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NOTEBOOK ON HYDROGEOLOGY OF THE SOUTH TRUCKEE MEADOWS

FEBRUARY 1991

WASHOE COUNTY

DEPARTMENT OF PUBLIC WORKS

UTILITY DIVISION

P.O. BOX 11130 RENO, NEVADA 89520

SEAL OF WASHOE COUNTY STATE OF NEVADA

NOTEBOOK ON
HYDROGEOLOGY OF
THE SOUTH TRUCKEE MEADOWS
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INTRODUCTION

In January 1982, the newly formed Washoe County Sanitation Division (renamed the Utility Division) began data collection of the water resources in the South Truckee Meadows (see Figure 1). The studies were undertaken to better quantify the water resources available to present and future development within this hydrologic basin. Initially, the studies entailed a water well survey and the monitoring of streams with gaging stations. In the last nine years since that time, four water companies are now owned by Washoe County and operated by the Utility Division. One sewage treatment facility is about to be replaced by a new, expandable plant. Seven municipal water wells have been built by the County with total control of 24 production wells and eleven storage tank reservoirs. Fourteen observation wells have also been constructed. In the near future, the County will be constructing a surface water treatment plant which will include ground water injection wells. Consequently, the collection of data has grown substantially.

Considerable work has been done in the South Truckee Meadows by a variety of professionals. For example, scientists from the USGS have studied the Steamboat Springs Geothermal System and have published several reports bent on pure science. Meanwhile, geothermal power exploration and development has produced a large body of work delineating the geothermal reservoir. This region has been the study area for four Master's thesis that have addressed Steamboat Creek, the geothermal system, geologic faulting on the Mt. Rose Pediment, and the overall hydrogeological system. Housing developers have contracted several studies on the hydrology and the hydrogeology of the Double Diamond Ranch. Other developers have provided information through the drilling and testing of water wells for subdivisions. The Desert Research Institute completed a precipitation study for the Truckee River drainage area. The Utility Division work has included a geophysical study, a ground water modelling study, geologic studies, a ground water observation well network, drilling and testing of wells, and chemical analysis of the ground and surface waters.

This report attempts to bring together all known hydrogeologic data of the South Truckee Meadows. From this bulk of information, a second ground water numerical model will be developed in order to better understand the complexity of the ground water system and to assist in the management of the water resources. This report also identifies future studies that should be undertaken as well as to certain speculation of the hydrogeology. Consequently, I would rather think of this report as a compilation notebook and a guidebook towards future studies.

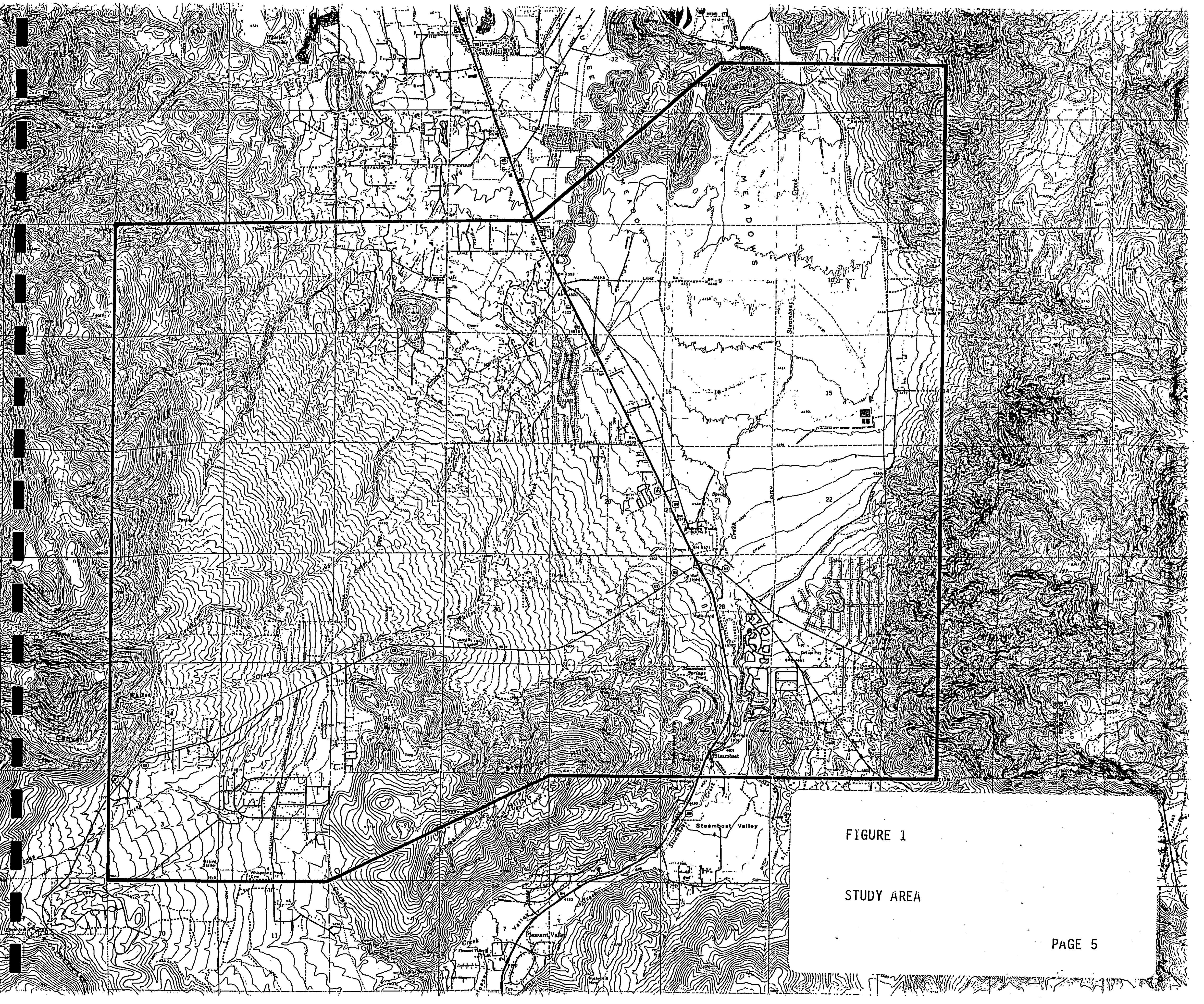


FIGURE 1

STUDY AREA

GEOLOGY

Regional Geology

The regional geology is part of the Basin and Range Province of the North American Cordilleran. The major features of the region are the result of the Sierra Nevada Batholith which is part of the Basin and Range Cenozoic Block Faulting that continues into recent times. This cenozoic uplift is the result of high-angle, normal faulting probably due to major extensional forces. Volumous tertiary volcanics are also part of the gross geology. The regional geology is well described by Thompson and White in their U.S.G.S. P.P. 458.

Cretaceous granitics have been uplifted during the Cenozoic Era as a result of block faulting. Developed from this are basins between the Carson and Virginia Ranges, both part of the Sierra Nevada Batholith. Tertiary volcanics (Alta and Kate Peak Formations) have covered most of the area of the Truckee Meadows and probably were derived from numerous vents in and at the margins of both mountain ranges. The volcanics are mostly andesitic in character, however, basalts and rhyolites are found.

Concurrent with the Cenozoic uplifting and volcanism are episodes of erosion and deposition of sediments derived from the volcanics and granitics. Thompson and White give evidence and discuss several pediments, particularly on the east flanks of the Carson Range. A unique structure of the region is the Steamboat Hills and the Steamboat Springs Geothermal Area. The Steamboat Hills are also uplifted, faulted, granitic and overlain with volcanics (basalt to rhyolite). These hills are the site of a geothermal discharge area thought to be one million years in age (White, et al, 1964). These springs are still active today.

During the Quaternary, the Sierra Nevadas experienced several episodes of glaciation. As a result, glacial deposits occur in the Truckee Meadows from the Donner Lake and Tahoe Outwash as well as the Pre-Lake Lahontan and Truckee Lake deposits. Today's structure is that of the Carson and Virginia Ranges with elongated basins between them. Alluvial fans and pediments form between the mountain fronts and the bajada and valley floor deposits.

Local Faulting

Refering to Plate 1 (Geologic Map), extensive faulting has occured 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 are presently active (Cordova, 1969). Several scarplet grabens have been formed, most notably in Section 30 (T.18N.,R.20E.). According to Cordova, approximately 60% of the 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. To illustrate this, Cordova proposes "Gilbert's Theory of Fault Scarps in Alluvium" as a mechanism that has resulted in the numerous scarplets in the study area. Figure 2 presents four drawings of Gilbert's Theory. The "simple fault scarp" illustrates the block fault movement to the right (vertical lines) with a portion of the alluvium (horizontal lines) slipping to the left. The result is a fault scarp as depicted. The other three figures are elaborations of the simple fault scarp.

It has not been verified at this time as to whether or not east-west faulting exists in the Whites and Thomas creek drainages. North-south faulting does appear to capture these streams in sections 25 (Thomas) and 30 (Whites). Also, more work needs to be done to verify whether or not north-south faulting occurs near U.S. 395 (i.e. along the axis of the basin).

Pediment

Cooke and Warren (19xx) describe a pediment as "a complex surface comprising patches of bedrock and alluvium, in places capped by weathering and soil profiles, punctuated by inselbergs, and scored by a network of drainage channels." This is indicative of an erosional environment. A pediment may also consist entirely of bedrock with a thin veneer of alluvium, sloping away from a mountain front and towards an area of bajada deposits. Conversely, an alluvial fan is made up entirely of sediments, is an area of deposition that grades from coarse to fine grained away from the canyon mouth, and thicknesses of alluvium are greatest at the mouths of canyons, diminishing away from the canyon.

Thompson and White (1964) discussed this area as a pediment. More precisely, it is a pediment overlain with a thick alluvial veneer. Evidence from geologic maps (Thompson and White, 1964; Bonham and Rogers, 1983) and well driller logs indicate the Kate Peak Formation and other volcanics (Alta?) underlie the study area and are volumuously exposed at the margins of the area. Drill logs indicate or show that the slope of the volcanics is nearly constant with topography - that is the alluvium is of nearly constant thickness on the pediment. Drill logs and inspection also indicate the alluvium as being poorly sorted throughout the study area, at least to a change in slope near U.S. 395.

Alluvial Deposits

Most driller's logs for the pediment area were drilled to depths of 200-300 feet for domestic wells. Nearly all logs indicate poorly sorted granitic and volcanic sediments. Good lithologic descriptions are given in several sections. All logs in the SW pediment area indicate sediments greater than 300 feet thick. The USGS Open File Report 84-433 suggests alluvial deposits 600 - 800 feet thick just south of the Mt. Rose Highway (sections 34, 35 and 3) based on gravity studies and that the deposits thin towards the mountain front and Steamboat Hills. Drill logs and resistivity data indicate the alluvial veneer to be 500 - 700 feet thick throughout most of the pediment west of the Steamboat Ditch.

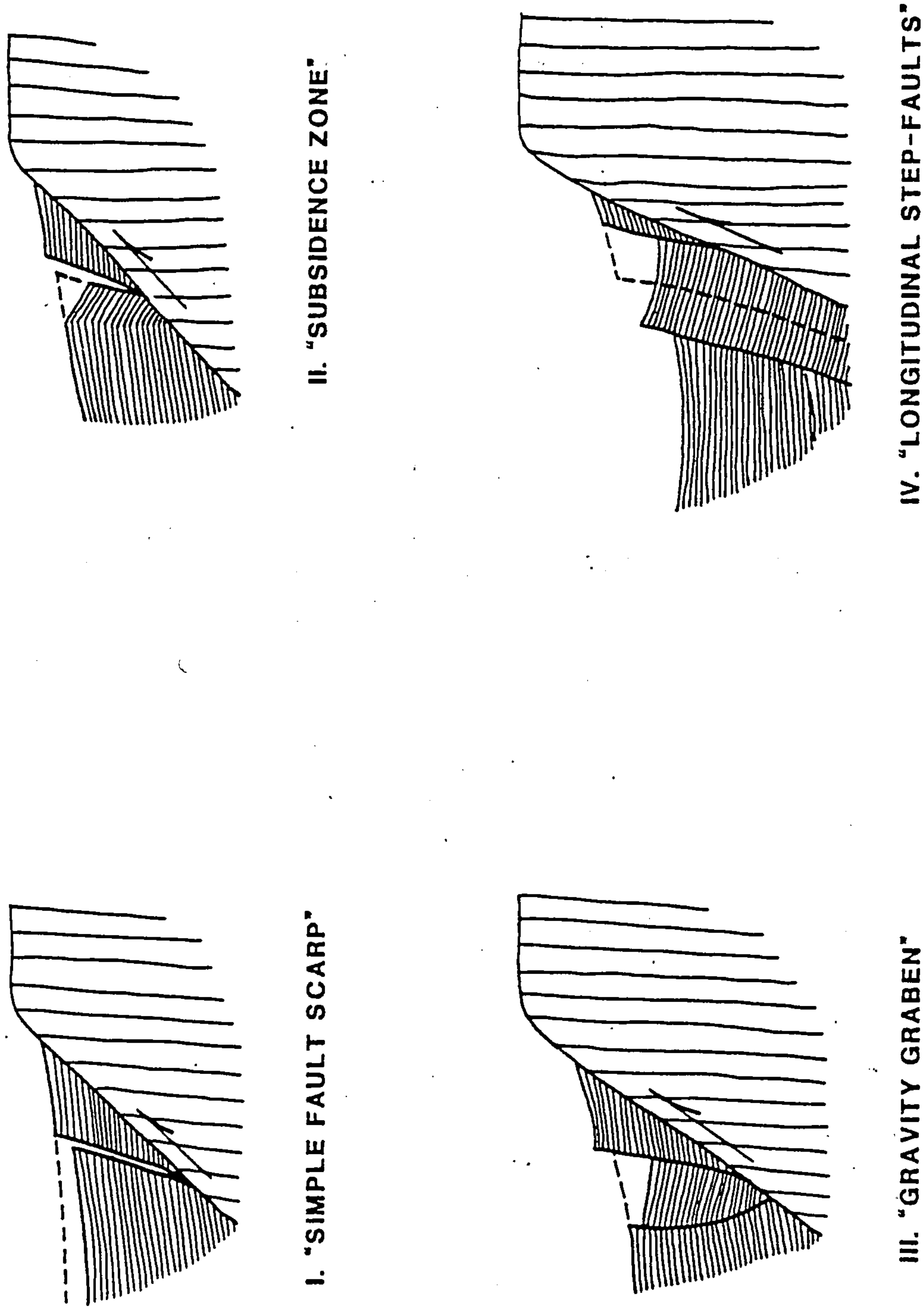


FIGURE 2 DRAWINGS OF "GILBERT'S THEORY OF FAULTSCARP IN ALLUVIUM"

Geologic Cross Sections

Four geologic cross sections for the pediment are shown in plates 2 - 3. On Plate 3 is a map showing the locations of the cross sections. Also shown on the map are the locations of test holes and municipal wells where significant hydrogeologic information exists. This information includes accurate lithologic interpretation, geophysical logs, well construction and/or pumping tests. The cross sections are based on this data.

Cross section A-A' is an west-east schematic from the top of the pediment 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 section 36 and is inferred to extend northward through the western half of section 25 and beyond. The STMGID wells 5 and 6 are on opposite sides of this fault. It appears that this fault inhibits groundwater movement as the piezometric head is much higher on the west side of the fault. A pumping test conducted on the STMGID #6 indicated that an impermeable boundary was reached, inferred to be this fault. Additional evidence of this fault is that a small groundwater discharge area exists in Whites creek in section 25 west of the fault trace. This fault is considered tectonic in nature and not the result of gravity as the fault is traceable in the Steamboat Hills.

This consequence of faulting also occurs at the Lancers Fault in section 19. The piezometric level offset is not so apparent on the cross section. It can be seen from the cross section that a tectonic 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 compared to STMGID PW#3. Otherwise, the volcanics would be displaced higher on the uphill side of the Lancers Fault relative to PW3. In section 21, on the valley floor, a Phillips Petroleum Stratigraphic test hole was drilled 2000 feet into alternating lenses of gravel, sand, clay and volcanics. According to the log, the volcanics were never thicker than 20 feet. This may lend support to a north-south trending fault offsetting the pediment from the valley fill deposits. It is assumed that the pediment volcanics are on the order of hundreds of feet thick.

Cross section B-B' traverses the pediment perpendicular to the topography. At the southwest end the Winburn Well indicates alluvial thickesses of at least 480 feet at the mountain front. A nearby well of 240 feet has a piezometric head of approximately 14 feet above land surface. On the downhill side of the Mountain Front fault the static is approximately 160 feet below land surface. At the STMGID MW#1 an alluvial thickness of 600 feet is encountered before volcanic bedrock. From the lithologic log the alluvial grain size diminishes in size with depth and that cemented sands and gravels overlie the volcanics. At the Piccolo Well mixed alluvium is encountered for 400 feet with clay increasing with depth. The Double Diamond Well #1 was drilled to a depth of 190 feet. Volcanics were encountered at a depth of 150 feet. The alluvium was mixed from clay to boulders. The volcanics appeared to be andesitic, reddish purple in color. 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 (STMWWTP) was drilled 250 feet, encountering 70 feet of mixed sand and clay lenses and then light blue/grey andesite.

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 approximately 2000 feet and encountered granitics (granodiorite ?) at 80 and 370 feet, respectively below undifferentiated alluvium. STMGID PW#3 and MW#4 have been discussed in section A-A' and in this section illustrate a different perspective. What is significant is the volcanic offset due to faulting (?). The site at PW#1 has a similar

lithology as at PW#3 and is inferred to be in the graben depicted in cross section A-A'. The Holcomb test hole drilled by SPPCo encountered lenses of clays with mixed sands and gravels to a depth of 336 feet. At their Huffaker site the same type of lithology was encountered to a depth of 345 feet.

Cross section D-D' traverses from the Dry Creek drainage southeast to the Steamboat Hills. At the Dry Creek drainage the Hunter Creek sequence of the Truckee Formation is mapped. Field inspection shows cemented silt/clay lenses dipping at 40 degrees and striking north. It is not known how far this formation extends to the south. As discussed earlier, the STMGID PW#5 site encountered relatively undifferentiated alluvial deposits to a depth of 690 feet. At STMGID PW#4, well drillers logs are confusing. Two wells exist. The first hole was drilled by Wayne drilling to a depth of 325 feet, cased then drilled to 525 feet, then redrilled to 812 feet by Sierra Pump and Drilling. It is assumed then, that only 325 feet are cased and that the hole collapsed below this point. The well has not been sounded as a pump exists in the well. The cased portion is also assumed to be constructed in alluvium. A piezometric surface is at 200 feet below land surface. Later in 1981, Paul Williams drilled approximately 30 feet adjacent to this first well and completed a production well to a depth of 831 feet. It is difficult to rely on his lithologic interpretation, but it is apparent that the well's production zone is in hard rock. The pumping of this well does not affect the static level in the adjacent well. The piezometric level in the production well is 500 feet. Because of the well's location next to the Lancers Knob (volcanics), it's possible that the lithology has alluvium overlying volcanics which overlie granitics as depicted. Strat Hole #5 has alluvium overlying granitics at 370 feet.

Valley Floor

The South Truckee Meadows valley floor is approximately 10 square miles in area. Thomas and Whites creeks are tributary to Steamboat Creek which flows south to north in this ground water discharge area. Alluvial deposits are reported to be in excess of 1900 feet as reported by Phillips Strat Hole 1 (1966 feet) in section 21 and by a Double Diamond test hole (1770 feet) drilled in section 16, both in T18N R20E. While being a discharge area for ground water moving off the Carson Range, it is also a discharge area for discrete geothermal waters associated with the Steamboat system (Bateman and Scheibach, 1975). See figure 3.

Huffaker Hills

These hills are extensions of the Virginia Range and generally trend SW - NE and topographically seperate the North and South Truckee Meadows. They appear to extend southwestward nearly to the Carson Range or to section 12, T19N R20E. It is thought that this extension forms a ground water divide so that little ground water movement occurs from south to north.

Steamboat Hills

The geology of the Steamboat Hills has been well described by Thompson and White (1964). Since that date several geothermal exploration companies have drilled test holes in and around this area. Figure 4 is a map of these test hole locations. Also shown are production and injection wells of two geothermal operations. Plate 5 shows cross sections of the Steamboat Hills.

Cross section E-E′ trends SW-NE through the Steamboat Hills. An alluvial fan emminates from the Galena drainage on the east side of the Carson Range. This alluvial fan is believed to be on the order of 300 to 500 feet thick. Immediately east of Galena Creek, shown on the cross section, Strat Hole 12 was drilled to a depth of approximately 1800 feet. It penetrated approximately 700 feet of volcanics, 500 feet of tuffs and 500 feet of metamorphosed sediments and volcanics. Strat Hole 8 was drilled nearly 2000 feet into approximately 100 feet of tuffs and tuff breccia, nearly 300 feet of sand and gravel and then 1600 feet of quartzite and metamorphosed sediments. The boreholes further east predominately drilled into granodiorite. Obviously, faulting has offset the volcanics, the metamorphosed rocks, and the granodiorite from each other given the close proximities. Detailed investigations of this area are available from the USGS Professional Papers 458A - C.

This cross section shows the geothermal and injection wells of the Yankee-Caithness project. Those wells are the 21-5, 28-32 (production) and the Cox (injection). The geothermal waters are located in the fractures of the granodiorite.

Two geothermal companies are currently generating power from geothermal processes. These area the Yankee-Caithness and the ORMAT operations. ORMAT's operation is located to the north east of Yankee-Caithness. These companies have determined that the two production zones are seperate and distinct from one another. ORMAT's production zones are also in granodiorite.

