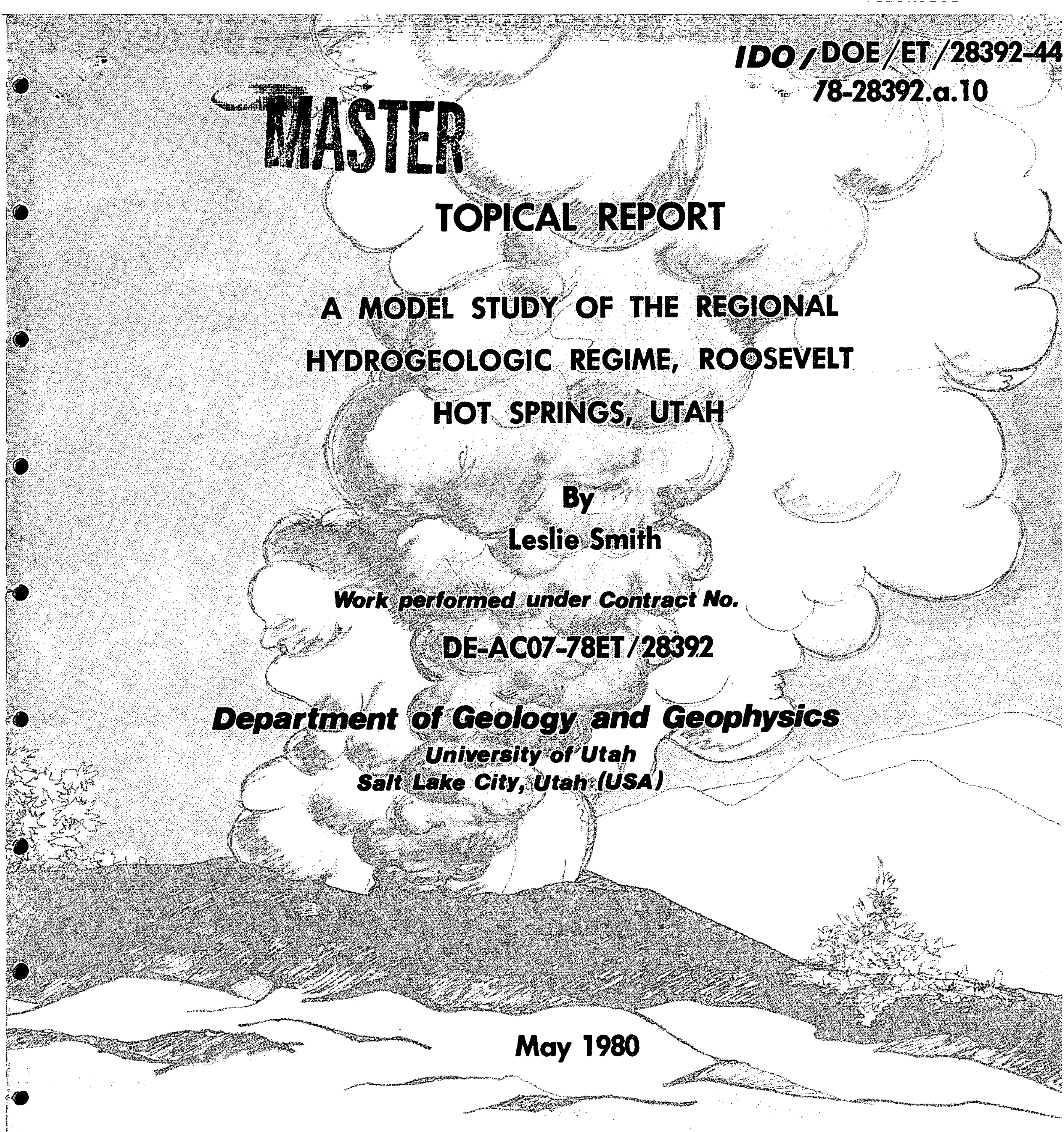
IDO/DOE/ET/28392-44
78-28392.a.10



MASTER

TOPICAL REPORT

A MODEL STUDY OF THE REGIONAL HYDROGEOLOGIC REGIME, ROOSEVELT HOT SPRINGS, UTAH

By

Leslie Smith

Work performed under Contract No.

DE-AC07-78ET/28392

Department of Geology and Geophysics

University of Utah
Salt Lake City, Utah (USA)

May 1980

Prepared for

DEPARTMENT OF ENERGY

Division of Geothermal Energy

DISCLAIMER

NOTICE

NOTICE

DOE/ET/28392-44
78-28392.a.10

TOPICAL REPORT

A MODEL STUDY OF THE REGIONAL HYDROGEOLOGIC REGIME, ROOSEVELT HOT SPRINGS, UTAH

Leslie Smith
Dept. of Geology and Geophysics
University of Utah
Salt Lake City, Utah

ABSTRACT

A regional hydrogeologic model is used to investigate the potential for water recharging in the Tushar Mountains to move at depth beneath the Mineral Mountains to discharge in Milford Valley. Simulations carried out over a range of water table positions and assumed depths to a lower impermeable boundary suggest it is unlikely that the topographic configuration alone could drive such a flow system. Specific geologic conditions are necessary if interbasin flow is to occur. However, simulations based on a simplfied hydrologic model of the regional geology suggest this is not the case. A regional hydraulic anisotropy greater than 10:1 (Kx/Kz) leads to interflow if the granitic Mineral Mountain pluton and the volcanics in the Tushar Mountains have similar hydraulic conductivites. If either of these units is more nearly isotropic or if the granitic rocks have a greater vertical than horizontal hydraulic conductivity, no interbasin flow is observed. On the basis of available geologic evidence, this latter case seems to be the most likely.

ACKNOWLEDGEMENTS

I would like to thank Cristian Smith, Earth Sciences Lab, University of Utah Research Institute for his help in synthesizing the available data on the regional hydrogeology in the vicinity of the Roosevelt KGRA.

TABLE OF CONTENTS

INTRODUCTION

The regional topography in the vicinity of the Roosevelt Hot Springs thermal area suggests the possibility of interbasin flow (Figure 1). The Tushar Mountains to the east reach elevations of over 10,000 feet. The smaller Mineral Mountains attains elevations up to 9000 feet. The surface elevation of the intervening Beaver Valley ranges from 5800 to 6200 feet. The valley floor west of the Mineral Mountains has a surface elevation of 4900 feet. Water recharging in the Tushar Mountains may move at depth beneath the Mineral Mountains to discharge in Milford Valley. If this is the case, natural recharge to the thermal area would be greater than that originating solely from precipitation in the Mineral Mountains. During thermal production, long-term withdrawals from storage will be influenced by this recharge source. It may also contribute to the deep circulation patterns tied to the origins of the geothermal resource.

This report describes a model study of the regional hydrogeologic regime. A two-dimensional vertical cross section perpendicular to the strike of the regional topography forms the basis of the model. Two questions are addressed. First, is a topographically driven flow system from the Tushar Mountains tc Milford Valley possible? Second, what geologically reasonable conditions may lead to interbasin flow?

Three parameters determine the nature of the regional groundwater flow regime. These are: i) the topographic configuration of the water table; ii) the subsurface geology which determines the spatial distribution of hydraulic conductivity; and iii) the ratio of the depth to lateral extent of the flow domain. This last parameter is fixed by the depth to an

