DESERT RESEARCH INSTITUTE
UNIVERSITY OF NEVADA SYSTEM

BASIN DEVELOPMENT AND WATER ALLOCATION

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WATER RESOURCES CENTER

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FOREWORD

This study was undertaken to simulate the combined surface and subsurface hydrology of a desert basin undergoing development to define the area hydrology and the effects of the application of water right law on the hydrologic system. The utilization of the simulation models developed in conjunction with computerized water right information can provide the basis for approval or rejection of applications to appropriate water and criteria for allocation of water to users during periods of deficient supply.

This work was supported in part by the Office of Water Research and Technology, U.S. Department of the Interior under PL 95-467, (Project B-038-NEV, Contract 14-31-0001-3104, and Project B-050-NEV, Contract 14-31-0001-3612) and in part by the Water Resources Center, Desert Research Institute, University of Nevada System.

Peter A. Krenkel
Executive Director

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INTRODUCTION

This investigation was directed toward development of simulation techniques which would aid in the allocation of ground and surface water in semi-arid basins. Models were developed to define the hydrologic constraints within which the water rights doctrine operates and to evaluate the hydrologic system responses to changes in flow regime by the allocation of water to new areas and new areas of application.

LOCATION AND FEATURES

The area chosen for study was Hualapai Valley in the northwestern Great Basin about 115 miles north of Reno, Nevada (Figure 1). The basin has an area of about 315 square miles and ranges in elevation from a playa at 4050 feet to above 9000 feet. Hualapai Valley is essentially an enclosed basin. An area called Hualapai Flat occupies some 20 percent of the southcentral part of the Valley (65 square miles). The southern part of the area is an alkali flat (playa) of about 12 square miles and is the topographic low of the basin. Granite Peak (9,056 feet) and Fox Mountain (8,222 feet) are the highest points in the Granite Range to the southwest. On the northeast the highest peak of the Calico Mountains is 8,491 feet.

Vegetation in the basin is a typical Great Basin steppe shrub at the lower elevations and a mixture of shrub, aspen and open meadows in the higher elevations.

Climatically the area has cold moist winters and hot dry summers with extreme daily and seasonal fluctuations in temperature and precipitation. Pacific storms account for 90 percent of the winter precipitation and 65 percent of the total annual precipitation (Houghton 1969). Orographic effects control the precipitation pattern due to the orientation of the north-south trending mountains.

GEOLOGY

The mountains surrounding Hualapai Valley are composed principally of igneous rocks with some small areas of metamorphics and sedimentary rocks. The igneous

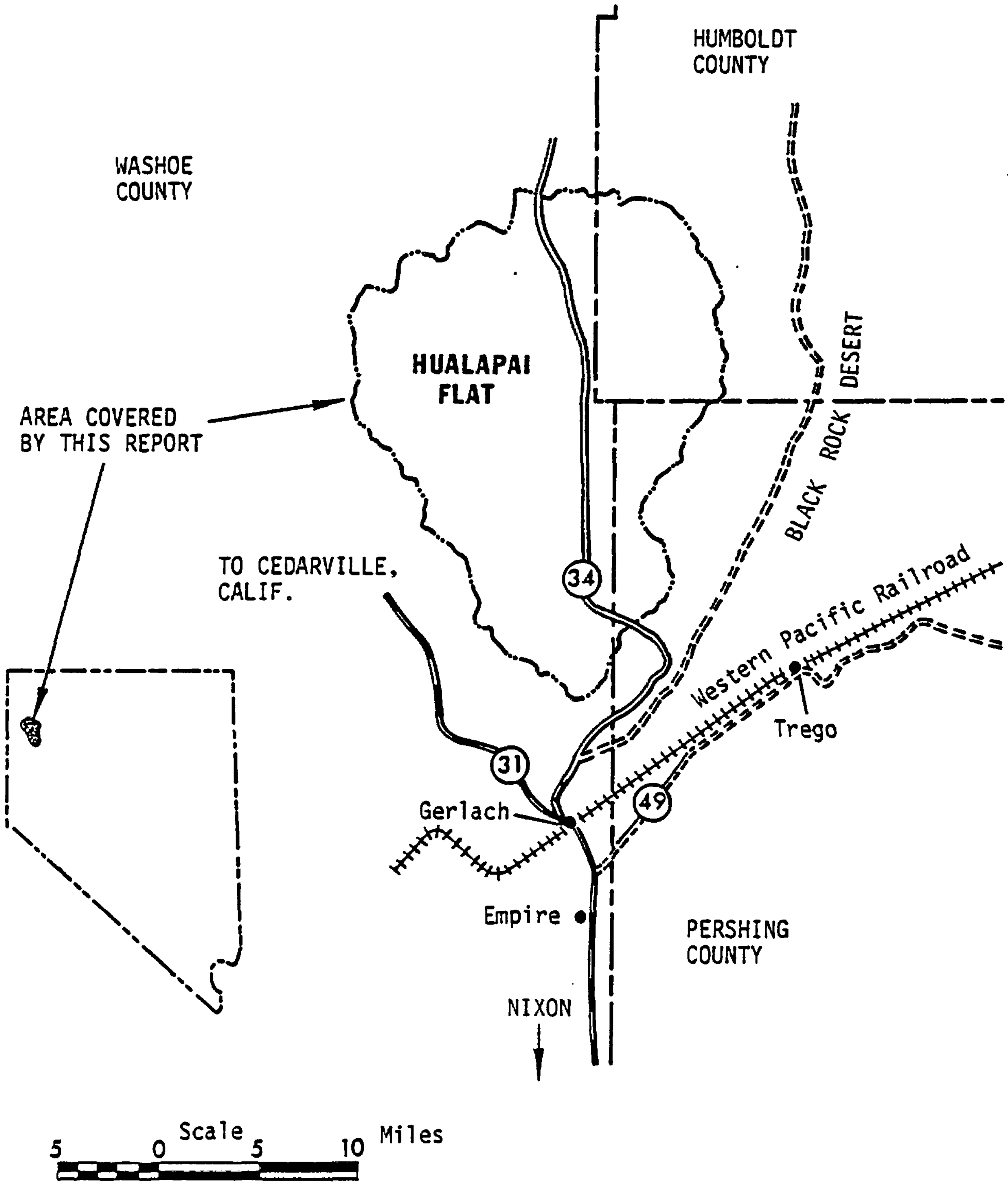

FIGURE 1. Location of study area.

rocks are mainly intrusive in the southern mountains and volcanic extrusive in the northern section.

Quaternary units occur mainly as sedimentary deposits in the valley basin. The Quaternary deposits are differentiated into older and younger units. The older units are mainly alluvial fan deposits with some deposits of slope wash and talus. They are generally exposed on the margins of the valley basin and are being dissected by present day streams.

As the older alluvial deposits are traced toward the central portion of Hualapai Valley, they extend beneath the younger Quaternary deposits. In general the older alluvium is poorly to moderately sorted with a larger percent of the coarser material occurring nearer the mountain fronts. The deposits get progressively finer as they extend toward the center of the valley.

The younger Quaternary deposits are primarily unconsolidated. As surface deposits they cover the main portion of the valley basin, including the western area of the valley that extends toward the mouth of Red Mountain Canyon.

HYDROGEOLOGY

Downcutting by streams has affected the valley alluvium. Recent stream action has produced channel and floodplain deposits along channel reaches in both bedrock canyons and the valley fill. Where the streams leave their channels they spread out over the valley floor leaving alluvial fan and braided channel deposits. This is especially pronounced in the northern end of the valley where South Willow Creek empties onto the valley spreading into a myriad of shallow channels. The alluvial deposits made by the streams have been largely destroyed or modified by present day agricultural development.

A small amount of dendritic tufa and tufa debris are located near the eastern alluvial divide and probably represent near shore or shoreline algal precipitation from prehistoric Lake Lahontan. There are numerous tufa mounds on the western edge of the valley where hot springs are present. These springs issue from a mound area that has been built up primarily by precipitates forming within and on top of the sediments through which the hot waters flow. These springs are on an interbasin horst trending north-northeast and are bounded on the east by a fault scarp. This fault cuts through younger alluvial and lake sediments and the hot spring mounds are being built upon the Quaternary sedimentary deposits. Thus, the hot springs must be relatively recent in age.

Wind action has formed and is still modifying small sand dunes and phreatophyte mounds that occur mainly on the east side of the Hualapai Flat. An area of large dunes start along the eastern alluvial divide and extends towards the Black Rock Desert Playa. Most of these dunes have been stabilized by vegetation. The dunes are probably formed from reworked, lake and alluvial sediments and from sediments blown in from the surrounding playas and alluvial slopes.

Most stream flows that reach the playa bring in only finegrained materials such as silt and clay. Since the water table is close to the playa surface and the silts and clays deposited on the playa are not very permeable, most of the surface runoff that reaches the playa is ponded and evaporates. Evaporation leaves behind a buildup of salts in the playa sediments. When the playa surface is exposed to the air, the groundwater table or its capillary fringe may extend close enough to the land surface to permit evaporation which will result in further buildup of salts. During dry periods the wind may move the fine sediments from the playa to adjacent areas, helping to build dunes, vegetation mounds and their sand shadows.

In several areas of the valley cracking is taking place in the sediments with the greatest number appearing in the northern part of the valley. These cracks vary from ten feet in length to several miles long, less than one inch to several feet wide, and open to depths of tens of feet. Their alignment is mainly north to northeast and is some areas they are grouped together in a parallel pattern. These cracks show no vertical or horizontal displacement and some are very recent in age. Grose and Keller, (1975 a,b) have interpreted this cracking to be tectonic in origin as their orientation seems unrelated to the slope of the basin and the drainage lines along the valley floor, and they were present before extensive groundwater pumping commenced.

Thermal springs in the southern part of Hualapai Valley have created an interest in the goethermal resources of the area. Several exploratory holes have encountered hot mineralized water under considerable pressure. However, to-date, no geothermal areas have been developed.

The subsurface geology of the valley-fill was determined mainly through interpretation of well logs. The valley-fill reservoir tends to get deeper from north to south, going from a thickness of around 450 feet in the northwest to a depth of over 800 feet in the southwest. However, the depth to the hot water zone suggests that the maximum depth may be over 1,000 feet in the playa area. In the northern part of the valley, the fill is relatively thinner on the east and west margins and is relatively thicker and coarser in the central portion along a zone trending northwest to southeast. In general, the valley-fill is coarser to the north, becoming finer grained to the south, where the few well logs in the playa area indicate greater thickness of clay with interbedded sands. The valley-fill shows a rather abrupt change in cross section in the vicinity of the alluvial divide, going from a depth of 755 feet to 175 feet and a width of many miles to 4,000 feet within a distance of two or three miles.

A contour map of the head distribution, as determined from measurements of water levels in wells, is one means of delineating the general groundwater flow pattern. Figure 2, is a contour map of the water level elevations of the valley-fill reservoir of Hualapai Flat measured in the spring of 1960, as modified from Sinclair (1962) and Harrill (1969). The map represents the hydraulic head conditions prior to the large-scale use of groundwater for irrigation farming. The configuration of the contours gives an indication of the hydrogeologic parameters of the valley-fill reservoir. The contours indicate that the main recharge is from the western and northern highlands. This recharge is mainly from precipitation in the mountains, but takes place mainly along the relatively permeable alluvial slopes. In general, the groundwater flow is from the recharge areas along the mountain fronts toward the playa and the alluvial divide.

The inferred hydraulic head contours in the valley area south of the playa indicate flow through the playa and beneath the alluvial divide. There would be a very gentle gradient across the playa due in large part to the decrease in flow rate through evapotranspiration. It is postulated that the valley-fill is thickest in this area, and this would tend to increase the transmissivity. However, the decrease in hydraulic conductivity due to the increase in the percent of clay would be an offsetting factor. This would indicate that the decrease in flow rate is the largest contributor to a shallow gradient.

Flowing wells, springs and seep areas are present around the margins of the playa, with the greatest concentration of flowing wells on the north side of the playa. This region is the main evaportranspiration discharge area. Due to the pumping action of the transpiring phreatophytes and evaporation of groundwater from the playa, groundwater is moving upward toward the surface. This pumping action establishes a vertical gradient that is independent of confining conditions, and this vertical gradient alone could cause flow from a well that is tapping the aquifer at some depth. Although in the region of the playa only a few wells have logs, these logs indicate that the flows from wells are due primarily to the confining conditions created by the interbedded clay and sand.

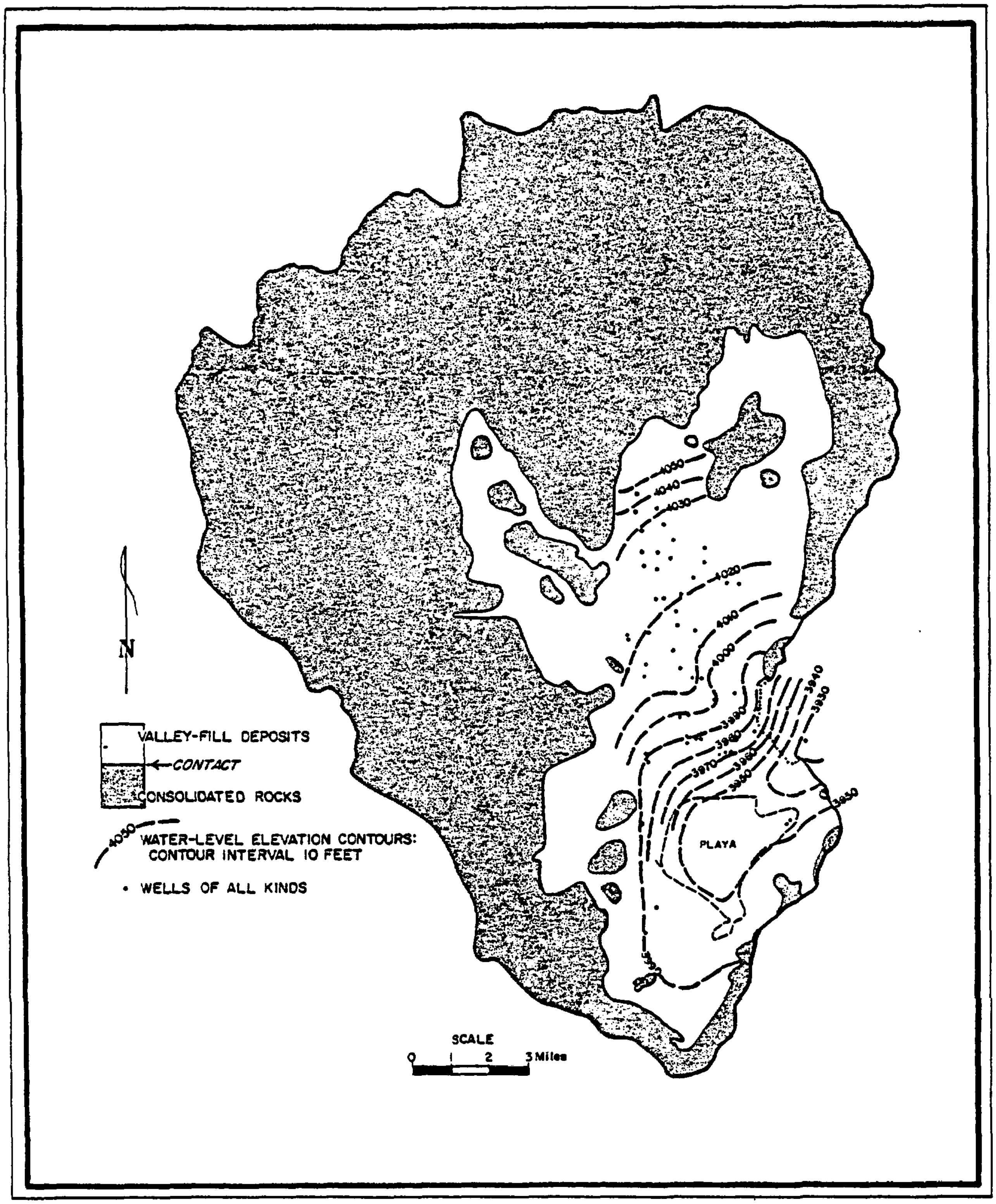

FIGURE 2. Water level elevations, Spring 1960.

