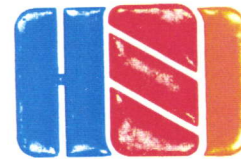


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**SOUTH TRUCKEE MEADOWS
GROUND-WATER FLOW and
TRANSPORT MODEL**

October 10, 1991

Hydro-Search, Inc.



HYDROLOGISTS - GEOLOGISTS - ENGINEERS



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TRANSPORT MODEL**

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Utility Division
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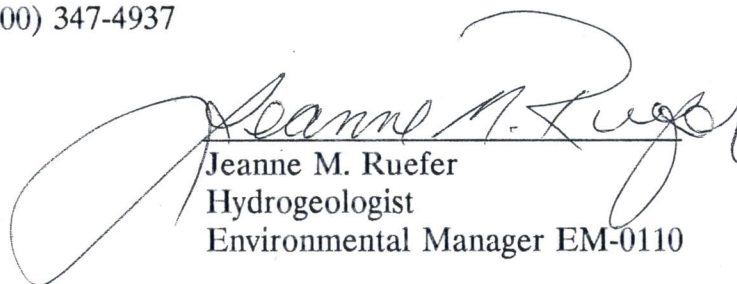

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1.0 EXECUTIVE SUMMARY

This report presents the results of ground-water flow and solute transport modeling in the South Truckee Meadows. The models are used to evaluate water supply and water quality issues, including basin recharge, the effects of municipal water supply wells, and the relationship between ground and surface water. Water quality effects in Steamboat Creek are also analyzed.

1.1 Objective

The objective of building a numerical model of the South Truckee Meadows is to provide the Utility Division with a flexible water resource planning tool. Specific modeling objectives include:

- ♦ quantification of recharge, natural and man-made;
- ♦ quantification of discharge;
- ♦ quantification of geologic and physical parameters for the major hydrostratigraphic units;
- ♦ simulation of basin-wide water-quality mixing from the principal recharge sources; and
- ♦ simulation of water quality impacts to Steamboat Creek.

The benefits of using a ground-water model for resource management include:

- ♦ The model provides a check on the sufficiency of hydrogeologic characterization data available for the South Truckee Meadows;

- ♦ Placement of water supply and injection wells can be optimized within the modeled area to minimize well interference, inefficiencies, and aquifer depletion;
- ♦ Growth and development in the South Truckee Meadows can be evaluated with respect to water supply feasibility and constraints;
- ♦ The effects of drought on water supply can be evaluated for the modeled area; and,
- ♦ Budget projections can be made by the county for presentation to the Budget and Planning Commissioner. Ground-water modeling allows the county to assess the need for water resource exploration programs, and provides an estimate of the number and depths of water supply wells required to meet future needs.

A ground-water model has credibility only when its assumptions, methodology, and data interpretations are explained and documented. For example, consider that the MODFLOW modeling code has four types of boundary conditions. Each has advantages and disadvantages, and model results may vary significantly, depending on which type is used. Thus, the rationale for choice of boundary conditions is a consideration in establishing credibility for the model. Interpretation and use of input data also have a significant effect on model results. Thus, the rationale for data analysis is another consideration in establishing model credibility.

The primary objective of this report is to promote acceptance outside of the Utility Division of decisions based on the model described herein. This is accomplished with these specific objectives:

- ♦ documentation and description of the conceptual model and design of the numeric model;

- ♦ documentation and description of the data, methodology, and assumptions used for the numerical model; and
- ♦ interpretation of the results of model simulations.

1.2 Results and Conclusions

The ground-water flow model is used to simulate the effects of pumping existing and proposed production and injection wells on the ground water system. The water quality model simulates the transport of chloride from the geothermal system.

Model Calibration

The numerical model is calibrated to a level of accuracy where most of the predicted water levels are within plus or minus 1.5% of observed values. The assumption that observed water levels are in steady-state results in a comparable limitation on the accuracy of observed water-level contours. Therefore, most of the modeled water levels are calibrated to the optimum level of accuracy. Predicted recharge and discharge rates are in good agreement with estimated values, the largest discrepancy being 22.6% (discharge to Steamboat Creek). The ranges of calibrated conductivity values for alluvium and bedrock include almost all of the observed values. At observed data locations, calibrated alluvial conductivities tend to be somewhat higher than observed values.

1.2.1 Scenario 1

In Scenario 1, existing wells are pumped at 75% of maximum capacity, discharging 6896 af/yr. Maximum predicted drawdown is 40 feet after 20 years at STMGID #6. This scenario results in no excessive drawdown, and appears to be a viable alternative for long-term water supply.

1.2.2 Scenario 2

Scenario 2 predicts the effects of pumping existing wells and 5 proposed wells at 75% of maximum capacity. The total discharge rate for these wells is 8892 af/yr. Predicted drawdown after 20 years in the vicinity of the Mount Rose Fan is about 45 feet. The layer-one block containing STMGID #8 is dewatered in this scenario, indicating that the discharge rate for this well is too high. This scenario resulted in widespread drawdown of over 30 feet, causing considerable depletion of storage in the aquifer.

1.2.3 Scenario 3

The effects of operating two proposed injection wells are simulated in Scenario 3. The net discharge rate for this scenario is 4557 af/yr. Maximum predicted drawdown after 20 years is about 45 feet in the vicinity of the Mount Rose Fan. Predicted ground-water mounding appears to stabilize at 15 feet.

In this scenario, drawdown is concentrated in the Mount Rose Fan, with 10 to 15 feet less drawdown than for Scenario 2. This amount of drawdown is still sufficient to cause significant depletion of storage in the Mount Rose Fan.

After 5 years of pumping, drawdown associated with pumping wells located in the Mount Rose Fan interferes with the injection wells, causing the areal extent of mounding to decrease. This will reduce the effectiveness of the injection system for temporary storage of ground water.

1.2.4 Scenario 4

Scenario 4 simulates the effects of discontinuing irrigation in the South Truckee Meadows on discharge to Steamboat Creek and evapotranspiration. Cessation of irrigation reduces discharge to the creek by 9.5%, and evapotranspiration by 16.8% after a 20 year period.

1.2.5 Scenario 5

Changes in recharge rates due to prolonged drought are simulated in Scenario 5. Predicted recharge to the Mount Rose Fan is decreased by 12.6% after a five year drought is simulated. Based upon a sensitivity analysis, the total recharge predicted for the Model should vary by less than 12.6%, due to the effects of calibration accuracy.

1.2.6 Water Quality

The water quality model simulates the transport of chloride from the Steamboat Hills area to the discharge area in the vicinity of the former Double Diamond Ranch. Maximum predicted chloride concentration in layer 1 is approximately 3200 mg/l. Predicted chloride concentrations in Steamboat Creek average about 200 mg/l.

Injecting chloride in layer 3 in the Steamboat Hills area produces a final distribution of chloride that is consistent with the observed chloride data. High concentrations of chloride are predicted in the area west of Steamboat Creek, where there are currently no data. Chloride concentrations predicted at Steamboat Creek are within the levels inferred from the work performed by Shump (1985). Until more extensive chloride data becomes available the water quality model is considered to be valid.

1.3 Recommendations

- ♦ Results of Scenario 2 indicate a considerable depletion of storage in the aquifer. To avoid this depletion, it is recommended that either fewer new wells be completed or that new wells be completed in the bedrock aquifer. In addition, the proposed well STMGID #8 should either be moved or pumped at a lower rate at the proposed location.
- ♦ In Scenario 3, the effectiveness of the proposed injection system as a storage facility can be improved by decreasing the rate of discharge from the wells located in the Mount Rose Fan area.
- ♦ Particle tracking is recommended to simulate the movement and fate of injected water, and to determine the residence time during which most of the injected water can be retrieved.

- ♦ Relocation of the proposed injection wells to areas where vertical and horizontal gradients are smaller will increase the residence time for the storage system.
- ♦ HSI recommends that the numerical ground-water flow and water quality model be transferred to a Utility Division computer. A users manual for the model should be written to facilitate the transfer process.
- ♦ The hydrologic database should also be transferred to the Utility Division. RBASE* training is required to operate the database.

2.0 INTRODUCTION

2.1 Project Background

The Washoe County Utility Division has conducted numerous water resources investigations, drilling programs and pumping tests in the South Truckee Meadows, resulting in a large data base. In 1985, a two-dimensional numerical ground-water model was developed for the South Truckee Meadows incorporating data collected by the Utility Division. From this model, preliminary estimates were made of recharge rates, ground-water flow directions, and future impacts from large-scale pumpage from municipal supply wells. In an attempt to gain greater insight into ground-water resources in the South Truckee Meadows, the Utility Division pursued the development of a more sophisticated numerical model and enlarged the study area to include Steamboat and Pleasant Valleys, and the Galena area. The study area is depicted on Figure 2-1.

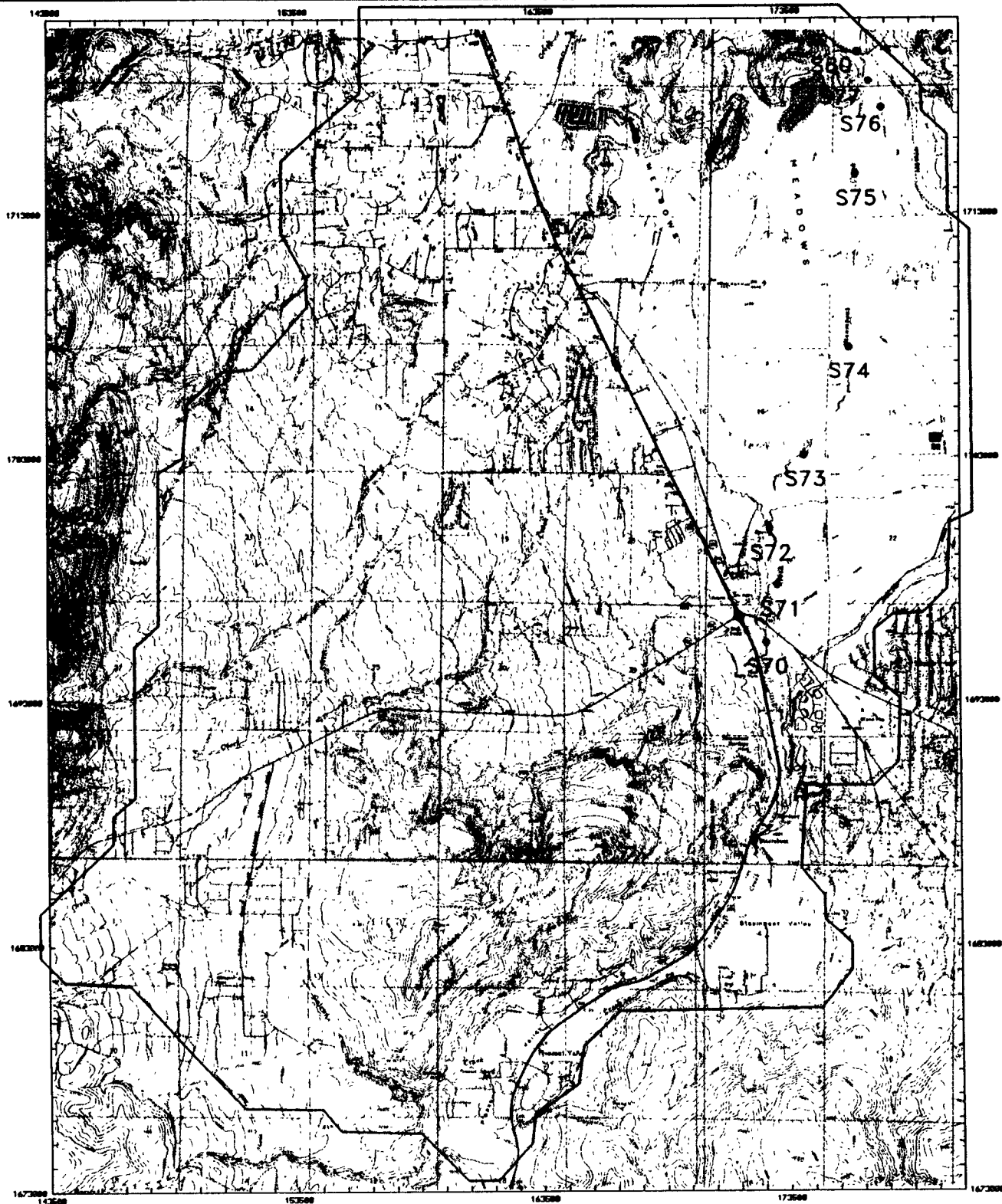
2.2 Purpose

In October 1990, Hydro-Search, Inc. was contracted by the Washoe County Utility Division to construct a three-dimensional numerical ground-water model. The purpose of this model is to be a tool for water resource management. The specific objectives of the model are; 1) to evaluate the quantity and quality of ground water, 2) predict future patterns of flow and drawdown due to large scale pumpage, and 3) assess future impacts to water quality in Steamboat Creek.

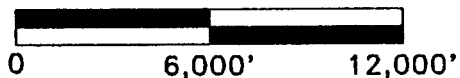
2.3 Scope

The scope of this work consists of four tasks. The tasks are: 1) to develop a computer data base of hydrogeologic data, 2) to construct a calibrated numerical model, 3) to run five predictive scenarios on the model, and 4) to construct a numerical water quality model.

This report relates the results of that effort.



SCALE: 1"=6,000'



Explanation

- Stream Sampling Locations
(from Shump, 1985)
- └ Model Boundary

South Truckee Meadows
Washoe County, NV

**Study Area and
Stream Sampling
Locations**

DATE: 10/9/91

DRAWN: **KEK**

CHECKED:

APPROVED:

DWG NO:

PROJ.: 396U23201



Hydro-Search, Inc.
HYDROLOGISTS-GEOLOGISTS-ENGINEERS
Reno Denver Milwaukee Irvine

Figure 2-1

3.0 GEOLOGIC AND HYDROLOGIC SETTING

3.1 Geology

The South Truckee Meadows is located in a transitional area between the Sierra Nevada Province and the Basin and Range Province. The area is bounded by the Carson Range to the west and the Virginia Range to the east. The northern and southern ends of the basin are marked by the Huffaker Hills and the Steamboat Hills respectively. The major features of the region are the result of a combination of Basin and Range faulting, upwarping of mountain blocks and downwarping of basins, and faults associated with this flexure (Bingler and Bonham, 1976). The regional geology is well described by Thompson and White (1964).

3.1.1 Regional Structure

Uplift of the Carson Range during the Cenozoic appears to have been a result of flexure. The basin between the Carson and Virginia Range containing the South Truckee Meadows developed as a result of flexure and normal faulting. The basin is deepest along Steamboat Creek, north of Steamboat Springs (Thompson and White, 1964).

Extensive faulting has occurred in the study area due to large scale regional extensional forces associated with the Basin and Range Province (Thompson and White, 1964). These faults predominately trend north-south and many are presently active (Cordova, 1969). Several scarplet grabens have been formed on the Mount

Rose and Galena Fans, most notably in T18N, R20E, Section 30. According to Cordova, approximately 60% of the recent scarps in the study area are reverse scarplets. Cordova proposes that many of the scarplets are actually secondary features due to gravity rather than tectonic activity.

A unique structure of the region is the Steamboat Hills and the Steamboat Springs Geothermal Area. The Steamboat Hills consist of a granite basement intruded by volcanics (basalt to rhyolite). The structural relief is provided by a combination of uplift and normal faulting. These hills are the site of a geothermal discharge area thought to have originated one million years before present (White, et al, 1964). Presently active thermal springs emerging from vents and fissures are probably associated with continued volcanic activity.

3.1.2 Regional Stratigraphy

The regional stratigraphy is discussed in terms of the hydrostratigraphic units used in the ground-water flow model. The units used in the model are bedrock, which consists of volcanics and sedimentary rock, and alluvium.

3.2.1.a Bedrock

The volcanic bedrock consists of flows and stratified tuff-breccias of the mid-Pliocene Kate Peak Formation. The volcanic formation intrudes and overlies the Cretaceous granodiorite of the Carson Range. Near vents, large xenoliths of granodiorite are

present in the intrusion. The flows and tuff-breccias of the Kate Peak Formation are areally extensive in the South Truckee Meadows, where it underlies and interfingers with the Truckee Formation. The minimum thickness of the Kate Peak is 1000 feet in the project area.

The Kate Peak Formation is overlain by the sedimentary Truckee Formation in the Double Diamond area of the South Truckee Meadows. In this area, the sedimentary unit is considered part of the bedrock for the purposes of modeling. The Truckee Formation consists of Miocene to Pliocene age deposits of lake and stream deposits (Thompson and White, 1964). Deposition of Truckee Formation sediments occurred primarily in structural basins, where the thickness of the unit may exceed 2000 feet.

Figure 3-1 depicts the elevation of the top of bedrock in the numerical model. Bedrock elevation is determined from well logs and exploration borehole data.

3.1.2.b Alluvium

Alluvium in the South Truckee Meadows consists of Pre-Lake Lahonton stream and lake deposits and younger alluvial deposits. Gravels, sands and silts of the Pre-Lake Lahonton deposits are distinguished from younger alluvium by the presence of mature soil horizons, rotted granodiorite boulders, and structural deformation. Pre-Lake Lahonton deposits are areally extensive in the fans of Galena, White, Thomas and Dry Creeks. Younger alluvium overlies the Pre-Lake Lahonton deposits in the

Double Diamond area and Pleasant Valley. Alluvial thickness in the South Truckee Meadows reaches 750 feet, based on analysis of well logs.

3.1.3 Geologic Cross Sections

Four geologic cross sections for the Mount Rose Fan are shown in Plates 1 and 2. A location map is included on Plate 2. Also shown on the map are the locations of test holes and municipal wells where hydrogeologic information exists.

Cross-section A-A' is a west-east schematic from the top of the fan to the valley floor. A mountain front fault is mapped and an inferred dip is depicted. The Serendipity Lane fault is mapped in the Steamboat Hills in T18N, R19E, Section 36 and is inferred to extend to the northwest through the western half of Section 25 and beyond. STMGID wells 5 and 6 are on opposite sides of this fault. It appears that this fault inhibits groundwater movement as indicated by a much higher potentiometric head on the west side of the fault. Analysis of data from a pump test performed on well STMGID #6 indicates that an impermeable boundary was reached, interpreted as being caused by the Serendipity Lane fault. Additional evidence of this fault is a small ground water discharge area in the Whites Creek drainage in Section 25, west of the fault trace.

A similar situation exists at the Lancers fault, located in T19N, R20E, Section 19.

The offset of the potentiometric head is not apparent at the scale of the cross

section. It can be seen from the cross section that a small graben has been formed in the Whites Creek drainage in Section 19. The volcanics are much higher in elevation in Monitor Wells 3 and 4 than in STMGID PW#3. In T18N, R20E, Section 21, on the valley floor, a Phillips Petroleum Stratigraphic test hole drilled to depth of 2000 feet, encountered alternating lenses of gravel, sand, clay and volcanics. According to the log, the individual volcanic intervals were never thicker than 20 feet. The volcanic layers may represent the basalt member of the Truckee Formation, as the lower Truckee is thought to have been deposited contemporaneously with the Kate Peak Formation (Thompson and White, 1964).

Cross-section B-B' parallels the slope of the Mount Rose Fan from southwest to northeast, perpendicular to the topography. At the southwest end of the cross section, a log of the Winburn Well indicates alluvial thicknesses of at least 480 feet at the mountain front. At STMGID MW#1 an alluvial thickness of 600 feet is encountered above volcanic bedrock. The lithologic log from STMGID MW#1 indicates that alluvial grain size generally diminishes with depth and cemented sands and gravels overlie the volcanics. At the Picollo Well, mixed alluvium is encountered to a depth of 400 feet, with reported amounts of clay increasing with depth. The Double Diamond Well #1 penetrates 150 feet of clay through boulder-sized alluvium before encountering 40 feet of reddish-purple andesite (total depth = 190 feet). This same approximate description also was noted in STMGID test holes that encountered volcanics or clays inferred to overlie the volcanics. Finally, the South

Truckee Meadows Waste Water Treatment Plant well was drilled to a depth of 250 feet, encountering 70 feet of mixed sand and clay lenses above a light blue/grey andesite.

Thick sequences of alluvial sands, clays and gravels are encountered in the fan area of cross-section B-B'. Alluvium thins out in the northeast portion of the cross-section, where pyroclastic breccia and lahars have formed the Huffaker Hills.

Cross-section C-C' traverses from the Steamboat Hills north to the North Truckee Meadows. Phillips Petroleum Stratigraphic Test Holes 14 and 5 were both drilled to depths of approximately 2000 feet and encountered granodiorite at 80 and 370 feet respectively, below undifferentiated alluvium. Between STMGID PW#3 and MW#4 the volcanics are offset, probably due to faulting. The lithology at STMGID PW#1 is similar to that at PW#3. Thus, PW#1 is assumed to be in the graben depicted in cross-section A-A'.

Cross-section D-D' traverses from the Dry Creek drainage southeast to the Steamboat Hills. At the Dry Creek drainage the Hunter Creek Member of the Truckee Formation is exposed. Field inspection shows cemented silt/clay lenses dipping at 40 degrees and striking north. Alluvium overlies the Truckee Formation outside the Dry Creek drainage. Water-level elevations in the bedrock aquifer were measured in a production well located approximately 30 feet from STMGID PW#4

and in the Phillips Petroleum Stratigraphic test hole #5. Pumping from these wells has no discernable effect on the water level in STMGID PW#4.

Cross-section E-E' (Figure 3-2) extends from the Carson Range front east to the Virginia Range. This schematic cross-section depicts the location of the top of bedrock for the numerical model, relative to the land surface. The range front on both the Carson and Virginia Ranges is shown as steeply sloping beneath a thick layer of alluvial material.

3.2 Regional Hydrologic Setting

3.2.1 Occurrence and Movement of Ground Water

Figure 3-3 illustrates water level elevations in alluvium, based on measurements taken in domestic and municipal water-supply wells. Contours of alluvial water levels are projected through bedrock areas such as Steamboat Hills, where there are no data for characterizing the shallow flow system. Bedrock water-level elevations are shown in Figure 3-4, based on water-supply and geothermal wells that are generally 500 to 1000 feet deep.

Ground water in both the alluvium and the bedrock flows from the mountain front east toward the discharge area located in the vicinity of the former Double Diamond Ranch. A portion of the flow from the Galena Fan is diverted into Pleasant Valley, where movement is northward through Steamboat Valley and into the discharge area.

3.2.2 Recharge and Discharge Areas

Ground-water recharge was estimated for the Mount Rose Fan from work performed by the Utility Division. Three methods were used to derive an average recharge rate of approximately 9,000-15,000 af/yr. These methods were the Maxey-Eakin, the Arteaga-Durbin and an estimation based upon the cross-sectional area of the creek canyon mouths.

Ground-water recharge also occurs from irrigation, stream infiltration, and septic tank effluent. Irrigation is the most significant of these sources of recharge, estimated at 2400 af/yr in the South Truckee Meadows.

Several irrigation ditches bring Truckee River water into the study area. Flood irrigation occurs mostly on the valley floors. Guitjens, et. al. (1978), estimated that 1 acre foot per acre (af/a) of flood irrigation water infiltrates to the water table. This figure varies widely because of soil conditions and application rates. However, since 1984 the Federal Watermaster has reduced ditch flows to more accurately reflect decreed rights and current needs. Also, flows have been curtailed due to drought conditions since 1988. For example, ditch flows ceased to the South Truckee Meadows on August 25, 1990. The effect of these events is a reduction in ground-water recharge from the 1 af/a value. Irrigated land application rates have historically ranged from 4.0 to 4.5 feet per acre on both alfalfa and pasture.

The ground-water discharge area in the South Truckee Meadows is located in sections 3, 4, 9, 10, 15 and 16. The discharge area is characterized by a shallow water table and flowing wells. Discharge occurs as evaporation, transpiration, and discharge into Steamboat Creek. Transpiration also occurs on the periphery of this area in the unsaturated zone where the water table is as much as ten feet below land surface. The approximate surface area of the discharge area is 5,000 acres. Aerial photo interpretation indicates that phreatophytes grow on approximately 1,900 acres, irrigated pasture occupies 1,950 acres, 500 acres contain irrigated alfalfa, and sage and salt evaporative areas encompass 550 acres.

Evapotranspiration from croplands is estimated to remove about 3.7 feet of water per year (Guitjens, et al., 1979). Phreatophyte evapotranspiration as well as free standing water and salt evaporative areas are estimated to remove 4.8 feet per year. Ground-water discharge to Steamboat Creek is estimated at 6600 af/yr by Schump, for stations S70 through S77 (1985, pp. 58, Table 8).

3.2.3 Major Surface Streams

Steamboat Creek discharges from Washoe Lake in Washoe Valley. It flows northward and enters the Truckee River near Vista in the North Truckee Meadows. The major tributaries of Steamboat Creek are Galena and Browns Creeks in Pleasant Valley and Whites and Thomas Creeks in the South Truckee Meadows. The tributaries to Steamboat Creek are perennial and originate in the Carson Range.

3.2.4 Hydraulic Properties

The Utility Division supplied HSI with the results of pumping tests performed on municipal wells in the South Truckee Meadows. Hydraulic properties for the numerical model were estimated from these data. A table of pumping test results and associated data are located in Appendix A.

3.2.5 Steamboat Springs Geothermal System

The Steamboat Springs Geothermal System is not specifically addressed in this study. White's work is the most complete study to date. White indicated that 1 - 2 cfs of geothermal water represented the flux rate through the system. This estimate is based on measurements of spring discharge and inflow to Steamboat Creek. Geothermal water also enters the ground-water system by upwelling along faults. These areas are depicted by Bateman and Scheibach in their 1975 DRI report titled, Evaluation of Geothermal Activity in the Truckee Meadows, Washoe County, Nevada.

Geothermal water appears to be composed of meteoric water. Meteoric water enters the system as precipitation recharging at the mountain fronts of the Carson and Virginia Ranges, and flows to the basement rock through faults and fractures. The water is heated by magma under Steamboat Hills and rises by convection along faults (White, 1968).

3.2.6 Water Quality

Water quality analyses and data interpretations were supplied to HSI by the Utility Division.

3.2.6.a Ground-Water Quality

Water quality in the South Truckee Meadows is impacted by geothermal activity in the vicinity of Steamboat Springs. In order to delineate the geothermal influence, water quality analyses were collected from a number of sources. Most information was made available through the Nevada State Department of Human Resources. Additional analyses were collected from other sources. Throughout most of the study area the water is of excellent quality with a total dissolved solids (TDS) range of 150 - 220 ppm. The TDS increases near U.S. 395 and in the vicinity of Steamboat Springs. Bicarbonate is the dominant anion, whereas calcium, magnesium and sodium are the dominant cations. Constituents that exceed drinking water standards are arsenic, chloride, and sodium, which are related to the geothermal system. Iron is occasionally present in anomalously high concentrations, although it is difficult to ascertain whether this is due to natural processes or iron from well casings.

A primary reason for looking at water chemistry in this study is to determine the extent of geothermal influences. Geothermal waters at Steamboat Springs contain high concentrations of chloride (800-1000 ppm), sodium (500-800 ppm), sulfate (50-150 ppm), potassium (20-70 ppm), and silica (100-300 ppm). TDS values range

from 1000-3000 ppm. Geothermal waters also contain high concentrations of arsenic (0.054-4.00 ppm), boron (1.0-50.0 ppm) and fluoride (3-6 ppm). Ground-water samples from wells in the Steamboat Springs area indicate the water is predominantly a sodium chloride type (Washoe County, 1990.)

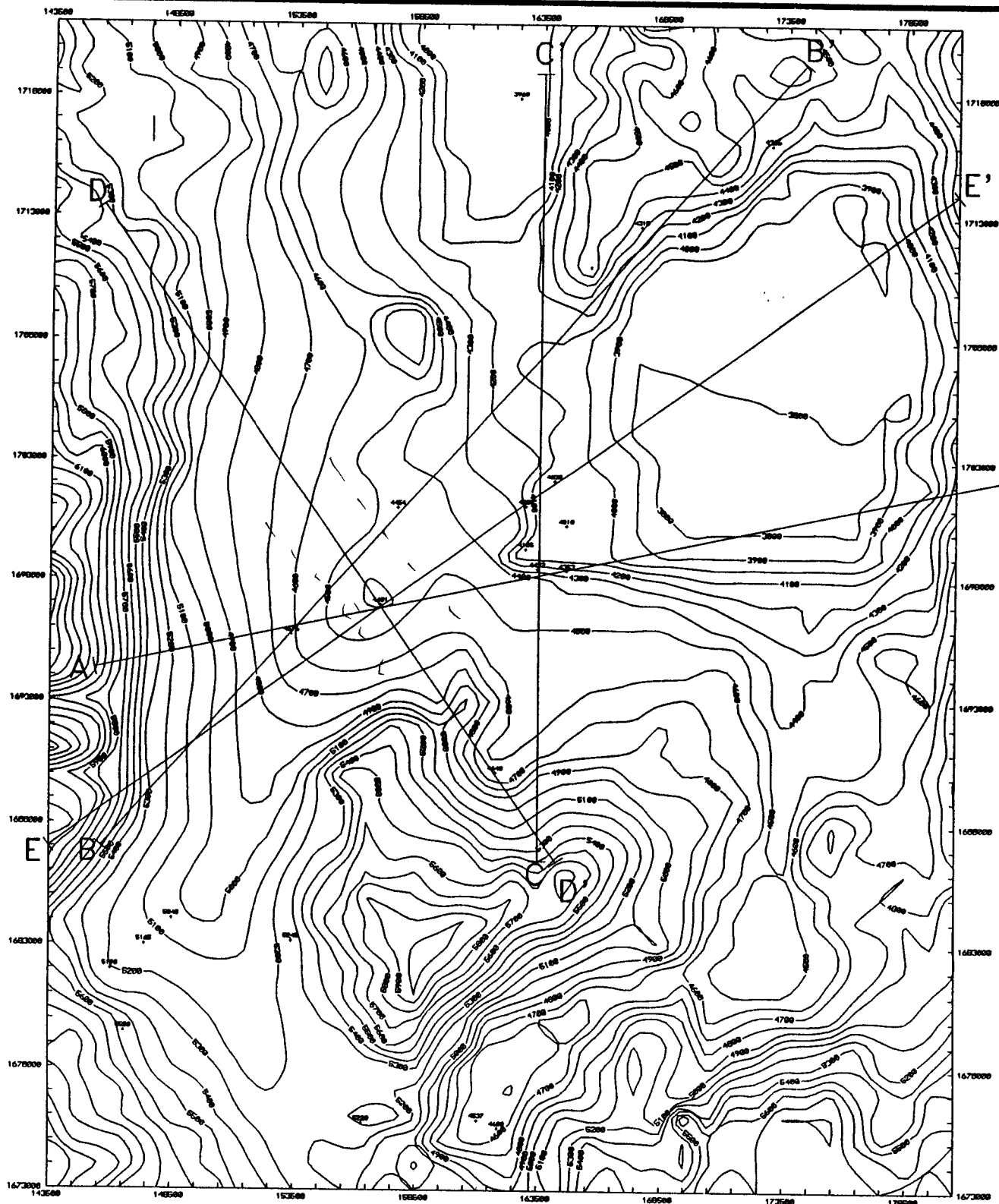
Water quality in the Virginia Range is affected by the presence of hydrothermally altered rock. Altered rock in the Range is shown by the presence of bleached zones at the surface. Ground water in the Range is characterized as a calcium-sulfate type, with sulfate as the dominate anion (Washoe County, 1990).

Chloride was selected as the constituent for modeling the impacts of geothermal water on water quality. Chloride is a major constituent contributing to the high TDS values characteristic of geothermal water. Figure 3-5 shows that concentrations of chloride in alluvium appear to be highest in the east-central portion of the study area. Figure 3-6 shows that the concentration of chloride in samples from wells penetrating bedrock are highest in the vicinity of Steamboat Hills. The distribution of data for both aquifers is limited, however, and contoured trends are projected into areas devoid of data. Therefore, the utility of Figures 3-5 and 3-6 is to illustrate trends only in areas that have data.

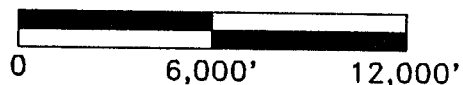
3.2.6.b Surface-Water Quality

Surface-water quality in Browns, Galena, Whites, and Thomas Creeks is excellent with concentrations of TDS ranging from 50 to 100 ppm. These waters are predominately calcium-bicarbonate type. The ditch water originating from the Truckee River has TDS concentrations ranging from 50 to 100 ppm and is also of the calcium-bicarbonate type. Steamboat Creek and ditches originating from Washoe Lake are influenced by Browns and Galena Creeks before entering the study area. These waters are a calcium/sodium-bicarbonate type, with a TDS range of 130 to 280 ppm. The Steamboat geothermal springs flow overland into Steamboat Creek and geothermal ground waters also discharge into Steamboat Creek. Consequently, the quality degrades slightly and constituents such as arsenic and boron increase significantly. The water becomes a sodium-bicarbonate type with TDS values that increase about 10 %. This occurs in the area from Rhodes Road to Geiger Grade.

Ground water in the discharge area has an impact on water quality in Steamboat Creek. The discharge area is the endpoint for both fresh and geothermal groundwater. Ground water discharges to Steamboat Creek as documented by Shump (1985). An increase in flow of about 2 - 3 cfs is common for the reaches measured. The water quality then should increase in dissolved solids. TDS concentrations in Steamboat Creek at the Narrows range from 200 ppm in the winter months to 500 ppm in the summer. TDS concentrations in Alexander Ditch at the Narrows (just before flowing into Steamboat) also range from 200 - 500 ppm.



SCALE: 1"=6,000'



Explanation

- Well location and bedrock top elevation (ft.,msl)
- Contour of equal bedrock top elevation (ft.,msl)

A A'
Cross-section base line

South Truckee Meadows
Washoe County, NV

South Truckee Meadows
Top of Bedrock
Elevation

DATE: 9/22/91

DRAWN: KEK

CHECKED:

APPROVED:

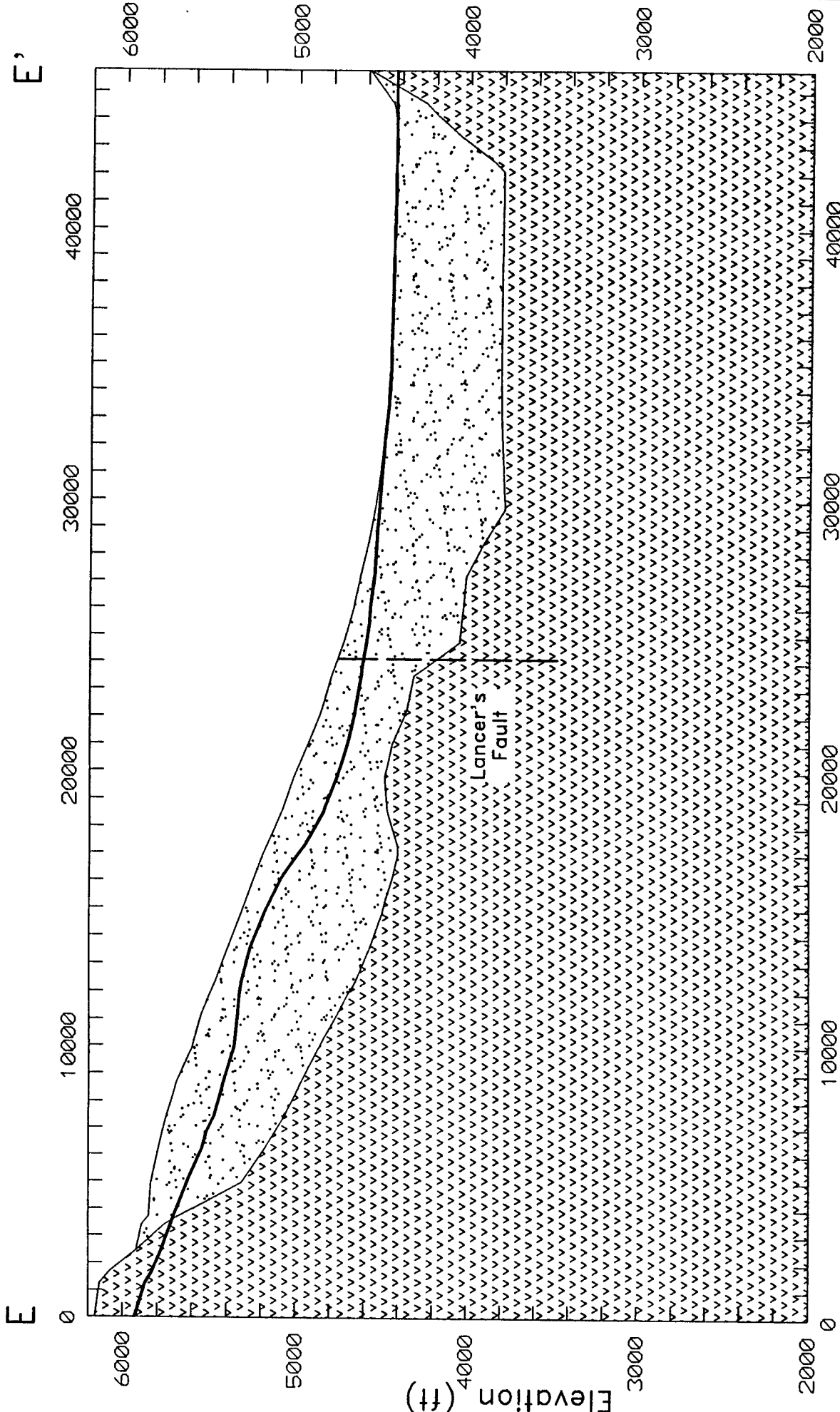
DWG NO:

PROJ.: 396U23201



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
Figure 3-1



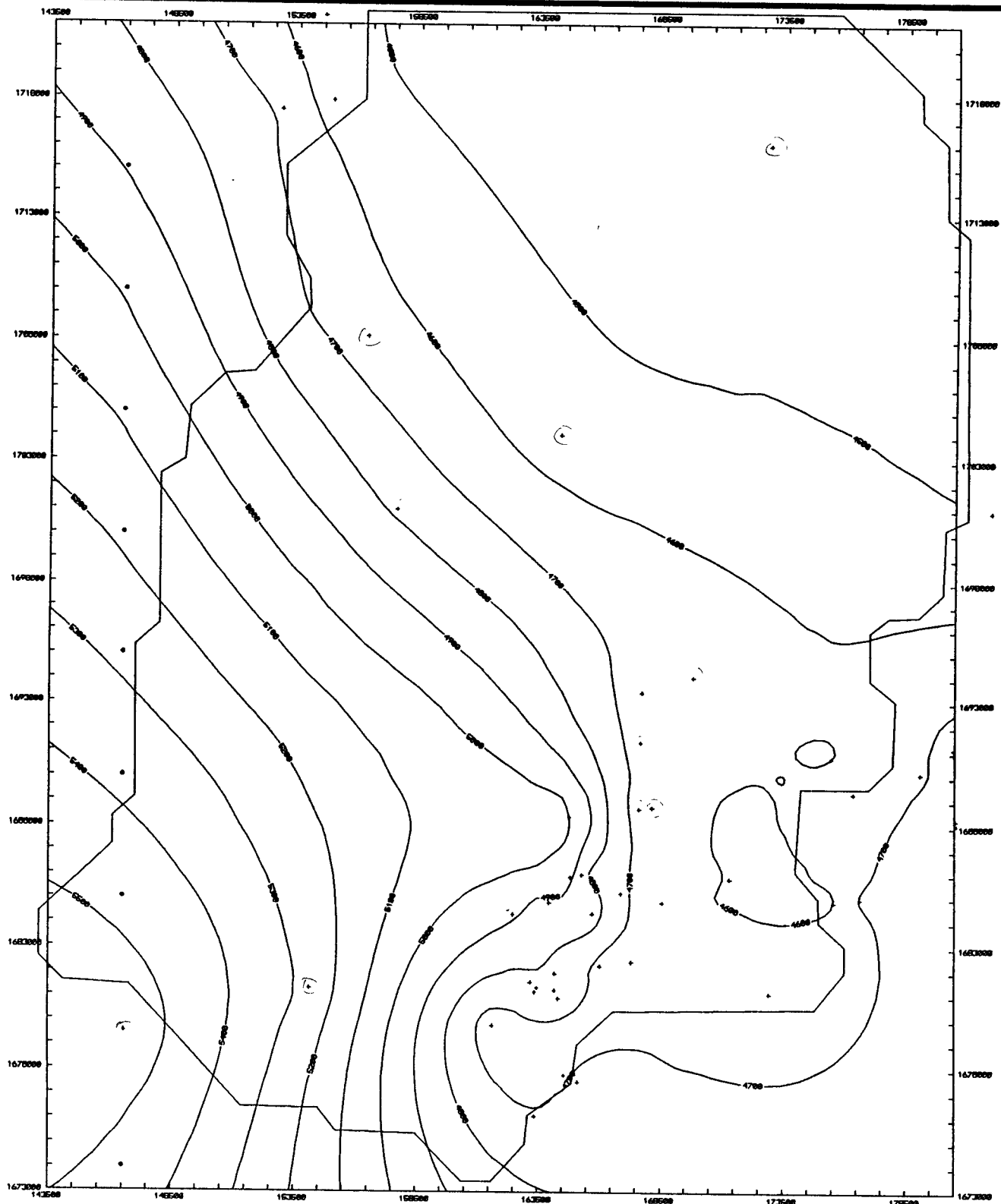
South Truckee Meadows Washoe County, NV		DATE: 9/22/91
Cross-Section E - E'		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
PROJ.: 396U23201		Figure 3-2

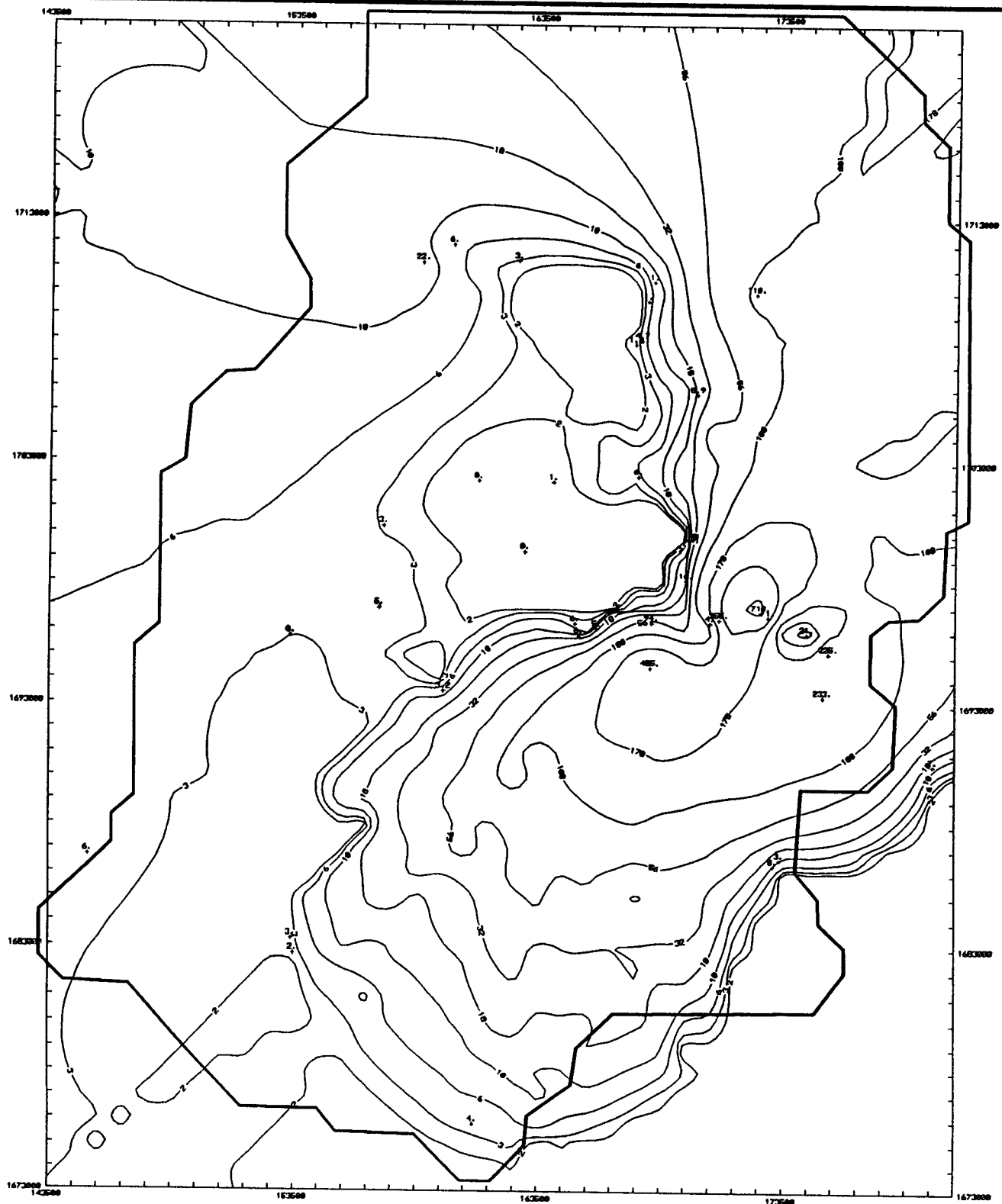
Offset (ft)

Explanation

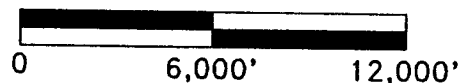
-  Alluvium
-  Bedrock
-  Alluvial water-level
-  $H:V=6.25:1$
- $X\text{-Scale } 1"=5000'$







SCALE: 1"=6,000'



Explanation

- Well location and chloride concentration (mg/l)
 - Contours of equal chloride concentration (mg/l)*
 - Boundary of modeled area
- *Contour interval is 1/4 of a log cycle.

South Truckee Meadows
Washoe County, NV

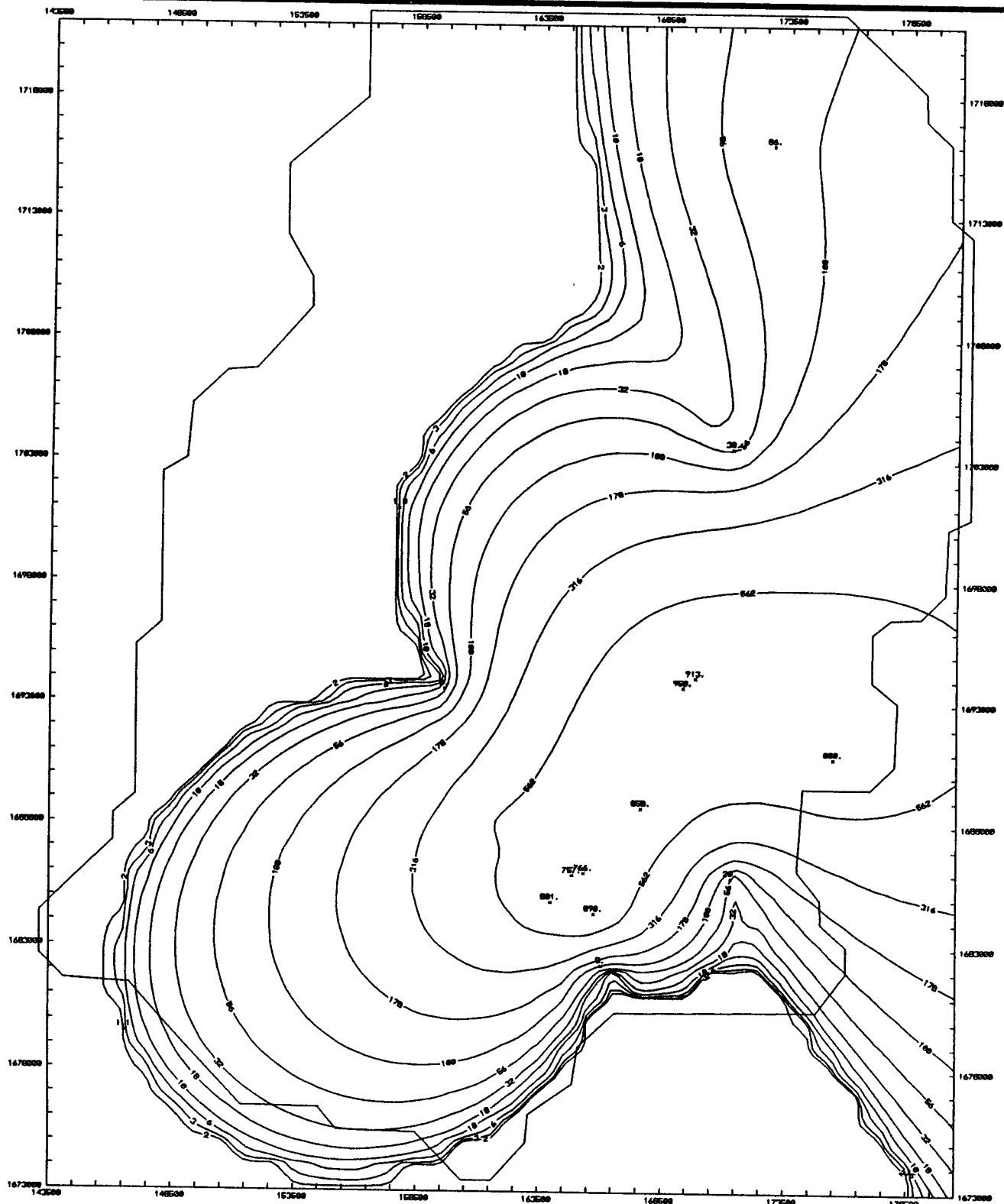
**South Truckee Meadows
Observed Chloride Concentration
in Alluvium**

DATE:	9/22/91
DRAWN:	KEK
CHECKED:	
APPROVED:	
DWG NO:	
PROJ.:	396U23201

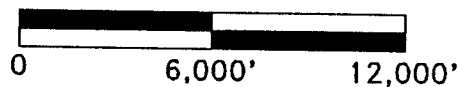


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Figure 3-5



SCALE: 1"=6,000'



Explanation

- Well location and chloride concentration (mg/l)
- Contours of equal chloride concentration (mg/l)*
- Boundry of modeled area

*Contour interval is 1/4 of a log cycle.