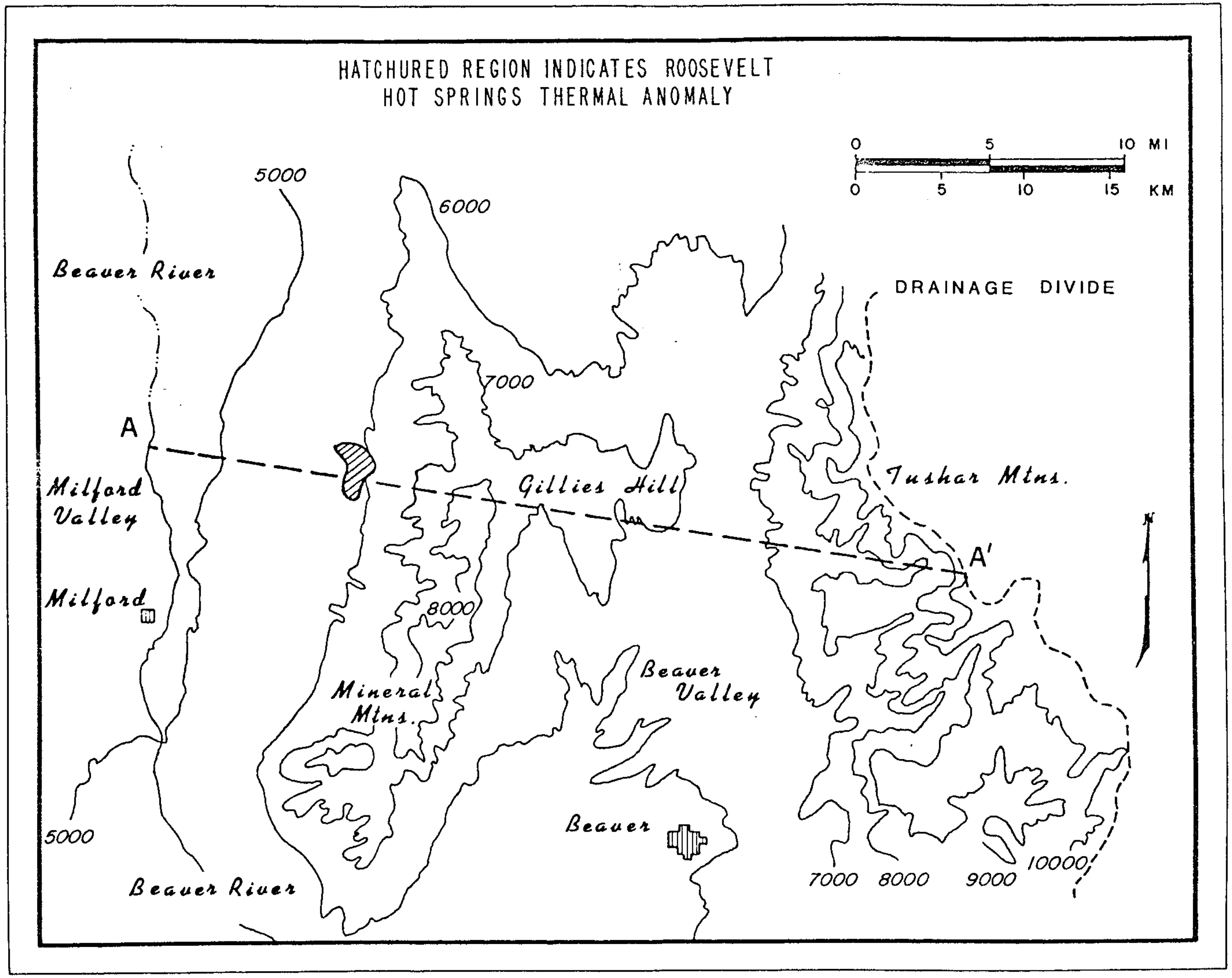


Figure 1: Location map showing trace of cross-section used in groundwater simulations.

assumed lower impermeable boundary.

Any model of a real-world system must be calibrated against field conditions before being used in a predictive mode. Input to the model (e.g., hydraulic conductivity, water table elevation) is normally varied in a trial-and-error adjustment to match model output with measured hydraulic head values from the field. In our case, the paucity of field data on a regional scale precludes a definitive assessment of the flow system. Rather, a detailed sensitivity analysis is carried out over reasonable parameter ranges and plausible geologic conditions.

The report comprises three sections. First, using published data, the regional geology will be summarized in a hydrologic context. Second, the modeling technique will be briefly reviewed along with the assumptions which must be made in applying the model to this field site. Third, the results of the sensitivity analysis will be presented and implications for interbasin flow discussed.

REGIONAL HYDROGEOLOGY

The region of flow for the groundwater simulations is a vertical cross-section taken from Beaver River in Milford Valley to the drainage divide in the Tushar Mountains. The trace of the section is shown in Figure 1. The section passes through the Roosevelt KGRA in the vicinity of the Opal Mound. It crosses the northern end of Beaver Valley at Gillies Hill. As such, Beaver Valley proper does not enter into the simulations.

A simplified model of the hydrogeologic system is shown in Figure 2. The upper boundary of the simulated flow field is the estimated water table position. The base of the flow field is set at elevation -600 ft. Both

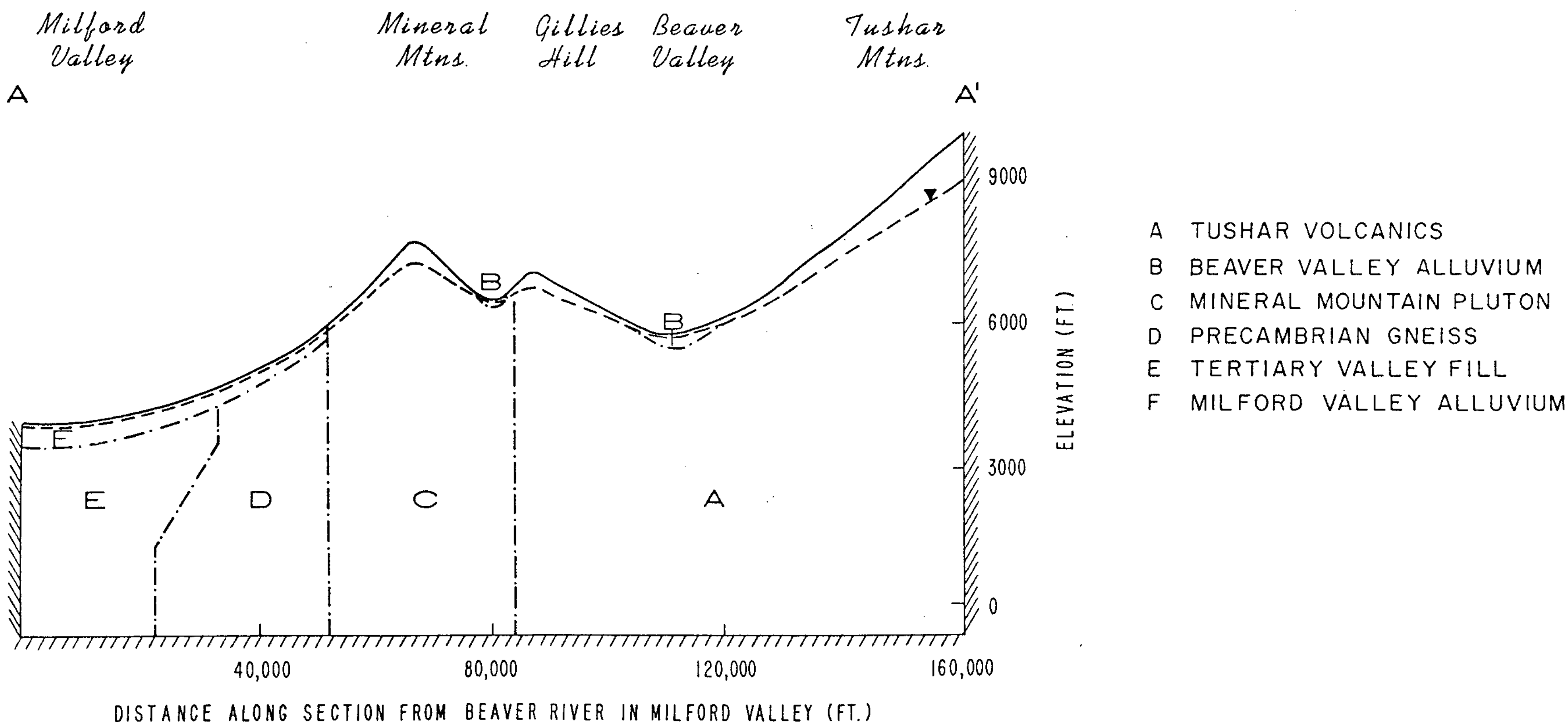


Figure 2: Basic hydrogeologic configuration.

the upper and lower boundaries on the flow field will be varied in the sensitivity analysis. The geologic configuration identifies an assumed set of homogeneous hydrologic units. The boundaries between these units are varied in a subset of the simulation trials in light of the uncertainty in their location. In some simulation runs, identical values of hydraulic conductivity will be assigned to several or all of these geologic units. In other simulation runs, various hydraulic conductivity contrasts between units will be specified. Available and inferred hydrologic data for each of these units is summarized below.

The western side of the Tushar Mountains consist of a thick pile of Tertiary volcanics (Callaghan and Parker, 1961). The bulk of the rocks belong to the Bullion Canyon volcanics, composed of andesitic flows, tuffs and breccias. The Mount Belnap rhyolite forms the peaks of the Tushars in the region of interest. It is a tuffaceous rhyolite with features characteristic of welded tuffs. Both units are fairly well jointed in outcrop. A quartz monzonite stock is located in the vicinity of the cross-section modeled. These units are considered as a single hydrologic unit in the model study. The total thickness of the volcanics at this site and the nature of the underlying geology is not known.