ECONOMIC DEVELOPMENT

The major economic development in Hualapai Valley has been irrigated cropland. Prior to this development, there was an unsuccessful attempt at dry farming in the 1920's. Over the years some meadowland, alfalfa and hay have been irrigated by streamflow and spring discharge mainly in connection with the local cattle and sheep operation. The first large diameter irrigation well was drilled in 1951. However, large scale development of irrigated farmland did not start until the 1960's.

By 1967, twenty-eight large diameter irrigation wells had been drilled in the valley basin. In 1972, there were 38 irrigation wells, most of them located in the northern half of the valley basin. However, only 21 were pumped for irrigation. By 1972, about 7,000 acres of land had permits for irrigation by groundwater, but during the growing season only about 4,000 acres of land were being irrigated by groundwater.

PRECIPITATION SIMULATION

There are almost no climatic data for Hualapai Valley so a new technique was employed to develop an isoheytal map of the area. The rationale behind the method employed in this study was that vegetation is a function of topography and climate among other parameters. Two variables used in this study with the vegetation component were elevation and precipitation. Conversely, an approximate mean annual precipitation may be determined for any point from its elevation and the vegetation present. This first precipitation approximation may be further modified by additional topographic parameters not detected in the vegetation but affecting total precipitation.

The first step taken in this method is to determine the vegetation associations present and categorize them in general units so they can be mapped (Figure 3). A network of points was established in the area using a 1.2 mile grid for coordinates. At each point the average annual rainfall was estimated based on vegetation type and its elevation. Using a statistical coaxial correlation technique (Linsley, 1956) adapted to numerical data with a computer program, precipitation for each point was further modified according to topographic features. Utilizing a trend surface analysis the data points were smoothed, by finding points of equal value. These points were then plotted on an isohytel map for total average annual rainfall.

Each topographic parameter was defined and its effect on the initial and subsequent precipitation graphed. The equation used for this general relationship is:

$$P_m = P_5 = f_5 \left\{ f_4 \left[f_3 \{ f_2 [f_1 (V\ E), S], OR \}, EXP \right], RS \right\}$$

Where P_{2-5} are successive approximations of the precipitation expressed as functions of V (vegetation), E (elevation), S (slope), OR (orientation), EXP (exposure) and RS (rainfall shadow). P_m is the modified precipitation for each point and is used as input to the trend surface analysis routine.

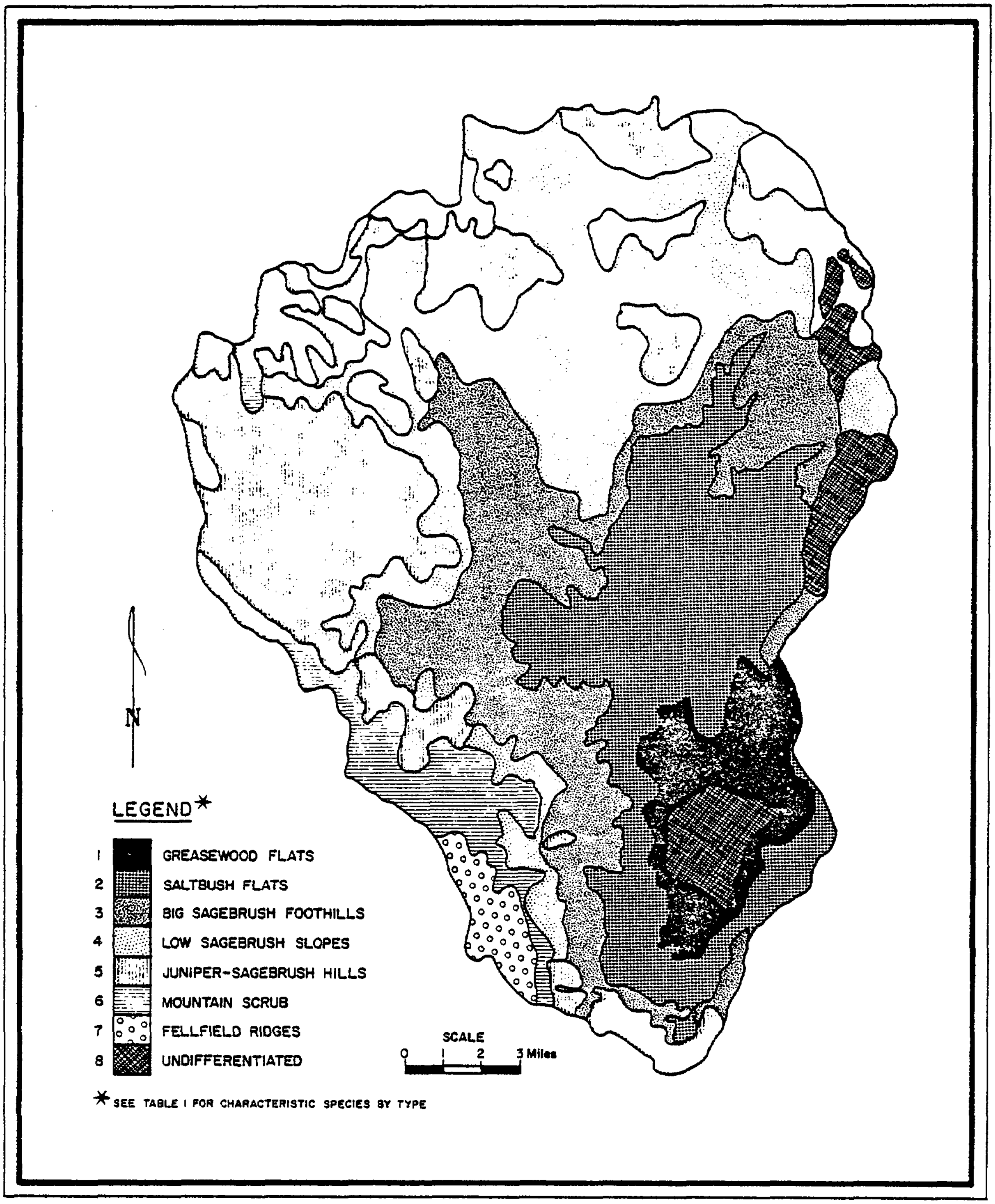

FIGURE 3. Distribution of vegetation in Hualapai Valley, by type.

VEGETATION

Vegetation was represented as an ideal vegetation on a moderate slope that was well-drained and open with no obvious edaphic control such as high salinity or hardpan. Altitudinal limits and characteristic species for each type of vegetation were determined by site visitation and transects up the mountain slopes. The precipitation range and additional distribution information for each vegetation type were determined from published data (Blackburn, et al, 1968a and b, Passey and Hugie, 1960). The types were numbered with gradients of altitude and precipitation increasing with the number 1 through 8. The plants categorized in types 1 through 8 are listed in Table 1. Actual field observations indicate some vegetational deviations from the altitude limits presented. These deviations were taken into consideration in constructing the equations used.

The graph for determining precipitation (P_1) is shown in Figure 4 along with the equations used for each line.

SLOPE

Slope was determined as the average change in elevation at seven compass points in direction the slope faces at a distance four miles from the point. The effect of slope varies with altitude due to the strong orographic effect of the predominant southwest winds. The steeper the slope, the greater effect on the precipitation either to increase on the southwest facing slopes or to decrease on the lee or northeast facing slopes. One anomolous situation in the basin is the combined effects of 1) air lift producing precipitation on the lee slopes behind barriers as in the Granite Peak area and upper Cottonwood Creek drainage, and 2) snow being blown off the peaks and ridges into catchment areas to the lee slopes on the northeast. Figures 5 through 8 are graphs of the slope function broken down into quadrants and altitudes.

ORIENTATION

Orientation is determined as the center of the greatest open slope to a distance of 15 miles expressed in compass degrees. Orientation affects the precipitation by determining the strength with which storms moving from southwest to northeast impinge on a slope. Points with a barrier to the southwest receive less precipitation due to airflow being diverted around them.

Generally, at low altitudes precipitation is decreased by a northeast and east aspect, and increased by a southwest and west aspect. At higher altitudes there is a

TABLE 1. Characteristics of Hualapai Valley vegetation by type.

TYPE	ALTITUDE RANGE	PRECIPITATION RANGE (INCHES)	CHARACTERISTIC SPECIES
1	4000-5000 (GREASEWOOD FLATS)	4 - 6	*SARCOBATUS VERMICULATUS, S. BAILEYI, ATRIPLEX CONFERTIFOLIA, SHEPHERDIA ARGENTEA, ARTEMISIA TRIDENTATA, ELYMUS CINEREUS*
2	4200-5000 (SALTBUSH FLATS)	4.5 -7.5	*ATRIPLEX CONFERTIFOLIA, CHRYSOTHAMNUS NAUSEOSUS, SARCOBATUS VERMICULATUS, PURSHIA TRIDENTATA, GRAYIA SPINOSA, ARTEMISIA SPINESCENS, SHEPHERDIA ARGENTEA*
3	4200-5600 (BIG SAGEBRUSH FOOTHILLS)	6.5-10.5	*ARTEMISIA TRIDENTATA, A. ARBUSCULA, GRAYIA SPINOSA, STIPA THURBERIANA, ORYZOPSIS HYMENOIDES, ELYMUS CINEREUS, TETRADYMIA CANESCENS*
4	4800-7000 (LOW SAGEBRUSH SLOPES)	8.5 -14	*ARTEMISIA ARBUSCULA* (ON THE SLOPES), *ARTEMISIA TRIDENTATA* (SWALES), *AGROPYRON SPICATUM, CHRYSOTHAMNUS VISCIDIFLORUS, LUPINUS SAXOSUS, LUPINUS CAUDATUS*
5	5000-7500 (JUNIPER-SAGEBRUSH HILLS)	10 -16	*JUNIPERUS OSTEOSPERMA, ARTEMISIA TRIDENTATA, A. ARBUSCULA, FESTUCA IDAHOENSIS, STIPA LETTEMANII*
6	5000-8000 (MOUNTAIN SCRUB)	12 -20	SLOPES: *ARTEMISIA ARBUSCULA, POA SECUNDA, LUPINAUS SAXOSUS, ARTEMISIA NOVA, CHRYSOTHAMNUS VISCIDIFLORUS, BALSAMORHIZA, SAGITTATA* OPEN MEADOWS: *JUNCUS BALTICUS, IRIS MISSOURENSIS, CAREX SP., ACHILLEA LANULOSA*
7	7000-9000 (FELLFIELD RIDGES)	15 -25	EXPOSED SLOPES: *ARTEMISIA NOVA, CHRYSOTHAMNUS PARRYI* ssp. *NEVADENSIS, ARTEMISIA ARBUSCULA, ARENARIA KINGII, ERIOGONUM* ssp., *ERIGERON LINEARIS, LEPTODACTYLON PUNGENS, SITANION HYSTRIX* LEE SLOPES: *AMELANCHIER PALLIDA, SYMPHORICARPOS LONGIFLORUS, ARTEMISIA TRIDENTATA, ELYMUS CINEREUS, LUPINUS LAXIFLORUS*
8			UNDIFFERENTIATED; PLAYAS, ROCK OUTCROP, CLAY, ETC.

slight increase to most aspects with an espcially strong increase in the southwest and northeast due to the orographic effect and snow accumulation areas. Figure 9 is a graph of the orientation function.

EXPOSURE

Exposure is determined by

$$EXP = (1/2)\ (OS)\ (D)$$

where

OS = number of degrees of greatest open slope

D = distance to nearest barrier over 1000 feet (up to 15 miles)

The exposure or openess of the slope determines the extent to which storms passing a point are intercepted, funneled, or blown by. This is a function of the distance of the fetch and the degree of concavity of a slope. Narrowly exposed slopes have decreased precipitation, with precipitation increasing up to 90° open, decreasing to 180° open, and neutral or slightly decreasing up to completely open. Figure 10 is a graph of the exposure function.

RAINFALL SHADOW

Rainfall shadow is determined by

$$RS = (\frac{D}{2})\ (H)$$

where

D = distance to the highest barrier in SW quadrant

H = height of that barrier

There are two effects from a high barrier on slopes in the lee side. First, airlfows are intercepted and forced to rise thereby losing their moisture before reaching the lee slopes (except near the top of the barrier as explained in the section on slope effects). Second, air flowing rapidly down a slope is heated adiabatically by turbulent friction (Chinook winds) raising the temperature and lowering the relative humidity. These are drying winds which can draw moisture from plants and soil. Figure 11 is a graph of the rainfall shadow function.

For each point on the grid the parameters were determined from the vegetational, coordinate, and topographic maps and coded. Table 2 is a sample of the coded numerical data. The codes correspond to equation numbers shown on the graphs in Figures 4-11.

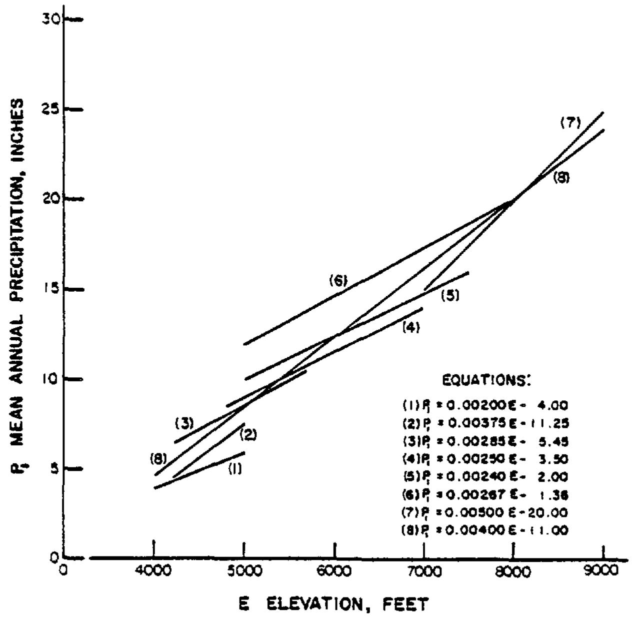

FIGURE 4. Estimation of precipitation, P_1, from vegetation type and elevation.

