WATER BALANCE METHODS AND CALCULATIONS
FOR GREAT BASIN WATERSHEDS
(THE WINNEMUCCA RANCH)

FOR WASHOE COUNTY UTILITY DIVISION

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EXECUTIVE SUMMARY

A study was conducted on the Dry Valley Drainage Basin, Northwestern Nevada, to determine the water yield and select an appropriate method for calculating a water balance within the Western Great Basin.

The comparison of 5 reference evapotranspiration methods indicate the Radiation method (Doorenbos and Pruitt, 1975) is the most appropriate for the region. Water balance results utilizing this method were compared with the ERHYM-II and SWRRB models estimates. The SWRRB model, the more appropriate model for large watersheds, is better utilized for prediction of the impact of site changes on documented watersheds than for initial prediction of water yield on ungaged watersheds.

Spring and stream flow within the basin totaled 450 acre ft of which 140 acre ft was discharged from the basin. For a normal precipitation year it is predicted that approximately 1300 acre ft of water would be available for collection.

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INTRODUCTION

THE WATER BALANCE

For water resources investigations, apart from simply estimating surface water runoff, it is often necessary to conduct a water balance investigation and to estimate future water yield variations as affected by climatic and managerial changes.

The water balance is the hydrologist's tool that accounts for the conservation of mass within a system, where input equals output minus the change in storage. The water balance for a watershed can be shown as:

$$P - [ET + RO + DP] \pm \Delta SW = 0 \qquad (1)$$

Where P, precipitation minus; ET, evapotranspiration plus RO, runoff or stream flow plus DP, deep percolation or ground-water recharge plus or minus ΔSM, change in soil water is equal to zero.

The use of this equation requires measured values of precipitation and runoff or stream flow. Conducting an annual balance will allow the Δ change in soil moisture content to be zero. The evapotranspiration term of the equation needs to be calculated and the deep percolation or ground-water recharge term can be determined by subtraction.

There are numerous methods available to calculate evapotranspiration. Each one has advantages and disadvantages for various climatic conditions, plant communities and data availability. Although many evapotranspiration methods have been utilized for agricultural crops, few have been derived for natural rangeland environments (Wight et al. 1986). The procedures and results of a study to determine the most appropriate method for calculating evapotranspiration and the water balance within sagebrush communities of the Great Basin are presented herein.

OBJECTIVES

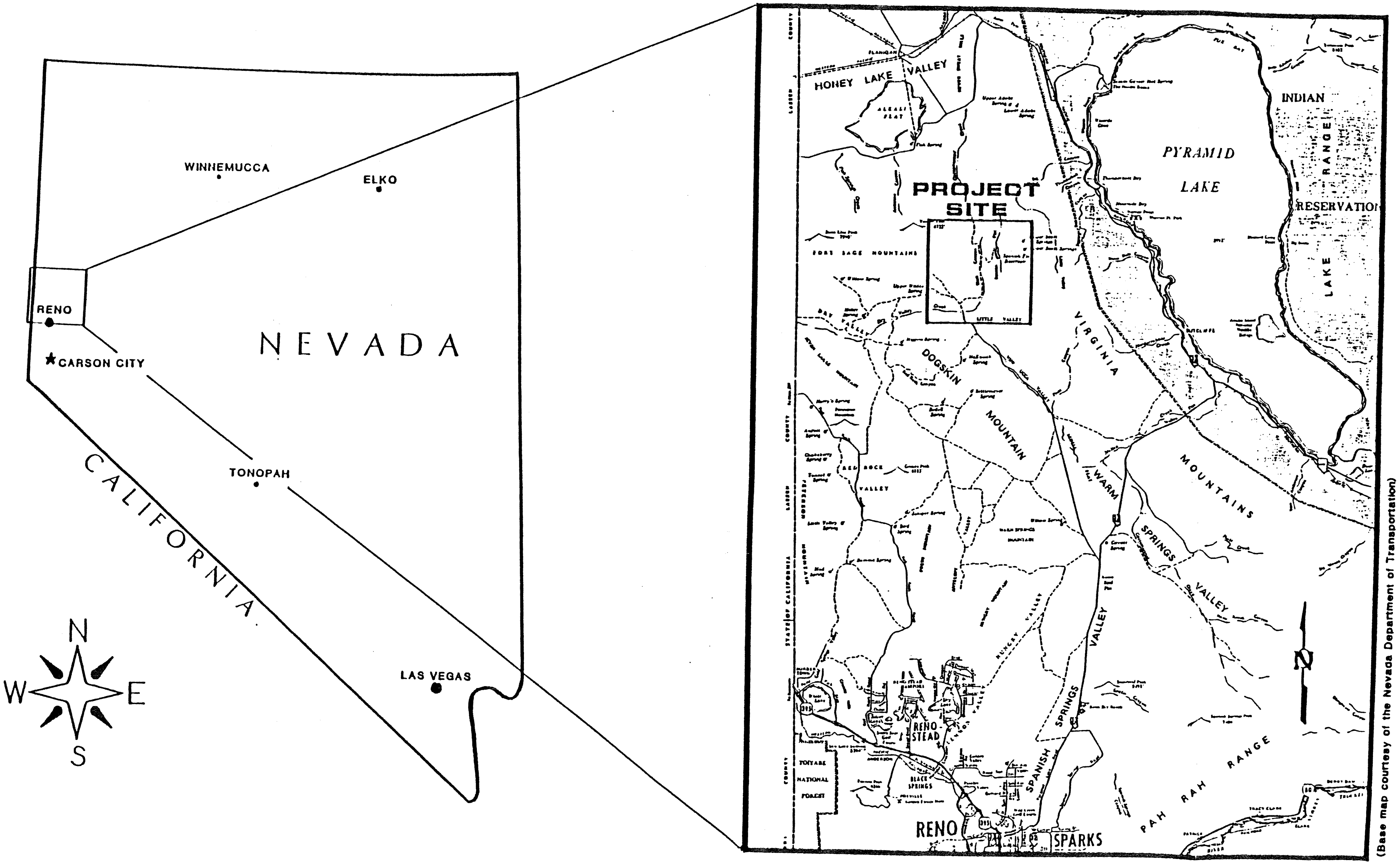
Select appropriate methods for calculating evapotranspiration of sagebrush ecosystems within the Northwestern Great Basin.

Determine through field methods and the appropriate evapotranspiration equations, an approximate water balance on two sagebrush watersheds near Reno, Nevada.

Estimate the normal water year yield of the watersheds from the study year results.

BACKGROUND

Washoe County has acquired and/or applied for 4400 acre-feet of water rights at the Winnemucca Ranch thirty miles north of Reno (Figure 1). The Winnemucca Ranch can be



LOCATION MAP

NO SCALE

VICINITY MAP

MILES 0 2 4 6 8

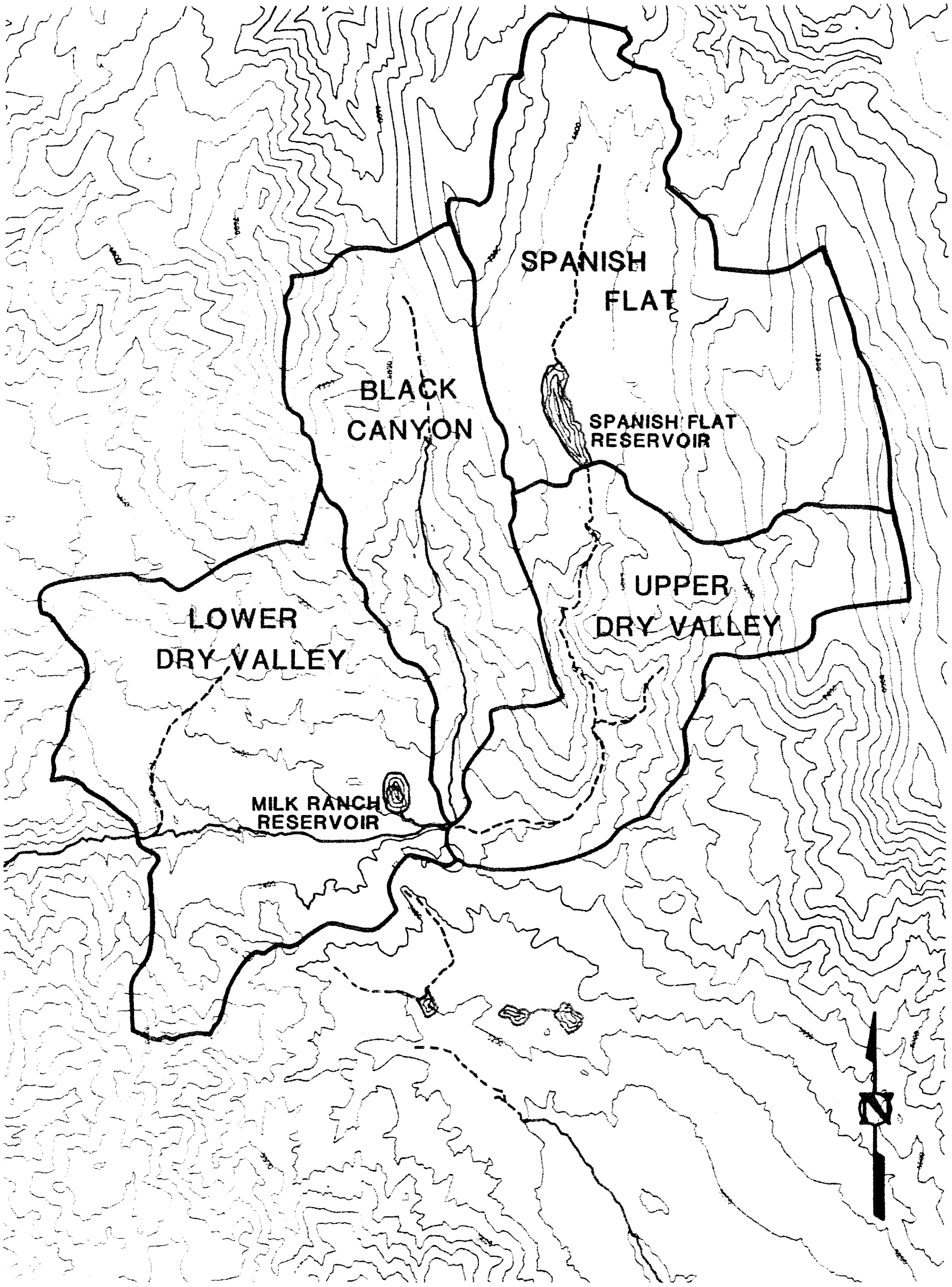
FIGURE 1

divided into two separate drainages. The southern portion drains south into Warm Springs Valley, while the northern portion, the Dry Valley drainage, drains west toward Long Valley (Figure 2). The Dry Valley drainage basin is associated with 2000 acre-feet of water rights and was the location utilized to calibrate and compare selected water balance methods.

SITE CHARACTERISTICS

Vegetation and Topography

The northern portion of Winnemucca ranch (Dry Valley drainage) encompasses 21.7 square miles (mi^2). Approximately 1 % of this area is irrigated pasture (in lower Dry Valley). The rest of the watershed has a soil cover composed of approximately 50 % sagebrush and 25 % rock and erosion pavement, with occasional Juniper overstory. There are three distinct sub-basins within this watershed: Black Canyon, Spanish Flat and Dry Valley. Black Canyon (4.23 mi^2) is a steep sided canyon ranging in elevation from 5400 feet (ft) to 7950 ft, with an average slope of 32 %. The Spanish Flat watershed (6.73 mi^2) is characterized by a large playa reservoir at 6700 ft elevation as well as the highest point on the site, Tule ridge at 8620 ft elevation. Dry Valley (10.76 mi^2) ranges in elevation from approximately 5020 ft to 8600 ft. The pasture located in the valley is irrigated



DRY VALLEY DRAINAGE BASIN

MILES 0 1 2 3 4

FIGURE 2

by the perennial flow from Black Canyon, the manually operated discharge from the Spanish Flat reservoir and several springs within the valley.