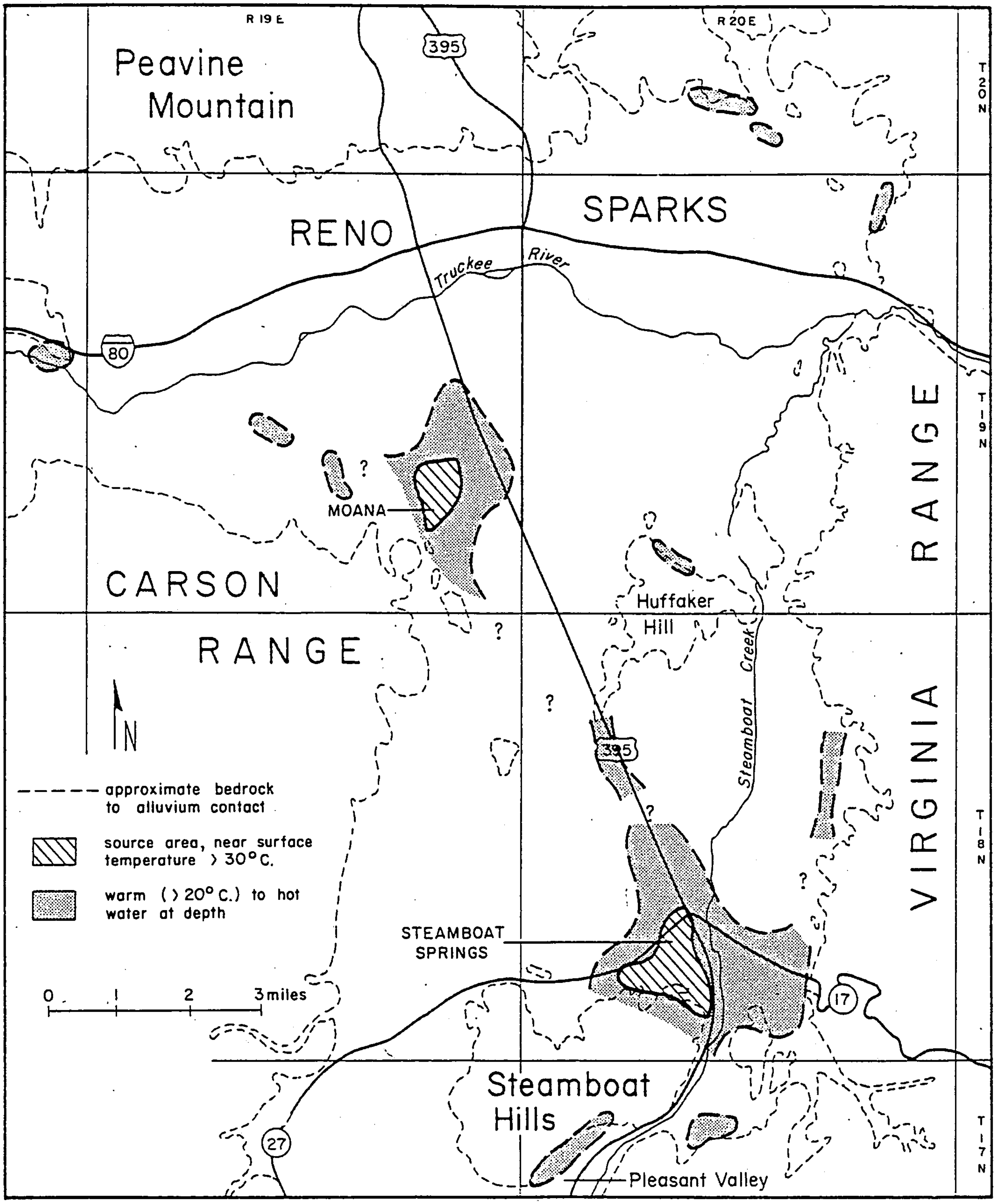


FIGURE 3 AREAS OF KNOWN THERMAL GROUND-WATER OCCURANCE IN THE TRUCKEE MEADOWS

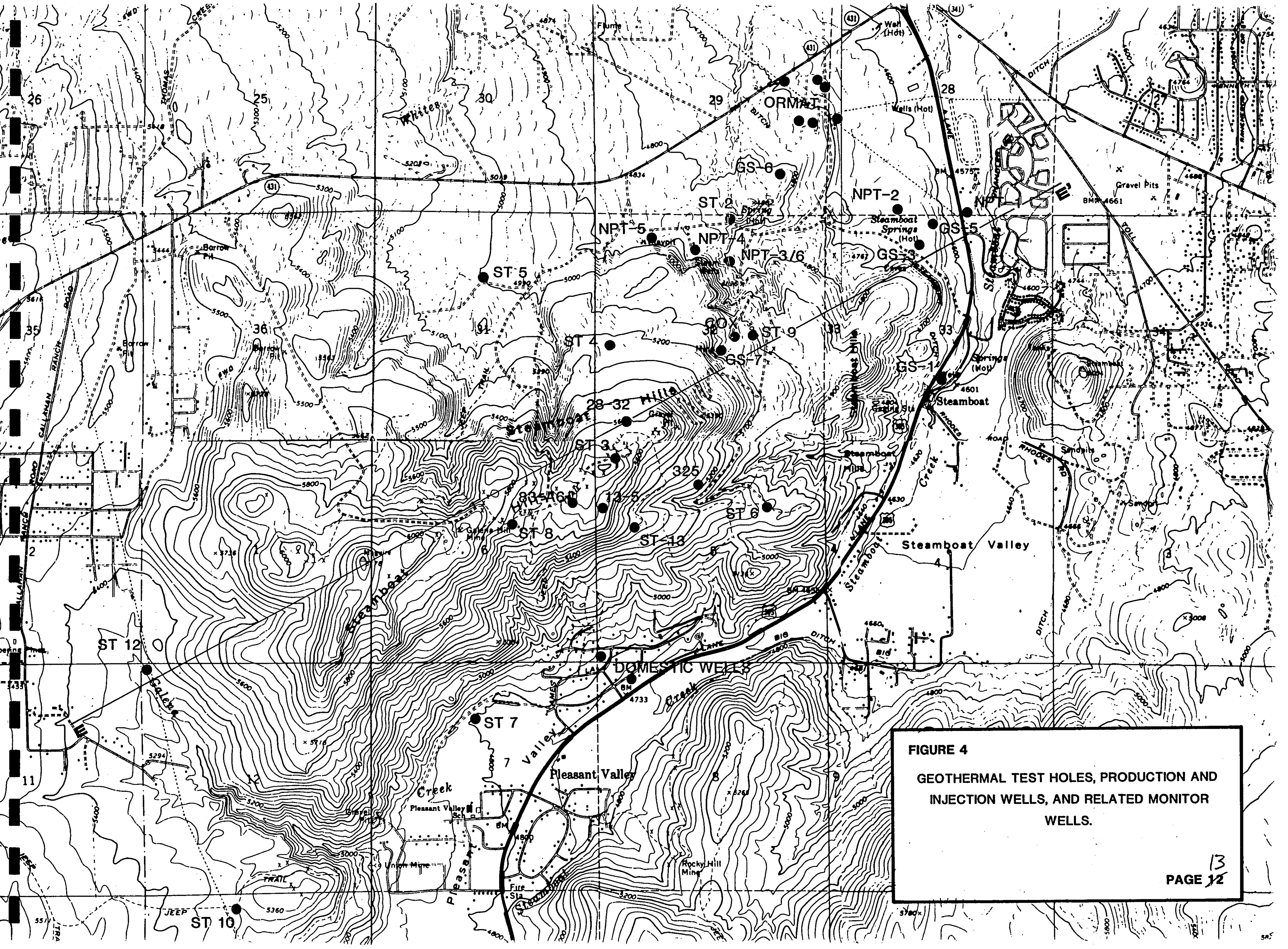


FIGURE 4

GEOTHERMAL TEST HOLES, PRODUCTION AND INJECTION WELLS, AND RELATED MONITOR WELLS.

HYDROLOGY

Precipitation

Precipitation in the Truckee River drainage system has been surveyed by the Desert Research Institute from 1979 to present. The report (Klieforth, 1983), which evolved from the study, provides an excellent record (1966 to 1983) of precipitation for this study area. Figure 5 is an isoheyatal map of the study area. Stream flow on the pediment is derived from the Carson Range where precipitation ranges from 60 inches to 20 inches. This range of values is from west to east respectively. Precipitation continues to decrease eastwardly to 10 inches in the valley and Virginia Range. Snowfall amounts to 80% of the precipitation in the Carson Range, 40% at the mountain front and 16% in the valley. At the higher elevations snowfall occurs October through April. This same period accounts for 80% of the total precipitation annually. Summer precipitation usually occurs as a result of thunderstorm activity. Snowpacks generally begin accumulating in October and November and linger through May and June. Depths of accumulation vary according to elevation and range from 5 to 25 inches at the mountain front to in excess of 100 inches above 9,000 feet elevation.

Stream flow

The Mount Rose Pediment contains two perennial creeks, Thomas and Whites. Both headwaters are situated east and northeast of Mt. Rose well above the study area. The drainage areas for Thomas and Whites above the mountain front are approximately seven and eight square miles, respectively. Before irrigational practices prevailed, both streams confluenced with Steamboat Creek at the valley floor. Steamboat Creek eminates from Washoe Lake in Washoe Valley to the south. It flows northward and is confluenced with Galena and Browns creeks in Pleasant Valley and finally confluences with the Truckee River near Vista. See figure 6.

Whites Creek's channel has been altered by man in section 30 approximately 2/3 down its reach of the pediment. It has been altered to four branches for irrigational purposes. Consequently, its full flow does not always reach Steamboat Creek.

The discharge record of Thomas and Whites Creeks is poor. The U.S.G.S. maintained a constant recording station on Whites Creek from 1962 until it was destroyed by flash flooding in 1967. Washoe County began monitoring flows on Thomas and Whites in 1982 to present. Based on these records by the U.S.G.S., Washoe County, and synthetic stream flow analysis done by Hydro-Search, Inc in 1980, the average annual flow of Thomas and Whites are 3800 AF and 6400 AF, respectively.

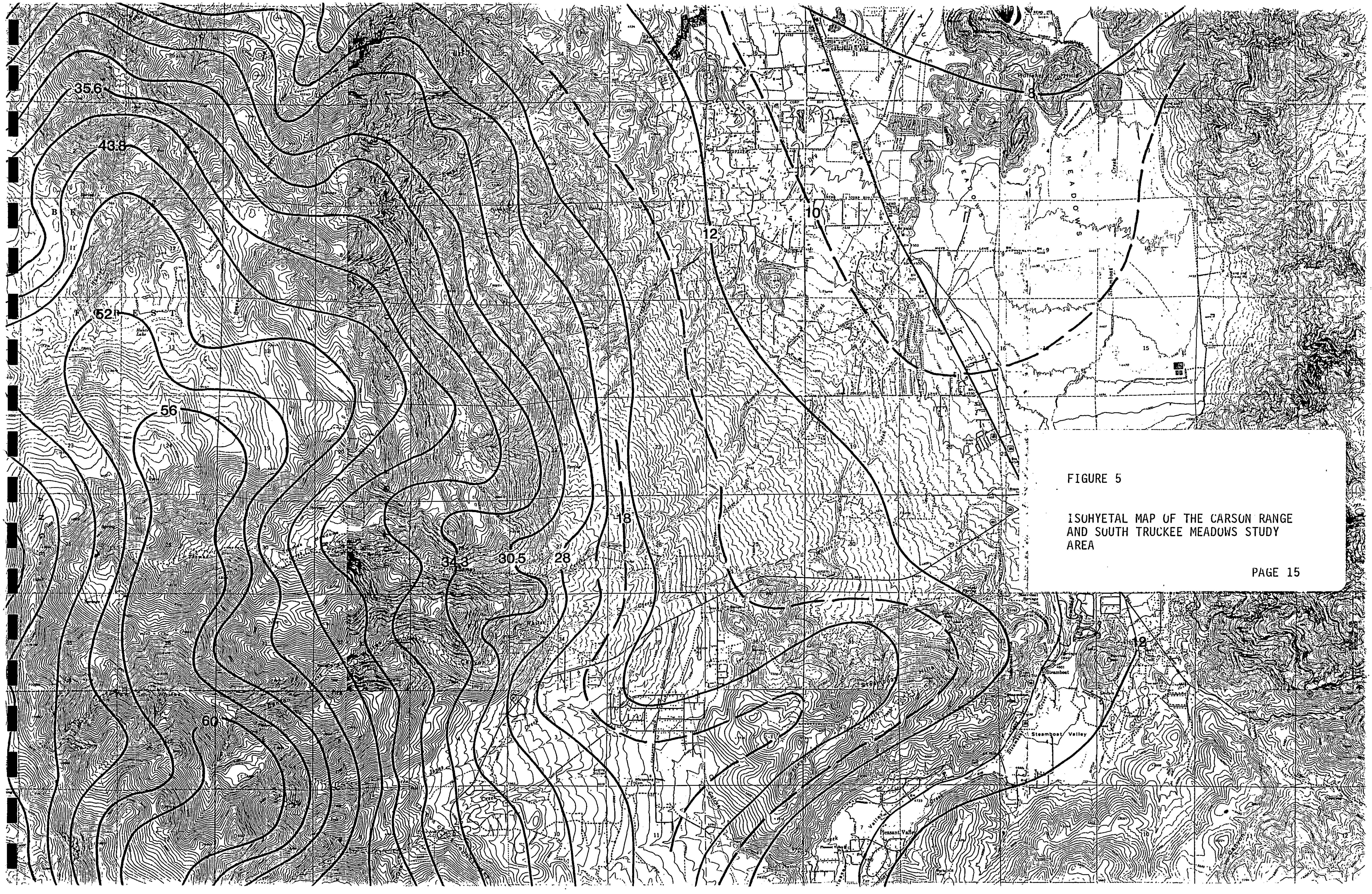


FIGURE 5

ISOHYETAL MAP OF THE CARSON RANGE AND SOUTH TRUCKEE MEADOWS STUDY AREA

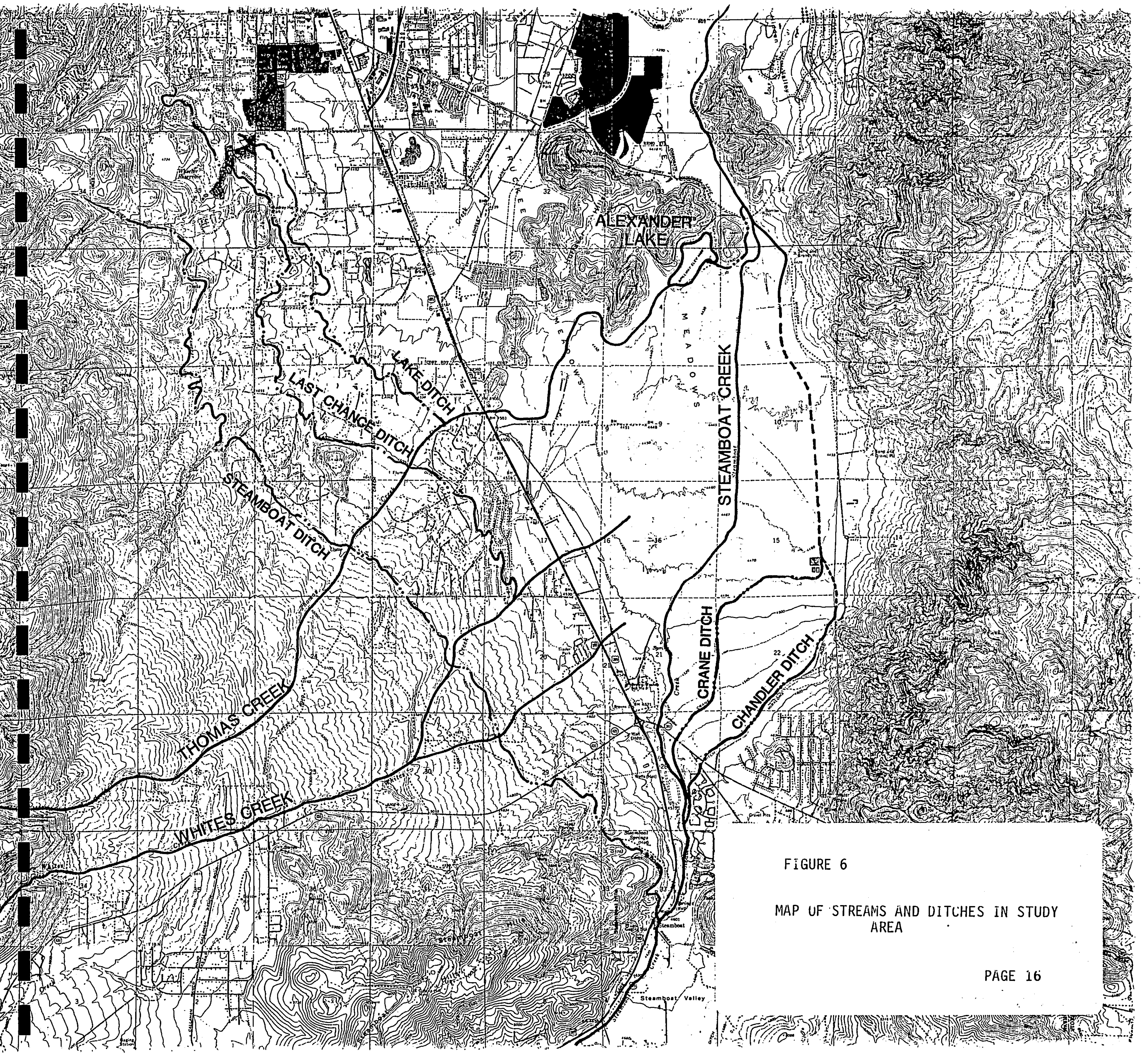


FIGURE 6

MAP OF STREAMS AND DITCHES IN STUDY AREA

Major ditches in the study area include Steamboat, Last Chance and Lake (see figure 6). All three ditches derive their flows from the Truckee River. Steamboat Ditch terminates into Steamboat Creek, Last Chance terminates at Whites Creek and Lake at Thomas Creek. Three major ditches exist in the meadows area. Crane and Chandler take water out of Steamboat Creek at Steamboat Springs and Alexander Ditch transports Alexander Lake water from the South Huffaker Hills to the east of the hills. Alexander Lake's source is Thomas Creek. Table 1 lists the flows for the ditches during 1982 and 1983.

TABLE 1
STM DITCH FLOW 1982/1983

DITCH	1982 (AF)	1983 (AF)
Chandler	2,900	3,800
Steamboat	4,300	5,400
Crane	3,400	6,200
Last Chance	3,200	3,300
Lake	1,800	1,900

Annual flows for all streams and ditches for the South Truckee Meadows are shown in table 2 for 1983 in terms of inflow and outflow.

TABLE 2
SURFACE WATER BALANCE FOR 1983

INFLOW	(AF)
Thomas Creek	6,400
Whites Creek	10,600
Steamboat Creek	83,400
Steamboat Ditch	5,400
Last Chance Ditch	1,500
Lake Ditch	1,900
	109,200
OUTFLOW	**(AF)**
Steamboat Creek	103,800
Alexander Ditch	16,800
	120,600

An imbalance of 11,400 AF results in outflow. This is inferred to be predominately ground water discharge to Steamboat Creek. One check on this is to look at stream flow during the non-irrigational time of December 1982. Table 3 displays stream flow amounts.

TABLE 3
STREAM FLOW DURING DECEMBER 1982

INFLOW	(AF)
Thomas Creek	330
Whites Creek	420
Steamboat Creek	6,930
	7,700

OUTFLOW	(AF)
Alexander Ditch	1,620
Steamboat Creek	7,650
	9,270

An outflow imbalance of 1,570 AF results. Then considering measurement errors, ground water discharge to Steamboat was probably 1,400 to 1,600 AF during this period. This does not consider rainfall during this period. (Note. Search the record for a dry month and without irrigation to better document the ground water discharge to Steamboat.)

Irrigation Practices

Since 1984, ditch flow has been decreased significantly by the Federal Watermaster. Consequently, irrigation application rates have been reduced and certain fields "dried up". Figure 7 shows irrigation areas as of 1984.

According to Guitjens, et. al. (1978), it is estimated that 1 acre foot per acre of flood irrigation water infiltrates to the water table. This figure varies widely because of soil conditions and application rates. For the purposes of computer modelling, the 1 AF/A figure was used. However, since 1984, the Federal Watermaster has significantly reduced ditch flows to more accurately reflect decreed rights and current needs. Also, to date, 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 is that ground water recharge from irrigation practices will probably be reduced from the 1 AF/A figure.

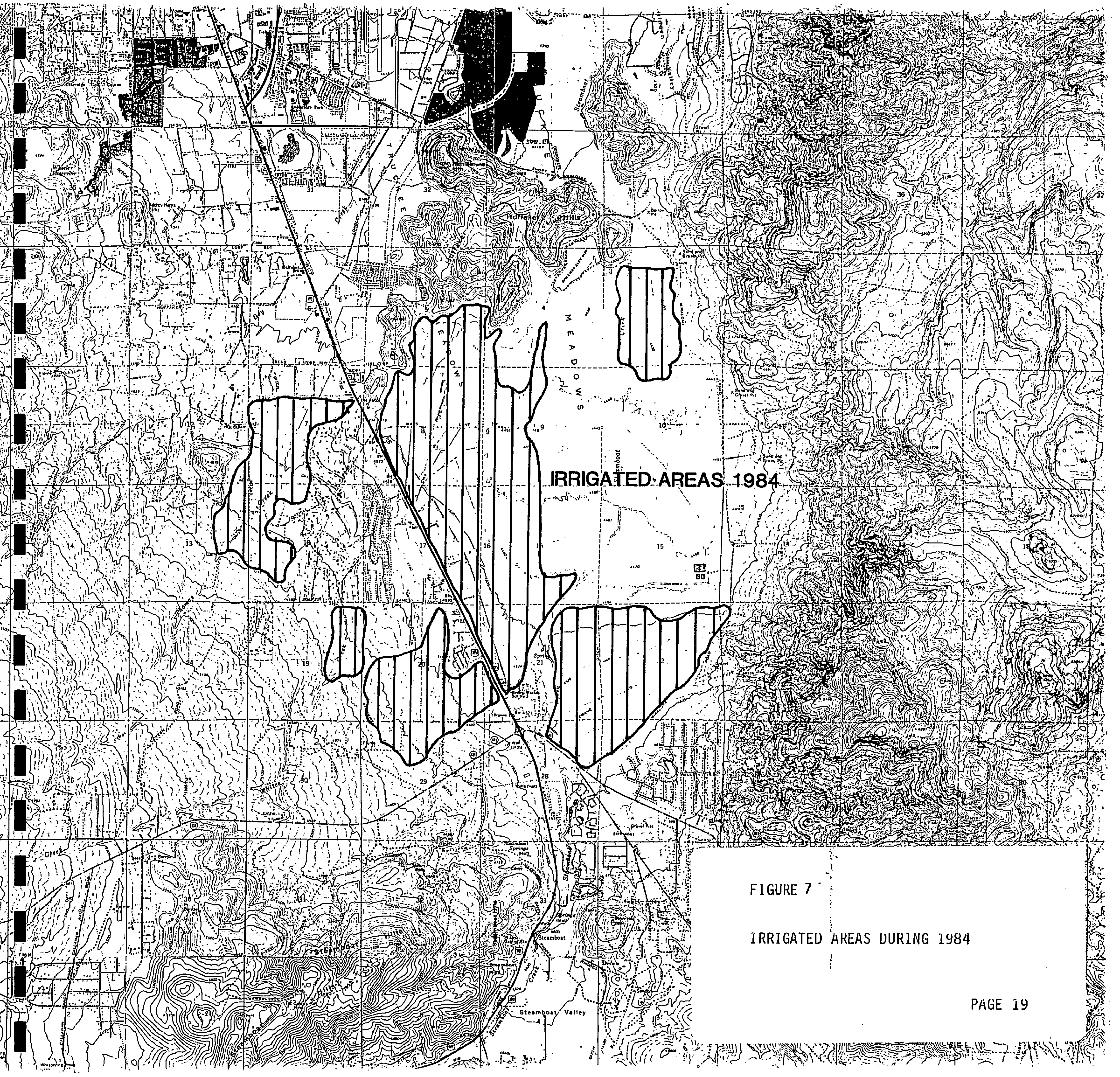


FIGURE 7

IRRIGATED AREAS DURING 1984

HYDROGEOLOGY

Occurence and Movement

As a result of a domestic well inventory and from the geophysical data, a piezometric contour map was prepared for the South Truckee Meadows (figure 8). A breif overview shows a hydraulic gradient that generally follows the topography with a recharge area in the Carson Range and a discharge area in the Meadows. An influx of ground water moves northeast from the Galena Fan area into the pediment area. Faulting causes barriers to flow in two areas, one at the Lancers Fault and the other at the Serendepity Fault. The general direction of ground water movement is west to east.

The major ground water influx to the study area occurs at the mountain front and at the Mt. Rose Highway (from the Galena Area). It is inferred that most of the ground water entering the study area occurs at the canyon mouths of Thomas and Whites Creeks. It is possible that at the mountain front ground water may be upwelling along the fractures of the faulted bedrock. This is an area for future study. Influx to the study area from the Galena Fan occurs in section 35 where the piezometric surface is depicted as a wide and flat gradient. The U.S.G.S. has estimated that the alluvial thickness in this area is on the order of 800 - 900 feet thick. They have also estimated that the influx is approximately 2700 AF/YR. This estimate may be questionable by viewing the contour map (figure 8). A flow net and streamlines may indicate a cross-sectional area too, small for this amount of flux.

