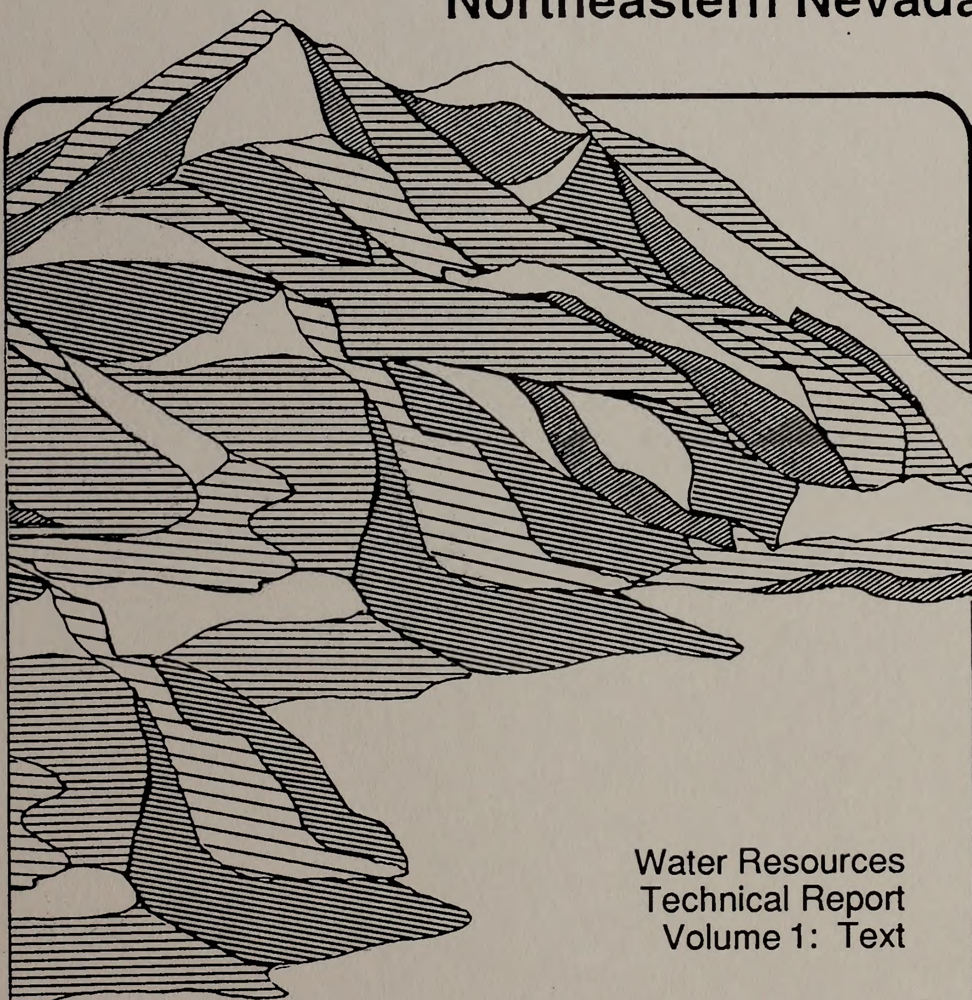
Draft Environmental Impact Statement
Thousand Springs Power Plant
Northeastern Nevada



Water Resources
Technical Report
Volume 1: Text

U.S. Department of the Interior
Bureau of Land Management
Elko District Office
Elko, Nevada

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1.0 EXECUTIVE SUMMARY

This report presents the results of an investigation conducted to assess the quantities and locations of water resources present in Thousand Springs Basin, in northeastern Nevada, and to evaluate the environmental effects associated with various development alternatives that might be implemented to make some of those water resources available for the proposed Thousand Springs Power Plant (TSPP). The power plant would be owned and operated by the Thousand Springs Generating Company (TSGC). Lands of Sierra, Inc. (LOS) has contracted to provide water for power plant construction and operation.

The proposed TSPP would be a coal-fired, steam electric generating station, consisting of eight generating units at ultimate planned development. Each generating unit would have a net output capacity of 250 megawatts (MW). The units are planned for initial startup at approximately 2-year intervals, and each unit is expected to have a 35-year operating life. Startup of the first generating unit presently is planned to be in 1994. Each unit would have an estimated maximum water requirement of 4000 acre-feet/year (ac-ft/yr), or a maximum total plant requirement of 32,000 ac-ft/yr. The power plant water supply would be groundwater, to be supplied from wells and wellfields. Other major planning factors pertaining to the project water supply, and the major conclusions of this investigation, are summarized in this section of the report. It is noted that where the conclusions are quantitative in nature, the quoted values are estimates based on presently available information.

Woodward-Clyde Consultants' (WCC) best estimate of the renewable water resources (average annual) of Thousand Springs Basin is 60,000 ac-ft/yr. The probable error of this estimate is believed to be within the range of plus or minus approximately 20,000 ac-ft/yr. For Toano Draw Subbasin, the best estimate is 10,000 ac-ft/yr, with the probable error of the estimate believed to be within the range of plus or minus approximately 4000 ac-ft/yr. Several different approaches were used to estimate the resources, for both the basin and the subbasin. All of the estimating procedures indicated that the total basin renewable resources significantly exceed the maximum power plant water requirement of 32,000 ac-ft/yr.

LOS owns practically all of the decreed, certificated, and permitted water rights that have been granted in Thousand Springs Basin. Those rights are presently used to support its ranching operation, primarily for irrigation of pasture and hay fields. LOS is committed to phasing out irrigation uses as power plant uses progressively increase.

Thousand Springs Groundwater Basin has been designated by the state engineer as an area of active management. In the interest of the public welfare, the state engineer is authorized and directed to designate preferred uses of the water within an area so designated. The state engineer has designated industrial use (power plant water use) as a preferred use to irrigation use. LOS is contractually obligated to make application for converting its rights to water in Thousand Springs Basin from irrigation uses to industrial use, as required to supply the water needs of the TSPP.

LOS owns (October 1989) certificated and permitted groundwater rights totaling 36,033.46 ac-ft/yr in Thousand Springs Basin, plus other minor, nonquantified stock watering rights. In addition, LOS owns decreed, certificated, and permitted surface water rights in Thousand Springs Basin totaling 41,983.16 ac-ft/yr.

LOS is contractually obligated to supply water to the TSGC on an as-needed, priority-of-use basis. It is anticipated that surface waters covered by owned water rights, beyond the amount required for maintenance of riparian and wetlands habitat, will be managed and utilized for groundwater recharge, primarily by controlling reservoir releases to rates compatible with streambed infiltration rates. LOS will take all necessary actions to certificate its rights to presently permitted water rights, as required to satisfy its obligations to provide water to the power plant.

Wellfield locations, and well locations within wellfields, would be selected and operated so as to prevent or minimize changes in the natural flows in Thousand Springs Creek, and the effects of project water withdrawals on riparian habitat and wetlands along the creek. As necessary, LOS would limit or terminate its use of surface water for irrigation and make water available for maintaining wetlands and riparian habitat along Thousand Springs Creek.

Wellfields would be required in two general locations to supply the total water requirements of the planned eight units, as follows:

- The broad valley of Toano Draw Subbasin where the power plant would be located. The renewable water resources available in this valley are believed to be adequate to supply at least 8000 ac-ft/yr, sufficient to supply the requirements of two units, and may be adequate to supply a third unit.

- The broad valley of Thousand Springs Creek, in the Gamble Ranch vicinity, upstream from Dake Reservoir and the Town of Montello, and extending upstream to near the confluence of Crittenden Creek with Thousand Springs Creek. The renewable water resources in the Gamble Ranch vicinity appear to be sufficient to satisfy the balance of the power plant needs, beyond what would be supplied from the Toano Draw area.

The principal aquifer to be utilized in each water source area is unconsolidated alluvium. In each valley the alluvium is estimated to extend to a depth of 800 feet or more, based on examination of available well logs and the results of surface geophysical studies conducted as part of this investigation, and in the Toano Draw area based also on the results of exploratory drilling performed to correlate the surface geophysical data with drill cuttings and downhole geophysical data.

Precipitation falling within the watershed boundary of the basin constitutes the gross renewable water resource of the basin. Available information indicates there is neither surface nor groundwater inflow to nor outflow from the basin across the watershed boundary, except at the downstream limit of the area, where Thousand Springs Creek discharges into Utah and Great Salt Lake Basin.

The total area of Thousand Springs Basin, as considered in this investigation, is approximately 1450 square miles, or approximately 930,000 acres. The estimated average annual precipitation over the watershed is approximately 1 foot. This estimate includes the orographic effects of the mountains around the perimeter and within the basin. On a volumetric basis the average precipitation over the basin is estimated to be about 945,000 ac-ft/yr.

The estimated current average surface water discharge at the downstream limit of the basin (approximately the Utah state line) is about 4000 ac-ft/yr. In addition, a Darcian analysis of groundwater flow through a cross section of the valley in the same vicinity indicates about 30,000 ac-ft/yr is currently discharging into Utah.

Current net consumptive use of water in the basin by irrigated agriculture is about 15,000 ac-ft/yr. Other water uses in the basin, including domestic and stock watering uses, are estimated to not exceed 200 ac-ft/yr, and no significant increase in this category of use is expected during the operating life of the power plant.

Streamflow derived from the headwaters area of Thousand Springs Creek, i.e., the approximately 68 square miles of the Snake Mountains drainage above the Wilkins streamflow gaging station, is equal to about 25 percent of the average precipitation in that part of the basin, or an average of about 12,000 ac-ft/yr. Most of the runoff from Wilkins Subbasin generally occurs during the late winter or spring due to rapid snowmelt; e.g., in 1986, when total flow measured at the United States Geological Survey's (USGS's) Wilkins streamflow gage was 14,640 acre-feet (ac-ft), approximately 40 percent of that total, or 5856 ac-ft, was recorded during the last 14 days of February, and almost 90 percent of the total was recorded from February through May.

Downstream from the Wilkins streamflow gaging station and the Highway 93 crossing of Thousand Springs Creek, the total average annual flow in Thousand Springs Creek decreases progressively, indicating that there is relatively little runoff from other parts of the basin that reaches Thousand Springs Creek and that the runoff reaching the creek from those areas is less than the losses from the creek, including irrigation diversions from the creek. For comparative purposes, upstream from the Wilkins streamflow gage, the estimated average runofff is about 180 acre-feet/square mile/year (ac-ft/sq mi/yr), whereas the estimated runoff actually entering Thousand Springs Creek downstream from the Wilkins gage from the rest of the watershed is only about 5 ac-ft/sq mi/yr.

A substantial portion of the runoff from the relatively large areas of steeply sloping mountains at elevations comparably high to those in Wilkins Subbasin, which produce large amounts of runoff, is believed to percolate to the groundwater before reaching Thousand Springs Creek.

The power plant would be located in Toano Draw Subbasin. The total area of the subbasin is about 252 square miles, or about 160,000 acres. Surface water discharging from Toano Draw to Thousand Springs Creek occurs infrequently and probably averages less than about 1000 ac-ft/yr.

Chemical analyses of numerous groundwater samples, collected from wells and springs at widely distributed locations throughout Toano Draw Subbasin, indicate that much of the recharge to the alluvial aquifer underlying the broad central part of the subbasin must occur directly from infiltration of surface water on the valley floor. Relatively high rates of recharge to the aquifer in that area are indicated by the areal trends in total dissolved solids (TDS) and chloride concentrations in the groundwater. In the south-central portion of the Toano Draw aquifer, the TDS and chloride contents of the groundwater are lower than those of groundwater flowing towards the aquifer through the volcaniclastic soils on the flanks of the mountains which generally surround the alluvial aquifer.

Significant additional groundwater recharge may be contributed to Toano Draw Subbasin, or the alluvium underlying Thousand Springs Creek, from the area north and west of Toano Draw and along Thousand Springs Creek.

There currently is little use of water, for either stock watering or irrigation purposes, in Toano Draw Subbasin.

A potentially large amount of groundwater may be flowing within the Paleozoic carbonate rocks that underlie the alluvium within, and crop out in the mountains surrounding, Toano Draw Subbasin. It seems likely that this carbonate rock aquifer receives recharge from the alluvial aquifer, and that it discharges along deep flow lines beneath the mountains forming the eastern side of the subbasin. The probable area of discharge of this deep flow is the alluvial aquifer underlying the Montello area and ultimately Great Salt Lake Basin.

The depth to groundwater in Toano Draw Subbasin varies from essentially zero at the north end of Toano Draw, where it joins Thousand Springs Creek, to about 160 feet at the power plant site, which is about 10 miles south of Thousand Springs Creek. Five miles south of the power plant site, the depth to water is about 200 to 300 feet.

It is proposed that water for the first two generating units be supplied from a wellfield located a few miles south of the power plant site. This wellfield would tap the deep alluvial aquifer underlying the central part of Toano Draw Valley. Of the 8000 ac-ft/yr (maximum) required for those two units, it is believed that all would be replaced by natural recharge from precipitation.

To offset the progressive reduction in groundwater flow from Toano Draw to the Thousand Springs Creek underflow, it is proposed that the use of water for irrigation upstream from Twentyone Mile Reservoir be curtailed by an equivalent amount. It is expected that there would be no significant environmental impacts to riparian habitat along any part of Thousand Springs Creek due to power plant water uses for the first two generating units.

Withdrawing water from Toano Draw Subbasin aquifer would not significantly affect the rate of groundwater recharge within the subbasin, because under presently existing conditions there is practically no runoff entering Thousand Springs Creek from the subbasin. Almost all runoff from the mountains surrounding the subbasin currently infiltrates as it flows across the alluvial sediment that fills the broad central valley of the subbasin.

To supply water for power plant Units 3 through 7, and possibly Unit 8, it is proposed that a wellfield be developed within Thousand Springs Valley downstream from the confluence of Crittenden and Thousand Springs creeks. Ultimately, this wellfield may extend southward to near the Town of Montello and east to near Dake Reservoir. A pipeline sized for serving five or six units (about 33 inches diameter) would be installed for transporting the water to the power plant site.

Present net consumptive water use for irrigation downstream from Twentyone Mile Dam is about 9000 ac-ft/yr. This water use will be curtailed, as necessary, to offset the power plant water uses for Units 3 and 4, and part of Unit 5.

Water for the balance of the requirements for Unit 5, about 3000 ac-ft/yr not offset by reduced irrigation, plus all of the requirements for Units 6 and 7 probably will be offset by aquifer recharge from precipitation within Montello Subbasin--by the Maxey-Eakin estimating procedure this amounts to about 12,000 ac-ft/yr.

The quantity of groundwater presently discharging to Utah from Thousand Springs Basin was estimated to be on the order of 30,000 ac-ft/yr. Pumping of the Montello Subbasin alluvial aquifer ultimately will reduce the groundwater discharge to Utah by the amount the net pumpage exceeds the present net consumptive use, about 15,000 ac-ft/yr, in the subbasin.

The average groundwater recharge rate to Thousand Springs Basin as a whole has been estimated, using the Maxey-Eakin procedure, to be approximately 61,000 ac-ft/yr. Hydrologic budget calculations have yielded approximate estimates of basin recharge rates that are of the same order as the estimates based on the Maxey-Eakin method; they range from about 33,000 to 61,000 ac-ft/yr. Thus, it appears that the renewable resources of the basin, on an average annual basis, are substantially larger than the maximum water requirement of the power plant.

Present expectations are that the water resources within Toano Draw subbasin are adequate to supply a third generating unit, i.e., Unit 8. It is proposed that initial development of the water resources in this subbasin be limited to the requirements of the first two units to be constructed, and that an aquifer water-level monitoring network be installed and operated to assess the aquifer response to the withdrawals required for supplying those two units. When a decision is required concerning the source of water for Unit 8--about 10 years (minimum) after the startup of Unit 2, according to the present project development plan--the data from the aquifer monitoring program should be evaluated to determine if the Toano Draw aquifer can sustain the production required for Unit 8. If not, the unused resources in the Montello area aquifer can be developed for this purpose.

Aquifer transmissivities were estimated for both the Toano Draw and the Montello area aquifers. For Toano Draw Subbasin, aquifer transmissivity estimates range from 3000 to 50,000 gallons per day/foot (gpd/ft). For the Montello area, the estimates are in the range of about 130,000 to 200,000 gpd/ft.

Numerical modeling of the Toano Draw alluvial aquifer, to portray the aquifer response to several wellfield development alternatives, indicated that the environmentally most favorable plan would be to supply water for three generating units from a single wellfield south of the power plant site. Maximum aquifer drawdown estimated for this case would be on the order of about 70 feet and would occur in the wellfield area. The indicated groundwater level decline at the north end of the Toano Draw aquifer, along Thousand Springs Creek, would be negligible in this case.

Water quality in both the Toano Draw and the Montello area aquifers appears to be acceptable for power plant uses. However, pre-treatment may be needed to reduce the total dissolved solids (TDS) and silica content of the water prior to use as makeup water for the steam generators. The TDS content of the groundwater ranges from about 200 to 500 milligrams per liter (mg/L) within the Toano Draw aquifer. In the Montello area aquifer the TDS is generally higher. The silica content of the groundwater is relatively high in the Toano Draw area, up to about 80 mg/L, whereas in the Montello area the silica content of the groundwater is significantly lower, ranging from about 12 to 34 mg/L.

An existing irrigation well, about 3 miles north of the power plant site, and a pilot production well, installed as part of this investigation about 2 miles south of the plant site, are both available and adequate to supply construction water for the first power plant unit.

In this reconnaissance-level investigation of Thousand Springs Basin as a whole, surface geophysical survey techniques were found to be useful, expedient, and economical for identifying areas with substantial thicknesses of potential aquifer materials. These geophysical techniques are believed applicable and appropriate for guiding the locations of more detailed exploratory drilling investigations that should be completed before starting project wellfield developments.

Wellfield development for the first two generating units should start with a detailed surface geophysical survey of the area south of the power plant site that was identified in this investigation as potentially favorable for the purpose. Pilot borings should be drilled in the areas indicated as most favorable from the geophysical survey to check the validity of the geophysical survey results. These surveys and exploratory drilling should be undertaken at least 2 years before planned startup of the first generating unit. Placement of production wells should be based on the conclusions of the two investigatory techniques.

Groundwater and surface water monitoring programs should be initiated as soon as reasonably possible in both the Toano Draw and Gamble Ranch vicinities. The Gamble Ranch program should also include drilling, aquifer testing, and compilation of records of current water uses from both surface water and groundwater sources.

2.0 INTRODUCTION

2.1 PROJECT OVERVIEW

This report presents the results of a study to assess the water resources of Thousand Springs Basin, in northeastern Nevada (see Figure 2-1). The study was performed as part of the process of preparing the Environmental Impact Statement (EIS) for the proposed Thousand Springs Power Plant (TSPP) Project. A major objective of the study was to provide information needed for developing the groundwater resource of the basin and evaluating the hydrologic balance with and without the proposed power plant. For this purpose, it was necessary to identify the most likely sources of water for supplying the power plant requirements, and prepare conceptual plans for how those resources would be developed and utilized. The proposed power plant, at ultimate planned development, would contain eight coal-fueled, 250-megawatt (MW) generating units. Each generating unit would require a maximum of 4000 acre-feet/year (ac-ft/yr) of makeup water to support its operation.

It is believed that the total water resources of Thousand Springs Basin are derived from precipitation falling within the watershed boundary of the basin. An investigation of groundwater levels in the limited number of springs and wells within and surrounding the basin (Section 4.0) found that the hydraulic gradients of the water table on both sides of the topographically elevated watershed divide were consistently away from the divide, suggesting that there was no flow across the line marking the divide.

For the purposes of this study, the basin of concern lies upstream from the United States Geologic Survey's (USGS) Montello streamflow gaging station, located about ½ mile upstream from where Thousand Springs Creek flows into Utah and Great Salt Lake Basin. Outflow from Thousand Springs Basin at the Montello station consists of surface water flow in the stream channel, which is measured by a recording gage, and underground flow. In order to derive the basin hydrologic balance, the total basin precipitation was estimated and equated to total evapotranspiration within the basin plus surface and groundwater outflow. It is noted that within the basin as a whole there is, and has been historically, relatively little groundwater development and use, when considered in relation to the total water resources of the basin. Therefore, when considering long-term trends, the groundwater basin as a whole is essentially in equilibrium with the climatic regime; i.e., precipitation infiltrating to the groundwater is essentially equal to the long-term groundwater discharge from the basin. The minor inequality is the result of the relatively small net amount of groundwater extracted for ranching operations--primarily irrigation uses--within the basin.

It is expected that the power plant water requirements would be supplied from wellfields that tap the groundwater resources of the basin. As a result, the present equilibrium in the groundwater system would be modified. One result of this modification is expected to be that some of the groundwater which presently discharges from the basin would instead be captured by the project wellfields. An important focus of this study was to estimate the average annual streamflow in Thousand Springs Creek under present conditions, the extent to which this flow contributes to groundwater recharge, and how recharge rates would change after the power plant began operation.

2.2 PURPOSE OF REPORT

This Water Resources Evaluation Report has been prepared by Woodward-Clyde Consultants (WCC) to provide the information needed to evaluate the groundwater resources available for supplying the proposed TSPP. The report has been prepared for Lands of Sierra, Inc. (LOS), a subsidiary of Sierra Pacific Resources. LOS owns practically all of the water rights in Thousand Springs Basin that have been granted by the State of Nevada. LOS is contractually obligated to provide water to TSPP on an as-required, priority-of-use basis. The principal purpose of the report is to provide the detailed geologic, hydrogeologic, and hydrologic data and analyses required to characterize the groundwater resources and flow systems in Thousand Springs Basin. Included in this report are assessments of potential groundwater system yields, recharge rates, streamflow characteristics, the interaction between surface water and groundwater systems, and water budget analyses. An additional objective of the report is to provide an evaluation of the effects of project-related groundwater withdrawals on existing water uses, basin productivity, groundwater levels, water quality, and the existing environment. For this report, special emphasis was placed on characterizing the groundwater system of Toano Draw Subbasin, relative to the water needs of the first proposed power plant unit, i.e., approximately 4000 ac-ft/yr. However, the report also includes an evaluation of the regional water resources for supplying the water needs of the power plant as it expands to its planned ultimate size of eight units, each requiring a maximum of 4000 ac-ft/yr, and the potential water resources impacts of pumping at those levels (up to a maximum of 32,000 ac-ft/yr of water) for the anticipated 49-year life of the project, from initial startup of the first generating unit to final shutdown of the eighth generating unit.

2.3 OVERVIEW OF SCOPE OF WORK AND REPORT ORGANIZATION

The scope of this investigation included many types of geologic and hydrologic data acquisition, compilation, mapping, analyses, and interpretation. The characterization of aquifer thickness and extent was based on regional geologic mapping, extensive geophysical surveys, compilation of existing well logs, and exploratory drilling and logging of new wells, as described in Section 3.0. A total of 12 new wells was installed by WCC for groundwater monitoring and aquifer testing, as described in Section 4.0. The hydrogeologic setting of the basin was characterized, based on a comprehensive analysis of groundwater-level data from approximately 70 wells and results of six aquifer pumping tests. These data supplement information provided by the geologic characterization, and by results of aquifer tests reported by previous investigators, notably Rush (1968) and Guyton and Associates (1982). Groundwater characteristics and quality trends were analyzed and mapped, and are discussed in Section 5.0 relative to elucidating the flow system. Concentrations of hydrochemical constituents in groundwater that are considered significant to the power plant water supply are also described in Section 5.0.

Available precipitation records and streamflow measurements were compiled and analyzed to estimate basin, and selected subbasin, runoff and groundwater recharge rates. These data have been incorporated into hydrologic budget analyses of the basin and selected subbasins, as described in Section 6.0.

A numerical groundwater flow model was developed for Toano Draw Subbasin and vicinity, for quantitative evaluation of the water resources described in Section 7.0. This computer model was applied to simulate the drawdown effects of anticipated project wellfields, as described in Section 8.0. In addition, Section 8.0 contains the results of analytical modeling that was performed to estimate the effects of pumping in the area of Gamble Ranch, which was outside the boundary of the numerical flow model.

Project-related water rights issues are discussed in Section 9.0. Results of the flow modeling analyses have been used to assess the potential for the various hypothetical wellfields to meet the plant water requirements, and the potential impacts of pumping on existing water rights, supply wells, streamflow, springs, and riparian habitat. Descriptions of these estimated environmental impacts, and the potential water quality impacts of groundwater extraction, are described in Section 10.0.

Hydrologic monitoring plans for precipitation, streamflow, groundwater extraction quantification, groundwater levels, water quality and subsidence, designed to establish baseline conditions, and to detect and evaluate project-related effects of power plant operation as they occur, are included in Section 11.0. Section 12.0 of this report provides recommendations for the next phase of work for development of the groundwater supply wellfields and systems.

The appendices to this report provide basic data, and descriptions of the methods of data collection and analysis, that were used as a basis for the findings of the report.

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Available precipitation records and streamflow measurements were compiled and analyzed to estimate basin, and selected subbasin, runoff and groundwater recharge areas. These data have been incorporated into hydrologic budget analyses of the basin and selected subbasins described in Section 6.0.

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Projected ground water level declines are discussed in Section 9.0. Results of the flow modeling analyses have been used to assess the potential for and effects of groundwater withdrawals to meet the plant water requirements, and the potential effects of pumping on existing water rights, springs and seeps, streamflow, springs, and riparian habitat. Descriptions of these effects and of the potential effects on water quality, including groundwater chemistry, are described in Section 10.0.

Hydrologic monitoring plans for project wellfields, groundwater extraction, potential effects on private wells, water quality, and subsidence, and for potential sensitive springs and seeps, and to evaluate project-related effects on these resources and other issues, are included in Section 11.0. Section 12.0 presents conclusions and recommendations for the next phase of work for development of the groundwater supply wellfields and systems.

The appendices to this report provide basic data, and descriptions of the methods and data interpretations which were used as the basis for the findings of the report.

3.0
GEOLOGY AND GEOPHYSICS

Geologic and geophysical mapping was conducted within Toano Draw Subbasin to provide hydrogeologic information regarding groundwater availability for the proposed Thousand Springs Power Plant (TSPP). Two objectives were established for this task:

- Identify and describe surface geologic deposits and structural features that might affect groundwater availability within the subbasin.
- Provide a preliminary estimate of the areal extent, thickness, and depth of the principal aquifer and aquitards within the subbasin.

These objectives were accomplished by integrating both geological and geophysical data. Surficial deposits and structural features were identified by review of available literature, aerial photographic reconnaissance, and field mapping. Estimates of aquifer dimensions were established by surface and borehole geophysical surveys and modeling correlated to geologic mapping and petroleum and water well data.

The geological and geophysical studies were conducted by Woodward-Clyde Consultants (WCC) personnel. Time domain electromagnetic (TDEM) and dipole-dipole resistivity surveys and modeling were performed by Blackhawk Geosciences, Inc., of Golden, Colorado.

3.1 GEOLOGIC MAPPING

The geologic mapping was conducted during three principal phases: (1) available geologic data including published reports, well geophysical and lithologic logs, and consultants' reports were reviewed, (2) aerial photographs were examined, and (3) field mapping, consisting of ground reconnaissance and an aerial overflight, was performed to augment and verify aerial photograph interpretations.

3.1.1 Available Geologic Data

Although little geologic mapping has been conducted in the Toano Draw Subbasin, several reports written about nearby areas are available which provide basic data important to the understanding of the geology within the study area.

Eakin, Maxey, and Robinson (1951) and Eakin and Maxey (1951) authored two groundwater hydrology reports regarding the Goshute and Antelope valleys to the south and the Clover and Independence valleys to the southwest. These reports, published within a compilation of similar studies concerning the hydrology of eastern Nevada, contain cursory information about the regional geology.

Rush (1968) conducted one of the first geologic reconnaissance projects in the area. The purpose of the study was to evaluate the water resources of Thousand Springs Basin, an area which encompasses the adjacent Montello-Crittenden Subbasin to the east, Rock Spring Valley to the north, Herrell Siding Subbasin to the west, and the Rocky Butte area at the confluence of Twentyone Mile Draw and Thousand Springs Creek to the northeast, as well as Toano Draw. Rush developed a preliminary geologic map which roughly delineates the areal extent of Paleozoic rocks, Tertiary volcaniclastic deposits, and unconsolidated sediments. In addition, Rush identifies several Basin and Range style normal faults along the western side of Toano Draw and along the southeastern flank of the HD Range to the north of Thousand Springs Creek. Rush described four broad lithologic units based primarily on hydrologic properties: carbonate rocks, noncarbonate rocks, and older and younger alluvium. He speculated that a large volume of water moves through the carbonate rocks in the north part of the basin and beneath the channel of Thousand Springs Creek.

The geologic map of Nevada (Stewart and Carlson 1974) provides generalized stratigraphic and structural information about the study area at a scale of 1:500,000. Toano Draw Subbasin is located in a zone of transition between the northern portion of the Basin and Range physiographic Province and the Snake River Plain to the north. Typically, the Basin and Range province is characterized by well-defined, linear, northward-trending valleys and mountain ranges bounded by normal faults. However, as shown on the regional map, Toano Draw Subbasin is broad and the adjacent mountains are less linear than those to the south. Also, as on the Snake River Plain, volcanic rocks, including volcaniclastic sediments, are more abundant than most of the Basin and Range Province. This map indicates that surficial deposits of Toano Draw Subbasin primarily consist of volcaniclastic sediments with alluvium lying only in stream channels.

A 1:100,000 scale geologic map (Hope and Coats 1976) of Elko County depicts the extent of volcaniclastic deposits in greater detail and identifies lithologies of Paleozoic and Mesozoic rocks which outcrop in the mountains surrounding the study area. Surficial deposits of the Toano Draw Subbasin are more accurately shown to consist of a large volume of volcaniclastic sediments interfingering with sediments of a large alluvial fan complex that surrounds the Toano Draw channel.

WCC (1981, 1982) performed preliminary geologic and geotechnical investigations within Toano Draw Subbasin to provide a preliminary assessment of material conditions at the proposed plant site, an ash disposal site, and some potential borrow areas. The investigation included geologic reconnaissance and mapping, subsurface drilling, and laboratory analysis of geotechnical samples. These investigations concluded that surface materials are silt at the ash disposal site and cemented pyroclastic sediments at the proposed plant site.

Erwin (1980) produced a 1:250,000 scale Bouguer gravity map providing coverage of the Wells 2° Sheet. This map, although regional in scale, provides information about the structural configuration of the Paleozoic basement within the Toano Draw Subbasin. A reinterpretation of the gravity data by West (1987) shows the following additional faults: north-trending Basin and Range normal faults along the eastern and western margins of Toano Draw Subbasin, a northwest-trending normal fault along the southern basin margin bounding the northern Pequop Mountains, and several northeast-trending faults at the southern end of Twentyone Mile Draw and to the north of Thousand Springs Creek in the northern part of the valley. West (1987) also indicates that the upthrown sides of the range-front faults at the margins of the subbasin are comprised of relatively shallow occurrences of bedrock or piedmont fronts. This suggests that the bedrock was eroded at some time in the past and has subsequently been elevated along the faults.

Guyton and Associates (1982) performed a preliminary study of the groundwater conditions in the Thousand Springs Creek area. The report subdivides the rocks in the area into three major categories: noncarbonate consolidated formations, carbonate formations, and unconsolidated sediments. Unconsolidated deposits are further subdivided into four categories: lake deposits, tuffaceous sedimentary material, older alluvium, and recent alluvium. The lake sediments, which were deposited in late Pleistocene time and reached an upper elevation of 5100 feet, are located primarily within Montello Valley to the east.

A report prepared by the Bureau of Land Management (BLM) (1986) in anticipation of a land exchange between Lands of Sierra (LOS) and the BLM supplies lithologic descriptions of rock units, a brief history of the regional geology, and an assessment of the mineral potential of the land considered for the exchange.

Additional geologic information was gathered from petroleum and water well logs and a report summarizing well log data (Guyton and Associates 1982). The water well logs were provided by the Nevada State Engineer's Office, Carson City, Nevada, and R.D. Reynolds Drilling, Inc., Wells, Nevada. Petroleum logs were obtained from Nevada Bureau of Mines, Reno, Nevada, and the Petroleum Information Corporation of Bakersfield, California.

3.1.2 Aerial Photograph Reconnaissance

Interpretation of geologic features using aerial photographs is a standard procedure in most geologic evaluations. Aerial photographs provide an expeditious means of conducting an initial investigation of a large area, such as Toano Draw Subbasin. The aerial photographic reconnaissance is supplemented by field mapping to verify observations.

A total of 285 black and white, stereoscopic aerial photographs at a scale of 1:36,000 were purchased from the U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota. The photographs were taken along two flight lines: GS-VBNM, along the eastern portion of Thousand Springs Valley, flown in 1966, and GS-VBST, along the western portion of Thousand Springs Valley, flown in 1967.

Aerial photographs were examined in stereoscopic perspective to map surficial stratigraphic units and structural and geomorphic features. Stratigraphic units were differentiated based on several criteria, including texture and pattern, tonal contrast and color, aerial extent, and vegetation.

Structural features such as faults, folds, joints, and lineaments were identified based on several criteria defined by Ray (1960). These criteria include alignments of vegetation; straight stream segments; knickpoints or waterfalls across streams; alignments of ponds, springs, lakes, and marshy areas; linear changes in photographic tone, drainage, or erosional texture; tonal changes due to vegetation differences along a linear feature; alignments of topography such as facets, spurs, ridgelines, and scarps; and linear depressions, such as saddles, and rectilinear depressions.

Preliminary geologic interpretations were recorded on Mylar overlays attached to individual photographs. These observations were later checked during field reconnaissance and transferred to a topographic map base at a scale of 1:100,000.

3.1.3 <u>Geologic Field Reconnaissance</u>
This phase of geologic mapping involved ground reconnaissance and a fixed-wing aerial overflight. The field mapping was conducted during two site visits, from July 14 to 18, 1988, and August 29 to 31, 1988. The aerial overflight was performed on the morning of August 30, 1988.

The purpose of field mapping was to provide verification of the aerial photographic interpretation and to gather field data that could not be obtained at the photograph scale. Mapping consisted of a series of traverses across Toano Draw Subbasin and a loop around the perimeter of the subbasin using a four-wheel-drive vehicle. Locations were plotted using aerial photographs, 7.5 minute topographic sheets at a scale of 1:24,000, and topographic sheets at a scale of 1:100,000.

The aerial overflight, using a fixed-wing aircraft provided by Sierra Pacific, provided closer views than aerial photographs of areas inaccessible by four-wheel-drive.

Observations from geologic field mapping were incorporated with aerial photographic interpretations and available literature to construct a geologic map at a scale of 1:100,000 (Figure 3-1).

3.2 GEOPHYSICAL DATA

3.2.1 Regional Data

A review of the available regional geophysical data, both gravity and aeromagnetics, was conducted prior to development of the geophysical field program. This information was utilized to concentrate efforts, during the field reconnaissance, in areas thought to be geologically favorable for substantial quantities of groundwater.

3.2.1.1 Gravity Data. Regional Bouguer gravity data for the Toano Draw area is depicted on a 1:250,000 scale map of the Wells 2° sheet by Erwin (1980). Supplemental interpretation of these data by West (1987) was also obtained for this investigation. Regional gravity data provides general information about the depth and geometry of basins, regional and local structures, and the predominant materials in the area. The Basin and Range Province is especially conducive to gravity evaluations because of the elevation contrast between valley basements and adjacent mountains, and the density differences between the Paleozoic rocks, Tertiary volcanics, and unconsolidated Quaternary sediments. Density values for rocks in the study area range from 2.6 to 2.7 grams per cubic centimeter (g/cc) for the consolidated Paleozoic rocks, to less than 2.4 g/cc for the unconsolidated valley sediments, and as low as 1.7 g/cc for the pumiceous volcanic sediments.

In general, the large gravity lows in the valleys and basins reflect low-density volcanic and sedimentary rocks overlying denser consolidated rocks. Faults and steeply dipping bedrock are represented as closely spaced contour lines, especially along valley margins. Local undulations in the contour patterns of the gravity data may indicate small subbasins or pediments (erosion surfaces) (Erwin 1980). The wide spacing of gravity survey stations, however, limit the map resolution.

West (1987) reports that the basement in the southern part of the Toano Draw Subbasin is 7000 to 9000 feet below the ground surface. The basin shallows northward to less than 5000 feet deep. In addition, he suggests that faults, probably having normal displacement, bound the valley on all sides. Erwin (1980) and West (1987) conclude that pediments extend into the basin from the range fronts along the west, east, and south margins of the basin. These pediments are truncated by the frontal faults. Small northeast-trending features in the gravity contours in the southern part of the valley near Deadman Creek, and to the north near the southern end of Twentyone Mile Draw (Erwin 1980), may be related to smaller subbasins.

3.2.1.2 Aeromagnetics. A regional aeromagnetic map of the Wells quadrangle at a scale of 1:250,000 (DOE 1979) defines some of the larger-scale features in the study area. The resolution of the data is limited because the flight lines were widely spaced. The data suggest that the volcanic deposits in the northern end of the basin are magnetically low and possibly felsic in composition. Also, two magnetic anomalies to the north and west of the basin may reflect intrusive bodies, possibly remnants of the volcanic sources for the area.

3.2.2 Surface Geophysical Data Collection

Two geophysical surveys were conducted in Toano Draw Subbasin during the period July 11 to 18, 1988, to determine the more effective method of detecting the presence and extent of potential water-bearing aquifers. One survey consisted of 23 time-domain electromagnetic (TDEM) soundings at 21 locations. Most sites were located at proposed or existing well locations. The other survey consisted of two dipole-dipole resistivity-induced polarization lines totaling about 27,000 linear feet in length.

These two geophysical methods have been used by the petroleum and mining industries in Nevada for several years. TDEM soundings have been employed for deep basin exploration and have been used in Nevada to map limestone and volcanic units at intermediate depths. This method is also used to define aquifer thickness at individual sounding stations. Dipole-dipole resistivity provides a tool for mapping lateral variations in resistivity of materials such as clay and gravel. It can also define shallow subsurface variability of aquifer thickness and character. The data from these two surveys were interpreted using available regional gravity and aeromagnetic data, lithologic and geophysical logs from new Woodward-Clyde Consultants (WCC) borings and as available from existing water and petroleum wells, and results of geologic mapping.

The TDEM method was determined to provide the most conclusive information regarding aquifer thickness and character. As a result, an additional survey, consisting of 77 TDEM soundings in Toano Draw Subbasin (Figure 3-2) and 9 soundings in the adjacent Montello area of the Thousand Springs Basin, was conducted.

3.2.2.1 TDEM Soundings. TDEM soundings map vertical variations in resistivity beneath an array consisting of a large transmitter loop and a smaller receiver loop placed on the ground. Most transmitter loop sizes for this survey were 1000 feet per side, although a few loops were 500 feet per side. A current with a square waveform is pulsed through the transmitter loop and received by the smaller loop located at the center of the array. The receiver records decaying voltages at specified times after the pulse is turned off in the transmitter loop. The measured rate of decay at the receiver is proportional to the rate of decay of the vertical magnetic field inside the loop. This in turn is proportional to the resistive structure below the station. The depth of penetration is a function of loop size, frequency of signal, and ground resistivity. Generally, the maximum exploration depth is approximately one to two times the length of one side of the loop. Based on correlation of the TDEM data with available well logs, the depth of exploration for this survey was 500 to 1000 feet for most soundings.

TDEM sounding sites were placed near existing or proposed wells and selected geographic features. Sounding locations were also selected where they were expected to provide the best information for constructing basin cross sections.

3.2.2.2 Dipole-Dipole Resistivity Mapping. Dipole-dipole resistivity surveys provide a combination of profiling (detection of lateral resistivity changes) and sounding (detection of vertical resistivity changes) to a depth of about 1000 feet. Two dipole-dipole surveys were conducted within Toano Draw Subbasin. The basic array consists of two dipoles, a transmitter, and a receiver. Each dipole is 500 feet long and both dipoles are oriented along the same line. The dipoles are separated by varying distances equal to a multiple of the dipole length, e.g., 500, 1000, 1500, and 2000 feet. The array is moved along the profile line with each dipole acting alternately as a transmitter and as a receiver. High-voltage current is applied to the transmitting dipole and a voltage is detected along the receiver dipole. The received voltage is interpreted as a resistivity value representative of the mean resistivity of the material between the dipoles. The mean values are plotted along the profile to create a cross section of resistivity values representing lateral and vertical changes.

3.2.2.3 Induced Polarization. Induced polarization (IP) was initially considered as a possible method to evaluate aquifer potential. Investigations performed in similar conditions have reported that clays often have a unique IP response which distinguishes them from other materials. Preliminary evaluation of the IP data indicates that a condition referred to as inductive coupling exists at the site. This condition "masks" the clay responses and reduces the effectiveness of the IP survey. Thus, it was decided that the IP survey would not provide useful information for this study.

3.2.3 Borehole Geophysical Data

Geophysical logging is routinely conducted during development of oil and gas wells and also many water wells. The various logging methods provide additional descriptive tools beyond lithologic logging. Typically, several methods are used in a single borehole to insure that as much information is retrieved as possible. The most often used methods include:

- Long and short normal resistivity - These two methods measure the resistivity of materials at the borehole interface. The long normal method employs an electrode separation of 64 inches, which allows it to detect material resistivities deeper into the boring wall. The short normal method uses an electrode separation of 16 inches, which decreases the detection distance within the borehole but allows for increased vertical resolution of layers. Highly resistive values generally reflect coarse-grained materials. Lower resistivity values are typically associated with highly conductive clay units.

- Self potential (SP) - This procedure measures the potential for current flow in a material. In a manner similar to normal resistivity, these intrinsic values can be used to map different units such as clays and gravels. In addition, SP can also be used to detect changes in water quality.

- Natural gamma - Clay materials generally contain relatively high percentages of potassium. As potassium-40 decays to argon-40, it emits gamma rays. The natural gamma ray method detects the emission of these rays. A clay-rich unit, which may act as an aquitard, will be associated with higher gamma ray values than sand or gravel units.
- Caliper - Calipers measure the diameter of the boring wall. Poorly consolidated gravelly materials tend to slough, which results in an increased hole diameter. Clays, however, either retain the original dimension of the hole or, in the case of expansive clays, decrease the hole diameter.

3.2.3.1 WCC Monitoring Wells. The various downhole geophysical methods described in the previous section were utilized at the study site for select WCC monitoring wells. Strata Data of Elko, Nevada, was contracted to conduct downhole geophysical surveys on the selected wells. The results of the surveys were used to interpret the TDEM data and are discussed in Appendix A-2, Correlation of TDEM Data with WCC Monitoring Wells.

3.2.3.2 Existing Water and Oil Wells. Several existing agricultural well logs, provided by the Nevada State Engineer's office, were used to confirm the interpretation of the TDEM data. In addition, an isopach map of the principal aquifer unit was constructed using selected well and TDEM data (Figure 4-3). Production records from Wells 41-65-35ab and 41-65-35bd show relatively high yields. These wells are located within the coarse-grained unit defined by the geophysical data. Toano Well No. 1, Toano Well No. 2, and Fivemile Draw Well, active stock wells with moderate to low production, lie near the margin of the proposed aquifer unit.

Wells drilled in primarily fine-grained material and with poor production histories generally lie outside the coarse-grained unit defined by the TDEM data. Examples include the small wellfield west of WCC Well MW-2 and the Toilet and Jog Wells at the southern end of Twentyone Mile Draw (Figure 4-3, map of well locations and isopach).

Logs from three exploration oil wells were also used to refine the basin stratigraphy: Gulf Refining Company Thousand Springs No. 1 (T40N, R66E, sec. 8), Sun Exploration Company Southern Pacific No. 1 (T39N, R65E, sec. 33), Sun Exploration Company Southern Pacific No. 3-13 (T39N, R65E, sec. 13). Information from Sun Exploration and Production Company Toano Federal No. 1 (T40N, R65E, sec. 10), located in the area, was not used because only natural gamma logs, which do not provide much stratigraphic information, were available.

Thousand Springs No. 1 is located about 1 mile southeast of WCC Well MW-12 (EM-14). TDEM Sounding EM-47, located near the petroleum well, yielded stratigraphic information that was similar to the lithologic interpretation derived from electric and SP logs from the well.

Southern Pacific Wells No. 1 and No. 3-13 are located in the southwest portion of the basin. Logs from these wells provide the following information:

- Several hundred to thousands of feet of volcaniclastic sediments are present in both wells.
- Well SP No. 3-13 lies near the gravity low at the basin center. The upper 800 feet of section in this well is described as valley fill, probably equivalent to the channelized alluvial units described in this report.
- An minimum slip of 8800 feet down-to-the-east can be estimated for a fault lying between the two wells. The upper, probably eroded, contact of Triassic marine sediments is located at a depth of 1615 feet in SP No. 1 and 10,422 feet in SP No. 3-13. No direct correlation of stratigraphic units could be made, so the displacement estimate is a minimum value.

3.3 GEOPHYSICAL MODELING AND RESULTS

3.3.1 TDEM Data Analysis and Modeling

The iterative inversion program used for the TDEM data in this study, AARTI by INTERPEX Ltd. of Golden, Colorado, is based on ridge regression. The modeling process begins with a seed model, usually consisting of three or four layers of specified resistivities and thicknesses. The program generates a forward solution of the voltage decay curve based on the seed model. Model and field data curves are then compared and, through iterations, an approximate match of the curves is developed. The number of layers and layer parameters (thickness and resistivity) can be changed, as required, to improve the match between the model and the field data curve. The final result is an approximation of the layering of materials beneath the sounding site.

3.3.1.1 Correlation of TDEM Data. Data from other sources were used to correlate the TDEM data with the site-specific number, thickness, and lithologies of layers. Data sources include lithologic and geophysical well logs, production records from wells, and geologic mapping. The TDEM data were in reasonably good agreement with the applicable lithologic logs (see Appendix A-2 for discussions of correlations). In general, wells located in areas suggested by the TDEM results to consist of large amounts of coarse material intersected thick sections of sand and gravel. It is noted, however, that the well logs did list some clay layers up to 20 feet thick that were not identified by the TDEM model.

Downhole geophysical logging, including short and long resistivity, spontaneous potential, natural gamma, temperature, sonic, and caliper methods, was conducted in the well boreholes. Of these methods, downhole resistivity logs provided the best correlation with TDEM resistivities and were primarily used, in conjunction with lithologic logs, to infer lithologies based on TDEM values.

Stratigraphic units described from geologic mapping were compared to results of the TDEM survey. Major lateral changes in TDEM resistivity values correspond to lithologic changes mapped at the ground surface. In addition, several faults mapped by geologic reconnaissance were also identified by TDEM methods.

3.3.1.2 Limitations. Several factors associated with the geophysical modeling can affect results. First, the principle of equivalence states that for any given set of field data, such as the decay curve obtained at a TDEM sounding site, several different layered models may be applied equally well; the geophysicist has to use judgment in deciding the number and thicknesses of layers which are most likely present at the site. This problem can be minimized by integrating other hydrogeologic information into the model.

Also, the TDEM model considers materials at a sounding site to consist of discrete, homogeneous layers. Actual conditions are typically highly variable and materials are heterogeneous. This limitation in the model may be minimized by correlation of sounding data with lithologic and electric well log records.

It should be noted that although TDEM soundings may provide a general indication of the thickness and distribution of coarse- and fine-grained deposits, the TDEM method alone does not have the capability to define the hydraulic properties of the material. However, it may be used as a general exploration tool to indicate the water-bearing potential of the unconsolidated sediments. Based on the available subbasin data, it appears that TDEM provides better information regarding areas to avoid due to poor aquifer potential rather than pinpointing areas of promising production.

3.3.2 Dipole-Dipole Resistivity Analysis and Modeling

Dipole-dipole resistivity data were processed in the field using a Zonge Engineering TIP-16 receiver. During data collection, a resistivity and induced polarization value is computed for each station. The apparent resistivity value is divided as a function of the dipole spacing, the input transmitter current, and the measured receiver voltage. The induced polarization value is computed by a complex algorithm which compares the waveform detected by the receiver with the transmitter input waveform. The resultant values are then plotted onto a pseudo-section.

3.3.3 Toano Draw and Vicinity Results

3.3.3.1 TDEM Survey. TDEM soundings may be used to establish a range of resistivities applicable to specific geologic materials. These resistivity values are then verified using data from electric and lithologic logs. In Table 3-1, the resistivity ranges considered applicable to the various geologic materials in the Toano Draw Subbasin are presented. The TDEM model, utilizing these derived resistivities, defines the depth of the contact between a resistor overlying a conductor. Two such contacts were located during this study in Toano Draw Subbasin. They are:

- The interface between a coarse-grained aquifer unit (15-30 ohm-meters [ohm-m]) and a clay rich unit (8-15 ohm-m)
- The contact between a clay-rich unit (8-15 ohm-m) overlying a clay-rich tuffaceous volcanic unit (<8 ohm-m)

Because of the limited resolution of the TDEM model, these contacts may actually be gradational and represent an interval 100 to 200 feet thick.

Several cross sections of Toano Draw and vicinity were developed using the TDEM data (Appendix A-1). Profiles I through VIII trend east-west across the axis of the basin, and Profiles IX through XI parallel the Toano Draw drainage. Discussions of individual profiles are included in Appendix A-1.

The TDEM modelling and geologic mapping indicate that the coarse-grained aquifer occupies a relatively narrow but thick zone near the axis of Toano Draw. In the subsurface, this zone extends to the east and west of the present surface expression of the drainage (Figure 4-3). A relatively wide range of resistivity values has been assigned to this coarse-grained unit. This reflects the heterogeneity of the unit caused, in part, by local interfingering of finer-grained alluvial fan deposits.

In general, the three alluvial stratigraphic units defined by the TDEM model are all present near the axis of the basin. However, the upper two units thin and are commonly absent near the valley margins, where finer-grained deposits are more abundant.

The configuration of sediments in this basin is not typical of the majority of basins in the Basin and Range Province. More commonly, fine-grained sediments predominate the center of the valley and coarse-grained sediments make up the majority of deposits along the range front. This difference in stratigraphy might be due to several factors:

- Pluvial lakes, which deposit primarily fine-grained materials, have not extensively occupied Toano Draw Subbasin.
- Toano Draw is relatively narrow, allowing alluvial fans to extend farther into the center of the valley as compared to wider valleys. The fans have constrained the course of Toano Draw to the valley axis.
- Unlike many valleys in the Basin and Range Province, Toano Draw has an external drainage into Thousand Springs Creek. Fine-grained materials are washed out of the valley by the streams, leaving the coarser fraction behind.

3.3.3.2 Dipole-Dipole Resistivity Survey. The dipole-dipole survey was conducted in the southern part of Toano Draw, primarily between Toano Wells No. 1 and No. 2 (Figure 3-2). Apparent resistivities vary between 10 and 40 ohm-meters along the profiles. In addition, resistivity values generally decrease with depth. Higher resistivities are considered indicative of zones of sand and gravel, while lower resistivities are associated with clay-rich layers. A thick, highly resistive section is located between Stations 110 and 125 on Line No. 1 (Figure 3-2), thus indicating this site may be favorable for water production. Well MW-15, drilled to a depth of 425 feet within this section, encountered 125 feet of gravel and sand at a depth of 275 feet. This was overlain by gravelly and sandy clay to the ground surface.

WCC Well MW-3, located at Station 22.5, is situated on the edge of a resistive unit. The upper 740 feet of this well is primarily coarse sand and gravel. Toano Well No. 2, a stock well, is located on a resistive feature with similar characteristics to that at Station 22.5. Both wells have relatively low yields which may be due to the proximity of the margin of the resistive unit.

3.3.4 Montello Valley

TDEM soundings were conducted in Montello Valley along a reconnaissance survey profile. Results of these soundings reveal a relatively thick section of material with resistivities from 24 to 31 ohm-m. These resistivity values have been evaluated in conjunction with other lines of evidence and suggest that coarse-grained sediments of relatively high water-transmitting capacity are present along this profile. This evidence includes:

- Relatively high water-production rates from large-capacity wells in Montello Valley.
- Well logs of existing water wells show thick sections of coarse-grained materials.
- Gravity data suggest that a thick section of sedimentary material (>9000 feet) exists in the area.

The TDEM data suggest that the bottom of the coarse-grained unit overlies low resistivity materials, most likely associated with volcaniclastic clays. Alluvial clays (8-15 ohm-m) are indicated at the southeast end and as a small wedge near the northeast end of the profile. A disparity in the apparent depth to bedrock between soundings EM-69 and EM-68 might be due to faulting.

3.4 STRATIGRAPHIC CHARACTERISTICS

Generalized stratigraphic descriptions of the rocks within the Toano Draw Subbasin have been written during previous hydrogeologic studies (Guyton and Associates, Inc. [Guyton] 1982; Rush 1968). Guyton divided the geologic units into three major categories based chiefly on anticipated water-bearing capacities. The units, listed by increasing groundwater productivity, are noncarbonate consolidated formations comprised of Precambrian to Tertiary metamorphic rocks, shales, quartzites, granitic intrusives and volcanic rocks; carbonate rocks composed of Cambrian to Permian age limestone, lesser dolomite, and minor interbedded sandstone and shale; and unconsolidated sediments including lake deposits, tuffaceous sedimentary rocks, older alluvium, and recent alluvium.

In this study, the geologic deposits are divided into five general stratigraphic units (Figure 3-3). This departure from the categories described in Guyton (1982) reflects the need to further define the water-bearing properties of the materials. These units, in order of increasing age, are Holocene channelized alluvium, Pleistocene and late Tertiary channelized alluvium, Pleistocene and late Tertiary alluvial fan deposits, middle to late Tertiary volcanic rocks and volcaniclastic sediments, and Paleozoic and early Mesozoic carbonate and noncarbonate sediments and intrusive rocks. The Holocene channelized alluvial deposits, while not mappable at the scale of the geologic map (Figure 3-1), were considered important as a stratigraphic unit. They are represented on the map as lying within the Quaternary and Tertiary channelized alluvial unit. The ability of these groundwater units to transmit groundwater varies with their permeability.

Generalized cross sections across the width of Toano Draw Subbasin (Figure 3-4 to 3-7) and along the trend of Toano Draw (Figure 3-8) were constructed using selected well data, TDEM profiles, and surface geologic mapping data.

3.4.1 Holocene Channelized Alluvium

The youngest sediments within Toano Draw Subbasin are composed primarily of channelized, unconsolidated alluvium. These deposits are located within the central portions of the larger channel systems such as Toano Draw, Fivemile Draw, Twentyone Mile Draw, and Thousand Springs Creek. They are also found within the numerous small, shallow tributary channels that drain into Toano Draw from the mountains and hills to the east, south, and west. These deposits have not been shown on the geologic map (Figure 3-1) because the scale of the map is too small to adequately represent them. The sediments are poorly to moderately sorted, coarse gravels and cobbles to sand, silt, and clay. They are derived from the older Tertiary and Quaternary alluvium, Tertiary volcanic rocks and sediments, and Paleozoic and Mesozoic rocks. In general, the alluvium is confined to the present stream channel and is no more than a few hundred feet wide along the larger streams but only several tens of feet wide along the reaches of the smaller tributaries. Within the wider channels, such as Toano Draw, narrow, complex meanders exist within a broad floodplain. These smaller channels have incised into and reworked older Quaternary alluvium, which makes up a large portion of the floodplain. The recent alluvium also exists as a thin veneer of overbank silt and sand along the margins of the channels. The thickness of these deposits varies as a function of channel width and length; the narrower, shorter channels contain Holocene alluvium only tens of feet thick while the larger stream channels have recent alluvium up to 100 feet thick.

The Holocene alluvial deposits are relatively well-sorted, coarse-grained, and permeable. Thus these deposits are more conducive to groundwater production. However, their limited thickness and the lateral extent of these sediments minimize their potential as a viable water supply.

3.4.2 Pleistocene and Late Tertiary Channelized Alluvium

Older alluvial deposits in the Toano Draw Subbasin occur as channel fill, gravel bars, and terrace remnants. These deposits are commonly overlain and incised by Holocene alluvium. They are composed primarily of detritus from Paleozoic and Mesozoic strata and Tertiary volcanic rocks and volcaniclastic deposits. The pre-Cenozoic lithologies range from limestone and dolomite to sandstone and mudstone. Volcanic clasts include rhyolite and andesite to basaltic composition. The oldest alluvium of this unit may have been deposited prior to Tertiary volcanism in the area. This may explain the virtual absence of volcanic clasts in a limestone-rich gravel bar exposed along the western margin of Toano Draw (Winecup Ranch, Nev. 7.5' topo. T40N, R65E, Sec. 5). Minor pluvial lakes most certainly occupied the lower elevations of the subbasin in late Tertiary and Pleistocene time. The associated deposits consist of coarse beach gravels and sands along the lake margins grading to fine sands and clay toward the valley center. These sediments have been located in borrow pit exposures as thin (less than 3 feet) interbeds within the alluvial deposits. It is also possible that Thousand Springs Creek was blocked by large volumes of volcaniclastic debris during eruptive periods. The debris dams would form lakes which would deposit sediments similar to those associated with pluvial lakes.

The composition of the Pleistocene and Tertiary channelized alluvial unit is similar to the Holocene alluvial unit. It consists of poorly to moderately sorted cobble and gravel to sands, silts, and clays. The degree of cementation is greater than that of the younger unit. These deposits may occur as layered successions of fluvial and pluvial subunits.

The subareal extent of these deposits has not been clearly defined because the lateral contacts with adjacent alluvial fans are complex. Both the channelized alluvium and the adjacent fans were being deposited at the same time. Small variations in climate would allow one type of deposit to dominate the other. When the alluvial fans that presently form the extensive bajada along the adjacent range fronts were smaller, the channel of Toano Draw was wider than at present. However, at other times, the prograding fans confined the channel and limited its lateral extent. Thus, the lateral boundaries of this unit are diffuse as a result of interfingering with the alluvial fans and debris flows along its flank. The present surface exposure of this unit that is restricted in the center of the valley does not represent its full extent because it has been buried by alluvial fans and debris flows. Along the valley flanks it has been buried beneath Tertiary volcaniclastic sediments and Tertiary-Quaternary alluvial fans.

Geophysical mapping using TDEM has provided approximate bounds for this unit. The depth to the base of the unit varies along the trend of Toano Draw; however, it does attain thicknesses estimated to be greater than 800 feet. Laterally, the unit is more difficult to define because of the diffuse nature of the boundary. It has been estimated from TDEM soundings that at the approximate latitude of Twentyone Mile Draw, the unit could be up to 9 miles wide. However, the TDEM results also indicate that the unit is not homogeneous and could be highly variable in composition, especially away from the center of the valley.

The alluvium thickness decreases sharply in the reaches of Thousand Springs Creek and Twentyone Mile Draw where pre-Cenozoic consolidated rocks closely bound the channel. The stream channel is less than 700 feet wide along Thousand Springs Creek southeast of Eccles Ranch. It is even narrower along Twentyone Mile Draw 6 miles south of Twentyone Mile Dam. No major faults or folds which may cause deep incision have been observed along these reaches. Alluvial thicknesses of 150 feet or less might be expected in these areas.

3.4.3 <u>Pleistocene and Late Tertiary Alluvial Fan Deposits</u>

Coalescing alluvial fans form the extensive bajada that occupies the majority of the surface of Toano Draw. Along the upper reaches of the fans, they are in faulted contact with Tertiary volcanic rocks and volcaniclastic sediments. They extend valleyward where they bound the Toano Draw channel for its entire length. Clasts are primarily derived from the volcaniclastic rocks and consist of rhyolite, andesite, and minor basalt compositions. The fans are generally poorly sorted except along established drainages. Grain sizes vary from coarse gravel to fine silt and clay. The relatively fine-grained nature of the fan materials is due to the erodible nature of the volcanic unit.

These fans have a low, rounded relief characterized by numerous broad, shallow channels. These channels form nearly linear courses along the length of the fans and have virtually no integration with adjacent drainages. The majority of the channels head at the faulted contact with the volcaniclastic unit. Through-going drainages between the volcanics and the alluvial fans are infrequent. This may be due, in part, to the dip of the volcanic beds, which opposes surface flow.

The thickness and subsurface lateral extent of the alluvial fans is variable. The fans interfinger with the Pleistocene and Tertiary channelized alluvium near the center of the valley. The overall thickness of the unit is probably greater than 1000 feet based on lithologic logs from petroleum exploration wells. This thickness can be attributed to the progressive downdropping of the valley along the frontal faults.

The alluvial fans do not appear to be good sources of groundwater to individual wells. However, on a large scale these deposits are capable of transmitting substantial amounts of groundwater. They are composed of relatively fine-grained clasts with considerable silt and clay in the matrix. Wells drilled in this unit (WCC Nos. 40-65-27 and 40-65-35) have produced relatively small quantities of water.

3.4.4 Tertiary Volcanic Rocks and Volcaniclastic Sediments

Volcanic rocks are exposed at the surface along both margins of Toano Draw, adjacent to the Paleozoic core of the mountains, and along the northern margin of the subbasin (Figure 3-1). These rocks are composed primarily of acidic rocks such as rhyolites, andesites, and associated tuffaceous sediments. In addition, basaltic flows occur in the northern portion of the subbasin. The volcanic rocks are expressed as low, undulating hills, between 5900 feet and 6500 feet in elevation, that have north-south trending crests. In the northeastern part of the study area, along Twentyone Mile Draw, the volcanic sediments dominate the topography along the lower elevations. They lap onto the flanks of the Paleozoic and early Mesozoic bedrock and fill the lowlands. It appears that these sediments have buried a more extensive previous drainage system.

Normal faults along the range fronts on both sides of Toano Draw have rotated the volcaniclastic units so that bedding dips steeply toward the mountains (greater than 60°) and away from the center of the valley. As a further consequence of faulting, volcanic rocks valleyward of the faults have been downdropped. Two fault splays mapped on the western side of the valley form the western and eastern contacts of the volcanic unit. Two petroleum exploratory wells drilled on the southwestern side of the valley by Sun Exploration Company penetrated these rocks. Well SP-1 (WCC No. 39-65-33cb) is located in Deadman Creek between the two faults. Lithologic logs suggest that the top of the volcanic rocks is at about 750 feet below the ground surface and the base is at 1700 feet. In contrast, Well SP 3-13 (WCC No. 39-65-13dd), located east of the range front faults, penetrated the top of the volcanic unit 1600 feet below the ground surface. The bottom of the unit is greater than 4500 feet deep. This concurs with analysis of TDEM soundings which suggests the volcanic rocks occur at a much greater depth on the downdropped side of the faults.

Permeabilities of the volcanic rocks vary. Welded tuffaceous units, which consist of a large component of glass, generally contain low effective porosities and are, therefore, of low permeability. Tuffaceous sandstones and vesicular rocks exhibit relatively large permeabilities and effective porosities. These welded and nonwelded units are closely associated within the volcanic unit and typically occur as sedimentary groups. Their individual thicknesses may range from tens of feet to several hundred feet. Therefore, some sections of this unit may be capable of yielding small to moderate flows to wells and are capable of transmitting substantial quantities of groundwater.

The dip of bedding, away from the valley center, opposes the flow of surface and groundwater. Several drainages, such as Hunter's Draw, Deadman Creek, and Immigrant Creek, have established courses which drain from the higher elevations of the mountains into Toano Draw. Few other drainages transport water along the surface across the volcanics. A substantial quantity of the water draining from the higher mountain areas is probably infiltrating into and is recharging the volcanic unit.

3.4.5 Paleozoic and Early Mesozoic Carbonate and Noncarbonate Sediments and Igneous Intrusive Rocks

The oldest rocks in the study area are Paleozoic sediments that make up the cores of the Windermere Hills to the west, the Gamble Range to the east, and the Pequop Mountains to the south and form the basement beneath Toano Draw. The rocks range from Cambrian to Permian in age and are principally carbonate rocks such as limestone and lesser dolomite of the Pequop Formation (Hope and Coats 1976). Additional lithologies include mudstones, siltstones, and granitic intrusive rocks. A small erosional remnant of early Mesozoic marine sediments is located in the northern part of the Windermere Hills to the west of Toano Draw Subbasin.

These rocks have been rotated by range bounding normal faults resulting in strata which dip between 20° and 45° away from Toano Draw. These rocks have been faulted to a substantial depth near the middle of the basin. Sun Exploration Company Well SP 3-13 (WCC No. 39-65-13dd) penetrated mudstone and limestone at a depth of 4500 feet in the southern portion of the valley.

The permeability of these rocks has not been clearly characterized. Numerous karst caverns and voids are visible in limestone outcrops on both sides of Toano Draw. Dissolution along fractures and faults within the limestone rocks is also common. However, the number and extent of possible water conduits has not been estimated. Discussion has existed for some time in technical journals as to the role the carbonate rocks might play in the storage and transmission of groundwater in this area of Nevada. Maxey (1968) postulated that areas in eastern Nevada having predominantly carbonate mountains and valley basements must contain appreciable amounts of water. Rush (1968) estimated that water flow rates between the Toano-Rock Springs area and the Montello-Crittenden Creek area may be between 6000 and 12,000 ac-ft/yr.

The [illegible] geology and [illegible] opposite the [illegible] of surface [illegible] water [illegible] drainages, such as [illegible] Draw, [illegible] Creek, and [illegible] have [illegible] which drain from the higher elevations [illegible] into [illegible] drainages [illegible] transport [illegible] surface [illegible] volcanic [illegible] quantity of the water draining from the higher [illegible] infiltrating into and is recharging the volcanic unit.

3.4.5 Paleozoic and Early Mesozoic Carbonate and [illegible] Sedimentary and [illegible] Rocks

The oldest rocks in the study area are Paleozoic sediments [illegible] the cores of [illegible] to the west, [illegible] Range [illegible] east, and the [illegible] Mountains [illegible] and form the [illegible] Toano Draw. The rocks range from Cambrian to Permian in age and are principally [illegible] limestone and lesser dolomite [illegible] Pequop Formation [illegible] includes mudstones, siltstones, [illegible] sandstones [illegible] remnants of early Mesozoic [illegible] in the northern part of the [illegible] Hills [illegible].

These rocks have been rotated by range bounding normal faults resulting in strata which dip between 20° and 45° [illegible] Toano Draw. These rocks have been [illegible] Exploratory Company [illegible] Well [illegible] in the [illegible] of [illegible] valley.

Permeability [illegible] of these rocks [illegible] clearly [illegible] numerous [illegible] faults [illegible] on both sides of Toano Draw [illegible] along [illegible] faults [illegible] water [illegible] the carbonate rocks [illegible] the storage [illegible] Maxey (1968) [illegible] carbonate [illegible] of water. Rush (1968) [illegible] Rock Springs area and the Montello-Crittenden Creek area may be between 6000 and 12,000 acre-ft/year.

4.0 HYDROGEOLOGIC SETTING

4.1 HYDROSTRATIGRAPHY

For the purposes of this study, the stratigraphic units of importance for characterizing the groundwater flow system have been subdivided based on the general water-bearing properties of the units. The titles of the following subsections indicate the stratigraphic units of interest in this study.

4.1.1 Alluvial Aquifer

The relatively coarse-grained, unconsolidated alluvial channel deposits, which are present within the central portions of the valleys and along the ephemeral streams, comprise the alluvial aquifer. This aquifer is the principal groundwater-bearing unit within the Toano Draw Subbasin, along Thousand Springs Creek, and within Montello Valley. It consists of a heterogeneous mixture of stream-deposited sand and gravel, with interbedded silt and clay deposits. The permeability of these alluvial channel deposits is related primarily to the grain size and degree of sorting of the grains during deposition. In general, the permeability is higher in the more well-sorted, coarse-grained channel deposits. Typically, the deposits having a higher degree of sorting would occur in the central portion of such a basin because the streams depositing these sediments would have had relatively low gradients in this area as compared to the higher gradients of those stream reaches along the mountain front margins of the basin. The lithologic characteristics of this alluvium, which is Holocene (Recent) to Tertiary in age, are further described in Sections 3.4.1 and 3.4.2. The thickness and extent of this aquifer are described below in Section 4.2. The hydraulic characteristics of this aquifer are described in Section 4.6 below.

4.1.2 Alluvial Fan - Volcaniclastic Aquitard

The very fine-grained, alluvial fan, lake, and volcaniclastic sediments that have been deposited along the mountain fronts, on the margins of the valleys, constitute the alluvial volcaniclastic aquitard. This aquitard consists of great thickness of silt and clay, including significant amounts of volcanic ash. These fine-grained sediments occur adjacent to and extend beneath the alluvial aquifer unit in Toano Draw Subbasin. This unit is not capable of yielding economically significant quantities of water to wells because of its low hydraulic conductivity (low permeability). However, on a large scale, this unit contains large volumes of water because of its high effective porosity. Also on a large scale, this unit is capable of transmitting a significant amount of groundwater into the alluvial aquifer. The lithologic and stratigraphic characteristics of the aquitard, which consists of Quaternary alluvial fans and Tertiary volcaniclastic sediments, are further described in Section 3.4.3.

4.1.3 Paleozoic Carbonate Aquifer

Consolidated carbonate rock formations of Paleozoic age are exposed in the mountain ranges that form the margins of the subbasins within Thousand Springs Basin; it is believed that they are continuous between the ranges, although covered by the alluvial valley infill materials. The extent, distribution, and hydraulic properties of these formations is not well-defined because of the great depth at which they occur beneath Toano Draw Subbasin. However, significant secondary porosity features, including vugular and cavernous openings along fractures, have been observed in outcrops of these rocks along the northeastern margin of Toano Draw Subbasin and in the Gamble Range. From observation of these features it may be inferred that this unit might have a high capacity for transmitting groundwater regionally, particularly along deep flow lines. This may account for deep groundwater movement out of Toano Draw Subbasin as recognized by Rush (1968). Regional groundwater flow through these carbonate rocks has been discussed by Maxey (1968). In addition, Rush (1968) has noted that many areas of eastern Nevada are underlain by carbonate rocks that convey groundwater flow beneath and between valleys and supply water to large springs.

4.2 DEFINITION OF AQUIFER THICKNESS

The late Tertiary and Pleistocene channelized alluvium and Holocene channelized alluvium are the most likely shallow (less then 1000 feet) groundwater sources in Toano Draw. They consist of unconsolidated sediments that are porous and have relatively high permeabilities. The youngest unit, the Holocene channelized alluvium, is relatively unimportant as a potential source of groundwater because of its limited areal extent and thickness. However, it must be considered part of the aquifer system because it incises or directly overlies the older alluvium in the central portion of the valley and along the major tributaries. The younger unit also attains its greatest thickness, about 50 feet and possibly as great as 100 feet, at these locations. In addition, both alluvial units possess similar lithologies. The older unit, however, has a higher degree of cementation. Because of the similarities and spatial relation of the two units, they have been considered a single aquifer for this study.

Estimates of the alluvial aquifer thickness are based on data from water and petroleum well logs, geologic reconnaissance, and geophysical exploration. These data have been utilized to construct isopach maps of the aquifer (Figure 4-3). Significant features include an irregularly shaped, elongate form that trends northwest-southeast; the thickest portion of the aquifer is generally along the central axis of the basin; its thickness varies from less than 50 feet near the margins of the Toano Draw

Subbasin to greater than 800 feet near the center of the valley; it is bounded by faults to the east, west, and southeast; and irregularities in the configuration of the aquifer appear to be structurally controlled. A more detailed description of the aquifer from north to south follows.

In more detail, the aquifer is oriented generally along the central axis of Toano Draw. It trends north-northwest and has an irregular form which roughly conforms with the shape of Toano Draw Subbasin. The width of the unit, based on time domain electromagnetic (TDEM) and well log data, varies along the length of the valley. The width of the unit at several points from north to south is about 2 miles wide at the north, in the area between Thousand Springs Creek and Fivemile Draw; greater than 9 miles at about the latitude of the southern reach of Twentyone Mile Draw; less than 3 miles from just north of Toano Well No. 1 to slightly north of the confluence of Deadman Creek and Toano Draw; almost 9 miles along a narrow spur which coincides with Deadman Creek; and less than 4 miles wide south to Valley Pass, the drainage divide with Goshute Valley.

The above estimates of width of the aquifer are minimum values. Few data are available from the margins of the basin because there are few wells around the margins and the area was not extensively covered during the TDEM survey. The resistivity values from the few TDEM sites located along the margins suggest that the aquifer is relatively thin, i.e., less than 50 feet thick. The TDEM data indicate that these materials are more fine-grained than the main body of the aquifer due to interfingering with tuffaceous sediments and alluvial fan deposits. The maximum width of the aquifer is controlled by the generally north-trending Basin and Range style normal faults that bound the valley near the range fronts.

The prominent, wider sections of the aquifer are attributed to established drainages, cross-valley structures, or both. An example is the northeast-trending lobe coinciding with Deadman Creek in the southwest corner of the basin. The drainage overlies a slight gravity low possibly caused by a fault or warp in the bedrock basement (Erwin 1980). The increased depth to basement caused by the structure is responsible for greater thicknesses of the deposits. Estimated thickness of the aquifer along this lobe exceeds 800 feet.

Another relatively large extension of the aquifer is located 3 miles east of Winecup Ranch in the northeast portion of the valley. This north-trending feature is 4 miles long, about 2 miles wide, and estimated to be up to 800 feet thick. Aerial photograph analysis and surface reconnaissance show this feature to be an older gravel deposit, possibly related to the lower section of the late Tertiary and Pleistocene channelized alluvium unit. The gravel deposit is an erosional remnant forming a topographic high 20 to 30 feet above the surrounding broad, low alluvial fans. The gravels are bounded by north-trending normal faults which created a depositional basin. This would account for the increased thickness of deposits at this location. A Woodward-Clyde Consultant (WCC) monitoring well (MW-5) was drilled on the west side of a range front fault at the western end of the Deadman Creek lobe of the aquifer. This 290-foot-deep boring encountered only 170 feet of fine-grained alluvial fan material. This supports the interpretation that the frontal fault bounds the western end of the deeper part of this aquifer lobe.