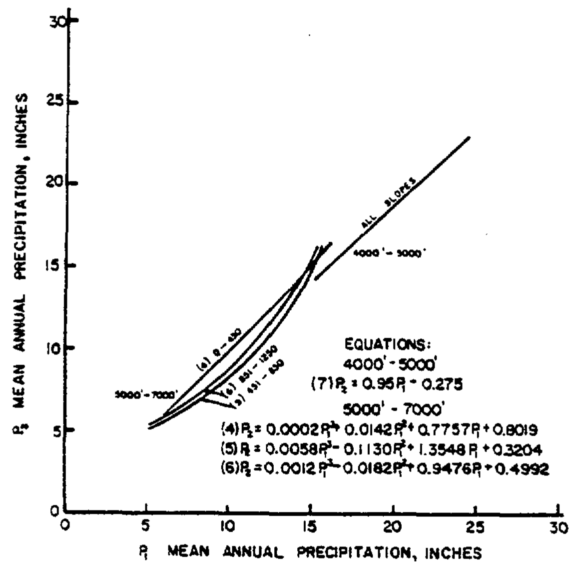

FIGURE 5. Average slope adjustment of P_1 to P_2, NE quadrant, 7000 ft. to 9000 ft.

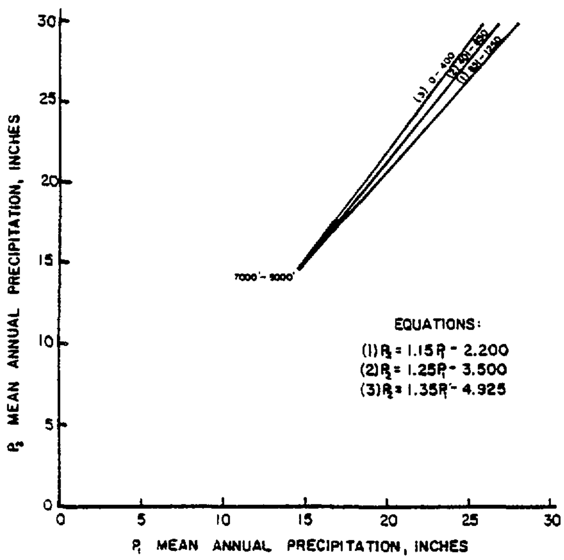

FIGURE 6. Average slope adjustment of P_1 to P_2, NE quadrant, 4000 ft. to 7000 ft.

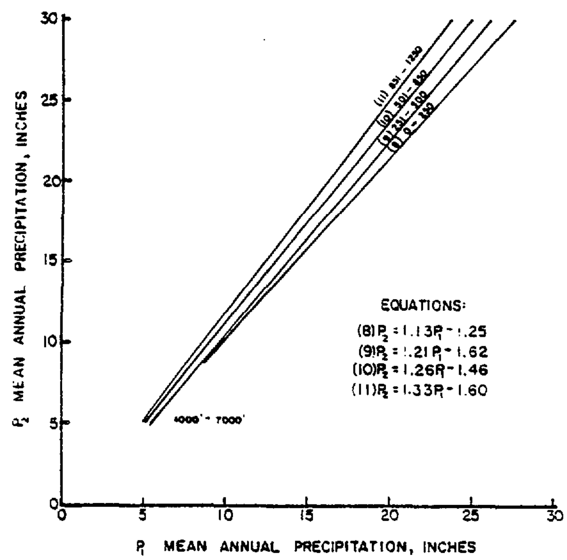

FIGURE 7. Average slope adjustment of P_1 to P_2, SW quadrant, 4000 ft. to 7000 ft.

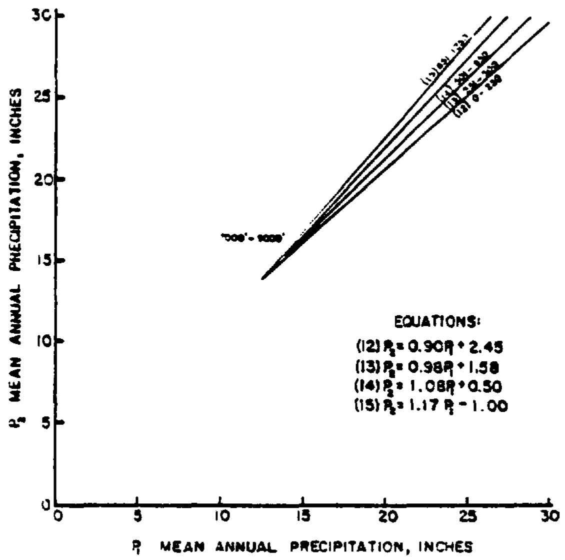

FIGURE 8. Average slope adjustment of P_1 to P_2, SE quadrant, 7000 ft. to 9000 ft.

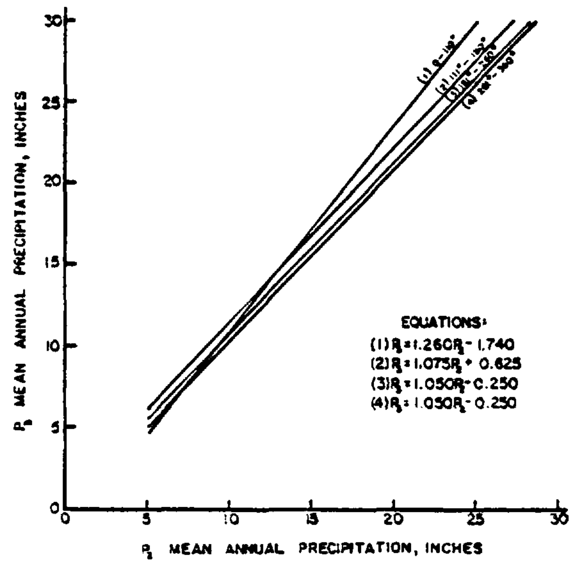

FIGURE 9. Orientation adjustment of P_2 to P_3.

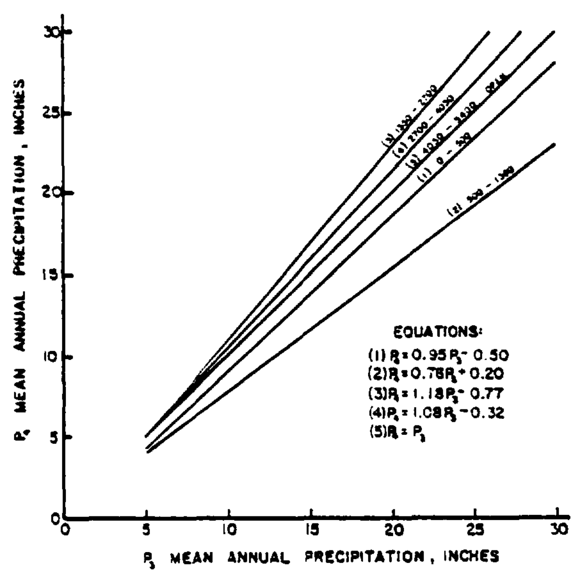

FIGURE 10. Exposure adjustment of P_3 to P_4.

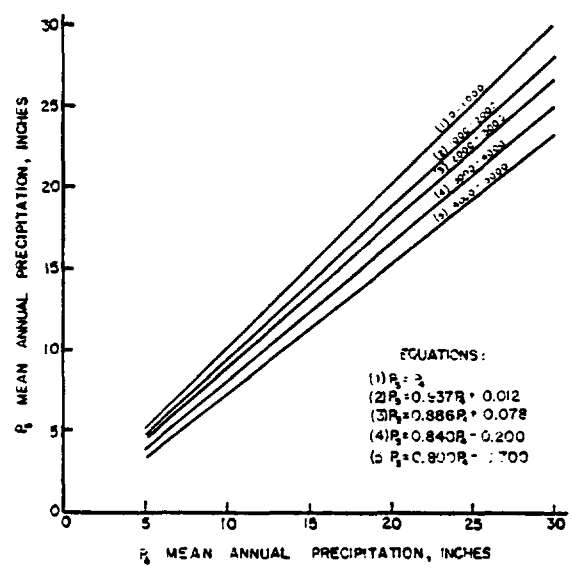

FIGURE 11. Rainfall shadow adjustment of P_4 to P_5.

TABLE 2. Sample input to estimation computation program for precipitation simulation.

	COORDINATES X	COORDINATES Y	VEG. TYPE	ELEV.	OR	SLOPE	EXP.	RAIN SHAD
1 2 3 4	5 6 7 8 9	10 11 12 13 14	15 16 17 18 19 20	21 22 23 24 25	26 27 28 29 30	31 32 33 34 35	36 37 38 39 40	41 42 43 44 45
	2860	5320	6	6100	1	4	4	1
	2860	5340	5	6000	2	8	3	1
	2860	5360	5	6000	1	4	4	1
	2860	5380	5	6200	3	8	3	1
	2860	5400	5	6600	3	8	3	1
	2860	5420	5	6800	3	8	3	1
	2860	5440	6	7200	3	9	1	1
	2840	5420	5	6800	2	8	3	1
	2880	5320	5	6400	1	4	2	1
	2880	5340	5	6100	2	8	4	1

TREND SURFACE ANALYSIS

The P_m data were used as input to a trend surface analysis program designed to fit the data to a polynomial equation and produce a contoured map of the computed values. The fifth degree polynomial produced the best fit, therefore the computed values of the fifth degree surface were used in subsequent steps of the estimation procedure. These values are identified as the P_6 set. Relevant error measures computed yield,

Standard deviation = 2.74

coefficient of determination = 0.76

coefficient of correlation = 0.87

The coefficients of the fifth degree equation are presented below:

$$
\begin{aligned}
Z = {} & 274258.79 - 80516.80X + 64037.43Y - 2023.40X^2 + 2808.27XY \\
& - 3092.59Y^2 + 84.75X^3 - 25.11X^2Y + 80.57XY^2 + 11.22Y^3 + \\
& 1.41X^4 - 3.56X^3Y + 1.05X^2Y^2 - 2.23XY^3 + 0.63Y^4 + 0.03X^5 - \\
& 0.11X^4Y + 0.142X^3Y^2 - 0.06X^2Y^3 + 0.02XY^4 - 0.006Y^5
\end{aligned}
$$

where

Z = computed precipitation at point (X, Y)

X = grid point value on abscissa

Y = grid point value on ordinate

X and Y values in distance east and north, respectively, from the initial point

DISCUSSION

This estimation procedure provided a set of a mean annual rainfall point determinations based on vegetation and topographic parameters where no climatic data were available. Table 3 is an example of these data point determinations for the grid established in the basin. P_1 is the original precipitation determination from vegetation and altitude, and P_5 is the topographically modified precipitation. Intermediate values P_2 through P_4 are for different topographic parameters.

TABLE 3. Sample output from estimation program for precipitation simulation.

Coordinates		Precipitation Estimates					
X	Y	P(1)	P(2)	P(3)	P(4)	P(5)	P(5)-P(1)
2840	5420	14.320	14.932	16.676	18.908	18.908	4.588
2860	5320	14.927	14.880	17.008	18.049	18.049	3.122
2860	5360	12.400	12.762	14.344	16.156	16.156	3.756
2860	5380	12.880	13.304	14.220	16.009	16.009	3.129
2860	5400	13.840	14.389	15.359	17.353	17.353	3.513
2860	5420	14.320	14.932	15.928	18.025	18.025	3.705
2860	5440	17.864	19.995	21.245	19.683	19.683	1.819
2880	5320	13.360	13.223	14.921	11.360	11.360	2.000
2880	5340	12.640	13.033	14.636	15.487	15.487	2.847
2880	5360	12.880	13.304	14.220	13.009	13.009	.129

The deviation of the P_m set from the P_1 shows a few anomalous data points and a wide variation due to small differences in topography, however since storm patterns and other controls on precipitation would have a much greater influence, longer term trends would smooth these precipitation amounts.

Data points generated by the trend surface program were assumed to smooth these data points to more closely resemble long-term trends. However, the smoothed data points were extened due to the configuration of the open-ended dish-shaped basin resulting in underestimates in the lower elevations and irrelevant high values out beyond the valley rim. The fifth degree polynomial of the trend surface analysis could not take into account the irregularities of the basin nor the sharp relief between the highest and lowest values; consequently, the low values were a little too low. Prior to further analysis, the low values on the valley floor were adjusted upward to a 3.5 inch minimum. The trend surface program could have input data at points outside the basin for correcting this anomaly; however, this might result in excessive smoothing with overestimates on the valley floor and underestimates at mountain tops. Average precipitation and total estimated precipitation volumes for each of P_1 through P_6 are shown in Table 4.

TABLE 4. Estimated average annual precipitation and estimated precipitation volumes for P_1 through P_6.

Average Precip., Inches			Precip. Volumes, Acre-Feet		
P(1)	=	9.74	V(1)	=	163,667.56
P(2)	=	9.78	V(2)	=	164,370.75
P(3)	=	10.59	V(3)	=	177,936.81
P(4)	=	10.58	V(4)	=	177,856.06
P(5)	=	10.26	V(5)	=	172,354.00
P(6)	=	10.09	V(6)	=	169,482.69

The estimated average precipitation over the entire basin for P_5 = 10.26 inches, and for P_6 = 10.09 inches. The P_6 value produces 2871 acre-feet less annual precipitation volume than did the P_5 value. There was a significant difference in the areal distribution of this precipitation, as can be seen on the isohyetal maps (Figures 12 and 13).

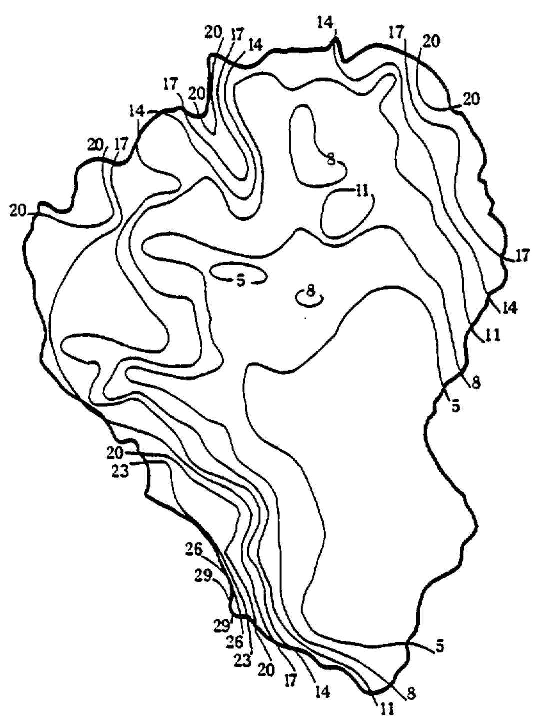

FIGURE 12. Isohyetal map of P_5 values.

