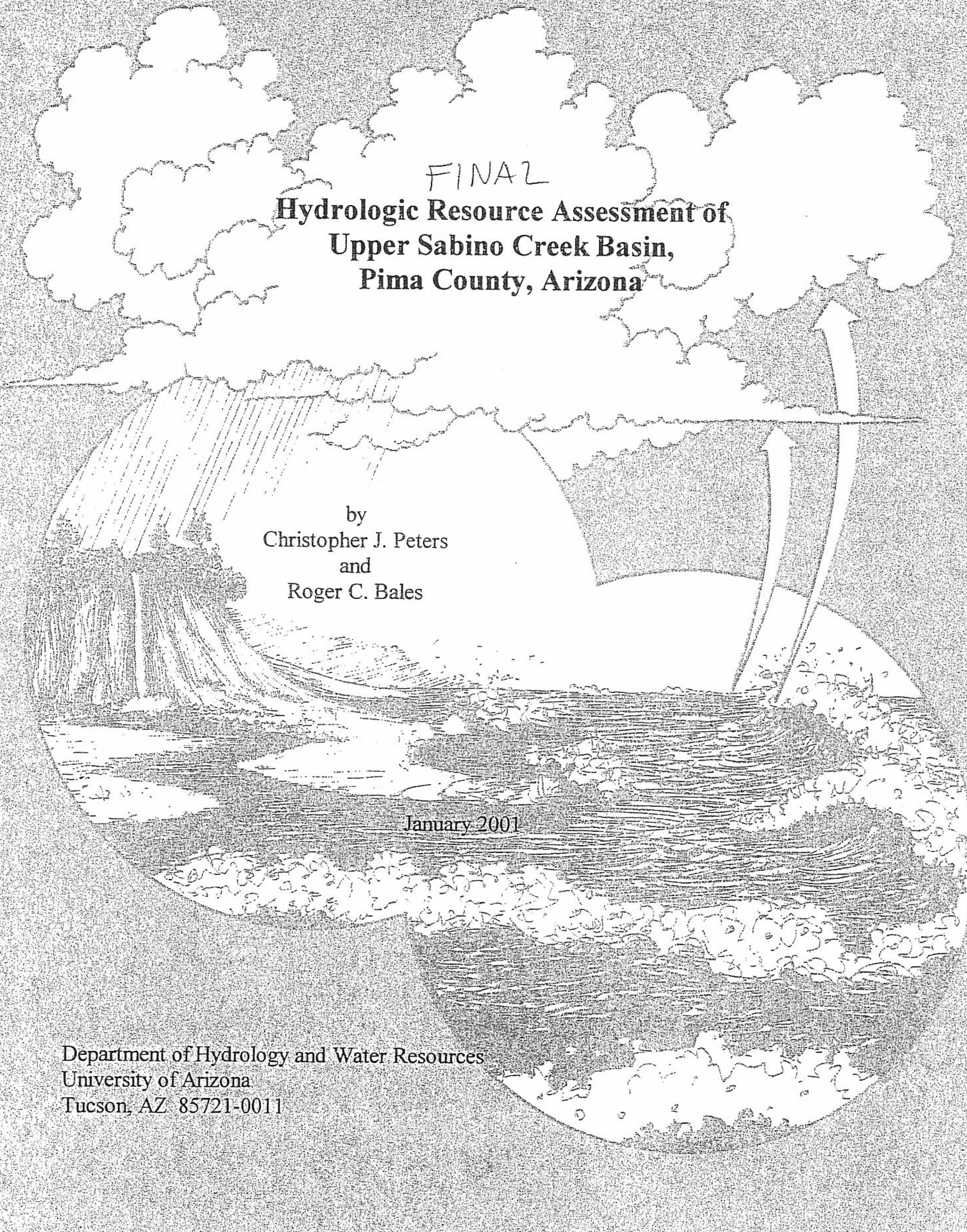
Appendix V

HWR 01-020

FINAL

Hydrologic Resource Assessment of Upper Sabino Creek Basin, Pima County, Arizona



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Preface

This report is part of a series of publications issued by the University of Arizona, Department of Hydrology and Water Resources. The purpose of this series is to disseminate research findings related to natural resource systems to a broad audience of persons conducting research in natural resources. This particular report is based on the M.S. Thesis of the first author. Contact the author or the Department of Hydrology and Water Resources for further information.

Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the agencies and individuals whose support we acknowledge.

Acknowledgments

This study would not have been possible without the assistance of several individuals. Michael Stanley, Operations Manager of the Mt. Lemmon Cooperative Water Company provided us with complete access to his files and records. Special thanks to: Bob Lefevre (U.S. Forest Service, Coronado National Forest), Andrew Wigg (Pima Country Flood Control Distric), Steve Hensel (Coronado National Forest), Gerald Gottfried (U.S.F.S. Rocky Mountain Research Station), and Peter Ffolliott (University of Arizona School of Renewable Natural Resources); all of whom helped make this study possible by sharing data and offering many helpful suggestions.

Chuck Dickens, president of Groundwater Resources Consultants, allowed CJP to maintain a flexible schedule and balance the demands of school and employment. Shel Clark and Alan Cuddy of GWRC made suggestions, answered questions, and took the time to read the first draft. We appreciate the assistance provided by other HWR students, particularly Anne Kramer-Huth, Tom Meixner, and Chris Gutmann. Hans Huth was of great assistance with the GIS aspects of this project. Carrie Teague helped prepare the maps. Jessica Novak provided encouragement, support and motivation.

TABLE OF CONTENTS

TABLE OF CONTENTS - *Continued*

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - *Continued*

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

A hydrologic resource assessment was performed for upper Sabino Creek basin, using data from a variety of local, state, and Federal agencies and organizations. Hydrologic fluxes were identified and quantified in order to create a monthly water budget. Snowmelt and rainfall are the major inputs to the watershed. Evapotranspiration accounts for the greatest loss of water. Human consumption and streamflow, while important for regulatory and aesthetic reasons, are relatively minor components of the water budget.

Evapotranspiration, precipitation, and groundwater recharge / soil moisture account for the greatest fluxes of water in the basin. Precipitation is the most variable hydrologic process in the study area. Over a 47-year period, the greatest amount of water moving through the system in any one month was 6,300 acre-feet in October of 1983. The month with the lowest movement of water was December 1996, with 400 acre-feet. A comparison of Sabino Creek data with the El Niño Southern Oscillation phenomenon shows a strong correlation with precipitation and streamflow in upper Sabino Creek basin.

CHAPTER 1
INTRODUCTION

Problem Statement

Sabino Creek is one of the few remaining perennial streams in Southern Arizona, and the closest to the growing metropolis of Tucson. The creek is an integral part of the recreational experience for over three million people who visit the Coronado National Forest each year. Sabino Creek supports a rich riparian habitat, forming a true desert oasis for plants and wildlife. Springs that feed Sabino Creek also serve as the primary source of drinking water for the community of Summerhaven and the facilities of the Santa Catalina Ranger District of the Coronado National Forest. The Sierra Club and the U.S. Forest Service (U.S.F.S.) have filed in-stream flow applications on Sabino Creek. The Coronado National Forest and the Mount Lemmon Water Cooperative (M.L.W.C.) are continuing to resolve water rights issues within the Upper Sabino Creek watershed. There are concerns that domestic consumption during the summer months could negatively impact the streamflow. Currently there is insufficient storage capacity on Mt. Lemmon to offset higher summer municipal demands. Despite the importance of this stream to many users; to date, no comprehensive hydrologic resource assessment of the watershed has been conducted. The goals of this study are to quantify the monthly water budget and examine the variability of the hydrologic processes so that various stakeholders will have a basis on which to make sound policy decisions.

Previous Work

Shreve (1915) was among the first to study the Santa Catalina Mountains. While his report concentrated on vegetation; his work on precipitation, evaporation, and other climatological parameters is quite complete. More recent studies of Sabino Creek have focused primarily on water-quality issues.

Motschall (1976) was the first to study water quality in lower Sabino and Bear Creeks. He showed the extent of sewage contamination in Sabino Creek and gathered baseline water quality data. Brickler et. al. (1977) produced a report on water quality in Summerhaven and Marshall Gulch for the U. S. Forest Service. Patterson (1977) studied ten water quality parameters and found regular violations of standards for drinking water and partial body contact. These reports delineated the extent of sewage pollution and made specific recommendations to help reduce problems. Proposed solutions included upgrading sewage facilities, chlorination of drinking water, and steps to reduce erosion and suspended sediment in Sabino Creek. These efforts have been very successful: Patterson (1977) found *Escherichia coliform* and fecal *streptococcus* at concentrations exceeding 100,000 colonies per 100 ml; Arizona Department of Environmental Quality sampling between 1991 and 1993 yielded mean concentrations of 51 and 30 colonies per 100 ml for *E. coli.* and *strep.*, respectively (AZ Dept. Health Services, 1991-1993).

Several water supply and engineering studies have been conducted. Kurupakorn (1973) evaluated the feasibility of constructing a reservoir on lower Sabino Creek. He estimated flood frequencies, precipitation, and evaporation. De Jong and Associates (1974) made a preliminary assessment of the water supply for the M.L.W.C. They recommended water demand reduction efforts, an increase in storage facilities, the installation of horizontal wells, and the construction of small dams or reservoirs to capture surface flow. Scheuder and Laine (1974) examined groundwater as a potential water supply source for the M.L.W.C.. Their report advocated the current program of horizontal well drilling be halted and alluvial fill along streambeds be exploited as a source of water. The Pima County Flood Control District (1980) investigated the hydrology of the study area in conjunction with several road repair projects. The Environmental Impact Statement for the expansion of Mt. Lemmon Ski Valley (U.S.F.S., 1992) examined vegetation, recreation, climate, and wildlife. Collins and Piña Consulting Engineers (1997) summarized water rights and municipal usage in a preliminary report on upgrades to the M.L.W.C. system.

Description of Study Area

Regional Setting Sabino Creek is a perennial stream located in the Santa Catalina mountain range immediately north of Tucson, Arizona (Figure 1.1). The creek begins as a series of springs near the summit of Mt. Lemmon. It winds its way through the community of Summerhaven before descending to the desert floor through Sabino Canyon. This study will focus on the watershed consisting of the upper three miles of Sabino Creek and is tributaries (Figure 1.2); between its source and a gaging station located approximately two thirds of a mile downstream from the Marshall Gulch picnic area.

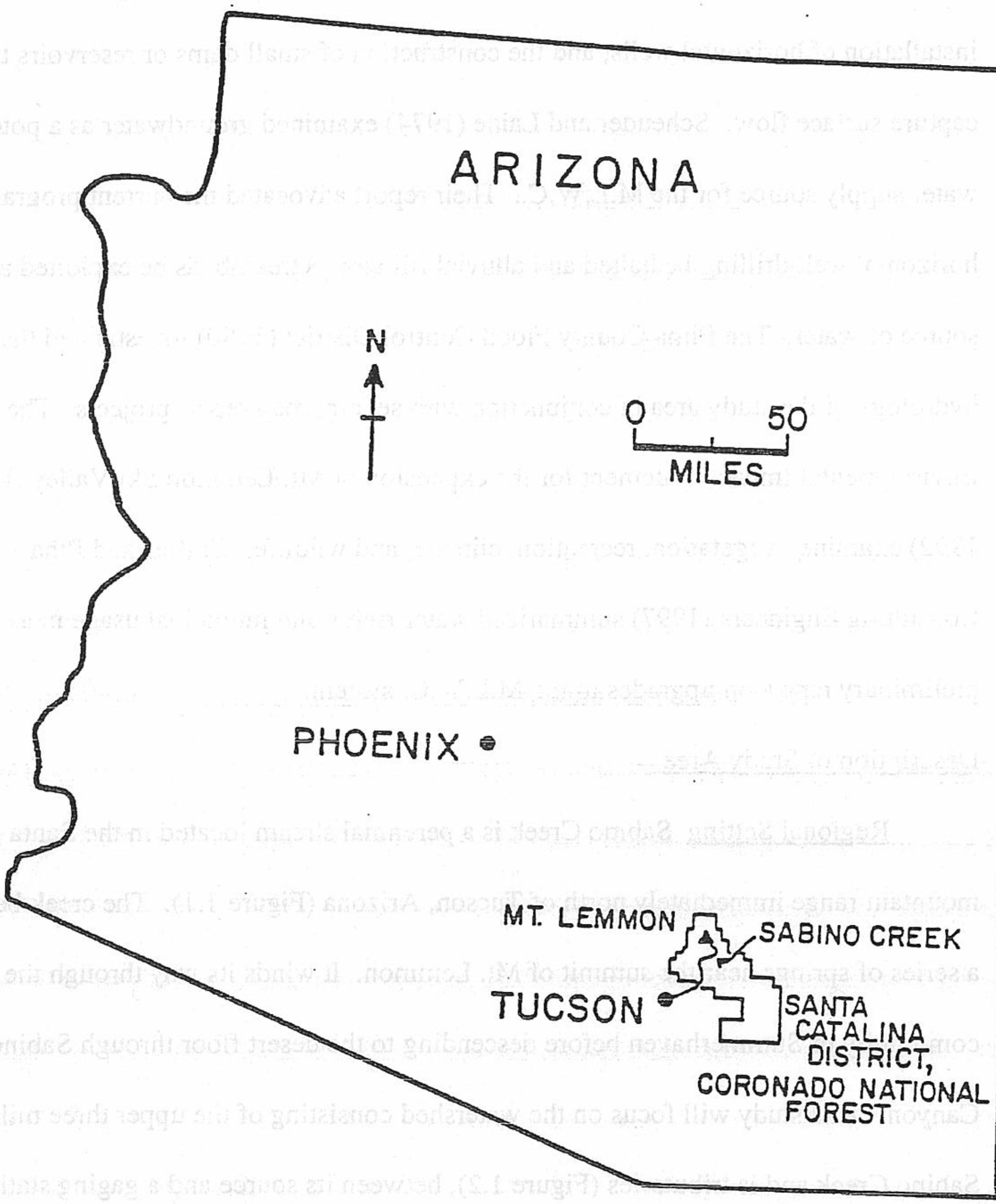

Figure 1.1, Regional location of study area (from Patterson, 1977)