Hydraulic conductivity data are not available for the volcanics in the Tushar Mountains. Published data for similar rock types from nearby areas are used as a guide in characterizing its hydrologic behavior. Winograd (1971) reviews the hydrogeology of welded ash flow tuffs from sites within the central Great Basin of Nevada and Utah. Eakin (1966) briefly discusses the hydrogeology of similar volcanic rocks in eastern Nevada. Blankennagel and Weir (1973) detail the hydrologic behavior of ash flow tuffs and rhyolitic lava flows at the Nevada test site.

The hydraulic conductivity of these rocks is fracture dominated. Interstitial hydraulic conductivity is generally very low. Winograd (1971) suggests values of hydraulic conductivity from 10^{-5} to 1 ft/day for ash flow tuffs. Fracture density is related to the degree of welding in the ash flow tuffs. The degree of welding within a single flow is variable. A section built up from many individual flows will behave hydraulically as a layered sequence of higher and lower conductivities. Blankennagel and Weir (1973) suggest the combined thickness of intervals with significant fracture conductivity may amount to 3-10% of the total section. At the Nevada test site, the fractures are observed to remain open to depths greater than 5000 ft although the higher conductivities are commonly at depths less than 4000 ft.

A Tertiary granitic pluton underlies most of the central portion of the Mineral Mountains. Nielson et al. (1978) identify at least 5 major felsic phases in the pluton. For the purposes of this study, it is recognized as a homogeneous unit. The rhyolitic flows and domes along the crest and western flank of the Mineral Mountains will not be differentiated hydraulically from the granitic rocks. The pluton is highly fractured, with joint spacings ranging from inches up to tens of feet (Yusas, 1979). Two sets of steeply dipping joints are present, orientated primarily north-south and east-west. Surfaces of the joints are generally planar and open. A secondary joint set dips 20 to 50 degrees to the west. No direct information is available on the depth to sound rock. Recent electrical surveys (Wannamaker, per. comm.) suggest a boundary at about 6600 ft which could identify the transition to a much less fractured rock.

No hydraulic conductivity measurements are available for the granitic rocks. A suggested range for fractured granite (Freeze and Cherry, 1979) is 10^{-3} to 10 ft/day. Unfractured granitic rocks typically have hydraulic conductivities ranging from 10^{-8} to 10^{-5} ft/day. Fracturing in the granite may lead to hydraulically anisotropic behavior.

The hydrology of the shallow groundwater reservoir in Beaver Valley is described by Mower (1978). The valley fill consists of unconsolidated to moderately consolidated deposits of gravel, sand, silt and clay. It extends to depths of at least 800 ft and possibly more than 1000 ft. In the northern half of Beaver Valley, the average hydraulic conductivity of the valley fill ranges from less than 0.1 ft/day to about 5 ft/day. The water table is relatively shallow, ranging in depth from 0 to 30 ft below ground surface. A shallow water table supports the inference that Beaver Valley is a major discharge area for waters recharging the system in the Tushar Mountains.

The total depth of alluvial fill in Beaver Valley is not known. Neither is there data on the underlying bedrock. It is assumed the volcanic rocks of the Tushar Mountains are continuous beneath Beaver Valley. The eastern boundary of the Mineral Mountain pluton has yet to be clearly defined. The volcanic rocks are assumed to abut against the granitic pluton. The contact is placed to the west of Gillie's Hill.

The Mineral Mountains pluton is flanked on the west by a Precambrian gneiss (Nielson et al., 1978). This unit is the reservoir rock for the Roosevelt KGRA. Production tests on wells completed within the KGRA suggest locally higher hydraulic conductivities controlled by fracturing within the gneiss. On the regional scale of the hydrologic model, no attempt can be made to identify individual zones of faulting. Hydrologic data on the thermal reservoir is presently proprietary and not available to aid in model calibration. Away from major zones of faulting, the gneiss is intact with little jointing, shearing or brecciation (Nielson et al, 1978). In these areas, the hydraulic conductivity can be assumed to be very low. Textbook values suggest a range from 10^{-8} to 10^{-5} ft/day (Freeze and Cherry, 1979).

The shallow groundwater reservoir in Milford Valley has been described by Mower and Cardova (1974). They identify it as a stratified sand-clay sequence. The suggested depth of this system is about 500 ft in the central part of the valley. An upper value on the depth-averaged hydraulic conductivity can be estimated as 10 ft/day (Mower and Cardova, 1974, Figs. 4 and 5). The water table is generally at depths of 50 ft to 100 ft below the surface.

An interpretation of deeper units beneath Milford Valley is given by Gertson and Smith (1979) on the basis of a seismic refraction study. They conclude a Tertiary valley fill underlies the near surface alluvium to depths of at least 6000 ft in the center of the valley. The bedrock is presumed to be Precambrian gneiss. The lithology of the Tertiary fill is not identified, although it is thought not to be sandstone. The hydraulic conductivity of this unit is likely significantly lower than that of the near surface alluvium.

Inferred reasonable ranges for the hydraulic conductivity of each of the geologic units are compiled in Table 1. For this purpose, an isotropic hydraulic conductivity is assumed. These values can be adjusted in the simulation runs to account for hydraulic anisotropy.

Table 1

Hydrogeologic Unit	Range of Values for Hydraulic Conductivity (ft/day)
Tushar volcanics	10^{-4} - 1
Beaver Valley alluvium	10^{-1} - 5
Mineral Mountain pluton	10^{-5} - 1
Precambrian gneiss	10^{-8} - 10^{-5}
Tertiary Valley fill	10^{-6} - 10^{-3}
Milford Valley alluvium	10^{-1} - 10^{1}

No reliable information is available on the position of the water table within the Tushar and Mineral Mountains. Springs may indicate the location of small perched systems rather than the main zone of saturation. Simulations were carried out with the water table in an estimated median and high position. The water table in its median position is shown in Figure 2. At the drainage divide in the Mineral and Tushar Mountains, the water table elevation is set at 7400 ft and 9000 ft, respectively. The water table is extended across the section assuming it is a subdued replica of the topography. For the water table in a high position, its assumed elevation at the drainage divide is 7600 ft and 9600 ft in the Mineral and Tushar Mountains, respectively. Simulations with the water table in a lower position are not reported as such a condition reduces the possibility of interflow.

The isotopic composition of the Roosevelt KGRA thermal water suggests the dominant recharge source is precipitation in the Mineral Mountains. However, the possible presence of a small component of recharge water from the Tushar Mountains cannot be eliminated (J. Bowman, per. comm.)

METHOD OF SOLUTION AND MODEL LIMITATIONS

The information in the previous section allows us to construct the mathematical boundary value problem describing the flow system in our two-dimensional section. A numerical finite element technique is used to solve for hydraulic head at a set of nodal points within the flow field. The nodal grid forms a set of irregularly-sized, linear quadrilateral elements. A mesh with 269 elements and 278 nodes was constructed.

The nodal hydraulic head values can be contoured to provide the hydraulic head patterns; allowing determination of whether interbasin flow is occurring. For each element on the water table, the inflow or outflow rate is calculated. A water budget on the inflow-outflow function is used to quantify the percent of discharge in Milford Valley originating as recharge outside of the Mineral Mountains.

A computer model of the regional flow system can provide theoretical evidence for or against interbasin flow. Our interpretation is constrained by the limitations inherent in the modeling technique. The main assumptions can be summarized:

1) The fractured porous media behaves hydraulically as a continuum obeying Darcy's law. In practice, this implies that flow is through an interconnected network of fractures rather than being concentrated in a few wide fractures. Flow in the fractures must be laminar.
2) The flow domain is modeled as a two-dimensional system. Such a section has strict meaning only if the topography and geology do not change along the perpendicular to the section. In practice we require that there are no important components of groundwater flow into or out of the section. The model is oriented at right angles to the regional topographic slope. Unless there are unforeseen geologic controls, this assumption seems reasonable for the Tushar and Mineral Mountains and Milford Valley. There may be a component of flow across the section in the vicinity of Gillies Hill. Beaver Valley slopes to the south here. However, the dominant flow direction at depth likely

remains in the plane of the section.

3) The simulations consider only steady state flow. An average position for the water table is estimated. Transient variations due to seasonal fluctuations in the water table are not accounted for. This could be important in predicting hydraulic head distributions within the Mineral and Tushar Mountains. Because the main recharge event is concentrated in a short period during snowmelt, there may be fairly large seasonal fluctuations in the water table within these fractured media.