The alluvial aquifer overlies Tertiary volcaniclastic sediments that have also been downdropped along the range front faults on both sides of the basin. Sun Exploration Company Petroleum Well SP 3-13 (WCC No. 39-65-13dd), located in the southern portion of the valley, penetrated the top of the volcanics about 1600 feet below the ground surface. The lithologic logs indicate that the alluvial aquifer extends to almost 900 feet. A finer-grained siltstone section lies directly beneath the aquifer and above the volcanic unit. The base of the aquifer does not lie at a consistent depth throughout the valley. Gravity data suggest that the basin is deepest in the southern third of the valley (Erwin 1980). This is roughly coincident with the thick section of aquifer mapped at approximately the confluence of Deadman Creek and Toano Draw. Another deep portion of the basin occurs at the wider portion of the aquifer at the latitude of the southern extent of Twentyone Mile Draw. This thick section of material continues northward along the narrowed section of the aquifer to Thousand Springs Creek.

The thickest part of the aquifer does not coincide with the present course of the Toano Draw drainage channel in the northern half of the sub-basin. The thickest part instead lies 1 to 1.5 miles east of the surface drainage. Possible causes for this deviation from the present drainage course include more rapid progradation of alluvial fans on the east side of the valley relative to the west side, which forced Toano Draw to the west; tilting of Toano Draw Subbasin toward the west by dominant normal faults along the Windermere Hills; and natural migration of Toano Draw to the west. To the south the aquifer axis is believed to lie directly beneath the present drainage course. The valley is much narrower in this part of the basin and confines the drainage more than in the north.

4.3 WELL AND SPRING INVENTORY

An inventory of wells and springs in the project vicinity was performed by WCC hydrogeologists in July and August 1988. Records of drillers' logs were researched at the Nevada State Engineer's office in Carson City. Information regarding springs in the project area was provided by the Regional Office of the Bureau of Land Management (BLM) in Elko. Groundwater level measurements for selected wells in Toano Draw Subbasin were provided by the Elko field office of the United States Geological Survey (USGS).

The well and spring inventory was performed to:

- Summarize well ownership, well construction, pumping data, and groundwater use (Appendix I)

- Identify wells and springs to be sampled to characterize background water chemistry and provide information regarding groundwater origin and age (Section 5.0)

- Obtain groundwater level measurements to develop a water table contour map, and assess groundwater flow direction and aquifer hydraulic gradient (Section 4.5)

- Supplement the knowledge of the distribution of aquifer materials (Sections 3.0 and 4.2 above)

- Identify wells and springs that may be affected by groundwater development in the project area (Section 10.0)

Information obtained from the agencies listed was used to develop a well and spring location map (Figure 4-1) and a detailed tabulation of data regarding well and spring characteristics (Appendix I). Information contained in the WCC well and spring inventory extends and expands the information provided on wells and springs by Guyton (1982) and Rush (1968).

A field reconnaissance of selected wells and springs was conducted by WCC hydrogeologists to confirm and update information gathered from the agencies and from the existing technical reports by previous investigators. Approximately 100 wells and 30 springs were visited. A description of the condition of each well and spring, and other pertinent information, was noted. If a well was being pumped, an estimate of discharge was made. Spring discharge was also estimated. Depth-to-water measurements were performed where possible. Photographs were taken of selected wells and springs.

4.4 INSTALLATION OF MONITORING AND TEST WELLS

A total of seven monitoring wells and five test wells were drilled under the supervision of WCC hydrogeologists in the project vicinity. Three additional exploratory borings were drilled at proposed monitoring well locations but were not completed as wells because of the hydrogeologic conditions encountered. Well locations are shown on Figure 4-2 and completion details are listed in Table 4-1. The method used to drill a particular well was dependent upon the purpose of the boring, formation characteristics, and sampling needs. Lithologic logs for each well were prepared from drill cutting samples as drilling progressed (Appendix E). A suite of borehole geophysical logs was also performed as described below. The three drilling methods used were air rotary, mud rotary, and cable tool.

4.4.1 Description of Air Rotary Drilling Methods

Air rotary drilling is identical to mud rotary drilling except that air is used to carry cuttings to the surface instead of mud. Compressed air is forced down the inside of the drill string, where it escapes from ports in the drill bit to transport cuttings to the ground surface. Injecting a small volume of water or surfactant decreases the amount of dust produced. Air drilling is useful for drilling through consolidated or semi-consolidated materials because of the generally rapid penetration rate and because it is possible to detect major changes in groundwater conditions while drilling. When loose, unstable formations are encountered, and where sticky clay formations are encountered at depths greater than about 400 feet, drilling mud must be used in the borehole. The rigs utilized by WCC on this project had the capability to drill with both air and mud. Test wells TW-1, TW-12, TW-14, TW-15, and monitoring wells MW-1, MW-2, MW-3, MW-4, MW-5, MW-6, MW-7, and MW-12 were drilled using air rotary methods to the maximum possible depths and then, as conditions required, continued deeper using mud rotary methods.

4.4.2 Description of Mud Rotary Drilling Methods

For mud rotary drilling, the borehole is advanced by rotating a bit and removing cuttings by continuous circulation of a drilling mud. The bit is attached to the lower end of a string of drill pipe. A gasoline- or diesel-powered engine provides power to rotate the entire drill string. Drilling mud is pumped down through the drill string and ejected from ports or jets in the drill bit. Drill cuttings are carried in suspension by the drilling mud to the ground surface in the annulus between the borehole and the drill pipe. At the surface, the drilling fluid is channeled to a pit or tank where the solids are allowed to settle. Clean mud is then recirculated down the borehole. Formation samples can be obtained from the drilling mud stream as it discharges from the annulus. However, these samples may not be representative of the formation material at the drilling depth. Clay and silt may be separated from the formation material as it is carried in the mud stream. It is also difficult to accurately determine if a sample is truly from the depth at which the bit is working. Mixing of formation material from different intervals occurs as the cuttings are broken from the formation and when they appear at the ground surface. The rotary drilling method is most useful in that it allows for rapid drilling rates and deeper drilling depths.

4.4.3 Description of Cable Tool Drilling Methods

During drilling using the cable tool method, the borehole is advanced by repeatedly lifting and dropping a heavy string of drilling tools into the borehole. The drill bit or chisel breaks or crushes consolidated materials into small fragments, whereas the bit primarily loosens the material when drilling in unconsolidated formations. The crushed or loosened materials are mixed by the reciprocating action of the tools with added or formation water to form a sludge or slurry at the bottom of the borehole. When the crushing action of the tools is diminished by the accumulation of the slurry, the drill bit is removed from the borehole and the slurry is removed using a bailer.

Because the cable tool drilling method inherently does not disrupt the formation being drilled as much as rotary methods, formation samples obtained during cable tool drilling are representative of the actual formation materials at the depth from which the sample is obtained. For this reason, test well TW-3 was drilled using the cable tool method.

Samples were obtained from this well at 10-foot intervals from a 178-foot depth to a total depth of 408 feet. Petrographic analyses were performed by Core Laboratories of Irving, Texas, on samples from selected depth intervals. Analytical methods and results are summarized in Appendix H.

The cable tool method was used to drill monitoring wells MW-16 and MW-17 in November 1988 and January 1989. Because drilling muds are not needed with this method, subfreezing temperatures did not present major problems. Additionally, the mechanical operation and maintenance of a cable tool rig, as compared with a rotary drill rig, is much easier and less problematic during subfreezing weather.

4.4.4 Borehole Geophysical Logging

Geophysical logging was conducted immediately after the drilling of each borehole. Temperature, caliper, spontaneous potential, natural gamma ray, acoustic (sonic), and short and long normal resistivity logs were run in each borehole. The techniques of borehole geophysical logging are further discussed in Section 3.2.3. Reproductions of each log are presented in Appendix D.

4.4.5 Test Well and Monitoring Well Installation

After determining the appropriate well completion intervals and depths from the results of geophysical logging, installation of casing and well screen commenced. If necessary, the bottom of the borehole was backfilled to the level where well completion was to start with a low-permeability seal consisting of a mixture of bentonite and gravel. An additional seal of pure bentonite was placed at the base of the completion depth interval. The well screen was set in the completion interval adjacent to coarse-grained aquifer material, lowered on casing that was installed in the borehole to ground surface. A filter pack consisting of clean silica sand and gravel was then placed in the annulus of the borehole between the casing and well screen and borehole wall. A bentonite seal was set above the filter pack. Cement grout was poured into the borehole to ground surface and a length of protective steel pipe with a lockable cap was installed to protect the well.

4.4.6 Test Well and Monitoring Well Development

All wells were developed after an appropriate time had elapsed to allow cement and grout to set. Development is necessary to remove fine-grained sediment from the formation surrounding the well screen and to facilitate the movement of groundwater into the well bore.

All monitoring wells and test wells, with the exception of test well TW-3, were developed by air-lift pumping. An air line and eductor pipe were placed in the well extending to the screened interval. Water was ejected from the well by compressed air supplied by the rig compressor. Fine-grained sediment was removed from the surrounding formation material by the movement of water into the wellbore and was expelled as air-lift pumping progressed. Pumping was periodically ceased and then resumed to allow for water movement into and out of the formation. This agitation facilitates removal of fine-grained sediment from the filter pack. Development was considered complete when water produced from the well contained insignificant amounts of sand and was no longer turbid.

Test well TW-3 was developed by a combination of surging, bailing, and pumping using a diesel-powered vertical line-shaft turbine pump. These methods were used because the large diameter of the casing and greater volume of fine-grained sediment expected excluded the use of air-lift pumping. Surging was accomplished by inducing flow into and out of the well screen by the use of a surge block. The surge block was moved up and down the inside the screened sections of the well in a vigorous reciprocating action. As sediment was removed from the formation, it settled at the bottom of the well, where it was removed by bailing. This action was repeated along all sections of well screen several times. When development by surging and bailing had continued sufficiently, a diesel-powered vertical line-shaft turbine pump was installed in the well. The well was then pumped at rates substantially greater than its sustainable yield. When drawdown in the well reached the pump intake, pumping was ceased and water allowed to run back into the well from the pump column. This created flow into the formation, minimizing bridging of sediment. TW-3 was developed until the water discharged did not contain sand and was not turbid.

4.5 GROUNDWATER FLOW SYSTEM

This section describes the available measurements of groundwater levels in the context of defining hydraulic head distribution and inferring flow directions within the groundwater flow system. First, the scale and components of flow systems are briefly presented. A groundwater flow system within a basin may be described, following the concepts of Toth (1963), Maxey (1968), and Freeze and Witherspoon (1966), as consisting of three areas or zones. These areas of a basin are listed below, in order of decreasing topographic elevation.

1) A recharge area where the movement of water is primarily downward

2) A zone of predominantly lateral flow

3) A discharge area where the movement of water is primarily upward

Groundwater flow systems may also be defined on three different scales: regional, intermediate, and local. Flow path length and depth increase with the increasing areal scale of the flow system. Recharge areas for these regional systems lie within the mountainous areas having the highest topographic elevation present within the regional watershed. Discharge areas for regional flow systems are in the topographically depressed areas (lower elevations) of the same large-scale watershed in which the recharge zone flow lines originate. Typically, the springs that are regional discharge points have large flow rates, relatively high temperature, and little seasonal fluctuation in flow rate (Maxey 1968).

Local groundwater systems are characterized by short flow paths. Local flow systems typically underlie small watersheds and contain flow lines that extend only to shallow depths. These local flow systems typically have spring discharge points with water of relatively low temperature and large seasonal fluctuations in flow rate (Maxey 1968).

In the area of this study, the regional groundwater flow system extends from a recharge area in the Snake Mountains, on the west of Thousand Springs Basin, to the discharge area that is within Montello Valley and points further east. Several flow systems of intermediate scale, such as the flow system of Toano Draw Subbasin, are superimposed on this regional flow system.

Examples of local flow systems include those underlying the watersheds of Deadman Creek, Hunter Draw, and Immigrant Creek. The boundaries of, and flow directions within, these flow systems have been characterized in this study, with emphasis on Toano Draw Subbasin, based on several lines of hydrogeological evidence. These include the analysis of groundwater level data, distribution of hydraulic head data, and the configuration of the water table, as described below.

4.5.1 Groundwater Level Data

Water level measurements were collected by WCC during August 1988 through February 1989, in 41 existing wells, 2 existing piezometers (installed by WCC in 1982), and 12 monitoring wells and test wells installed by WCC during summer and fall 1988. These groundwater level measurements are provided in the detailed tabulation of well and spring characteristics included in Appendix I. These data are supplemented by well measurements provided by the USGS (open file data), Guyton and Associates (1982), Gabbay (1987), and Rush (1964).

The available groundwater level data within and in the vicinity of Toano Draw Subbasin, which are assumed to represent the water table, show a close correlation with the ground surface topography (Figure 4-4). From this correlation it may be inferred that the water table is closely related to the ground surface. Establishing this relationship provided a basis for interpolating and extrapolating the available water level data to areas where no water level data were available (i.e., no wells were present for making measurements and no springs existed which constituted a surface expression of the water table).

4.5.2 Water Table Configuration

The elevation and configuration of the water table was mapped in the areas of Toano Draw Subbasin, Thousand Springs Creek, and Montello Valley (Figure 4-5). This water table contour map was prepared using the available water level measurements described in Section 4.5.1 above. Only the measurements that were judged to approximately represent static (non-pumping) water table conditions were used in constructing this map.

The water table surface conforms to topography and drainage basin morphology (Figure 4-5). Groundwater divides are present beneath topographic divides. That is, in areas underlying topographic ridges, the water table is elevated with and reflective of the topography. Conversely, the water table forms trough-like depressions, reflecting topography, in areas underlying the valleys.

This water table contour map illustrates the approximate direction and magnitude of the groundwater hydraulic gradients. The contours represent the approximate areal configuration of the water table, not the vertical components of the hydraulic gradient. However, it may be inferred that the hydraulic gradient is approximately perpendicular to the contours, in the direction of decreasing elevation. The contours on this map represent lines of equal hydraulic head at depths near the water table surface. Thus the change in elevation of the water table indicated by the water table contours, for a given distance in the direction perpendicular to the contours, represents the approximate magnitude of the hydraulic gradient.

Hydraulic gradients, as indicated by contour spacing on Figure 4-5, are generally steeper in the topographically elevated areas surrounding Toano Draw Subbasin, Thousand Springs Creek, and Montello Valley. In the central portion of Toano Draw Subbasin, and similarly along Thousand Springs Creek and in Montello Valley, the hydraulic gradients are relatively much smaller in magnitude. From this observation, assuming constant groundwater flux through the flow system as a whole on a large scale and under steady-state conditions, it may be inferred that the areas of relatively low hydraulic gradient (i.e., widely spaced water table contours) are the areas underlain by portions of the aquifer that have relatively high transmissivities (i.e., thicker and/or more permeable aquifer materials). Convergence of the flow paths from the margins of the valley to an area in the center of the valley where the hydraulic gradients are lower is also indicative of the presence of an aquifer of higher water-transmitting capacity in the center of this subbasin. This inference is consistent with other lines of evidence that indicate higher aquifer transmissivities in the central portions of the basins, such as geological mapping (Section 3.1), results of geophysical surveys (Section 3.3), and the geological definition of aquifer thickness (Section 4.2).

4.5.3 <u>Groundwater Flow Directions</u>

Groundwater flows, as a result of the hydraulic gradient, through sediment and rocks containing sufficient effective porosity to provide a continuum for flow. That is, groundwater flows from areas of higher hydraulic head to areas of lower hydraulic head. On a large scale, it is reasonable to assume that geologic units that provide the framework for a hydrologic flow system are homogeneous and isotropic (Maxey 1968). Thus by inference from the configuration of water table contours (Figure 4-5), groundwater flows generally away from topographically elevated areas and converges toward topographic valleys and depressions.

In Toano Draw Subbasin, flow is generally toward Toano Draw from the Pequop Mountains, Windermere Hills, and the Gamble Range. In the central portion of Toano Draw, the flow direction is generally northward. The water table contours shown on Figure 4-5 are judged to represent the intermediate-scale flow system of Toano Draw Subbasin. Of course, where surface topography has created local flow systems, on a small scale the flow directions may be substantially different from those represented by the intermediate-scale system that was mapped. For example, on the northern side of the Canyons of Hunter Draw at Deadman Creek, the small-scale flow directions would be southward, in general accord with the topographic slope. Within the larger-scale Toano Draw flow system, it is reasonable to assume that there is a significant downward component of flow in the topographically elevated areas surrounding the subbasin and an upward component of flow in the topographically depressed areas in the northern end of the subbasin near Thousand Springs Creek. This description of the flow system is consistent with the model described by Maxey (1968) and Toth (1963). It is also consistent with the increased hydraulic head observed with increasing depth in the MW-1 boring, which is located near the confluence of Toano Draw and Thousand Springs Creek.

On a regional scale, the groundwater flow directions are influenced by the large-scale topographic relief. Flow paths in the regional flow system of Thousand Springs Basin probably originate in the higher elevations of the Snake Mountains and Pequop Mountains, west and south, respectively, of Thousand Springs Basin, following the model described by Maxey (1968) and Toth (1963). In these recharge areas, flow lines would have a steep downward component. Areally, flow would be generally eastward toward the lower-elevation discharge areas lying in eastern Montello Valley and points further east in Great Salt Lake Basin. In these discharge areas there is a significant upward component in the flow paths, as evidenced by the deep wells which have been observed to flow under artesian conditions in the Montello area.

4.6 HYDRAULIC CHARACTERISTICS

The hydraulic characteristics of unconsolidated sediments in Toano Draw Subbasin were estimated from the results of six constant-rate aquifer pumping tests performed at test well locations TW-1, TW-3, TW-12, TW-14, TW-15, and the pre-existing irrigation well 41-65-35ad (Figure 4-1). Duration of five of the tests ranged from 8 hours to 48 hours each. The long-term test conducted in Well 41-65-35ad, which is located approximately 100 feet east of Well MW-17, had a pumping duration of approximately 14 days. The hydraulic characteristics estimated from these aquifer tests include transmissivity, hydraulic conductivity, and storage coefficient. These data were used in conjunction with aquifer test data reported by others, as input to the groundwater flow model, which in turn was used in evaluating the groundwater resource and drawdown effects of pumping to supply the power plant.

In addition, an empirical relationship was developed between specific capacity and transmissivity based on the tests performed by WCC and data reported by Guyton and Associates (1982). This correlation will enable estimates of transmissivity to be made where only specific capacity data, based on short-term tests performed in previous investigations, are available.

4.6.1 Aquifer Testing Approach and Procedures
The test well locations were selected to provide a wide spatial distribution of aquifer hydraulic data within Toano Draw Subbasin (Figure 4-1). MW-series monitoring wells were installed within 100 feet of test wells TW-1, TW-3, TW-12, and Well 41-65-35ad to enable collection of additional water level data during the aquifer tests.

The aquifer tests were conducted using the methods and instrumentation summarized below. Details of the standard operation procedures (SOP) are provided in Appendix F.

Prior to conducting each test, water levels were monitored in the test well and observation wells, as applicable, to observe that the water levels were fully recovered from the previous well development activities. Prior to the testing, a short period of trial pumping at various rates was performed at each test well to identify an appropriate pumping rate for each aquifer test. The final pumping rate was selected based on the pump capacity, the depth to the pump intake, and the amount of drawdown at selected (stepped) pumping rates. For each constant rate test, the maximum sustainable pumping rate was selected, given the limitations of well casing diameter, lift, and pump capacity. Water levels in all monitoring wells and test wells were allowed to fully recover to static conditions prior to initiation of each constant rate pumping test. Each of the aquifer tests was conducted by pumping at a constant flow rate (Q) throughout the test.

Water level data were recorded for each test using both a programmable datalogger (In-Situ) and a manually operated water level indicator (Solinst). The pressure transducers used with the datalogger were installed in both the test well and the observation well. Manual water level measurements were made and recorded frequently in both the well being pumped and during both the pumping and recovery phases of each test.

4.6.2 Data Analysis Methods
The methods used to analyze the aquifer test data were selected based on the characteristics of the data and the hydrogeologic setting of the well location. The methods used were the Cooper-Jacob modified non-equilibrium analysis method (Cooper and Jacob 1946; Driscoll 1986) for both drawdown and recovery data. Drawdown and recovery plots for each test, including analysis of the data, are shown on Figures 4-6 through 4-18.

Water level responses measured in the pumping well and observation well, as applicable, were analyzed. The aquifer hydraulic properties were evaluated using the drawdown data from the portion of the test that was judged to be most representative of the aquifer within the zone of influence of the test well. In all cases, borehole storage effects were apparent in the early-time data and, therefore, early-time data were excluded from the analysis to avoid misinterpreting the hydraulic response of the aquifer.

4.6.3 Hydraulic Properties

The values of transmissivity, hydraulic conductivity, and storage coefficient, estimated from the aquifer tests, are summarized in Table 4-2. Transmissivity values range from approximately 2000 gallons per day per foot (gpd/ft) to 50,000 gpd/ft. The lowest transmissivity was observed at the TW-3 well location and the highest transmissivities were observed at Well TW-15 and Well 41-65-35ad. This wide range of values reflects the locally variable hydraulic properties of the heterogeneous unconsolidated sediments in Toano Draw. In an environment of stratified stream deposits, such as Toano Draw, aquifer materials commonly exhibit a fairly large range of hydraulic properties.

The values of transmissivity considered to be representative of the aquifer properties at each test well are as follows:

TW-1	7200 gpd/ft
TW-3	2600 gpd/ft
TW-12	20,400 gpd/ft
TW-14	11,700 gpd/ft
TW-15	50,400 gpd/ft
Well 41-65-35ad	42,570 gpd/ft

These values are the rounded-off averages of the transmissivity values reported in Table 4-2 for each test location.

It is important to note that the very late-time drawdown data from many of the tests, particularly Wells MW-3, MW-12, TW-12, TW-14, and TW-15, show a diminishing rate of drawdown with time. This effect is probably caused by a delay in release of water from storage in the finer-grained portions of the aquifer near these wells. Such an effect increases the apparent transmissivity of the aquifer, possibly only for a short time, to values higher than those reported above. Thus, for the purpose of predicting long-term aquifer response from these tests, it is more conservative to use the estimated average transmissivity values shown above. However, the water-level measurements in observation Well MW-17, during the long-term pumping test of Well 41-65-35ad (Figure 4-17), also show a similar effect of diminishing drawdown with time. Data from Well MW-17 show that the rate of drawdown decreased after pumping for a period of approximately 48 hours. Thereafter, this diminished rate of drawdown continued steadily until the end of the test, approximately 330 hours after pumping began in Well 41-65-35ad. This pumping response indicates that the apparent increase in transmissivity that occurred in this well and others after pumping periods of 1 to 2 days is probably not a short-term transient effect but rather is representative of the long-term water-transmitting capacity of the aquifer at these locations.

The values of storage coefficient calculated from the drawdown data and the averages of the data at each of the observation wells range from approximately 1.3×10^{-3} to 1.2×10^{-4}. Representative storage coefficients can also be calculated from the drawdown data at pumping wells if the well efficiencies are fairly high. As shown in Table 4-2, estimated values of storage coefficients calculated from the pumping well data are consistent with the values calculated from the observation well data.

The values of storage coefficient (specific yield for unconfined aquifers), which were calculated from the aquifer test data, are lower than typical values for unconfined conditions in unconsolidated sedimentary aquifers, such as these in Toano Draw Subbasin. The calculated storativities from the aquifer tests in Toano Draw are more indicative of semi-confined conditions. However, the specific yield of the aquifer, which would be relevant to long-term pumping, would be much higher than the storativities calculated from the short-term pumping tests. A common range of specific yield for unconfined sand-and-gravel aquifers is 0.01 to 0.30 (Freeze and Cherry 1979). The effective porosity values measured in the laboratory on samples of the aquifer sediment, which were collected from Boring TW-3 while drilling using the cable tool method, range from approximately 30 to 38 percent (Table 4-3). Although there is some uncertainty as to how well these samples represent in-situ conditions because of the disturbance in porosity that results from sampling unconsolidated sediments in this manner, these lab values would be consistent with specific yield values in the upper end of the range commonly reported for alluvial sediments, possibly greater than 20 percent. Therefore, considering the variability and depositional environment of the sediments, the specific yield of this aquifer is estimated to range from approximately 10 to 20 percent.

To enable estimation of hydraulic characteristics in areas with relatively limited well data, an empirical relationship between transmissivity and specific capacity was developed. As shown in Table 4-4, values of transmissivity and specific capacity are known for seven wells in this region. These values are plotted on Figure 4-19. Using the least-square method of regression analysis, the regression line shown on Figure 4-19 was drawn. The resulting correlation coefficient for the seven data points is high ($R^2 = 0.99$), thus indicating a close linear relationship between specific capacity and transmissivity for the available aquifer tests. From this regression analysis, values of either transmissivity or specific capacity may be estimated if either of the two parameters is known for a well in a similar hydrogeologic setting.

4.7 GROUNDWATER USE IN THOUSAND SPRINGS BASIN

Groundwater in Thousand Springs Basin is used for a variety of purposes, including domestic and municipal, livestock and wildlife, and irrigated agriculture. There is currently no identified groundwater use associated with oil or gas production, mining, or manufacturing activities in the basin.

Various published reports provide information on historical groundwater use in Thousand Springs Basin. These information sources include Rush's 1968 Water Resources Appraisal of Thousand Springs Valley, Guyton and Associates' 1982 Report on Ground-Water Conditions in the Thousand Springs Creek Area, and Gabbay's 1987 Ground Water Supplies for the Indian Springs Project. The Nevada Regulations for Drilling Water Wells (Morros 1985) provided information on regulatory requirements and constraints on domestic wells, useful for estimating potential domestic well water production.

In addition to these published information sources, in 1988 WCC conducted a well and spring inventory, which is discussed in detail in Section 4.3. Figure 4-1 shows the locations of the 240 wells identified in the inventory and tabulated in Appendix I. Information regarding water well completion details was obtained from driller logs and supplemented during the field well inventory. Eight industrial wells were identified; all are currently unused. The industrial wells were apparently associated with sand and gravel quarries or oil and gas exploration.

Current use of groundwater in the vicinity of the proposed power plant is limited to stock watering.

4.7.1 Domestic, Municipal, and Stock Watering Uses of Groundwater

Morros (1985, p. 12, part 12.01) stated that "a domestic well must be of sufficient depth to provide a capacity of 1800 gpd [2 acre-feet/year], taking into account the normal annual fluctuations and, if the well is in a developed area, some annual drop in static water level." Additionally, 'domestic [water] use' is defined to extend to "culinary and household purposes, in a single-family dwelling, the watering of a family garden, lawn, and the watering of domestic animals," under Chapter 534.010 of the Nevada Revised Statues.

Rush (1968, p. 36) noted that groundwater is pumped from wells for domestic use in all four hydrologic segments of Thousand Springs Creek Valley--Herrell Siding-Brush Creek Area, Toano-Rock Spring Area, Rocky Butte Area, and Montello-Crittenden Creek Area. He estimated that the net pumpage in each segment for domestic and stock watering uses probably was less than 50 acre-feet/year (ac-ft/yr).

For the purposes of this overall basin resources evaluation, Mr. Rush's estimate of fewer than 200 ac-ft/yr of domestic, municipal, and stock watering uses within the basin is considered still applicable and conservative. The estimated current population of Thousand Springs Basin is about 200 persons, of which about 150 people live in the town of Montello and vicinity (Rush 1968). No significant growth in population within the basin has occurred since the estimates of Mr. Rush were prepared, and little growth is expected during the operating life of the Thousand Springs Power Plant (TSPP). A conservative estimate of the average domestic use of water in this area is 200 gallons per person per day, calculated on an annual basis, and on that basis the total domestic water use is about 45 ac-ft/yr.

The livestock-carrying capacity of range within Thousand Springs Basin probably does not exceed about 10,000 cattle (about 1,000,000 acres, 1 animal per 100 acres). Assuming an average water consumption of 10 gallons per day per animal, the total annual direct water use to support livestock would be on the order of 110 ac-ft/yr. The combined estimated totals for domestic, municipal, and livestock water uses (155 ac-ft/yr) are consistent with Mr. Rush's estimate of less than 200 ac-ft/yr for the basin as a whole. Even if the use were to expand by a factor of five, to 1000 ac-ft/yr, over the life of the power plant project, the quantity would be less than the probable error in the estimates for both the quantity of water available within the basin and the projected power plant uses. Accordingly, it is considered appropriate not to address this category of water use in greater detail in this analysis.

4.7.2 Irrigated Agricultural Use of Groundwater

According to Rush (1968, p. 1), "agriculture, other than grazing, is limited to the mile-wide floodplain of Thousand Springs Creek, where hay and pasture land are irrigated. Sampled well and surface waters were generally chemically suitable for irrigation in the three western (hydrologic) segments [Herrell Siding-Brush Creek Area, Toano-Rock Spring Area, and Rocky Butte Area], but samples collected in Montello Valley were more highly mineralized."

The Elko, Nevada, office of the Soil Conservation Services (SCS) provided data in February 1989 on current irrigated acreage, irrigation water uses, and source of irrigation water in Thousand Springs Basin. Those data are summarized in Table 4-5. The SCS data indicate that irrigated agricultural uses of water in the basin currently are significantly greater than those reported by either Rush (1968) or Guyton and Associates (1982). The SCS data are representative of the same time period as other data collected for this investigation and, therefore, provide consistency in the data base used for these analyses.

Net consumptive use of groundwater by irrigated agriculture in the basin currently is about 4200 ac-ft/yr. In addition, surface water diversions and springs contribute about 11,060 ac-ft/yr to irrigated agriculture in the basin. The SCS estimates that the efficiency of water use by irrigated agriculture is in the range of 30 to 50 percent, and, therefore, about 2.3 times as much water (35,535 ac-ft/yr) is applied to the land as is consumptively used by the crops being irrigated. As discussed in the water rights section of this report (Section 9.0), it is planned that water rights currently used for irrigated agriculture will be converted to industrial use for the power plant.

5.0
GEOCHEMICAL CHARACTERIZATION OF AQUIFER MATERIAL AND GROUNDWATER

The geochemical characteristics of the aquifer material and groundwater have been evaluated to determine the chemical suitability of the water for use in the plant. In addition, areal trends in concentrations of hydrochemical constituents have been evaluated as a means of further characterizing the groundwater flow system. Existing data have been reviewed and samples of aquifer material and well and spring water have been collected and analyzed as part of this study. The results of this characterization are described below in this section. The potential effect of water resource development on water quality is discussed in Section 10.6.

5.1 AVAILABLE GEOCHEMISTRY DATA ON AQUIFER MATERIAL

The chemical properties of aquifer material that influence the composition of groundwater are mainly a reflection of the mineralogy and composition of the rocks comprising the aquifer. The stratigraphy of the rocks within Toano Draw Basin has been described in detail in Section 3.4 of this report. Five general stratigraphic units have been designated. In order of decreasing age, these units are Paleozoic carbonate and noncarbonate rocks, middle to late Tertiary volcaniclastic sediments, Pleistocene and late Tertiary alluvial fan deposits, Pleistocene channelized alluvium, and Holocene channelized alluvium. The alluvial channel deposits comprise the alluvial aquifer, which is the principal groundwater-bearing unit in Toano Draw Subbasin. The general compositions of these units are presented by Rush (1968) and Guyton and Associates (1982).

The carbonate and noncarbonate consolidated rocks typically form the core of the highlands and outcrop in the ranges. The rocks range from Cambrian to Permian in age and are principally carbonate rocks such as the limestone and lesser dolomite of the Pequop Formation (Hope and Coats 1976). Additional lithologies include mudstones, siltstones, Triassic marine volcanic rocks, and granitic intrusive rocks. The Tertiary volcaniclastic sediments are composed of rhyolites, andesites, associated tuffaceous sediments, and some basalt flows. The alluvial fan deposits are generally derived from the volcaniclastic rocks and their weathering products, such as clays and devitrified glass. The Pleistocene and Holocene alluvial deposits in the channels are also generally derived as weathering products of the other deposits. They contain rock fragments and alteration products of most of the available source material.

5.2 SOIL SAMPLING AND ANALYSIS

In order to provide additional information on the composition and mineralogy of the alluvial aquifer material, five samples of these sediments from Woodward-Clyde Consultants (WCC) Well TW No. 3 were collected and submitted for petrographic study.

Two types of analyses were conducted on the sediment samples by Core Laboratories (Irving, Texas). Thin-section analyses of whole rock samples were performed as well as X-ray diffraction (XRD) analyses on the clay-size and sand/silt-size fractions. A complete description of the analytical methods may be found in the laboratory reports (Appendix H).

Thin-section analysis was performed to provide information on the relationship between rock textures, detrital grains, cement, and matrix composition. The sample fractions are prepared for thin-section analysis by first impregnating the sample with epoxy to augment sample cohesion and to prevent loss of material during grinding. A blue dye is added to the epoxy to highlight the pore spaces. Each sample is mounted on a glass slide and then cut and ground to an approximate thickness of 30 micrometers. Prepared thin sections were stained to identify certain minerals (e.g., calcite and potassium feldspar). The thin sections were analyzed using a standard petrographic microscope.

XRD analysis provides information on mineral type and abundance. The clay-size fraction is first analyzed dry and then after treatment with ethylene glycol to differentiate expandable clays. The sand/silt-size fraction is made into a pellet using standard powder techniques. All analyses were run on a Phillips APD3600 X-ray diffractometer. The weight percentages of the rock-forming minerals and the relative abundances of the clay minerals were determined by a peak-area-ratio model. The detectability limit is 1 to 2 weight percent.

The thin-section and XRD analyses of the five samples of alluvial aquifer sediment show them to be of similar material. They are poorly consolidated tuffs of volcanic origin with the primary constituents being rock fragments, crystals, and glass shards set in a groundmass of clay and devitrified glass. Rock fragments are mostly volcanics, chert, sandstone, and argillite, with lesser amounts of micrite (calcite-containing) clasts and undifferentiated rock fragments. Crystals include plagioclase, quartz, muscovite, hornblende, and pyroxene. Trace abundances of calcite cement and pyrite were observed in the thin section. Most of the pyrite in these samples has been replaced by iron oxides (limonite, goethite, and magnetite). XRD analyses reveal that variable amounts of calcite (3.4 to 10.9 weight percent) and pyrite (0.4 to 1.7 percent), as well as the zeolite mineral heulandite (0.4 to 2.2 percent), are present. The major minerals are quartz, plagioclase, and clays (principally illite and smectite).

5.3 AVAILABLE GROUNDWATER QUALITY DATA

Groundwater and spring water chemical analyses have been published in several studies conducted in Thousand Springs Creek Basin. Rush (1968) conducted a water-resources appraisal of Thousand Springs Valley and analyzed major cations and anions in water samples collected from several spring and domestic wells. In the Toano-Rock Spring area he sampled Well 38-66-24d (Figure 4-1) on 6-22-67. Water from this well had a near-neutral pH (7.8), dissolved species were predominantly calcium and bicarbonate, and it had relatively low total dissolved solids (TDS <500 mg/L). The three surface water samples he collected from Thousand Springs Creek and Rock Springs Creek in the area had a similar pH but had a variable TDS and sodium was the dominant cation in some cases. Rush (1968) sampled Crittenden Spring (S11, Figure 5-1) in 1967 and found it had a pH of 8.01, low TDS, and was predominantly calcium-magnesium bicarbonate. Guyton (1982) recompiled the hydrochemical data of Rush (1968) and sampled and analyzed water from 15 wells and one spring in the study area. He found that in general the water is primarily a calcium-bicarbonate type with low TDS and a near-neutral pH. Gabbay (1987) published a report on the groundwater supply for the Indian Springs Project. As part of this work he collected and analyzed water samples from Cold Spring (43-68-10bb, Figure 4-1), Crittenden Spring (S11, Figure 5-1), Rock Spring (44-67-4dd, off map boundary, Figure 4-1), and the stock tank at the Signboard Well (44-68-23db, off map boundary, Figure 4-1). These waters had a composition similar to that given in the earlier reports. This suggests that water composition is relatively stable over the 20-year period between measurements.

5.4 WELL AND SPRING SAMPLING PROGRAM

WCC conducted a sampling and analysis program of water from 15 springs and 13 wells in the vicinity of Toano Draw Subbasin to better characterize the water quality and support the hydrological study of the area. The sampling locations are listed in Table 5-1 and shown on Figure 5-1. This section summarizes the sampling methodology and analytical procedures. Details of the sampling methods are provided in Appendix G.

5.4.1 Sampling Methodology and Procedures

Prior to well sampling, water levels were measured in newly installed monitoring wells and selected existing wells to determine the gradient of the water table so that estimates of groundwater flow direction and velocity could be made. After the measurement of static water level in a well, the standing water in the well bore was removed so that a sample of groundwater representative of the aquifer could be collected. Well purging was conducted using the existing pumping apparatus in the well, if available, or by using a portable, electric pump. At least three casing volumes of water were purged from each well prior to sampling.

Following purging of a well, the temperature, pH, alkalinity, and specific conductance of the water were measured. These parameters are sensitive to environmental conditions and are not easily preserved, so they are normally measured in the field. Water samples were then collected and preserved for laboratory analysis of major cations, anions, and trace/minor inorganic compounds in the water. Water samples collected for major cation and trace/minor inorganic compound analysis were filtered in the field with a 0.45-micrometer pore size filter prior to addition to the sample bottle. In addition to the parameters listed above, the tritium concentration and the content of stable isotopes of hydrogen and oxygen were measured in selected samples. A complete list of compounds analyzed in the water samples is given in Appendix G.

Selected seeps and springs were also sampled and analyzed to provide background water quality data and aid in determining the source of the surface water. Grab samples were taken at the surface water sampling locations. Where possible, the water was collected directly in the container used to make the measurement or hold the sample. If the flow was not sufficient to allow for this, then the sample was collected first into a clean container that was rinsed with spring water and then transferred into the appropriate sample bottle. Water samples collected for major cation and trace/minor inorganic compound analysis were filtered in the field with a 0.45-micrometer pore size filter prior to addition to the sample bottle. The field measurement procedures and sample bottle protocols for the surface water samples were similar to those for the groundwater samples.

For all water samples a strict chain-of-custody procedure was used to ensure safe arrival of the samples at the analyzing laboratory. The bottles were packed in ice chests with bubblepack or other protective material to prevent breakage, and ice was added to the cooler as a preservative when necessary. Samples were shipped to the laboratories to arrive within the specified holding times for analysis.

5.4.2 Analytical Methods

A detailed list of analytical procedures used by the laboratories is provided in Appendix G. Most of the major cations and trace/minor inorganics were analyzed by inductively coupled plasma atomic emission spectroscopy. Mercury was analyzed by the cold vapor atomic absorption method. The major anions were analyzed by ion chromatography and fluoride was measured by an ion-specific electrode. The stable isotopes of hydrogen and oxygen were analyzed by mass spectrometry and the tritium analyses were done by low-level gas proportional counting.

5.5 GROUNDWATER CHEMISTRY AND QUALITY CHARACTERISTICS

5.5.1 Areal Trends in Water Quality

The majority of the groundwater samples reported in Table 5-1 show that calcium and bicarbonate (reported as alkalinity) are the dominant cation and anion, respectively. In several cases (MW-1, MW-2, MW-4, and Well 40-65-10) sodium is the dominant cation. The cation dominance of sodium relative to calcium may result from increased residence time and reaction between the groundwater and the aquifer material. Trends in several hydrochemical constituents reflect the generally northward groundwater flow path that exists within the central portion of Toano Draw Subbasin. Wells TW-14, TW-15, TW-3, Toano No. 1, 40-65-10, and MW-4 are located in a line that is generally parallel to and along this flow path. Wells TW-14, TW-15, and TW-3 are located in areas of the subbasin that contain relatively younger water of a calcium bicarbonate type. As contact time increases, i.e., with increasing distance along this flow path, the sodium concentration in the water increases from 15 to >50 mg/L and surpasses calcium. The modified water composition is apparent in the data from downgradient Wells MW-4 and 40-65-10. This trend is probably a result of the higher solubility of sodium minerals and the exchange of dissolved calcium for sodium adsorbed on the clay surfaces. The dissolved sulfate also increases with distance along this flow path but does not surpass the bicarbonate concentration.

The areal trends in chloride, TDS, and silica concentrations in groundwater and spring water provide useful information on groundwater recharge characteristics and chemical reactivity of the aquifer materials. Silica concentrations in groundwater are shown on Figure 5-2. As can be seen from Figures 5-3 and 5-4, the TDS and chloride concentrations in Toano Draw and the surrounding highlands show a noticeable distribution of low values in the south-central portion of the draw and higher levels in the northern portion of the draw near Thousand Springs Creek. This pattern supports the hypothesis that recharge occurs in the southern and possibly south-central portions of Toano Draw and that relatively fresh water moves rapidly with the shallow portions of the alluvial aquifer in the draw, northward toward Thousand Springs Creek. The low chloride and TDS values compared to some values in the nearby highlands suggest rapid flushing and short residence time for this water. The higher concentrations in the uplands surrounding the subbasin may be a result of longer residence times (contact time between water and rock), slower flow velocities, and less flushing along these flow paths. The sulfur odor detected in the artesian water produced from the lower portion of the MW-1 boring may be indicative that the deep groundwater has had a long residence time along a deep regional flow line. Silica concentrations (S_iO_2) in groundwater are illustrated on Figure 5-2. The high silica concentrations of 60 to 70 mg/L for even the young water with a short contact time with the rock is probably a result of the high reactivity of the volcanic glasses in the sediments that allow for rapid dissolution of silica-containing phases.

5.5.2 Water/Rock Interactions Controlling Water Chemistry

The chemical properties of aquifer material that influence the composition of groundwater are mainly a reflection of the mineralogy and composition of the rocks comprising the aquifer. However, in many cases the major minerals present in the rock do not provide the dominant influence because of their relatively low reactivity on the time scale of groundwater residence time. Oftentimes, it is the minor and trace minerals in the rock matrix, or minerals that occur as cementing agents, that control water chemistry. These minerals include calcite, pyrite, clays, and metal hydroxides.

The thin-section and petrographic analyses of the rock samples showed that calcite, pyrite, clays, and iron oxides are components of the aquifer material. Much of the pyrite had been altered to iron oxides, which is expected under the oxidizing conditions that currently exist at least in the shallow aquifer. The hydrogen released by the oxidation of pyrite is neutralized by reaction with calcite, which is present at higher concentrations in the rock than pyrite. Therefore, as pyrite in this rock is oxidized, the pH of the water remains in the neutral range.

It appears, by comparing the spring and well water samples, that most of the major ion chemistry is fixed very early during contact time of precipitation/snowmelt with the shallow alluvium/bedrock. This is quite common. The dissolved calcium and bicarbonate, which are the dominant species in the water, are a product of biological activity, carbon dioxide gas exchange with the atmosphere, and calcite equilibrium. The other major cations and anions come from dissolution and leaching of minerals in the aquifer. The metals are trace constituents in the soil.

The stable isotopes of hydrogen (H/D) and oxygen ($^{18}O/^{16}O$) were measured in six spring and eight well water samples because these isotopes have been shown to be useful in "fingerprinting" water types and determining the source of water (meteoric vs. juvenile) in geothermal systems. The results of the stable isotope analyses of all the water samples are given in Table 5-1. They show a relatively small variation in values for the isotopes (delta D = -130 ± 8; delta O-18 = -17 ± 1.6). All the values are close to the meteoric water line. This suggests that all of the groundwater and spring water comes from meteoric sources as rainfall or snowmelt, and that orographic and seasonal effects on stable isotope composition are either minimal or masked by dispersion in the groundwater. The chemistry of Hot Spring (S7) is discussed separately in the following section.

5.5.3 Geochemical Data Regarding the Origin of Springs

The water chemistry data for the 15 springs sampled show much greater variability than the composition of the groundwater. The TDS of the springs range from 8 to 2140 mg/L, while the TDS range of the groundwater is 187 to 920 mg/L. The pH of the springs also have a relatively wide range of 6.41 to 8.31. The variability in spring composition is expected for springs that discharge from local flow systems, i.e., those that drain small watersheds or shallow, perched zones of groundwater. Local mineral compositions may have a large effect on water composition, and evapotranspiration can also have a strong influence on water chemistry along restricted flow paths. In these cases, separate water types can develop, which are then measured as different chemical compositions for the springs. The major cations and anions of the various springs are similar; however, the overall concentrations are different because of variable groundwater residence times and concentrating factors (most likely evapotranspiration). Four of the six springs sampled had measurable tritium (Table 5-1), supporting the hypothesis that the springs discharge a relatively shallow system and are not at the end of a deep groundwater flow system.

Hot Spring (S7) has a somewhat different chemistry than the other springs. Its TDS is relatively high (515 mg/L), pH is low (6.4), and sodium is the dominant cation. The temperature of water from Hot Spring (60.9°C) is at least 40° higher than that of the other springs; this allows for water/rock interactions to proceed at a faster pace. Also, calcite ($CaCO_3$) becomes less soluble at higher temperatures, so calcium may be removed from the water as this mineral precipitates. The presence of tritium in the Hot Spring water and the fact that the delta-D and delta O-18 values of this water are not significantly different from the other spring and well water samples suggest that water in Hot Spring is relatively young (<50 years old), has a meteoric water source, and has probably not reached isotopic equilibrium with its host rock.

5.5.4 Water Quality Impacts on Plant Operation

Guyton (1982), citing a letter from E.D. Banks, states that water for plant operation having or exceeding any of the following characteristics should be avoided, if at all possible:

1) Silica (SiO_2) - 75 milligarams per liter (mg/L) (35 mg/L as silicon, Si)
2) Specific Conductance - 2000 micromhos per centimeter (µmhos/cm) at 25°C
3) Chloride + Sulfate - 500 mg/L

None of the waters sampled during this investigation exceeded the specific conductance limit and only Tripon Pass Spring exceeds the chloride + sulfate limit. The water from Tripon Pass Spring is an unlikely major source of water for the plant because of its low discharge rate of less than 1 gallon per minute (gpm). None of the spring water samples exceeded the silica level; however, four of the well samples (TW-3, MW-4, 40-65-10, and 41-65-35ad) exceed the silica limit and one well (39-66-24) is at the limit. These wells are all located along Toano Draw and thus represent the most likely source of water for the first operating plant. Therefore, in general, this groundwater quality appears favorable for plant uses. However, the potential effect of high silica water on plant operation should be further evaluated, and the possible necessity of pre-treatment methods should be considered.

5.6 HYDROCHEMICAL MODEL

5.6.1 Groundwater Recharge

Some aspects of the chemistry of the groundwater can be used to estimate the age of the water and provide qualitative information on recharge to the aquifer. Tritium is a radioactive isotope of hydrogen that has a half-life of 12.26 years. A large amount of tritium was added to the atmosphere during atmospheric testing of nuclear weapons in the 1950s and 1960s. Some of the tritium dissolves in precipitation and its presence in groundwater is a good indicator of whether or not the groundwater has mixed with recent (post 1952) water (Fontes 1980). If tritium is in the water, then some component of the water is a result of recharge within the past few decades. Tritium was analyzed in water from eight wells for this study (Figures 4-1 and 4-2) and detected in four of the wells (TW-3, TW-15, Toano No. 1 [24bd], and Fivemile Draw [33ac]). This suggests that recharge through the unsaturated zone in the vicinity of Toano Draw is occurring and is relatively rapid. The wide distribution of wells with detectable tritium also suggests that recharge may be occurring along the entire Toano Draw and may not be entirely localized in the highlands or southern portion of the draw.

5.6.2 <u>Hydrochemical Variations along Flow Paths</u>

The areal trends of major cations and anions were described previously in Section 5.5.1. Major changes in cation/anion chemistry were not noted, except for the increasing concentration of sodium relative to calcium along potential flow paths. In almost all cases, the analyses of water samples from this study are very similar to results obtained by previous investigators. This suggests that the chemical system is relatively stable both temporally and spatially.

6.0
SURFACE WATER HYDROLOGY

6.1 INTRODUCTION

This section of the report presents the results of analyses to assess the surface water resources of Thousand Springs Basin in northeastern Nevada. The analyses were performed as part of the basin water resources evaluation required for developing general plans to supply water to the proposed Thousand Springs Power Plant (TSPP). The purpose of the study was to provide information needed for estimating the hydrologic balance. The proposed power plant, at ultimate planned development, will contain eight coal-fueled, 250-megawatt (MW) generating units. Each generating unit will require a maximum of 4000 acre-feet/year(ac-ft/yr) of makeup water to support its operation.

The renewable water resources of Thousand Springs Basin are derived from precipitation falling within the watershed boundary of the basin. Groundwater levels and flows (Section 4.0) were characterized as another part of the overall project water resources evaluation. Results of hydrogeologic characterization indicate that groundwater flow divides exist along the topographically elevated watershed boundaries. Thus, there is no groundwater inflow as underflow into the basin.

For the purposes of this study, the basin of concern lies upstream from the United States Geologic Survey's (USGS) Montello streamflow gaging station, located about ½ mile upstream from where Thousand Springs Creek flows into Utah and Great Salt Lake Basin. Outflow from Thousand Springs Basin at the Montello station consists of surface water flow in the stream channel, which is measured by a recording gage, and underground flow.

A water budget (hydrologic balance) was performed for Thousand Springs Basin to provide an estimate of groundwater recharge within the basin, and groundwater outflow from the aquifer as underflow, independent of that developed during hydrogeologic characterization groundwater flow modeling activities (Sections 7.0 and 8.0). In order to estimate the basin hydrologic balance, the total basin precipitation was estimated and equated to total evapotranspiration within the basin plus surface and groundwater outflow. It is noted that within the basin as a whole, there is, and has been historically, relatively little water development and use when considered in relation to the total water resources of the basin.

It is expected that the power plant water requirements will be supplied from wellfields that tap the groundwater resources of the basin. As a result, the present equilibrium in the groundwater system will be modified. One result of this modification is expected to be that, as the power plant approaches the planned ultimate size, some of the groundwater which presently discharges from the basin will instead be captured by the project wellfields. An important focus of this study was to estimate the average annual streamflow in Thousand Springs Creek under present conditions, the extent to which this flow contributes to groundwater recharge, and how recharge rates will change after the power plant begins operation.

In summary, the objectives of the surface water hydrology investigation were:

- To provide estimates of long-term average annual precipitation and the extent to which precipitation recharges the groundwater system
- To provide information on groundwater-surface water interaction and estimates of the gains to or losses from Thousand Springs Creek due to groundwater flow
- To characterize the seasonal and long-term variations in precipitation and, if feasible, streamflow

The scope of this investigation included:

- Compilation and analysis of available precipitation records to derive measures of long-term average monthly and annual precipitation and to derive annual precipitation-elevation relationships
- Compilation and analysis of available streamflow records to estimate long-term average annual streamflows
- Compilation of data on water uses in the basin, location and type of use--primarily irrigated agriculture
- Estimates of evapotranspiration losses in the basin as a percentage of average annual precipitation, for use in one method of estimating the basin water budget
- Estimates of the hydrologic budget for the basin and selected subbasins

6.2 AVAILABLE HYDROLOGIC DATA AND HYDROLOGIC BACKGROUND

Available hydrologic data for Thousand Springs Basin include hydrologic data collected for this project and previously published hydrologic data. Measurements of precipitation, streamflow, and reservoir stage were made about once a month by Chilton Engineering and Surveying Ltd., Elko, Nevada (Chilton) during 1982 and 1983, and from 1986 to 1988. It is noted that the only available streamflow data for Thousand Springs Creek prior to about 1985 were the measurements made by Chilton. Sources of published data were the National Oceanic and Atmospheric Administration (NOAA) (precipitation), the Bureau of Land Management (BLM) (precipitation-elevation), and the USGS (streamflow). Figure 6-1 shows the location of available surface water data stations.

6.2.1 Hydrologic Data Collection

A field program to collect hydrologic data in the site vicinity was performed by Chilton, which later became Kennedy/Jenks/Chilton and then later again became Chilton Engineering and Surveying, Ltd.--its present name. The hydrologic monitoring stations for precipitation, streamflow, and reservoir stage data are shown on Figure 6-1. Data at each station were obtained by field measurement on an approximately monthly basis. More frequent measurements were sometimes taken following major rainfall events and during periods of high snowmelt runoff. These data were collected initially to provide approximate measures of streamflow, because there was no existing record of flow, and to provide indications of how precipitation varied around the watershed, and later to supplement the published hydrologic data discussed in Section 6.2.

The periods of record for the Chilton hydrologic monitoring data are shown in Table 6-1. As may be seen, data collection at most stations began in February and March 1982 and continued through September 1983. Field data collection was discontinued between October 1983 and January 1986, after which time certain monitoring stations were added and others deleted. Data collection, on a schedule of approximately once a month, at the new set of stations, resumed in February 1986 and continued through October 1988.

The Chilton hydrologic data included information from precipitation stations, streamflow stations, and reservoir stations. Precipitation data were cumulative precipitation since the last measured date, for monthly or shorter periods. Streamflow data were instantaneous flow estimates in streams, based on direct current measurement using a current meter, or estimates based on the observers' estimates of flow velocity and channel cross section. Reservoir stage data were measurements of stage relative to a bench mark. The precipitation data were based on nonstandard rain gages and were not used in the following analysis.

The Chilton hydrologic data were collected on a periodic rather than a continuous basis. These data were not used for the detailed hydrologic analyses which are discussed later, since flow conditions between times of field measurement were not known. Furthermore, the data were collected during two periods of about 1½ and 2½ years, respectively, with a break between measuring periods of about 3 years. Therefore, they were considered not suitable for use in estimating long-term basin characteristics. Due to these limitations, the Chilton hydrologic data were used only for qualitative interpretation of basin characteristics.

6.2.2 Published Hydrologic Data

The hydrologic monitoring stations providing published precipitation and streamflow data in the site vicinity are shown on Figure 6-1. The reporting agencies, types of data, and periods of record for these stations are shown in Table 6-2. A discussion of these stations and the data provided for subsequent hydrologic analyses are presented below.

As shown in Table 6-2, precipitation is monitored by NOAA at five locations in the site vicinity. Three of these monitoring stations (Contact, Montello, and Wells) had daily records at least 40 years in length. Data from these stations were used to estimate long-term average monthly and annual precipitation in the site vicinity.

In addition to the NOAA stations, the BLM monitored a network of 23 rain gages in the Rock Springs Creek watershed from 1963 to 1980. The locations of these gages are indicated on Figure 6-1. The BLM stations were at elevations ranging from 5460 to 7380 feet. Although monitoring of these stations was discontinued in 1980, these BLM stations provided monthly totals of precipitation for 18 years which were used together with the NOAA monitoring station data to estimate the orographic variations in precipitation in the site vicinity.

As shown in Table 6-2, streamflow is continuously recorded by the USGS at three locations along Thousand Springs Creek. These three gaging stations, which have been identified by the USGS as the Wilkins, Shores, and Montello gaging stations, have drainage areas of approximately 68, 483, and 1453 square miles, respectively. Although having relatively short periods of record (maximum range available for this analysis, 1985-1988), the streamflow data from these gaging stations were used for detailed hydrologic analysis since continuous flow measurements were recorded at the stations. Lands of Sierra, Inc. (LOS), shares in the cost of operating these stations through a cooperative program with Elko County, Nevada, and the USGS.

In addition to the three continuous gaging stations, the USGS operates eight other stream gaging stations in the site vicinity. Five of these stations are crest-stage gages, and three are stations where spot measurements are made on an as-convenient basis. These stations are not shown on Figure 6-1 nor included in Table 6-2, because instantaneous streamflow data from these stations were not utilized quantitatively in the subsequent hydrologic analysis.

6.2.3 Hydrologic and Meteorologic Setting

Thousand Springs Basin lies within the Great Basin and is drained by Thousand Springs Creek, flowing generally west to east and discharging to Great Salt Lake Desert and Great Salt Lake Basin. Four north-trending mountain ridges divide the basin into seven subareas or subbasins: Herrell Siding Area, Brush Creek Valley, Toano Draw, Rocky Butte Valley, Rock Springs Valley, Crittenden Creek, and Montello Valley (Rush 1968).

Elevations range from about 4600 feet (1400 meters) on the valley floor, near the Utah state border, to about 8900 feet (2700 meters).

Winters in the basin are long, with snow on both valley floors and mountains. Summers are short, with warm daytime temperatures and cool nights. Winter precipitation includes snowfall and rainfall, which account for most of the storms. Winter storms are frequently frontal storms. Except for occasional thunderstorms, little precipitation occurs in late summer and early fall. The variability of storm size and temporal distribution is high. The average monthly precipitation is affected by the number, intensity, size, and distribution of storms.

Streams originate at the higher elevations in the watershed and are generally intermittent. The exceptions are several small perennial streams in the headwater areas of the surrounding mountains, and Thousand Springs Creek below Twentyone Mile Dam, where streamflow also is generally perennial. Streamflow in Thousand Springs Creek is variable from month to month and from year to year, as well as from location to location. Below the Wilkins streamflow gaging station, streamflow decreases in the downstream direction, indicating natural stream losses to groundwater recharge, evapotranspiration, and irrigation diversions. There are some perennial springs, especially downstream from Twentyone Mile Dam, which contribute flow to the creek.

6.2.4 <u>Precipitation and Streamflow Characteristics</u>

The data described in Section 6.2.2 were used to characterize the distribution of precipitation and streamflow in the site vicinity. The total monthly precipitation at the Contact, Montello, and Wells precipitation monitoring stations for the period 1985 through 1987 are shown on Figure 6-2. The average monthly streamflows at the Wilkins, Shores, and Montello gaging stations during the same time period are shown on Figure 6-3. Clearly, the monthly precipitation totals are affected by the number, size, and distribution of storms in the basin.

As may be seen on Figure 6-2, precipitation is highly variable from month to month. As discussed in Section 6.3.1, May and June generally are the wettest months, and February and July are the driest months, based on long-term precipitation records. Although the available streamflow records were too short to constitute an adequate base for calculating monthly streamflow averages, it appears that high streamflow periods occur during late winter and spring as a result of melting of the winter snowpack, particularly on the higher-elevation parts of the basin. As may be seen on Figure 6-3, streamflow is generally highest during the spring and is highly variable from year to year. Streamflow generally decreases in the downstream direction along Thousand Springs Creek. The reduction of streamflow in the downgradient direction is a result of groundwater recharge from water in the stream channel, evapotranspiration along the creek, and surface water withdrawals for irrigation purposes.

Analysis of precipitation and streamflow data in the region are presented in Sections 6.3 and 6.4, respectively.

6.2.5 Basin Surface Water Uses

Surface water in Thousand Springs Basin is used for a variety of purposes, including domestic, recreation, livestock and wildlife, and irrigated agriculture. There is currently no identified surface water use associated with oil or gas production, mining, or manufacturing activities in the basin. Water discharging from springs is considered to be groundwater and is discussed in Section 4.7 (Groundwater Use in Thousand Springs Basin).

Limited published information is available on historical surface water use in Thousand Springs Basin. The major source of this information is "Water Resources Appraisal of Thousand Springs Valley" (Rush 1968). In addition to this source, the U.S. Soil Conservation Service (SCS) (1988-1989), Elko, Nevada, provided data for estimating current irrigated agricultural use of surface water. The Rush (1968) data are summarized in the following paragraphs for background information, but are not used in subsequent analyses.

6.2.5.1 Recreational Use of Surface Water. Twentyone Mile Reservoir is an irrigation reservoir with some flood control and recreational use. Dake Reservoir is a recreational reservoir used primarily for fishing. Crittenden Reservoir is an irrigation reservoir with some recreational use.

6.2.5.2 Livestock Use of Surface Water. Data on surface water use for livestock and wildlife are currently not available, but such use is thought to be minor--probably less than 200 ac-ft/yr--compared to the total water use in the basin. Generally, livestock obtain their drinking water primarily from wells, and wildlife obtains its water from creeks, springs, reservoirs, and ponds.

6.2.5.3 Irrigated Agricultural Use of Surface Water. Surface water is currently used for irrigation of native and improved pasture at several locations along Thousand Springs Valley. Additionally, surface water and springs are used to augment wells for irrigation of alfalfa haylands in the lower reaches of Thousand Springs Valley, below Twentyone Mile Reservoir.

According to Rush (1968, p. 1), "agriculture, other than grazing, is limited to the mile-wide floodplain of Thousand Springs Creek, where hay and pasture land are irrigated. Sampled well and surface waters were generally chemically suitable for irrigation in the three western [hydrologic] segments [Herrell Siding-Brush Creek Area, Toano-Rock Spring Area, and Rocky Butte Area], but samples collected in Montello Valley were more highly mineralized." Currently, irrigated agriculture remains limited to the floodplain of Thousand Springs Creek and Crittenden Creek.

Rush (1968, p. 32) says that "water is diverted from Thousand Springs and Crittenden Creeks for irrigation on their floodplains. Most of the diverted flow of Thousand Springs Creek west of Eccles Ranch is from snowmelt. East of the ranch, springs and seeps supply most of the diverted flow. Most of the diverted flow of Crittenden Creek is from Crittenden Spring (42/69-8b)."

Rush (1968, p. 2) estimated that crops in Thousand Springs Valley consumed 4700 ac-ft/yr of surface water on 6400 acres. Rush distributed the 4700 ac-ft/yr as 1500 ac-ft/yr in the Herrell Siding-Brush Creek Area, 2000 ac-ft/yr in the Toano-Rock Spring Area, 200 ac-ft/yr in the Rocky Butte Area, and 1000 ac-ft/yr in the Montello-Crittenden Area. He reported the growing (and presumably irrigation) seasons as 70 to 100, 90 to 140, 90 to 140, and 80 to 140 days, respectively.

Rush (1968, pp. 32-33) based net consumptive-use rates for meadow, pasture, and alfalfa on Houston (1950), and concluded that the rates average about 1.5 feet per season for two cuttings. He also noted that pumped and/or subirrigation groundwater use supplemented surface water consumed by crops in the Herrell Siding-Brush Creek, Toano-Rock Spring, Rocky Butte, and Montello-Crittenden Creek areas (Rush 1968, p. 33). Presumably, subirrigation groundwater is water extracted from shallow groundwater by crop roots. He estimated that the 1500 ac-ft/yr of surface water used on crops in the Herrell Siding-Brush Creek area was used, along with 300 ac-ft/yr of pumped water and 800 ac-ft/yr of subirrigation, on 1700 acres of meadow grass and alfalfa on Winecup Ranch; the 2000 ac-ft/yr of surface water used on crops in the Toano-Rock Spring area was used with 1000 ac-ft of subirrigation on 2000 acres of mostly meadow grass on Winecup and Eccles ranches; the 200 ac-ft/yr of surface water used on crops in the Rocky Butte area was used with 400 ac-ft/yr of subirrigation on 400 acres of alfalfa on Eighteen Mile Ranch; and the 1000 ac-ft/yr of surface water used on crops in the Montello-Crittenden Creek area was used, along with 1000 ac-ft/yr of pumped water and 1400 ac-ft/yr of subirrigation, on 2300 acres of meadow grass and alfalfa on Crittenden, Twelve Mile, and Gamble ranches.

In 1988 and 1989, the SCS, Elko, Nevada, conducted site reconnaissances of irrigated agricultural practices in Thousand Springs Basin. It is noted that net streamflow diversions for irrigation cannot exceed the flow in the creek although total diversions may include tailwaters returning to the creek and diverted one or more times before being consumed, lost to groundwater, or discharged from the basin. The SCS provided data on irrigated acreages, by crop, and by location along Thousand Springs Creek. Also, it estimated the average amount of water applied and consumptively used, by crop, and the sources of the water used. Woodward-Clyde Consultants (WCC) reviewed the data provided by the SCS and from those data estimate that the current average net consumptive use of surface water for irrigated agriculture is approximately 10,900 ac-ft/yr over approximately 6590 acres. The surface water usage, when water is available in the indicated amounts, is distributed as 2966 ac-ft/yr in the Herrell Siding-Brush Creek area on 1454 acres of improved pasture, 2799 ac-ft/yr in the Toano-Rock Spring area on 1700 acres of native and improved pastures, 1278 ac-ft/yr in the Rocky Butte area on 1160 acres of native and improved pastures, and 3867 ac-ft/yr in the Montello-Crittenden Creek area on 2275 acres of native and improved pastures and alfalfa haylands.

According to the SCS, the current surface water use estimates are based on net consumptive-use rates which range from 0.95 to 2.21 feet per season. Consumptive-use estimates by crop type and number of cuttings are as follows: native pasture, 0.95 feet for one cutting, or for one and one-half cuttings using tail water irrigations, 1.43 feet for one and one-half cuttings, 1.91 feet for two cuttings; improved pasture, 1.53 feet for one and one-half cuttings, 2.04 feet for two cuttings; and alfalfa haylands, 2.21 feet for the entire growing season (presumably two cuttings). The term "one and one-half cuttings" means that only one cutting applies to some lands, while two cuttings applies to other lands and represents an average for the area and for the year.

The current estimates of surface water use for irrigation by subbasin, based on SCS data, were included in Table 4-5, together with the data on groundwater use for irrigation. The table includes the estimated net water use and acreage discussed above. In addition, the table includes water-applied volumes based on indicated application efficiencies. The table also shows water sources, such as Thousand Springs Creek, Brush Creek, Crittenden Reservoir, and wells and springs. Based on the indicated application efficiencies, the total volume of surface water applied to all subbasins is approximately 26,900 ac-ft/yr over about 6600 acres for all surface water sources (creeks and reservoirs).

It is noted that surface water use in any year is limited to the quantity of water available, from the various indicated sources, at the times when the water is needed. Also, the indicated quantity of water applied probably includes a significant quantity of return flow to Thousand Springs Creek from upstream irrigation uses.

For comparative purposes, current use of groundwater for irrigated agriculture (alfalfa haylands) is approximately 4310 ac-ft/yr over 1950 acres. The total volume of water applied to all subbasins is approximately 8620 ac-ft/yr over the same acreage, based on the application efficiencies indicated in Table 4-5, for all groundwater sources (wells and springs).

6.3 ANALYSIS OF PRECIPITATION

Analyses conducted on precipitation data from Thousand Springs Basin and vicinity were averages by month and year, orographic relationship, and correlation relationships.

6.3.1 Average Precipitation

The average precipitation in the site vicinity was calculated on both a monthly and annual basis. This analysis made use of NOAA precipitation data from the Contact, Montello, and Wells precipitation monitoring stations. These stations were selected because they were the nearest stations to Thousand Springs Basin with relatively long, essentially continuous NOAA records, and they were essentially equidistant from the center of the basin--the Contact station being located northwest, the Montello station east-southeast, and the Wells station southwest of the basin center, respectively. Because of these factors, data from these stations were considered appropriate for evaluating long-term precipitation in the site vicinity.

The basic analyses to estimate average monthly and annual precipitation at the three monitoring stations were performed using data from 1949 through 1983. This 35-year period was selected for analysis because it was the longest concurrent period of record from all three stations. By using this concurrent period of data, the averages are believed to be good measures of the areal variation in precipitation between the monitoring stations. Appendix B shows the annual precipitation records (Table B-2) for these stations.

The results of the analyses of average precipitation at the Contact, Montello, and Wells precipitation monitoring stations are presented in Table 6-3 and on Figure 6-4. May and June are the wettest months, having average precipitations of 1.33 and 1.14 inches, respectively. February and July are the driest months, with average precipitations of 0.55 and 0.52 inches, respectively; overall, February through April and July through October tend to have an average precipitation of less than 0.75 inches/month. The average annual precipitation for all three monitoring stations is 9.41 inches and ranges from 7.69 inches at Montello to 10.37 inches at Wells. These averages are arithmetic averages (means).

The 1949-1983 annual average precipitation at Montello and Wells monitoring stations was compared to the longer-term records at these stations. There is no comparable longer-term record at the Contact Station. The 1949-1983 Montello station annual average of 7.69 inches compares closely to the 1886-1983 Montello station annual average of 7.57 inches, or about 1.59 percent higher than the longer-term average of 97 years. The 1949-1983 Wells station annual average of 10.37 inches compares closely to the 1890-1983 Wells station annual average of 9.89 inches, or about 4.85 percent higher than the longer-term average of 93 years.

6.3.2 Orographic Relationship

As noted above, different geographic locations may receive widely different quantities of precipitation over the same period of time. These differences may be thought of as having two components (Gilman 1964): one due to differences in geographic location and the other due to differences in elevation. This latter component, due to elevation differences, is considered the orographic effect on precipitation (Gilman 1964, p. 9-24).

The analysis of orographic effects made use of data (Table 6-4) from the BLM precipitation monitoring stations located in the Rock Spring Creek watershed and also the Contact, Metropolis, Montello, Pequop, and Wells

NOAA monitoring stations. The mean annual precipitation for each of these stations during the 1963 through 1980 monitoring period was plotted against the station elevation. A regression analysis was then performed to define the best fit straight line through the data points. Two data points that appeared inconsistent with all the others were eliminated from the regression analysis because of their apparent inconsistency with respect to the other precipitation points. It is noted that the orographic analysis does not account for windward or leeward variations in elevation.

The result of analyses of orographic effects is shown on Figure 6-5. The regression line (Figure 6-5) is considered applicable throughout Thousand Springs Basin and its vicinity. Also shown on this figure is the equation of the regression line and the correlation coefficient squared (coefficient of determination) of 0.818. This coefficient represents a relatively good fit of the regression line to the observed data.

The relationship presented on Figure 6-5 was used to estimate annual precipitation at various elevations. For the 1963 to 1980 period, this figure shows the actual relationship between elevation and mean annual precipitation. For other annual periods, annual precipitation at any elevation for a given year may be estimated as follows. First, a point with known elevation and annual precipitation during the given year is plotted as on Figure 6-5. Second, a new line, with the same slope as the regression line of Figure 6-5, is drawn through the plotted point. From this new line, the corresponding annual precipitation at other elevations may be estimated for the same year.

6.3.3 <u>Correlation Relationship</u>

In addition to the above orographic relationship, correlation relationships (Yevdjevich 1964) were developed for monthly precipitation at the Contact and Wells stations and Montello and Wells precipitation monitoring stations. This correlation was necessary to estimate monthly precipitation values which were missing for some months from the Contact and Montello monitoring stations. To develop these relationships, plots of total monthly precipitation at Contact and Montello versus Wells were prepared for each month. For each set of data, a regression analysis was performed to derive the best fit straight line through the data points. These relationships permitted estimation of monthly precipitation at Contact and Montello based on precipitation during the same month at Wells.

The regression plots and equations for all months are included in Appendix B, on Figure B-1. The correlation coefficient squared (coefficient of determination) for these correlation relationships varies from 0.238 to 0.730, indicating large variations in goodness-of-fit and less than the previously determined value of 0.818 for the orographic relationship (Figure 6-5).

6.4 ANALYSIS OF STREAMFLOW

Analysis of streamflow in Thousand Springs Creek included use of a geographical model of the drainage basin and development of a streamflow generation model. These two models are discussed in the following subsections.

6.4.1 Drainage Basin Model

A geographical drainage basin model of Thousand Springs Basin was developed to assist in the analysis of streamflow. This model was developed using WCC's in-house Geographic Information System (GIS). The GIS is a computerized data base management system designed to store, process, and analyze cartographic data. The drainage basin model was developed from the USGS Jackpot and Wells topographic maps, having a scale of 1:100,000 (1 centimeter equals 1 kilometer) and a contour interval of 40 meters.

The drainage basin model for Thousand Springs Basin is shown on Figure 6-6. This figure shows Thousand Springs Basin above the USGS Montello streamflow gaging station, which is located just upstream of the Nevada-Utah border. In the figure, Thousand Springs Basin has been subdivided into vertical intervals of 120 meters each, or three contour intervals, from the USGS topographic maps.

Included on the overall drainage basin map showing elevation zones are two other categories of lines. The irregular lines of Figure 6-6 represent the boundaries of watershed areas above the Wilkins and Shores streamflow gaging stations, a proposed streamflow gaging location below the confluence with Crittenden Creek, and Toano Draw Subbasin. The straight lines on the figure represent boundaries of Thiessen polygons for the Contact, Montello, and Wells precipitation monitoring stations. The subareas within each polygon boundary are the areas within each watershed that are located nearest to the respective precipitation monitoring station. The Thiessen polygon method of estimating the average amount of precipitation over a specific area is intended to account for areal variations in precipitation by providing an area weighting factor for data from each monitoring station (Linsley et al. 1982, p. 71). Orographic effects of precipitation within the polygons are accounted for using the regression relationship discussed in Section 6.3.2 and the 35-year (1949-1983) average annual precipitation figures from each of the three monitoring stations.

A tabulation of the drainage areas, derived from the drainage basin model, is presented in Table 6-5. This table shows the drainage areas within each of the Thiessen polygon subareas previously discussed. Also shown is the total drainage area at each location, which is the sum of the respective subareas. For the drainage areas outlined on Figure 6-6, breakdowns of drainage areas within each of the elevation zones are tabulated in Appendix B, Table B-4.

6.4.2 Streamflow Generation Model

WCC developed a hydrometeorological streamflow generation model to estimate the long-term streamflow characteristics for the subareas contributing flow to Thousand Springs Creek. Development of the model was necessary because, as previously noted, no long-term streamflow gaging stations exist in Thousand Springs Basin. The model utilized data from long-term precipitation monitoring stations to estimate and predict long-term streamflow characteristics. The available short-term streamflow data, input to the streamflow generation model, represents current streamflow conditions, i.e., current withdrawals for irrigation are presumed applicable to long-term conditions, as predicted by the model.

The streamflow generation model for Thousand Springs Creek was developed based upon the following methodology:

1) The periods of record at the Wilkins, Shores, and Montello streamflow gaging stations were examined, and the monthly periods with no missing data were identified. The period with no missing data defined the period of analysis for each gaging station. The total volume of streamflow during the period of analysis at each gaging station, V_s, was determined from the streamflow records. For the Montello gaging station, V_s was adjusted to include estimated changes in storage and evaporation from Twentyone Mile and Dake reservoirs.

   Reservoir stage data were measured by Chilton Engineers, as indicated in Table 6-1 and reported in Appendix B. Volume and area versus elevation curves were provided for Twentyone Mile Reservoir by Chilton and were derived from the USGS Tecoma 1:24,000 scale topographic quadrangle for Dake Reservoir. Evaporation data were based on NOAA (1968).

2) For the same periods of analysis, the total amounts of precipitation at the Contact, Montello, and Wells monitoring stations were calculated from the station precipitation records. Missing monthly precipitation data from the Contact and Montello stations were estimated, based on the precipitation during the same month at Wells, and utilizing the monthly correlation relationships (Appendix B) for precipitation previously developed.