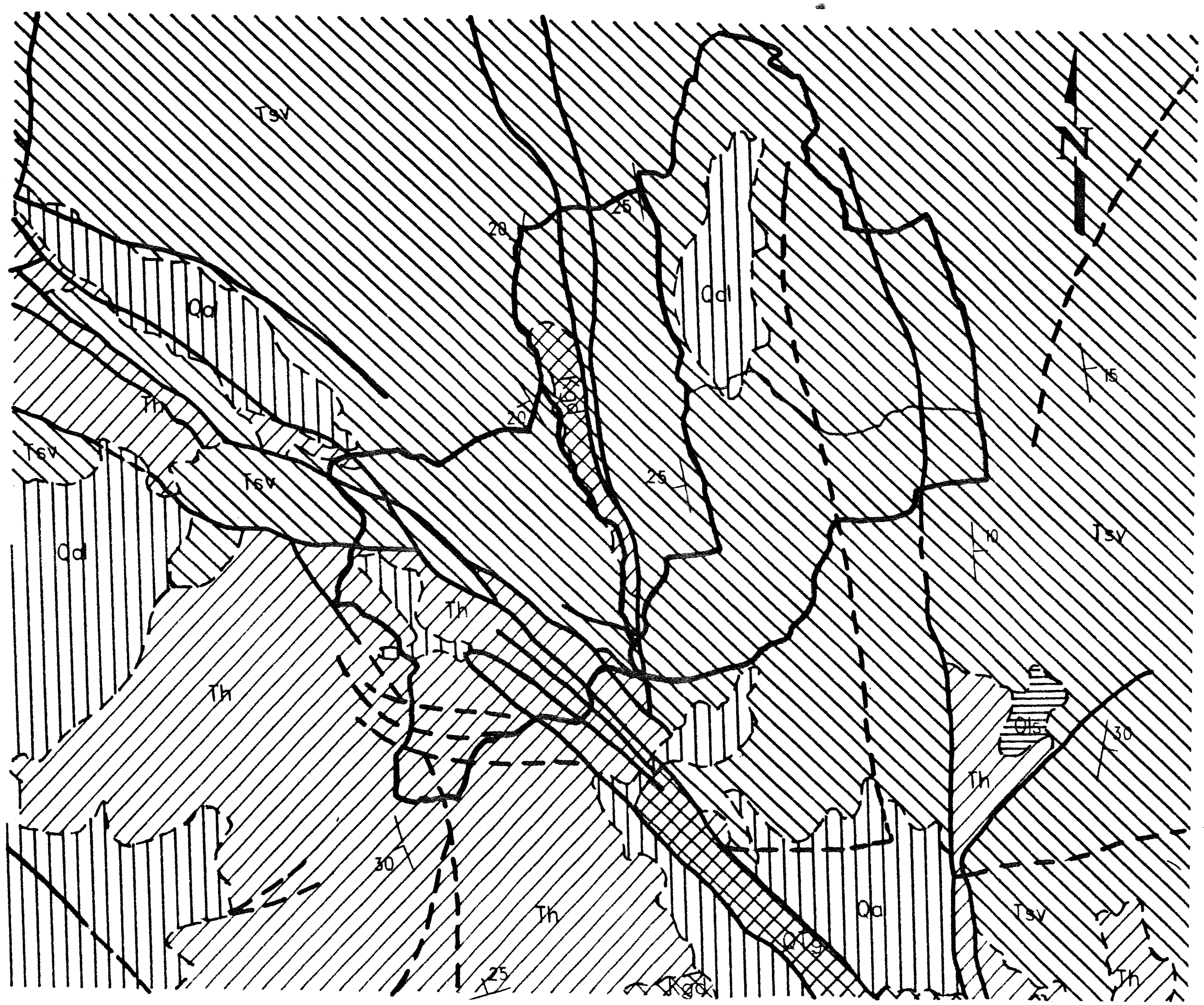
Geology

The geology of the site (Figure 3) indicates that several major faults constitute the basis for formation of the valleys. The general information available (Bonham, 1969) indicates the predominant rock types are of the Pyramid Sequence. This sequence consists of basalts, andesites, dacite flows and various breccias and tuffs, with shales and sandstones intercalated in sequence. Recent stream deposits (Pleistocene or younger) are located in lower Dry Valley and Spanish Flat. The only other formations are a small intrusive granodiorite and the Hartford Hill Rhyolite, which is predominantly ash flows and tuffs.

Because of the numerous faults, breccias, propylitic alterations and intercalated sequences, the hydraulic properties of the bedrock are complex. These same characteristics also indicate sufficient conduits may exist for deep aquifer communication.

Soils

The soils of the site (Figure 4) are predominantly stony loams such as the Arzo and Softscrabble series, derived from volcanic origin. The permeabilites of the soils vary greatly and the average effective rooting depth is



SITE GEOLOGY

Qal

Stream deposits, talus, slope wash, alluvial fan and eolian deposits.

Qls

Landslide deposits

Granite rubble and sand in Slide Mountain area. Chaotic mixtures of basaltic and tuffaceous rocks elsewhere.

QTg

Pre-Lake Lahontan deposits

Terrace, alluvial fan and pediment gravels. Includes lacustrine deposits in Washoe Valley. These gravels are deeply weathered, highly dissected and have been faulted and tilted.

Tsv

Pyramid Sequence

Basalt, andesite and dacite flows, flow breccias, mudflow breccias, agglomerates, tuffs and associated intrusives. Lenses of silicic waterlain tuff, diatomite, shale and sandstone intercalated in sequence. Includes Pyramid Formation of MacJannet (1957), Chlorpagus Formation, and Old Gregory Formation of Rose (1969) in Truckee Canyon.

Th

Hartford Hill Rhyolite

Predominantly ash-flow tuffs, variable welded, ranging from rhyolite to quartz latite in composition. Includes som beds of ash-fall tuff and lenses of clastic sediments. Ash-flow tuff typically consists of phenocrysts of quartz, plagioclase, alkali feldspar and biotite in a matrix of devitrified glass shards. Extensive propylitic alteration present in unit.

Kgd

Intrusive rocks

Undifferentiated plutonic rocks ranging from gabbro to granite in composition. Granodiorite and quartz monzonite are most abundant rock types. Typical granodiorite is a medium-grained rock containing 15-25 percent quartz, 40-50 percent plagioclase, 15-20 percent microcline and 10-20 percent hornblende and biotite. Includes pegmatite-aplite dikes.

WATERSHED BOUNDARIES

FAULT

CONCEALED FAULT

25 STRIKE & DIP OF BEDS

CONTACT

0 3000

SCALE 1" : 3000'
APPROXIMATELY

FIGURE 3

SCS SOILS SURVEY

176 Indian Creek – Reno – Washoe Association
181 Tunnison Devada Association
311 Risley – Rock Out Crop – Complex Association
314 Risley – Xman – Rock Out Crop Association
513 Settlemeyer – Notus – Complex
683 Reno – Stoney – Sandy – Loam
702 Graufels – Clenbrook – Hayp ess Association
710 Thuiepah Hutchley Association
711 Thulepah – Hutchley – Rock Out Crop Association
721 Softscrabble – Sumine – Hutchley Association
722 Softscrabble – Sumine – Hutchley Thulepah – Association
723 Softscrabble – Gabica – Burnborough Association
725 Softscrabble – Sumine – Purnie Association
728 Softscrabble – Gabica – Burnborough Association
730 Arzo – Indiano – Barnard Association
894 Indiano – Duco – Skeddadle Association
895 Indiano – Zephan – Duco Association
900 Playas
930 Old Camp – Stoney – Sandy Loam 15 – 30%
1270 Tristan – Indiano – Barnard Association

WATERSHED BOUNDARIES
SOIL TYPE BOUNDARY

MILES 0 1 2 3

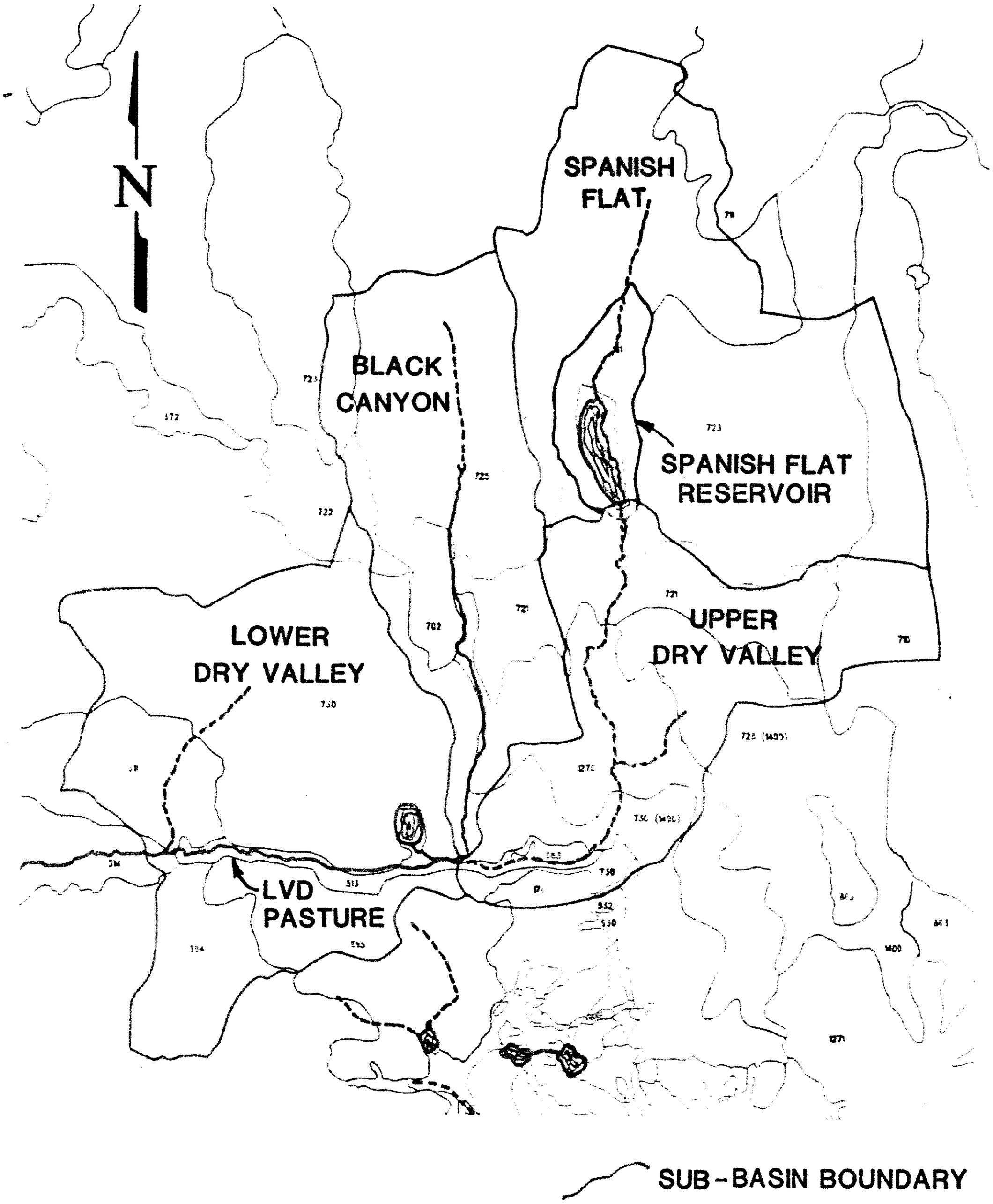
FIGURE 4

approximately 40 inches (Soil Conservation Service, 1983).

METHODS

The water balance methods and models were compared in two phases. The first phase was conducted on the relatively small and well documented watershed of Black Canyon. Five reference evapotranspiration methods were compared to determine the most appropriate one for use in the water balance calculations. The water balance values, which were calculated from actual site data, were then compared to results of two computer models run with both extrapolated climatological data and actual site data.

The second phase of analysis was conducted on the entire Dry Valley watershed which included Black Canyon, the Spanish Flat and Milk Ranch reservoirs as well as some irrigated pasture. This second phase provided a comparison of the water balance estimates to the results of the two models on a larger more complex area. Both extrapolated and actual climatic data were used in the models. The results were compared for the entire watershed and for a summation of four sub-basins within the watershed (Figure 5).