South Truckee Meadows Washoe County, NV		DATE: 9/22/91
South Truckee Meadows Observed Chloride Concentration in Bedrock		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201

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Figure 3-6

4.0 DATA BASE

The Utility Division's hardcopy data base of geologic and hydrologic information has been incorporated into RBASE™, a data base program for the IBM PC. Use of a computer data base allows storage of information in a consistent format, and provides easy access to data. Information can be easily printed or transferred to application programs such as LOTUS™, SURFER™, and GRAPHER™, for further analysis.

The data base contains information on a total of 281 wells. Almost all of these wells are domestic or municipal water supply wells. Of these, 56 are completed in bedrock and 195 in alluvium, with the remainder being completed in both units. Water-level measurements have been obtained from 268 wells. Six-hundred and forty seven water level measurements are included. Water quality data have been obtained from 83 wells. A total of 164 water quality analyses are incorporated into the data base.

Information stored on each well includes specifications such as northing, easting, and elevation coordinates, height of casing above land surface, depth drilled, screened intervals, aquifer(s) intercepted, U.S. Geological Survey (USGS) well name, well owner, address, and date drilled. Due to the possibility of changes in well ownership, the USGS well names are designated as the 'official' well names for this project (wells are also referred to by owner in this report). For each well, several types of data are stored, depending on data availability. These include: water-level measurements, depth to top of bedrock, water-

quality analyses, and aquifer-test analyses. Information stored in the database was verified by hand-checking computer printouts versus the original hardcopy data, and by analyzing computer-generated contour maps for various parameters.

To illustrate a typical database application, hydrographs for 23 representative wells are presented in Appendix B (Figures B-1 through B-23). These wells are distributed across the STM as shown in Figure B-24. Data for the hydrographs were selected by using RBASE™ to identify the wells that have the most measurements. All of the most-measured wells turned out to be in the southern half of the STM, so additional (northern) wells were selected to obtain a representative areal distribution (Figures B-6 through B-13, and B-15 through B-16). Data selected with RBASE™ were then transferred to GRAPHER™ for plotting. The process of data selection and plotting was accomplished in a fraction of the time that would be required without using RBASE™.

5.0 GROUND-WATER MODEL

5.1 Conceptual Ground-Water Model

The purpose of the conceptual model is to summarize the principal hydrologic features and processes of the study area. The numerical model is then designed to accurately simulate these features and processes.

Bedrock topography in the South Truckee Meadows forms a north-south trending structural basin. The STM basin is bounded on the east, south, and west by mountains, and is open to the north (Figure 2-1). The basin is filled with alluvium to a maximum thickness of 750 feet. Pleasant Valley and Steamboat Valley are minor structural basins on the southern flank of the STM basin, and are also filled with alluvium. Depth to water in the alluvium ranges from 2 feet in the northeastern corner of the STM basin (Double Diamond Ranch area) to 300 feet on the west side of the basin (Carson Range foothills). The alluvium and bedrock units are considered to be the two principal aquifers in the STM.

Ground-water recharge to the alluvium occurs mainly along the western margin of the STM basin, especially in the southwest, in the vicinity of the Mount Rose Fan. Minor recharge occurs along the southern and eastern margins. Ground-water flow is to the east and northeast in both aquifers (Figures 3-3 and 3-4). In the southwestern part of the basin there is a vertical component of flow, where the alluvium loses water downward to the bedrock aquifer. Conversely, the vertical component of flow is upward in the northeastern part of the

basin, where the alluvium gains water from the bedrock. These areas are characterized on the map of vertical gradients, Figure 5-1, as areas of positive and negative contours, respectively.

Two major outcrops of bedrock punctuate the STM alluvium and help to shape the ground-water flow system. Steamboat Hills influences the alluvial aquifer by truncating the Mount Rose Fan and diverting most ground-water flow to the northeast. In addition, the Steamboat Hills geothermal system influences flow in the bedrock aquifer by providing a major source of recharge. Huffaker Hills acts to impede the flow of alluvial ground water exiting the structural basin on the eastern half of its northern boundary. The result is that ground water and dissolved constituents tend to accumulate in the northeastern part of the alluvial aquifer, because ground water discharges primarily by evapotranspiration and flow into Steamboat Creek. To the west of Huffaker Hills, alluvial ground water exits the structural basin through its open northern boundary.

5.2 Numerical Ground-Water Model

Three-dimensional ground-water flow is simulated using MODFLOW, a numerical model developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). A finite-difference code such as MODFLOW creates a digital representation of an aquifer system by sub-dividing the system into a number of small rectangular blocks. These blocks form the rows and columns of a horizontal grid, which is repeated in the vertical direction to form 'layers'. Physical properties such as hydraulic conductivity and head are assigned to

each individual block. The complete set of blocks and their associated parameters is called the 'model', and the corresponding volume of the aquifer system is called the 'modeled region'. The size and number of blocks used to set up the model is selected according to dimensions of the modeled region, and the level of spatial resolution desired.

The code simulates the response of the actual aquifer by computing flow between each block and its adjacent blocks during a specified time step. This calculation is repeated for every block in the model, and the resulting heads are saved. These heads become the initial conditions for the next time step, and the process is repeated until the cumulative simulation time reaches a specified limit. Time steps used for the STM model are expressed in days, and distances are expressed in feet.

5.2.1 Model Design

5.2.1.a Dimensionality

A three-dimensional numerical model is used for the STM study area, in order to adequately represent the conceptual model described in Section 5.1. The three-dimensional approach has some major advantages for this study. First, the alluvial and bedrock aquifers are represented as separate units with individually-specified properties. Second, the geometry of the alluvium-bedrock interface is incorporated into the model. Finally, a two-dimensional horizontal grid cannot account for vertical flow components in the important recharge and discharge areas of the STM basin. Thus, a two-dimensional model would represent only a portion of the ground-water

flow regime, and would not include the influence of the bedrock aquifer on alluvial flow.

5.2.1.b Layer Designations

The STM model has three layers, two of which are composed of a combination of alluvium and bedrock, and a third (deeper) layer composed entirely of bedrock. This section describes how the layers are defined and how they relate to the alluvial and bedrock aquifers.

McDonald and Harbaugh (1988, pp 2-29 through 2-31) present two methods for vertical discretization of the modeled region: the rectilinear grid and the deformed grid. The first method has the advantage of honoring certain mathematical assumptions incorporated into the MODFLOW code, such as the assumption that the blocks have rectangular faces. The deformed-grid method, which is used for the STM model, has model layers which conform to geohydrologic units. The advantage of this method is that hydraulic properties and vertical heads are likely to be uniform within individual blocks, thus satisfying hydrologic assumptions of the MODFLOW code. Based on the relative importance of these advantages, the deformed-grid method produces the best model results in most instances. The rectilinear-grid method is favored where stratigraphic contact surfaces dip steeply, causing the block faces to be greatly distorted from their assumed rectangular shapes.

The essence of the deformed-grid method is that layer boundaries coincide with actual stratigraphic contact surfaces, such as the alluvium-bedrock interface. However, modifications are required where the alluvium pinches out at the margins of the basin and around the bedrock highs. At a pinch-out, alluvial thickness and transmissivity are reduced to zero, creating a discontinuity in the model grid. This discontinuity could impede the simulated exchange of ground water between the alluvial and bedrock aquifers, producing unrealistic model results. Therefore, the deformed-grid method is modified by extending the layers through pinch-out areas, to form a smooth transition from alluvium to bedrock.

Layer continuity is assured in the STM model by assigning a minimum thickness of 100 ft. for the first layer, and 200 ft. for the second layer. A consequence of the minimum-thickness constraint is that the first two layers are composed of a combination of alluvium and bedrock, with the transition occurring in the vicinity of the alluvial pinch-outs. Where the alluvial thickness exceeds the above minimum values, the alluvium-bedrock interface is used for defining the boundary between Layers two and three. Figure 5-2 is a cross section showing the layer boundaries and thicknesses.

A brief description of the rationale behind the layer designations is presented below.

- ♦ Layer 1 - The top elevation of the first layer is defined by the alluvial water table where the layer is composed of alluvium, and by the projected alluvial

water table where the layer is composed of bedrock (Figure 3-3). The thickness of Layer 1 corresponds to the saturated interval intercepted by domestic water-supply wells in the area (constrained to a minimum of 100 ft.). Contours of Layer 1 thickness are shown in Figure 5-3. The layer is defined such that predicted water levels correspond to observations from domestic wells. This feature increases the practical value of the model by providing results that are representative of conditions in existing wells. The MODFLOW layer type for this layer is 'one', meaning that it is unconfined, and transmissivity is a function of current saturated thickness at each block (McDonald and Harbaugh, 1988, pp 5-34).

- ♦ Layer 2 - The top elevation of the second layer is defined as the elevation of the bottom of Layer 1 (Layer 1 top minus the Layer 1 thickness). The thickness of Layer 2 is defined as the Layer 2 top elevation minus the elevation of the top of bedrock. Where this difference is less than 200 ft., the thickness is re-defined to 200 ft. Contours of Layer 2 thickness are shown in Figure 5-4. Layer 2 is always bounded above by the bottom of Layer 1 (Figure 5-2). In areas where the thickness constraint is not in effect, Layer 2 is bounded below by the alluvium-bedrock interface. Some of the municipal wells in the STM penetrate Layer 2. However, STMGID #4 is the only well screened solely in this layer. The MODFLOW layer type for this layer is 'two', meaning that it may alternate between confined and unconfined conditions.
- ♦ Layer 3 - The top elevation of the third layer is defined as the elevation of the bottom of Layer 2 (Layer 2 top minus the Layer 2 thickness). The thickness of Layer 3 is assigned a uniform value of 1760 ft., based on calculations performed during model calibration (Section 5.4). The purpose of Layer 3 is to simulate water levels observed in bedrock wells, and to allow the model to exchange flow between the alluvial and bedrock aquifers. The MODFLOW layer type for this layer is 'zero', because the layer is confined.

5.2.1.c Modeled Area

The modeled area extends from the center of Huffaker Hills in the North to the southern tip of Pleasant Valley in the South. In the east-west direction, the modeled area extends from the Virginia Range foothills to the Carson Range foothills. The approximate range of thickness spanned by the model is from 2100 to 2500 ft.

Vertically, the model begins at the water table and extends downward into the bedrock aquifer to an elevation which depends on the local value of total thickness.

The areal extent of the modeled region is the same for all three layers, but conditions in the first layer are used to locate the model boundary. The western model boundary is defined where the alluvium begins to pinch out on the east flank of the Carson Range. Specifically, the modeled region begins with the western-most blocks that have a full thickness of alluvium (little or no bedrock) in Layer 1. This scheme takes advantage of the fact that heads in the alluvium are well known, while heads in the Carson Range are not. The eastern model boundary is defined in a similar fashion, where the alluvium begins to pinch out on the west flank of the Virginia Range. The southern model boundary is based on alluvial pinch-outs on the southern flank of the Mount Rose Fan, and the southern end of Pleasant Valley. The rest of the southern boundary consists of a line connecting these two areas, passing south of Steamboat Hills. The northern model boundary is simply an east-west line passing through the center of Huffaker Hills.

5.2.1.d Grid Dimensions

The model for the South Truckee Meadows has 38 columns, 49 rows, and 3 layers. Figure 5.5 shows the model grid as a set of north-south and east-west lines that intersect at model block centers. The horizontal block dimensions are 1000 ft by 1000 ft, so the grid spans 38000 ft in the east-west direction and 49000 ft in the north-

south direction. The vertical block dimension reflects the layer thickness at each block. This thickness is 100 to 300 ft for Layer 1, 200 to 650 ft for Layer 2, and 1760 ft for Layer 3. The area of the full grid is 66.8 sq. miles, and the area of the modeled region is 44.3 sq. miles. There are 1236 active blocks per layer for a total of 3708 in the modeled region.

5.2.1.e Time Steps

The MODFLOW code can use a fixed-length time step, or a multiplication factor to increase the length of successive time steps. The STM model uses a multiplier of 1.4 to 1.5 for increasing the step lengths up to a maximum of 2.5 years. Thereafter, a multiplier of 1.0 is used to maintain the step length at 2.5 years for purposes of obtaining model output at specific times. The initial step length is relatively short (between one and two days), because each simulation typically includes a new set of stresses, and accuracy is improved if the model responds quickly. As the simulation progresses, flow changes tend to occur at slower rates, and so the time step length can be increased with little effect on accuracy.

5.2.2 Model Input Data

5.2.2.a Geologic Parameters

The stratigraphic distinction between bedrock and alluvium is incorporated into the bedrock top surface shown in Figure 3-1. No further subdivision of geology is used for the model. Top-of-bedrock data values for the model blocks were developed and

entered by hand, using information from drilling logs in conjunction with topographic and geologic maps. The resulting surface is used to define the boundary between layers two and three (Section 5.2.1.b) as well as the boundary of the model area (Section 5.2.1.c). The top-of-bedrock surface primarily represents the contact between alluvium and volcanic bedrock, but in the ^{NW} northeastern STM basin, it is the contact between alluvium and sedimentary rocks of the Hunter Creek Formation. The surface includes Steamboat and Huffaker Hills, and scarps due to the major faults of the study area.

5.2.2.b Hydrologic Parameters

Wells in the STM database are classified according to the aquifer(s) they intercept: alluvial, alluvial/bedrock, or bedrock. These classifications are used to select water level, aquifer test and chemical data for characterizing the two aquifers. Data from the alluvial/bedrock wells are used only for reference, because they are not representative of either aquifer. All data for each aquifer are input to a kriging program (see Appendix C), which generates a value at each model block. The kriged block values form a surface which can be contoured and input to MODFLOW.

Water-level data in the STM database are mostly sporadic measurements, made over a long period of time. Figure 5-6 shows the number of wells measured during each year from 1970 through 1991. A total of 268 wells were measured at least once, yet the largest number measured in a single year is only 98 (in 1982). The most complete

set of contemporaneous measurements occurred between Fall, 1990 and Spring, 1991 when a total of 120 wells were measured. A kriged water-level surface based on these measurements would exclude more than half of the total wells. This surface could easily differ by 100 ft. from water levels measured at the excluded wells, due to the large range of water-level elevations across the study area (about 1570 ft. for the alluvial aquifer).

The STM model avoids the significant loss of accuracy that could result from excluding a large number wells, by using the most recent measurement for each well. The loss of accuracy associated with this method is relatively small, based on an evaluation of hydrographs for STM wells. Appendix B presents hydrographs for 23 wells in the study area. Of these, thirteen extend back to 1980 and three extend as far back as 1970. The typical variation in water level for any particular hydrograph is about 20 ft., which is much less than the estimated 100 ft. errors that could result from excluding a large number of wells (as in kriging with contemporaneous data).

The use of most-recent measurements as representative water levels for the model provides maximum benefit from available data at the expense of having kriged surfaces that are noncontemporaneous. Contoured surfaces developed by this method are shown in Figures 3-3 and 3-4, for the alluvial and bedrock aquifers. For purposes of model calibration (Section 5.4), these water-level surfaces are assumed to represent steady-state conditions.

Observed values, used as
starting conditions for model
calibration process

Alluvial and bedrock water levels (Figures 3-3 and 3-4) are used as initial heads for Layers 1 and 3, respectively. Initial heads for Layer 2 are calculated as a weighted average of the initial heads in the other layers, using layer-elevation difference as the weighing factor.

Aquifer properties for the alluvium and bedrock are obtained from the table presented in Appendix A. Hydraulic conductivity surfaces for model input include kriged data for the alluvium, ranging from 1.3 to 16.6 feet per day (ft/d), and a representative constant value of 0.9 ft/d for the bedrock. Constant storage coefficient values of 0.0014 for Layer 2 and 0.00125 for Layer 3 are input to the model (these are the median values for the alluvium and bedrock, respectively). A specific yield value of 0.1 is assumed for Layers 1 and 2. Layer 2 has both a storage coefficient and a specific yield, because it can convert from confined to unconfined conditions (MODFLOW layer type two). Note that storage coefficient and specific yield are specified by layer, because they are depth-dependent properties, while hydraulic conductivity is specified by aquifer because it is primarily a material-dependent property.

Layers 1 and 2 have blocks that are composed of a combination of alluvium and bedrock (Section 5.2.1.b), so the effective hydraulic conductivity depends on the proportion of each material that is present. To account for different aquifer materials, the hydraulic conductivity at each block is computed as a thickness-

weighted average of the alluvial and bedrock conductivities assigned to the block. The weighing factor used is the thickness of each material within the block. Therefore, if a block contains only one material, then the conductivity of only that material is assigned to the block. The thickness-weighting method described here is also used for porosity and chloride data in the solute-transport model.

5.3 Boundary Conditions

Constant-flow boundary conditions are used for the entire perimeter of the modeled region, on all three layers. In addition, constant-flow conditions are specified for a group of four blocks in Layer 3, centered on Steamboat Hills. The purpose of the constant-flow boundaries is to simulate natural recharge and discharge rates for the study area.

Three other types of boundary conditions were rejected as alternatives to constant-flow, including no-flow, general-head, and constant-head. The no-flow option is considered to be unrealistic because of the relatively low contrast between the alluvial and bedrock conductivities (two orders of magnitude at most). This lack of contrast results in widespread exchange of flow between the two aquifers, so a true no-flow boundary could not be found. The general-head boundary would be good choice for the STM model, except that it requires definition of water levels at some distance beyond the model boundary. Currently there is little or no data available to define heads beyond the eastern, western, or southern model boundaries. Finally, the constant-head option was rejected because it allows recharge and discharge rates at the boundaries to vary without limit, in response to head changes

within the modeled region. Actual recharge and discharge rates are expected to vary only slightly, under the normal range of climatic conditions for the area. An exception to the exclusive use of constant flow boundaries is made in Scenario 5, for which constant-head boundaries are used under carefully-controlled conditions to investigate the effects of drought on predicted recharge rates (Section 7.5).

The MODFLOW river, evapotranspiration and recharge packages may also be viewed as boundary conditions, that simulate specific hydrologic processes. These packages are used in the northeastern part of Layer 1 to simulate discharge to Steamboat Creek, evapotranspiration, and recharge from crop and pasture irrigation.

The river package is used to simulate the reach of Steamboat Creek that receives groundwater discharge. This reach extends from Geiger Grade to the narrows at Huffaker Hills. Values for the riverbed hydraulic conductance ranging from 3623 to 30076 feet squared per day (ft^2/d) are calculated for model input, based on calibration trials. For purposes of comparison, riverbed hydraulic conductance values are also calculated from data measured by Shump (1985). In his study of influences on Steamboat Creek, Shump used miniature piezometers to measure the hydraulic conductivity of the streambed at several points. These data are input to the equation for riverbed conductance described in the MODFLOW manual (McDonald and Harbaugh, 1988, pp 6-5), with a stream-reach length of 1000 ft to represent a model block. Resulting values of hydraulic conductance range from 17,500 to

59,500 ft²/d, indicating that Schump's data are in good agreement with the values obtained from model calibration.

The evapotranspiration package is set up using an average rate of 0.0116 ft/d (4.2 ft/yr), and an extinction depth of 6.0 ft. The rate of 4.2 ft/yr is based upon an average of rates for cropland and phreatophytes (Section 3.2.2). MODFLOW uses the maximum rate where the depth to water is zero, and a rate of zero where the depth to water is greater than or equal to the extinction depth. The evapotranspiration rate varies in a linear fashion where the depth to water is between zero and the extinction depth. McDonald and Harbaugh state that values for extinction depth typically are on the order of six to eight feet (1988, pp 10-5). The STM model value of 6.0 ft. is chosen at the low end of this range, to simulate the effect of a non-linear relationship between evapotranspiration and depth to water. The assumed non-linear relationship would cause a disproportionate amount of evapotranspiration to occur in the upper portion of the extinction-depth interval. This is simulated in the model using a linear relationship with a shallower extinction depth.

The recharge package is set up using three different rates, to reflect irrigation for alfalfa, pasture, and no irrigation. The irrigation rates input to the model are 0.011 ft/d (4.0 ft/yr), 0.0068 ft/d (2.5 ft/yr), and 0.0 ft/d, respectively. The model assumes that 25 percent of the irrigation water recharges the aquifer. Figure 5-7 shows the areal distribution of the irrigation rates.

5.4 Ground-Water Flow Calibration

5.4.1 Procedure

The objective of calibration is to improve the accuracy of model predictions through refinements to the input data. For the STM model, conductivity values and flow rates are adjusted in order to produce increasingly accurate predictions for water levels and recharge/discharge rates. The relative accuracy of these predictions is determined by comparing them to known values, such as the water levels shown in Figures 3-3 and 3-4. Predicted flow rates are compared to the independent estimates presented in Table 5-1.

Water levels shown in Figures 3-3 and 3-4 are used as initial heads for the model. These data are noncontemporaneous, and are therefore assumed to represent steady-state conditions (Section 5.2.2.b). To simulate these conditions during calibration, the model is run without any pumping wells. Horizontal and vertical aquifer conductivity values are adjusted, and weighted averages for the layers recomputed, in order to produce the best match between predicted and initial heads. The thickness of Layer 3 is adjusted to obtain an effective transmissivity that is compatible with heads in Layers 1 and 2. Flow rates at the model boundaries are adjusted as needed to improve the agreement for heads and estimated recharge and discharge rates. Streambed conductivities are also adjusted, to improve the agreement between predicted and estimated ground-water discharge rates.

5.4.2 Results

Hydraulic conductivity and transmissivity surfaces resulting from the calibration process are shown in Figures 5-8 through 5-15. Flow-rate calibration required that all data shown on these figures be multiplied by 1.5 upon input to the model. Thus, the values shown are two-thirds of the values actually used. Alluvial and bedrock conductivities for Layers 1 and 2 are shown in Figures 5-8 and 5-9, respectively. Bedrock conductivities for Layer 3 are shown in Figure 5-10. Transmissivities for Layers 1 through 3, which are based on thickness-weighted averages of the hydraulic conductivity surfaces, are shown in Figures 5-11 through 5-13. V_{cont} (or leakance between layers) surfaces for Layers 1 and 2 are shown in Figures 5-14 and 5-15. V_{cont} is defined as the vertical hydraulic conductivity divided by the thickness from a layer to the layer beneath it (McDonald and Harbaugh, 1988, pp 5-12).

Calibrated alluvial conductivities (after multiplying by 1.5) vary from 2.4 to 24.0 ft/d, compared to a range of 1.3 to 16.6 ft/d for the observed data (13 values). For the alluvium, every modeled value is within a factor of 1.4 of an observed value. At observed data locations, modeled and observed values differ by an average of 11.3 ft./d (modeled values are higher).

Calibrated bedrock conductivities vary from 0.09 to 9.0 ft/d, compared to a range of 0.35 to 1.5 ft/d for the observed data (three values). The discrepancy in data ranges for the bedrock may be due to the small number of observed values. For the

bedrock, every modeled value is within a factor of six of an observed value. At observed data locations, modeled and observed values differ by an average of less than 0.1 ft./d.

The head-matching procedure required for calibration (Section 5.4.1) is unusually difficult for the STM model, because the study area has high vertical and horizontal flow gradients. The vertical gradients exceed 0.15 ft./ft. in some areas (Figure 5-1), meaning that a head difference of one foot can occur within a vertical distance of only seven feet. The horizontal gradients exceed 0.09 ft./ft. in some areas (Figure 3-3), so a head difference of one foot can also occur within a horizontal distance of only eleven feet. High gradients such as these impact the calibration process by causing predicted heads to be extremely sensitive to changes in conductivity. However, the sensitivity caused by high gradients provides greater accuracy and confidence for the final conductivity values.

The accuracy of calibrated heads is expressed as a percentage by dividing the head difference for a block (observed minus predicted) by the range in head (maximum minus minimum) for the corresponding layer. This calculation is repeated for all blocks in the layer, and the results are displayed as a histogram. The method of expressing accuracy as a percentage facilitates comparison of calibration results to other modeled sites that have different flow gradients and head ranges.

Figures 5-16 through 5-18 show histograms of calibration accuracy for Layers 1 through 3, respectively. These histograms are based on results of the steady-state calibration procedure described in Section 5.4.1. Note that for Layer 2 'observed' heads are not available, so predicted heads are compared to the weighted-average initial heads used for the layer (Section 5.2.2.b). The calibration-accuracy histograms show that most of the predicted heads are accurate to within plus or minus 1.5 percent. This percentage corresponds to plus or minus variations of 23.6 ft. for Layer 1, 21.9 ft. for Layer 2, and 17.0 ft. for Layer 3. The assumption that observed heads are in steady-state results in a comparable limitation on the accuracy of observed data contours (plus or minus 20 ft.), based on hydrographs of STM wells (Section 5.2.2.b). Therefore, most of the modeled heads are calibrated to the optimum level of accuracy.

Table 5-1 shows the accuracy of calibrated flows by comparing independent estimates of recharge and discharge rates to corresponding predictions from the model. The estimated discharge to Steamboat Creek of 6600 af/yr corresponds to the rate of 9.13 cfs reported by Schump for stations S70 through S77 (1985, pp 58, Table 8). All other estimated recharge and discharge rates are obtained from Washoe County Utility Division (1990). The percent difference column in Table 5.1 indicates that the predicted rates are in reasonable agreement with estimated values, with the possible exception of Steamboat Creek discharge (22.6% below the estimate).

Table 5-1 Comparison of Estimated and Predicted Flow Rates				
	Probable Range (af/yr)	Estimated Value (af/yr)	Model Prediction (af/yr)	Difference (%)
Mt. Rose Fan Recharge	9000 - 15000	12000	13146	9.6
Irrigation Recharge	2000 - 2800	2400	2249	-6.3
Steamboat Creek Discharge	6000 - 11000	6600	5109	-22.6
Evapotranspiration Discharge	8000 - 12000	9850	10099	2.5

5.5 Historical Pumping

The calibration process (Section 5.4) produces heads that represent steady-state conditions. However, the predictive Scenarios (Section 7.0) require starting heads that correspond to current conditions, to increase the practical value of Scenario results. Thus, historical pumping is simulated in order to generate a set of starting heads that incorporate current drawdown effects.

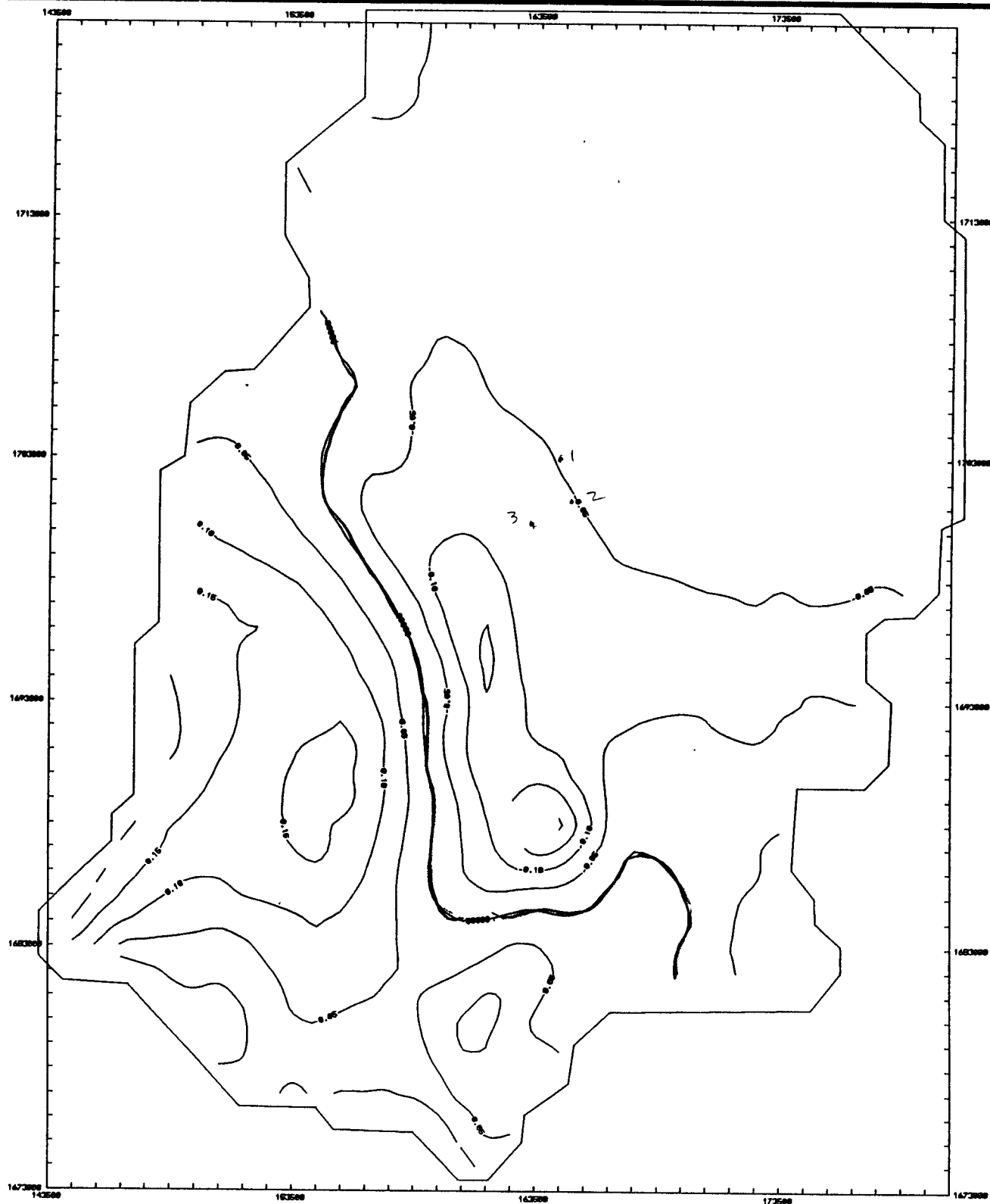
The simulation process is divided into two 'stress periods' according to the historic pumping schedules for major water-supply wells in the STM. The first stress period begins with the final steady-state heads and conductivities from calibration, and simulates the effects of pumping major wells in the STM from May, 1985 through December, 1989. Table 5-2 lists all the pumping wells, and shows which model layers are intercepted by each well. Pumping schedules for the wells are also shown. For wells that intercept more than one layer, the

total pumping rate is distributed between the layers in proportion to the layer transmissivities. This calculation is performed prior to model input, as suggested by McDonald and Harbaugh (1988, pp 8-2).

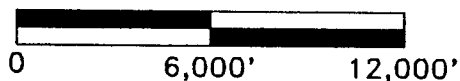
The second stress period begins with the final heads from stress period one, and simulates the effects of pumping major wells in the STM from December, 1989 to December, 1991. For purposes of this stress period, historical pumping rates for 1990 are assumed to remain in effect throughout 1991. The final heads from this stress period are used as starting heads for the scenarios described in Section 7.0.

Head's for
this
Scenario

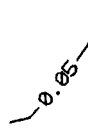
Table 5-2 Pumping Well Summary:									
Pumping Well	Layers Intercepted		Historic Pumping Rates (gpm)				Scenario Pumping Rates (gpm)		
	Layer 1	Layer 2	5/85 - 12/89	12/89 - 12/91	Scenario #1	Scenario #2	Scenario #3	Scenario #4	Scenario #5
STMIGID Prod. #1	X		✓ 123	172	375	375	0		0
STMIGID Prod. #2	X		0	0	113	113	0		0
STMIGID Prod. #3	X		✓ 222	300	300	300	0		0
STMIGID Prod. #4 (Shadowridge)		X	18	26	113	113	0		0
STMIGID Prod. #5	X	X	0	75	225	225	0		0
STMIGID Prod. #6	X	X	0	75	563	563	0		0
Mt Rose Cinder Well	X	X	0	0	375	375	0		375
Mt. Rose Replacement Well	X	X	93	93	150	150	150		150
Windburn Pumping Well #1	X		0	0	75	75	75		75
Windburn Pumping Well #2	X		0	0	38	38	38		38
New Sunrise Estates #1 & 2	X		0	0	150	150	150		150
Piccolo School Well	X		0	0	75	75	75		75
Double Diamond North (DDT1)	X		0	0	113	113	113		113
Double Diamond South (DDT2)	X	X	0	0	338	338	338		338
Holcomb Ln Well	X	X	0	0	375	375	375		375
Longley Ln / Huffaker well	X	X	0	375	375	375	375		375
South Virginia Well	X	X	✓ 375	375	375	375	375		375
Steamboat Water Co. #1 & 2	X	X	0	100	150	150	150		150
STMIGID Prod. #7	X	X	0	0	0	0	300		300
STMIGID Prod. #8	X	X	0	0	0	0	300		300
STMIGID Prod. #9	X	X	0	0	0	0	225		225
Galena South	X	X	0	0	0	0	225		225
Browns Creek	X	X	0	0	0	0	188		188
Injection #1	X	X	0	0	0	0	0		-500
Injection #2	X	X	0	0	0	0	0		-500
Total Pumping Rate (gpm)			831	1966	4275	5513			2825
Total Pumping Rate (af/yr)			1340	3170	6896	8892			4557



SCALE: 1"=6,000'



Explanation

 Contour line of equal change in head per vertical foot (foot/foot)
 positive values imply downward flow, negative values imply upward flow.

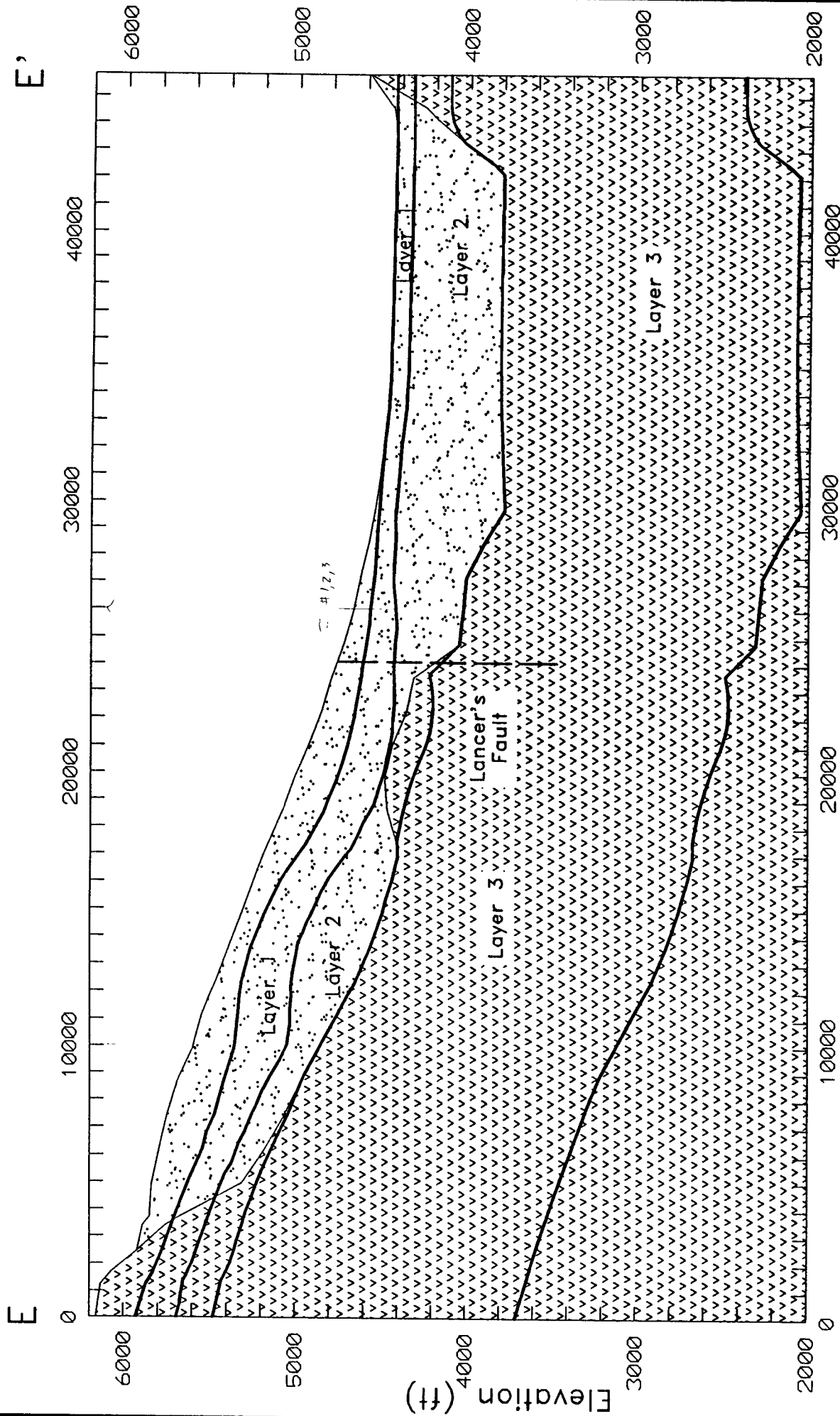
Contour interval is .05 feet.


South Truckee Meadows Washoe County, NV		DATE: 10/8/91
South Truckee Meadows Vertical Gradient Map		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201






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Figure 5-1



South Truckee Meadows Washoe County, NV	DATE: 9/22/91
	DRAWN: KEK
	CHECKED: <input type="checkbox"/>
	APPROVED: <input type="checkbox"/>
Cross-Section E - E'	DWG NO:
	PROJ.: 396J23201
 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine	
Figure 5-2	

Explanation

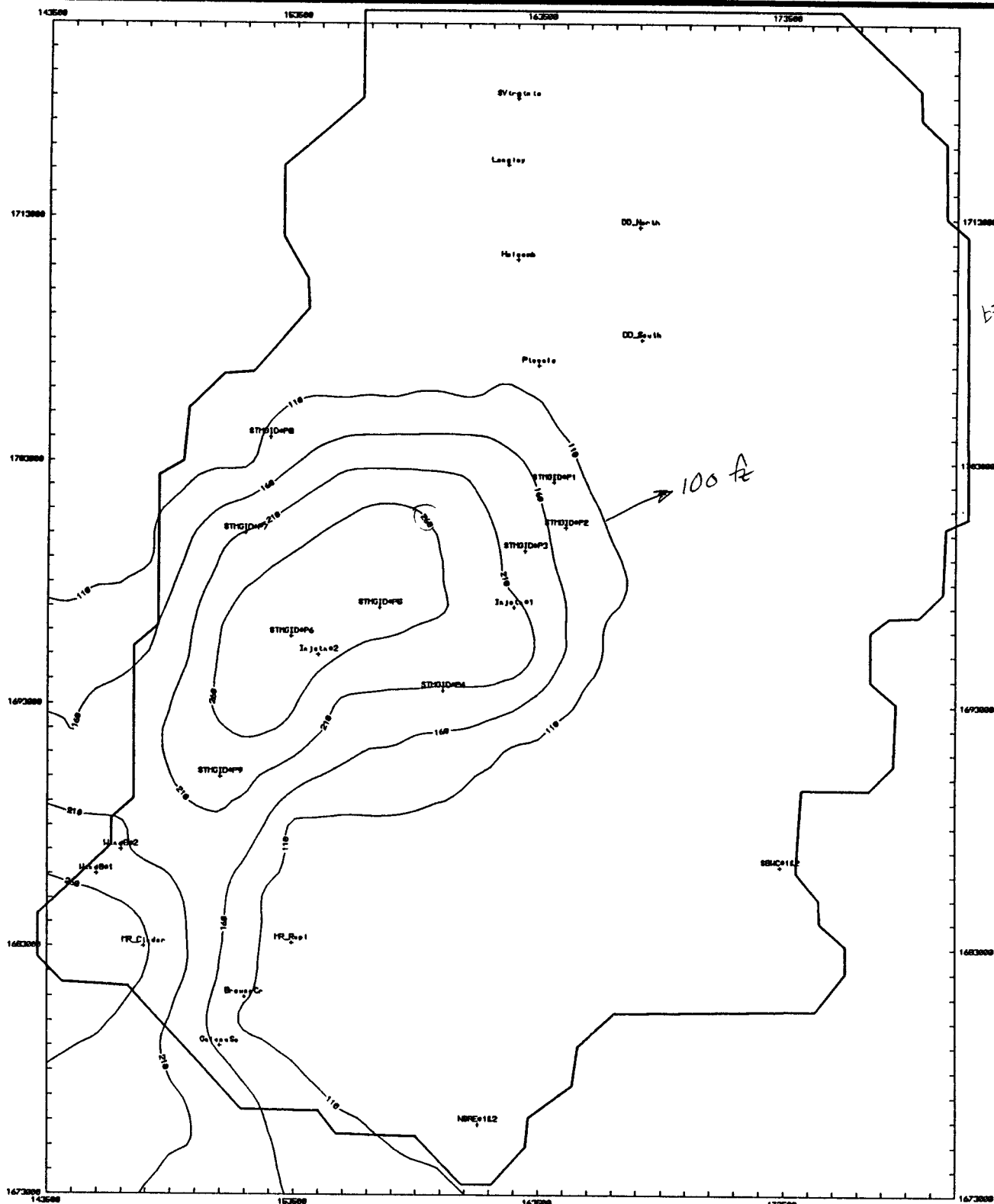
-  Alluvium
-  Bedrock
-  Layer boundary



H:V=6.25:1

X-Scale 1"=5000'

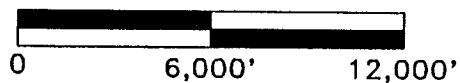
Offset (ft)




Explanation

- Longley Well location and name
- 110 Contour of equal layer thickness (feet)
- Boundary of modeled area
- Contour interval is 50 feet

SCALE: 1"=6,000'



South Truckee Meadows Washoe County, NV		DATE: 9/22/91
South Truckee Meadows Layer 1 Thickness		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine		Figure 5-3

Distribution of Water-Level Measurements Years

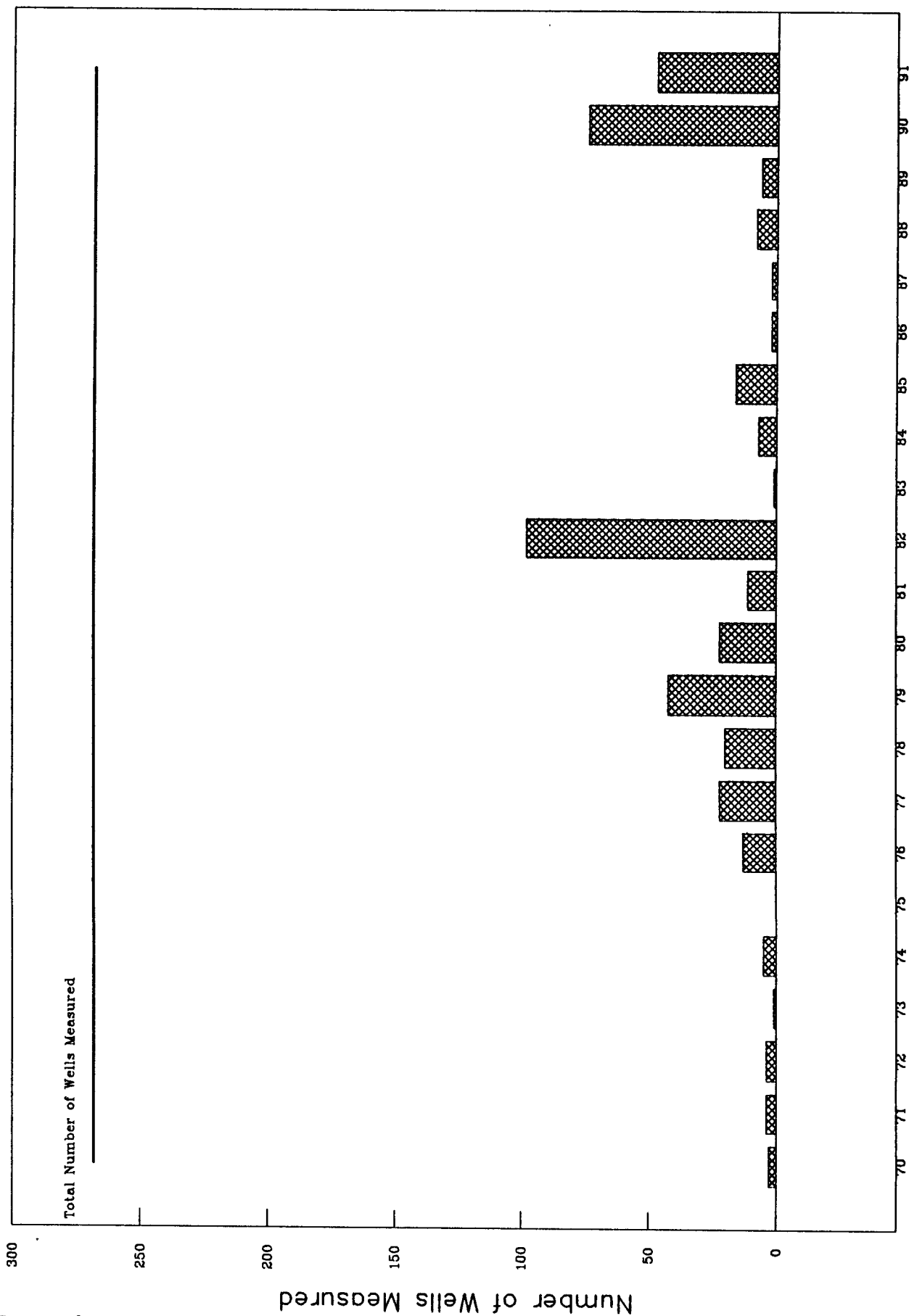
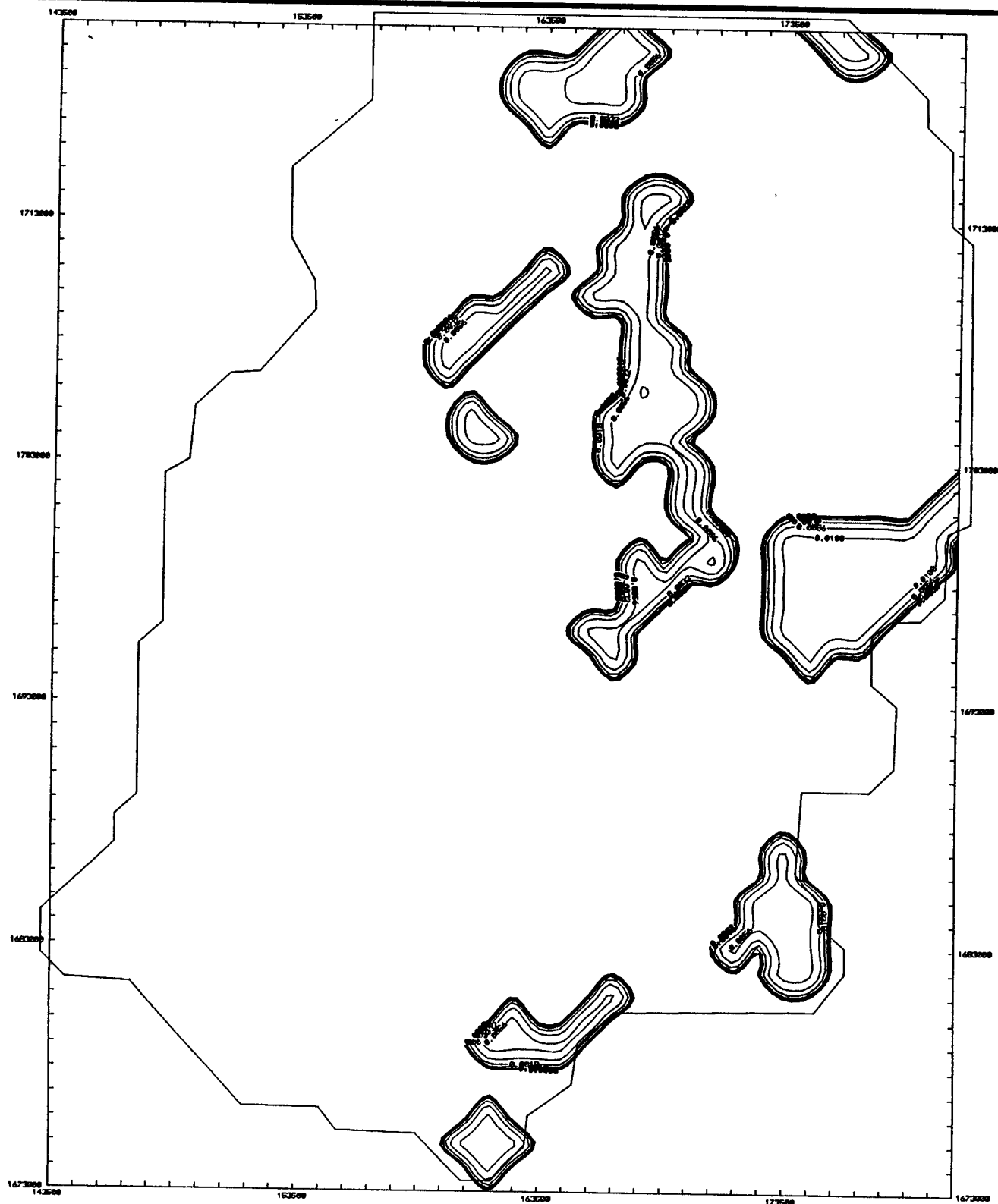
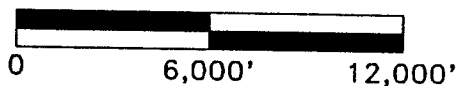