3) The total precipitation amounts within the analysis period at Contact, Montello, and Wells monitoring stations, from Step 2, were utilized as primary inputs for calculating precipitation within the respective Thiessen polygon boundaries for the drainage basins upstream of the Wilkins, Shores, and Montello gaging stations. The orographic relationship for precipitation, described in Section 6.3.2, was used to estimate the corresponding precipitation within each elevation zone within each subbasin within the polygons. The total volume of precipitation over each drainage basin, V_p, was computed from the calculated precipitation depths and measured (map) areas within each elevation zone.

4) The total volume of streamflow at each gaging station, V_s (from Step 1), was divided by the total volume of precipitation over its drainage basin, V_p (from Step 2). The resultant streamflow coefficient, K, was defined as the fractional amount of precipitation that was recorded as streamflow at the gaging station during the period of analysis. The values of the streamflow coefficients, K, for the Wilkins, Shores, and Montello gaging stations were determined to be 0.158, 0.0268, and 0.0027, respectively.

5) The streamflow coefficients, K, derived in Step 4, were then adjusted to reflect average precipitation, where the rainfall over the basin was equal to the average monthly rainfall for each month of the analysis period. This adjustment was necessary because the precipitation amounts during the periods of analyses (from Step 2) were different than the long-term average values. An average streamflow coefficient, $\overline{K}$, was developed by this procedure. It represents the coefficient which would have resulted if the long-term monthly average precipitation had occurred each month during the periods of analyses. Also for the Wilkins gaging station, separate analyses were performed which accounted for the wet and dry rainfall periods of record. At Shores and Montello stations, a scaling factor was developed by relating the K values to the longer-term and more consistent data at Wilkins.

   The Wilkins analysis included a plot of $V_p/\overline{V}_p$ (see Step 7), where $\overline{V}_p$ was the volume (assuming precipitation each month was equal to the long-term average for the month), versus $K/\overline{K}$. The plot included the total period of analysis plus separate plots for a relatively dry year and a relatively wet year (both of which happened to occur during the analysis period). A curved line was fitted to the plot. $(K/\overline{K})$ was estimated as the K value corresponding to a value of V_p/V_p of unity.

   To estimate $\overline{K}$ for Shores and Montello, a scaling factor was developed. The factor was based on assuming $(K/\overline{K})$ at Wilkins was equal to $(K/\overline{K})$ at Shores and Montello, respectively, for the same time periods. As all quantities were known for Wilkins Subbasin, and K was known for Shores and Montello, the $\overline{K}$ values for Shores and Montello were calculated by solving for the equality.

   The values of the average streamflow coefficients, $\overline{K}$, for the Wilkins, Shores, and Montello gaging stations were estimated to be 0.246, 0.0270, and 0.0042, respectively. At Shores, the period of analysis (March 1985 through October 1986) was significantly shorter than at Wilkins (April 1985 through May 1988) and Montello (same periods as Wilkins, with 3 missing months), as shown in Table B-6 (Appendix B). This difference in periods of analysis accounts for why the K values for Wilkins and Montello are significantly greater than their unadjusted $\overline{K}$ values from Step 4, while the $\overline{K}$ value for

Shores is similar to the corresponding unadjusted $\overline{K}$ value from Step 4.

The long-term period (1949-1983), on which average monthly precipitation values were based, was wetter (more precipitation) on the average than the short-term periods (1985-1986 for Shores; 1985-1988 for Wilkins and Montello) of analysis for streamflow. Therefore, a higher percentage of precipitation would be expected to appear as streamflow during a period experiencing average long-term precipitation. Thus, the long-term streamflow coefficients would be expected to be higher than the coefficients derived for the simulation period.

6) The average streamflow coefficients, $\overline{K}$, for the Wilkins, Shores, and Montello gaging stations were plotted against their drainage areas so that predictions could be made of $\overline{K}$ as a function of drainage area. A smooth curve was then drawn through the points, as shown on Figure 6-7. From this relationship, the average streamflow coefficient, $\overline{K}$, can be estimated for ungaged locations along Thousand Springs Creek. Based upon the total drainage area that was shown in Table 6-5, the $\overline{K}$ coefficient for Thousand Springs Creek below Crittenden Creek was determined to be 0.0070.

7) The long-term average annual precipitation amounts at the Contact, Montello, and Wells precipitation monitoring stations, together with the orographic relationships derived in Section 6.3.2, above, were applied to the five basins shown in Table 6-5 so that the average annual precipitation could be estimated for each subbasin. The total volumes of precipitation over each subbasin under average annual conditions, $\overline{V}_p$, were then determined. These analyses were performed as previously discussed in Step 3.

8) The average streamflow coefficient for each drainage basin, $\overline{K}$ (from Steps 5 and 6), was multiplied by the average annual precipitation volume, $\overline{V}_p$ (from Step 7), to obtain the average annual streamflow volume, $\overline{V}_s$. The volumes $\overline{V}_s$, derived from the streamflow generation model, were then converted to discharges to compare average annual streamflows.

As may be seen on Figure 6-7 and in Table 6-6, the average streamflow coefficients were 0.0042 to 0.0270 for drainage areas above Montello and Shores gaging stations, respectively. These coefficients reflect streamflow conditions affected by evapotranspiration, irrigation withdrawals, and gains or losses from or to groundwater, respectively. The average streamflow coefficient for the drainage area above Wilkins gaging station was 0.246, reflecting streamflow conditions unaffected by irrigation withdrawals and groundwater interactions. In addition, hydrometeorological conditions, which affect evapotranspiration rates, upstream are different from the Wilkins gaging station downstream conditions due to orographic, geologic, and vegetative differences.

The results of the streamflow generation model for Thousand Springs Creek are summarized in Table 6-6. As may be seen, the computed average annual streamflows were 17.23 cubic feet per second (cfs) and 5.50 cfs at the Wilkins and Montello gaging stations, respectively. When distributed over the respective drainage areas, average annual streamflows equate to 3.45 inches and 0.051 inches of areawide runoff at the same two locations.

As previously noted, streamflow at the Montello gaging station, as estimated using the streamflow generation model, includes adjustments for changes in reservoir storage and evaporation losses from Dake, Crittenden, and Twentyone Mile reservoirs. However, the model does not account for irrigation uses of water in the basin. Assuming that all of the net consumptive use of surface water by irrigation, about 11,000 ac-ft/yr, would appear as streamflow at the Montello gage if there were no irrigation in the basin, then the average flow past the gage would be increased by approximately 11,000 ac-ft/yr, and the total flow at the gage would be approximately 15,000 ac-ft/yr. On a unit-of-area basis, the watershed above the Wilkins gage presently contributes an average of approximately 180 acre-feet/year/square mile (ac-ft/yr/sq mi) to the flow in Thousand Springs Creek, whereas, with no irrigation uses of water in the basin, the watershed downstream from the Wilkins gage would contribute only approximately 5 ac-ft/yr/sq mi to the flow in the creek. The latter figure also represents the runoff contribution to flow in the creek under present conditions even though little of that contribution appears at the Montello streamflow gaging station.

The streamflow analyses did not evaluate short-term runoff from the various watershed areas but only long-term average streamflow at selected locations. Runoff is surface water flow resulting from precipitation. Changes in streamflow between any two locations, over any time interval, are the result of contributions from runoff, gains from or losses to groundwater, evapotranspiration losses, irrigation diversions and return flows and changes in channel storage, including reservoirs, between the two locations. To evaluate runoff characteristics, data on short-duration storms and flows are required. The available rainfall and streamflow data were examined and were found inadequate to evaluate the percentage of rainfall that becomes runoff or that infiltrates to recharge groundwater. Recharge information, however, may be inferred from the hydrologic water budget (Section 6.6).

Because only 3 years of streamflow data were available, and the flows during the period of record were highly variable, these data were unsuitable for characterizing average monthly streamflow on a long-term basis. However, on a short-term basis, the available monthly measurements were analyzed to provide meaningful qualitative information. For instance, Figure 6-3, which shows average monthly streamflows at Wilkins, Shores, and Montello gaging stations from 1985 to 1987, indicates that flows progressively decrease in the downstream direction. The decrease in downgradient streamflow is a result of groundwater recharge from water in the stream channel, surface water withdrawals for irrigation purposes, and evapotranspiration losses along the channel.

Estimates were also made of average annual streamflow for the subbasins of Thousand Springs Basin identified by Rush (1968). These subbasins are Herrell Siding-Brush Creek, Toano-Rock Spring, Rocky Butte, and Montello-Crittenden Creek. For the purpose of this analysis, Toano-Rock Spring Subbasin was subdivided into two separate subbasins: Toano Draw and Rock Spring subbasins. To be consistent with the numerical groundwater model discussed in Section 8.0, Thousand Springs Creek was selected as the boundary between the Toano Draw and Rock Spring Creek subbasins. Average annual streamflows for each of the subbasins were estimated using the streamflow generation model and the methodology outlined above.

The results of the streamflow generation model for the subbasins identified by Rush (1968) are shown in Table 6-7. As shown, the computed average annual streamflow from Herrell Siding-Brush Creek Subbasin is 16.85 cfs, or 1.44 inches over the subbasin. As also shown, the average annual streamflows from the Toano Draw, Rock Spring Creek, Rocky Butte, and Montello-Crittenden Creek subbasins range from -1.31 to -5.02 cfs, or -0.06 to -0.21 inches, over the respective subbasins. The negative streamflows for these subbasins indicate a net reduction in streamflow due to some combination of infiltration to groundwater, withdrawals for irrigation, and evapotranspiration (ET) losses along the creek. Additionally, the drainage basin at the Montello gage includes all the subareas identified above. The basin, as a whole, presently discharges to Utah an average annual streamflow of 5.80 cfs or 0.051 inches.

The average annual streamflows, estimated above, cannot be compared directly with Rush's 1968 estimates of runoff because the streamflow estimates account for springflows, groundwater recharge, and consumptive use of surface water for irrigation. Rush's estimates of runoff are the assumed part of precipitation that becomes surface flow, i.e., does not infiltrate to groundwater or evapotranspirate to the atmosphere where it falls.

6.5 EVAPOTRANSPIRATION

No data are available from the Thousand Springs Basin that permit a direct estimate of the applicable ET rate for the basin. Therefore a literature search was conducted to try to locate quantitative information from other watersheds that would be generally applicable for estimating natural ET which takes place within Thousand Springs Basin. This search was focussed on locating data to estimate actual (rather than potential) ET rates for natural vegetative species within the basin. Due to the considerable depth to groundwater throughout much of the basin, most of the natural ET is expected to result from direct evaporation of precipitation and removal of near-surface soil moisture by nonphreatophyte vegetation (transpiration). Along portions of Thousand Springs Creek, where the water table is near the ground surface, additional ET of groundwater by phreatophytes would be expected to take place.

Natural ET is affected by many factors and, hence, is difficult to estimate with precision. ET rates vary with the type and density of vegetative cover, available moisture within the root zone as it varies over time, extent of cloud cover, wind velocity and direction, air temperature, humidity, and topographic patterns. Also, for any basin, it will vary from year to year, depending on the total precipitation during the year and the pattern of the precipitation throughout the year. A number of empirical formulae exist that are useful for estimating approximate average ET values, based on parameters such as those indicated above that can be measured (Veihmeyer 1964). These methods are approximate and are generally limited to being useful for estimating potential ET. Potential ET is defined as the ET that would occur if there was an adequate moisture supply present in the soil at all times, rather than the actual ET, which would be much smaller in the arid environment of this basin. In addition, most of these estimating techniques, including the well known Blaney-Criddle Method, were developed to estimate ET for crops rather than for natural vegetation, as is needed here (Blaney 1959; Criddle 1958).

Due to the inherent limitations in the available analytic techniques, a literature search was conducted to determine whether ET had been estimated or measured for natural vegetation and conditions representative of Thousand Springs Basin. The principal, nonbeneficial phreatophytes throughout the basin have been identified as rabbitbrush, greasewood, and saltgrass (Rush 1968). That reference provides reconnaissance-level estimates of ET from groundwater by these species; i.e., it does not include precipitation and soil moisture. Limited measurements of consumptive use of water by greasewood and saltgrass, made during 1926 and 1927, are available for Escalante Valley in Utah (Young and Blaney 1942). Additional measurements of consumptive use of water by rabbitbrush, greasewood, and other native species, made during 1963 through 1967, are available for Humboldt River Valley in Nevada (Robinson 1970). These latter two references provide a total ET for the vegetative species desired, but only in areas of shallow depth to groundwater. Hence, these data would not be applicable to regions with considerable depth to groundwater, as exists throughout most of Thousand Springs Basin. Furthermore, these data would not be directly applicable to other locations having differences in climate, geology, topography, or density of vegetative cover. No other references, providing applicable estimates or measurements of ET for these species, were found during the literature search.

Due to the lack of applicable data, and the limitations of analytic techniques as previously discussed, an alternative method to estimate ET was needed. The approach taken was to estimate average annual ET for the watershed as a whole, expressed as a percentage of the average annual precipitation over the basin.

Estimates of ET are available for Humboldt River Basin, which is located adjacent to the southwestern portion of Thousand Springs Basin

(Eakin and Lamke 1966). Within this basin, they estimated that approximately 90 percent of the total precipitation is lost to ET "about where it falls," or local ET--e.g., ET prior to that which occurs by phreatophytes near and in groundwater discharge areas along stream channels. Eakin and Lamke (1966) state that "of the approximately 10 percent of the total precipitation that becomes runoff or groundwater, nearly all of it is ultimately lost by ET within the basin." Their statement pertains to Humboldt River Basin, which is a basin of interior drainage. However, this is not true for that part of Thousand Springs Basin being considered here. There is a net outflow from the basin to Utah, and the outflow occurs as both surface water and groundwater. The outflow is, of course, ultimately lost by ET from Great Salt Lake Desert and Great Salt Lake Basin. For this analysis, it was judged appropriate to assume that local ET is equal to 90 percent of the total precipitation estimated to fall within the part of the basin located in Nevada. There were no additional data or information available upon which to base a more precise estimate of local ET.

The streamflow coefficients previously developed could be used to provide independent estimates of ET for drainage areas where streamflow is not influenced by irrigation withdrawals or net losses to or gains from groundwater. In this instance, ET may be computed from precipitation less streamflow (Linsley et al. 1982). These conditions, however, are believed to be generally representative of the drainage area above the Wilkins streamflow gaging station. However, there probably is some base flow (groundwater flow) in the alluvial streambed that is not measured by the gage.

The estimated average streamflow coefficient for Thousand Springs Creek at the Wilkins streamflow gaging station is 0.246, as shown in Table 6-6. This streamflow coefficient indicates that average annual ET from the drainage area above the gage could not exceed about 75 percent of average annual precipitation. Hence, the previously assumed average annual ET of 90 percent of average annual precipitation for the basin as a whole would not apply to the 68-square-mile drainage area above the Wilkins station. It seems likely that other areas within Thousand Springs Basin, at the same general elevation, and having similar physical characteristics as the area that produces a large amount of runoff from above the Wilkins gage, also produce comparable amounts of runoff, on a unit-of-area basis, as Wilkins Subbasin. Little of the runoff from those other, higher-elevation areas reaches Thousand Springs Creek, but since much of it probably is derived from snowmelt, when ET rates are relatively low, a substantial fraction of that runoff probably infiltrates to groundwater.

If it is assumed that all areas within Thousand Springs Basin lying above the elevation of the Wilkins streamflow gaging station (approximately 5750 feet or 1760 meters) produce runoff at approximately the same rate as Wilkins Subbasin (about 180 ac-ft/yr/sq mi) than about 860 square miles of incremental watershed area, above elevation 1760 meters, probably produces an average of about 160,000 ac-ft/yr of runoff. If it is further assumed that, for all areas above elevation 1760 meters, local ET equals 75 percent, and for all areas below elevation 1760 meters local ET is 100 percent of precipitation, then the weighted average local ET for the basin as a whole would be about 84 percent. Accordingly, using a value of 90 percent as representative of local ET for Thousand Springs Basin as a whole, as is done in the water budget analysis which follows, is believed to be conservative.

6.6 HYDROLOGIC BUDGET ESTIMATE

Hydrologic budget estimates were prepared for Thousand Springs Basin and Toano Draw Subbasin for two reasons: to provide estimates of groundwater recharge within the basin and subbasin, respectively, independent of the Maxey-Eakin method presented in Section 8.0; and to provide estimates of groundwater outflow as underflow leaving the basin and subbasin, respectively, independent of Darcian type analysis of flow through a cross section of the valley of the downstream limits of the basin (Appendix I), and through a cross section near the northern limit of Toano Draw Subbasin.

The hydrologic budget regimes analysis quantifies hydrologic inflows and outflows into two components, the watershed land surface and the underlying aquifer. Under steady-state conditions (no change in either surface or groundwater storage), inflow would equal outflow for both components of the basin. The basic budget equations and associated assumptions are discussed below.

The hydrologic budget for the watershed land surface may be expressed as follows by equating inflows to outflows:

$$\text{Sum of Inflows} = \text{Sum of Outflows} \qquad (6\text{-}1)$$

$$P + GA = ET + NI + S + IR + GR + RE \qquad (6\text{-}2)$$

where:

P = Average annual precipitation over watershed
GA = Average annual groundwater applied to the watershed from groundwater by wells for irrigation
ET = Average annual local evapotranspiration from watershed
NI = Average annual irrigation consumptive water use from both surface and groundwater sources
S = Average annual streamflow discharge from watershed
IR = Average annual irrigation return flow from surface and groundwater sources to the aquifer
GR = Average annual net groundwater recharge from watershed to the aquifer
RE = Average annual evaporation from stored water in reservoirs

In the above hydrologic budget (Equation 6-2), average annual precipitation (P) and streamflow (S) are known from the results of the streamflow generation model, as previously discussed (Section 6.4.2). Groundwater applied (GA) is estimated from water applied for irrigation from wells (Section 6.2.5) (data from SCS). Local ET is estimated to be 90 percent of average annual precipitation (P), as discussed in Section 6.5. Net irrigation (NI) is estimated from net water use for irrigation from both surface and groundwater sources (Section 6.4.2). Irrigation return flow (IR) is estimated from the difference between water applied for irrigation and net irrigation water use, from both surface and groundwater sources (Section 6.4.2). Net groundwater recharge (GR) is the difference between natural groundwater recharge from the watershed to the aquifer and spring flow from the aquifer to the watershed. Reservoir evaporation (RE) is estimated from the estimated average annual area of water surface of the three principal reservoirs in the basin and published information on average annual evaporation from lakes in the basin vicinity.

Groundwater recharge (GR) is the unknown term in Equation 6-2, and may be solved by rearranging terms of the equation as follows:

$$GR = P + GA - ET - NI - S - IR - RE \qquad (6\text{-}3)$$

Similarly, the hydrologic budget for the aquifer component may be expressed as follows:

$$\text{Sum of Inflows} = \text{Sum of Outflows} \qquad (6\text{-}1)$$

$$GR + IR = GA + GO + PE \qquad (6\text{-}4)$$

where:

GO = Average annual groundwater outflow from the aquifer as underflow leaving Thousand Springs Basin

PE = Average annual ET by phreatophytes obtaining water directly from the aquifer, from Rush (1968)

All other terms in Equation 6-4 are as previously defined for Equation 6-2 and estimated as discussed above. Rush (1968) estimated ET by phreatophytes to be about 5700 ac-ft/yr for the basin as a whole, and this value (rounded to 6000 ac-ft/yr) was assumed to be applicable to this analysis. Groundwater outflow then becomes the unknown term in Equation 6-4 and may be solved by rearranging terms of the equation as follows:

$$GO = GR + IR - GA - PE \qquad (6\text{-}5)$$

The following assumptions apply to Equations 6-1 through 6-5 above:

- Steady-state conditions prevail; i.e., there is no change in water storage, either in soil moisture or reservoirs (watershed component) or in groundwater storage (aquifer component).

- There is no inflow to the aquifer as underflow; i.e., inflow equals zero.

- All irrigation return flow (IR) recharges the aquifer; i.e., there is no return flow to surface water.

- Natural use of groundwater by crops; i.e., sub-irrigation is included in the net consumptive use estimate.

- Irrigation water applied is internal to the watershed land surface, and is fully accounted for by net irrigation (NI), and irrigation return (IR) from surface water sources.

- Net groundwater recharge (GR) is natural groundwater recharge from the watershed land surface less natural spring discharge from the aquifer.

- Reservoir evaporation averages 3.5 feet/year (USDC 1968) and the estimated average combined water surface area of Dake, Twentyone Mile and Crittenden reservoirs is about 600 acres--i.e., RE = 2000 ac-ft/yr.

The combined results of both the surface and aquifer components of the hydrologic budget analysis, for Thousand Springs Basin above the Montello streamflow gaging station, are summarized on Figure 6-8. The figure presents the hydrologic budget based on the conservatively estimated local ET rate of 90 percent of total basin precipitation. Other ET losses, as indicated in the figure, bring the total ET for the basin to about 92.5 percent of total basin precipitation. As shown on Figure 6-8, natural groundwater recharge (GR) is estimated to be about 61,000 ac-ft/yr, whereas groundwater outflow (GO) is estimated to be about 67,000 ac-ft/yr, with the difference accounted for by surface water diverted for irrigation, some of which infiltrates to groundwater. If the local ET rate was assumed to be 93 percent of precipitation, then the resulting groundwater recharge rate, estimated from the budget analysis, would be about 33,000 ac-ft/yr and the groundwater outflow would be about 39,000 ac-ft/yr.

The hydrologic budget estimate presented in Table 6-8 is based on existing conditions at Thousand Springs Creek at Montello gaging station. This table includes estimates of net groundwater recharge (GR) and groundwater outflow (GO) derived by other procedures, for comparison with the value computed by the hydrologic budget analysis. The comparative estimate of groundwater recharge (GR) derived by the Maxey-Eakin method (Section 8.0) of about 61,000 ac-ft/yr is comparable to the 61,000 ac-ft/yr computed above in the hydrologic budget analysis, based on the assumption that local ET is equal to 90 percent of precipitation. The estimate of groundwater outflow (GO) based on a Darcian flow analysis (Section 7.0 and Appendix J) of 30,000 ac-ft/yr is significantly less than the 67,000 ac-ft/yr computed above and using the assumption that local ET is equal to 90 percent of precipitation. The difference is believed to be the result of the cross section analyzed by the Darcian flow equation not encompassing all of the flowpaths for groundwater leaving the basin. The hydrologic budget analysis of Table 6-8 includes a column headed "modified conditions." This refers to conditions as they would exist if there was no irrigation use of water in the basin, i.e., net irrigation, groundwater applied, and irrigation return were all zero, and as would be applicable when irrigation is terminated to make the water available for power plant uses. Under this condition, streamflow discharging to Utah would increase to an average of about 15,000 ac-ft/yr from the present average of about 4000 ac-ft/yr and groundwater outflow would be about 71,000 ac-ft/yr.

Because TSPP will be located within the Toano Draw watershed, and initial generating units are planned to be supplied with water from the aquifers underlying the area, a water budget analysis for this watershed was performed. An approximate water budget was developed because streamflows have not been measured in the draw, although it is known that surface water discharges from the area are rare, and generally small in flow rate and of short duration when they do occur. The streamflow generation model developed for Thousand Springs Creek required continuous streamflow measurements, which are not available for Toano Draw. Efforts to apply the streamflow generation model applying the streamflow coefficient for Thousand Springs Creek as a whole over Toano Draw Subbasin are believed to overestimate streamflow from Toano Draw, based upon numerous streamflow observations made by Chilton and others and, therefore, are not presented. Hence, an approximate technique was required to compute the water budget for Toano Draw.

The approximate water budget analysis for Toano Draw was performed as follows. First, precipitation was estimated utilizing the orographic relationship and Thiessen polygon areas, within the various elevation zones, as had been done for calculating precipitation for the basin and other subbasins. Streamflow was estimated on the assumption that runoff from the subbasin entering Thousand Springs Creek would average about 5 ac-ft/sq mi--the same as for the basin as a whole downstream from the Wilkins gaging station. Local ET was assumed to be 90 percent of precipitation. Irrigation, irrigation return, and groundwater applied are all zero in this subbasin, and there are no reservoirs or phreatophytes in the subbasin. Accordingly, groundwater recharge is simply precipitation minus local ET and streamflow.

The results of the approximate hydrologic budget analyses for Toano Draw are included in Table 6-8. This table shows independently derived estimates of net groundwater recharge (GR) and groundwater outflow (GO) for comparison with the range of values derived by the approximate hydrologic budget analysis for Toano Draw. The Toano Draw estimate of groundwater recharge (GR) derived by the Maxey-Eakin method (Section 8.0) is about 12,000 ac-ft/yr, whereas it is about 16,000 ac-ft/yr computed by the water budget analysis. Similarly, the estimate of groundwater outflow (GO), calculated by a Darcian Analysis (Section 7.0), is about 6100 ac-ft/yr, and about 16,000 ac-ft/yr computed by the water budget analysis. Referring to Equation 6-5 and Figure 6-8, it may be seen that groundwater outflow (GO) is equal to net groundwater recharge (GR) when groundwater applied (GA) and irrigation return (IR) equal zero, as is the case for Toano Draw.

[illegible] all of the [illegible] budget analysis of Table [illegible] includes a "predevelopment conditions." This refers to conditions as they would exist if there was no irrigation use of water in the basin, i.e., net irrigation, groundwater applied, and irrigation return were all zero, and as would be applicable when irrigation is terminated to make the water available for power plant uses. Under this condition, streamflow discharging to Utah would increase to an average of about 15,000 ac-ft/yr from the present average of about 4200 ac-ft/yr and groundwater outflow would be about 11,000 ac-ft/yr.

Because TSPP will be located within the Tosne Draw watershed, and initial generating units are planned to be supplied with water from the aquifers underlying the area, a water budget analysis for this watershed was performed. An approximate water budget was developed because streamflows have not been measured in the area, although it is known that surface water discharges from the area are rare, and generally small in flow rate and of short duration when they do occur. The streamflow generation model developed for Thousand Springs Creek required continuous streamflow measurements, which are not available for Tosne Draw. Efforts to apply the streamflow generation model applying the streamflow coefficient for Thousand Springs Creek as a whole over Tosne Draw Subbasin are believed to overestimate streamflow from Tosne Draw, based upon numerous streamflow observations made by Chilton and Gilbert and, therefore, are not presented. Hence, an approximate technique was required to compute the water budget for Tosne Draw.

The approximate water budget analysis for Tosne Draw was performed as follows. First, precipitation was estimated utilizing the orographic relationship and Thiessen polygon areas, within the [illegible] elevation zones, as has been done for calculating precipitation for the basin and other subbasins. Streamflow was estimated on the assumption that runoff from the subbasin entering Thousand Springs Creek would average about [illegible] ac-ft/sq mi—the same as for the basin as a whole downstream from the Wilkins gaging station. Local ET was assumed to be [illegible] percent of precipitation. Irrigation, irrigation returns, and groundwater applied are all zero in this subbasin, and there are no reservoirs or phreatophytes in the subbasin. Accordingly, groundwater recharge is simply precipitation minus local ET and streamflow.

The results of the approximate hydrologic budget analyses for Tosne Draw are included in Table [illegible]. This table shows independently derived estimates of net groundwater recharge (GR) and groundwater outflow (GO) for comparison with the range of values derived by the approximate hydrologic budget analysis for Tosne Draw. The Tosne Draw estimate of groundwater recharge (GR) derived by the Maxey-Eakin method (Section [illegible]) is about [illegible] ac-ft/yr, whereas it is about [illegible] ac-ft/yr computed by the water budget analysis. Similarly, the estimate of groundwater outflow (GO), calculated by a Darcian Analysis (Section [illegible]), is about [illegible] ac-ft/yr, the

7.0 WATER RESOURCES DEVELOPMENT FOR PLANT OPERATION

7.1 AVAILABLE WATER RESOURCES

In evaluating the available water resources of Thousand Springs Basin, it is necessary to consider the amount of perennial (average annual) recharge to the groundwater system at present, the amount of groundwater in storage, and the changes in the rates of recharge and discharge that will occur as a result of developing and utilizing the groundwater resource to supply the power plant project. Early investigators in water resource planning applied the concept of "safe yield" to evaluate the amount of water available from a groundwater basin. As defined by Todd (1959), the safe yield of a groundwater basin is the amount of water that may be withdrawn annually without producing an undesired result, such as intrusion of water of undesirable quality, contravention of existing water rights, or unacceptably severe environmental impacts associated with streamflow depletion. In the classical sense, the concept of safe yield would limit the amount of water withdrawn to the perennial recharge rate of the basin. It is the general policy of the State Engineer of Nevada to limit groundwater withdrawals to the perennial recharge rate of the basin being utilized.

It is generally recognized by groundwater professionals that significant economic benefits may be derived, and in some cases insignificant adverse consequences may result, from developing a groundwater basin to levels of pumping that exceed the natural rate of perennial recharge in order to take advantage of the potentially large amount of groundwater that may be in storage (Maxey 1968; Freeze and Cherry 1979) and lower groundwater levels in the basin by pumping, thus increasing the rate of natural groundwater recharge and decreasing the amount of groundwater lost through evapotranspiration and nonbeneficial types of discharge (Maxey 1968; Bredehoeft and Young 1970).

In the concept of "optimum yield" of a groundwater basin, groundwater has value only by virtue of its use, and the optimal yield of a basin is defined by the water development plan that makes use of the available water most effectively (Domenico 1972; Freeze and Cherry 1979). The total renewable surface and groundwater resources of Thousand Springs Basin are estimated to be significantly greater than the maximum water requirements of the proposed power plant. Yield optimization for the basin as a whole, therefore, is not an inherent project requirement. However, considering only Toano Draw Subbasin, which cannot provide enough water for the entire power plant, project economics are more favorable if the subbasin yield is essentially optimized and transfer of water from other subbasins is deferred until the Toano Draw resources are developed to their optimum level.

The purpose of this section is to address the potentially available groundwater resources, for pumping at the rates and from the locations which most effectively and efficiently utilize the resources without inducing unacceptable environmental effects. In the subsections that follow, the perennial recharge rates and the amount of groundwater in storage will be estimated. Following this, potential wellfields will be identified in favorable areas, and a wellfield development program outlined in accordance with the presently planned development schedule for the overall project. The general effects of pumping to supply the project will be outlined, based on the groundwater modeling results described in Section 8.0 and further discussed in Section 10.0. The groundwater development plan, which is proposed in Section 12.0, is believed to be consistent with the policy of the State Engineer of Nevada.

7.1.1 Estimates of Perennial Recharge

There are several lines of reasoning that have been used to estimate the perennial (average annual) groundwater recharge rates. First, an empirical relationship between precipitation and recharge rates, developed by Maxey and Eakin (1949), was applied. This method has been established as a means of deriving approximate estimates of basin groundwater recharge, in the arid basins of Nevada (Watson et al. 1976). The details of this analysis are provided in Section 8.2.4.1. Applying this method to Toano Draw Subbasin, using available precipitation data and orographic relationships, the average annual subbasin groundwater recharge rate was estimated to be approximately 12,000 acre-feet/year (ac-ft/yr) (Section 6.6).

A second hydrological line of reasoning was used to estimate the recharge rate in this subbasin. From the results of a hydrologic budget analysis of Toano Draw Subbasin (Section 6.6), the perennial groundwater recharge within this subbasin watershed was estimated to be about 16,000 ac-ft/yr.

The Chilton observations and measurements of streamflow, as discussed in Section 6.0, found that there rarely was flow in the lower reaches of Toano Draw Channel, near its discharge to Thousand Springs Creek Channel. When flow did occur, it was generally small in volume and of short duration. Similarly, for all other tributaries discharging into Thousand Springs Creek, downstream from Wilkins and the Highway 93 crossing of the creek, surface water discharges were generally small and of short duration. Chilton's observations did not cover the upper reaches of Toano Draw Subbasin, or any other subbasin, except in the headwaters area of Thousand Springs Creek, as observed at the Highway 93 crossing, and as presently being measured at the U.S. Geological Survey (USGS) Wilkins streamflow gaging station, located about 3 miles upstream from the Highway 93 crossing.

Considering Thousand Springs Basin as a whole and Toano Draw Subbasin, it seems reasonable to assume that in the headwaters area of the basin and the subbasin, on the higher and steeper slopes of the mountains around and within the basin, precipitation and surface runoff characteristics are similar to those for the Snake Mountains which form the headwaters area of Thousand Springs Creek. For the latter area, large amounts of surface runoff have been observed and measured where Highway 93 crosses the creek and at the Wilkins streamflow gaging station. Flows in Thousand Springs Creek Channel decrease progressively in the downstream direction from the Highway 93 crossing. A similar phenomenon is believed to occur in Toano Draw Subbasin and other subbasins of Thousand Springs Basin, i.e., the surface runoff from the mountains infiltrates to groundwater as it flows across the long and broad alluvial infill material of the Toano Draw Valley and other areas with similar alluvial deposits.

It is noted that at the Wilkins streamflow gaging station, the total average annual flow in the creek is estimated to be about 12,500 ac-ft/yr, or about 25 percent of the precipitation falling on the watershed area above the gage. It is further noted that this estimate is based on using 18 years of precipitation data collected in Rock Springs Creek Subbasin, to derive orographic effects on precipitation in northeastern Nevada (as discussed in Section 6.0), and applying this relationship to the headwaters area of Thousand Springs Creek. This analysis used the available short-term (3 years) streamflow data records from the Wilkins streamflow gaging station and the available long-term (35 years) precipitation records for deriving the above precipitation/streamflow relationship.

Further extrapolation of the Wilkins streamflow and subbasin precipitation estimates to indicate a probable qualitative relationship between watershed elevation and runoff may be done by examining Table 7-1, which presents watershed areas within zones spanning 120 meters elevation (approximately 400 feet) and cumulative areas, starting from the highest zone within the watershed, for Thousand Springs Basin as a whole, Toano Draw Subbasin, and Wilkins Subbasin. Table 7-1 also includes the estimated total average annual precipitation within each of the elevation zones and the cumulative precipitation starting from the highest zone within each watershed considered in the table.

Based on the relatively large amount of runoff known to occur from Wilkins Subbasin, and the relatively large percentage of the subbasin area that exists at relatively high elevations (e.g., 32 percent above 2000 meters or 69 percent above 1880 meters elevation), it was judged reasonable to conclude that in this subbasin a substantial portion of the precipitation falling on the higher-elevation land appears as runoff at Wilkins. It also seems reasonable to assume that lands at the same higher elevations, in other parts of Thousand Springs Basin, would have similar precipitation runoff relationships.

For Toano Draw Subbasin, it is noted that, for all contour intervals below 2360 meters elevation, the area within each interval is greater than the corresponding area in Wilkins Subbasin. Therefore, it seems likely that there is as much or more high-elevation runoff from Toano Draw Subbasin as from Wilkins Subbasin. But there is practically no surface water discharge from Toano Draw Subbasin to Thousand Springs Creek. To account for the high-elevation runoff from Toano Draw Subbasin requires that it be stored, lost by evapotranspiration, or infiltrate to groundwater. There is no significant surface water storage within the subbasin. The runoff is believed to be a result primarily of snowmelt, when evapotranspiration losses would be relatively low. Also, evapotranspiration rates for the higher-elevation zones of the Wilkins and Toano Draw subbasins should be similar. Therefore, it seems reasonable to expect that most of the runoff from the higher elevations of Toano Draw Subbasin infiltrates to groundwater within the subbasin.

For Thousand Springs Basin as a whole, for all elevation zones considered in this discussion, there is a greater area of land in each zone (see Table 7-1) than in Wilkins Subbasin. Therefore, it seems reasonable to expect that for the basin, there is correspondingly greater runoff from higher-elevation lands in the basin than there is from Wilkins Subbasin. Based on the available streamflow and irrigation records, there is only a relatively small amount of runoff contribution (about 3000 ac-ft/yr on an annual basis) to Thousand Springs Creek below the Wilkins stream gage. Therefore, much of the runoff from the higher elevations of the basin probably infiltrates directly to groundwater.

For both Toano Draw Subbasin and Thousand Springs Basin, the groundwater recharge estimates derived by the Maxey-Eakin procedure seem consistent with and probably conservative (i.e., low) based on the above line of reasoning.

A high rate of deep infiltration for Toano Draw Subbasin is consistent with the trends noted in the hydrochemical data (Section 5.0). The patterns of concentrations of chloride, total dissolved solids, and tritium indicate that recharge is occurring at a relatively rapid rate along the stream channels, particularly in those channels in the southern-central portion of the subbasin (Section 5.6). Several wells in Toano Draw that are located near the recent alluvial channels were found to contain measurable tritium content. This indicates that groundwater below the water table in these areas has received recharge from precipitation occurring within about the past 35 years.

By making several reasonable hydrogeological assumptions to simplify calculations, it is possible to use a third line of hydrogeological reasoning to estimate the rates at which recharge water has migrated from the ground surface through the vadose zone to the water table in these areas. (Calculations and assumptions are provided in Appendix J.) Using the available tritium data as an approximate indication of flow rates through the vadose zone, the estimated rates of recharge range from approximately 7600 to 12,700 ac-ft/yr. The range of values is consistent with the range of recharge rates derived using the hydrologic budget analysis approach and also the recharge rate based on the Maxey-Eakin method.

A fourth method of estimating the perennial recharge rate in Toano Draw Subbasin is based on available hydrogeological data. By assuming that the perennial recharge of the subbasin is at least equal to the present steady-state groundwater discharge through the northern end of the subbasin, it is possible to estimate a "probable minimum" value for long-term perennial recharge rate to the subbasin. This estimation method may result in a lower-than-actual recharge rate value because the underlying assumption neglects the possibility of groundwater discharge from the subbasin through pathways other than shallow groundwater flow through the northern end of Toano Draw.

The rate of groundwater discharge northward through a representative hydrogeologic cross section has been estimated in the northern end of the subbasin (Cross Section B-B', shown on Figure 3-5), using the following equation (Equation 7-1 below). This equation is based on Darcy's Law and assumes steady-state conditions and that flow is through a homogeneous, isotropic medium.

$$Q = KiA \tag{7-1}$$

where

Q = the groundwater discharge rate
K = the hydraulic conductivity
i = the hydraulic gradient
A = the cross-sectional area through which flow occurs

In order to estimate Q, values were assigned to the parameters in this equation, as follows (details of this calculation are presented in Appendix J). The hydraulic gradient, i, was estimated to be 0.003 across the area of the cross section, based on the water table contour map (Figure 4-5). The cross-sectional area for flow, A, was estimated to be about 13,400,000 square feet (sq ft), using the results of the TDEM survey in the area, and geological logs of borings along geological Cross Section B-B' (Figure 3-5). The average hydraulic conductivity value, K, was estimated to be approximately 18 feet/day (ft/day), based on the results of aquifer tests that were conducted in the Toano Draw area. Inserting these estimated parameter values into the above equation results in an estimate of the groundwater discharge, Q, from the subbasin northward, to the Thousand Springs Creek drainage system, equal to approximately 6100 ac-ft/yr. This value is less than the value estimated for average annual recharge rate based on the hydrologic budget analysis, those values estimated from the tritium data, and those values estimated using the Maxey-Eakin method.

The apparent discrepancy between the recharge rate estimate based on groundwater discharge from the northern end of the subbasin and the higher recharge rate estimated by other methods may be a result of an oversimplified assumption: namely, the assumption that perennial recharge is equal to the discharge from the northern end of the subbasin. In the hydrogeologic setting of Toano Draw, there probably is significant discharge from the subbasin downward along deep flow lines through the Paleozoic carbonate aquifer to the regional flow system. Such deep discharge through basement Paleozoic rocks would be consistent with the discussions of regional flow through the Paleozoic carbonate aquifer by Rush (1968) and Maxey (1968). It is also conceivable that there may be groundwater flow leaving Toano Draw to the east beneath Twentyone Mile Draw. If the regional flow system in the Paleozoic carbonate aquifer is receiving recharge from the valley fill sediments in Toano Draw Subbasin, or if there is discharge of groundwater from the subbasin along other flow paths, then the actual perennial recharge rate would be higher than the rate of discharge through Cross Section B-B' in the northern end of Toano Draw Subbasin.

To summarize, the various estimates of recharge to Toano Draw Subbasin aquifer fall within the range of about 6000 to 16,000 ac-ft/yr. Discharge from the aquifer is estimated to be about 6000 ac-ft/yr through the alluvium at the northerly end of Toano Draw plus some unquantified amount entering the Paleozoic carbonate aquifer that appears to underlie the subbasin at great depth. Deep groundwater flow through this aquifer may discharge to the east--probably contributing groundwater to the alluvial aquifer in the Montello area. It is concluded that the renewable groundwater resource within Toano Draw Subbasin is at least 6000 ac-ft/yr. In addition to this amount, there is also a significant amount (estimated to be greater than about 2000 ac-ft/yr) of perennial recharge to the subbasin along Thousand Springs Creek that may be derived from areas of the basin north of Toano Draw and from the higher elevations of the Thousand Springs Creek watershed to the west of the subbasin.

An additional water resource present in Toano Draw Subbasin is a large quantity of groundwater now stored in the alluvial aquifer. The estimated total volume of unconsolidated sediment present as valley infill in the alluvial aquifer along the broad valley of Toano Draw is 44,000,000 acre-feet (ac-ft). The volume of water stored within this aquifer is probably on the order of 10,000,000 ac-ft (porosity about 25 percent). However, it seems likely that only water present within 100 feet of the water table surface might be available for power plant uses, and that the aquifer within this zone would yield only 10 percent of its gross volume to wells. Based on those assumptions, it is estimated that at least 500,000 ac-ft of water may be present as a potentially available, nonrenewable resource in Toano Draw Subbasin.

The Maxey-Eakin method has also been applied to estimate the average annual recharge rate for Thousand Springs Basin as a whole. Using this method, with available precipitation data and the orographic relationship described in Section 6.3, it was estimated that approximately 61,000 ac-ft/yr of water is recharged to the groundwater system in the basin as a whole. This estimate is consistent with the estimate of recharge rate derived by the hydrologic budget analyses for the basin, i.e., about 61,000 ac-ft/yr (Section 6.6).

For comparison to these estimates of recharge, an estimate was made of the perennial groundwater discharge rate through the eastern end of Thousand Springs Valley in the Montello area. For this purpose, a north-south cross section near the Utah state line was developed, based on the results of the line of time domain electromagnetic (TDEM) soundings run in the area (described in Section 3.3.4). Using the same method to estimate the discharge rate (Q) as described above for Toano Draw Subbasin, Q has been estimated to be approximately 30,000 ac-ft/yr. (Details of this calculation are provided in Appendix J.)

The values of the parameters that were inserted into Equation 7-1 for this estimate were based on available data from wells in the area and were as follows:

$K = 270$ ft/day
$i = 0.003$
$A = 3{,}560{,}000\ ft^2$

The hydraulic conductivity, K, used for this estimate was based on an average of available data from pumping tests conducted in the Montello area. The hydraulic gradient, i, was based on available groundwater level measurements (WCC 1988) near the cross section. The area of the cross section was based on available drillers logs of wells in the area and the TDEM soundings. However, it is noted that the water-bearing sediments may extend to considerably greater depths than those assumed for the estimate of the cross-sectional area, A, provided above, based on the results of the TDEM survey.

Even though there are significant hydrogeological factors of uncertainty in this groundwater discharge estimate, the estimate indicates that at present there are tens of thousands of acre-feet/year of groundwater discharge from Nevada to Utah in the Montello area. Groundwater flow eastward through the Montello area represents the discharge of the regional groundwater flow system of the entire Thousand Springs Basin. The perennial recharge rate must be higher than the subsurface groundwater discharge rate in order to account for consumptive uses within the basin (mainly evapotranspiration losses from irrigated agriculture). Thus, there is reasonably close agreement between the estimate of discharge from Thousand Springs Basin (30,000 ac-ft/yr plus 15,000 ac-ft/yr net consumptive use by irrigated agriculture, i.e., 45,000 ac-ft/yr) and the amount of perennial recharge predicted by applying the Maxey-Eakin method (61,000 ac-ft/yr), and the value estimated from the regional hydrologic budget analysis of the basin (Table 6-8). It is noted that the estimated annual average surface water flow in Thousand Springs Creek, and discharging across the Utah border, is about 4000 ac-ft/yr. This flow is in addition to the groundwater discharge discussed above. The conclusion drawn from these several methods of estimating groundwater recharge and flow is that there is at present significantly more groundwater circulating through the regional flow system of the basin, and discharging as groundwater from the basin, than the amount proposed for use by the full-scale power plant development (32,000 ac-ft/yr). Additional evaluation of the potential yield of the groundwater system in Toano Draw Subbasin and vicinity has been conducted using groundwater flow modeling as described below in Section 8.0.

7.2 OPTIONS FOR WATER RESOURCES DEVELOPMENT

Several resource development options are available for supplying groundwater to the power plant. Potentially favorable wellfield locations for supplying the power plant are outlined on Figure 7-1. The three water supply options that have been evaluated are summarized in Table 7-2 and described as follows:

<u>Option 1</u>: Withdrawal of 20,000 ac-ft of water/year from wellfields in Toano Draw Subbasin. The remaining water demand of 12,000 ac-ft/yr would be met from wellfields located along Thousand Springs Creek, between Twentyone Mile Reservoir and Montello.

<u>Option 2</u>: Withdrawal of 12,000 ac-ft/yr of water from Toano Draw Subbasin. The remaining water demand of 20,000 ac-ft/yr would be supplied from wellfields in the Montello area.

<u>Option 3</u>: Withdrawal of 16,000 ac-ft/yr of water from Toano Draw Subbasin. The remaining water demand of 16,000 ac-ft/yr would be supplied from wellfields in the Montello area.

The potential of the groundwater system to supply the anticipated needs of the power plant is discussed below. In order to further evaluate the potential groundwater resources of the basin, and the effects of pumping in the potentially favorable wellfield locations, groundwater flow modeling has been performed using numerical and analytical methods (Section 8.0). A schematic layout of wells for a hypothetical wellfield is depicted on Figure 7-2.

7.2.1 <u>Water Supply for Units 1 and 2 - Options 1, 2, and 3</u>

The amount of water needed to supply the needs of the first two power plant units, 8000 ac-ft/yr, can be supplied from a wellfield in Toano Draw Subbasin. For all three development options evaluated, it was assumed that Units 1 and 2 would be supplied water from the same wellfield located south of the power plant site. Based on the available hydrogeologic data and aquifer test results, a favorable location for this wellfield would be in the southern portion of Toano Draw (Figure 7-1). This rate of groundwater withdrawal would probably be less than the perennial recharge rate in the subbasin (Section 7.1), especially considering the potential for additional recharge along Thousand Springs Creek. However, because the steady-state water table elevation in the area of the proposed wellfield is about 200 feet higher than the water table elevation at the confluence of Toano Draw with Thousand Springs Creek, pumping of the wellfield at 8000 ac-ft/yr will have no effect on the rate of aquifer recharge from the creek for many years. At present, a significant amount of water is diverted from Thousand Springs Creek, upstream of Twentyone Mile Dam, for irrigation use. It is estimated that present consumptive use in this area for irrigation is approximately 6000 ac-ft/yr (Section 6.2.5). It is proposed that irrigation in this area will be progressively reduced and ultimately terminated at such time as it appears that water supplied to the power plant is affecting the amount of water flowing in Thousand Springs Creek downstream from Toano Draw.

7.2.2 Water Supply for Units 3, 4 and 5 - Option 1

For this option the two areas north of the power plant site in Toano Draw that were identified as potentially favorable for wellfields would both be developed for the project. The area located approximately 2 to 6 miles north of the plant site (Figure 7-1) would be developed first. It is expected that a wellfield at this location would serve generating Units 3 and 4. For Unit 5, wellfield development would be in the potentially favorable area farther to the north and generally lying along the south side of Thousand Springs Creek. Initially, pumping of the Toano Draw aquifer at the rates required to supply Units 3, 4, and 5 would be essentially all from aquifer storage. It is important to note that the data presently available are not adequate for accurate determination of the specific yield of the aquifer. However, based on assumptions that are believed to be conservative, the amount of groundwater potentially available from storage appears to be large relative to potential demands of the power plant. Furthermore, it is expected that within a few years the aquifer would be drawn down to the extent that recharge from the flow in Thousand Springs Creek would be significantly increased and flow in the creek downstream from the Shores streamflow gaging station would be correspondingly decreased. Ultimately, it is expected that the only times there would be surface water flow in Thousand Springs Creek upstream of Rock Springs Creek would be during times of rapid snowmelt and intense summer storms.

7.2.3 Water Supply for Units 6 and 7 - Option 1

For this option, to supply Units 6 and 7, a wellfield would be developed within the valley of Thousand Springs Creek, between Twentyone Mile Dam and the confluence with Crittenden Creek. Irrigation within the part of the valley near the proposed wellfield, which presently accounts for about 1560 ac-ft/yr of net consumptive use of water, would be terminated, and the water made available for the power plant. A transmission pipeline would be required between the wellfield and the power plant. The presently planned route for this pipeline is from a booster pumping station to be located near Eighteen Mile Ranch and through Twentyone Mile Draw to a low saddle (about elevation 5900 feet) about 5 miles northeast of the power plant site. The balance of the requirements for the two units would be obtained from base flow in the creek and aquifer storage beneath the creek. Although the data presently available are not adequate for determining if this source can sustain the indicated pumping rate, i.e., 8000 ac-ft/yr, it seems possible that it will. It is noted that present pumping rates in the valley, for irrigation purposes, do not appear to significantly stress the aquifer. If monitoring of future pumping effects on groundwater levels (Section 11.0) indicated that the pumping rate needed for both these units could not be sustained in this area, it should be a simple matter to extend the wellfield downstream in the direction of Montello to the much greater quantity of water stored in the aquifer in that area. Also, some or all of the water presently used for irrigated agriculture in the area, about 7500 ac-ft/yr, can be converted to power plant uses. It is expected that if this option is pursued, the ultimate effect would be to significantly reduce flow in the creek downstream from Twentyone Mile Dam (Section 10.3).

7.2.4 Water Supply for Unit 8 - Option 1

The water supply for Unit 8, with this option, would be provided from a wellfield in the valley north of the town of Montello. The water would be pumped to the power plant through the transmission main required for supplying Units 6 and 7 with this option. In addition, a transmission main extension would have to be installed within Thousand Springs Valley, between the booster pumping station at Eighteen Mile Ranch and Crittenden Creek, if it had not already been installed as part of a wellfield expansion required for serving Units 6 and/or 7. The available resources for serving Unit 8 from this wellfield include the water presently used in the area for irrigated agriculture (about 7500 ac-ft/yr, net), groundwater recharge from precipitation over the subbasin (about 12,000 ac-ft/yr, based on the Maxey-Eakin estimating procedure) and discharge from the regional, deep flow system in the Paleozoic carbonate rocks being recharged from the mountainous areas of the rest of Thousand Springs Basin (a major part of the estimated approximately 30,000 ac-ft/yr presently discharging to Utah through the shallow groundwater system).

7.2.5 Water Supply for Units 3 through 7 - Option 2

The 20,000 ac-ft/yr required to supply water for Units 3 through 7, under Option 2, would all be obtained from a wellfield to be developed progressively in the valley of Thousand Springs Creek, along the reach downstream from its confluence with Crittenden Creek and extending south to near the town of Montello. Exercise of this option would require the installation of a transmission pipeline to deliver the water to the power plant site. It is expected that the pipeline would follow the same route as discussed above with respect to supplying water for Units 6, 7, and 8, (Option 1), i.e., it would follow the valley of Thousand Springs Creek from Crittenden Creek to Eighteen Mile Ranch and then Twentyone Mile Draw to Toano Draw. The pipeline diameter would be larger than required for Option 1 to accommodate the larger ultimate flow of Option 2. The transmission system probably would include storage tanks that would serve to blend the water from the different supply wells and thereby permit delivering a more nearly consistent quality water to the water treatment facilities at the power plant. Also, the system probably would include one or more booster pumping stations.

The water resources to be utilized for supplying these five units would include the following:

- Transfer of about 9000 ac-ft/yr of net consumptive use by irrigated agriculture, downstream from Twentyone Mile Dam, to power plant uses.
- Capture by wellfields of the aquifer recharge from precipitation in the subbasin. Based on the Maxey-Eakin method of estimating this recharge, there may be an average of about 12,000 ac-ft/yr available from this source.
- Capture by wellfields of some part of the present groundwater discharge to Utah--about 30,000 ac-ft/yr based on an estimate of the flow through a cross section of Thousand Springs Valley near the state border. The source of a major part of this water is believed to be Thousand Springs Basin as a whole and deep flow paths from the basin recharge areas, i.e., the mountains ringing and within the basin, to the aquifer in the Montello area via the regional flow system through the deep Paleozoic carbonate rocks.
- The quantity of aquifer storage, within the upper 100 feet of saturated material, and considering only the area likely to be affected by the project wellfields north of the town of Montello, is estimated to be on the order of 200,000 ac-ft.

The expected effects of increased utilization (above current levels) of the available groundwater resources in lower Thousand Springs Valley are as follows:

- Surface water and groundwater discharge to Utah will be reduced.
- Irrigated forage crops will no longer be raised in the area.
- Water inflow to Dake Reservoir will be reduced.

Further discussion of these potential effects and possible mitigation measures are provided in Section 10.0.

7.2.6 Water Supply for Unit 8 - Option 2

Present expectations are that there is sufficient water available in Toano Draw Subbasin to supply the needs of Unit 8. The sources of the water include groundwater recharge from precipitation in the subbasin. The actual perennial recharge rate in this subbasin is likely to be significantly greater than the probably conservative estimate adopted for this analysis (8000 ac-ft/yr). Also, water in storage in the aquifer is estimated to be at least 500,000 ac-ft within the upper 100 feet of saturated aquifer materials. However, before a firm commitment is made to obtain water from Toano Draw for Unit 8, long-term groundwater level monitoring data (Section 11.0) on the effects of supplying Units 1 and 2 from this source should be collected and analyzed. The approximately 10 years available (minimum) between the initial startup of Unit 2 and the time when wellfield development for Unit 8 should be started should be adequate for assessing if the Toano Draw resources are capable of supplying more than two units. If the long-term perennial yield proves to be not more than 8000 ac-ft/yr, or less, then it is expected that Unit 8 will be supplied from the wellfield north of Montello. For now, it is expected that Unit 8 will be supplied water from a wellfield in Toano Draw.

Numerical modeling of the Toano Draw aquifer to assess aquifer drawdown extent and characteristics indicated that drawdown effects adjacent to Thousand Springs Creek would be significantly less, at the end of the power plant's planned operating life, if the Unit 8 wellfield were located south of the plant site in the same general area as the wellfield for Units 1 and 2, than if it were placed north of the plant site. Based on the results of this modeling, it is tentatively proposed that the Unit 8 wellfield be located south of the plant site. Assuming that the modeling results present a generally accurate portrayal of aquifer drawdown at the end of the planned project operating life, then it is expected that the project would have little effect on the amount of surface water flowing in Thousand Springs Creek upstream from its confluence with Crittenden Creek. Anticipating that present irrigation by Lands of Sierra, Inc. (LOS) for forage crops will be ceased in areas along the creek, it may be inferred from the model results that there will not be any significant change in the amount of flow in the creek that infiltrates to the Toano Draw aquifer as recharge. However, there would be a reduction in the Toano Draw aquifer groundwater discharge to the underflow beneath Thousand Springs Creek.

7.2.7 Water Supply for Units 3, 4, 7, and 8 - Option 3

With this option, the wellfield development north of Montello would be essentially the same as for Option 2, except the extent of the development would be for only four units instead of five units, and the schedule for development would be extended by 2 years. The size of the required transmission pipeline would be reduced to accommodate the smaller ultimate capacity, and the extent to which the groundwater resources of the subbasin would be utilized would be less. However, the environmental effects in this subbasin with this option probably would be about the same as with Option 2. The environmental effects likely would be greater upstream from the junction of Crittenden and Thousand Springs creeks because more water would be diverted for power plant uses in the Toano Draw area with Option 3 than with Option 2.

7.2.8 Water Supply for Units 5 and 6 - Option 3

This option requires developing wellfields in the Toano Draw area for supplying a total of four units. That is, relative to Options 1 and 2, it is an intermediate level of development. With Option 3, the wellfield development for Units 5 and 6 would be the same as the development for serving Units 3 and 4 in Option 1, except the schedule for the development would be extended by about 4 years, according to the presently planned schedule for the overall power plant project.

Numerical modeling of the Toano Draw alluvial aquifer indicated that the aquifer drawdown adjacent to Thousand Springs Creek would be significantly less if the wellfield for supplying Units 5 and 6 was all within the apparently favorable wellfield area immediately north of the plant site, than if the wellfield for one of the units was located in the area south of but adjacent to Thousand Springs Creek. Based on these modeling results, it is planned that a single wellfield will be developed to supply water for Units 5 and 6.

The sources of water for Units 5 and 6 with Option 3 would be full utilization of the subbasin recharge from precipitation and an increase in aquifer recharge from flow in Thousand Springs Creek due to lowering of the water table in the vicinity of the creek adjacent to the Toano Draw Area. Flow in the creek would be correspondingly reduced in all reaches downstream from Toano Draw (Section 10.3).

would be enhanced by [illegible] check levels of the overall floodplain [illegible]

Numerical modeling [illegible] the aquifer [illegible] with [illegible] to supply water for Units 5 and 6.

The [illegible] aquifer [illegible] flow in the [illegible] Creek.

8.0
GROUNDWATER FLOW MODELING

The objectives of the groundwater flow modeling conducted for the Thousand Springs Power Plant (TSPP) Project were as follows:

1) To estimate the groundwater system yield and flow characteristics of the basins underlying Toano Draw and along Thousand Springs Creek north of Toano Draw

2) To estimate the overall water balance for Thousand Springs Basin, i.e., the rates of natural recharge/discharge and inflow/outflow in the basin

3) To estimate potential groundwater level decline and effects on streamflow and springs as a result of pumping to meet the water requirements of the power plant

4) To provide information for selecting wellfield locations, estimates of well spacing, and potential sustainable long-term pumping rates

In order to meet the above objectives, a numerical (finite-difference) groundwater flow model was implemented to analyze the groundwater flow system in Toano Draw Subbasin and vicinity and an analytical model was utilized to analyze the flow system in the valley of Thousand Springs Creek, in the Gamble Ranch vicinity.

The area selected for numerical flow modeling included Toano Draw Drainage Basin and part of Rocky Butte Drainage Basin (Figure 8-1). That area, referred to in the discussion that follows as the model area, is bounded on the north by Thousand Springs Creek in the reach between its confluence with Toano Draw and Crittenden Creek, and to the south by the drainage divide along the Pequop Mountains. To the west, the drainage divide formed by the Windermere Hills (Black Mountain) serves as the boundary, while the drainage divide along the Gamble Range serves as the eastern boundary. Accordingly, the model area includes all of the land which drains to Thousand Springs Creek from the south within the reach which forms the northern boundary of the model area. The area enclosed within the model boundaries is about 450 square miles.

The model area for the analytical model encompassed the broad, gently sloping valley of Thousand Springs Creek, from its confluence with Crittenden Creek downstream to Dake Reservoir. The area is bounded on the west, north, and east by steeply rising hills. On the south, the valley widens, and the gradient reverses, to a watershed and aquifer divide separating it from Pilot Creek Valley. The divide is located about 5 miles south of the Town of Montello. An analytical model was considered appropriate for analyzing this aquifer, because a general, conceptual understanding of how the aquifer will respond to pumping was considered adequate for pre-project planning. It appears that the available water resource of the aquifer significantly exceeds the planned utilization. Several years will elapse before wellfield development is scheduled to begin in the area. Before that development is started, there will be time to collect additional data on aquifer characteristics in the area, and the Toano Draw numerical model can then be expanded to include the Gamble Ranch vicinity.

A steady-state calibration of the numerical model was performed, representing pre-project, no development conditions. The calibration runs simulated flow characteristics of the model area, as well as rates of natural recharge, discharge, and inflow/outflow to the area. Using the calibrated model, the above objectives were evaluated as described below.

8.1 CONCEPTUAL MODEL OF REGIONAL FLOW

The hydrogeology of the model area was described above, in Section 4.0. The stratigraphic units of importance for characterizing the groundwater flow system are the alluvial aquifer, the alluvial fan-volcaniclastic aquitard, and the Paleozoic carbonate aquifer. Note that in this analysis the term "aquitard" denotes a saturated stratum that does not yield water freely to wells, but that does transmit appreciable water to or from adjacent aquifers. The alluvial aquifer is the principal groundwater-bearing unit within the model area; it is present within the central portions of Toano Draw Subbasin and along ephemeral streams discharging from the mountains. The alluvial fan-volcaniclastic aquitard is generally located along mountain fronts and on the margins of the valleys. In the center of the basin, the alluvial fan-volcaniclastic aquitard underlies the alluvial aquifer. In general, the alluvial fan-volcaniclastic aquifer is not capable of yielding economically significant quantities of water to wells because of its low permeability; however, because of its large contact area with the alluvial aquifer, it can contribute a large volume of recharge to the alluvial aquifer. Flow through the alluvial fan-volcaniclastic aquifer is an important source of recharge water to the alluvial aquifer. The Paleozoic carbonate aquifer is exposed in the mountain ranges around the perimeter of Toano Draw. It is believed that these rocks are continuous between the ranges, but at great depth below the valley in the center of the subbasin where they are overlain by the alluvial valley sediments. Significant secondary porosity features, including large pores and cavernous openings along fractures, have been observed in outcrops of these rocks along the northeastern margin of Toano

Draw Subbasin and in the Gamble Range. From observation of these features, it may be inferred that this unit probably has high capacity for transmitting groundwater regionally, particularly along deep flow lines. At present, neither the subsurface extent of these fractured carbonate rocks or their actual hydraulic properties are known.

Because of lack of data, and uncertainty as to the capabilities of these fractures to transmit groundwater, it was decided to include only the alluvial aquifer and alluvial fan-volcaniclastic aquifers in the model. In doing so, areal recharge estimated by the model would be conservative because the model would not account for that component of the recharge that may enter from the bottom of the water table aquifer.

Pumping tests in Toano Draw Subbasin indicate that the alluvial aquifer is unconfined in some areas and semiconfined in other areas. The aquifer appears to be generally unconfined in areas abutting the surrounding mountains and semiconfined in areas abutting Thousand Springs Creek. However, geologic investigations to date have not identified any regional confining layer. Thus, on a regional basis, the aquifer is considered unconfined, although during short periods of pumping, the aquifer will respond more like a semiconfined system.

Hydrogeologic investigations have shown that the Toano Draw alluvial aquifer is probably recharged through a combination of two processes. First, there is substantial evidence that a major part of the recharge occurs by direct infiltration from surface water flowing in the numerous drainage channels (ephemeral streams) crossing the valley floor. The source of the surface water is snowmelt and precipitation flowing from the higher-elevation, steeply sloping mountains that essentially surround the valley. The groundwater chemistry data, collected as a part of this investigation (discussed in Section 5.0), indicate that much of the water in the alluvial aquifer, which underlies the central part of the Toano Draw Valley, has probably had limited contact, if any, with the alluvial fan-volcaniclastic aquitard that transitionally abuts the alluvial aquifer, because the total dissolved solids and chloride concentrations in the alluvial aquifer are significantly less than those in the alluvial fan-volcaniclastic aquitard. Also, the concentration of these parameters in the aquifer's water are lower in the central portion of Toano Draw Valley than along the perimeter of the valley. The presence of detectable tritium in the water, from some wells in the central portion of the valley, further confirms that at least some of the groundwater in this portion of the valley was relatively recently recharged to the groundwater flow system. The second mechanism is the direct infiltration of precipitation into the alluvial fan-volcaniclastic aquitard that crops out in and adjacent to the mountains. This water probably flows through the more-pervious portions of the aquitard from the perimeter of the valley into the alluvial aquifer.

Because of lack of specific data on the relative contribution of each recharge mechanism, and in order to be conservative in the modeling, it was assumed, for the purpose of modeling the flow system, that aquifer recharge occurred essentially as follows:

1) Recharge from precipitation on the exposed carbonate rocks of the mountains flowed overland onto the alluvial fan-volcaniclastic aquitard and then infiltrated there along the model boundaries. In the model this recharge occurs as inflow to the cells (nodes) abutting the Paleozoic rocks. The quantity of recharge originating within the outcrop areas of the Paleozoic rocks was estimated by the Maxey-Eakin method, and the quantity of precipitation on these mountain areas was estimated based on the areal extent of land within discrete elevation zones and the relationship between elevation and precipitation derived above in Section 6.0.

2) Recharge from precipitation on areas of exposed alluvial fans, volcaniclastics, and alluvial soils occurred where it fell, and the quantity of recharge was based on the same Maxey-Eakin method and orographic relationship as noted in Paragraph 1 above. Accordingly, for each cell there was a recharge contribution that was a function of the estimated precipitation on the cell.

As noted above, most of the recharge to the aquifer was assumed to occur along the mountain fronts and within the upland areas of the modeled area. Hydraulic heads within the modeled area, under present, no development conditions, vary from about 6500 feet above mean sea level at the Pequop Well to about 5000 feet at the outlet of the modeled area near Crittenden Creek. Groundwater flow from the mountains generally converges towards the central part of Toano Draw and then northerly along the valley axis to Thousand Springs Creek. There also appears to be some groundwater flow from Toano Draw Subbasin into Twentyone Mile Draw Subbasin based on the available water table data. Subsurface flow appears to enter the aquifer from Thousand Springs Creek, which constitutes the northwest side of the model domain.

Near Eccles Narrows, close to the extreme north of the modeled area, the flow area along Thousand Springs Creek is restricted by carbonate rock outcrops. Because of this constriction, groundwater levels do not decline as rapidly as the declining land surface (see Figure 4-5). This results in a shallow water table in the area upstream from Eccles Narrows. Because of the near-surface water levels in this part of the model area, significant groundwater losses occur due to evapotranspiration and discharge to the creek. Along other parts of the stream channel, where the groundwater levels are below the water level in Thousand Springs Creek, evapotranspiration losses are less, and the creek may serve as a source of recharge to the aquifer. Below Eccles Narrows, near the confluence of Crittenden Creek with Thousand Springs Creek, water levels again are near the land surface. This is probably due to a decrease in the cross-sectional area of the alluvial aquifer, and possibly to upward hydraulic gradients. Here again evapotranspiration (ET) rates may be high, as evidenced by the presence of phreatophytes. Groundwater may also discharge to the creek except in the vicinity of Twentyone Mile Reservoir, where water levels in the reservoir may be higher than the groundwater elevation.

Available data were not adequate to estimate, a priori, the stream-aquifer interaction. The interaction was simulated during calibration of the model using the available streamflow data as a guide.

8.2 DESCRIPTION OF THE NUMERICAL MODEL

Groundwater flow modeling was performed with a modular, quasi-three-dimensional, finite-difference model (MODFLOW, version 3.0) which simulates two-dimensional flow in multi-layered aquifers. However, for the case of a single aquifer, as is the case in this study, the model simulates two-dimensional flow. The details of the model are presented in McDonald and Harbaugh (1984). The model requires the flow domain to be discretized into homogeneous elements using a finite-difference mesh. Aquifer parameters are assumed to be constant for each element but these can vary between elements to reflect any known heterogeneities within the domain. The model consists of a number of subroutine programs (packages), each of which consists of one or more program modules.

Two packages of particular interest for application to Toano Draw Subbasin are the ET and river packages. The ET package estimates the ET losses based on a user-specified maximum ET rate where the water table is at the ground surface, and decreasing linearly to some depth where ET losses are assumed to be negligible.

The river package simulates stream-aquifer interactions based on user-specified conductance of the river bottom sediments. Note that conductance is defined as the product of the width of the stream, the length of the stream, and the hydraulic conductivity of the stream bottom sediments, divided by the thickness of the stream bottom sediments. Darcy's Law is used to compute the flow between the stream and the aquifer.

The current river package of MODFLOW is a simplified representation of the aquifer-stream interaction. The module requires the user to specify a depth for the water in the river. The current version does not include a river water mass balance or a river routing algorithm. Accordingly, the user-specified depth is treated as a constant for a given stress period and remains unchanged even when there is flow from the creek to the aquifer or vice versa. Hence, it may indicate more flow from the river to the aquifer than the available water in the river. Similarly, for the case where flow is from the aquifer to the stream, it may underestimate flow from the aquifer to the stream. However, for a stream channel with relatively flat sideslopes, large changes in streamflow will result in only small changes in depth of water in the channel. For such cases, the model results will be reasonable as long as the seepage from the creek is less than the available streamflow.

Given appropriate aquifer parameters and pumpage rates, as well as initial and boundary conditions, the model simulates hydraulic heads within the flow domain. Model outputs include hydraulic heads, drawdowns, and, if desired, fluxes at specific nodes. Further, the model outputs an overall water balance for the basin. Based on studies reported in the literature (McDonald 1984), the model algorithm has been well tested and found to be accurate.

8.2.1 Discretization for the Regional Flow Model

For simulating the regional flow, the model area was discretized into a rectangular area having a total of 3186 nodes, with 59 rows and 54 columns (Figure 8-2). Nodal length varies from a minimum of 1667 feet to a maximum of 5000 feet. Nodes are generally closely spaced in the vicinity of the site of the proposed power plant. The areas represented by each node range from about 65 to 572 acres.

8.2.2 Boundary Conditions

Appropriate boundary conditions and aquifer hydraulic parameters are required in order to effectively simulate subsurface flow in a groundwater basin. Available measured water table elevations within the modeled area were not sufficient to accurately define all boundary conditions or to draw a detailed water table contour map. For virgin groundwater basins, with no significant groundwater development, such as this one, a detailed water table contour map will usually serve as a guide for the type of boundary conditions to impose. Therefore, to supplement the available data, a linear regression of water table elevation against ground surface elevation was performed as shown on Figure 4-4 (Section 4.4). This regression relationship was found to be:

$$Y = 1.03X - 88.6 \qquad (8\text{-}1)$$

where

X = the ground surface elevation [feet above mean sea level from U.S. Geological Survey (USGS) topo map]
Y = the water table elevation [feet above mean sea level]

The above relationship was used to estimate the water table elevations at selected locations where water table data were not available. The results were used to draw the water table contour map shown on Figure 8-3. Note that Equation 8-1 was not applied within the Toano Draw valley floor because sufficient water level data from wells in that area were available to define the flow divisions. Therefore, the general flow patterns depicted on Figure 8-3 within the valley floor are based on the measured field conditions. In areas where Equation 8-1 was used to estimate water levels (in the vicinity of mountain ranges and Twentyone Mile Draw), the flow directions should be considered approximate.

The strong correlation found between topographic elevation and measured water table elevations implies that topographic divides (watershed divides) represent areas of flow divide between groundwater basins. Hence, on Figure 8-3, flow divides, or "no flow" conditions, occur along the crests of mountain ridges. In these areas, water table contours would tend to parallel the ridges. Similarly, for the areas along the boundary of the model that do not correspond to mountain peaks, but represent watershed divides, groundwater flow divides, i.e., no flow conditions, were assumed. These areas include the gap between the Pequop Mountains and the Gamble Range and also the gap between the Windermere Hills and Pequop Mountains. Within the range of depths of wells checked within the model area (less than 600 feet deep), flow did not appear to enter the model area from adjoining groundwater basins except along Thousand Springs Creek, at the northwest boundary of the area where the water table contour map indicates the possibility of subsurface inflow.

Groundwater leaves the model area through the narrow alluvial channel immediately upstream from the confluence of Crittenden Creek with Thousand Springs Creek. A constant-head boundary condition of 4970 feet, mean sea level (MSL) (based on linear interpolation of available data) was assigned to the node in this region. At that point the groundwater level is expected to be essentially constant since there is no existing or proposed nearby wellfield that would influence the water table there. Also, this area is a natural groundwater discharge area as evidenced by the presence of several unnamed springs emerging from the base of the hills abutting the valley and apparent convergence of flow lines. These boundary conditions for the domain are shown on Figure 8-2. Previous studies conducted in the modeled area, by Maxey (1968) and Rush (1968), have made the observation that there is a likelihood of groundwater transfer between subbasins within Thousand Springs Basin. The existence of groundwater transfer between subbasins probably is possible only through deep flow paths.

The water table contour map portrays flow convergence along Thousand Springs Creek. This flow convergence is with respect to lateral groundwater flow from the north (outside the model area) and from the south (within model area). Therefore a "no flow" boundary condition was set along the northern boundary. The creek, however, has been demonstrated to be in hydraulic communication with the aquifer. This hydraulic interaction between the creek and the aquifer is in terms of vertical flow. Therefore, even though the model prohibits lateral flow across the northern boundary, flow between the aquifer and the creek is permitted at the boundary. The interaction between the creek and the aquifer is handled automatically by the model depending on the relative elevation of the water table and the stage of the creek.

The boundaries of the model shown on Figures 8-1 and 8-2 represent the physical extent of the modeled area. For modeling purposes, the Paleozoic rock outcrops were generally considered to be impermeable since few data were available to characterize the flow within the outcrops. Hence, within the model area, the model grid nodes that coincide with the Paleozoic rock outcrops, e.g., Ninemile Mountain, were assigned inactive status. In those areas the effective model boundaries were the intersection of the Paleozoic rock outcrops and the alluvial fan-volcaniclastic aquitard. The estimated recharge to the Paleozoic rock outcrops were accordingly transferred to this intersection. Thus, the boundaries that represent the intersection of the Paleozoic rock outcrops and the alluvial fan-volcaniclastic aquitard in effect became flux boundaries in the model. The model domain, therefore, encompasses the alluvial aquifer in the center of the basin and the alluvial fan-volcaniclastic aquitard extending to the mountain fronts. In addition, areal recharge within the modeled area was incorporated in the model. Such recharge is supported by the strong hydrochemical evidence that recharge occurs within the central part of the modeled area.

The alluvial fan-volcaniclastic aquitard underlying the alluvial aquifer was not incorporated in the model for lack of data on hydraulic heads and hydraulic conductivity for this material. Todd (1980) gives the hydraulic conductivity of fine-grained sediments typical for this type of material as varying from 0.0007 feet/day for clay to 0.7 feet/day for tuff. Such fine-grained material is slowly permeable and its exclusion, below the alluvial aquifer, would not significantly affect the model results. Towards the basin margins where the alluvial aquifer is thin or non-existent, the bottom of the model was made to pinch out to conform with the geology of the area. The bottom elevation of the modeled domain is shown on Figure 8-4. Note that the bottom of the modeled domain is not flat and the downdropped nature of the basin fill (variations in thickness and depth) has been incorporated in the model.