DRY VALLEY SUB-BASINS

MILES 0 1 2 3 4

FIGURE 5

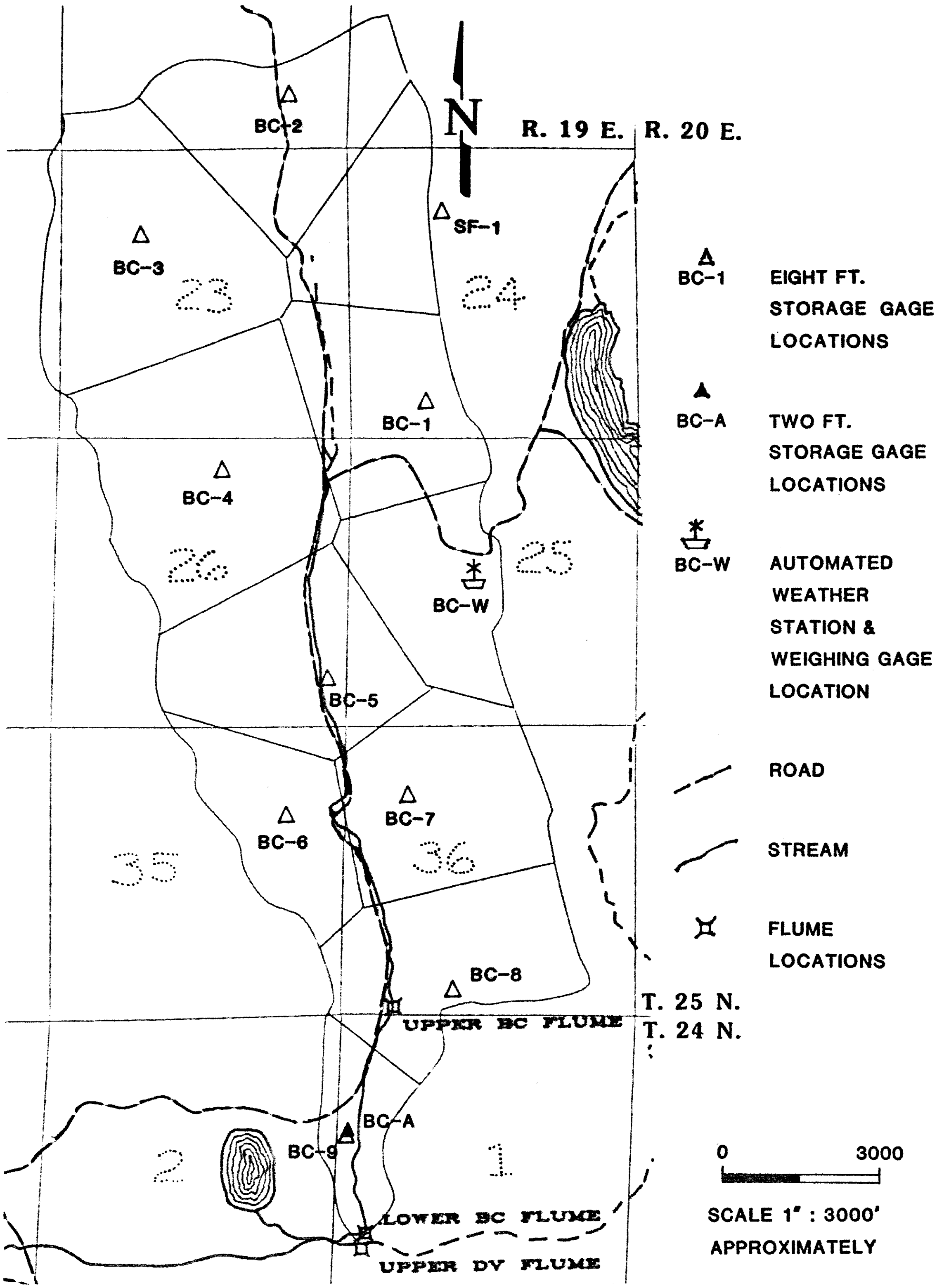
DATA COLLECTION

Precipitation

Precipitation measurements were collected using 6 inch (in) X 2 ft polyvinylchloride (PVC) and 8 in X 8 ft and 13 ft aluminum storage gages with wind screens, obtained from the Bureau of Land Management (BLM). A weighing gage (Handar model 454A-8) was installed to collect daily precipitation measurements. A network of nine 2 ft gages, one 8 ft gage and the weighing gage were dispersed throughout Black Canyon (Figure 6). The rest of the basin was equipped with four 2 ft gages, two 8 ft gages and one 13 ft gage (Figure 7). The 2 ft gages were set in surrounding sagebrush for wind screening action wherever possible. One hundred milliliters (ml) mixture of 20% WD-40 and 80% automatic transmission fluid was placed in all the gages to avoid evaporation. Approximately 6 inches of automobile antifreeze was placed in the gages prior to winter to prevent freezing in the gages. Precipitation data was collected from the gages approximately once a month, depending on accessibility.

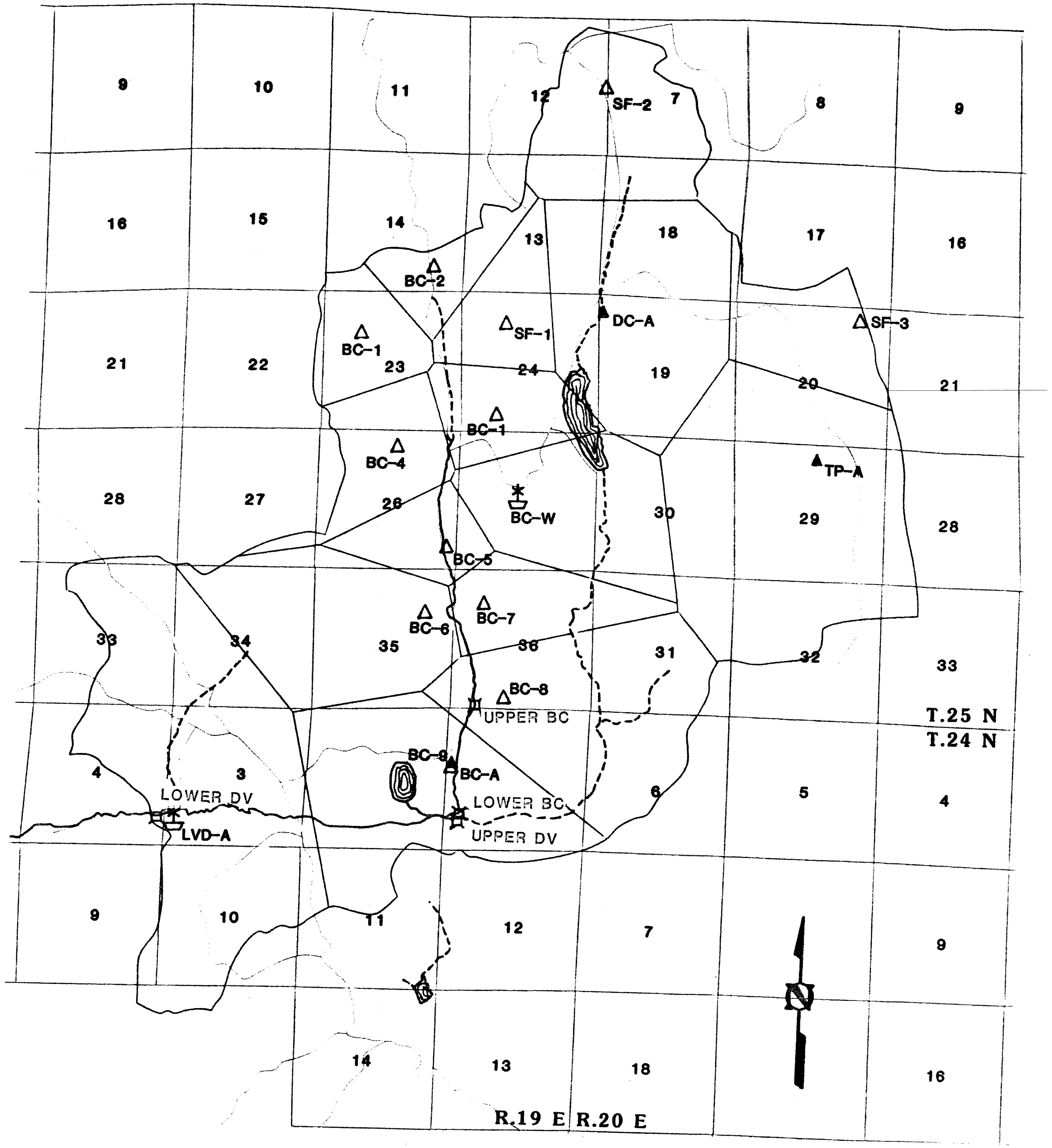
Evaporation

Evaporation data was collected from two class A pans located at the weather stations (WeatherMeasure model 6820-A). Staff gages in both Spanish Flat reservoir and the Milk Ranch reservoir were installed for evaporation and



BLACK CANYON WATERSHED

INSTRUMENT LOCATIONS FIGURE 6



BC-1 △ TWO FT. STORAGE GAGE LOCATIONS

BC-W AUTOMATED WEATHER STATION LOCATION

FLUME LOCATIONS

LVD-A MANUAL WEATHER STATION & EIGHT FOOT STORAGE GAGE LOCATION

TP-A ▲ 13 FT. STORAGE GAGE LOCATION

DC-A ▲ EIGHT FT. STORAGE GAGE LOCATION

0 5280'

SCALE 1" : 1 MILE APPROXIMATELY

DRY VALLEY DRAINAGE BASIN

INSTRUMENT LOCATIONS

FIGURE 7

irrigation water usage measurements.

Other Climatologic Information

Two weather stations were installed on the site for collection of pertinent weather information. An automated Handar ALERT system, with telemetry, was installed in Black Canyon. Instantaneous temperature (°F), wind speed and direction, solar radiation and precipitation were recorded with the following instruments: model 585D data transmitter; model 548D decoder; model 454A-8 weighing gage (mentioned previously); model 430A wind speed indicator; model 431A wind direction sensor; model 435A relative humidity/air temperature sensor; and model 441A solar radiation sensor. The manual weather station, located in lower Dry Valley, included: minimum and maximum thermometers in degrees Fahrenheit (°F) WeatherMeasure models 4425 and 4429; a continuous temperature (°F) and relative humidity (%) strip chart (Weathermeasure Hi-Q hygrothermogragh model 5022); a sling psychrometer (°F) (Weathermeasure model 5210) and a radiometer (langleys/min) strip chart recorder (Belfort pyrheliometer model 5-3850).

Stream Flow

Stream flow measurements were collected from permanent flumes at two locations in Black Canyon, at one location between upper and lower Dry Valley and one location at the watershed mouth in lower Dry Valley (Hinde Engineering H flumes of 2 ft, 0.75 ft, 0.75 ft and 3 ft respectively). Stevens Type F Model 68 continuous water level recorders were installed on the upper Black Canyon 2 ft flume and the lower Dry Valley 3 ft flume at the watershed mouth. Manual measurements were collected monthly at all four flumes.

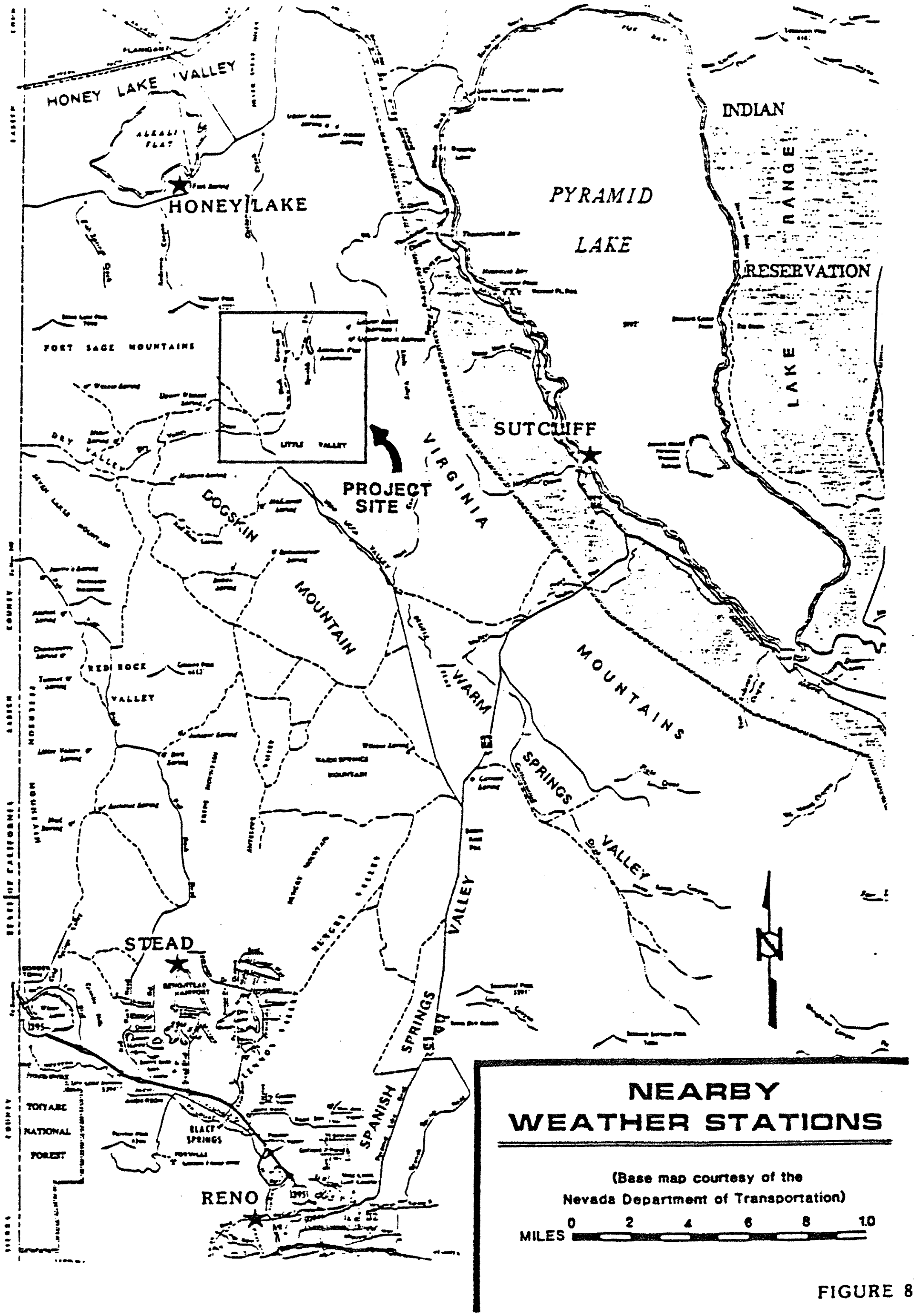
PARAMETER ESTIMATION

Precipitation

Precipitation measurements collected were first averaged by the Thiessen polygon method (Dunne and Leopold, 1978) (Figures 6 and 7). The area weighted average for each measurement was then divided into daily rates. (Precipitation measurements and daily precipitation interpolation are available in Appendix A-1 and A-2.) When daily on-site measurements were not available an estimate was made using daily precipitation measurements from four surrounding weather stations; Reno and Stead to the south, Sutcliffe to the east and Honey Lake to the northwest (Figure 8, Appendix A-3). For missing data at individual gages, estimated values were obtained by use of the normal-ratio formula:

$$Pm = 1/3\ [tPm * Pa/tPa + tPm * Pb/tPb + tPm * Pc/tPc] \quad (2)$$

Where Pm is the precipitation at the missing station, tPm is the total precipitation for the year (excluding the missing



NEARBY WEATHER STATIONS

(Base map courtesy of the Nevada Department of Transportation)

FIGURE 8

period), Pa (b, c) is the precipitation for the period of interest at nearby station a, b and c, and tPa (b, c) is the total precipitation for the year (excluding the missing period) for each station a, b and c (Dunne and Leopold, 1978).