Figure 5-6



SCALE: 1"=6,000'



Explanation

-  Contour of equal irrigation application rate (ft/yr)
-  Boundary of modeled region

South Truckee Meadows
Washoe County, NV

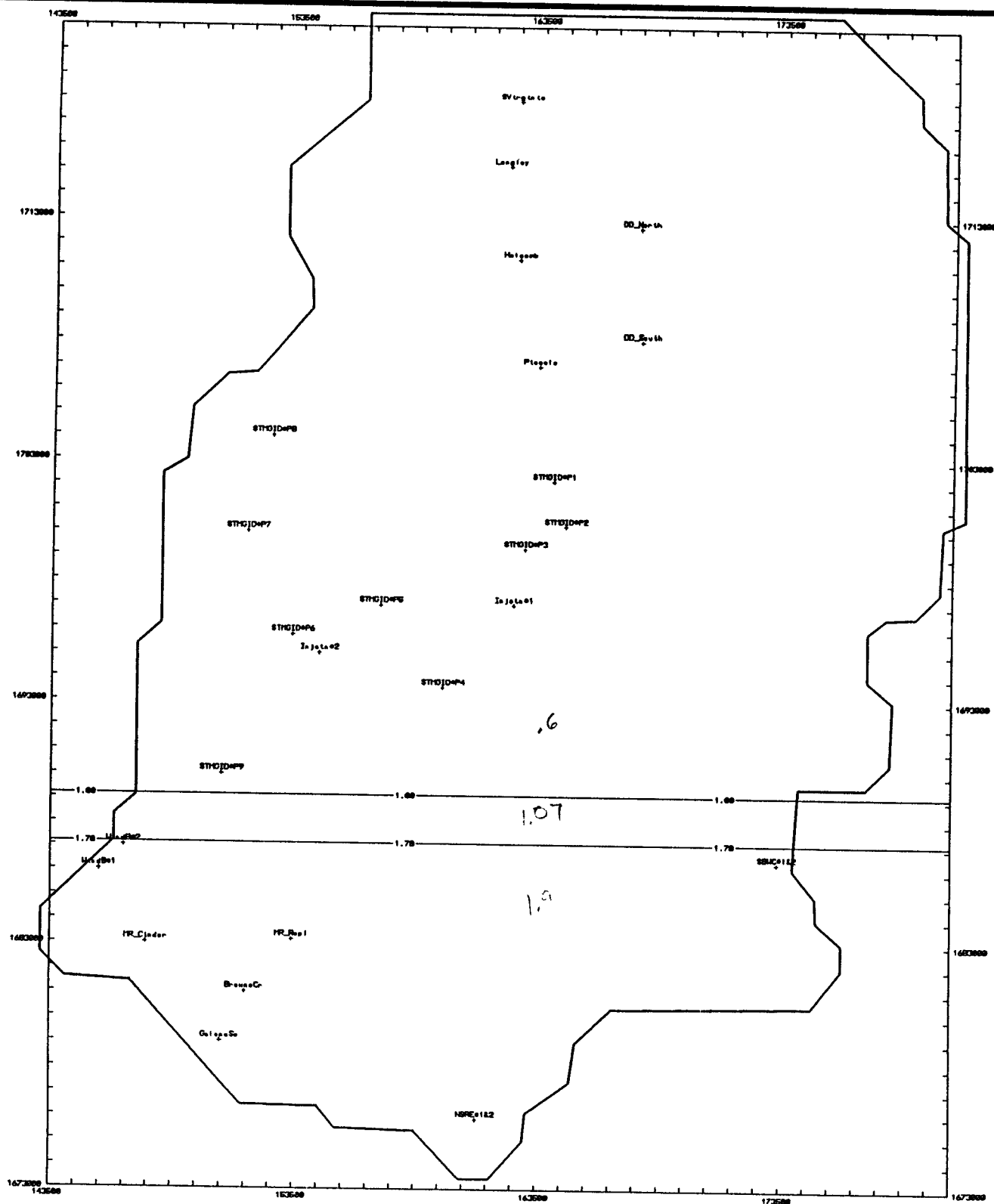
Irrigation Rates

DATE: 9/23/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201






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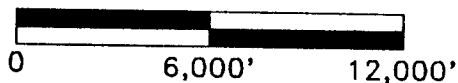
Figure 5-7



Explanation

-  Well location and name
 -  Contour of equal hydraulic conductivity (ft./day)*
 -  Boundary of modeled area
- *Contour interval is 1/4 of a log cycle.

SCALE: 1" = 6,000'



South Truckee Meadows
Washoe County, NV

Bedrock
Hydraulic Conductivity
Layers 1 and 2

DATE: 9/22/91

DRAWN: KEK

CHECKED:

APPROVED:

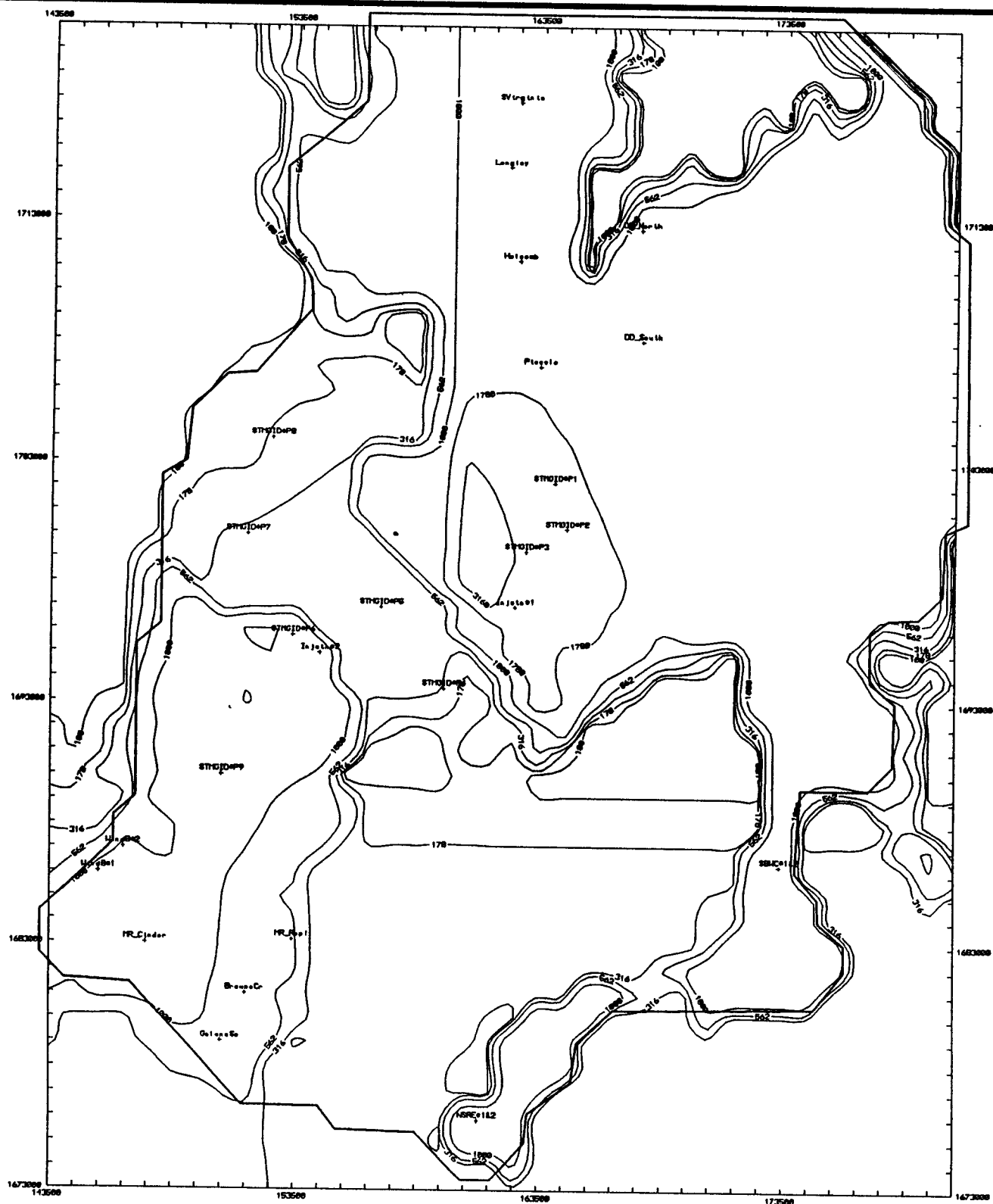
DWG NO:

PROJ.: 396U23201

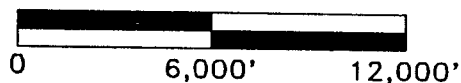


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Figure 5-9



SCALE: 1"=6,000'



Explanation

- Well location and name
 - Contour of equal transmissivity (ft²/day)*
 - Boundary of modeled area
- *Contour interval is 1/4 of a log cycle.

South Truckee Meadows
Washoe County, NV

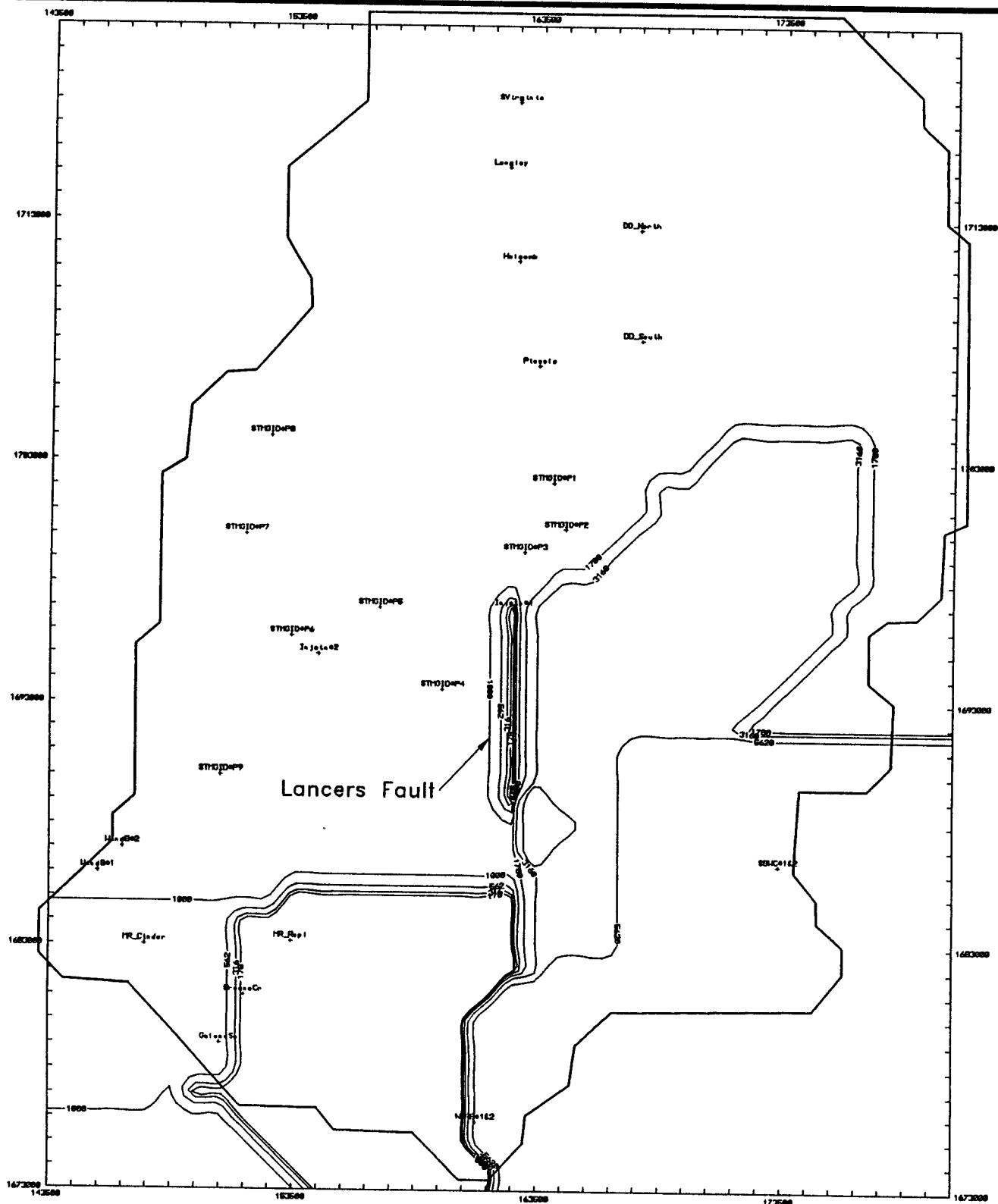
South Truckee Meadows
Transmissivity
Layer 1

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201

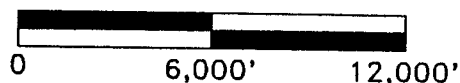


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Figure 5-11




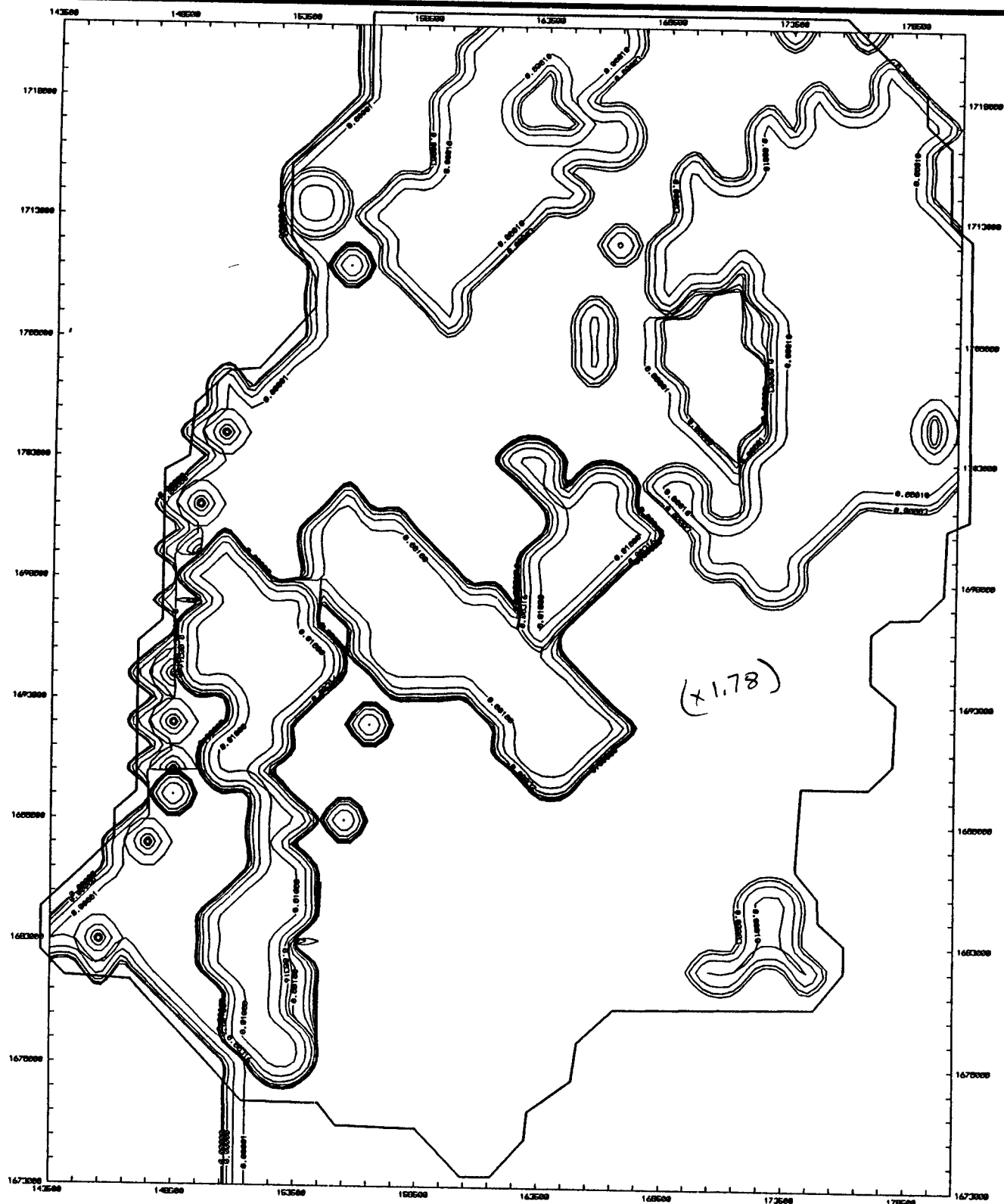
SCALE: 1"=6,000'



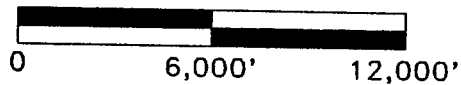
Explanation

- Well location and name
 - Contour of equal transmissivity (ft²/day)*
 - Boundary of modeled area
- *Contour interval is 1/4 of a log cycle.

South Truckee Meadows Washoe County, NV		DATE: 9/22/91
South Truckee Meadows Transmissivity Layer 3		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine		Figure 5-13



SCALE: 1"=6,000'



Explanation

Contour of equal vcont (day^{-1})*

* Contour interval is 1/4 of a log cycle.

Boundary of modeled area

South Truckee Meadows
Washoe County, NV

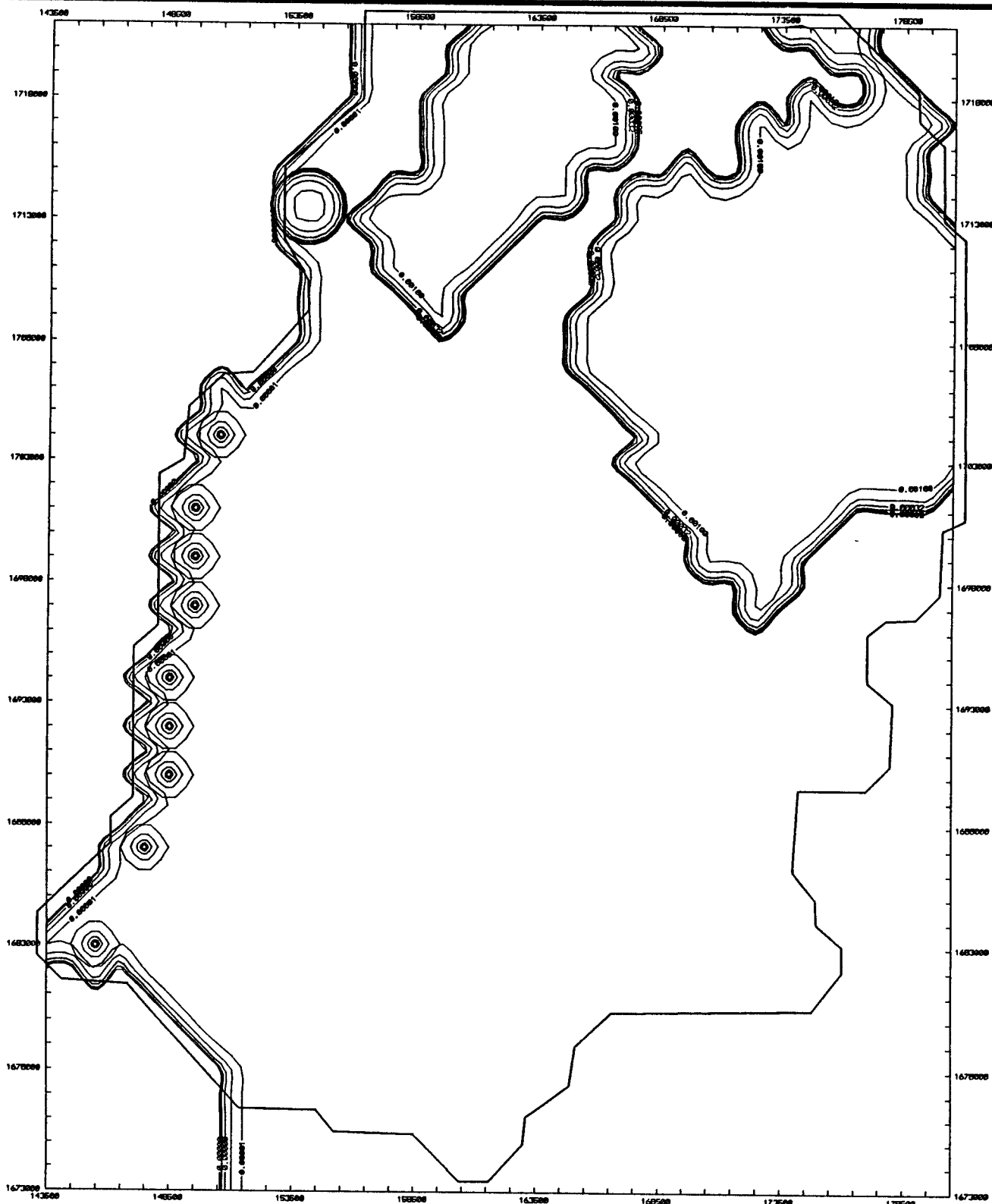
**Vcont
Between Layers
1 and 2**

DATE:	9/23/91
DRAWN:	KEK
CHECKED:	
APPROVED:	
DWG NO:	
PROJ.:	396U23201





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Figure 5-14



Explanation

-  Contour of equal vcont (day^{-1})*
- * Contour interval is 1/4 of a log cycle.
-  Boundary of modeled area

SCALE: 1"=6,000'

0 6,000' 12,000'

South Truckee Meadows Washoe County, NV	DATE: 9/23/91
Vcont Between Layers 2 and 3	DRAWN: KEK
	CHECKED:
	APPROVED:
	DWG NO: PROJ.: 396U23201



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Figure 5-15

Layer 1. Calibration Accuracy (%)
 $100 * (\text{Observed Head} - \text{Predicted Head}) / (\text{Max Head} - \text{Min Head})$

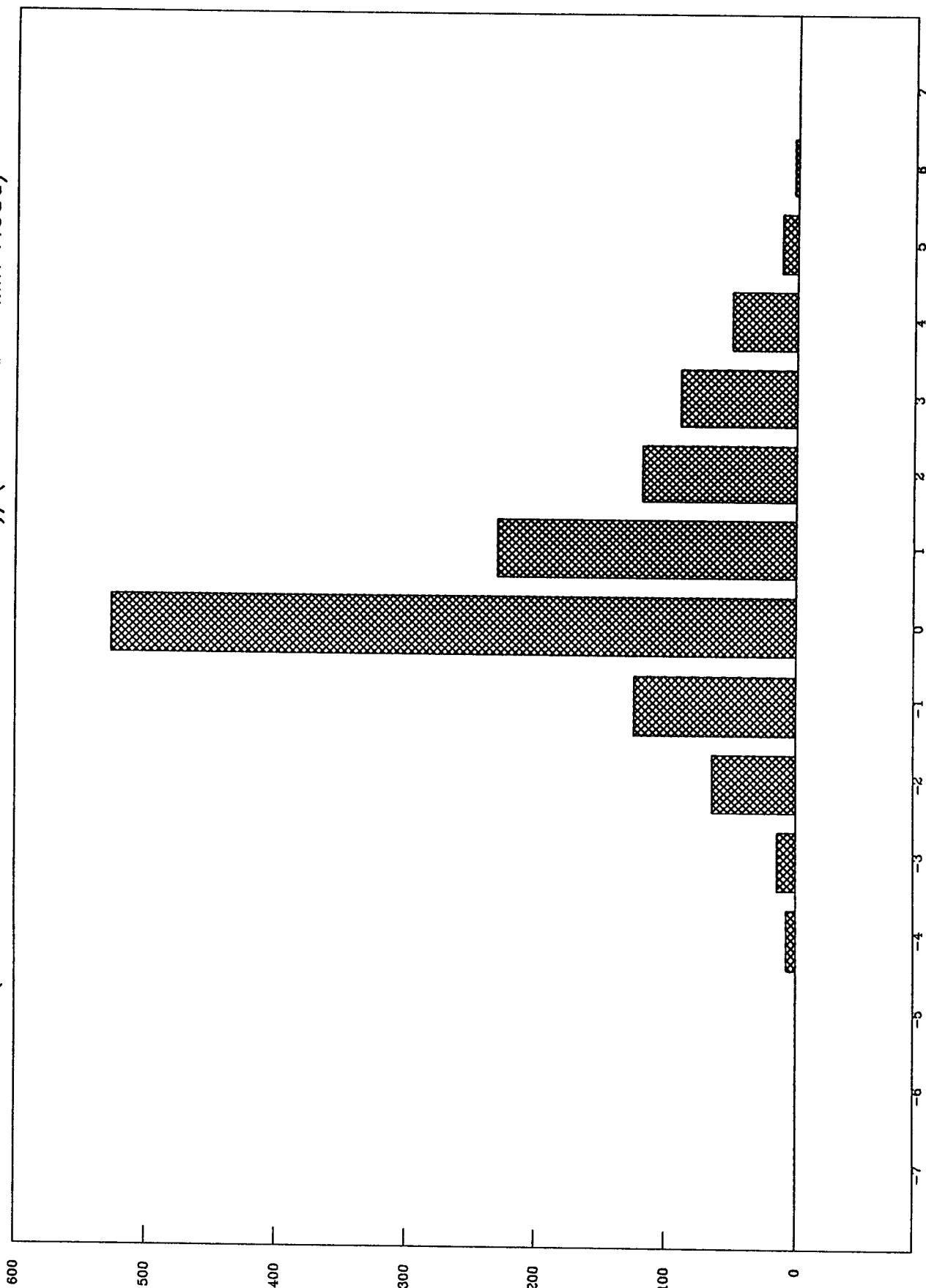


Figure 5-16

Layer 2. Calibration Accuracy (%) $100 * (\text{Observed Head} - \text{Predicted Head}) / (\text{Max Head} - \text{Min Head})$

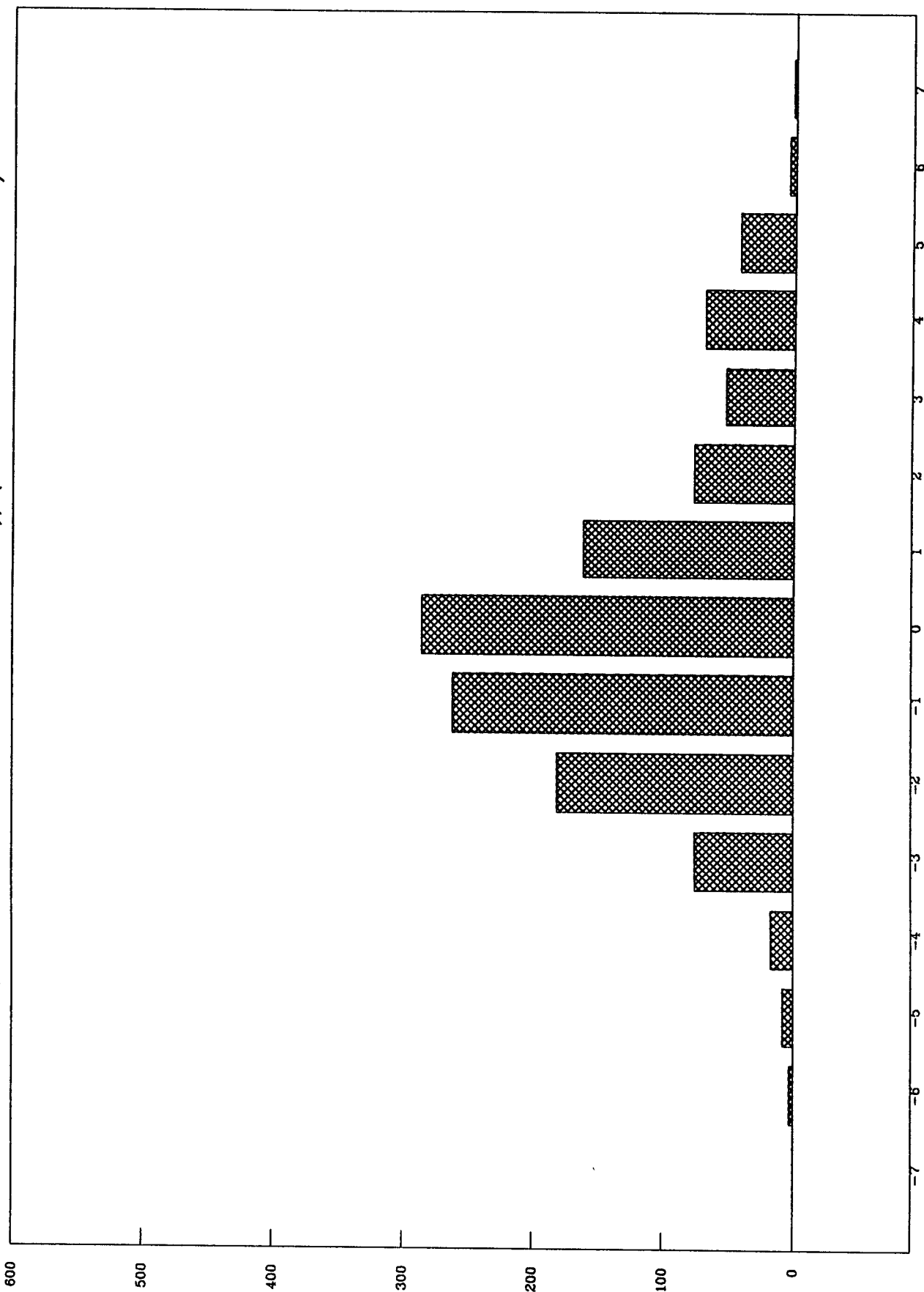


Figure 5-17

Layer 3. Calibration Accuracy (%) $100 * (\text{Observed Head} - \text{Predicted Head}) / (\text{Max Head} - \text{Min Head})$

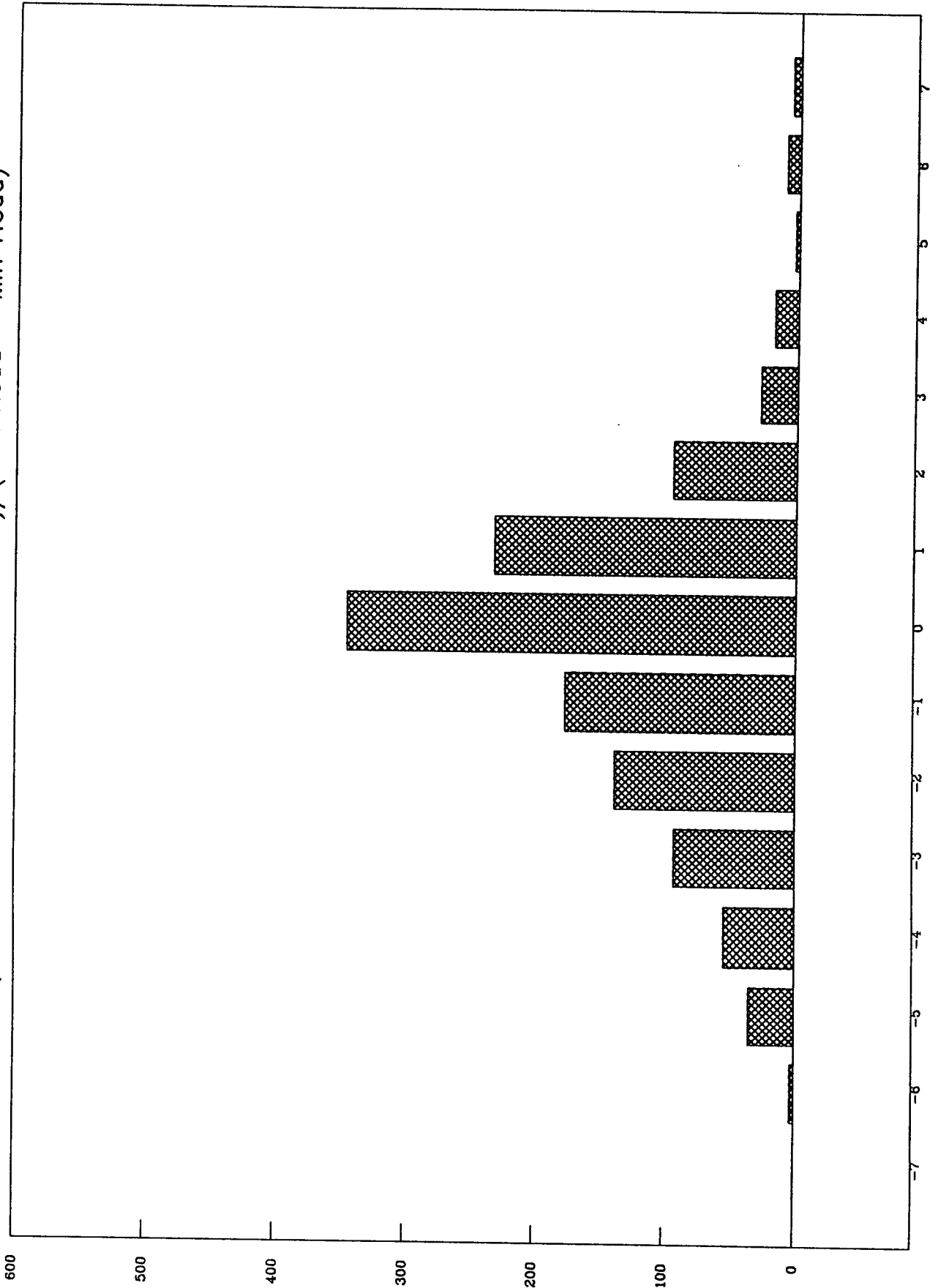


Figure 5-18

6.0 WATER-QUALITY MODEL

The numerical transport model MT3D (Papadopoulos & Associates, Inc., 1991) is used to simulate the transport of chloride in the South Truckee Meadows. MT3D is designed to be used in conjunction with MODFLOW. Flow data derived from MODFLOW are written to files which are retrieved by the transport model. The code can be used to predict changes in concentration of selected constituents temporally and spatially in two- or three-dimensions, in response to hydraulic conditions set in the flow model.

The water quality model can be used to simulate the effects of agriculture and effluent management on water quality in the South Truckee Meadows. It can also be used to predict the effect on water quality of pumping near the geothermal area. The model simulates mixing of waters of differing concentrations for a single constituent. Presently, the water quality model is set up to simulate the transport of chloride, because it is a useful tracer for indicating solute migration, and it may be contributed from several sources in the South Truckee Meadows, including geothermal, agricultural and septic effluent.

6.1 Conceptual Water Quality Model

Water quality data were provided to HSI by the Utility Division of Washoe County. Analysis of these data indicate that geothermal water originating at depth is mixing with fresh water at shallow depths in the South Truckee Meadows. The impact of geothermal water is greatest in the bedrock aquifer. Geothermal water appears to migrate to the

surface along fault zones, and has also impacted alluvial ground water in the Steamboat Springs area. This impacted water flows towards the discharge area in the vicinity of the Double Diamond Ranch, and exits the alluvial aquifer through seepage to Steamboat Creek or the bedrock.

Geothermal water in the South Truckee Meadows is characterized by relatively high concentrations of arsenic, boron, fluoride, sodium, chloride, sulfate, potassium, and total dissolved solids (TDS). Chloride is a major constituent contributing to the high TDS values characteristic of geothermal water. It is considered to be a conservative ion, i.e., it does not readily enter into chemical reactions or sorb onto aquifer materials. For these reasons chloride was selected as the constituent for modeling the impacts of geothermal water.

6.2 Water Quality Model Design

The design of the solute transport model is completely analogous to that of the flow model. Transport is simulated in the three layers by incorporating the flow terms designated in MODFLOW. Recharge from the Carson Range and the Virginia Range is simulated at rates derived from the calibrated flow model. Ground-water recharge to the alluvium occurs primarily along the western boundary of the South Truckee Meadows, mainly in the vicinity of the Mount Rose Fan, with minor contributions along the southern and eastern boundaries (see Section 5.1).

In a ground-water flow system, dissolved constituents are transported by advection at the same rate as ground-water flow. Where a constituent plume exists, some mixing may occur along the leading edge of the plume, causing dispersion of dissolved constituents in advance of the main body of the plume. Advection is considered the predominant mechanism affecting solute transport in the modeled area. The regional scale of the South Truckee Meadows model and the existence of diffuse sources of chloride in the Steamboat Hills area make the effects of dispersion insignificant (Anderson, 1979). Thus, dispersive effects are neglected. Using advection only allows predictions to be made regarding average changes in water quality on a regional scale and in the discharge area in the vicinity of the former Double Diamond Ranch and Steamboat Creek.

6.3 Model Input Data and Boundary Conditions

The input data for the South Truckee Meadows ground-water quality model come from several sources, including unpublished reports by the Utility Division of Washoe County, Master's theses, USGS reports and consultants reports. These data include surface water analyses for samples collected from streams and ditches in the area and ground-water quality analyses for water samples collected from domestic and municipal wells, and springs.

Water samples were identified as being derived from either the alluvial or bedrock aquifer (See Figures 3-5 and 3-6). Steamboat Hills is identified as a source area for geothermal activity in the South Truckee Meadows. Chloride concentrations in the geothermal reservoir have been estimated at approximately 700 mg/l chloride (Nehring, 1980). Input

concentrations in the vicinity of Steamboat Hills are estimated by assuming a minor amount of mixing of reservoir water with non-thermal water. Thus, model nodes in layer 3 in the Steamboat Hills area are assigned a constant chloride concentration of 600 mg/l.

The data base indicates concentrations of chloride in recharge water from the Carson Range and the Virginia Range are similar, ranging from 0 to about 7 mg/l. This is true despite the fact that Carson and Virginia recharge waters have significant differences for other parameters, such as sulfate. These water quality differences are apparently related to the fact that Virginia Range recharge water is affected by movement through zones of hydrothermally altered rock, where the primary impact is an increase in sulfate concentration. Inspection of tabulated water quality data by Nehring (1980) and White (1968), verify this observation.

Actual background concentrations of chloride in ground water outside the influence of the geothermal system range from about 1 mg/l at the model boundary to 7 mg/l. Background conditions are simulated by assigning a concentration of 4 mg/l to every active node in each layer. To simulate the effects of recharge water coming in at the model boundaries, concentrations are held constant at 4 mg/l at boundary nodes where water flows into the model.

Irrigation water derived originally from the Truckee River is assigned a value of 6 mg/l chloride. Historically, chloride concentrations in Truckee River water have ranged from

approximately 2 to 5 mg/l (Kaiser Engineers, 1973). The choice of 6 mg/l is based upon the effects of evaporation on irrigation water causing concentration of chloride to increase slightly.

In the modeled area, alluvium is assigned an effective porosity of approximately 30% and bedrock 10% (Freeze and Cherry, 1979). These values are based upon published values of porosity for alluvium and fractured crystalline rock. Effective porosity values for the three layers are calculated using a weighted average of aquifer thickness in each layer. Figures 6-1 and 6-2 depict effective porosity for layers 1 and 2 respectively. Porosity in layer 3 is held constant at 10%.

6.4 Solute Transport Model Calibration

The purpose of model calibration is to match predicted and observed water quality data by varying parameters such as formation porosity and initial and boundary concentrations. To calibrate the South Truckee Meadows solute transport model conditions were simulated for twenty-year periods using one year time increments. This was an iterative process using concentration and flow data from the first twenty year period as input data for the next twenty year period, and repeating the process until conditions approached steady state.

The system is considered to be in steady state when the mass of chloride leaving the system is equivalent to the mass of chloride entering the system per unit of time. Figure 6-3 shows the relationship between chloride entering and leaving the modeled area over a simulation

period of 1700 years. These results indicate that the total mass leaving the system is within approximately 12% of the total mass entering the system at the end of the simulation period. The rate at which the model is approaching steady state is decreasing over time. Results of the calibration process are discussed in Section 7.6.

Water quality data for calibration matching were obtained from wells in the data base and from samples taken from Steamboat Creek by Shump (1985). Data from wells can be compared directly to model predictions, while Schump's quality data are used to compute an estimate for ground-water quality in the discharge area.

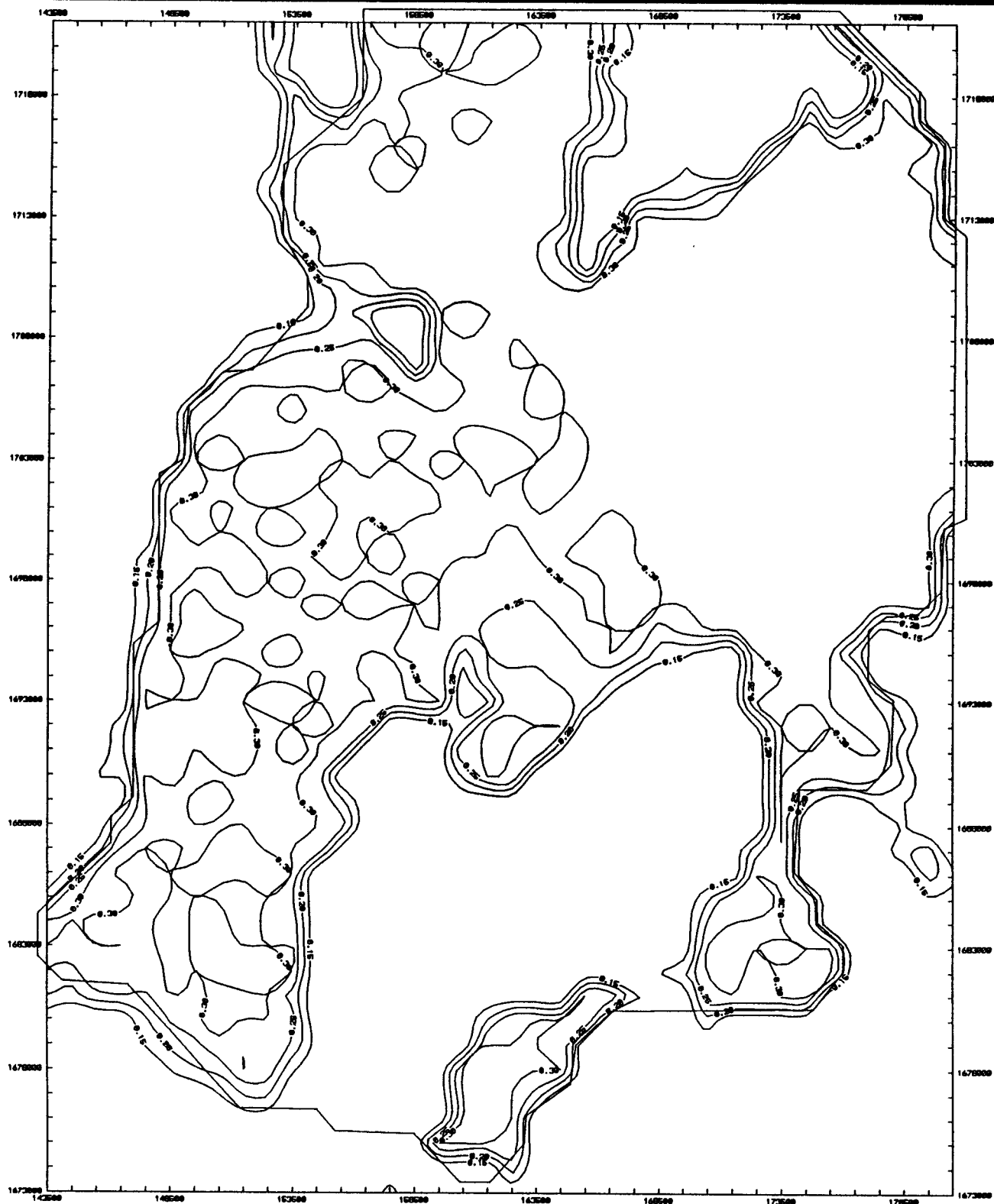
Anticipated concentrations of chloride in the discharge area (Double Diamond) were calculated based upon concentrations of chloride and flow rates in Steamboat Creek and tributaries observed by Shump (Table 8 and Appendix 2, 1985). Observed inflows and outflows and chloride concentrations in the Creek are shown in Table 6-1. Also shown are estimated chloride concentrations for tributary waters for which no chloride data were available. Analysis of sensitivity to an assumed range of laboratory error shows that calculated chloride concentrations in ground water discharged to Steamboat Creek range from approximately 375 to 700 mg/l.