As discussed earlier in the geology section there are two major local faults, north trending, that act as barriers to flow. These occur in section 30, the Lancers Fault, and in section 25, the Serendepity Fault. The Serendepity Fault has been mapped by the Nevada Bureau of Mines. Washoe County conducted a pumping test at STMGID PW 6 (NE quarter of section 26) and an impermeable barrier was inferred on the drawdown curve to further support this fault's existence. Also, the water level in this well is anomalious higher than that at a lower well, STMGID PW 5 (north quarter quarter of section 25) indicating that ground water flow is inhibited between the two wells. At the Lancer's Fault the contour map shows a steep gradient across the scarp indicating an impedence to flow.

In the SW corner of section 25, the contour map shows an equipotential line (5350 ft) that parallels Whites Creek. A possible explanation for this is that the creek recharges the ground water along a west-east fault line. This equipotential line turns perpendicular at the Serendepity Fault. Also, influx from the Galena Fan occurs in this area. More work should be done to verify the existence of this proposed fault. It seems plausible that this is an extention of faulting along the south face of Mt. Rose where fault scarps are reasonably aligned. Also, future work should consider whether or not this area could possibly be a recharge area to the Steamboat Geothermal Area. This has been proposed by Yeamans (personal communication) and others.

On the east side of the Lancers Fault a fairly flat gradient exists. Drill logs indicate thick sequences of clay and low permeability especially in section 30. As discussed in the geology section, a graben exists and extends into central sections 30 and 19 that can be traced along Whites Creek. In section 29, chemistry indicates that the ground water is predominately affected by the Steamboat Hills Geothermal System. This occurs from geothermal waters moving up the Mud Volcano Breccia Fault scarp and mixing with the "fresh" ground water. This scarp is traced in a north-south trend that generally bisects section 29. Geothermal influences can also be located in the northwest corner of section 29 by chemical analysis of water samples.

East of the Lancers Fault and northward, the local gradient flattens due to increased thicknesses of sediment. It is believed that the sediments increase from 600 feet to well over 1000 feet eastward into the meadows. The water table also approaches land surface as it nears Highway 395. East of Highway 395, a ground water discharge area develops. Ground water movement from the Steamboat Valley and the Bailey Canyon flows northward into the meadows and quantifiably is approximately 400 AF/Yr. In the meadows, ground water discharges into Steamboat Creek (Shump, 1985) and discharges as evapotranspiration.

To the north of the study area in section 7, ground water flows north into the North Truckee Meadows. The flux rate is probably about 500 Af/YR based on computer modelling. Section 14 is an area that needs more study in order to determine ground water movement. It is inferred that movement occurs from sections 13 and 14 into sections 11 and 12, however, the Truckee Formation occurs in the Dry Creek drainage which is realatively impermeable. As a result, ground water movement is limited by the cross sectional area in section 12 and the southwest quarter of section 11 that contains more permeable sediment.

On the pediment, only one hard rock well exists, in section 30 (STMGID PW 4), so that very little can be said about ground water movement in the Kate Peak Formation that is inferred to underlie the sediments. The scope of this study is limited to the alluvial aquifers.

Ground Water Recharge

Two methods of estimating ground water recharge to the pediment are the Maxey-Eakin method and the Arteaga-Durbin method. Both attempt to quantify water yield that results from precipitation based on elevation. Water yield is described as both surface and ground water. The Maxey-Eakin method was developed in the late 1940's for the State Engineer in order to estimate ground water recharge in east central Nevada. Annual precipitation is segmented into zones based on elevation and a percentage of this precipitation is considered water yield. The Arteage-Durbin method relates stream flow to precipitation and indirectly determines ground water by difference. As in the Maxey-Eakin method, percentages of precipitation at specified elevations are estimated as water yield. By measuring stream flow, ground water recharge is determined by difference.

Using the Maxey-Eakin method, precipitation is segmented in zones of 0-8 inches, 8-12 inches, 12-15 inches, 15-20 inches and greater that 20 inches. Ground water recharge is estimated at 0 percent, 3 percent, 7 percent, 15 percent and 25 percent respectively. Applying this method to the Carson Range gives a water yield estimate of 10,250 AF/YR.

Precipitation was estimated from Kleiforth (1983). Using 8,800 AF/YR of surface water runoff (Thomas and Whites) will approximate recharge at 1,450 AF/YR by difference. Using the Arteaga-Durbin method, an estimate of 18,000 AF/YR of water yield results. Subtracting 8,800 AF/YR of surface water will approximate 9,200 AF/YR.

If ground water recharge to the pediment occurs mostly at the canyon mouths of Thomas and Whites, a cross sectional area of the canyon can be determined and recharge estimated. Several estimates of these areas were made. An effective porosity of 10 % and a darcian velocity of 0.002 ft/s gave estimates of 2200 AF/YR for Whites Canyon and 1300 AF/YR for Thomas Canyon for ground water recharge to the alluvial portion of the pediment.

Ground water movement into the study area also occurs from the Galena Fan area. The U.S.G.S. Open File Report 84-433 determined that 2700 AF/YR flows into the study area based on a numerical model. The report estimated this flux based on a conductivity of 2 ft/day. A pumping test on the Windburn Well (SW of section 34) yielded a conductivity of 1.3 ft/day. Based on this latter conductivity 1700 AF/YR is derived. A flow net would shed some light on ground water movement in this area.

Ground Water Discharge

The ground water discharge area in the South Truckee Meadows occurs in sections 3, 4, 9, 10, 15 and 16 where the water table is at land surface and where several flowing wells are located. (Note: Vertical gradients should be determined for the discharge area.) 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. Figure 9 shows the approximate area. Using aerial photography it is estimated that phreatophytes grow on 1,900 acres, 550 acres can be mapped as sage and salt evaporative areas, irrigated pasture occupies 1,950 acres and 500 acres contain irrigated alflafa.

Figure 10 is a schematic of a water balance for the discharge area. Irrigated land application rates have historically been 4.0 to 4.5 feet per acre on both alfalfa and pasture. Evapotranspiration from croplands is estimated at 3.7 feet (Guitjens, et al., 1979). Phreatophyte evapotranspiration as well as free standing water and salt evaporative areas are estimated at 4.8 feet (reference). Ground water discharge to Steamboat Creek is estimated at 12500 AF/YR (Shump, 1985). Based on these estimates a very loose estimate of 33,000 AF/YR of ground water discharge can then be derived.

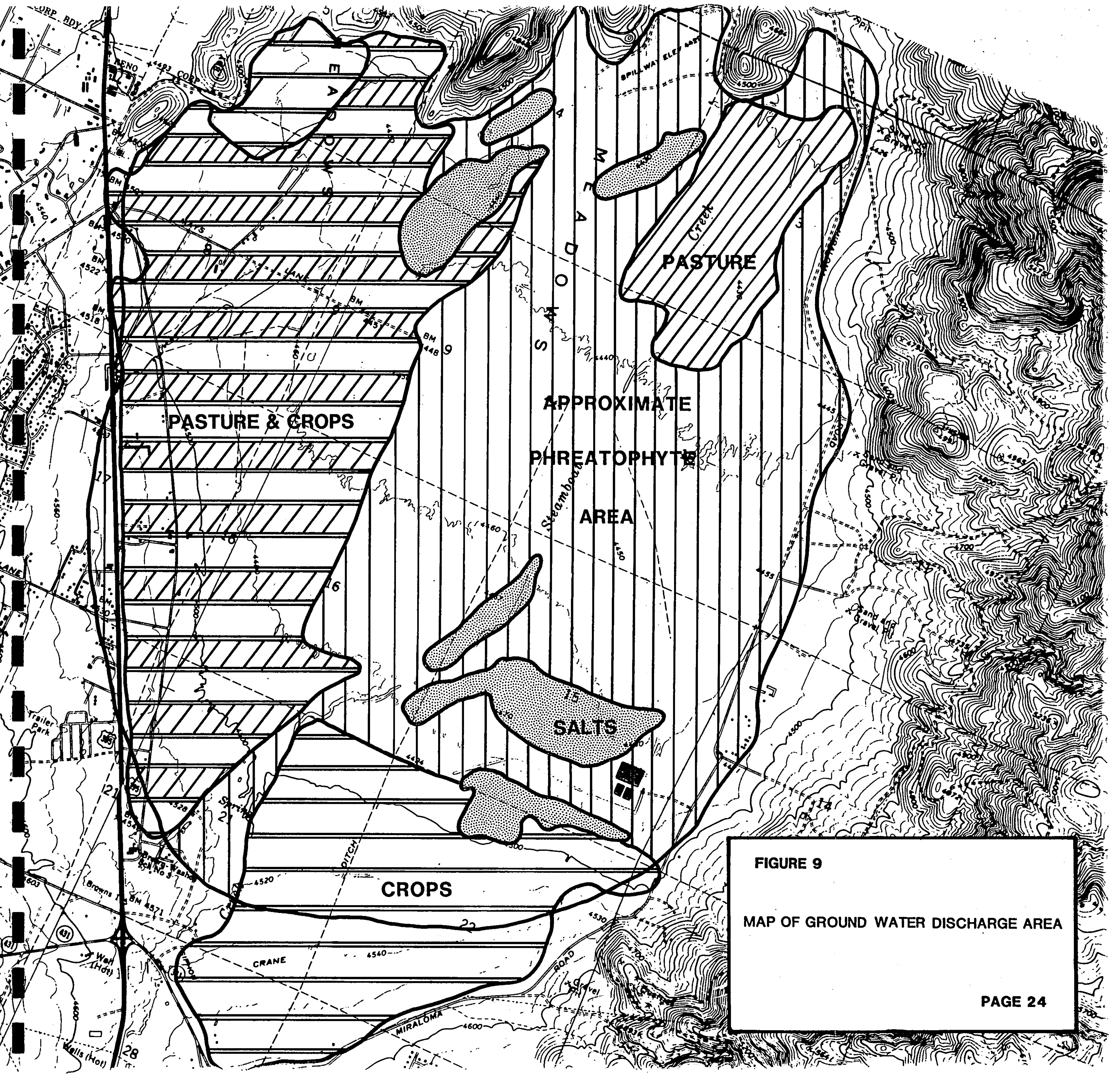


FIGURE 9

MAP OF GROUND WATER DISCHARGE AREA

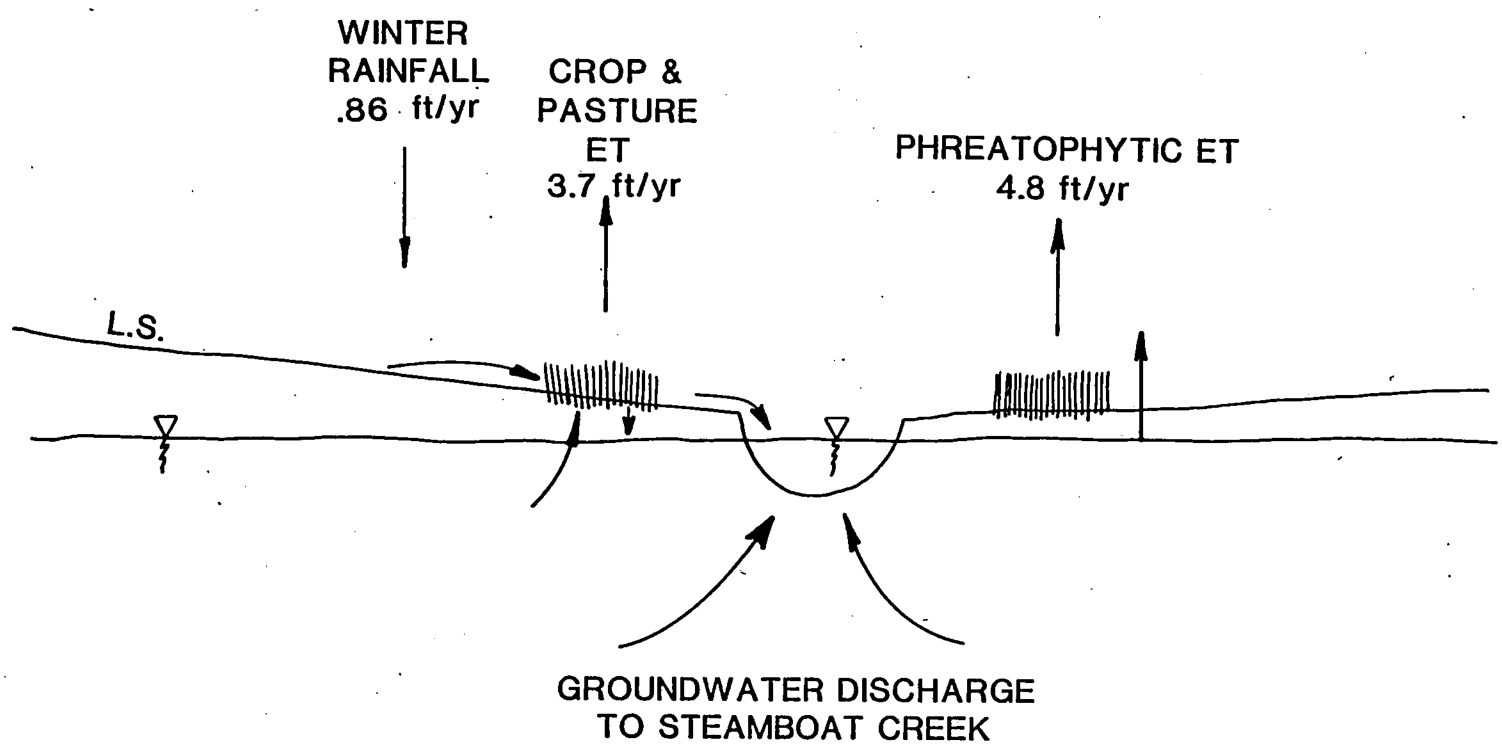


FIGURE 10 WATER BALANCE SCHEMATIC FOR DISCHARGE AREA

TABLE 4
SOUTH TRUCKEE MEADOWS WATER BALANCE

Recharge Peripherial to Valley Floor	
Mountain Front recharge	4700 AF
Galena Fan inflow	2700 AF
Thomas & Whites creek infiltration	500 AF
septic tank recharge @ 0.2 AF/dwelling	430 AF
irrigation recharge @ 1.0 AF/A @ 950 acres	950 AF
recharge from Virginia Range	350 AF
inflow from Stmbt Valley	400 AF
Sub Total	10030 AF
Recharge to Valley Floor	
crop & pasture irrig. @ 4.5 AF @2950 Ac	13300 AF
precip on valley floor @.85 Ft @6300 Ac	5500 AF
Sub Total	18800 AF
Total	28830 AF
Discharge	
ET from irrig. @3.7F/A @ 2955 Ac	10900 AF
ET from phreatophytes @4.8 F @2050 Ac	9850 AF
discharge to Steamboat Creek	12500 AF
pumpage	1000 AF
Total	34250 AF
Percent Difference	16 %

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 was based on measurements of spring discharge and influx to Steamboat Creek. What he was unable to address was the influx of geothermal water along faults, at depth, north and east of the springs area proper. 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.

South Truckee Meadows Water Balance

Table 4 is a water balance for the South Truckee Meadows. A water balance is an accounting process that attempts to quantify all ground and surface water as ground water recharge and discharge. The process is based on the best available information about the various processes. In this study the water balance is used as a starting input for the numerical modelling effort. An important point to be considered of this particular area is that irrigation practices are occuring in the area of ground water discharge. This tends to complicate the description of the discharge area. Consequently, the water balance includes water application to the valley floor that should not necessarily be considered ground water recharge in the classic sense.

Recharge to the valley floor from the periphery considers the area west of US 395, the Virginia Range and the ground water inflow from the Steamboat Valley area. Recharge from the Mountain Front (average from three methods used) and from the Galena Fan have already been discussed. Previous studies indicate that Thomas and Whites creeks leak some surface water. Measurements show that this rate is probably 0.5 - 1.0 cfs per creek on the pediment. Septic tank infiltration does occur by its very design and has been estimated at 0.2 AF per dwelling at 2150 dwellings (reference). Recharge from irrigation up gradient from the discharge area is estimated at 1.0 AF per acre. This is determined from difference as with an application rate of 4.5 AF/A and a crop usage rate of 3.5 AF/A (Guitjens, etal, 1979). Recharge from the Virginia Range is estimated from the Maxey-Eakin method. Inflow from Steamboat Valley is based on flow through a cross sectional area. Total ground water recharge to the periphery of the discharge area is approximately 10030 AF.

Recharge on the Valley Floor is considered as the total irrigation rate and all precipitation. Precipitation is not considered elsewhere as previous studies (Koltermann, 198x) indicate that precipitation is quickly evaporated or helps to satisfy soil moisture conditions. The total estimated application of water on the discharge area is 18800 AF.

In determining the approximate amount of ground water discharge, evapotranspiration is considered for the irrigated areas and the area predominated by phreatophytes, bare soil (salt deposition through evaporation of ground water), and standing water (Alexander Lake and the CDB ponds). These rates of ET are 3.7 AF/A for the irrigated areas and 4.8 AF/A for the other discharge areas. These rates are based on studies by Guitjens, et al. Ground water pumpage is based on domestic wells and municipal water systems in the South Trucke Meadows. Discharge to Steamboat Creek is based on various studies and more specifically, on Shump's work.

The balance indicates, based on these various estimates, that ground water discharge is nearly 34,000 AF annually. Of that, half is attributable to man's irrigation practices (14,250 AF) and septic tank effluent (430 AF). Accordingly, without man's influence the natural discharge is closer to 12,000 AF annually. The water balance method of determining recharge and discharge should only be considered as a rough estimate. It more specifically, identifies orders of magnitude of the various contributors of recharge and discharge. To refine these numbers, numerical modelling is appropriate.

WATER CHEMISTRY

Ground water

Many of Nevada's water supplies are often influenced by geothermal activity. The South Truckee Meadows is no exception. Indeed, one of the world's oldest geothermal systems is the Steamboat Springs System (White, 1964). In order to delineate such influence, all available water quality analysis were collected in the study area (1984). Most information was made available through the Nevada State Department of Human Resources. Additional analysis were collected from other sources. The analysis were plotted on a base map in terms of milli-equivalents (meq) of anions. An interpretation could then be made with respect to the geochemistry of the study area. Also, since geothermal waters often flow along fracture planes, surficial expressions of faults were also plotted.

Plate 6 is a water chemistry map for the study area. The numbers plotted are anion milli-equivalents (meq). Throughout most of the study area the water is of excellent quality with a total disolved solids (TDS) range of 150 - 220 ppm. The TDS increases near U.S. 395 and in the vicinity of Steamboat Springs. Bicarbonate in the dominant ion, whereas calcium, magnesium and sodium are the dominant cations. Ions that exceed drinking water standards are arsenic, chlorine and sodium and these appear to be related to the geothermal system. Iron is also occasionally anomalous, yet it is sometimes difficult to discern whether its origin is from geology or from well casings.

The water quality in the southwest study area is excellent (sections 26, 34, 35, 36). Anions average 2.46 meq (TDS = 170 ppm) with bicarbonate the major anion. Some wells have anomalous iron concentrations (0.53 - 0.89 ppm). If the iron anomalies were derived from the ground water and not from the well casings, a possible source may be from ground water movement from hard rock fractures (andesite) into the alluvium that contain more dissolved iron or dissolution of iron rich biotite. However, deeper wells in the area do not indicate any correlation. Excellent water quality is also found in the center of the pediment (sections 24 and 19). Bicarbonate dominates with low TDS values (140 - 180 ppm). Anion values average 3.5 meq. It is interesting to note that a trend of very low anion values exist from the center of section 19, across Zolezzi Lane, into the Westridge area. This may be influenced by recharge from Whites Creek into the inferred graben as discussed in the geology section.

In the north sections of the study area the quality is also excellent. Anion values average 3.5 meq with TDS levels of 230 ppm. Five wells in the west of section 12 have anion values from 4.71 to 5.46 meq whereas values of 2.4 meq are common down gradient (west to east). The higher vlaues reflect increased levels of SO_4, NO_3, and HCO_3. Well depths vary from 160 - 350 feet so that depth may not have a correlation. Again, a cause could be from fracture flow ground water or influenced from the Truckee Formation especially with respect to SO_4. Water quality in the Foothill Road area is also quite good and not influenced from geothermal sources. The average anion value is 2.8 meq. Only two anomalous values of iron were located at the south end of Foothill Road (1.68 and 0.26 ppm).

A primary reason for looking at water chemistry in this study is to discover the occurence of geothermal influences. Geothermal waters at Steamboat Springs are anomalous in the anions chloride (1000-2000 ppm), sodium (500-800 ppm), sulfate (50-100 ppm), potassium (20-70 ppm) and silica (100-300 ppm). TDS values are 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).

An area of geothermal interest is in section 29 at the MacKay residence. There a geothermal well has an anion value of 30 and a depth of 300 feet. This well is located in the Mud Volcano Breccia Fault (see geologic discussion). The northward trend of this fault surficially ends at the sites of two other wells with anion values of 35.23 and 20.53 meq. It is believed that these wells are drilled in or nearly into the fault plane and produce almost entirely geothermal waters.

Figure 11 shows an idealized cross section of the geothermal waters that flow along a fault plane, vertically, to the horizontal break in the bedrock. Thick sequences (300-1000 feet) of alluvium overlay the bedrock. Upgradient of the fault is the phreatic system with relatively cold "fresh" ground water that eventually mixes with the geothermal waters downgradient from the fault plane. The figure also illustrates the water quality that wells can expect to encounter depending on their location and depth relative to the fault plane. At the north end of the Mud Volcano Breccia Fault, the depth of the well will determine the concentration of geothermal water captured. The Flame well has an anion value of about 20 meq. with a depth of 90 feet. The Peigh well has a depth of 440 feet and an anion value of 35 meq.

This situation also occurs in the northwest corner of section 29. The Wood's well is located west of a fault trace and has an anion vlaue of 1.58 meq at a well depth of 82 feet. It is assumed that this water is the "fresh" water although dilution probably occurs from Steamboat Ditch, Whites Creek and irrigation practices. In the vicinity of the fault, well depth again determines the production quality. Three wells have depths of 85, 110 and 190 feet with anion values of 2.73, 13.21 and 31.88 meq, respectively.

A third, less defined occurrence is in the Valley Springs Road area (section 20). A fault trace is inferred east of Valley Springs Road that could be common with the "Peigh" fault. A domestic geothermal well, used for space heating, exists in the area with a depth of 300 feet, but the water quality is not known. Three wells in this area have anion values approaching 4 meq and this trend seems to trend northward. Anion values west of the fault trace are about 1.8 meq and east are about 2.6 meq.