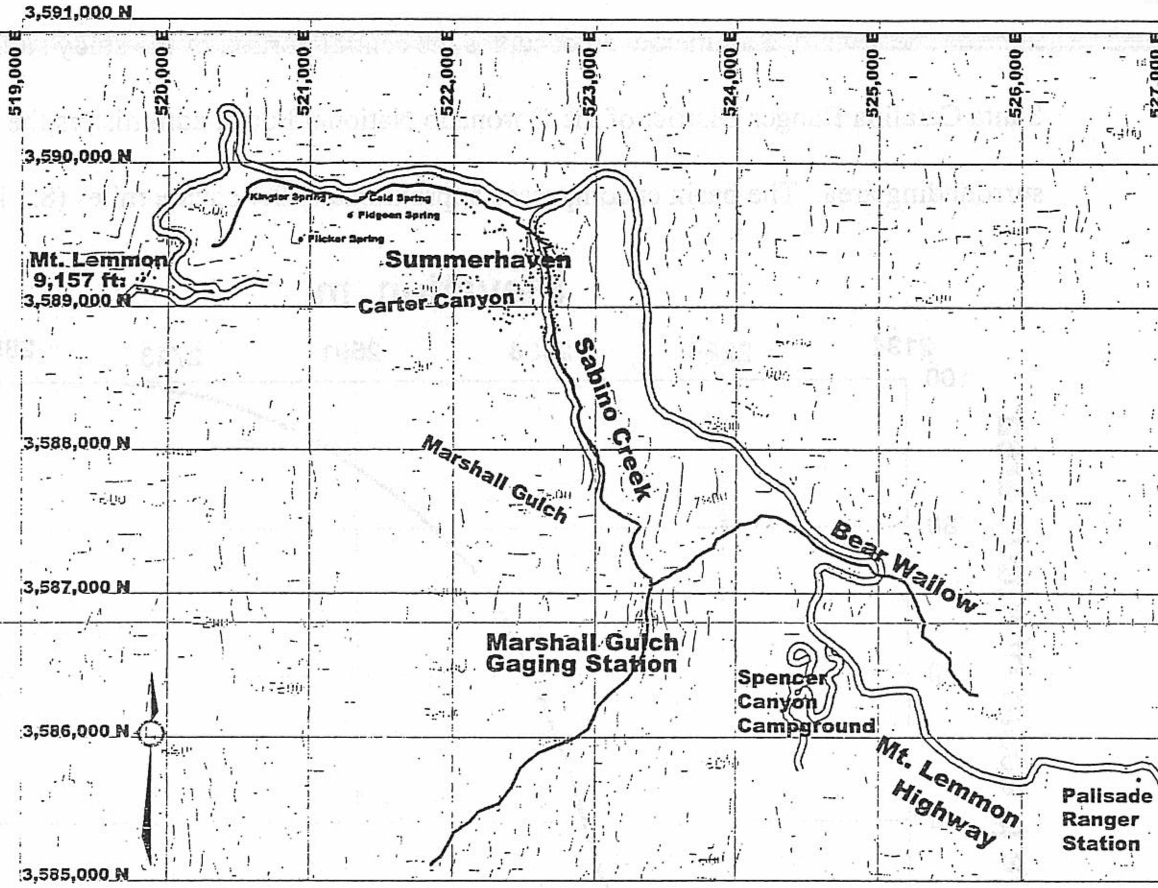

Figure 1.2, Study Area

It is the most developed area along the creek, and is immediately downstream from the source of several water supply systems. The study site is located in the following land survey sections of Pima County, Arizona:

- Sections 25, 26, 35 and 36 of Township 11 South, Range 15 East
- Sections 30 and 31 of Township 11 South, Range 16 East
- Sections 4, 5, and 6 of Township 12 South, Range 16 East

The town of Summerhaven occupies the central portion of the study site. The Santa Catalina Ranger District of the Coronado National Forest administers the surrounding area. The basin encompasses approximately 3.1 square miles (8.1 km^2).

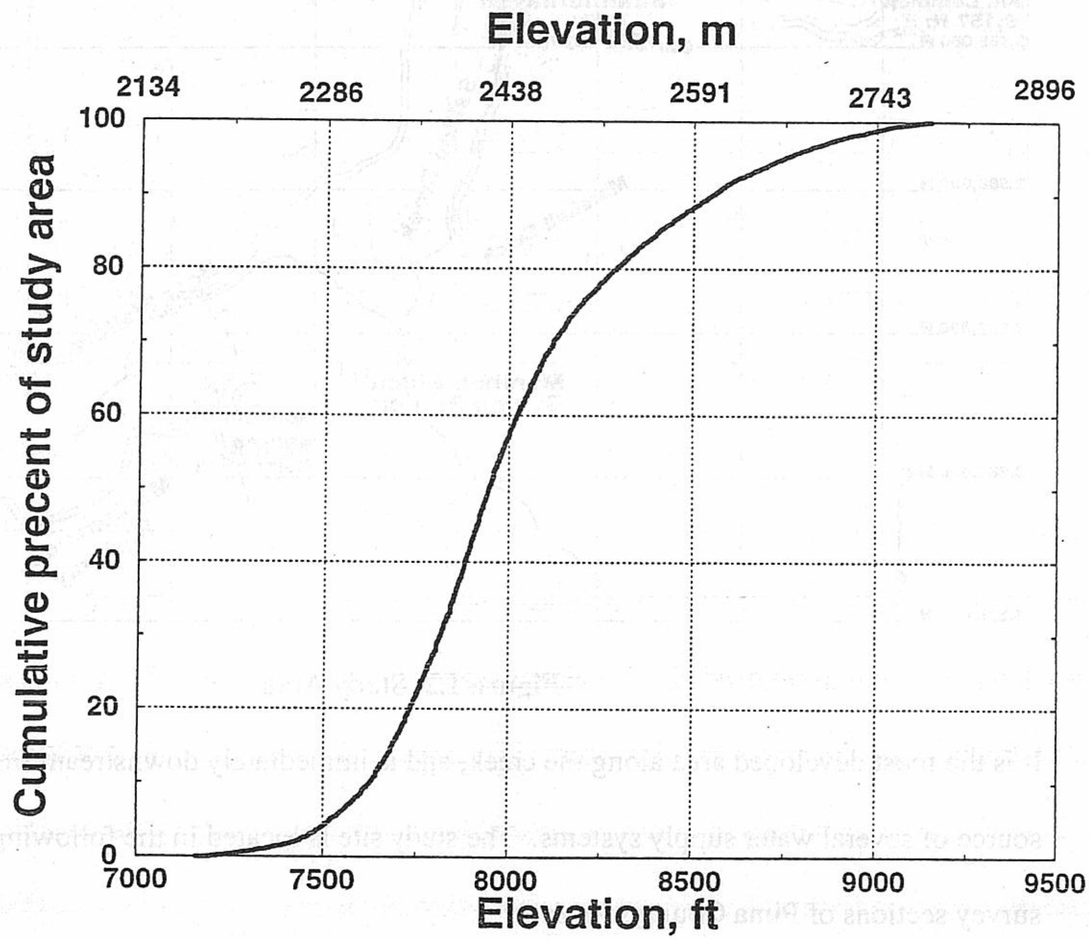

Figure 1.3, Cumulative frequency distribution of elevation

<u>Topography</u> The highest point in the study area is the summit of Mt. Lemmon at 9,157 ft. above sea level (2,791 m). The lowest is the Marshall Gulch stream gage, at an elevation of 7,120 ft. (2,170 m). The terrain primarily consists of steep slopes, with some flat land occurring in the central portion of the basin where Summerhaven is located.

Sabino Creek and Bear Wallow are well incised in areas of high relief, and Sabino Creek is partially channeled through the town of Summerhaven. The cumulative frequency distribution of elevation (derived from U.S.G.S. digital elevation models - see Chapter 3) is shown in Figure 1.3. Slopes range from horizontal to greater than 50 degrees.

Geology The Santa Catalina mountains are part of the Rincon-Catalina metamorphic core complex of the Basin and Range Province (Chronic, 1983). The intense metamorphism makes accurate age and structural determinations difficult at best. The most recent explanation by Force (1997) is briefly summarized below.

The Pinal Schist (pre-Cambrian) and Oracle Granite (emplaced 1,351 - 1,450 million years ago) was overlain by sedimentary units (Apache Group) and cut by diabase dikes and sills approximately 1,040 to 1,150 million years ago (Ma) (Force, 1997). More sedimentation took place throughout the Paleozoic era, producing the Bolsa Quartzite (Cambrian), Abrigo Formation (Cambrian), Martin Formation (Devonian), Escabosa Limestone (Mississippian), and the Naco Group (Pennsylvanian). Mesozoic sedimentation produced the Bisbee Group and American Flag Formation. The Leatherwood granite intruded during the Cretaceous, causing extensive deformation and metamorphism. In the Cenozoic era the Wilderness Suite granites intruded during the Eocene. The region was further metamorphosed during the Laramide Orogeny. Arching and uplift began with the intrusion of the Catalina granite during the Galiuro Orogeny (35-15 Ma) (Wilt, 1993). Basin and Range extension and detachment faulting continued the deformation. Erosion and other Quaternary processes have produced the present-day topography.

Exposed rock in the study area primarily consists of the Abrigo Formation (silty dolomite and dolomitic sandstone) near the summit of Mt. Lemmon, the Leatherwood granidiorite in the area of Summerhaven, and the Lemmon Rock pegmatite aplite of the Wilderness Suite downstream towards Marshall Gulch (Force, 1997). Rocks near Bear Wallow and Marshall Gulch consist of the Pre-Cambrian Apache Group: the Pioneer Formation (argilite and siltstone to phyllite and schist) and the Dripping Springs Quartzite (feldsparthic quartzite and shale and phyllite) (Force, 1997). There are smaller exposures of sedimentary units such as the informal Mt. Lemmon Unit (Devonian) (Force, 1997), the Bolsa Quartzite, and several diabase intrusions (Force, 1997).

The current path of Sabino Creek provides some indication of the faulting present at the study site. From its source near the summit of Mt. Lemmon, Sabino Creek flows eastward along an unnamed fault. It then turns to the south, flowing through Summerhaven and then follows another fault past Marshall Gulch. Bear Wallow flows west along a thrust fault until it intersects a splay of the fault running through Marshall Gulch and joins Sabino Creek approximately one mile downstream from the town of Summerhaven. Several miles below, Sabino Creek intersects the Romero Pass fault zone and turns to the east before following the Sabino Canyon fault through the Front Range Anticline and continuing to the desert floor.

Soils A soil survey was conducted in 1977 in conjunction with the construction of a wastewater treatment facility. Soils in the study area consist of the Mirabel-Baldy-Rock Outcrop Association (Finical & Dombowski, 1977a). The soils in this association are defined as "shallow to deep, gravelly and cobbly, moderately coarse textured, hilly to very steep mountain soils and rock outcrop" (Finical & Dombowski, 1977a). Soil depths range from 10 in (25.4 cm) to 40 in (1 m) (Finical & Dombowski, 1977b), with an average depth of 25 inches (63.5 cm).

Water Resources There are no significant surface water bodies in the study area. A small dam constructed in 1923 on Bear Wallow near the end of Soldier's Camp Road has formed a pond known as Soldier's Lake (Bowden, 1994), approximately one third of an acre (1,350 m^2) in size. However, this pond is almost completely silted up and not considered to be a significant component of the basin hydrology.

Springs have historically been preferred to wells as a source of drinking water in the study area. This may be due to several factors, including the availability and accessibility of springs as opposed to the high cost of drilling wells. There are nine registered wells in the study area (Arizona Dept. of Water Resources, 1994).

The majority of streamflow results from the discharge of several springs along the course of Sabino Creek and its tributaries. Snowmelt and seasonal precipitation recharge these springs, which may dry up during periods of little rain. Groundwater may be present in the alluvium along the valley floors and in fractured bedrock underlying the study site, but not in quantities sufficient for resource development. The availability of surface water (springs) has limited interest in groundwater exploration.

Climate Unlike the surrounding Sonoran desert, mild summers and cold winters characterize the climate of the study site. Summer high temperatures rarely exceed 90° F (32° C), and winter low temperatures less than 30° F (-1° C) are common. Shreve commented extensively on climate, examining the effect of elevation on vegetation. He noted that:

> The character of the temperature conditions, and their relation to altitude and topography, in an isolated desert mountain is not without complexities.... The relative smallness of the entire mountain mass and its position in the midst of arid plains make its temperature conditions very different from those of extensive plateaus at the same elevation. The currents of warm air which ascend by day and the streams of cold air which descend by night serve to increase the diurnal amplitude of temperatures in certain situations and to give striking differences within very short distances (Shreve, 1915)

Figure 1.4 is a plot of mean monthly high and low temperatures recorded at several locations in the study area. The period of record and other pertinent details about each station may be found in Table 2.1.

Although Mt. Lemmon Ski Valley is situated at a higher elevation than the other stations and on a north-facing slope, its minimum temperatures are still higher than those measured at the other stations. Assuming the measurements were recorded correctly, the lower minimum temperatures at lower elevations may be due to the cold-air drainage noted by Shreve (1915).

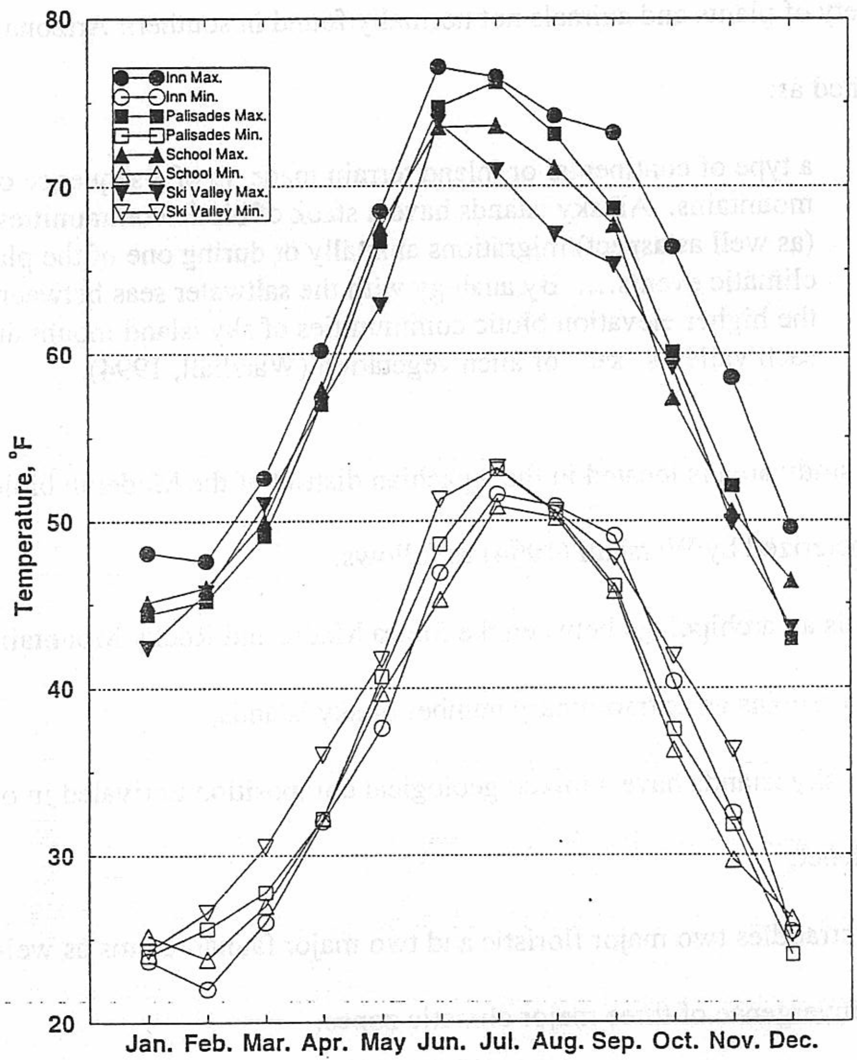

Figure 1.5, Mean monthly maximum and minimum temperatures

Flora and Fauna. As a "sky-island" the Santa Catalina Mountains are home to a variety of plants and animals not normally found in southern Arizona. A sky-island is defined as:

> a type of continental or inland terrain made up of a sequence of valleys and mountains. All sky islands have a stack of biotic communities that allow vertical (as well as aspect) migrations annually or during one of the planet's long-term climatic events.... By analogy with the saltwater seas between oceanic islands, the higher elevation biotic communities of sky island mountains are isolated by each valley's "sea" of alien vegetation (Warshall, 1994).