4) The regional flow field is modeled as an isothermal system. Two factors are consequently omitted: i) the additional driving force due to differences in fluid density with depth and ii) the influence of a lower fluid viscosity at depth on hydraulic conductivity. Density differences due to the regional geothermal gradient will favor interbasin flow, although the effects are probably not large in comparison to the driving force controlled by the topographic configuration. Not enough is known about the hydraulic conductivity of the geologic units to consider viscosity corrections. Use of an isothermal model should not misrepresent the basic nature of the regional flow system.

5) The lack of information about the hydraulic conductivity distribution is the main limitation in the model analysis. The only calibration that can be carried out is a simple water budget analysis. This allows the bulk hydraulic conductivity to be approximated but gives no information on the internal arrangements of units with differing hydraulic conductivities.

SIMULATION RESULTS

Table 2 presents a summary of selected simulation experiments. Each run is identified by its data deck label: ROS1, ROS2...etc.

Homogeneous, isotropic systems

The first set of runs assume the entire geologic system can be described as a homogeneous, isotropic medium. Figure 3a shows the hydraulic head distribution for a simulation with the water table in the median position and the impermeable base set at -600 ft (ROS1). Under these conditions, no interbasin flow occurs. Along this section, all recharge in the Tushar Mountains discharges in Beaver Valley. Groundwater discharging in Milford Valley originates solely from recharge in the Mineral Mountains.

A plot of the hydraulic head values along the impermeable base is given in Figure 4. This figure demonstrates the form in which the results of many of the computer runs are presented. The minimum in hydraulic head beneath Beaver Valley implies flow converges toward that region at depth. It must then move upward to discharge at the surface. In this case, no interbasin flow occurs.

Runs ROS2 and ROS3 (Fig. 4) consider the effect of the depth to the lower impermeable boundary. The impermeable base is set at elevation -1600 ft and -2600 ft, respectively. In neither case does interbasin flow occur, although increasing the depth/lateral extent ratio does favor the possibility of a larger scale regional flow system. There is no geologic evidence to suggest that the active flow regime extends to these greater depths.

TABLE 2

DATA DECK	HYD. BEHAVIOR	LOWER BOUND.	WATER TABLE	TUSHAR* VOLCANICS	BEAVER VALLEY ALLUVIUM	GRANITE	GNEISS	TERTIARY VALLEY FILL	MILFORD VALLEY ALLUVIUM
ROS1		-600	MEDIAN			10^{-2}			
ROS2	HOMO.	-1600	MEDIAN			10^{-2}			
ROS3	ISO.	-2600	MEDIAN			10^{-2}			
ROS4		-600	HIGH			10^{-2}			
ROS5		-600	MEDIAN	10^{-2}	10^{-1}	10^{-2}	10^{-5}	10^{-4}	1
ROS6	HETERO.	-600	MEDIAN	1	10^{-1}	10^{-2}	10^{-5}	10^{-4}	1
ROS7	ISO.	-600	MEDIAN	10^{1}	10^{-1}	10^{-2}	10^{-5}	10^{-4}	1
ROS8		-600	MEDIAN			Kx $5x10^{-2}$	Kz 10^{-3}		
ROS9	HOMO.	-600	MEDIAN			Kx 10^{-1}	Kz 10^{-3}		
ROS10	ANISO.	-600	MEDIAN			Kx 10^{-2}	Kz 10^{-3}		
ROS11	HETERO.	-600	MEDIAN	Kx$5x10^{-2}$ Kz 10^{-3}	10^{-1}	Kx 10^{-2} Kz 10^{-2}	10^{-5}	10^{-4}	1
ROS12	ANISO.	-600	MEDIAN	Kx 10^{-2} Kz 10^{-2}	10^{-1}	Kx 10^{-2} Kz 10^{-1}	10^{-5}	10^{-4}	1

*ft/day

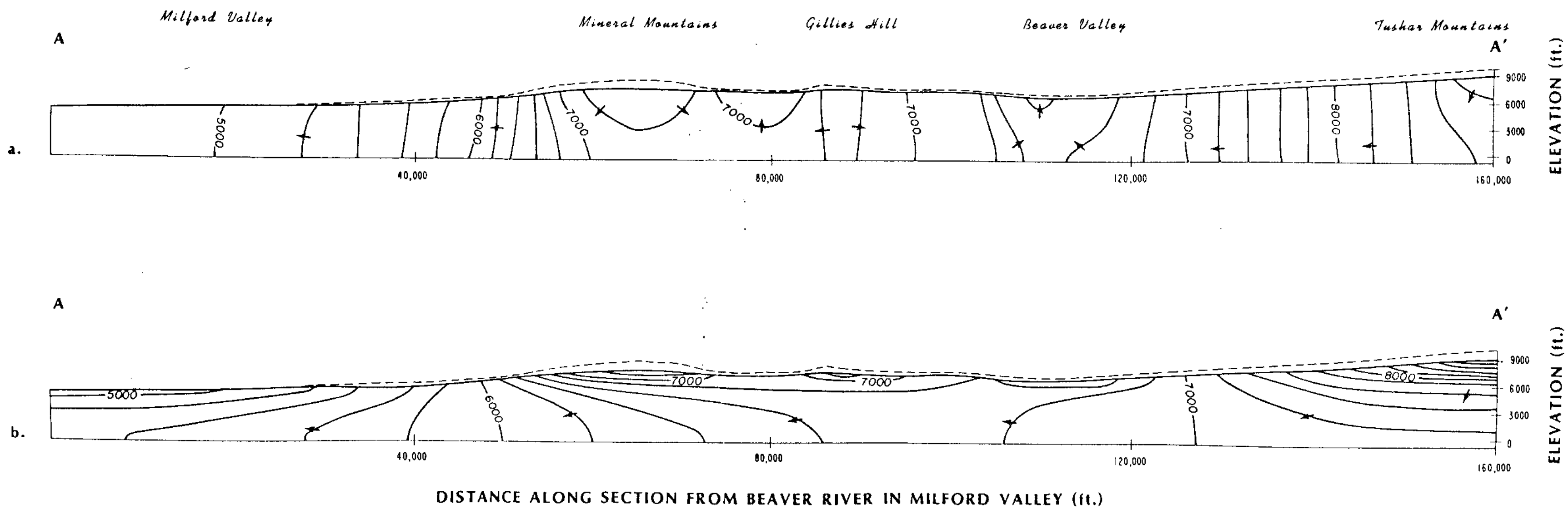


Figure 3: Hydraulic head distribution for simulation runs ROS1 and ROS8.