Table 6-1. Flow and Chloride Concentration Data for Steamboat Creek

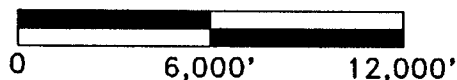
Reach	Surface Flow Return (cfs)	Surface Flow Diversion (cfs)	Creek Flow in Reach (cfs)	Ground- Water Discharge to Creek (cfs)	Chloride in Creek (mg/l)	Chloride in Return Flow (mg/l)	Chloride in Ground Water (mg/l) ⁽¹⁾
69-70			18.29	*	42.8 ⁽²⁾	5	515
70-71	0.51	0	18.8	0.34	51.1 ⁽¹⁾	5	515
71-72	0.26	1.04	18.6	0.52	63.2 ⁽¹⁾	5	515
72-73	0	0	20.5	1.81	102.9 ⁽¹⁾	5	515
73-74	0	0	22.9	2.52	148.8 ⁽¹⁾	5	515
74-75	0	11.16	13.3	2.01	209.1 ⁽¹⁾	5	515
75-76	2.97	0	17.5	1.29	204.5 ⁽¹⁾	45	515
76-77	0	0	18.2	0.64	214.8 ⁽¹⁾	5	515
77-80	22	0	38.7	-1.46	84.4 ⁽²⁾	5	515

⁽¹⁾ Calculated chloride concentration⁽²⁾ Concentrations observed by Shump, Appendix 2, 1985



NOTE: Table derived from Shump, Table 8, 1985



SCALE: 1"=6,000'



Explanation

-  Contour line of equal effective porosity
Contour interval is 0.05 units.
-  Boundary of modeled region

South Truckee Meadows
Washoe County, NV

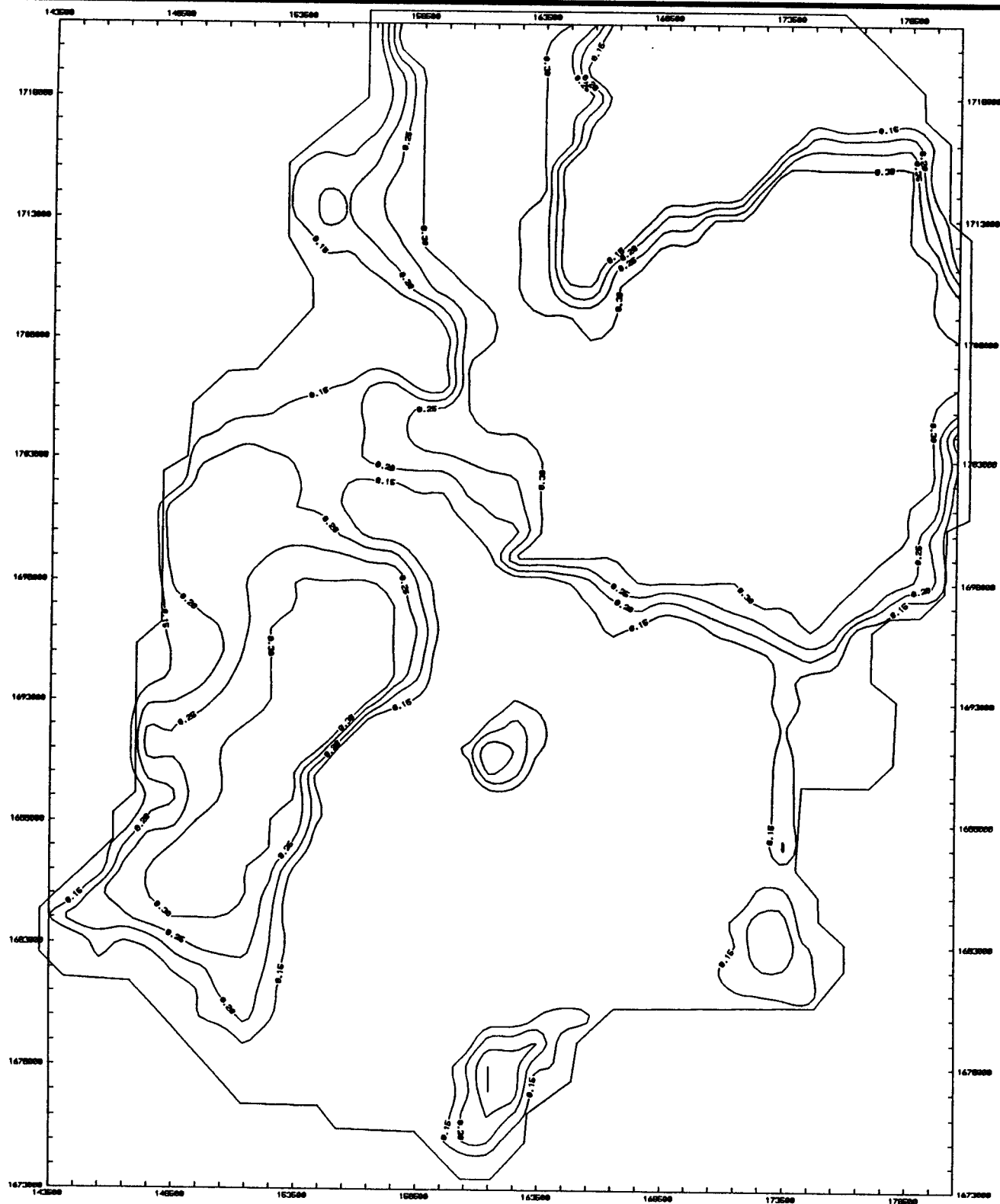
**South Truckee Meadows
Effective Porosity
Layer 1**

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201

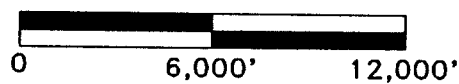


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
Figure 6-1




SCALE: 1"=6,000'



Explanation

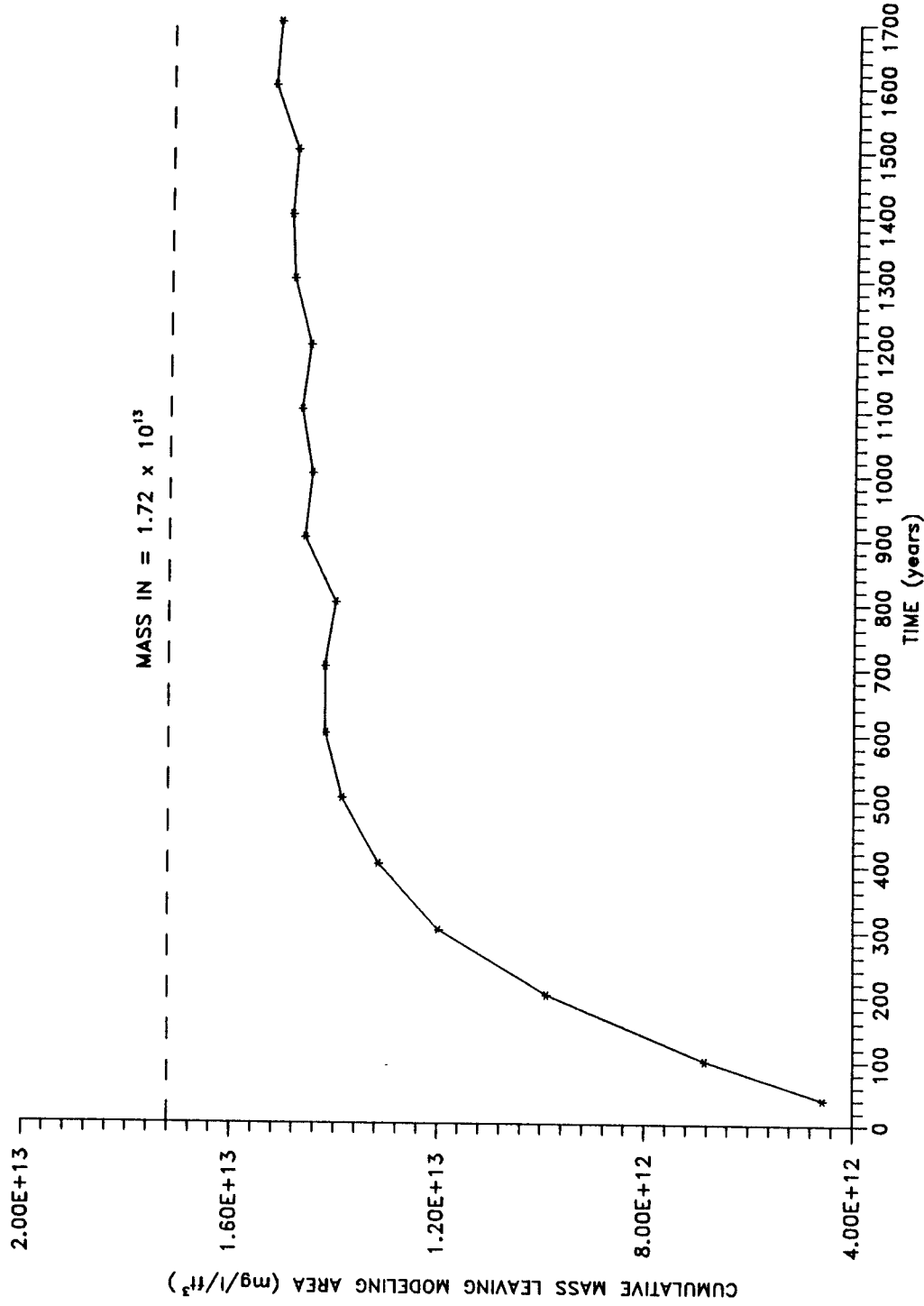
-  Contour line of equal effective porosity
Contour interval is 0.05 units.
-  Boundary of modeled region


South Truckee Meadows Washoe County, NV	DATE: 9/22/91
South Truckee Meadows Effective Porosity Layer 2	DRAWN: KEK
	CHECKED:
	APPROVED:
	DWG NO: PROJ.: 396U23201



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Figure 6-2



South Truckee Meadows Washoe County, NV	DATE: 9/20/91
Chloride Cumulative Mass Balance Relationship	DRAWN: KEK
	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS-GEOLGISTS-ENGINEERS Reno Denver Albuquerque Irvine	
Figure 6-3	

7.0 RESULTS OF MODEL SIMULATIONS

The calibrated ground-water model is used to simulate five scenarios in which hypothetical stresses are placed on the aquifer system. Scenarios 1 through 3 simulate drawdown due to pumping existing production wells at higher rates, in conjunction with pumpage from proposed new wells (Refer to Table 5-2). Scenarios 4 and 5 simulate the effects of changes in recharge parameters under current pumping conditions. The first four scenarios each cover a twenty-year period, with results reported after 2, 5, 10 and 20 years. Scenario 5 covers a five-year period with results reported at the end of the period.

The starting time for the scenarios is December 31, 1991. Therefore, water levels predicted for that date (Section 5.5) are used as initial conditions for modeling flow and computing drawdown. Contours of these water levels are shown in Figures 7-1 through 7-3, for layers 1 through 3 respectively. Choosing a starting time in the near future makes the scenarios more realistic in terms of the probable future pumping schedule. In addition, the use of model-predicted heads as initial conditions facilitates the interpretation of scenario results. This is because effects due to calibration accuracy (discussed in Section 5.4) are apparent only when model predictions are compared to observed data. However, the scenario results presented in this section consist of comparisons between two sets of model predictions: initial conditions for December 31, 1991 and final conditions for the scenario. This type of comparison causes calibration effects to cancel out, producing results that show only the effects that the scenario is designed to investigate.

It should be noted that for model blocks containing pumping wells, predicted head and drawdown values do not represent conditions in the well bore. Instead, MODFLOW predicts values averaged over the 23-acre surface area of a block. For a block containing a pumping well, the actual drawdown is greatest at the wellbore and least at the perimeter of the block. The average drawdown predicted for the block is between these two extremes.

The solute transport model simulates the movement of chloride from the Steamboat Hills Geothermal System through the alluvial and bedrock aquifers to the discharge area in the northeastern STM basin. The starting date for this simulation is 1700 years before present, as explained in Section 6.4. No pumping wells are included in the solute transport simulation.

7.1 Scenario 1

The purpose of Scenario 1 is to simulate drawdown from pumping the twenty major production wells in the STM at 75% of maximum capacity. The wells and corresponding pumping rates are shown in Table 5-2. The total pumping rate is 6896 af/yr, which is more than twice the current value of 3170 af/yr. Figures 7-4 through 7-11 show contours of drawdown in layers one and two after 2, 5, 10, and 20 years.

Drawdown is greatest at STMGID #6, the well with the highest simulated pumping rate (563 gpm). Pumping STMGID #6 produces 15 ft of drawdown in layer one after two years and 40 ft after twenty years. Predicted drawdown for layer two is comparable to that for

layer one. Because STMGID #4 and #5 are in an area of relatively low transmissivity, pumping them at lower rates (113 and 225 gpm, respectively) produces almost as much drawdown as for STMGID #6.

7.2 Scenario 2

Scenario 2 is a 'reasonable worst case' which includes all of Scenario 1's pumping wells and rates together with five proposed wells pumping at 75% of their anticipated maximum capacities (see Table 5-2). The simulation and reporting periods are the same as for Scenario 1.

As shown on Figures 7-12 through 7-19, the five proposed wells are in the area of the Mount Rose Fan. Note that the planned location for the proposed Brown's Creek well is outside of the modeled region, 5400 ft south-southeast of the symbol shown on Figures 7-12 through 7-19. The well was simulated at the location shown on the Figures in order to include its pumpage in Scenarios 2 and 3.

The combined pumping rate for Scenario 2 is 8892 af/yr, which is two-thirds of the total annual recharge to the Mount Rose Fan (see Table 5-1). Therefore, the water balance for the STM basin is significantly affected by well pumpage under this scenario. Discharge to the wells is partially offset by a corresponding reduction in natural discharge to evapotranspiration and Steamboat Creek. This reduction, which is caused by lower water levels in the discharge area, amounts to 4406 af/yr after 20 years. However, the discharge

reduction is only half of the total pumpage, and a net outflow of 4486 af/yr remains. The imbalance can only be satisfied by removing water from storage in layers one and two.

Predicted drawdown is greatest at proposed well STMGID #8, which is in an area of low transmissivity near the western model boundary. At the end of the 20-year simulation, STMGID #8 dewateres the layer-one block in which the well is located. Also in layer one, several blocks are dewatered along the southern model boundary (Figure 7-18). Drawdown values throughout the Mount Rose Fan range from 30 to 50 ft for both layers one and two, after 20 years (Figures 7-18 and 7-19).

It is apparent that Scenario 2 results in over pumpage of the aquifer system. The Brown's Creek Well accounts for only a small fraction (7%) of this over pumpage, which is not enough to change the outcome of the scenario. A more favorable result could be obtained by decreasing the pumping rates, or by completing some of the proposed wells in the bedrock aquifer instead of alluvium.

7.3 Scenario 3

The purpose of Scenario 3 is to simulate the effects of operating two proposed injection wells in the northern Mount Rose Fan, for temporary storage of surface water in the alluvial aquifer. As shown on Figures 7-20 through 7-27, this scenario includes the five proposed pumping wells from Scenario 2. Existing wells STMGID #1 through #6 are not included in Scenario 3 due to their proximity to the injection wells.

Stresses for this scenario include 6170 af/yr pumpage and 1613 af/yr injection, for a net value of 4557 af/yr. This is an increase of less than 50% over the current rate. Because of the areal distribution of pumping and injection wells, most drawdown occurs in the Mount Rose Fan, upgradient of the two injection wells. Drawdown values in the Fan area are 10 to 15 feet less than for Scenario 2, ranging from 5 to 45 feet in the first two layers. Although this is an improvement over Scenario 2, the results still indicate significant depletion of aquifer storage in the Mount Rose Fan.

At the injection wells, predicted mounding (negative drawdown) reaches a peak value of -15 ft after only two years, and remains stable for the rest of the simulation. Comparison of the 2, 5, 10 and 20-year drawdown contours (Figures 7-20 through 7-27) shows that the areal extent of mounding is greatest at five years. Decreases in the extent of mounding after five years are apparently due to the cumulative effects of pumping upgradient of the injection wells.

7.4 Scenario 4

Scenario 4 simulates changes in discharge to Steamboat Creek and evapotranspiration which result from a complete cessation of irrigation in the STM. It is assumed that current pumping conditions (December, 1989 through December, 1991 in Table 5-2) remain in effect during the 20-year simulation. Table 7-1 compares the results of simulations performed with and without irrigation recharge. In all other respects, the simulations are identical.

Table 7-1 shows that the cessation of irrigation reduces discharge to Steamboat Creek by 9.5%, and evapotranspiration by 16.8%, after 20 years. The total reduction in discharge after 20 years is 2063 af/yr, somewhat less than the 2249 af/yr of irrigation that was removed. Therefore, the effects of removing irrigation do not subside in 20 years, and further effects would be observed if the simulation period were longer.

Table 7.1 Discharge Rates (af/yr) for Scenario 4

	0 Years	2 Years	5 Years	10 Years	20 Years
SB Creek with Irrigation	5109	5075	5049	5028	5009
SB Creek without Irrigation	5109	4722	4622	4570	4534
Change	0	353	428	458	474
ET with Irrigation	10099	9851	9693	9563	9443
ET without Irrigation	10099	8630	8257	8023	7854
Change	0	1222	1436	1540	1589

7.5 Scenario 5

This scenario simulates changes in mountain-front recharge rates that would result from a prolonged drought. Typically, drought conditions decrease the quantity of water available for recharging the aquifer, and this produces observed declines in water levels. For purposes of this simulation, however, specified water-level declines are used as input to predict corresponding decreases in recharge rates. The apparent reversal of the natural cause-and-effect relationship merely facilitates the calculation, and does not affect the final results.

Based on hydrograph data presented in Appendix B, it is assumed that a drought would cause the elevation of the alluvial water table to decline by 25 ft on the west side of the STM. It is also assumed that the water table would remain at this lower level for five years. To calculate the resulting decrease in recharge to the Mount Rose Fan, the MODFLOW boundary conditions are re-defined to constant head (for Scenario 5 only). This allows flow rates at the boundaries to vary in response to a new set of initial heads. As with Scenario 4, it is assumed that current pumping conditions remain in effect during the five-year simulation.

Figure 7-28 depicts contours of specified water-level decline or 'drawdown' which are imposed on Layers 1 and 2, for purposes of calculating the change in recharge. The Figure shows a 25-ft decline on the west side of the STM, decreasing eastward to 0 ft near Steamboat Creek. Initial heads for Layers 1 and 2 are obtained by subtracting the drawdown shown in Figure 7-28 from the initial heads used in the other scenarios (Figures 7-1 and 7-

2). Layer 3 is assumed to be too deep to be affected by a five-year drought, so initial heads shown in Figure 7-3 are used without modification.

After five years of simulation time, predicted recharge to the Mount Rose Fan is decreased by 12.6%, or 1668 af/yr. This amount corresponds to about half of the current pumping rate, or one-fifth of the Scenario 2 pumping rate. Therefore, the simulated drought produces only a moderate change in the overall water budget for the STM basin.

An additional objective of this scenario is to determine the sensitivity of predicted recharge rates to the accuracy of model calibration. The scenario shows that a 25-ft decrease in head reduces the recharge rate by 12.6%. Calibration accuracy is expressed as head difference in feet (observed minus predicted). Thus, the 12.6% variation in recharge rates is related to model calibration for blocks that have head differences smaller than 25 ft. Calibration results presented in Section 5.4 indicate that about 70% of the blocks in layer 1 meet the 25-ft accuracy standard. For this group of blocks, recharge rates are expected to vary by less than 12.6% due to model calibration effects.

The uncertainty in total predicted recharge for the model should be comparatively small, because plus and minus variations for individual blocks tend to cancel out when computing a total value. In contrast, the range in estimated recharge rates for the Mount Rose Fan (Table 5-1) corresponds to a 25% variation, which is significantly greater than the uncertainty in model predictions.

7.6 Water Quality

The purpose of the water quality model is to simulate the effects of the geothermal system on water quality in the basin and in Steamboat Creek, and the effects of mixing ground-water recharge from distinct sources in the Steamboat Hills, Carson Range, and the Virginia Range. The model may also be used to predict the effects of various effluent management schemes, such as use of septic tanks or spray irrigation, and agricultural impacts.

The objective of the solute transport simulation described in Section 6.0 is to reproduce observed data as closely as possible with the model. The calibrated model is ready to perform predictive scenarios, such as determining the water-quality effects due to large-scale pumping in the Mount Rose Fan area. The model can also be used to predict long-term water quality changes in Steamboat Creek due to changes in ground-water discharge rate or concentration.

The water quality model is currently set up to simulate the transport of chloride associated with the geothermal influence at Steamboat Hills. However, transport of any constituent of interest may be simulated. The primary limitation of the transport model is that only a single constituent may be simulated at once. The model does not presently simulate upwelling of geothermal water along specific faults and fracture zones, as insufficient data are available to characterize this phenomena. As data become available in the future, the model can be updated to accommodate these local effects on water quality.

The results of the 1700 year solute transport simulation for chloride are presented in Figures 7-29 , 7-30, and 7-31, for layers 1, 2, and 3 respectively. Generally, the results show chloride moving vertically upward from the source area (Steamboat Hills) in layer 3 to layer 1, and then horizontally to the discharge area in the vicinity of Double Diamond. Comparisons between observed and predicted values for specific areas of the model are discussed below.

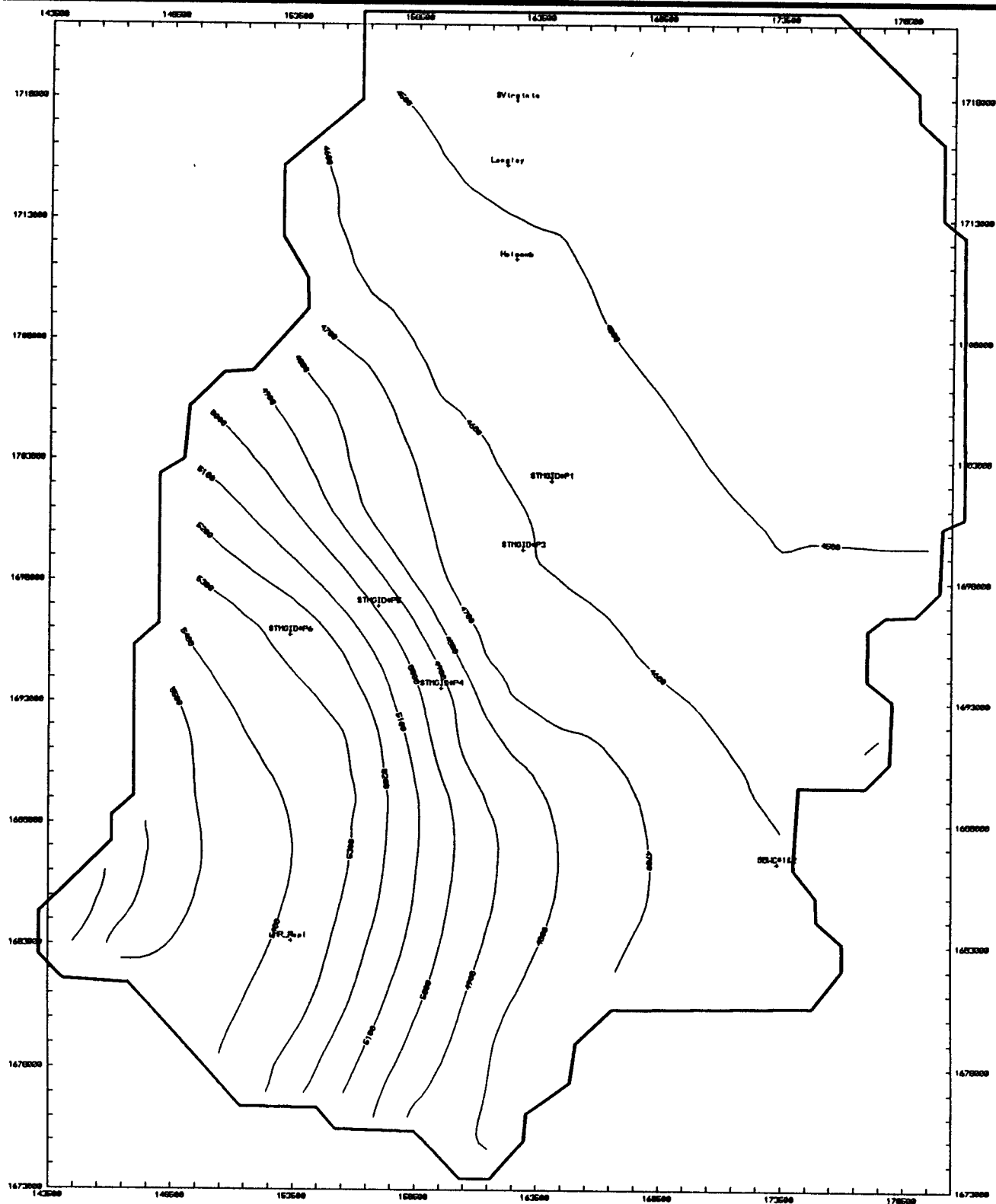
In general, the calibration of the water quality model is good. Model predicted chloride concentrations in layer one match observed data at 72% of alluvial water sample points (Figure 7-29). Predicted chloride concentrations for the western half of the model are in excellent agreement with observed data. In the southeastern quadrant of the modeled area, layer one predicted values are less than observed by as much as 200 mg/l at two of 10 observation points. These two sample points may be located along a fault zone where geothermal water is upwelling, and thus not representative of local water quality. Generally, predicted chloride concentrations in this area are in good agreement with observed data.

Layer one predicted chloride concentrations for the discharge area (northeastern quadrant of the model) can be compared with one ground-water sample (well 18/20-09caba) and with estimates of water quality discharged to Steamboat Creek (Section 6.4). Predicted concentrations at well 18/20-09caba exceed the observed value of chloride by approximately 400 mg/l, however, predictions 1000 feet west of the well agree with the observed value (Figure 7-29). Well 18/20-09caba is a flowing well of unknown depth, and may be completed in layer two. Thus, the well may be sampling a zone where chloride values have not been

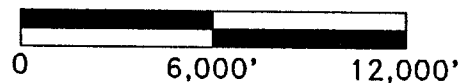
increased by evapotranspiration. Good agreement has been achieved between predicted chloride concentration of ground-water discharged to Steamboat Creek and values estimated from creek samples obtained by Shump (1985). Chloride concentrations in ground-water predicted at the nodes representing Steamboat Creek range from 57 to 809 mg/l, compared to a value of approximately 515 mg/l estimated from Schump's data (See Table 6.1). Figure 7-32 shows predicted ground-water chloride concentrations discharged at each stream reach within the discharge area. Stream reaches are analogous to Shump (Table 8, 1985). The maximum predicted chloride concentration in Steamboat Creek is at stream reach S76-S77, at the north end of the discharge area.

Predicted chloride concentrations in layer three are representative of observed data in 75% of bedrock water samples (Figure 7-31). Predicted values are lower than observed chloride concentrations in wells penetrating the bedrock in the vicinity of the geothermal area. These wells generally have higher concentrations of chloride than the geothermal source water, probably due to concentration of chloride in well water by boiling as pressure changes with depth (Nehring, 1980). Predicted chloride concentrations are also lower than observed in wells which penetrate fracture zones. However, in general, very good agreement between predicted concentrations and observations has been achieved in the western portion of the modeled area. The single observation in the northeastern section of the modeled area is much higher than the predicted values. This may be due to a greater extent of geothermal influence than is portrayed by the water quality model.




The good correspondence between observed and predicted chloride values indicates that the Steamboat Hills geothermal system is the dominant influence on chloride distribution in the STM. By correctly simulating the geothermal system, the model is able to account for virtually all of the observed sample data.




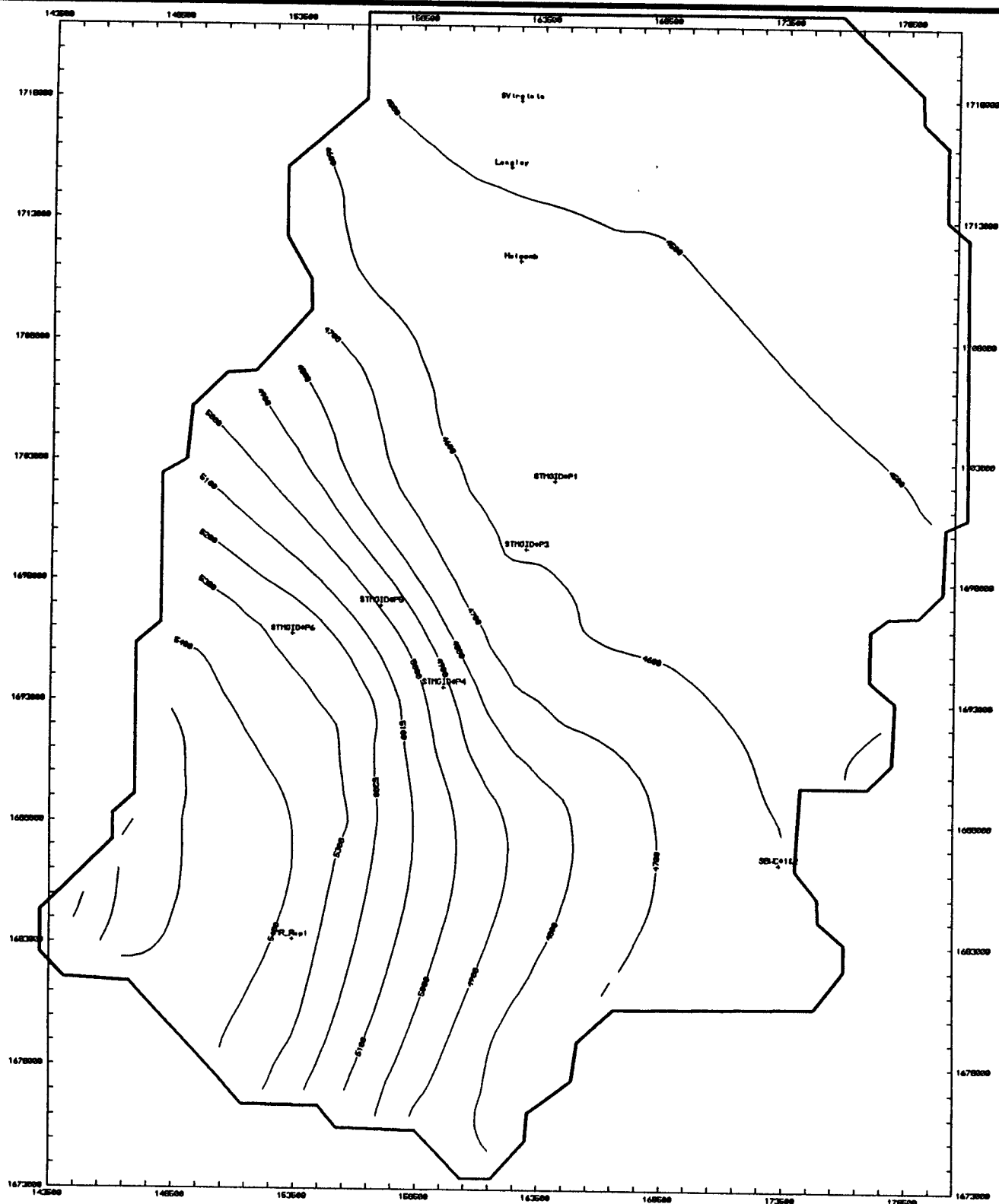
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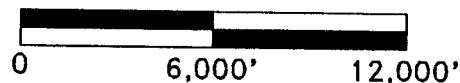
Explanation

-  Well location and name
-  Contour of equal water-level elevation (ft.,msl)
-  Boundary of modeled area
- Contour interval is 100 feet.

South Truckee Meadows Washoe County, NV		DATE: 9/22/91
South Truckee Meadows Layer 1 Initial Water-Level Conditions		DRAWN: KEK
		CHECKED: KEK
		APPROVED: KEK
		DWG NO: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine		Figure 7-1



SCALE: 1"=6,000'



Explanation

- Well location and name
- Contour of equal water-level elevation (ft.,msl)
- Boundary of modeled area
- Contour interval is 100 feet.

South Truckee Meadows
Washoe County, NV

South Truckee Meadows Layer 2 Initial Water-level Conditions

DATE: 9/22/91

DRAWN: KEK

CHECKED:

APPROVED:

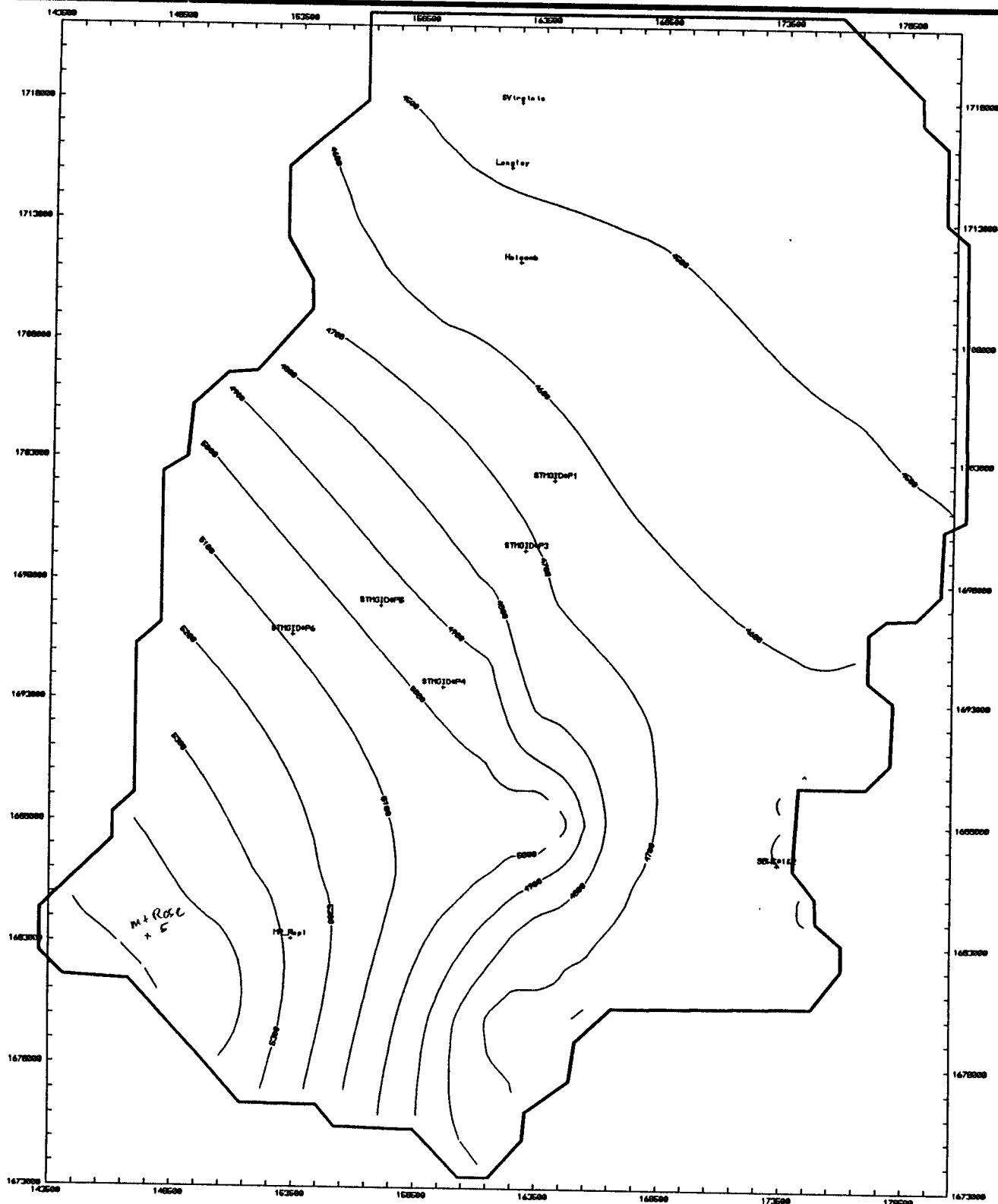
DWG NO:

PROJ.: 396U23201



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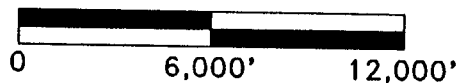
Figure 7-2




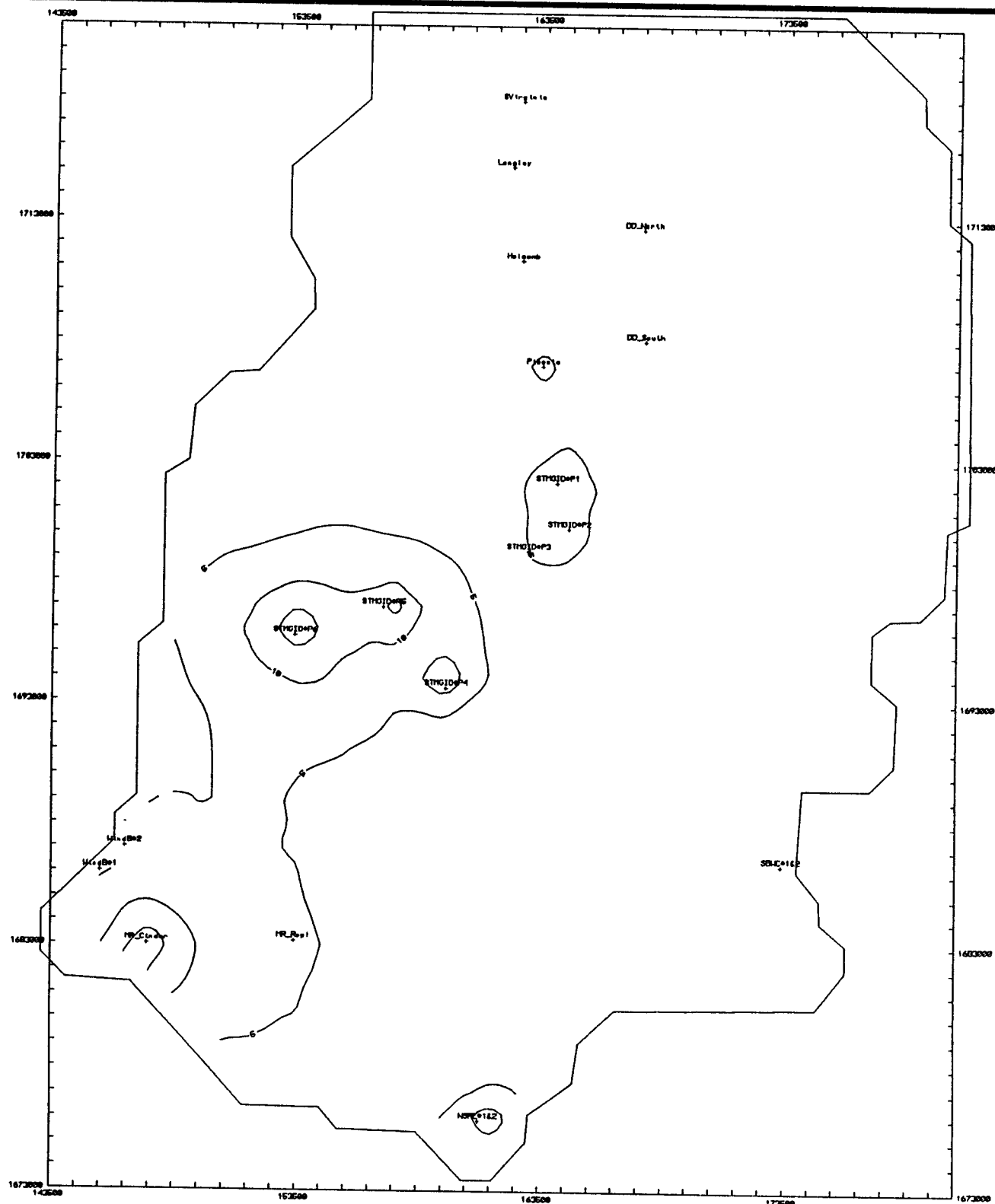
Explanation

- Well location and name
- Contour of equal water-level elevation (ft.,msl)
- Boundary of modeled area
- Contour interval is 100 feet.

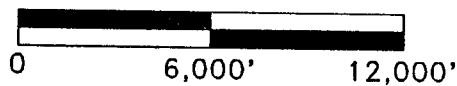
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South Truckee Meadows Washoe County, NV		DATE: 9/22/91
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		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS-GEOLGISTS-ENGINEERS Reno Denver Milwaukee Irvine		Figure 7-3



SCALE: 1"=6,000'



Explanation

Longley Well location and name

Contour of equal drawdown
due to pumping (feet)
Contour interval = 5 feet

Boundary of modeled region

South Truckee Meadows
Washoe County, NV

Scenario 1
Drawdown in Layer 1
2 Year Simulation

DATE: 9/22/91

DRAWN: KEK

CHECKED:

APPROVED:

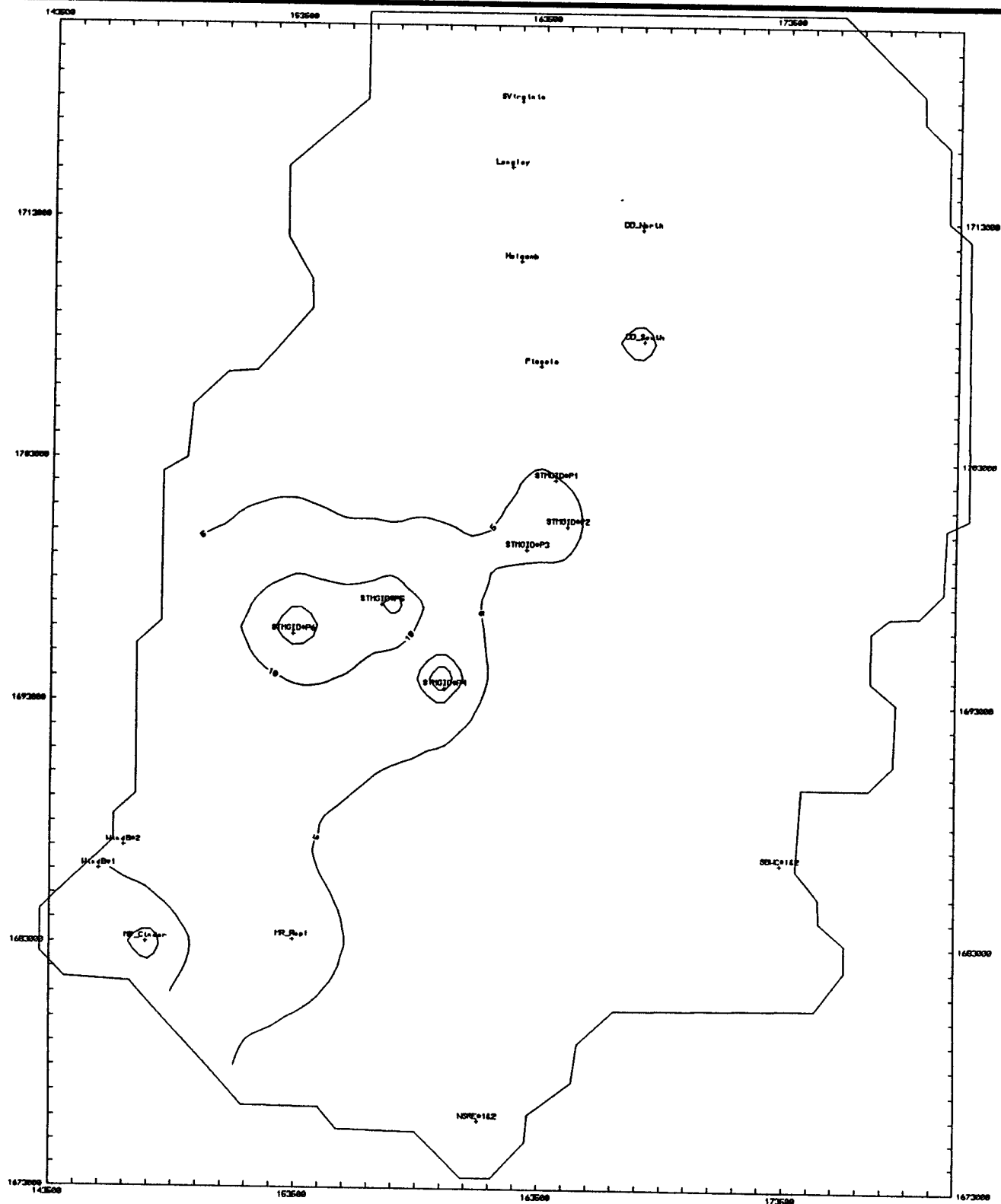
DWG NO:

PROJ.: 396U23201



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Figure 7-4



Explanation

- Langley Well location and name
- Contour of equal drawdown due to pumping (feet)
- Contour interval = 5 feet
- Boundary of modeled region

SCALE: 1"=6,000'

0 6,000' 12,000'

South Truckee Meadows
Washoe County, NV

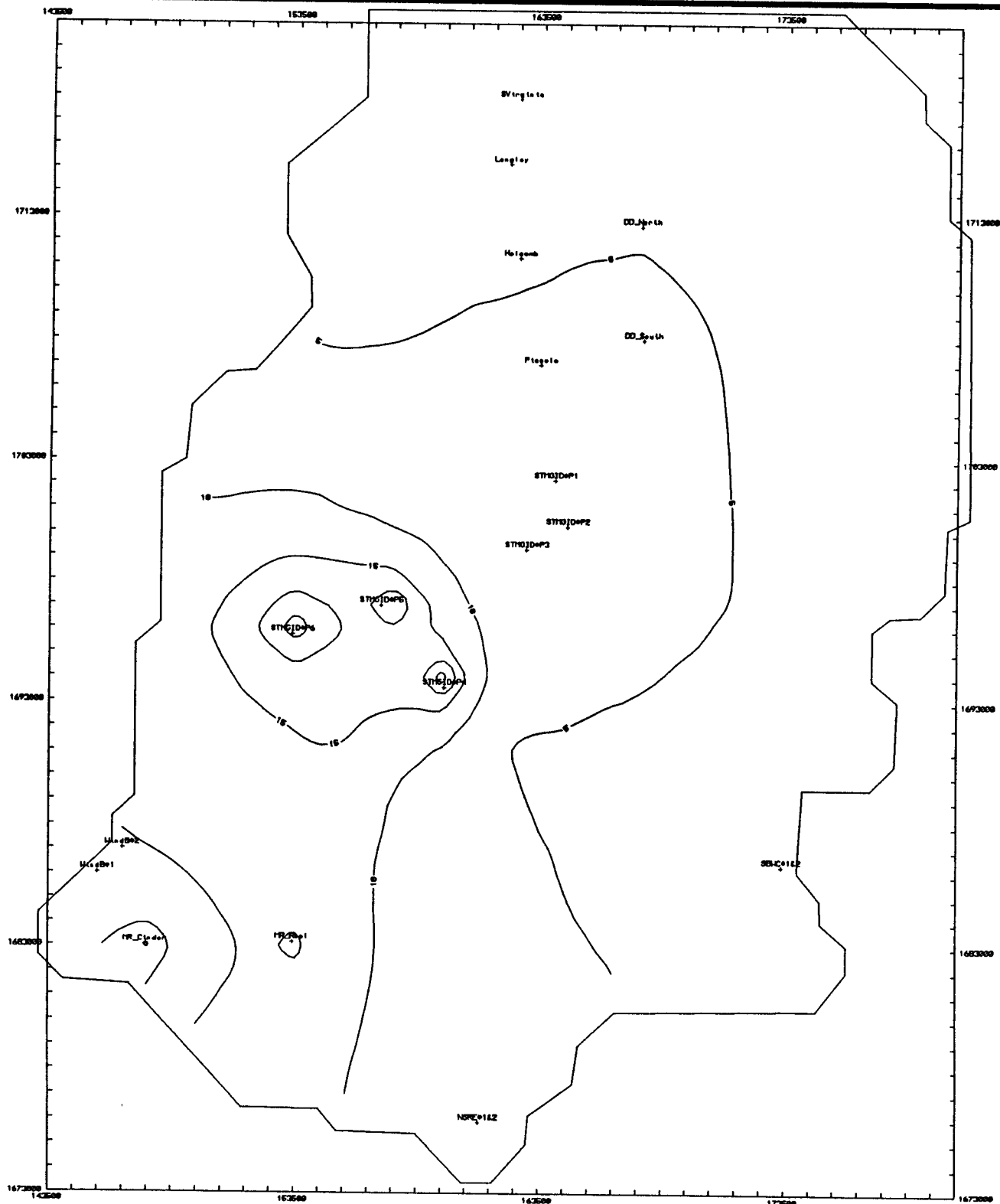
Scenario 1
Drawdown in Layer 2
2 Year Simulation