Temperature and Relative Humidity

The daily minimum and maximum temperatures utilized for the site standard were collected from the strip chart hygrothermograph located in lower Dry Valley (Appendix A-4). Supplemental measurements for days these recordings were unavailable were taken from the minimum and maximum thermometers at the same location and from the Alert weather station in Black Canyon. Mean daily temperatures were calculated as maximum plus minimum divided by two (Doorenbos and Pruitt, 1975).

Relative humidity was measured with the hygrothermograph at the lower Dry Valley location. As relative humidity is extremely site specific no external data was introduced for interpolation of missing data. Instrument accuracy was checked using a sling psychrometer and tables converting dry/wet bulb differences to relative humidity values (National Weather Service, 1976).

Solar Radiation

Solar radiation values recorded on the pyrheliometer strip chart were used in the evapotranspiration equations.

Total daily radiation was calculated by integration with a ALVIN KP-92N digital planimeter. Missing values were estimated using available tables (Dunne and Leopold, 1978). Cloudiness and percent of maximum sunshine hours used with these tables were estimated from Reno monthly weather summaries (National Weather Service, 1989-90). No correction factor was applied to the table estimated values.

Evaporation

Water level depletion measurements of the Class A Pans (located in Black Canyon and lower Dry Valley) were collected approximately every two weeks, when accessibility permitted. Precipitation for the same period was added to the measurements to obtain total evaporation for the period. These values were then divided into monthly totals for use in the Pan method evapotranspiration equation. Due to control difficulties, such as evaporation pan water consumption by cattle, overflow of pan during winter storms and site inaccessibility, one complete year of reliable evaporation measurements were compiled by combining data from the two pan records.

Stream Flow

Stream flow records were limited to point sample events for the first 7 months of the study. The flow volume for the period between measurements was based on an average of the two readings. During the five months of flow records with continuous recording devices, the volume of flow was calculated from an integration of the curve using an ALVIN KP-92N digital planimeter.

Wind Run

Wind run information required for the water balance equations was unobtainable on site due to the unreliability of the automated system and lack of instrument calibration. When estimates of wind speed were required, data from the Reno monthly summaries were utilized (Appendix A-2). Because Reno wind run data appeared to be lower than the few measurements obtained from Black Canyon, the Reno wind run measurements provided a conservative estimate.

Curve Number

The curve number method is the primary method of determining the proportion of precipitation going to infiltration or runoff. Curve numbers, used in the ERHYM-II and SWRRB models to predict rainfall-runoff correlations were estimated from three different precipitation events in Black Canyon. Curve numbers were calculated for the April 20-24 event of 1.04 inches, May 28-29 event of 0.82 inches and for the event of August 9-10 of 0.43 inches using the Soil Conservation Service (SCS) formulas:

$$CN = 1000 / 10 + S \qquad (3)$$

and:

$$S = 5(P + 2Q -[4 * Q^2 + 5 * P * Q]^{0.5}) \qquad (4)$$

Where: CN is the curve number, S (storage) is the maximum potential difference between P and Q at the time of the storm's beginning (including all potential storage by soil, leaves, litter, etc. on the watershed), P is the precipitation and Q is the runoff.

These calculations gave curve numbers of 70.9, 70.9 and 85.2, for the three events respectively. These calculations assumed an antecedent moisture condition class I, which is defined as the moisture condition at the beginning of the event when less than 0.5 inches precipitation has occurred within 5 days prior to the event (SCS, 1971). The average rainfall event (of the 70 days precipitation occurred) was 0.18 inches. Curve numbers tend to decrease with increasing event size (Hawkins, 1979). The smallest event showing measurable stream flow fluctuation, Aug. 9-10 of 0.43 inches precipitation, (with a curve number of 85.2) was determined to be the most appropriate. This calculated curve number for Black Canyon was higher than both estimates from the SCS tables. The tables suggested for hydrological soils group C, antecedent moisture condition class I, a curve number of 71 be used for a poor condition range and 56 for a poor condition sagebrush.

For the remaining portions of the study site, as no visual observation of runoff was made for individual storms, estimates of curve numbers were made from visual observations of cover, soils and range condition with respect to the calculated curve number for Black Canyon.

Soil Albedo

The soil albedo, or the reflectivity of the soil, affects the amount of solar energy available for evaporation from the soil. Soil albedo for the representative soil was estimated from general soil color, for light soil as 0.15 and for dark soil as 0.10 (Arnold et al. 1990).

Universal Soil Loss Equation Parameters

Although prediction of soil loss from erosion was not part of the study, the SWRRB model required the input of the universal soil loss equation (USLE) parameters. The equation is:

$$A = R\ K\ LS\ C\ P \qquad (5)$$

where A, soil loss per unit of area (in tons/acre) is given by R a rain fall factor expressed as the product of rainfall energy and maximum 30 minute intensity for a given rainstorm; K the soil erodibility in tons/acre; LS a dimensionless length slope factor accounting for variations in length and slope; C a dimensionless cover factor relating to a the effectiveness of cover in reducing erosion; and P a dimensionless conservation practice factor (Wischmeir and Smith, 1965).

Soils factors K, P and C were estimated from tables (Branson et al. 1981) using SCS soils survey information (Table 1).

TABLE 1 SCS SOIL SURVEY SUMMARY

SOIL TYPE	NAME	HYDROLOGIC CLASS
176	INDIAN CREEK-RENO-WASHOE-ASSOC.	D,D,B
181	TUNNISON-DEVADA-ASSOC.	D,D
311	RISLEY-ROCK OUT CROP-COMPLEX-ASSOC.	D
314	RISLEY-XMAN-ROCK OUT CROP-ASSOC.	D,D
513	SETTLEMEYER-NOTUS-COMPLEX	D,A
683	RENO-STONEY-SANDY-LOAM	D
702	GRAUFELS-GIENBROOK-HAYPRESS ASSOC.	C,D
710	THULEPAH-HUTCHLEY-ASSOC.	C,D
711	THULEPAH-HUTCHLEY-ROCK OUT CROP-ASSOC.	C,D
721	SOFTSCRABBLE-SUMINE-HUTCHLEY ASSOC.	C,C,D
722	SOFTSCRABBLE-SUMINE-HUTCHLEY-THULEPAH-ASSOC.	C,C,C
723	SOFTSCRABBLE-GABICA-BURNBOROUGH-ASSOC.	C,D,C
725	SOFTSCRABBLE-SUMINE-PURNIE-ASSOC.	C,C,D
728	SOFTSCRABBLE-GABICA-BURNBOROUGH-ASSOC.	C,D,B
730	ARZO-INDIANO-BARNARD-ASSOC.	D,C,D
894	INDIANO-DUCO-SKEDDADLE-ASSOC.	C,D,D
895	INDIANO-ZEPHAN-DUCO-ASSOC.	C,C,D
900	PLAYAS	D
930	OLD CAMP-STONEY-SANDY LOAM 15-30%	D
1270	TRISTAN-INDIANO-BARNARD-ASSOC.	B,C,B

SOIL	THICKNESS (IN.)	BLK DEN (G/GM)	PERMIABILITY (IN/HR)	AVAIL WATER CAP. (IN/IN)	ORGANIC CONT. %	MAX POTENTIAL YIELD LBS/AC
176	47-60		0.06-20.0	0.03-0.16		800
181	17-42	1.10-1.40	0.06-2.0	0.07-0.16	0.5-3.0	900
311	40		0.0-0.60	0.00-0.18		700
314	29-40		0.0-0.60	0.00-0.18		700
513	60		0.6-6.0	0.03-0.19		3000
683	47		0.6-6.0	0.08-0.16		400
702	23-40	1.30-1.65	6.0-20.0	0.05-0.10	0.5-3.0	900
710	18-60	1.30-1.60	0.06-6.0	0.07-0.18	2.0-5.0	2200
711	19-60	1.15-1.55	0.0-6.0	0.00-0.18	0.0-5.0	1500
721	18-64	1.20-1.55	0.06-6.0	0.07-0.19	1.0-5.0	1400
722	28-64	1.20-1.55	0.06-2.0	0.08-0.19	1.0-5.0	1400
723	19-60	1.15-1.55	0.06-6.0	0.08-0.19	1.0-5.0	2200
725	25-64	1.10-1.60	0.0-2.0	0.08-0.19	1.0-5.0	1400
728	19-89		0.6-6.0	0.05-0.19		1100
730	25-29	1.10-1.55	0.6-6.0	0.06-0.19	1.0-2.0	1100
894	19-33		0.2-6.0	0.06-0.19		900
895	15-42		0.6-6.0	0.07-0.19		1100
900	60		0.0-0.6	0.02-0.04	0.0-0.1	--
930	17		0.2-6.0	0.07-0.11		1100
1270	33-60		0.2-20.0	0.06-0.19		600

For example, for a 50 % vegetal cover of short brush, with 60 and 80 % ground cover the C factors are 0.075 and 0.039 respectively. The C factor used was 0.05 assuming a 50 % vegetal cover with approximately 75 % total cover.
The USLE slope length and slope steepness parameters were obtained from topographic maps using the method outlined by Williams and Berndt (1976).

$$S = 0.25\ Z\ (LC_{25} + LC_{50} + LC_{75})\ /\ DA \qquad (6)$$

where S average slope equals 0.25 times Z, the total watershed height multiplied by the contour length of the 25 % (LC_{25}), the 50 % (LC_{50}) and the 75 % (LC_{75}) contours of the total height, divided by the drainage area (DA). To obtain LS, S is then multiplied by L which is obtained from:

$$L = LC\ /\ 2EP \qquad (7)$$

where the length L is determined from the same 25, 50 and 75 % contours (LC) each divided by twice the number of extreme points (EP) which are the locations channels appear on the contour line.

The measurement of lengths and areas were digitized from topographic maps using the ARC/INFO Geographic Information System (GIS) digitizing package from Environmental Systems Research Inc.(ESRI), Redlands California.

EVAPOTRANSPIRATION CALCULATIONS

Determination of a water balance requires an accurate means of calculating actual evapotranspiration. Actual evapotranspiration (ET) is calculated from potential or reference evapotranspiration (ETo) which is based on climatic data available. ETo calculation methods may utilize temperature data, solar radiation data or a combination of these and other climatic variables. Numerous comparisons of available ETo formulas have been published (Singh, 1989).

Based on recommendations of accuracy from available literature, while considering simplicity and acceptance regionally, the following were selected (ETo equations are available in Appendix B): 1) The Blaney-Criddle method (Blaney and Criddle, 1945) recommended for most practical use in arid and semi-arid areas due to it's use of readily obtainable data (Cruff and Thompson, 1967) 2) the Jensen Haise method (Jensen and Haise, 1963) due to it's recent popularity and simplicity 3) the Radiation method (Makkink, 1957) due to it's regionally wide spread use 4) the Class A Pan method (Kohler et al. 1955) and (5) the Penman method (Penman, 1948),for their accuracy. The FAO modifications (Doorenbos and Pruitt, 1975) were used for the Blaney-Criddle, Radiation, Class A Pan and Penman methods. These modifications involve utilization of empirical methods to fit actual measured values world wide. Climatic and environmental conditions such as wind, relative humidity, solar radiation and day/night weather differences were included in equations originally published without such parameters (Pennington, 1978). Estimates of ETo published by the University of California, Davis from a combination of the Class A Pan method, the Penman method and the Blaney-Criddle method (Pruitt et al. 1987) were tabulated and included for comparison.