The study area is located in the Apachian district of the Maderan biological province, characterized by Warshall (1994) as follows:

- It is an archipelago between the Sierra Madre and Rocky Mountains;
- It contains an extraordinary number of sky islands;
- Its sky islands have a mixed geological composition unrivaled in other areas of the planet;
- It straddles two major floristic and two major faunal realms as well as the convergence of three major climatic zones.

There are two distinct vegetation zones in the study site. Ponderosa pine (*Pinus ponderosa*) and silverleaf oak (*Quercus hypoleucoides*) are prevalent in the lower zone (7,000 to 8,000 ft. (2,130 to 2,440 m.)) (Niering and Lowe, 1984). The upper zone (above 8,000 ft. (2,440 m.)) predominantly consists of Ponderosa pine on south-facing slopes and Douglas fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*) on north-facing slopes (Niering and Lowe, 1984).

Birds, squirrels, white-tailed deer, black bears, and the occasional mountain lion inhabit the study area. Threatened, sensitive, or endangered species include the peregrine falcon, northern Apache goshawk, Mexican spotted owl, red bat, Santa Catalina Mountains gray squirrel, Santa Catalina Mountains wood rat, and the coatimundi (U.S. Forest Service, 1992).

Human developed land accounts for only a small fraction of the study area, and is concentrated in the community of Summerhaven, the University of Arizona's Steward Observatory, and other radio communication facilities near the summit of Mt. Lemmon.

Human Habitation The first known inhabitants of the Catalinas were the Hohokam, who lived throughout the lower elevations. Archeological surveys have found no prehistoric sites above an elevation of 7,000 ft. (2,130 m.) (U.S.F.S., 1992). The Hohokam disappeared around 1400 AD, leaving petroglyphs and grinding holes in the rock along creek beds (Alexander, 1991). Shortly thereafter the Apaches occupied the mountains until they were displaced by Anglo settlement in the late 19th century. Mt. Lemmon, known as *Babat Duag* (Frog Mountain) to the Papago (Bowden, 1994) was named in 1881 to honor Sarah Plummer Lemmon, a botanist from California. Permanent settlement on Mt. Lemmon began in 1882 when Frank Webber filed a mining claim and built a cabin near the junction of Sabino and Carter Canyons (Bowden, 1994). The last Apaches reported in the area were seen in Lower Sabino Canyon in 1890 (Alexander, 1991). The present community of Summerhaven was established in 1917 when Webber's claim expired and new homes were built in the area. The first road to the high country

~~was constructed in 1920, from the town of Oracle to Summerhaven. This rugged dirt~~ track wound its way up the north side of the Catalinas, and provided the first access for automobiles. A paved road was begun up the south face of the Catalinas in the 1940's and completed in 1950. The Catalina Highway was built partly with federal convict labor, including conscientious objectors to the World War II draft (Erikson, 1998). Summerhaven currently consists of nearly 500 structures, the majority of which are vacation homes or rentals. Mt. Lemmon Ski Valley was constructed in 1952 and expanded in 1982. It is the southernmost ski resort in the United States.

CHAPTER 2
HYDROLOGY

The hydrology of the study site is typical of a small sub-alpine basin in a semi-arid region. Sporadic summer precipitation and spring snowmelts are the major inputs to the watershed. Runoff and evapotranspiration are the major outputs. There is virtually no surface storage, and evapotranspiration is limited by the amount of soil moisture available. Groundwater exits the basin through the alluvium in the streambed of Sabino Creek and as mountain-front recharge to the Tucson Basin.

Hydrologic Boundaries

The study area is bounded topographically by ridgelines (Figure 2.1). Sabino Creek drains to the south and east. Bear Wallow drains to the west and joins Sabino Creek near Marshall Gulch. The area of the basin is approximately 3.1 square miles (8.1×10^6 m^2). Groundwater boundaries are unknown, but groundwater inflow is unlikely since the study area occupies the highest elevations in the Santa Catalina Mountains. Estimations of groundwater outflow are presented in Chapter 4.

Precipitation

The study area receives precipitation with mean annual totals ranging from 27 inches (69 cm) to 37 inches (94 cm) at various locations. Precipitation is highly variable in spatial and temporal extent. There are eight rain gages located in or immediately adjacent to the study area. Pertinent information about each gage is presented in Table 2.1, while the location of each gage is shown in Figure 2.2.

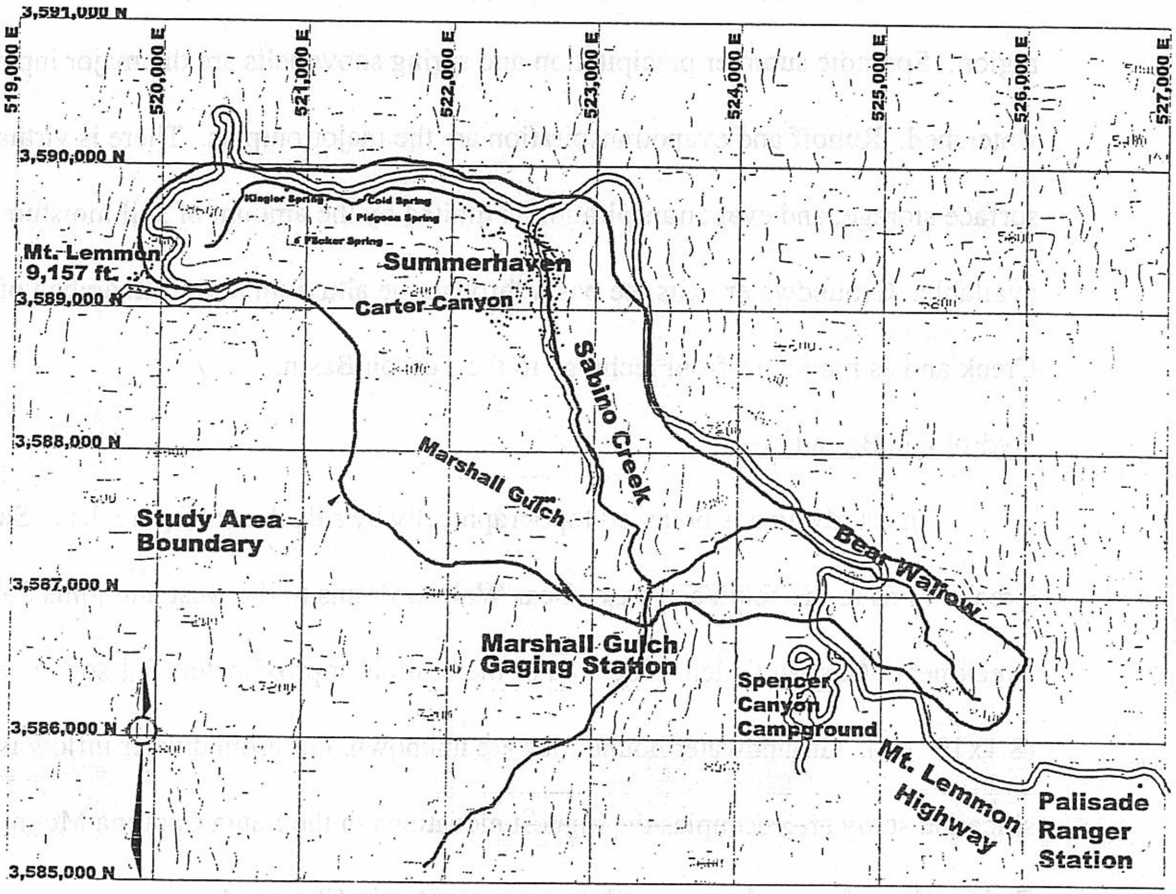

Figure 2.1, Study area boundaries

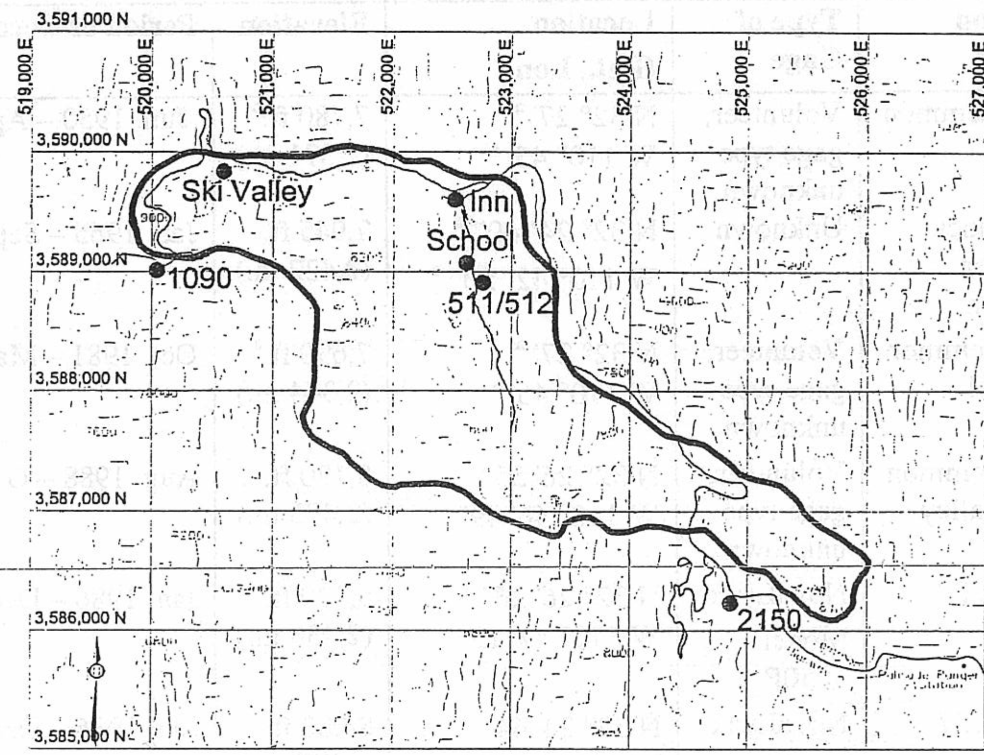

Figure 2.2, Location of precipitation gages

Table 2.1. Precipitation station information.

Station Name	Type of Gage	Location (Lat., Lon.)	Elevation	Period of Record
Mt. Lemmon Inn	Volunteer, gage type unknown	N 32° 27' [a] W 110° 45' [a]	7,780 ft.[a] (2,371 m.)	Jun. 1950 – Apr.1963
Palisades Ranger Station	Unknown	N 32° 24' 40" [a] W 110° 42' 50" [a]	7,945 ft. (2,422 m.)	Jan. 1965 – Sep. 1981
Mt. Lemmon School	Volunteer, gage type unknown	N 32° 27' [a] W 110° 45' [a]	7,690 ft.[a] (2,344 m.)	Oct. 1981 – Mar. 1986
Mt. Lemmon Ski Valley	Volunteer, gage type unknown	N 32° 26' 55" W 110° 46' 49"	8,120 ft. (2,475 m.)	Aug. 1988 – Oct.1991
ALERT / 1090	NovaLynx Model 5050P	N 32° 26' 26" W 110° 47' 15"	9,120 ft. (2,438 m.)	Jan. 1986 – Dec. 1997
ALERT / 2150	NovaLynx Model 5050P	N 32° 24' 44" W 110° 44' 04"	8,000 ft. (2,780 m.)	Jan. 1986 – Dec. 1997
ALERT / 511	Edwards Tru-Check	N 32° 25' 15"[a] W 110° 45' 30" [a]	7,800 ft.[a] (2,377 m.)	Jan. 1990 – Dec. 1997
ALERT / 512	Edwards Tru-Check	N 32° 24' 25" [a] W 110° 45' 15" [a]	7,720 ft.[a] (2,353 m.)	Jan. 1990 – Dec. 1997

Note: a - estimated from topographic map

The mean monthly precipitation for each station is presented in Figure 2.3. All stations receive the least amount of rain from April to June. The greatest amount of rain is brought on by seasonal monsoon precipitation. For 31 years of record (1965 to 1996), the mean beginning day of the monsoon season is July 5 and the mean ending day is September 15 (National Weather Service, 1998). Figure 2.4 shows average monthly