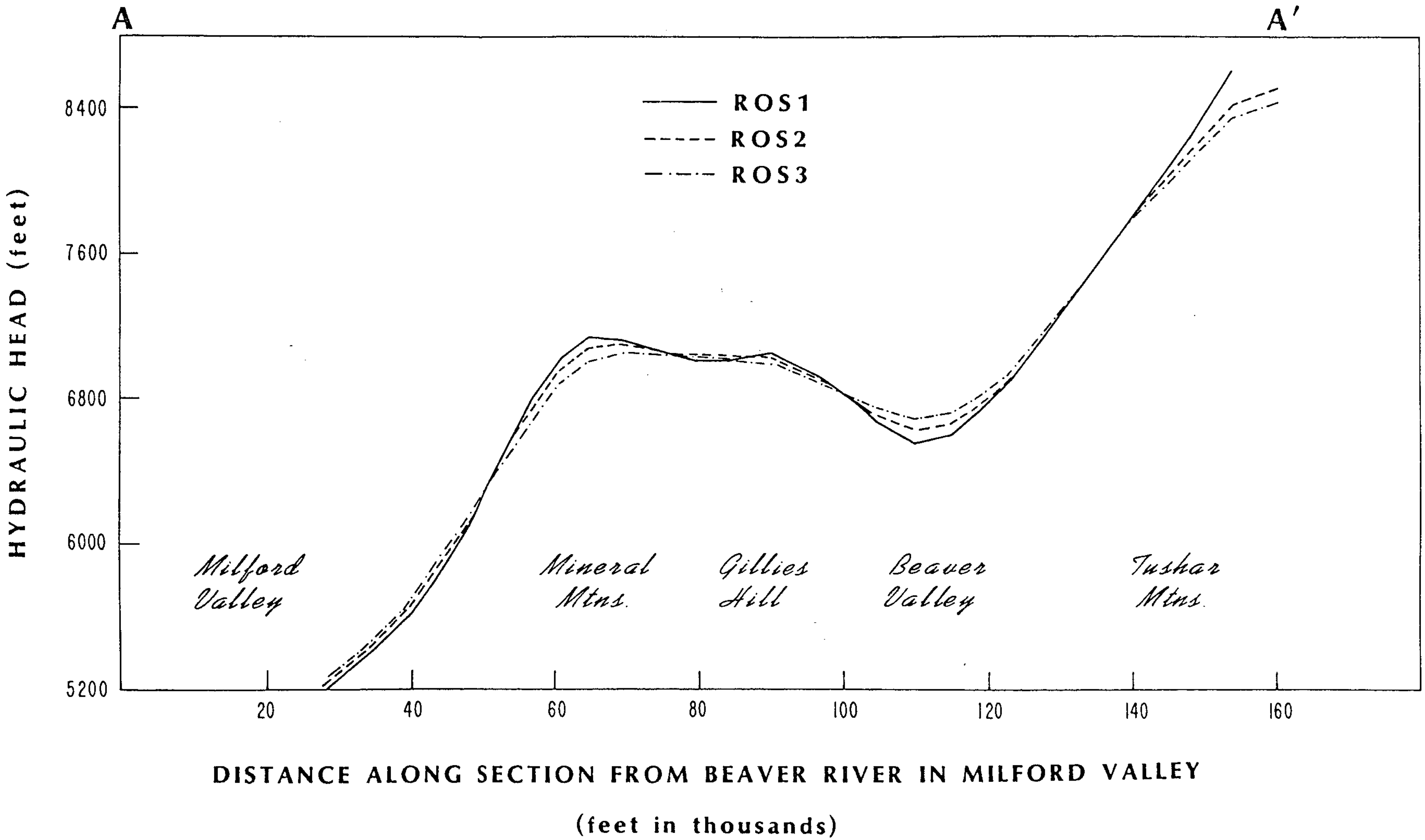


Figure 4: Hydraulic head distribution along basal boundary; homogeneous isotropic system.

The hydraulic head along the lower impermeable boundary for the case of a high water table (ROS4) is shown in Figure 5. The distribution of hydraulic head changes in accord with the higher hydraulic head on the water table. However, the basic nature of the two independent flow systems is unchanged.

An order of magnitude approximation to the average hydraulic conductivity of the Mineral Mountains granite can be obtained by comparing the groundwater recharge predicted by the computer model with that estimated from precipitation-recharge relations. A hydraulic conductivity of 10^{-2} ft/day was assumed for the above simulation. For the median water table position, the total recharge along the section across the Mineral Mountains was 9.14 ft^2/day. Assuming a representative section and taking the length of the range as 100,000 ft, the estimated total recharge in the Mineral Mountains is 7650 acre-ft/year. This value is reasonable considering the total annual precipitation and applying a Maxey-Eakin estimate of groundwater recharge (C. Smith, per. comm.). Hydraulic conductivities of 10^{-3} ft/day and 10^{-1} ft/day would lead to an estimated total recharge of 765 acre-ft/year and 76,500 acre-ft/year, respectively. The estimated recharge with the water table in the high position is 14% greater. Although there is considerable uncertainty associated with this estimate, it does indicate a limit on the range of hydraulic conductivity for the Mineral Mountains pluton.

These results suggest that a topographically driven flow system from the Tushar Mountains to Milford Valley is not likely. Specific geologic conditions, coupled with the topographic configuration, will be required if interbasin flow is to occur.

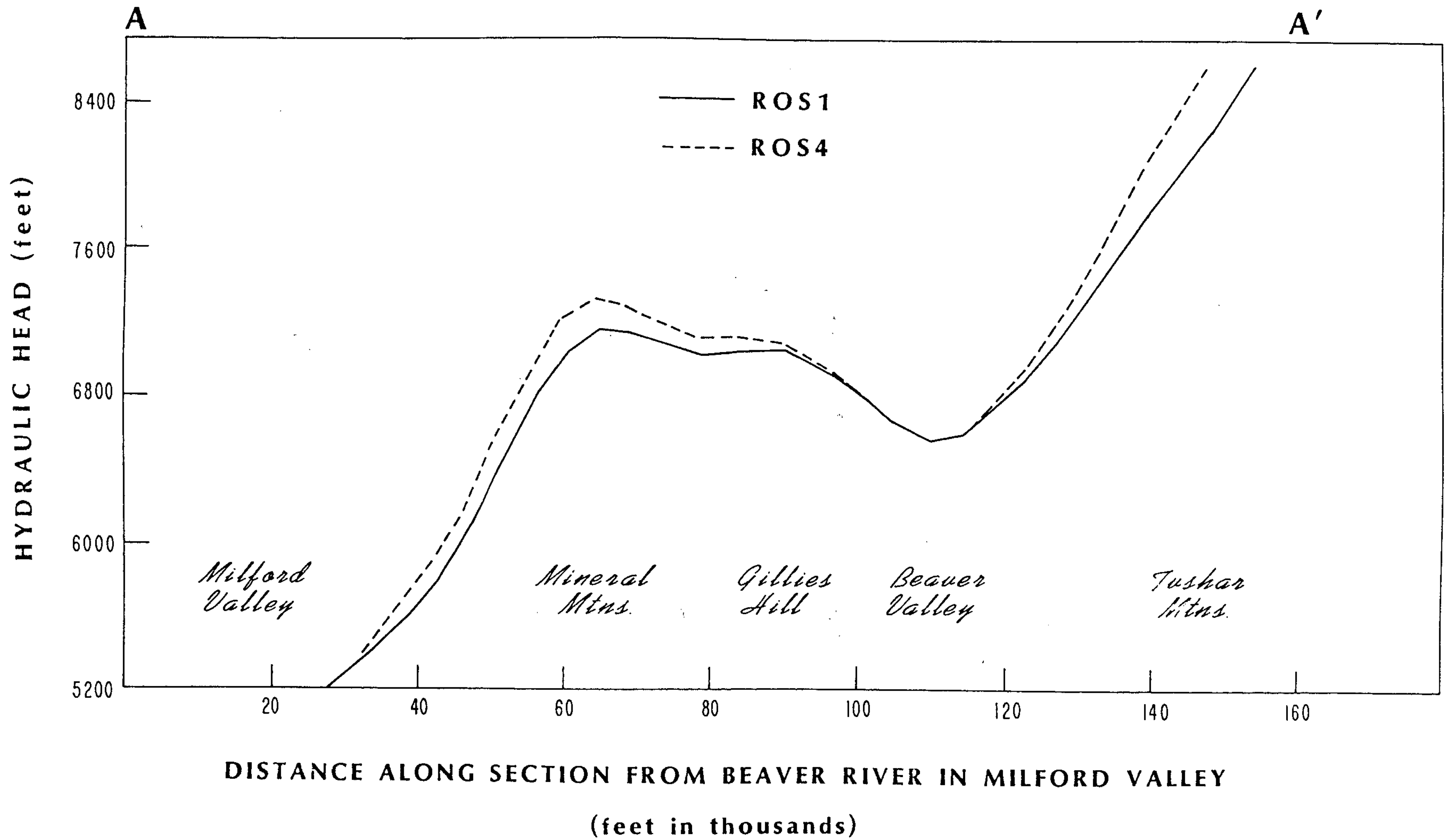


Figure 5: Hydraulic head distribution along basal boundary; homogeneous isotropic system, high water table.

Heterogeneous, isotropic systems

An alternate representation of the hydrogeologic system recognizes the probable differences in the hydraulic conductivities of the various geologic units (Fig. 2). Runs ROS5 through ROS7 consider the effects of various hydraulic conductivity contrasts between these units.

In ROS5 the volcanics in the Tushar Mountains and Mineral Mountains granite are assigned a hydraulic conductivity of 10^{-2} ft/day. The gneiss and Tertiary valley fill west of the Mineral Mountains and the Milford and Beaver Valley alluvium are recognized as distinct hydrologic units (Table 2). The hydraulic head distribution along the impermeable base is plotted in Figure 6. Not unexpectedly, no interbasin flow occurs for this hydrologic configuration. The influence of the gneiss, Tertiary valley fill and alluvium on the hydraulic head distribution is localized in Milford Valley. Simulations in which the hydraulic conductivities of these units are varied over a reasonable parameter range lead to the same conclusion. The hydrologic behavior of the Mineral Mountain pluton and the volcanics in the Tushar Mountains will control the nature of the regional flow systems.