8.2.3 <u>Available Data on Aquifer Flow Properties</u>

Six aquifer pumping tests were conducted by Woodward-Clyde Consultants (WCC) (see Section 4.5) within Toano Draw Subbasin. The tests showed that the aquifer transmissivity varied from 2600 gallons per day per foot (gpd/ft) at Well TW-3 to 50,000 gpd/ft at Well TW-15, as discussed in Section 4.5. The indicated storage coefficient from the test data varied from 0.00012 at Well TW-1 to 0.0013 at Well TW-3. Two short-duration aquifer pumping tests were conducted by Guyton and Associates, Inc. (1982). Guyton reported that Well 41-65-35bd had an estimated transmissivity of 11,000 gpd/ft and Well 41-65-35ad had an estimated transmissivity of 26,700 gpd/ft. No equivalent storativity values were reported for the Guyton tests. In 1989, Well 41-65-35ad was pumped continuously for 13 days at a rate of 900 gpm by WCC. From this test, the transmissivity was estimated to be 46,500 gpd/ft, with an indicated storage coefficient of 0.003. Equivalent hydraulic conductivities at the pumped wells were obtained by dividing the transmissivity values by the well screen length. If drawdown occurred during a test to a depth below the top of the well screen, the thickness of saturated aquifer was assumed to be the depth of water in the well at the end of the pumping. Using this approach, the hydraulic conductivity was estimated to vary from 4 feet/day (ft/day) at Well TW-3 to 56 ft/day at Well TW-15. A more detailed discussion of these tests is presented in Section 4.5.

Rivers may either contribute water to an aquifer or drain water from it, depending on the hydraulic gradient between the river and the aquifer. In this analysis, the direction of groundwater movement is handled automatically within the model. At any particular node, a river supplies water to the aquifer if the river stage is higher than the hydraulic head in the aquifer and vice versa. Since the modeled area is bounded on the north by Thousand Springs Creek, the river package of MODFLOW was used to simulate the interaction between the aquifer and Thousand Springs Creek.

As discussed at the beginning of Section 8.2, the river package of MODFLOW that was used in this analysis does not include river water mass balance, and the depth of water in the river is kept constant during a given stress period. The constant water depth is a reasonable approximation when the channel sideslopes are relatively flat, since large changes in flow rate result in small changes in water depth. The available channel cross section data from Thousand Springs Creek, within the modeled area (Appendix C-2), show that the sides of the creek are fairly flat. The average sideslope is about 5:1 (horizontal:vertical). Hence, for this creek, large changes in the flow rate will result in small changes in the depth of water in the creek. Hence, the river package of MODFLOW should provide a reasonable portrayal of stream-aquifer interactions as long as seepage from the creek is less than the flow available in the creek.

8.2.4 Model Calibration

The parameters used to calibrate the model included the hydraulic conductivity, areal recharge, and river bottom conductance for the modeled area. Initial estimates of the hydraulic conductivity and the areal recharge were made as discussed below.

8.2.4.1 Initial Estimate of Areal Recharge. To estimate the areal groundwater recharge from precipitation, a variation of the method proposed by Maxey and Eakin (1949) (reported in Watson et al. 1976) was used. Using data for groundwater basins in Nevada, Maxey and Eakin found that groundwater recharge is related to the amount of precipitation (Table 8-1). The percentage of precipitation percolating to aquifer recharge increases with increased precipitation to a maximum of about 25 percent when annual precipitation is about 20 inches or more. For annual precipitation below 8 inches, Maxey and Eakin (1949) concluded that no significant groundwater recharge occurs. Using the data of Table 8-1, the recharge rate derived by the Maxey and Eakin method corresponding to the mean annual precipitation for each of the five precipitation ranges was estimated. A plot of mean annual recharge against mean annual precipitation showed that a power function could be used to describe the Maxey and Eakin relationship, as shown on Figure 8-5. The plot shows that recharge is related to precipitation by the following function:

$$R = 2.8\exp{-5}(P)^4 \qquad (8\text{-}2)$$

where

R = total annual recharge [in.]
P = mean annual precipitation [in.]

The coefficient of determination for the above regression is 0.998.

To estimate the annual recharge rate using Equation 8-2, it is necessary to estimate the annual precipitation for each nodal point within the modeled area. Analysis of precipitation data indicates the presence of orographic effects (see Section 6.3.2). The relationship between precipitation and elevation was found to be:

$$P = -12.7 + .0043E \qquad (8\text{-}3)$$

where

P = mean annual precipitation [in.]
E = ground surface elevation [ft, above MSL], E not less than 5000 feet

The modeled area was divided into 11 elevation zones, each spanning about 400 feet elevation (120 meters) (Appendix C). The mapped area within each elevation zone was measured, with the aid of an electronic digitizer (Talos Digitizing Tablet). Using Equation 8-3, the mean precipitation within each elevation zone was estimated, and Equation 8-1 was then used to estimate the annual average recharge within each zone. By this approach, the total recharge to the modeled area was estimated to be about 18,000 acre-feet/year (ac-ft/yr). The recharge calculated by this method, for each grid element, was assigned as the initial estimate of recharge. For the model application, no recharge was assumed in areas where carbonate rocks outcrop, but instead, it was assumed that the equivalent recharge flowed overland to the next active node downgradient and became recharge in that node (see Figure 8-11).

8.2.4.2 Initial Estimates of the Hydraulic Conductivity. Estimates of the aquifer hydraulic conductivity were available for only six locations within the modeled area, as discussed in Section 8.2.3. For simulation purposes, it was necessary to estimate the hydraulic conductivity at each element in the finite-difference grid. Electromagnetic surveys conducted in Toano Draw Subbasin measured the electrical resistivities of major formation materials, to depths of several hundred feet, at numerous locations within the modeled area. Urish (1981) demonstrated that there is a correlation between resistivity and hydraulic conductivity. A plot of measured hydraulic conductivity against electrical resistivity indicated a strong linear relationship (Figure 8-6). The following regression relationship (with a coefficient of determination [R^2] equal to 97 percent) was used to obtain a first approximation of hydraulic conductivity in grid cells where aquifer pump test data from wells were not available:

$$K = -18.1 + 1.39R \qquad (8\text{-}4)$$

where

K = hydraulic conductivity [ft/day]
R = electrical resistivity [ohm-m]
$R \geq 15$

The resistivity and hydraulic conductivity data for Well TW-15 did not fit the above relationship and it was therefore eliminated from the plot. The measured hydraulic conductivity in the vicinity of Well TW-15 was higher than the relationship established using the other five wells, hence the relationship used is on the conservative side. Urish (1981) pointed out that the characteristics of this relation are dependent on in situ factors of porosity and layering as well as the pore water. This may explain why Well TW-15 did not fit the general pattern of the other well data.

8.2.4.3 Data for Stream-Aquifer Interaction. To simulate the stream-aquifer interaction, it was necessary to have estimates of the elevation of the bottom of the stream, the water level elevation, the width and length of the stream, the thickness of the stream sediments, and the hydraulic conductivity of the stream bottom sediments. The thickness and hydraulic conductivity of the river bottom sediments, together with the width and length of the stream at each node, were combined into one parameter that was referred to as the river bottom conductance. Inputs to the river package included the river bottom conductance, the river stage, and the bottom elevation of the river.

Cross sections of Thousand Springs Creek from five locations (Appendix D) were available (Chilton Engineering 1982-1988). Stream bottom elevations at the locations of the cross sections were estimated from topographic maps. Linear interpolation was used to develop the streambed profile for the part of Thousand Springs Creek within the modeled area. Logs of the two wells near this reach of Thousand Springs Creek (Wells TW-1 and MW-1) for which geologic logs were available indicated the presence of semi-pervious material between the river bottom and the aquifer. The representative thickness of this semi-pervious material was estimated to be about 30 feet. The thickness of the river bottom sediments could not be discerned from the well logs. Hence, river bottom conductance could only be estimated during model calibration.

The depth of water in Thousand Springs Creek is controlled in some sections by the level of Twentyone Mile Reservoir. Between February 1982 and October 1988 (period for which data were available), the water level in Twentyone Mile Reservoir varied from 5156, MSL, in October 1988 to 5193 feet, MSL, in March 1983 (Table B-1), with a mean of about 5180 feet, MSL. For model calibration, the water level in the reservoir was assumed to be 5180 feet, MSL. The water level elevation of the river nodes upstream of the reservoir that would be affected by the reservoir elevation were assigned the same elevation as the reservoir. The depth of water in the other sections of Thousand Springs Creek, not affected by the reservoir elevation, varied from zero (during dry periods) to about 5 feet (during very wet periods).

Using topographic data, the average longitudinal slope of Thousand Springs Creek between the western boundary of the model area and Eccles Narrows was estimated to be about .0016. Based on the cross sections of the creek (Appendix C-2), the average side slope of the channel was assumed to be about 5:1 (horizontal:vertical) with a bottom width of about 4 feet. The average annual streamflow entering the model area was estimated to be about 12,500 acre-feet (ac-ft). Using a Manning's roughness coefficient (n) of .04, and assuming uniform flow, averaged over a year, the estimated average depth of water in the creek entering the model area was approximately 1.3 feet. Between the western boundary of the model area and Eccles Narrows, irrigation diversions are estimated to be 6200 ac-ft/yr. Allowing for these diversions, the streamflow at Eccles Narrows is estimated to be 6300 ac-ft/yr. Using the same channel properties as above, the depth of water in the creek at Eccles Narrows will be approximately 1 foot. The above analyses did not take groundwater discharge to the creek into account. However, is expected that the impact of such discharges on the water level depth in the creek would be minimal.

Based on the above discussion, the depth of water in Thousand Springs Creek, in areas that would not be directly affected by the reservoir level, was set equal to 1 foot. Given the data available, this assumption was considered reasonable. In using this value of 1-foot depth of water in the creek, the model probably overestimates the stream-aquifer interactions in certain sections of the creek and underestimates the interactions in other sections. Over the entire reach of the creek, the model was expected to yield reasonable stream-aquifer interchanges.

8.2.4.4 <u>Initial Estimates of Maximum Evapotranspiration Rate</u>. The uptake of groundwater by phreatophytes depends on the climate, depth to groundwater, and the type of phreatophyte. Within Toano Draw Subbasin, deep-rooted phreatophyte growth is sparse and, as such, groundwater depletion would be limited to only shallow-rooted vegetation. The maximum evapotranspiration rate, if the water table was near the ground surface, was initially assigned an annual value of 12 inches. The evapotranspiration rate decreased linearly to 0 when the water table surface was at a depth of 10 feet below the ground surface. Robinson (1970) performed quantitative studies of water use by woody phreatophytes such as greasewood, rabbitbrush, willow, and wildrose near Winnemucca, Nevada. He concluded that the annual water use rate varied from 1.2 ac-ft/acre (greasewood) to over 3 ac-ft/acre (willow).

8.2.4.5 <u>Results of Model Calibration</u>. Model calibration was achieved through an iterative process. Aquifer hydraulic conductivity, areal recharge, and the maximum evapotranspiration rate were changed for each iteration until the modeled hydraulic heads closely simulated the measured hydraulic heads. After a reasonable match was obtained between the measured hydraulic heads and the simulated hydraulic heads, the river bottom conductance was adjusted until a reasonable match was achieved between measured streamflows and simulated values.

The calibration procedure, whereby both hydraulic conductivity and recharge were changed to match simulated hydraulic heads with measured hydraulic heads, would not result in a unique model calibration. However, if the calibrated hydraulic conductivity values obtained from model calibration approximated the values obtained from pump tests, the calibrated values would be considered reasonable. Hence, in the model, the distribution of hydraulic conductivity values were kept close to the values obtained from pump tests in areas where pump test data were available. No pump tests were conducted within the alluvial fan-volcaniclastic aquitard. However, it was known that the alluvial fan-volcaniclastic aquitard has a much lower permeability than the alluvial aquifer. Todd (1959) lists the hydraulic conductivity of sediments similar to the alluvial fan-volcaniclastic aquitard as varying from 0.0007 ft/day for clay to 0.7 ft/day for tuff. Within the alluvial fan-volcaniclastic aquitard, the calibrated hydraulic conductivities values were considered to be reasonable.

Figure 8-7 and Table 8-2 show the measured and simulated heads at each of the existing 31 wells within the model area for which water level data were available. The "serial number" depicted on Figure 8-7 corresponds with the well number on Figure 8-2. Of these 31 data points, the model overestimated the heads of 12 wells, with a mean overestimation of 20 feet, and underestimated the heads of 19 wells, with a mean underestimation of 11 feet. The mean absolute deviation between the computed and measured heads was 15 feet. The minimum absolute deviation of simulated head from measured head was 0.9 feet at Wells 42-66-35b and 39-65-3ad, and the maximum was 102 feet, at Well 41-67-22bc.

Note that Well 41-67-22bc is located within Twentyone Mile Draw where the geologic map indicates interspersed Paleozoic outcrops in some sections. In the model these outcrops were considered impermeable. However, some of these outcrops may be permeable due to the presence of fracture openings. This well was located in an area where the aquifer has steep gradients and the model grid may not be sufficiently fine to simulate the changing hydraulic heads. These two reasons may explain the discrepancy between the model and the simulated heads.

The overall flow patterns, indicated by the simulated water table contour map shown on Figure 8-8, agree well with the flow patterns indicated by the measured water table contour map (Figure 8-3). A linear regression between the simulated and the measured hydraulic heads for the 31 wells, shown on Figure 8-9, shows a correlation coefficient (R) close to 1.0. The best-fit curve is given by:

$$Y = 153.4 + 0.97X \tag{8-5}$$

where

Y = simulated hydraulic head [ft above MSL]
X = measured hydraulic head [ft above MSL]

Hypothesis tests were performed on both the slope of the regression line (0.97) and the intercept (153.4). At the 95 percent confidence level, the tests showed that the slope was not different from 1.0 and the intercept was not different from zero.

Several reasons may account for the discrepancy between the measured and simulated water level elevation. First, the spatial variability (heterogeneity) of aquifer parameters probably is more complex than can be specified in a model. Second, the degree of discretization determines how well model results will match actual values. In particular, the measured water level elevation at a well represents a point measurement, whereas the simulated water level at a node represents the average head over the nodal area. This is particularly a problem in the vicinity of sinks and sources, where hydraulic heads change rapidly with distance. Finally, for calibration purposes, it was assumed that the aquifer was in steady state, i.e., there were no significant temporal variations in the hydraulic head. This assumption was generally valid for undeveloped aquifers such as Toano Draw Subbasin, where groundwater utilization was essentially zero. However, some of the water levels may have been measured in wells during a period when there was some minor pumping in the area, which may have resulted in some minor discrepancy between the simulated and the measured value.

Figure 8-10 shows the distribution of calibrated hydraulic conductivity assigned to the model. Generally, the hydraulic conductivity was highest along Toano Draw and in the vicinity of Twentyone Mile Draw. It decreased from a maximum of about 72 ft/day in the southern parts of the basin to about 12 ft/day in the northern parts. However, low hydraulic conductivities generally exist to the east and west of Toano Draw and Twentyone Mile Draw. The distribution of calibrated recharge to the model area is shown on Figure 8-11. The high recharge values at the active model boundaries reflect the transfer of estimated recharge from Paleozoic rock outcrops to these areas.

Table 8-3 indicates the calibrated water balance for the subbasin. The average recharge to the modeled area was about 8400 ac-ft/yr. As noted previously, this estimated rate of recharge may be substantially less than the actual recharge because the flow model did not take into account possible flow through the deep Paleozoic carbonate aquifer. Under steady-state conditions, the model indicates that about 4600 ac-ft/yr would be lost to evapotranspiration at locations of high water table (depth to water less than 10 feet) along Thousand Springs Creek, and 1200 ac-ft/yr would leave the basin as groundwater outflow to the Montello Subbasin.

The area where the natural water table was within 10 feet of the ground surface was estimated to be about 10,000 acres. The average phreatophyte water use in this area would be about 5 inches/year. This would be approximately equivalent to the water use by a greasewood community covering 35 percent of the area or a willow community covering about 14 percent of the area based on the rates of evapotranspiration of these plants as estimated for the Humboldt River Basin by Robinson (1970). Considering the sparse distribution of phreatophytes within the modeled area, the simulated phreatophyte water use was judged to be reasonable.

Based on the assumptions concerning the river bottom conductance and the depth of water in the creek, the total amount of water infiltrating from Thousand Springs Creek, along its entire reach within the model area into the groundwater system, under steady-state conditions, was about 1700 ac-ft/yr. The total groundwater discharge, along the entire reach of the creek within the model area, was estimated to be 4200 ac-ft/yr. This translates to a net groundwater discharge to the creek of about 2500 ac-ft/yr. Between the western boundary of the modeled area and the Shores gaging station, net annual groundwater discharge to the creek was estimated to be about 1300 ac-ft. This value was consistent with the streamflow generation model and estimates of irrigation usage in the reach, which indicated that the sum of groundwater discharge and irrigation return flow between Wilkins and Shores was about 1700 ac-ft/yr. Between the Shores gaging station and the eastern boundary of the model area, the groundwater flow model estimated the net discharge to the creek to be about 1200 ac-ft/yr. Allowing for irrigation diversions of 2400 ac-ft/yr, and evapotranspiration of 3000 ac-ft/yr, the streamflow generating model predicts the groundwater discharge to the creek in this river reach to be approximately 1700 ac-ft/yr. The overall steady-state water balance for the calibrated model is shown in Table 8-3.

8.3 REGIONAL FLOW MODEL

The calibrated model was used to simulate the effects of groundwater pumping on the water levels in Toano Draw Subbasin, the depletion of flow to Thousand Springs Creek, and change in subbasin evapotranspiration losses. Since this was a transient simulation, an additional parameter (specific yield), not required for steady-state calibration, was required for the simulation. Because of the long period covered by the simulation, and the possibility of large drawdowns, the pump tests reported in Section 4.0 were considered too short in duration to yield representative values of the specific yield. The values obtained from such short-term tests are generally significantly smaller than the long-term specific yield of this type of aquifer material. Based on the composition of the aquifer material, the specific yield was expected to be within the range of 0.1 to 0.3 (Walton 1970; Freeze and Cherry 1979; Driscoll 1987). A more detailed discussion of this parameter was presented in Section 4.5. The simulations reported here were based on assuming a specific yield of 0.1, the same value assigned by Rush (1968) for these aquifer sediments. Sensitivity analyses, assuming a specific yield value of 0.2, showed significantly less drawdown than the simulations presented herein.

In order to maximize the use of the water in the subbasin, it would be necessary to capture the water that is presently lost as evapotranspiration, reduce the baseflow to Thousand Springs Creek, and simultaneously increase the aquifer recharge from Thousand Springs Creek. However, because of environmental considerations, it would be preferable to maintain the phreatophytes and not significantly alter the natural flow in Thousand Springs Creek. Because of these considerations, several scenarios of groundwater development were addressed. For each scenario, a power plant water requirement of 4000 ac-ft/yr per unit, and new unit startups at 2-year intervals, were input to the model, i.e., Unit 1 starts operating at T = 0, Unit 2 at T = 2 years, Unit 3 at T = 4 years, etc. Each unit would operate for a total of 35 years, and it was assumed that the water requirement would remain constant at 4000 ac-ft/yr per unit throughout the operation period. The simulated scenarios were as follows:

Case 1

This was referred to as the Least Cost Alternative. For this case, it was assumed that water for the first five units would be obtained from Toano Draw Subbasin, Units 6 and 7 would be supplied from wellfields along Thousand Springs Creek between Twentyone Mile Dam and Crittenden Creek, and Unit 8 would be supplied from a wellfield in Montello Valley. This alternative represents the minimum costs for water pipelines and pumping.

Case 2

This is referred to as the Least Environmental Impact Alternative. For this case, Units 1 and 2 would be supplied from a wellfield in Toano Draw, located south of the power plant site; Units 3 through 7 would be supplied from wellfields in Montello Valley; and Unit 8 would be supplied from a wellfield in Toano Draw. To determine the environmental effects of the location of the Unit 8 wellfield, two model runs were made as follows:

Case 2A. Unit 8 would be supplied from a wellfield north of the plant site.

Case 2B. Unit 8 would be supplied from a wellfield south of the plant site.

Case 3

This was referred to as the Intermediate Cost and Environmental Impact Alternative. For this case, it was assumed that Units 1 and 2 would be supplied from the wellfield south of the power plant site, Units 3 and 4 would be supplied from Montello Valley, Units 5 and 6 would be supplied from wellfields in Toano Draw north of the plant site, and Units 7 and 8 would be supplied from Montello Valley. Like Case 2, two model runs were made to assess the differences between supplying Units 5 and 6 either from a single wellfield or two wellfields, located as follows:

Case 3A. Units 5 and 6 would be supplied water from a single wellfield located just north of the plant site.

Case 3B. Units 5 and 6 would be supplied water from two separate wellfields, one just north of the plant site and the other nearer Thousand Springs Creek.

Figures 8-12, 8-13, and 8-14 show the assumed locations of extraction wells for Cases 1, 2, and 3, respectively.

The projected effects of these water withdrawals on the water balance of the modeled area is shown in Table 8-4. As expected, Case 1 would produce the highest environmental impacts, with the annual net flow to the creek changing from 2523 ac-ft (at time zero) to -2820 ac-ft after 147 years. Hence, the maximum annual water loss from the creek would be 5343 ac-ft. The least environmental impact alternative (Case 2B) produces a net annual water loss of 1544 ac-ft from the creek. The highest average drawdown in the subbasin would be produced by Case 1, with an average drawdown value of 50 feet. Cases 2A and 3B would each result in an average subbasin drawdown of about 42 feet. The average drawdown for Cases 2B and 3A would be about 38 and 47 feet, respectively. Figure 8-15 shows the rate of water loss from Thousand Springs Creek with time for the different cases. The estimated drawdowns within the modeled area, at the end of the planned life of the power plant, for Cases 1, 2A, 2B, 3A, and 3B are shown on Figures 8-16 through 8-20, respectively. The estimated water table elevation for Case 2B is shown on Figure 8-21.

Sensitivity analyses were performed on the numerical model input parameters to assess whether the model results would vary significantly if other reasonable parameters were used. The sensitivity of the model to reasonable variations in recharge, specific yield, and hydraulic conductivity distribution were tested. These sensitivity runs showed that the model was significantly sensitive only to the specific yield value specified for the alluvial aquifer. The specific yield value used for the base case, and on which the proposed aquifer development plan was based, was at the low end of the range (0.10 to 0.25) considered likely to be applicable to the modeled area, and therefore conservative with respect to predicting aquifer drawdown, i.e., overpredicting. The details of the sensitivity analyses are presented in Appendix C.

By running the model with an assumed aquifer specific yield of 0.2, instead of the 0.1 previously discussed, the drawdowns were found to be much smaller, and therefore, potentially adverse environmental impacts would be reduced in each case.

8.3.1 Description of Montello Valley

Montello Valley lies to the east of Toano Draw Subbasin (numerical groundwater model area). Based on results of the numerical model, groundwater subsurface flow within the alluvium of Thousand Springs Creek from Toano Draw Subbasin to Montello Subbasin is about 1200 ac-ft/yr. However, there may be a large additional component of flow into Montello Subbasin along deep flow lines, through the Paleozoic carbonate aquifer. Thus it appears that most of the groundwater flow into Montello Subbasin is through groundwater recharge within the subbasin, flow within the alluvium of Thousand Springs Creek, or regional discharge from the Paleozoic carbonate aquifer. The channelized alluvium within Montello Subbasin has a high capacity for transmitting groundwater flow. Pump tests conducted within Montello Valley Subbasin (reported in Rush 1968 and Guyton and Associates 1982) show that the alluvial aquifer in this basin is much more transmissive than the alluvial aquifer in Toano Draw Subbasin. Transmissivity values from pump tests reported by Guyton and Associates (1982) ranged from 160,000 gpd/ft to 200,000 gpd/ft. Additional data were available, from both drillers logs and short-term pump tests, on the specific capacity of wells in the area. A correlation between specific capacity and transmissivity, using available data for the entire Thousand Springs Basin, was made (Section 4.6.3). This relationship was used to estimate transmissivity values in areas where long-term pumping test results were not available in Montello Valley Subbasin. By this approach, the average transmissivity of the channelized alluvium was estimated to be about 140,000 gpd/ft in the area that appears potentially favorable for a wellfield to supply the project. Although there were no field or laboratory test data available regarding the specific yield of the alluvial aquifer in this area, based on the composition of the alluvial material, the specific yield of the aquifer was estimated to be in the range of 0.1 to 0.3. For the analytical model solution presented below, a transmissivity of 140,000 gpd/ft and a specific yield of 0.2 was assumed for the aquifer.

For ease of solution, analytical models usually assume that an aquifer is of infinite extent. However, in hydrogeologic settings, such as Montello Subbasin, bedrock outcrops, which are assumed to be essentially impermeable, are present in the vicinity of hypothetical pumped wells. Hence, a correction needed to be made to the analytical model to account for the boundary effects. The method used to simulate these hydrologic boundary effects in the model is explained in Section 8.3.3. The analytical solution selected for this analysis used the Theis solution technique. The Theis well functions are calculated by polynomial approximations (Appendix C-4).

8.3.2 <u>Application of Analytical Model to Predict Drawdown from Wellfield</u>

The analytical model described above was used to predict the drawdown from a wellfield. From the simulation cases presented in Section 8.3, the maximum annual water requirement from Montello Valley would be 20,000 ac-ft, to serve five power plant units. The analytical model was used to simulate the effects of withdrawing 20,000 ac-ft of water annually for a period of 35 years. This demand was distributed equally among 12 potential well sites. These potential well sites were spaced so as to reduce interference between wells. In areas where existing wells appear to be favorable well sites, they were incorporated into the model.

In Montello Subbasin, the alluvial channel to the north is narrow and is bounded by rock outcrops of Paleozoic age. The model used in this analysis was modified to represent these boundaries by using the image well method that is based on the principle of superposition of well development predicted by the Theis nonequilibrium well formula. Since the actual transmissivities of the rocks were not known, it was conservatively assumed, for purposes of the modeling, that these rocks form impermeable boundaries. In this approach, when a well was sufficiently near an impermeable boundary, such that the cone of depression of the well extended to the boundary, an image well (with the same pumping rate as the pumped well) was placed an equal distance on the opposite side of the impermeable boundary. Where the river appeared to be hydraulically connected to the aquifer, the same procedure was applied, but in this case, the image well was a recharge well or, if appropriate, a line of recharge wells. The image well theory was applied for proposed wells that were located near such hydrologic boundaries. The location of the boundaries applied to the model is shown on Figure 8-22.

The assumptions used in this analysis were that the aquifer is homogeneous and isotropic, the aquifer was infinite in areal extent, groundwater surface slope was zero, and there was no recharge (except that simulated using image recharge wells). Presently there are no data available to determine whether the aquifer is homogeneous and isotropic. However, because of the relatively small range in values of aquifer transmissivity from available test data, the assumption that the aquifer is homogeneous and isotropic was considered reasonable. As explained above, corrections were made to the model, using the image well theory, to correct for boundary effects. For wells near the impermeable boundaries, image discharge wells (with the same pumping rate as the pumped wells) were placed an equal distance on the opposite side of the impermeable boundaries. With pumping, it was expected that water would infiltrate into the groundwater system as leakage from Thousand Springs Creek. At present, about 9000 ac-ft/yr of water is used for irrigation within Montello Valley Subbasin. It is anticipated that with the inception of the power plant project, these agricultural diversions would cease and, therefore, an additional 9000 ac-ft/yr of water would be available in the creek. It was assumed that this additional 9000 ac-ft/yr of water in the creek would be induced to recharge the aquifer as a result of pumping. Therefore, for modeling purposes, maximum recharge anticipated from the creek as a result of groundwater withdrawals was limited to 9000 ac-ft/yr. This recharge from the creek was represented in the model as a line source consisting of eight injection wells uniformly distributed along Thousand Springs Creek, with each well injecting 1125 ac-ft/yr (700 gallons per minute [gpm]) of water to the aquifer. Leakage from Dake Reservoir was limited to 4000 ac-ft/yr (2500 gpm).

The Maxey and Eakin method (discussed in Section 8.2.4.1) was used to estimate the precipitation recharge to the aquifer. Using this method, the areal recharge to Montello Subbasin was estimated to be 12,000 ac-ft/yr. This recharge was assumed to enter Montello Valley along the edges of rock outcrops (Gamble Range to the west and Pilot Range to the east). A line source (represented by 20 injection wells, with each injecting water at 600 ac-ft/yr) was specified along the edges of the Gamble Range and Pilot Range outcrops. Water level data within the area selected for the analytical model show that the slope of the water table is very gentle, and therefore, the assumption that the water table is essentially horizontal was reasonable.

The resulting drawdowns in Montello Valley Subbasin, for a total annual pumping rate of 20,000 ac-ft for a period of 35 years, is shown on Figure 8-22. The estimated drawdowns within the model area vary from about 2 feet to 40 feet.

9.0
WATER RIGHTS

9.1 INTRODUCTION

Water for operating the Thousand Springs Power Plant (TSPP) will be supplied, on an as-needed basis, by Lands of Sierra, Inc (LOS). LOS owns extensive lands and the vast majority of all water rights that have been granted in Thousand Springs Basin. Those lands and the water appurtenant thereto are presently used primarily for agricultural purposes. Under the water supply contract between LOS and Thousand Springs Generating Company (TSGC), it will be the responsibility of LOS to conduct water exploration and water planning studies to locate well sites. It will be the responsibility of TSGC to drill, complete, and develop all wells required to supply water to the power plant project. TSGC will construct, operate, and maintain all facilities required for pumping, transporting, storing, and treating water for the power plant; and will perform groundwater level monitoring, as may be required by the State Engineer and/or the Bureau of Land Management (BLM), to assess the effects of power plant water uses. LOS will provide meters on all wells, as required by the terms of its certificated and permitted water rights, in order to document the quantity of water pumped from each well, and will operate and maintain the meters. It will be the responsibility of LOS to satisfy the requirements of Nevada's water law in connection with the provision of water for the TSPP. This may include perfection of existing permits and applications, changes in existing points of diversion, places of use or manner of use, and the acquisition and perfection of new water rights, or any combination thereof.

Present plans are that LOS will continue its agricultural uses of water for the foreseeable future, so long as there clearly is enough water available for both power plant and agricultural uses without inducing unacceptable environmental effects. However, under the terms of its contract with TSGC, LOS will give precedence to supplying the water requirements of the power plant, and will curtail its uses of water for agricultural purposes if at any time it appears to either the State Engineer or TSGC that there is not enough available water for both types of use.

9.2 SUMMARY OF WATER RIGHTS

Chilton Engineering and Surveying Ltd., Elko, Nevada, provided data (October 16, 1989) on the current water rights owned by LOS within Thousand Springs Basin. Those annual[1] water rights are summarized as follows:

Surface Water Rights (acre-feet [ac-ft])	
By:	
Decree	24,398.1
Certificate	6,594.06
Permit	11,000
Application	200,000

Underground Water Rights (ac-ft)	
By:	
Certificate	8,513.46
Permit	27,520
Application	20,000

In addition to the above quantities, LOS owns numerous unquantified stock watering rights. Typically, no annual (or other period) duty is assigned to stock watering sources by the Nevada Division of Water Resources. However, the total quantity of water that could be used for stock watering purposes within the basin would not exceed 200 acre-feet/year (ac-ft/yr), assuming a maximum of 10,000 animals were each consuming 15 gallons per day (gpd). The above tabulation shows that LOS owns more than 32,000 ac-ft of groundwater rights, the estimated maximum power plant water requirement. Further, regulated surface water releases from reservoirs, and increased groundwater recharge from surface water sources, as may occur as a result of water table lowering due to pumping for power plant uses, would be covered by LOS's existing surface water rights.

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1 The quantities listed are the maximums that may be used in any calendar year, but some of the rights presently restrict the use to some lesser part of a year, e.g., a typical irrigation season. The applications to be filed by LOS, requesting authorization to change the points of use and type of use for the rights, will include a change in the period of use, as appropriate.

10.0

EFFECTS OF WATER RESOURCE DEVELOPMENT

Groundwater withdrawals to serve the Thousand Springs Power Plant (TSPP) Project may create several potentially adverse effects. These effects include groundwater level declines, reduced surface and groundwater discharge from the basin, reduced streamflow and springflows, ground surface subsidence, and deterioration in quality of groundwater and surface water. Groundwater level declines may adversely impact the productivity of wells, and will increase pumping costs in direct proportion to the increased lift. Water table drawdowns could result in the decline or elimination of phreatophyte vegetation. Increased pumping costs and/or deteriorating water quality may make irrigated agriculture uneconomic. Possible reductions in streamflow, springflows, and basin discharge and/or changes in water quality may affect aquatic and wildlife habitat. In this section, each of these potential effects of groundwater utilization is described, assuming wellfields will be installed at the potentially favorable locations, and pumped at the rates needed to supply the power plant. Potentially favorable areas for wellfields, and groundwater development options, were described in Section 7.2. Groundwater level drawdowns, as a result of pumping associated with the various water development options considered, were evaluated using the numerical and analytical modeling methods described in Section 8.0.

In general, the discussion that follows relates to the expected results of constructing and operating the power plant in accordance with the presently planned development schedule, i.e., eight generating units, constructed with 2-year intervals between initial startup of the individual units, and each unit having an operating life of 35 years and requiring 4000 acre-feet/year (ac-ft/yr) of makeup water throughout its operating life.

10.1 GROUNDWATER LEVEL DRAWDOWN

Groundwater pumping results in the lowering of water levels (drawdown) in an aquifer. The amount of drawdown at a point depends on its distance from the pumping well or wells, the pumping rate and duration of pumping, aquifer recharge rate, the aquifer transmissivity and specific yield, and the point's proximity to an aquifer boundary. Drawdowns increase inversely with aquifer transmissivity and/or specific yield. With lower transmissivity, the area of influence of the pumping well is reduced for a given pumping rate, and therefore, higher drawdowns are required to transmit the water from the aquifer to the well. At the start of pumping, the area of influence of the pumping well is small, and the initial drawdown rates are high, but with time, the area of influence expands and this results in a decrease in the drawdown rate. Drawdown is highest at the pumping well and decreases exponentially with distance away from the well.

As discussed in Section 8.3, groundwater drawdown was simulated for three groundwater development options (alternatives). The major differences between the alternatives were the assumption that three, four, or five generating units would be supplied water from wellfields in the Toano Draw area, and the balance of the requirements for eight total units would be from wellfields along the lower reaches of Thousand Springs Creek in Nevada. The aquifer drawdown effects associated with each of these alternatives, and the corresponding water balance of the model area, are discussed below. The proposed wellfield locations, for the various pumping scenarios, are shown on Figures 8-12, 8-13, and 8-14.

10.1.1 Drawdown Created by Groundwater Withdrawal for Case 1

For this alternative (5 units supplied water from Toano Draw), the highest drawdowns (about 80 feet) would be produced in the vicinity of the two wellfields north of the power plant. The combined pumping rate from these two wellfields would be 12,000 ac-ft/yr. In the vicinity of the wellfield south of the power plant, the average drawdown would eventually be about 60 feet with a pumping rate of 8000 ac-ft/yr. For the wellfield located between Twentyone Mile Dam and Crittenden Creek, the average drawdown in the vicinity would eventually be about 60 feet for a pumping rate of 8000 ac-ft/yr. The overall average drawdown for this alternative would eventually be about 50 feet.

10.1.2 Drawdown Created by Groundwater Withdrawal for Case 2

The groundwater withdrawal rate from Toano Draw Subbasin for this alternative would be 12,000 ac-ft/yr (3 units). As discussed in Section 8.3, two simulation runs were made for this alternative. In both cases a wellfield would be located south of the power plant and the pumping rate from the field would be 8000 ac-ft/yr. For the Case 2A alternative, the wellfield for the third unit would be located north of the power plant. For Case 2B, the third unit would be supplied from the wellfield south of the power plant. The greatest drawdown for Case 2A would eventually be about 55 feet, and it would extend from the south, within the southern wellfield, to the wellfield in the north. The average subbasin-wide drawdown would be about 42 feet. For the Case 2B alternative, the highest drawdown would eventually be about 70 feet (but of limited areal extent). This drawdown would be produced within the wellfield south of the plant site. In this case, the average subbasin-wide drawdown would be about 38 feet.

10.1.3 Drawdown Created by Groundwater Withdrawal for Case 3

The groundwater withdrawal rate from Toano Draw Subbasin for this alternative would be 16,000 ac-ft/yr (four units). Like Case 2, two simulation runs were made for this alternative. In both cases, a wellfield would be located south of the power plant and the pumping rate from this wellfield would be 8000 ac-ft/yr. The wellfields to supply two additional units would be located either within one wellfield just north of the plant site, for the Case 3A alternative, or for the Case 3B alternative, two wellfields with one wellfield just north of the plant site and the other farther north near Thousand Springs Creek. The highest drawdown for Case 3A would eventually be about 80 feet and would occur within the two wellfields north of the plant site. The drawdown in the wellfield south of the plant site would eventually be about 60 feet. The average subbasin-wide drawdown would eventually be 47 feet. For the Case 3B alternative, the highest drawdown would eventually be about 65 feet, but of limited areal extent, and would be produced within the wellfield just north of the plant site; the drawdown within the wellfield nearer Thousand Springs Creek would eventually be about 60 feet and the drawdown within the wellfield south of the plant site would be about 55 feet. The average subbasin-wide drawdown for this alternative would be about 42 feet.

10.2 EFFECTS ON BASIN GROUNDWATER DISCHARGE

Groundwater withdrawals for supplying the power plant, as it expands progressively, would reduce the amount of groundwater discharging from Toano Draw Subbasin and from Thousand Springs Basin as a whole. The present groundwater use in the subbasin is limited to a few acre-feet/year for stock watering purposes. The present groundwater discharge from the basin includes about 4200 ac-ft/yr of water used consumptively for irrigation purposes and about 30,000 ac-ft/yr of groundwater underflow into Utah through Thousand Springs Valley. For the basin as a whole, it is estimated that groundwater discharge to Utah ultimately would change by an amount approximately equal to the net extraction rate, which would be the same for each of the water supply options. The proposed action includes terminating irrigation uses of water to offset part of the power plant water uses. There is at present an unknown but probably significant amount of groundwater discharged naturally through evapotranspiration (ET) by phreatophytes. (Rush [1968] estimated this quantity as 5700 ac-ft/yr for the basin as a whole.) Although it is not possible to measure the amount of phreatophyte ET, it was estimated that within the model area (downstream from the Winecup Ranch land upstream from the confluence with Crittenden Creek), based on parameter values assumed for the numerical flow model, ET by phreatophytes and evaporation in areas of shallow water table totals about 4600 ac-ft/yr.

If water development Option 1 (Section 7.0) were to be implemented, the amount of phreatophyte ET near Thousand Springs Creek would be reduced in the area upstream of Crittenden Creek by a factor of about 90 percent of present ET. From results of numerical flow modeling (Table 8-4), it was estimated that ET along these reaches of the creek would be reduced by about 4000 ac-ft/yr, and groundwater discharge to the creek would be reduced by about 5300 ac-ft/yr. (Effects on streamflow are discussed in Section 10.3 below.) There would be minor effects downstream of Crittenden Creek on ET rates. Groundwater underflow discharge to Utah for Case 1 ultimately would be reduced by an amount essentially equal to the groundwater extraction rate.

If Option 2 were to be implemented, there would be less of an effect than with Option 1 on groundwater discharge from Toano Subbasin to areas downstream. There would be less of a reduction in ET in areas along the creek. The flow model predicts that there would be about 500 ac-ft/yr less ET then at present in the model area after 49 years of pumping (Case 2B). There would be significant but not quantified reductions (greater than Option 1) in ET in the Montello area.

If Option 3 were to be implemented, the effects of pumping on groundwater discharge would be similar to Cases 1 and 2 for the basin as a whole. The reduction in groundwater discharge to the stream and by ET would be at intermediate levels between Options 1 and 2.

Before pumping (initial condition), the model indicates that within the model area the average net groundwater flow (baseflow less amount of infiltration from the creek to the aquifer) to Thousand Springs Creek is about 2500 ac-ft/yr, ET loss is about 4600 ac-ft/yr, and subsurface outflow is about 1200 ac-ft/yr. For the Case 1 pumping simulation, after 47 years of pumping, the net groundwater flow to the creek decreases to about -2820 ac-ft/yr, with the negative sign indicating net water loss from the creek to the aquifer. Initially, when only Units 1 through 4 are operating, the effect of pumping on the creek is negligible. This is because the wellfields are located relatively far from the creek and, therefore, their cones of depression do not extend to the creek. In addition, the time period where only the first four units are operating (T = 0 to 8 years from startup of Unit 1) is short and the effects of the pumping have not been fully developed. With the addition of the fifth unit (T = 8 years), which is located nearer the creek, the drawdowns near the creek become pronounced. This results in higher induced infiltration from the creek, and less baseflow to the creek. The addition of Units 6 and 7 (T = 10 and 12 years, respectively) results in further declines in the groundwater flow to the creek (see the steep slope on Figure 8-15). The rate of flow depletion from the creek starts to decrease with time, as the basin approaches dynamic equilibrium with the pumping, after about 20 years of pumping. By the end of year 35, when the first generating unit is scheduled to be deactivated, the depletion rate from the creek becomes almost constant, about 2800 ac-ft/yr.

As expected, Case 2B appears to have the least impact on the net flow to the creek. The imposition of Case 2B is estimated to reduce the net flow to the creek from an annual value of about 2523 acre-feet (ac-ft) in year zero to about 979 ac-ft in year 49, which represents a net loss of about 1544 ac-ft/yr. This is because the pumping scenario for this case calls for the least amount of pumping from Toano Draw Subbasin, together with the fact that the wellfield is the most distant from the creek. The Case 2A groundwater development alternative may result in a net loss of about 1859 ac-ft/yr. With the application of Case 3A groundwater development alternative, the flow to the creek may be reduced by about 2231 ac-ft/yr, while the Case 3B alternative may reduce the flow to the creek by about 2404 ac-ft/yr.

10.3 EFFECTS ON STREAMFLOWS AND SPRINGFLOWS

10.3.1 Groundwater Development Option 1

Supplying groundwater to the power plant following Option 1 (Section 7.0) would cause significant decreases in the flow of Thousand Springs Creek downstream from Winecup Ranch, and may reduce or eliminate the flow from some springs located along the creek. In the early years of project development (years 1 through 8, Units 1 to 4) the flow rate of the stream could be essentially maintained by implementing water management practices to reduce irrigation diversions as the power plant was being expanded. There is currently consumptive use of groundwater and surface water along Thousand Springs Creek equal to about 15,000 ac-ft/yr. Assuming this amount of consumptive use for irrigation would cease, and an equal amount of groundwater would be supplied to the power plant project instead, streamflows could generally be maintained as at present, so there would be only a nominal long-term net decline in streamflow. However, in later years (years 8 to 47), there would be progressive decreases in the flow rate to Thousand Springs Creek, and possibly decreased flow in springs located along the creek. The results of numerical flow modeling (Table 8-4) illustrate the approximate magnitude of the decline in net groundwater discharge to the creek according to the assumed development schedule of the project. Although these values do not reflect the positive effect on streamflow that would be created by eliminating irrigation along the creek, it is apparent that there would be a significant net decrease in total annual flows in the creek after about year 8.

The extent and magnitudes of the simulated drawdowns for this option (Figure 8-16) also illustrate the effects on surface water, given that Thousand Springs Creek, and springs adjacent to it, is hydraulically interconnected in many areas with the alluvial aquifer that will be pumped by project wellfields. Springs that are located along the periphery of the valley floor of Toano Draw may be affected by pumping from the alluvial aquifer in the central part of the valley, e.g., Mud Spring, Pequop Spring, and Lower Deadman Spring. Even though the elevations of these springs appear to be above the water table (as depicted on Figure 4-5), they may be connected with the water table. However, other ephemeral streams, and springs located in topographically more elevated areas above the proposed project wellfields, will not be adversely affected. Ephemeral streams in the upland areas surrounding Toano Subbasin, and in the mountains that form the basin divides, presently lose water along their lower reaches by natural percolation, and contribute to groundwater recharge in the basin. Because these streams are significantly elevated above the present water table, there will be no effect of pumping withdrawals and resultant drawdowns on these ephemeral streams. Similarly, the springs that are topographically elevated above the present water table in these areas will not be affected by pumping because they are hydrogeologically disconnected from the regional water table (i.e., perched above it) or they represent discharge from small-scale groundwater flow systems as described in Section 4.5.

10.3.2 Groundwater Development Option 2

If Option 2 were to be followed for supplying water to the power plant, the effects of groundwater pumping on streamflows and springflows would be minimal in the areas along Thousand Springs Creek upstream of Crittenden Creek. The results of numerical modeling (Section 8.0) have been used to estimate the potential effects of groundwater withdrawals for this case. Based on the records of flow in Thousand Springs Creek, an average of approximately 12,000 ac-ft/yr originates upstream from the Wilkins streamflow gaging station. By contrast, only about 3000 ac-ft/yr discharges to the Creek from the approximately 95 percent of the basin watershed draining to the Creek downstream from the Wilkins gage. The results of the numerical modeling indicate there would be a small decrease (about 10 feet maximum) in the water table surface near Thousand Springs Creek with Option 2 and slightly less with Option 2B, and therefore there would be a correspondingly small increase in percolation of creek water to the aquifer. Termination of surface water diversions, for irrigation, as proposed, would offset the increased percolation and maintain the flow in the creek. As illustrated on Figures 8-17 and 8-18, the groundwater drawdowns would be confined mainly to the areas in the south-central portion of Toano Draw Subbasin. Effects of pumping on wells and springs would be localized to the area in the southern and central portions of Toano Draw. Effects on ephemeral streams and springs in the uplands surrounding the subbasin would be insignificant for the reasons stated above for Option 1. There may be a decrease in groundwater discharge to Thousand Springs Creek, which may become noticeable after about 20 years, if one of the wellfields were located in the northern end of Toano Draw (Case 2A) (Table 8-4). However, there would still be a substantial net discharge of groundwater to the creek throughout the project life from the area lying north of the creek.

If the wellfield to supply three units (Units 1, 2, and 8) were located in the southern portion of Toano Draw (Figure 7-1), as simulated in numerical modeling case 2B, there would be an even smaller, and probably unnoticeable, impact on streamflows and springflows along Thousand Springs Creek. The net reduction in groundwater discharge to the stream in this case (about 1500 ac-ft/yr) would be substantially less than the present amount of consumptive use of water for irrigation along Thousand Springs Creek upstream of Twentyone Mile Reservoir (about 6100 ac-ft/yr).

For the areas along Thousand Springs Creek, downstream of Crittenden Creek, there would be substantially greater effects with Option 2 than with Option 1 on streamflow unless mitigation measures were implemented to augment streamflow in environmentally sensitive areas. Results of analytical groundwater flow modeling (Section 8.0) of the hypothetical wellfield that may be located in the Gamble Ranch area indicate that water table drawdown in this area would be less than about 40 feet (Figure 8-

22). These results indicate that the flow of Gamble Springs may be affected, and there may be an effect on the water level in Dake Reservoir. However, water management alternatives that would utilize the water presently diverted for irrigation could be implemented to mitigate these potential effects.

10.3.3 Groundwater Development Option 3

The effects of pumping on the ephemeral streams and springs in Toano Draw Subbasin would be similar to those resulting from Option 2. That is, there would be essentially no effect of pumping on the ephemeral streams in this subbasin. Effects on springs in this area would be localized to those that are near the proposed wellfields and that may be interconnected with the water table. Springs in the upland and mountainous areas should not be impacted by pumping from the project wellfields.

Effects on streamflows and springflows would be greater for Option 3 than for Option 2, but less than for Option 1. Based on the numerical model simulations of Case 3A and 3B, the net groundwater discharge to Thousand Springs Creek, between Winecup Ranch and Crittenden Creek, would decline from about 2500 to 100 ac-ft/yr (Table 8-4). However, anticipating that irrigation diversions would be progressively phased out, the net streamflow should not decrease significantly as a result of implementing Option 3. Rather, in the areas upstream of Crittenden Creek, net average annual streamflow may be maintained by terminating irrigation diversions, similar to Option 2. During the dry season, however, there could be less streamflow downstream from Twentyone Mile Dam than presently, unless water releases from Twentyone Mile and Crittenden reservoirs were timed to compensate for the loss in groundwater discharge at these times of the year. Option 3 would also result in a smaller amount of spring discharge along Thousand Springs Creek, mainly in the area north of Toano Draw and extending downstream beyond Twentyone Mile Dam.

For the area along Thousand Springs Creek downstream of Crittenden Creek there would be similar, but reduced, effects on streamflow relative to those with Option 2. Anticipating that present irrigation uses would cease, and water from Crittenden and Twentyone Mile reservoirs would be released as needed to augment streamflows, there should only be minimal effects of the pumping on streamflow as a result of implementing Option 3. However, the possible effects on flows of Gamble Spring and Dake Reservoir would be similar to, but probably less than, the effects of implementing Option 2.

10.4 EFFECTS ON IRRIGATED AGRICULTURE AND PHREATOPHYTES

The effects of groundwater withdrawals on phreatophytes would be relatively great if the groundwater resource development proceeded according to Option 1, whereas there would be minimal impacts to phreatophytes if Option 2 were selected, and an intermediate level of impacts if Option 3 were selected. The results of numerical flow modeling (Figure 8-16) of Case 1 show that there could eventually be drawdown of the water table to a sufficiently large degree to adversely impact phreatophyte growth in the areas along Thousand Springs Creek north of Toano Draw and downstream of Twentyone Mile Reservoir. These effects would probably be manifested after development of the wellfield to supply Unit 5 (beginning of year 8) and become progressively larger as the development and pumping proceeded. On the other hand, for Options 2 and 3 the model-simulated drawdowns (Figures 8-17, 8-18, 8-19, and 8-20) appear to be so minor that there would be essentially no impact to phreatophytes in those areas. However, in the Gamble Ranch vicinity there would be significant groundwater level drawdowns associated with supplying water according to Options 2 and 3. These drawdowns would adversely affect phreatophytes unless appropriate mitigation measures were implemented. Such mitigation measures could include regulated releases of waters from Twentyone Mile and Crittenden Creek reservoirs at selected times, to limit and control the effects.

Another mitigation measure--part of the proposed action--would be to cease irrigation diversions to offset water uses by the power plant. This practice would adversely impact the current level of agricultural development, which consists mainly of irrigated pasture and hay production for cattle raising purposes. It would not preclude continued hay production using dry-farming practices at a significantly reduced level of production, or maintaining ranching operations as at present by importing hay to the basin to offset lost production in the basin.

10.5 EFFECTS ON EXISTING WELLS

Withdrawing groundwater to supply the power plant would in general have relatively minor effects on existing water supply wells. These effects would include increased pumping costs because of increased lifts resulting from the water table drawdowns near the proposed wellfields. In a few instances, stock watering wells, completed at shallow depths below the present water table, could eventually go dry because of long-term drawdown of the water table. There are only about 30 wells currently used in Toano Draw, all for stock watering purposes (Figure 4-1). Of these, approximately 10 wells could be significantly affected by pumping because of their proximity to the proposed wellfields.

In the Gamble Ranch vicinity, there are several wells currently in use, mainly for irrigation and stock watering purposes (Figure 4-1). The magnitude of the effects of drawdown on those existing wells would vary for each water development option described below.

10.5.1 Effects of Option 1 on Existing Wells

Drawdowns created by the Option 1 wellfields would primarily affect existing stock watering wells in the south-central and northern portions of Toano Draw Subbasin. The groundwater flow model simulates that after 47 years of pumping there would be a maximum of about 20 feet of drawdown in the south-central portion and about 100 feet of drawdown on the northern portion of Toano Draw, near the confluence with Thousand Springs Creek.

Thus there would be significantly increased pumping lifts created for the few stock wells located in these areas. A few of the wells located near the proposed wellfields (e.g., 39-65-14cd) could go dry because they are completed at shallow depths. However, most of the 10 stock wells that would be affected appear to be completed to sufficient depths, and would remain usable, assuming the existing pumps would be lowered or modified to accommodate the additional lift requirements.

In the Montello area, the effects of Option 1 pumping would probably be insignificant. The current rate of groundwater pumping for irrigation use exceeds the amount that would be supplied to the plant from this area, and it is anticipated that irrigation pumpage would be curtailed to meet project needs.

10.5.2 Effects of Option 2 on Existing Wells

The effects on wells in Toano Draw Subbasin as a result of pumping would be less for Option 2 than for Option 1. Drawdowns of the water table in the south-central portion of Toano Draw Subbasin were predicted by the numerical flow model to be a maximum of about 60 to 70 feet. Thus, the few existing stock wells in this area would have increased pumping lifts but these additional lifts would not be as large as for Option 1 pumping.

In the Montello area, there would also be increased pumping lifts, and thus somewhat higher pumping costs, created by groundwater supply Option 2. The analytical flow modeling conducted for this area predicts that up to about 30 to 35 feet of drawdown could occur, after 35 years, in areas 3 to 5 miles north of the town of Montello.

Essentially all of the wells that could be affected in this area are currently owned by Lands of Sierra, Inc. (LOS) and operated for irrigation or stock watering purposes.

10.5.3 Effects of Option 3 on Existing Wells

Option 3 would create an intermediate level of effects on existing water supply wells. In the Montello area, these effects would be similar to the effects of Option 2, but slightly less in magnitude, whereas the effects would be significantly greater than those of Option 1. In Toano Draw Subbasin, the effects of Option 3 would be somewhat greater than Option 2 but substantially less than for Option 1.

10.6 EFFECTS ON WATER QUALITY

10.6.1 Surface Water

The quality of surface water in Thousand Springs Basin may be impacted by water resource development. Unless appropriate water management practices are implemented, the potential reduction in flow from springs, and in Thousand Springs Creek, could result in increased evaporation of remaining water, and subsequent increases in the total dissolved solids (TDS) in the water. The water could become oversaturated with respect to minerals (especially carbonates, sulfates, and chlorides), that would then precipitate from solution. These minerals would then be present on the land surface or in the shallow soil and would affect the water chemistry of freshwater emanating from a spring or flowing down the stream channel. Increases in dissolved constituents in the water could affect the usefulness of the water. Currently, much of the springwater has a TDS level of less than 500 milligrams per liter (mg/L), which is the recommended maximum concentration for TDS specified in the Environmental Protection Agency (EPA) secondary drinking water standards. Evaporation losses could raise the TDS above this level. Furthermore, evaporation could preferentially increase the sodium level of the water because other major cations would be removed from solution as minerals containing those cations were formed. An increase in dissolved sodium would affect the usefulness of the water for irrigation purposes because moderately high levels of sodium in the water causes clay minerals in the soil to expand, thereby lowering the permeability of the soils.

The degree to which surface water quality could be affected by water resources development was estimated, for the various groundwater withdrawal scenarios, by considering the resultant discharges to the creek for the different water development options. The three options were simulated, based on application of groundwater flow models (Cases 1, 2, and 3) as described in Section 8.0 and summarized in Table 8-4. For Option 1, in which water for the first five units would be obtained from Toano Draw Subbasin, and water for the remaining units would be obtained from wells downstream of Twentyone Mile Dam, the Case 1 simulation showed a considerable reduction in groundwater discharge to the river upstream of Twentyone Mile Dam. The baseline discharge of 4149 ac-ft/yr would be reduced to 340 ac-ft/yr after 20 years of plant operation and to less than 20 ac-ft/yr for the subsequent 17 years that were modeled. These low flows would lead to increases in dissolved solids levels because of increased evaporation effects. Under these conditions, mineral precipitation from the water would be likely to occur, and it would probably influence the concentration of dissolved constituents in fresh surface water that contacted these minerals. These effects would be concentrated along Thousand Springs Creek north of Toano Draw Subbasin because most of the water would be withdrawn from this subbasin. The wellfields below Twentyone Mile Dam in the Gamble Ranch vicinity would also affect surface water quality in those areas. However, effects in these areas would be minimal assuming that present diversions for irrigation would be ceased.

For Option 2, the amount of groundwater obtained from Toano Draw Subbasin would be less than for the two other options considered, and as a result there would be the least reduction in discharge to Thousand Springs Creek with this option. Based on the Case 2 simulation, the discharge would be reduced by a maximum of 40 percent of the baseline value throughout the 49-year timeframe assumed for the modeling. Therefore, it is less likely that this distribution of wellfields would have as large an impact on surface water quality near Toano Draw Subbasin as that for Option 1. However, because five of the eight units would be supplied from wellfields located in the Gamble Ranch vicinity in Option 2, surface water quality in Montello Valley would be affected more by groundwater withdrawal in this area then by implementation of the other two options evaluated. That is, unless mitigation measures were implemented, to increase streamflow by timely releases of water from reservoir storage, there would be significant increases in salinity of the surface water as a result of implementing Option 2 for Units 3 through 7.

For Option 3, the model-predicted discharge to Thousand Springs Creek near Toano Draw would be smaller, although similar, to that simulated in Case 2. Therefore, it is expected that the effects on surface water quality of Option 3 wellfield distribution would be similar to development according to Option 1, in areas along Thousand Springs Creek near Toano Draw. Option 3 would probably have less of an adverse effect on surface water quality in the Gamble Ranch vicinity than would Option 2.

10.6.2 Groundwater

The apparent chemical stability of the groundwater, as shown by comparing samples spatially (Section 5.5.1) and temporally (Section 5.3), suggests that groundwater that would be drawn into pumping wells for the plant would have a fairly uniform composition. In addition, future recharge water that entered the system in the highlands should have a composition similar to the past composition, and should not alter groundwater chemistry significantly. However, the quality of recharge water entering the aquifer through Thousand Springs Creek could be affected by the placement of the wellfields. As discussed above, in Section 10.6.1, Option 1 would significantly reduce groundwater discharge to the creek after about year 10 in the development schedule. This could result in higher levels of TDS in surface water in the creek in the areas north of Toano Draw Subbasin and downstream thereof. Because the creek would be a greater source of groundwater recharge under these pumping conditions, it is likely that the TDS level of the groundwater near the creek would increase locally by implementing Option 1.

Because of the wider geographic distribution of wellfields for Options 2 and 3, they would probably not have a large-scale impact on groundwater quality in Toano Draw Subbasin. However, the TDS levels in groundwater in the Gamble Ranch vicinity could increase as a result of implementing Option 2 or 3, unless the potential salinity increases in the creek during the dry season were precluded by timely releases of water from Crittenden and Twentyone Mile reservoirs.

The drawdowns of the water table for the three evaluated cases were discussed in Section 8.0. In general, it is expected that none of the wellfield distributions would produce a decline in water level of greater than about 100 feet. In most areas the drawdowns would be much less. Although few data are available on the changes in groundwater chemistry with depth in the aquifer, it is doubtful that drawdowns of this magnitude would produce significant changes in the quality of water pumped from the production wells. It is anticipated that these wells would be screened over intervals of several hundred feet; therefore, the mixing of water from throughout these depths in the aquifer would probably result in a fairly uniform water composition for the duration of the project.

In the case of shallower domestic or ranch wells, it is possible that lowering the water table would result in the production of water of higher TDS and somewhat different quality. This is because there would be less mixing of water in those wells that are screened over a shorter distance than the power plant production wells. The deeper, warmer water would form a larger fraction of the pumped water as the water table declines. Because of its higher temperature and probable longer residence time in the alluvium, the deeper groundwater would be expected to have reacted more completely with the aquifer material and thus contain a higher concentration of dissolved constituents. As drawdown occurs in the aquifer, more of this deeper water would be drawn into the wells.

10.7 SUBSIDENCE

Based on the available hydrogeological data, land surface subsidence does not appear to be a potentially significant effect that may result from the proposed groundwater withdrawals. In many areas, where significant subsidence of the land surface has accompanied extensive groundwater withdrawals, groundwater level declines usually exceeded 50 feet, and the basic cause of the subsidence was an increase in the effective stress on the fine-grained, compressible materials within the aquifer. Because of the isolated and distant locations of the proposed wellfields, with drawdowns being most pronounced in the area of the wellfields, the potential effects of land surface subsidence on the existing environment would not appear to be significant. Even though the water table under the plant site may be drawn down tens of feet, and there may be some slight surface subsidence in the area of the power plant, the subsidence is expected to be essentially uniform over the area of the plant site.

11.0 HYDROLOGIC MONITORING PROGRAMS

11.1 APPROACH AND RATIONALE

The preceding sections of this report have discussed the geology of Thousand Springs Basin, presented an assessment of the quantity and quality of the water resources of the basin, a general plan for developing the water resources to meet the requirements of the proposed Thousand Springs Power Plant (TSPP) as they will increase over time, and an assessment of the effects of utilizing the resources on the surface and groundwater flows in the basin. However, it is recognized that the data base, from which the water resource assessments of this study were developed, is limited, and the projected effects of project water uses are estimates based on the presently available information. The estimates indicate that the planned groundwater withdrawal rates are significantly less than the long-term sustainable yield of the basin as a whole. However, the proposed development plan is based on utilizing essentially all of the renewable resources of Toano Draw Subbasin aquifer to provide water for up to three of the planned eight units at ultimate project development. Monitoring will be required to improve the estimates of the resources available from the Toano Draw alluvial aquifer to make sure that no overdraft situation occurs. The transfer of water from the Montello-area subbasin to Toano Draw Subbasin, for the balance of the project water requirement, will be planned and implemented so as to prevent any overdraft from the Toano Draw aquifer.

This section presents a proposed long-term program to monitor the natural hydrologic events in Thousand Springs Basin, and the induced hydrologic effects of the power plant water uses. Specifically, the objectives of the proposed monitoring program are as follows:

- Precipitation will be monitored at selected sites, and the extent to which seasonal precipitation in the basin deviates from the estimated long-term averages used in this study will be recalculated.

- Streamflow will be measured at selected sites to significantly extend the record base for estimating the available surface water resources and to provide a basis for re-assessing the project's effect on streamflow.

- Project water uses will be monitored by measuring the quantity of water pumped from each project well, as required by the State Engineer and the conditions specified in the permits for the water rights granted for the project.
- Groundwater levels will be measured in selected wells to determine the effect of groundwater withdrawals by the project.
- The land surface elevation, in areas overlying the aquifers supplying water to the project, will be periodically checked for possible subsidence caused by project water withdrawals.

11.2 PRECIPITATION

Sierra Pacific Resources (SPR) has installed and is operating a meteorologic monitoring station adjacent to the power plant site. It is planned that the station will continue operations throughout the life of the power plant, in order to monitor precipitation and other meteorological parameters. It is expected that the existing precipitation monitoring stations at Montello and Wells, which are both within the National Oceanographic and Atmospheric Administration (NOAA) network, will be continued in operation as at present. Collectively, the three stations are expected to provide an adequate record of precipitation and precipitation trends in the power plant vicinity. Data from the Thousand Springs meteorological station will be of a quality and frequency suitable for incorporation in the records presently compiled and published by NOAA.

11.3 PROJECT GROUNDWATER EXTRACTION

All wells completed to supply water for power-plant-related uses will be equipped with flow meters. The meters will be of the flow-indicating and -totalizing type. Meters will be calibrated at the time of initial installation and will be recalibrated on approximately an annual basis. If a meter must be removed for servicing, calibration, or replacement, the well will not be operated until a meter has been reinstalled in the well discharge pipeline. A record will be maintained of total monthly and annual pumpage from each well, and copies of the record will be provided annually to the State Engineer.

11.4 STREAMFLOW

Streamflow in Thousand Springs Creek will continue to be monitored throughout the operating life of the power plant at the Wilkins, Shores, and Montello stations. Those stations are being operated under a cooperative program between the U.S. Geological Survey (USGS) and Elko County, Nevada. Lands of Sierra, Inc. (LOS) provides funding for the Elko County part of the program.

Present expectations are that project-induced changes in streamflow may occur downstream from the confluence of Crittenden and Thousand Springs creeks as a result of power plant groundwater withdrawals. Therefore, it is proposed that an additional streamflow gaging station be installed on Thousand Springs Creek downstream from the confluence with Crittenden Creek, possibly at the upstream side of the existing County Road crossing of Thousand Springs Creek. All flow in the creek is confined to a single channel at this location, whereas both upstream and downstream from this point the flow occasionally may be in two or more channels. It is proposed that the station be operated under the same cooperative agreement between the USGS, Elko County, and LOS as the three existing stations mentioned above.

11.5 WATER LEVELS IN WELLS AND SPRING DISCHARGE

The water surface elevation of aquifers being pumped for project purposes will be monitored to track the aquifer water level responses to the pumping. The proposed monitoring network, in both the Toano Draw and Gamble Ranch areas, will include wells pumped for the project, nearby monitoring wells that have been installed for the purpose, or selected other existing wells within the expected areas of drawdown due to the pumping (Figure 4-1). Also, selected springs that may be affected by the project water withdrawals will be periodically checked. Measuring the water table elevation in all selected monitoring wells, and checking the condition of selected springs, should be performed annually, preferably in late summer.

11.6 SURFACE AND GROUNDWATER QUALITY

The chemistry of the water being pumped from each project water supply well will be checked periodically in order to evaluate the continued stability of the water quality for power plant uses, and to provide a more comprehensive understanding of the water chemistry of the groundwater system. By monitoring water chemistry it may be possible to anticipate potential problems in plant operations due to changes in water chemistry.

The surface water chemistry is so variable in the region that general monitoring is considered not warranted.

11.7 SUBSIDENCE

A network of surveyor monuments (bench marks) should be established over the areas of anticipated greatest groundwater level drawdowns, for purposes of monitoring possible changes in the land surface elevation due to water extraction for the power plant. Elevations of the bench marks should be checked annually. It is proposed that the Toano Draw network include two lines of monuments, incorporating as many existing monuments as reasonably possible. It is noted that monuments have been set at numerous section corners in the project vicinity, and some of those monuments could appropriately be included in the subsidence monitoring network. The monument lines would be tied to control monuments based in rock outcrops, where no project-induced subsidence is expected. The lines' configurations would be determined by the Engineer after geotechnical evaluations have been completed.

It is proposed that an additional streamflow gaging station be installed on Thousand Springs Creek downstream from the confluence with Crittenden Creek, possibly at the upstream side of the existing county road crossing of Thousand Springs Creek. All flow in the Creek is confined to a single channel at this location, whereas both upstream and downstream from this point the flow occasionally may be in two or more channels. It is proposed that the station be operated under the same cooperative agreement between the USGS, Elko County, and LDS as the three existing stations mentioned above.

II.5 WATER LEVELS IN WELLS AND STREAM DISCHARGE

The water surface elevation of aquifers being pumped for project purposes will be monitored to check the aquifer water level responses to the pumping of the proposed well-field network. In both the Thousand Springs and Gamble Ranch areas, wells not being used or pumped for the project, nearby monitoring wells that have been installed for the purpose, or existing other wells in the vicinity of the predicted areas of drawdown due to the pumping (Figure 4-11.4). Also, selected springs that may be affected by project water withdrawals will be periodically surveyed. Measuring the water table elevation in all of these monitoring wells, and checking the condition of selected springs, should be performed annually, preferably in late summer.

II.6 SURFACE AND GROUNDWATER QUALITY

The chemistry of the water being pumped from each project water supply well will be checked periodically in order to evaluate the continued stability of the water quality for power plant uses, and to provide a more comprehensive understanding of the water chemistry of the groundwater system. The monitoring data on chemistry may be provided to analyze potential interference to plant operation due to changes in water chemistry.

The surface water chemistry is to be sampled in the region that generally monitoring is considered not warranted.

II.7 SUBSIDENCE

A network of surveyor monuments (bench marks) should be established over the areas of anticipated greatest groundwater level drawdown for purposes of monitoring possible changes in the land surface elevation due to water extraction for the power plant. Elevations of the bench marks should be checked annually. It is proposed that the bench mark network include two lines of monuments, incorporating any existing monuments when reasonably possible. It is noted that monuments have been set by Sweetwater section corners in the project vicinity, and some of these monuments could appropriately be included in the subsidence monitoring network. These monument lines would be tied to control monuments based in rock outcrops, where no project-induced subsidence is expected. The final configurations would be determined by the engineer after groundwater installations have been completed.

12.0 RECOMMENDATIONS

This section presents recommendations for performing additional water resources investigations in Thousand Springs Basin, as required for final design and development of wellfields to supply the Thousand Springs Power Plant (TSPP). Recommendations are also presented for other investigative work that is required for developing a more detailed understanding of the basin hydrogeology, and for early perception of the effects of using the basin water resources. Finally, recommendations are given for the preparation of a water resources management and monitoring plan and program that will be consistent with the proposed action, as detailed in this report and described in the project Environmental Impact Statement.

In preparing this section it was assumed that the water supply for the individual generating units will be obtained from wellfields developed in accordance with the following schedule. The general outlines of the areas where the wellfields will be located are indicated on Figure 7-1.

Generating Unit	Planned Location of Wellfield
1	Toano Draw south of plant site
2	Toano Draw south of plant site OR, Toano Draw northwest of plant site
3 through 7	Thousand Springs Valley, downstream from Crittenden Creek and extending to near Dake Reservoir
8	Toano Draw south of plant site OR, Toano Draw northwest of plant site OR, Thousand Springs Valley extending the wellfield for Units 3 through 7

12.1 PROPOSED HYDROGEOLOGIC INVESTIGATIONS FOR WELLFIELD DEVELOPMENT

The investigations on which this report is based were generally at the reconnaissance level, as required for obtaining an overall general understanding of the magnitude and locations of the water resources present in Thousand Springs Basin, and the general characteristics of the aquifers containing the groundwater resources. Further investigation will be required to select specific locations for installing wells and to design the well to be installed at each selected location. The recommendations for conducting this investigation are presented in this subsection. The primary objectives of the investigation will be to further characterize aquifer transmissivity, specific yield, and thickness at each of the two primary wellfield locations identified in this study as most favorable for development based on indicator aquifer characteristics and environmental considerations (i.e., Toano Draw south of the power plant site, and Thousand Springs Valley below Crittenden Creek). If the Toano Draw wellfield south of the plant site proves to be less productive than presently expected, then the area northwest of the plant site (outlined on Figure 7-1 as a potential wellfield location) should be considered as an alternative for supplying either Unit 2 or Unit 8.

12.1.1 <u>Surface Geophysical Surveys -- Toano Draw</u>

It is proposed that surface geophysical surveys be conducted within the outlined area (Figure 7-1) south of the power plant site in Toano Draw. This area is located about 1 to 5 miles south of the plant site and has dimensions of approximately 4 miles by 6 miles. In the recently completed reconnaissance survey, two surface geophysical survey techniques were tested, i.e., time domain electromagnetic (TDEM) and dipole-dipole resistivity. Both techniques provided useful information, of differing characteristics, for locating potential aquifer materials. Therefore, it is proposed that both techniques be utilized again, in a complementary fashion, in the survey. As a first-phase investigation, about four lines of TDEM soundings would be run, spaced at about 1.5 miles between lines, and extending across the outlined area in a northwest-southeast direction. Based on interpretation of the data from the TDEM soundings, subsequent dipole-dipole surveys would be run along selected lines.

12.1.2 <u>Pilot Borings</u>

Based on careful review and interpretation of the surface geophysical survey results, locations and target depths for a series of pilot borings would be selected. Locations would be selected based on their appearing most favorable for placing wells. The exact number of borings actually completed in the initial boring program would depend, to large extent, on the materials encountered in the first group (Phase I) of borings completed. If the correlation between the materials predicted by the surface geophysical results and the recovered pilot boring materials, and downhole geophysical logs from the completed borings, was consistently high, and the materials had good aquifer properties, then the Phase I boring program probably would require only a few borings. In any case, enough borings should be completed in the first-phase program to be relatively confident that wells which were completed in the more favorable identified locations would have a combined capacity adequate for the maximum requirement of the first generating unit--probably about 3000 gallons per minute (gpm). The second-phase (Phase II) boring program could then be deferred until well locations were to be identified for supplying the second generating unit. It is expected that some or all pilot borings would be completed either as aquifer monitoring wells or as pilot holes for production wells. The geophysical and geological data obtained from the drill holes, together with the data from the surface geophysical investigations, would be used to define trends in aquifer characteristics that would be used to select favorable production well locations.

During drilling of the first few pilot borings, several undisturbed soil samples should be collected from various depths below the water table. The samples should be submitted for laboratory analyses. In order to provide measures of aquifer specific yield, the laboratory should test the samples for saturated, drained, and dry density. It is noted that an aquifer specific yield of 0.10 was assumed in this evaluation. Although this value is believed to be conservative, it should be checked because of its importance in estimating the quantity of water removed from aquifer storage in order to develop the required sustained production of the wellfield. Also, the samples should be tested for consolidation/ compressibility, and the data used to prepare estimates of subsidence likely to occur as a result of groundwater level drawdown.

12.1.3 Well Drilling, Completion, and Development Program

Following completion of the Phase I pilot boring program and detailed review of the geophysical and boring program results, the well drilling program for the first generating unit should be initiated. This program would start with selecting locations for wells and preparing preliminary well completion plans for each well in the program. Completion details to be specified in the preliminary plans would include the boring diameter, total boring depth, surface seal requirements, and casing size. Estimates of depth to water and approximate lengths and locations of screened intervals should be included in the preliminary design. The final design for the well would be based on the lithology encountered in the well boring, and would specify the well screen slot size and screened intervals, the gradation and location of the gravel pack, and a pump setting depth for the test pumping that would follow well development. Well development would be continued until the well produced water that was clear and free of drilling mud and fine formation materials. An aquifer test would be performed on each completed well, with the pumping rate for the test based on the results of a step drawdown test, and the test's duration in the range of 3 to 15 days, as specified by the Engineer following well development. The pilot boring stratigraphic logs, and geophysical logs of those borings, together with data to be collected during aquifer testing, would be used to further characterize the aquifers investigated. Of particular interest would be additional information on aquifer thickness and aquifer transmissivity as it varied with depth. The data on aquifer characteristics, from all of the wells tested, would be used to develop a numerical model (Section 12.2) of the aquifer and to reassess the probable aquifer drawdown that would result from pumping the aquifer at various rates to supply water to the power plant. Also, the data from each well tested would be used for specifying the capacity, setting depth, and lift of the production pump to be installed in the well.