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201



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Figure 7-5



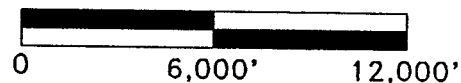
Explanation

Well location and name

Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet

Boundary of modeled region

SCALE: 1"=6,000'



South Truckee Meadows
Washoe County, NV

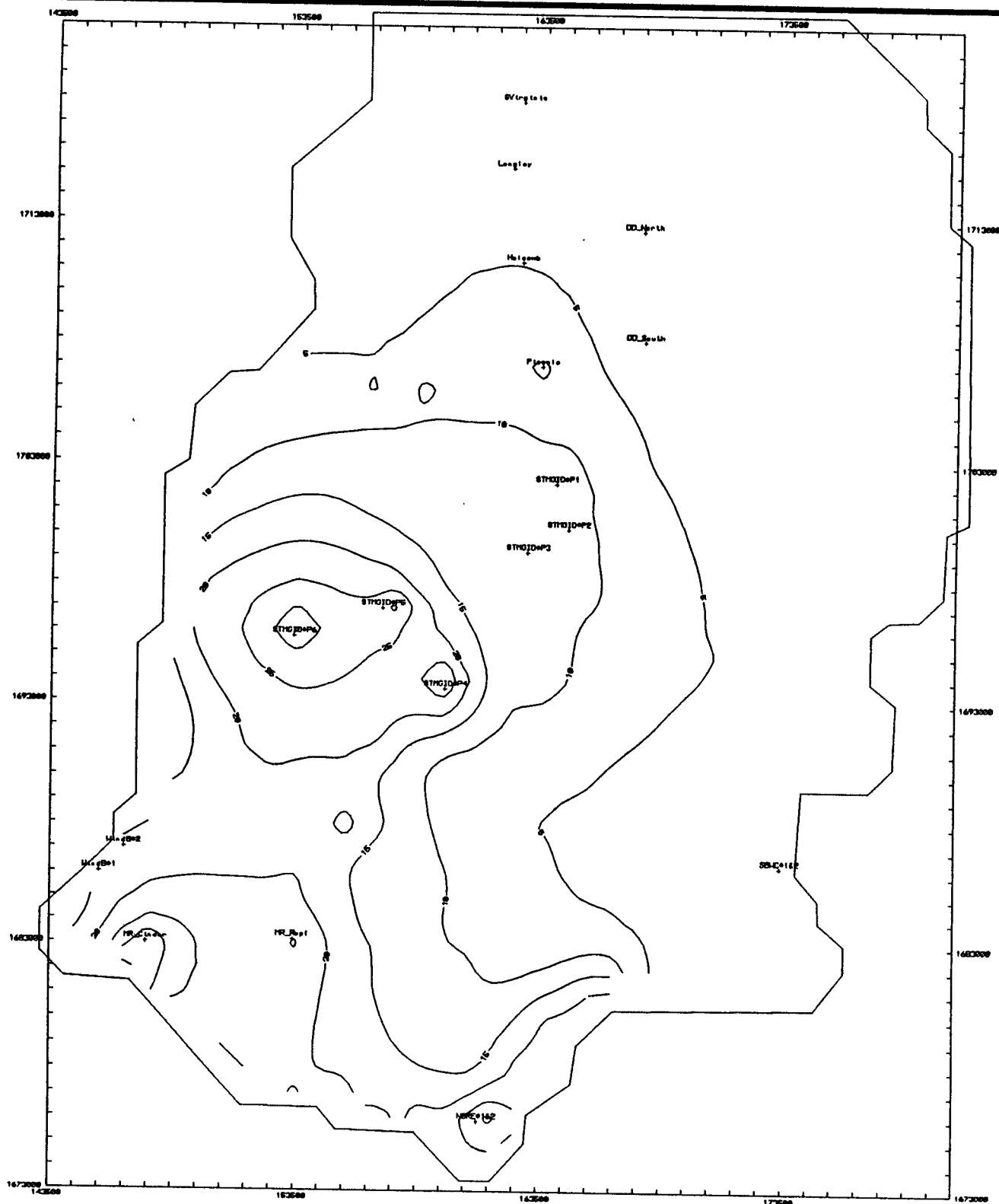
Scenario 1
Drawdown in Layer 2
5 Year Simulation

DATE: 9/22/91
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CHECKED:
APPROVED:
DWG NO:
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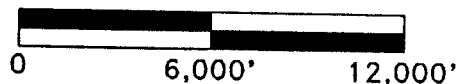


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Figure 7-7



SCALE: 1"=6,000'



Explanation

Longley Well location and name

Contour of equal drawdown
due to pumping (feet)
Contour interval = 5 feet

Boundary of modeled region

South Truckee Meadows
Washoe County, NV

Scenario 1
Drawdown in Layer 1
10 Year Simulation

DATE: 9/22/91

DRAWN: KEK

CHECKED:

APPROVED:

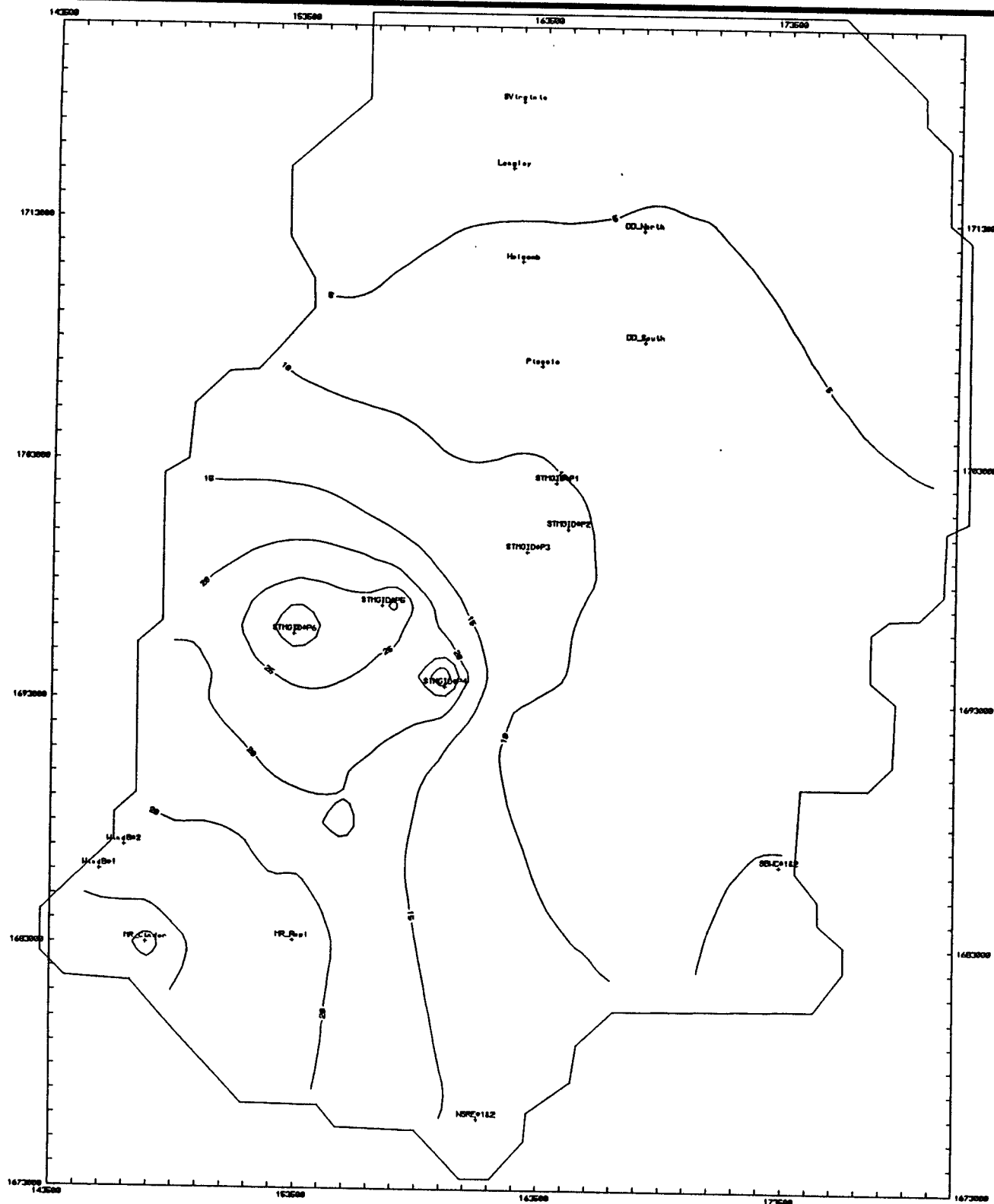
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PROJ.: 396U23201

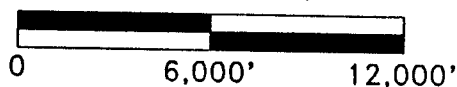


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Figure 7-8



SCALE: 1"=6,000'



Explanation

Longley Well location and name

Contour of equal drawdown due to pumping (feet)

Contour interval = 5 feet

Boundary of modeled region

South Truckee Meadows
Washoe County, NV

Scenario 1
Drawdown in Layer 2
10 Year Simulation

DATE: 9/22/91

DRAWN: KEK

CHECKED:

APPROVED:

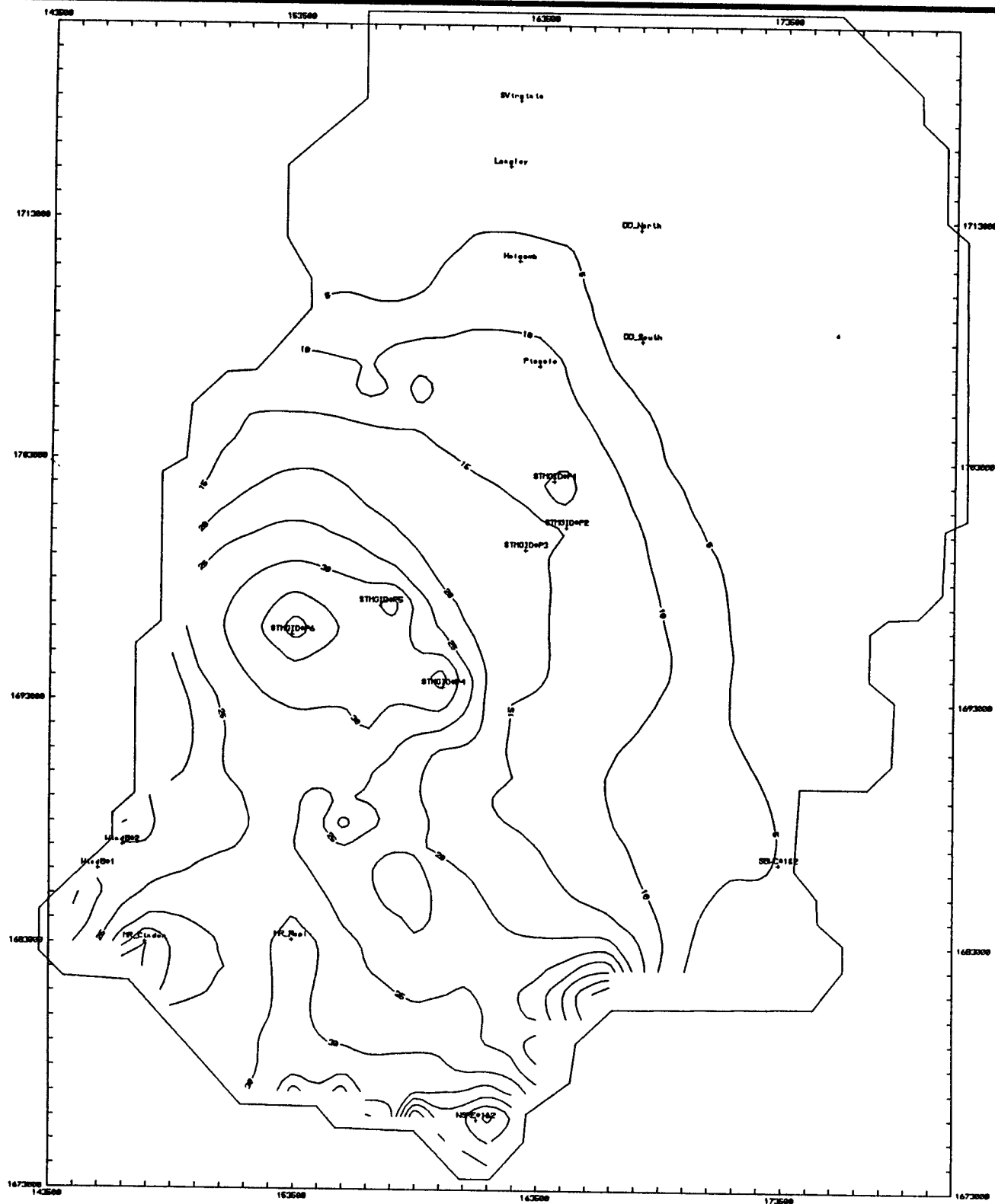
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PROJ.: 396U23201



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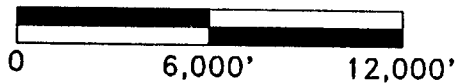
Figure 7-9



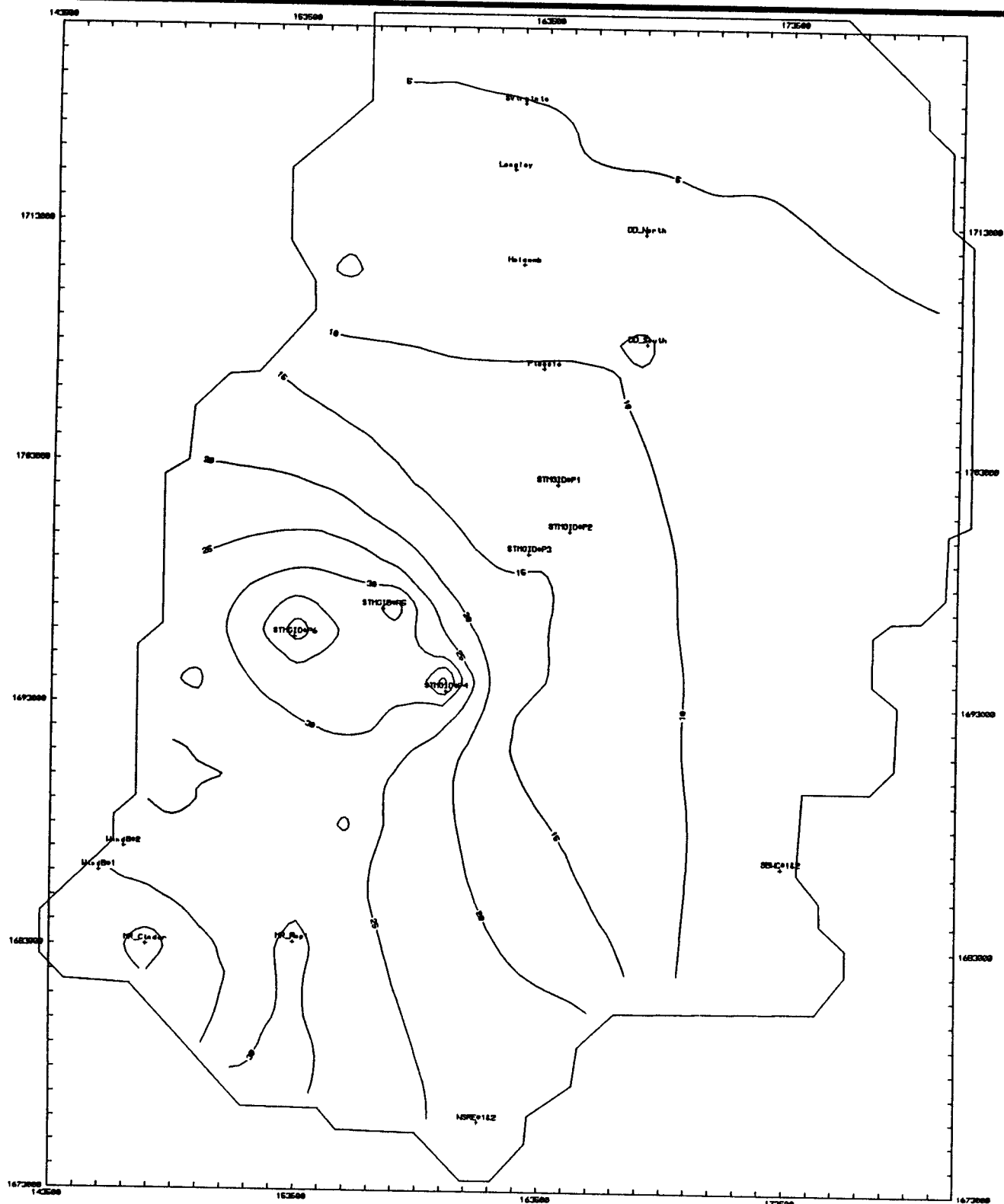
Explanation

- Longier Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

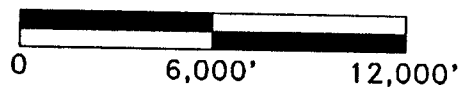
SCALE: 1"=6,000'



South Truckee Meadows Washoe County, NV		DATE: 9/22/91
Scenario 1 Drawdown in Layer 1 20 Year Simulation		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine		PROJ.: 396U23201 Figure 7-10



SCALE: 1"=6,000'



Explanation

Longley Well location and name

Contour of equal drawdown
due to pumping (feet)
Contour interval = 5 feet

Boundary of modeled region

South Truckee Meadows
Washoe County, NV

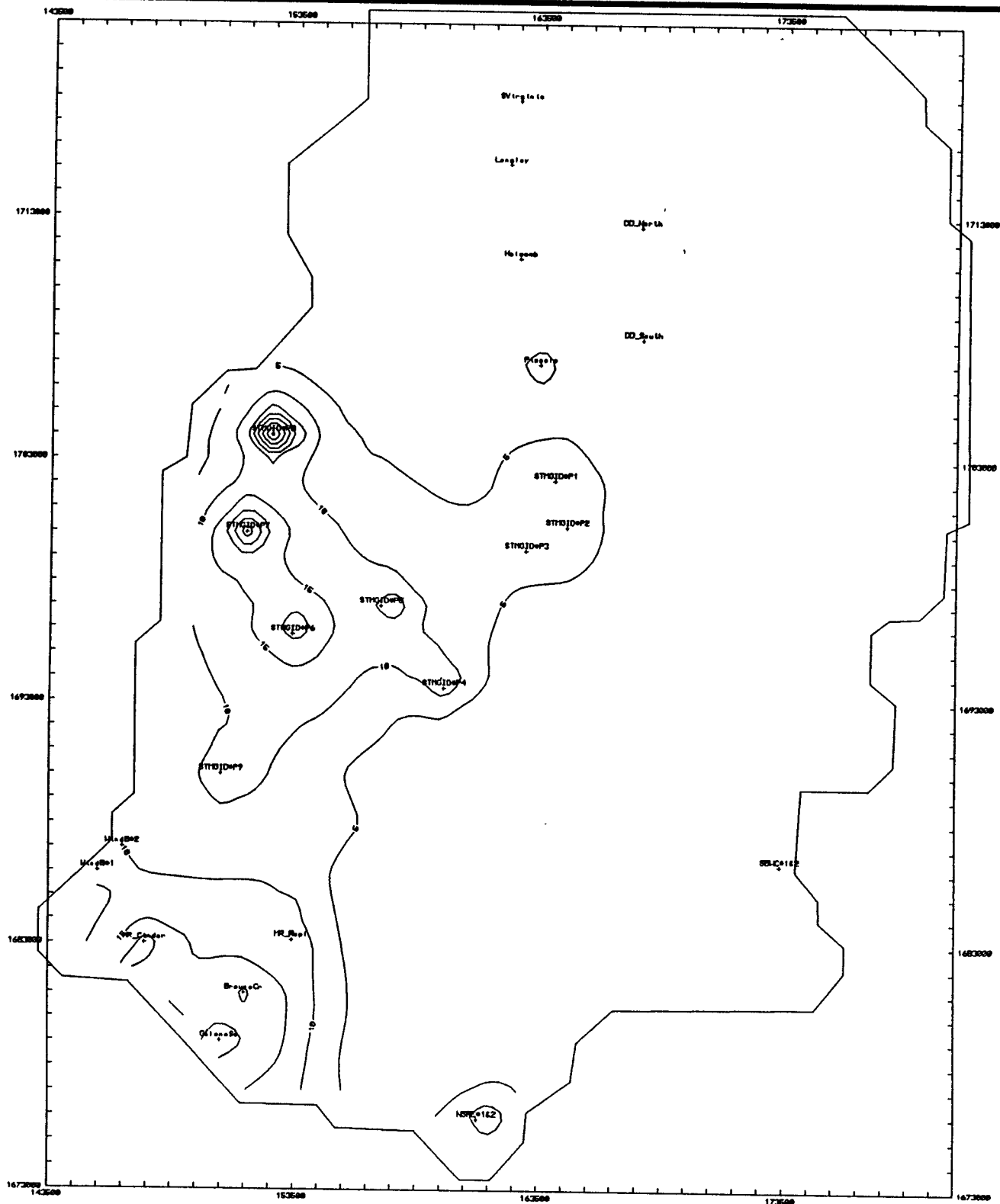
Scenario 1
Drawdown in Layer 2
20 Year Simulation

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201

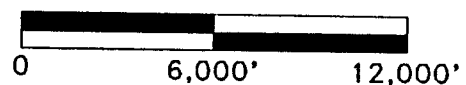


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Figure 7-11




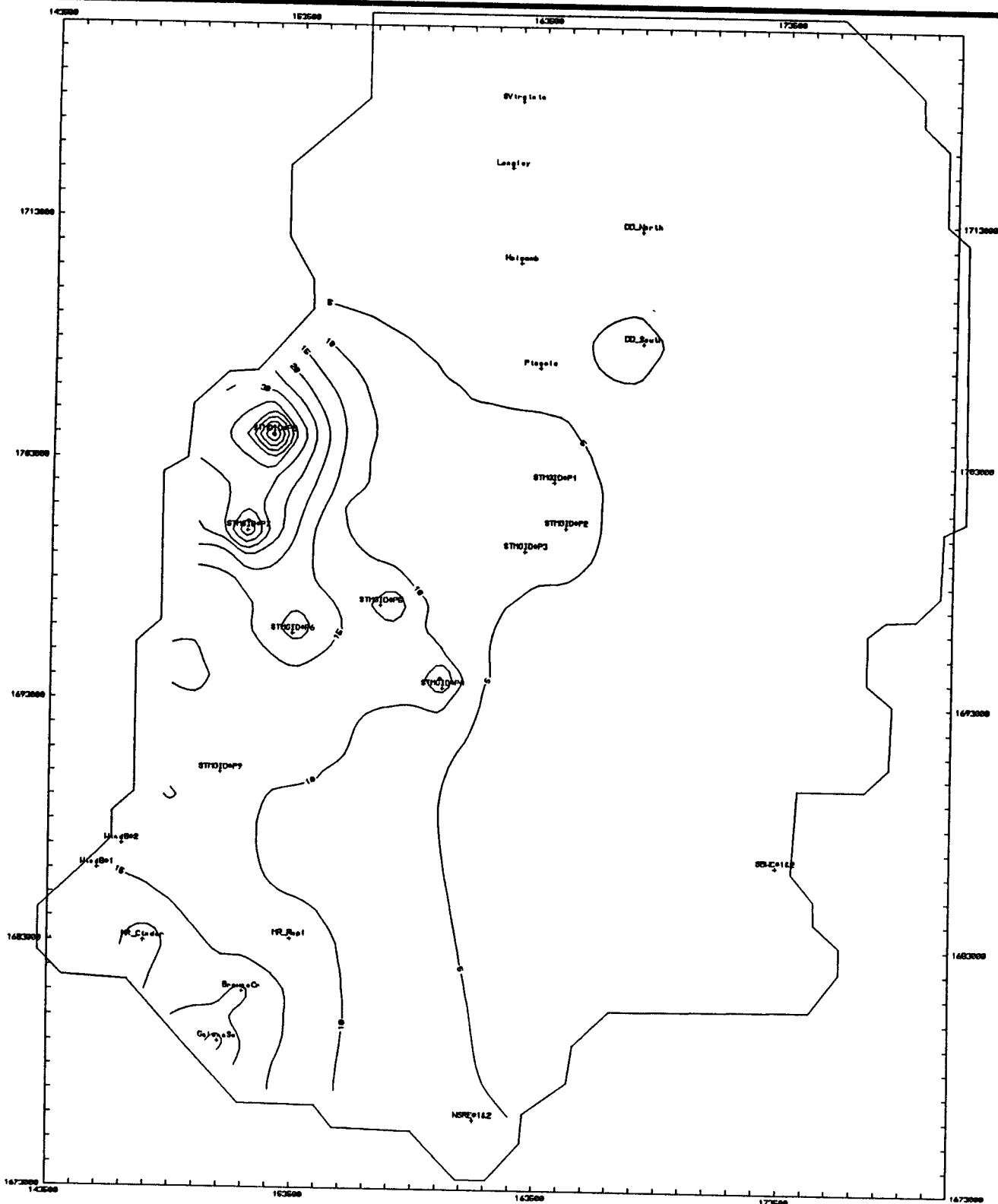
SCALE: 1"=6,000'



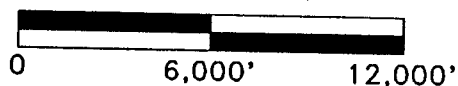
Explanation

- Langley Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows Washoe County, NV		DATE: 9/22/91
Scenario 2 Drawdown in Layer 1 2 Year Simulation		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine		PROJ.: 396U23201 Figure 7-12




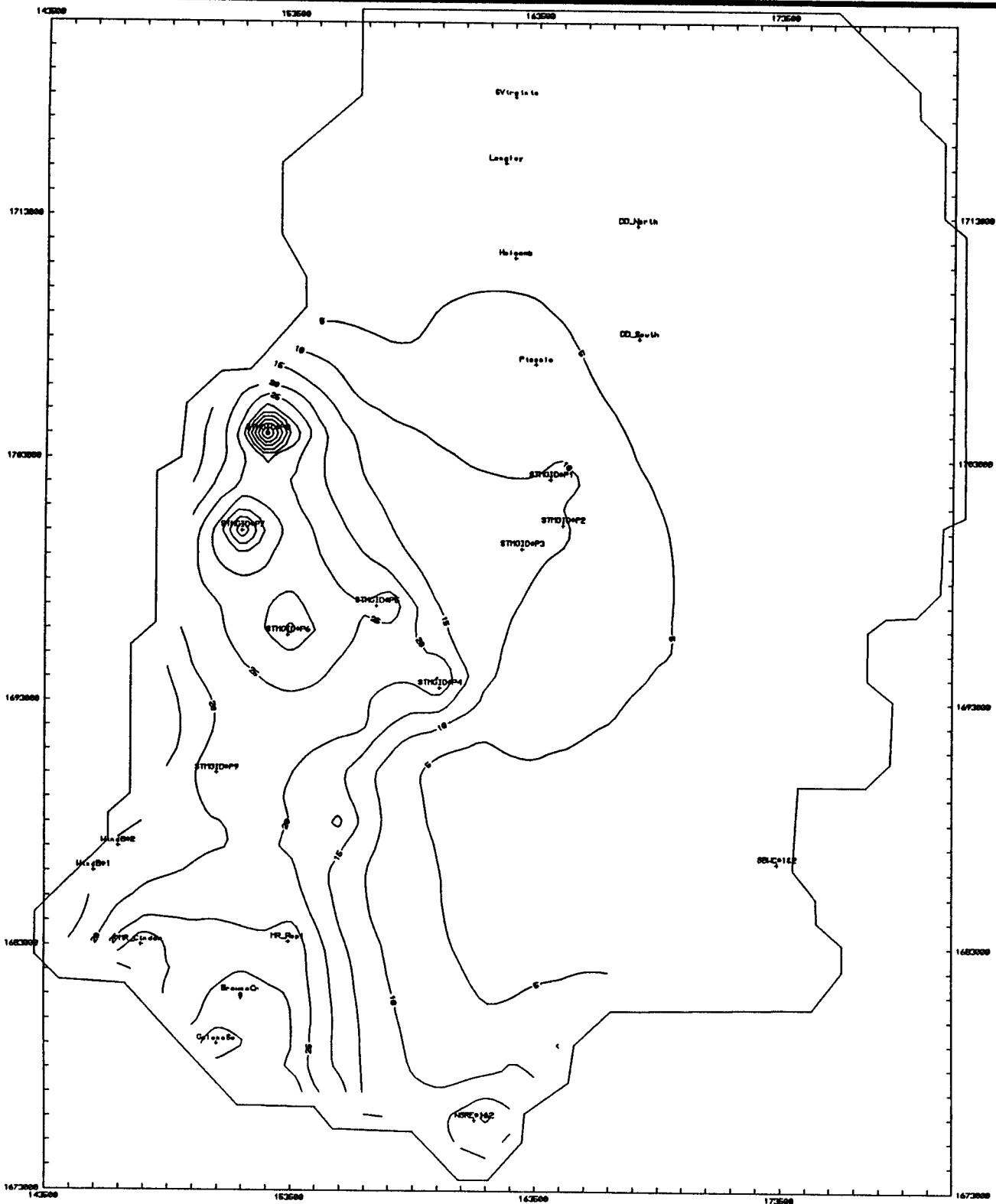
SCALE: 1"=6,000'



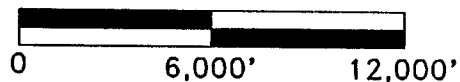
Explanation

- Well location and name
- Contour of equal drawdown due to pumping (feet)
- Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows Washoe County, NV		DATE: 9/22/91
Scenario 2 Drawdown in Layer 2 2 Year Simulation		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine		Figure 7-13



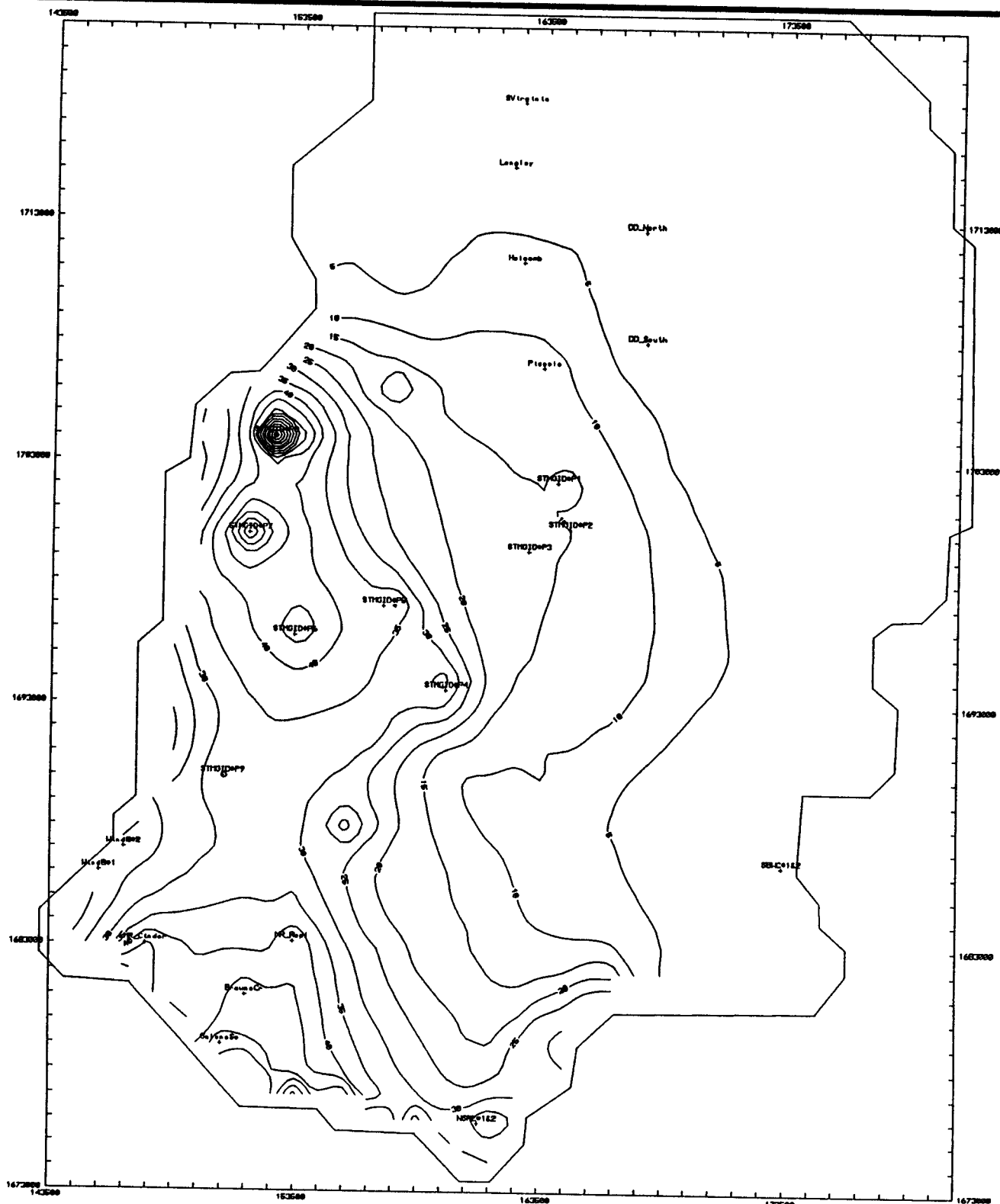
SCALE: 1"=6,000'



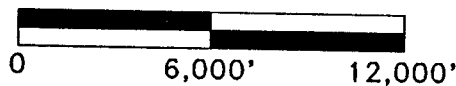
Explanation

- Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows Washoe County, NV		DATE: 9/22/91
Scenario 2 Drawdown in Layer 1 5 Year Simulation		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine		PROJ.: 396U23201 Figure 7-14



SCALE: 1"=6,000'



Explanation

- Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows
Washoe County, NV

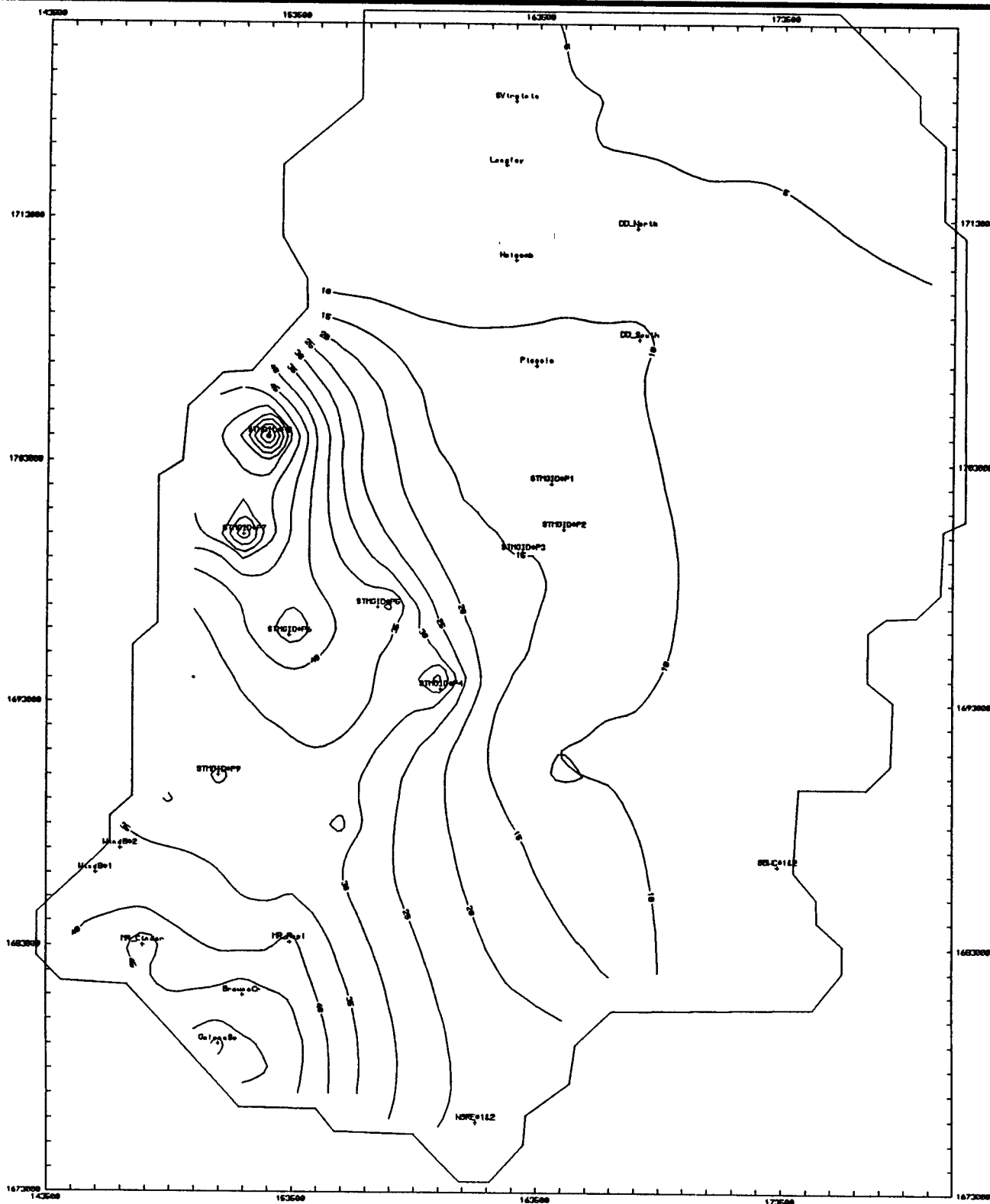
Scenario 2
Drawdown in Layer 1
10 Year Simulation

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201

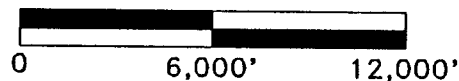


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Figure 7-16



SCALE: 1"=6,000'



Explanation

- Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows
Washoe County, NV

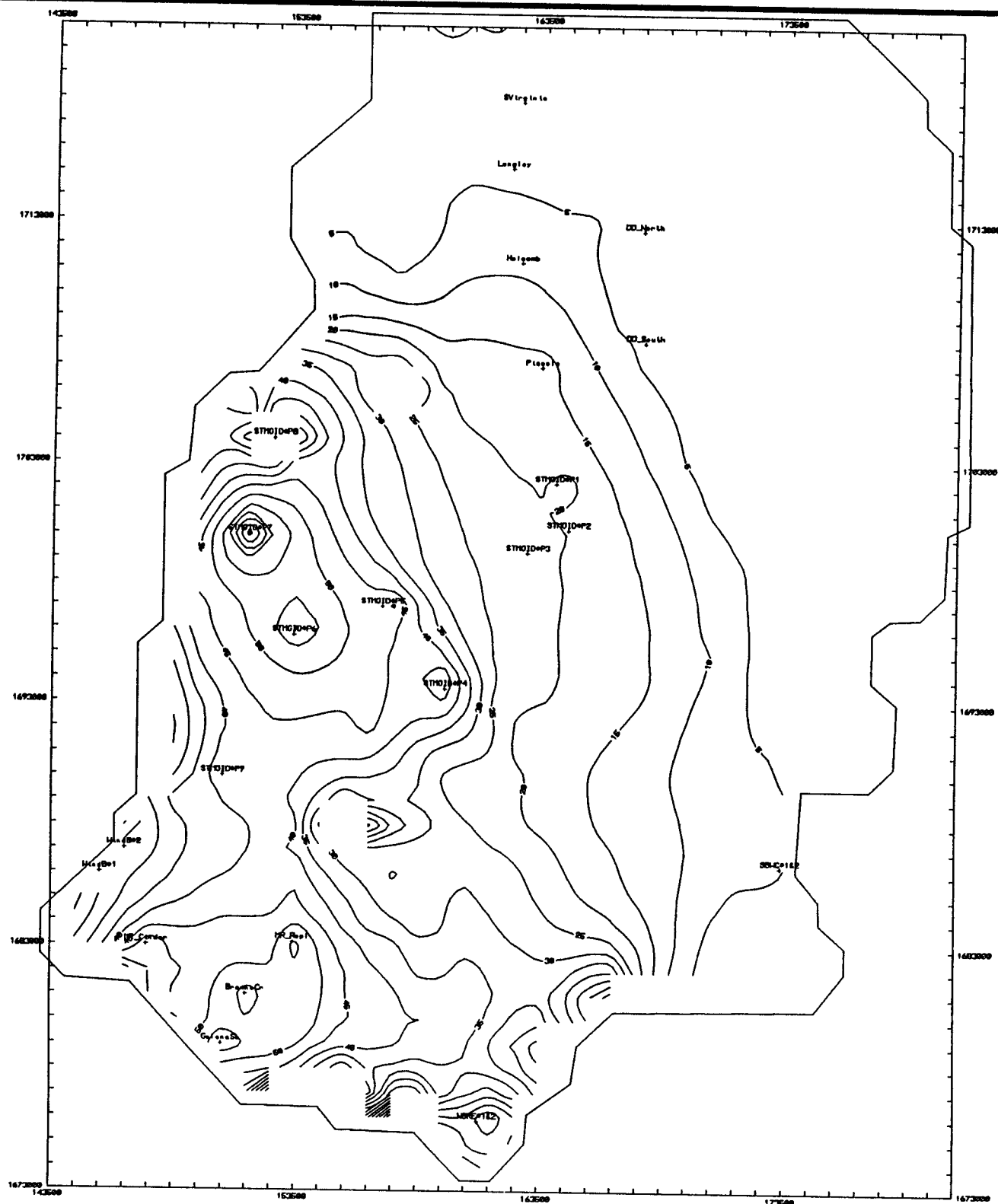
Scenario 2
Drawdown in Layer 2
10 Year Simulation

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201

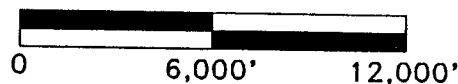


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Figure 7-17



SCALE: 1"=6,000'



Explanation

- Langley Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows
Washoe County, NV

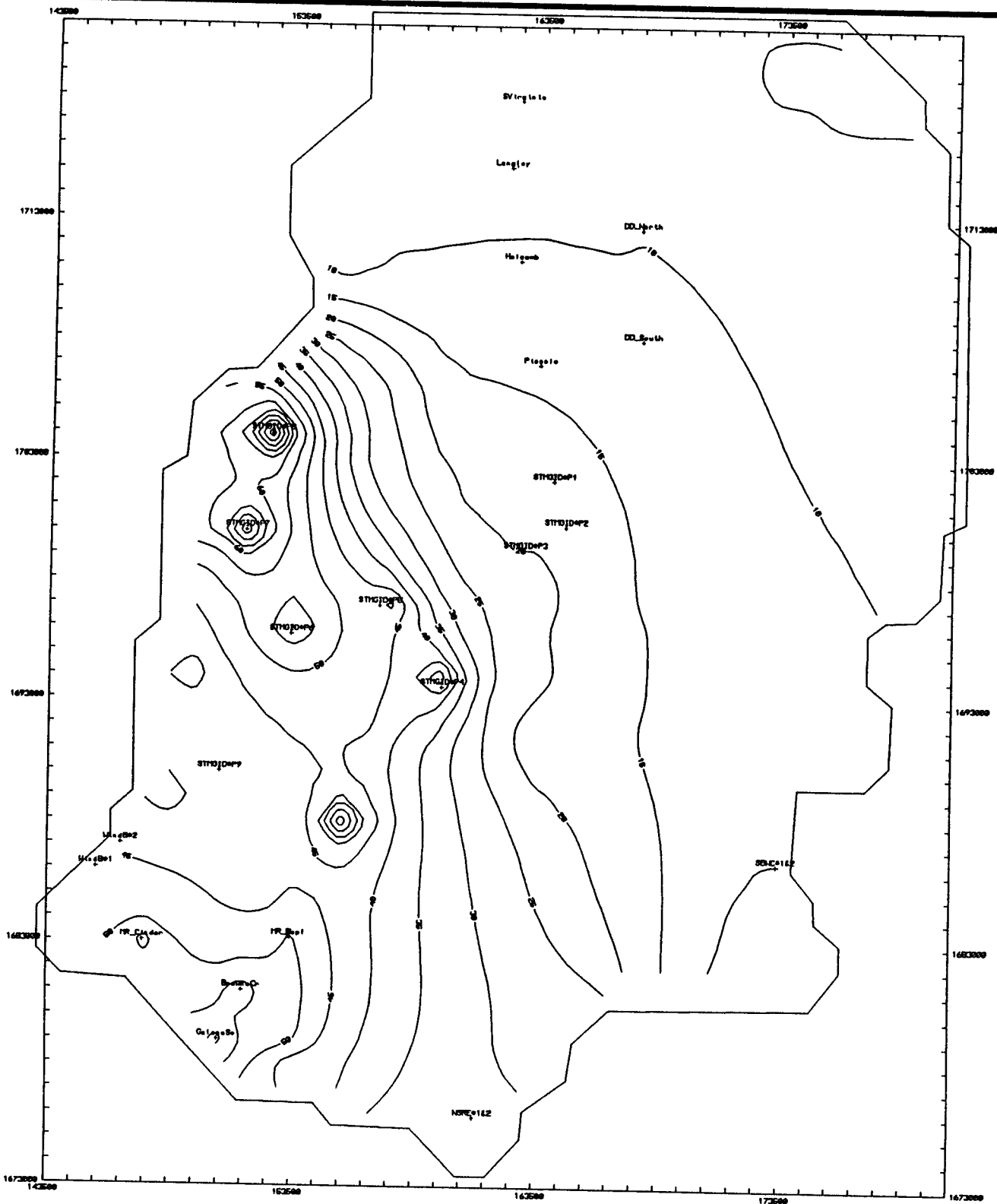
Scenario 2
Drawdown in Layer 1
20 Year Simulation

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201



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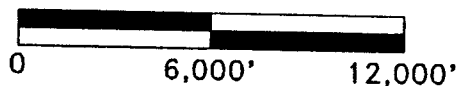
Figure 7-18




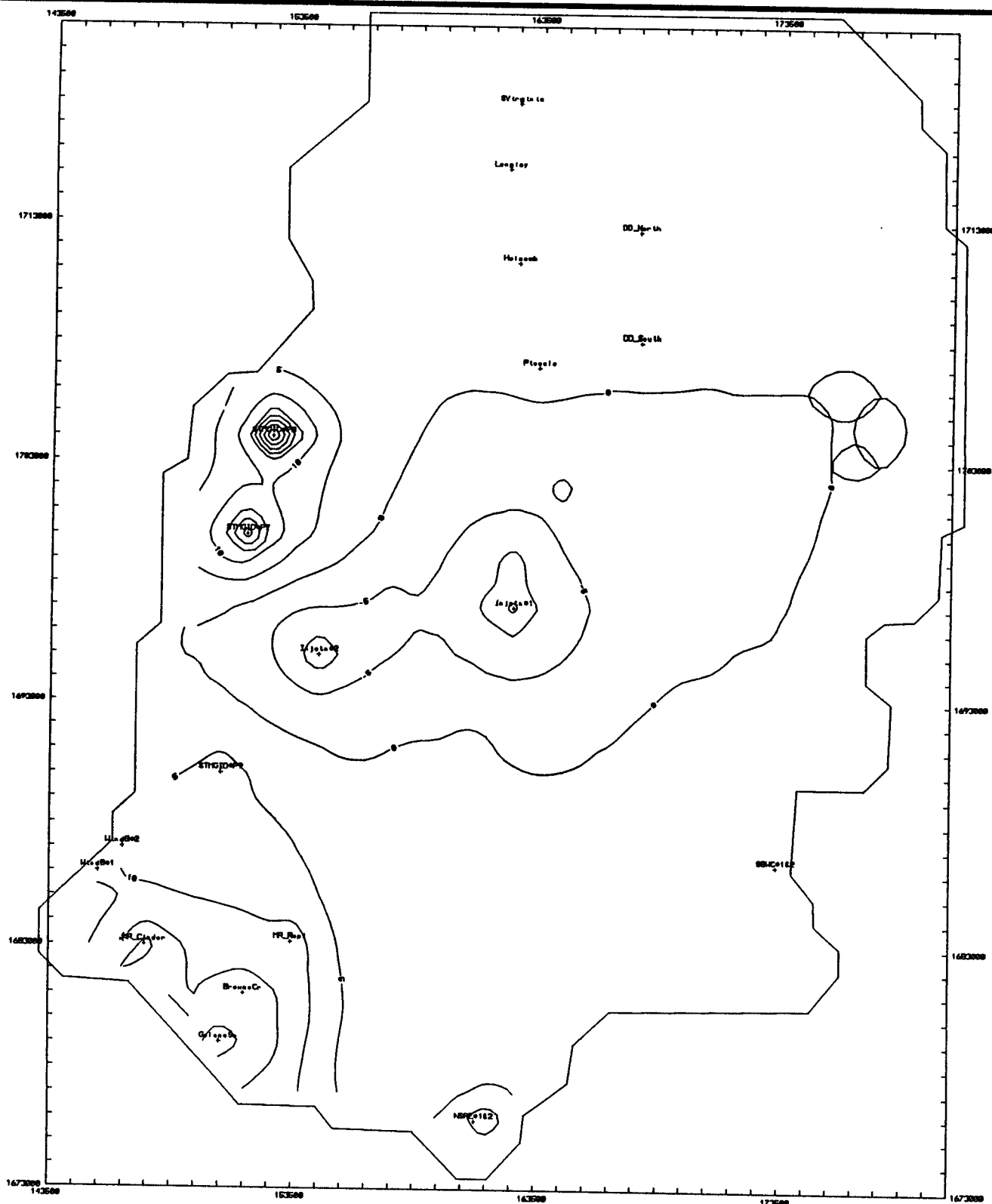
Explanation

- Longley Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

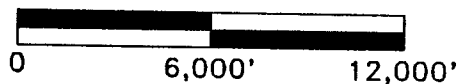
SCALE: 1"=6,000'