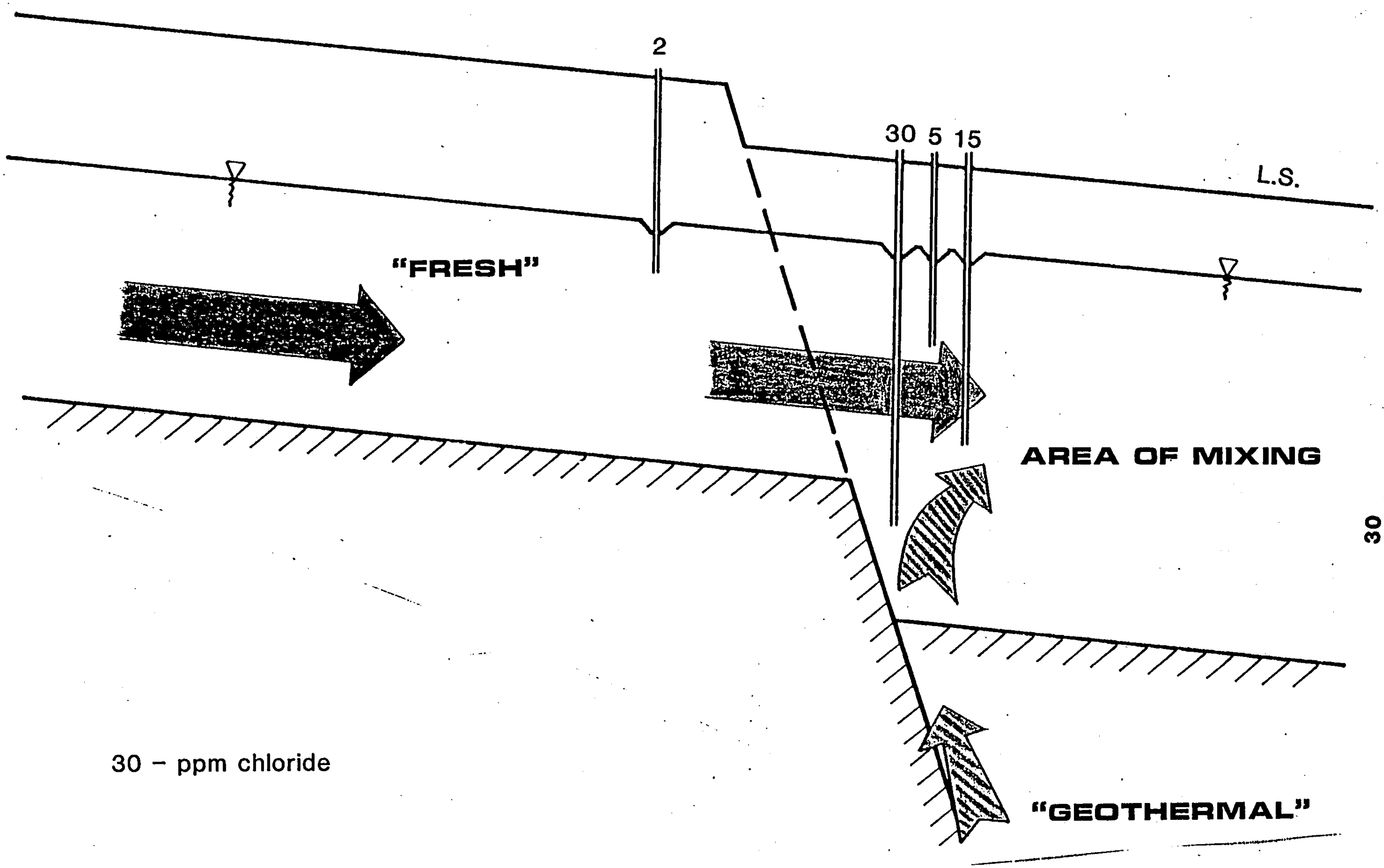


FIGURE 11 IDEALIZED SCHEMATIC OF GEOTHERMAL MOVEMENT ALONG FAULT SCARP

Geothermal occurrences in section 21 are not well defined as various anion concentrations are found regardless of well depth. For example, on Sutherland Road, neighboring wells with depths of 46 to 50 feet have anion values of 11.2 and 3.2 meq, respectivlely. This area probably reflects a mixing zone and is not well understood.

A final note is that the heavier, ion-rich, geothermal waters may be capped by less dense "fresh" ground waters from the local regional gradient keeping the geothermal waters relatively deep. However, convection from geothermal heat probably allows some mixing to occur rather than just plain contact between the two waters. Large pumpage of the "fresh" water will allow the geothermal waters to rise because of the change in head. This may be a potential problem if housing development occurs on the Double Diamond and Damonte Ranches. In these areas, ground water levels would have to be lowered for housing construction to be stable thereby allowing geothermal waters to rise.

Water quality in the Virginia Range foothill area is influenced primarily by hydrothermal alteration of the mountain block. Ground waters migrating through these rocks will dissolve mineral constituents thereby increasing it's TDS. The hydrothermal alteration is associated with the "Comstock Lode" in and near Virginia City. Anion values in the Geiger Grade and Toll Road area range from 5 to 85 meq. This chemistry differs from the Steamboat Springs geothermal waters in that the geothermal waters are mostly sodium-chloride whereas the "hydrothermally altered" waters are mostly calcium-sulfate.

In the meadows area the anion values range from 1.3 to 12.09 meq and probably reflect well depths and proximity to geothermal discharge areas (see Bateman and Scheibach, 1975). All chemistry for plate 6 is included in appendix C.

Figure 12 shows stiff diagrams for the study area. Please note the legend for a description of the diagram. The figure generally shows the same chemistry for the pediment. Changes occur in the Steamboat Springs area where sodium and chloride dominate. In the Virginia Foothills area the chemistry is displayed with sulfate dominating. Finally, in the meadows area the waters are shown to be predominately sodium-bicarbonate.

Surface Waters

Figure 13 shows the stream flow and ditch system for the South Truckee Meadows including sampling sites for chemistry. In 1982 and 1983, a surface water sampling program was implemented. The results are included in appendix C. A sampling program for most of these sites has been continued since 1987 by the Nevada Department of Environmental Protection. Water quality from the Carson Range (Browns, Galena, Whites and Thomas) is of excellent quality with a range of TDS of 50 to 100 ppm.

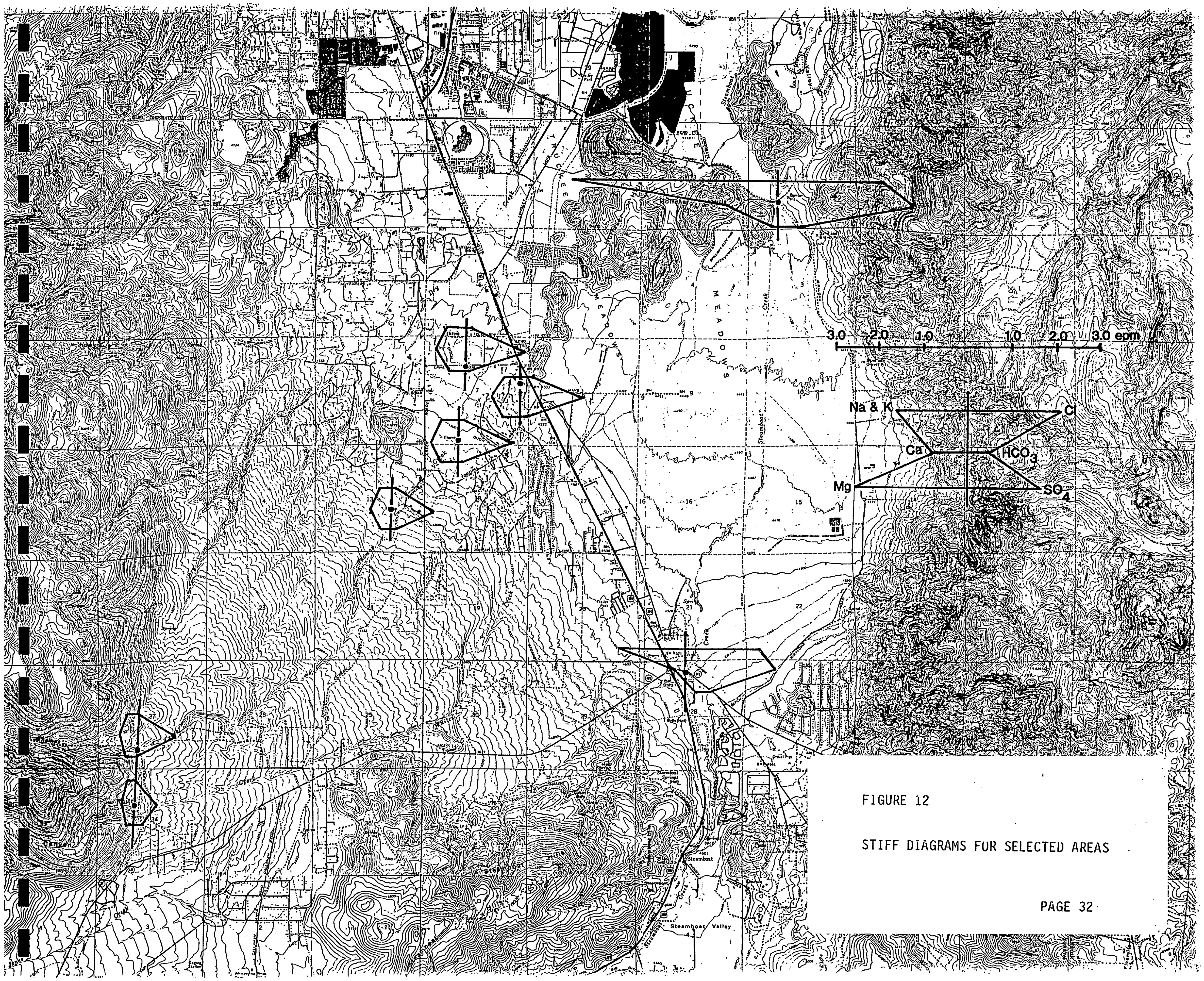


FIGURE 12

STIFF DIAGRAMS FOR SELECTED AREAS

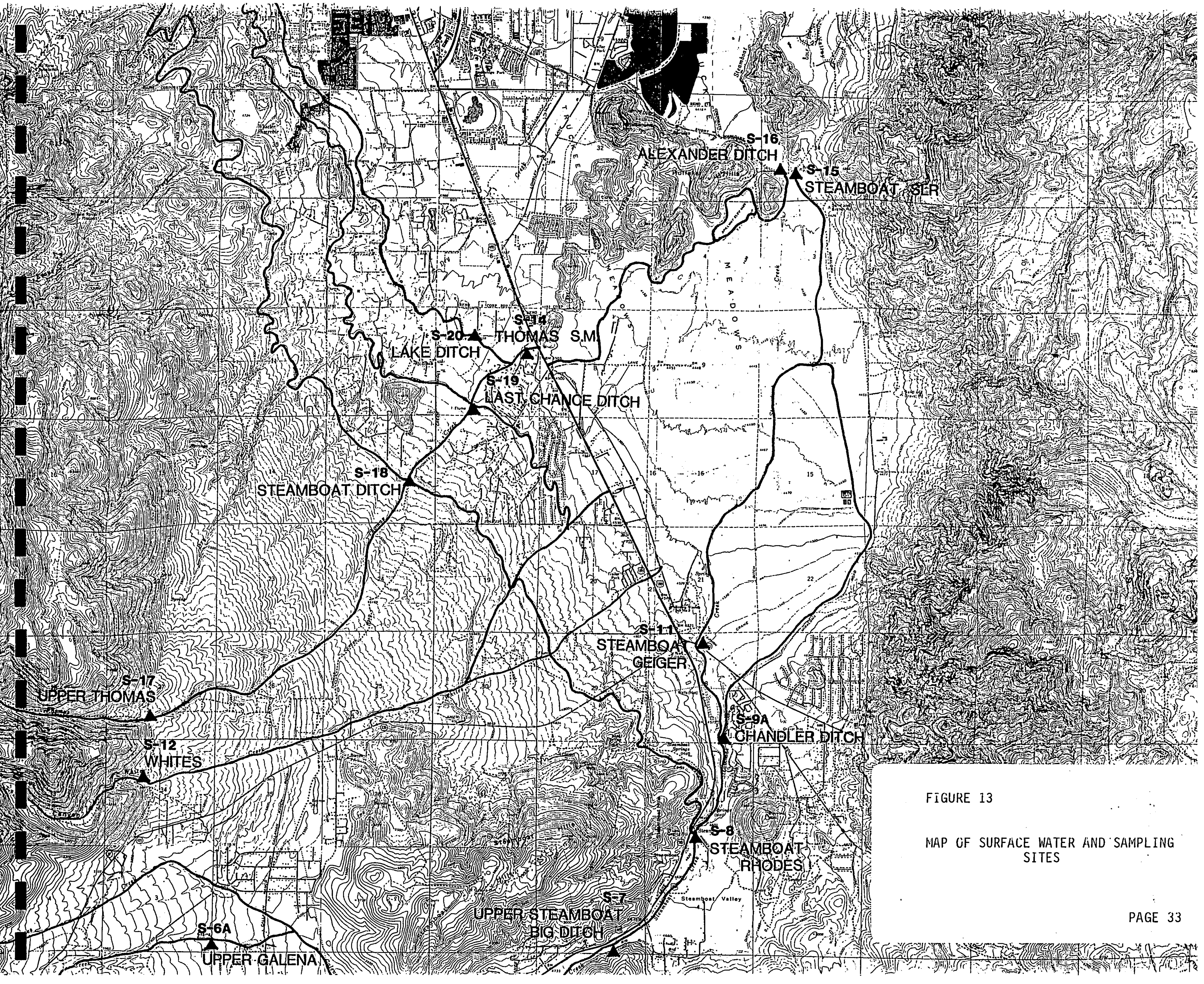


FIGURE 13

MAP OF SURFACE WATER AND SAMPLING SITES

These waters are predominately calcium-bicarbonate. The ditch waters originate from the Truckee River and have TDS values that range from 50 to 100 ppm and are also calcium-bicarbonate waters. The Steamboat Creek and ditches originate from Washoe Lake with influence from Browns and Galena creeks before entering the study area. These waters are calcium/sodium -bicarbonate 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 as the geothermal volume is low, but constituents such as arsenic and boron increase significantly. The waters become sodium-bicarbonate with TDS values that increase about 10 %. This occurs in the area from Rhodes Road to Geiger Grade.

In the meadows area, Whites and Thomas creeks eventually confluence with Steamboat. Irrigational practices influence this as to how much and where this occurs, but generally this occurs at the narrows at the Huffaker Hills. As discussed, the meadows is a ground water discharge area. This occurs for both the geothermal waters (Bateman and Scheibach, 1975) and the "fresh" waters. Consequently, this discharge also contributes to Steamboat Creek as documented by Shump (1984). An increase in flow of about 2 - 3 cfs is common. The water quality then, should increase in dissolved solids. The quality of Steamboat at the narrows ranges from 200 ppm in the winter months to 500 ppm in the summer of total dissolved solids. The quality of Alexander Ditch at the narrows (just before flowing into Steamboat) also ranges from 200 - 500 ppm.

Figure 14 displays stiff diagrams for the surface waters. The chemistry for the Carson creeks and the Truckee ditches are virtually the same. Steamboat Creek changes from calcium-bicarbonate at Rhodes Road to a sodium-chloride/bicarbonate at Geiger Grade.

GEOPHYSICAL SURVEY

Electrical Resistivity

An electrical resistivity survey was conducted in 1983 on the pediment. The purpose was to determine the depth to the water table surface and if possible the depth to bedrock. This was especially important in areas of the pediment where little, if any, information was available. Figure 15 is a map showing the locations of the vertical electrical resistivity profile sites.

The principal theory for electrical resistivity is derived from Ohm's Law as the resistance of a material (wire, rocks,etc.) to an induced current. More specifically, a current is introduced into the ground, an electric field is generated and the potential difference across the resistance is measured. In other words, the resistance between the current electrode and the potential electrode is calculated by measuring the potential difference. The equation used to solve for resistance is:

$$P=\frac{AV}{LI} \qquad (1)$$

where P is resistivity, A is the cross sectional area, I is the current, L is the length and V is the potential difference (Zhody, et al, 1980). The units of resistance are ohm-meters. The resistance of saturated alluvium is less than that of unsaturated alluvium as current is conducted electrolytically by interstitial water in pores. Resistance to current is further reduced by an increase in salinity of the interstitial water. Clays are also conductive (conductance is the inverse of resistance) because of the dipole alignment of individual clay particles. The overall purpose of electrical resistivity soundings is to determine the depth to the ground water table. Additional information sought after are lithological differences, water quality differences (salt water - fresh water interaction) and porosity.

The equipment used was a "Soiltest R-60 D.C. Earth Resitivity Meter", a transit for surveying each sounding site and radios which enabled the field crew to communicate easily. The current electrodes, copper stakes approximately 30 inches long, are driven partially into the ground at predetermined spaces and connected to an electrical cable attached to the power supply. The potential electrodes are porous ceramic pots saturated with a copper-sulfate ($CuSO_4$) solution, mostly buried in the soil and connected to an ampremeter by electrical cable. The Schlumberger configuration for electrode placement was used.

When power is induced into the current electrodes and hence into the ground, a reading of that current is given at the voltmeter. The potential drop is measured at the potential electrodes and depicted with the ampremeter. A field resistivity is quickly calculated. The resistance is calculated from the equation

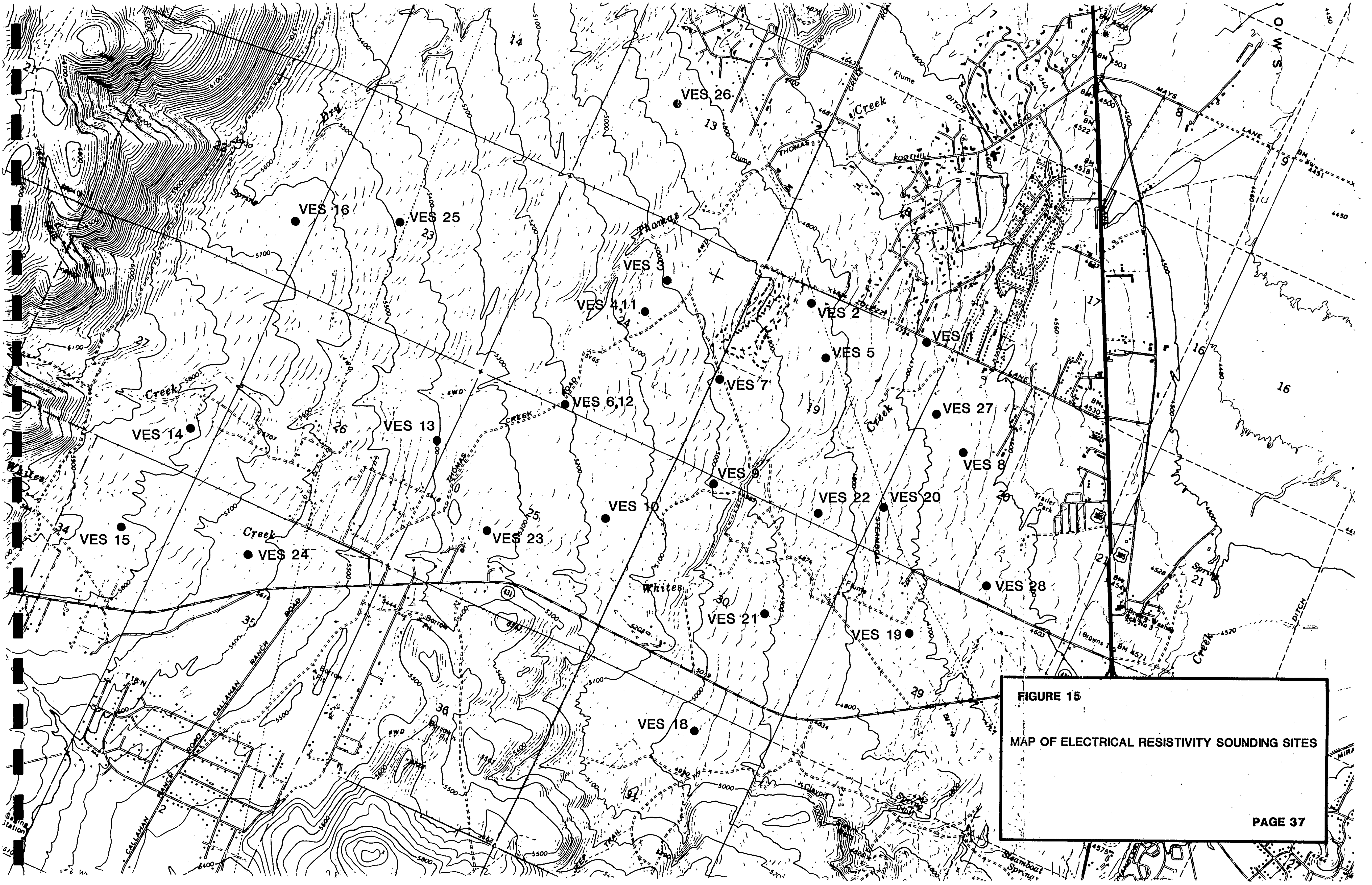


FIGURE 15

MAP OF ELECTRICAL RESISTIVITY SOUNDING SITES

$$\rho = \frac{\frac{AB^2}{2} - \frac{MN^2}{2}}{MN} \frac{AV}{I} \qquad (2)$$

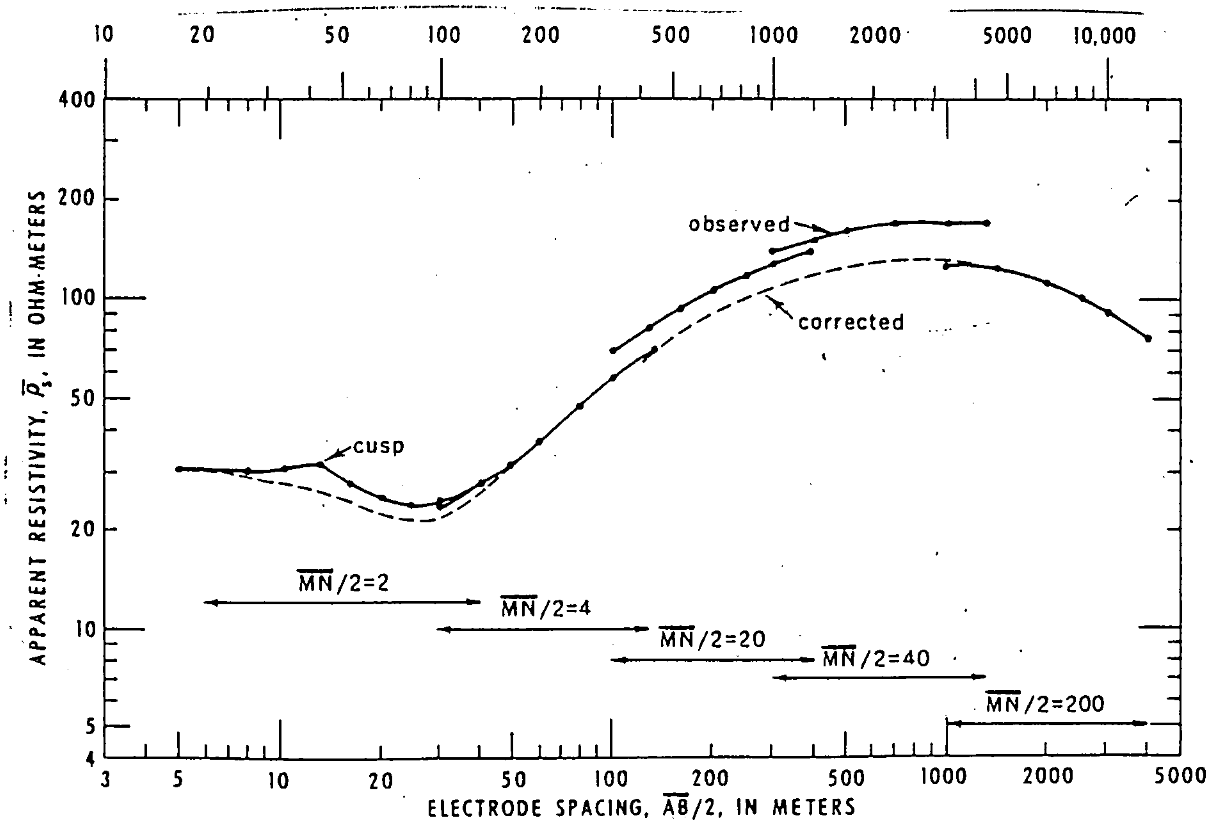
where AB and MN are electrode spacings measured in feet. ρ is apparent field resistivity as opposed to a true resistivity measured under ideal conditions. Readings are made at various predetermined electrode spacings.