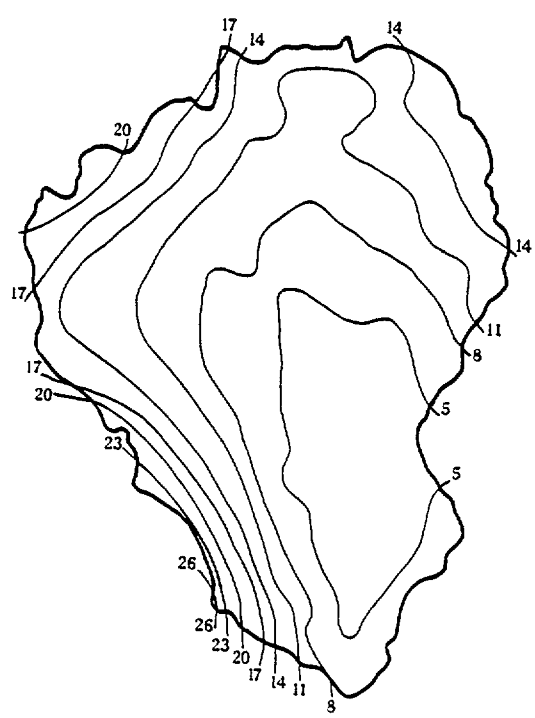

FIGURE 13. Isohyetal map of P_6 values (smoothed).

Estimating procedures demonstrated herein yielded gross results similar to estimates derived from assigning precipitation rates to altitude rates (Harrill, 1969). However, the altitude zone method, while simpler to compute and accurate enough for preliminary analysis, did not give adequate or necessary consideration to orographic effects and therefore did not yield the desired areal distribution required for streamflow or groundwater simulation.

WATERSHED SIMULATION

This phase of the project was directed toward establishing a complete water budget for seven major watersheds in Hualapai Valley. These watersheds were Granite Creek, Rock Creek, Unnamed Creek, Cottonwood Creek, Red Mountain Creek, Negro Creek, and South Willow Creek as shown in Figure 14. A description of these watersheds can be found in the Appendix.

A digital computer model was developed to reproduce runoff and account for all additions and losses of moisture. The model was then used to simulate other watersheds of interest. This model is modification of the Stanford Watershed Model as developed for the USDA Soil Conservation Service for application to mountainous areas (Fordham 1968, Fordham and Wilkes, 1970).

The model evaluated precipitation, evapotranspiration, streamflow and groundwater accretion and depletions using relationships between hydrologic parameters and variables. Data used were watershed area, elevation, basic soils data, and average annual precipitation values for each elevation zone determined from the isohyetal map prepared for this study. Snow accumulation and melt for each basin were determined using temperature and precipitation values as parameters. The model was designed to use daily precipitation and maximum and minimum temperatures as input data as well as some physical properties of the watershed.

ANNUAL PRECIPITATION

The effect of elevation on precipitation within a basin tends to remain the same from year to year. Precipitation for any given elevation zone calculated by multiplying precipitation at a base station (which is assumed to be representative of the entire watershed) by a precipitation ratio for the elevation zone. The precipitation ratio is the ratio between average annual precipitation for the elevation zone and average

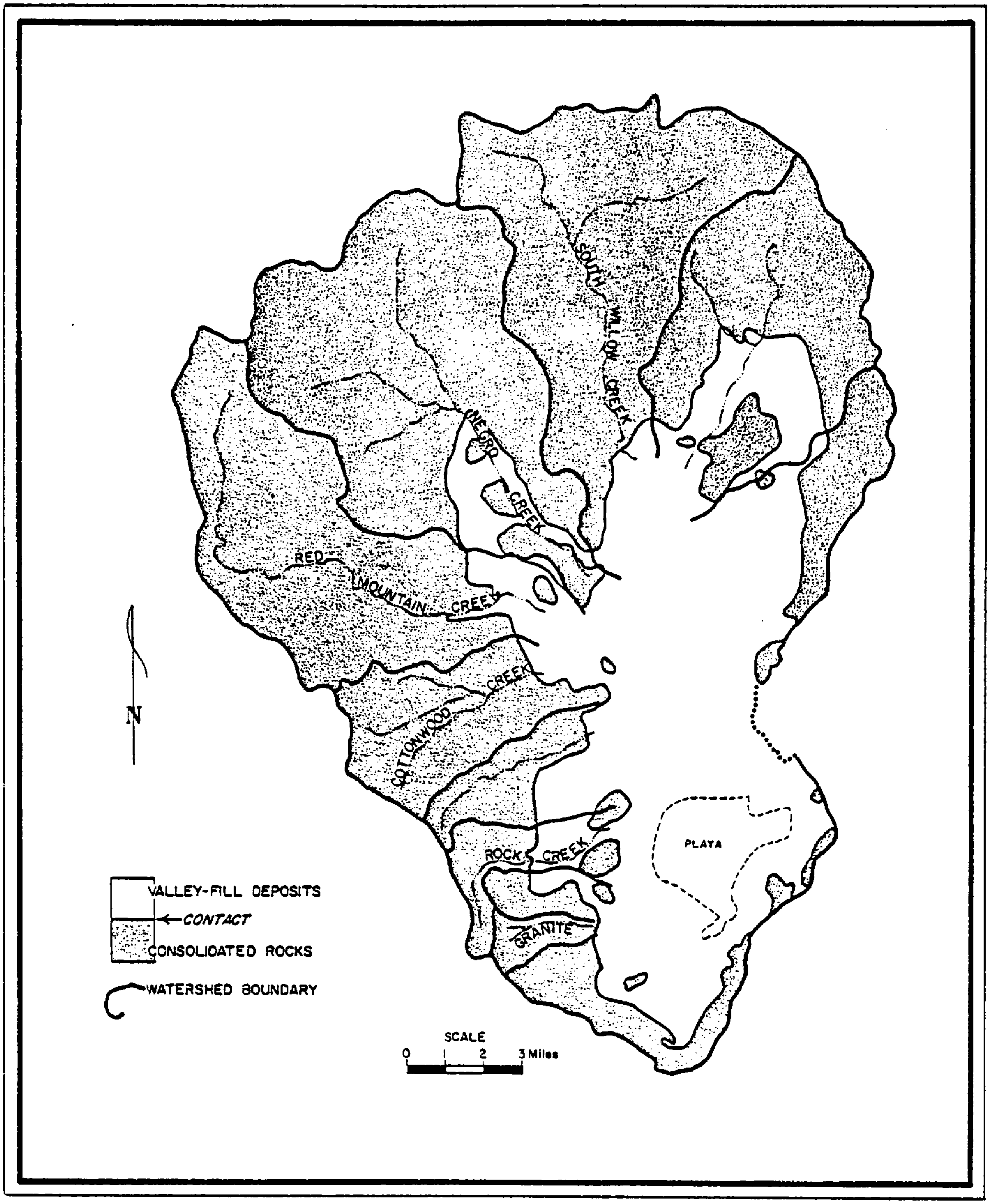

FIGURE 14. Watersheds in Hualapai Valley.

annual precipitation at the base station. Annual precipitation values, taken from the isohyetal map, (Figure 13) were supplemented by snow course or other available data.

Air temperature variations over the watershed are based strictly on change in elevation. Temperatures recorded at the temperature base station were adjusted using a constant lapse rate. This lapse rate was applied independent of season and enabled extrapolation of air temperature to any place on the watershed.

Base station records of minimum and maximum temperatures are not believed to be representative of the mean temperature during each half day period used for analysis of precipitation and melt. In order that a more representative temperature could be used, a straight line relationship between the daily maximum and minimum temperatures was assumed and the average temperature for each half day was used to determine the form of precipitation and the amounts of melt.

SNOW MELT

Snow accumulations and melt were computed on an elevation zone half day basis. To determine whether precipitation were in the form of snow or rain at particular location, a temperature index of $35^{\circ}F$ was used. At or below $35^{\circ}F$ precipitation was assumed to be in the form of snow and above $35^{\circ}F$, rain. To determine the snow accumulation in an elevation zone, air temperature for the zone had to be calculated for each half day by applying the lapse rate. If there were precipitation during the time period being analysed, the form was determined using the $35^{\circ}F$ criteria. If precipitation was in the form of snow, it was added to the existing pack or became the snow pack if none previously existed. The snow pack may gain moisture from rain, if the rain does not exceed the snow pack's ability to retain liquid water. If retained by the snowpack, the water is held in the pack and freezes. If the rain plus melt exceeds the liquid-water-holding capacity of the pack, the amount in excess either infiltrates to the soil or becomes overland flow.

Snow melt was calculated using only air temperature as an index since other data necessary for energy budget melt calculations were not available. Melt due to rainfall was small but easily calculated knowing the amount of rainfall and assuming its temperature to be the same as the air temperature. All other snowmelt was based on a degree half-day factor. When the elevation zone half-day temperature was calculated to be above $32^{\circ}F$ snowmelt is assumed.

The half-day melt factor in inches of water for each degree above $32^{\circ}F$ varies throughout the year due to variations in the amount of incident shortwave radiation, the inferred albedo of the snow surface, and the maximum/minimum temperature spread. Therefore, monthly melt factors vary from a low in winter months to a high in the late spring since there is more incident radiation in the spring, and a reduction in the snow surface albedo due to decreased storm frequency in the late spring months. Actual monthly snow melt factors were obtained by trial and error.

The water created by snowmelt was assumed to percolate into the snowpack. During the early part of the snowmelt season melt water penetrating the pack is held by capillary tension on the grains of snow and trapped. Once the snowpack's water holding capacity is filled, additional melt water is discharged into the soil.

INFILTRATION

Once the amount of water available to the ground in the area was calculated, it was treated as follows: 1) the upper zone moisture requirement must be satisfied first to account for detention and depression storage; and 2) excess water becomes either surface runoff or may infiltrate into the soil. Surface runoff and infiltration are computed by assuming a straight-line relationship between the maximum and minimum infiltration rates for the soil (Figure 15). The maximum infiltration rate was applied when the soil was dry and the minimum rate was applied when field capacity was reached. Water from the root zone percolates to the groundwater aquifer at a rate determined by trial runs and measured stream flow recessions.

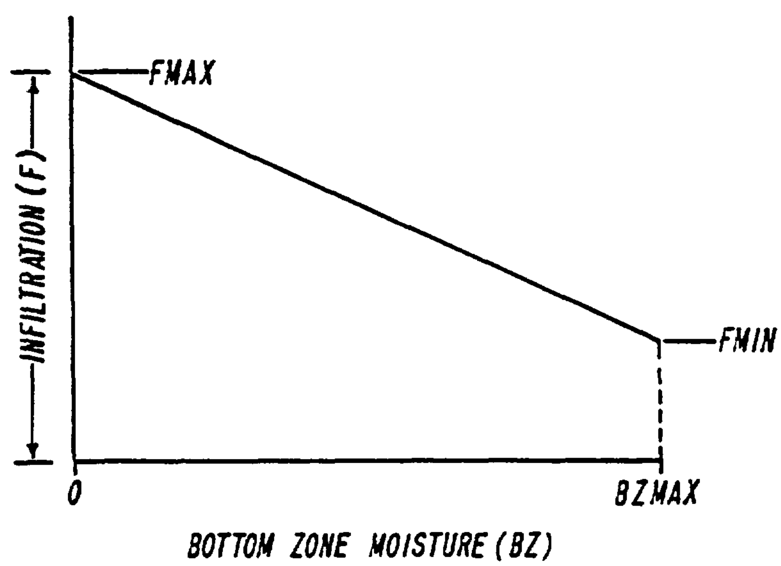

FIGURE 15. Infiltration variation.

For any bottom zone moisture content (BZ) the infiltration (F) may be computed by,

F = FMAX - (FMAX - FMIN) x BZ/BZMAX

Two cases can exist as illustrated in Figure 16. Case (a) where F$\leq$ moisture available from the upper zone and Case (b) where F > moisture available from the upper zone. For case (a),

Direct Runoff = AVM - F/2

and for case (b),

Direct Runoff = $(AVM)^2$ /(2xF)

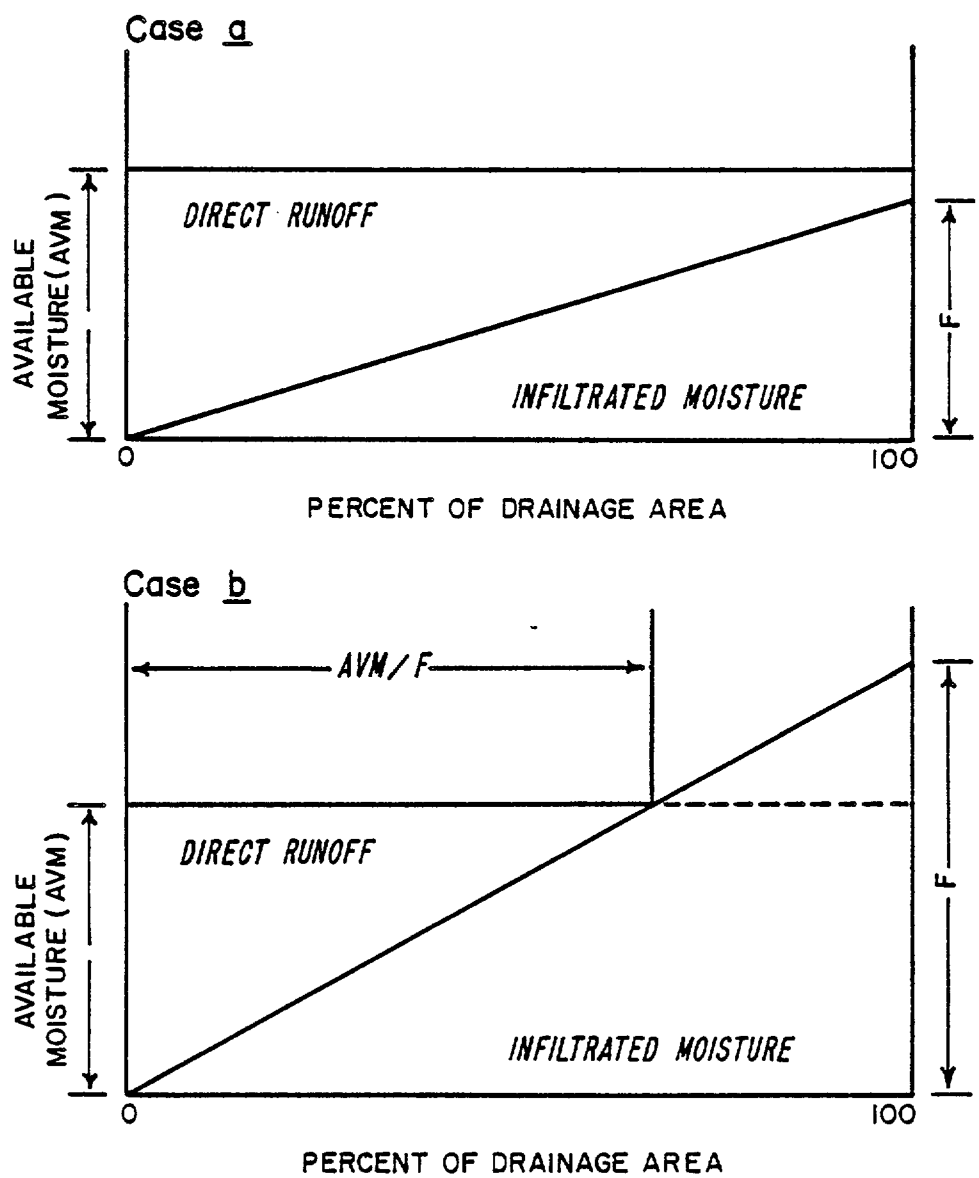

FIGURE 16. Responses of infiltration to incoming moisture.