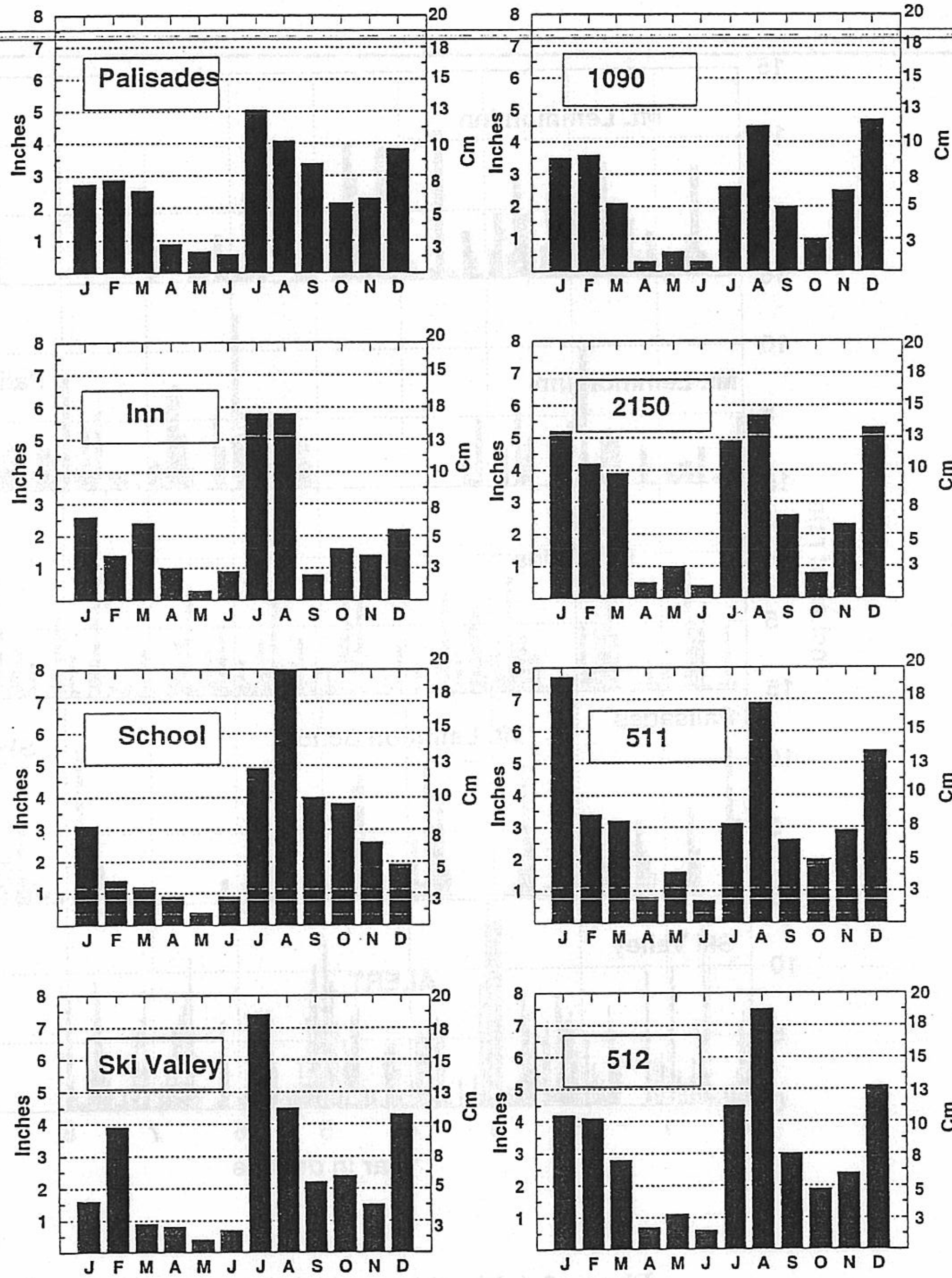

Figure 2.3, Mean monthly precipitation recorded in rain gages

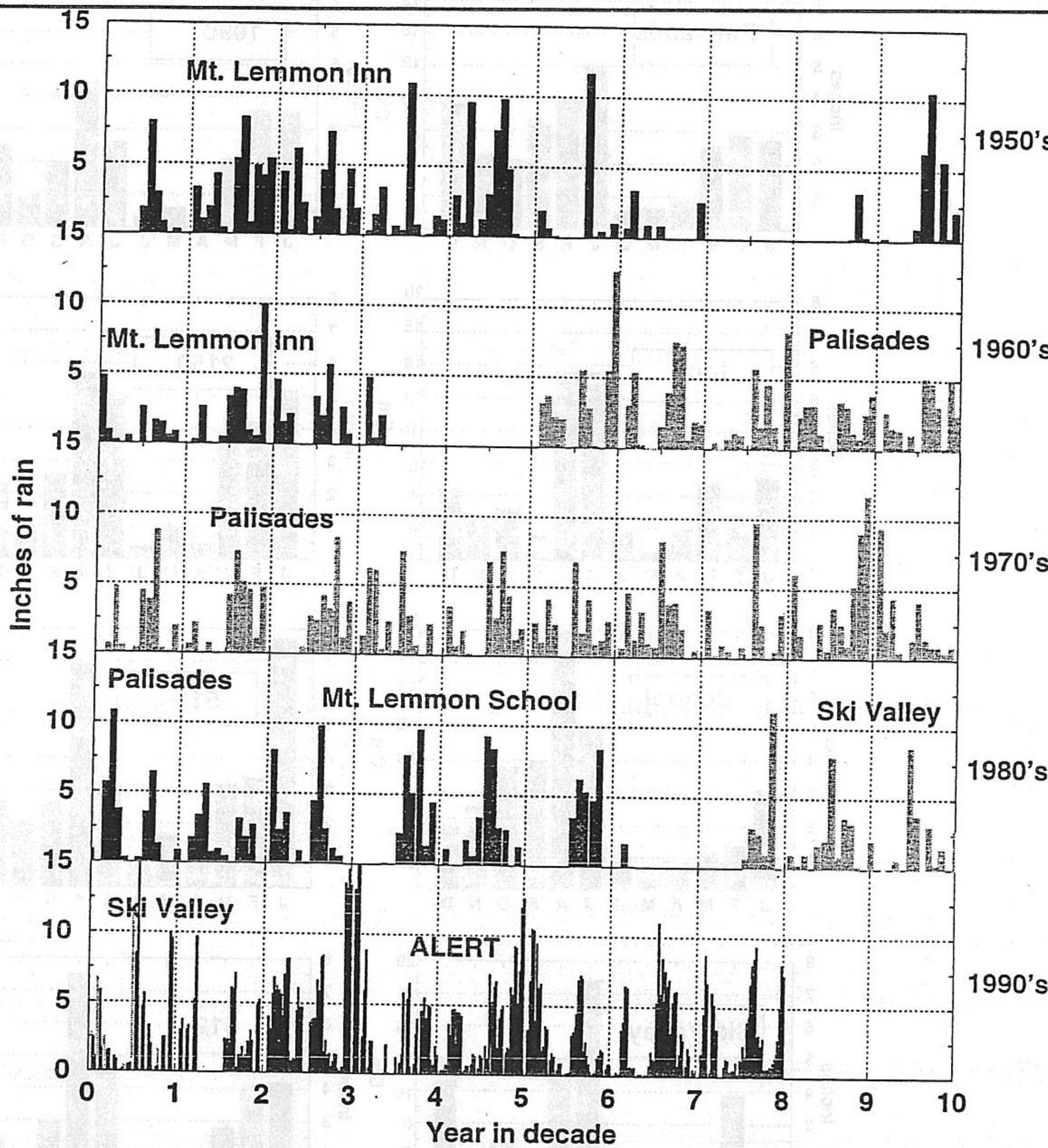

Figure 2.4, Monthly precipitation, period of record

precipitation for the period of record. The precipitation data may also include snow or hail. Existing records do not always account for other forms of precipitation besides rainfall, and it is impossible to quantify the snowfall or hail components in the precipitation record.

Snow

Snowfall generally occurs in the study area from December to April. Figure 2.5 is a plot of snow water equivalent (SWE) measured every two weeks between January and April at the Bear Wallow Snow Course. The greatest SWE values were recorded in 1966 and 1968. The lowest SWE values were found in the intervening year: 1967. Mean snowpack depths range from 7 in. (17.8 cm.) to 12 in. (30.5 cm.) over the course of a typical snow season (Jones, 1981).

At 7,200 ft. (2,195 m.), the Bear Wallow snow course was considerably lower than the majority of the basin. It was located on a former ski area, in a clearing in the forest. The area is a shallow canyon, receiving little sunlight and protected from the wind. Gottfried *et. al.* (1998) reported depths ranging from 8 in. (20 cm.) to 53 in. (135 cm.) and SWEs ranging from 4 in. (10 cm.) to 15 in. (38 cm.) on the northern side of Mt. Lemmon in the winter of 1967 - 1968.

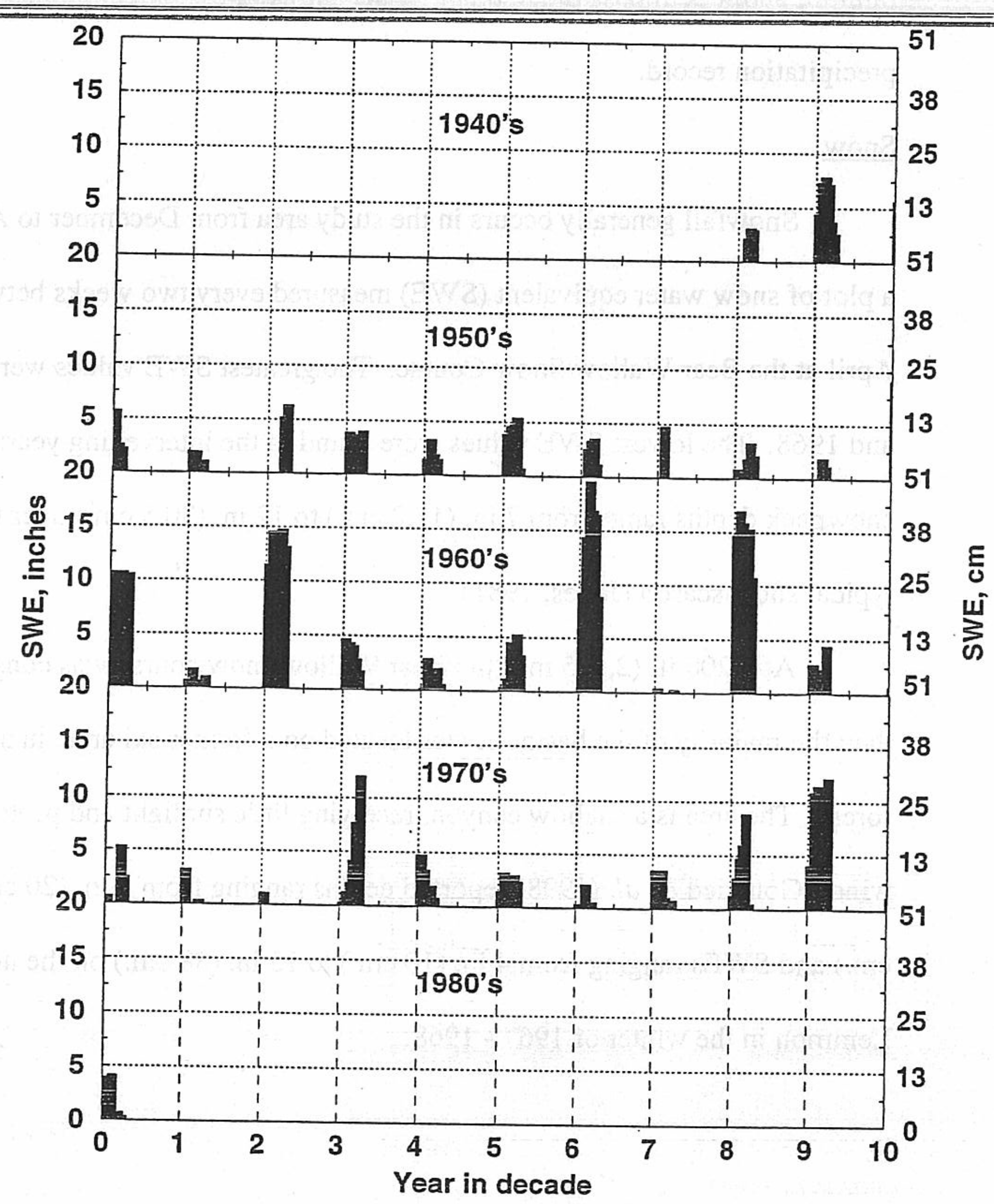

Figure 2.5, Snow water equivalent, Bear Wallow snow course

Streamflow

Sabino Creek begins as a series of springs on the northeast slope of Mt. Lemmon. The creek bed consists of cobbles and boulders with a few quiet pools. The United States Geological Survey (U.S.G.S.) established a stream gaging station (# 09483300) on Sabino Creek approximately two thirds of a mile (1.1 km) downstream from the Marshall Gulch picnic area (see Figure 1.2) in 1951. Stream stage was recorded from 1951 to 1959; the station was then abandoned for over 20 years. The United States Forest Service re-established the station in 1982, and continues to record stream stage. The gage is a stilling well with a float recorder and revolving paper chart. Discharge is derived from stream stage by formulae and rating tables developed by the U.S.G.S. Table 2.2 lists the equations used to convert stage measurements into discharge rates. Discharge at Marshall Gulch often ranges from zero to several hundred cubic feet per second (cfs) over a short time period.

Table2.2 Rating formulae

Gage Height, ft.	Flow range, cfs	Equation
4.6 – 4.9	0.004 – 0.34	Discharge = exp(14.69286 * height (ft) – 73.0743)
4.9 – 6.2	0.34 – 39.00	Discharge read from U.S.G.S. rating tables in 0.05 ft. increments
6.2 – 6.6	39.00 – 61.00	Discharge = (55 * height (ft)) – 302
6.6 and higher	61.00 –	Discharge = 63.16246 * height (ft) – 356.962

Figure 2.6 is a plot of monthly discharge for the period of record.

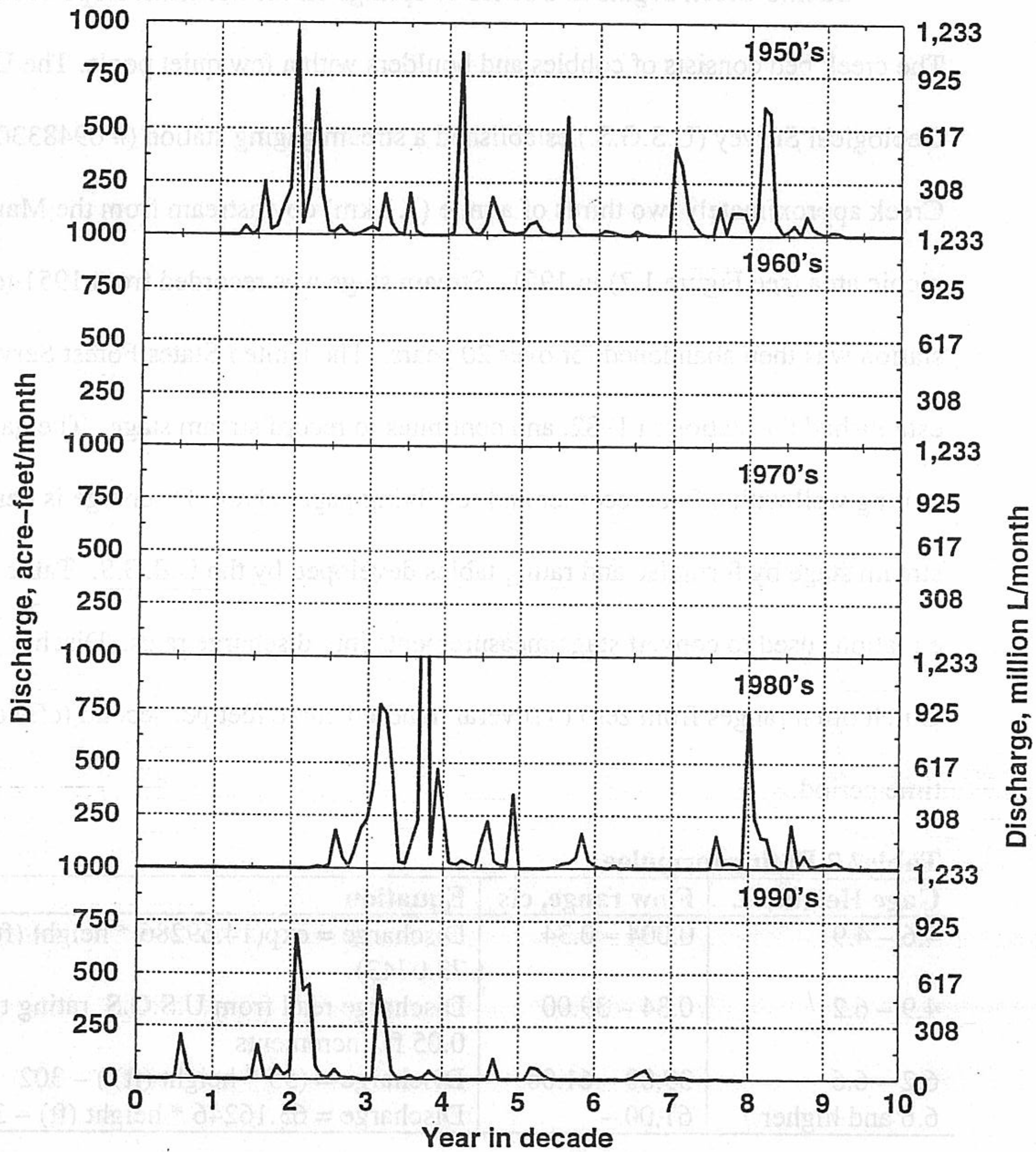

Figure 2.6, Monthly discharge, period of record

Figure 2.7 is a chart showing the mean monthly distribution of flow recorded at Marshall Gulch for the period 1951-1959 and 1982-present.