South Truckee Meadows Washoe County, NV		DATE: 9/22/91
Scenario 2 Drawdown in Layer 2 20 Year Simulation		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS-GEOLGISTS-ENGINEERS Reno Denver Milwaukee Irvine		Figure 7-19



SCALE: 1"=6,000'



Explanation

- Longley Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows
Washoe County, NV

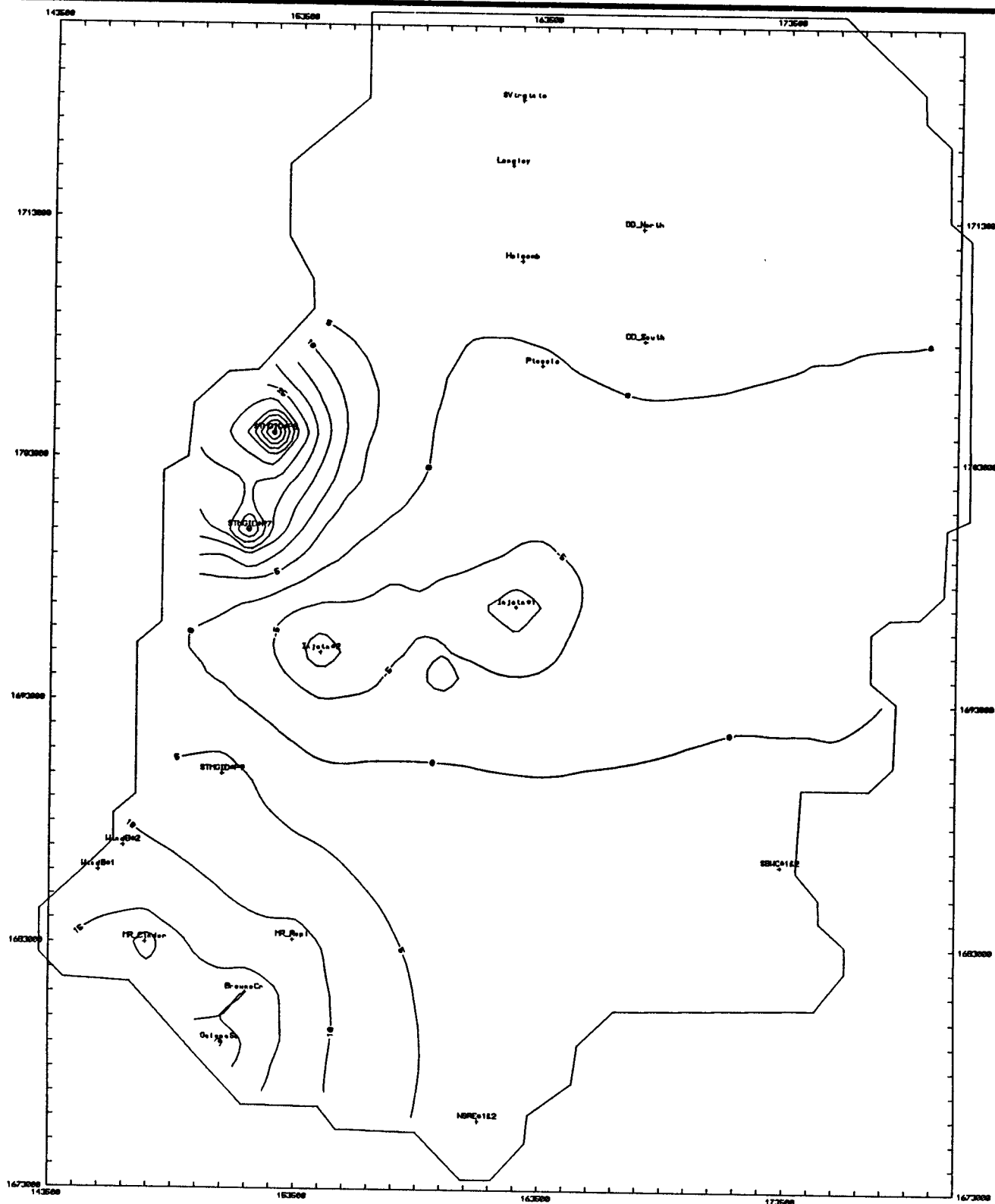
Scenario 3
Drawdown in Layer 1
2 Year Simulation

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201

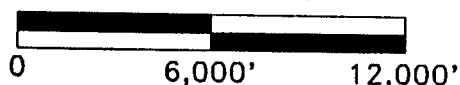


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Figure 7-20



SCALE: 1"=6,000'



Explanation

- Langley Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows
Washoe County, NV

Scenario 3
Drawdown in Layer 2
2 Year Simulation

DATE: 9/22/91

DRAWN: KEK

CHECKED:

APPROVED:

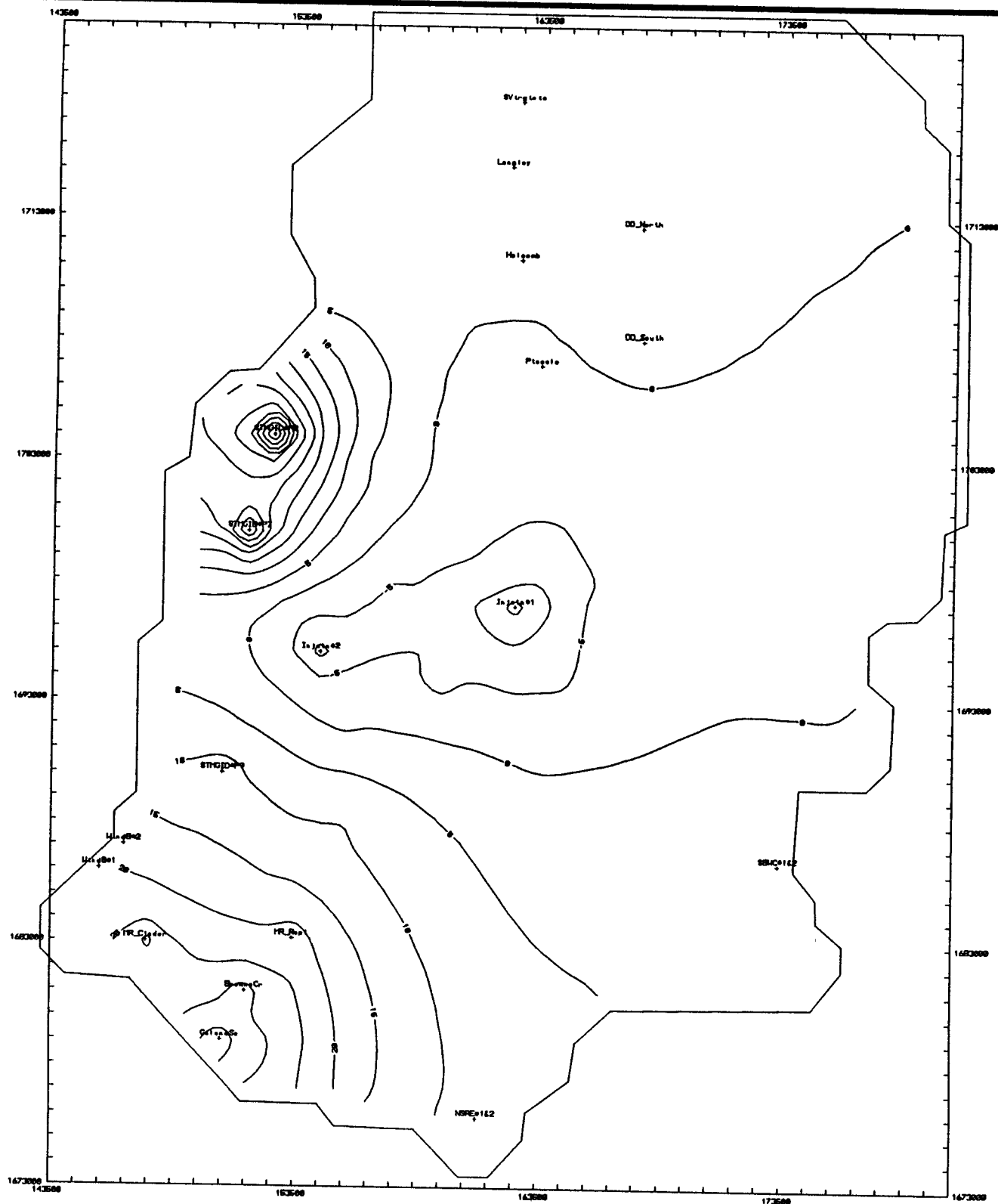
DWG NO:

PROJ.: 396U23201

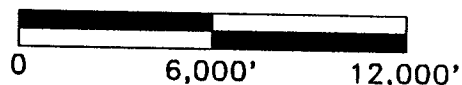


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Reno Denver Milwaukee Irvine

Figure 7-21



SCALE: 1"=6,000'



Explanation

- Longier Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows
Washoe County, NV

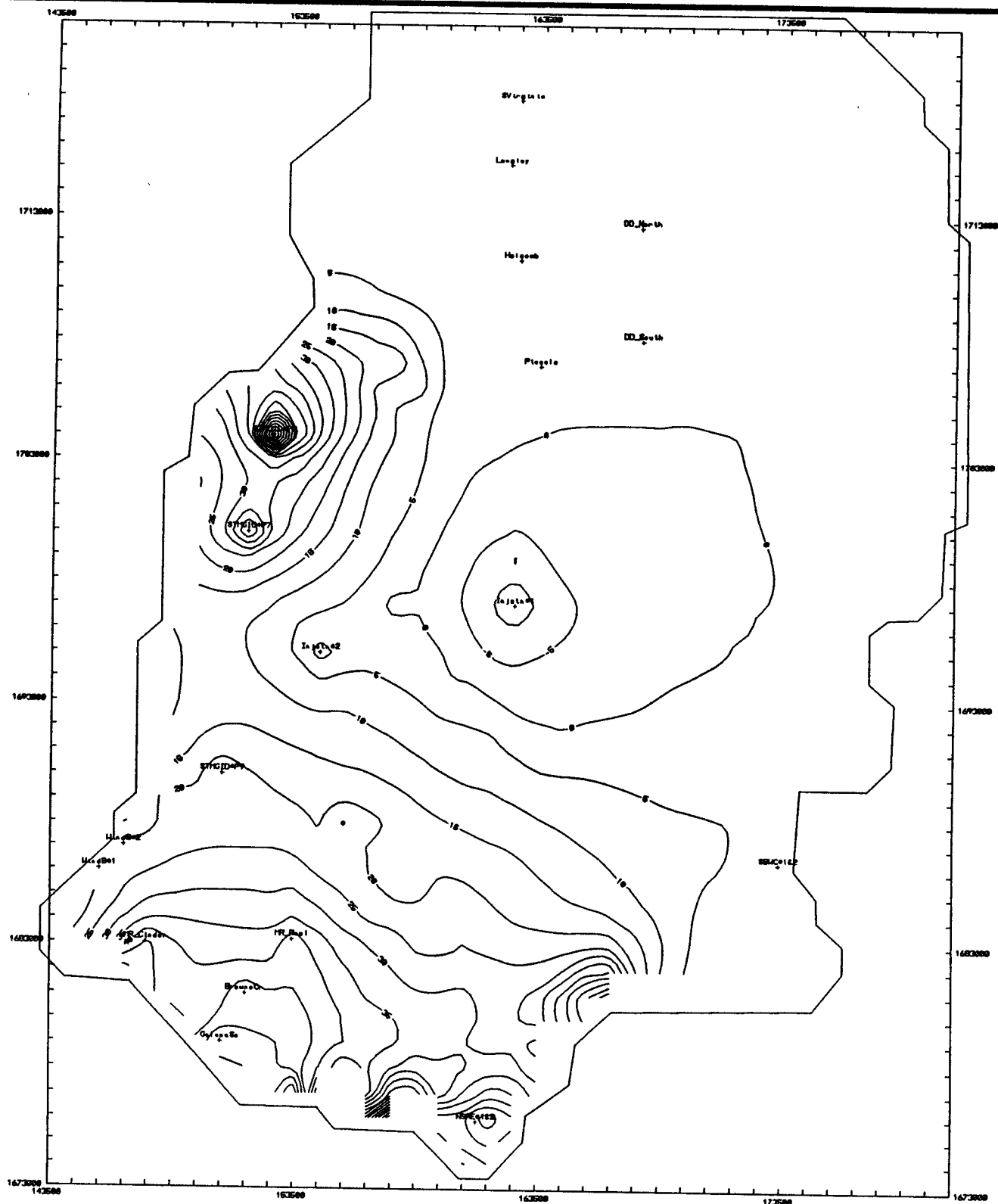
Scenario 3
Drawdown in Layer 2
5 Year Simulation

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201

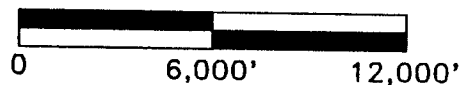


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Figure 7-23



SCALE: 1"=6,000'



Explanation

- Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

South Truckee Meadows
Washoe County, NV

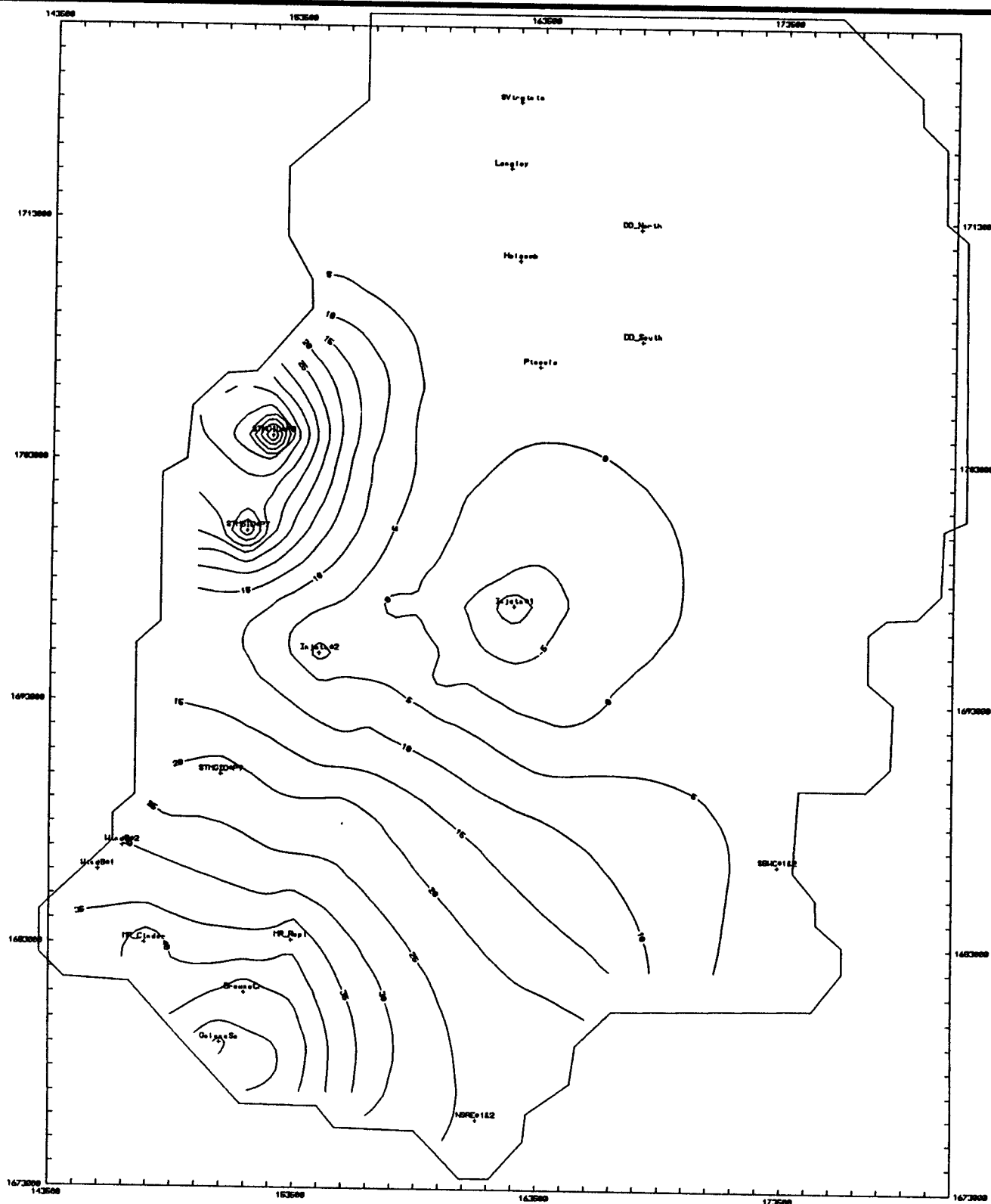
Scenario 3
Drawdown in Layer 1
20 Year Simulation

DATE: 9/22/91
DRAWN: KEK
CHECKED:
APPROVED:
DWG NO:
PROJ.: 396U23201



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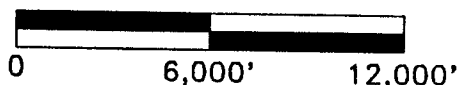
Figure 7-26




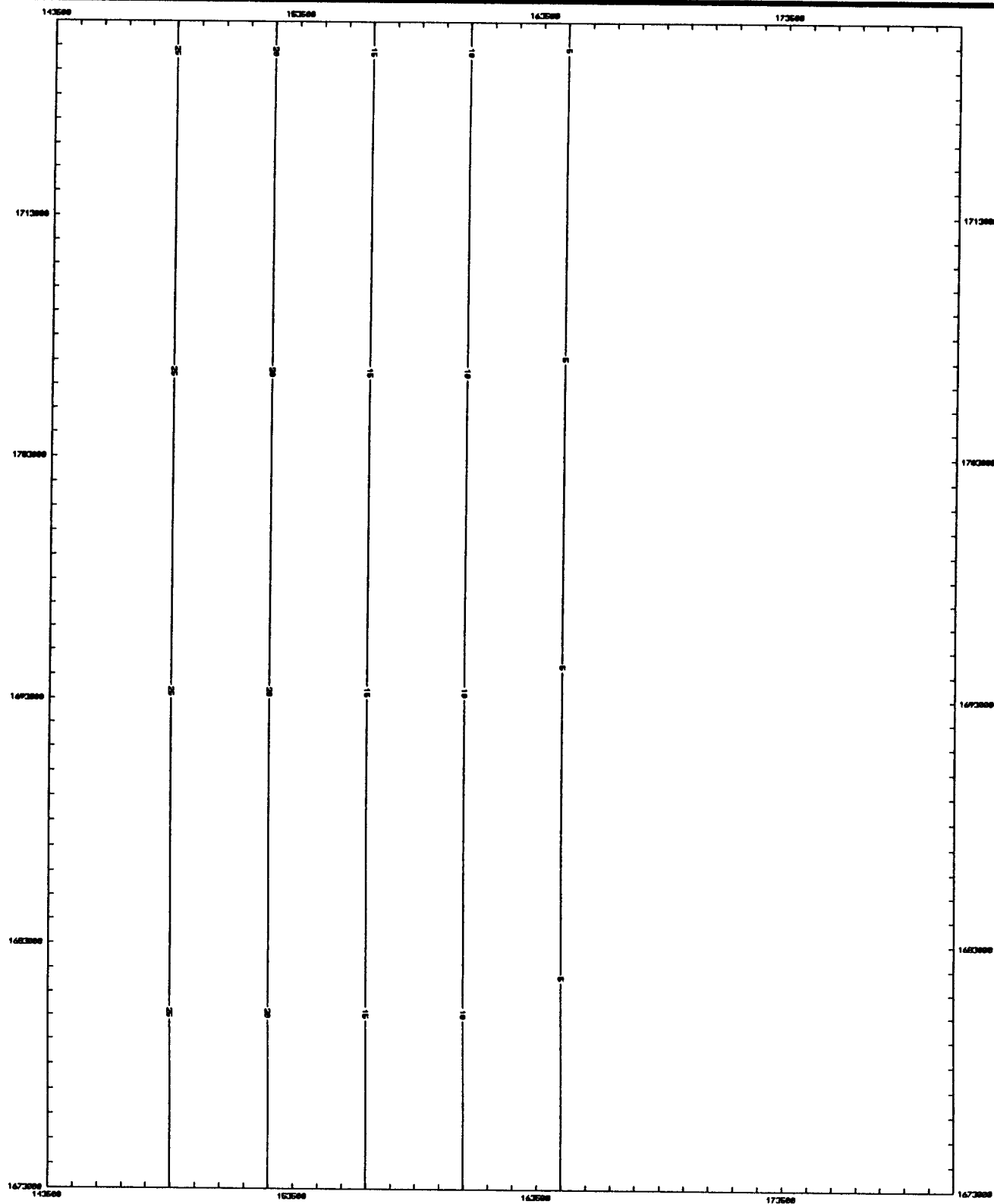
Explanation

- Longley Well location and name
- Contour of equal drawdown due to pumping (feet)
Contour interval = 5 feet
- Boundary of modeled region

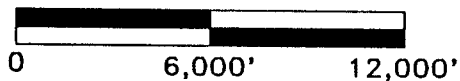
SCALE: 1"=6,000'



South Truckee Meadows Washoe County, NV		DATE: 9/22/91
Scenario 3 Drawdown in Layer 2 20 Year Simulation		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS-GEOLGISTS-ENGINEERS Reno Denver Milwaukee Irvine		Figure 7-27




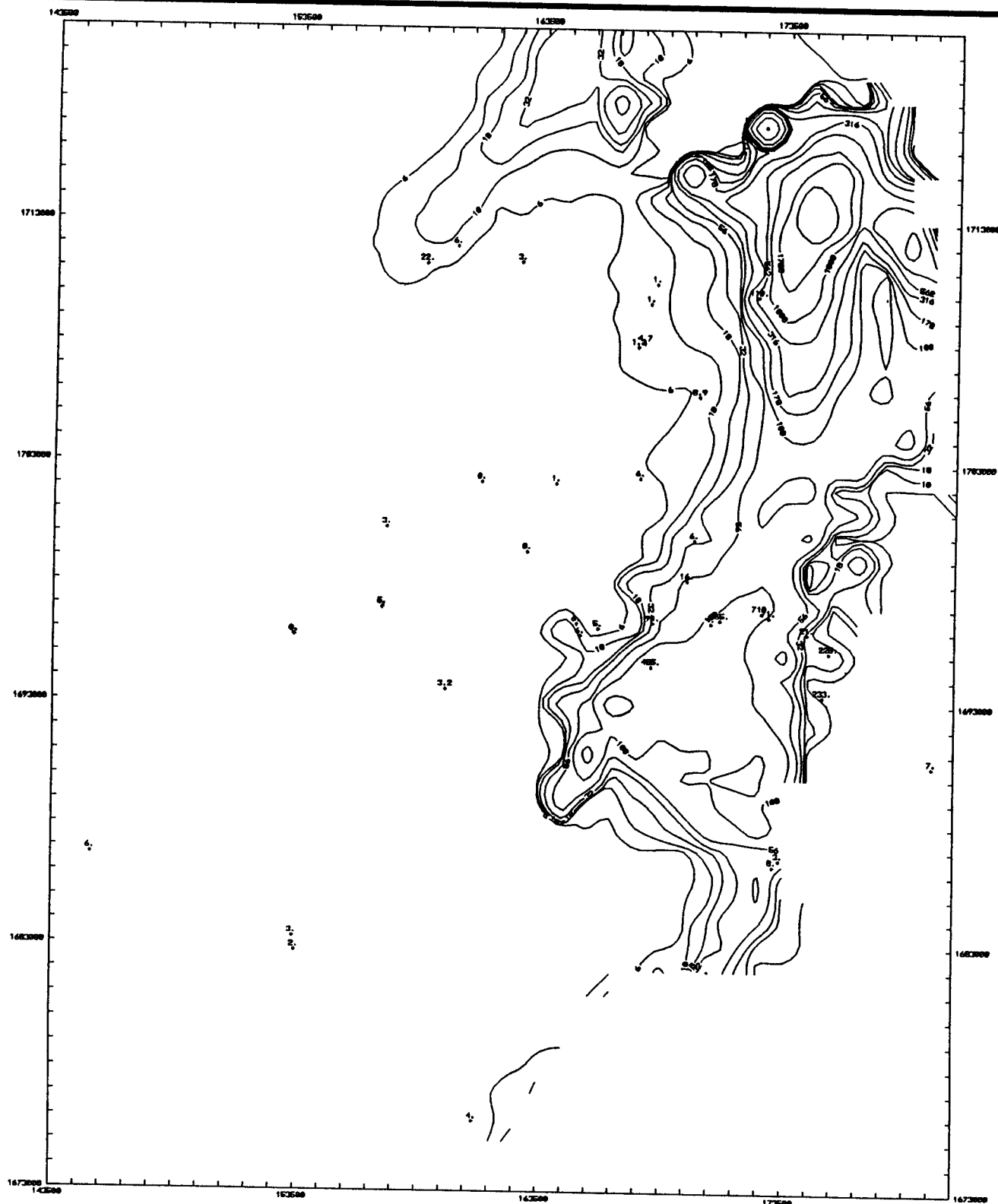
SCALE: 1"=6,000'



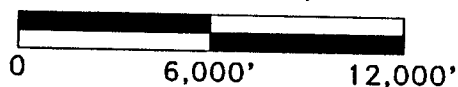
Explanation

N Contour of equal specified drawdown (feet)

South Truckee Meadows Washoe County, NV		DATE: 10/8/91
Scenario 5 Specified Drawdown		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine		PROJ.: 396U23201
		Figure 7-28



SCALE: 1"=6,000'



Explanation

• Well location and observed chloride concentration (mg/l)

— Contour of equal chloride concentration (mg/l)*

*Contour interval is 1/4 of a log cycle

South Truckee Meadows
Washoe County, NV

**Predicted Chloride
Concentration in Layer 1
Near Steady-State**



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DATE: 9/22/91

DRAWN: KEK

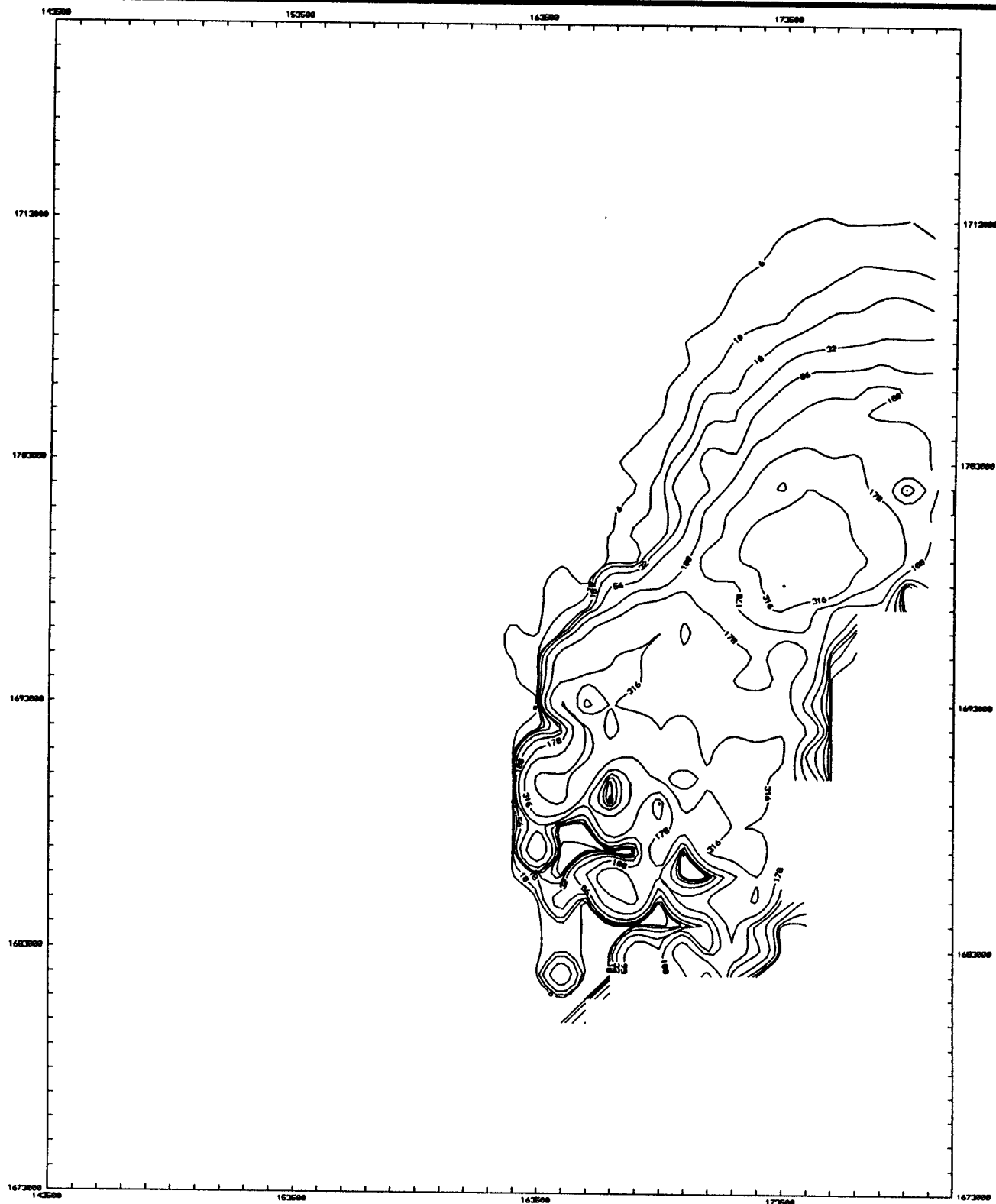
CHECKED:

APPROVED:

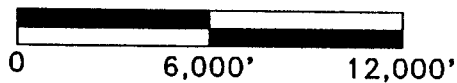
DWG NO:

PROJ.: 396U23201

Figure 7-29




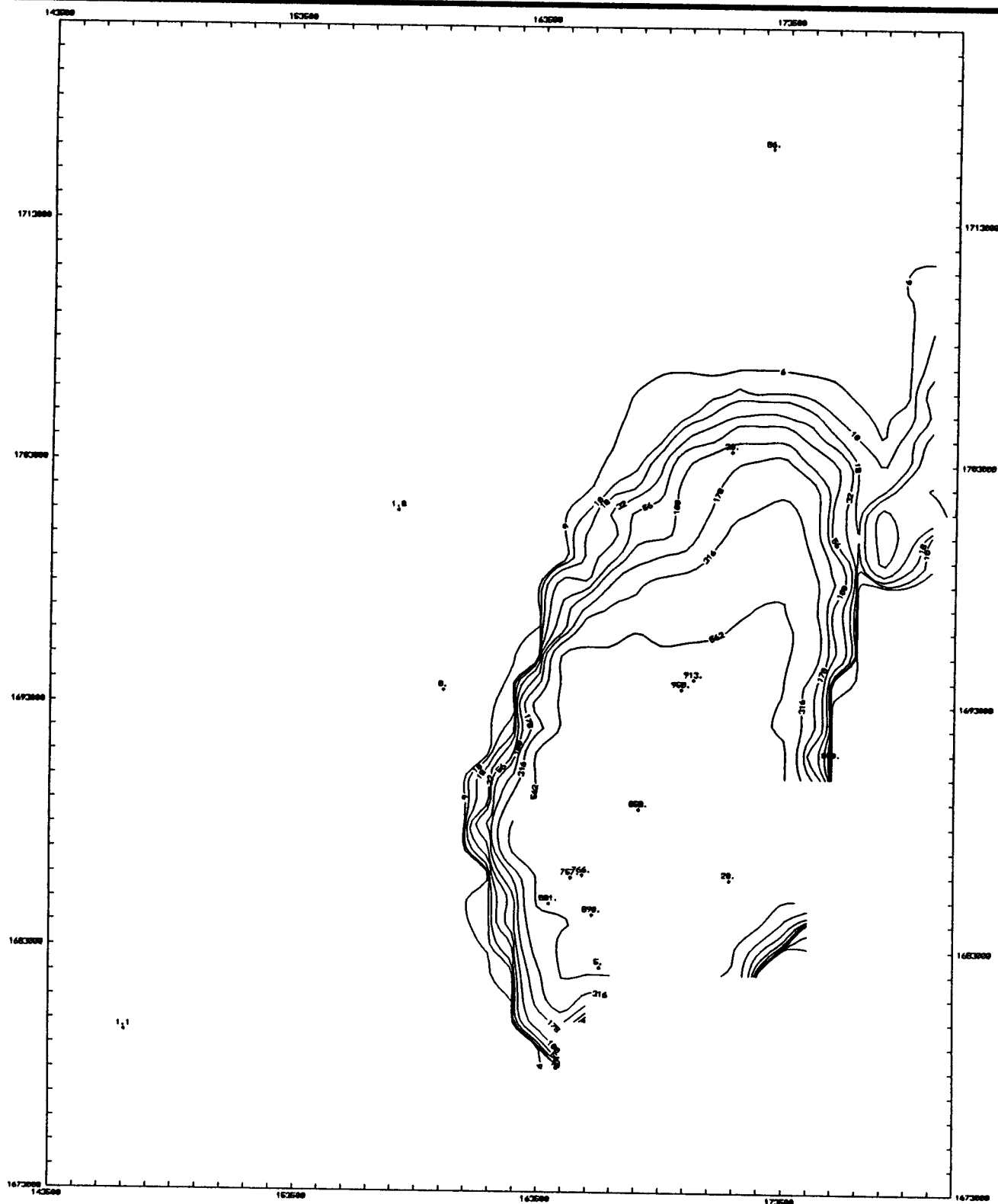
SCALE: 1"=6,000'



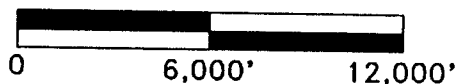
Explanation

- Well location and observed chloride concentration (mg/l)
- Contour of equal chloride concentration (mg/l)*
- *Contour interval is 1/4 of a log cycle

South Truckee Meadows Washoe County, NV		DATE: 9/22/91
Predicted Chloride Concentration in Layer 2 Near Steady State		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine		PROJ.: 396U23201 Figure 7-30




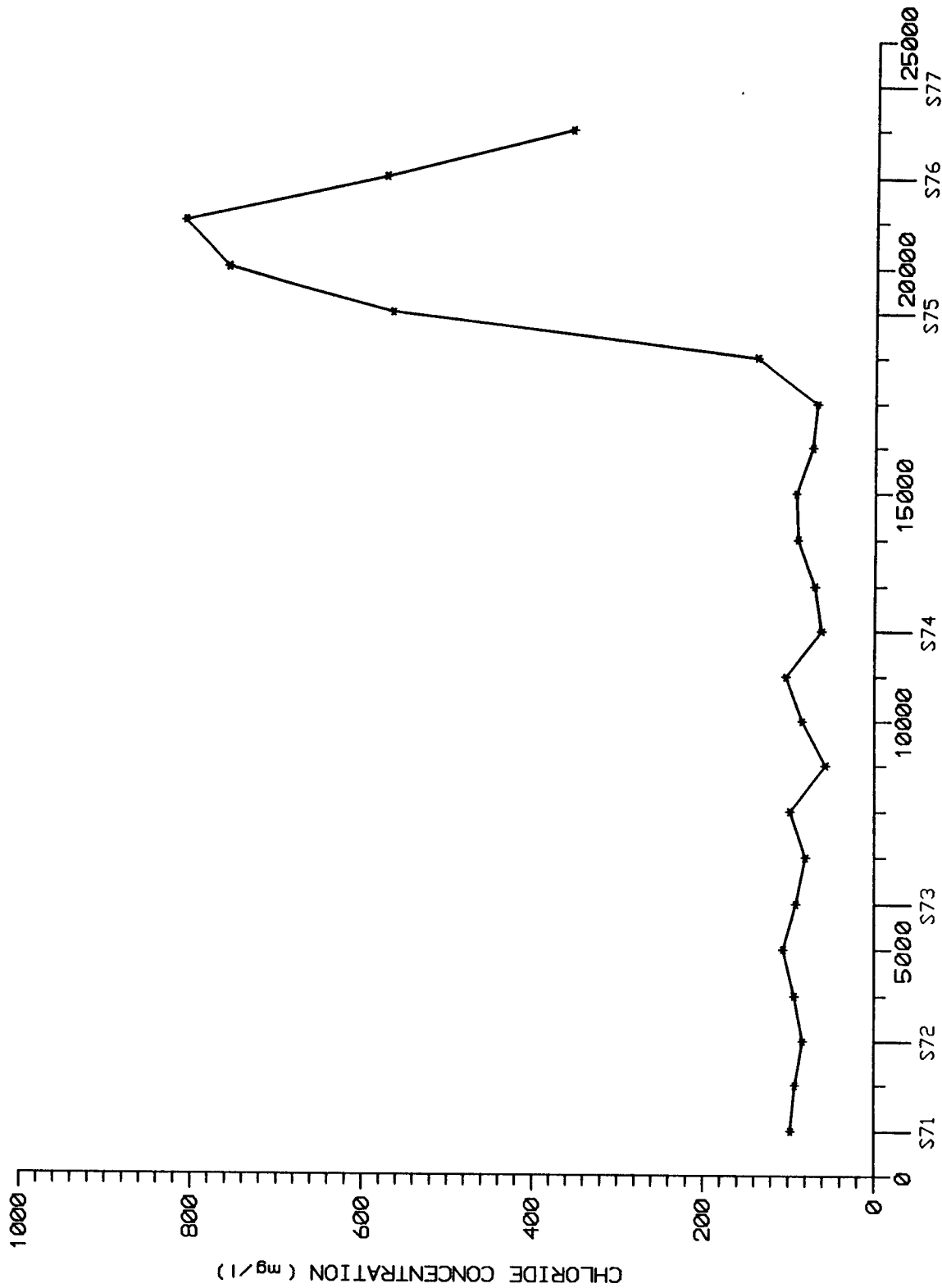
SCALE: 1"=6,000'



Explanation

- Well location and observed chloride concentration (mg/l)
- Contour of equal chloride concentration (mg/l)*
- *Contour interval is 1/4 of a log cycle

South Truckee Meadows Washoe County, NV		DATE: 9/22/91
Predicted Chloride Concentration in Layer 3 Near Steady-State		DRAWN: KEK
		CHECKED:
		APPROVED:
		DWG NO:
 Hydro-Search, Inc. HYDROLOGISTS—GEOLOGISTS—ENGINEERS Reno Denver Milwaukee Irvine		PROJ.: 396U23201 Figure 7-31



Explanation

- * Predicted Chloride Concentration in Ground-Water Discharge (mg/l)

S71 Sample Points Identified by Shump, 1985

South Truckee Meadows
Washoe County, NV

**Predicted Chloride
Concentrations Discharged to
Steamboat Creek**

Distance Downstream
from Sample Point S71 (ft)

DATE: 10/9/91

DRAWN: KEK

CHECKED:

APPROVED:

DWG NO:

PROJ.: 396U23201

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Reno Nevada Millersville Indiana

Figure 7-32

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APPENDIX A
Pumping Test Summary

A - 1

STM PUMPING TESTS SUMMARIES

1. STMGID PW # 1
 - a. well depth = 530 feet w/ screen = 260 ft
 - b. pumping rate = 600 gpm @ 48 hours
 - c. $T = 6800 \text{ gpd/ft}$, $K = 3.5 \text{ ft/day}$, $SC = 7 \text{ gpm/ft}$, $S = 0.0002$
 - d. alluvial aquifer (700 ft to bdrk), fully penetrating for analysis
 - e. comments
 1. data could use a little more work, but T value is appropriate
 2. observation data
2. STMGID PW # 2
 - a. well depth = 515 feet w/screen = 250 feet
 - b. pumping rate = 250 gpm @ 24 hours
 - c. $T = 2500 \text{ gpd/ft}$, $K = 1.3 \text{ ft/day}$, $SC = 3 \text{ gpm/ft}$
 - d. alluvial aquifer (700 ft to bdrk), fully penetrating for analysis
 - e. comments
 1. Aquifer is probably partially sealed from bentonite intrusion during drilling operations.
 2. Use values from PW#1 as drill cuttings similar
 3. no observation data
3. STMGID PW # 3
 - a. well depth = 590 feet w/screen = 340 feet
 - b. pumping rate = 500 gpm @ 48 hours
 - c. $T = 7000 \text{ gpd/ft}$, $K = 2.8 \text{ ft/day}$, $SC = 5.9 \text{ gpm/ft}$
 - d. alluvial aquifer (700 ft to bdrk), fully penetrating for analysis
 - e. comments
 1. good test, no observation data
4. STMGID PW # 4 (Shadowridge)
 - a. well depth = 831 feet w/screen = 130 feet
 - b. pumping rate = 355/246 gpm @ 240 hours
 - c. $T = 1500 \text{ gpd/ft}$, $K = 1.5 \text{ ft/day}$
 - d. rock aquifer
 - e. comments
 1. good test, no hard rock observation data
5. STMGID PW # 5
 - a. well depth = 760 feet w/screen = 350 feet
 - b. pumping rate = 885 gpm @ 72 hours
 - c. $T = 26,000 \text{ gpd/ft}$, $K = 9 \text{ ft/day}$, $SC = 16.7$, $S = 0.0016$
 - d. alluvial aquifer

- e. comments
 - 1. observation data needs work up
 - 2. re-work data, include step test
- 6. STMGID PW # 6
 - a. well depth = 650 feet w/screen = 390 feet
 - b. pumping rate = 1207 gpm @ 72 hours
 - c. $T = 46,000$ gpd/ft, $K = 15.8$ ft/day, $SC = 23$ gpm/ft, $S = 0.0012$
 - d. alluvial aquifer, shows boundary effect (fault)
 - e. comments
 - 1. rework data, observation well also
- 7. WWTP Well
 - a. well depth = 237 ft w/screen = 160 ft
 - b. pumping rate = 36 gpm for 24 hours
 - c. $T = 420$ gpd/ft, $K = 0.35$ ft/day, $SC = \text{unk}$
 - d. Rock aquifer
 - e. Comments
 - 1. aquifer affected by recharge boundary (surface water)
 - 2. data should be re-analyzed
- 8. Piccolo Well
 - a. well depth = 360 ft w/ screen = 200 ft
 - b. pumping rate = 427 gpm @ 72 hr
 - c. $T = 10,000$ gpd/ft, $K = 7$ ft/day, $SC = 7.9$ gpm/ft, $S = 0.0006$
 - d. alluvial aquifer (700 ft ?), partial penetration
 - e. comments
 - 1. good test with monitoring wells
 - 2. more analysis to follow
- 9. Mt. Rose Replacement Well
 - a. well depth = 223 feet w/screen = 90 feet
 - b. pumping rate = 400 gpm @ 72 hours
 - c. $T = 8,500$ gpd/ft, $K = 12.6$ ft/day, $SC = 8.3$ gpm/ft, $S = 0.0025$
 - d. hard rock @ 170 feet, screens @ 120-210, two aquifers
 - e. comments
 - 1. re-analyze using WHIP
- 10. Mt. Rose Cinder Well
 - a. well depth = 802 feet w/ screen = 380 feet
 - b. pumping rate = 625 gpm @ 44.5 hours
 - c. $T = 22,000$ gpd/ft, $K = 7.8$ ft/day, $SC = 100$ gpm/ft, $S = 0.0005$
 - d. bottom 250 feet in cinder deposits
 - e. comments

1. re-work data w/WHIP
11. Timberline Estates Main Well
 - a. well depth = 236 feet w/screen = 61 feet
 - b. pumping rate = 200 gpm @ 48 hours
 - c. $T = 1500 \text{ gpd/ft}$, $K = 3.2 \text{ ft/day}$, $SC = 1.5 \text{ gpm/ft}$, $S = 0.0015$
 - d. Alluvial aquifer, partial penetration, flowing well
 - e. comments
12. Timberline Estates Back-up Well
 - a. well depth = 440 feet w/screen = 280 feet
 - b. pumping rate = 70 gpm @ 72 hours
 - c. $T = 1500 \text{ gpd/ft}$, $K = 0.8 \text{ ft/day}$, $SC = 0.9 \text{ gpm/ft}$, $S = 0.002$
 - d. Alluvial aquifer, partial penetration, flowing well
 - e. comments
13. Double Diamond North Well (DD-1)
 - a. well depth = 184 feet w/screen = 122 feet
 - b. pumping rate = 250 gpm @ 72 hours
 - c. $T = 11,600 \text{ gpd/ft}$, $K = 17.5 \text{ ft/day}$, $SC = 8.1 \text{ gpm/ft}$, $S = 0.00025$
 - d. Alluvial aquifer (151 ft to bdrk), fully penetrating
 - e. comments
 1. two pumping tests completed
14. Double Diamond South Well (DD-2)
 - a. well depth = 428 feet w/screen = 314 feet
 - b. pumping rate = 650 gpm @ 72 hours
 - c. $T = 12,600 \text{ gpd/ft}$, $K = 5.4 \text{ ft/day}$, $SC = 11 \text{ gpm/ft}$, $S = 0.0018$
 - d. alluvial aquifer, partial penetration
 - e. comments
 1. two tests run
15. New Sunrise Estates #1
 - a. well depth = 375 feet w/screen = 140 feet
 - b. pumping rate = 205 gpm @ 72 hours
 - c. $T = 2200 \text{ gpd/ft}$, $K = 2 \text{ ft/day}$, $SC = 1.8 \text{ gpm/ft}$, $S = \text{NA}$
 - d. alluvial aquifer, leaky, strongly anisotropic, partial pen
 - e. comments
 1. Washoe County test result (as opposed to Nork's)
 2. much well monitoring data, but difficult to analyze
 3. re-work data with WHIP
16. New Sunrise Estates #2
 - a. well depth = 343 feet w/screen = 209 feet