It is expected that the planned wellfield south of the power plant site could be expanded to serve two, and possibly three, generating units, and that to expand the wellfield would simply require doing more pilot borings at locations identified in the original area geophysical surveys. Wells to supply the additional units would be installed at selected locations based on the results of the pilot boring program. However, if that wellfield were less productive than presently expected, then the potential wellfield area located northwest of the power plant site should be investigated and developed. The procedures to be followed would be similar to those described above, but modified as appropriate to take advantage of the hydrogeological information obtained and experience gained in the area south of the plant site.

12.1.4 Wellfield Development North of Montello

There presently are several irrigation wells within the area north of Montello, which is outlined on Figure 7-1 as a potential wellfield. The combined capacity of those existing wells significantly exceeds the requirements of at least one generating unit. It is suggested that the first step in obtaining water for the power plant from this area would be to thoroughly explore the potential for using existing wells to supply the power plant, and exploit that potential insofar as is feasible from environmental and economic perspectives. After this potential has been fully realized, and when additional water is required for the power plant, then a hydrogeologic investigation should be performed of the overall area likely to be required for the ultimate wellfield. The procedures of investigation and wellfield development would be similar to those described above for the Toano Draw wellfields, but modified as appropriate based on experience in Toano Draw and on the known differences in aquifer and geologic characteristics between the two areas.

12.2 GROUNDWATER FLOW MODELING

The existing numerical model should be expanded to include the Montello area. Also, a numerical flow model of the southern Toano Draw area should be developed, incorporating the results of the drilling and testing program recommended above in conjunction with developing a wellfield to supply Unit 1. The larger, more detailed model would provide a better understanding than presently possible of the overall long-term effects of the project water withdrawals.

12.3 HYDROGEOLOGIC MONITORING

It is recommended that the hydrologic monitoring program described in Section 11.0 be initiated after approval of the program--modified as appropriate--is received from the Nevada State Water Engineer. Of particular importance is continuation of the existing cooperative program between the U.S. Geological Survey (USGS) and Elko County, Nevada, for monitoring flows in Thousand Springs Creek. (Lands of Sierra, Inc. [LOS] provides funding for the Elko County portion of the program.)

The possible benefits of monitoring precipitation at the higher elevations on the mountains draining to Thousands Springs Basin, particularly Toano Draw, and runoff from those higher areas, should be assessed. The data would be used to prepare estimates of runoff from the highland areas, and aquifer recharge from runoff flowing across the broad alluvial valley of Toano Draw.

12.4 WATER MANAGEMENT PLAN

A basin-wide water management plan should be developed in conjunction with other users. The plan should include a program for management and regulation of surface water flows, particularly during periods of above-normal runoff and flows in Thousand Springs Creek, to enhance aquifer recharge. The plan should address criteria for progressively reducing the amount of water used for irrigation. The objective would be to have the reductions occur in such a way that there would be no significant environmental effects in or along Thousand Springs Creek upstream from the confluence with Crittenden Creek throughout the duration of power plant operations; the effects downstream from Crittenden Creek would be limited to the maximum practical extent. Also, the plan should address criteria relating aquifer drawdown to planned responses. For example, if the drawdown is significantly different from the predicted drawdowns, either locally or areawide, it probably would be appropriate to modify the manner or the amount the aquifer is being pumped. The extent to which the plan anticipates realistic contingencies will be its measure of success.

The possible benefits of monitoring groundwater [illegible] elevations [illegible] Springs [illegible] particularly [illegible] runoff [illegible] alluvial [illegible]

12.4 WATER MANAGEMENT PLAN

A basin-wide water management plan should be developed in conjunction with other users. The plan should include a program of [illegible] regulation of surface water flows, particularly during [illegible] normal runoff and flows in Toquerville [illegible] Creek, to enhance aquifer recharge. The plan should contain [illegible] program [illegible] the amount of water [illegible] reductions [illegible] there [illegible] environmental effects in [illegible] confluence [illegible] to the maximum practicable [illegible] relating aquifer [illegible] drawdowns [illegible] locally or regionally [illegible] interstate [illegible]

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TABLES

Table 3-1. SUMMARY OF RESISTIVITIES OF LITHOLOGIC UNITS

Resistivity Range	Depth Range	Lithology
30-200 ohm-m	0-150 feet	Holocene unsaturated alluvium, not well defined in TDEM data.
15-30 ohm-m	Near surface to several hundred feet	Coarse-grained alluvial deposits, interpreted to be the potential regional aquifers, although they may locally contain large percentages of clay; further subdivided into two units on the interpreted profiles.
8-15 ohm-m	Near surface to several hundred feet, often seen below the 15-30 ohm-m unit	Predominantly clays and interbedded alluvial fan deposits, probably gradational with the 15-30 ohm-m unit, also more clay-rich.
<8 ohm-m	Several hundred to several thousand feet	Upper tuffaceous volcanic unit, predominantly clays, possibly saturated with saline waters.
>200 ohm-m	Variable	Paleozoic or older bedrock, observed by only a few soundings, mostly near the basin margins.
50-200 ohm-m	Relatively thin layers, buried a few hundred feet	Possible thin Tertiary volcanic unit suggested by TDEM data at some sites, not the same unit as the one shallow unit of similar resistivity.

Table 4-1. CONSTRUCTION DETAILS OF MONITORING WELLS AND TEST WELLS INSTALLED BY WCC

Well Number	Location	Total Boring Depth (feet)	Total Well Depth (feet)	Well Casing Diameter (inches)[1]	Screen Interval (feet)	Ground Surface Elevation (MSL)	Top of Casing Elevation (MSL)	Ground-water Elevation (MSL)[2]
TW-1	T42N, R65E, Sec 35	330	315	6	60-100	5386	5388.3	5385.3
					140-150			
					160-170			
					190-260			
					285-295			
TW-3	T39N, R66E, Sec 5	415	410	12	200-260	5710[4]	--[4]	5517.5
					290-360			
					380-390			
TW-12	T41N, R66E, Sec 31	370	370	6	170-270	5595	5596.4	5471.2
					280-310			
					330-360			
TW-14	T39N, R65E, Sec 24	600	508		380-490	5831	5832.4	5516.6
TW-15	T39N, R66E, Sec 9	425	415	6	275-395	5721	5722.9	5510.9
MW-1	T42N, R65E, Sec 35	540	200	2	180-200	5385	5387.1	5385.5
MW-2	T40N, R65E, Sec 23	607	310	2	270-290	5663	5664.2	5484.3
MW-3	T39N, R66E, Sec 5	947	319	2	299-319	5713[4]	--[4]	5517.8
				1.25	160-180			
MW-4	T41N, R65E, Sec 21	390	95	2	75-85	5491	5491.8	5457.0
MW-5[3]	T39N, R65E, Sec 27	286	--	--	--	5927	--[4]	--
MW-6[3]	T42N, R66E, Sec 19	526	--	--	--	5376	--[4]	--
MW-7[3]	T41N, R66E, Sec 21	160	--	--	--	5784	--[4]	--
MW-12	T41N, R66E, Sec 31	601	300.5	2	280.5-300.5	5594	5595.2	5470.2
				1.25	130-150	5594	5595.2	--[5]
MW-16	T40N, R67E, Sec 8	600	320	2	300-320	5750[4]	--	--
MW-17	T41N, R65E, Sec 35	650	260	2	230-250	5515[4]	--	5465.0

1 The TW-series wells are constructed with threaded and coupled Schedule 40 steel casing. The MW-series wells are constructed with flush-threaded Schedule 80 PVC casing.
2 Water levels measured by Woodward-Clyde Consultants August 1988 to March 1989.
3 Borehole abandoned by backfilling with cement grout.
4 Elevation not surveyed at time of report.
5 Obstacle in pipe, unable to measure depth to water.

Table 4-2. SUMMARY OF AQUIFER TEST RESULTS

Test Well	Well Observed	Transmissivity (gpd/ft)	Hydraulic Conductivity[a] (gpd/ft^2)	Storage Coefficient (dimensionless)	Data Used
TW-1	TW-1	8000	57	$1.2x10^{-4}$	pumping phase
	TW-1	6000	43	NA	recovery phase
	MW-1	7400	53	$4.2x10^{-4}$	pumping phase
TW-3	TW-3	2100	15	NA	pumping phase
	MW-3	3000	21	$1.3x10^{-3}$	pumping phase
	MW-3	2800	20	NA	recovery phase
TW-12	TW-12	21,400	133	NA	pumping phase
	TW-12	20,900	131	NA	recovery phase
	MW-12	18,900	118	$3.5x10^{-4}$	pumping phase
TW-14	TW-14	13,200	132	$4.8x10^{-4}$	pumping phase
	TW-14	10,300	103	NA	recovery phase
TW-15	TW-15	52,800	440	$3.8x10^{-4}$	pumping phase
	TW-15	48,000	400	NA	recovery phase
41-65-35ad	MW-17	54,000	250	$4.7x10^{-3}$	pumping phase
		39,300[c]	180	$2.7x10^{-3}$	pumping phase
		34,400	160	NA	recovery phase

NA = Not analyzed

[a] Hydraulic conductivity was calculated by dividing the average transmissivity by the length of well screen below the water table in the pumping well. The well screen fully penetrated the aquifer in each case.

[b] Hydraulic conductivity was calculated by dividing the average transmissivity by the estimated total thickness of coarse-grained aquifer material penetrated by well MW-17 (b = 214 ft).

[c] Transmissivity was calculated based on distance-drawdown analysis at t = 8700 min.

Table 4-3. SUMMARY OF LAB TESTS OF EFFECTIVE POROSITY

Sample Depth (ft)	Grain Density (g/cc)	Calculated Overburden Stress (psi)	Effective Porosity At Estimated Overburden Stress	At 500 psi Stress
208-218	2.56	144	35.2	30.7
238-248	2.55	170	37.6	34.5
268-278	2.55	195	36.2	33.5
298-308	2.54	220	35.6	33.0
328-338	2.53	244	35.7	33.6

Source: Western Atlas International Core Laboratories

Table 4-4. SUMMARY OF TRANSMISSIVITY AND SPECIFIC CAPACITY DATA

Well Designation	Average Transmissivity (gpd/ft)	Specific Capacity (gpm/ft)
TW-1	7,000	3.80
TW-12	21,175	8.20
TW-14	11,765	6.80
TW-15	50,400	29.30
TW-3	2,150	3.03
41-65-35bd	11,000	6.30
40-69-27ba	160,000	68.00

Table 4-5. ESTIMATED IRRIGATION WATER USE BY SUBBASINS, THOUSAND SPRINGS BASIN

Location and Type of Use	Irrigation Water Use by Subbasin: Area (ac)	Net Water Use (ac-ft/ac)	Net Water Use (ac-ft)	Application Efficiency (Percent)	Water Applied (ac-ft)	Water Source
I. Montello-Crittenden						
A. Native Pasture						
Rocky Ford No. 4	108	1.43	154	30	513	Thousand Springs Creek
Upper Gamble No. 3	254	1.43	363	30	1210	Thousand Springs Creek
Dake & Warm Springs	1000	1.91	1910	30	6367	Thousand Springs Creek[a]
	1362		2427		8090	
B. Improved Pasture						
Crittenden Nos. 6-8	107	1.53	164	50	328	Thousand Springs Creek
Gamble Ranch Nos. 1,2	743	1.53	1137	50	2274	Thousand Springs Creek
	850		1301		2602	
C. Alfalfa Haylands						
Gamble Farm Nos. 1-18	1448	2.21	3200	50	6400	Wells
Twelvemile No. 19	68	2.21	150	50	300	Spring
Twelvemile Nos. 21-23	434	2.21	959	50	1918	Wells
Twelvemile Nos. 24,25	63	2.21	139	50	278	Crittenden Reservoir
	2013		4448		8896	
Subtotal	4225		8176		19,588	
II. Rocky Butte						
A. Native Pasture						
Twentyone Mile Pasture	187	0.95	178	30	593	Thousand Springs Creek
Eighteen Mile No. 11	236	0.95	224	30	747	Thousand Springs Creek
Eighteen Mile No. 16	433	0.95	411	30	1370	Thousand Springs Creek
Eccles No. 10	856		813		2710	

Table 4-5. ESTIMATED IRRIGATION WATER USE BY SUBBASINS, THOUSAND SPRINGS BASIN (concluded)

Location and Type of Use	Area (ac)	Net Water Use (ac-ft/ac)	Net Water Use (ac-ft)	Application Efficiency (Percent)	Water Applied (ac-ft)	Water Source
B. Improved Pasture						
Eighteen Mile Nos. 12-15	304	1.53	465	50	930	Thousand Springs Creek
Subtotal	1160		1278		3640	
III. Toano-Rock Spring(b)						
A. Native Pasture						
Ninemile Nos. 8,9	614	0.95	583	30	1943	Thousand Springs Creek
B. Improved Pasture						
Wine Cup Nos. 4-7	1086	2.04	2216	50	4432	Thousand Springs Creek
Subtotal	1700		2799		6375	
IV. Herrell Siding - Brush Creek						
A. Improved Pasture						
Brush Creek	349	2.04	712	50	1424	Brush Creek
Wine Cup Nos. 1-3	1105	2.04	2254	50	4508	Thousand Springs Creek
Subtotal	1454		2966		5932	
Subbasins I to IV, TOTAL	8539		15,219		35,535	

Irrigation Water Use by Subbasin

(a) Includes subirrigation by shallow groundwater.

(b) Native and improved pastures indicated below exist across Thousand Springs Creek floodplain, and would be in both Toano Creek and Rock Spring Creek Subbasins. Data provided or derived from Soil Conservation Service, 1988-1989. Subbasin classifications adopted from Rush 1968. Net water use (acre-feet) and water applied (acre-feet) derived by Woodward-Clyde Consultants.

Table 5-1 Sierra Pacific Spring and Well Water Analyses

	1	2	3	4	5	6	7	8	9	10
	Pequop Spring	Tripon Pass Spring	Brush Creek Spring	Ledge Spring	Unnamed Spring	Indian Spring	Hot Spring	Unnamed Spring	Black Rock Spring	Emigrant Spring
	38-65-10	39-64-14	40-64-21	40-63-21	40-63-18	40-65-6	41-64-25	41-64-26	42-65-6	44-69-30
Location Symbol on Figure 5-1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
FIELD PARAMETERS										
pH	8.31	6.76	7.59	6.73	7.38	7.21	6.41	7.59	7.39	7.66
Temperature (degrees C)	14.5	9	18	16	14	13.1	60.9	9.3	11.9	15
Specific Conductance(umhos/cm)	390	1750	320	40	308	280	1650	340	430	290
Alkalinity as CaCO3(mg/L)	206	460	184	23.6	278(202)	130	431	213	240	135
MAJOR CATIONS (mg/L)										
Calcium	65	334	49	7.5	50	30	70	68	88(88)	41
Magnesium	13	241	20	0.8	20	16	16	18	23(24)	9.6
Sodium	26	33	7.2	1.9	6.9	23	104	20	5.3(5.3)	19
Potassium	6	<5.0	<5.0	<5.0	<5.0	<5.0	34	<5.0	<5.0(<5.0)	6
MAJOR ANIONS (mg/L)										
Chloride	20	120	7	4	6	24	21	13	10(10)	10
Sulfate	12	674	23	4	30	25	46	31	57(57)	35
Nitrite as N	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<0.01(<0.01)	<0.01
Nitrate as N	0.7	<0.05	0.18	0.53	<0.05	0.36	<0.05	0.09	0.63(0.61)	<0.05
Fluoride	0.3	0.8	0.1	<0.1	0.4	0.4	1.8	0.2	0.2(0.2)	0.7
TRACE/MINOR INORGANICS (mg/L)										
Antimony	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05(<0.05)	<0.05
Arsenic	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1(<0.1)	<0.1
Barium	0.035	0.01	0.18	0.087	0.11	0.094	0.3	0.13	0.045(0.041)	0.092
Boron	0.07	0.1	0.03	<0.02	0.06	0.05	0.49	0.06	<0.02(<0.02)	0.05
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005(<0.005)	<0.005
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01(<0.01)	<0.01
Copper	<0.006	<0.006	<0.005	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006(<0.006)	<0.006
Iron	<0.05	4.7	<0.05	<0.05	0.45	<0.05	<0.05	<0.05	<0.05(<0.05)	<0.05
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05(<0.05)	<0.05
Lithium	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	0.54	<0.02	<0.02(<0.02)	0.05
Manganese	<0.005	1	<0.005	<0.005	0.15	<0.005	0.079	<0.005	<0.005(<0.005)	<0.005
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.002	<0.0002	<0.0002	<0.0002	<0.0002(<0.0002)	<0.0002
Selenium	<0.2	<0.2	<0.2	<0.2	N.D.	<0.2	<0.2	<0.2	<0.2(<0.2)	<0.2
Silicon (Si)	14	8.6	6.3	4.4	5.7	8.6	31	12	5.2(5.2)	9
Silica (SiO2)	30	18	13	9.4	12	18	66	26	11	19
Silver	<0.005	<0.0057	<0.005	0.005	<0.005	<0.005	<0.0073	<0.005	<0.005(<0.005)	<0.005
Zinc	0.06	4.7	0.01	0.18	<0.01	<0.01	<0.01	<0.01	0.13(0.13)	<0.01
TOTAL DISSOLVED SOLIDS (mg/L)	344	2140	103	8	173	193	515	280	361(352)	1110
ION BALANCE (%)	5.6	18.1	2.6	21	2.1	0.64	0.5	3.6	2.7(2.7)	1.6
STABLE ISOTOPES										
Delta-D (0/00)	ND	ND	ND	ND	-129	ND	-137	-127	ND	ND
Delta O-18 (0/00)	ND	ND	ND	ND	-17.3(-17.4)LD	ND	-17.8	-16.9(-17.0)LD	ND	ND
TRITIUM (tritium units)	ND	ND	ND	ND	-0.03	ND	1.36	1.81	ND	ND

Table 5-1 Sierra Pacific Spring and Well Water Analyses

	11	12	13	14	15	16	17	18	19	20	21
	Crittenden Spring	Gamble Spring	Near Montello Spring	North Spring	Lewis Spring	MW-1	MW-2#	TW-3	MW-4	TW-12	TW-14
	42-69-8	40-69-8	39-68-8	39-67-10	39-67-15	42-65-35	40-65-23	39-66-5	41-65-21	41-66-31	39-66-24
Location Symbol on Figure 5-1	S11	S12	S13	S14	S15	MW-1	MW-2	TW-3	MW-4	TW-12	TW-14
FIELD PARAMETERS											
pH	7.84	7.87	7.69	7.5	7.52	8.77	ND	7.44	8.1	7.22	meter down
Temperature (degrees C)	16	21	9.7	10.5	11.8	21.5	ND	14.5	ND	17	22
Specific Conductance(umhos/cm)	330	365	350	350	580	390	ND	215	ND	235	240
Alkalinity as CaCO3(mg/L)	160	171	211	300	215	206	158	130	214	129	120
MAJOR CATIONS (mg/L)											
Calcium	50	49	65	70	78	25	42	34	34	30	30
Magnesium	15	19	21	18	36	8.5	10	5.7	16	11	9.7
Sodium	13	9.4	17	14	46	83	53	18	59	17	15
Potassium	<5.0	<5.0	<5.0	<5.0	< 5	7	<5.0	8	18	5	7
MAJOR ANIONS (mg/L)											
Chloride	16	12	19	20	20	8	64	3	17	7	12
Sulfate	28	32	40	19	34	36	65	17	46	17	19
Nitrite as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.76	<0.01
Nitrate as N	0.64	0.21	0.41	0.88	0.43	<0.05	0.37	0.41	<0.05	<0.05	0.81
Fluoride	0.3	0.2	0.2	0.2	0.4	2.2	0.4	0.4	ND	0.4	0.4
TRACE/MINOR INORGANICS (mg/L)											
Antimony	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	ND	<0.05	<0.05
Arsenic	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	ND	<0.1	<0.1
Barium	0.089	0.11	0.075	0.11	0.045	0.027	0.049	0.039	ND	0.092	0.073
Boron	0.04	0.06	0.04	0.04	0.14	0.25	0.18	0.06	ND	0.07	0.06
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	ND	<0.005	<0.005
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	<0.01	<0.01
Copper	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	ND	<0.006	<0.006
Iron	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.1	0.12	<0.05	0.08
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	ND	<0.05	<0.05
Lithium	<0.02	<0.02	<0.02	<0.02	0.03	0.03	0.03	<0.02	ND	<0.02	<0.02
Manganese	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.014	0.01	0.01	0.016	0.01
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	ND	<0.0002	<0.0002
Selenium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.002	0.004	<0.2	ND	<0.2	<0.2
Silicon (Si)	11	7.1	6.2	6.6	9.7	30	18	38	35.5	28	35
Silica (SiO2)	24	15	13	14	21	64	39	81	76	56	75
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	ND	<0.005	<0.005
Zinc	<0.01	<0.01	0.01	0.08	0.13	<0.01	<0.01	<0.01	ND	0.09	0.11
TOTAL DISSOLVED SOLIDS (mg/L)	228	224	304	285	327	376	421	240	ND	187	229
ION BALANCE (%)	0.6	1.8	0.87	12	3.8			1.3	ND		
STABLE ISOTOPES											
Delta-D (0/00)	-128.0(-129.5)LD	-130.5	ND	-127(-125)FD	ND	ND	ND	-138.0	ND	ND	ND
Delta O-18 (0/00)	-17.6	-17.5	ND	-16.7(-16.9)FD	ND	ND	ND	-18.4	ND	ND	ND
TRITIUM (tritium units)	0.10	-0.01	ND	12.6(18.6)FD	ND	ND	ND	0.06	ND	ND	ND

Table 5-1 Sierra Pacific Spring and Well Water Analyses

	22	23	24	25	26.0	27	28
	TW-15	Toano Well #1	Unnamed Well	Rocky Butte Well	Unnamed Well	Fivemile Draw Well	Unnamed Well 28
	39-66-9	40-65-24	40-65-10	41-67-22	41-64-25	41-66-33	41-65-35
Location Symbol on Figure 5-1	TW-15	24bd	10ca	22bc	25bb	33ac	35ad
FIELD PARAMETERS							
pH	7.7	7.5	8.55	8.25	ND	7.54	ND
Temperature (degrees C)	N.D	10	16.5	20.5	ND	12.5	ND
Specific Conductance(umhos/cm)	N.D.	280	330	320	ND	880	ND
Alkalinity as CaCO3(mg/L)	124	108	165	121	ND	227	132.0
MAJOR CATIONS (mg/L)							
Calcium	32	51	34	35	ND	128	44
Magnesium	10	8.8	6.7	7	ND	61	6.5
Sodium	15	22	54	25	ND	53	33
Potassium	6	5	9	13	ND	13	10
MAJOR ANIONS (mg/L)							
Chloride	7	24	9	12	ND	21	11
Sulfate	21	47	50	29	ND	344	44
Nitrite as N	<0.01	<0.01	<0.01	<0.01	ND	<0.01	<0.01
Nitrate as N	1.1	1.6	0.43	1.5	ND	3.4	0.52
Fluoride	0.3	0.3	0.6	0.4	ND	0.5	0.4
TRACE/MINOR INORGANICS (mg/L)							
Antimony	<0.05	<0.05	<0.05	<0.05	ND	<0.05	<0.05
Arsenic	<0.1	<0.1	<0.1	<0.1	ND	<0.1	<0.1
Barium	0.12	0.061	0.055	0.071	ND	0.04	0.079
Boron	0.06	0.06	0.12	0.1	ND	0.14	0.10
Cadmium	<0.005	<0.005	<0.005	<0.005	ND	<0.005	<0.005
Chromium	<0.01	<0.01	<0.01	<0.01	ND	<0.01	<0.01
Copper	<0.006	<0.006	<0.007	<0.006	ND	<0.007	<0.006
Iron	<0.05	<0.05	0.13	<0.05	ND	<0.05	<0.05
Lead	<0.05	<0.05	<0.05	<0.05	ND	<0.05	<0.05
Lithium	<0.02	<0.02	0.04	0.02	ND	0.11	0.03
Manganese	<0.005	<0.005	0.009	0.005	ND	<0.005	<0.005
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	ND	<0.0002	<0.0002
Selenium	<0.2	<0.2	<0.2	<0.2	ND	<0.2	<0.2
Silicon (Si)	28	27	38	33	ND	30	39
Silica (SiO2)	60	58	81	71	ND	64	83
Silver	<0.005	<0.005	<0.005	<0.005	ND	<0.005	<0.005
Zinc	0.12	<0.01	0.01	0.21	ND	0.11	<0.01
TOTAL DISSOLVED SOLIDS (mg/L)	203	310	330	260	ND	920	330
ION BALANCE (%)		4.2	2.4	4.7	-	6.1	-
STABLE ISOTOPES						6.1	
Delta-D (0/00)	-136.0	-132.0	-137.0	-128.0	-133.0	-122.0	-137.0
Delta O-18 (0/00)	-18.6	-17.2	-17.9	-16.3 (-16.4 LD)	-17.7	-15.7	-18.0
TRITIUM (tritium units)	0.15	0.60	-0.08	0.00	0.00	1.25	-0.07

FD=Field Duplicate, LD=Lab Duplicate
( ) Values in parantheses are field or lab duplicate analyses
#Sample not chilled or preserved, holding times exceeded for TDS
ND=No Data

Table 6-1. HYDROLOGIC MONITORING STATIONS MONITORED BY CHILTON, THOUSAND SPRINGS BASIN AND VICINITY

Precipitation Stations	Period of Record
Wilkins	3/82 - 9/83, 2/86 - 10/88
Fivemile Ranch	3/82 - 9/83, 2/86 - 10/88
Lower Eccles	3/82 - 9/83, 2/86 - 10/88
Twelvemile Ranch	3/82 - 9/83, 2/86 - 10/88
HD Summit	2/83 - 9/83, 2/86 - 10/88
Moor Summit	2/83 - 9/83, 2/86 - 10/88
Pequop Summit	2/86 - 10/88
Cobre	3/86 - 10/88
Rocky Point	6/86 - 10/86
Pequop	3/83 - 9/83

Streamflow Stations	Period of Record
WC Lane/Beaver Culvert	2/82 - 9/83, 2/86 - 10/88
Toano Draw	2/82 - 9/83, 2/86 - 10/88
Rock Springs Creek	2/82 - 9/83, 2/86 - 10/88
Eccles Narrows	2/82 - 9/83, 2/86 - 10/88
Twentyone Mile Junction	2/82 - 9/83, 2/86 - 10/88
Lower Schoolhouse	6/82 - 9/83, 2/86 - 10/88
Crittenden Creek	2/82 - 9/83, 2/86 - 10/88
Rocky Ford	2/82 - 9/83, 2/86 - 10/88
Wilkins/Wilkins Canal	2/82 - 9/83, 2/86 - 3/86
Narrows	2/82 - 9/83, 2/86 - 3/86
Highway 30	2/82 - 9/83, 2/86 - 4/86

Reservoir Stations	Period of Record
Twentyone Mile Reservoir	2/82 - 9/83, 2/86 - 10/88
Dake Reservoir	2/82 - 9/83, 2/86 - 10/88

* Chilton Engineering (Kennedy/Jenks/Chilton), 1982-1988, Hydrologic Monitoring, Thousand Springs Creek, for Woodward-Clyde Consultants - Hydrologic Monitoring Summary

Table 6-2. STATIONS WITH PUBLISHED HYDROLOGIC MONITORING DATA, THOUSAND SPRINGS BASIN AND VICINITY

Agency	Precipitation Stations	Type of Data	Period of Record
NOAA[1]	Contact	Daily	1948 - 1987
	Metropolis	Daily	1964 - 1988
	Montello	Daily	1887 - 1988
	Pequop	Daily	1959 - 1985
	Wells	Daily	1891 - 1988
BLM[2]	Rock Spring Creek (23 stations)	Monthly	1963 - 1980

Agency	Streamflow Stations	Type of Data	Period of Record
USGS[3]	Thousand Springs Creek near Wilkins	Continuous	1985 - 1988
	Thousand Springs Creek near Shores	Continuous	1985 - 1986
	Thousand Springs Creek near Montello	Continuous	1985 - 1988

1 National Oceanic and Atmospheric Administration. 1940-1988. Climatological Data for Nevada.

2 Bureau of Land Management. September 1983. Nevada Watershed Studies, 1963-1980. Technical Publication BLMNVPT830014340.

3 United States Geological Survey. 1985-1988. Water Resources Data, Nevada, Water Year 1985, and Computer Generated Tables for Water Years 1986-1988.

Table 6-3. AVERAGE MONTHLY AND ANNUAL PRECIPITATION AT NOAA MONITORING STATIONS, 1949 - 1983, THOUSAND SPRINGS BASIN AND VICINITY

Month	Precipitation at Monitoring Station* (inches) Contact	Montello	Wells	Average
January	0.83	0.60	0.95	0.79
February	0.50	0.37	0.77	0.55
March	0.71	0.44	0.87	0.67
April	0.79	0.59	0.86	0.75
May	1.62	1.05	1.33	1.33
June	1.31	1.04	1.06	1.14
July	0.52	0.59	0.45	0.52
August	0.71	0.72	0.53	0.65
September	0.73	0.60	0.81	0.71
October	0.75	0.50	0.75	0.67
November	0.78	0.60	0.96	0.78
December	0.92	0.59	1.03	0.85
Annual Average	10.17	7.69	10.37	9.41

* Derived by Woodward-Clyde Consultants from National Oceanic and Atmospheric Administration, 1949-1983. Climatological Data for Nevada.

Table 6-4. AVERAGE ANNUAL PRECIPITATION AT NOAA AND BLM MONITORING STATIONS, 1963-1980, THOUSAND SPRINGS BASIN AND VICINITY

Agency and Monitoring Station	Elevation (feet)	Precipitation (inches)
NOAA Stations		
Contact	5365	10.81
Metropolis	5800	14.12
Montello	4880	8.32
Pequop	6030	13.17
Wells	5650	10.71
BLM Stations		
Rock Spring - 1	5500	11.45
Rock Spring - 2	5740	11.50
Rock Spring - 3	5900	10.84
Rock Spring - 4	6320	13.15
Rock Spring - 5	6480	15.54
Rock Spring - 6*	6600	13.02
Rock Spring - 7	5780	11.24
Rock Spring - 8	6240	12.82
Rock Spring - 9	6520	15.50
Rock Spring - 10*	7380	16.34
Rock Spring - 11	5700	11.34
Rock Spring - 12	5900	12.74
Rock Spring - 13	6200	14.64
Rock Spring - 14	6500	15.77
Rock Spring - 15	6320	15.03
Rock Spring - 16	5870	12.94
Rock Spring - 17	5880	11.89
Rock Spring - 18	5960	12.51
Rock Spring - 19	5940	11.82
Rock Spring - 20	5590	11.60
Rock Spring - 21	5460	11.55
Rock Spring - 22	6520	16.18
Rock Spring - 23	6440	14.83

Developed by Woodward-Clyde Consultants based on NOAA (1949-1988) and BLM (1983) data.

*Outlier data not used to develop orographic relationship.

Table 6-5. DRAINAGE AREAS FROM DRAINAGE BASIN MODEL, THOUSAND SPRINGS BASIN

Drainage Basin and Location	Drainage Area Within Each Subarea* (sq mi) Contact	Montello	Wells	Total
Thousand Springs Creek at Wilkins Gaging Station	9.23	0.00	58.64	67.87
Toano Draw at Confluence with Thousand Springs Creek**	0.00	188.89	62.72	251.61
Thousand Springs Creek at Shores Gaging Station	68.40	226.10	188.73	483.23
Thousand Springs Creek below Crittenden Creek	338.71	561.96	188.73	1089.40
Thousand Springs Creek at Montello Gaging Station	338.71	925.29	188.73	1452.73

* Each subarea corresponds to a Thiessen rainfall polygon.

** Drainage areas for Toano Draw were not used in the streamflow generation model.

Numerical values derived by Woodward-Clyde Consultants using geographic information system and U.S. Geological Survey. 1981. Wells Nevada-Utah, 1:100000 topographic map and 1982. Jackpot, Nevada. Utah-Idaho, 1:100,000 topographic map.

Table 6-6. ESTIMATES OF AVERAGE ANNUAL STREAMFLOW AT EXISTING AND PROPOSED STREAMFLOW GAGING STATIONS, THOUSAND SPRINGS CREEK

Location	Drainage Area (sq mi)	Average Streamflow Coefficient* $\overline{K}$	Average Annual Precipitation (in.)	Average Annual Precipitation (ac-ft)	Average Annual Streamflow from Streamflow Generation Model (in.)	Average Annual Streamflow from Streamflow Generation Model (ac-ft)	Average Annual Streamflow from Streamflow Generation Model (cfs)
Thousand Springs Creek at Wilkins Gaging Station	67.87	0.246	14.01	50,718	3.45	12,477	17.23
Thousand Springs Creek at Shores Gaging Station	483.23	0.0270	12.67	326,584	0.34	8,818	12.18
Thousand Springs Creek below Crittenden Creek	1089.40	0.0070	12.63	734,042	0.088	5,138	7.10
Thousand Springs Creek at Montello Gaging Station	1452.73	0.0042	12.20	945,307	0.051	3,979	5.50

* $\overline{K}$ is the ratio of average annual streamflow (ac-ft) to average annual precipitation (ac-ft).

Streamflow values derived by Woodward-Clyde Consultants, using the streamflow generator model.

Table 6-7. ESTIMATES OF AVERAGE ANNUAL PRECIPITATION AND STREAMFLOW FOR SUBBASINS DELINEATED BY RUSH (1968), THOUSAND SPRINGS BASIN

Name of Subbasin	Drainage Area: Individual (sq. mi.)	Drainage Area: Cumulative (sq. mi.)	Average Coeff. $\overline{K}$	Average Annual Precipitation: Cumul. (ac-ft)	Average Annual Precipitation: Indiv. (ac-ft)	Average Annual Precipitation: Indiv. (in.)	Average Annual Streamflow*: Cumul (ac-ft)	Average Annual Streamflow*: Indiv. (ac-ft)	Average Annual Streamflow*: Indiv. (cfs)	Average Annual Streamflow*: Indiv. (in.)
Herrell Siding	159.38	159.38	0.1110	109,912	109,912	12.93	12,200	12,200	16.85	1.44
Toano Draw	328.16	487.54	0.0261	328,072	218,160	12.47	8,563	-3,637	-5.02	-0.21
Rock Spring	281.71	769.25	0.0125	523,012	194,940	12.98	6,538	-2,025	-2.80	-0.13
Rocky Butte	186.34	955.59	0.0087	642,217	119,205	12.00	5,587	-951	-1.31	-0.10
Montello Crittenden	490.64	1446.23**	0.0042	945,307	303,090	11.58	3,979	-1,608	-2.22	-0.06

*Negative average annual streamflow values mean flow lost to groundwater or withdrawn for irrigation.

**Compares closely with 1,452.73 square miles for the same location, Thousand Springs Creek at Montello Gaging Station (Table 6-5).

Numerical values derived by Woodward-Clyde Consultants, using the streamflow generation model.

Table 6-8. HYDROLOGIC BUDGET ESTIMATES, WILKINS, SHORES, AND MONTELLO USGS GAGING STATIONS - THOUSAND SPRINGS CREEK, 1985-1988

Drainage Area/ Average Annual Parameter of Hydrologic Budget	Thousand Springs Basin Above Montello Gaging Station		Toano Draw Above Confluence With Thousand Springs Creek
	Existing Conditions	Modified Conditions[a]	
Drainage Area (sq mi)	1450	1450	250
Precipitation (P)	945,000	945,000	171,000
Local Evapotranspiration(ET)[b]	851,000	851,000	154,000
Reservoir Evaporation (RE)	2,000	2,000	0
Phreatophyte ET (PE)	6,000	6,000	0
Streamflow (S)	4,000	15,000	1,000[e]
Net Irrigation (NI)	15,000	0	0
Groundwater Applied (GA)	8,000	0	0
Irrigation Return (IR)	20,000	0	0
Groundwater Recharge (GR)	61,000	71,000	16,000
Maxey-Eakin[c]	61,000	61,000	12,000
Groundwater Outflow (GO)	67,000	71,000	16,000
Darcian Flow Calculation Estimate[d]	30,000	--	6,100

Numerical values estimated by Woodward-Clyde Consultants based on water budget analysis.

All hydrologic budget estimates in acre-feet/year except drainage area in square miles.

[a] Modified to account for net consumption of water by irrigated agriculture (NI, IR, and GA equal to zero). These estimates would be representative of conditions with no irrigation.

[b] Assumes local ET is 90 percent of precipitation; existing basin conditions total ET would be 92.5 percent.

[c] Estimate based on applying Maxey-Eakin method (Watson et al. 1975).

[d] Darcian flow through upper alluvial aquifer only. Flow through deeper aquifer and carbonate rocks would be in addition to indicated amount.

[e] Discharge to Thousand Springs Creek based on average runoff from Thousand Springs Basin, downstream from Wilkins Gage, of about 5 ac-ft/yr/sq mi.

Table 7-1. ESTIMATED AREAS AND PRECIPITATION ABOVE VARIOUS ELEVATIONS - THOUSAND SPRINGS BASIN AND TOANO DRAW AND WILKINS SUBBASINS

Contour interval (meters)	Area within Interval (square miles)			Cumulative Area						Total Average Annual Precipitation Within Interval (acre-feet)			Cumulative Total Average Annual Precipitation (acre-feet)		
				Thousand Srings Basin		Toano Draw Subbasin		Wilkins Gaging Sta. Subbasin							
	Thousand Springs Basin	Toano Draw Subbasin	Wilkins Gaging Sta. Subbasin	Area sq. mi.	Percent of total	Area sq. mi.	Percent of total	Area sq. mi.	Percent of total	Thousand Springs Basin	Toano Draw Subbasin.	Wilkins Gaging Sta. Subbasin	Thousand Springs Basin	Toano Subbasin	Wilkins Gaging Sta.
2600-2720	0.11	-	-	0.11	0.01	-	--	-	--	144	-	-	144	-	-
2480-2600	1.13	-	0.51	1.24	0.09	-	--	0.51	0.8	1352	-	595	1496	-	595
2360-2480	5.13	1.03	1.27	6.37	0.44	1.03	0.4	1.78	2.6	5672	1125	1367	7168	1125	1962
2240-2360	17.14	4.40	1.73	23.51	1.62	5.43	2.2	3.51	5.2	17,418	4410	1706	24,586	5535	3668
2120-2240	59.66	9.83	7.41	83.17	5.73	15.26	6.1	10.92	16.1	55,291	8986	6643	79,877	14,521	10,311
2000-2120	118.05	19.68	10.68	201.22	13.85	34.94	13.9	21.60	31.8	98,908	16,243	8611	178,785	30,764	18,922
1880-2000	240.13	52.73	25.32	441.35	30.38	87.67	34.8	46.92	69.1	179,075	38,811	18,135	357,860	69,575	37,057
1760-1880	419.40	103.78	20.72	860.75	59.25	191.45	76.1	67.64	99.7	277,040	67,612	13,463	634,900	137,187	50,520
1640-1760	353.36	60.14	0.23	1214.11	83.57	251.59	99.9	67.87	100	202,695	34,225	136	837,595	171,412	50,656
1520-1640	158.84	0.02	-	1372.95	94.58	251.61	100	67.87	100	76,669	10	-	914,264	171,422	50,656
1400-1520	79.78	-	-	1452.73	100	251.61	100	67.87	100	31,104	-	-	945,368	171,422	50,656

Source: WCC

Table 7-2. SOURCES OF POWER PLANT WATER BY GENERATING UNIT AND WATER DEVELOPMENT OPTION

Generating Unit	Development Option Case 1	Case 2	Case 3
1 & 2	Toano Draw South	Toano Draw South	Toano Draw South
3 & 4	Toano Draw Middle	Montello Area	Montello Area
5	Toano Draw North	Montello Area	Toano Draw Middle
6	Twentyone Mile Dam to Crittenden Creek	Montello Area	Toano Draw Middle (Case 3A) or North (Case 3B)
7	Twentyone Mile Dam to Crittenden Creek	Montello Area	Montello Area
8	Montello Area	Toano Draw Middle (Case 2A) or South (Case 2B)	Montello Area

NOTE: Cases are as evaluated by numerical modeling and discussed in Section 8.0

Table 8-1. ESTIMATE OF RECHARGE BASED ON THE MAXEY-EAKIN METHOD

Precipitation Range (in)	Recharge (% of Precipitation)	Equivalent Elevation Range (ft, msl)	Mean Precipitation (in)	Equivalent Recharge Rate (in)	Mean Recharge (in)
>20	25	>7678	20	>5	5
15-20	15	6503-7678	17.5	2.25-3.0	2.625
12-15	7	5799-6503	13.5	0.84-1.05	0.945
8-12	3	4859-5799	10	0.24-0.36	0.30
<8	0	<4859	0	0	0

Table 8-2. MEASURED AND SIMULATED HYDRAULIC HEADS AT THE OBSERVATION NODES

Serial Number	Well ID	Measured Head (ft, msl)	Simulated Head (ft, msl)	Difference* (ft)
1	42-66-35b	5230.0	5229.1	0.9
2	42-66-8ad	5290.0	5261.0	29.0
3	MW-1	5385.0	5372.7	12.3
4	MW-4	5457.0	5441.2	15.8
5	41-66-24cb	5873.0	5868.7	4.3
6	41-67-22bc	5152.0	5253.8	-101.8
7	41-65-35b	5465.0	5455.5	9.5
8	41-65-35a	5465.0	5456.7	8.3
9	41-66-35a	5526.0	5522.8	3.2
10	TW-12	5471.0	5484.2	-13.2
11	40-65-2ab	5470.0	5463.7	-6.3
12	40-67-11bb	5449.0	5439.9	-9.1
13	40-66-8cd	5567.0	5589.3	-22.3
14	40-67-21bb	5557.0	5576.2	-19.2
15	40-65-24bd	5498.0	5501.7	-3.7
16	MW-2	5484.0	5505.5	-21.5
17	40-67-28ad	6023.0	6018.9	4.1
18	40-65-27d	5502.0	5512.0	-10.0
19	40-66-25d	5822.0	5815.0	7.0
20	40-67-32b	6068.0	6036.6	31.4
21	40-65-27d	6002.0	6018.0	-16.0
22	40-66-25d	5523.0	5514.5	8.5
23	MW-3	5515.0	5516.2	-1.2
24	39-65-3ad	5710.0	5709.1	-0.9
25	TW-15	5511.0	5525.2	-14.2
26	39-67-18ad	6085.0	6062.0	23.0
27	TW-14	5517.0	5528.8	-11.8
28	39-66-16dc	5607.0	5577.1	29.9
29	39-67-21a	6402.0	6397.1	4.9
30	39-65-30b	6128.0	6138.8	-10.8
31	Spring	6060.0	6058.6	1.4

* Measured head - Simulated head

Table 8-3. CALIBRATED STEADY-STATE WATER BALANCE OF THE MODEL AREA

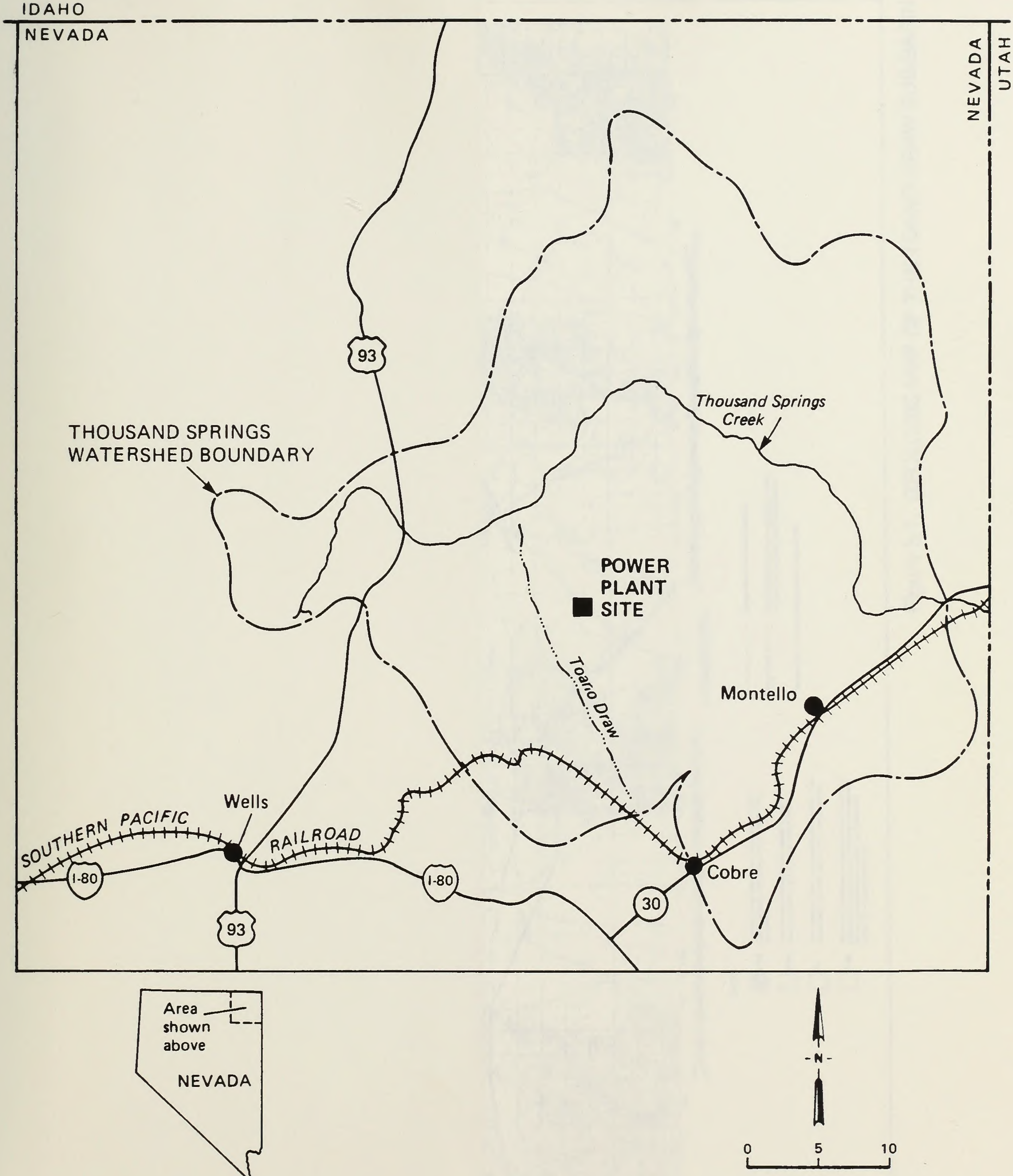
Flux	Acre-Feet/Year
Inflow	
Recharge	8340
Leakage from the creek to the aquifer	1669
Total Inflow	10,009
Outflow	
Constant Head	1208
Evapotranspiration	4612
Flow from aquifer to the creek	4192
Total Outflow	10,012

Table 8-4. SIMULATED WATER BALANCE FOR FIVE CASES OF GROUNDWATER DEVELOPMENT

Case	Demand (ac-ft/yr)	Elapsed Time (years)	ET (ac-ft/yr)	Recharge from River (ac-ft/yr)	Discharge to River (ac-ft/yr)	Net Discharge to River (ac-ft/yr)	Groundwater Outflow (ac-ft/yr)
0	0	0	4612	1669	4192	2523	1208
1	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	4	4597	1669	4072	2403	1207
	12,000	6	4573	1669	4000	2331	1207
	16,000	8	4515	1669	3819	2150	1207
	20,000	10	3994	1784	2822	1038	1207
	24,000	12	3549	1887	1842	-45	1193
	28,000	20	1358	2485	340	-2145	1055
	28,000	35	681	2766	16	-2750	849
	24,000	36	657	2773	15	-2758	833
	24,000	37	648	2780	14	-2766	814
	20,000	39	629	2792	12	-2780	775
	16,000	41	613	2804	10	-2794	735
	17,000	43	602	2815	8	-2807	695
	8000	45	592	2824	7	-2817	656
	4000	47	587	2825	5	-2820	634
2A	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	10	4585	1669	4037	2368	1207
	8000	14	4575	1669	4006	2337	1207
	12,000	20	4456	1669	3637	1968	1207
	12,000	35	4146	1780	2851	1071	1206
	8000	36	4121	1788	2820	1032	1205
	8000	37	4097	1797	2790	993	1205
	4000	45	3902	1839	2589	750	1204
	4000	49	3807	1850	2514	664	1203

Table 8-4. SIMULATED WATER BALANCE FOR FIVE CASES OF GROUNDWATER DEVELOPMENT (concluded)

Case	Demand (ac-ft/yr)	Elapsed Time (years)	ET (ac-ft/yr)	Recharge from River (ac-ft/yr)	Discharge to River (ac-ft/yr)	Net Discharge to River (ac-ft/yr)	Groundwater Outflow (ac-ft/yr)
2B	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	10	4585	1669	4037	2368	1207
	8000	14	4575	1669	4006	2337	1207
	12,000	20	4550	1669	3931	2262	1207
	12,000	35	4427	1682	3603	1921	1205
	8000	36	4417	1686	3579	1893	1205
	4000	37	4407	1690	3555	1865	1205
	4000	45	4252	1757	2991	1234	1204
	4000	49	4117	1786	2765	979	1203
3A	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	8	4589	1669	4047	2378	1207
	12,000	10	4566	1669	3981	2312	1207
	16,000	20	4215	1751	2902	1151	1207
	16,000	35	3172	1953	2472	519	1206
	12,000	36	3127	1961	2464	503	1205
	12,000	37	3104	1966	2456	490	1205
	8000	43	3029	1980	2399	419	1204
	4000	45	3010	1985	2377	392	1204
3B	4000	1	4611	1669	4149	2480	1207
	4000	2	4607	1669	4110	2441	1207
	8000	8	4589	1669	4047	2378	1207
	12,000	10	4566	1669	3981	2312	1207
	16,000	20	3546	1978	2431	453	1207
	16,000	35	2886	2068	2273	205	1206
	12,000	36	2879	2069	2262	193	1205
	12,000	37	2872	2072	2254	182	1205
	8000	43	2823	2098	2228	130	1204
	4000	45	2804	2100	2219	119	1204



Project No. 90270B	Thousand Springs Power Plant	FACILITY AREA MAP	Figure 2-1
Woodward-Clyde Consultants			

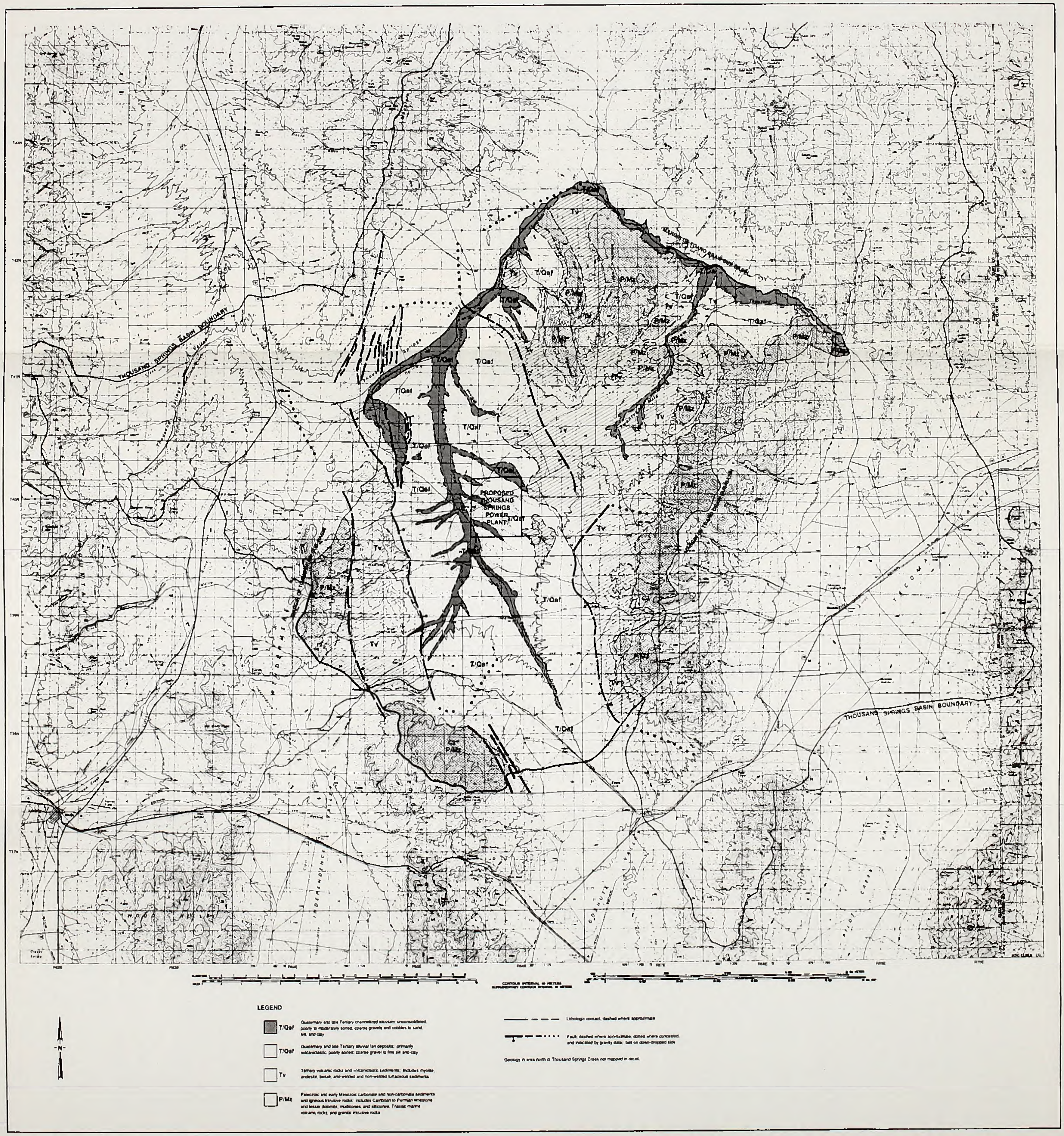


Figure 3-1. GEOLOGIC MAP OF THE TOANO DRAW SUB-BASIN

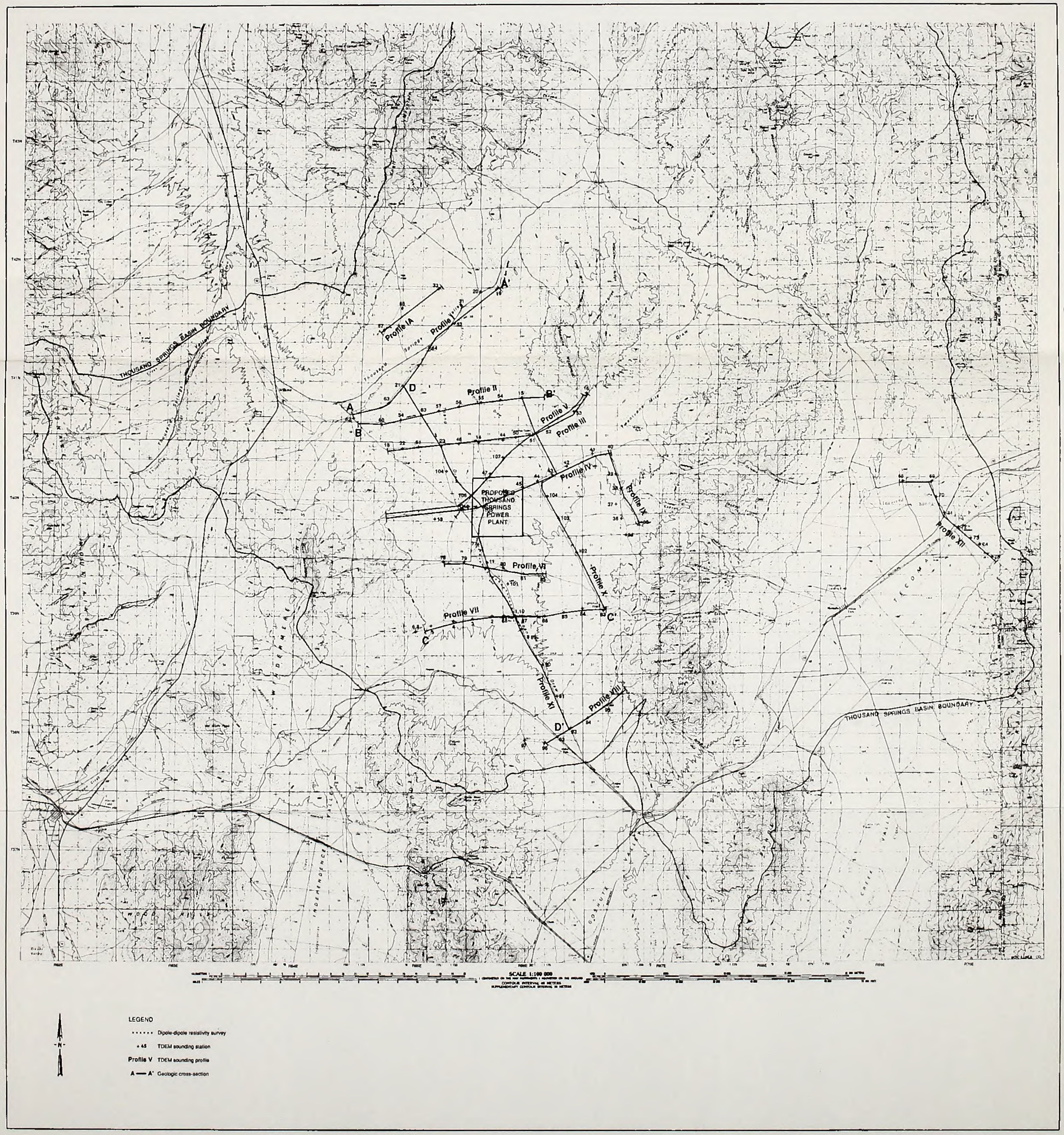
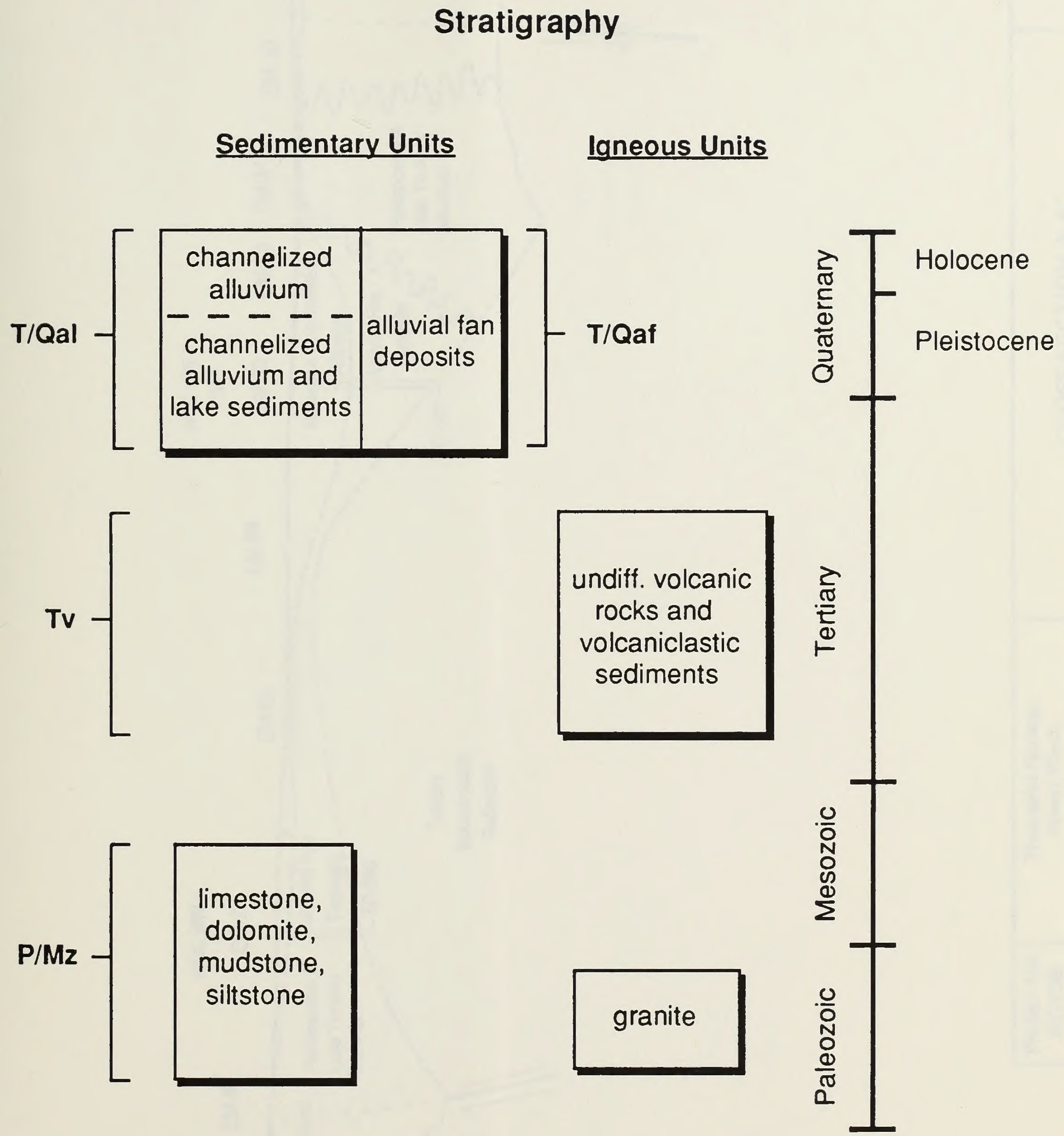
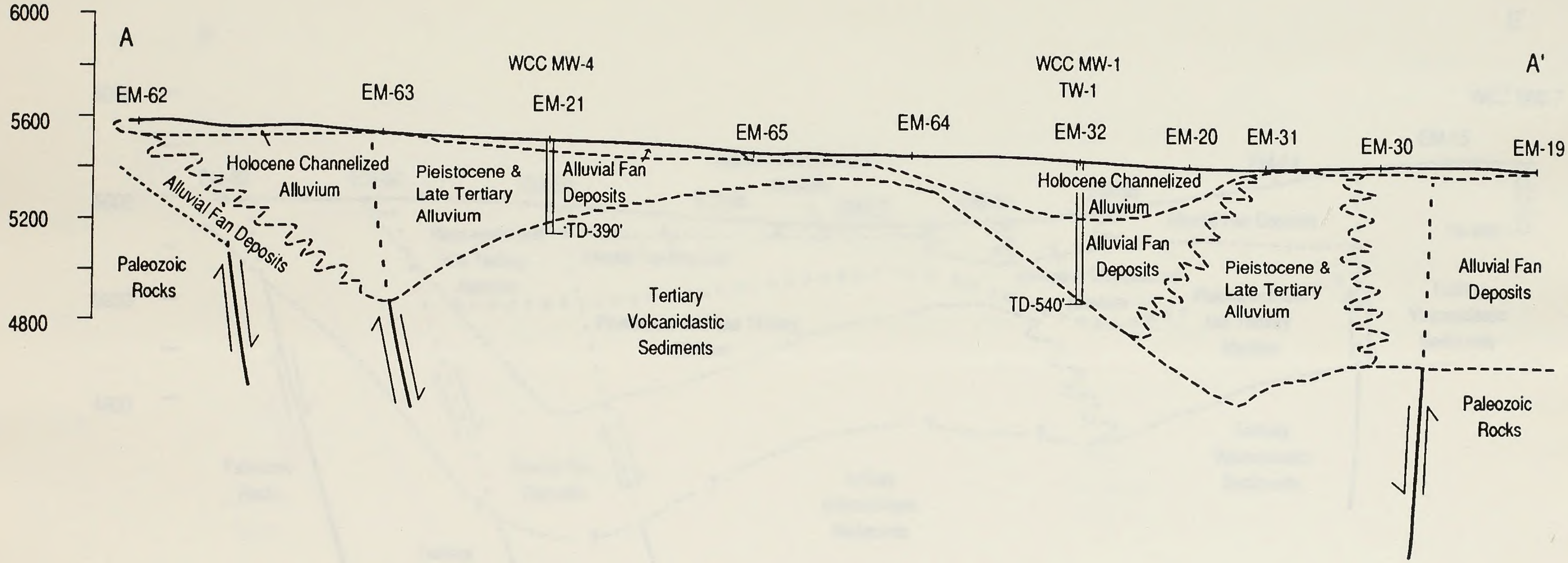


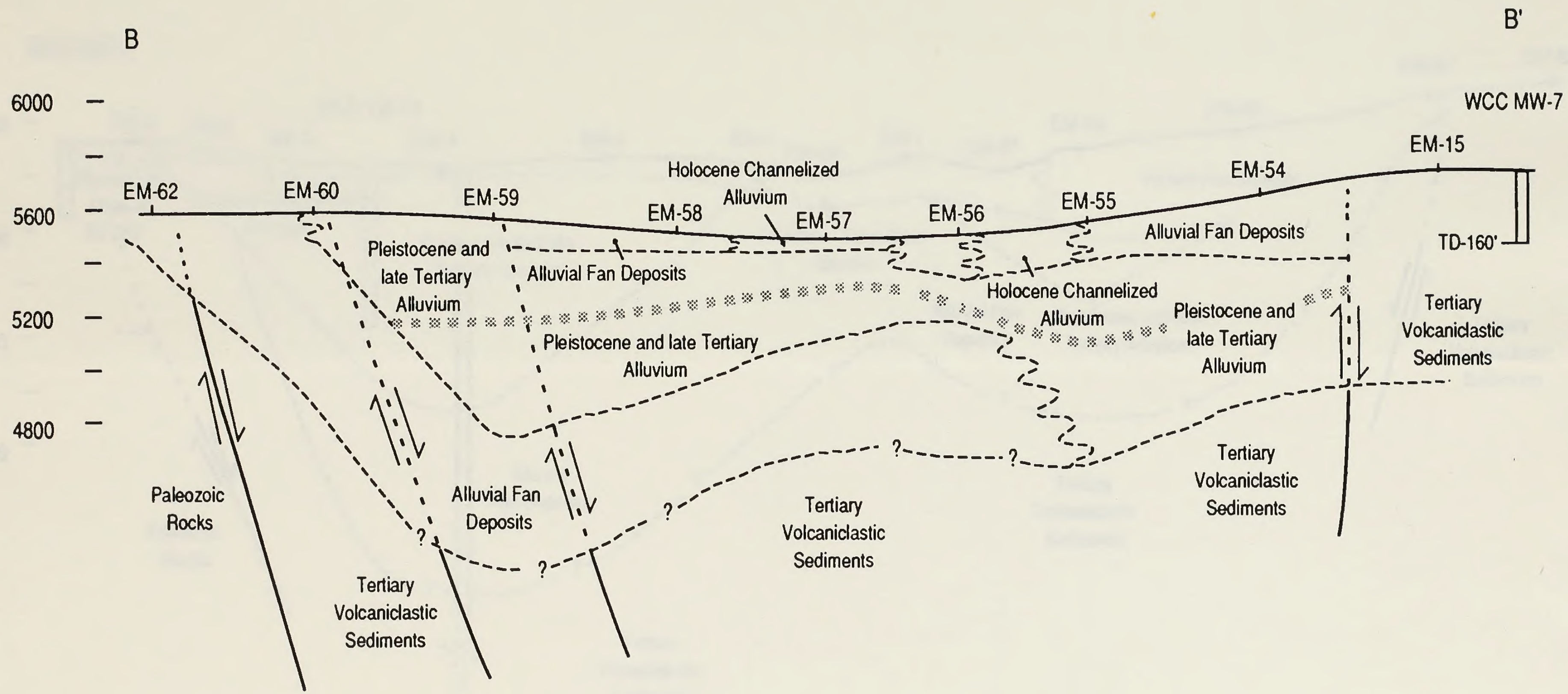
Figure 3-2. LOCATION OF TDEM SOUNDINGS DIPOLE-DIPOLE RESISTIVITY SURVEYS, GEOPHYSICAL PROFILES, AND GEOLOGIC CROSS-SECTIONS



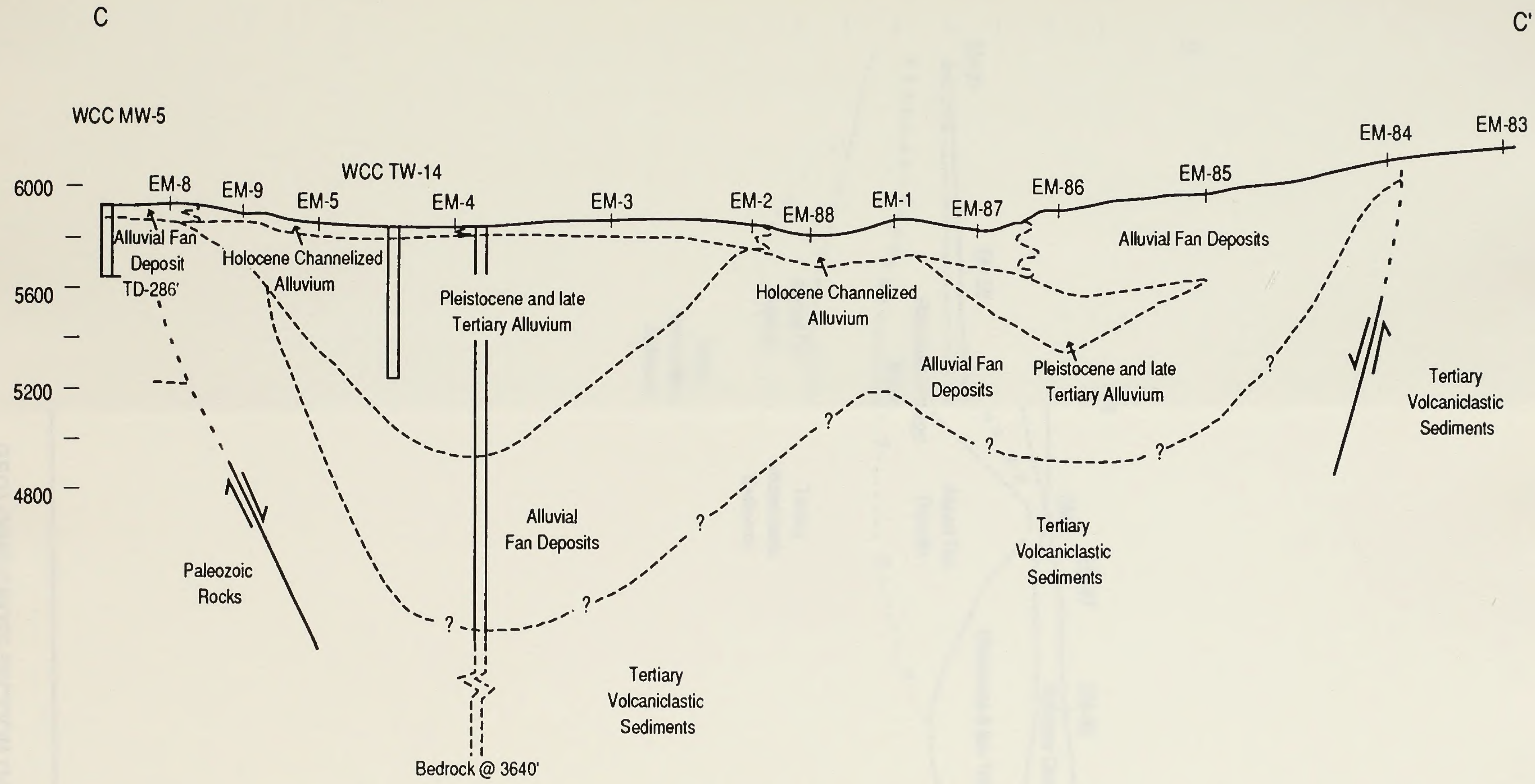
Project No. 90270B	Thousand Springs Power Plant	STRATIGRAPHIC CORRELATION CHART	Figure 3-3
Woodward-Clyde Consultants			



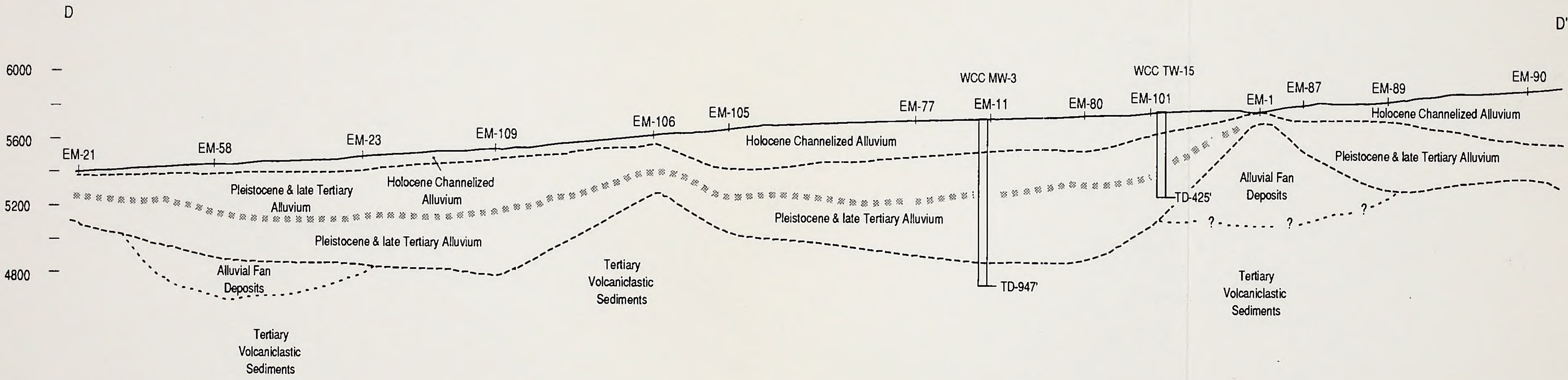
Project No. 90270B	Thousand Springs Power Plant	CROSS-SECTION A-A'	Figure 3-4
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power Plant	CROSS-SECTION B-B′	Figure 3-5
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power Plant	CROSS-SECTION C-C'	Figure 3-6
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power Plant	GEOLOGIC CROSS-SECTION D-D'	Figure 3-7
Woodward-Clyde Consultants			