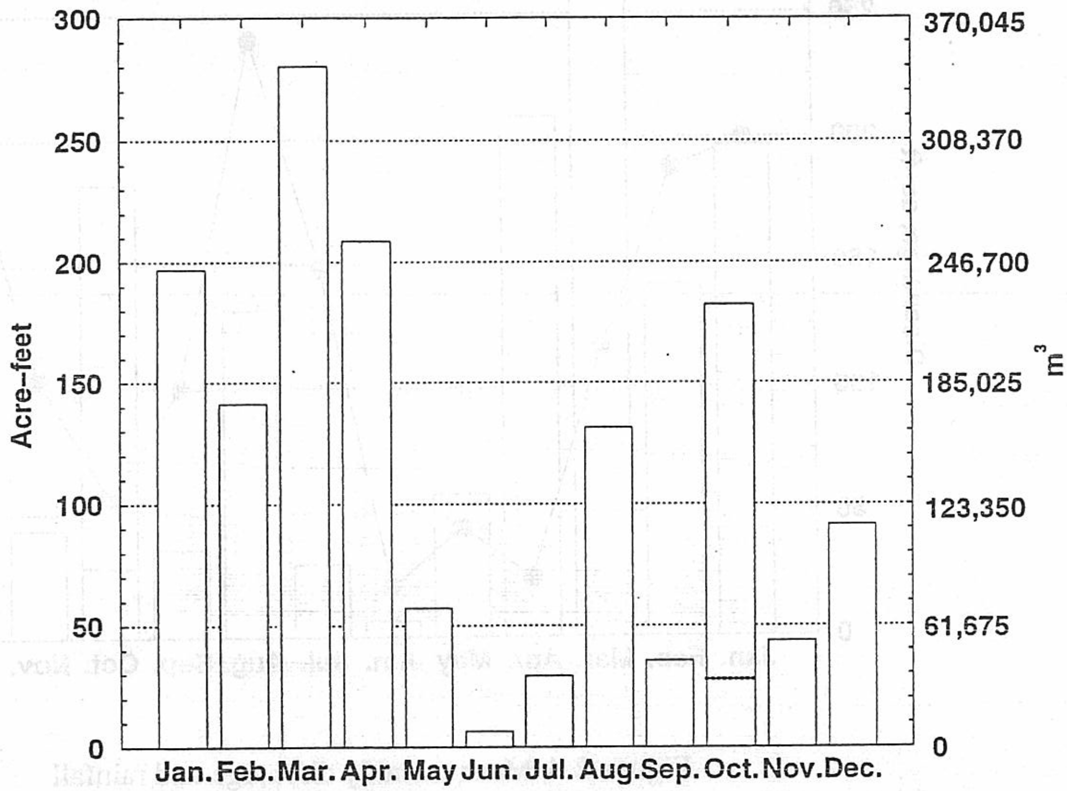

Figure 2.7, Mean monthly distribution of flow

Over half of the annual flow occurs from January to April. Although the greatest amount of rain falls from July to September, these three months make up less than 25% of the yearly streamflow. Low soil moisture and high evapotranspirative rates in the summer may account for this discrepancy. The remainder of the flow from October to December occurs in response to winter rains. Figure 2.8 is a plot of mean monthly discharge and the mean monthly precipitation of all the sites listed in Table 2.1.

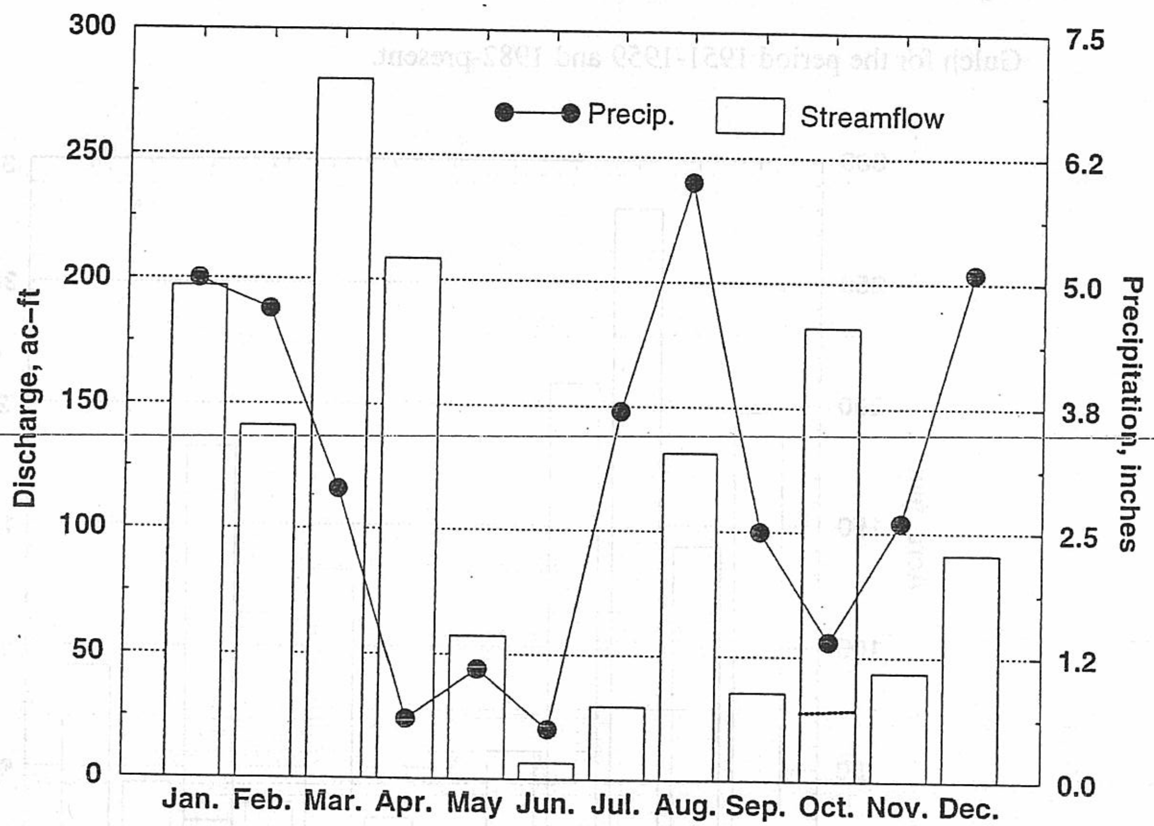

Figure 2.8, Mean monthly discharge and rainfall

There is poor correlation between rainfall and stream discharge: months that receive more rain do not necessarily have a greater discharge. The high discharges that occur in February and March reflect the influence of snowmelt.

A flow exceedence chart was prepared using 6,276 mean daily discharge measurements between 1951 and 1997 (Figure 2.9). For nearly 80% of the days measured, the mean discharge in Sabino Creek at Marshall Gulch was 1 cfs (2.0 ac-ft/day, 0.03 m^3/sec) or less.

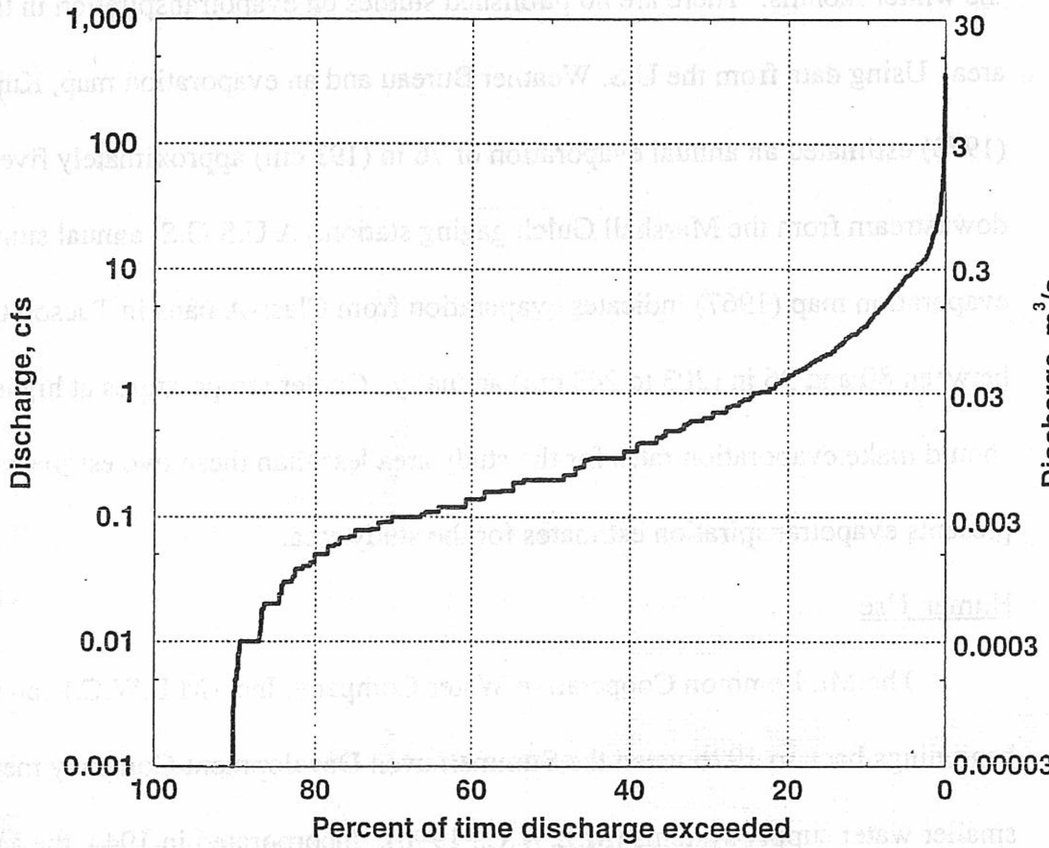

Figure 2.9, Flow exceedence chart, Sabino Creek at Marshall Gulch

The data show that streamflows above 1 cfs are the exception, rather than the rule. Indeed, for nearly one third of the dates on record, the streamflow is 0.1 cfs (0.2 ac-ft/day, 0.003 m^3/sec) or less.

Potential Evapotranspiration

Evapotranspiration is greatest during the summer growing season, and least during the winter months. There are no published studies on evapotranspiration in the study area. Using data from the U.S. Weather Bureau and an evaporation map, Kuprakorn (1973) estimated an annual evaporation of 76 in (193 cm) approximately five miles downstream from the Marshall Gulch gaging station. A U.S.G.S. annual sunshine and evaporation map (1967) indicates evaporation from Class-A pans in Tucson to be between 80 and 96 in (203 to 243 cm) annually. Cooler temperatures at higher elevations should make evaporation rates for the study area less than these two estimates. Chapter 4 presents evapotranspiration estimates for the study area.

Human Use

The Mt. Lemmon Cooperative Water Company, Inc. (M.L.W.C.) can trace its beginnings back to 1926 when the Summerhaven Development Company merged several smaller water supply systems (M.L.W.C., 1996). Incorporated in 1944, the M.L.W.C. operated on a voluntary basis until the 1960's. The M.L.W.C. currently holds water rights for 28.47 acre-feet (35,119 m^3) per year. The United States Forest service has water rights to approximately 32.84 acre-feet (40,504 m^3) per year. The only other major water user in the study area is the University of Arizona's Steward Observatory, but its water use is not metered and is only for personal consumption. The United States Air Force maintains a communications facility near the summit of Mt. Lemmon, and shares water with the Steward Observatory.

CHAPTER 3
SOURCES OF DATA

This chapter describes the sources of data used in this thesis. The period of record, data collection frequency, and other pertinent facts are presented for each agency or individual providing data. Where possible, quantitative or qualitative assessments of the error in each data set are made. Corrections, additions, or additional modifications to the data set not covered in Chapter 4 are presented here. Data used in this project were obtained from many people and agencies. Information from any one source was checked against other sources wherever possible, but this was not always feasible, primarily due to the lack of overlap between or among data sets.

Mt. Lemmon Water Company

Records from the Mt. Lemmon Water Company include monthly consumption totals [1991 to 1997] (M.L.W.C., 1998). Transmission losses in the M.L.W.C. storage and distribution system have been estimated at between 25 and 50 percent (Stanley, 1998). Other data from the M.L.W.C., such as volumes stored in various storage tanks, pumping amounts, etc. were available, but not used separately since they were incorporated in the monthly consumption totals.

United States Geological Survey

Streamflow records for Sabino Creek at Marshall Gulch (U.S.G.S. gage #09483300) consist of daily mean discharge measurements from 1951 to 1959. U.S.G.S. streamflow records for Sabino Creek in Sabino Canyon (U.S.G.S. gage #09484000) consist of daily mean discharge measurements from 1932 to 1974 and 1989 to the present. While this data set contains some missing or estimated data, overall it provides an excellent long-term record of streamflow for Sabino Creek basin. The accuracy of the stage-discharge relationship for gaging stations is typically on the order of ± 5% (WMO, 1980).

U.S.G.S. digital elevation models (DEMs) for the 7.5 minute topographic quadrangles of Mt. Lemmon (U.S.G.S, 1981) and Mt. Bigelow (U.S.G.S, 1981) were used with ARC/Info (ESRI, 1994), a geographic information system (GIS), for elevation, slope, and aspect analysis. The DEMs were comprised of elevations, measured in 30 m by 30 m blocks for the above U.S.G.S. quadrangles. The standard root mean square error (RMSE) in vertical elevation for the U.S.G.S. DEMs used in this project was 7 meters, with a maximum allowable RMSE of 15 meters. The DEMs were obtained electronically from the Arizona Land Resources Information Service, and converted into ARC/Info grids. A mask for the study area was obtained by using the WATERSHED command. The mask was then applied to a point coverage created by appending the two DEMs. Slope and aspect were determined using the SLOPE and ASPECT commands in ARC/Info's GRID package.

United States Forest Service

United States Forest Service data includes daily stream discharge measurements from the Marshall Gulch gage from 1982 to the present. Approximately 47 percent of the data (on a monthly basis) are missing. Errors in the Forest Service discharge data are expected to be the same as those in the U.S.G.S. data since the data are from the same gage. The U.S. Forest Service also provided meter readings from their pumphouse [1990 to 1997] and well in Sabino Canyon [1989 to 1991] (Hensel, 1998). The flow meter is read to the nearest gallon.