MODEL SELECTION

Computer models considered for appropriateness in calculating a water balance for a sagebrush community included: CREAMS (Chemical, Runoff, and Erosion From Agricultural Management Systems) which was developed for nonpoint-source pollution estimates from field sized areas (Knisel, 1980); SPUR (Simulation of Production and Utilization of Rangelands) which was developed for economic evaluation of plant and animal growth on western rangelands (Wight and Skiles, 1987); SPAW (Soil, Plant, Air, Water) which was developed for use with cultivated crops in the Midwest (Saxton et al. 1974); ERHYM-II (Ekalaka Rangeland Hydrology and Yield) which was originally developed for use during the growing season on field sized grasslands of the Great Plains, but was adapted for use in Western Rangelands

(Wight, 1987); and SWRRB (Simulator for Water Resources of Rural Basins) which was developed in Texas for prediction of management decisions on water and sediment yields for ungaged rural basins (Arnold et al. 1990).

Of these models, only ERHYM-II and SWRRB were developed or adapted specifically for hydrologic modeling and have been utilized on western rangelands and were therefore the two chosen for comparison.

The ERHYM-II model predicts ET using the Jensen/Haise formula, separating evaporation and transpiration, while the SWRRB model uses the Priestly and Taylor method (1972) to calculate ETo and the Ritchie model (Ritchie, 1972) to determine actual ET.

RESULTS

REFERENCE EVAPOTRANSPIRATION ESTIMATES

The ETo results were obtained by utilizing the appropriate monthly parameters in each equation (Table 2). The results (Table 3) indicate the ETo calculations were all relatively similar except for the Jensen Haise method and the Blaney Criddle method. Compared to the Pan method results, which are typically the most precise (Singh, 1989) (Jensen, 1990) in agricultural situations, the Jensen-Haise

Table 2 DRY VALLEY MONTHLY PARAMETER SUMMARY

MONTH	MAX T (deg F)	MIN T (deg F)	MEAN T (deg F)	PAN EVAP (in.)	BLK CAN PRECIP (in.)	DRY VAL PRECIP (in.)
JAN	41.6	13.2	27.4	2.4	1.81	1.62
FEB	34.9	13.8	24.4	2.17	0.89	0.8
MAR	48	23.3	35.6	2.77	0.55	0.49
APR	60.3	26.8	43.6	5.54	1.79	1.48
MAY	58.3	29.9	44.1	7.14	1.33	1.26
JUN	71.8	34.7	53.2	8.19	0.23	0.23
JUL	86.5	39.1	62.8	10.53	1.76	1.55
AUG	77.6	41.1	59.4	8.91	0.69	0.62
SEP	61.4	43.3	52.3	7.52	1.12	1.01
OCT	26	61.4	43.7	3.68	0.32	0.28
NOV	55.6	13.4	34.5	4.43	2.07	1.85
DEC	41.6	13.2	27.4	3.07	0.21	0.18
AVE.	55.3	29.43	42.37			
TOTAL				66.35	12.77	11.37

MONTH	SOL RAD lang/day	REL HUM %	WIND (est.)	STREAM FLOW UP BLK CN acre ft.	LW BLK CN acre ft.	LW DRY VL acre ft.	UP DRY VL acre ft.
JAN	117	77	low	8.34	9.623	21.88	22.44
FEB	196	77	mod.	7.438	9.009	21.54	18.05
MAR	315	76	mod.	8.114	10.517	24.87	17.76
APR	577	57	mod.	6.537	9.557	12.4	14.36
MAY	564	68	mod.	4.733	5.107	6.63	8.21
JUN	645	59	mod.	4.733	4.703	8.81	7.88
JUL	571	58	mod.	2.029	4.806	1.56	11.05
AUG	570	55	mod.	3.156	3.391	0.17	15.87
SEP	394	43	mod.	4.057	4.131	1.94	8.79
OCT	193	50	mod.	5.184	5.448	4.5	3.99
NOV	235	76	low	7.889	7.646	11.61	16.02
DEC	181	74	low	8.34	9.489	20.52	22.23
AVE.		64					
TOTAL				70.55	83.427	136.43	166.65

Table 3 REFERENCE EVAPOTRANSPIRATION ESTIMATE SUMMARY (for a short green grass ETo) (inches)

MONTH	CLASS A PAN 0.7	CLASS A PAN variable		CALIFORNIA ETo for Milford	JENSEN-HAISE Alfalfa ref.cor
JAN	1.68	(.80)	1.92	0.7	0.77
FEB	1.52	(.75)	1.63	1.1	0.00
MAR	1.94	(.75)	2.08	2.2	1.80
APR	3.90	(.70)	3.90	4.1	5.90
MAY	5.00	(.65)	4.64	6.1	6.20
JUN	5.73	(.60)	4.91	7.1	10.38
JUL	7.37	(.55)	5.79	7.9	12.89
AUG	6.24	(.55)	4.90	7.3	11.68
SEP	5.26	(.55)	4.14	4.7	6.13
OCT	2.58	(.65)	2.39	2.9	2.06
NOV	3.10	(.70)	3.10	0.9	1.15
DEC	2.15	(.80)	2.46	0.5	0.10
ANNUAL	46.7		41.86	45.5	59.06

	BLANNEY-CRIDDLE FAO modifications	PENMAN (Doorenbos and Pruitt, (1975)	RADIATION
JAN	0.0	0.00	0.0
FEB	0.0	0.00	0.0
MAR	1.6	2.19	2.3
APR	2.8	4.84	5.3
MAY	2.4	8.06	5.8
JUN	5.7	9.45	7.1
JUL	7.4	6.59	8.0
AUG	5.9	7.69	7.8
SEP	4.1	6.85	4.5
OCT	2.4	2.93	2.0
NOV	0.1	1.42	1.6
DEC	0.0	0.00	0.0
ANNUAL	32.4	42.33	44.4

method was high while the Blaney-Criddle method was low. The California published ETo values for Herlong (Pruitt et al. 1987) are an average of the Blaney-Criddle, Radiation and Penman method estimated values, calibrated with lysimeter and pan data. The annual value of these (for Herlong) being 45.5 inches. The annual mean of all the methods utilized for the Dry Valley drainage was 44.6 inches. The mean of all excluding the Jensen-Haise and Blaney-Criddle methods was 44.15 inches. The Radiation method predicted an ETo of 44.4 inches, the closest result to the Herlong value and the mean(s). It was determined that the Radiation method is the most appropriate method for use in the Northwestern Great Basin due to: suggestion of its accuracy in the literature, the difficulty utilizing the Pan method on non-agricultural sites, it's similarity to the mean of the methods utilized for the Dry Valley study and it's simplicity.

ACTUAL EVAPOTRANSPIRATION

Actual Evapotranspiration estimates were determined for each ETo method using the representative soil of Black Canyon, Softscrabble along with the Thornthwaite soil water balance method (Table 4). The maximum possible AET (for the year of study), total precipitation minus streamflow, was determined to be 12.46 inches. The variable coefficient Pan and the Penman method produced results higher than this

Table 4 COMPARISON OF AET RESULTS (inches)
(using Thornthwaite soil water balance method
for Softscrabble Soils in Black Canyon)

MONTH		CLASS A PAN VARIABLE COEF. ETo	EST. AET	CLASS A PAN 0.7 COEF. ETo	EST. AET
JAN	(.80)	1.92	0.0	1.68	0.0
FEB	(.75)	1.63	0.29	1.52	0.19
MAR	(.75)	2.08	0.26	1.94	0.18
APR	(.70)	3.90	0.41	3.90	0.29
MAY	(.65)	4.64	4.55	5.00	4.90
JUN	(.60)	4.91	3.23	5.73	3.21
JUL	(.55)	5.79	1.85	7.37	1.81
AUG	(.55)	4.90	0.75	6.24	0.71
SEP	(.55)	4.14	0.16	5.26	0.12
OCT	(.65)	2.39	0.31	2.58	0.31
NOV	(.70)	3.10	1.9	3.10	0.12
DEC	(.80)	2.46	0.0	2.15	0.0
ANNUAL		41.86	13.71	46.70	11.84

	PENMAN ETo	PENMAN EST. AET	RADIATION ETo	RADIATION EST. AET
JAN	0.0	0.00	0.0	0.0
FEB	0.0	0.00	0.0	0.0
MAR	2.19	0.32	2.3	0.41
APR	4.84	0.52	5.3	0.67
MAY	8.06	4.43	5.8	5.69
JUN	9.45	2.25	7.1	1.98
JUL	6.59	2.24	8.0	1.81
AUG	7.69	1.09	7.8	0.71
SEP	6.85	1.26	4.5	0.12
OCT	2.93	0.34	2.0	0.31
NOV	1.42	0.07	1.6	0.10
DEC	0.0	0.00	0.0	0.00
ANNUAL	42.33	12.52	44.4	11.80

maximum, 13.71 and 12.52 inches respectively. The constant coefficient Pan and the Radiation method produced values under this maximum with values of 11.84 and 11.80 inches respectively. Since AET cannot exceed 12.46 inches, the pan method and the Radiation method were of most value for determining AET. The Radiation method was determined to be the most appropriate method for use in AET estimation (due to Pan maintenance difficulties in remote areas). Actual ET values in the sub-basin and basin water balances that follow are calculated by use of the radiation method for ETo and the Thornthwaite soil water balance procedures.

WATER BALANCE CLOSURE

The concept of a water balance is to account for all the components of water use, including an estimate of ground water recharge (deep percolation). Ideally this measurement would utilize an independent method to avoid recurring error. Under such circumstances, the water balance equation may not balance and the difference (η) is a result of empirical errors. When it is not possible to independently measure a parameter, the parameter estimated by subtraction from the rest of the formula will include the formula error (η). The difference between effective precipitation (precipitation minus streamflow) and AET results in a water deficit or surplus. During deficit periods water may be withdrawn from the ground-water aquifer if it is within reach of the plant roots. Likewise during surplus periods ground-water recharge may occur.

The geologic structure of the study site indicates major faults which could conduct deep percolation of soil water to aquifers below the rooting zone. In this study, the difference between precipitation and AET and streamflow is assumed to be contribution from or recharge to ground-water.

PHASE I BLACK CANYON

Water Balance Calculations

The water balance for Black Canyon is summarized in Table 5. With an annual effective precipitation of 2809 acre ft and 2660 acre ft of AET, an annual surplus of 149 acre ft exists. This surplus (which includes η) is approximately 5 % of precipitation. An error of this magnitude may be an empirical error in the calculation of AET. This surplus however is assumed to represent loss to ground-water recharge in this study.

Phase I Model Results

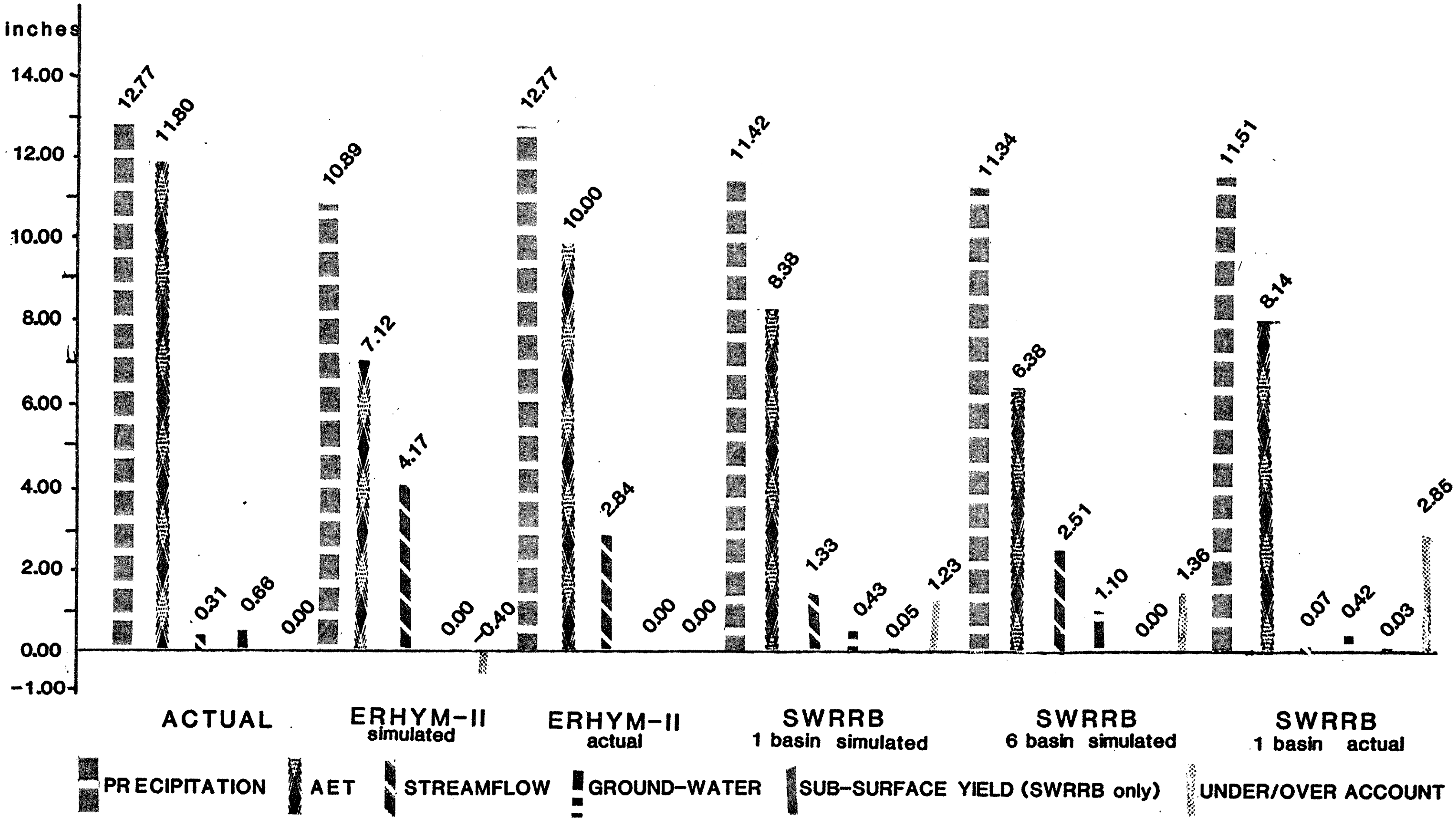
The ERHYM-II model was run using both simulated and actual data from the watershed. The difficulty with the use of the ERHYM-II model is the size limitation, and the assumption of homogeneity (see Appendix B-1 model input