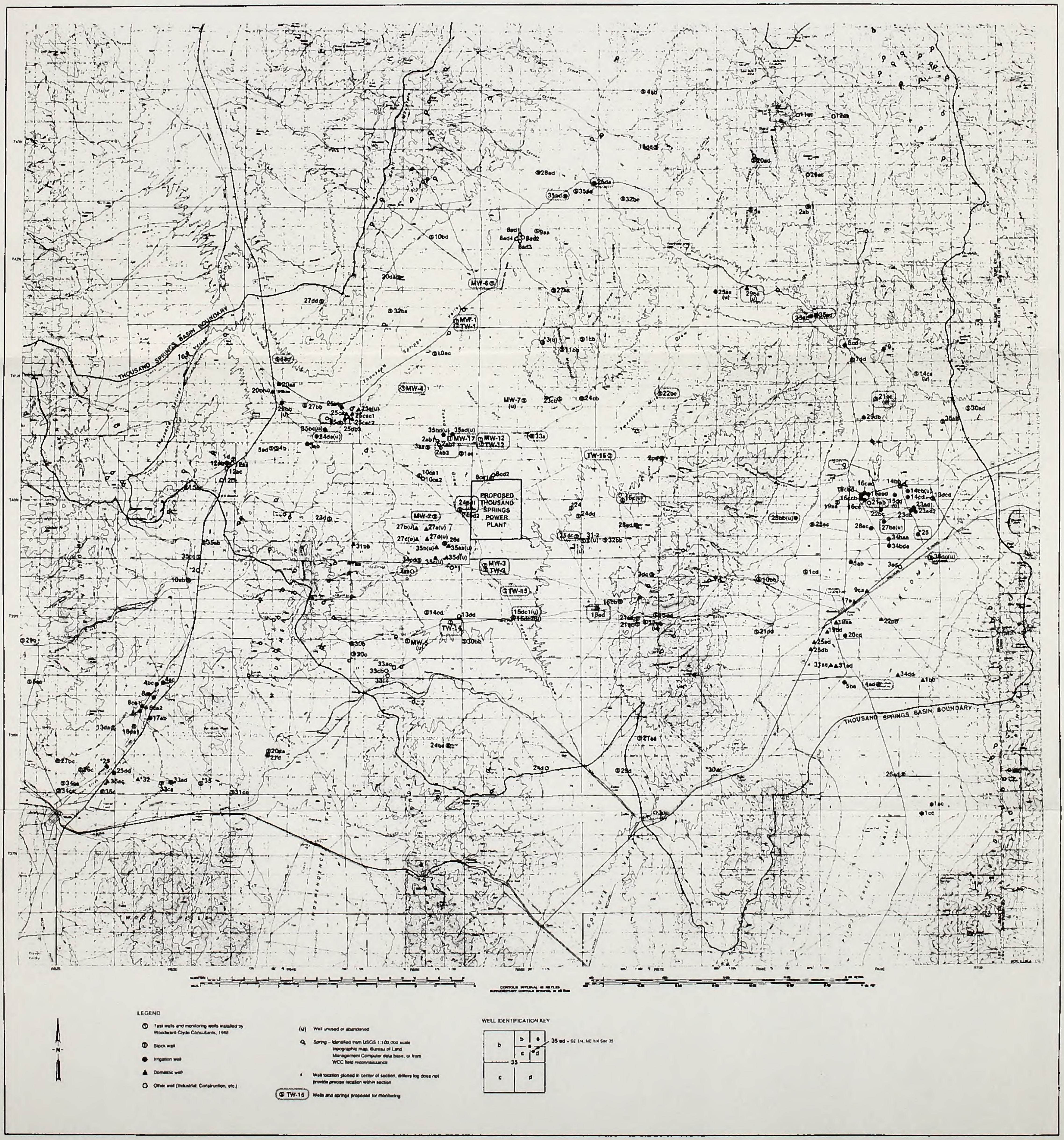


Figure 4-1. WELL AND SPRING LOCATION MAP AND WELLS AND SPRINGS PROPOSED FOR HYDROLOGICAL MONITORING PROGRAM

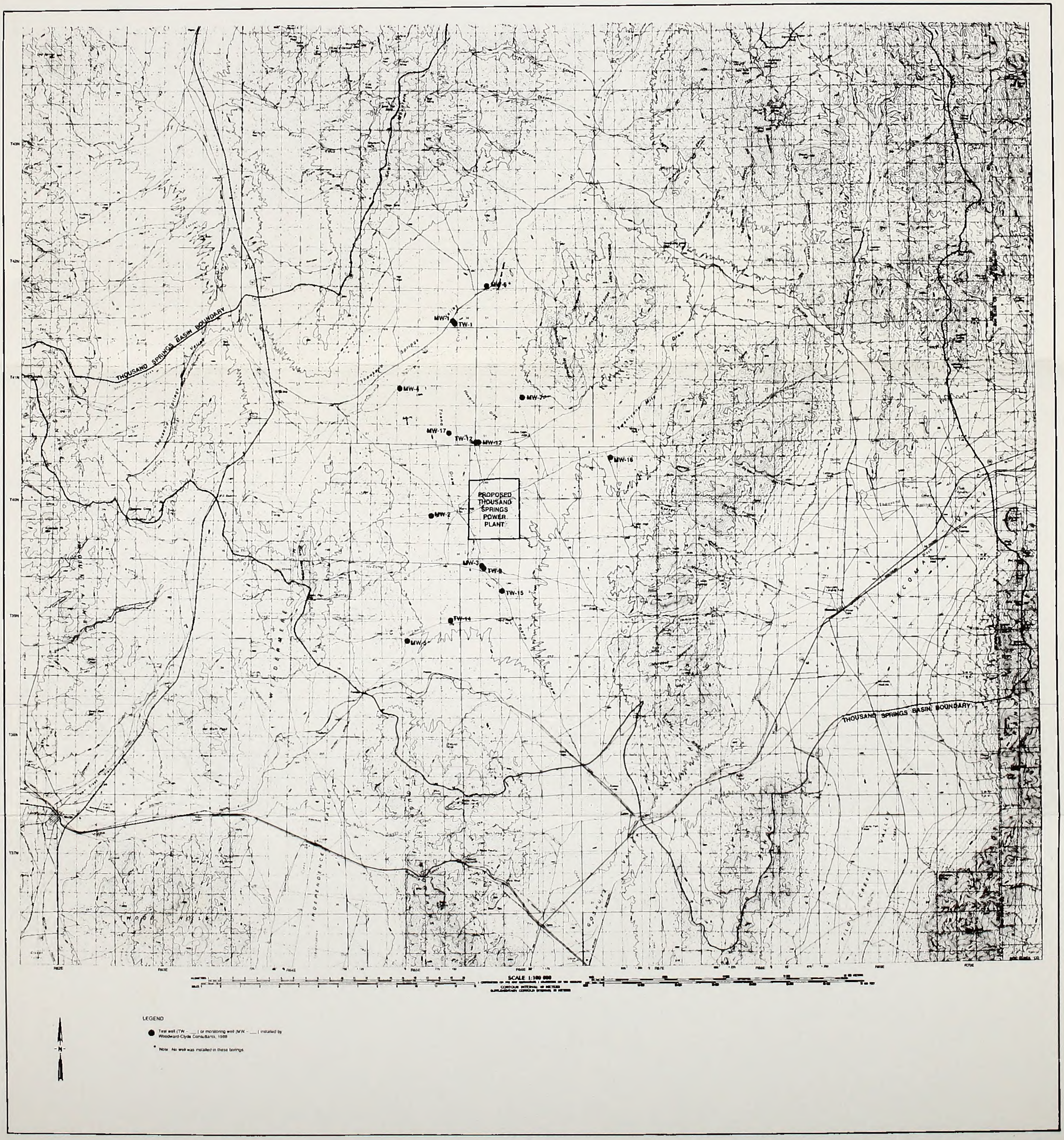


Figure 4-2. LOCATIONS OF MONITORING WELLS AND TEST WELLS

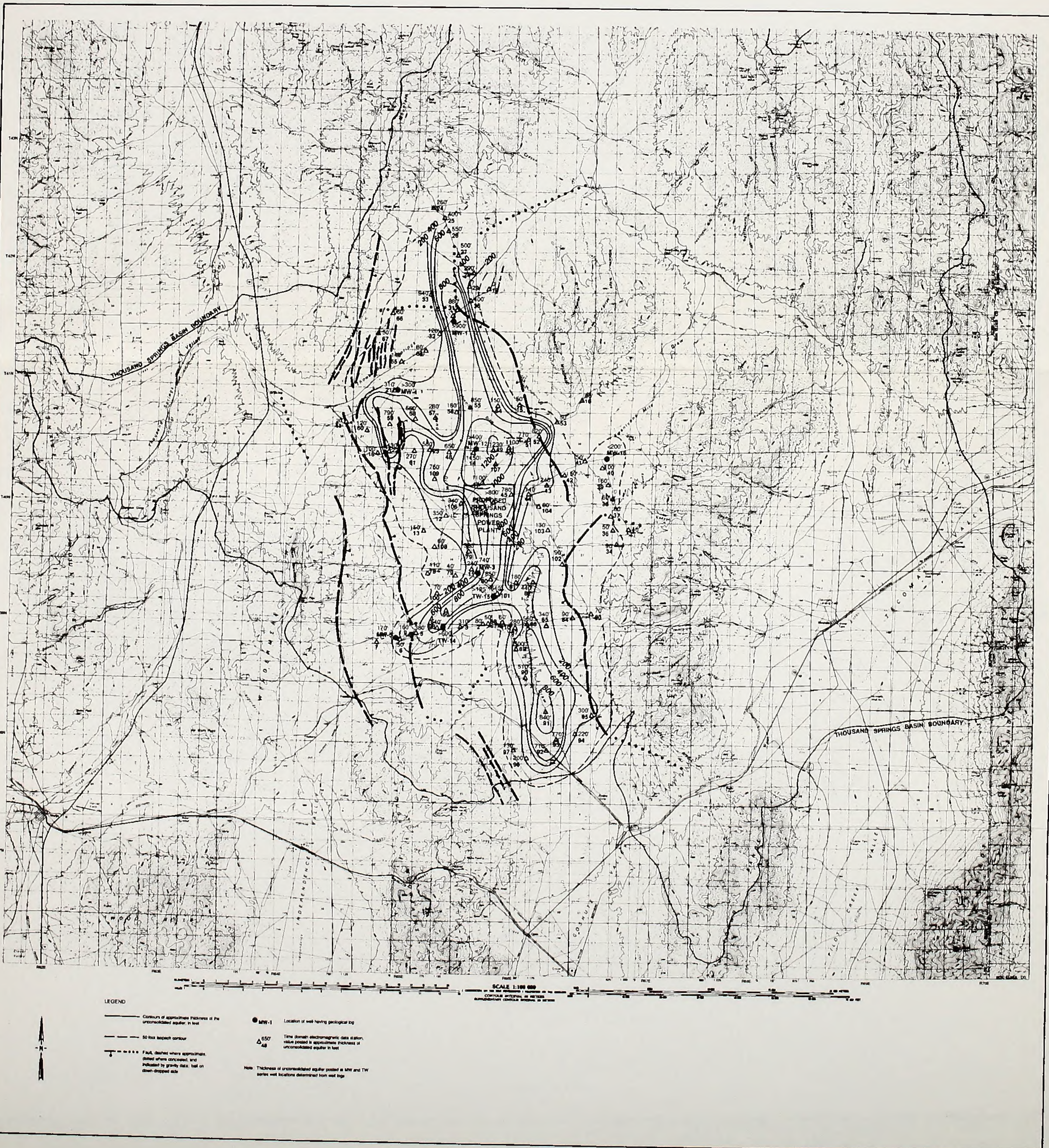
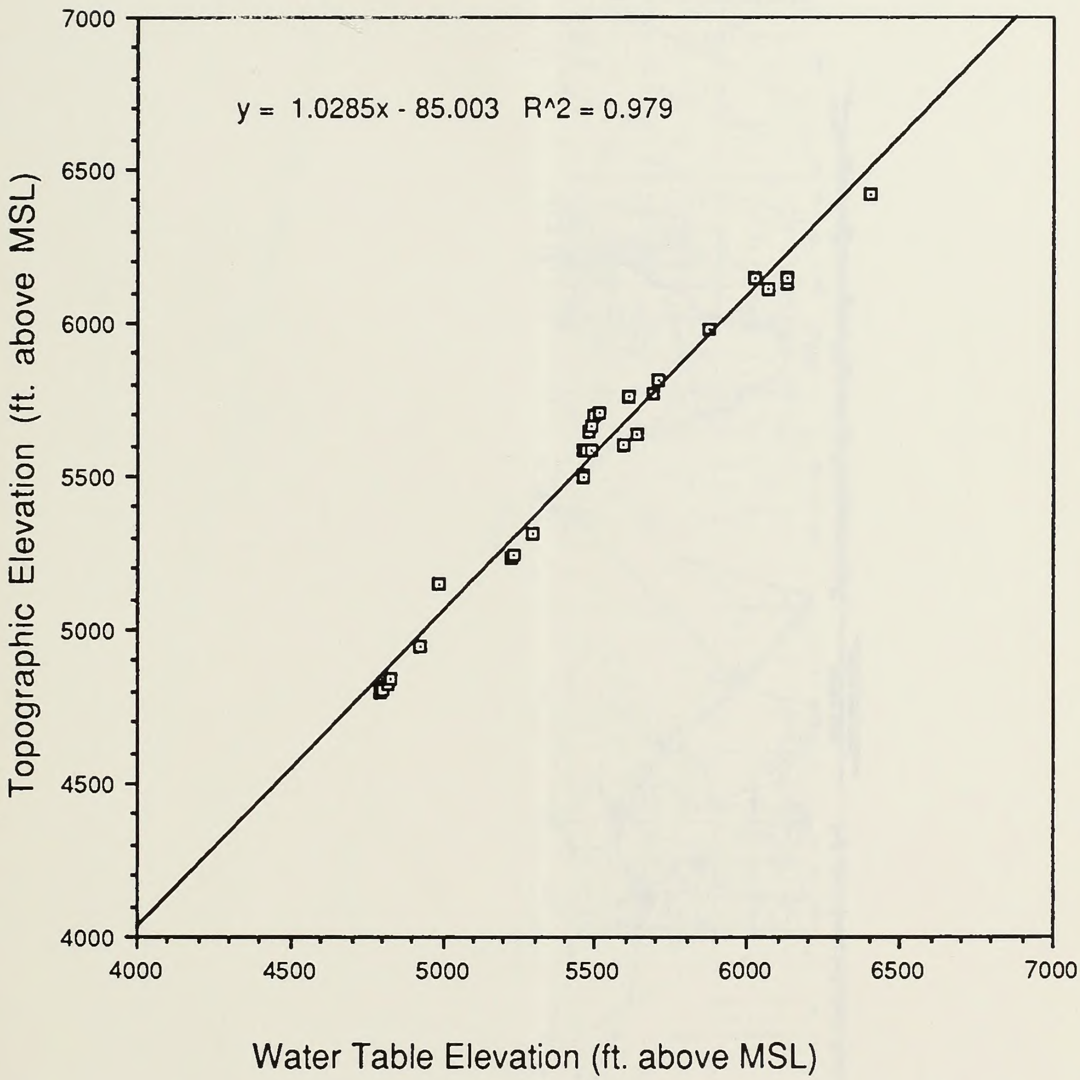


Figure 4-3. ISOPACH MAP OF THE ALLUVIAL AQUIFER



Project No. 90270B	Thousand Springs Power Plant	RELATIONSHIP OF WATER TABLE TO TOPOGRAPHIC ELEVATION	Figure 4-4
Woodward-Clyde Consultants			

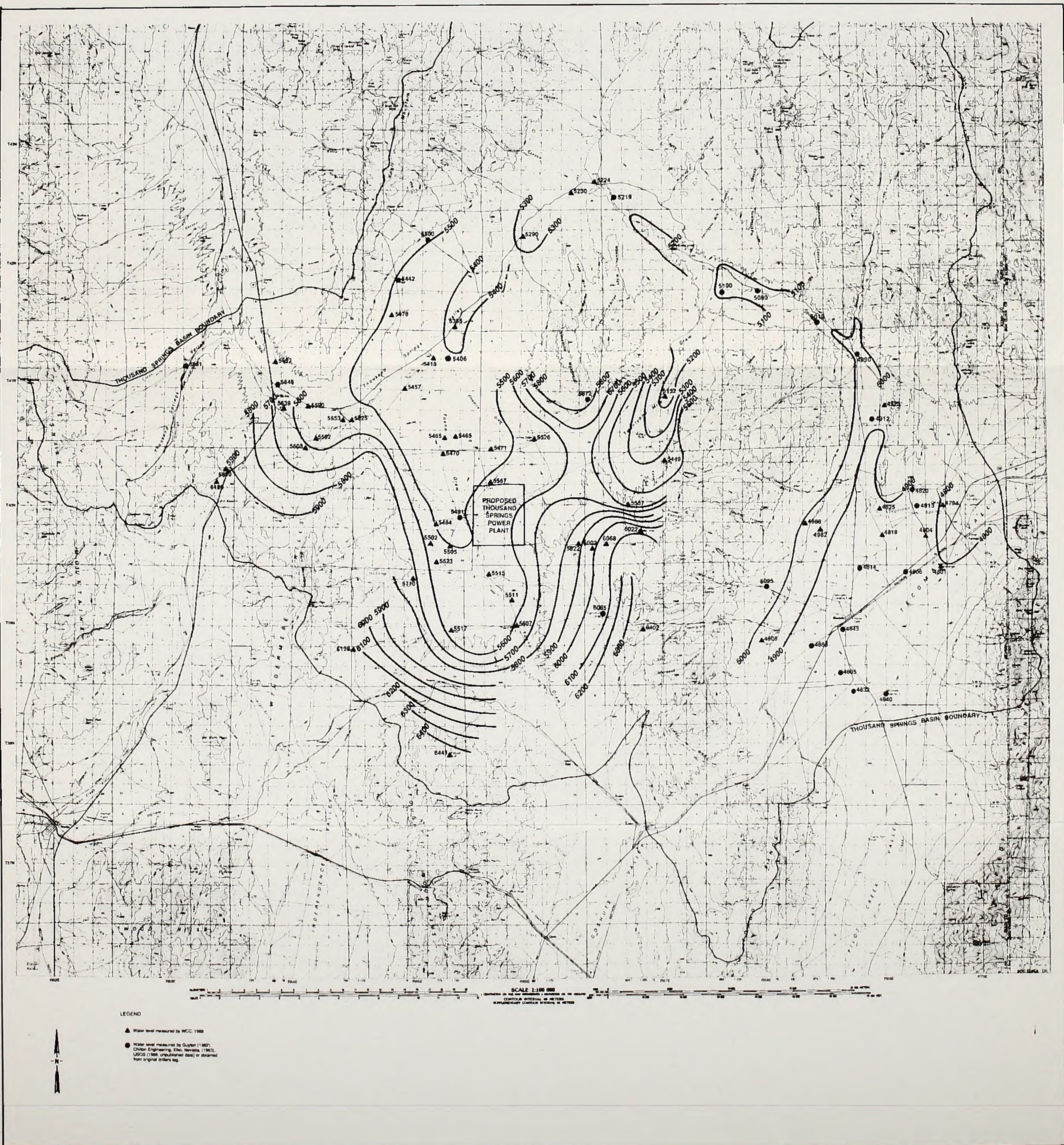
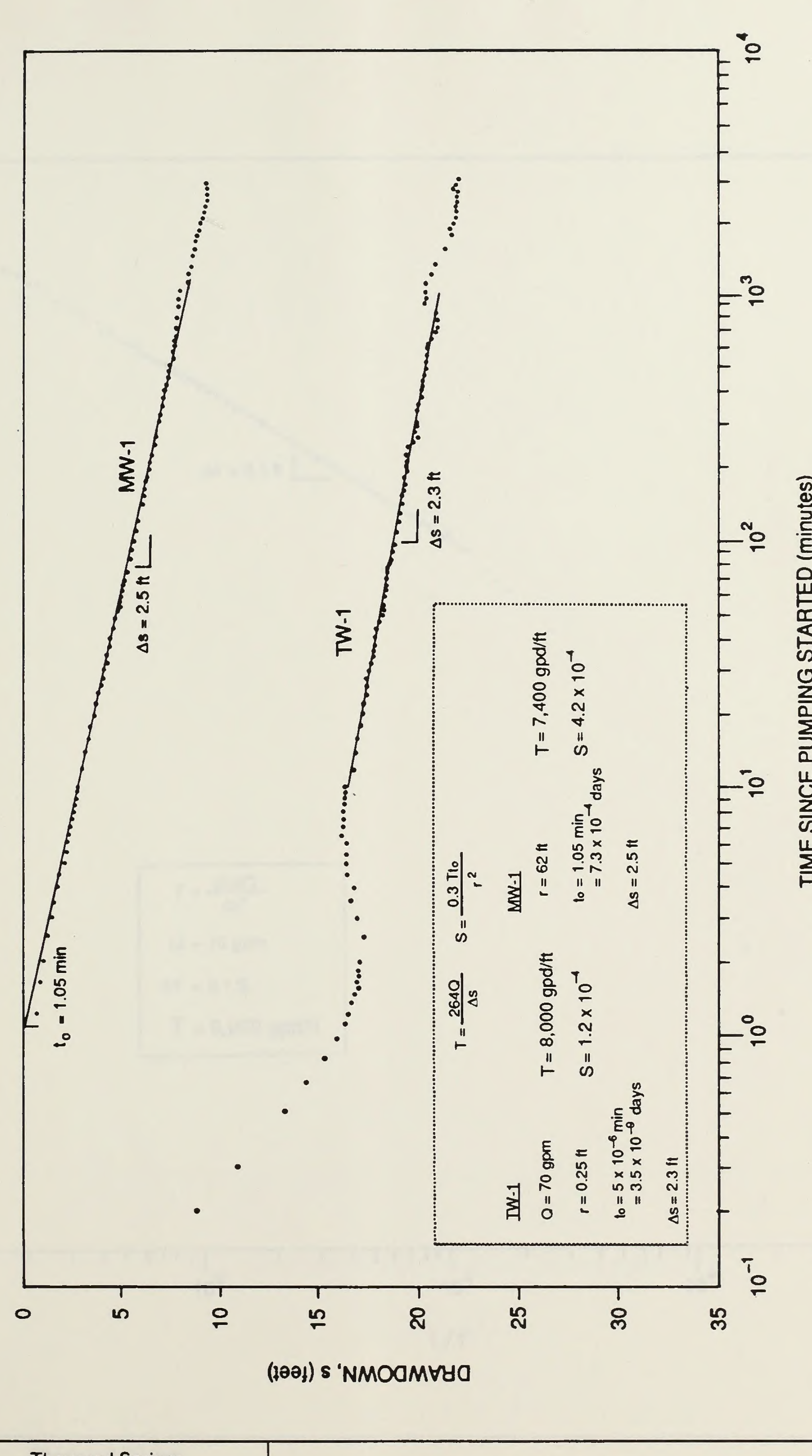
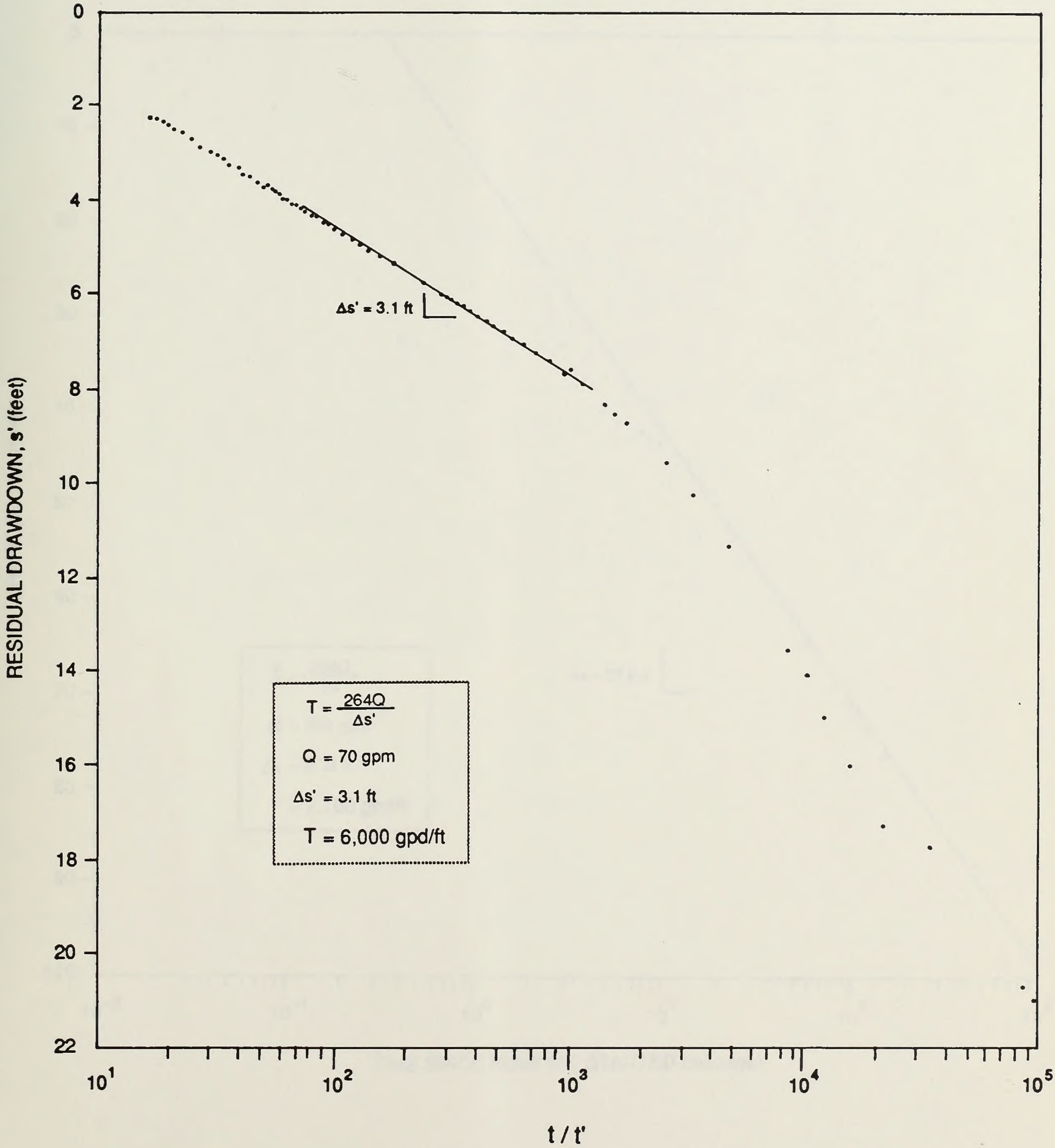


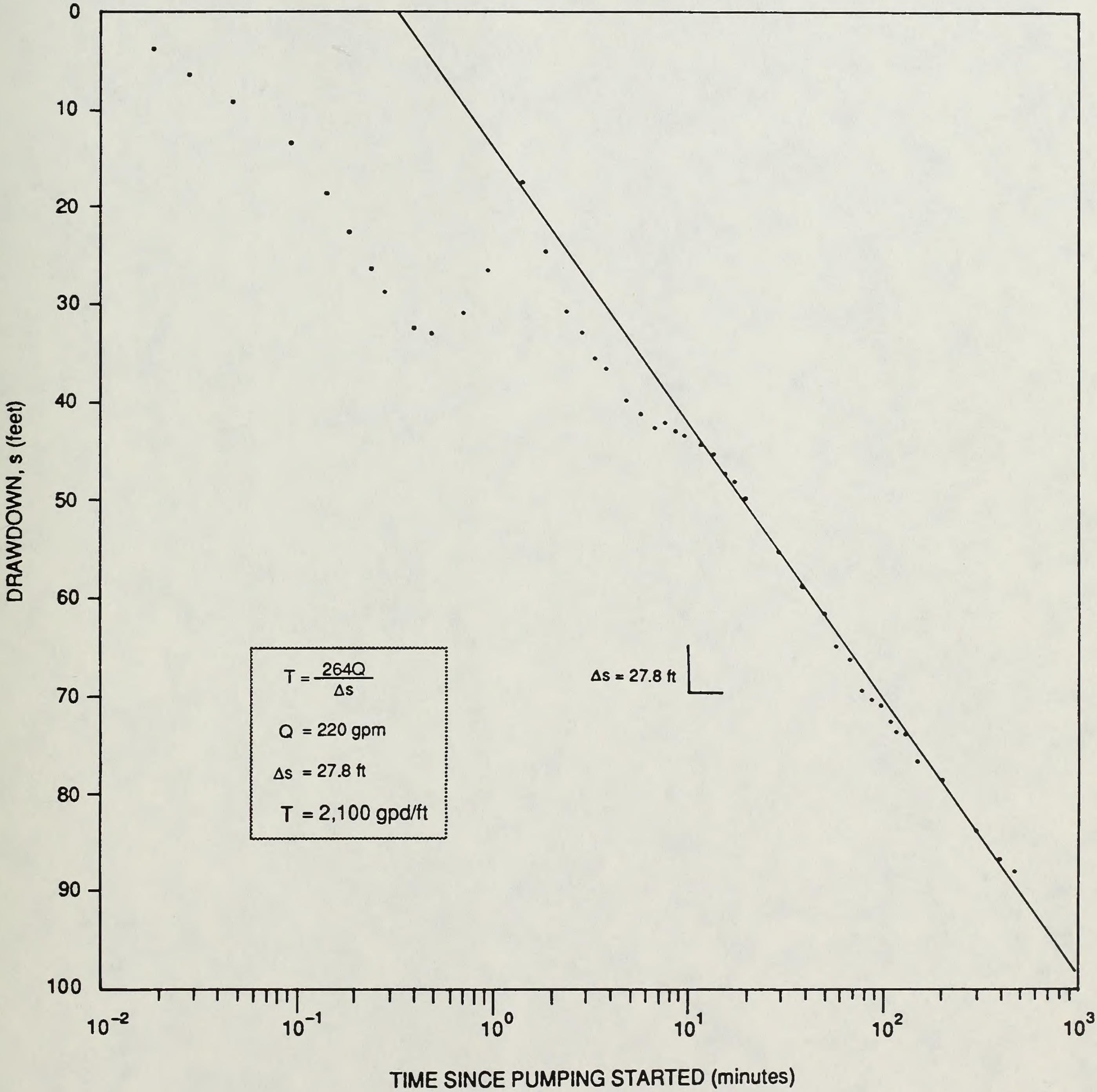
Figure 4-5. WATER TABLE CONTOUR MAP



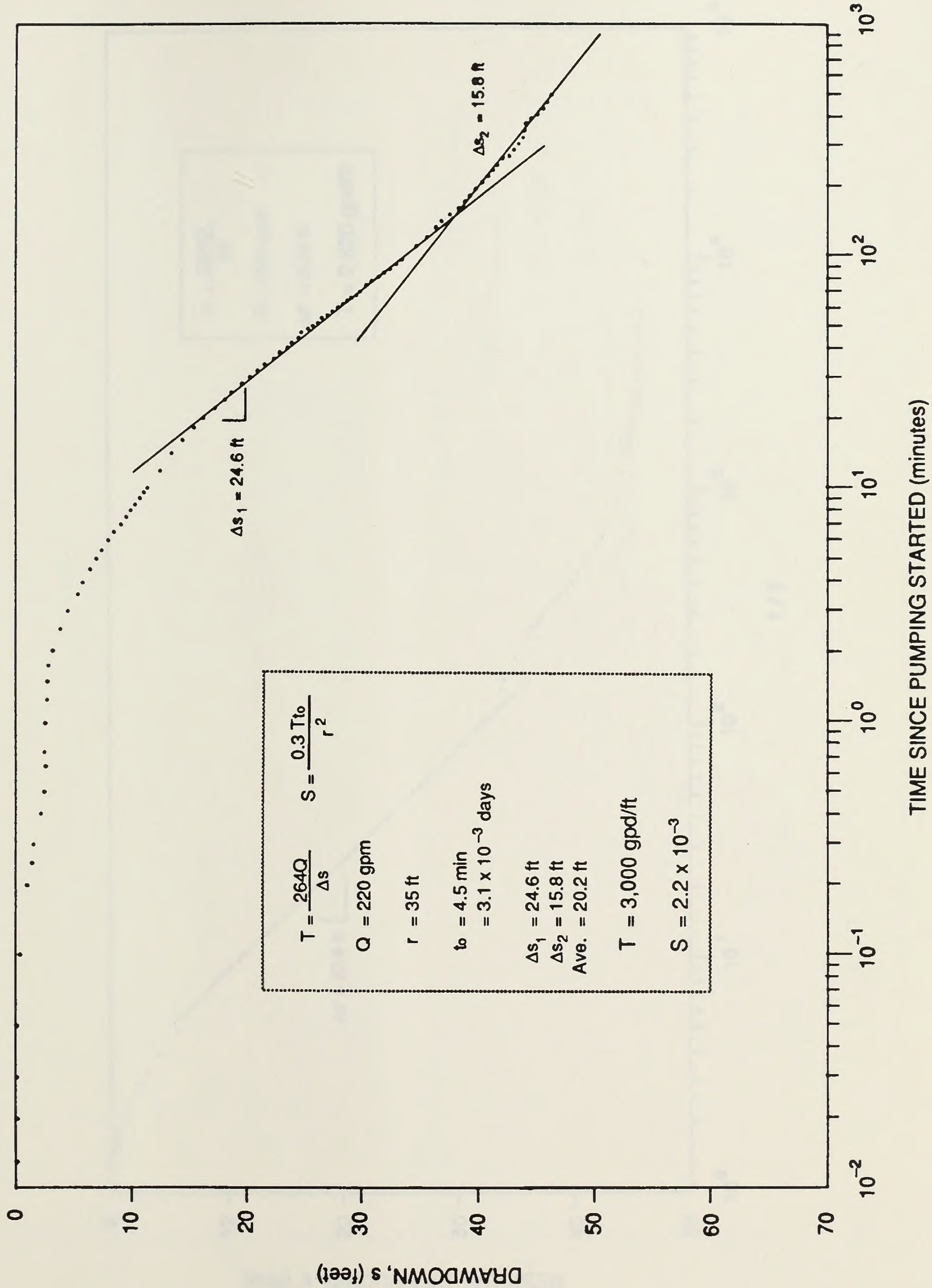
Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR TW-1 AND MW-1 COOPER-JACOB METHOD	Figure 4-6
Woodward-Clyde Consultants			



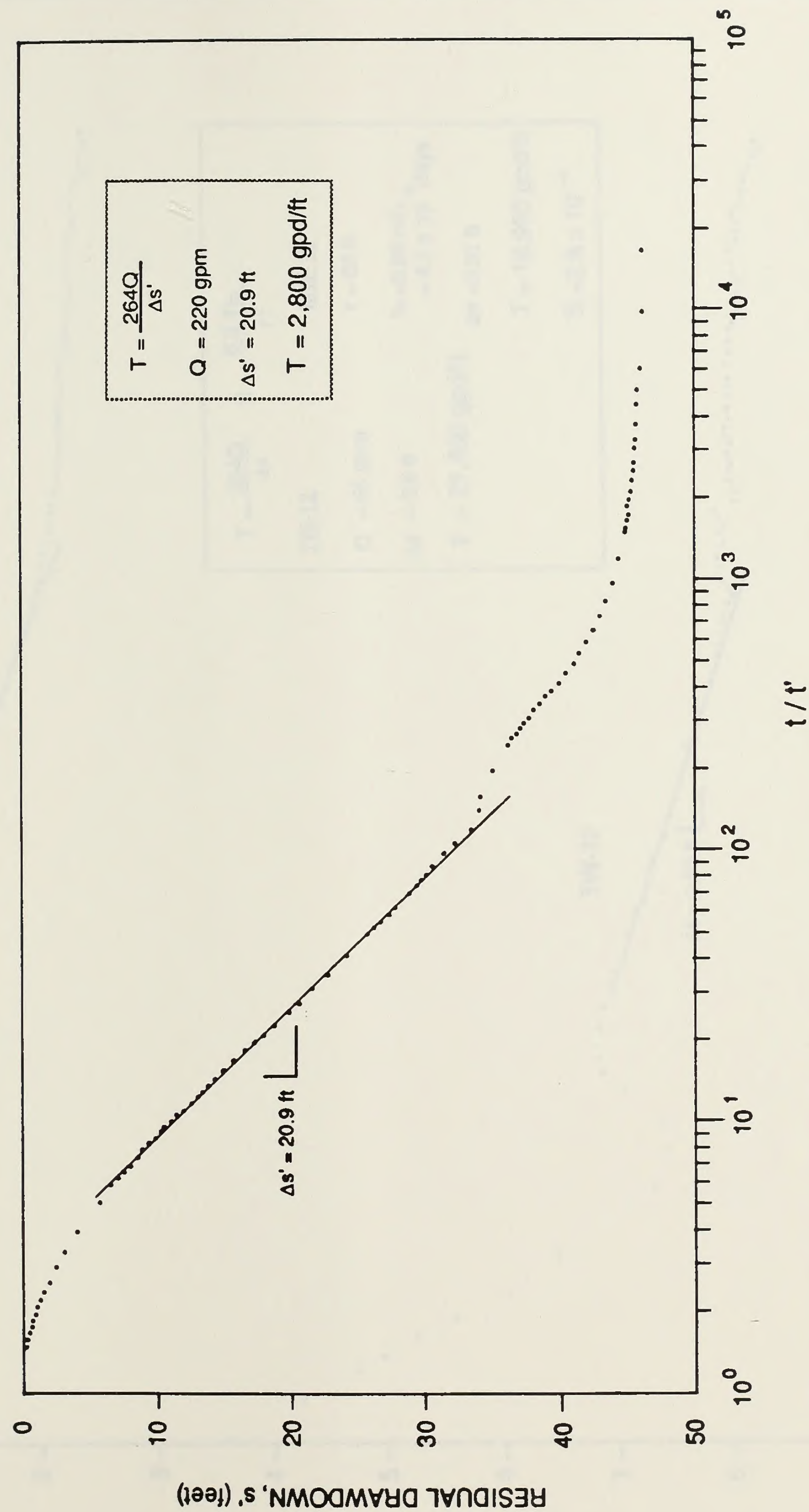
Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR TW-1 COOPER-JACOB METHOD	Figure 4-7
Woodward-Clyde Consultants			



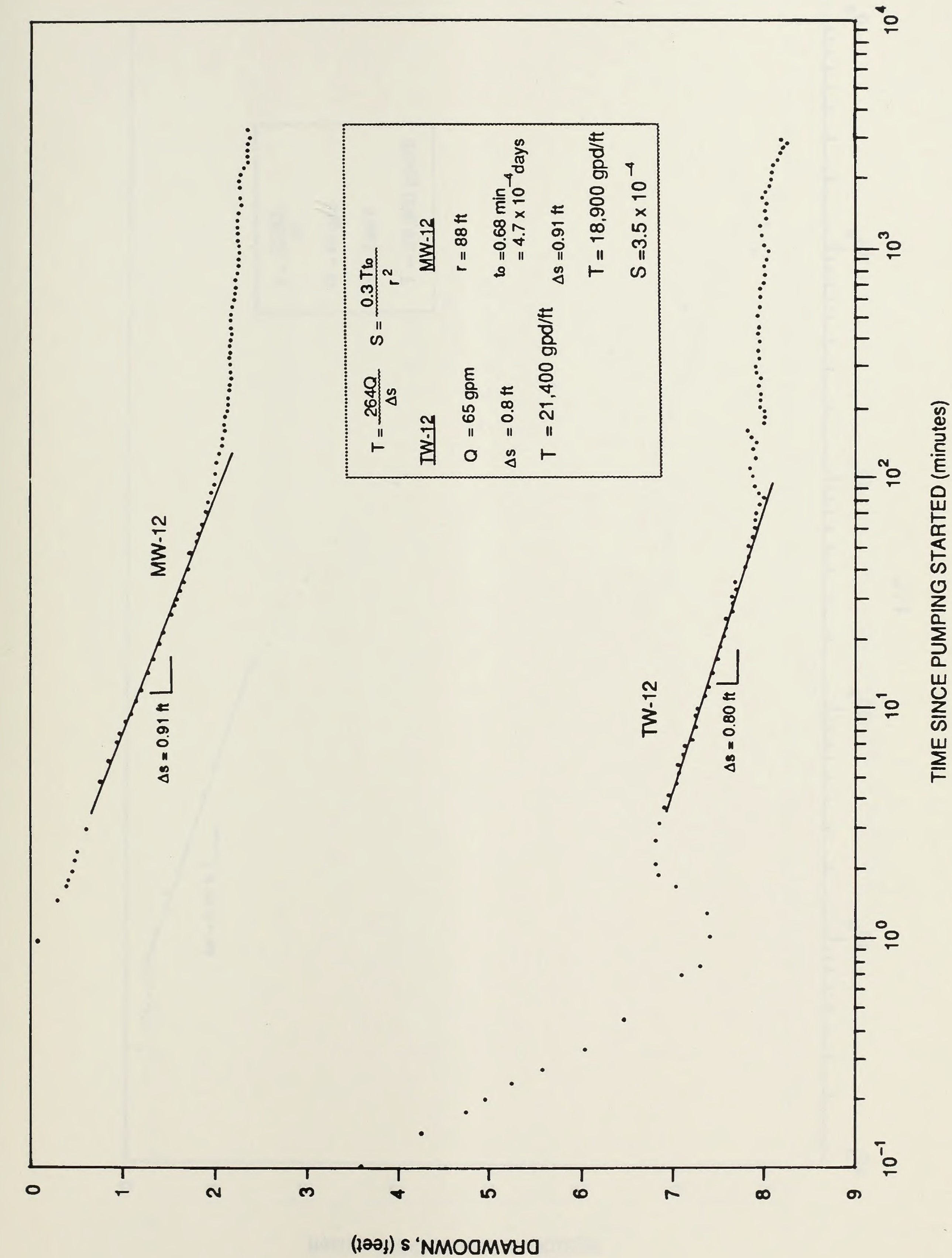
Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR TW-3 COOPER-JACOB METHOD	Figure 4-8
Woodward-Clyde Consultants			



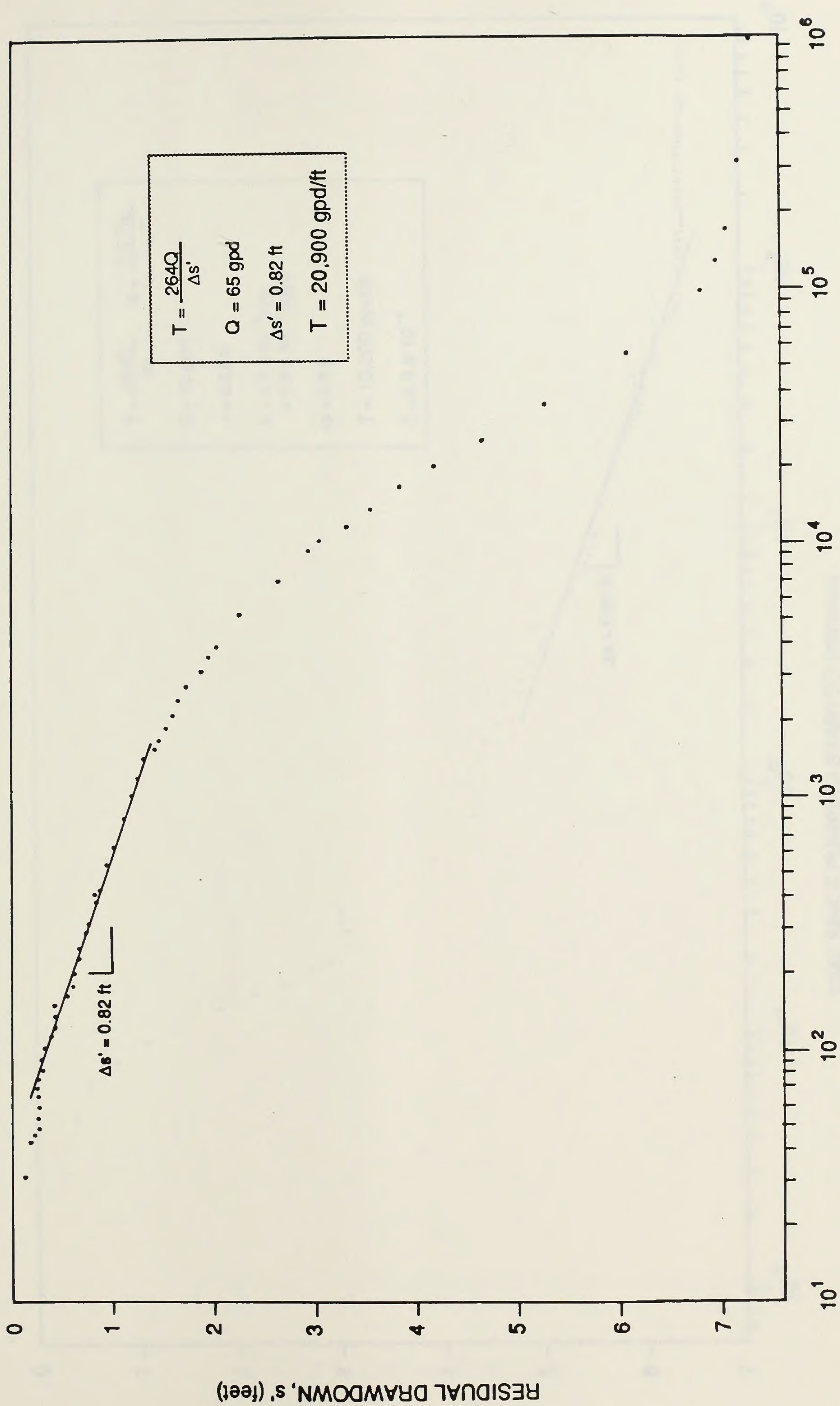
Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR MW-3 COOPER-JACOB METHOD	Figure 4-9
Woodward-Clyde Consultants			



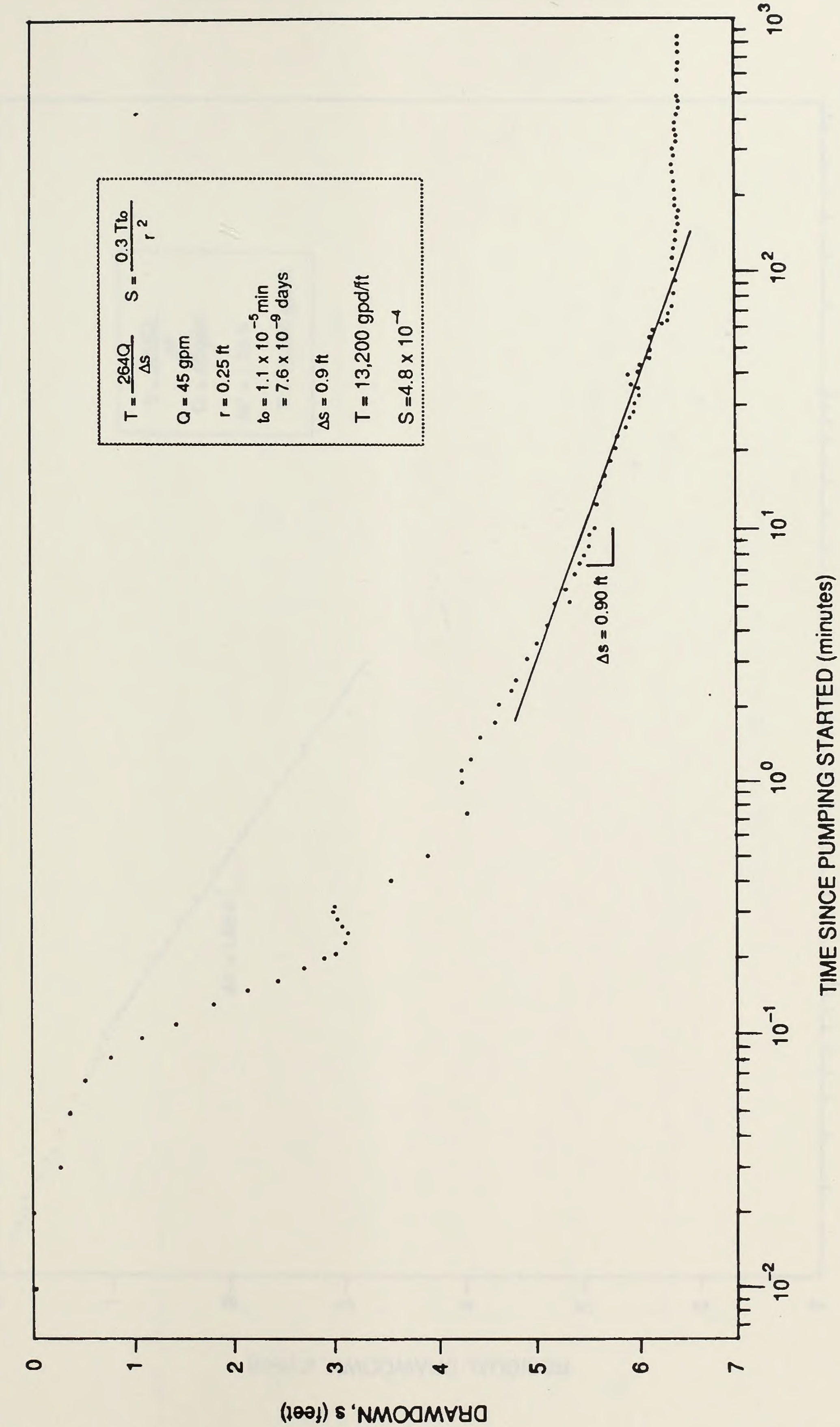
Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR MW-3 COOPER-JACOB METHOD	Figure 4-10
Woodward-Clyde Consultants			



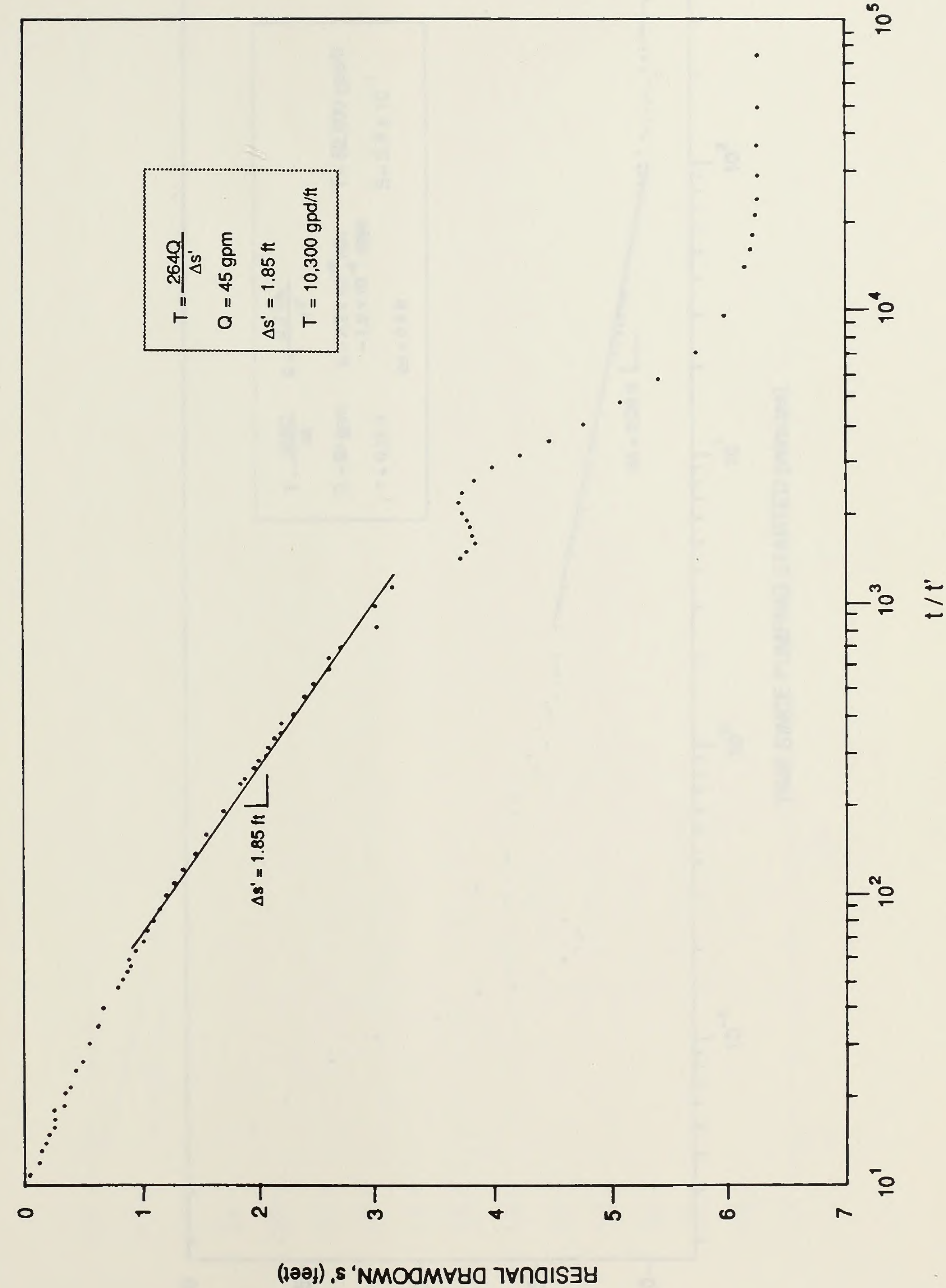
Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR TW-12 AND MW-12 COOPER-JACOB METHOD	Figure 4-11
Woodward-Clyde Consultants			



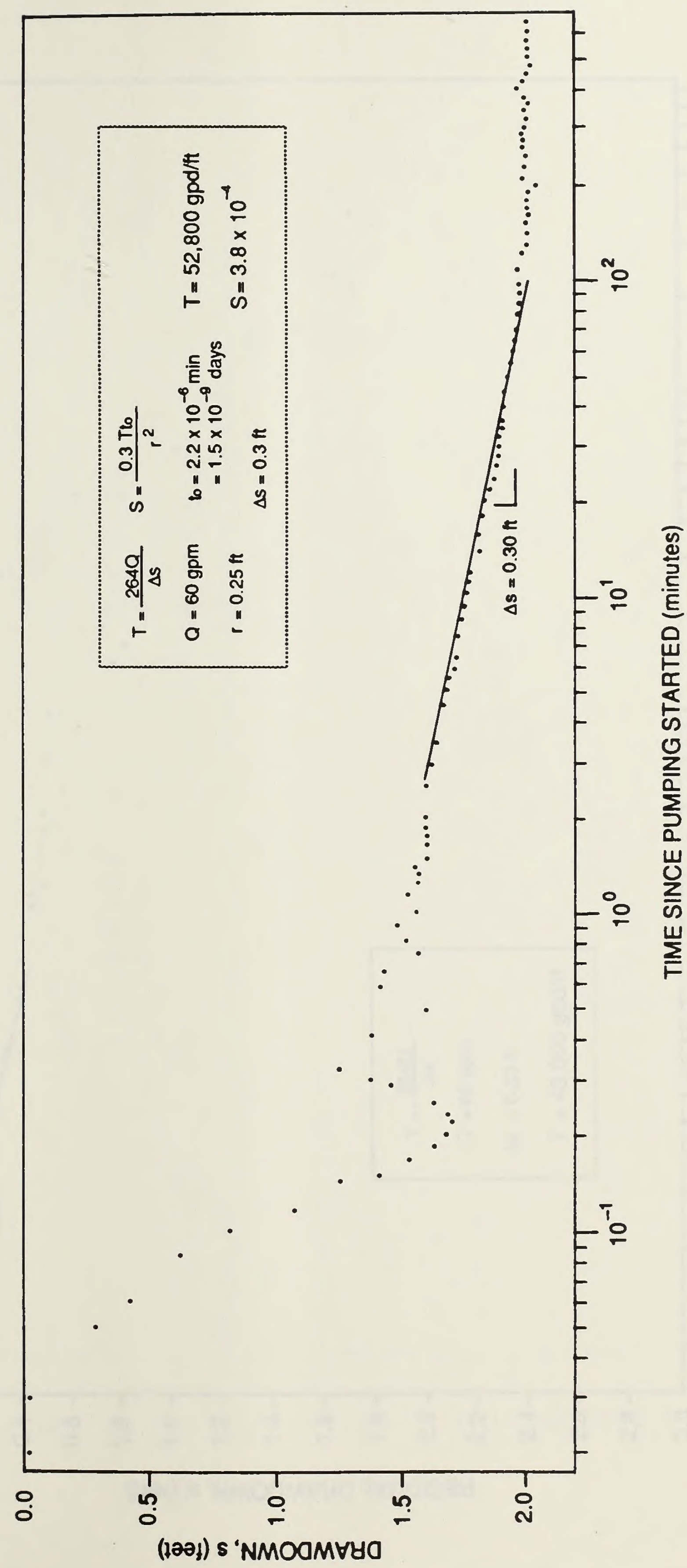
Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR TW-12 COOPER-JACOB METHOD	Figure 4-12
Woodward-Clyde Consultants			



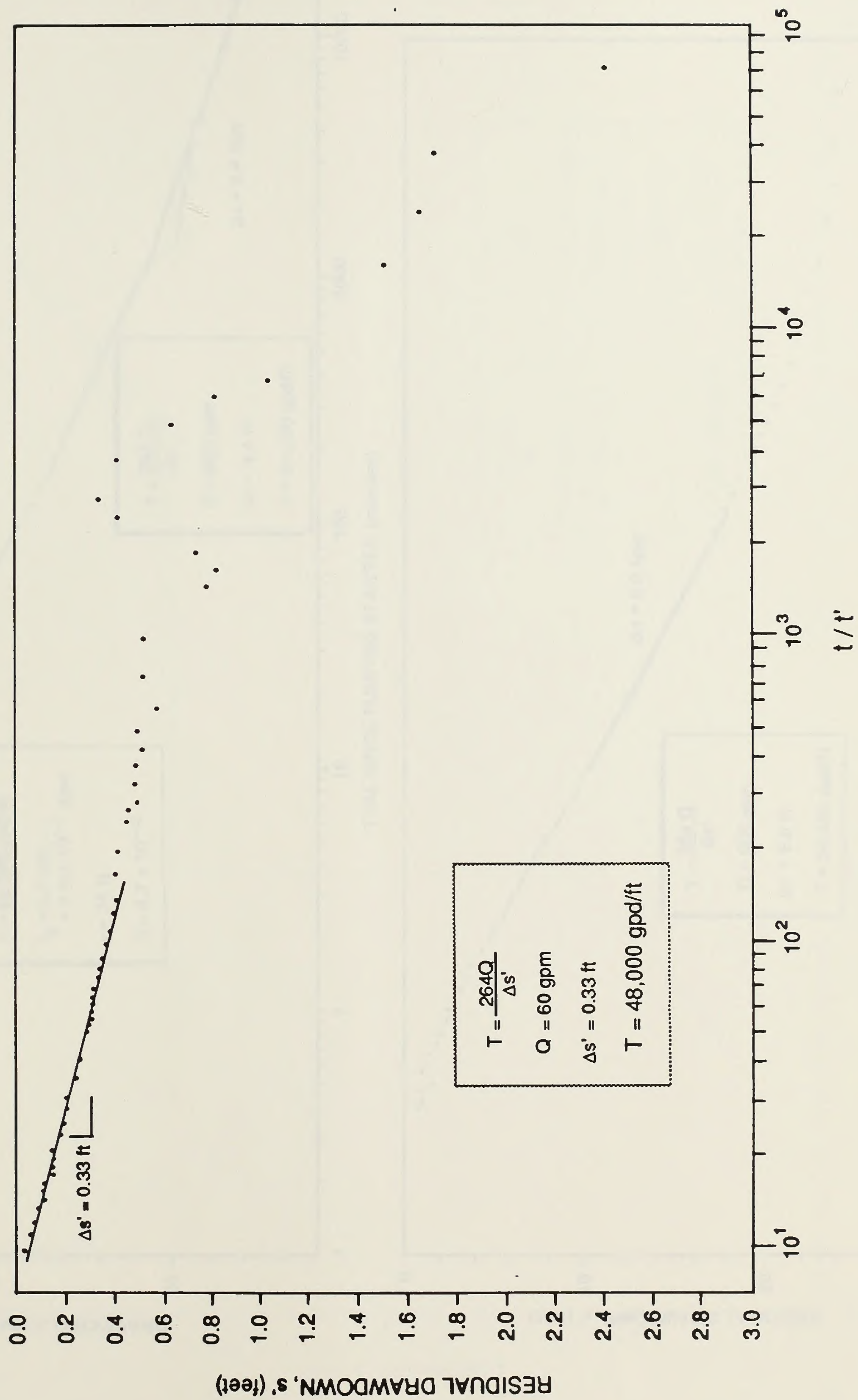
Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR TW-14 COOPER-JACOB METHOD	Figure 4-13
Woodward-Clyde Consultants			



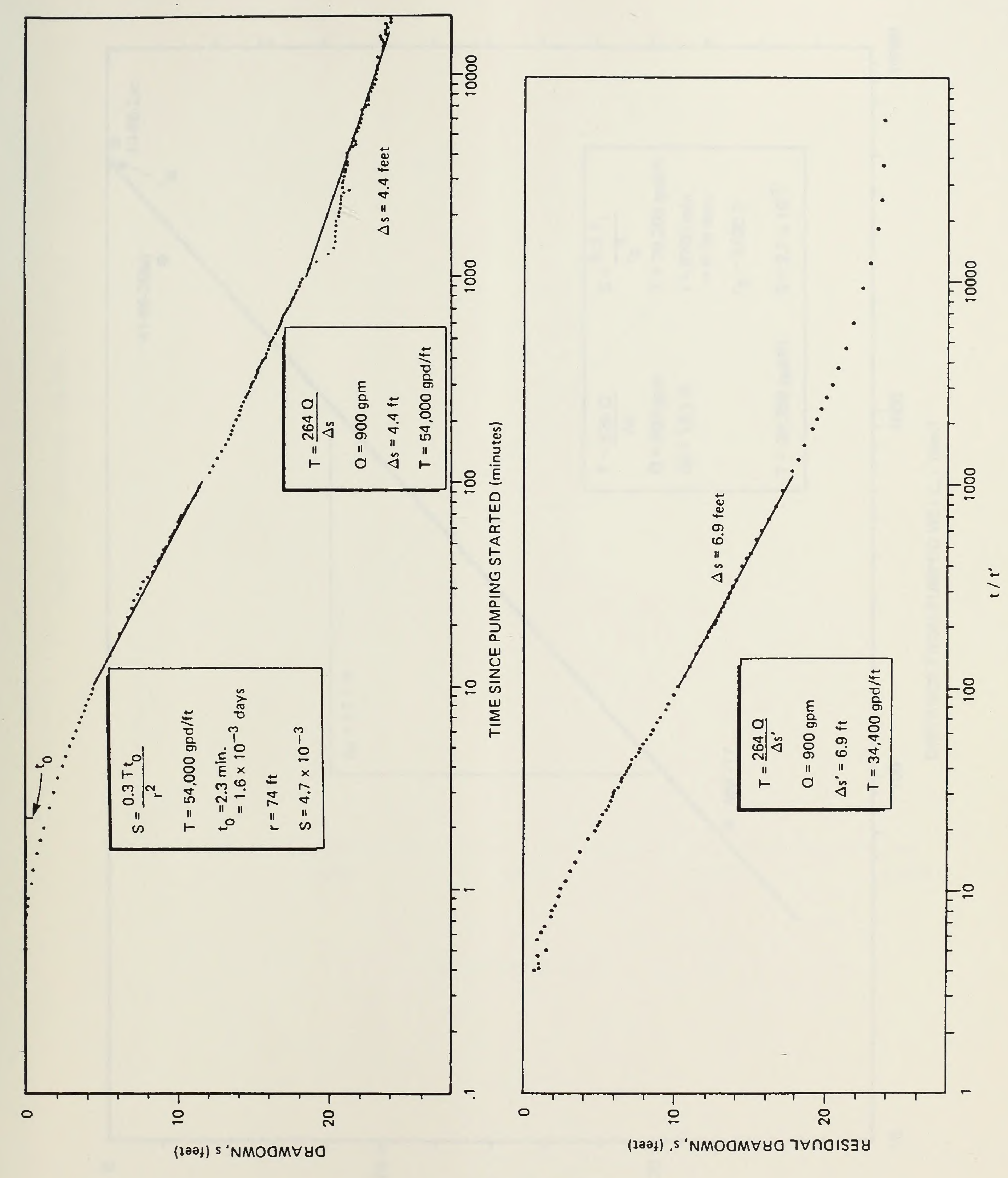
Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR TW-14 COOPER-JACOB METHOD	Figure 4-14
Woodward-Clyde Consultants			



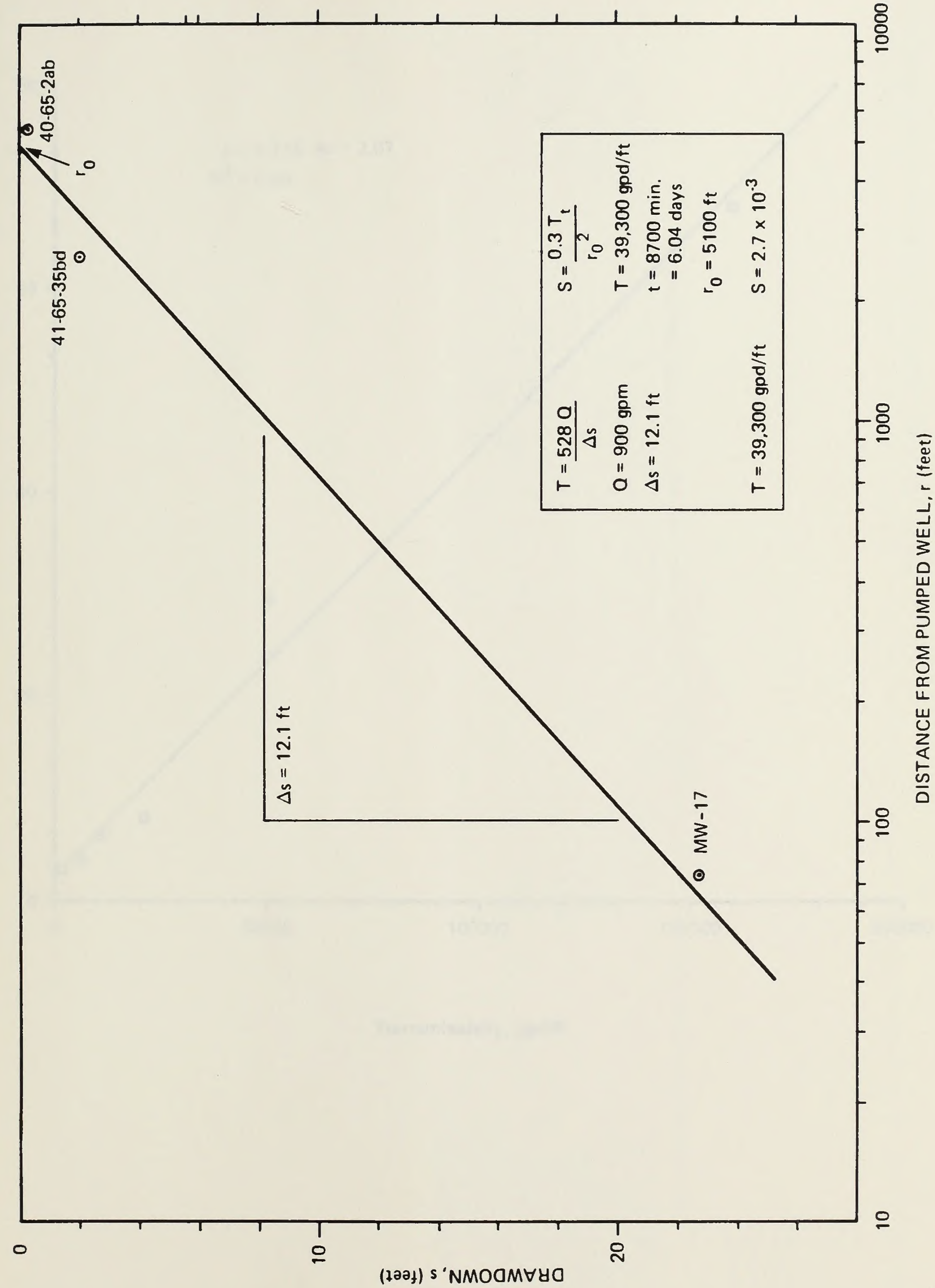
Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN PLOT FOR TW-15 COOPER-JACOB METHOD	Figure 4-15
Woodward-Clyde Consultants			



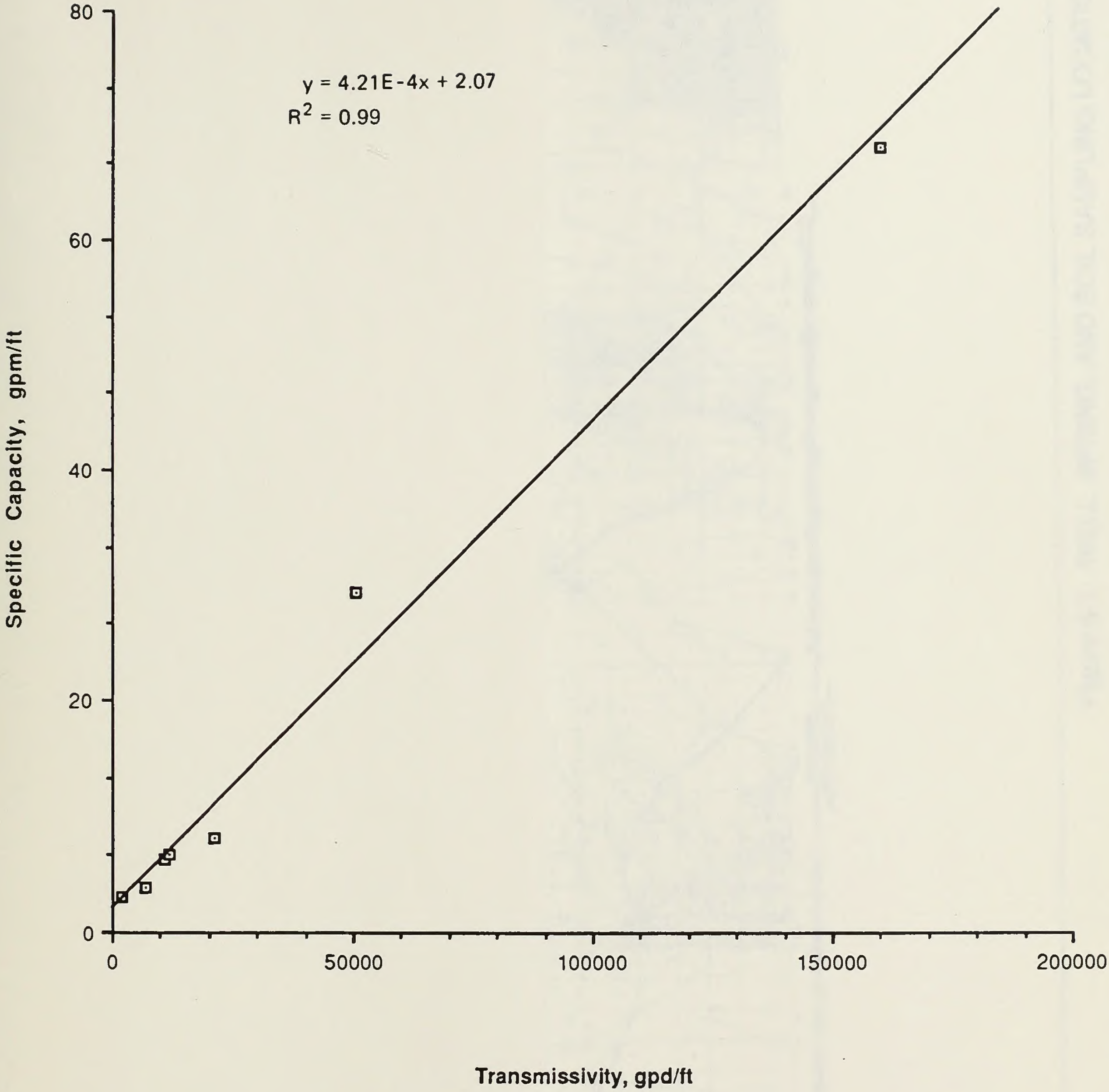
Project No. 90270B	Thousand Springs Power Plant	RECOVERY PLOT FOR TW-15 COOPER-JACOB METHOD	Figure 4-16
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN AND RECOVERY PLOT FOR MW-17	Figure 4-17
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power Plant	DISTANCE-DRAWDOWN PLOT OF MONITORING WELLS IN VICINITY OF WELL 41-65-35ad	Figure 4-18
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power Plant	CORRELATION OF SPECIFIC CAPACITIES OF WELLS TO AQUIFER TRANSMISSIVITIES	Figure 4-19
Woodward-Clyde Consultants			