Runs ROS6 and ROS7 consider the effect of a greater hydraulic conductivity for the volcanics in the Tushar Mountains. The hydraulic conductivity of the other geologic units is fixed as in ROS5. Increasing the hydraulic conductivity of the volcanics from 10^{-2} ft/day to 10 ft/day causes the hydraulic head distribution to change in the direction necessary to get interbasin flow (Fig. 6). However, no interbasin flow occurs in these cases. A hydraulic conductivity of 10 ft/day is an upper limit for the average hydraulic conductivity of the volcanics. Note the hydraulic

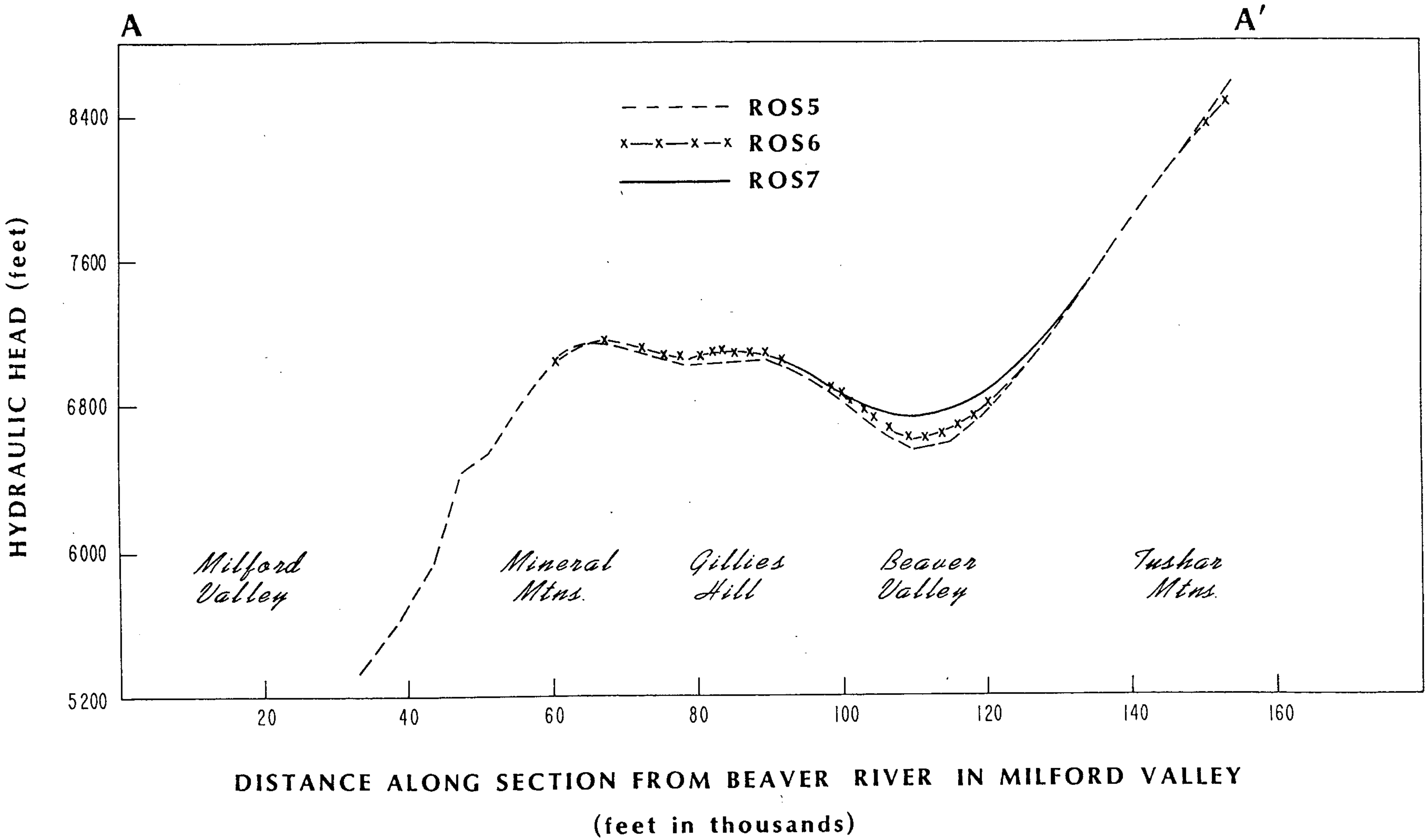


Figure 6: Hydraulic head distribution along basal boundary; heterogeneous isotropic system.

head distribution in Milford Valley is insensitive to the hydraulic conductivity assigned to the volcanics in the Tushar Mountains, reflecting the separate nature of the flow systems in the two valleys.

Simulations were carried out for the case where the hydraulic conductivity of the granitic pluton is greater than the hydraulic conductivity of the volcanics in the Tushar Mountains. Results suggest separate flow systems in Beaver and Milford valleys can be expected even if the hydraulic conductivity of the granite is up to two orders of magnitude greater than the volcanics.

Homogeneous, anisotropic systems

Fracturing in the Mineral Mountain pluton may impart a significant hydraulic anisotropy to the granite. On a regional scale, it is also reasonable to consider the Tushar volcanics as an anisotropic medium. Layering within the volcanic pile; with the resulting sequence of higher and lower hydraulic conductivities, could cause this unit to behave hydraulically as an anisotropic medium. In this case the horizontal hydraulic conductivity would be greater than the vertical conductivity.

To examine the implications of hydraulic anisotropy in terms of interbasin flow, simulations were carried out assuming the entire geologic system is described as a homogeneous, anisotropic medium. Unlike in isotropic media, flow in anisotropic media is not perpendicular to lines of constant hydraulic head. Figure 3b shows the hydraulic head distribution for a simulation (ROS8) with the horizontal hydraulic conductivity equal to 5×10^{-2} ft/day and the vertical hydraulic conductivity equal to 10^{-3}ft/day ($K_x/K_z = 50$). Arrows indicate the direction of groundwater flow. Water recharging in the Tushar Mountains moves at depth beneath Beaver Valley to discharge in Milford Valley. A water budget calculation indicates approximately 31% of the water discharging in Milford Valley originates from recharge outside of the Mineral Mountains.

The hydraulic head distribution along the impermeable base is plotted in Figure 7. For comparative purposes, the head distribution in the homogeneous, isotropic system is also plotted (ROS1). There is a continual decline in hydraulic head along the section. Although flow is not perpendicular to the hydraulic gradient, the absence of a minima beneath Beaver Valley indicates throughflow.

Figure 7 shows the basal hydraulic head distribution for various anisotropic ratios K_x/K_z. These results indicate that in a homogeneous system, an anisotropic ratio greater than approximately 10 (ROS10) can lead to interbasin flow. For this case, a water budget calculation indicates approximately 8% of the water discharging in Milford Valley originates from recharge outside of the Mineral Mountains. For an anisotropic ratio of 100 (ROS9), the proportion increases to 38%. These estimates of interflow increase slightly for simulations with the water table in the high position. The marked differences between the hydraulic head distributions in the anisotropic and isotropic systems should make it possible to distinguish between these two cases if field data become available.

Heterogeneous, anisotropic systems

The assumption of homogeneity for the Mineral Mountain granite and the Tushar volcanics may not be suitable in light of the fracture patterns and the origins of anisotropy. A more general representation of the