Table 5 Black Canyon Water Balance (acre ft)

month	PRECIP	AET	STREAMFLOW	η, DEFICIT OR SURPLUS
JAN	408	0	8	400
FEB	201	0	7	194
MAR	124	92	8	24
APR	403	151	7	245
MAY	300	1283	5	-988
JUN	52	446	5	-399
JUL	397	408	2	-13
AUG	156	160	3	-7
SEP	252	27	4	221
OCT	72	70	5	-3
NOV	467	23	8	436
DEC	47	0	8	39
YR	2879	2660	70	149

parameters and Appendix B-2 results). The model results for the simulated run, using extrapolated climatic data from Reno, and the run with actual climatic data, both underpredict AET and overpredict streamflow, as can be seen by the results in Table 6, which are graphed in Figure 9.

The SWRRB model (also compared in Table 6), which can be used for any size basin and divided into numerous sub-basins, produced similar results (for input parameters and results see Appendix C-1 - C-4). The SWRRB model also underpredicted AET and overpredicted stream flow in the simulated runs and underpredicted stream flow in the run with actual data. Ground-water recharge prediction, which is predominantly soils and curve number dependent, was relatively accurate for the actual and simulated runs with 1



COMPARISON OF ANNUAL RESULTS, BLACK CANYON

FIGURE 9

Table 6 Comparison of Annual Results for Black Canyon (inches)

	PRECIP	AET	%	STRMFLW	%	η, or GRND-WTR	%	total %
ACTUAL 1 Basin	12.77	11.8	92	0.31	2	0.66	5	99
ERHYM-II simul	10.89	7.12	65	4.17	38	0	0	103
ERHYM-II actul	12.77	10.0	78	2.84	22	0	0	100
SWRRB 1,b,s*	11.42	8.38	73	1.33	12	0.43	4	89
SWRRB 6,b,s*	11.34	6.38	56	2.51	22	1.10	10	88
SWRRB 1,b,a*	11.51	8.14	71	0.07	1	0.42	4	76

* 1,b,s - 1 basin with simulated climatic data
* 6,b,s - 6 sub-basins with simulated climatic data
* 1,b,a - 1 basin with actual climatic data

basin but overpredicted for the run with 6 sub-basins.

The SWRRB model results did not account for between 1.23 and 2.85 inches of input. The ERHYM-II model results using actual climatic data balanced, while the run with simulated data showed stream flow and AET utilized 0.4 inches more water than was available.

PHASE II DRY VALLEY WATERSHED

Sub-basins

The sub-basin distinctions utilized in the phase 2 modeling were derived from a combination of hydrologic boundaries, soils distinctions and topographic differences (see Figure 5). The Spanish Flat reservoir area was designated as one sub-basin due to its flatness, lack of plants and low permeability soils. The surrounding portion of the Spanish Flat Watershed was empirically evaluated independently but due to its similarity with upper Dry Valley, was combined with that area as a second sub-basin during modeling. Black Canyon constituted a third sub-basin and lower Dry Valley below the Black Canyon inlet constituted the fourth.

Water Balance Calculations

A) Lower Dry Valley

In order to calculate the water balance for lower Dry Valley (see figure 4) it was necessary to treat portions of the sub-basin separately. Lower Dry Valley sub-basin contains the Milk Ranch Reservoir and a small portion of irrigated pasture as well as sagebrush rangeland. The manual diversion of either the Black Canyon stream flow or the upper Dry Valley spring water into the Milk Ranch reservoir along with reservoir leakage made it impractical to conduct a water balance on the reservoir alone. All incoming water, to the sub-basin was therefore treated as irrigation water. A pasture is situated along the stream the entire length of the sub-basin, consequently all stream flow was available for pasture irrigation including any leakage from the reservoir.

Direct evaporation from the reservoir was calculated by multiplying pan evaporation by a coefficient of 0.75 (Singh, 1989), and reservoir area. Reservoir area was estimated from a detailed topographic survey and staff gage readings (Appendix E-1).

The water available for plant consumption in the pasture was assumed not to include potential runoff from the surrounding portion of the site, as this would be relatively minor compared to the influent stream content. The soil of the pasture area is the Settlemeyer-Notus complex. The Notus soil type which occurs along the stream has a relatively high permeability and little water holding capacity. For the water balance calculations, water in excess of that required for soil moisture recharge, was assumed to be held in the Milk Ranch Reservoir. The reservoir water was released in May for irrigation at which time sufficient soil storage capacity should have been available. As can be seen (in Table 7) by the summary of the water balance, 136 acre ft were estimated to contributed to ground-water recharge and only 139 acre ft of surface yield was recorded. The conservative assumptions made in this balance, such as no runoff from the sagebrush area (which would increase the amount of surplus water in the pasture balance), suggests the estimate of ground-water recharge may be low even though it includes η (calculation error).

Table 7 WATER BALANCE FOR LOWER DRY VALLEY
(acre ft)

LOWER DRY VALLEY PASTURE BALANCE

	input UDV	BC	PRECIP.	output LDV	AET	EVAP.	η, DEFICIT OR SURPLUS
JAN	22	8	23	22	0	1	30
FEB	18	7	11	22	0	2	12
MAR	18	8	7	25	3	2	3
APR	14	7	21	12	6	4	20
MAY	8	5	18	7	60	3	-39
JUN	8	5	3	9	45	3	-41
JUL	11	2	22	2	35	3	-5
AUG	16	3	9	0	27	2	-1
SEP	9	4	14	2	25	1	-1
OCT	4	5	4	5	8	1	-1
NOV	16	8	26	12	1	2	35
DEC	22	8	3	21	0	1	11
YR	166	70	161	139	210	25	23

LOWER DRY VALLEY SAGEBRUSH BALANCE

	input PRECIP.	output AET	η, DEFICIT OR SURPLUS
JAN	523	0	523
FEB	258	0	258
MAR	158	133	25
APR	478	216	262
MAY	407	1423	-1016
JUN	74	417	-343
JUL	500	665	-165
AUG	200	251	-51
SEP	326	326	0
OCT	90	90	0
NOV	597	35	562
DEC	58	0	58
YR	3669	3556	113

TOTAL ANNUAL BALANCE

PRECIP	3830
INFLOW	236
EVAP	25
AET	3766
OUTFLOW	139
GRND WTR	136

C) Upper Dry Valley

For the upper portion of the Dry valley watershed, no stream flow was observed. Because AET equaled precipitation (Table 8), theoretically all water was held in the soil

Table 8 Upper Dry Valley Water Balance (acre ft)

month	PRECIP	AET
JAN	384	0
FEB	190	0
MAR	116	97
APR	351	159
MAY	299	541
JUN	55	783
JUL	368	536
AUG	147	223
SEP	240	259
OCT	66	74
NOV	439	26
DEC	43	0
YR	2698	2698

horizon until plant use and therefore no ground-water recharge occurred.

B) Spanish Flat Reservoir

The reservoir at Spanish Flat was established to contain spring runoff for use in late summer or early fall. During the year of study, this water was not used due to the exceptionally low volume available. The Reservoir balance calculations (Table 9) indicate that the effect of runoff (spring thaw only) from the surrounding watershed was 270 acre ft. Using a reservoir evaporation coefficient of 0.75 (relative to pan evaporation), evaporation from the water surface, with an average area of 113 acres (for topographic survey information see Appendix E-2), was 469 acre ft. Direct precipitation on the 486 acre playa along with 270 acre ft of runoff from the surrounding area

Table 9 Spanish Flat Reservoir Water Balance
(486 acre area with ave. water surface of 113 acres)

date	elevation ft msl	area acres	volume acre ft	change acre ft
Sep 14	6666.9	3	3.7	
Mar 21	6675.5	102.1	250.7	+247.0
May 02	6674.0	73.4	151.7	-99.0
Jun 20	6673.3	61.6	119.5	-32.2
Jul 20	6672.7	52.7	99.0	-20.5
Aug 03	6672.3	45.5	84.7	-14.3
Aug 28	6671.8	38.3	68.6	-16.1
Sep 28	6671.3	34.1	55.6	-13.0

	precip	evap	change	net change
Sep 14 - Mar 21	259.0	177.0	+247.0	165.0 (runoff)
Mar 21 - Sep 28	201.5	291.6	-195.1	104.9 (grnd-wtr)
				51.9 (storage)

Annual precip - 461; evap - 469; grnd-wtr 210
runoff - 270; storage - 52

resulted in an increase of 731 acre ft. The ground-water recharge for March 21 to September 28 was 105 acre ft. It was assumed that the infiltration rate was constant so that 210 acre ft contributed to ground water recharge annually.

E) Spanish Flat surrounding area

The spring thaw runoff entering the Spanish Flat reservoir from the surrounding area, 270 acre ft, is equivalent to 0.85 inches of precipitation. The effective precipitation was 3348 acre ft of which 3346 was utilized in AET and 2 acre ft represent ground-water recharge and/or η (calculation error).

D) Dry Valley Basin

The water balance for the entire basin is a summation of the individual components. Evaporation and AET were compiled from each sub-basin. Streamflow and runoff (from one sub-basin into another) were included in the "effective precipitation" of the sub-basin except where leaving the basin or entering reservoir storage. Taken individually each sub-basin produced a surplus or deficit that reflects an estimation of ground-water recharge (assuming minimal η). When compared with a balance calculated for the site as a whole (Table 10) with one soil type and no evaporation from water surfaces, the difference is 231 acre ft, approximately 0.19 inches for the entire site or 1.7 % of precipitation.

Table 10 Annual Water Balance For Dry Valley Basin (Acre ft)

	EFF.PRECIP	AET & EVAP	RUNOFF/STOR.	GRND-WTR
LDV PASTURE	397	235	139	23
LDV SAGEBRUSH	3669	3556		113
BLACK CANYON	2809	2660		149
UDV WATERSHED	2698	2698		0
SF RESERVOIR	731	469	52	210
SF SUR. AREA	3348	3346		2
summation	13652	12964	191	497
WHOLE AREA	13169	12764	139	266
			difference	231