For this survey a typical sounding entailed a resistance measurement at current electrode spacings beginning at 4.64 meters and increasing logrithmatically to 305.00 meters. The field resistivity is then plotted against the current electrode spacing divided by two as illustrated in figure 16. The resulting curve was interpreted visually and mathematically. In most cases, a large drop in the resistance indicated saturated alluvium. The results of each sounding were reduced by Zhody's Convolution Method which is really a computerized curve matching technique. The results give an approximation of layers with resistivities and thicknesses. An interpretation as to the phreatic surface and other anomalies are then made. Of secondary importance was to try to determine the thickness of alluvium on the pediment. This was met with poor success as the power source was not strong enough to "look" below approximately 500 feet.

An example is shown in figure 17 of the field curve generated. Initially, resistance to current increases with depth. The middle sequence of the sounding maintains a resistance at approximately 200 ohm-meters. The resistance drops off quickly, usually indicating saturation of the lithology or a different and more conductive lithology. Zhody's method characterizes the data into sequences of resistivity as shown in figure 18. An average resistance of 83 ohm-meters, thirteen feet thick; 277 ohm-meters, 102 feet thick and so on. Then the phreatic surface is inferred at 115 feet as the average resistance drops from 277 to 106 ohm-meters. This conclusion is common with other resistivity studies on alluvium in the Southwestern United States (personal communication with Clyde Ringstad, Geo Recon International, Ltd.). This figure also indicates that at 318 feet an anomalously conductive lithology is encountered which is most likely a relatively thick sequence of clay.

Results and Discussion

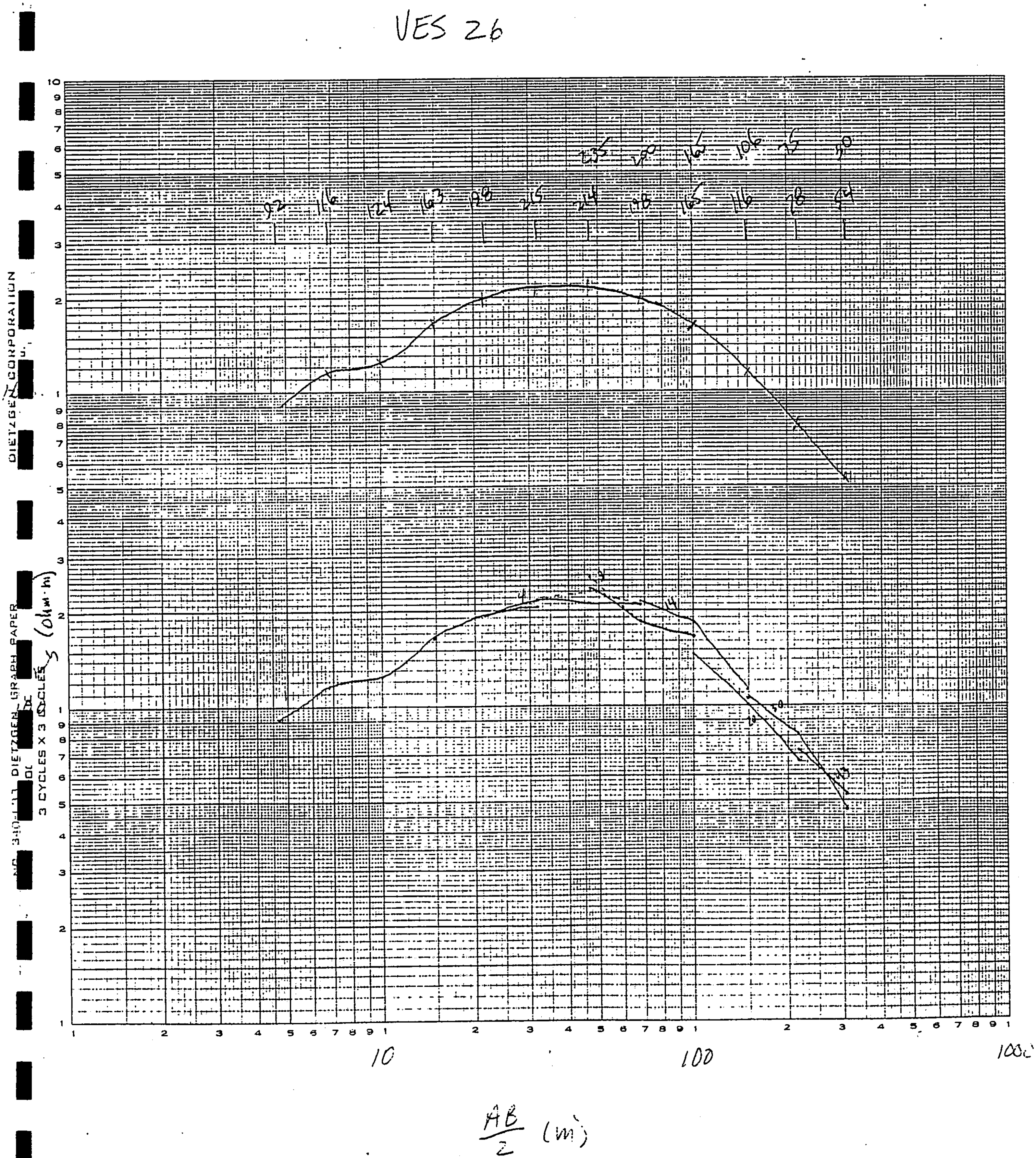
Table 5 displays the results of the survey. The table indicates each sounding's inferred depth to water (ft), saturated resistance (ohm-m), average unsaturated resistance (ohm-m) and a subjective rating on each results reliability. It was felt that 64% of the soundings were good, 15% fair and 21% poor. Sites 1 and 3 were located in areas where the phreatic surface was known for calibration purposes. The results at these two sites are good, especially at site 1 where the predicted water level is within 1 foot. Site 3 was within 8 % of the known depth. Some sites rendered poor



Example of a distorted HK-Schlumberger curve and the method of correction.

FIGURE 16 ILLUSTRATION OF FIELD PLOTTING TECHNIQUE

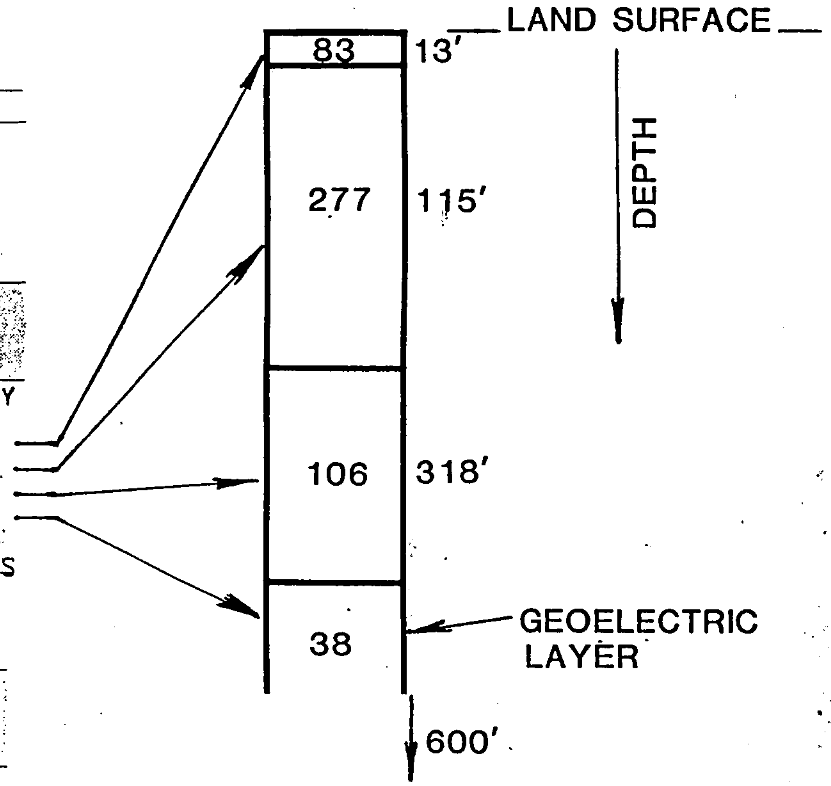
FIGURE 17 ILLUSTRATION OF RESISTIVITY DATA FIELD POINTS



REDUCED DZ DEPTH	REDUCED DZ RESISTIVITY
3.98862	82.69187
37.79282	236.10114
107.38975	144.28099
99999999.00000	37.75750

D THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.98862	3.98862	82.69187
31.00026	34.98888	277.19453
61.96170	96.95058	106.05535
99779.76641	99999876.71700	37.75742

AB/2	CALC. VES	OBSERVED VES
.45400	83.00059	82.74545
.68106	83.12283	82.88183
.99966	83.27068	83.10429
1.46730	83.65620	83.53170
2.15370	84.69701	84.55043
3.16120	87.51281	87.43502
4.64000	94.88488	94.66774
6.81000	110.15599	108.34391
10.00000	133.71958	128.95809
14.70000	161.89838	155.64779
21.50000	188.68324	184.07278
31.60000	208.65450	206.84759
46.40000	213.53455	214.07946
68.10000	196.56330	200.03476
100.00000	159.69649	165.71926
147.00000	114.99248	120.39087
215.00000	77.33428	79.54813
305.00000	55.18245	54.55064



VES #26

FIGURE 18 RESISTIVITY MODELLING PRINTOUT RESULTS

results due to operator errors, geologic faults or man-made objects shorting out the current. See the appendix E for field data and results of the computer runs.

TABLE 5
ELECTRICAL RESISTIVITY RESULTS

VES	DEPTH H2O FT	KNOWN DEPTH FT	SAT. RESIST. (OHM-M)	AVG. UNSAT. (OHM-M)	RESULTS
1	96 ft	95 ft	90	164	good
2	94	170	164	358	poor
3	200	185	130	245	good
4					no reliable results
5	132	165 ?	106	217	fair to good
6					no reliable results
7	122	200 ?	147	200	fair to poor
8	76	80	105	221	good
9	217	220	140	274	good
10	150	170	106	268	good
11	136	210	129	311	poor
12	216	280	85	203	fair
13	109	100	100	220	good
14	100	130	156	275	good to fair
15	254	260 ?	91	330	good
16	152	150 ?	52	273	good
17					no reliable results
18					no reliable results
19	53	55	79	123	good
20	120	180	96	150	fair
21	282	290	31	281	good
22	137	210 ?	119	210	poor
23	190	180	152	226	good to fair
24	210	200 ?	46	304	good
25	215	UNK	32	137	good
26	115	85 ?	106	270	good
27	106	110	170	220	good
28	70	70	72	147	good

NUMERICAL MODELLLING

Methodology

This study entailed considerable field work and the collection of data to better delineate the hydrogeology of the pediment and basin. The work included a well survey, a geophysical survey, compiling chemical analysis, surface water monitoring, and a compilation of previous work in geology as well as hydrogeology. With this data base a water balance was completed in order to better conceptualize and quantify the hydrogeologic processes as a whole. To test and improve the conceptual model, a numerical model was completed. The water balance attempts to preserve the laws of conservation of mass whereas the numerical model also applies the laws of physics in order to equibrilate the water balance and to attempt to match results with what we observe in the field.

The model used for this study was the USGS 2D Finite Difference Model for Aquifer Simulation developed by Trescott, Pinder and Larsen and published in 1975. The strongly implicit procedure for solving the flow equation was used in this study.

Figure 19 is the layout used for this modelling study. The 14 x 20 node grid is oriented in the direction of expected ground water movement; southwest to northeast. Of the 280 nodes, 154 are active. Each node was assigned an estimated bedrock elevation and a land surface elevation. These elevations are indicated in Figure 20. Injection wells (13) that simulate natural ground water recharge are shown in figure 21 with an estimated annual flux based on previous work (see hydrogeology section). Ground water discharge to Steamboat Creek is simulated as leakage. Figure 22 shows the estimated vertical hydraulic conductivity used for the streambed. This number reflects the streambed area averaged over the entire node with a five feet thickness.

The input parameters hydraulic conductivity and storativity were based primarily on estimation. Pumping tests run on water wells helped to determine the range of expected values and occurence. Calibration procedures and sensitivity analysis was used to better estimate the values. Figure 23 is a display of the hydraulic conductivity value assigned to each node. Figure 24 is a display of the storativity value assigned to each node. Ground water recharge due to irrigation (1 AF/A) is for the applicable nodes as displayed in Figure 25. This is based on averages and is discussed more thoroughly in the section on ground water discharge.

An evapotranspiration rate of 4.8 AF/A was used based on Guitjens, et al, work. For this model an effective level of 5 feet below land surface was used, meaning that when the water table drops below 5 feet, no evapotranspiration occurs. It is being assumed that on the area where the water table is deeper than 5 feet, rainfall and irrigation satisfies the

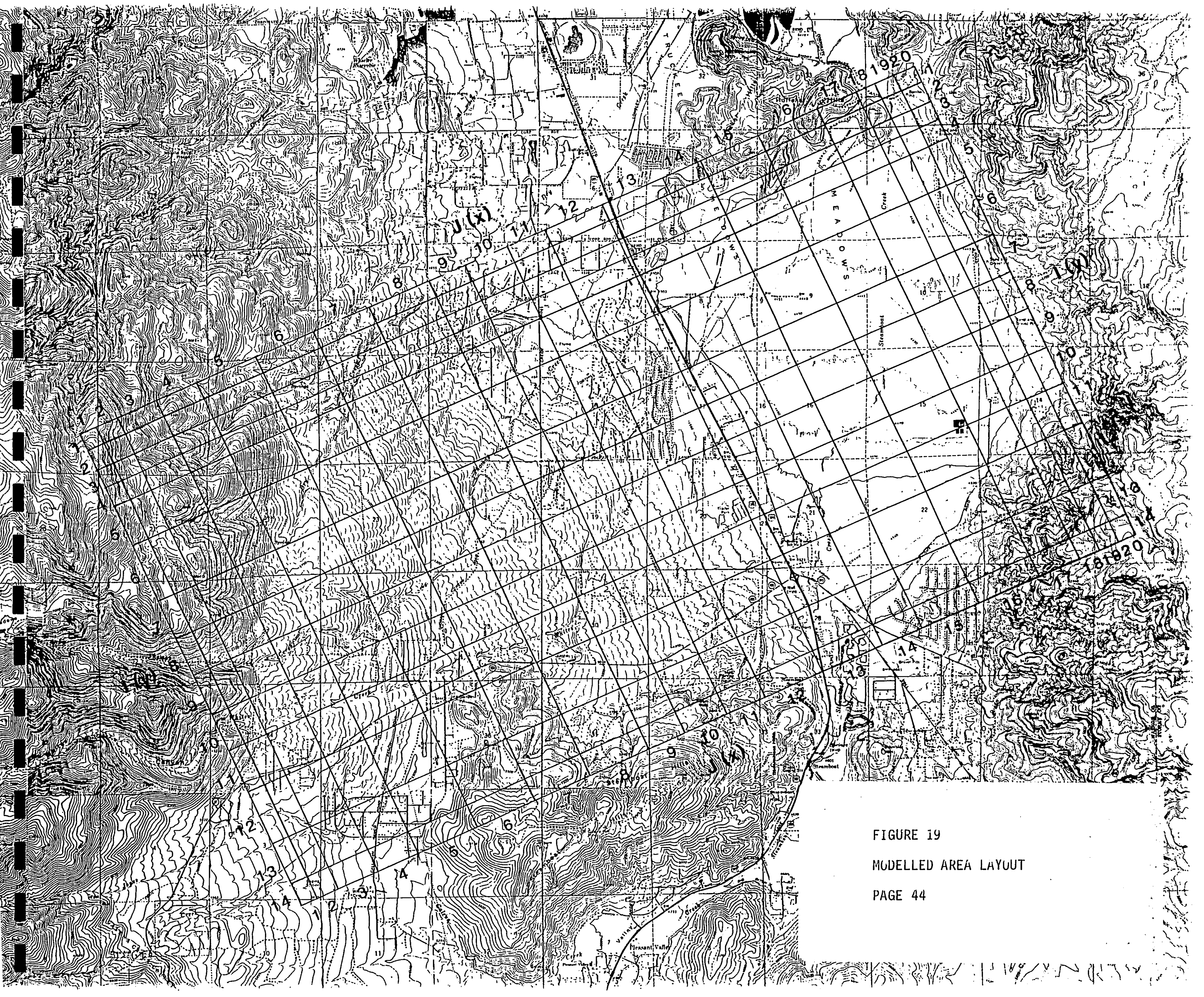


FIGURE 19

MODELLED AREA LAYOUT

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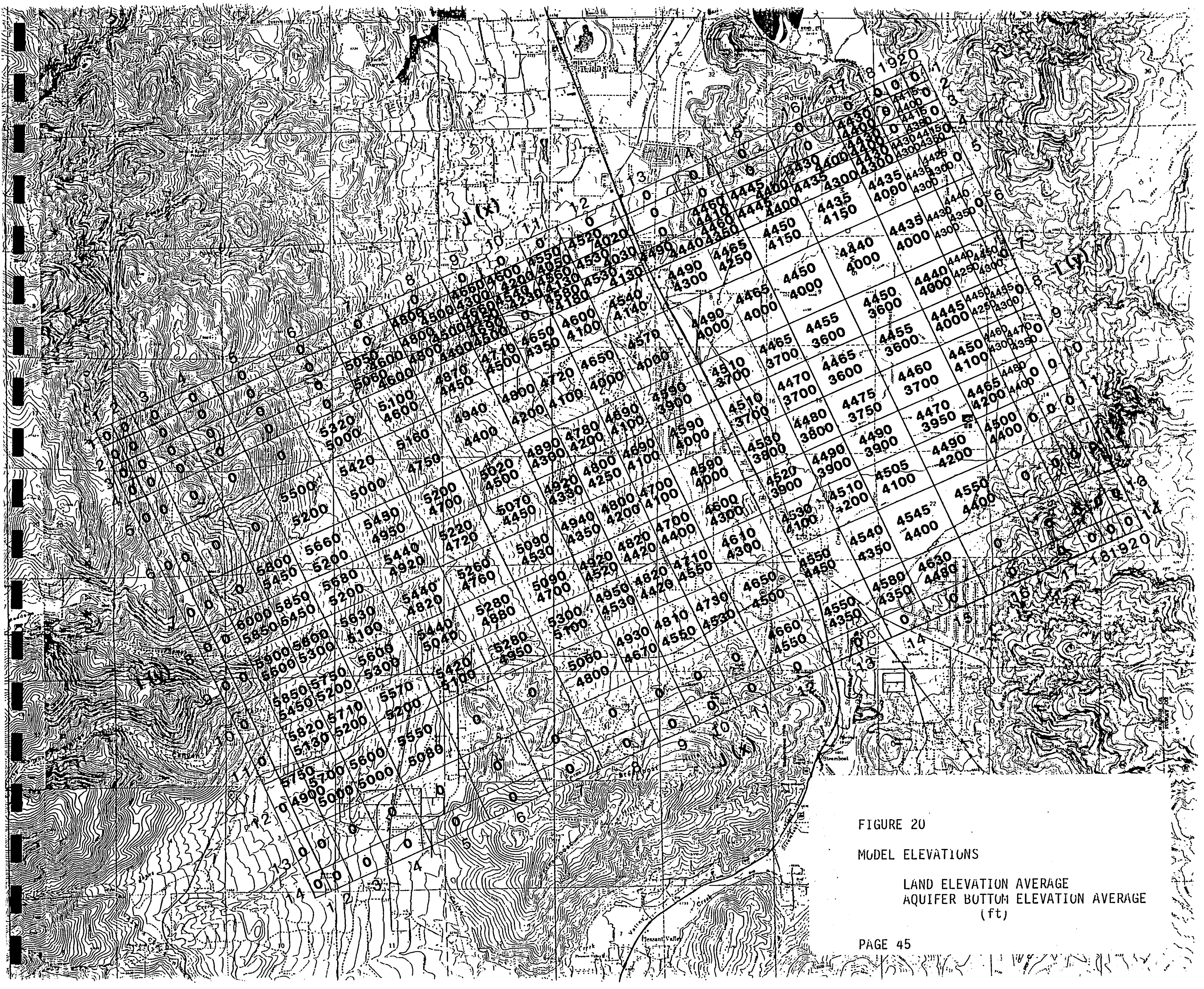

FIGURE 20

MODEL ELEVATIONS

LAND ELEVATION AVERAGE
AQUIFER BOTTOM ELEVATION AVERAGE
(ft)