- b. pumping rate = 205 gpm @ 72 hours
 - c. $T = 3000 \text{ gpd/ft}$, $K = 1.9 \text{ ft/day}$, $SC = 1.7 \text{ gpm/ft}$, $S = \text{NA}$
 - d. see above
 - e. comments see above
17. Trans Sierra Wells #1-4
- a. well depth range from 105 - 188 feet
 - b. production pumping rates are from 200 to 400 gpm
 - e. no reliable T and S values (Q meter suspect)
18. Steamboat Water Co. Well #1
- a. well depth = 144 feet w/slots = 84 feet
 - b. pumping rate = 185 gpm @ 14 hours
 - c. $T = 17,000 \text{ gpd/ft}$, $K = 16 \text{ ft/day}$ ($T/140 \text{ ft}$), $S = 0.0008$
 - d. alluvial aquifer, partial penetration
 - e. comments- recharge boundary
19. Steamboat Water Co. Well #2
- a. well depth = 144 feet w/screen = 40 feet
 - b. pumping rate = 240 gpm @ 72 hours
 - c. $T = 17,400 \text{ gpd/ft}$, $K = 16.6 \text{ ft/day}$ ($T/140 \text{ ft}$), $S = 0.0004$
 - d. alluvial aquifer, partial penetration
 - e. comments - recharge boundary
20. Damonte Wells
- a. well depth = 157 feet w/screen = 65 feet
 - b. pumping rate = 500 gpm @ 24 hours
 - c. $T = \text{unknown}$, but perhaps 20,000 gpm/ft
 - d. alluvial aquifer, partial penetration
 - e. no test data at this time
21. SPPCo's Holcomb Well
- a. well depth = 340 feet w/screen = 188 feet
 - b. pumping rate = 973 gpm, tested @ 813 gpm @ 48 hrs (?)
 - c. $T = 14,100 \text{ gpd/ft}$, $K = 10 \text{ ft/day}$, $SC = 18 \text{ gpm/ft}$
 - d. alluvial aquifer, partial penetration
 - e. comments- no pumping test data from SPPCO
22. SPPCo's Huffaker Well
- a. well depth = 313 feet w/screen = 165 feet
 - b. pumping rate = 999 gpm @ 48 hours
 - c. $T = 18,300 \text{ gpd/ft}$, $K = 14.8 \text{ ft/day}$, $SC =$
 - d. alluvial well, partial penetration
 - e. no pumping test data

23. SPPCo's Virginia Well

- a. well depth = 286 feet w/screen = 164 feet
- b. pumping rate = 1069 gpm @ 105 hours
- c. $T = 20,400 \text{ gpd/ft}$, $K = 16.6 \text{ ft/day}$, $S = 0.0014$ $SC = 18 \text{ gpm/ft}$
- d. alluvial well, partial penetration
- e. no pumping test data

24 SPPCo's Delucchi Well

- a. well depth = 323 feet w/screen = 194
- b. pumping rate = 548 gpm @ 48 hrs
- c. $T = 12,500 \text{ gpd/ft}$, $K = 8.6 \text{ ft/day}$, $SC = 10 \text{ gpm/ft}$
- d. alluvial well, partial penetration
- e. no pumping test data

25. SPPCo's Lakeside Well

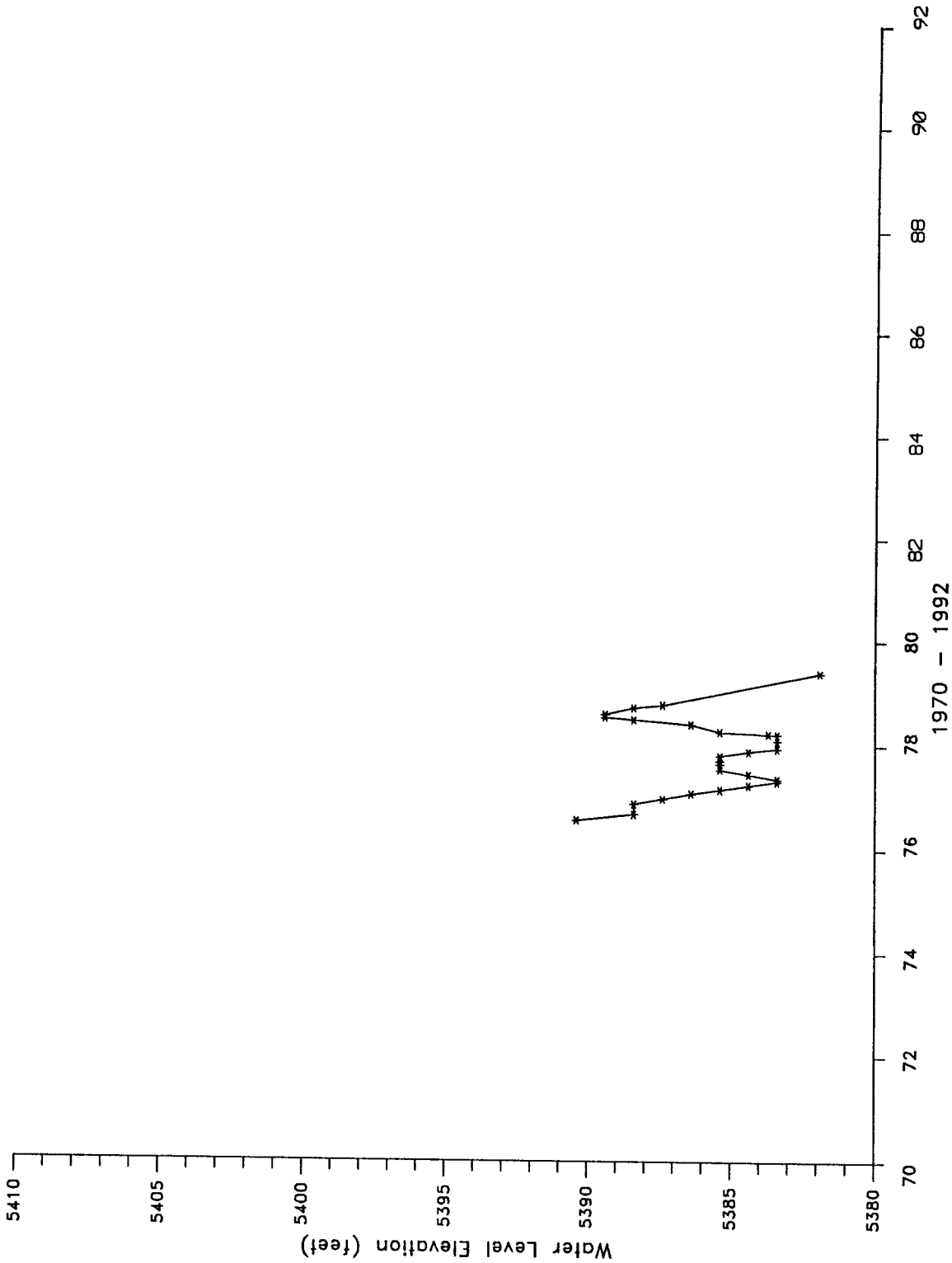
- a. well depth = 400 feet w/screen = 220 feet
- b. pumping rate = 900 gpm @ 112 hrs
- c. $T = 24,000 \text{ gpd/ft}$, $K = 14.6 \text{ ft/day}$,
- d. alluvial/hard rock aquifer (?)
- e. no pumping test data


26. SPPCo's Meadowridge Well

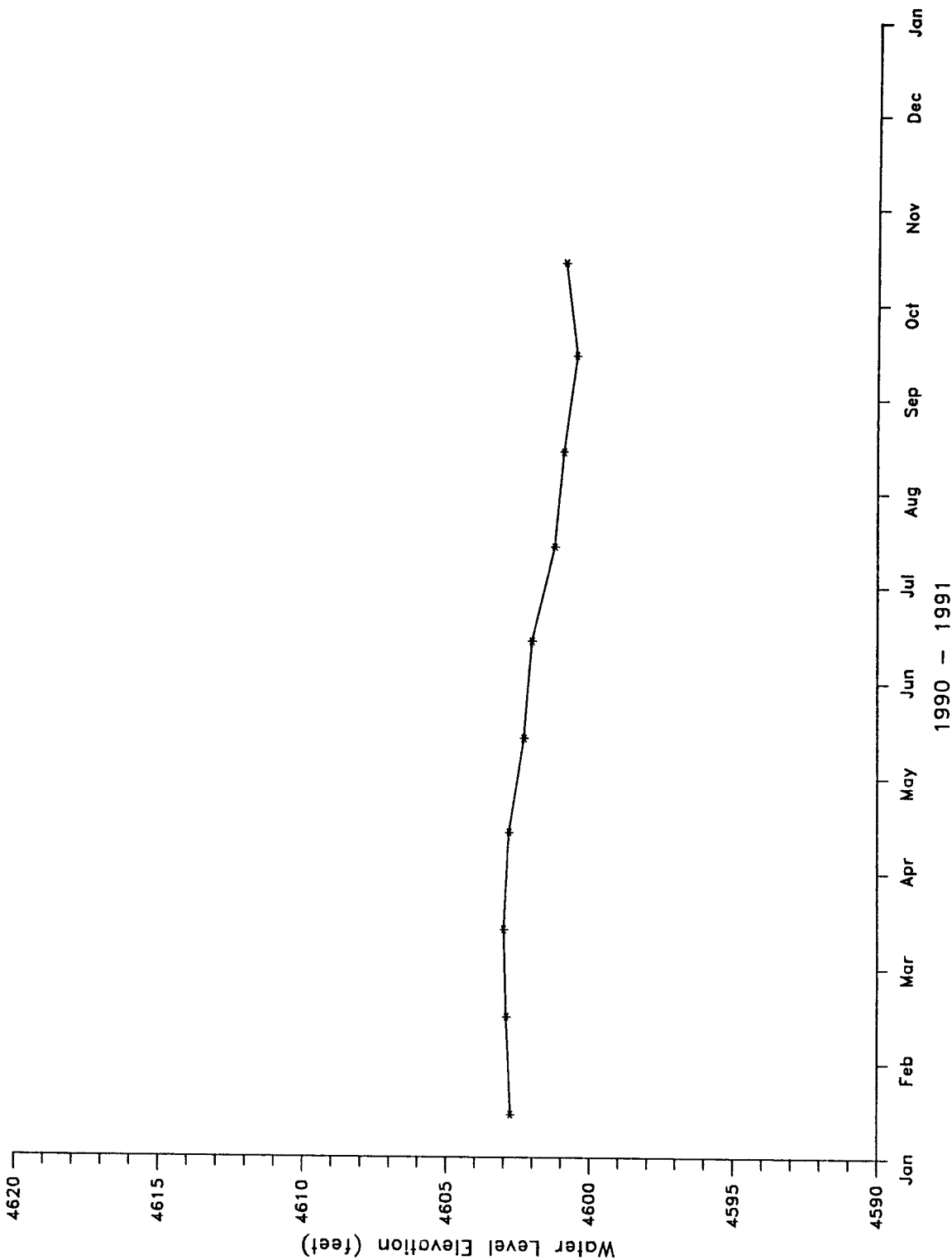
- a. well depth = 470 feet w/screen = 210 feet w/50' blank
- b. pumping rate = 300 gpm (?), tested @ 200 gpm @ 118 hrs
- c. $T = 13,000 \text{ gpd/ft}$, $K = 8 \text{ ft/day}$, $SC = 3.5 \text{ gpm/ft}$
- d. hard rock aquifer (?)
- e. no pumping test data


APPENDIX B

Hydrographs

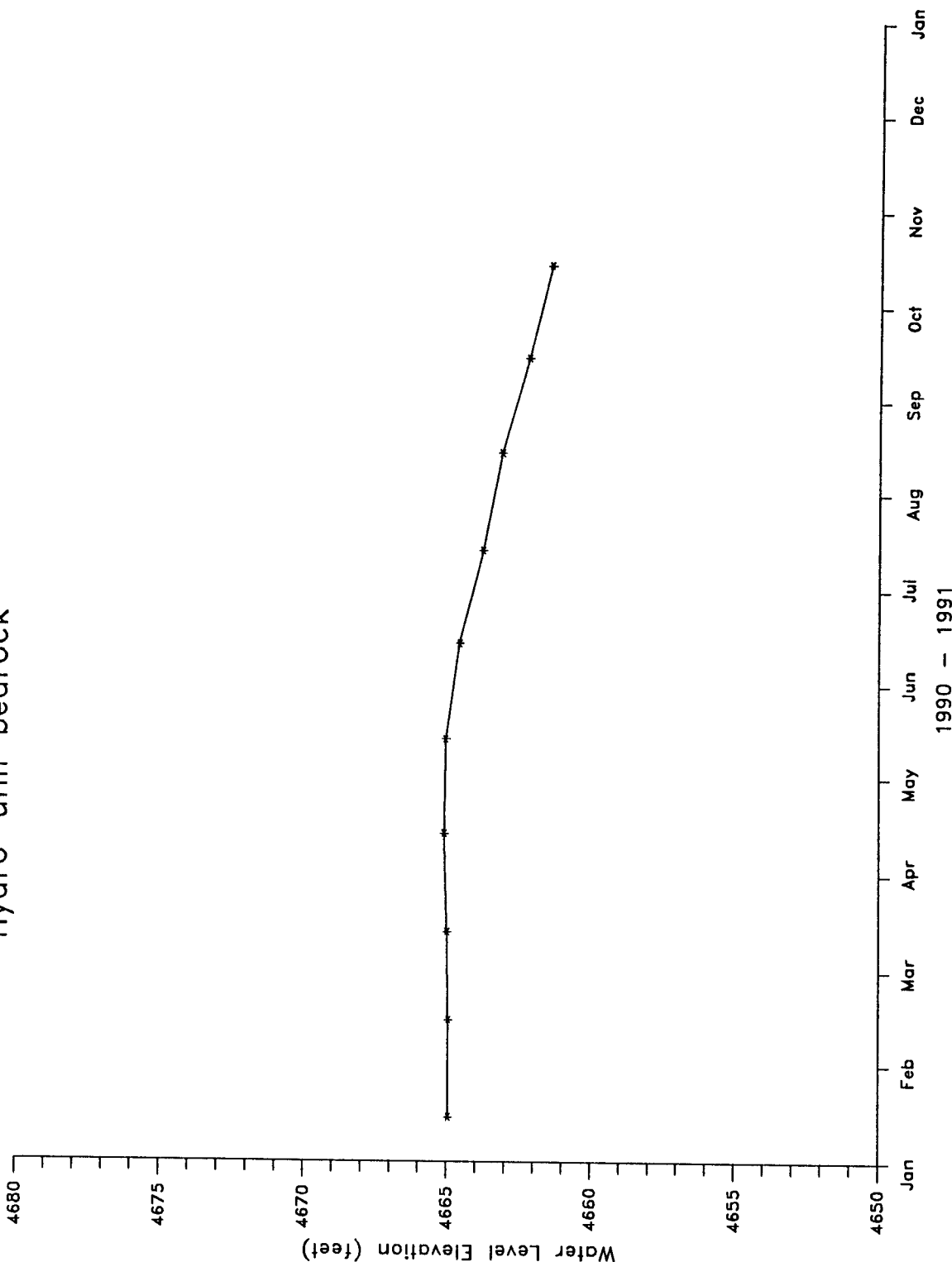


South Truckee Meadows Washoe County, NV		DATE: 9/18/91
Hydrograph of Well 17/19-02cddd1		DRAWN: KEK
Hydro-Unit Alluvium		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine		Figure B-1




South Truckee Meadows Washoe County, NV		DATE: 9/18/91
Hydrograph of Well 17/20-04bacb		DRAWN: KEK
Hydro-Unit Bedrock		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine		Figure B-2

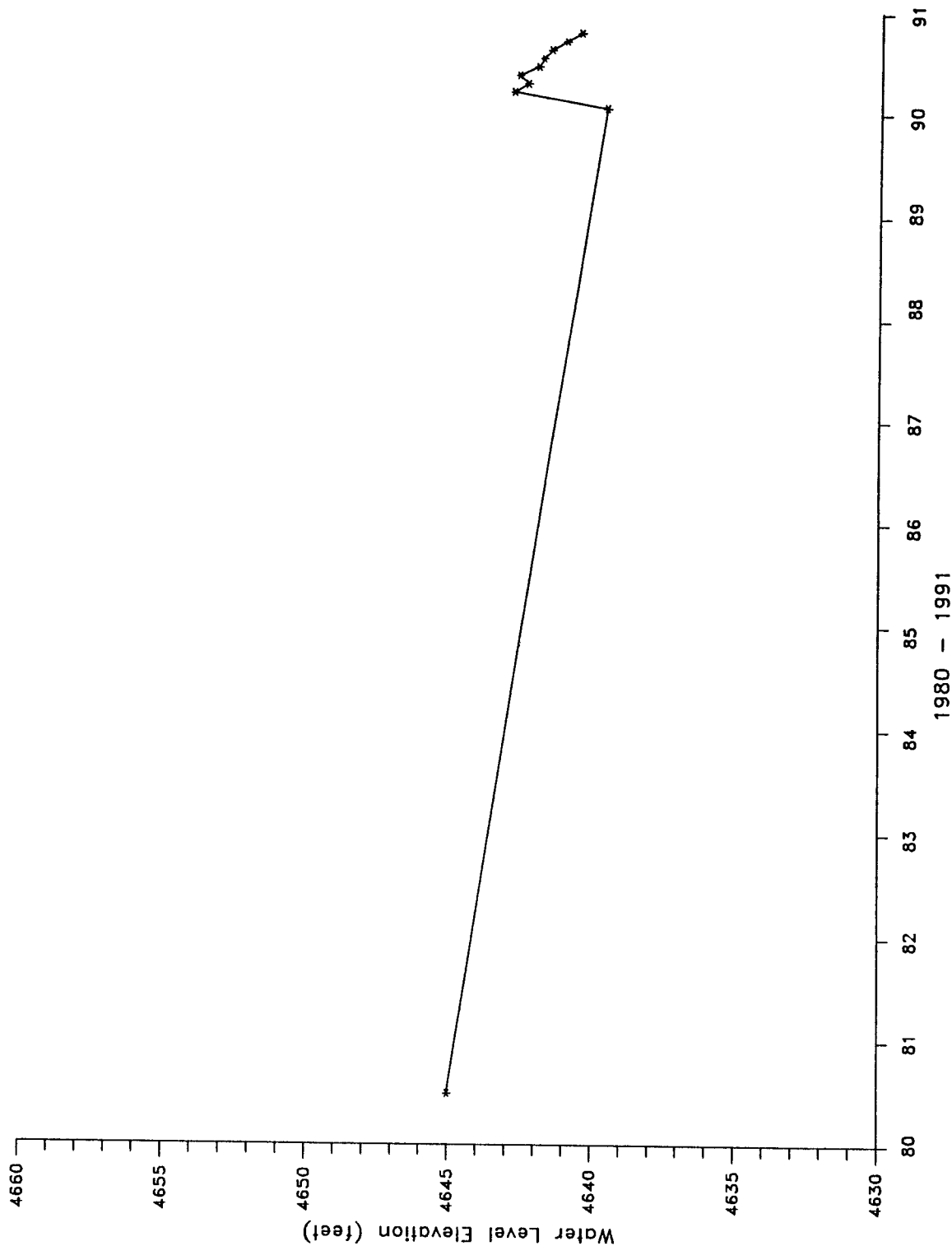
Hydrograph of well 17/20-05cdbb Hydro-unit bedrock




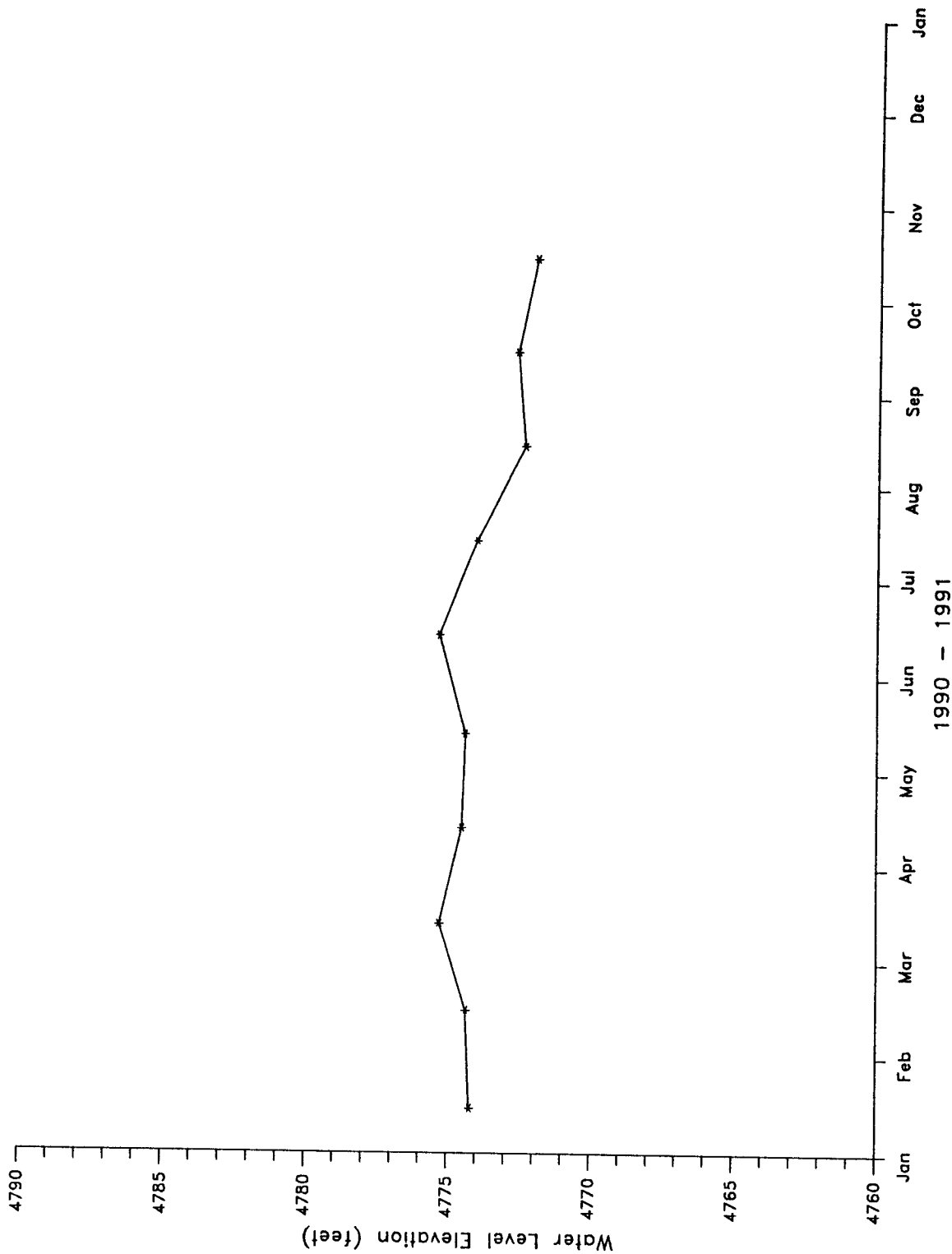
Hydro-Search, Inc.


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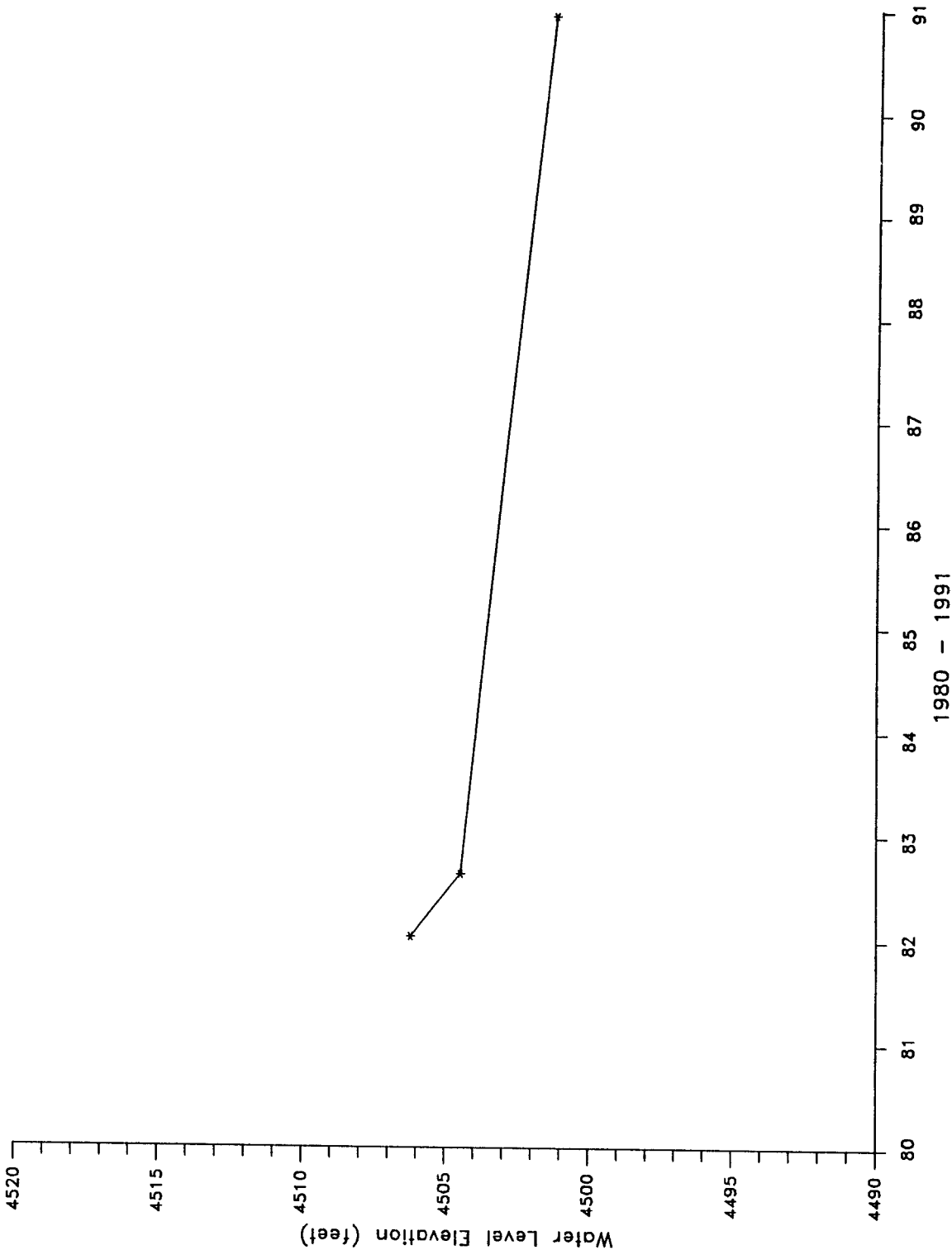
South Truckee Meadows Washoe County, NV		DATE: 9/18/91
Hydrograph of Well 17/20-05cdbb		DRAWN: KEK
Hydro-Unit Bedrock		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine		Figure B-3




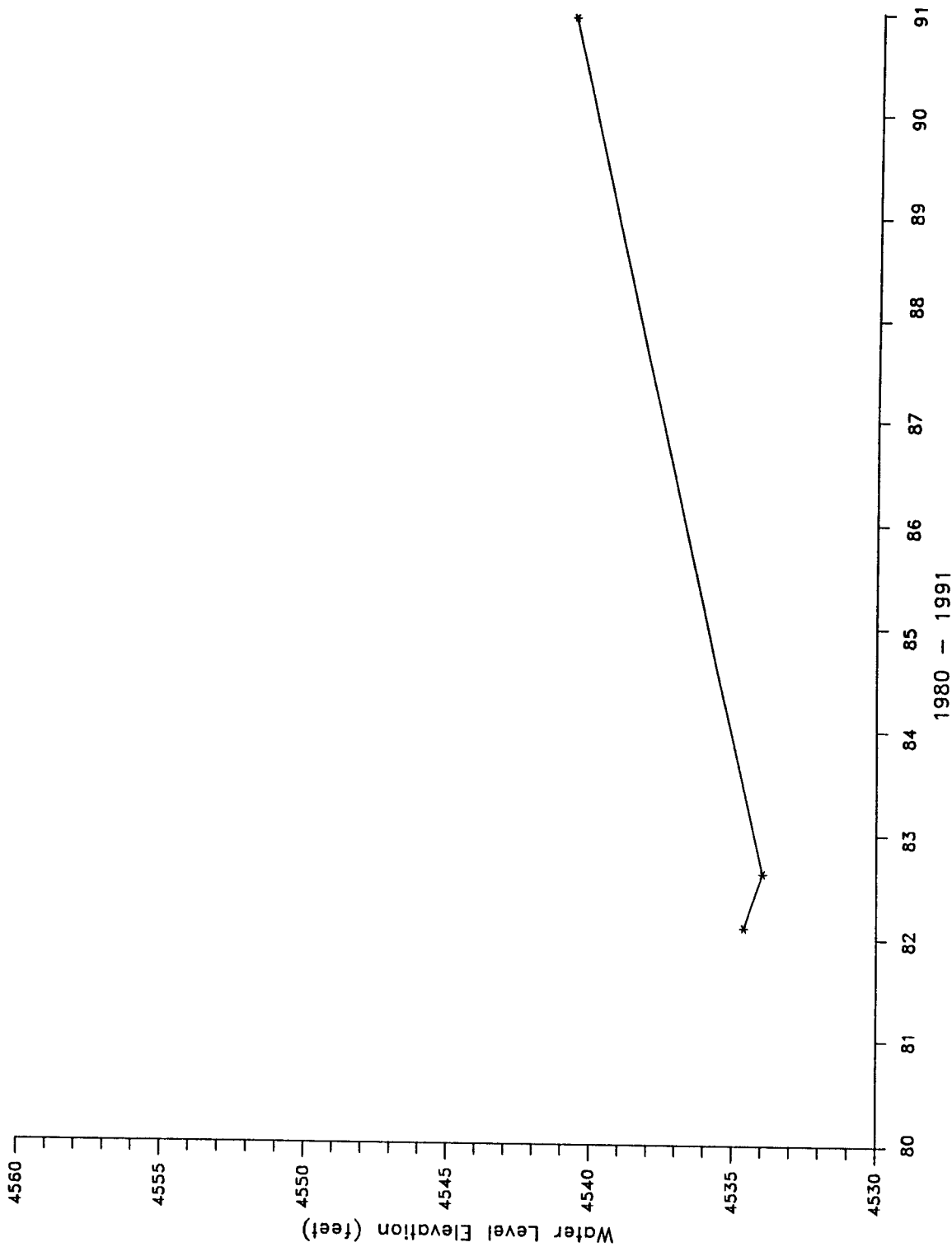
South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograph of Well 17/20-07bdaa Pleasant Valley	DRAWN: KEK
	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine	
Figure B-4	




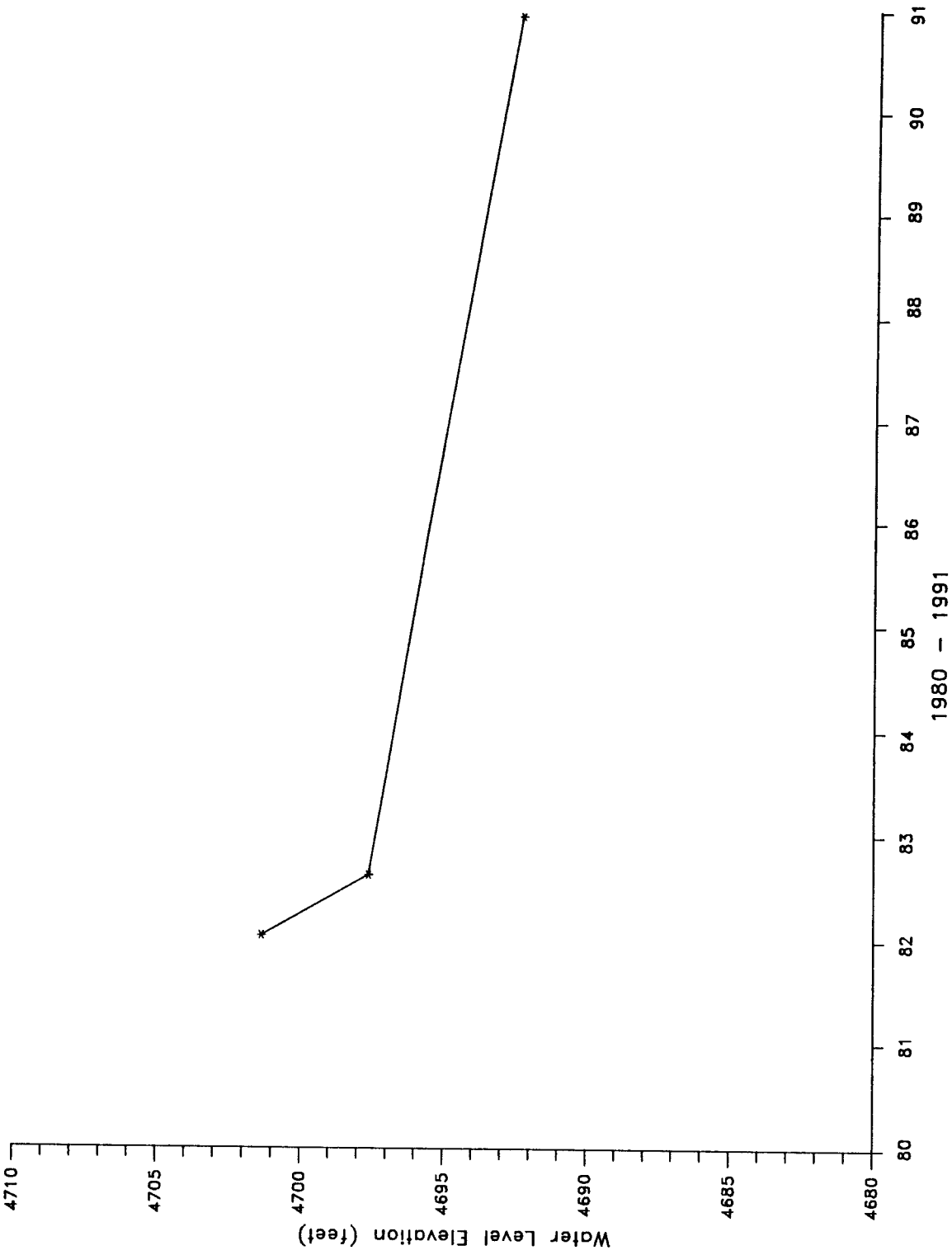
South Truckee Meadows Washoe County, NV		DATE: 9/18/91
Hydrograph of Well 17/20-08bbbb Pleasant Valley		DRAWN: KEK
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
Figure B-5		




 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine	South Truckee Meadows Washoe County, NV	DATE: 9/18/91
	Hydrograph of Well 18/19-01abdc	DRAWN: KEK
	Hydro-Unit Alluvium	CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
		Figure B-6



South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograph of Well 18/19-01dcab	DRAWN: KEK
Hydro-Unit Alluvium	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine	
Figure B-7	

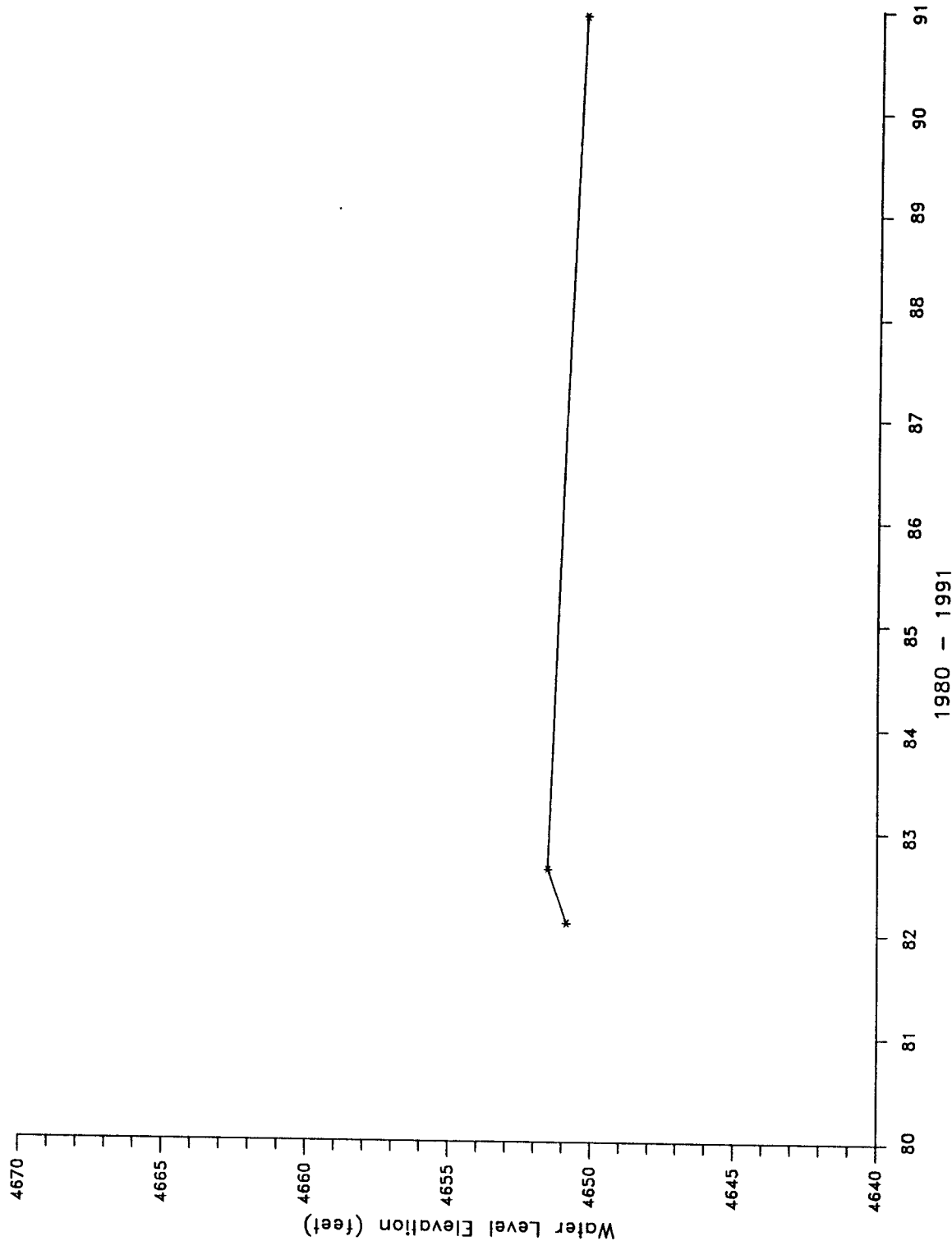


South Truckee Meadows Washoe County, NV		DATE: 10/8/91
Hydrograph of Well 18/19-02abad		DRAWN: KEK
Hydro-Unit Bedrock		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201



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Figure B-8

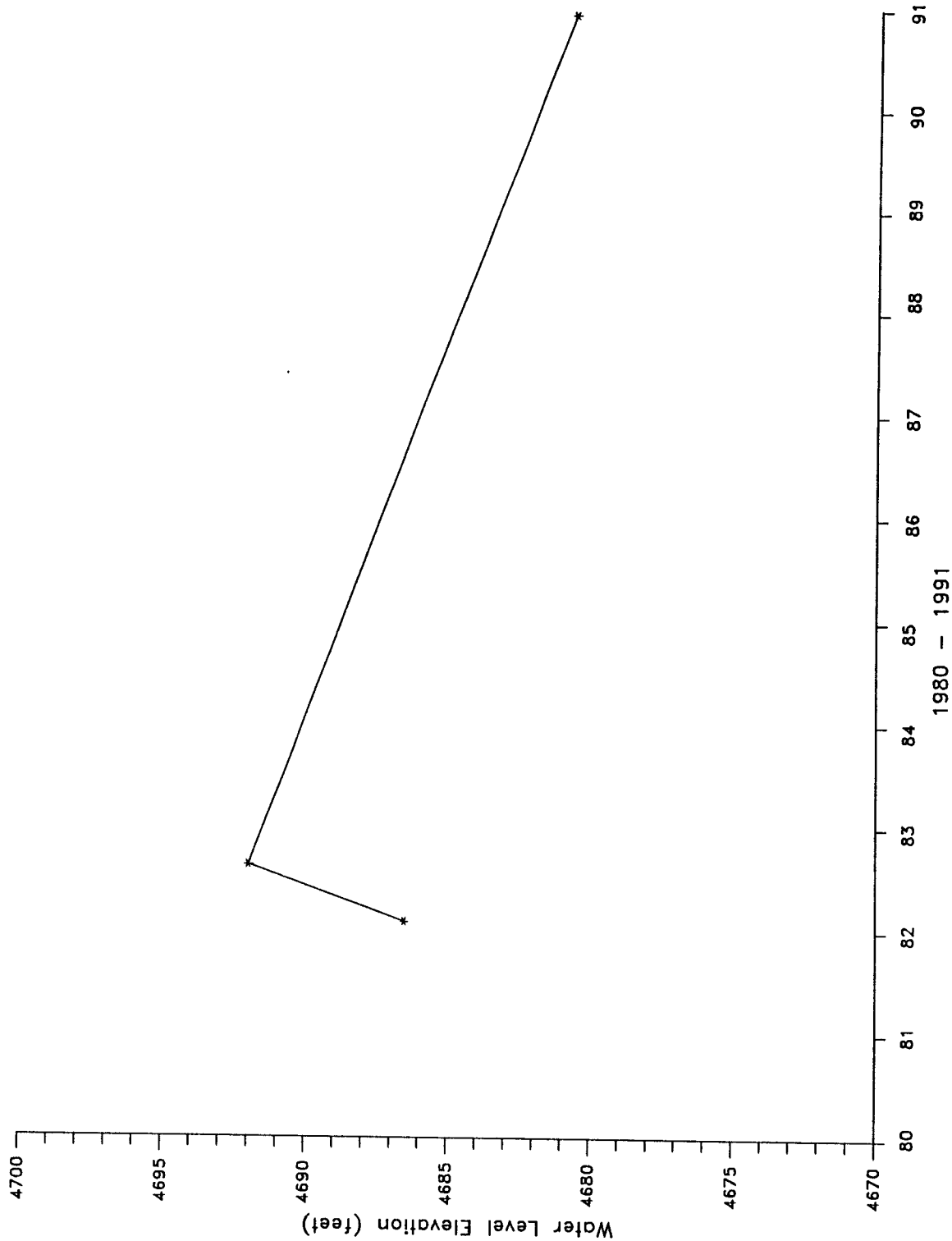


South Truckee Meadows Washoe County, NV		DATE: 9/18/91
Hydrograph of Well 18/19-02dadc		DRAWN: KEK
Hydro-Unit Alluvium		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201

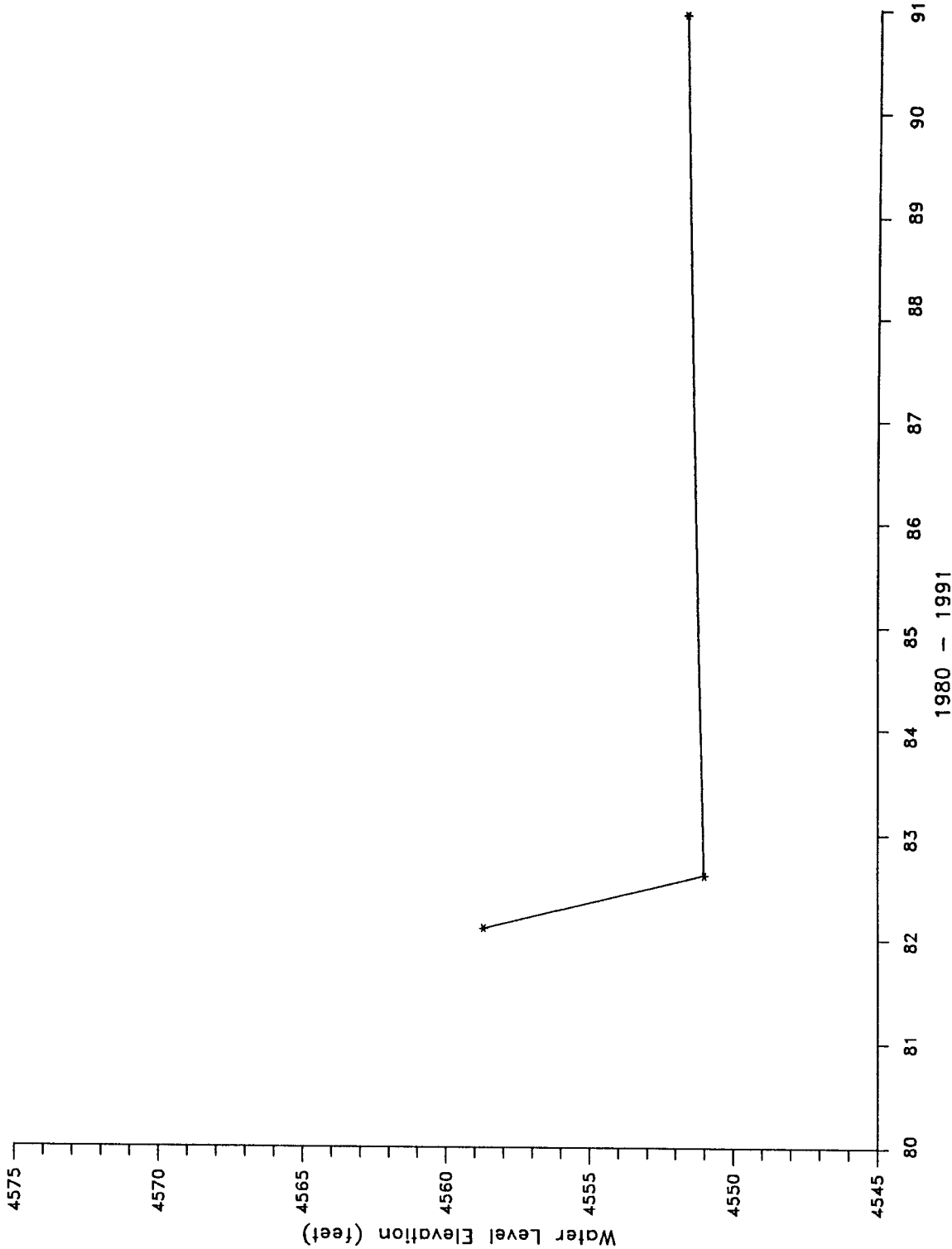
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Figure B-9



South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograph of Well 18/91-02dcba	DRAWN: KEK
Hydro-Unit Alluvium	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201