National Climatic Data Center / Western Regional Climate Center

National Weather Service Cooperative Precipitation Network data for various sites in the Catalinas from 1950 to the present were used to estimate rainfall. These data consist of handwritten monthly station summaries listing daily high, low, and observed temperatures; rain and/or snowfall; and other pertinent weather observations. The Western Regional Climate Center provided temperature and precipitation data for Palisades Ranger Station in electronic format (WRCC, 1998). Daily temperatures recorded at the Tucson International Airport were obtained from the National Climatic Data Center (NCDC, 1999). Southern Oscillation Index (SOI) values were obtained from the Western Regional Climate Center (WRCC, 1999).

The error in point measurement of rainfall can vary widely, and is highly dependent upon the amount of precipitation, wind speed, and the topography (Sevruk, *et. al.*, 1992). Furthermore, the scaling of point measurements to areal measurements introduces another source of error.

Pima County Flood Control District

Daily precipitation data from the Pima County Flood Control District (PCFCD) ALERT flood warning system were obtained in both printed and electronic format. The ALERT data are collected by automated stations, which measure daily rainfall totals with tipping buckets. PCFCD also receives rainfall reports from two volunteer observers in the town of Summerhaven. It is expected that errors in rainfall point measurement would be lower than those of volunteer observers with a rain gage due to the use of an automated tipping bucket with a larger area. The error involved in approximating areal precipitation from point measurements is expected to be similar.

National Resources Conservation Service

The Natural Resources Conservation Service (formerly Soil Conservation Service) maintained a snow survey course in the study area at Bear Wallow from 1947 to 1981. Information from this course was used for water supply forecasting. Data were collected twice a month, generally on the 1st and 15th of each month, from January 15th to April 1st. Data were collected at eight sampling locations, 50 feet apart with a Federal sampler (Ffolliott *et. al.*, 1996). Snowpack depth and water equivalent were reported as averages for the entire course. The data are summarized by Jones (1981). Errors in the measurement of snowmelt data with a Federal sampler are on the order of ± 0.5 inches (1.27 cm) (Work *et. al.*, 1965).

CHAPTER 4
WATER BUDGET CALCULATIONS

The techniques used to determine monthly fluxes for the hydrologic processes operating in Upper Sabino Creek Basin are presented in this chapter. First, the water budget is described. Next, the methods used to determine the inflows (precipitation and snowmelt) are described. Finally, the procedures used to estimate outflows (stream discharge, underflow, municipal usage, groundwater pumping and evapotranspiration) are examined.

The Water Budget

The water budget method can be used to study hydrologic processes of regions ranging in scale from a few acres to an entire planet. Hydrologic data for the area of interest are collected and averaged over the entire basin area to obtain volumetric totals for each hydrologic process. Unknown volumes can then be estimated by quantifying known fluxes and bringing the system into balance. The water budget equation is developed by expanding the hydrologic continuity equation:

$$I - Q = dS/dt \qquad (1)$$

where: I is equal to inflow [L^3/T], Q represents outflow [L^3/T], and dS/dt is the change in storage with respect to time [L^3/T].

For any watershed, there are numerous inputs and outputs. Inflow consists of such hydrologic processes as precipitation, snowmelt, surface flow, and groundwater flow. Outflow includes human consumption, evaporation, transpiration, runoff, and groundwater discharge. Figure 4.1 is an idealized representation of the concept of the

~~hydrologic cycle. (Numbers indicate the global volume of water in each reservoir in km^3~~

x 1,000).

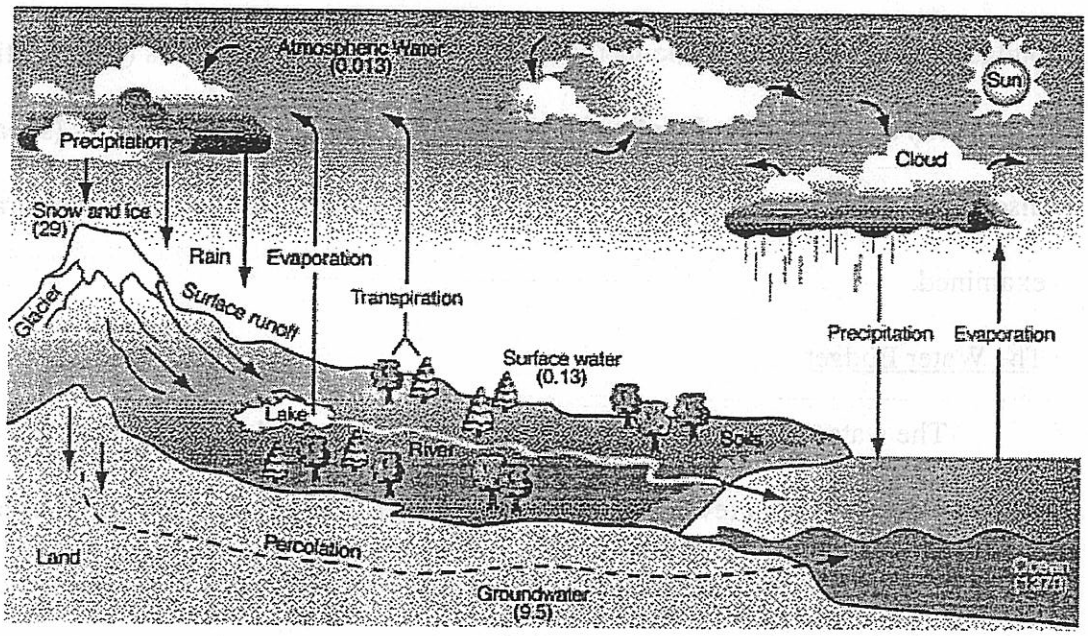

Figure 4.1, The hydrologic cycle (from GLOBE, 1998).

Water Budget Equation for Upper Sabino Creek Basin

Expanding Equation (1) to include the hydrologic processes operating in the study area, a water budget equation may be written as:

$$P + M - R - U - D + W - G - E = \Delta S \qquad (2)$$

where: P represents precipitation (rain, snow, sleet, and hail) [L^3], M is snowmelt [L^3], R is runoff [L^3], U equals underflow through streambed alluvium [L^3], D is consumptive use [L^3], W is waste discharge from septic systems [L^3], G is groundwater pumped from the U.S. Forest Service well and used outside the basin [L^3], E represents evapotranspiration [L^3], and ΔS equals change in storage (soil moisture, snowpack and/or groundwater) [L^3].

Assumptions

For this study, two assumptions were made about the natural system. First, there is no surface water or groundwater inflow. The study area includes the highest elevations in the Catalina Mountains. It is physically impossible for surface water to flow uphill, and there is no evidence of the existence of an artesian aquifer. Secondly, surface storage was neglected since there are no significant surface water bodies in the area where water could be stored.

Precipitation

Input from precipitation was determined using data from the sources listed in Table 2.1. While most observers recorded snowfall and rainfall separately, we lack the information needed to estimate the snow component of recorded rainfall. Automated rain gages do not distinguish between the two, either. The rainfall measurements may also include water from hail. For this analysis, precipitation may be defined as water in the form of rain, snow, or hail that is immediately available to participate in the hydrologic cycle (see Figure 4.1). Water input from snowmelt is discussed in the next section, and is considered a separate component of the water budget.

Daily rainfall totals were used to calculate the mean monthly rainfall for each station. The method of Thiessen polygons (Bedient and Hiber, 1992) was used to assign areal weights to each station (Figure 4.2). The monthly mean rainfalls for each station were weighted by their representative areas, and then summed to estimate the total precipitation input for each month. For months prior to 1990, there are no contemporaneous, spatially distributed precipitation data available. Missing nodes in the polygon network were reconstructed as follows:

1. Monthly ratios of precipitation at each station to the mean basin precipitation were calculated for the post-1990 gages.
2. These scaling factors were used to account for the different locations of pre-1990 gages within the polygon network.
3. Precipitation at each station was calculated by extrapolating the observed precipitation to the post-1990 stations based upon the monthly ratios and scaling factors.

Table 4.1 contains mean monthly precipitation values for the basin.

Table 4.1 Mean Basin Monthly Precipitation

Month	inches	ac-ft	cm	m^3
January	3.3	553.3	8.4	6.8×10^5
February	2.9	484.2	7.4	6.0×10^5
March	2.3	377.2	5.7	4.6×10^5
April	0.8	127.0	1.9	1.5×10^5
May	0.7	121.2	1.8	1.5×10^5
June	0.7	115.3	1.8	1.5×10^5
July	4.3	720.2	11.0	8.9×10^5
August	5.2	864.0	13.2	1.1×10^6
September	2.5	416.7	6.4	5.2×10^5
October	2.2	372.7	5.7	4.6×10^5
November	2.1	345.1	5.3	4.3×10^5
December	3.2	538.7	8.2	6.6×10^5
ANNUAL	30.2	5035.5	76.7	6.2×10^6

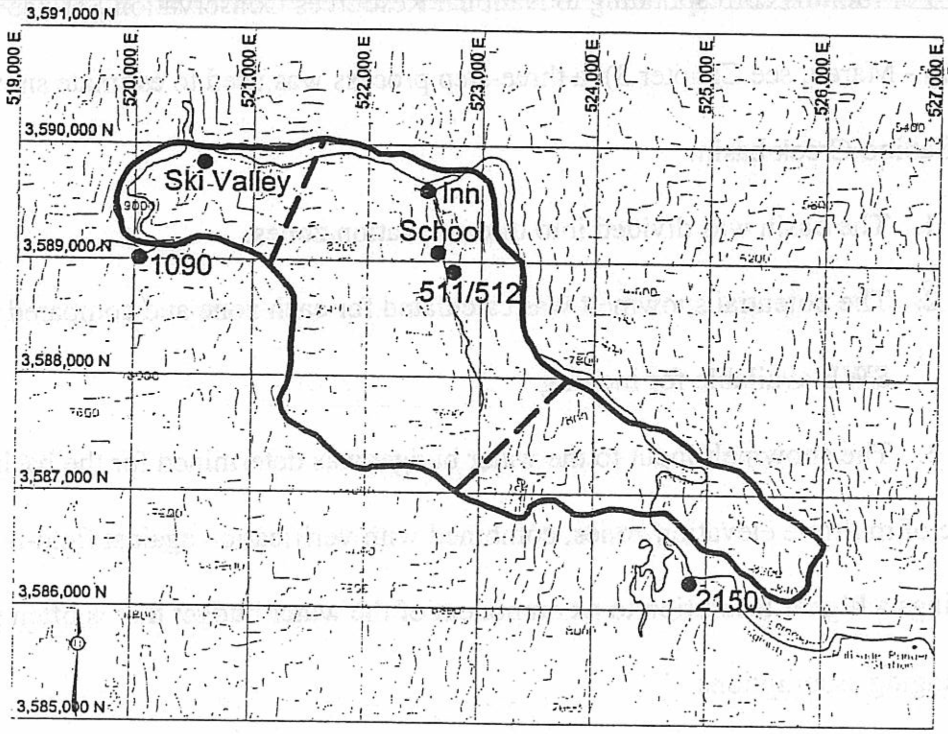

Figure 4.2, Thiessen polygons

Snowmelt

In a water budget performed on a temporal scale greater than one week, the amount of snow that falls from the sky in any one storm is generally of little concern. Some snow never enters the water budget due to evaporation from the snowpack or wind blowing snow out of the basin. The water produced by snow***melt*** is more important than the amount of snow***fall***. Snowmelt depends upon many factors, including air temperature, solar radiation, latent heat, sensible heat, and vegetation. Two methods were used to estimate water input from snowmelt.

For months corresponding to National Resources Conservation Service data (January - March, see Chapter 3), a three-step process was used to estimate snowmelt in upper Sabino Creek basin:

1. The basin was divided into three elevation zones.
2. The potential snowmelt was calculated for each zone and compared to the SWE available for melting.
3. The snowmelt input to the water budget was determined for the basin.

The use of multiple elevation zones, combined with verification against field-measured data brings a higher resolution to a component of the water budget that is often subject to wide-ranging assumptions.

For months lacking NRCS data (October - December), a temperature threshold of 0° C (32° F) was used to estimate whether a recorded rainfall event produced rain or snow in each zone. Any snow that fell in a given month was assumed to melt in the same month, as the higher mean monthly temperatures would encourage rapid melting and inhibit snowpack accumulation. While this assumption does introduce error, even greater error would be introduced by attempting to estimate depths, densities, and snow-covered areas without any data.

Assignment of elevation zones. Snow accumulation, melt rate, areal coverage, and water equivalent tend to vary with elevation. The study area was subdivided into three elevation zones to better account for the influence of elevation on snow accumulation and melt. Each zone covered approximately 650 ft. (200 m) in elevation. Table 4.2 contains area and aspect information about each zone.

Table 4.2 Description of elevation zones

Zone	Elevation range, ft.	Percent of basin area	Percent of zone with a north aspect	Percent of zone with a south aspect
Lower	7,200 – 7,875	40	41	59
Middle	7,875 – 8,530	50	54	46
Upper	8,530 – 9,157	10	71	29

The lower two zones cover roughly the same area and have similar distributions of slope aspect. The upper elevation zone occupies a much smaller area in the northwest corner of the study site, and faces primarily to the north..

Calculation of Potential Snowmelt for Each Zone The degree-day method was used to calculate snowmelt for each elevation zone. This method estimates snowmelt as a function of air temperature, and is widely used to estimate snowmelt for basins that do not have the extensive data records needed by other snowmelt models. The equation used is:

$$M = a\,Tm \qquad (3)$$

(Rango and Martinec, 1995) where: *M* represents snowmelt (cm), *a* is the degree-day factor (°C cm^{-1} d^{-1}), and *Tm* equals the number of degree days (°C d). A degree-day is defined as an exceedence of one degree per day in the daily mean temperature from an adopted reference temperature (Linsley, *et. al.*, 1982). For this study, the reference temperature was 32° F, 0° C. Degree-day factors are affected by snow density, the presence (or absence) of a forest canopy, solar radiation, and other factors (Rango and Martinec, 1995).

The daily mean air temperature for each zone was estimated using the lapse rate of -0.0038 °F / foot change in elevation obtained by comparing daily temperature data between Tucson International Airport and the stations in Table 2.1. Since there are no contemporaneous temperature data available, different base stations were used for different time periods, and scaled to the appropriate zone. See Table 2.1 for a description of each station and its temporal coverage.

An equation developed by Kuusisto (1980):

$$a = 1.04\, \rho s / \rho w - 0.07 \qquad (4)$$

(where a is the degree-day factor (°C cm^{-1} d^{-1}), ρs represents the density of snow, and ρw is the density of water) was used to calculate the degree-day factor from the SCS measurements of SWE and depth at Bear Wallow. This equation accounts for the effect of forest vegetation, which covers the study area. Because the snow "sampling equipment is so designed and the scales so calibrated... the weight of the snow core is converted directly to inches of water" (Jones, 1981) the density of snow is equivalent to the SWE divided by the snow depth. The density of water is assumed to be unity. Rango and Martinec (1995) note that "daily snowmelt depths cannot accurately be computed by the degree-day method." For this study, snowmelt was estimated on a bi-weekly basis, corresponding with the frequency of snow course data.

