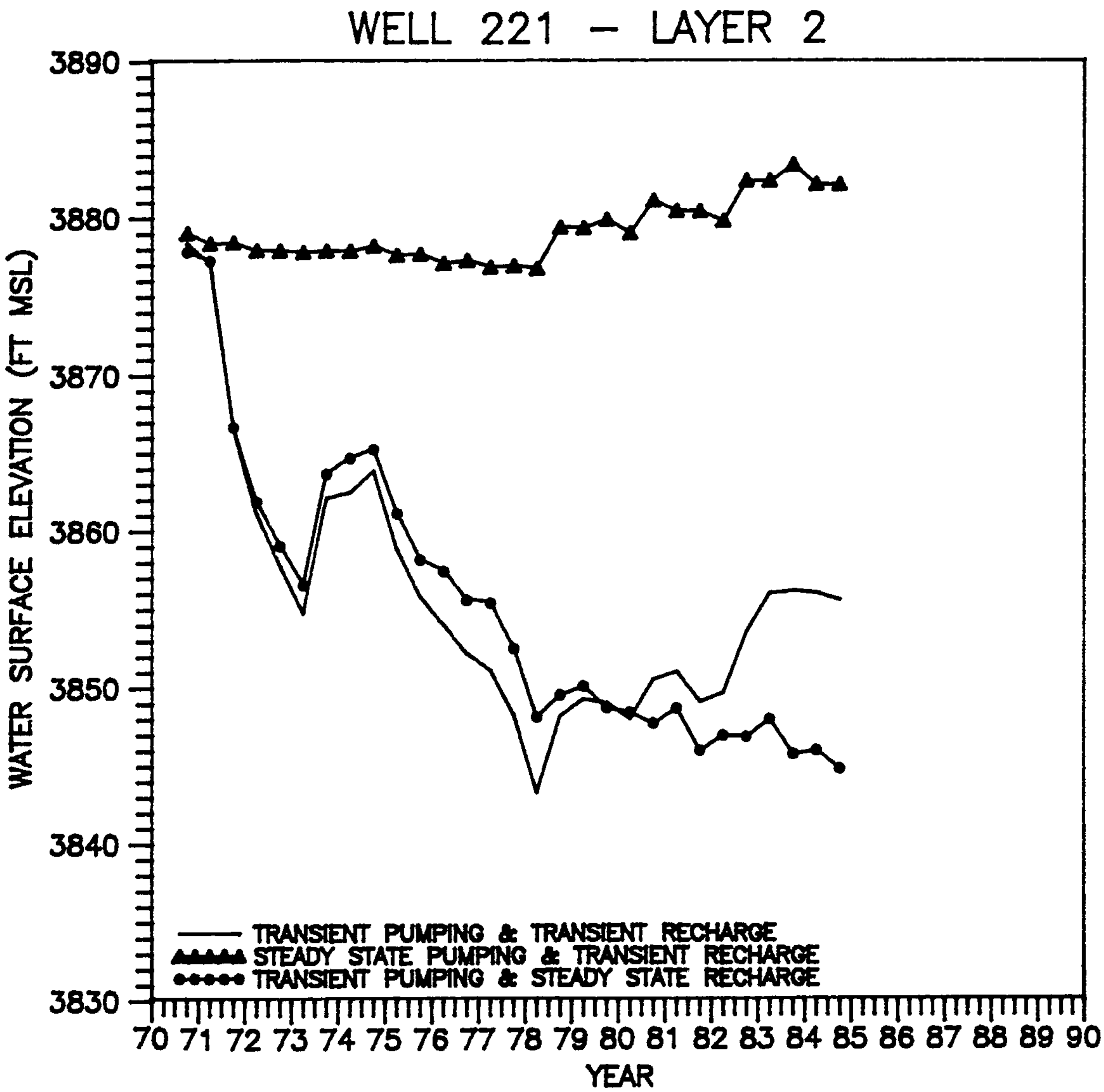
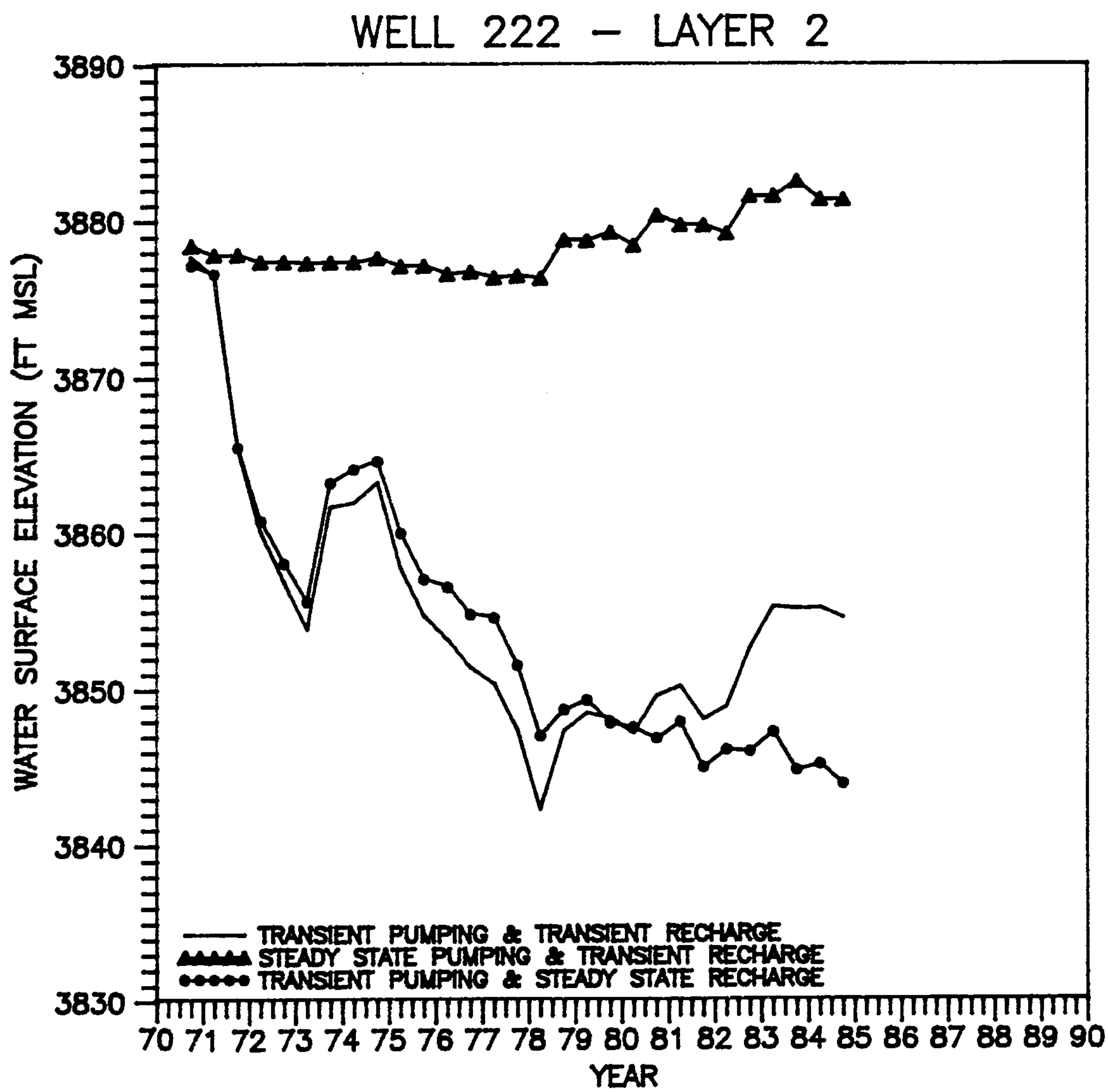
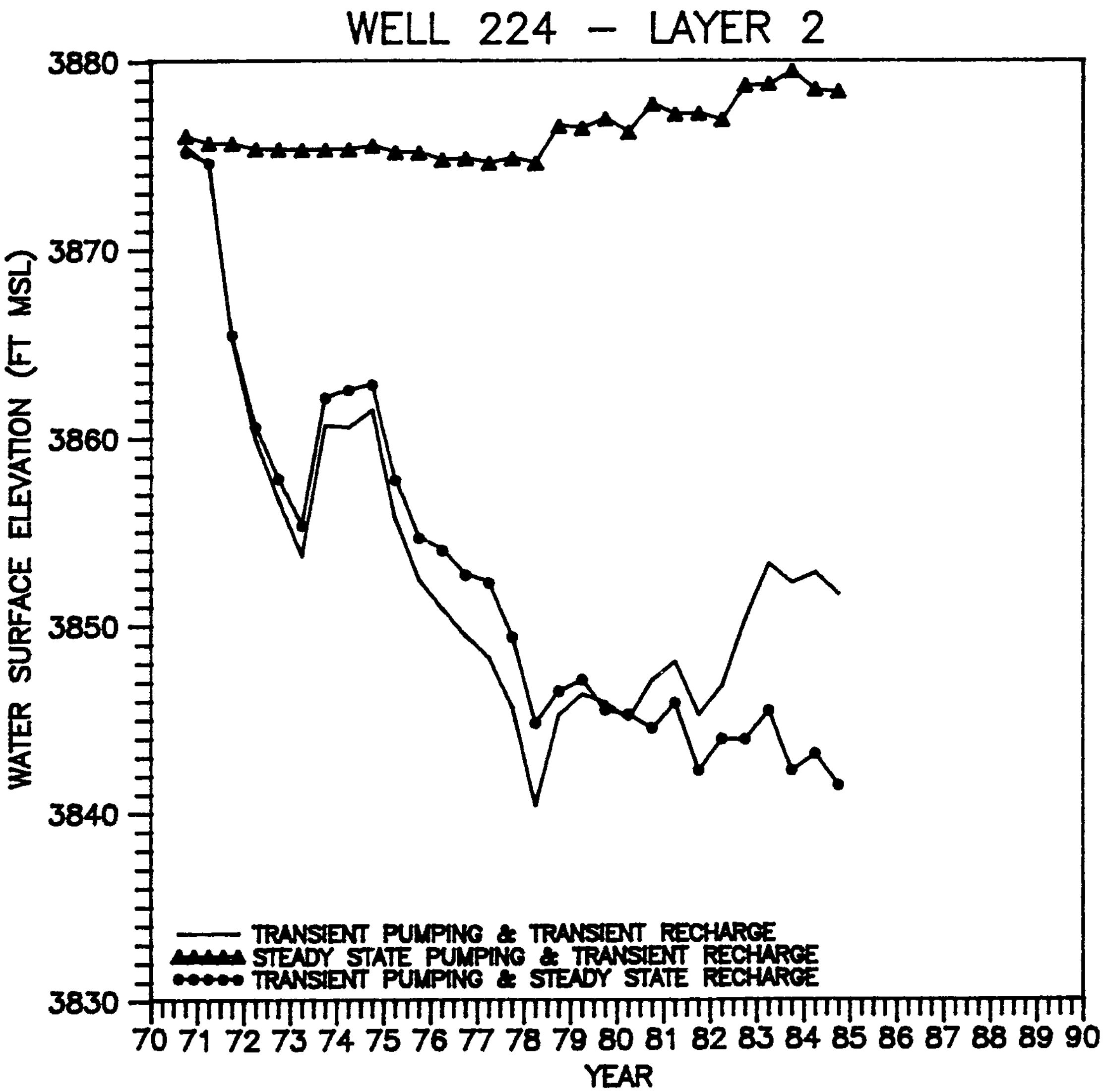
3860
3850
3840
3830
3820
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE

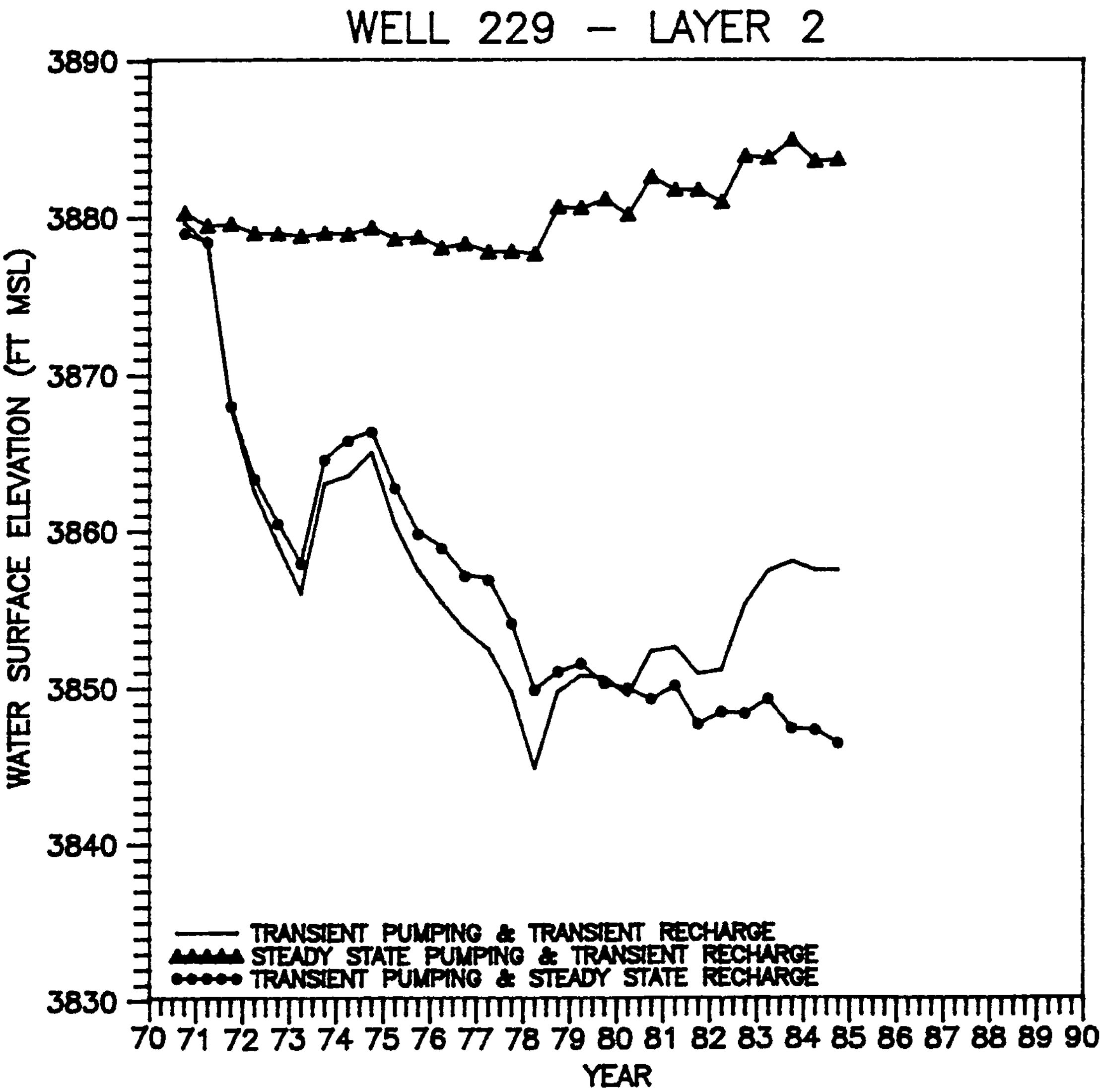


WELL 220 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
3890
3880
3870
3860
3850
3840
3830
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR

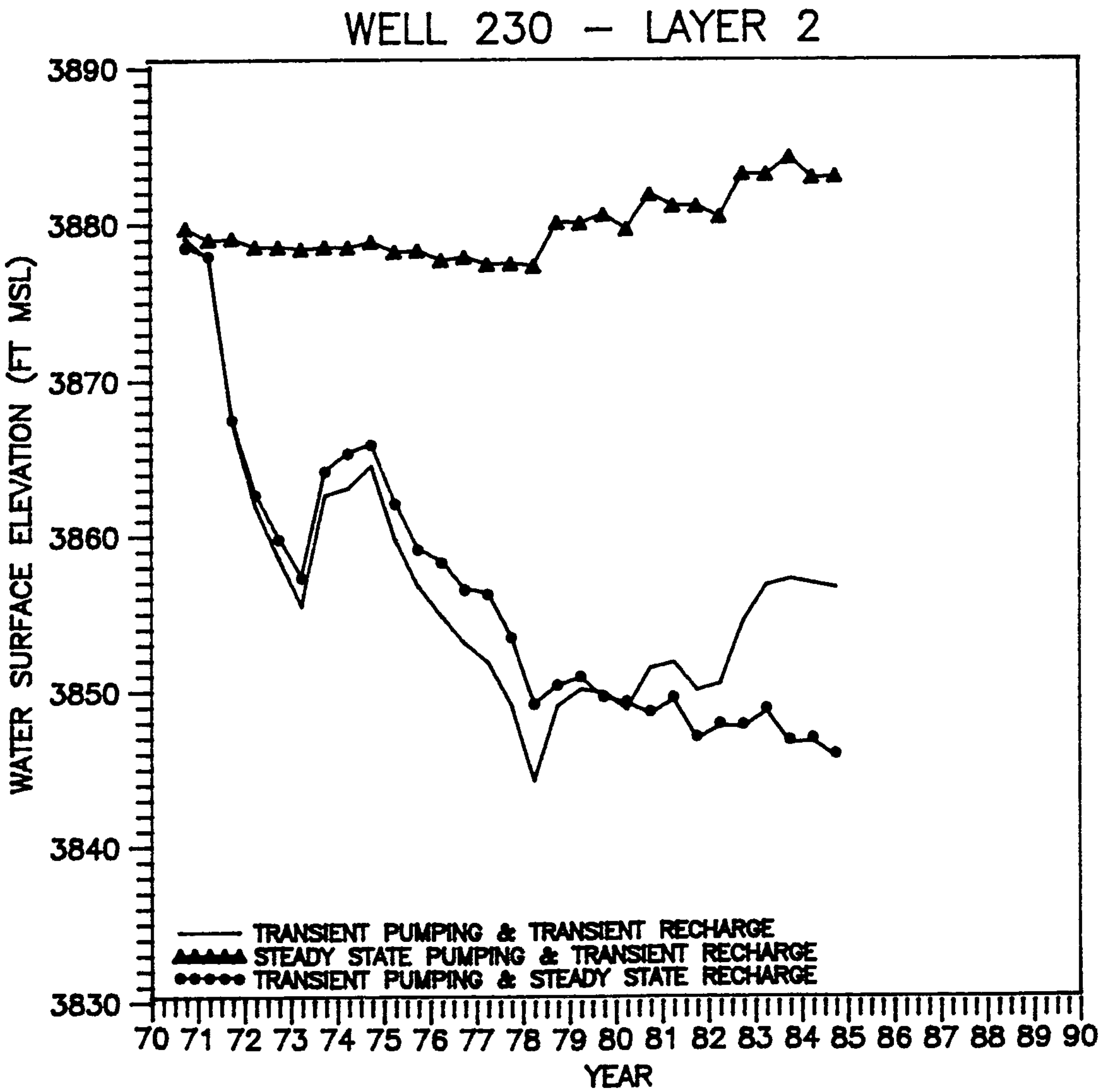

WELL 221 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
3890
3880
3870
3860
3850
3840
3830
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE

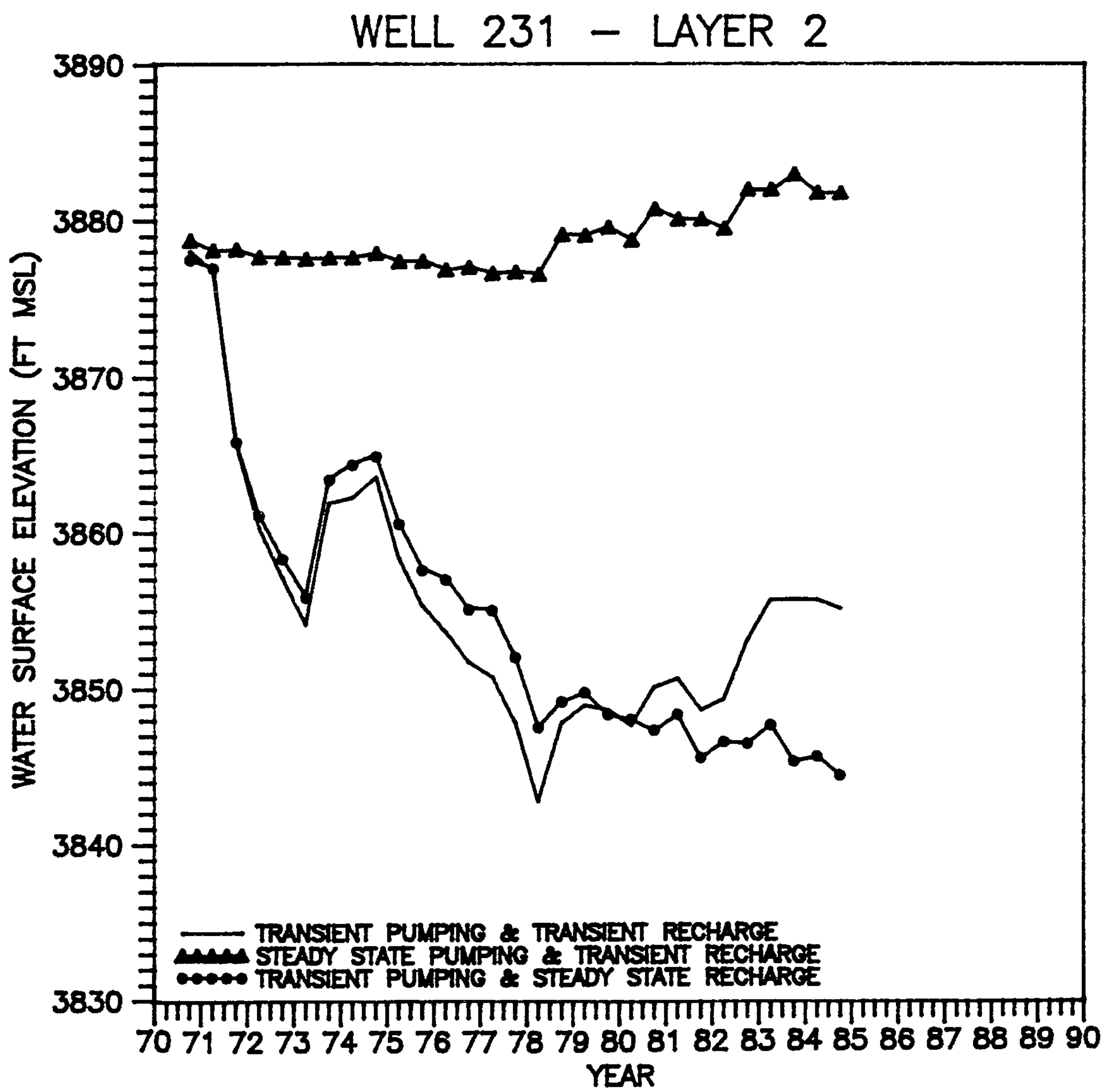

WELL 222 - LAYER 2
3890
3880
3870
3860
3850
3840
3830
WATER SURFACE ELEVATION (FT MSL)
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE

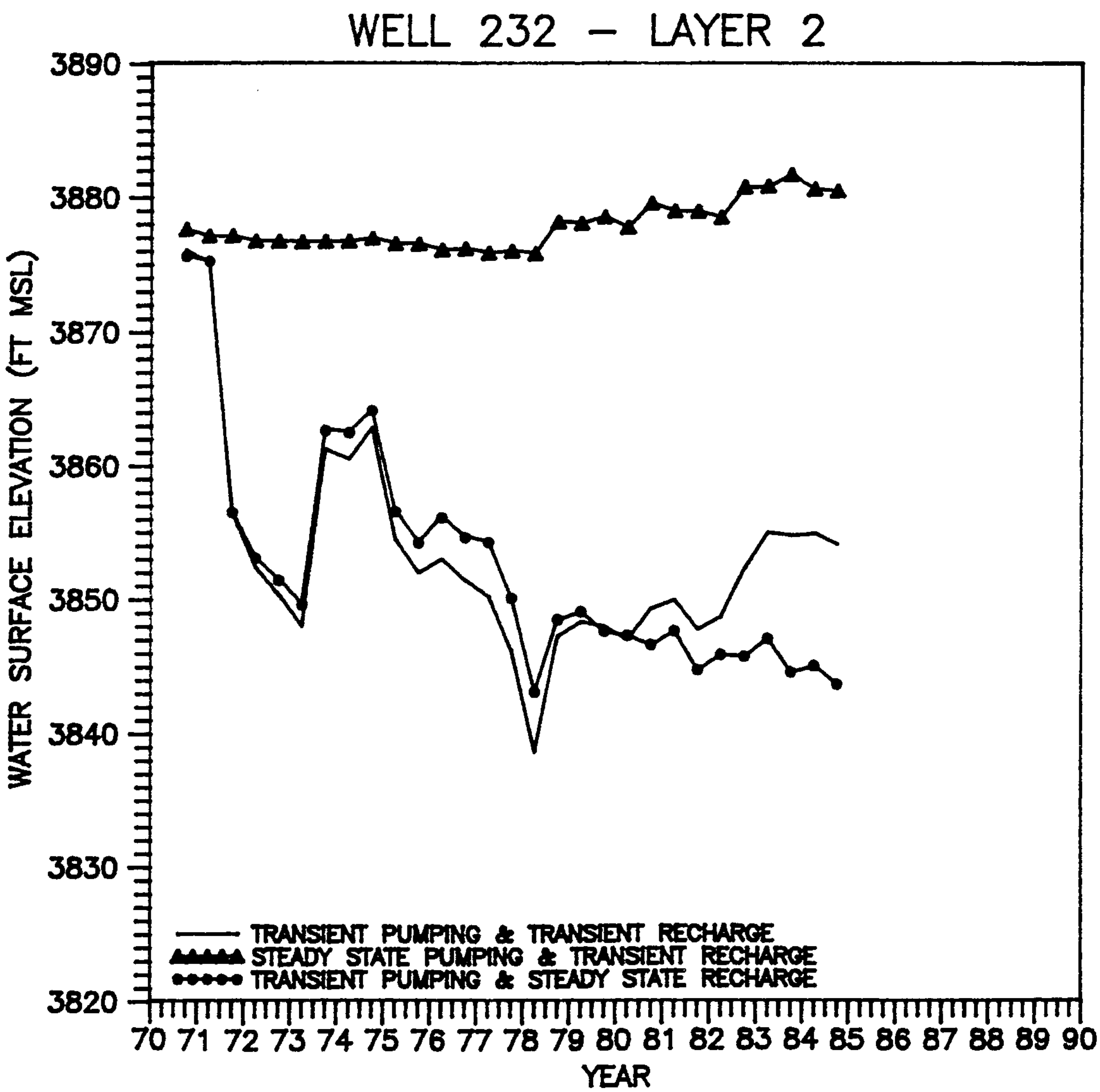

WELL 224 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
3880
3870
3860
3850
3840
3830
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE



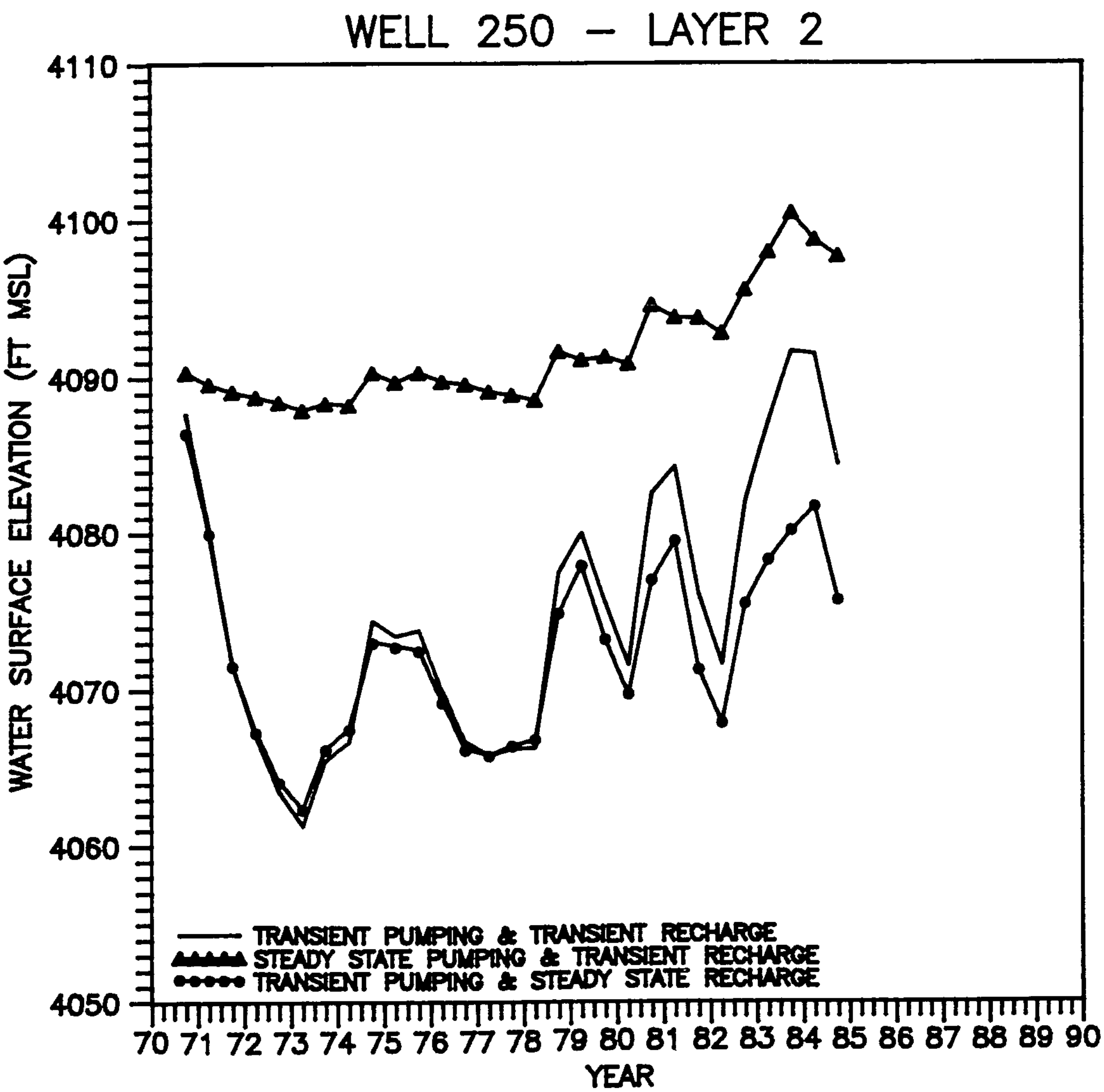
WELL 229 - LAYER 2
3890
3880
3870
3860
3850
3840
3830
WATER SURFACE ELEVATION (FT MSL)
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE

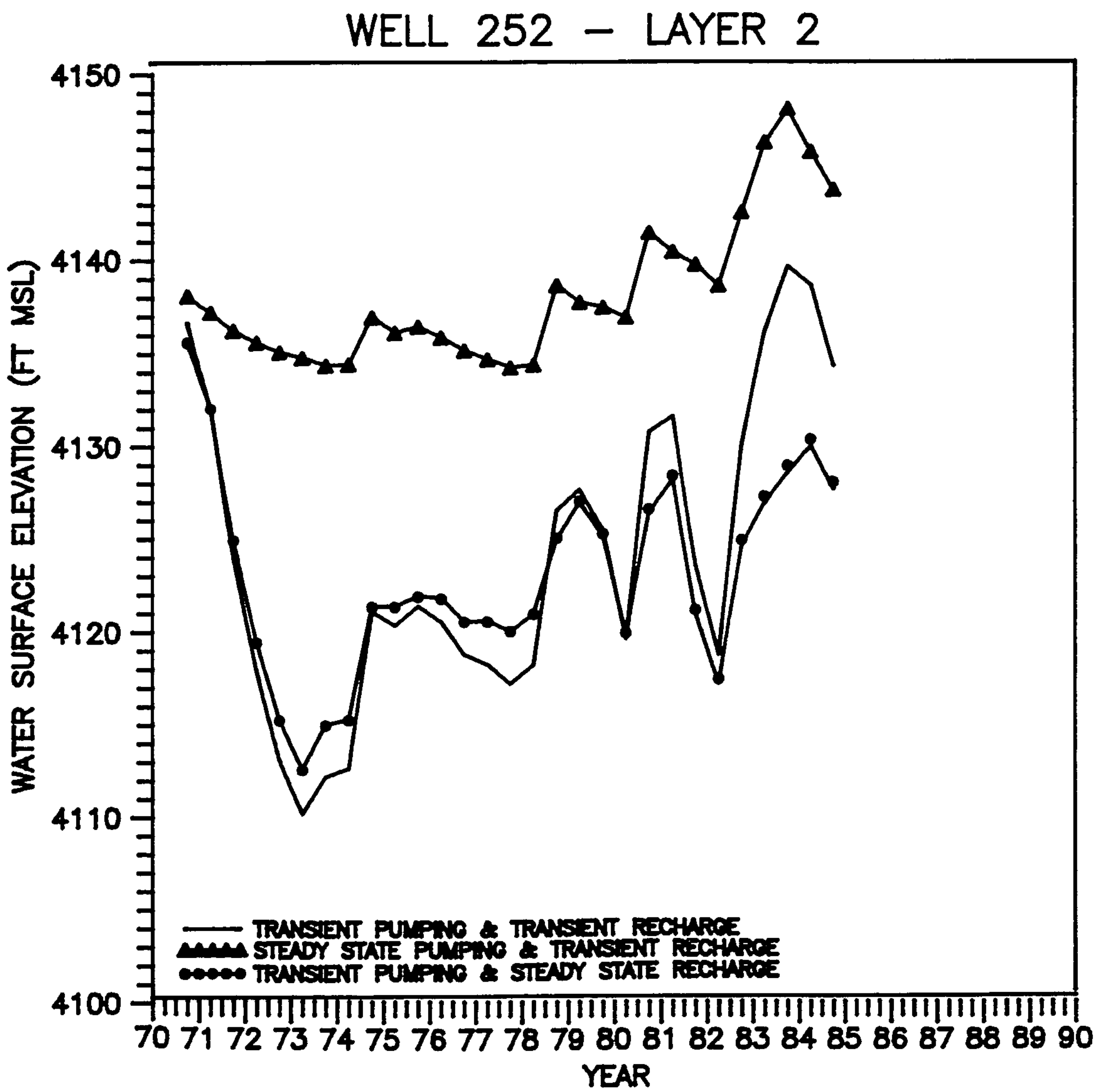

WELL 230 - LAYER 2
3890
3880
3870
3860
3850
3840
3830
WATER SURFACE ELEVATION (FT MSL)
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR

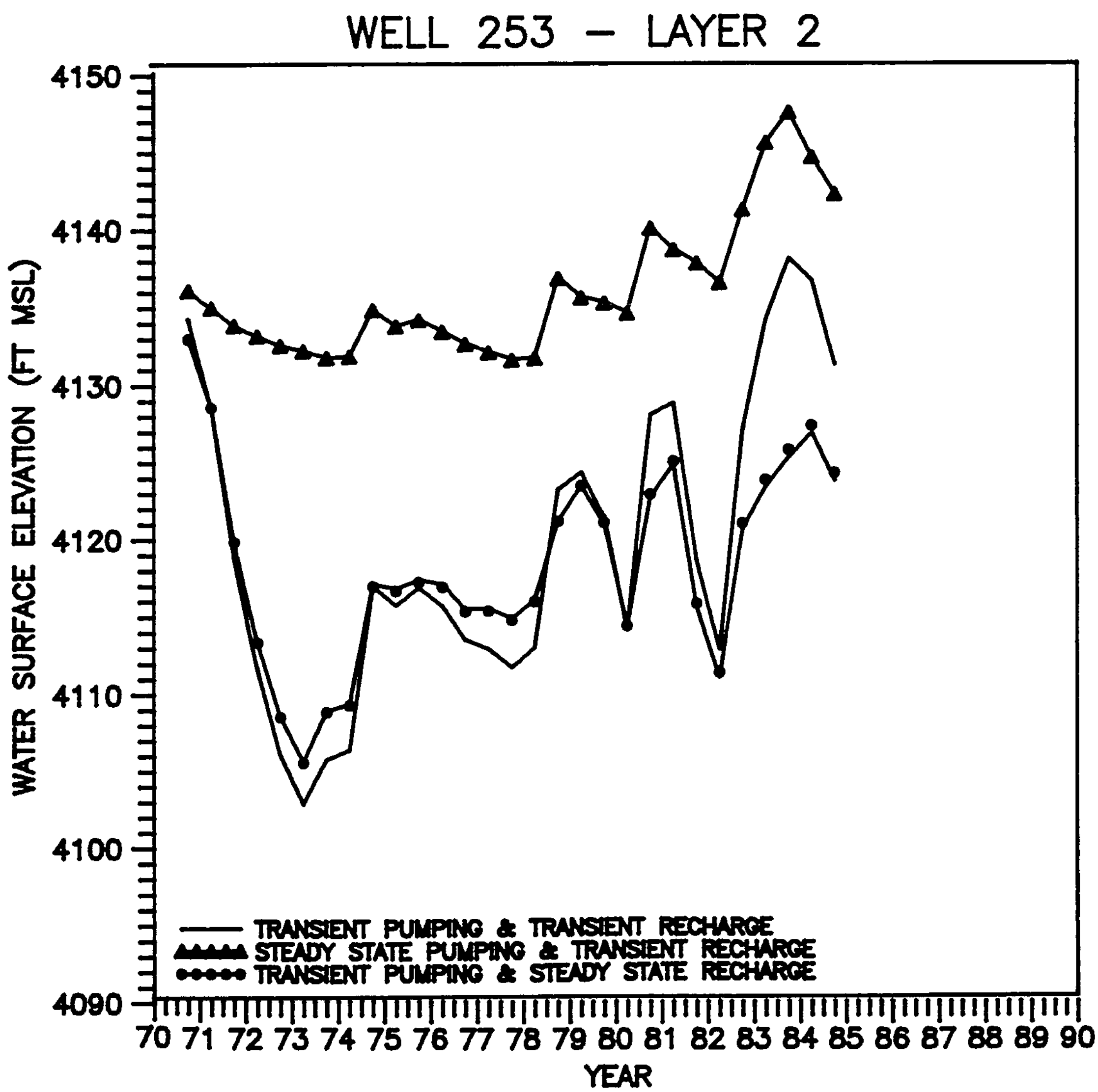

WELL 231 - LAYER 2
3890
3880
3870
3860
3850
3840
3830
WATER SURFACE ELEVATION (FT MSL)
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR

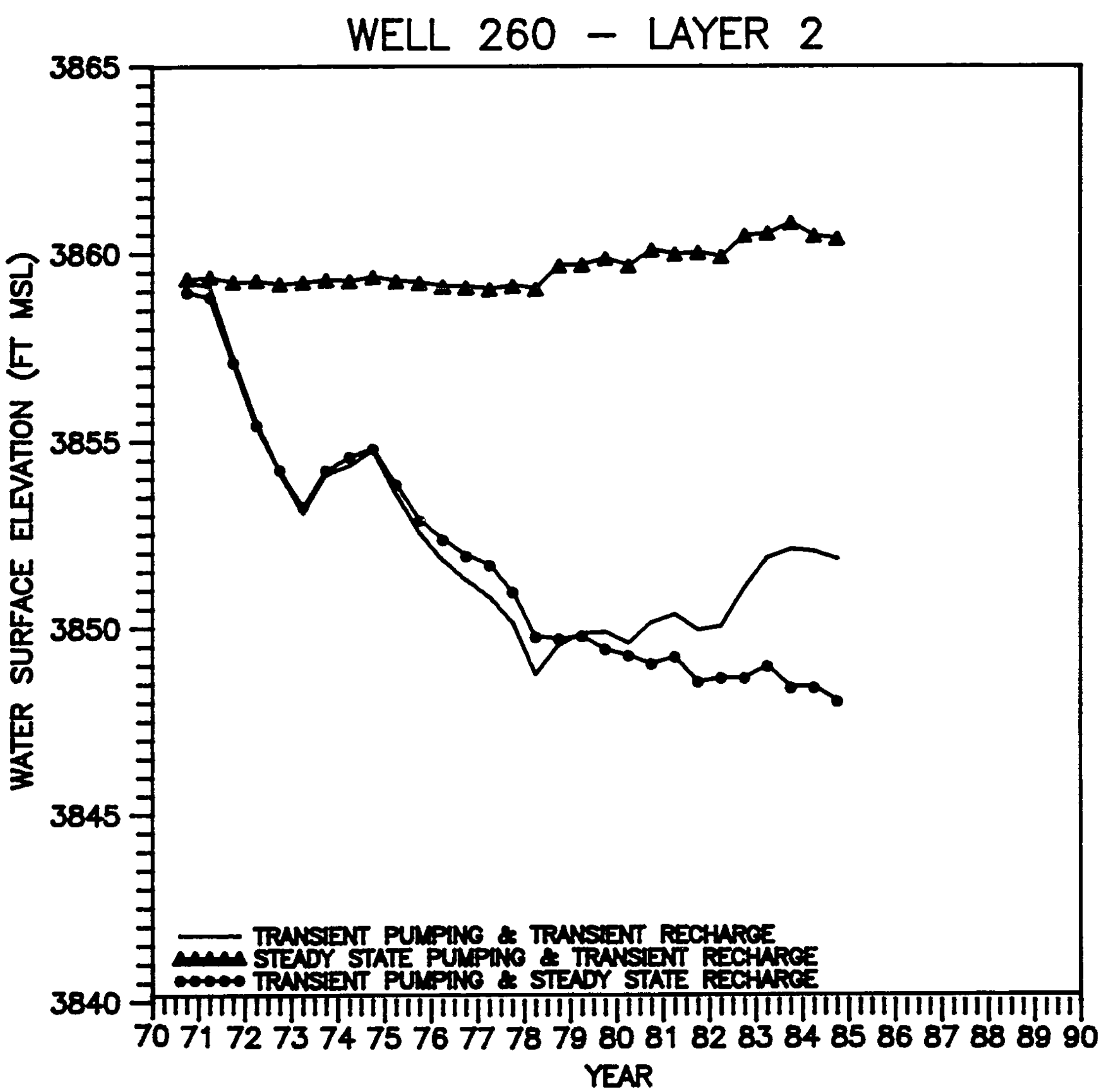


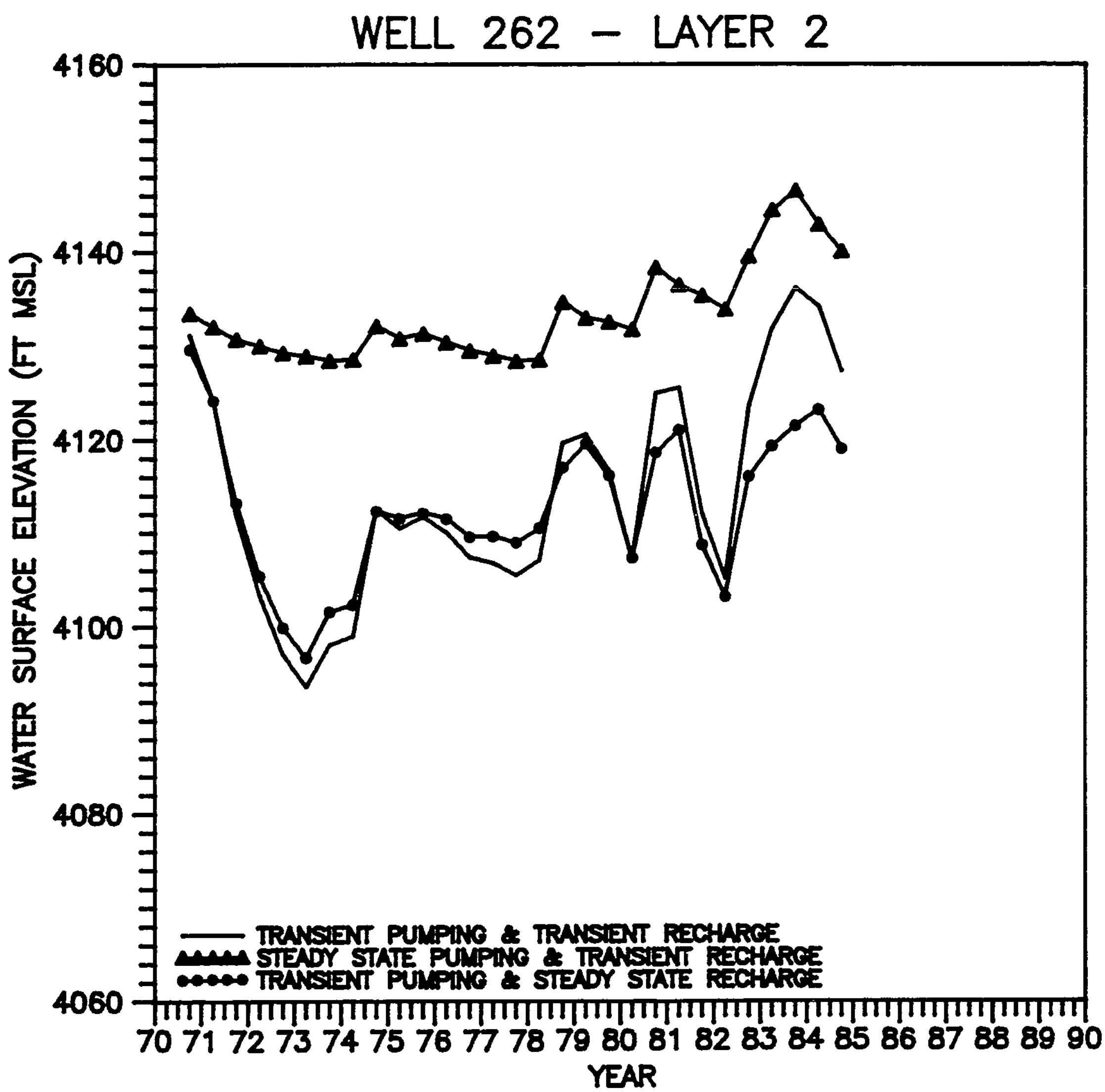
WELL 232 - LAYER 2
3890
3880
3870
3860
3850
3840
3830
3820
WATER SURFACE ELEVATION (FT MSL)
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR

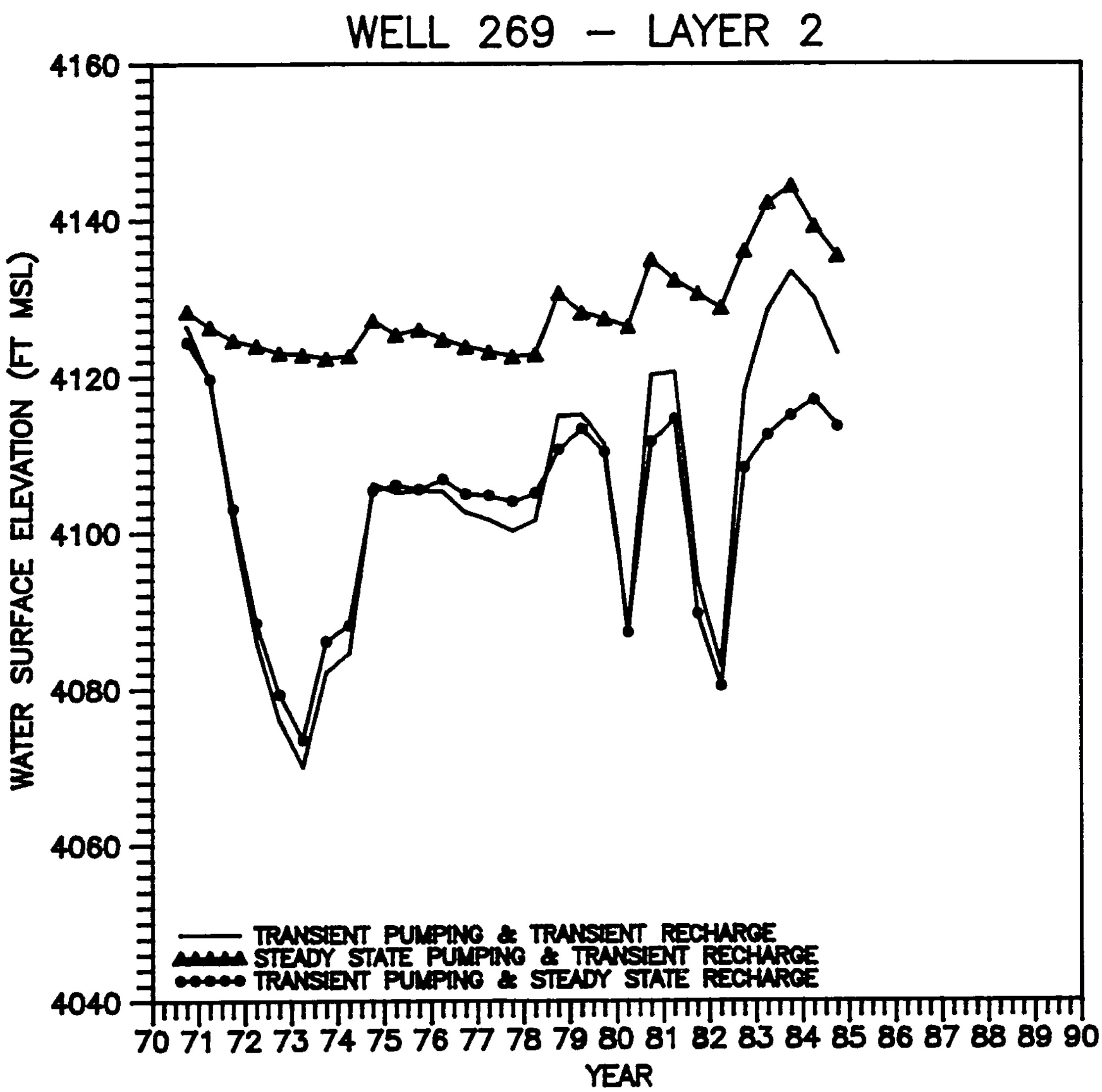

WELL 250 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
4110
4100
4090
4080
4070
4060
4050
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE

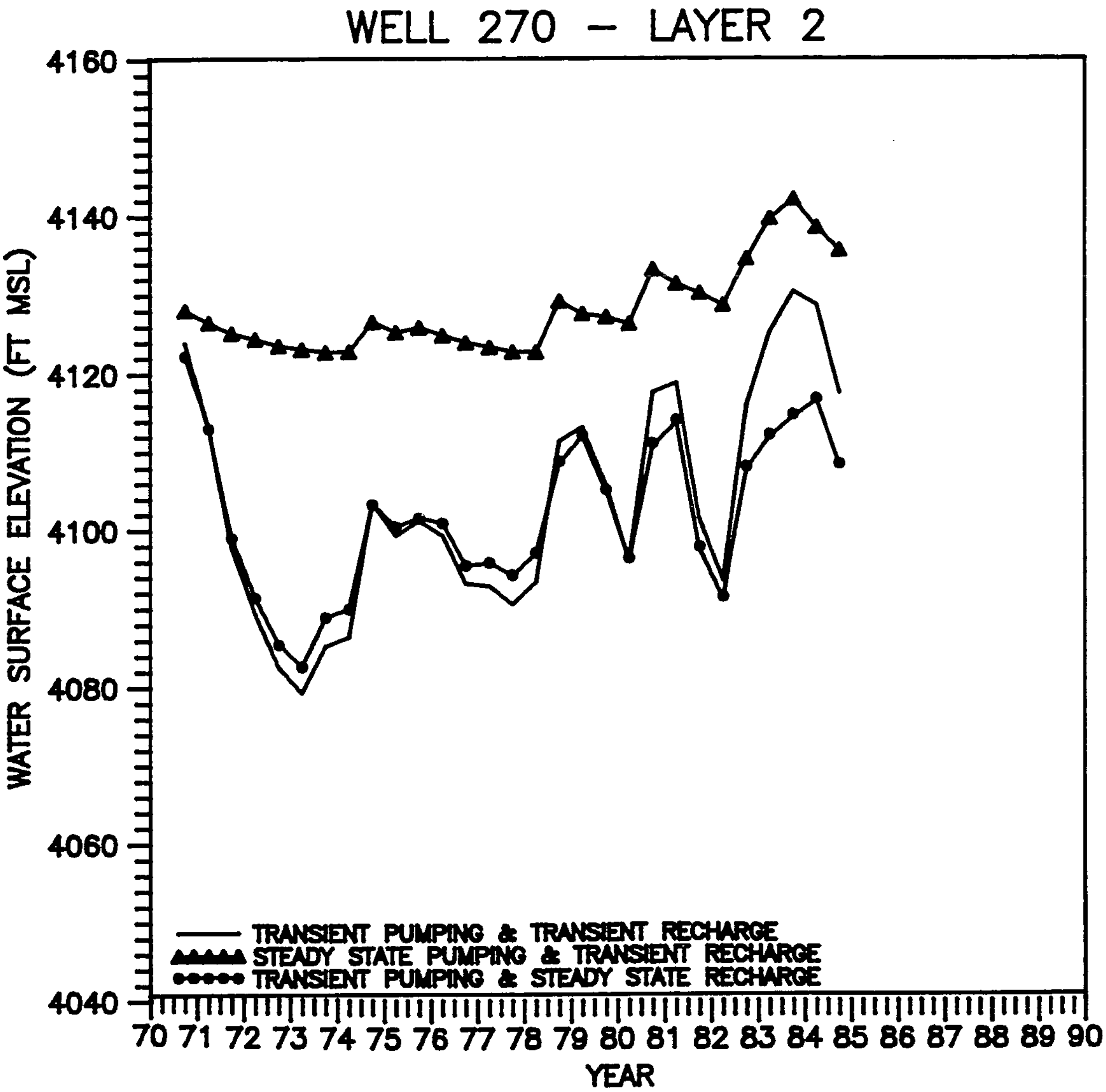

WELL 252 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
4150
4140
4130
4120
4110
4100
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE

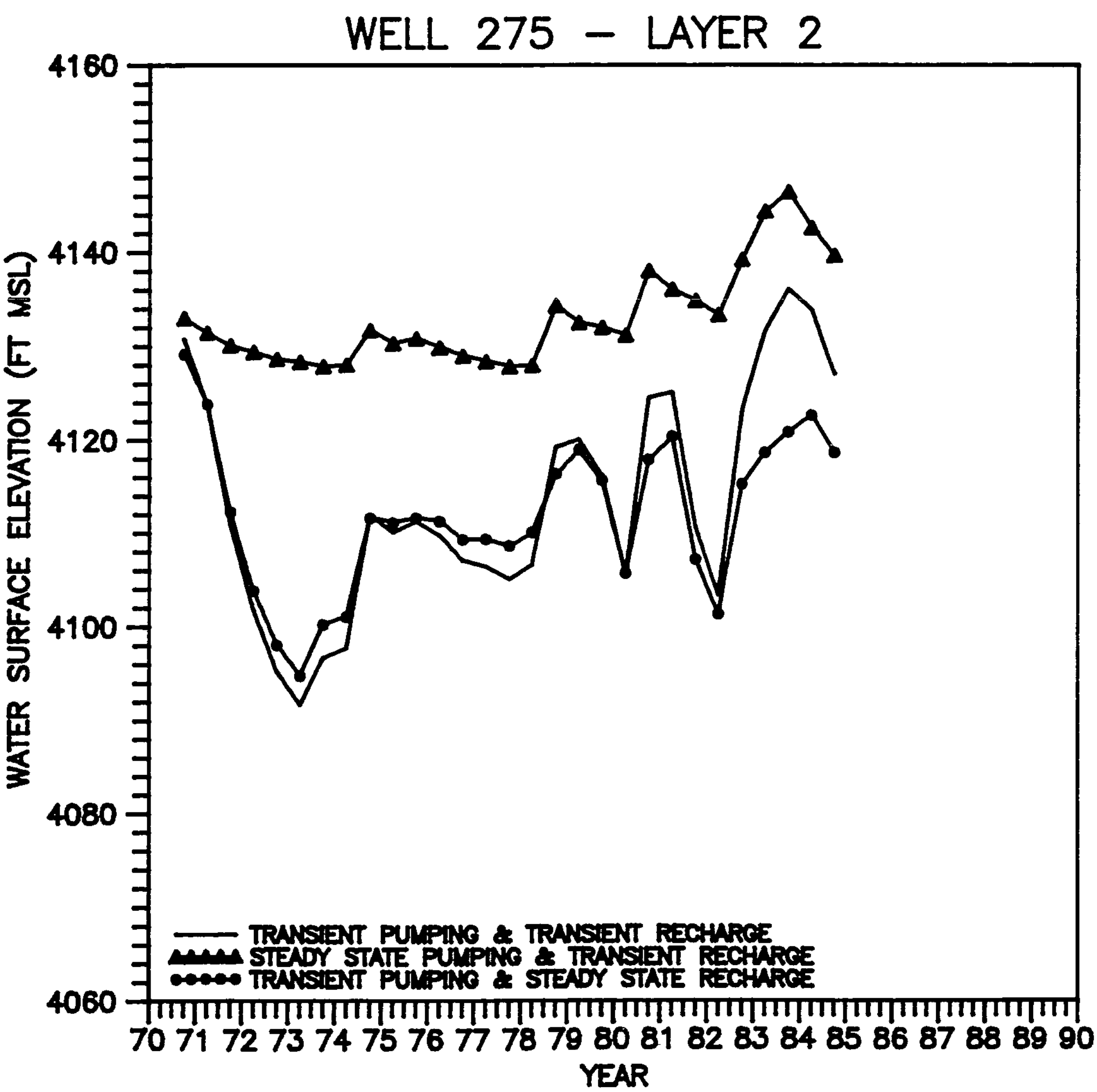

WELL 253 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
4150
4140
4130
4120
4110
4100
4090
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE

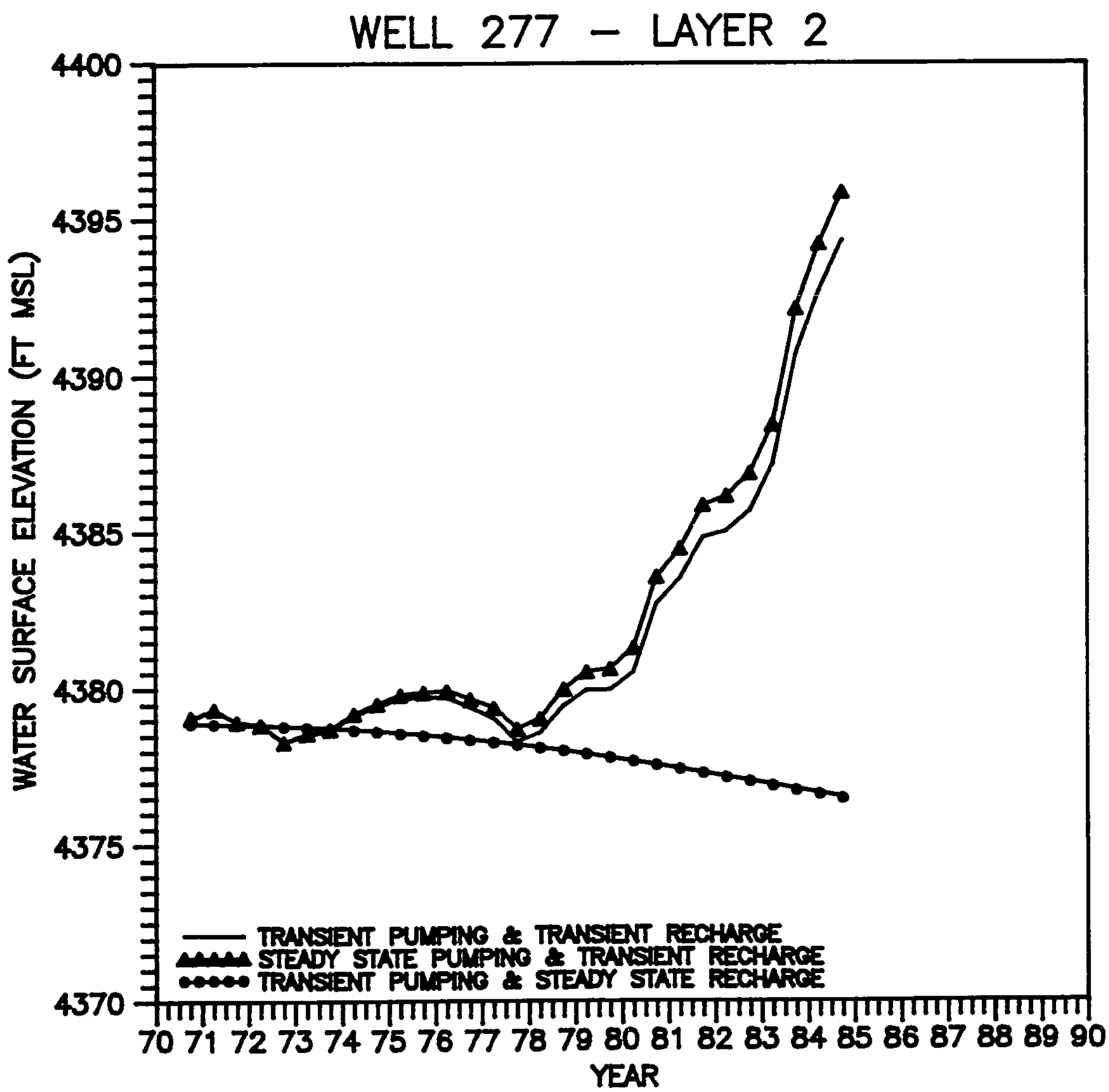

WELL 260 - LAYER 2
3865
3860
3855
3850
3845
3840
WATER SURFACE ELEVATION (FT MSL)
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR

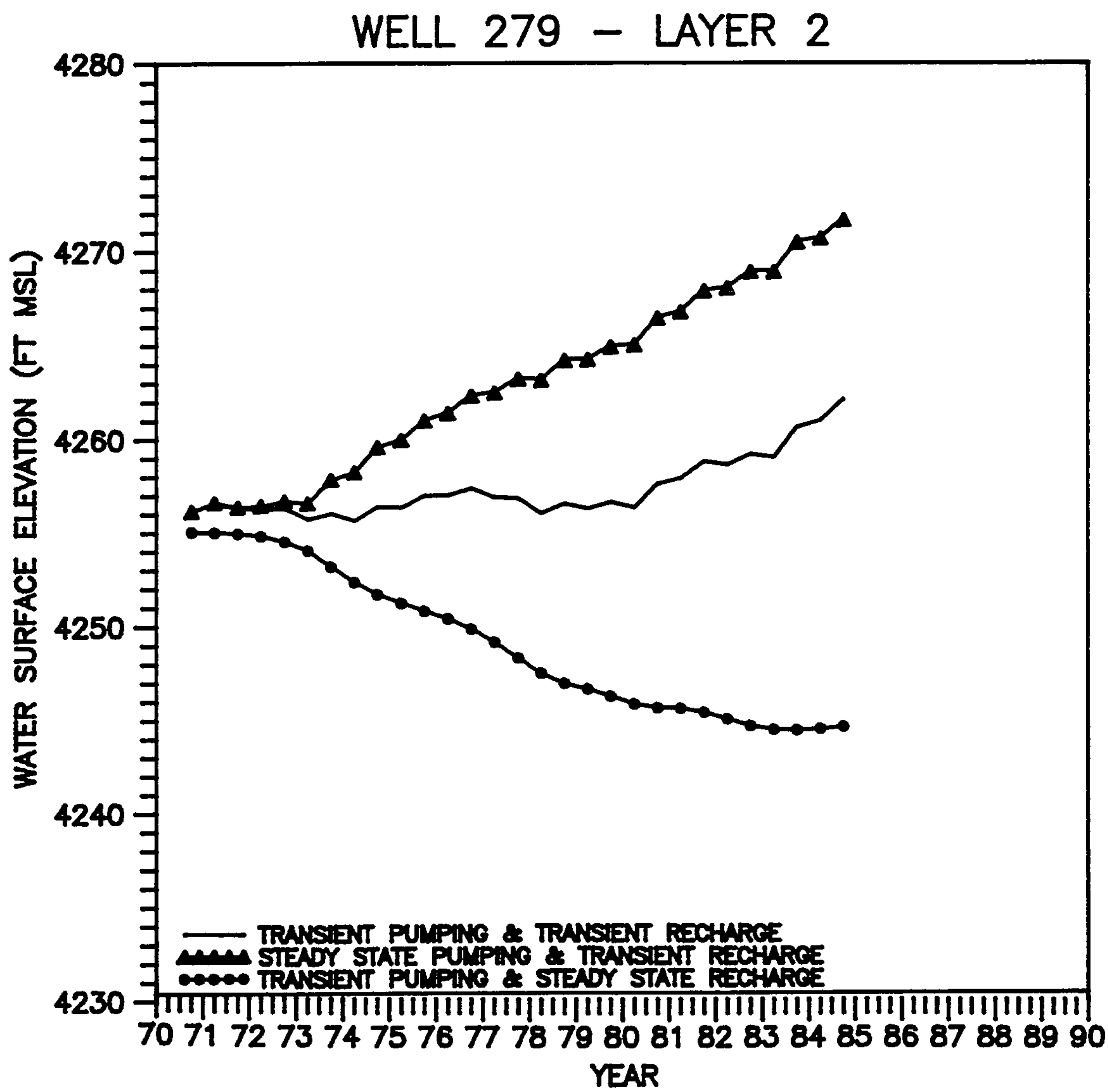

WELL 262 - LAYER 2
4160
4140
4120
4100
4080
4060
WATER SURFACE ELEVATION (FT MSL)
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR

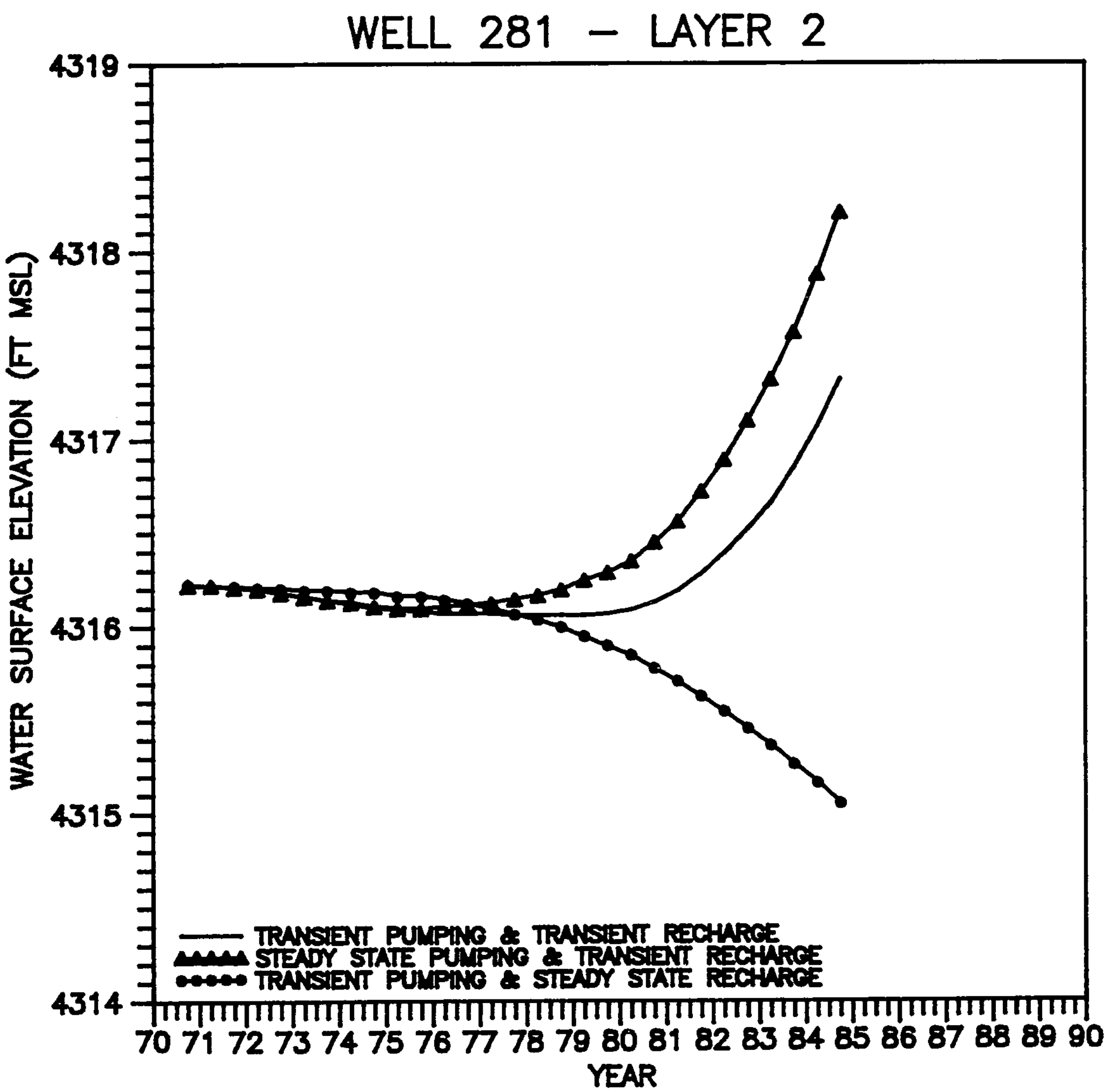

WELL 269 - LAYER 2
4160
4140
4120
4100
4080
4060
4040
WATER SURFACE ELEVATION (FT MSL)
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR

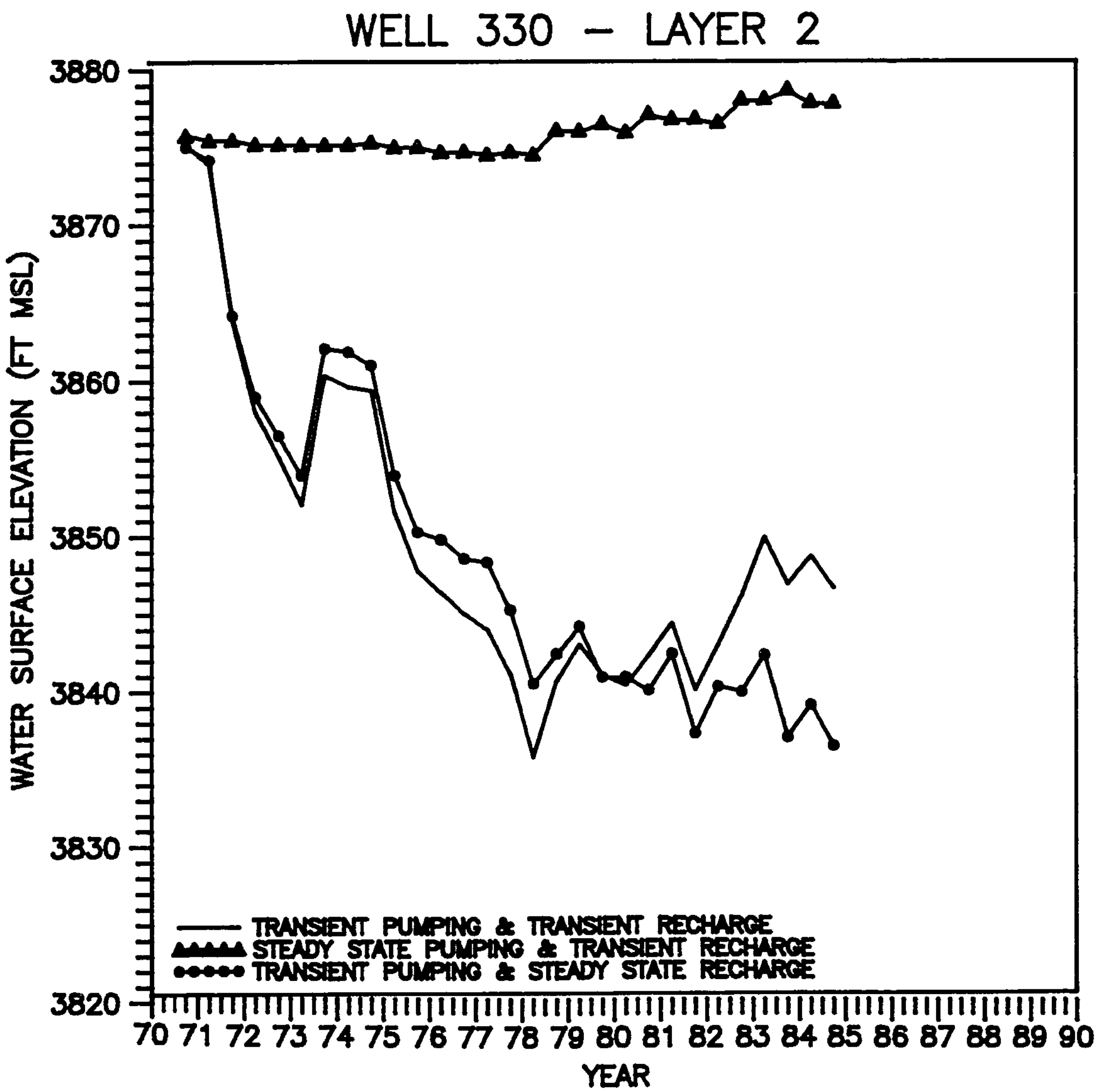

WELL 270 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
4160
4140
4120
4100
4080
4060
4040
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR

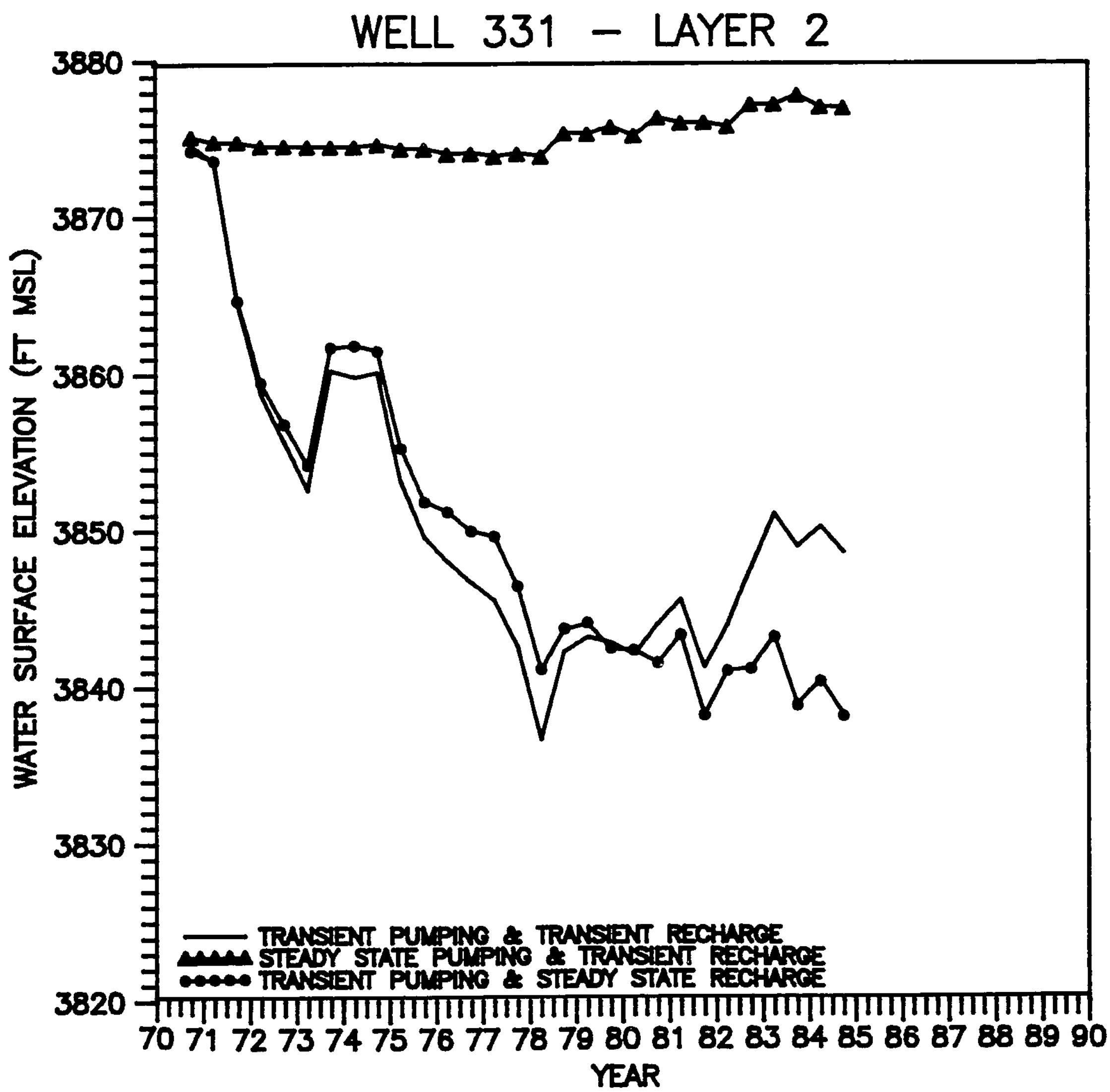

WELL 275 - LAYER 2
4160
4140
4120
4100
4080
4060
WATER SURFACE ELEVATION (FT MSL)
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE

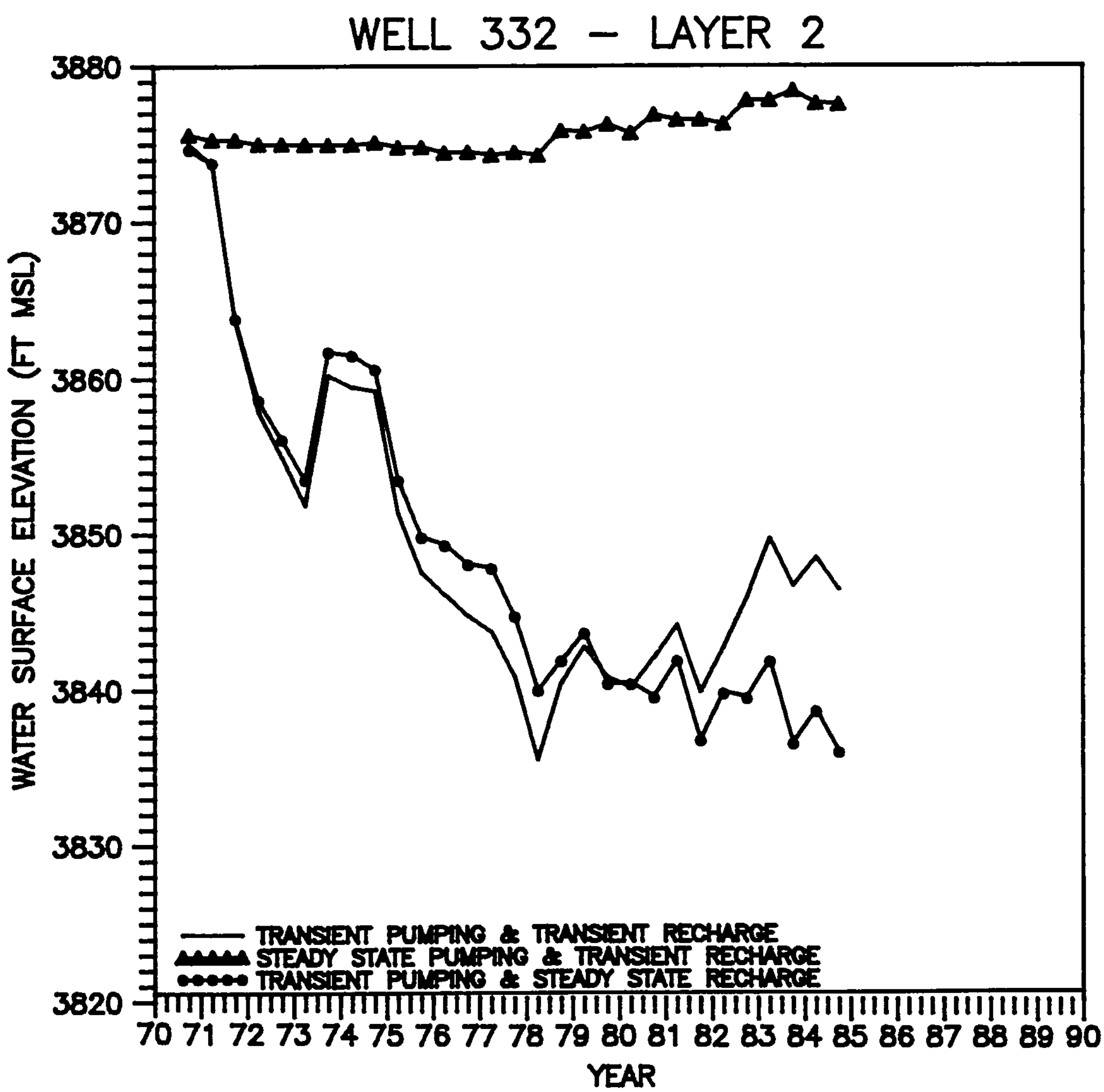

WELL 277 - LAYER 2
4400
4395
4390
4385
4380
4375
4370
WATER SURFACE ELEVATION (FT MSL)
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR


WELL 279 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
4280
4270
4260
4250
4240
4230
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE


WELL 281 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
4319
4318
4317
4316
4315
4314
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE


WELL 330 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
3880
3870
3860
3850
3840
3830
3820
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR


WELL 331 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
3880
3870
3860
3850
3840
3830
3820
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR


WELL 332 - LAYER 2
WATER SURFACE ELEVATION (FT MSL)
3880
3870
3860
3850
3840
3830
3820
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR
TRANSIENT PUMPING & TRANSIENT RECHARGE
STEADY STATE PUMPING & TRANSIENT RECHARGE
TRANSIENT PUMPING & STEADY STATE RECHARGE

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