PHASE II MODEL RESULTS

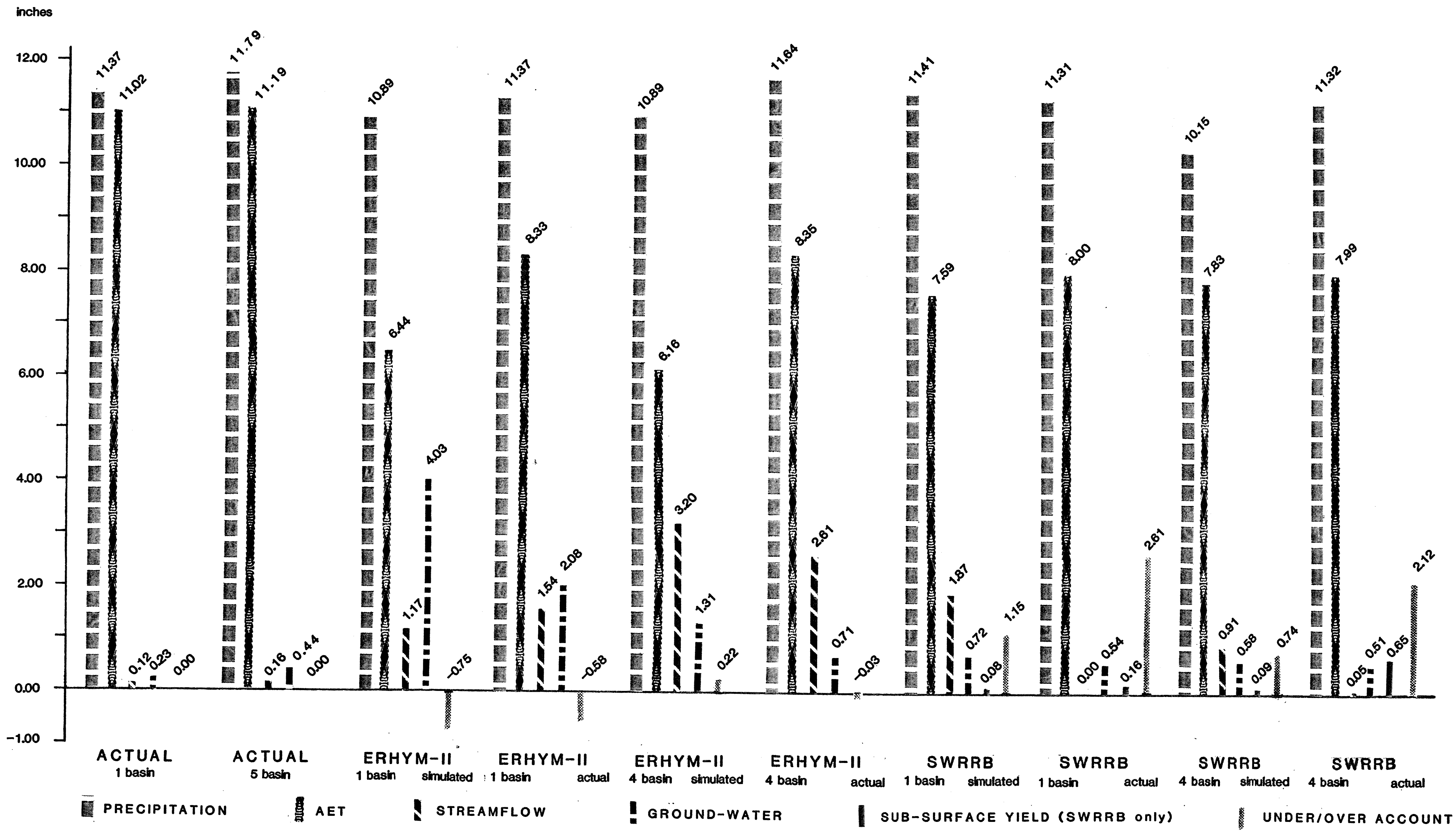
The results of the models run for the entire drainage basin were much the same as the results of the Black Canyon phase. Table 11, which compares the model results using actual and simulated climatic data for both the site as a

Table 11 Comparison of Annual Results Dry Valley Basin (inches)

	PRECIP	AET	STREAM FLOW	GROUND-WATER	SUB-SURFACE	TOTAL %
ACTUAL 1 BASIN	11.37	11.02	0.12	0.23		100
ACTUAL 5 BASIN	11.79	11.19	0.16	0.44		100
ERHYM-II 1,b,s*	10.89	6.44	1.17	4.03		107
ERHYM-II 1,b,a*	11.37	8.33	1.54	2.08		105
ERHYM-II 4,b,s*	10.89	6.16	3.20	1.31		98
ERHYM-II 4,b,a*	11.64	8.35	2.61	0.71		100
SWRRB 1,b,s*	11.41	7.59	1.87	0.72	0.08	89
SWRRB 1,b,a*	11.31	8.00	0.00	0.54	0.16	77
SWRRB 4,b,s*	10.15	7.83	0.91	0.58	0.09	93
SWRRB 4,b,a*	11.32	7.99	0.05	0.51	0.65	82

*1,b,s - one basin with simulated weather conditions
*1,b,a - one basin with actual weather
*4,b,s - four sub-basins with simulated weather
*4,b,a - four sub-basins with actual weather

whole and as a summation of sub-basins, indicates AET was underestimated in all cases. As can be seen in Figure 10, the predictions of AET in each case with the SWRRB model were relatively consistent. The predicted values of streamflow and ground-water recharge varied greatly for each situation. In the SWRRB model the water unaccounted for varied from 0.74 to 2.61 inches, similar to or greater than either the predicted streamflow or the ground-water recharge estimates. (SWRRB model input and complete results for Dry Valley Basin available in Appendix D-5 - D-8.)



COMPARISON OF ANNUAL RESULTS, DRY VALLEY WATERSHED

FIGURE 10

NORMAL YEAR CORRELATION

The proportion of precipitation in each part of the water balance is affected by antecedent moisture conditions, plant requirements (seasonal variation) and available water capacity as well as precipitation event size. For this reason, when attempting to predict the affect of greater annual precipitation, increasing the event size will have a different affect than increasing the number of events. An initial amount of precipitation in each event is utilized in storage on the watershed (initial abstraction). Increasing the amount of precipitation in each event generally results in greater infiltration and, after soil storage capacity is exceeded, greater runoff. Increasing the number of events will generally result in less runoff because of the initial abstraction and higher infiltration.

The SWRRB model utilizes a statistics file which includes statistics such as the probability of a wet day occurring after a wet day. With a statistics file compiled from several years of record, the SWRRB model can predict the effects of differing annual amounts which may include additional events. Without this record, to predict the effects of different annual precipitation, it is necessary to increase (or decrease) each event size.

The data utilized in this study was collected during the fourth year of drought in the region. According to Reno precipitation records, this year was approximately 70 % of normal. Utilizing Reno's statistics file and increasing each event size (1.5 X) (Table 15) results in a 1.3 X increase in AET, a 2.6 X increase in streamflow and a 1.3 X increase in ground-water recharge. This creates a discharge of 180 acre ft for Black Canyon, a flow into Spanish Flat reservoir of 700 acre ft and an increased spring flow into lower Dry Valley of 430 acre ft (167 acre ft during the study year). The total water available for collection would be approximately 1300 acre ft. Because a greater annual precipitation would generally mean a greater number of events and not just greater amounts in each event, these predictions are representative of the highest potential.

Table 12 NORMAL YEAR ESTIMATES (USING THE SWWRB MODEL) (acre ft)

	PRECIP	AET	STRM FLW	GRND WTR
SWRRB Current Year	12704	9548	1120	823
SWRRB Normal Year	19056	12804	2882	1047
multiplier	(1.5)	(1.3)	(2.6)	(1.3)
Actual Current Year	13652	12964	191	497
Estimated Normal Year	20000	17000	500	650

DISCUSSION AND RECOMMENDATIONS

FIELD INSTRUMENTATION

The collection of field data from remote watersheds is limited significantly by accessibility. In an attempt to avoid this problem an automated weather station with telemetry capabilities was installed on the site. In-spite of this advanced technology, the equipment was subject to failure for several reasons and calibration of instruments was not simple. The problems with the Alert system installed at the site was eventually analyzed as being battery recharge failure due to incompatibility with the solar panel. This resulted in the monthly replacement of batteries, after a significant amount of data was unavailable. Because most strip chart instruments are currently available with 30 day clocks, the telemetry system is not justified until the difficulties can be worked out. The difficulties with strip chart instruments typically involve the ink trace. The old style fountain pen type pen arms yielded better results than the cartridge pens, although this may be directly related to ink/cartridge type. Two complete weather stations or duplicate instruments would minimize loss of data and ensure continuous calibration.

The ratio of precipitation catch between the High Elevation gage and the 2 ft PVC gage at BC-9 where both types of gages were located, ranged from 0.76 to 4.5 for concurrent sampling periods. This large degree of difference is attributed to the effects of wind. The 2 ft PVC gage was surrounded by sagebrush of similar height which acted as a wind screen while the 8 ft tall High Elevation gage (with a standard louvered wind screen) was exposed to more wind thereby reducing the catch. Although not practiced in the United States, the United Nations, in Methods for Water Balance Computations suggests an additional 10-15 % for rain and 40-60 % for snow be applied to precipitation gages for correction of catch estimates (Sokolov and Chapman, 1974). No evidence is available suggesting any particular type of gage is more accurate; however, Handman (1989) (personal communication) indicated her experience with the high elevation gages was that they tended to underestimate true precipitation. The greater catch of the 2 ft PVC gage is likely to be the more accurate in this case.

Good success was observed utilizing the H and HS flumes to measure streamflow. These flumes, designed for small watersheds, can be obtained in many sizes. A continuous recording device such as the battery operated Steven's recorder is recommended for more accurate flow measurements. It was noted that during the period utilizing continuous recording devices the estimates made on point measurements were 10 % different than the integrated average. The major factor responsible for this error was the diurnal fluctuation of the water levels during periods of high evapotranspiration. Although a stilling well can easily be constructed and attached to the flume, obtaining flumes with pre-built stilling wells will reduce construction time and potential problems. Because stream volume can vary depending on ground-water contribution, two or more flumes per stream may be appropriate. Flumes should be sized according to the stream channel size. During the summer when construction of flumes takes place the stream volume may appear to be low, however the stream channel size indicates its potential volume during peak runoff.

Streamflow, which occurs year round in Black Canyon and much of Dry Valley, results in part from springs. If the spring water adding to stream flow resulted from infiltration during a period of significantly different precipitation than the year of study a large error would be introduced in the water balance. An isotope analysis was conducted on the spring water of the study site in an effort to determine it's relative age. Because the results of that study were inconclusive, it was necessary to assume that either the spring flow was a result of infiltration during the concurrent year or that the flow is constant from year to year. Conducting an isotope analysis on spring water in other studies may produce better results.If it is known that the spring water is from a year of higher or lower precipitation,this can be considered in the balance for the watershed.

Between the months of April and September the average water loss (after precipitation) in the evaporation pans on site was 1.6 inches per week. The result of allowing too much water loss is increased evaporation. Increased wind turbulence, wall shadow and increased water temperature can result in up to 15% error if the water level drops between 3 and 4 inches below the rim (Doorenbos and Pruitt, 1975). To maintain this level requires refilling the pans as often as once a week in some cases. Accurate measurements from locations where at least bi-weekly visits cannot be made can be conducted by means of an automated refilling mechanism. The simplest of these mechanisms would be a float valve such as is found in the common toilet tank. A more accurate method would be a pair of water level sensor switches such as found with submersible water well pumps that can be hooked up to a pump, with a volumetric flow meter.

The estimation of soil water content is the component of the water balance formula which has the highest potential for error. Soil water sampling could reduce error in future studies. Undisturbed soil samples collected quarterly can be analyzed for water content. Samples from 1 ft and 3 ft depth should be collected after spring thaw, in late-April before plant consumption begins, in mid-June at peak crop demand, and in late October after plant usage is completed.

Ground-water recharge was an important portion of two of the sub-basin water balances conducted. For watersheds where ground-water recharge to a shallow aquifer is expected, temporary hand augured piezometers can be installed. The identification of gradients (which may change seasonally) near perennial streams may indicate the magnitude of ground-water contribution and recharge.

REFERENCE EVAPOTRANSPIRATION EQUATION SELECTION

The Class A Pan method, due to the difficulty of maintaining the pan water content in remote basins, and the difficulty selecting a pan coefficient, is not the most practical. The FAO modified Radiation method, which produced the mean value of all the methods utilized in this study, requires measured values of temperature and sunshine or radiation and estimated values of relative humidity and wind. The use of a pyrheliometer with a 30 day clock produced reasonable results. Potential error with this method occurs during the curve integration process. Days with sporadic cloudiness may be more difficult to quantify on the charts with smaller time scales. For watersheds where a significant portion of the site has one topographic aspect affecting total radiation, the Radiation method can be adjusted with methods described by Mohler (1979).

CALCULATION OF AET

The results of the calculations of AET for the different sub-basins indicates no transpiration or evaporation occurred during the months of January, February or December. This is due to the fact that the mean temperature of the month was below freezing. During daytime hours temperatures in the Western Great Basin are high enough to warrant some evaporation. During cooling periods theoretically condensation may occur. Regardless of the high and low AET is calculated by mean temperature.

In order to determine the accuracy of this method for the Western Great Basin, an integration of hygrothermograph strip chart curves could be conducted and compared to the normal mean estimation method of maximum plus minimum divided by two.

MODEL USAGE

The ERHYM-II model which was intended for use on field sized areas is easy to use. The ERHYM-II model is appropriately used for prediction of variation in the water balance caused by crop management changes. The prediction of the effects on the water balance caused by such things as climatic changes is less certain.

The SWRRB model has a large number of input parameter requirements including a table of climatic statistics derived from long term records (see Appendix C). Adjustments of the statistics files dramatically influence all the output parameters including the precipitation whether measured or simulated. Significant effects on the results were seen with the adjustment of the precipitation and curve number. Such adjustment does not produce proportional changes in other terms of the water balance. Because of the detailed input requirements for the SWRRB model it needs to be calibrated on a well documented watershed with several years of record. On a well documented watershed prediction of the effects of managerial or climatic changes on the proportions of the water balance may be quite accurate. However the use of the model for prediction of hydrologic properties on un-gaged watersheds is subject to familiarity with the model, and the capability of estimating the site characteristics. Because the estimation of runoff curve numbers is difficult and the surface water yield prediction with the SWRRB model is sensitive to the curve number, water yield prediction from ungaged watersheds is also difficult with the SWRRB model.