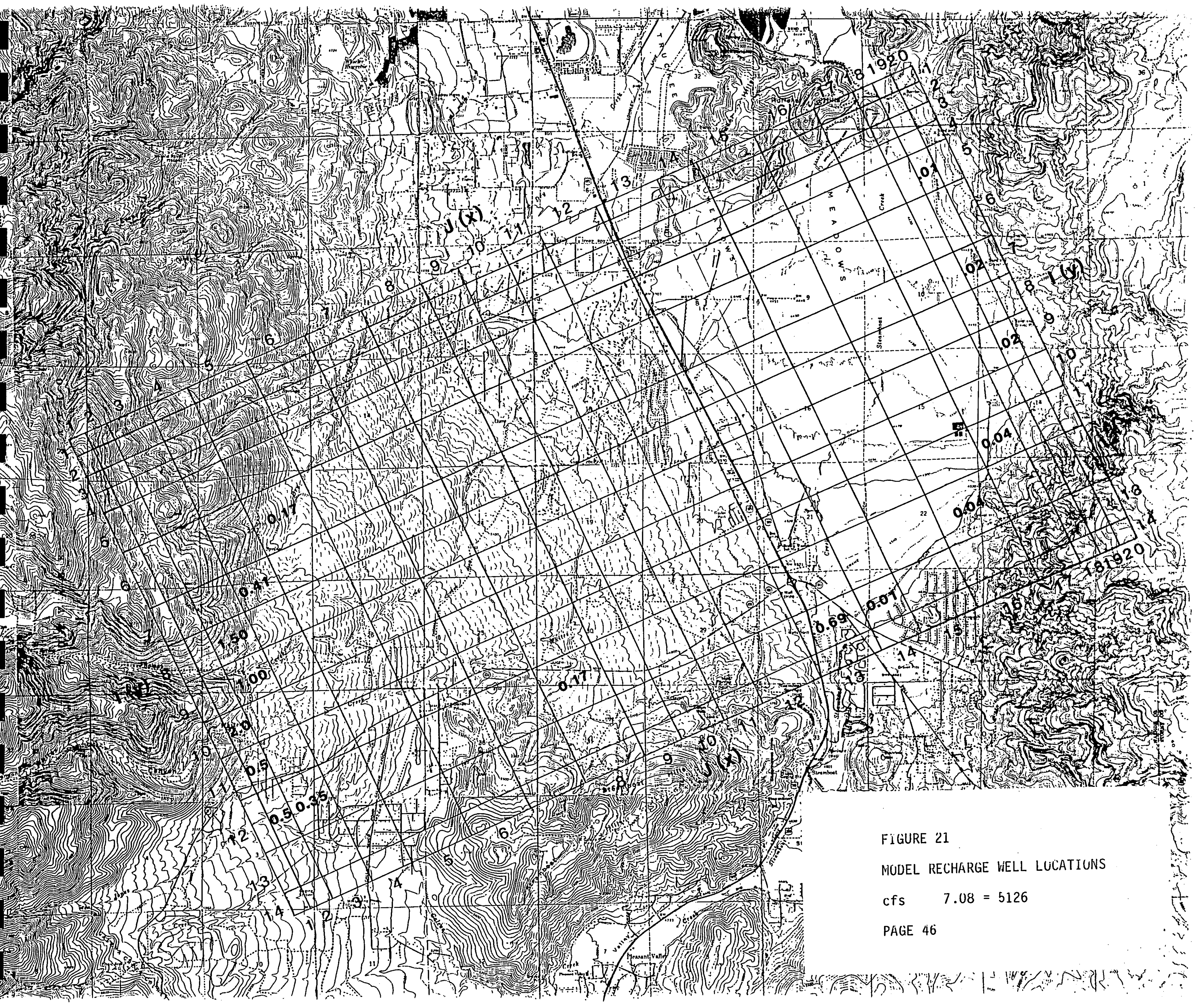

FIGURE 21

MODEL RECHARGE WELL LOCATIONS

cfs 7.08 = 5126

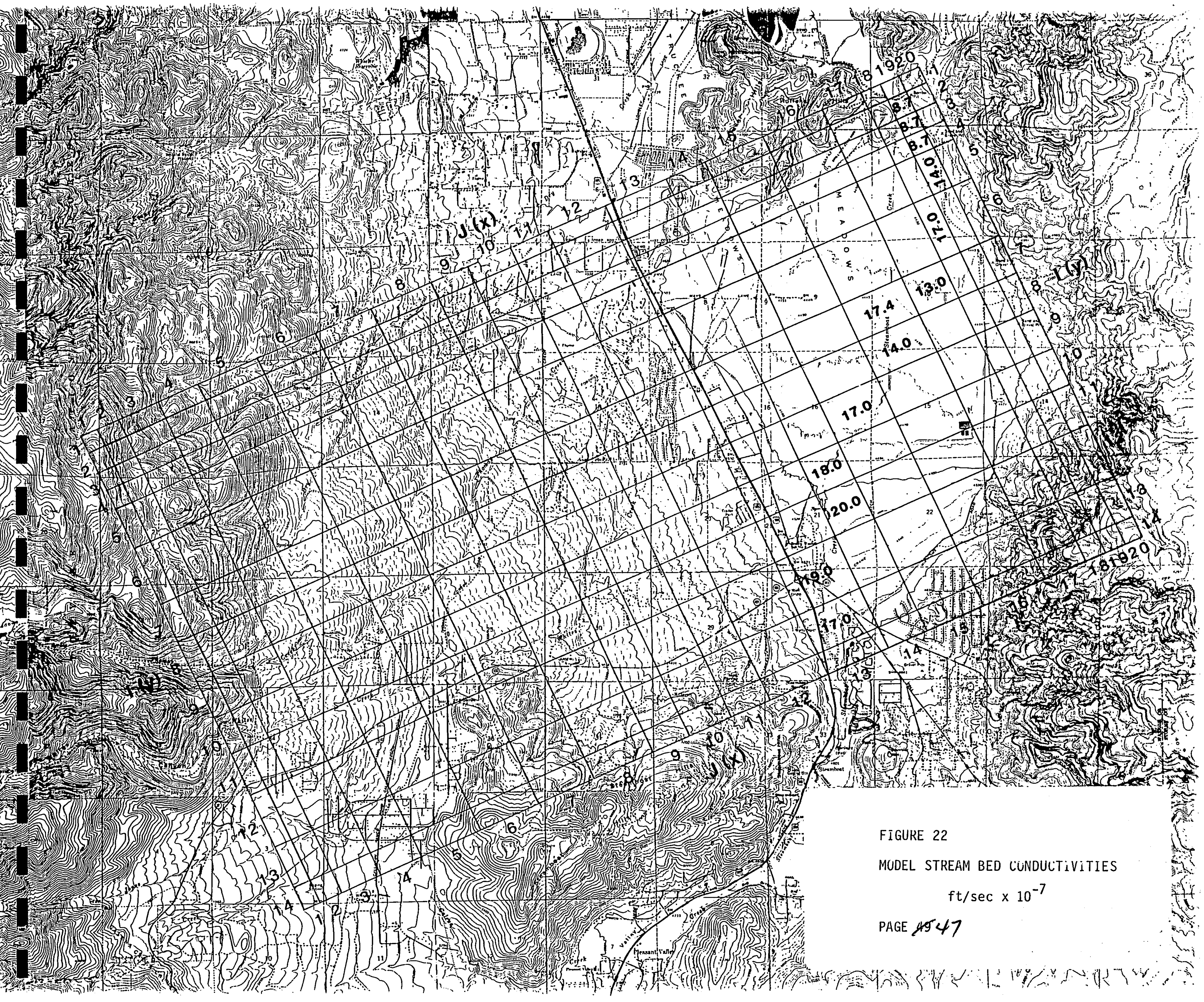

FIGURE 22

MODEL STREAM BED CONDUCTIVITIES

ft/sec x 10^{-7}

PAGE ~~49~~ 47

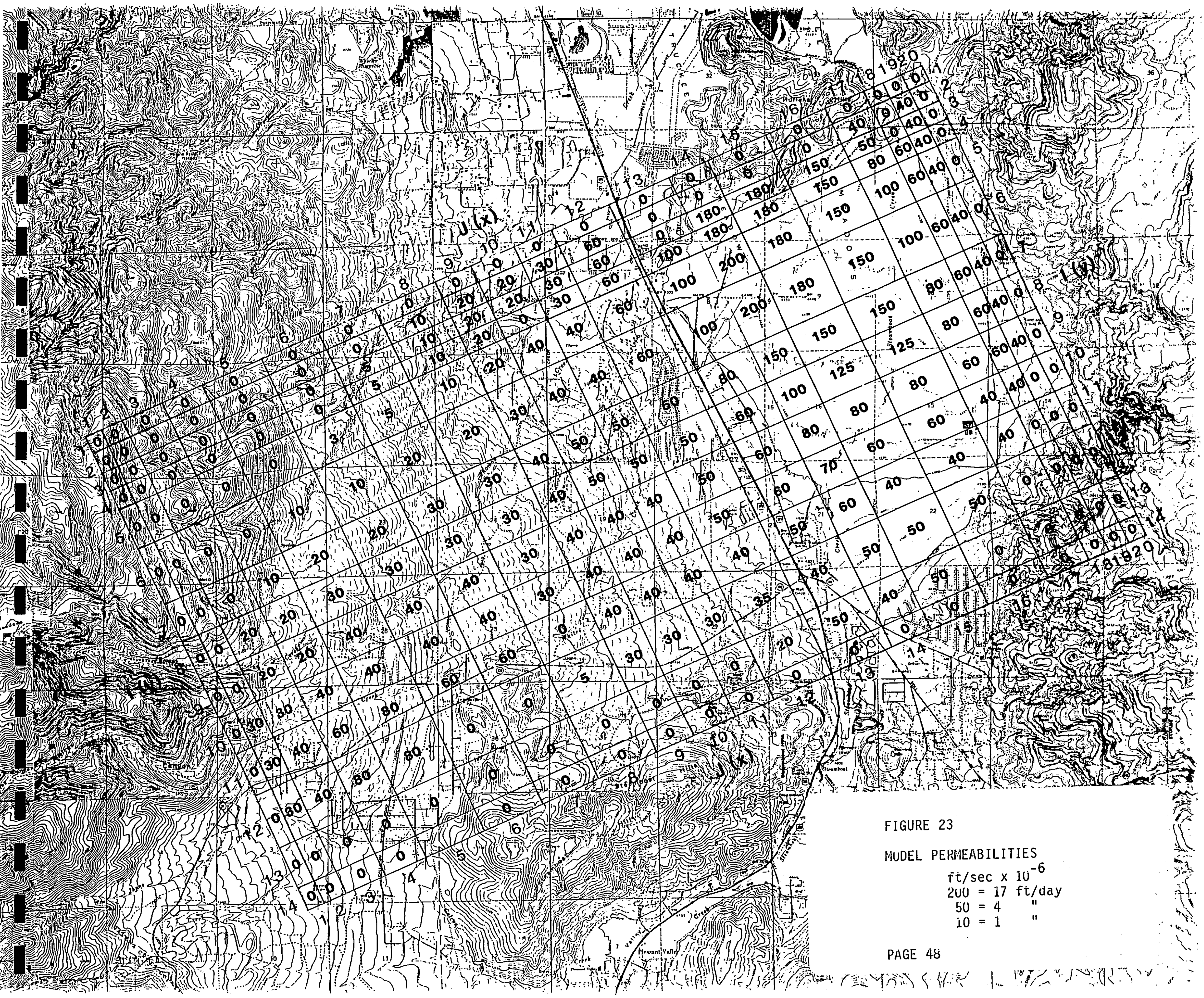

FIGURE 23

MODEL PERMEABILITIES

ft/sec x 10^{-6}
200 = 17 ft/day
50 = 4 "
10 = 1 "

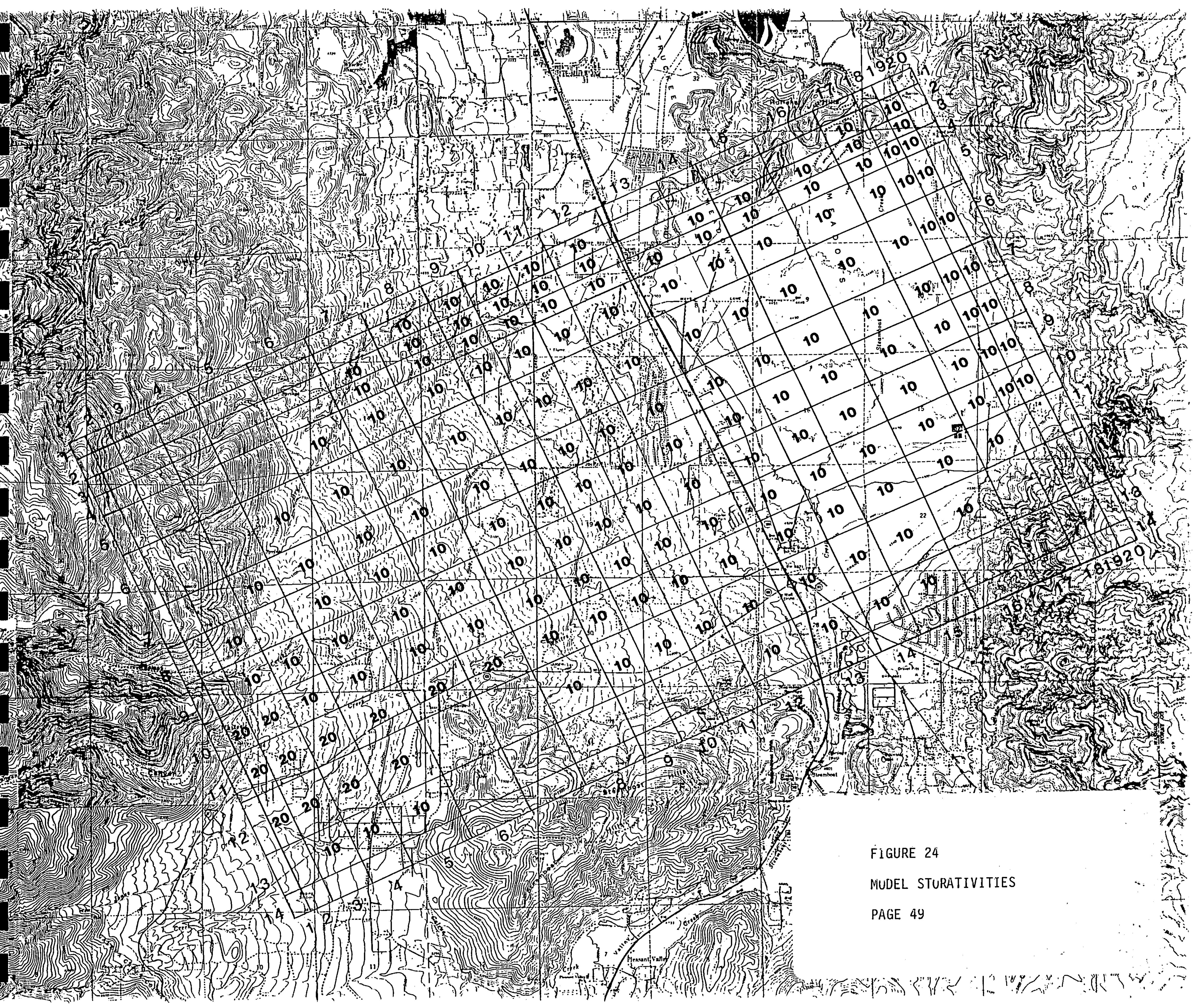

FIGURE 24

MODEL STORATIVITIES

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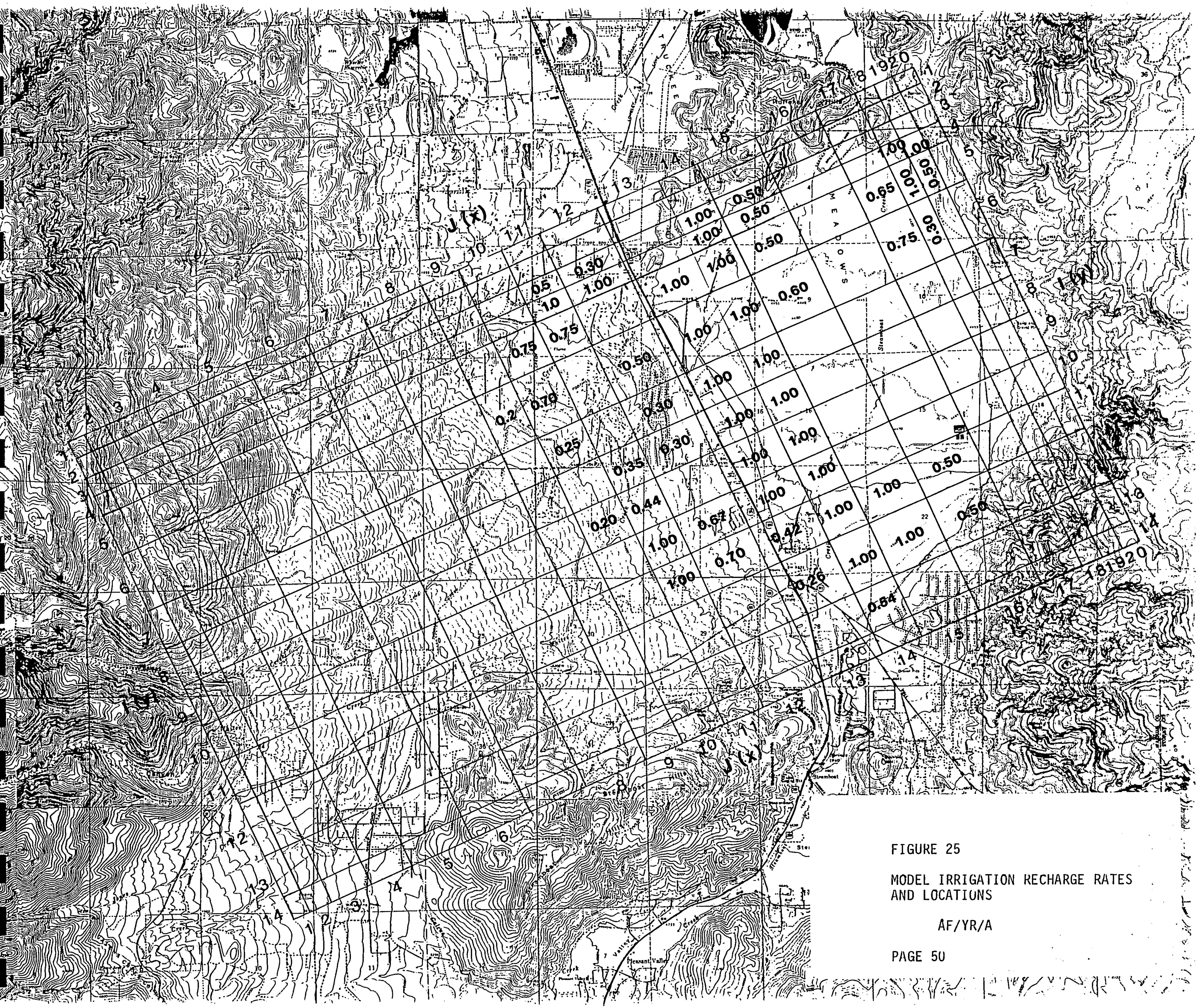

FIGURE 25

MODEL IRRIGATION RECHARGE RATES AND LOCATIONS

AF/YR/A

ET conditions. Basically, an attempt was made to reproduce, in the form of the net water balance, what was actually occuring in the vadose zone. Figure 11 is an illustration of this net balance.

Difficulties

Uncertainties arose in the modelling effort with respect to imput data. Future modelling efforts should address the following:

1. Determining depth to bedrock, especially near Dry Creek as this influenced the head distribution.
2. The fault at Lancer's influenced head distribution and was not fully understood.
3. Uncertainty about recharge values north of Thomas Creek Canyon.
4. The storativity had a large influence at Dry Creek.

Calibration and Sensitivity Analysis

The calibration process was an attempt to match the computer generated heads (steady state) to the heads observed in the field. Problems mostly developed near and south of Whites Creek, the Dry Creek area and near the Lancer's Fault. In the Whites Creek area, computed heads were often tens of feet above land surface. Adjusting recharge values down from the initial values (10,000 AF) was the most effective method of adjustment made. Adjusting aquifer thickness, hydraulic conductivity and/or storativity did not yield desirable results. In the Dry Creek area, nodes often "went dry" so that adjustments were made to aquifer thickness, hydraulic conductivity and storativity, all adjusted downward from initial values. In the Lancer's Fault area heads could not be calibrated correctly, but were close to reasonable.

Sensitivity analysis considered increasing or decreasing, by whole and half orders of magnitude, the input parameters of specific yield and hydraulic conductivity. No significant effects resulted in doing so. However, in the area near Dry Creek adjustments to aquifer thickness and storativity were sensitive, but did not appear to affect the overall modelling results. In the area of north central section 7, where nodes I=2, and J=10, 11, and 12; constant head boundaries are located. An analysis was made to determine if this type of boundary would contribute recharge to the model area uncharacteristically. No significant impacts were identified by moving this constant head further to the north and pumping wells in the southeast of section 7.

Results

Figures 20 through 25 are input parameters for the fully calibrated model. The calibrated model indicates that the starting heads given match the steady state heads and the heads observed and/or inferred in the field. Figure 26 shows those heads. The calibrated model, under steady state conditions, indicates the following from Table 6.

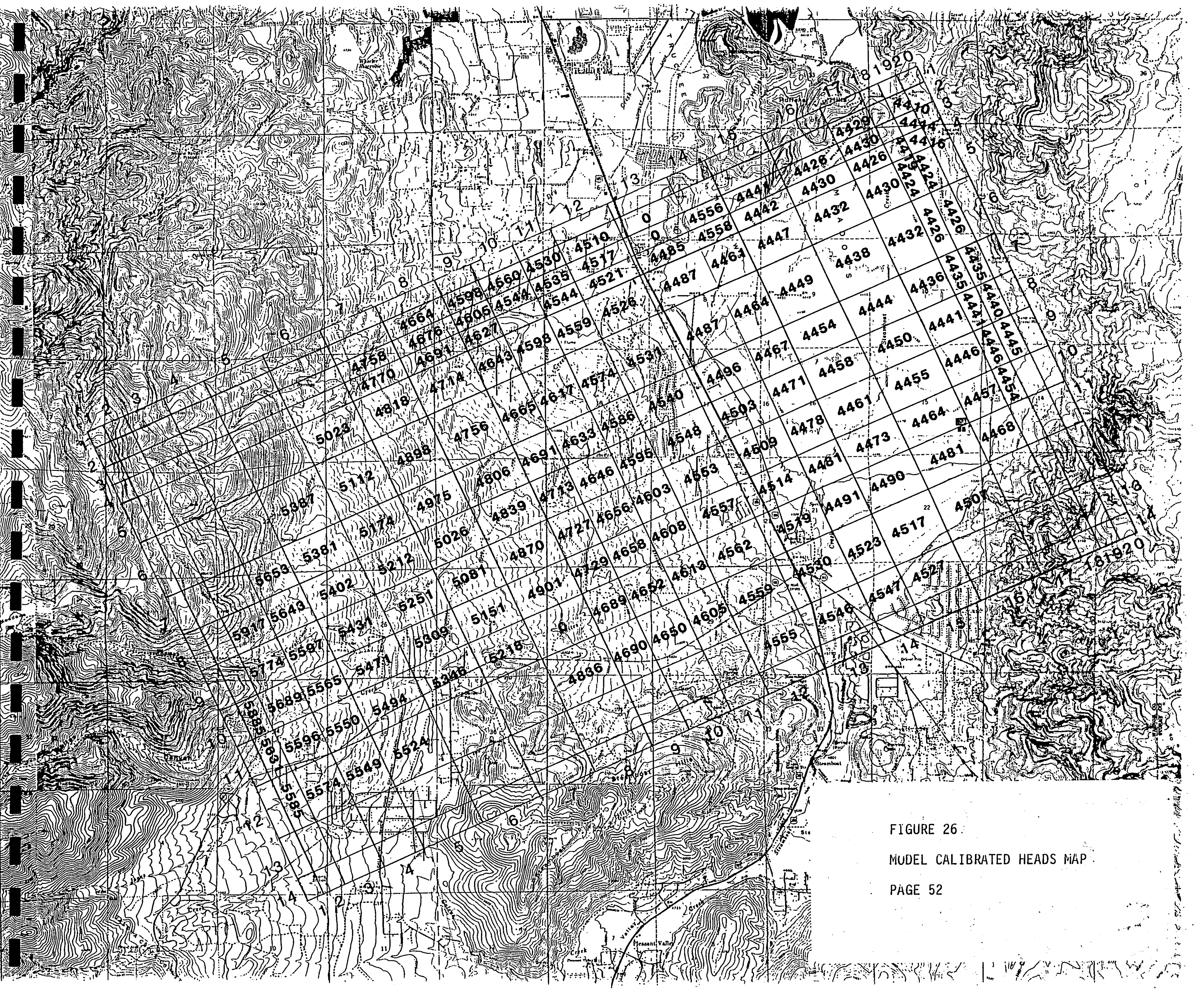

FIGURE 26

MODEL CALIBRATED HEADS MAP

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Table 6
Calibrated Model Results

Recharge.................	5126 AF
Irrigation rchrg.........	18823 AF
Leakage to Stmbt Ck......	1713 AF
Evapotranspiration.......	22286 AF
Gndwtr outflow...........	0 AF
Change storage...........	0 AF

The total input to the model is 23,950 AF of which only 5100 AF is natural recharge. Of this, 3700 AF is considered from the Whites and Thomas Creek area and 1000 AF from the Galena Fan area. Several attempts were made to increase the natural recharge as it seemed too, conservative. However, heads could not be matched in doing so. These values differ significantly from the values derived using the Durbin-Arteaga method. Those values are 10,250 AF from the Thomas and Whites creeks area and 2700 AF from the Galena Fan area. This discrepancy could be resolved by considering a component of recharge to the hard rock aquifer system that most certainly exists in the Kate Peak Formation of the pediment.

The leakage to Steamboat Creek is computed at 1713 AF which is much less than Shump's estimate of 12,500 AF. Shump concluded (oral communication) that it was difficult to account for all components of this estimate as irrigation practices complicated it. More work needs to be done on the streambed leakage factor concept, as applied in this study, in order to further compare this model's estimate with Shump's work. The least sensitive aspect of this modelling effort was the recharge-discharge relationship on the valley floor. Head distributions did not change throughout the modelled area when the irrigation application rates to the valley floor were significantly increased or decreased. Consequently, it was difficult to tell just what the reasonable range of ground water discharge is from this modelling effort.

Table 7 compares the numerical modelling results with those of the Water Balance listed in Table 4.