The groundwater component of runoff was determined from ground zone storage and released at a rate derived from analysis of the recession portion of the hydrograph which represented withdrawal of water from storage after surface flow ceased.

PROGRAM OPERATION

The program was set up to evaluate up to seven elevation zones each containing as many as twenty subareas. Figure 17 shows the generalized flow chart of the program. The operation sequence is as follows: watershed parameters such as area base station elevation, lapse rate, and lake evaporation are read in. If the watershed contains irrigated or semi-irrigated crops the constants reflecting irrigation efficiencies must also be read in.

Second, elevation zone parameters are read in. These parameters are area, base station index, mean elevation and precipitation ratios. For each subarea within the elevation zone the values of soil moisture holding capacity, cover type, maximum and minimum infiltration rates are read in. Subarea soil moisture values are initialized. Next, arrays of monthly values for each crop type for growth stage must also be read in. Other yearly values are initialized to zero. If the watershed contains a reservoir, values of inflow from other watersheds and the reservoir proposed or actual release rates must be read into storage. In a watershed with irrigated crops the program allows limits to be placed on water available for diversion, pumping and for irrigating marginal areas.

Next, daily precipitation and maximum/minimum temperatures for one or more base stations are read in and monthly variables are initialized to zero. Daily calculations begin by analyzing the precipitation, evapotranspiration and runoff. The sequence of calculation is as follows:

1. Potential daily evapotranspiration is calculated
   a. for native vegetation and water surface areas lake evaporation is used as the potential evapotranspiration,
   b. for phreatophyte and crop areas the modified Blaney-Griddle formula is used.
2. Elevation zone temperatures are calculated for each half day applying the lapse rate to base station temperature.
3. The snow accumulation and melt calculations are computed as previously described yielding available water. For water surfaces all precipitation is assumed to be in the form of rain so that all snow calculations are by-passed.

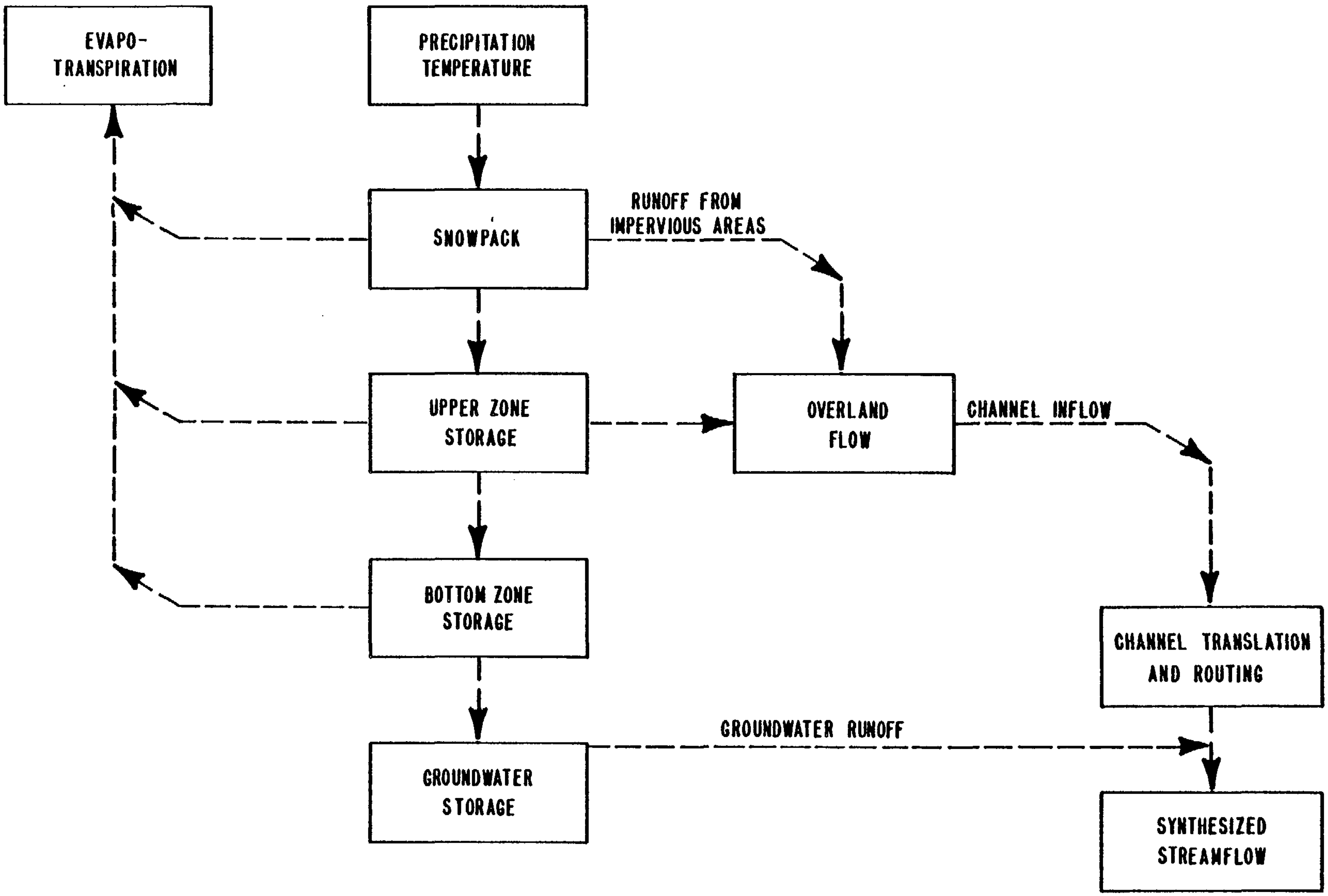

FIGURE 17. Watershed simulation model flow chart.

For each subarea within the elevation zone the water balance is now computed:

1. Water available to the ground from melt or rain on bare ground is divided among runoff, evapotranspiration, or soil moisture by the following steps:
   a. Water available to impervious areas is subtracted from the total available moisture.
   b. The upper zone moisture holding capacity is satisfied.
   c. Evapotranspiration is deducted from the upper zone at a potential rate if there is moisture in the upper zone.
   d. Excess available moisture either infiltrates to the root zone or becomes surface runoff using the previously described relationship.
   e. The infiltrated moisture is added to any existing in the root zone. If no moisture exists in the upper zone, evapotranspiration is subtracted from the root zone at a rate calculated proportional to the quantity in the root zone.
   f. Water from the root zone is percolated to the ground-water zone by a rate which is determined through trial computer runs.
   g. Water is released from ground zone storage at a rate which was determined from hydrograph examination.
2. Runoff from impervious areas is added to direct runoff to give total surface runoff.
3. Total runoff from the elevation zone is the sum of the surface runoff and the ground-water discharge from all subareas.

There exist three special cases in the water balance for subareas within an elevation zone:

1. Areas containing phreatophytes may remove water from the root and ground zones at a potential rate to satisfy their evapotranspiration requirements.
2. Reservoirs are handled by calling the reservoir subroutine which operated as follows:
   a. Total available water in the reservoir is calculated by summing precipitation on the reservoir, undiverted import water and runoff from all areas above the reservoir in the watershed which contribute to it.
   b. Evaporation is subtracted at the potential rate.
   c. The reservoir volume is adjusted for releases and seepage loss.
3. Irrigated areas are handled separately by calling the irrigation subroutines during a predefined irrigation season.

a. The irrigation requirement is calculated as the amount of water required to bring the soil moisture profile to 75% of field capacity.
b. If no irrigation is required, the analysis returns to the mainline program and analyzes the subarea the same as other areas.
c. If irrigation is required, the first sources checked are natural precipitation and known or assumed pumped water. If these satisfy the requirement, the analysis returns to the mainline program.
d. If the irrigation requirement is not satisfied, gross diversion must be calculated which includes estimated canal losses, tailwater losses and loss due to deep percolation.
e. The diverted irrigation water is taken first from runoff and upper areas in the watershed and then from imported wat
f. The irrigated subarea is treated the same as other subareas after the losses are subtracted from the diverted water.

Summaries are computed monthly for all subareas if desired and for elevation zone and watershed as a whole. The model furnishes results that comprise a breakdown of the water balance into monthly totals of rainfall, snowfall, potential and actual evapotranspiration, snowmelt, accumulation of snow pack, surface runoff, ground-water flow, and crop usage.

PROGRAM RESULTS

Simulation runs were made for each of the seven watersheds whose flow comprises all normal surface runoff in Hualapai Valley as well as being the major part of groundwater recharge. Each watershed was run simulating first the years for which gaged flows were available and then for years for which precipitation data were available but flow data were not.

Trial runs were performed to compare computed flows to the gaged flows. Using this comparison the model parameters were adjusted so that new calculated flows were more representative of the actual runoff. Through this trial and error process the model was calibrated for each watershed.

Once the model was calibrated it was run using precipitation data for years which had no gaged record thus providing a synthetic flow record. Table 5 shows a sample output for one elevation zone of Granite Creek as well as the 1970 annual summary for Granite Creek. This shows the type of output and the level of reproducibility, $\pm$ 10 to 15%, that one can normally expect applying this model in sparse data areas.

TABLE 5. Granite Creek flow simulation.

SUB BASIN AND ELEVATION ZONE SUMMARY

ELEVATION ZONE ELEV= 8200. NO. OF SUBAREAS= 1 AREA= .605SMI PRECIP RATIO= 2.50

YEAR 1970

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
RAINFALL	.31	.89	.70	1.55	.34	.50	.00	1.17	1.16	.02	.11	.19	6.94INCH
SNOWFALL	2.29	1.24	6.15	3.82	.74	1.07	.72	.15	.00	.00	.00	.00	16.19INCH
POT ET	2.85	1.63	1.10	.64	.85	1.95	3.19	4.45	5.44	6.56	5.77	4.35	39.00INCH
ACT ET	1.23	1.63	1.01	.64	.80	.36	.05	4.02	2.84	.49	.11	.19	13.37INCH
SNOWEVAP	.00	.12	.12	.16	.09	.16	.30	.06	.00	.00	.00	.00	1.01INCH
SNOWMELT	2.12	1.81	.94	.70	.19	.00	.00	13.58	.63	.00	.00	.00	
PACK EOM	.44	.00	5.79	10.31	10.56	12.52	12.95	.57	.00	.00	.00	.00	
SUFLOW	.00	.45	.00	.00	.00	.00	.00	7.12	.82	.00	.00	.00	8.39INCH
GWFLOW	.02	.02	.03	.04	.04	.04	.03	.03	.04	.03	.03	.02	.35INCH
TOT FLOW	.02	.47	.03	.04	.04	.04	.03	7.15	.85	.03	.03	.02	8.74INCH

FLOW TOTALS FOR GRANITE CREEK IN CFS-DAYS

YEAR 1970

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
SURFACE	.03	7.35	.78	24.22	65.92	11.87	.00	241.11	13.19	.00	.00	.00	364.46 SFD
GROUND-WATER	3.77	3.14	3.20	4.05	6.66	10.75	11.86	11.76	10.60	8.94	7.04	5.34	87.12 SFD
TOTAL	3.80	10.49	3.98	28.28	72.58	22.62	11.86	252.87	23.79	8.94	7.04	5.34	451.58 SFD

Although an exact reproduction of flow cannot be expected the approach used can yield probable runoff values which are valuable for planning purposes.

DISCUSSION

In general, the model as developed can reproduce monthly and annual volumes of runoff within the accuracy dictated by the input data. Results from application to watersheds in the Sierra Nevada Mountains (Fordham and Wilkes, 1970) show the model can compute flows that are within 10 percent of those recorded. Keeping in mind the accuracy of the input data and that the model is intended to be used for studies of watersheds on a macro scale where limited data are available, the results from this application in a semi-arid area show the model can be best used to produce probable outflow from the basins considered.

The ability of the model is primarily limited by the assumptions that the base precipitation station used is representative of the entire basin. If this assumption is incorrect, either the model will assign too much or too little moisture as input to a basin. In general, the estimated runoff from a summer rain far exceed the recorded runoff. This same error is evident on other hydrographs showing responses to local rainstorms which were assumed to be basin wide but in reality were not. On the other hand, the gaged hydrographs do not show a true response to heavy rainstorms or excessive response to rain may also be caused by the daily time period used for analysis.

The temperature index used to determine the form of precipitation over the basin is satisfactory over the snow accumulation and melt season as a whole, but for individual storms it may be in error causing runoff to be calculated at times where actual records show none. The overall simulation is not extremely sensitive to this index, but fall and late spring precipitation could be either rain or snow.

Some of the simulated flows are much greater than recorded flows due to rain on the snow pack. One could avoid the problem of precipitation form almost entirely if hourly precipitation and temperature values were available. Also, a separate temperature lapse rate during storm periods may be necessary to more accurately determine the precipitation form.

The timing of the snowmelt runoff is controlled by the liquid-water-holding capacity of the snow and by the monthly snowmelt factors which are keyed by air temperature. The use of a constant percentage of the snow pack for retaining liquid water in the pack works reasonably well serving to simulate the ripening process by retaining the initial melt water. Once the capacity to retain melt is satisfied, the ability to reproduce the actual snowmelt by use of monthly melt factors determines how well actual runoff is reproduced. The temperature relationship works well for most periods, but in some cases the relationship used is not adequate to represent the actual melt. This may be caused by the use of a constant lapse rate. By examinng the results and the input temperatures, it was observed that simulated hydrographs respond quickly to changes in daily temperature resulting in fast rises and drops in surface flow. The fast response of flows to temperature changes is due to the elevation zone method used to analyze the basins. Each entire elevation zone either contributes to surface flow or doesn't, depending upon mean temperatures for the zone and the ripeness of its snow pack. If more elevation zones were used the response would be slower giving more gradual rises and declines in surface flow.

A given snowmelt value for a month may yield satisfactory results for four out of five years, but will either overestimate or underestimate the melt for that particular year. This is due to meteorlogical factors not considered or a breakdown in the method used. To overcome the deficiencies of the snowmelt factors more meterological data such as actual incoming radiation, wind velocity, and actual temperatures for the snow pack and the surrounding air should be used. If these data were available, snowmelt could be computed more accurately using an energy budget; however, the complexity of the simulation procedure would be greatly increased.

This study shows the model as developed can be used to simulate runoff from the watersheds analyzed to produce extended runoff records in areas of sparce data.

The primary limitation of the model is the assumption that input precipitation and temperature data are representative of a given watershed. If the model were tested on many watersheds with diverse location and characteristics, it would be possible to correlate certain physical properties with some of the indexes used in the model, thus improving the model and enhancing its usefulness. This type of analysis has been performed by Ross (1970) for watersheds in Kentucky but it has not been done for arid and semi-arid areas of the United States.