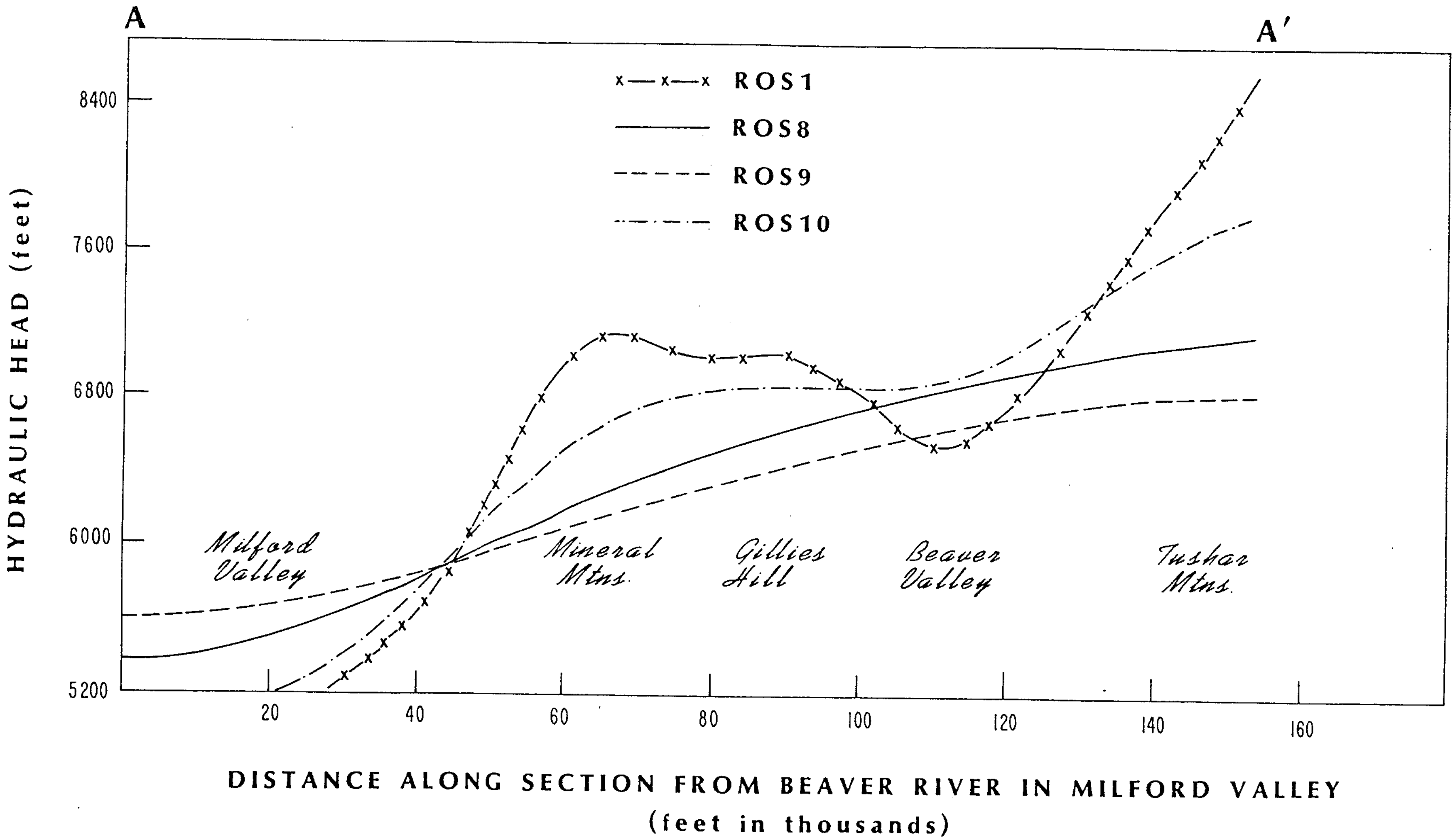


Figure 7: Hydraulic head distribution along basal boundary; homogeneous anisotropic system.

hydrogeologic system recognizes differences in the hydraulic conductivities and anisotropic ratios of the various rock units.

Runs ROS11 and ROS12 consider this possibility. In ROS11 the Tushar volcanics are assigned hydraulic conductivities $K_x = 5 \times 10^{-2}$ ft/day and $K_z = 10^{-3}$ ft/day. The Mineral Mountains granite is isotropic with $K_x = K_z = 10^{-2}$ ft/day. The gneiss, Tertiary valley fill and the Milford and Beaver Valley alluvium are also recognized as distinct hydrologic units. The hydraulic head distribution along the impermeable base is plotted in Figure 8. The isotropic granitic rocks effectively "block" the flow so that water recharging in the Tushar Mountains discharges in Beaver Valley. A similar behavior is observed for an anisotropic ratio K_x/K_z of 100 in the volcanics of the Tushar Mountains. If the hydraulic conductivity of the Mineral Mountain pluton is isotropic (or nearly so), a large scale regional anisotropy in the Tushar volcanics will not lead to interbasin flow as in the homogeneous problem.

Because the jointing pattern in the granitic rocks is dominated by a near-vertical orientation, the vertical hydraulic conductivity may be greater than the horizontal hydraulic conductivity. ROS12 represents such a case. The volcanics in the Tushar Mountains are isotropic with a hydraulic conductivity of 10^{-2} ft/day. The granitic pluton is anisotropic with K_x equal to 10^{-2} ft/day and K_z equal to 10^{-1} ft/day ($K_x/K_z = 0.1$). The hydraulic head distribution along the impermeable base (Fig. 8) shows that interbasin flow does not occur. The vertical anisotropy accentuates the 'blocking' effect of the Mineral Mountain pluton. A simulation assuming anisotropy in both the volcanics (as in ROS11) and the granitic pluton (as in ROS12) leads to a hydraulic head distribution very similar to

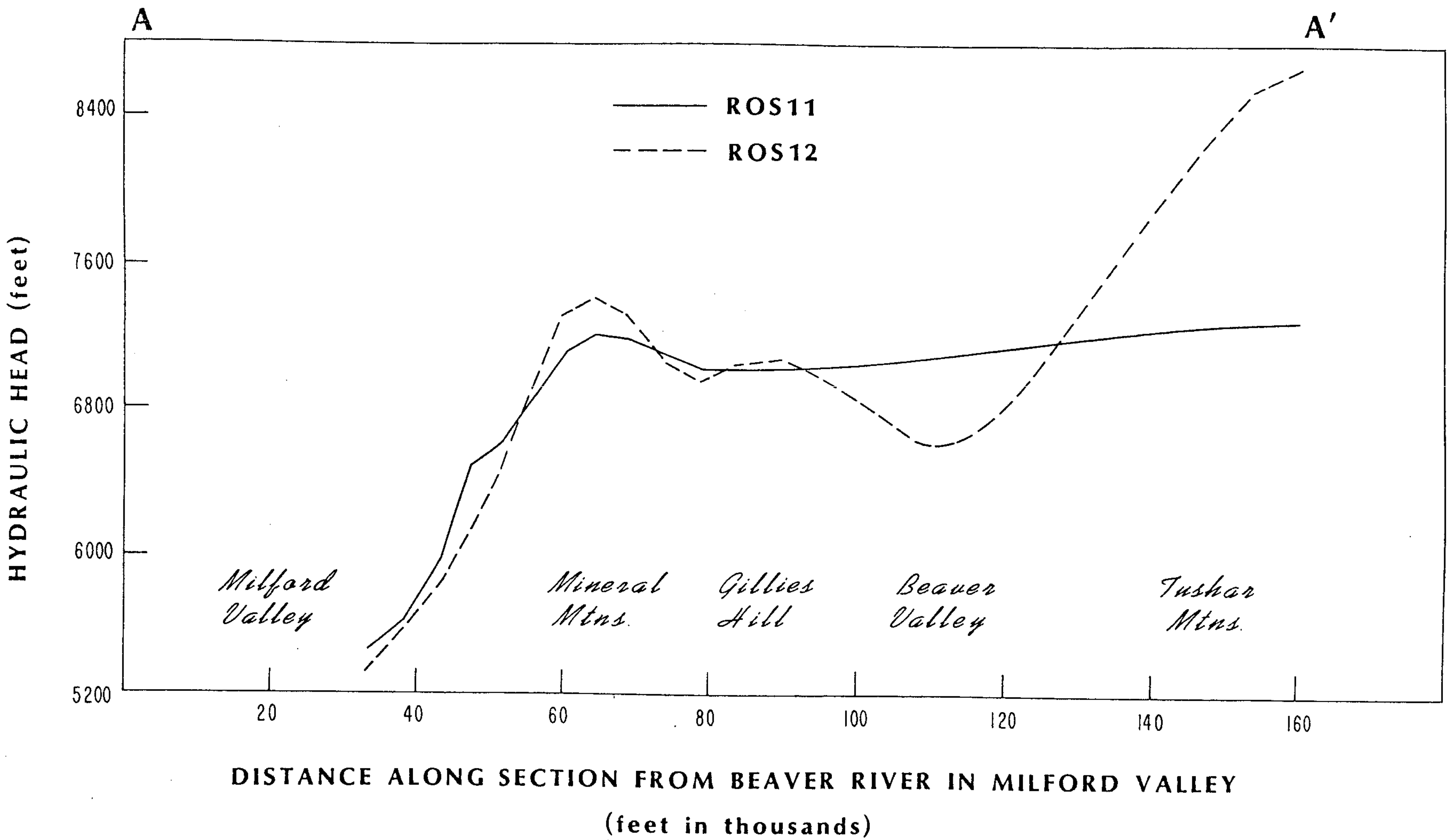


Figure 8: Hydraulic head distribution along basal boundary; heterogeneous anisotropic system.

ROS11 in the Tushar Mountains - Beaver Valley region and to ROS12 in the Mineral Mountains - Milford Valley region. This again reflects the separate nature of the two flow systems.