Table 7
Comparison of Water Balance with Model

	Water Balance	Model	Difference
Mt. Front Rchrg...	4700 AF	3680 AF	21 %
Galena Rchrg......	2700 AF	1000 AF	63 %
Other Rchrg.......	1680 AF	724 AF	57 %
Irr. Rchrg........	19750 AF	18823 AF	5 %
ET................	20750 AF	22286 AF	7 %
Leakage to Stmbt..	12500 AF	1713 AF	730 %
Total Inflow......	28830 AF	24227 AF	16 %
Total Outflow.....	34250 AF	24000 AF	30 %

As discussed, large differences occured with recharge from the Thomas, Whites and Galena areas as well as other recharge sources. Evapotranspiration and irrigation recharge are fairly close in comparison. Considering the differences in recharge, the total inflows are reasonably similar. Total outflow can not be compared as the net Water Balance is off by 16%. Summarily, the two methodologies are conceptually similar.

Well Field Impacts

Several pumping scenarios were run on the present and future well fields. Figure 27 shows the locations of these wells. The initial conditions were changed in that the irrigation to the valley floor was sharply reduced. This in effect says that irrigation water from the Truckee River has been converted to municipal use and that it is used outside the study area. This is a conservative scenario and it allows one to simulate how far reaching a cone of depression could reach. A mass balance for this scenario without pumpage is listed in Table 8 below. Note that nearly 400 AF of outflow occurs at the constant head boundary in section 7.

Table 8
Mass Balance without Pumpage

Recharge..........	5126 AF
Irr. recharge.....	4184 AF
ET................	6179 AF
Leakage to Stmbt..	2733 AF
GW outflow.........	398 AF

The present wells are the STMGID PW #1, PW #3 and the Thomas Creek well. For this simulation the pumping rates were 300 gpm, 100 gpm and 85 gpm for a total of 485 gpm annually. Table 9 below lists the mass balance summary after 2.4 years of pumpage.

Table 9
Mass Balance of STMGID Scenario, 2.4 yrs later

Recharge.............	5126 AF
Irr. recharge........	4184 AF
Chng storage.........	597 AF
Evapotranspiration...	6054 AF
Leakage to Stmbt.....	2685 AF
Pumpage..............	782 AF
GW outflow...........	385 AF

Most of the pumpage is derived from storage (76%) while the rest is derived from a reduction in ET and leakage to Steamboat Creek. Table 10 lists the mass balance after 37.5 years of constant pumping and when steady state is reached.

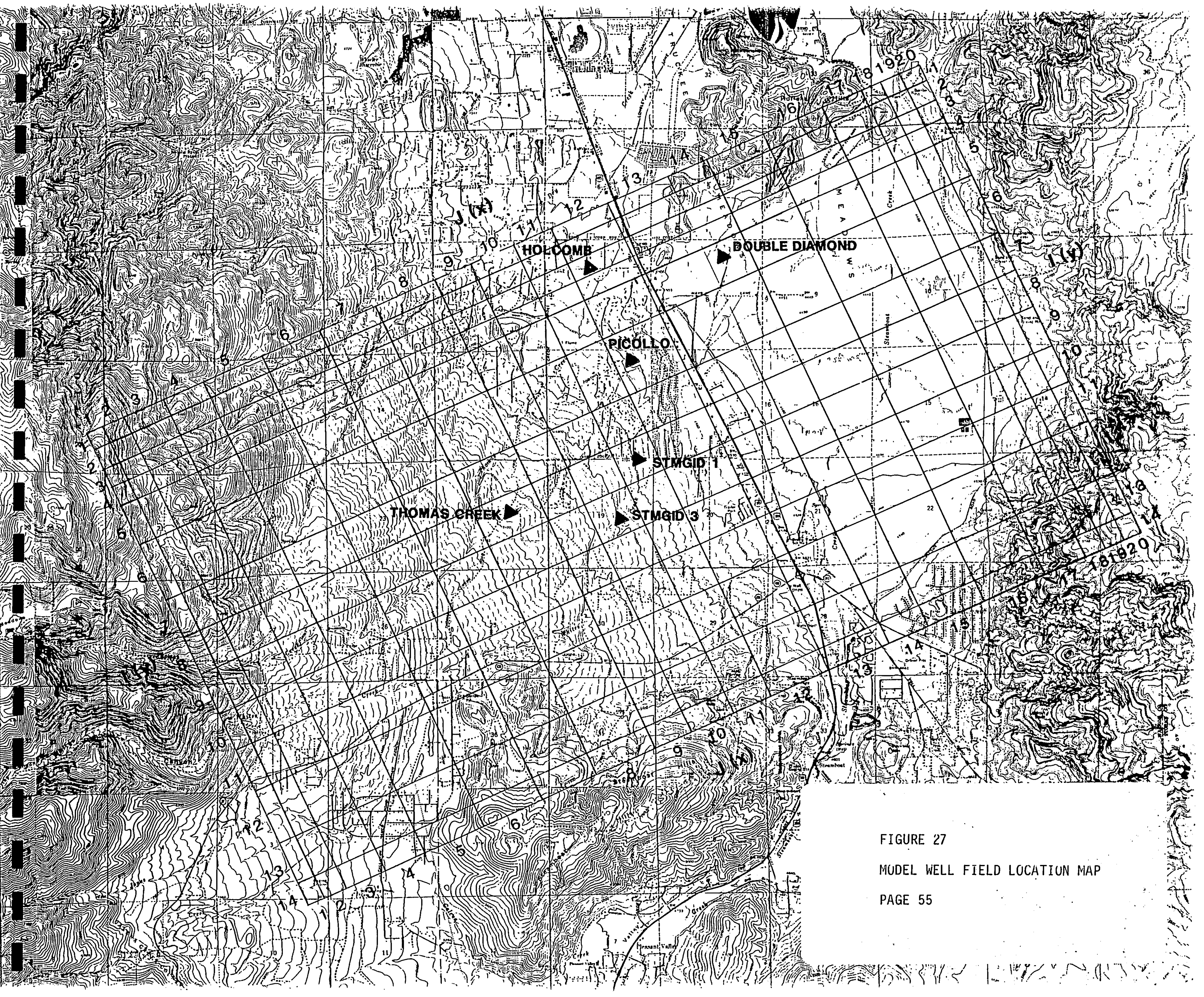

FIGURE 27

MODEL WELL FIELD LOCATION MAP

TABLE 10
Mass balance of STMGID Scenario, 37.5 yrs later

Recharge............	5126 AF
Irr. Recharge........	4184 AF
Chng in storage......	41 AF
Evapotranspiration...	5765 AF
Leakage to Stmbt.....	2507 AF
Pumpage..............	782 AF
GW outflow...........	297 AF

This run indicates that approximately 80% of the pumpage is derived from the reduction of ground water flow to the discharge area and the rest from storage and as outflow that would normally flow to the north. This result is misleading in that today's irrigation rate is probably 10,000 AF more so that ground water outflow would probably remain constant. What is important from this scenario is the projected cone of depression resulting from this amount of pumping.

Figure 28 shows the projected drawdowns for each node after 2.44 years of continuous pumping and after steady state conditions are achieved (37.5 years of pumping). This illustrates that after 2.4 years of pumping a cone of depression develops with an approximate radius of 14,000 feet. The center node has an average drawdown of 14 feet. After 37.5 years the cone has a radius of approximately 20,000 feet with a center node average drawdown of 23 feet. This appears to be rather far reaching given this conservative scenario. The drawdowns at the well nodes, however, do not appear to be relatively deep. It is surmised then that this aquifer system has low storativity and moderate transmissivity (Freeze and Cherry, 1979).

A second pumping scenario is to look at the effects of pumping the proposed Piccolo Well located on Foothill Road. Figure 29 shows the effects after pumping 2.4 and 37.5 years (steady state) at a pumping rate of 300 gpm. This also illustrates that the cone of depression is far reaching, yet shallow. Comparing Table 7 with Table 11 below indicates

Table 11
Mass Balance of Piccolo Scenario, 37.5 yrs later

Recharge..............	5126 AF
Irr. recharge.........	4184 AF
ET....................	5849 AF
Leakage to Stmbt......	2674 AF
Pumpage...............	485 AF
GW outflow............	308 AF

that 80% of the ground water capture comes from ET and Steamboat and 20% from capturing potential outflow from the study area.

A third scenario addresses SPPCo's well located on Holcomb Lane (see Figure 27). According to the model, Figure 30 shows the effects of pumping this well, alone, at 450 gpm. This Figure and Table 12 indicate

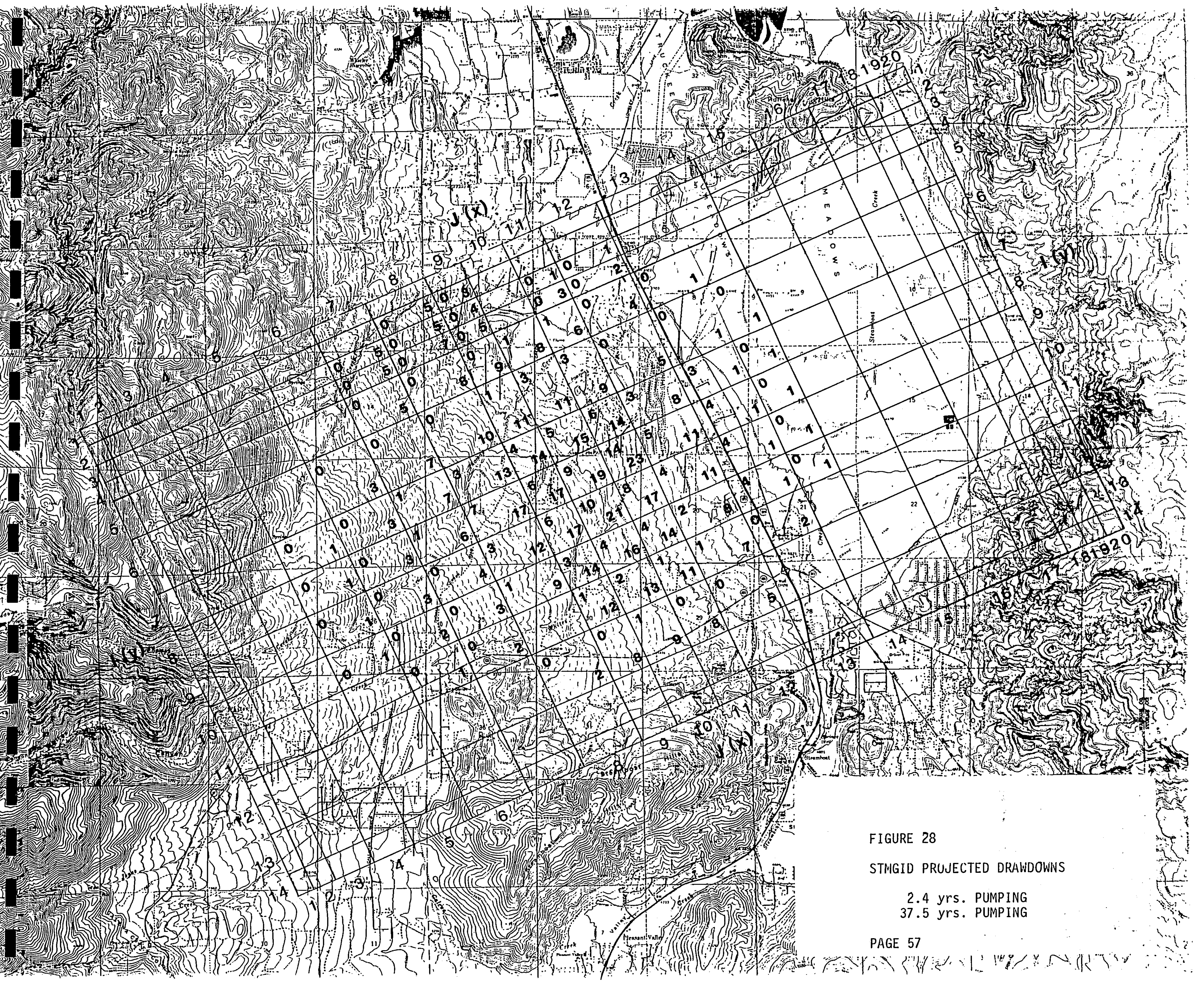

FIGURE 28

STMGID PROJECTED DRAWDOWNS

2.4 yrs. PUMPING
37.5 yrs. PUMPING

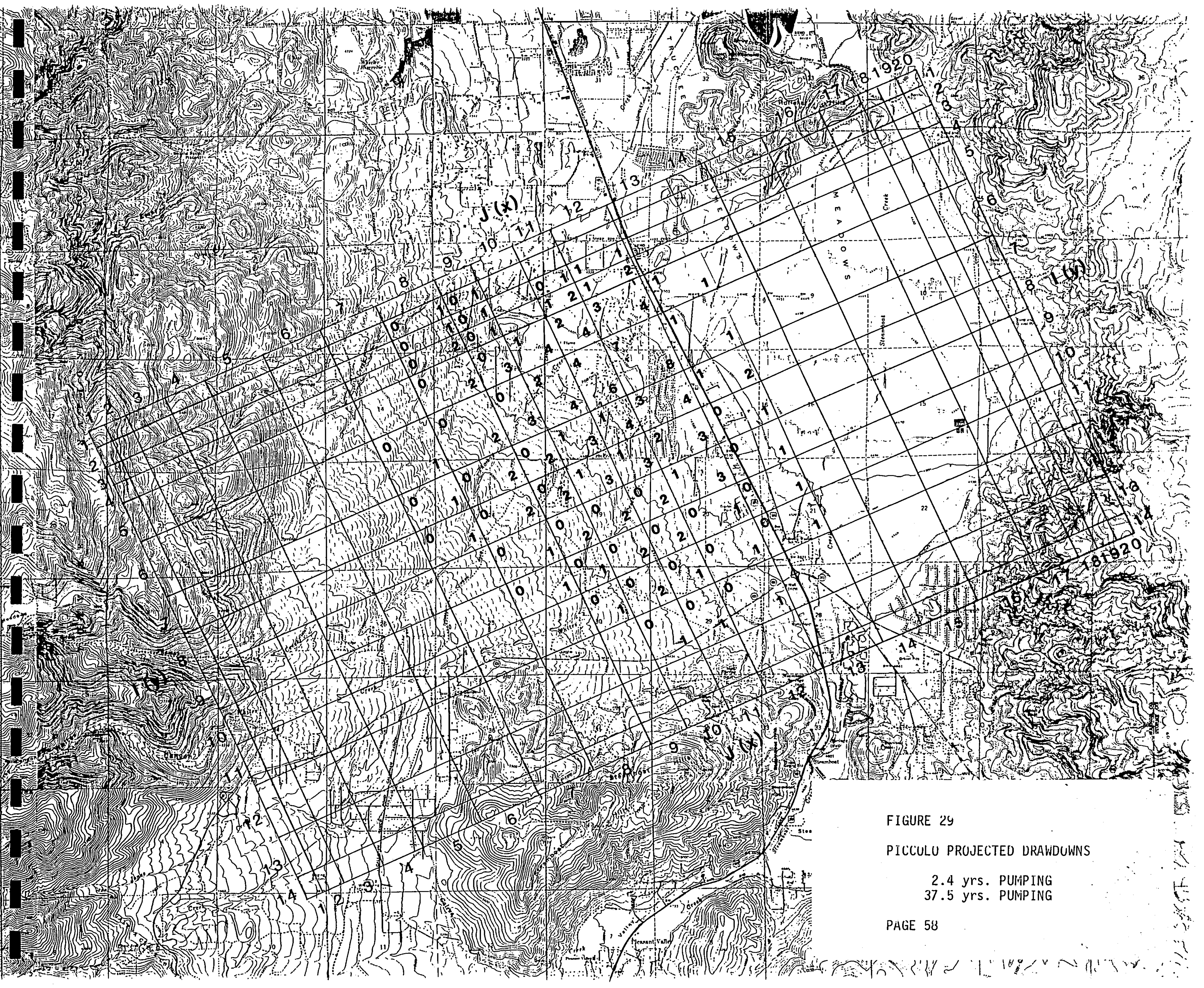

FIGURE 29

PICCULO PROJECTED DRAWDOWNS

2.4 yrs. PUMPING
37.5 yrs. PUMPING

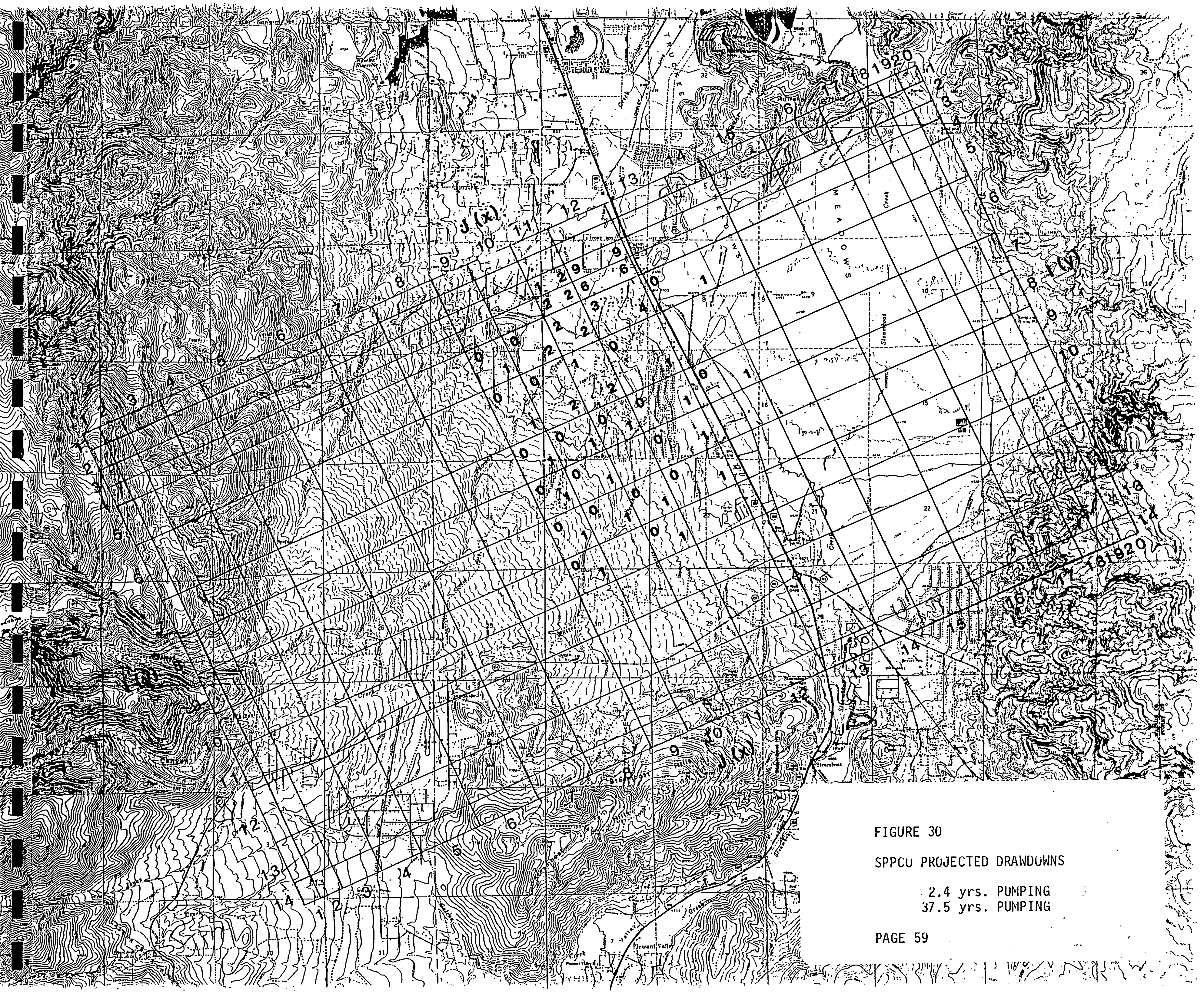

FIGURE 30

SPPCU PROJECTED DRAWDOWNS

2.4 yrs. PUMPING
37.5 yrs. PUMPING

Table 12
Mass Balance of Holcomb Scenario, 37.5 yrs later

Recharge..............	5126 AF
Irr. recharge.........	4184 AF
ET....................	6081 AF
Leakage to Stmbt......	2721 AF
Pumpage...............	724 AF
GW inflow.............	584 AF

that at least 80% of the capture is from north of the study area. According to the model a reversal of the gradients occurs between the well and the constant head boundary. This is to be expected given the model configuration, initial conditions and the aquifer geometry in this area.

A final pumping scenario is to pump all wells shown in Figure 27. The pumping rates are:

SIMGID PW #1.........	300 gpm
SIMGID PW #3.........	100 gpm
Thomas Creek.........	85 gpm
Piccolo Well.........	300 gpm
Double Diamond North.	300 gpm
SPPCo Holcomb Well...	450 gpm
Total................	1535 gpm

Table 13 shows the mass balance after 2.44 years of pumping beginning in 1990. This indicates that of the 2476 AF pumped, 30% is derived from storage, 41% is captured from the discharge area, and the balance is derived from outflow to the north (meaning a gradient reversal). After 37.5 years of pumping, the ground water system has reached a near steady state condition. Table 14 is the mass balance resulting from this scenario.

Table 13
Mass Balance 1990 Scenario, 2.4 yrs later

Recharge...........	5126 AF
Irr. recharge......	4184 AF
GW inflow..........	277 AF
Chng in storage....	790 AF
ET.................	5252 AF
Pumpage............	2476 AF
Leakage to Stmbt...	2648 AF

Table 14
Mass Balance 1990 Scenario, 37.5 yrs later

Recharge..........	5126 AF
Irr. recharge.....	4184 AF
GW inflow.........	407 AF
Chng in storage...	50 AF
ET................	4855 AF
Pumpage...........	2476 AF
Leakage to Stmbt..	2436 AF

This indicates that 65% of the capture is from ET and discharge to Steamboat Creek, ground water inflow from the north is 32%, and the remainder (3%) is still derived from storage. Figure 31 illustrates the effects of pumping after 2.4 and 37.5 years based on this conservative scenario (a significant reduction in irrigation). Comparing this figure with previous figures indicates that the overall drawdowns do not differ significantly. One could infer that most of the gradient reversal in section 7 is caused by the SPPCo well, which should come as no suprise. Ground water impacts are significant in the south study area (row 12) considering this distance from the well field. This is primarily caused by the relatively poor transmissivities in this area, the impedence to ground water flow caused by the Lancer Fault and the lack of recharge from the Steamboat Hills.

Conclusions

1. Mountain Front recharge to the alluvium may be much less than previously estimated. This may be by as much as 50%. It can not be determined, from the information at hand, how much the hard rock pediment is recharged. If the alluvial portion of the pediment is only recharge 5000 to 6000 AF/YR, municipalities must give serious consideration to limited growth dependent on this resource.

Flow net analysis may shed some light on inflow from the Galena area and the canyon mouths. Additionally, it is probably inaccurate to assume that mountain front recharge only occurs at the canyon mouths. Future work should attempt to look at the mountain front faulting as a recharge area. A concept would be similar to Figure 12. If this indeed the case, more inflow may occur in the Dry Creek area. This would tend to bolster ground water movement in the northwest study area. From the modelling it was difficult to move ground water to this area and is probably why it is so sensitive to aquifer parameter estimation.

2. Transmissivity and storativity values indicate that municipal pumping has shallow, but areally wide effects on the alluvial aquifer. This is based on limitations of the model. It does not consider localized heterogeneity or depth of pumping, well efficiencies and such. There cannot be too, much importance placed on this conclusion as parameter distributions are poorly understood especially storativity.