GROUNDWATER SIMULATION

The movement and storage of water within the saturated zone is of considerable importance in the study area as it is in most areas of the Southwest. Most of the economic development is dependent upon the groundwater resource for water supply. For this aspect of the investigation a two-dimensional, time dependent finite difference model was developed.

Input parameter values were determined for simulating the hydraulic head distribution under time independent and time dependent conditions. It was assumed that prior to large-scale pumping for irrigation, the groundwater system of Hualapai Valley was behaving under steady or long-term natural equilibrium conditions and the hydraulic heads were fairly stable. Therefore, in a groundwater budget average annual total recharge to the basin would approximate average annual total discharge from the basin. For time dependent values, all hydrologic parameters that might change with time had to be identified and values determined, including changes in the boundary values for when pumping effects reached the hydraulic boundary.

BOUNDARY CONDITIONS

The conditions on the hydraulic boundary can be expressed in terms of hydraulic head and rates of flow, either recharge or discharge.

The principal recharge, is considered to come from streamflow infiltration. The streamflow study by Soule (Harrill, 1969) and data collected for the watershed simulation of this project showed that significant stream depletion begins to take place near the bedrock-valley-fill contact and the major portion of flow is depleted on the outer margins of the valley-fill basin. Water that has infiltrated into the fractures and faults in the bedrock and that moves as a subsurface flow laterally into the valley-fill may be considered as boundary recharge. Several cold water springs in the valley-fill along the mountain fronts may be the result of this type of recharge. Groundwater moving from the bedrock fractures into zones of valley-fill of low permeability may be forced to the surface as a spring. No quantitative estimates of this boundary recharge were attempted, however, it would be relatively small compared to other sources of recharge.

Since most of the stream recharge appears to take place on the outer margins of the valley-fill, it was believed that distributing the average annual recharge values of each sub-basin along a hydraulic boundary through the margins would not create appreciable error in the area of irrigation wells. Therefore, the recharge boundary for the model is mainly the bedrock-valley-fill contact. However, this boundary was placed across several valley-fill areas because the unconsolidated sediments were relatively thin and, therefore, these areas could be considered the effective edge of the main valley-fill reservoir.

Seismic work of McGinnis and Dudley (1964) established groundwater continuity between Hualapai and the Black Rock Desert. A trench and terraces cut into bedrock, probably by a stream draining Hualapai Valley, now covered by unconsolidated sediments to a maximum depth of about 175 feet is indicated. U.S. Geological Survey test holes drilled in 1969 showed a hydraulic gradient toward the Black Rock Desert.

The alluvial divide was considered to be the only area of significant groundwater outflow across the basin boundary. An estimate of the outflow through this area was computed. Using the logs of the test holes, the different sediments were assigned appropriate conductivities and an average hydraulic conductivity was determined for the total depth of the saturated sediments of the alluvial divide. Applying Darcy's law expressed as, $Q = KIA$, the hydraulic gradient, I, as determined from heads in the test holes, the cross sectional area, A, of the sediments in the alluvial divide, as determined from McGinnis and Dudley (1964) and the average hydraulic conductivity, K, were used to give a discharge, Q, of 400 acre-feet per year. This value was the same as computed by Harrill (1969).

SOURCES AND SINKS

All the groundwater recharge and discharge that take place within the hydraulic boundary of the valley-fill reservoir is considered as a source or a sink. The difference between the hydraulic boundary recharge and discharge indicates that the greatest amount of discharge takes place from within the valley-fill reservoir. Under steady-state conditions, the total recharge to the valley-fill equals the total discharge from it. Therefore, the excess boundary flow (stream recharge less basin outflow) of 7,700 acre-feet per year has to be accounted for in the net difference of recharge and discharge from within the valley-fill reservoir.

Under steady-state conditions, the major discharges or sinks are phreatophyte evapotranspiration, bare soil evaporation and flow from springs. The phreatophytes are mainly around the playa but extend into other areas of shallow groundwater depth. The major bare soil area is the alakali flat (playa) of about 12 square miles.

Natural flow from springs have been modified somewhat by flowing wells drilled in the 1940's, or earlier, which are located in spring or seep areas. It was assumed that the discharges from these wells were directly compensated by reductions in the spring and seep discharges and therefore, the steady state condition of the groundwater system was not greatly disturbed.

There are areas of thermal or hot springs along a fault scarp in the southern portion of Hualapai Valley. Since these waters are super heated they must be associated with a deeper flow system. For purposes of modeling, these springs were considered to be coming from a confined system below the cooler system. These thermal waters are considered to be evapotranspired in the immediate area and are therefore not considered as a source or sink term in the model.

The cooler waters in the shallow system which flow into the area mix with the thermal waters with a ratio of about 2:1 based upon the temperature of the springs. Since these mixed water are evapo-transpired in the area an estimate of the loss (sink) of the cooler water is two thirds of the total spring discharge or about 135 gallons per minute. Because the springs are so numerous, the total cooler water flow was considered to be evenly discharged over the entire spring area.

For the time dependent simulation, the major inputs were the pumping rates of the irrigation wells and the pumping schedules. Discharges were measured for most of the pumped irrigation wells. For a few wells, the flow rates used were based on estimates from the farm operator. The range of measured flows was from 200 gpm to 1800 gpm. Pumping schedules at first were designed to reflect the exact on-off sequence of the pumps, but this was considered too detailed so a general on-off sequence, based on cutting and harvest, was used.

Consideration was also given to recharge of applied irrigation water and to discharge from crops acting as phreatophytes. There are few data on amounts of recharge to the groundwater table from irrigated crops, especially involving sprinkler irrigation. However, fluctuations of water levels in observation wells in and around the irrigated fields indicated that recharge was taking place, especially from flood-irrigated sandy soils. Flood irrigation appeared to use greater quantities of water than did sprinkler irrigation.

Recharge to the groundwater from applied irrigation water and discharge from evapotranspiration was distributed over the irrigated areas taking into consideration crop type, soil type and irrigation method. Pumping from wells was considered as a point discharge from the groundwater reservoir.

TRANSMISSIVITY AND STORAGE COEFFICIENT

Values of transmissivity and storage coefficients were determined from pumping tests of several wells in different parts of the irrigated pumping area. Pumping test data for the most part were collected during actual irrigation operations. Pumping conditions were such that the most reliable head change measurements were obtained after pumping had stopped during the water level recovery periods.

Equations were developed so that transmissivity and storage coefficient values could be determined from the use of recovery head data without the need of preceding drawdown measurements (Case, et al, 1974).

To supplement the pumping test data, several other methods were used to estimate transmissivity and storage coefficient values. Specific capacity data from nearly every irrigation well and several stock and domestic wells scattered throughout the entire valley basin were used to estimate transmissivity values. Recordings of water levels from several different wells showed water level fluctuation that corresponded to barometric changes. The barometric changes and the corresponding water level changes were used to compute values of barometric efficiency. General information on porosity of unconsolidated materials and the sediment descriptions from the well logs were used to determine the average porosities in the well site areas. The average porosity and barometric efficiency values were then used to estimate storage coefficient values, which ranged from 3.1×10^{-3} to 6×10^{-5}. The transmissivity distribution is given in Figure 18 and the storage coefficient distribution is shown in Figure 19.

MODEL DEVELOPMENT

A computer program that had been developed for simulating a confined, nearly horizontal aquifer was used as the basis for modeling the groundwater flow of Hualapai Valley. The groundwater simulation is based on the following two-dimensional, time dependent, areal flow equation:

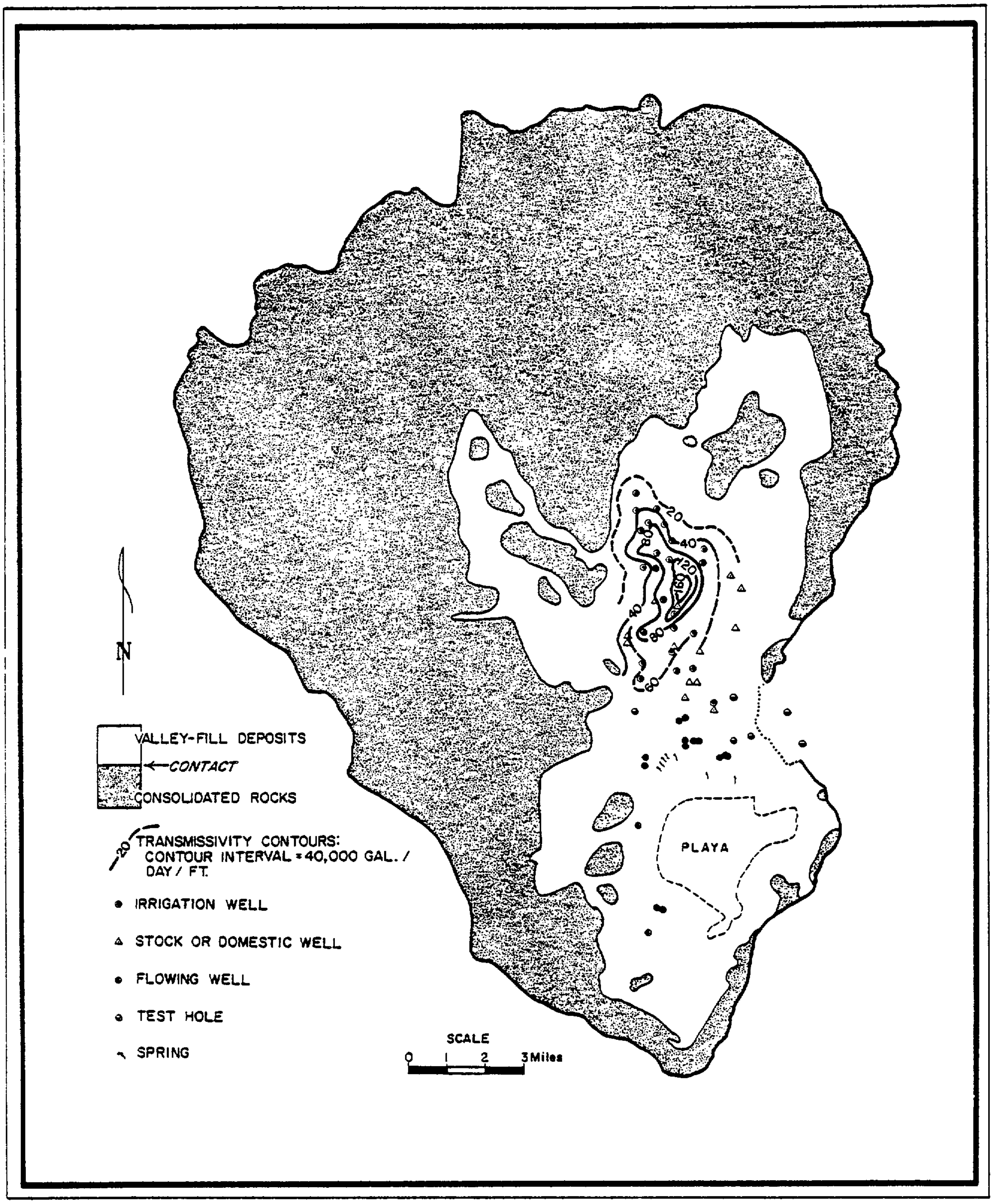

FIGURE 18. Contour map of transmissivity values.

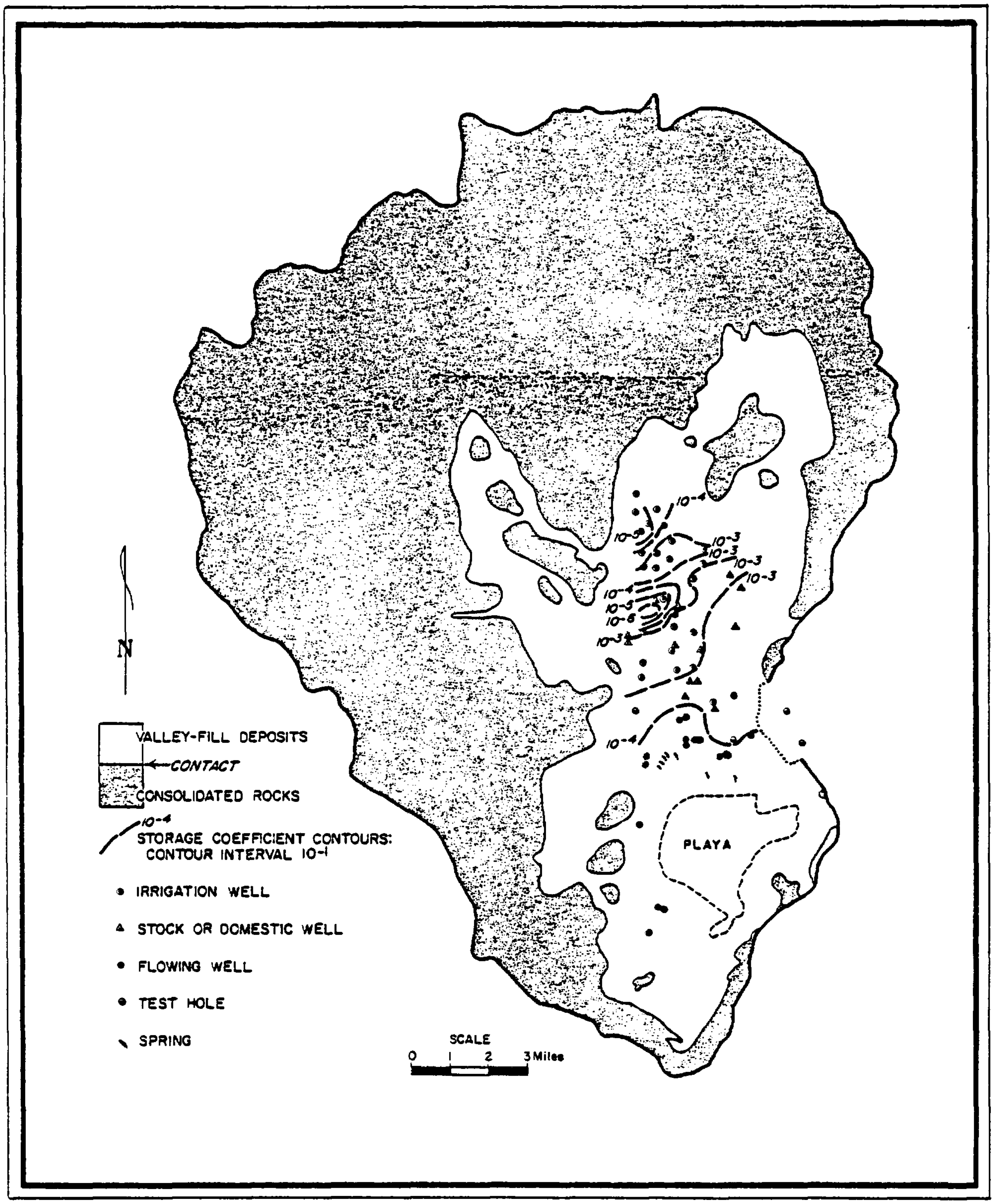

FIGURE 19. Contour map of storage coefficient values.

$$\frac{\partial}{\partial x}\left[T_{xx}\frac{\partial h(x,y,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[T_{yy}\frac{\partial h(x,y,t)}{\partial y}\right]$$

$$= S(x,y)\frac{\partial h(x,y,t)}{\partial t} + \frac{P(x,y,t)}{\Delta x\ \Delta y} - \frac{k'}{b'}\left[H_r - h(x,y,t)\right]$$

The input parameters for the program are as follows:

T_{xx} and T_{yy} are the transmissivities in the x and y direction, respectively, and S (x, y) is the storage coefficient. These parameters may vary in space but are considered constant in time. P (x, y, t) is the net difference of sources and sinks, and is considered to vary in space and time. k' and b' are the vertical hydraulic conductivity and thickness of an aquitard overlying or underlying the aqufier being modeled. H_r is the hydraulic head of the system contributing vertical leakage through the aquitard into the modeled aquifer. k', b' and H_r are assumed constant in time, but may vary in space. Since there was little information on vertical leakage, this term was considered to be accounted for in the P(x, y, t) terms.