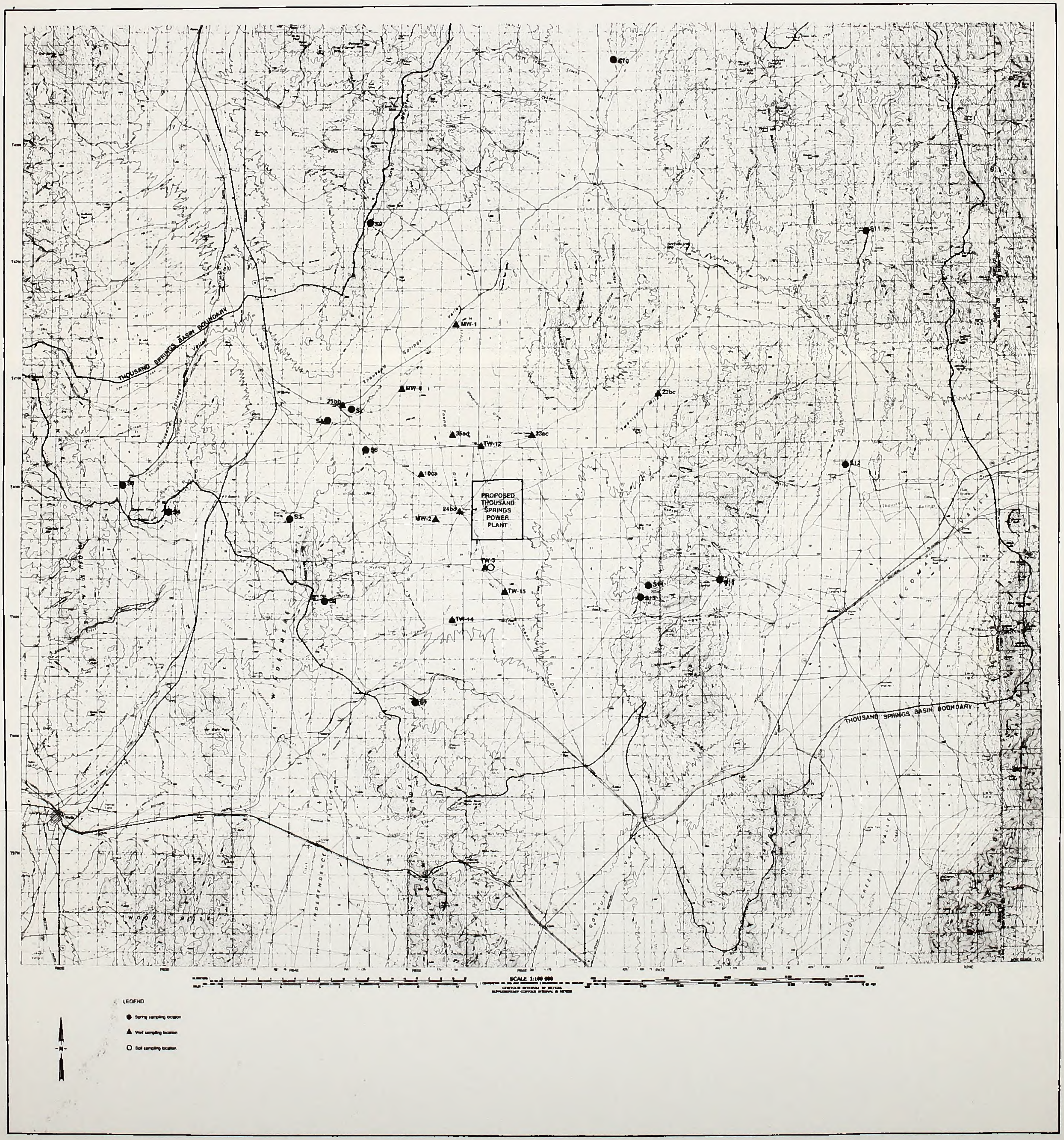


Figure 5-1. WELL, SPRING, AND SOIL SAMPLING LOCATION MAP

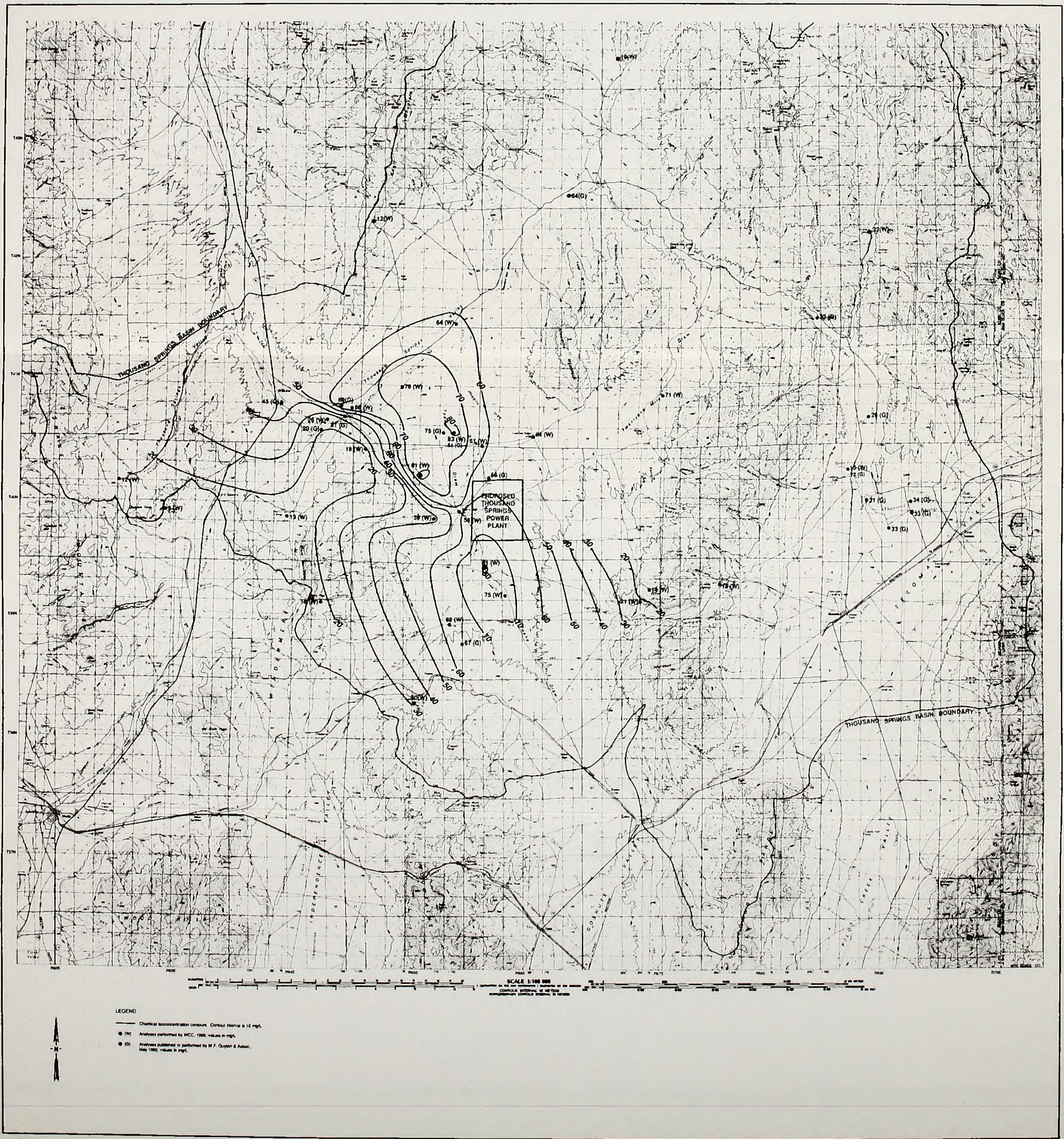


Figure 5-2. SILICA (SiO_2) CONCENTRATIONS IN GROUNDWATER SAMPLES OF WELLS AND SPRINGS

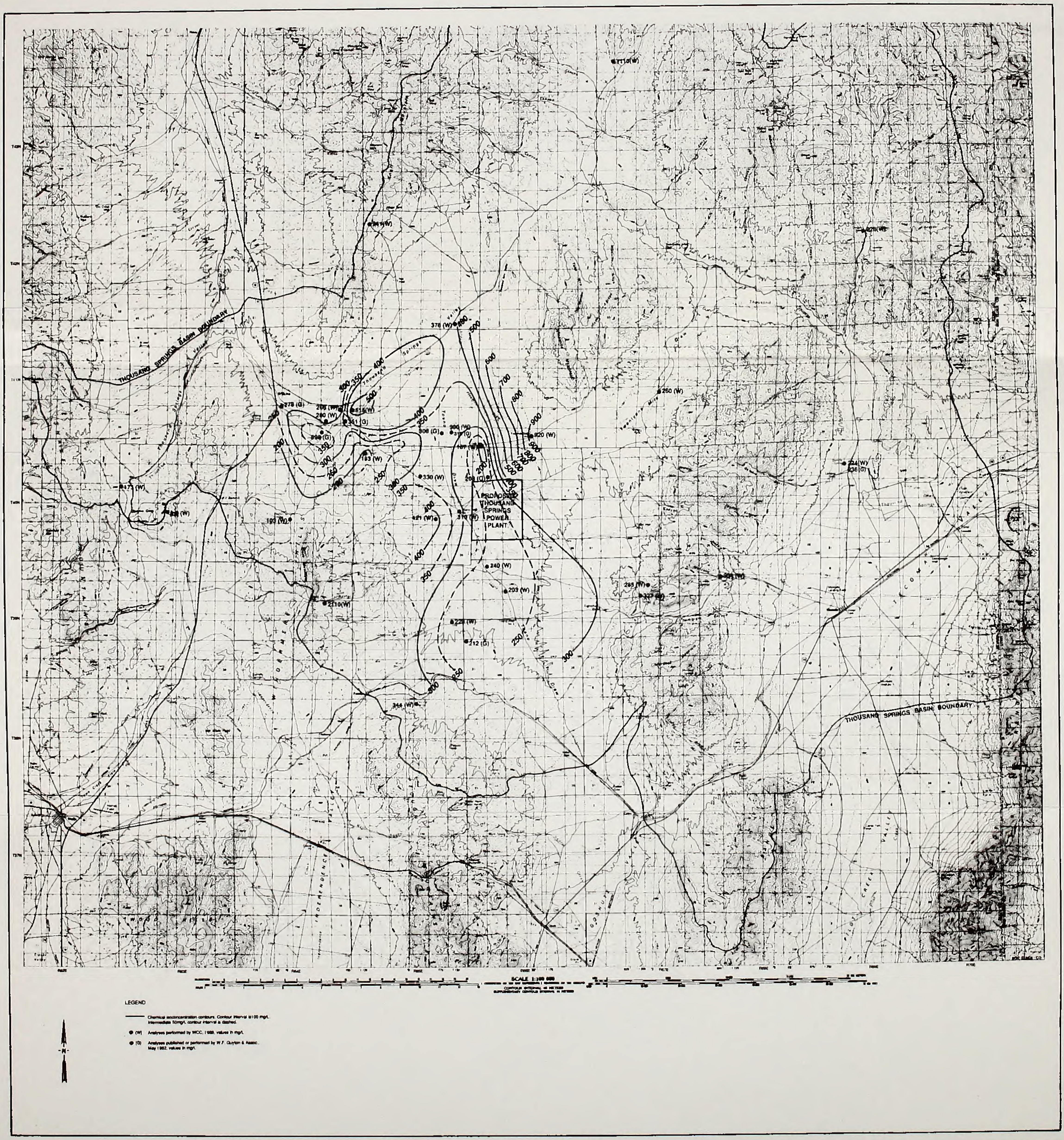


Figure 5-3. TOTAL DISSOLVED SOILDS CONCENTRATIONS IN GROUNDWATER SAMPLES OF WELLS AND SPRINGS

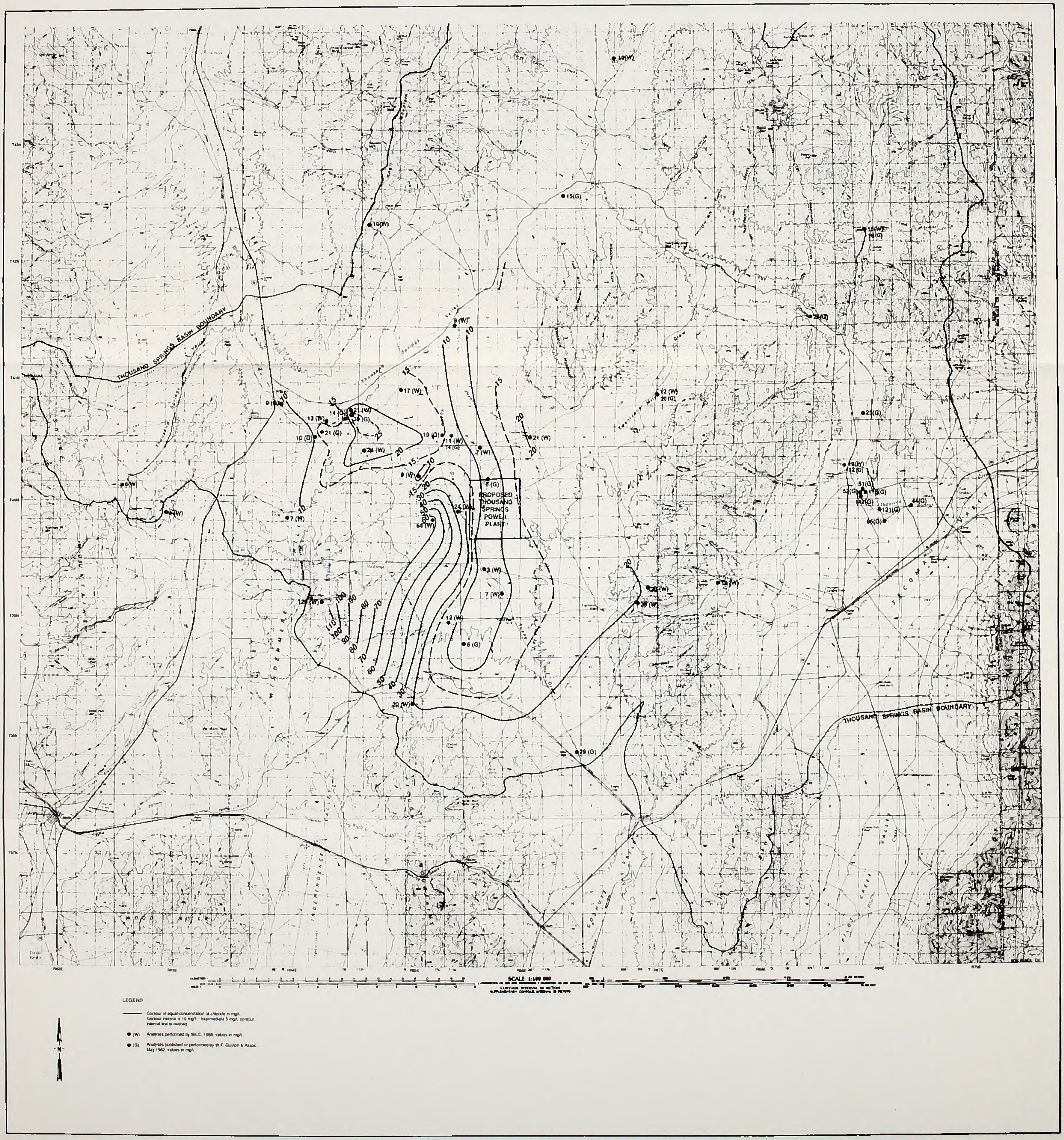


Figure 5-4. CHLORIDE CONCENTRATIONS IN GROUNDWATER SAMPLES OF WELLS AND SPRINGS

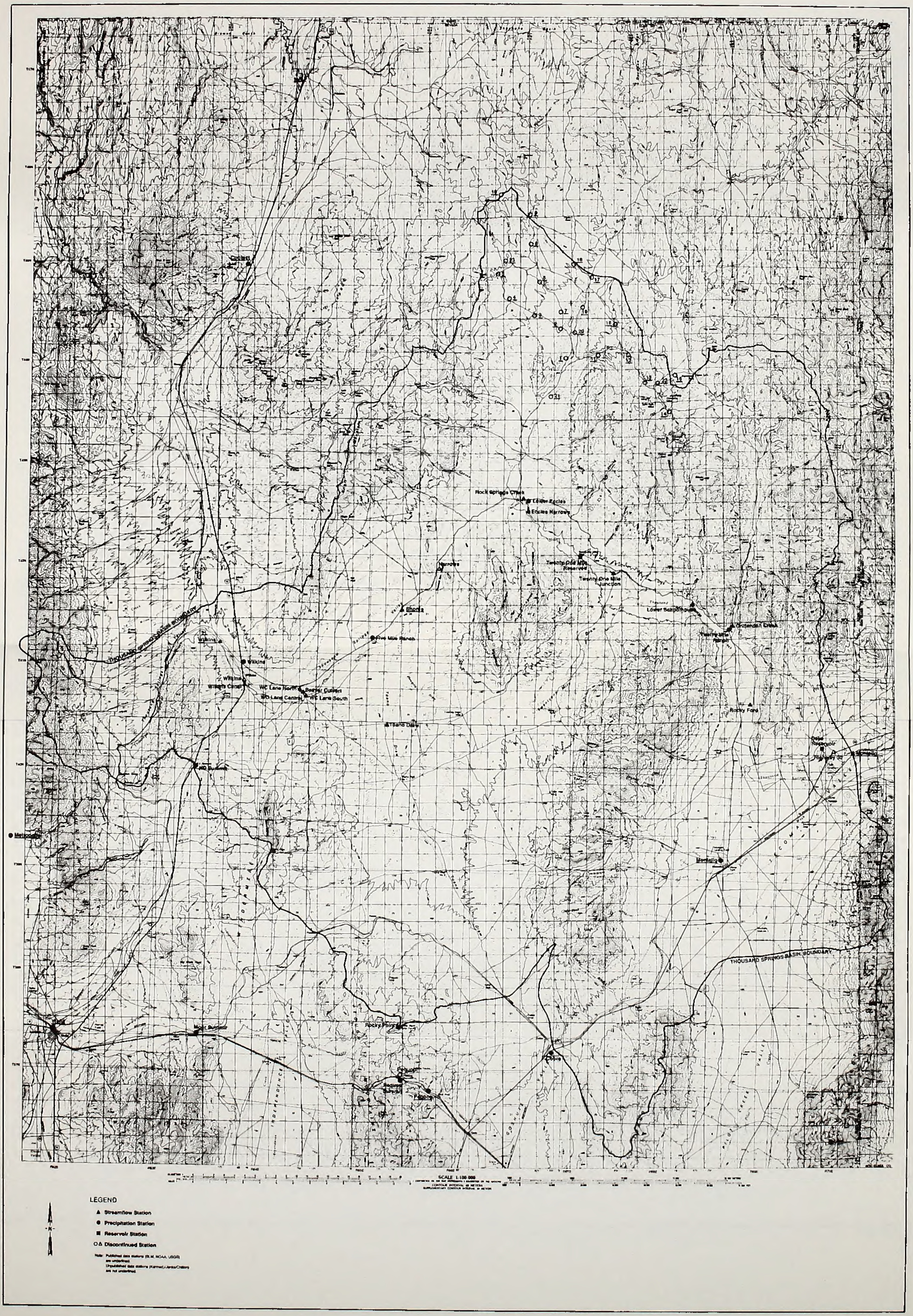
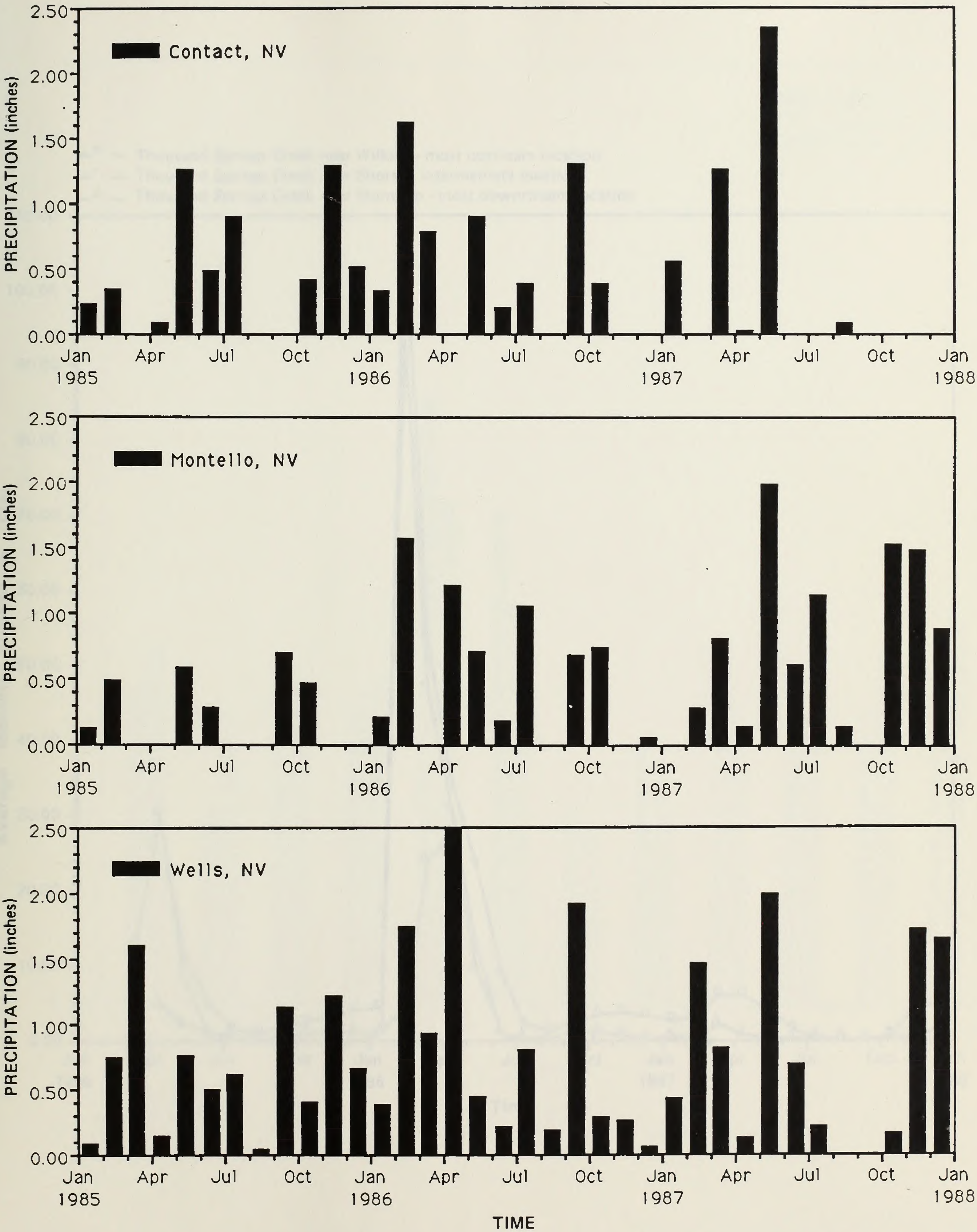
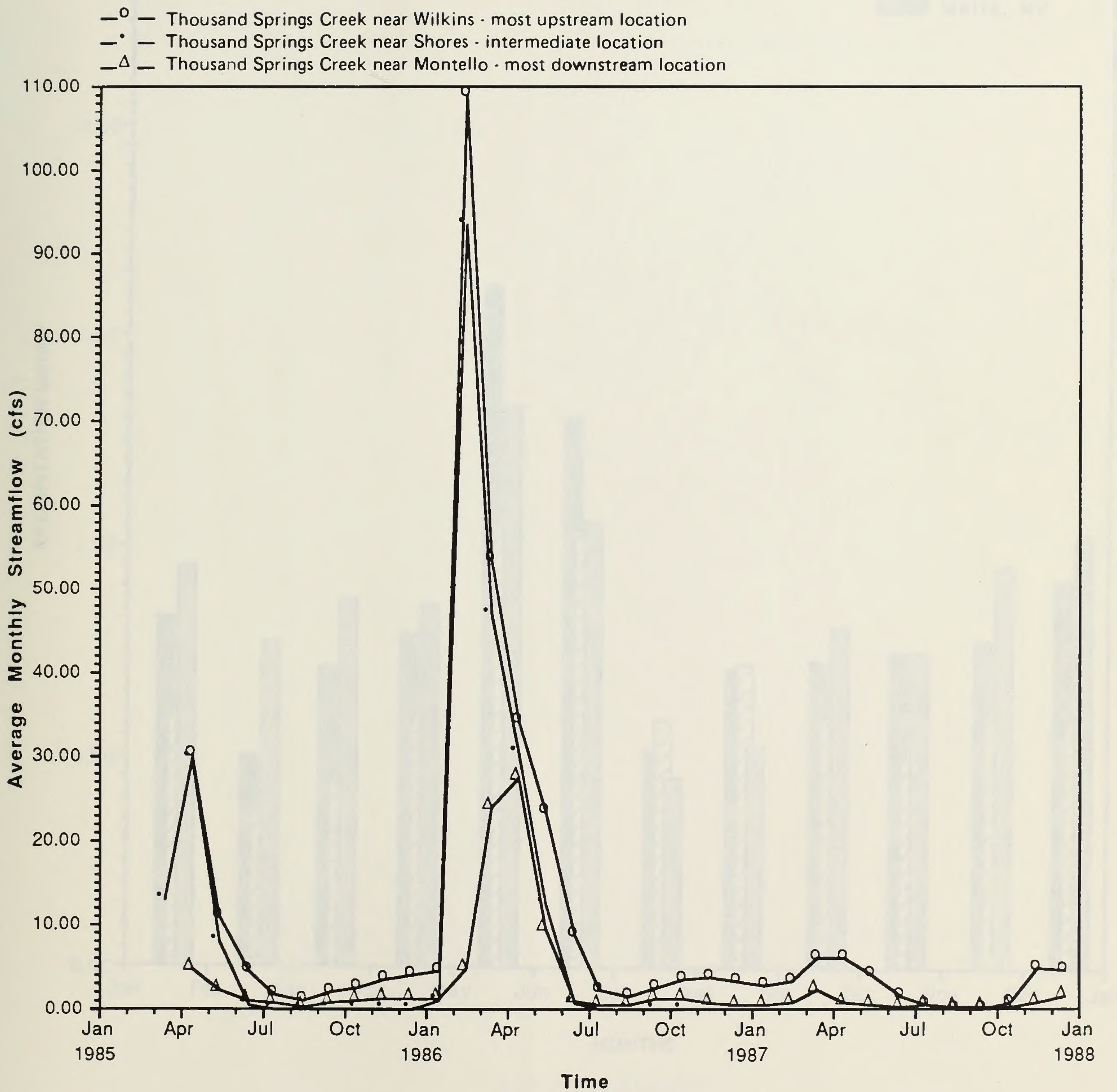


Figure. 6-1. STREAMFLOW, PRECIPITATION, AND RESERVOIR MONITORING STATIONS



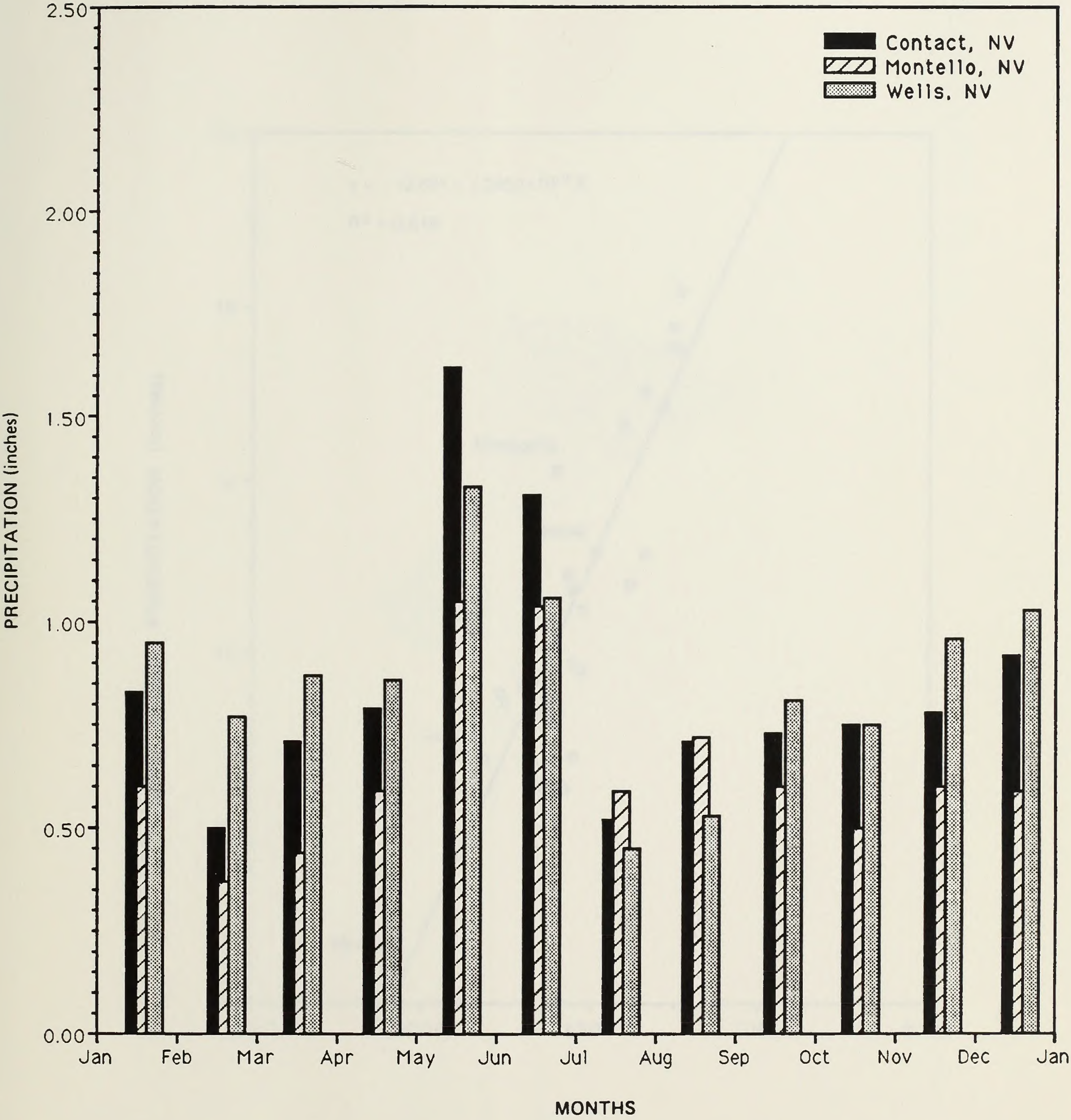
Data provided by Chilton Engineering.

Project No. 90270B	Thousand Springs Power Plant	TOTAL MONTHLY PRECIPITATION AT CONTACT, MONTELLO, AND WELLS MONITORING STATIONS, 1985 - 1987	Figure 6-2
Woodward-Clyde Consultants			



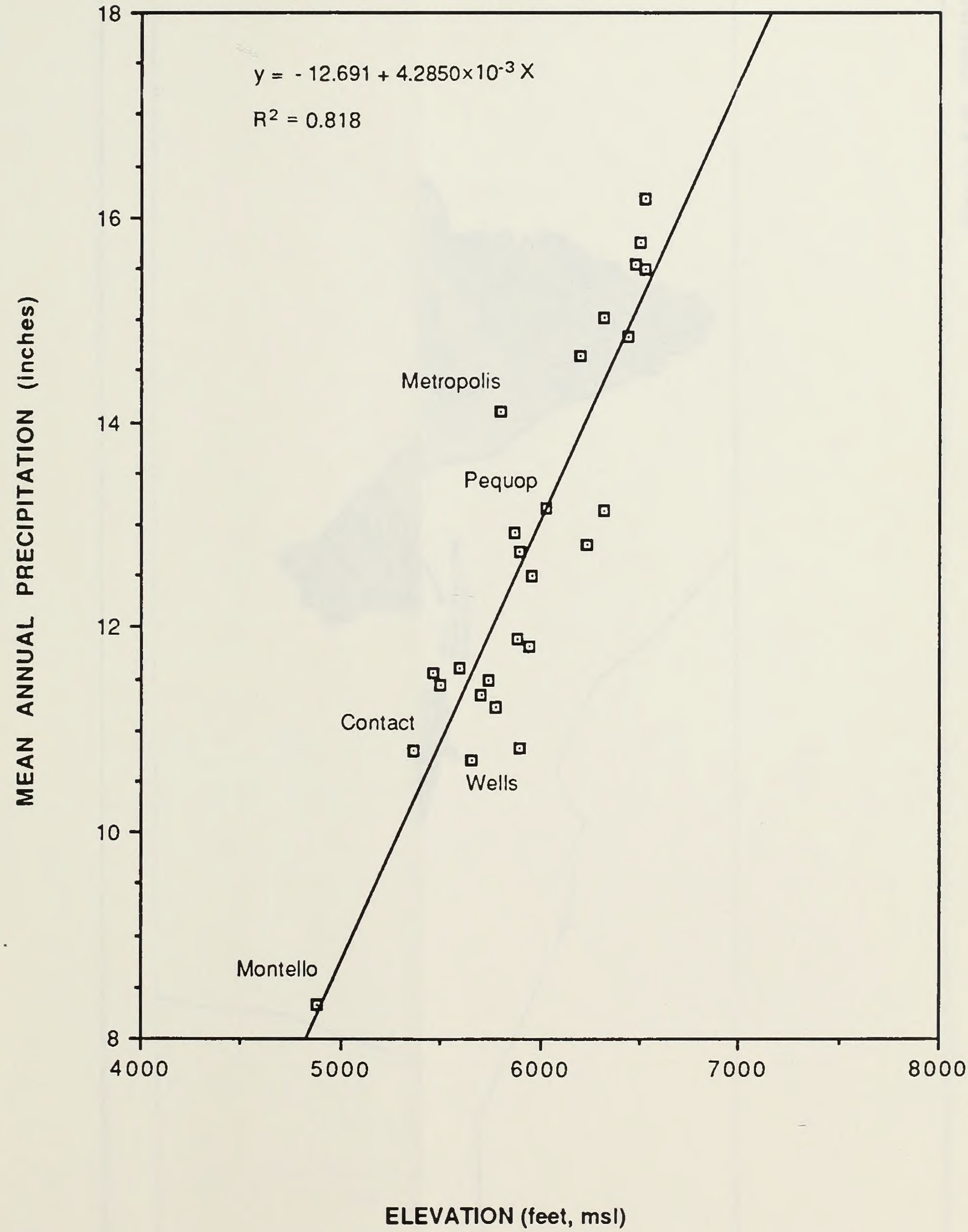
Data Provided by USGS

Project No. 90270B	Thousand Springs Power Plant	AVERAGE MONTHLY STREAMFLOW AT WILKINS, SHORES, AND MONTELLO GAGING STATIONS, 1985-1987	Figure 6-3
Woodward·Clyde Consultants			



Compiled by Woodward-Clyde Consultants from Data Provided by NOAA

Project No. 90270B	Thousand Springs Power Plant	AVERAGE MONTHLY PRECIPITATION AT CONTACT, MONTELLO, AND WELLS MONITORING STATIONS, 1949-1983	Figure 6-4
Woodward-Clyde Consultants			



Orographic analysis performed by Woodward-Clyde Consultants based on NOAA and BLM data

Project No. 90270B	Thousand Springs Power Plant	MEAN ANNUAL PRECIPITATION VERSUS ELEVATION AT NOAA AND BLM STATIONS 1963 – 1980	Figure 6-5
Woodward-Clyde Consultants			

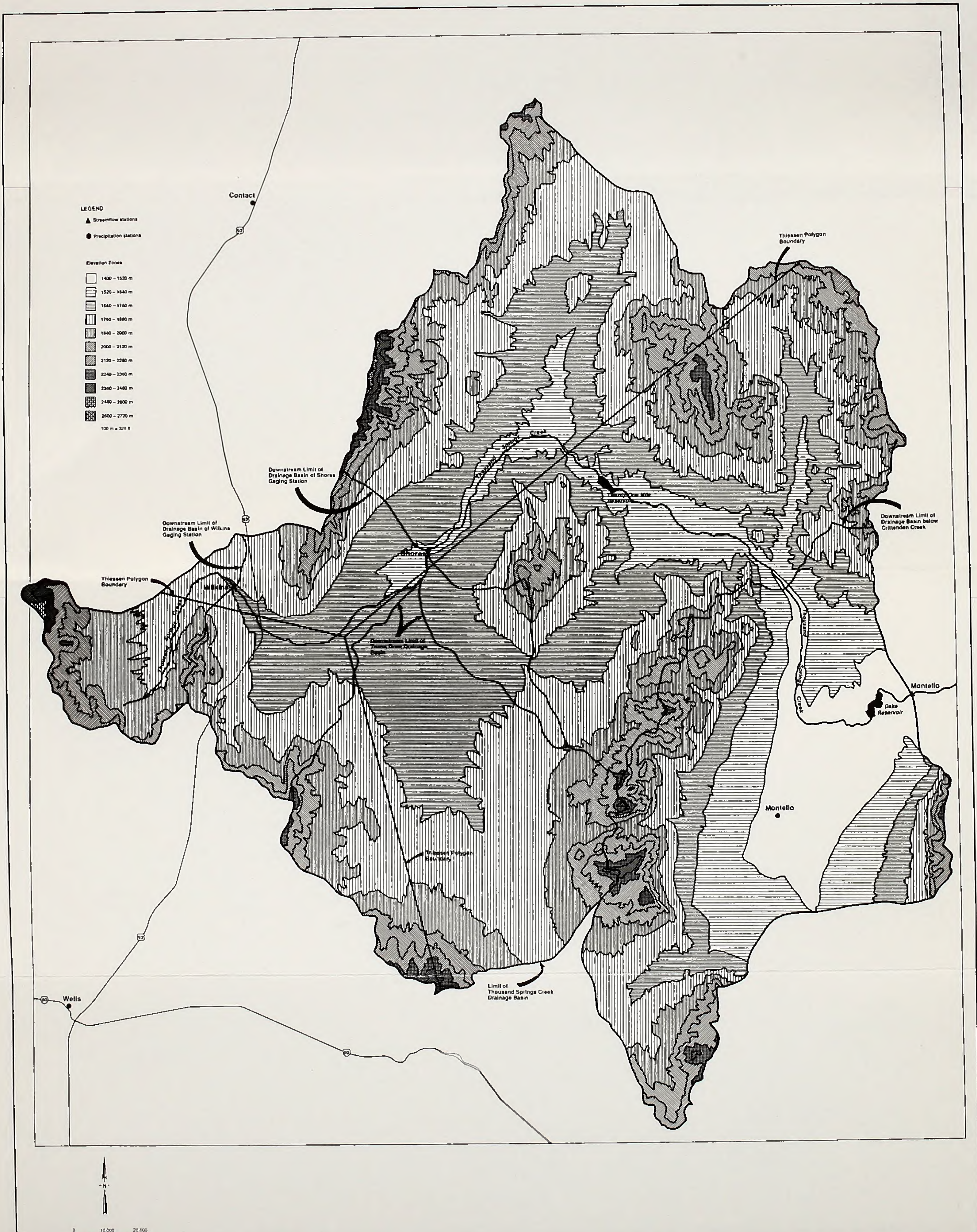
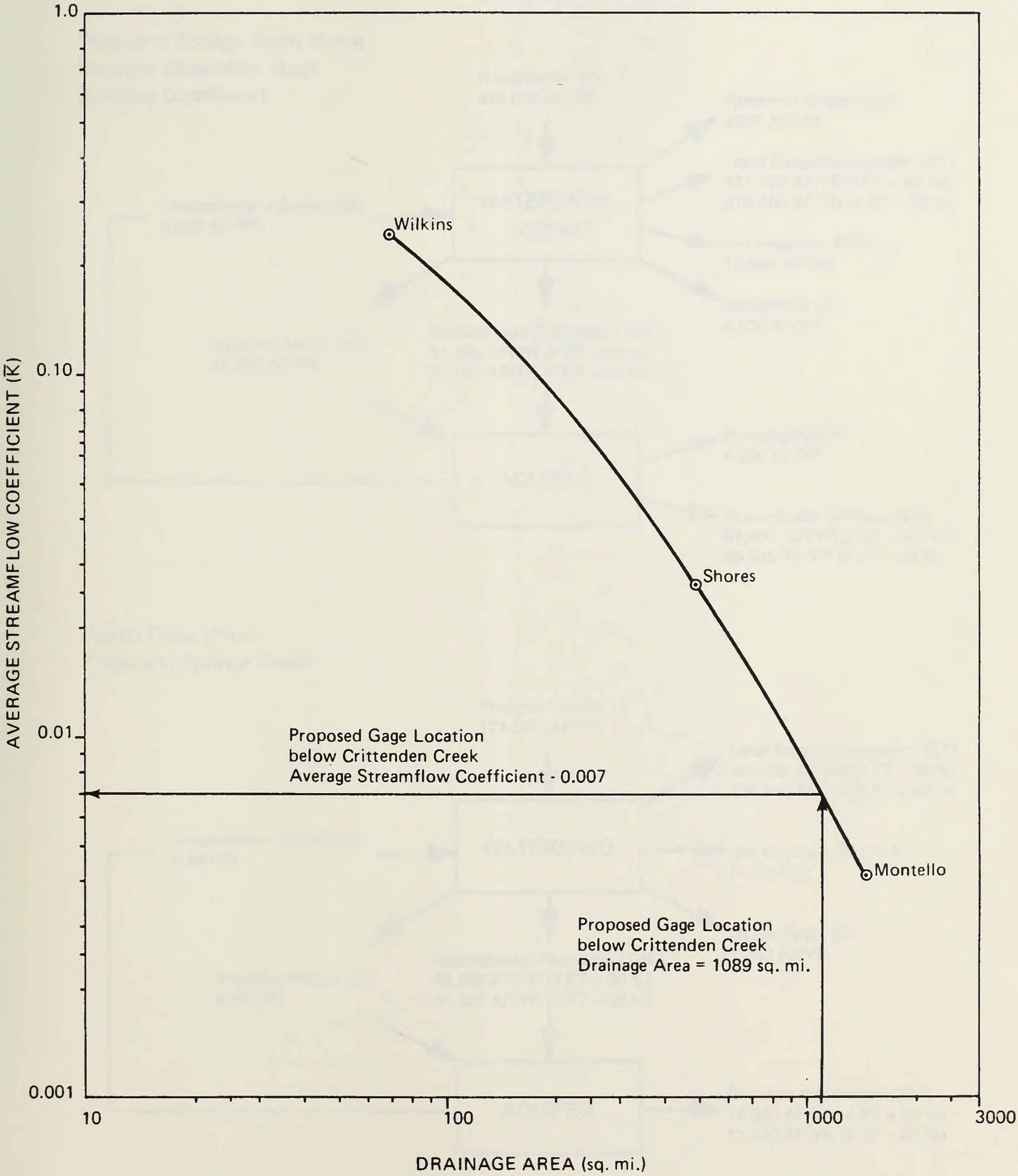
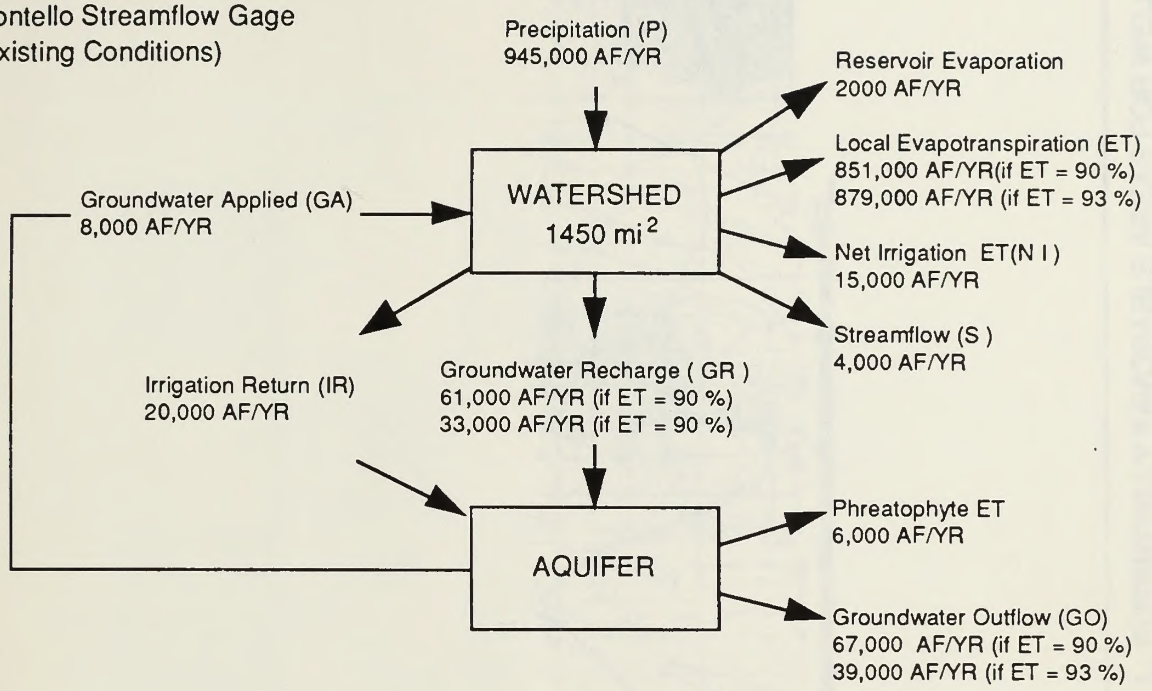


Figure 6-6. DRAINAGE BASIN MODEL

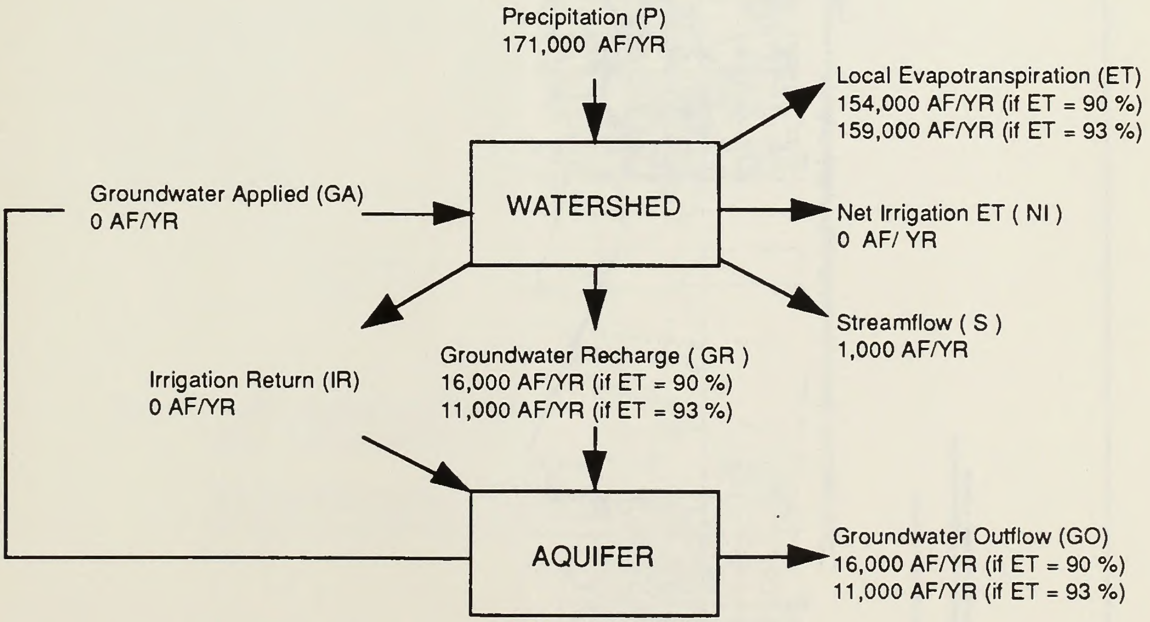


Project No. 90270B	Thousand Springs Power Plant	AVERAGE STREAMFLOW COEFFICIENT VERSUS DRAINAGE AREA FOR THOUSAND SPRINGS CREEK	Figure 6-7
Woodward-Clyde Consultants			

Thousand Springs Basin above
Montello Streamflow Gage
(Existing Conditions)



Toano Draw above
Thousand Springs Creek



Project No. 90270B	Thousand Springs Power Plant	HYDROLOGIC BUDGET ESTIMATES FOR THOUSAND SPRINGS BASIN AND TOANO DRAW SUBBASIN	Figure 6-8
Woodward-Clyde Consultants			

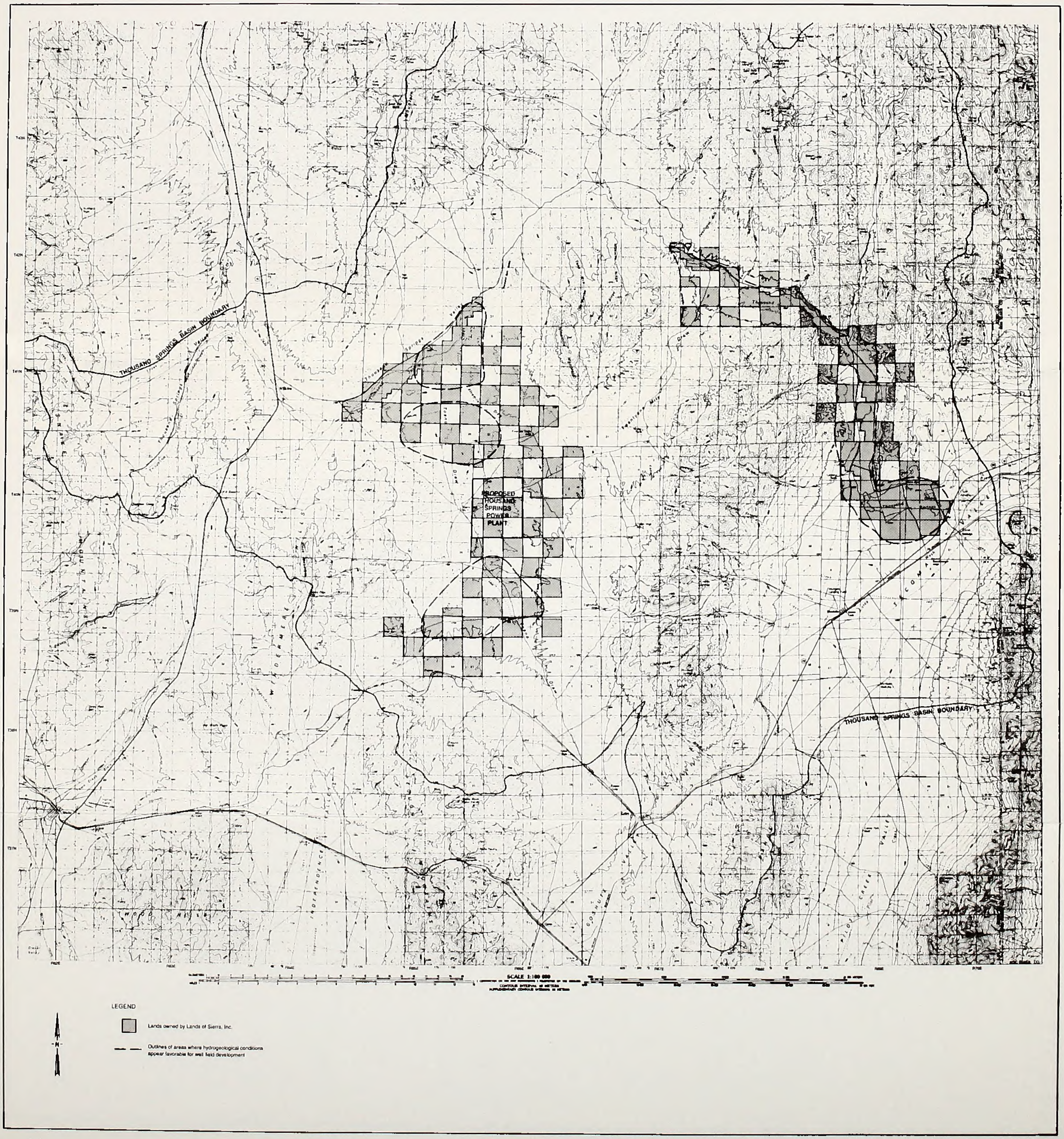
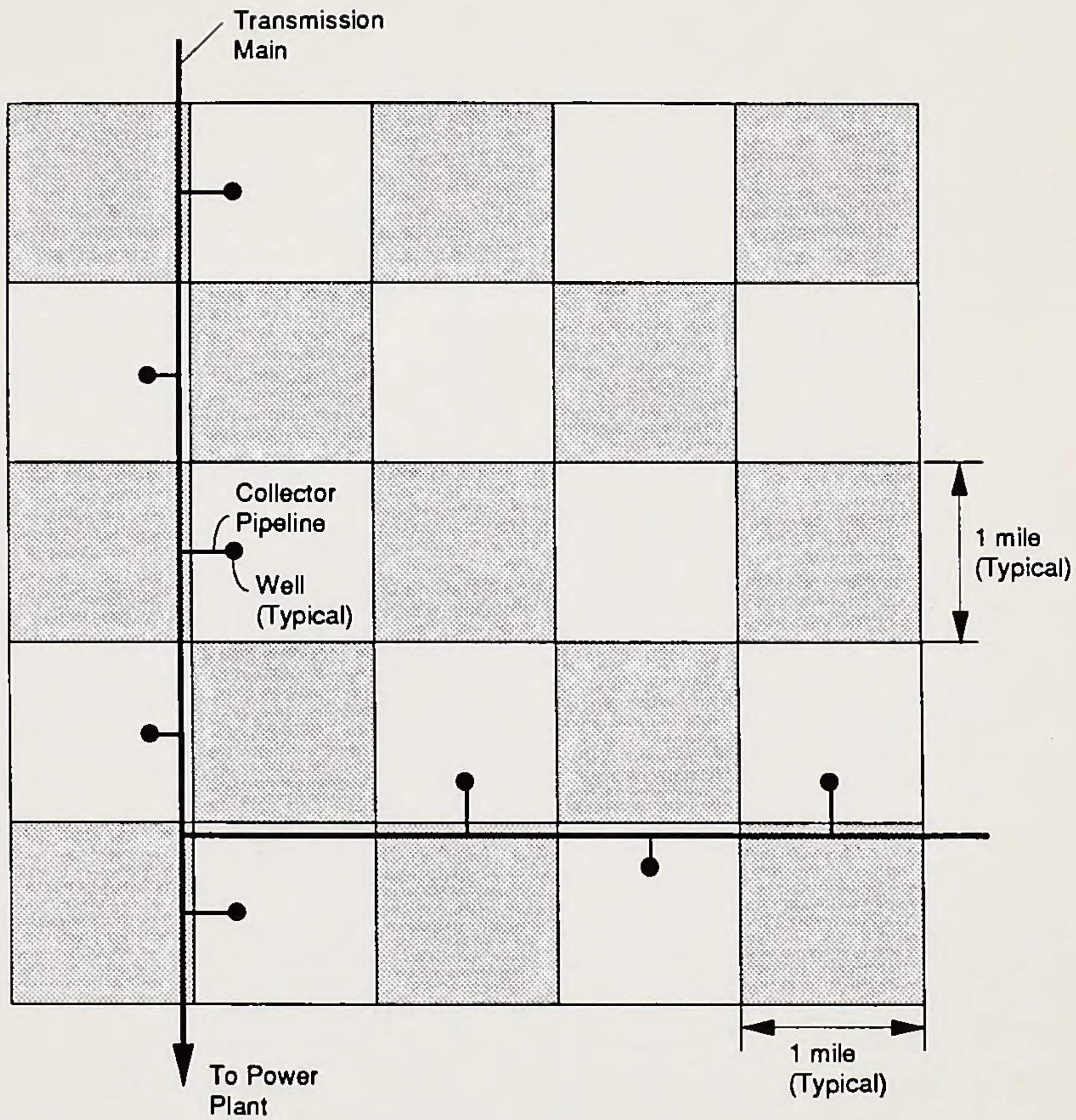


Figure 7-1. POTENTIALLY FAVORABLE AREAS FOR WELL FIELD TO SUPPLY POWER PLANT



Notes: Shaded sections are Public Lands administered by the BLM. Open sections owned by Lands of Sierra, Inc.

Actual well locations in selected sections will be based on results of detailed geophysical surveys and pilot borings

Project No. 90270B	Thousand Springs Power Plant	SCHEMATIC LAYOUT OF A WELL FIELD	Figure 7-2
Woodward-Clyde Consultants			

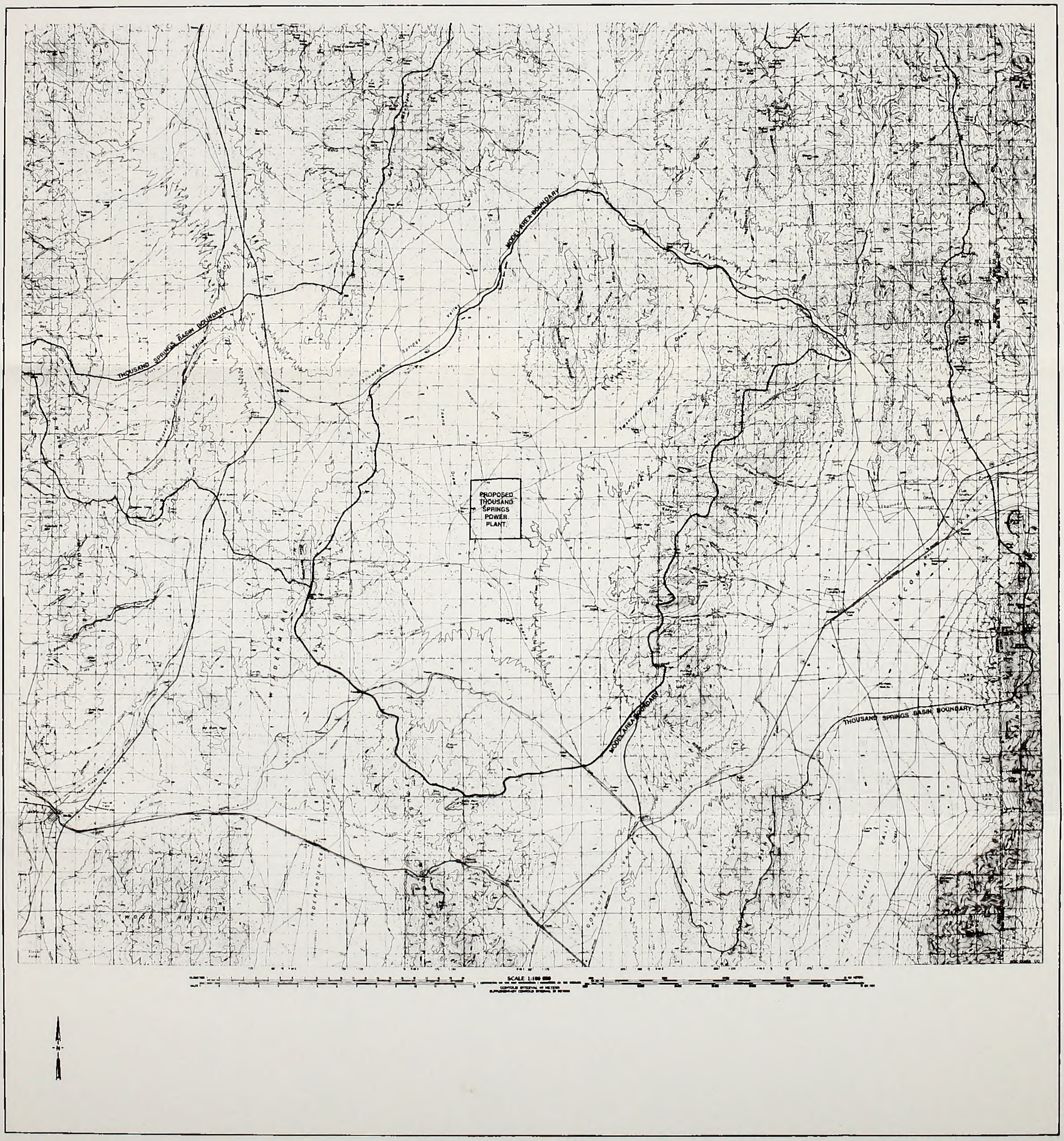


Figure 8-1. LOCATION OF THE MODEL AREA

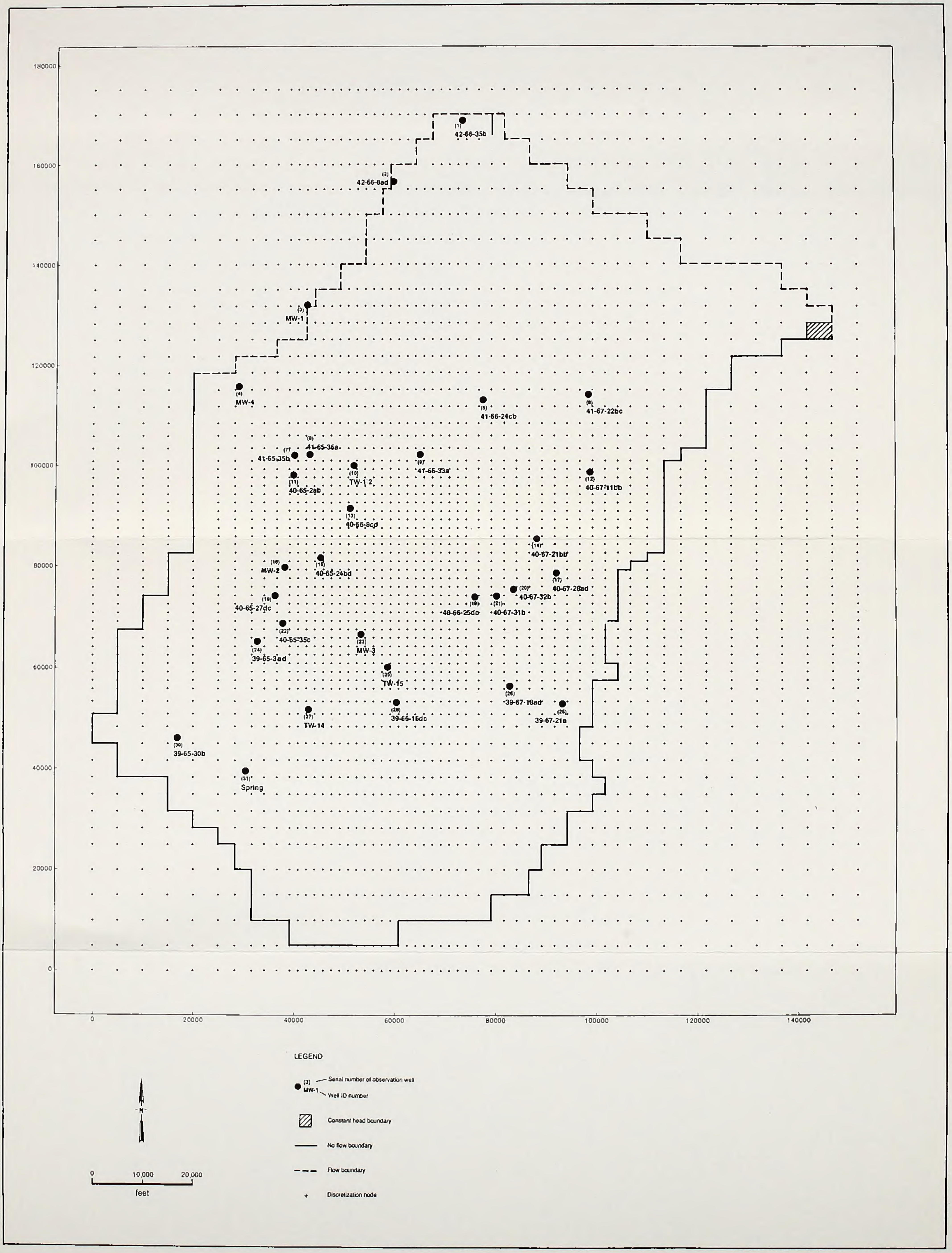
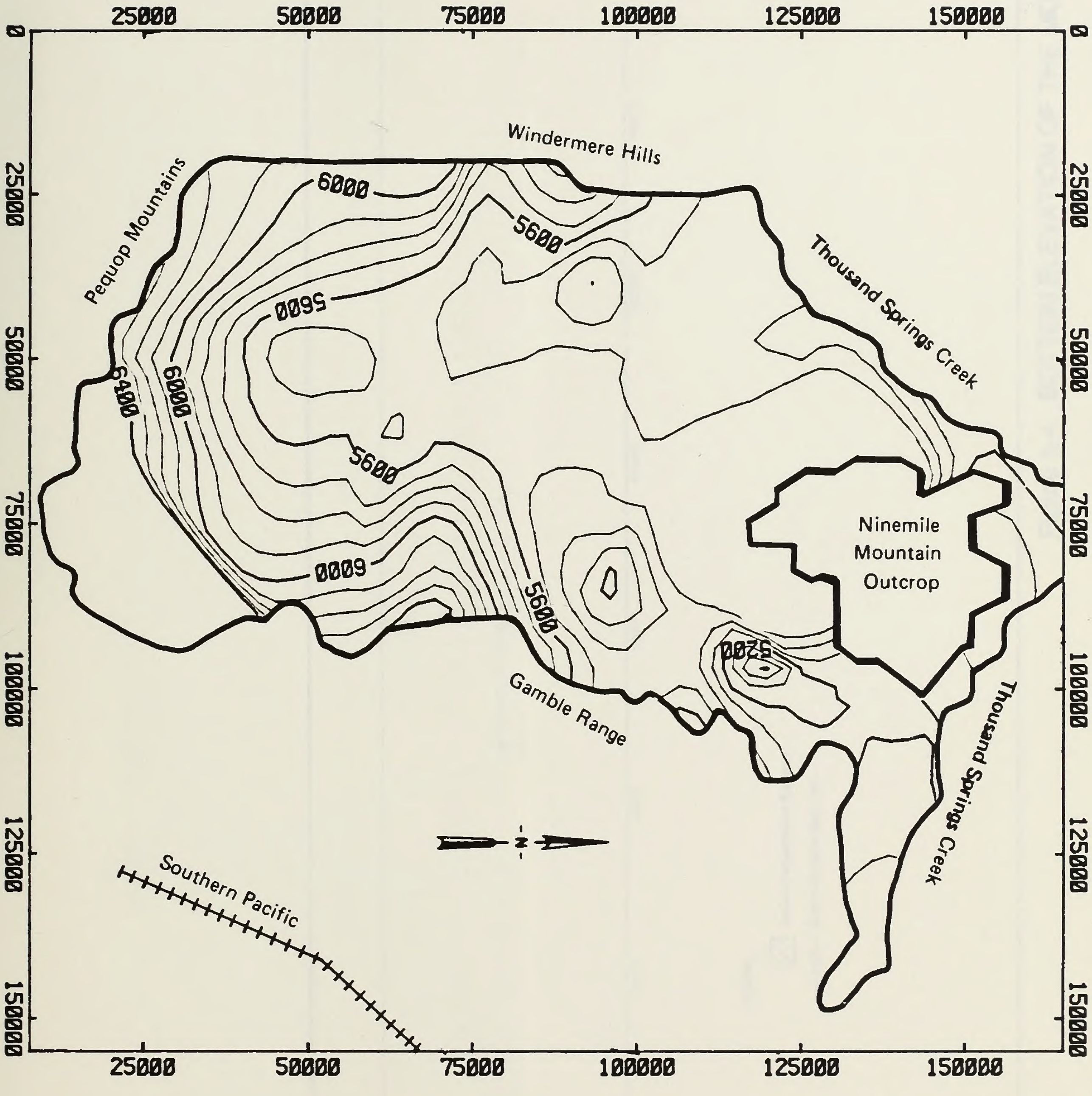


Figure 8-2. BOUNDARY CONDITIONS, SPATIAL DISCRETIZATION, AND LOCATION OF OBSERVATION WELLS



LEGEND

5600 Drawdown (feet)

Boundaries along mountain range correspond to the approximate edge of the Paleozoic rock outcrops

Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	WATER TABLE CONTOUR MAP BASED ON AVAILABLE DATA	Figure 8-3
Woodward-Clyde Consultants			

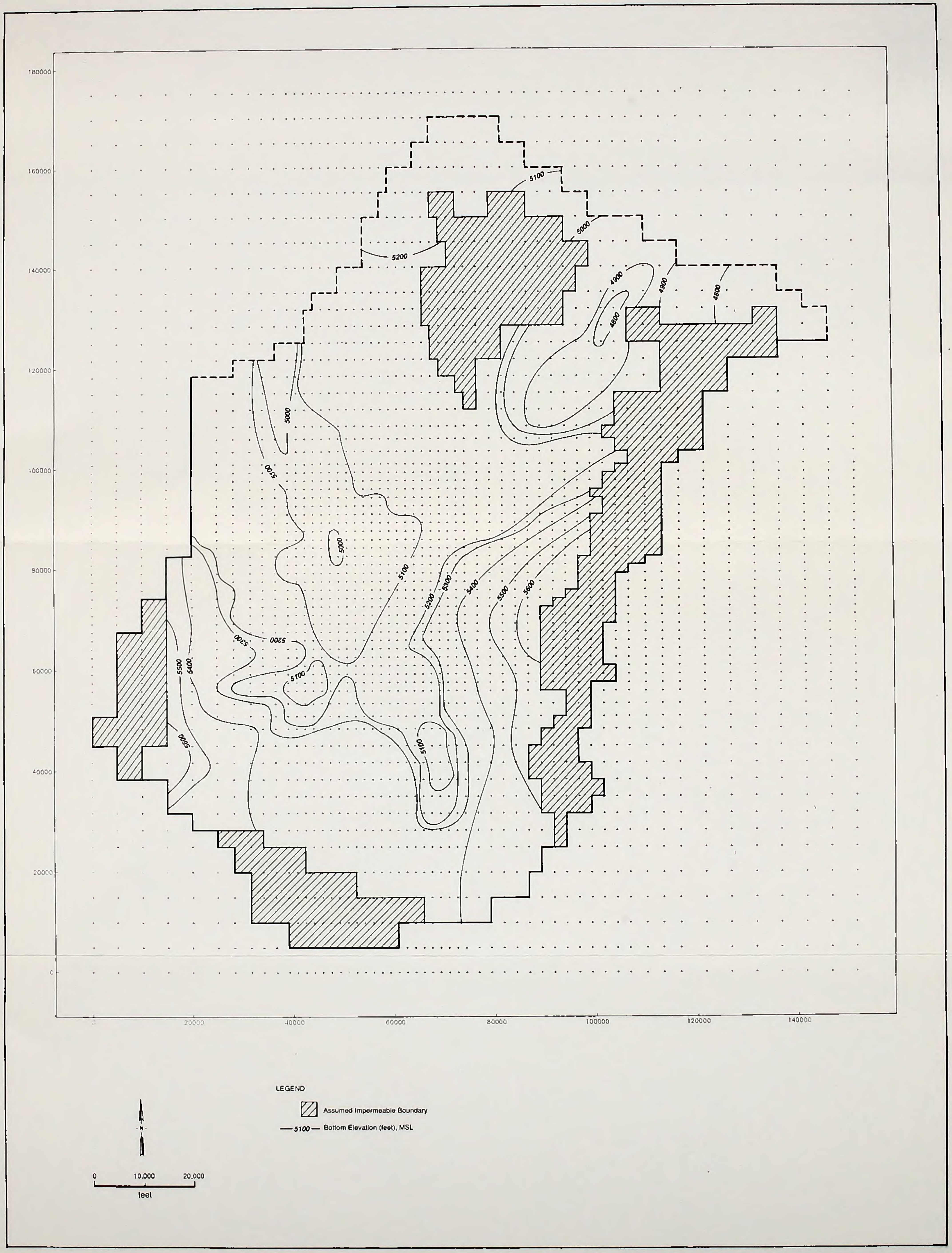
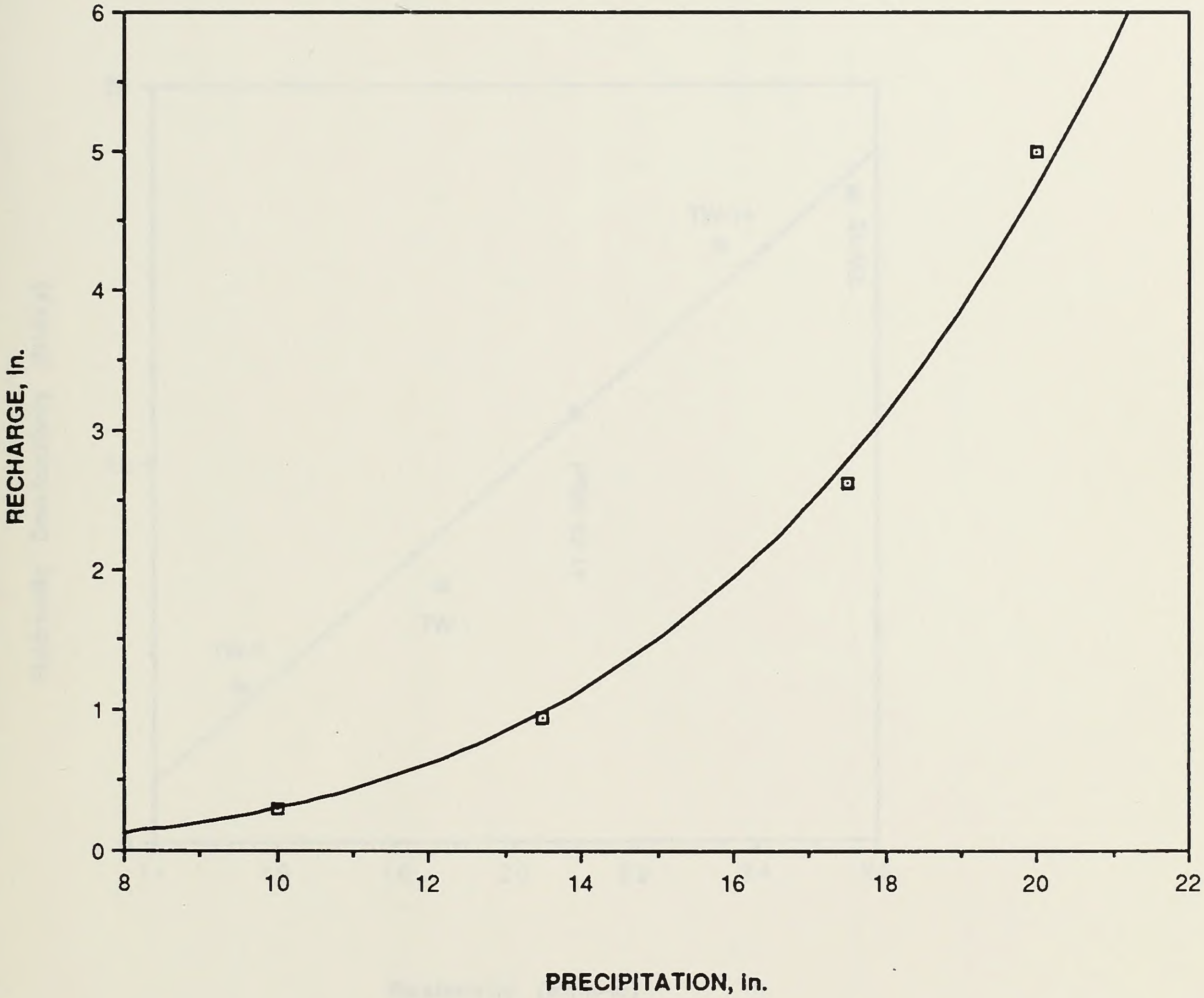
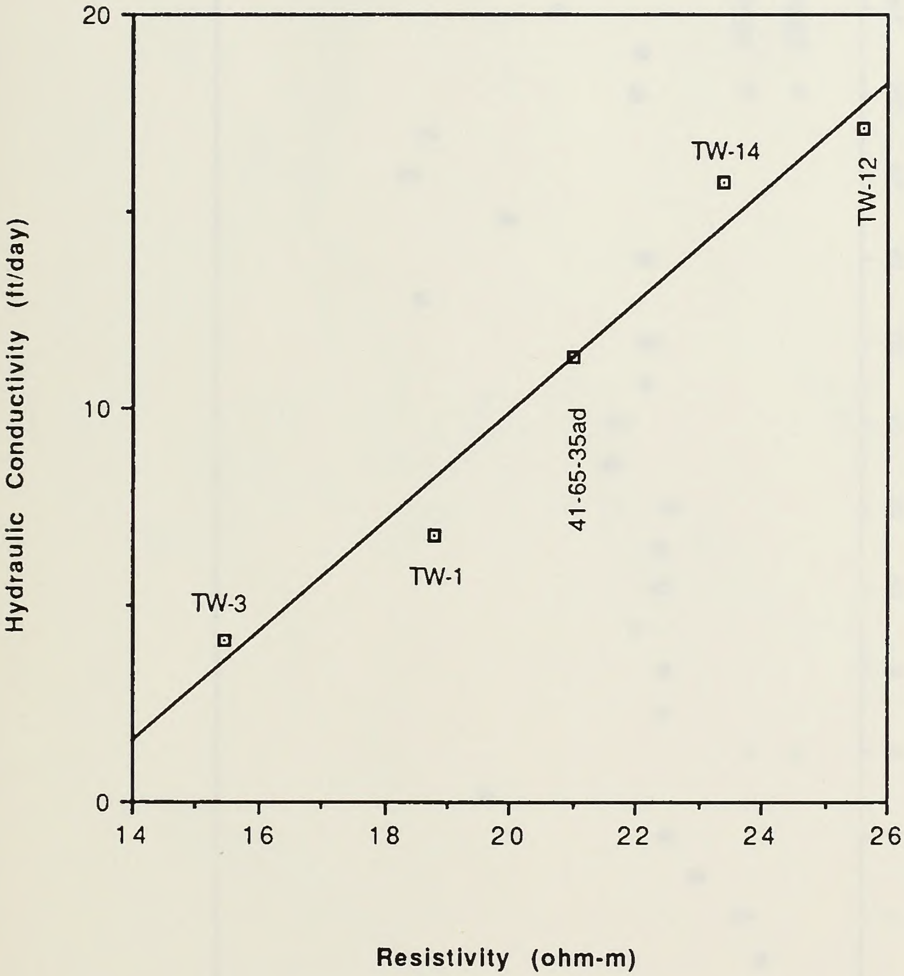


Figure 8-4. BOTTOM ELEVATION OF THE MODEL AREA

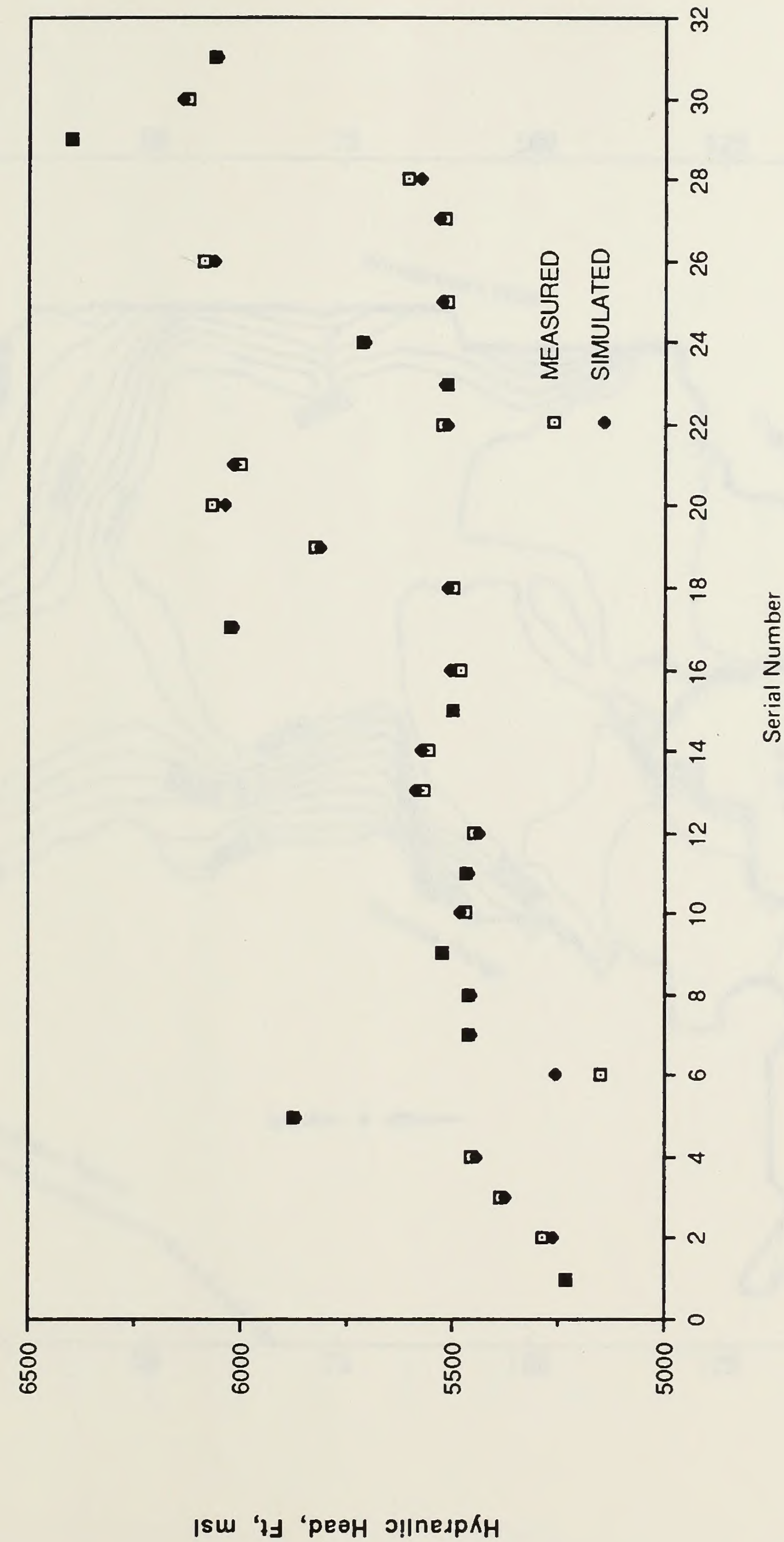


Source: Maxey and Eakin 1949.