This study is based on a simplified hydrologic model of the regional geology. However, it must be remembered that the regional geology is poorly constrained and field conditions may differ markedly from those postulated. For some units, differences will probably not be critical. For example, the thickness and hydraulic conductivity of the Beaver and Milford Valley alluvium has a minor effect on the regional flow patterns. The distribution of groundwater discharge in Beaver Valley depends upon the location of the contact between the volcanics and the granitic pluton, but the possiblity of interbasin flow is insensitive to its precise location.

Such may not be the case if a geologic structure at depth provides a hydraulic connection between Beaver and Milford Valleys. In nearby regions, the permeable Navajo sandstone or its equivalent is known to underlie the Bullion Canyon volcanics (e.g. Mace et al., 1979). Several simulations were carried out to consider the effect of a layer of higher hydraulic conductivity at depth. ROS13 represents a case where a 1000 ft thick basal layer with a hydraulic conductivity of 1 ft/day is continuous beneath the Bullion Canyon volcanics ($K=10^{-2}$ft/day). The layer truncates against the eastern flank of the granitic pluton ($K = 10^{-2}$ ft/day). The hydraulic head distribution along the impermeable base is plotted in Figure 9. This result indicates that if a higher conductivity layer is present beneath the Bullion Canyon volcanics but it truncates against the lower conductivity granitic pluton, water within this layer will discharge to Beaver Valley rather than feeding a flow system circulating deep within the

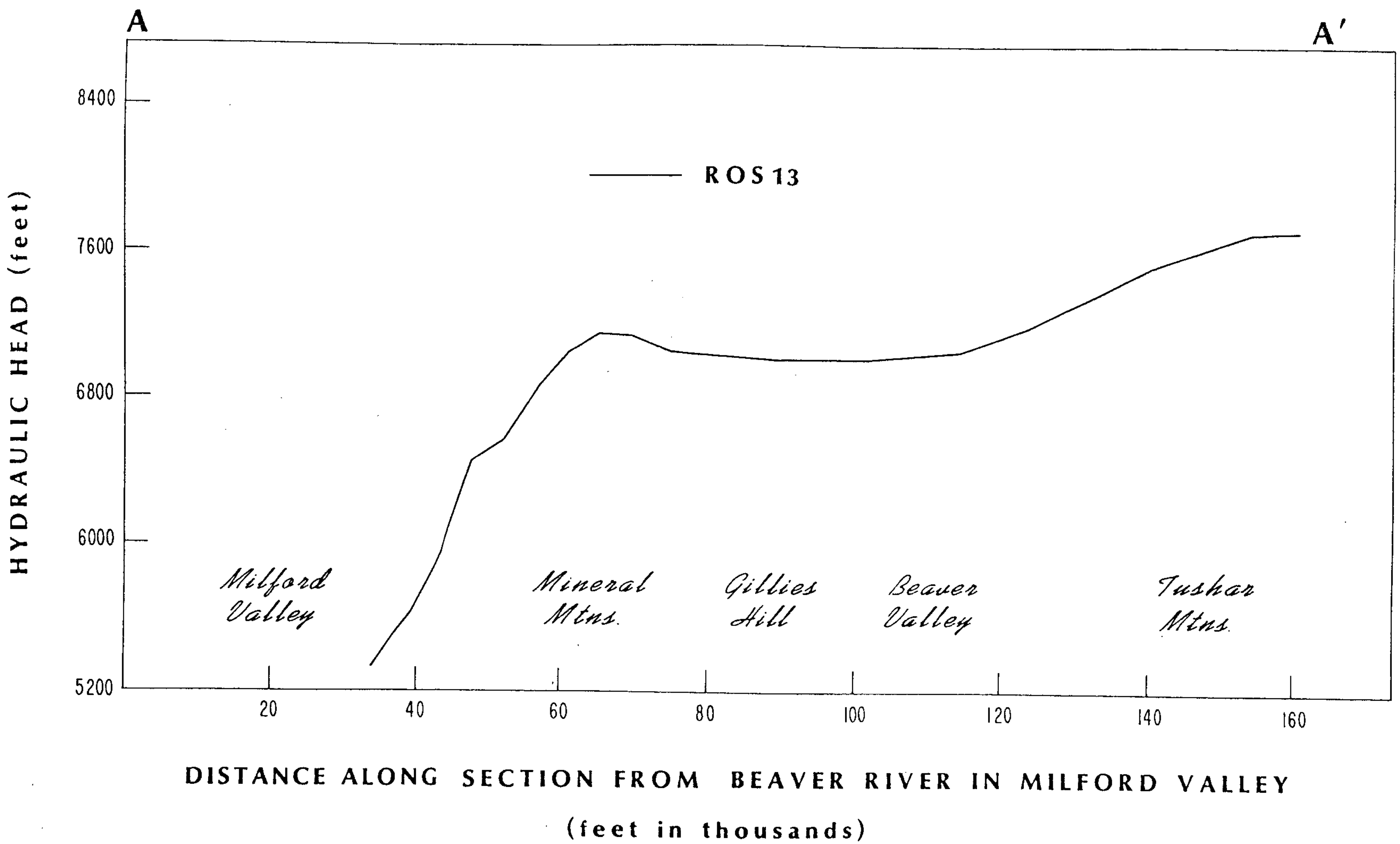


Figure 9: Hydraulic head distribution along basal boundary; deep permeable layer.

pluton. Only if this layer is continuous beneath the pluton can water be transferred to Milford Valley. However, such a condition is not seen as being geologically reasonable.

CONCLUSIONS

A model study of the regional hydrogeologic regime is used to investigate potential recharge areas for the Roosevelt Hot Springs thermal area under natural flow conditions. Precipitation within the Mineral Mountains is identified as the probable sole source of water entering Milford Valley from the east. Simulations carried out over a range of water table positions and assumed depths to a lower impermeable boundry suggest it is very unlikely that the topographic configuration alone could drive an interbasin flow system from the Tushar Mountains to Milford Valley. Specific geologic conditions must be invoked to observe interbasin flow.

The hydrologic behavior of the granitic Mineral Mountains pluton and the volcanics in the Tushar Mountains control the regional flow systems. A regional hydraulic anisotropy greater than 10:1 (K_x/K_z) leads to interbasin flow if the granitic rocks and the Tushar volcanics have similar hydraulic conductivities. However, if either of these units is more nearly isotropic or the vertical hydraulic conductivity of the pluton is greater than its horizontal conductivity, no interbasin flow is observed. On the basis of available geologic evidence this latter case seems to be the most likely.

REFERENCES

Blankennagel, R. K., and J. E. Weir, 1973, Geohydrology of the eastern part of Pahute Mesa, Nuclear Test Site, Nye County, Nevada, U.S.G.S. Prof. Paper 712-B, 35 pp.

Callaghan, E. and R. L. Parker, 1961, Geologic map of part of the Beaver Quadrangle, Utah, United States Geological Survey, Map MF-202.

Eakin, T. E., 1966, A regional interbasin groundwater system in the White River area, southeastern Nevada, Water Resources Research 2(2), 251-271.

Freeze, R. A. and J. A. Cherry, 1979, Groundwater, Prentice Hall, New York, 604 pp.

Gertson, R. C. and R. B. Smith, 1979, Interpretation of a seismic refraction profile across the Roosevelt Hot Springs and vicinity, Univ. of Utah Rept. Contract DE-AC07-78ET28392, 120 pp.

Mase, C. W., Chapman, D. S., and S. H. Ward, 1978, Geophysical study of the Monroe-Red Hill geothermal system, Univ. of Utah Rept. Contract EY-76-S07-1601, 89 pp.

Mower, R. W., 1978, Hydrology of the Beaver Valley area, Beaver County, Utah with emphasis on groundwater, State of Utah Dept. of Nat. Resource, Tech. Pub. 43, 106 pp.

Mower, R. W. and R. M. Cordova, 1974, Water resources of the Milford area, Utah, with emphasis on grondwater, State of Utah Dept. of Nat. Resource, Tech. Pub. 43, 106 pp.

Nielson, D. L., Sibbett, B. S., McKinney, D. B., Hulen, J. B., Moore, S. N., and S. M. Samberg, 1978, The geology of the Roosevelt Hot Springs KGRA, Beaver County, Utah, Univ. Utah Research Inst. Earth Science Lab. Rept., DOE Contract EG-78-C-07-1701, 120 pp.

Winograd, I. J., 1971, Hydrogeology of ash flow tuff: a preliminary statement, Water Resources Research, 7(4), 994-1006.

Yusas, M. R., 1979, Structural evolution of the Roosevelt Hot Springs geothermal reservoir, M. Sc. thesis, Univ. of Utah, Salt Lake City, Utah, 120 pp.