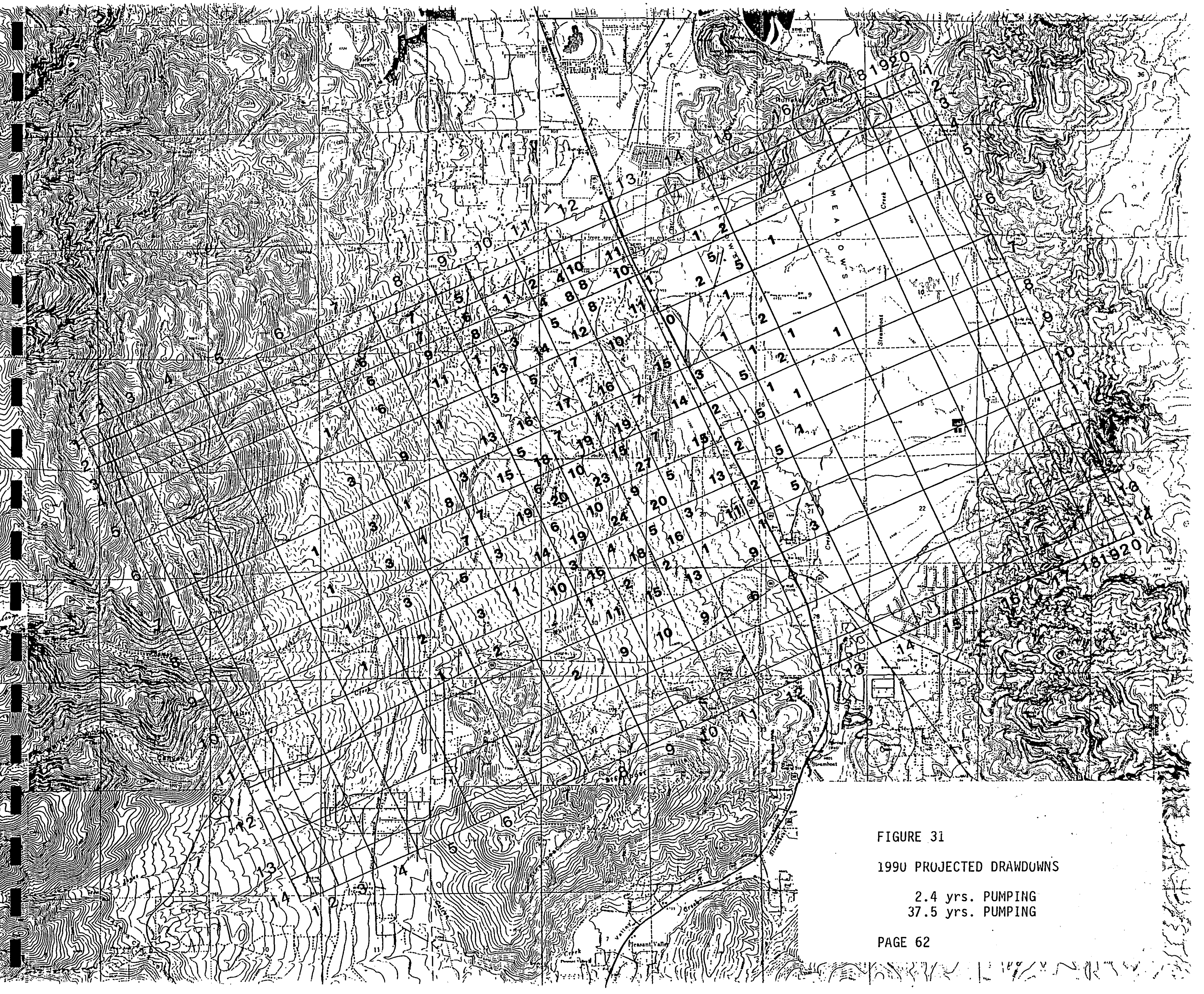

FIGURE 31

1990 PROJECTED DRAWDOWNS

2.4 yrs. PUMPING
37.5 yrs. PUMPING

3. The South Truckee Meadows could be considered a distinct basin from the North Truckee Meadows. Outflow from the South to the North via section 7 is not well understood and possibly occurs at the rate of 200-300 AF/YR.

4. Water levels are effected in the southern portion of the modelled area from northern production wells. The modelling supports field evidence that a significant change in transmissivity occurs in sections 29 and 30, T.18N., R.20E. The Lancer Fault also acts as a barrier to flow. The Steamboat Hills probably offer little recharge to this area so that ground water movement is minimal. Figure 9 shows that the gradient in this area is anomalously flat. Consequently, pumping in section 19 will cause drawdowns in the southern areas. This has future concerns given the geothermal activity associated with the Mud Breccia Fault.

5. The valley floor has interesting, complicating and not well understood hydraulics (other than theoretical concepts). Because of it being the discharge area and it's size, the model shows little sensitivity to input parameters, etc. This study offers little insight. The area can discharge large flux rates of ground water. The modelling does indicate that Steamboat Creek is a gaining stream.

6. The area in and around Dry Creek is sensitive w/r to alluvial depth, permeabilities and storativity. This area is a weak point in this particular modelling study. It comes as no suprise as it is the least understood area and has the least amount of hydrogeologic data.

7. The Lancers Fault appears to divert ground water to the north to some degree.

8. Wide scale pumping from municipal wells affects a significant area. Drawdowns, however, are relatively shallow. This is relatively good news for homeowners. Pumping 50% of the estimated upgradient recharge is a relatively liveable scenario for other users. More work must be done in order to determine the effects when irrigation ceases and of the possible geothermal consequences.

CONCLUSIONS

1. Ground water recharge occurs principally in the Carson Range and most probably above 6000 feet in elevation. Movement is generally eastward and discharges in the meadows through evapotranspiration and by discharging into Steamboat Creek. Through an accounting mass balance and from numerical modelling it appears that ground water recharge to the South Truckee Meadows is of the range of 5000 to 7500 acre feet per year.

2. Surface water inflow to the South Truckee Meadows during 1983, an above average year for precipitation, was measured at 109,000 acre feet. Surface water outflow was measured at 120,000 acre feet. The imbalance is from ground water discharge into Steamboat Creek. Since 1984, irrigation diversions and practices have been significantly altered so that much less Truckee River water enters the meadows area. This accounting should be revised with respect to the Utility Division records.

3. Little information exists on the extent of a hard rock aquifer in the Kate Peak Formation. The production capacity of the STMGID #4 Production Well indicates that this type of aquifer exists and could possibly be further developed. Considerable expense would be required to better delineate this aquifer. It is probably linked to the Steamboat Springs Geothermal Area to some extent.

4. The surface and ground water that originates in the Carson Range is of excellent quality. Poor quality water occurs in the extreme southeast of the South Truckee Meadows. This is a result of ground water being exposed to hydrothermally altered rocks in the Virginia Range. Ground water quality deteriorates to the north and east of the Steamboat Hills due to geothermal influence. This body of work does not address the geothermal area. Evidence does support a generalized theory that geothermal waters migrate up along fault planes, mixing with low TDS waters in several areas of the South Truckee Meadows. These areas should be further investigated in order to maintain good quality water production in municipal and domestic wells.

5. A calibrated numerical model of a portion of the South Truckee Meadows was constructed. This USGS two dimensional model supports the estimated ground water recharge and discharge rate of about 5000 acre feet. The model was sensitive to aquifer thicknesses in the northwest of the study area where little physical evidence can support the assumptions made. Ground water discharge to Steamboat Creek was not well calibrated.

6. This model was used to predict the long term effects from municipal pumping. The model predictions indicate that as a result of large scale municipal pumping, shallow, but areally wide effects on the water table will occur. In a general sense, this will not significantly impact domestic wells in the South Truckee Meadows. Water levels in the southern portion of the modelled area were significantly lowered. This is in the area of section 29 and 30, T18N R20 E.

7. As with all numerical models, there are limitations to these predictions because of poorly understood hydraulic parameters and unknown lithologies in the study area, particularly in the northwest. Further investigation of this area would significantly improve the understanding of the ground water flow system. This investigation would entail geophysical work and hydraulic testing of the aquifer. It would be prudent to also investigate the Kate Peak Formation in this area if a drilling program was pursued.

8. Advances in numerical modelling has progressed to the point of justifying the expense of constructioning a new ground water model of the South Truckee Meadows.

FUTURE WORK

Several areas of the South Truckee Meadows need considerably more investigation in order to more accurately understand and manage the ground water system. A better understanding of the system will more accurately identify the extent of the resource and therefore allow for more efficient management of ground water pumpage. It is also important that geothermal waters do not migrate towards municipal and domestic wells due to poor placement of future wells.

The first area of future study should be directed towards the northwest portion of the pediment. This is an area where there is virtually no subsurface information, particularly sections 14, 23, 24 and 27, T18N R19E. It is anticipated that this area will be an area of future water supply exploration. For modelling purposes, the geology needs to be understood and how it affects the general movement of ground water. A geophysical survey would better delineate the alluvial thickness and direct future drilling. The drilling program would determine the feasibility of municipal well siting, substantiate the geophysical results and allow for ground water monitoring if the exploratory boreholes were completed as monitoring wells. This area should be a top priority.

The second area of study would be towards modelling the geothermal area located at Steamboat Hills. This could possibly enable us to better understand the ground water flux rate through the system, where the recharge to the system occurs and to better delineate all of the areas of the geothermal discharge. This is important with respect to maintaining good water quality in municipal and domestic wells.

Third, more work should be directed towards the meadows area. This would be to better delineate the natural ground water discharge area, further substantiate the discharge rates to Steamboat Creek, identify major faulting and or displacement of the "bedrock" floor and to identify geothermal discharge areas if any. A numerical model should be constructed of the meadows area to further our understanding and for future management practices.

Also, a more detailed ground water model should be constructed. This model should be able to better detail that the previous moodel attempted to estimate. This would particularly be the ground water flow system, the quantity of ground water recharge and to better predict future impacts from municipal pumping. This model would become a recognized tool for ground water management in the South Truckee Meadows. Finally, work should begin to some extent on viewing the hard rock as another aquifer for ground water resource exploitation.

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APPENDICES
IN SEPERATE BINDER

Well data used in piezometric maps

Well data for geothermal sections

Chemistry data for wells

Chemistry data for surface waters

Electrical Resistivity Sounding data

STM PUMPING TESTS SUMMARIES

1. SIMGID PW # 1
   a. well depth = 530 feet w/ screen = 260 ft
   b. pumping rate = 600 gpm @ 48 hours
   c. T = 6800 gpd/ft, K = 3.5 ft/day, SC = 7 gpm/ft, S = 0.0002
   d. alluvial aquifer (700 ft to bdrk), fully penetrating for analysis

2. SIMGID PW # 2
   a. well depth = 515 feet w/screen = 250 feet
   b. pumping rate = 250 gpm @ 24 hours
   c. T = 2500 gpd/ft, K = 1.3 ft/day, SC = 3 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. SIMGID PW # 3
   a. well depth = 590 feet w/screen = 340 feet
   b. pumping rate = 500 gpm @ 48 hours
   c. T = 7000 gpd/ft, K = 2.8 ft/day, SC = 5.9 gpm/ft
   d. alluvial aquifer (700 ft to bdrk), fully penetrating for analysis
   e. comments

4. SIMGID PW # 4 (Shawowridge)
   a. well depth = 831 feet w/screen = 130 feet
   b. pumping rate=355/246 gpm @ 240 hours
   c. T = 1500 gpd/ft, K = 1.5 ft/day
   d. rock aquifer
   e. comments
      1. good test, no hard rock observation data

5. SIMGID PW # 5
   a. well depth =760 feet w/screen = 350 feet
   b. pumping rate =885 gpm @ 72 hours
   c. T = 26,000 gpd/ft, K = 9 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. SIMGID 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 = unk
   d. Rock aquifer
   e. Comments
      1. aquifer affected by recharge boundary (surface water)

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

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

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

11. Timberline Estates Main Well
   a. well depth = 236 feet w/screen =61 feet
   b. pumping rate = 200 gpm @ 48 hours
   c. T = 1500 gpd/ft, K = 3.2 ft/day, SC = 1.5 gpm/ft, S = 0.0015
   d. Alluvial aquifer, partial penetration, flowing well

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 gpd/ft, K = 0.8 ft/day, SC = 0.9 gpm/ft, S = 0.002
   d. Alluvial aquifer, partial penetration, flowing well

13. Double Diamond North Well (DD-1)
   a. well depth = 184 feet w/scren = 122 feet
   b. pumping rate = 250 gpm @ 72 hours
   c. T = 11,600 gpd/ft, K = 17.5 ft/day, SC = 8.1 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 gpd/ft, K = 5.4 ft/day, SC = 11 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 (screwy design !)
    b. pumping rate = 205 gpm @ 72 hours
    c. T = 2200 gpd/ft, K = 2 ft/day, SC = 1.8 gpm/ft, S = NA
    d. alluvial aquifer, leaky, strongly anisotropic/heter, partial pen
    e. comments
        1. Washoe County test result (as opposed to Nork's)
        2. much well monitoring data, but difficult to analyze

16. New Sunrise Estates #2
    a. well depth = 343 feet w/screen = 209 feet
    b. pumping rate = 205 gpm @ 72 hours
    c. T = 3000 gpd/ft, K = 1.9 ft/day, SC = 1.7 gpm/ft, S =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 gpd/ft, K = 16 ft/day (T/140 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 gpd/ft, K = 16.6 ft/day (T/140 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 = 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 gpd/ft, K= 10 ft/day, SC = 18 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 gpd/ft, K= 14.8 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 gpd/ft, K= 16.6 ft/day, S=0.0014SC = 18 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 gpd/ft, K= 8.6 ft/day, SC = 10 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 gpd/ft, K= 14.6 ft/day,
    d. alluvial/hard rock aquifer (?)
    e. no pumping test data

26. SPPCo'c 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 gpd/ft, K= 8 ft/day, SC = 3.5 gpm/ft
    d. hard rock aquifer (?)
    e. no pumping test data

27. ORMAT PW #1
    a. Well depth = 627 feet w/casing to 595 feet
    b. production rate =
    c. Hydraulics=
    d. aquifer type

28. ORMAT PW #2
    a. Well depth = 530 feet w/casing to 495 feet
    b. production rate =
    c. hydraulics =
    d. aquifer type

29 ORMAT PW #3 (?)

30. ORMAT IW #1
    a. well depth = 1640 feet w/casing to 322 feet
    b. injection rate
    c. hydraulics
    d. aquifer types

31. ORMAT IW #2
    a. well depth = 1414 feet w/casing to 730 feet
    b. injection rates
    c. hydraulics
    d. aquifer type

32. ORMAT IW #3
    a. well depth = 600 feet w/casing to 400 feet
    e. comments= no testing done

33. ORMAT OW #1
    a. well depth = 626 feet w/casing to 160 feet
    e. comments- no testing done ?

34. ORMAT OW #2
    a. well depth = 570 feet w/casing to 97 feet
    e. no testing done ?

35. ORMAT OW #3
    a. well depth = 966 feet w/casing to 99 feet
    e. comments- no testing done ?

36. Yankee Caithness PW 28-32
    a. well depth = 3031 feet w casing to 1460 feet
    b.
    c.
    d. hard rock aquifer
    e. comments
        1. production zone @ 2315 feet

37. Yankee Caithness PW SS#1
    a. well depth = 3073 feet w/casing to 1322 feet
    b.
    c.
    d. hard rock aquifer
    e. comments
        1. production zone @ 2250 feet

38. Yankee Caithness PW 23-5
    a. well depth = 3022 feet w/casing to 1496 feet
    b. production rate = 375,000 lbm/hr
    c. productivity index = 5830 lbm/hr/psi
    d. hard rock aquifer
    e. comments
        1. production zone @ 2315 feet

39. Yankee Caithness PW 32-5 (proposed)
    a. well depth =

40. Yankee Caithness PW 83-6 (proposed)
    a. well depth =

41. Yankee Caithness IW Cox
    a. well depth = 3471 feet w/casing to 1786 feet
    b. injection rate = 270,000 lbm/hr
    c. injectivity index = 36,400 lbm/hr/psi
    d. hard rock aquifer
    e. comments
        1. injection zones @ 2100 and 3100 feet

Reservoir Properties

SBH1
a. effective water T = 5805121 MD-FT/CP
b. effective water K = 552136 MD-FT
c. effective water P = 2761 MD

ST2
a. effective water T = 4845395 MD-FT/CP
b. effective water K = 460855 MD-FT
c. effective water P = 23043

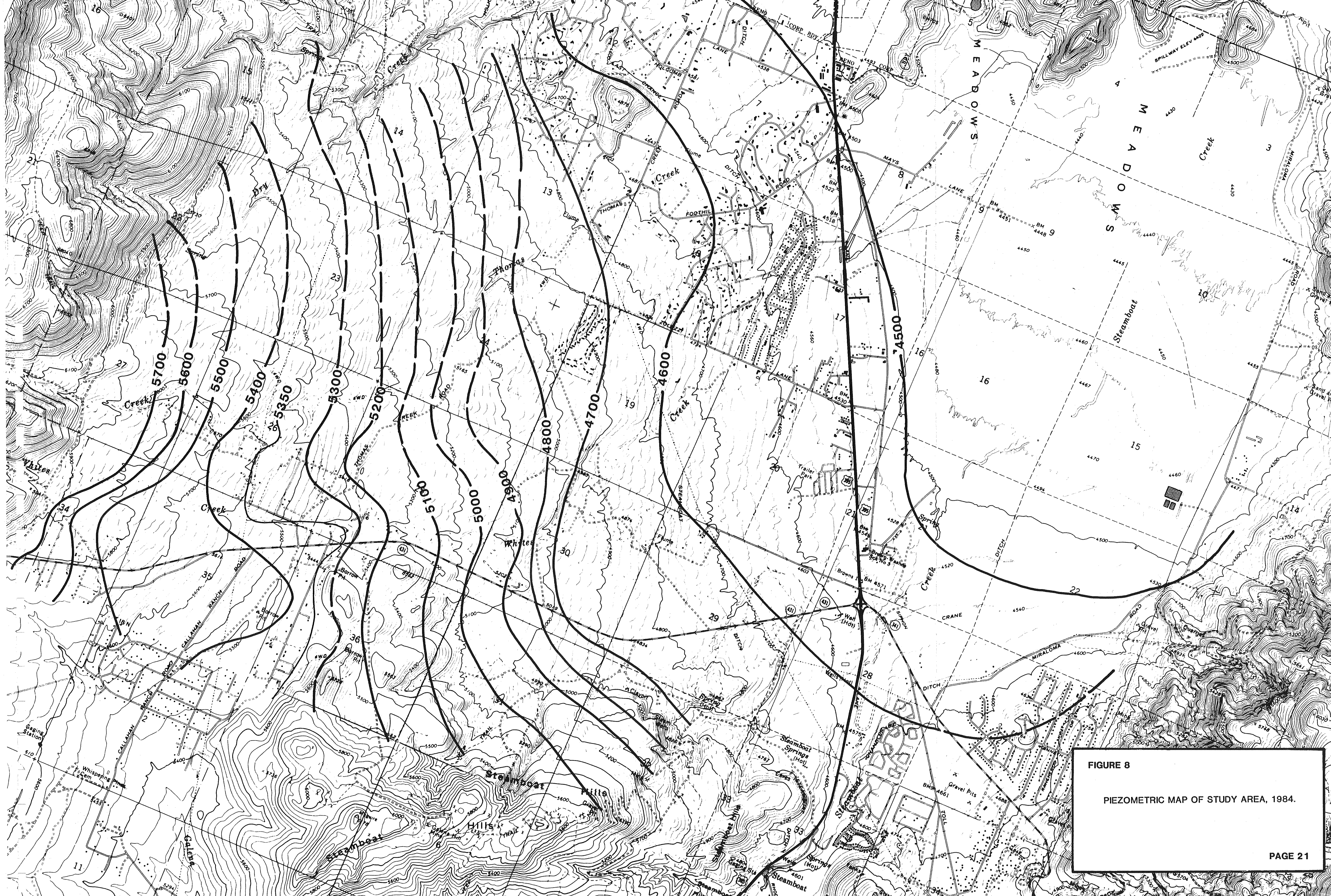

FIGURE 8

PIEZOMETRIC MAP OF STUDY AREA, 1984.

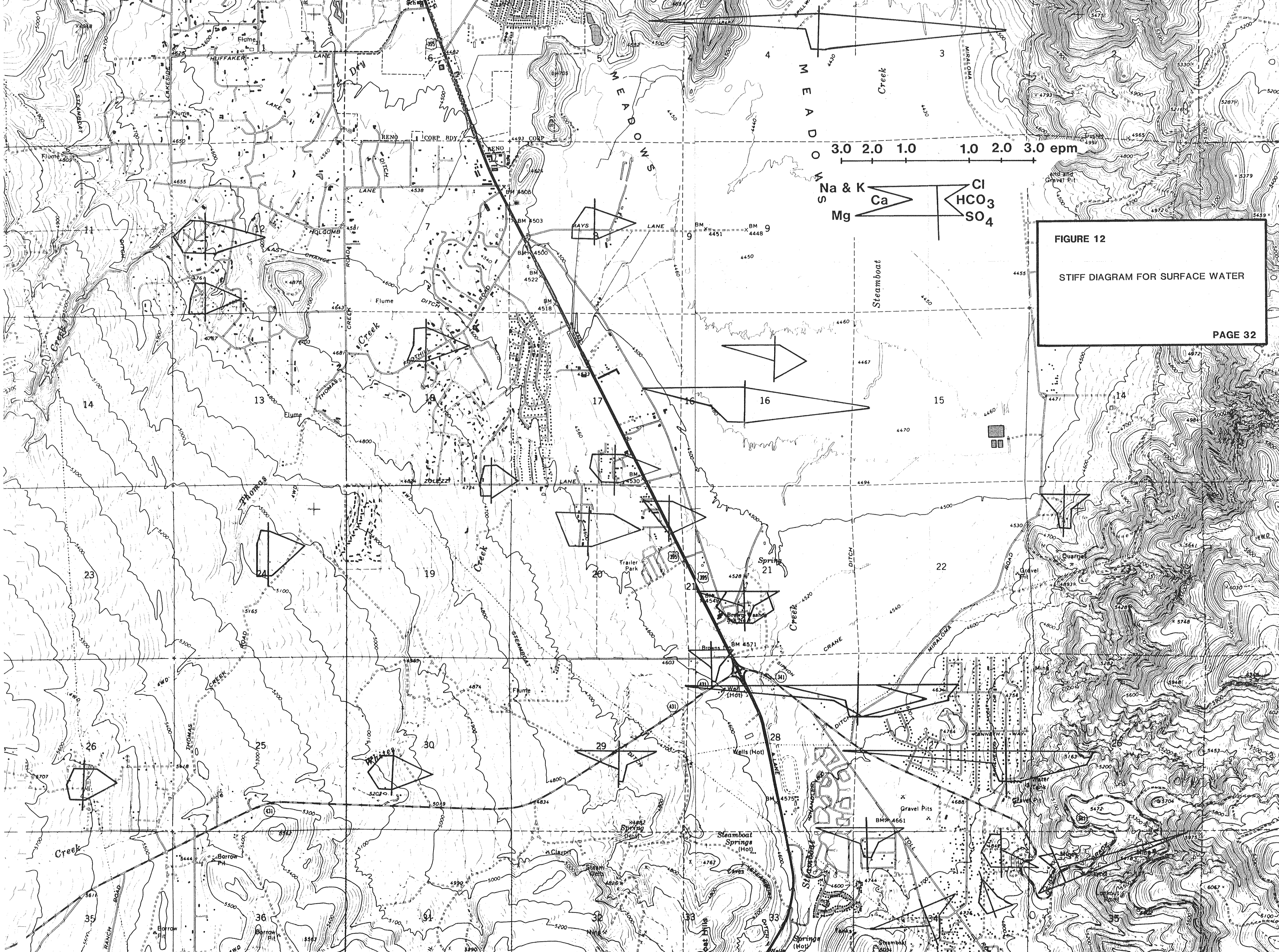

FIGURE 12

STIFF DIAGRAM FOR SURFACE WATER