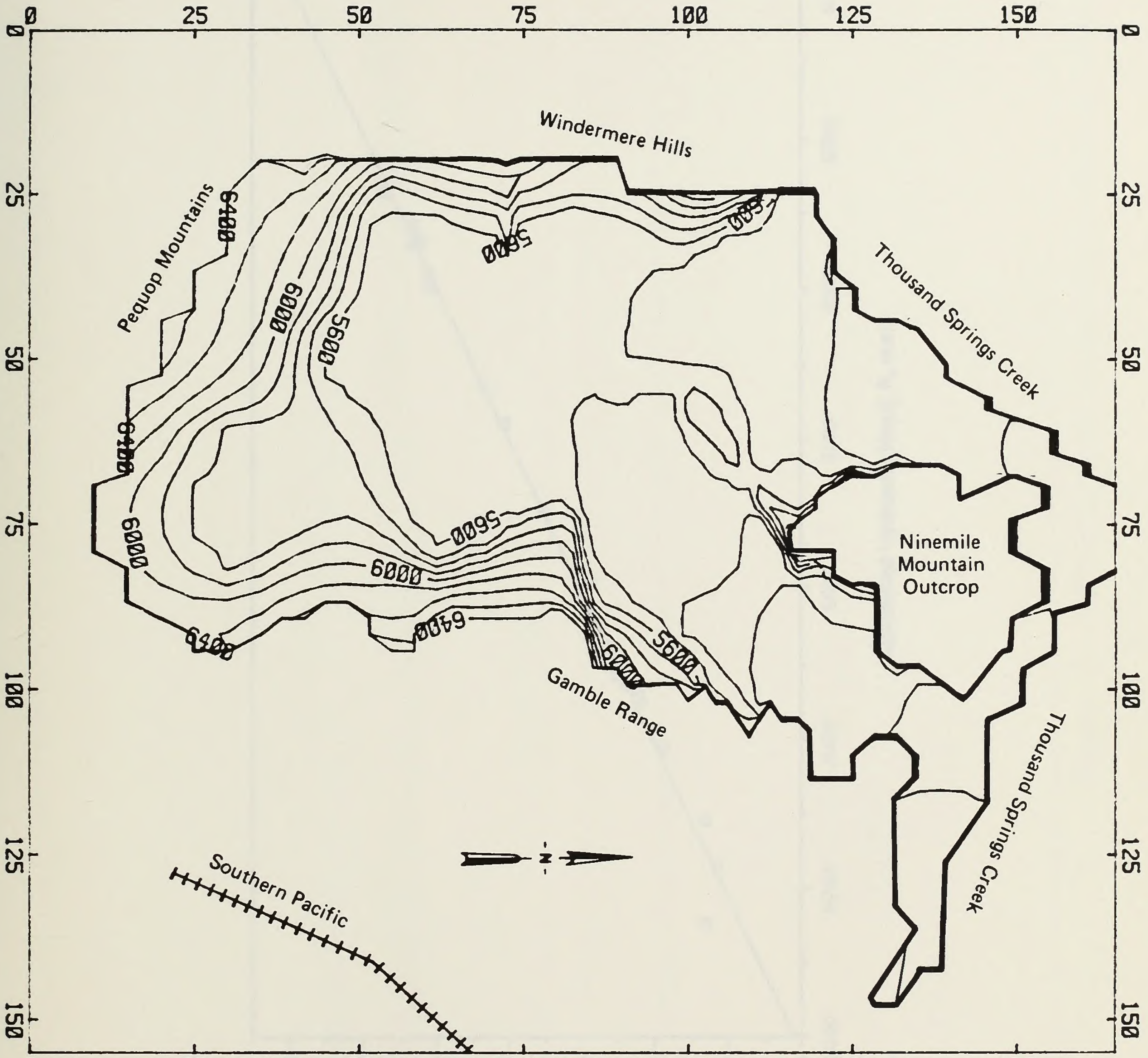
Project No. 90270B	Thousand Springs Power Plant	RELATIONSHIP BETWEEN RECHARGE AND PRECIPITATION (MAXEY-EAKIN METHOD)	Figure 8-5
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power Plant	HYDRAULIC CONDUCTIVITY VERSUS ELECTRICAL RESISTIVITY	Figure 8-6
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power Plant	MEASURED AND SIMULATED HYDRAULIC HEADS AT THE OBSERVATION NODES	Figure 8-7
Woodward-Clyde Consultants			



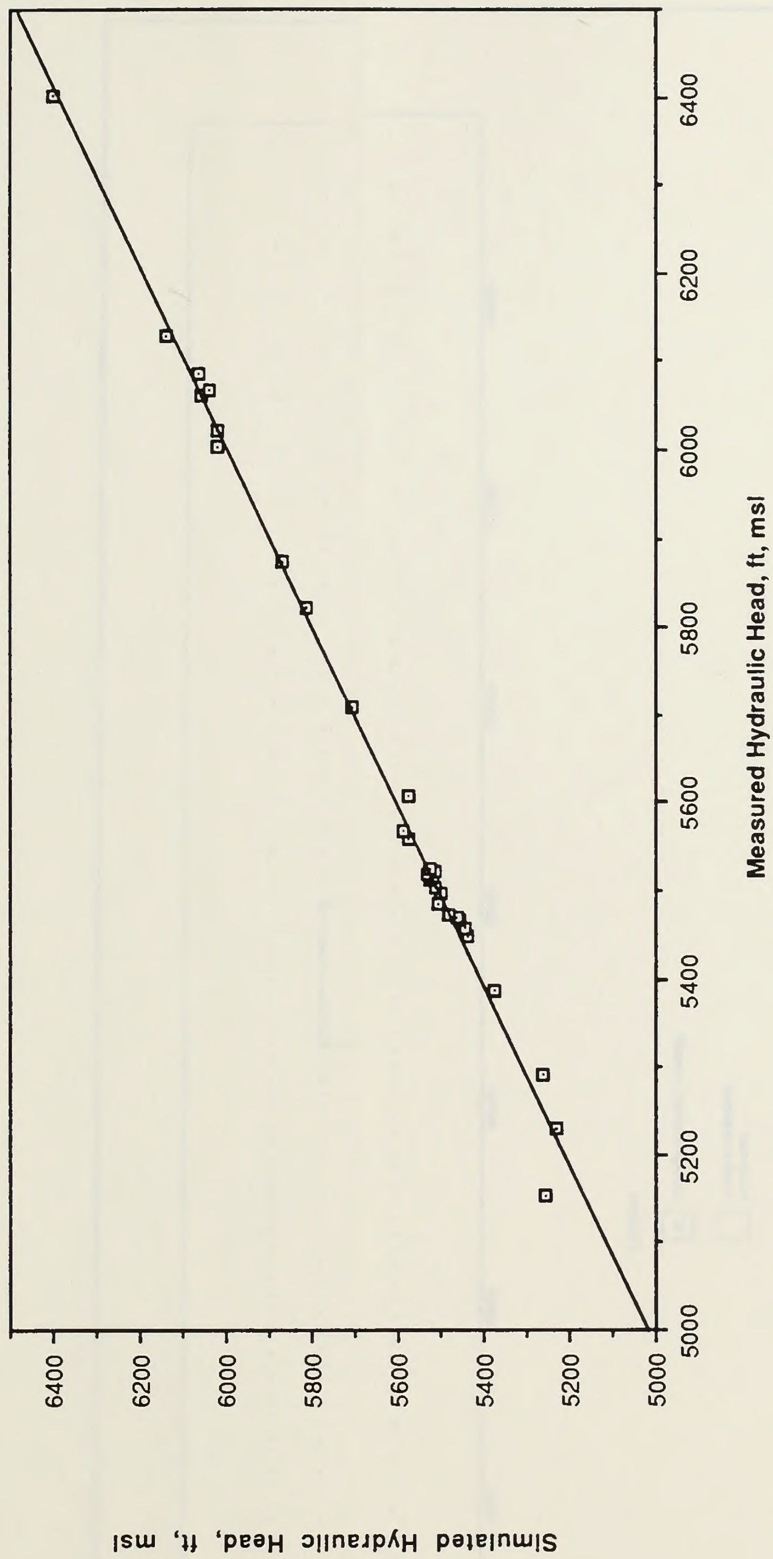
LEGEND

5600 Drawdown (feet)

Boundaries along mountain range correspond to the approximate edge of the Paleozoic rock outcrops

Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	WATER TABLE CONTOUR MAP BASED ON SIMULATED WATER LEVELS	Figure 8-8
Woodward-Clyde Consultants			



Project No. 90270B	Thousand Springs Power plant	MEASURED VERSUS SIMULATED HYDRAULIC HEADS	Figure 8-9
Woodward-Clyde Consultants			

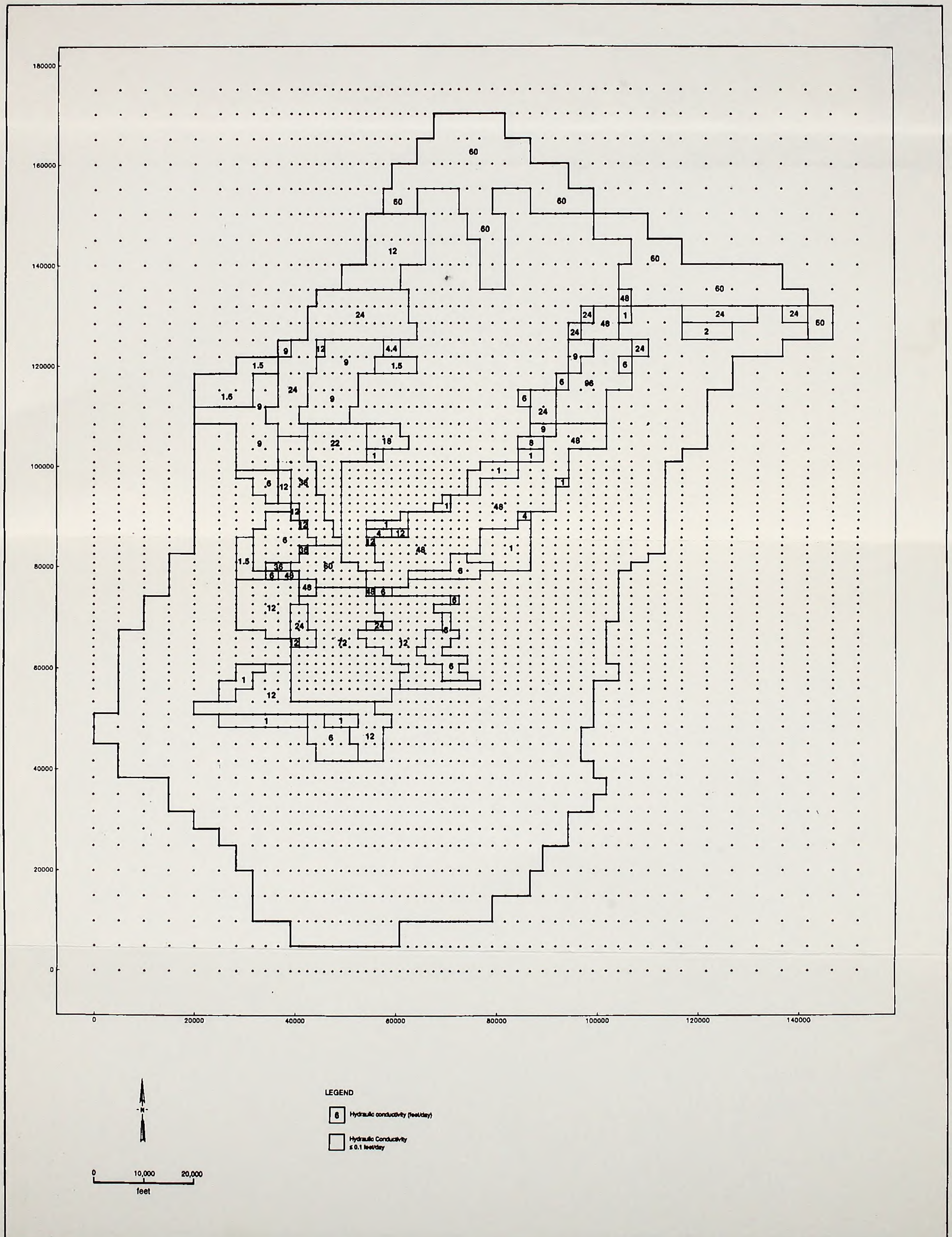
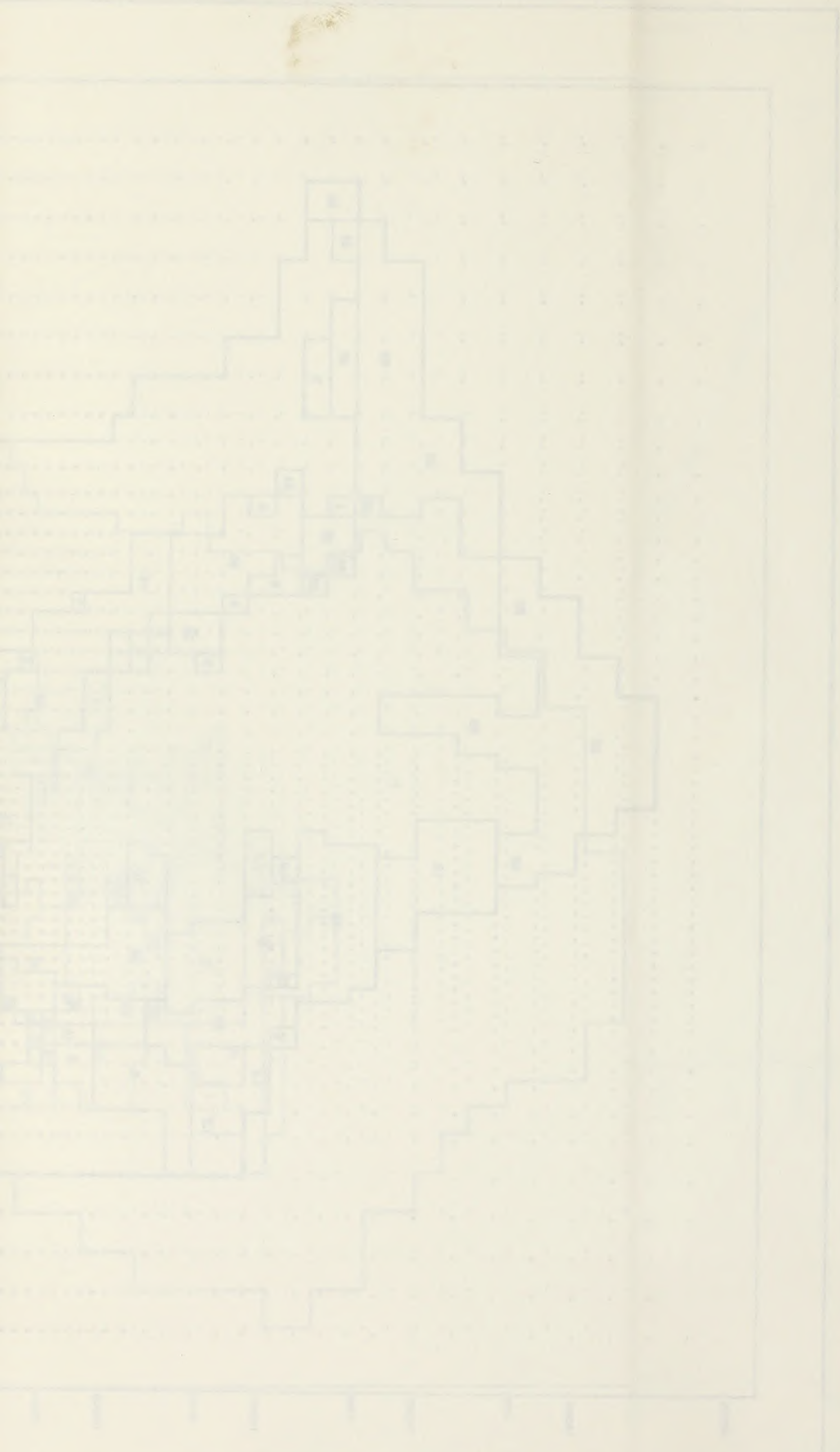


Figure 8-10. DISTRIBUTION OF CALIBRATED HYDRAULIC CONDUCTIVITIES



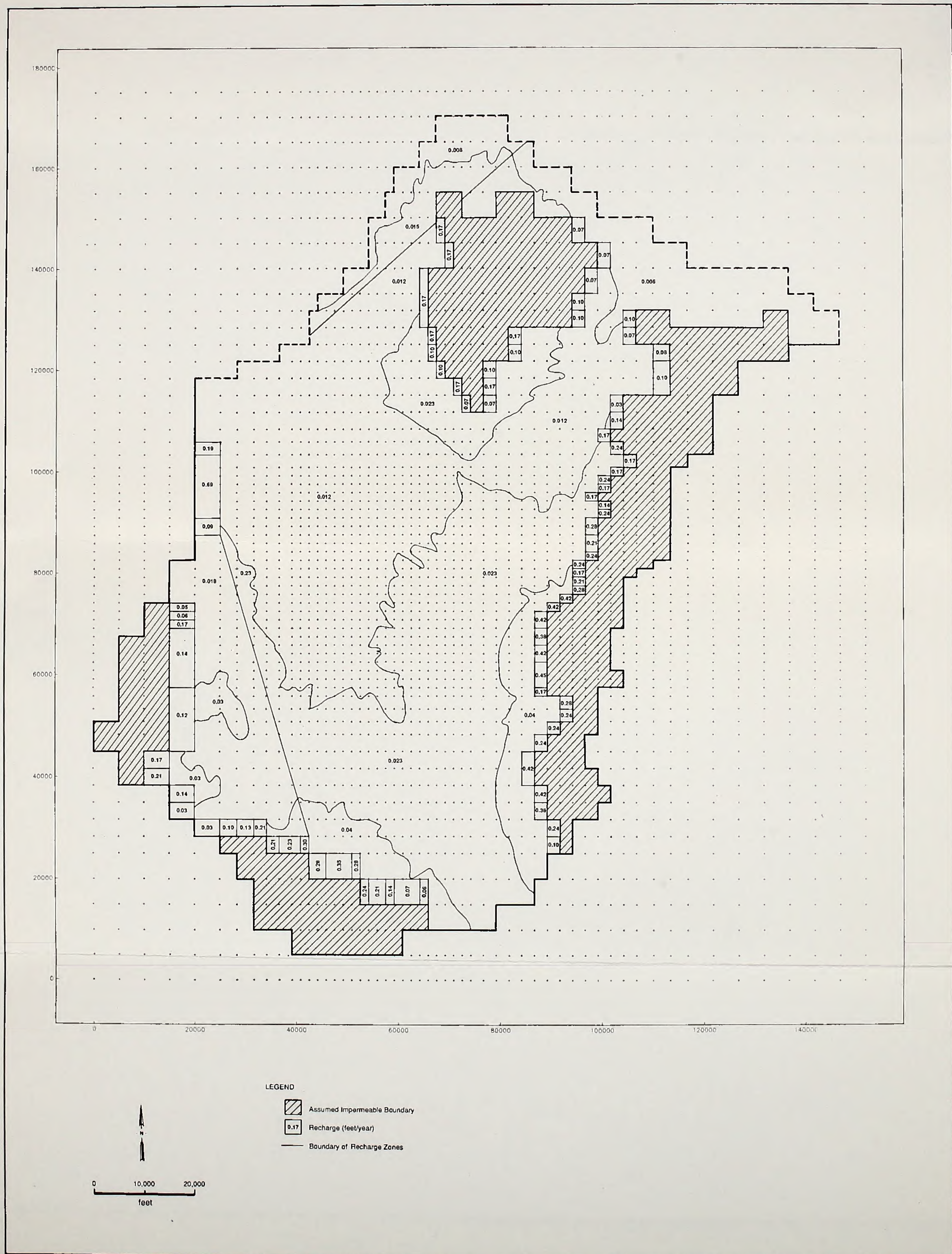


Figure 8-11. DISTRIBUTION OF ESTIMATED RECHARGE RATES

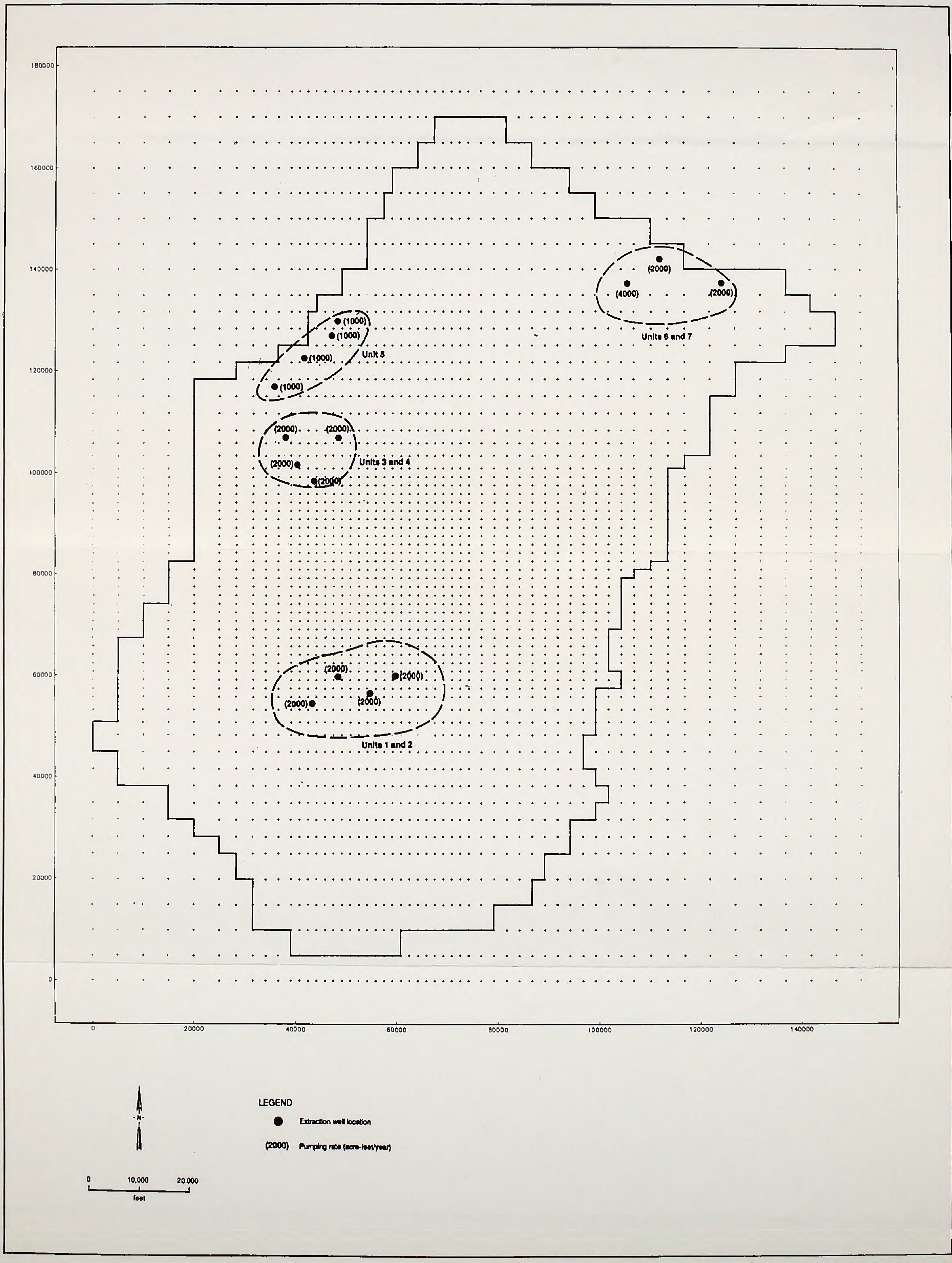


Figure 8-12. LOCATION OF EXTRACTION WELLS (Case 1)

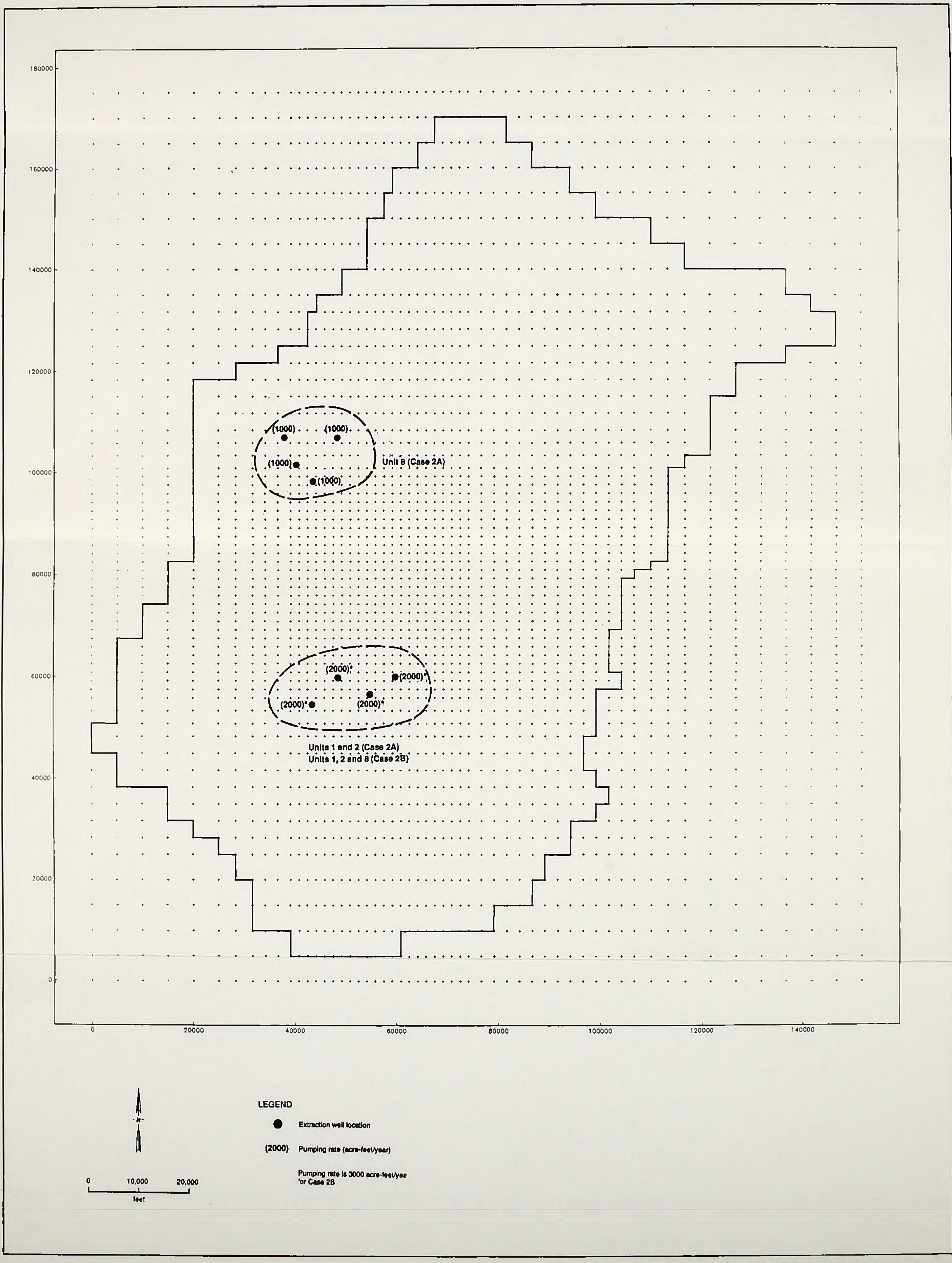


Figure 8-13. LOCATION OF EXTRACTION WELLS (Case 2)

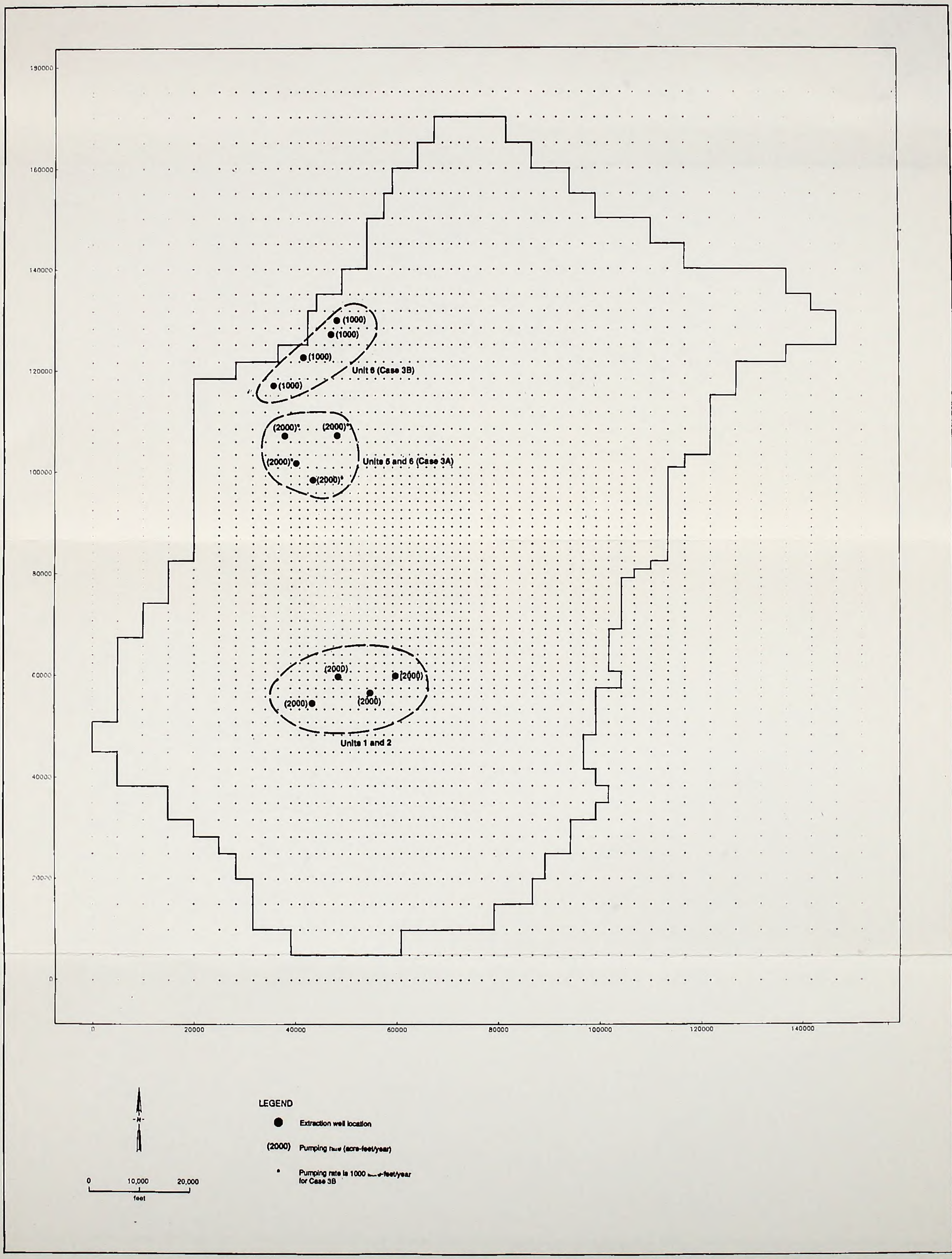
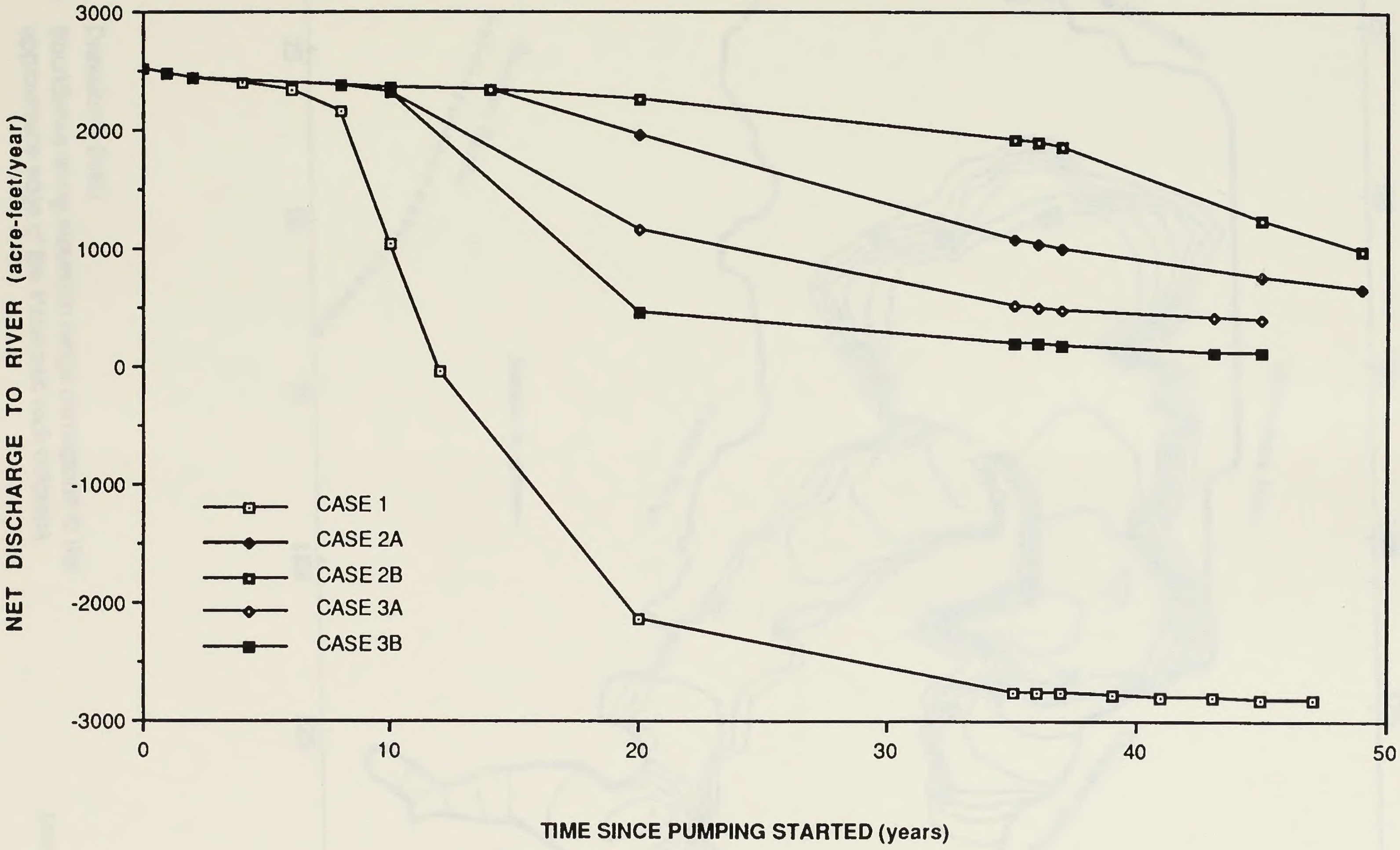
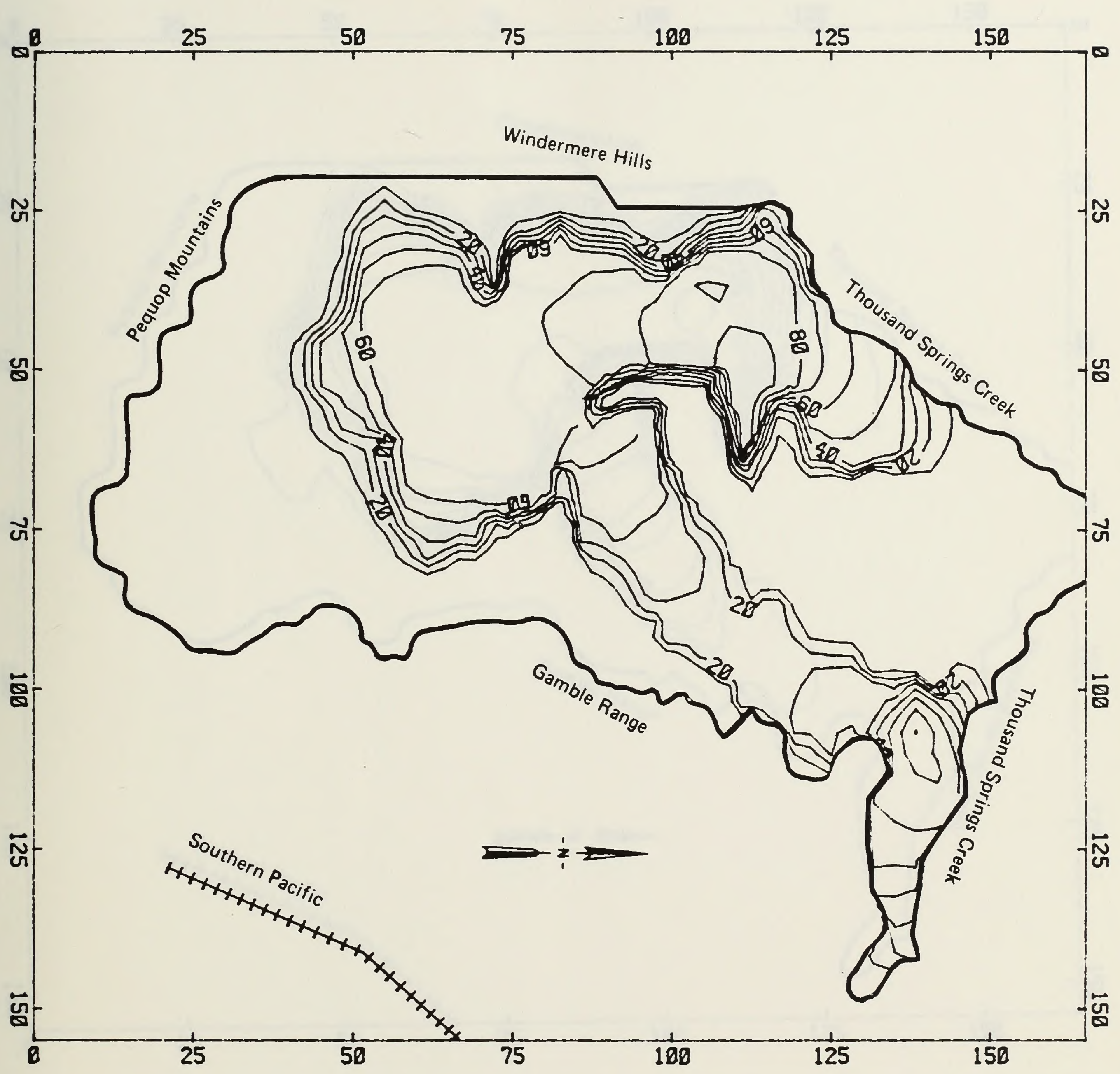


Figure 8-14. LOCATION OF EXTRACTION WELLS (Case 3)



Project No. 90270B	Thousand Springs Power Plant	RATE OF WATER LOSS FROM THOUSAND SPRINGS CREEK FOR FIVE CASES OF GROUNDWATER DEVELOPMENT	Figure 8-15
Woodward-Clyde Consultants			



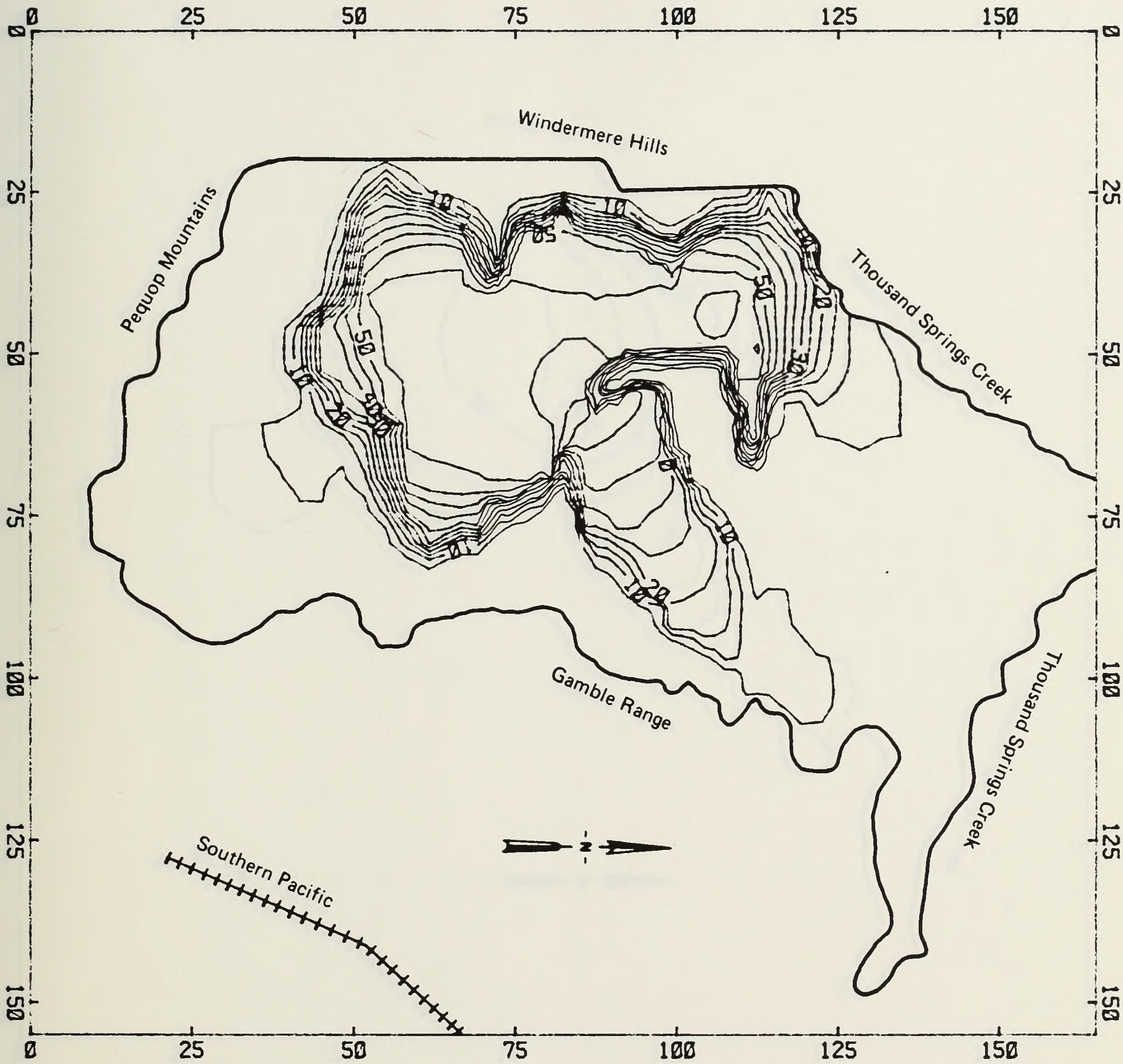
LEGEND

20 Drawdown (feet)

Boundaries along mountain range correspond to the approximate edge of the Paleozoic rock outcrops

Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 1 AT THE END OF THE POWER PLANT'S USEFUL LIFE (47 YEARS)	Figure 8-16
Woodward-Clyde Consultants			



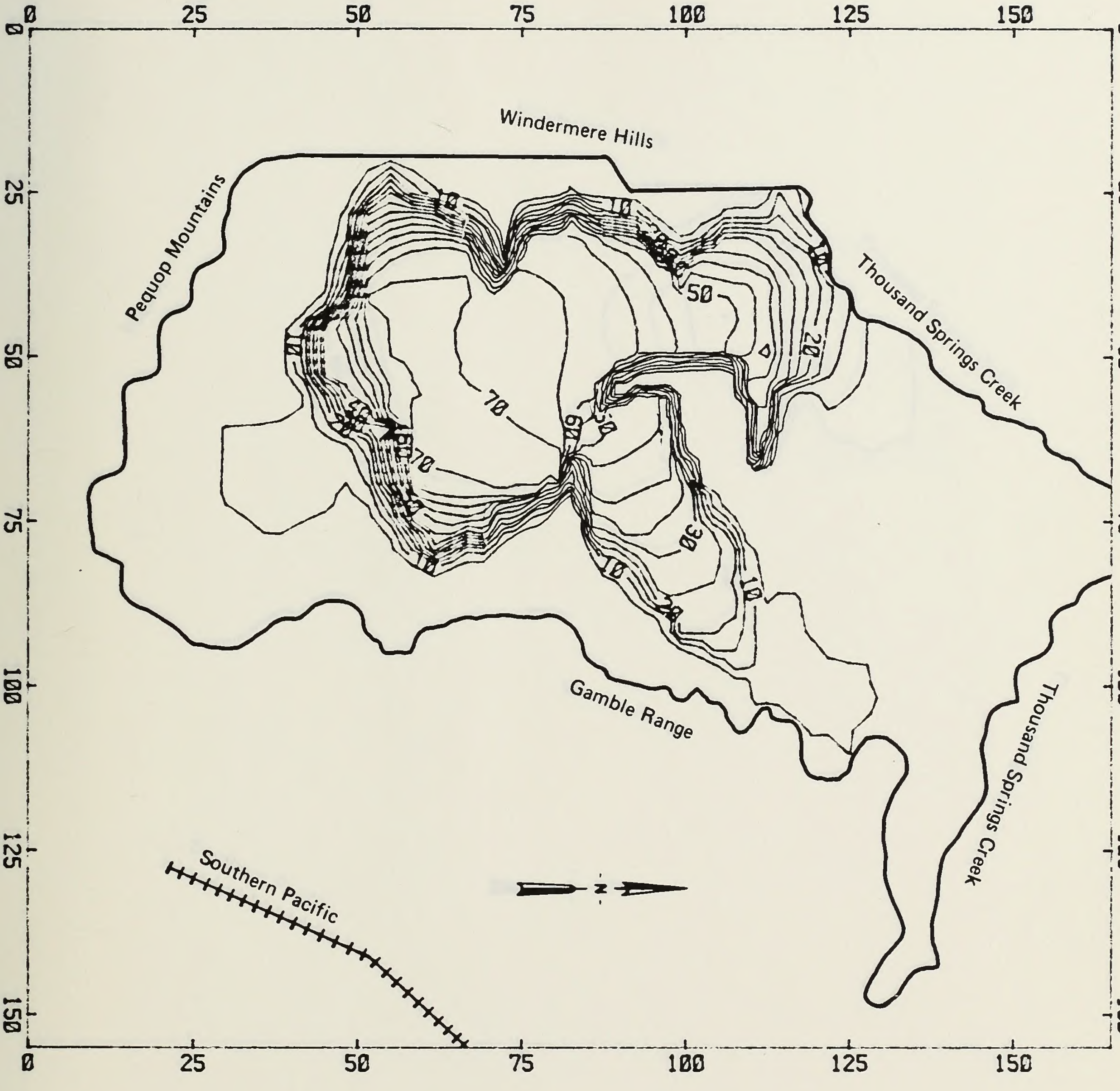
LEGEND

20 Drawdown (feet)

Boundaries along mountain range correspond to the approximate edge of the Paleozoic rock outcrops

Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 2A AT THE END OF THE POWER PLANT'S USEFUL LIFE (49 YEARS)	Figure 8-17
Woodward-Clyde Consultants			



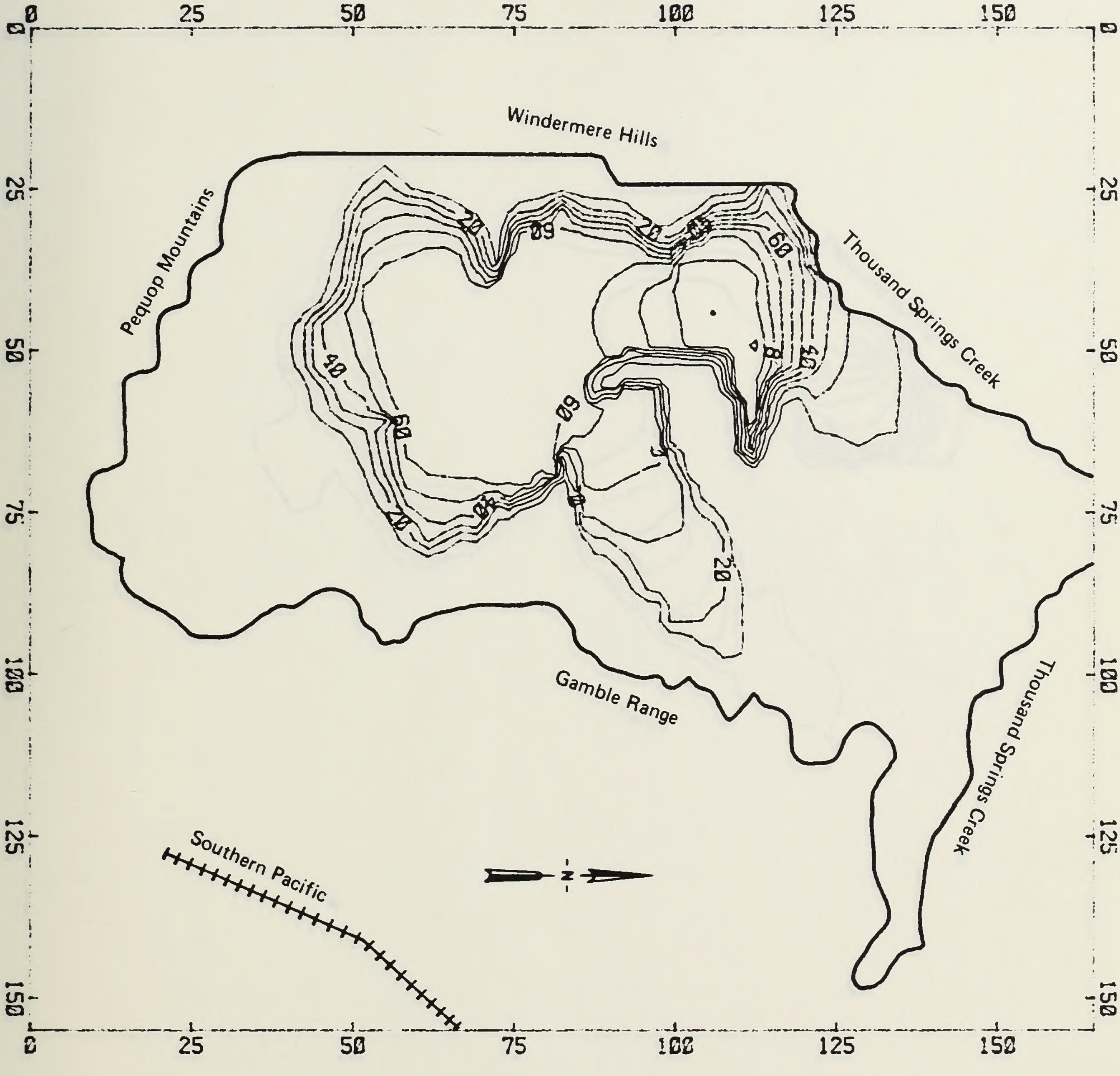
LEGEND

20 Drawdown (feet)

Boundaries along mountain range correspond to the approximate edge of the Paleozoic rock outcrops

Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 2B AT THE END OF THE POWER PLANT'S USEFUL LIFE (49 YEARS)	Figure 8-18
Woodward-Clyde Consultants			



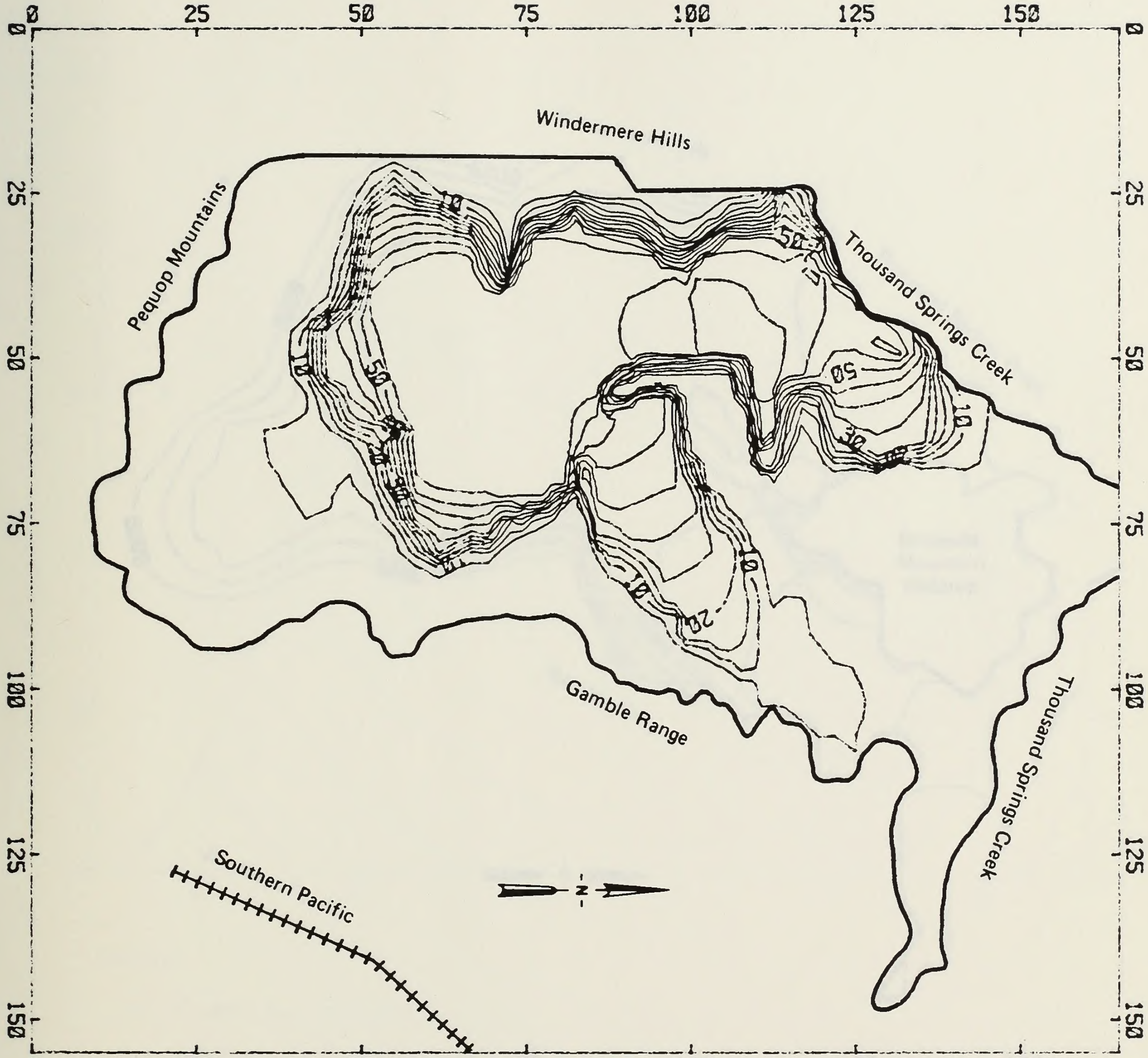
LEGEND

20 Drawdown (feet)

Boundaries along mountain range correspond to the approximate edge of the Paleozoic rock outcrops

Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 3A AT THE END OF THE POWER PLANT'S USEFUL LIFE (45 YEARS)	Figure 8-19
Woodward-Clyde Consultants			



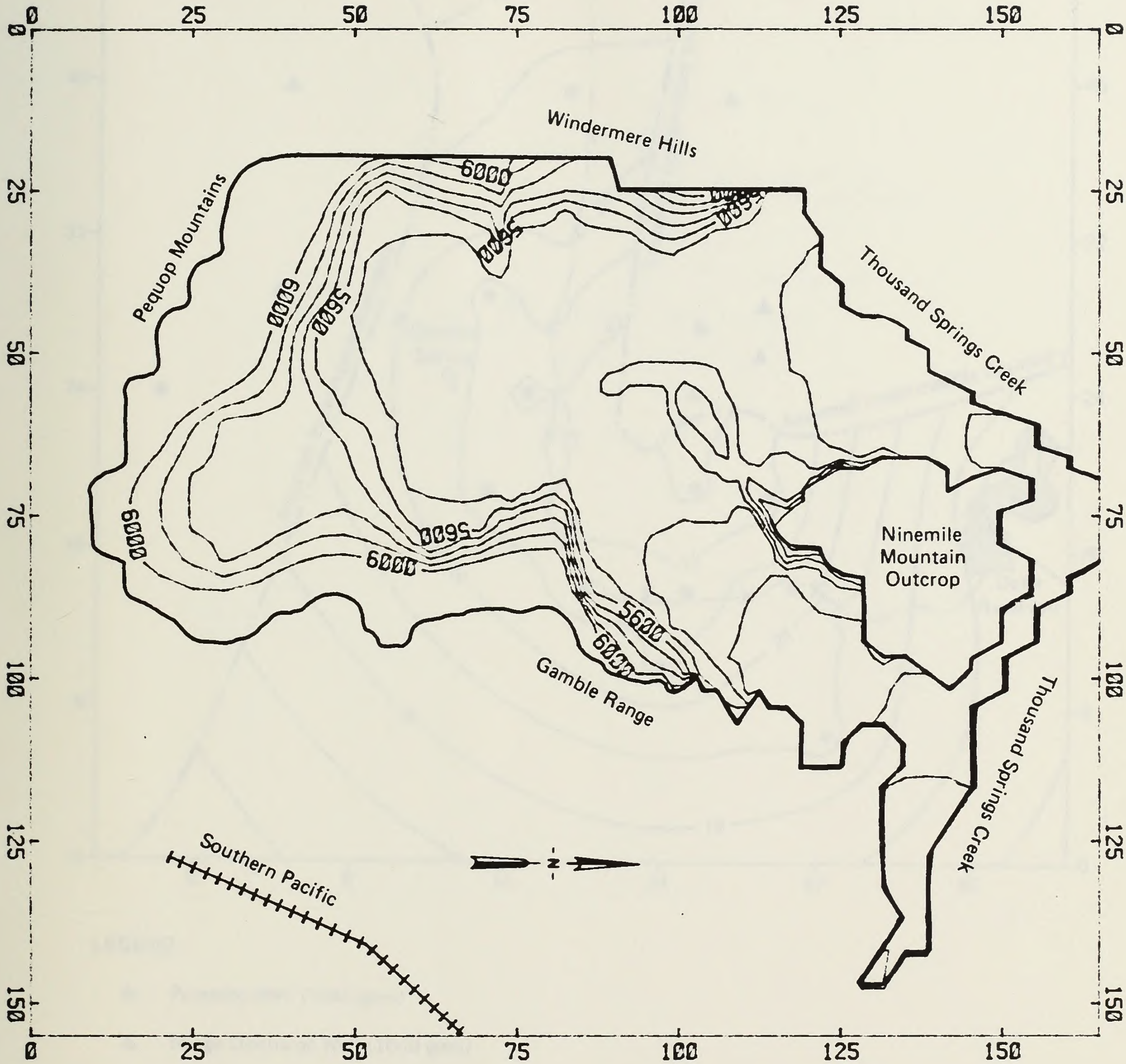
LEGEND

20 Drawdown (feet)

Boundaries along mountain range correspond to the approximate edge of the Paleozoic rock outcrops

Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR CASE 3B AT THE END OF THE POWER PLANT'S USEFUL LIFE (45 YEARS)	Figure 8-20
Woodward-Clyde Consultants			



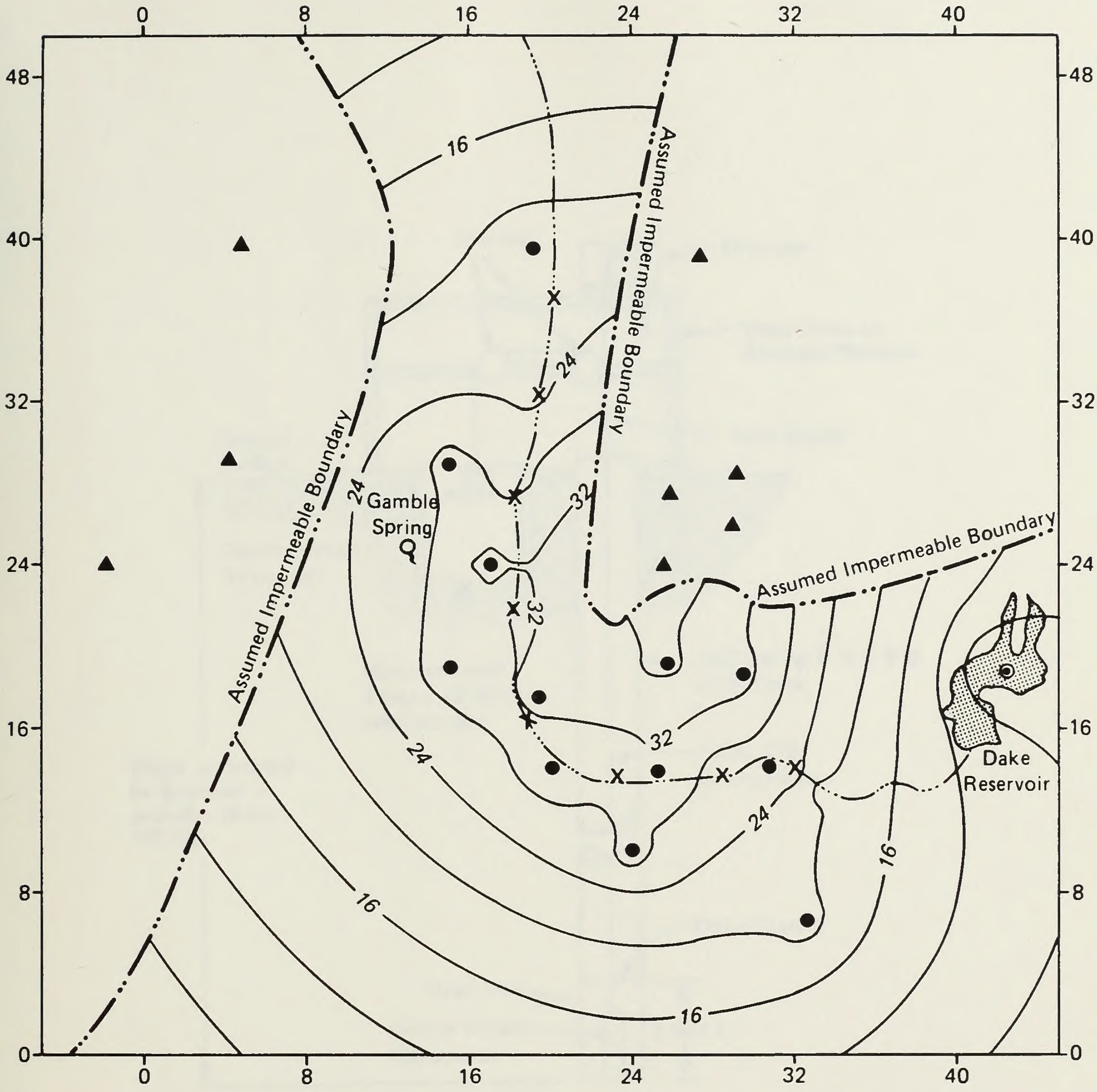
LEGEND

5600 Drawdown (feet)

Boundaries along mountain range correspond to the approximate edge of the Paleozoic rock outcrops

Scale 1:300,000

Project No. 90270B	Thousand Springs Power Plant	WATER TABLE CONTOUR MAP FOR CASE 2B AT THE END OF THE POWER PLANT'S USEFUL LIFE (49 YEARS)	Figure 8-21
Woodward-Clyde Consultants			



LEGEND

● Pumping Well (1040 gpm)

▲ Image Discharge Well (1040 gpm)

◉ Leakage from Dake Reservoir (2500 gpm)

X Leakage from Thousand Springs Creek (700 gpm)

—··— Assumed Impermeable Boundary

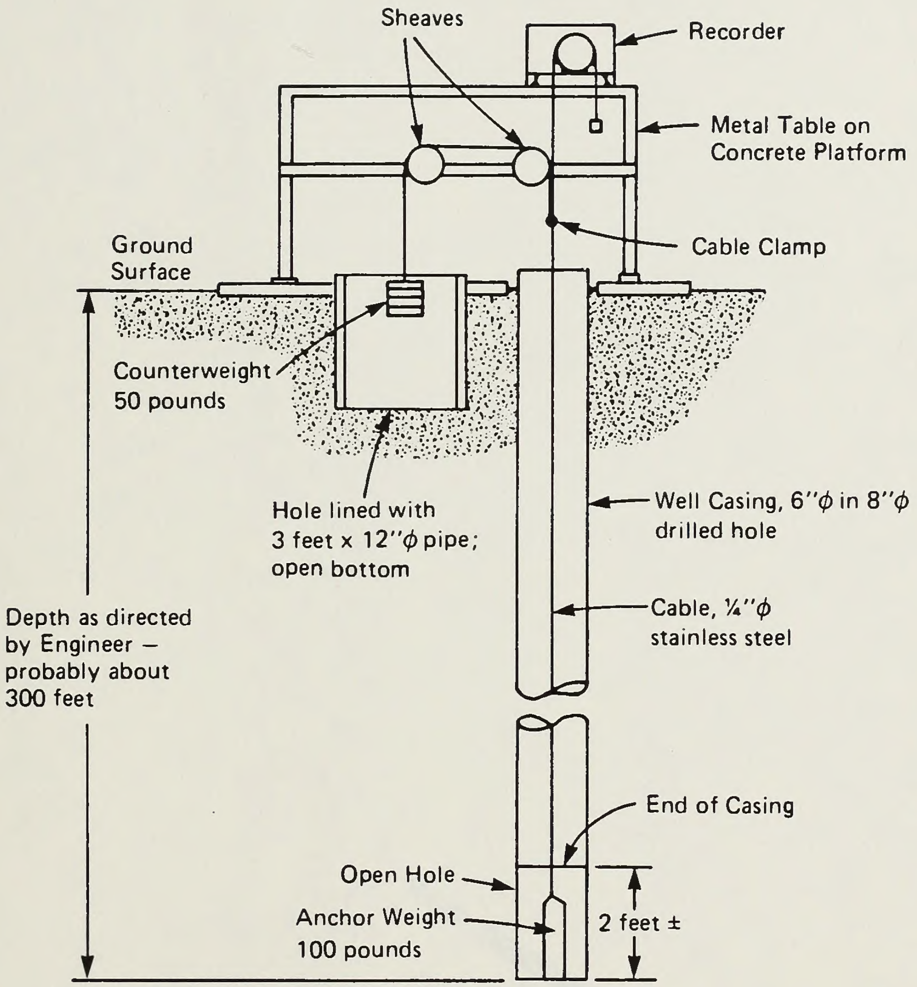
—···— Thousand Springs Creek

—16— Drawdown (feet)

- N -

Scale 1:100,000

Project No. 90270B	Thousand Springs Power Plant	DRAWDOWN MAP FOR MONTELLO VALLEY AFTER 35 YEARS OF PUMPING 20,000 ACRE-FEET/YEAR	Figure 8-22
Woodward-Clyde Consultants			



Note: Shelter required over this installation not shown.

Project No. 90270B	Thousand Springs Power Plant	SUBSIDENCE MONITORING RECORDER	Figure 11-1
Woodward-Clyde Consultants			