It is important to note that Equation (4) was developed for areas where snow is plentiful. Given the relatively low snowfalls observed in the Santa Catalina Mountains, care was taken to verify that the potential snowmelt did not exceed the amount of snow actually available for melting, thus distorting the water budget. Using the temperature threshold method, the total available SWE was estimated for each bi-weekly period. Snowfall was assumed to occur evenly throughout each month.

Determination of Snowmelt Input The bi-weekly volume of snowmelt (after adjusting for SWE available for melting) was determined by multiplying the melt for each elevation zone by the amount of snow-covered area for that zone. There are no records available on the distribution of snow in the entire study area. The average snow-covered area in the study area from January 15 to April 1 was determined from maps hand drawn by Stanley (1998), an 18-year resident of Summerhaven. Table 4.3 shows the percentage of snow-covered area within each elevation zone, and according to aspect.

Table 4.3 Seasonal distribution of snow-covered area

	Percent of area covered by snow					
	Lower elevation Zone		Middle elevation zone		Upper elevation zone	
Date	South aspect	North aspect	South aspect	North aspect	South aspect	North aspect
Jan. 15	100	100	100	100	100	100
Feb. 1	100	100	100	100	100	100
Feb. 15	100	100	100	100	100	100
Mar. 1	25	50	50	70	50	100
Mar. 15	5	10	0	10	20	100
Apr. 1	0	5	0	5	0	40

South-facing slopes receive more solar energy than north-facing slopes due to the inclination of the sun; hence they generally melt more quickly. Gottfried et. al. (1998)

found that south-facing slopes on Mt. Lemmon melted nearly twice as quickly as north-facing slopes. Table 4.4 lists the mean melt volume for each month.

Table 4.4 Mean snowmelt volumes

Month	Mean melt volume (ac-ft)	Mean melt volume (m^3)
October	92.3	113,850.8
November	208.7	257,428.7
December	410.4	506,222.9
January	285.3	351,913.8
February	140.3	173,058.2
March	43.0	53,039.9

Runoff

Runoff is water that exits the basin as surface flow. Figure 4.4 is a plot of mean monthly discharge and monthly standard deviation at Marshall Gulch using data from 1951 to 1959, and 1982 to 1997. An extreme drought affected the area in the 1950's (Betancourt, 1998), a period accounting for 46% of the streamflow record. The influence of a major flood in October 1983 is also apparent in Figure 4.3. Given the high variability of the data, it was desirable to reconstruct the streamflow record in order to have a longer period of record and obtain a more representative average monthly discharge.

Data from the U.S.G.S gaging station in Sabino Canyon, approximately nine miles (14.5 km.) downstream from the town of Summerhaven was used. Figure 4.4 shows the location of the two gages. There are approximately 50 years of data for the Sabino Canyon gage, compared to approximately 15 years of data available from Marshall Gulch (many missing 25% of the measurements or more).

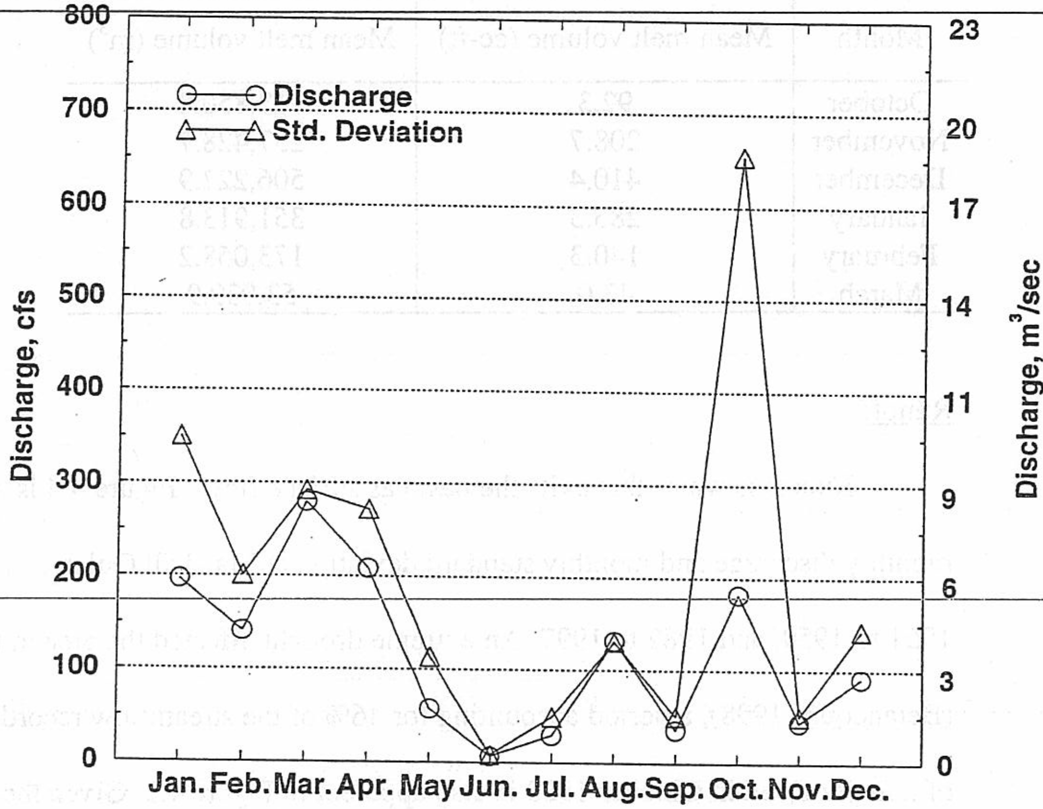

Figure 4.3, Monthly discharge and standard deviation; Sabino Creek at Marshall Gulch

Streamflow reconstruction is an estimation procedure whereby the flow at one gage is used to predict or reconstruct the flow at another gage on the same stream. A generalized mathematical model is:

$$\hat{y} = f(x) \tag{5}$$

where *y* is estimated flow, *x* is known flow, and *f* represents some predictive function. For this study, the independent variable (*x*) is the flow at Sabino Canyon. The dependent variable (*y*) represents the flow at Marshall Gulch.

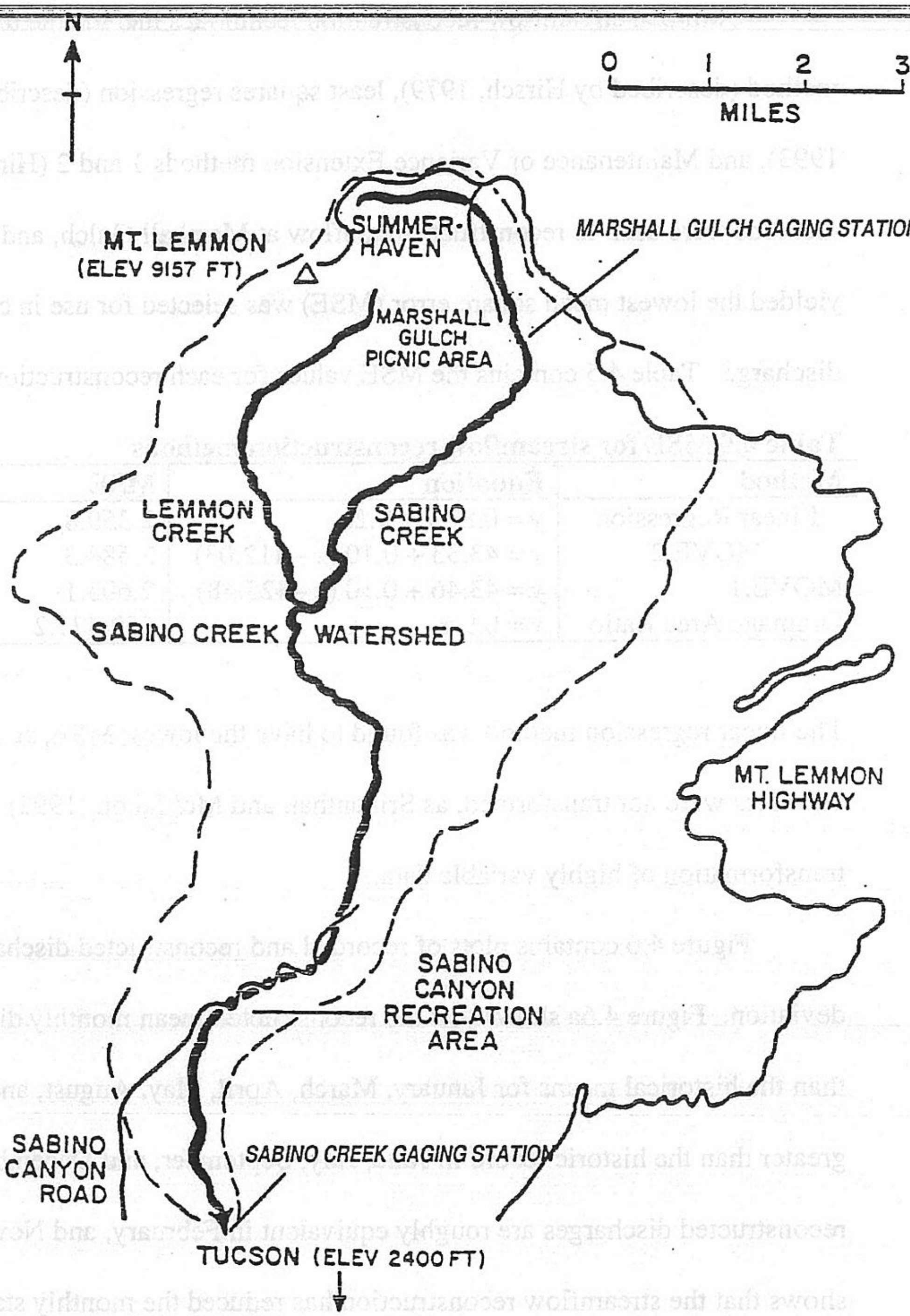

Figure 4.4, Location of stream gaging stations (adapted from Patterson, 1977)

Common streamflow reconstruction techniques include the drainage area ratio method (described by Hirsch, 1979), least squares regression (described by Hirsch *et. al.*, 1993), and Maintenance of Variance Extension methods 1 and 2 (Hirsch, 1982). All four methods were used to reconstruct streamflow at Marshall Gulch, and the method that yielded the lowest mean square error (MSE) was selected for use in calculating monthly discharge. Table 4.5 contains the MSE values for each reconstruction method.

Table 4.5 MSE for streamflow reconstruction methods

Method	Equation	MSE
Linear Regression	$y = 0.83\,x + 9.26$	2,359.8
MOVE.2	$y = 43.33 + 0.10\,(x - 412.03)$	2,584.3
MOVE.1	$y = 43.46 + 0.10\,(x - 425.48)$	2,603.1
Drainage Area Ratio	$y = 0.9\,x$	559,471.2

The linear regression method was found to have the lowest MSE, at 2,359.8. The variables were not transformed, as Srikanthan and McMahon (1992) do not recommend transformation of highly variable data.

Figure 4.6 contains plots of recorded and reconstructed discharge and standard deviation. Figure 4.6a shows that the reconstructed mean monthly discharge is lower than the historical means for January, March, April, May, August, and October; but is greater than the historic record in June, July, September, and December. The historic and reconstructed discharges are roughly equivalent in February, and November. Figure 4.6b shows that the streamflow reconstruction has reduced the monthly standard deviation; most markedly in the month of October. Standard deviation increases in September and December. This is most likely due to the larger drainage area of the Sabino Canyon gage, which captures flows resulting from precipitation events outside the Marshall Gulch gage's watershed. Flows resulting from isolated precipitation that did not fall in the study area could be recorded at the lower gage. There is virtually no change in the month of June. Figure 4.6c shows that the standard deviation is very close to the mean for each month in the reconstructed streamflow record, with the exception of October.

Table 4.6 contains descriptive statistics for the upper gage, incorporating both measured and estimated flows. Note that while the averaging period for the historic record is approximately 12 years, the reconstructed monthly averages are based on an additional 40+ years of reconstructed data.

Table 4.6. Descriptive statistics for measured and estimated discharge

Month	Monthly discharge, ac-ft			Standard deviation, ac-ft		
	Historic record	Recon-structed record	Difference	Historic record	Recon-structed record	Difference
Jan	197.03	168.39	-28.64	350.62	371.63	+21.01
Feb	141.30	136.87	-4.43	201.25	210.75	+9.50
Mar	280.12	188.40	-91.72	292.44	296.09	+3.65
Apr	208.68	106.01	-102.67	272.17	176.64	-95.53
May	57.39	34.70	-22.69	113.41	68.76	-44.65
Jun	6.52	10.79	+4.27	8.21	9.61	+1.40
Jul	29.35	38.33	+8.98	49.27	59.36	+10.09
Aug	131.52	93.96	-37.56	130.47	113.95	-16.52
Sep	35.54	61.66	26.12	50.51	112.84	+62.33
Oct	182.20	93.44	-88.76	654.94	406.10	-248.84
Nov	43.70	35.69	-8.01	50.48	45.17	-5.31
Dec	91.42	117.95	+26.53	143.20	203.94	+60.74
Total	**1,404.77**	**1,086.18**	**-318.59**	**2,316.97**	**2,074.84**	**-242.13**
Mean	**117.06**	**90.51**	**-26.55**	**193.08**	**172.90**	**-20.18**