With the above input data, the program solves for the hydraulic head (h(x, y, t)) distribution as a function of position and time. To implement the model, a rectangular grid of 37 columns and 61 rows of node points with a nodal spacing of one-quarter mile was superimposed on the valley-fill basin.

Aquifer parameters were tested by running the model under steady-state conditions. Information related to hydraulic head prior to irrigation pumping came from Sinclair (1962) and the Nevada Division of Water Resources. The head data came mainly from measurements of water levels of wells. Most of the wells were located around the margin of the playa with a few wells in the area of irrigation pumping. Due to the lack of head data throughout the valley basin, the hydraulic head contours for pre-irrigation pumping conditions were sketchy and in part inferred by topography.

Several trial runs under pre-pumping steady-state conditions established a set of probable aquifer parameters. Storage coefficient values and pumping rates and schedules were added for time-dependent modeling.

The model was operated for a maximum of thirty years. A year consisted of a period of pumping followed by a period of recovery. The heads at the end of recovery for one year were used as the initial heads for the beginning of pumping the next year. Significant deviations of the model heads from the measured heads showed up after several years of pumping. After various adjustments of input parameters, it became evident that, although qualitative agreement with measured drawdowns in many areas could be obtained, the model would not give reliable long-time head values. The parameter adjustments did indicate that the major problem was with the boundary conditions and/or sources and sinks, and that vertical flow components are a significant part of the Hualapai groundwater system.

DISCUSSION

The initial assumption was that the essentially horizontal component of flow was large enough to mask any vertical component. Another assumption was that the wells were receiving water primarily under confined conditions and that vertical leakage was not significant. Harrill (1969) made the assumption that in the short term the groundwater system would respond as if confined, but over the long run it would act as an unconfined aquifer. It now appears that the flow would best be modeled as a combination of these assumptions, an upper unconfined system and a deeper confined system with leakage probably becoming significant as pumping increases.

The well logs show extensive intertonguing of coarse and fine material, but it is difficult to demonstrate any laterally extensive confining layers. Because of the lensing and intertonguing nature of the sediments, the lateral variation may be such that no one zone of sediments may be truly confined from another and there may be a fair amount of hydraulic connection throughout the valley-fill, especially in the younger Quaternary deposits. Vertical differences in hydraulic head may be due to partial vertical confinement and to lateral movement through sediments of different permeability; that is, as the groundwater begins to move down gradient in response to gravity, sediments of different permeabilities that are across the general flow path will refract the groundwater, thus casing vertical components of flow, even though the system under these conditions is not strictly confined.

The casings of most of the irrigation wells are perforated from near the depth that water was first encountered, continuously downward to near the bottom of the casing. Under these conditions, differences in head with depth would not be measureable. If vertical differences in head did exist, ample interconnection would have been provided by the irrigation wells, and the water levels in these wells would represent a composite head. Also, with this type of well construction as the water level in a well drops during pumping, the perforations allow the exposed coarser lenses to drain laterally into the well. Although the lateral drainage of the fine-grained sediments may be slight, with time the exposed finer lenses may provide water by drainage into the coarser lenses. The overall effect would be to cause gravity drainage from the saturated sediments above the pumping water levels and thus help establish an unconfined condition throughout the well field in at least this upper zone. For modeling purposes, it may be best to consider the depth of saturated sediments penetrated by the irrigation wells to be an unconfined or highly leaky groundwater system. This type of system was indicated from more recent observations of water levels in wells during pumping.

More recent field data also indicate that the hot water system may be significantly affecting the groundwater flow in the area of the irrigation wells. The hot water may be moving into the valley-fill area at depth along the faults and slowly leaking upward into the overlying, unconsolidated sediments. Information from the Nevada Division of Water Resources shows that the temperature of the water pumped from one well increases significantly when the pumping rate is increased from about 1,200 gpm to 1,700 gpm (Winchester, personal communication, 1974). This would indicate that warm water at depth becomes a greater percentage of the water discharged as the pumping rate and drawdown are increased.

If, in fact, an unconfined cold groundwater flow system overlying a confined hot groundwater flow system does exist, then more information concerning the deeper hot water system would be needed to reliably model the upper cold water system. This would include data as to the areal extent of the deeper system, the spatial distribution of depths of the deeper system and the distribution of upward leakage into the upper system.

WATER RIGHTS DATA
STORAGE AND RETRIEVAL

The Nevada State Engineer's Office is charged with administering the Water Law of Nevada (NRS Title 48, Chapter 532-544). Activities of the State Engineers Office include analysis of groundwater quantities, analysis of surface water quantities, determination of groundwater recharge, establishment of safe perennial yield, maintenance of water level and pumping records, issuance of permits to appropriate water, issuance of water right certificates and accounting of proofs of appropriation (for water use prior to implementation of the permit system).

An objective of this investigation was to examine the current methods of records management within the State Engineers Office and to examine the potential of utilizing a computer based system which would provide a rapid means of examining relevant information related to water rights in an area.

Definition of several terms as used in this section are given below:

Application	-	Application for permit to appropriate the public waters of Nevada, together with any corollary applications such as change in the place of diversion, manner of use, or place of use.
Permit	-	An application approved by the State Engineer.
Certificate	-	A permit which has been perfected in accordance with prescribed statutes.
Proof	-	Proof of application of water with respect to surface water and groundwater from an artesian or defineable aquifer prior to 1913 and with respect to percolating water prior to 1939.
Vested right	-	Vested right of any person to use water where appropriations have been initiated in accordance with law prior to 1913.

Designated Groundwater Basin	-	Any hydrographic area or portion thereof designated by the State Engineer to deny further appropriation except for domestic purposes because the annual replenishment to the groundwater supply may not be adequate for the needs of all permittees and all vested-right claiments.

COMPUTER APPLICATION

In light of the numerous parameters associated with any given water right, the decision was made to define the problem as several steps. The first step was to capture certain of the most important parameters in summary form with the objective of being able to substantially reproduce a hydrographic area abstract. The second step was to define and resolve certain problems of data coding that prevent efficient capture of detailed data. The third step was to establish necessary office procedures to guarantee that all modifications and updates would be properly taken into account during the period the detailed data is captured. Last, the detailed data would be translated to a computer-accessible form.

Data coding was done for Hualapai Valley in summary form. This data form is designed to allow summarization of significant parameters from one application onto one data card set. However, there are more efficient methods now available (eg., CRT Terminals) for capture of data which should be explored prior to implementation of the methodology on a statewide basis.

Computer manipulation of these data, once stored, can be easily accomplished. Tabulations other than those described later can be obtained with relative ease by modifications to the developed software.

One significant problem not resolved during the course of this project bears upon the concept of identifying an area as distinguished from a point representing an area. Coordinates may easily be given for a point and a prescribed area may be associated with that point; however, without precise definition of the boundaries of the area, it is difficult to store the area as a unique entity. This is of particular importance in management of water rights in that water from two or more sources may be applied to one area (ie., one right supplemental to another) but the total application of water from all sources may not exceed the established duty of water for that area. The development of digitizers since the time of this investigation would allow resolution of this problem in that the area outline could be traced and translated to x, y coordinates in an efficient manner.

For purposes of this study a first approximation to correct for overlapping areas of water use was made based upon the expectation that appropriated water would be used on land in close proximity to the point of diversion. The fact that the point of diversion and the place of use may not be in the same section, while only a few feet apart, limits the usefulness of this approach.

From the coded input data, summaries were tabulated which provided information on the disposition of all applications for water rights made in Hualapai Valley. From this disposition record one is able to follow the status of a given application through certification or denial including modifications for assignment history (ownership), change in point of diversion and other pertinent information.

An active file was then created which contained all relevant information for those applications which had not been denied, cancelled or abrogated.

Selected program output obtained from the computer based storage and retrieval system included; 1) Summary of water appropriation by source and status (Table 6), 2) Permit data (Table 7), 3) Certificate data (Table 8) and 4) Proof data (Table 9).

GROUNDWATER AND SURFACE WATER RIGHTS

Hualapai Valley is a designated groundwater basin. The perennial yield (recharge) is about 8,000 acre-feet per year, while the vested, certificated and permitted groundwater rights total over 32,000 acre-feet per year. In addition nearly 13,000 acre-feet of surface water is appropriated in the Valley.

Perennial streams and springs issue from the slopes of Hualapai Valley to the north and west. Most appropriations for this surface water occur near its natural location. Diversion of these surface flows reduce their recharge potential to the groundwater basin. Almost all of the undiverted surface water flow is recharged to the groundwater basin shortly after leaving the mountain fronts.

DISCUSSION

As is evident, a serious depletion condition would develop if each right holder actually withdrew the approved amount annually. Under the appropriative doctrine the newest rights (latest in time) would be denied use of the water first with the oldest right (earliest in time) satisfied up to its approved amount. The rights listed in Tables 7 to 9 are sorted in ascending order of priority. Limitations to use could start with the newest permit and proceed back through all permits before affecting certificated rights, then through the certificated rights and then through the vested rights. As a matter of practice each right might be slightly limited prior to any right being totally

TABLE 6. Summary of water appropriations.

STATUS OF APP.	WE	ST	SP	AR	PO	WA	FL	TOTALS
CERTIF.	17918.40	468.14	419.17	0.00	0.00	0.00	0.00	18805.71
PERMIT	14549.60	7502.19	180.99	0.00	0.00	0.00	0.00	22232.78
PENDING	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PROOFS	0.00	3326.40	880.00	0.00	0.00	0.00	0.00	4206.40
TOTALS	32468.00	11296.73	1480.16	0.00	0.00	0.00	0.00	45244.90

TOTAL IRRIGATED ACREAGE = 11093.330

WE = WELL, ST = STREAM, SP = SPRING, AR = ARTESIAN WELL, PO = RESERVOIR,
WA = WASTEWATER OR DRAIN, FL = FLOOD WATERS

TABLE 7. Permit data sorted by filing date.

APPLICATION NUMBER	PRIORITY	DISPOSITION CODE	ACTION	REF NUMB	SOURCE	Q	Q	SEC	TWP	RNG	RATE OF APPLIC. (CFS)	ANIMALS OR ACRES	TYPE OF USE	DUTY	DAYS OF USE	VOLUME LIMIT ACRE FEET	OWNER OF RECORD
2010	4-14-11	20	PERMIT	-0	ST	SW	NE	3	34N	22E	1.20000	120.000 AC	-IRR.	0.00	183	434.808	HOLLAND, L J
2579	12- 6-12	20	PERMIT	-0	ST	NE	SE	27	35N	23E	3.20000	320.000 AC	-IRR.	0.00	183	1159.488	HOLLAND, L J
4048	11- 3-13	20	PERMIT	-0	ST	NW	SE	18	35N	23E	3.07000	307.300 AC	-IRR.	0.00	304	1847.894	HOLLAND, L J
6556	8-26-21	20	PERMIT	-8	SP	SE	NW	17	37N	23E	.25000	-1.000	MINING	0.00	365	180.994	LEADVILLE MINES CO
22716	7-22-59	20	PERMIT	-0	WE	SW	SE	24	35N	23E	4.00000	320.000 AC	-IRR.	4.00	365	1280.000	FITTS, JOSEPH W
22717	7-22-59	20	PERMIT	-0	WE	SW	SE	24	35N	23E	4.00000	320.000 AC	-IRR.	4.00	365	1280.000	FITTS, JOSEPH W
21588	7-27-59	20	PERMIT	-0	WE	SW	SW	7	35N	24E	4.50000	320.000 AC	-IRR.	4.00	365	1280.000	MOORE EQUIPMENT CO, INC
21971	7-27-59	20	PERMIT	-0	WE	NW	NW	1	35N	23E	4.50000	336.700 AC	-IRR.	4.00	365	1346.800	MOORE EQUIPMENT CO, INC
18401	10-30-59	20	PERMIT	-0	WE	NW	NE	31	35N	24E	3.12000	475.200 AC	-IRR.	4.00	365	1900.800	JACKSON, G C + A F
20380	3-27-62	20	PERMIT	-0	ST	NE	NW	29	35N	24E	5.00000	1015.000 AC	-IRR.	4.00	365	4060.000	JACKSON, G C + A F
23519	8- 6-62	20	PERMIT	-0	WE	NW	NW	19	35N	24E	8.00000	470.800 AC	-IRR.	4.00	365	1883.200	IVESON, DAVID E
22718	10- 9-62	20	PERMIT	-0	WE	SE	SW	19	35N	24E	5.40000	320.000 AC	-IRR.	4.00	365	1280.000	FITTS, JOSEPH W
22719	10- 9-62	20	PERMIT	-0	WE	NW	NW	30	35N	24E	4.70000	280.000 AC	-IRR.	4.00	365	1120.000	FITTS, GLADYS D
21637	11-18-63	20	PERMIT	-0	WE	SE	SW	6	35N	24E	5.40000	314.000 AC	-IRR.	4.00	365	1256.000	BAILEY, RICHARD L
21754	1-16-64	20	PERMIT	-0	WE	SW	NW	13	35N	23E	5.40000	320.000 AC	-IRR.	4.00	365	1280.000	FRERES, SHARON
22532	4- 9-65	20	PERMIT	-0	WE	NW	NW	7	35N	24E	5.40000	320.000 AC	-IRR.	4.00	365	1280.000	BAILEY, PATRICIA H
23235	7- 8-66	20	PERMIT	-0	WE	SE	SW	28	36N	23E	6.00000	400.000 AC	-IRR.	4.00	365	1600.000	BRESSON, ERNEST
23236	7- 8-66	20	PERMIT	-0	WE	NW	NE	33	36N	23E	6.00000	400.000 AC	-IRR.	4.00	365	1600.000	BRESSON, ERNEST
23419	9-27-66	20	PERMIT	-0	WE	NE	NW	12	35N	23E	4.50000	319.300 AC	-IRR.	4.00	365	1277.200	MCKAY, ART

TABLE 8. Certificate data sorted by filing date.