LAND MANAGEMENT AND WATER YIELD IMPROVEMENT

There is prevalent information in the literature regarding the effects of various land management practices on water yield. Much of this information involves plant species manipulation and grazing management.

Plant species manipulations in many studies indicate significant water yield increases. Studies of this nature however cannot be extrapolated due to variations in watershed size, annual precipitation, soil types, plant species and other variables. Vegetation manipulation in areas with less than 20 inches of annual precipitation, regardless of vegetation type, have little potential of water yield increase (Branson et al. 1981). Studies for increasing water yield in Arizona by vegetation manipulation (Ffolliot and Thorud, 1975) concluded that increasing recoverable water supplies by vegetation manipulation cannot be justified for the desert shrub vegetation zone because of the apparent association of water yield with high rainfall intensity.

Management of grazing activities on sagebrush watersheds has been subject to much attention. The detrimental effects (to the watershed) from improper grazing techniques, both overgrazing and poor seasonal rotation, are most significant on infiltration rates and forage plant species depletion (Blackburn et al. 1981). The correction of this mismanagement in the majority of watersheds will have an inverse effect on surface water yield by increasing infiltration rates and plant transpiration rates, thereby decreasing runoff. The streamflow of the Upper Dry Valley drainage basin is due predominantly to spring flow. Although increased infiltration will predominantly increase evapotranspiration it will also increase spring flow and therefore water yield.

Transmission and storage losses greatly affect the amount of water available for collection. At the upper end of lower dry valley the springs produce a substantial amount of water that goes to ground-water recharge and evapotranspiration as it flows through the relatively flat lower dry valley sub-basin. Black canyon, which is a gaining stream up to the end of the canyon, loses a significant amount in transmission to the Milk Ranch Reservoir. If transmission losses could have been avoided, during the year of study, these sources together would account for approximately 250 acre ft. The Spanish Flat reservoir, with an average surface area of 113 acres, lost approximately 400 acre ft of water to evaporation and ground-water recharge between March 21 and September 28. If the transmission and storage losses on-site could be avoided, over 500 acre ft more water would have been available for collection during the study year. During a normal water year, considering the larger surface area of the Spanish Flat reservoir, potential loss through transmission and storage would be over 1000 acre ft.

The Dry Valley Basin is severely overgrazed. Continued grazing during additional drought years will heavily impact the available forage. This will reduce future use of the area for grazing, reduce soil protection (increasing erosion) and reduce infiltration (decreasing water yield). The direct elimination of the plants (by continued grazing) as well as loss of rooting soil and nutrients through erosion will increase the watershed recovery time. Immediate correction of current grazing practices is critical to preserving the utility of the watershed. In order to obtain the water yield predicted for a normal year, the watershed itself will also need to be restored to normal.

SUMMARY

WATER BALANCE METHODS

Data Collection

The installation of two sets of climatological instruments including pyhrheliometers, hygrothermographs, min max thermometers and a sling psychrometer would alleviate the potential for data loss due to instrument failure.

An adequate precipitation gage network can be easily constructed of PVC pipe. The location and number of gages should reflect the accessibility of the watershed. At least one reliable recording gage is required to obtain daily precipitation records.

One or more continuous recording streamflow gages such as an H flume with a stilling well and a Steven's Recorder should be placed on all perennial streams within the watershed. The continuous flow recording will allow more accurate curve number calculation and reduce error in the estimation of annual streamflow. Two gages on a stream will allow ground-water recharge or discharge estimation. Additional measurement of ground-water recharge or discharge at the stream may be determined by installing piezometers along the stream bank.

<u>Water Balance Equation</u>

The use of the Radiation method is recommended for ETo determination for remote watersheds within the Northwestern Great Basin. In conjunction with the Thornthwaite soil moisture balance method, AET can be estimated by the Radiation ETo method.

Ground-water recharge may be a significant portion of a rangeland water balance. By subtraction of the estimated AET and measured stream flow from the measured precipitation an estimate of ground-water recharge can be made, if an independent measurement is not available.

Better water balance results are obtained by sub-dividing a basin into smaller more homogeneous sub-basins. The sub-basin divisions should consider topography, soils, plant communities and precipitation.

<u>Use Of Models</u>

The ERHYM-II model and the SWRRB model will provide rough estimations of water yield from un-gaged watersheds. The ERHYM-II model is most appropriately used on small homogeneous areas for prediction of the relative affects (on the water balance) of agricultural or crop related management practices. The SWRRB model which can be used on any size watershed with up to 10 sub-basins (using the version published in 1990) may prove useful in predicting the affects (on the water balance) of several potential changes to the watershed. These predictions would be most accurate on well gaged watersheds with several years of record from which to derive climatic statistics.

WATER BALANCE FOR DRY VALLEY DRAINAGE BASIN

Within the Dry Valley Basin, a discharge of 70 acre ft was recorded for Black Canyon. The springs at the head of lower Dry Valley produced 167 acre ft. Approximately 270 acre ft of runoff collected in the Spanish Flat reservoir, although after losses to ground-water recharge and evaporation 52 acre ft remained in storage. The stream flow leaving Dry Valley was 139 acre ft.

The components of the annual water balance for the Black Canyon watershed, for the year September 1989 to September 1990, are: precipitation - 12.77 inches; AET - 11.80 inches; streamflow - 0.31 inches and ground-water recharge - 0.66 inches. This is equivalent to: precipitation - 2880 acre ft; AET - 2660 acre ft; streamflow - 70 acre ft; and ground-water recharge - 150 acre ft.

The components of the annual water balance for the entire Dry Valley Basin are: precipitation - 11.68 inches; AET - 11.1 inches; streamflow - 0.16 inches; and ground-water recharge - 0.42 inches. This is equivalent to: precipitation - 13,700 acre ft; AET - 13,000 acre ft; streamflow - 200 acre ft; and ground-water recharge - 500 acre ft.

NORMAL ANNUAL WATER YIELD

During a normal precipitation year the yield of each of the sub-basins would be approximately 2.6 times greater. The streamflow from Black Canyon would be 180 acre ft. The potential harvest from Spanish Flat Reservoir would increase to 700 acre ft. The spring flow at the head of lower Dry Valley would be 430 acre ft and the streamflow from lower

Dry Valley would be 350 acre ft. In order to obtain the maximum utilization from the watershed, it needs to be restored to pre-grazing conditions and water losses due to transmission and storage can be avoided. With good management an average annual water yield of up to 1500 acre ft can be expected.

REFERENCES

Arnold, J.G., J.R. Williams, A.D. Nicks and N.B. Sammons. 1990. SWRRB A basin scale simulation model for soil and water resource management. Texas A&M University Press, College Station, Texas.

Blackburn, W.K., R.W. Knight and M.K. Wood. 1981. Impacts of grazing on watersheds, a state of knowledge. National Academy of Sciences/National Research Council, Committee on Developing Strategies for Rangeland Management, Workshop On: Impacts of Grazing Intensity and Specialized Grazing Systems on Use and Value of Rangelands. El Paso, Texas. 32 pages.

Blaney, H.F. and W.D. Criddle. 1945. Determining water requirements in irrigated areas from climatological data. Report, 17 pages, Soil Conservation Service, U.S. Department of Agriculture, Washington D.C.

Bonham, H.F. 1969. Geology and mineral deposits of Washoe and Storey Counties, Nevada. Nevada Bureau of Mines and Geology Bulletin 70, Mackay School of Mines, University of Nevada, Reno.

Boone, R.L., M.E. Campana and C.M. Skau. 1983. Relationship among precipitation, snowmelt, subsurface flow, groundwater recharge, and streamflow generation in the Clear Creek Watershed, Eastern Sierra Nevada. Desert Research Institute, Water Resources Center, Publication No. 41084.

Branson, F.A., G.F. Gifford, K.G. Renard, and R.F. Hadley. 1981. Rangeland Hydrology, Kendall/Hunt Publishing Co.

Cooley, K.R. and D.C. Robertson . 1984. Evaluating soil water models on western rangelands. Journal Of Range Management 37: 529-534.

Cruff, R.W. and T.H.Thompson. 1967. A comparison of methods estimating potential evapotranspiration from climatological data in arid and sub-humid environments. U.S. Geological Survey, Water-Supply Paper 1839-M. 28 pages.

Doorenbos, J. and W.O. Pruitt. 1975. Guidelines for predicting crop water requirements. Land and Water Development Division, Irrigation and Drainage Paper, no. 24, Food and Agricultural Organization, United Nations, Rome.

Dunne,T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H.Freeman and Company, New York.

Ffolliot, P.F. and D.B. Thorud. 1975. Water yield improvement by vegetation management: focus on Arizona, School of Renewable Natural Resources, College of Agriculture, University of Arizona, Tucson, National Technical Information Service, US Department of Commerce, Rep. PB-246 055.

Hanson, C.L. 1982. Distribution and stochastic generation of annual and monthly precipitation on a mountainous watershed in southwestern Idaho. Water Resources Bulletin 18: 875-883.

Hawkins, R.H. 1979. Runoff curve numbers from partial area watersheds. Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers 105: 375-389.

Jensen, M.E., R.D. Burman and R.G. Allen (editors). 1990. Evaporation and irrigation water requirements. American Society of Civil Engineers, Manuals and Reports on Engineering Practice no. 70, American Society of Civil Engineers, NY. NY.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. Journal of Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers 89: 15-41.

Knisel, W.G. (ed.). 1980. CREAMS A field-scale model for chemicals, runoff, and erosion, from agricultural management systems. Documentation and Users Guide, US Department of Agriculture, Conservation Research Report No. 26, 643 pages.

Kohler, M.A., T.J. Nordenson and W.E. Fox. 1955. Evaporation from pans and lakes. Weather Bureau Research Paper 38, U.S. Department of Commerce, Washington D.C.

Mohler, R.R.J. 1979. Radiation based water balance model for the pinyon juniper woodlands of the Great Basin. University of Nevada, Reno, Thesis No. 1342.

National Weather Service. 1976. Relative humidity and dew point tables. US Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service.

National Weather Service. 1989-90. Local climatological data monthly summary, Reno, Nevada. National Climatic Data Center, Asheville, North Carolina.

Penman, H.L. 1948. Natural evaporation from open water, bare soil and grass. Proceedings, Royal Society, London 193: 120-145

Pennington, R.W. 1978. Evaluation of empirical methods for estimating crop water consumptive use for selected sites in the State of Nevada. University of Nevada, Reno, Thesis No. 1287.

Priestly, C.H.B. and R.J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review 100: 81-92.

Pruitt, W.O., E. Fereres, K. Kaita and R.L. Snyder. 1987. Reference evapotranspiration (ETo) for California. Agricultural Experiment Station Bulletin 1922, University of California, Davis.

Ritchie, J.T. 1972. A model for predicting evaporation from a row crop with incomplete cover. Water Resources Research 8: 1204-1213.

Saxton, K.E., H.P. Johnson, and R.H. Shaw. 1974. Modeling evapotranspiration and soil moisture. Transactions of American Society of Agricultural Engineers 17: 673-677.

Singh, V.P. 1989. Hydrologic Systems Volume II, Watershed Modeling. Prentice Hall, Englewood Cliffs New Jersey.

Soil Conservation Service. 1971. National engineering handbook, hydrology, sect.4, supp. A. U.S. Dept. of Agriculture.

Soil Conservation Service. 1983. Soil survey of Washoe county, Nevada, south part. U.S. Dept of Agriculture.

Sokolov, A.A. and T.G. Chapman (editors). 1974. Methods for water balance computations, an international guide for research and practice. Studies and Reports in Hydrology 17, UNESCO Press, Paris.

Thornthwaite, C.W. and J.R. Mather. 1957; Instructions and tables for computing potential evapotranspiration and the water balance. Publications in Climatology Volume X, 3. Drexel Institute of Technology, Laboratory of climatology, Centerton, N.J.

Wight, J.R., C.L. Hanson and K.R. Cooley. 1986. Modeling evapotranspiration from sagebrush-grass rangelands. Journal of Range Management 39: 81-85.

Wight, J. R. 1987. ERHYM-II model description and users guide. U.S. Dept. Agriculture, Agricultural Research Service AR-59.

Wight, J.R. and J.W. Skiles. 1987. SPUR: Simulation of production and utilization of rangelands, documentation and users guide; US Department of Agriculture, Agricultural Research Service, ARS 63.

Wight, J.R. and C.L. Hanson. 1990. Crop coefficients for rangelands. Journal of Range Management 43: 482-485.

Williams, J.R. and H.D. Berndt. 1976. Determining the universal soil loss equation's length slope factor for watersheds. 217-255 <u>In:</u> Soil Erosion: Prediction and Control. Soil Conservation Society of America. Ankeny, Iowa.

Wischmeir, W.H. and D.D. Smith. 1965. Predicting rainfall erosion losses from cropland east of the Rocky Mountains. U.S.D.A. Agricultural Handbook No. 282.