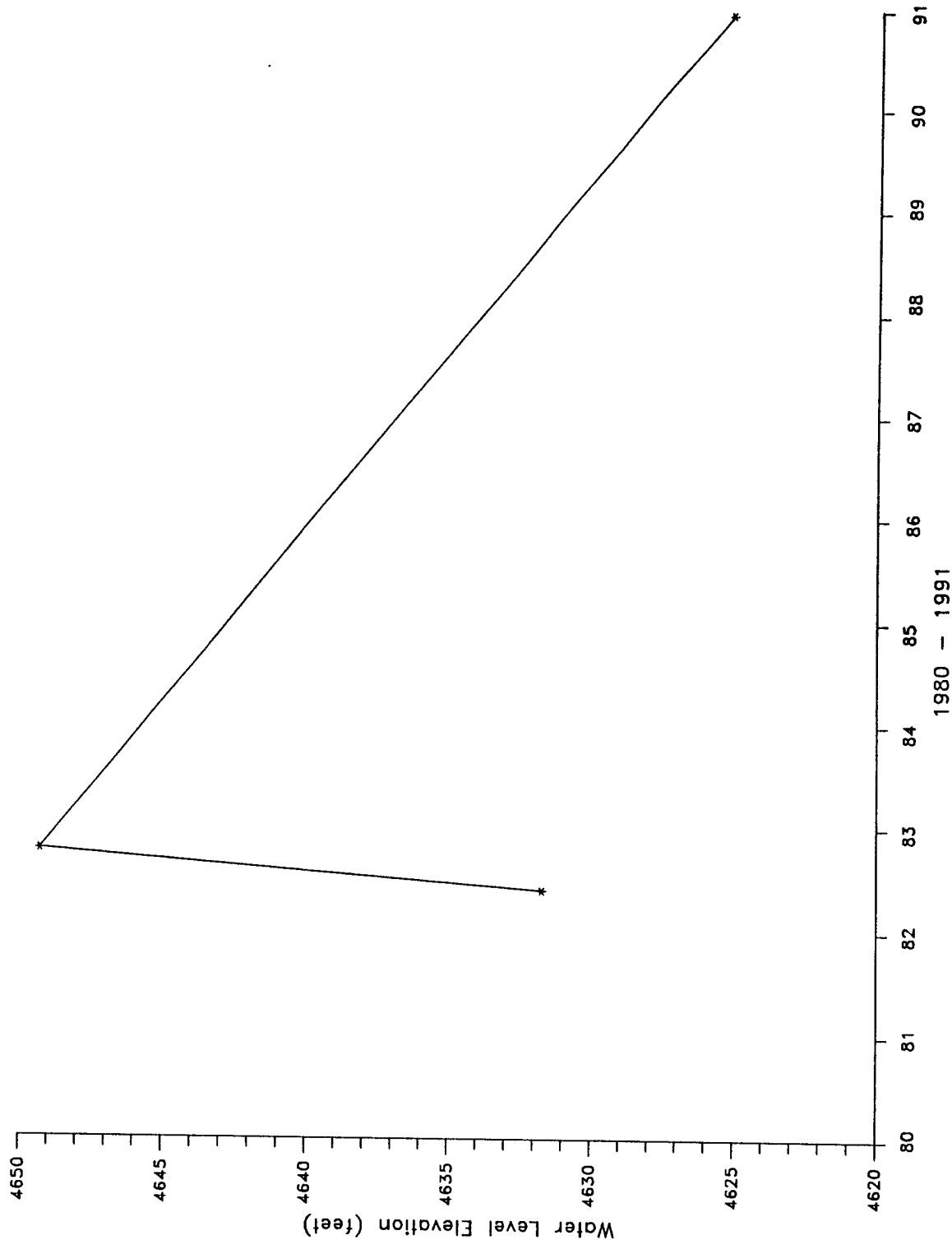
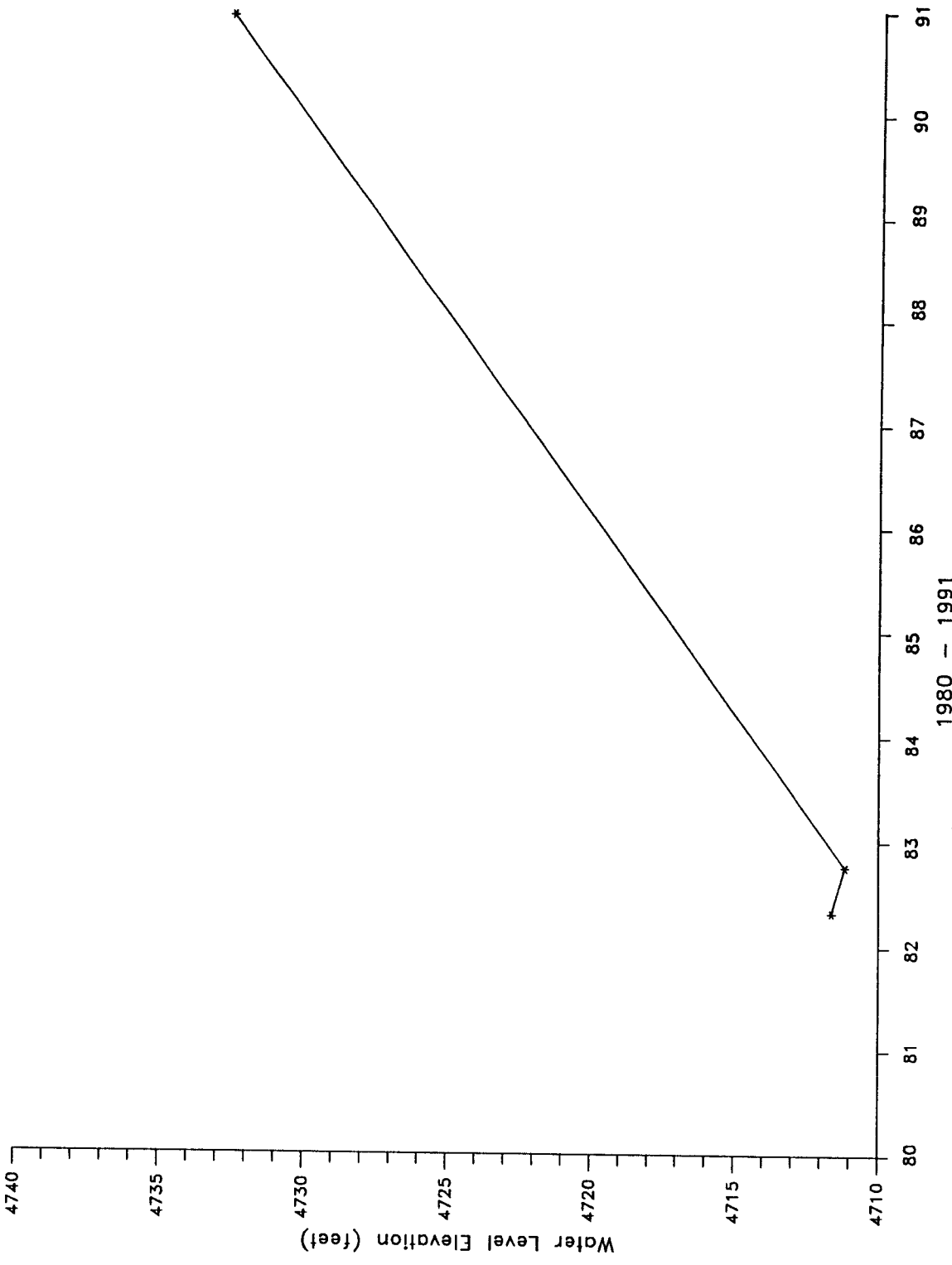

South Truckee Meadows Washoe County, NV Hydrograph of Well 18/19-12adbb Hydro-Unit Alluvium	DATE: 9/18/91
	DRAWN: KEK
	CHECKED:
	APPROVED:
	DWG NO:
PROJ.: 396U23201	
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine	

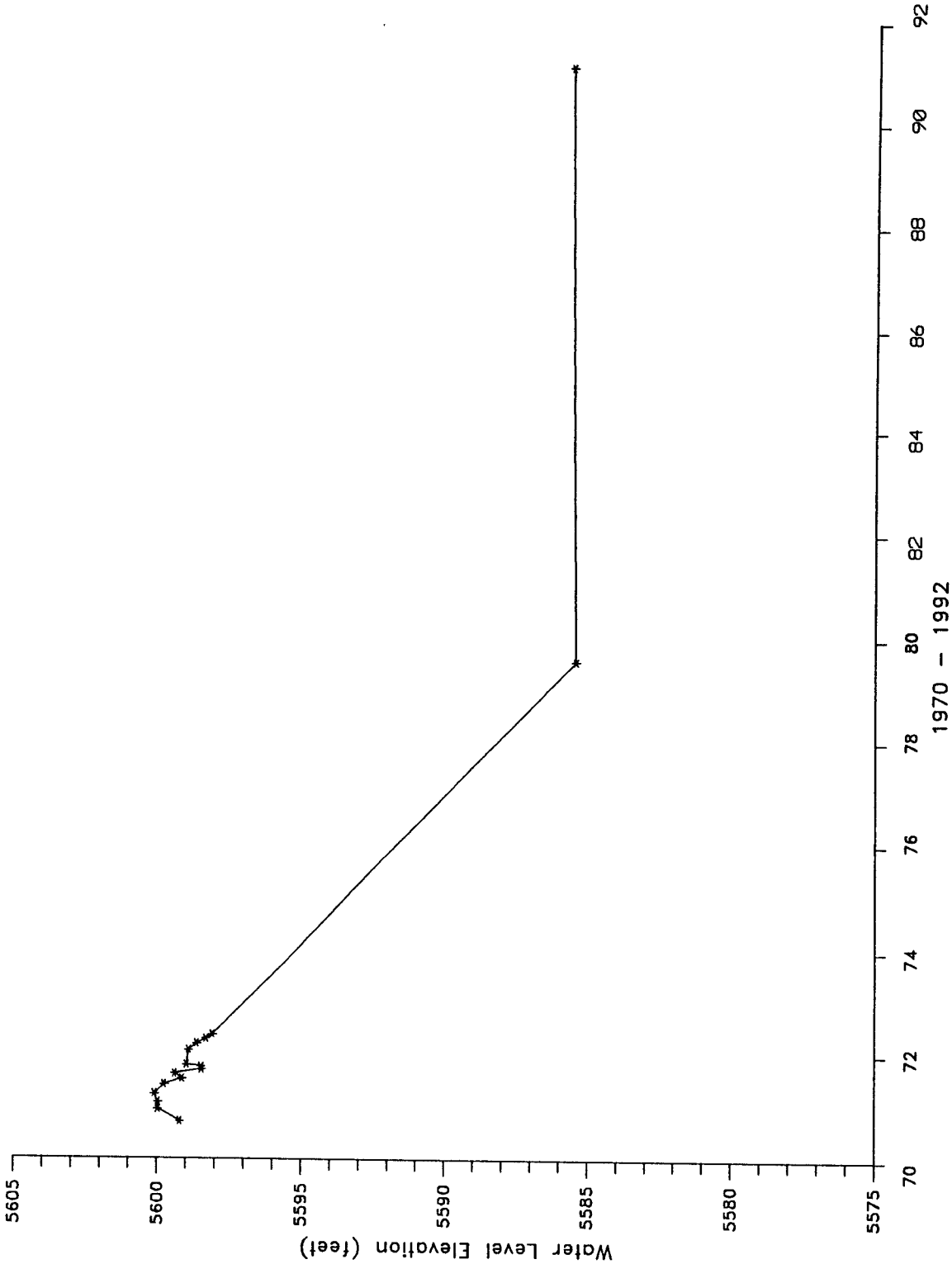
Figure B-11



South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograph of Well 18/19-13adaa	DRAWN: KEK
Hydro-Unit Alluvium	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201



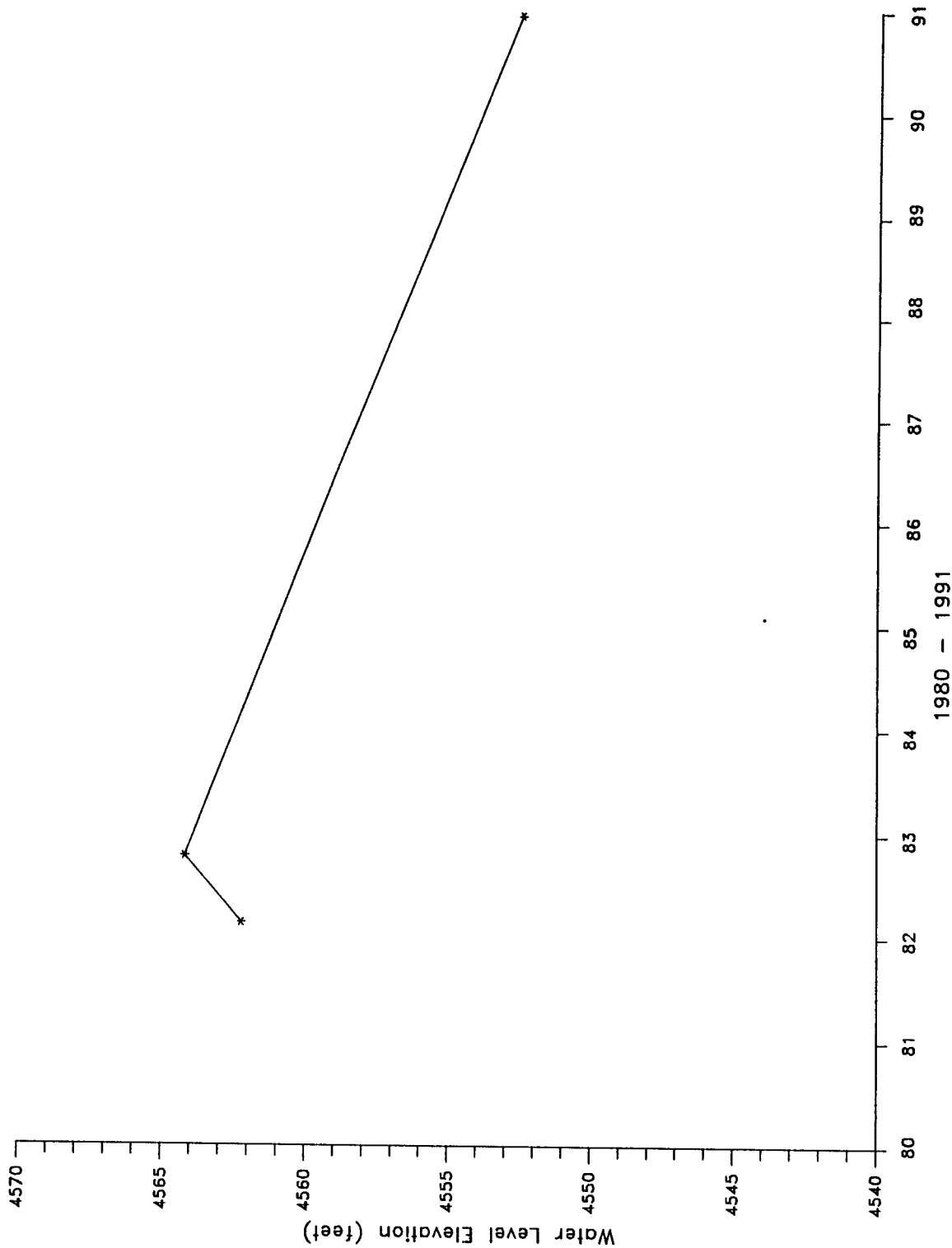
South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograph of Well 18/19-13bacc	DRAWN: KEK
Hydro-Unit Alluvium	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine	
Figure B-13	



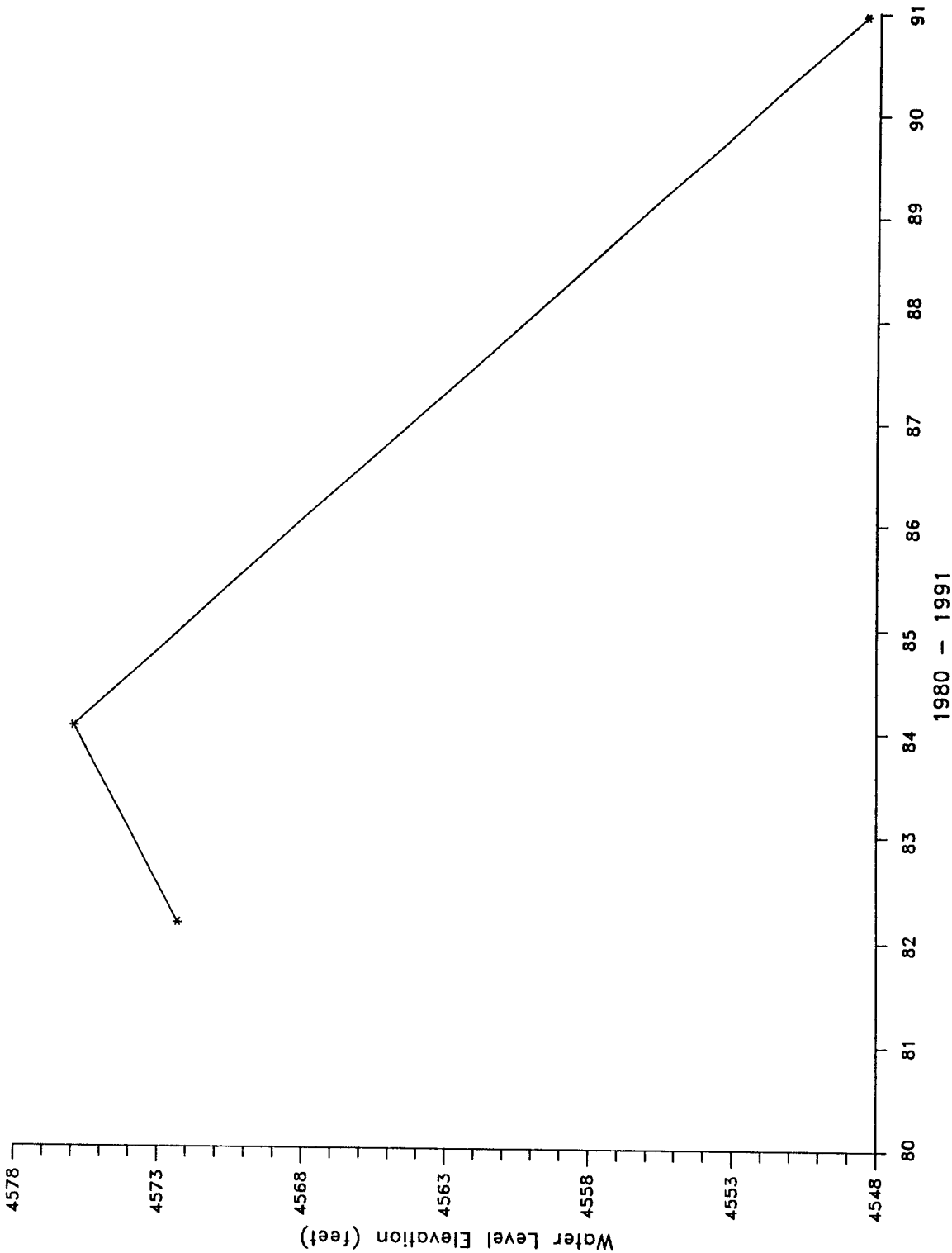
South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograph of Well 18/19-34ddcb	DRAWN: KEK
Hydro-Unit Alluvium	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201

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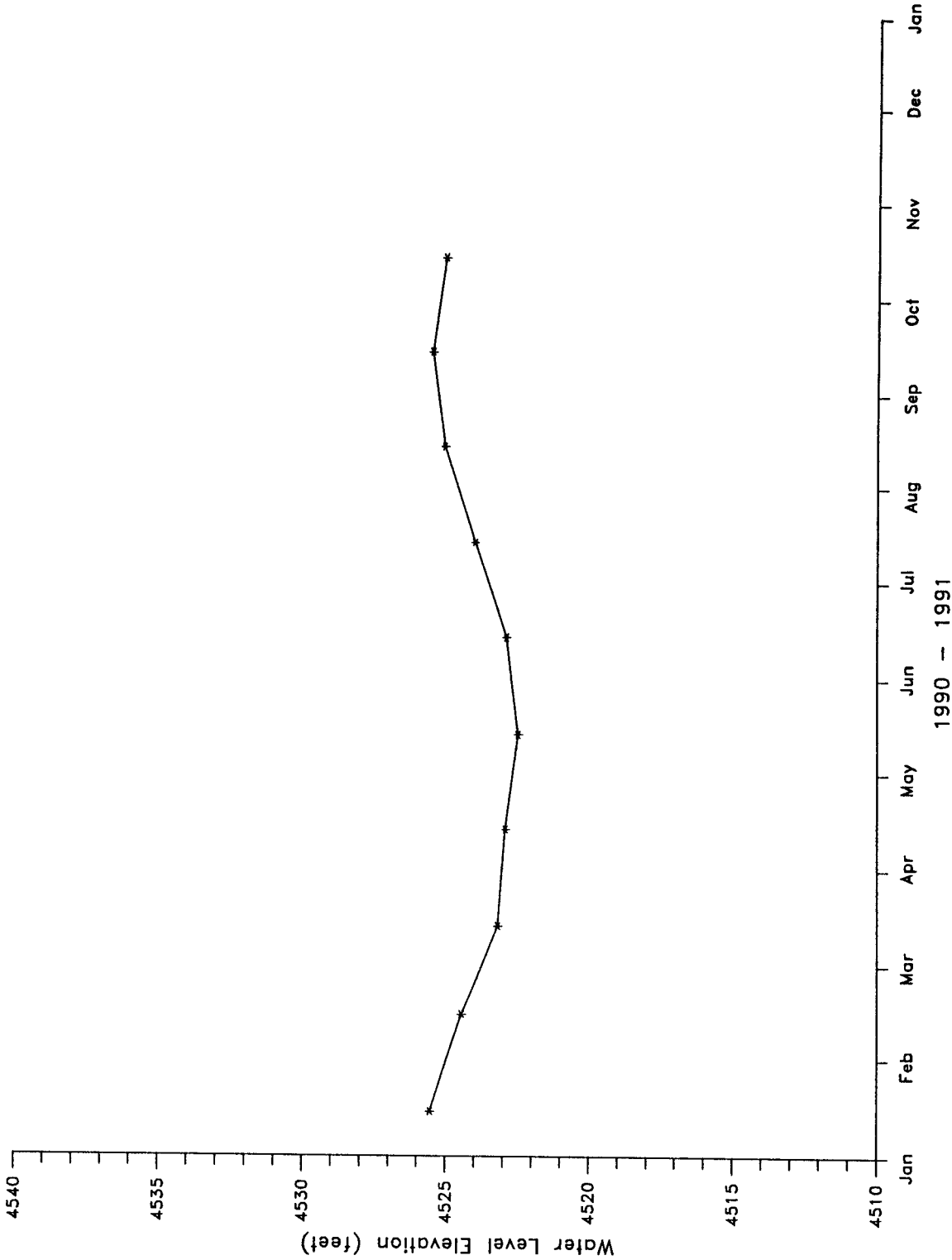
Figure B-14



<div> <div> <div></div> <div>Hydro-Search, Inc.</div> <div>HYDROLOGISTS - GEOLOGISTS - ENGINEERS</div> <div>Reynolds Turner International, Inc.</div> </div> </div>	South Truckee Meadows Washoe County, NV	DATE: 9/18/91
	Hydrograph of Well 18/20-07dcdc	DRAWN: KEK
	Hydro-Unit Alluvium	CHECKED:
		APPROVED:
		DWG NO: 396U23201
Figure B-15		



<div> <div></div> <div>Hydro-Search, Inc.</div> <div> RENO DENVER MILWAUKEE IRVINE </div> </div>	South Truckee Meadows Washoe County, NV		DATE: 9/18/91
	Hydrograph of Well 18/20-20bbbb		DRAWN: KEK
	Hydro-Unit Alluvium		CHECKED:
			APPROVED:
			DWG NO: 396U23201




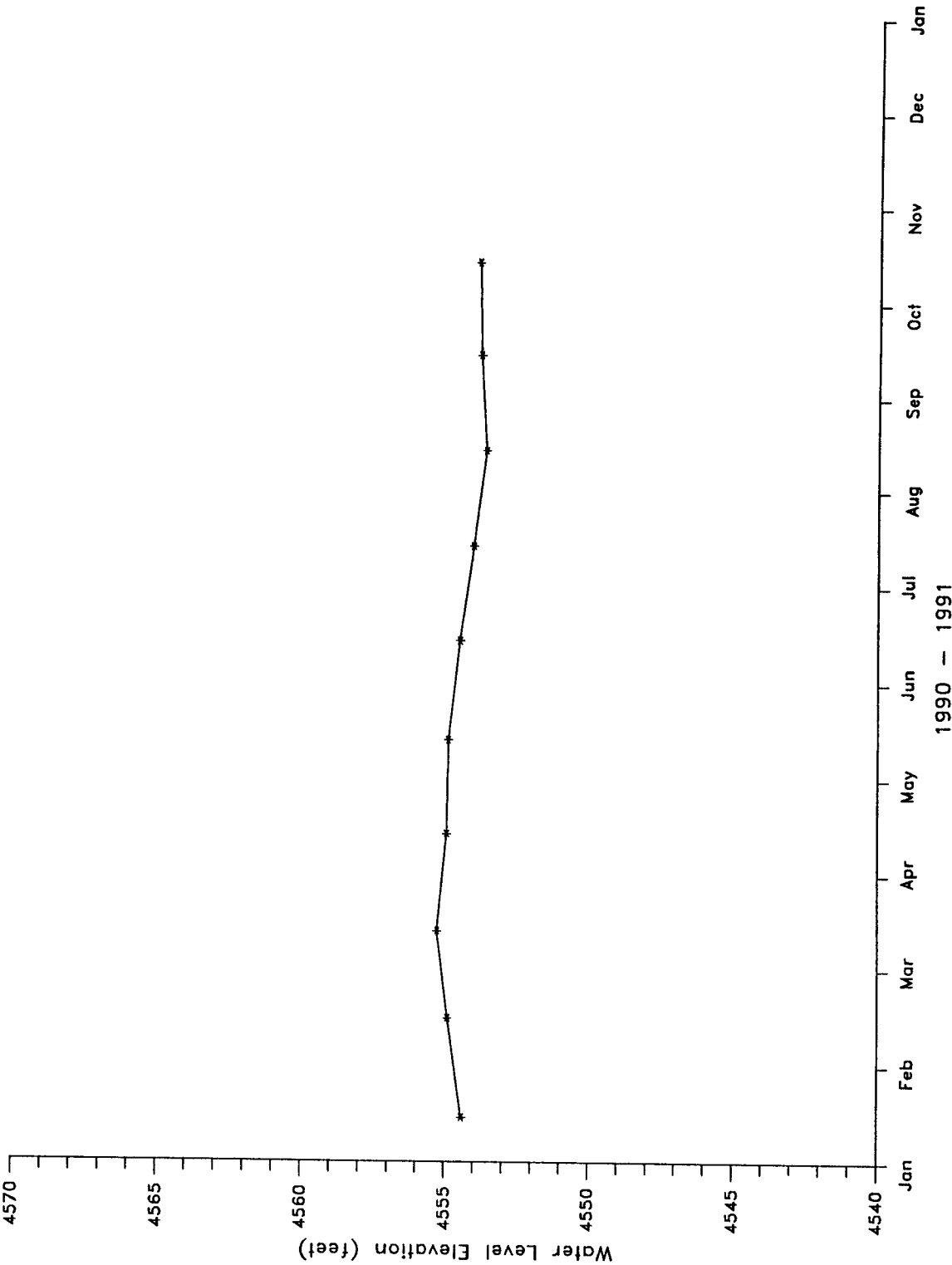

South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograp of Well 18/20-28daaa	DRAWN: KEK
Hydro-Unit Alluvium	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine	

Figure B-17

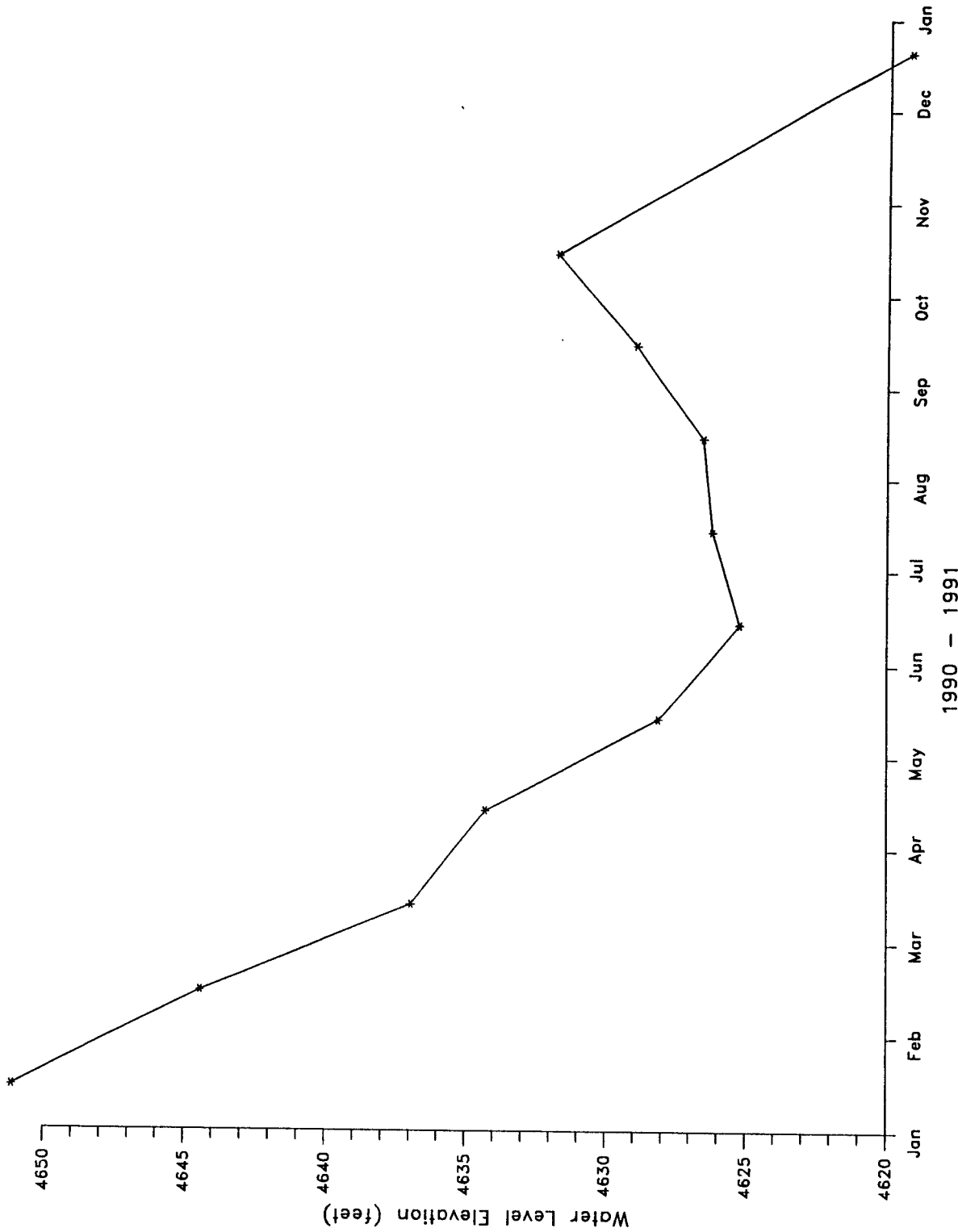



South Truckee Meadows Washoe County, NV		DATE: 9/18/91
Hydrograp of Well 18/20-29abad		DRAWN: KEK
Hydro-Unit Alluvium		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201

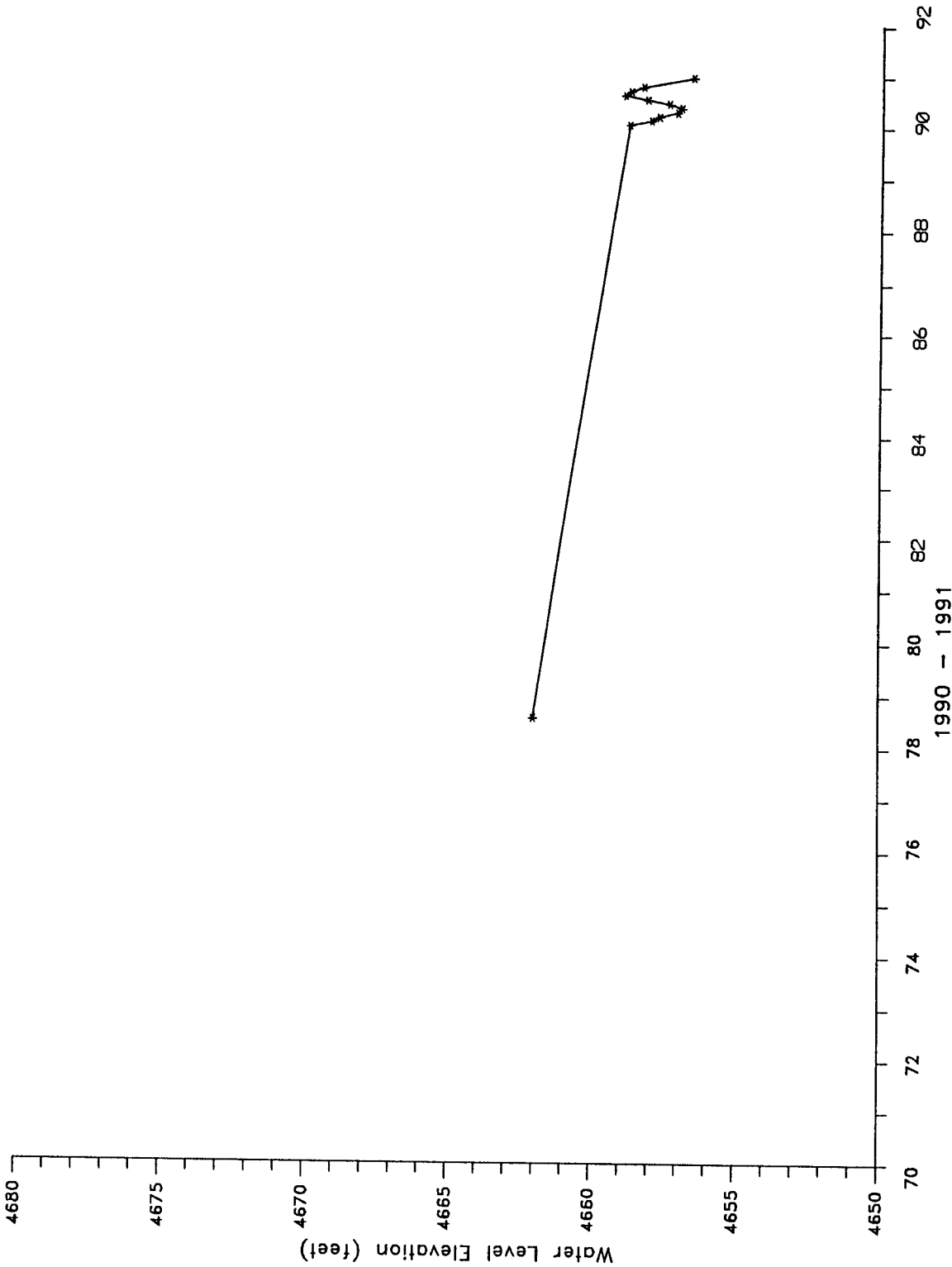



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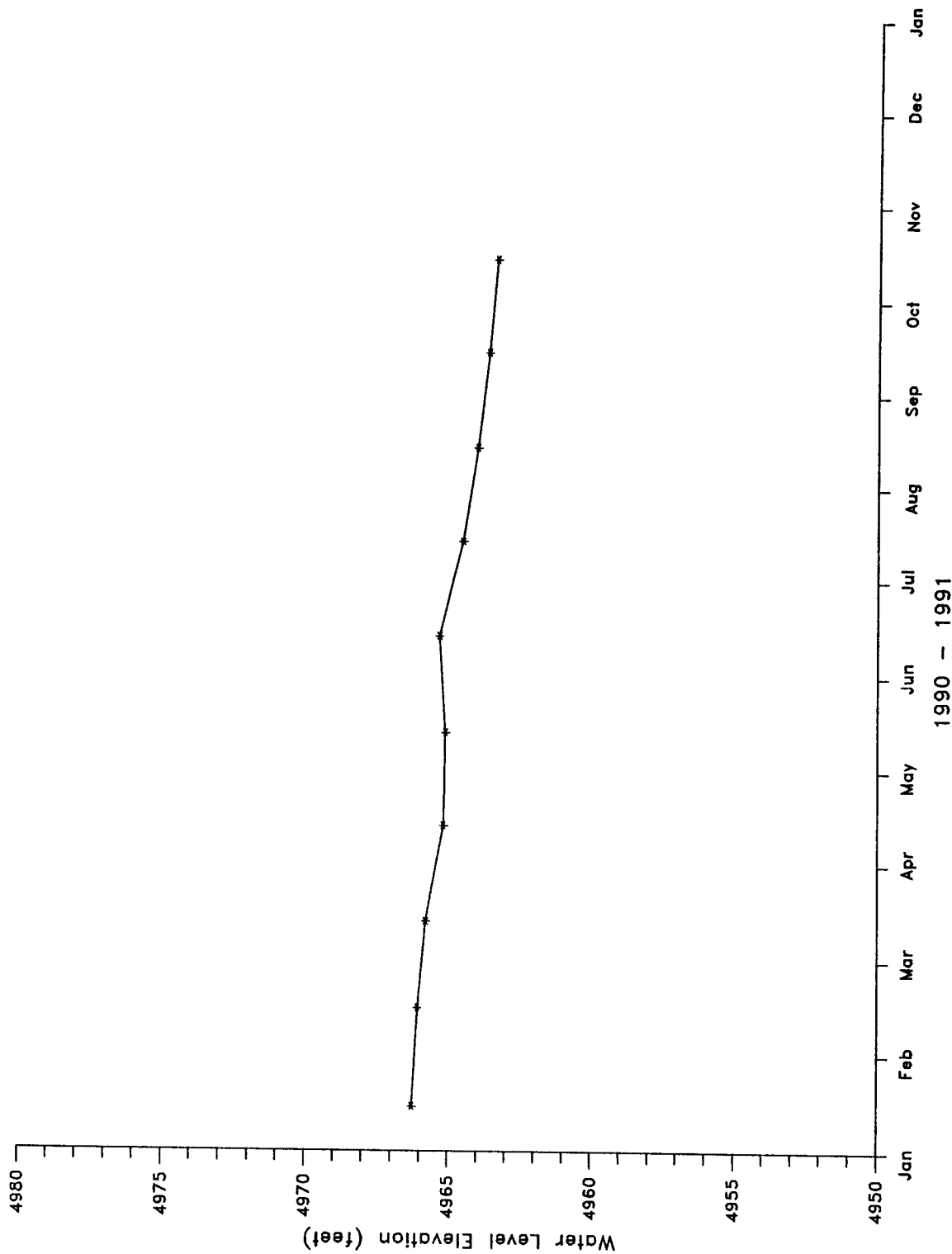
Figure B-18



South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograph of Well 18/20-29bbcd Hydro-Unit Alluvium	DRAWN: KEK
	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine	



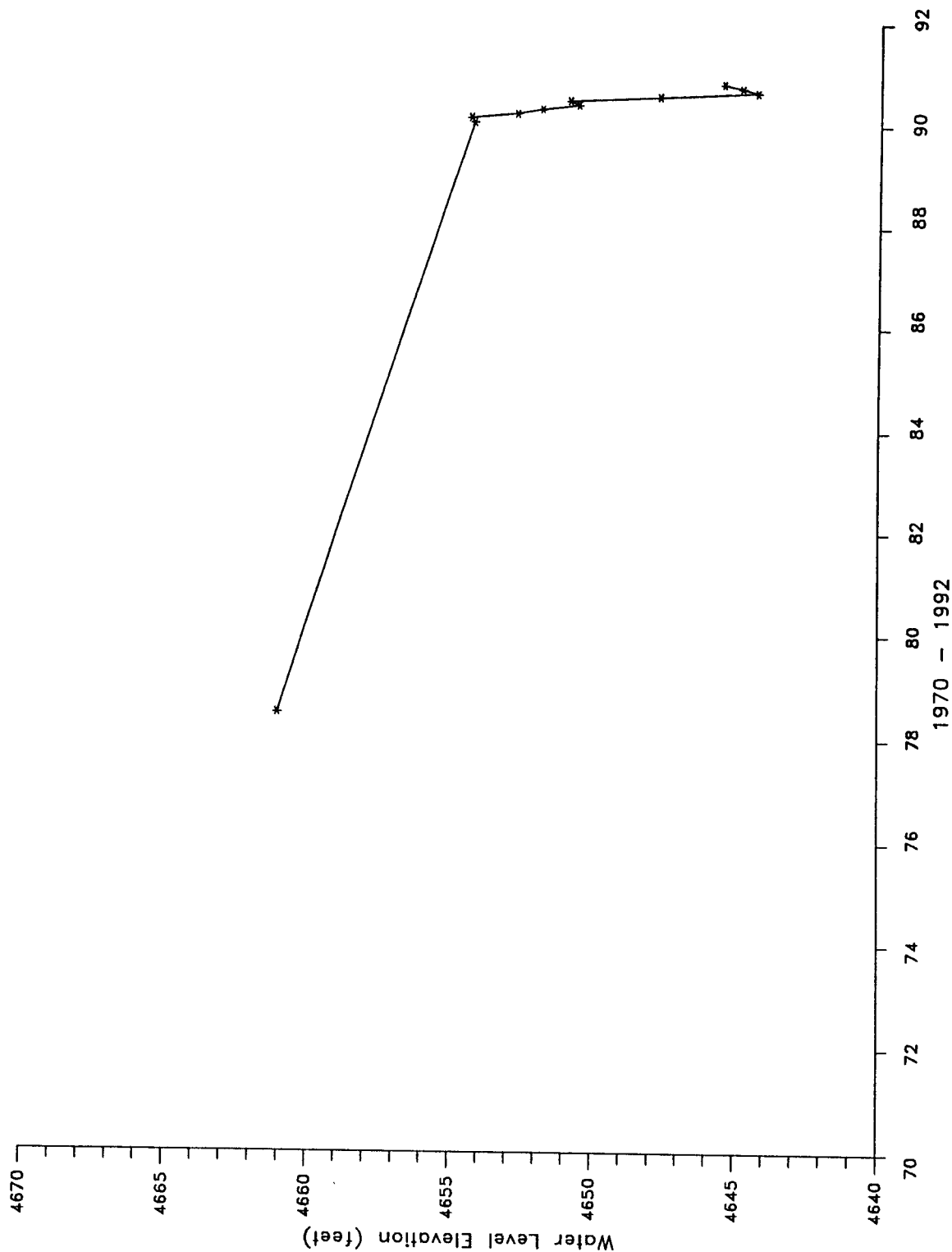
South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograph of Well 18/20-29dbcb2	DRAWN: KEK
Hydro-Unit Bedrock	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine	
Figure B-20	




Explanation

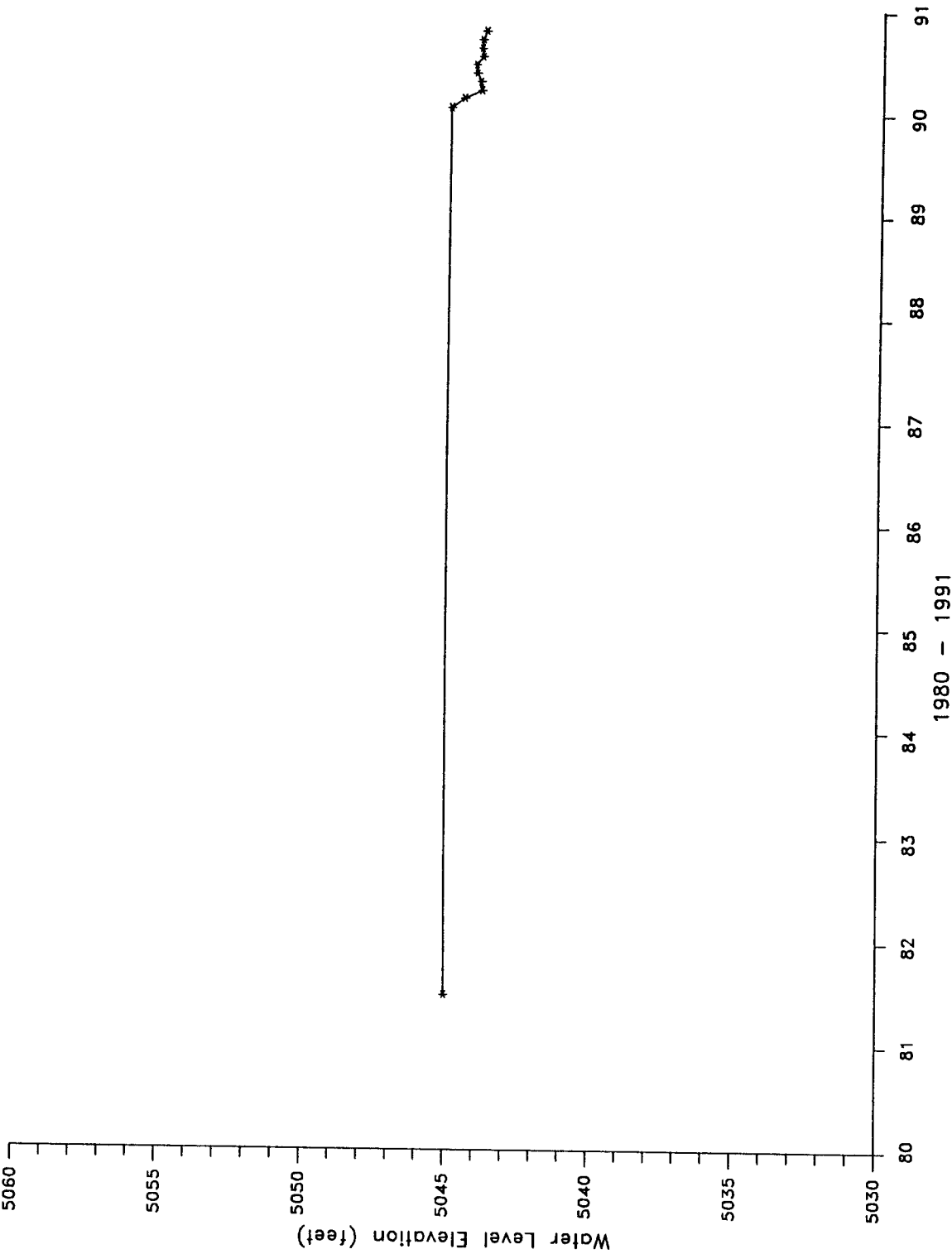
* Observed water-level elevation


South Truckee Meadows Washoe County, NV	DATE: 9/22/91
Hydrograph of Well 18/20-30cbcc2 Hydro-Unit Alluvium	DRAWN: KEK
	CHECKED:
	APPROVED:
	DWG NO:
	PROJ.: 396U23201



South Truckee Meadows Washoe County, NV	DATE: 9/18/91
Hydrograph of Well 18/20-31bdaa Hydro-Unit A1/Bedrock	DRAWN: KEK
	CHECKED:
	APPROVED:
	DWG NO:
PROJ.: 396U23201	

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South Truckee Meadows Washoe County, NV		DATE: 9/18/91
Hydrograph of Well 18/20-32cbcb		DRAWN: KEK
Hydro-Unit Bedrock		CHECKED:
		APPROVED:
		DWG NO:
		PROJ.: 396U23201
 Hydro-Search, Inc. HYDROLOGISTS - GEOLOGISTS - ENGINEERS Reno Denver Milwaukee Irvine		Figure B-23

APPENDIX C

Kriging

C - 1

Computerized mapping systems, in general, require that a horizontal "grid" be generated as a means of producing contours from randomly-spaced data (e.g., drill holes or wells). The grid is comprised of an array of values which are calculated for regularly-spaced locations to define a surface which is consistent with data observed at random locations. Once the grid values are generated, a variety of commercial software may be used to produce a contour map that represents this surface.

Kriging is a geostatistical method for generating a grid using observations from drill holes or wells. Each grid intersection is called a "block" in geostatistics, meaning that every grid intersection coincides with a block center.

Non-Geostatistical methods for gridding drill hole data typically compute each block value as a weighted average of nearby drill hole values. It is common for the weights to be inversely related to the separation distance between the block center and the drill hole (or inverse distance squared, cubed, etc.). The kriging method computes a linear weighted average of nearby drill hole values, to produce an estimate for a block. In this respect, kriging is similar to many of the non-geostatistical methods. The advantage of using kriging is in the way that the weights are assigned to observed values. Instead of assigning weights in a purely arbitrary manner (e.g., inverse distance squared), kriging utilizes information about the observed data, obtained from a variogram, to assign weights in such a way that the estimation error is minimized (i.e., the smallest confidence limits are obtained). The

variogram is a geostatistical tool which is used to obtain kriging input parameters that are customized for each individual data set, according to the statistical characteristics of the data. The parameters obtained from the variogram describe the relative importance of nearby observations as a function of separation distance. For highly-variable datasets, only the observed values closest to a block are important for estimating the block value. Distant observations are of no importance. For well-behaved datasets, distant observations have some importance, and can be used to produce more accurate estimates for block values.

The weighing method employed in kriging avoids two of the most common problems with non-geostatistical methods:

1. the tendency to extrapolate unrealistic trends into areas of sparse data and,
2. the tendency to over-emphasize the significance of extreme data values (either high or low).

Predicted stratigraphic elevations may be verified by referring to the observed elevations at the drill holes. Between drill holes, and especially around the perimeter of the drilled area, elevations produced by kriging tend to look realistic, and are normally confined within the range of observed elevations. Confidence contours produced by kriging can be qualitatively verified by referring to the well locations, i.e., areas of higher data density have smaller confidence limits, and vice-versa.