APPLICATION NUMBER	PRIORITY	DISPOSITION CODE	ACTION	REF NUMB	SOURCE	POINT OF DIVERSION Q Q	SEC	TWP	RNG	RATE OF APPLIC. (CFS)	ANIMALS OR ACRES	TYPE OF USE	DUTY	DAYS OF USE	VOLUME LIMIT ACRE FEET	OWNER OF RECORD
2497	8-30-12	10	CERTIF.	265	SP	SW SE	8	37N	23E	.20000	-1.000	MINING	0.00	365	144.795	TONOPAH MINING CO
2754	7-15-13	10	CERTIF.	218	SP	NE NW	9	37N	23E	.25000	-1.000	MINING	0.00	365	180.994	KING, SAM
5733	5-28-14	10	CERTIF.	1146	ST	NE NW	33	36N	23E	.82060	82.060	AC -IRR.	3.00	122	246.180	SIMMONS, JACOB M
7180	7-29-24	10	CERTIF.	1385	SP	NW NE	28	37N	23E	.01600	2500.000	SHEEP	0.00	91	2.792	HOLLAND, L J
8189	6-21-27	10	CERTIF.	1915	ST	SE SE	22	37N	23E	.00280	2500.000	SHEEP	0.00	122	.483	HOLLAND, L J
9463	5-25-31	10	CERTIF.	4786	ST	SW SW	3	35N	23E	.40000	13.540	AC -IRR.	4.00	365	54.160	IVESON, DAVID E + U C
11145	6- 8-40	10	CERTIF.	4787	ST	NE SE	33	36N	23E	.50000	41.830	AC -IRR.	4.00	365	167.320	IVESON, D E + D H
11276	4-30-45	10	CERTIF.	3081	SP	NE NW	9	37N	23E	.25000	25.000	AC -IRR.	0.00	183	90.585	BRESSON, ERNEST, ET UX
13781	7-17-51	10	CERTIF.	5486	WE	NE NW	24	35N	23E	2.00000	160.000	AC -IRR.	4.00	153	640.000	IVESON, DAVID E
15153	7-17-51	10	CERTIF.	5487	WE	NE NW	24	35N	23E	1.20000	62.000	AC -IRR.	4.00	153	248.000	IVESON, DAVID E
19579	6-12-59	10	CERTIF.	7179	WE	NW SE	13	35N	23E	3.50000	310.900	AC -IRR.	4.00	365	1243.600	GINOCHIO, LAWRENCE F.
21491	7-27-59	10	CERTIF.	6287	WE	SW SW	7	35N	24E	2.50000	318.000	AC -IRR.	4.00	365	1272.000	MOORE EQUIPMENT CO, INC
23122	7-27-59	10	CERTIF.	6582	WE	NW SE	1	35N	23E	1.70680	320.000	AC -IRR.	4.00	365	1280.000	MOORE EQUIPMENT CO, INC
23493	7-27-59	10	CERTIF.	6568	WE	NE NE	2	35N	23E	4.50000	188.800	AC -IRR.	4.00	365	755.200	GINOCHIO, LAWRENCE F.
23494	7-27-59	10	CERTIF.	6569	WE	NW NE	11	35N	23E	4.50000	320.000	AC -IRR.	4.00	365	1280.000	GINOCHIO, LAWRENCE F.
24645	7-27-59	10	CERTIF.	7115	WE	NE NW	12	35N	23E	4.00000	319.000	AC -IRR.	4.00	365	1276.000	MCKAY, VELMA MARIE
18725	4-15-60	10	CERTIF.	6555	WE	SW NE	25	35N	23E	5.40000	159.300	AC -IRR.	4.00	365	637.200	HOOKS, AARON G
18763	4-27-60	10	CERTIF.	6612	WE	NW SE	13	35N	23E	5.40000	310.900	AC -IRR.	4.00	365	1243.600	GINOCHIO, LAWRENCE F.
18951	6-28-60	10	CERTIF.	6028	WE	SE NE	23	35N	23E	5.40000	320.000	AC -IRR.	4.00	214	1280.000	SAND SPRINGS LAND CO
22659	6-28-60	10	CERTIF.	6298	WE	NW NE	26	35N	23E	5.40000	320.000	AC -IRR.	4.00	365	1280.000	SANDSPRINGS LAND CO
20165	11-22-61	10	CERTIF.	7258	WE	SE SE	36	36N	23E	2.00000	308.000	AC -IRR.	4.00	365	1232.000	GINOCHIO + WELKER
22657	8-31-62	10	CERTIF.	6296	WE	SE NE	23	35N	23E	2.70000	160.000	AC -IRR.	4.00	365	640.000	SANDSPRINGS LAND CO
22658	8-31-62	10	CERTIF.	6297	WE	NW SE	26	35N	23E	2.70000	158.000	AC -IRR.	4.00	365	632.000	SANDSPRINGS LAND CO
24644	4-23-64	10	CERTIF.	7114	WE	NW NW	12	35N	23E	4.00000	332.600	AC -IRR.	4.00	365	1330.400	MOORE EQUIPMENT CO
23862	3-24-66	10	CERTIF.	7180	WE	NW SE	11	35N	23E	3.75000	320.000	AC -IRR.	4.00	365	1280.000	GINOCHIO, LAWRENCE F.
23883	4- 4-66	10	CERTIF.	6286	WE	NW SW	12	35N	23E	4.50000	305.000	AC -IRR.	4.00	365	1220.000	MCKAY, FRANCIS I
23168	6- 7-66	10	CERTIF.	6828	WE	SE NE	13	35N	23E	5.40000	320.000	AC -IRR.	4.00	365	1280.000	FRERES, T G + MASIER

TABLE 9. Proof data (vested rights).

PROOF NUMBER	PRIORITY OF USE	DISPOSITION CODE	ACTION	REF NUMB	SOURCE	POINT OF DIVERSION Q Q	SEC	TWP	RNG	RATE OF APPLIC. (CFS)	ANIMALS OR ACRES	TYPE OF USE	DUTY	DAYS OF USE	VOLUME LIMIT ACRE FEET	CLAIMANT
1274	1904	1	PROOF	4048	ST	NW SE	28	35N	23E	1.17962	213.700	AC -IRR.	4.00	365	854.800	HOLLAND L J
1275	1904	1	PROOF	6052	ST	NW SW	29	34N	23E	2.04185	369.900	AC -IRR.	4.00	365	1479.600	HOLLAND L J
1276	1904	1	PROOF	-0	SP	NE SE	1	34N	23E	1.21440	220.000	AC -IRR.	4.00	365	880.000	HOLLAND L J
1277	1880	1	PROOF	-0	ST	NW NW	35	34N	23E	.72091	130.600	AC -IRR.	4.00	365	522.400	HOLLAND L J
1278	1904	1	PROOF	-0	ST	SW NE	27	34N	23E	.64805	117.400	AC -IRR.	4.00	365	469.600	HOLLAND L J

limited through cooperative agreement among all rights holders and with the concurrence of the State Engineer.

The computer storage and retrieval system for water right data provides a means of sorting the records in a manner to provide the managing agency with information needed to make necessary decisions which are predicated upon the most recent status of the existing water rights. The system as developed is not any more precise than the current "hand" abstracting procedures. Rather the system should be viewed as a methodology which, if implemented, would free existing personnel from routine abstracting, sorting and calculations so that they could concentrate on analysis and appraisal of any new application and its implications as it affects existing rights.

CONCLUSIONS

1. Mean annual precipitation can be estimated based upon vegetation and topographic parameters where no climatic data exist.
2. Precipitation simulation models utilizing vegetation and topographic features as input can provide improved estimates of mean annual precipitation over simpler altitudinal models.
3. Monthly and annual volumes of runoff can be predicted by use of watershed simulation models utilizing mean annual precipitation by elevation zone and daily precipitation and temperature data from a base station representative of the watershed to be modeled.
4. Accuracy of the watershed simulation model is limited by the respresentativeness of the base station data.
5. The watershed simulation model may overestimate or underestimate flow volumes for a given storm event, however, the mean values obtained are within 10 percent of those recorded.
6. A two-dimensional, time dependent finite difference model can be developed to accurately simulate groundwater movement and storage in a single aquifer system.
7. Where multiple aquifer systems exist, interaction between the aquifers introduce deviations in the modeled and measured head response, particularly when the groundwater system is stressed by pumping of large volumes of groundwater.
8. Deviations in modeled and measured head response in the multiple aquifer system became more pronounced over time.
9. Better definition of boundary conditions, sources and as well as a better definition of the underlying aquifer sinks (sources) are necessary as well as a better definition of the underlying aquifers before improvement in the modeled response can be obtained.

10. Computer storage and retrieval of water right data can be efficiently accomplished which can free personnel from routine abstracting, sorting and calculations and allow more efficient use of their time for analysis and appraisal of new water right applications.
11. Simulation models can be effectively utilized in conjunction with computerized water right information and can provide the hydrologic basis for approval or denial of water right applications and to set forth criteria for allocation of water to users during periods of deficient supply.

REFERENCES

Blackburn, W.H., P.T. Tuller and R.E. Eckert. 1968a. Vegetation and soils of the Crowley Creek Watershed. University of Nevada, College of Agriculture, Publication R42.

__________1968b. Vegetation and Soils of the Mill Creek Watershed. University of Nevada, College of Agriculture, Publication R43.

Case, C.M., W.W. Pidcoe, and P.R. Fenske. 1974. Theis Equation Analysis of Residual Drawdown Data. Water Resources Research, Vol. 10, No. 6.

Fordham, J.W. 1968. Basin Simulation Program. Report to the USDA Soil Conservation Service by the Water Resources Center, Desert Research Institute.

Fordham, J.W. and G.S. Wilkes. 1970. Application of Watershed Model to the Walker River Basin. Presented at 16th Annual Meeting of the AGU, Pacific Northwest Region, Portland, Oregon.

Grose, L.T., and G.V. Keller. 1975a. Progress Report No. 3: Colorado School of Mines, Nevada Geothermal Study.

__________, 1975b. Progress Report No. 4: Colorado School of Mines, Nevada Geothermal Study.

Harrill, J.R. 1969. Hydrologic Response to Irrigation Pumping in Hualapai Flat, Washoe, Pershing and Humboldt Counties, Nevada, 1960-67. Nevada Division of Water Resources Bull. No. 37.

Houghton, J.G. 1969. Characteristics of Rainfall in the Great Basin. Desert Research Institute, University of Nevada System, Reno, Nevada.

Linsley, R.K. 1956. The relation between rainfall intensity and topography in northern California. Department of Civil Engineering, Stanford University.

McGinnis, L.D., and W.W. Dudley, Jr. 1964. Seismic Studies of Three Areas in Northern Nevada, in Geophysical Studies in Nevada Relating to Hydrogeology. Desert Research Institute, University of Nevada Technical Report No. 2.

Passey, H.B. and V. Hugie. 1960. Soil-climate-vegetational relationship on range land. Progress Report, Soil Survey Investigations, Soil Conservation Service.

Ross, G.A. 1970. The Stanford Watershed Model: The Correlation of Parameter Values Selected by a Computerized Procedure with Measureable Physical Characteristic of the Watershed. University of Kentucky, Water Resources Institute. Report No. 35.

Sinclair, W.C. 1962. Ground-Water Resources of Hualapai Flat, Washoe, Pershing and Humboldt Counties. Nevada Dept. of Conservation and Natural Resources. Ground-Water Resources-Reconnaissance Series, Report 11.

APPENDIX

DESCRIPTION OF WATERSHEDS

GRANITE CREEK

Granite Creek originates on the east slope of the Granite Mountains and flows in an easterly direction toward the Black Rock Desert. Scattered spring and seep areas form three headwater tributaries which flow a distance of two to four miles down a precipitous water course. The three forks join at an elevation of approximately 4,300 ft. and continue flowing an additional two miles where water is diverted for irrigation. The drainage area above the confluence of the three forks is 4.6 sq. miles with a total elevation drop of 4,300 ft. The average discharge from two years of measurement following near normal precipitation was calculated to be 850 ac-ft per year.

ROCK AND UNNAMED CREEKS

These two creeks drain a portion of the eastern slope of the Granite Mountains and flow easterly toward the Black Rock Desert. They both originate at elevations of over 7,000 ft. draining mountaineous terrain, flow across desert fan areas and cross Highway 34 where they are diverted for irrigation. The drainage area above the fan for these two creeks is 7.5 sq. miles all lying above 5,000 ft. At the mountain front the measured combined discharge was 990 ac-ft/yr with a loss of over 30% by the time they reached Highway 34.

COTTONWOOD CREEK

Cottonwood Creek originates from spring and seep areas at approximately 7,500 ft. along the east slope of the Granite Mountains. Two headwater forks flow four and five mi. respectively before joining with a third minor fork to make up the main stream which flows to the valley floor across Highway 34 and is used for irrigation of alfalfa during the spring and summer months. The drainage area above the confluence of the forks is 12.7 sq. mi. and has an elevation drop from 8,000 to 4,600 ft. Below the confluence the stream begins to lose water to fan deposits through which it passes. Measurements show that the annual flow just below the confluence of the three forks was 450 ac-ft. in 1967 and 780 ac-ft. in 1971.

RED MOUNTAIN CREEK

Red Mountain Creek originates on the eastern slope of the Granite Mountains at an elevation of approximately 7,700 ft. The creek flows southeasterly toward Hualapai Flat accumulating flow at central elevations from seeps and springs. The stream length is approximately 12 mi. through mountainous terrain. Once the stream leaves its canyon it flows through a gradual sloping fan area losing flow to the fan sediments. The total drainage area above the measuring station near the canyon mouth is 33 sq. mi. with an elevation drop of 3,300 ft. The annual discharge for two years measurement, 1967 and 1971, were 1,330 ac-ft. and 540 ac-ft. respectively.

NEGRO CREEK

The stream originates at an elevation of 7,700 ft. on the eastern slope of the Granite Mountains and flows southeasterly toward Hualapai Flat. The total flow is made up from contributions of three forks; of which only the middle flows year round. The middle fork flows approximately 5 mi. before being joined by the north and south forks just below a rocky gorge. Below this point the stream is diverted into two small reservoirs and is used for irrigation. From the headwaters at elevation 7,700 ft. to a point of maximum flow above the reservoirs at 4,600 ft., the drainage area is 40 sq. mi. The measured discharge for 1967 was 620 ac-ft. and 640 ac-ft. for 1971.

SOUTH WILLOW CREEK

South Willow Creek drains the northern portion of the Granite Mountains from Hog Ranch Mountain east, as well as a portion of the Calico Mountains north of Hualapai Flat. Its discharge comes from snowmelt in the higher elevations west of the Leadville Mine, with only minor accretions from areas east of Highways 34. The creek flows down south Willow Canyon parallel to Highway 34 from an elevation of over 7,700 ft. to 4,400 ft. Although the stream flows year round along its upper reaches, it becomes intermittent near the mouth of the canyon. The total drainage area is 41 sq. mi. and the measured discharge at the valley margin was between 80 ac-ft. and 120 ac-ft in 1967 and 1971.