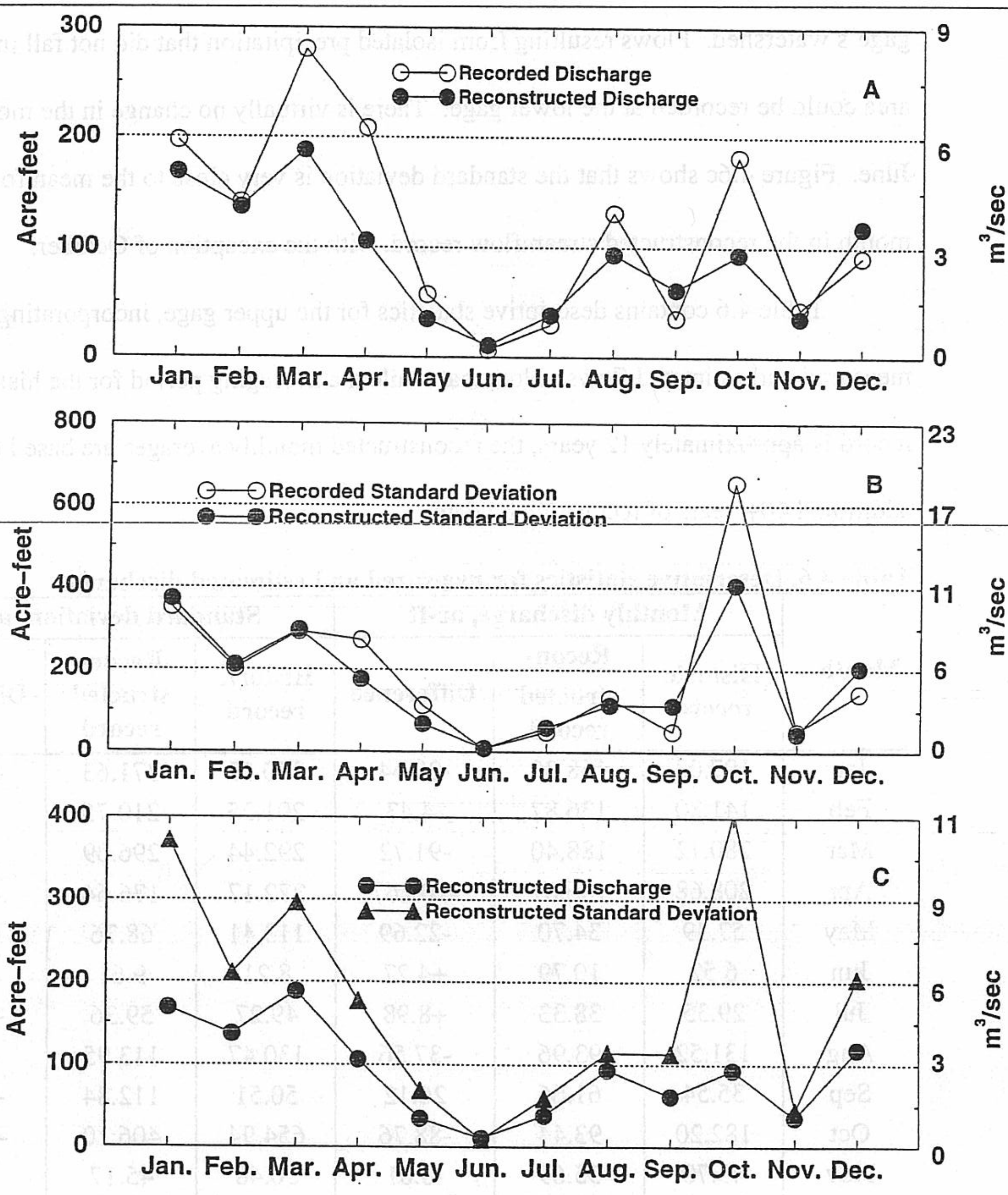

Figure 4.5, Historic and reconstructed streamflow record

Figure 4.6 is a time-series plot of recorded and reconstructed streamflow, which fills in the gaps in Figure 2.6.

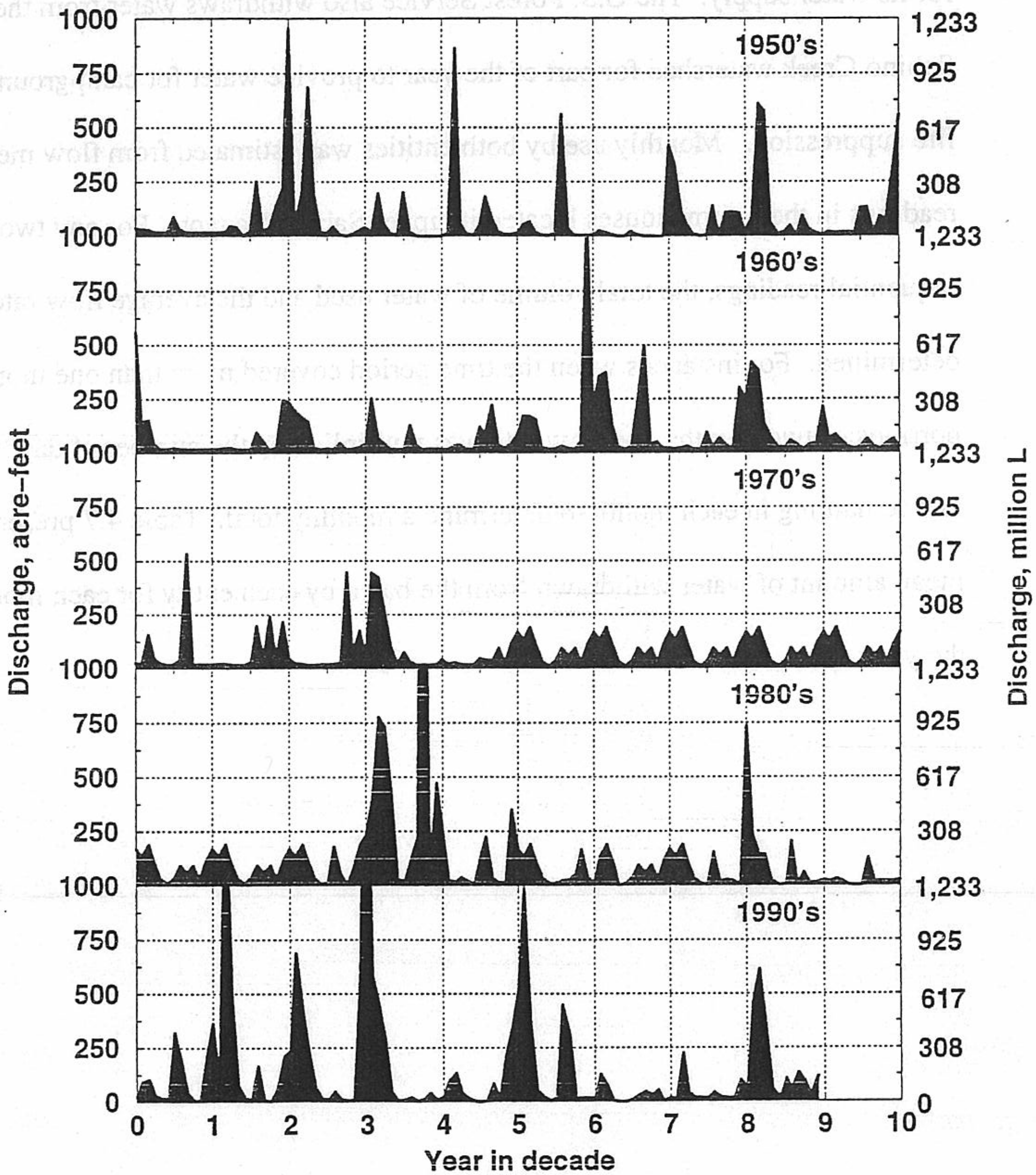

Figure 4.6, Reconstructed streamflow

Human Use

The town of Summerhaven relies upon the springs that feed Sabino Creek for its water supply. The U.S. Forest Service also withdraws water from the Sabino Creek watershed for part of the year to provide water for campgrounds and fire suppression. Monthly use by both entities was estimated from flow meter readings in their pumphouses located in upper Sabino Canyon. For any two sequential readings, the total volume of water used and the average flow rate were determined. For instances when the time period covered more than one month or portions of two months, the flow rate was multiplied by the number of days at that rate remaining in each month to determine a monthly total. Table 4.7 presents the mean amount of water withdrawn from the basin by each entity for each month of the year.

Table 4.7. Average municipal water withdrawn, 1991-1998

Month	Mount Lemmon Water Co.		U.S. Forest Service	
	Gallons	Acre-feet	Gallons	Acre-feet
January	503,195	1.54	81,638	0.25
February	469,589	1.44	57,226	0.18
March	566,286	1.74	57,358	0.18
April	545,150	1.67	183,091	0.56
May	235,349	0.72	245,812	0.75
June	479,946	1.47	268,797	0.82
July	428,665	1.32	263,143	0.81
August	380,342	1.17	186,922	0.57
September	683,932	2.10	169,616	0.52
October	546,920	1.68	202,906	0.62
November	621,266	1.91	93,263	0.29
December	497,330	1.53	202,958	0.62
Total	**5,957,972**	**18.29**	**2,012,728**	**6.17**

Monthly water withdrawn by the M.L.W.C. and the U.S. Forest Service is plotted in Figure 4.7. Aside from occasional fire suppression activity, none of the water pumped by the Forest Service is returned to the Upper Sabino Creek watershed.

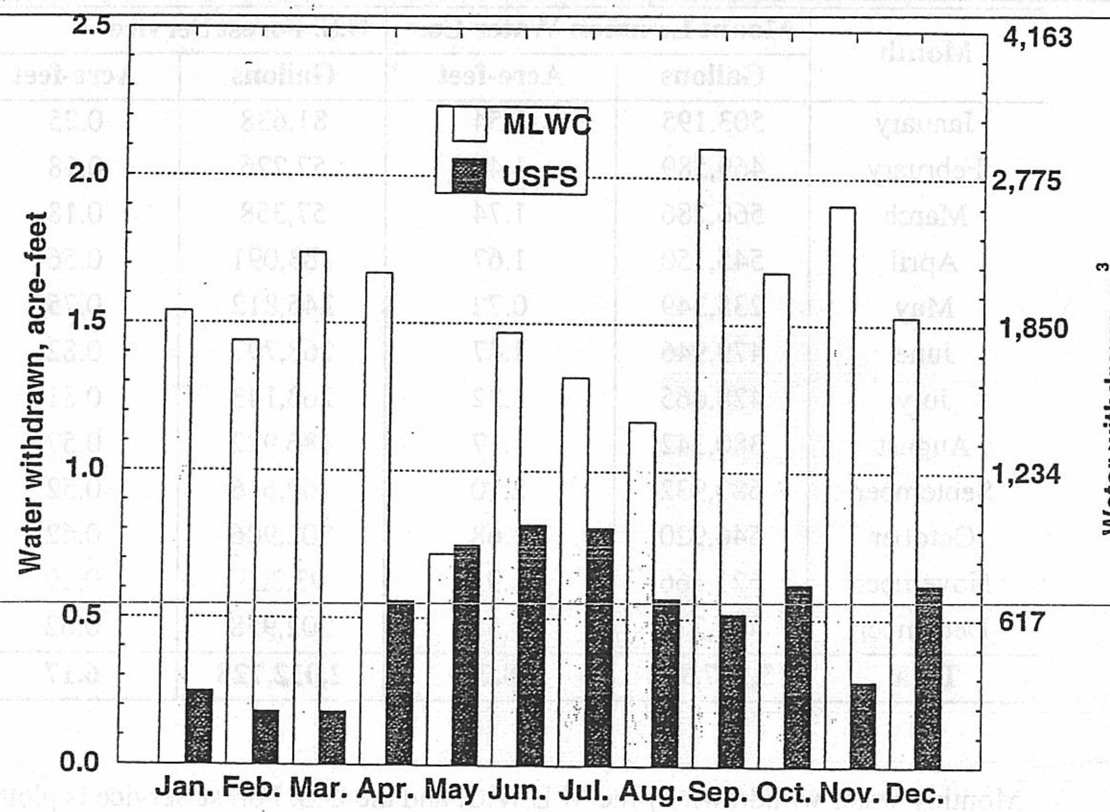

Figure 4.7, Monthly municipal water withdrawn

The spring and fall peaks in the M.L.W.C. data reflect the filling and draining of storage tanks, rather than the actual use of water. Because of this temporal discrepancy between pumping and use, it is necessary to determine not only how much water re-enters the watershed, but also when it re-enters the hydrologic cycle. This can be accomplished by looking at the amount of water consumed by customers each month rather than the amount of water pumped into the M.L.W.C. system.

Figure 4.8 shows the number of active water meters for each month of the year. As expected, the number of water users is greater during the summer than the winter.

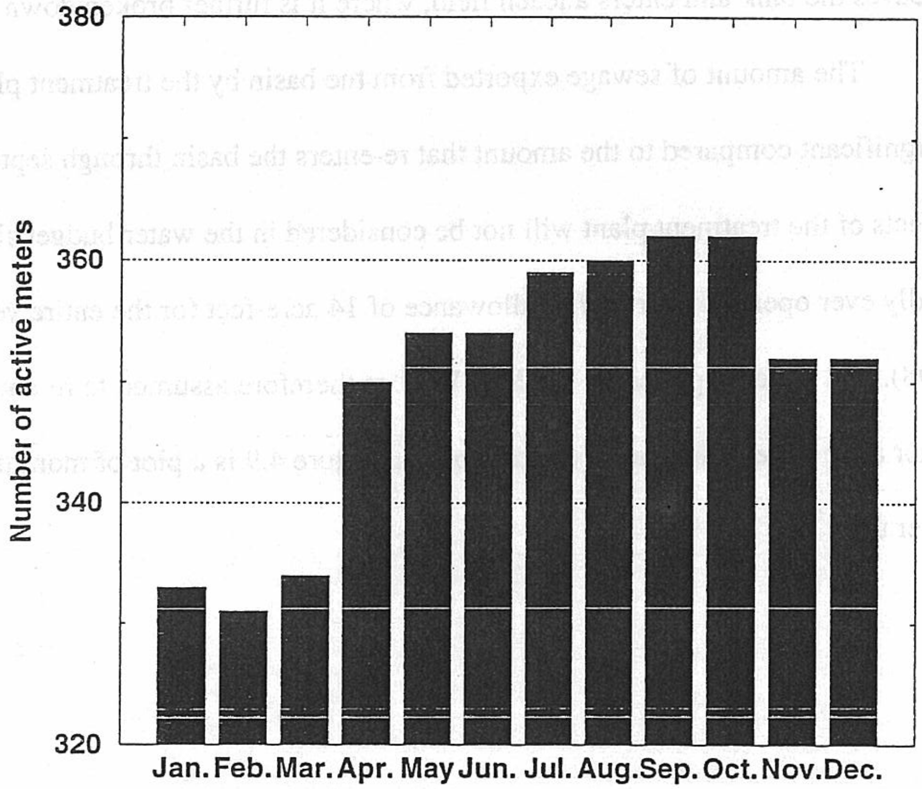

Figure 4.8, Number of active meters per month

All water supplied to M.L.W.C. customers is assumed to re-enter the basin as sewage. In the study area, sewage is disposed of through two means, septic tanks and a municipal sewage system operated by Pima County. Of the 488 structures in Summerhaven, only 36 are connected to the sewage system. Sewage treated by the Pima County treatment plant is discharged outside of the basin, on the north side of Mt. Lemmon into the San Pedro River watershed. The treatment plant has a permit to discharge 12,500 gallons of sewage per day (0.04 ac-ft/day, 14 ac-ft/year). The remaining homes dispose of sewage with a septic system. Septic tanks operate by allowing bacteria to break down solid waste material in an underground tank. After the waste is liquefied, it leaves the tank and enters a leach field, where it is further broken down by bacteria.

The amount of sewage exported from the basin by the treatment plant is insignificant compared to the amount that re-enters the basin through septic systems. Effects of the treatment plant will not be considered in the water budget since the plant hardly ever operates near its full allowance of 14 acre-feet for the entire year (Stanley, 1998). All water supplied by the M.L.W.C. is therefore assumed to re-enter the basin, either as sewage or irrigation (landscaping). Figure 4.9 is a plot of monthly domestic water use.

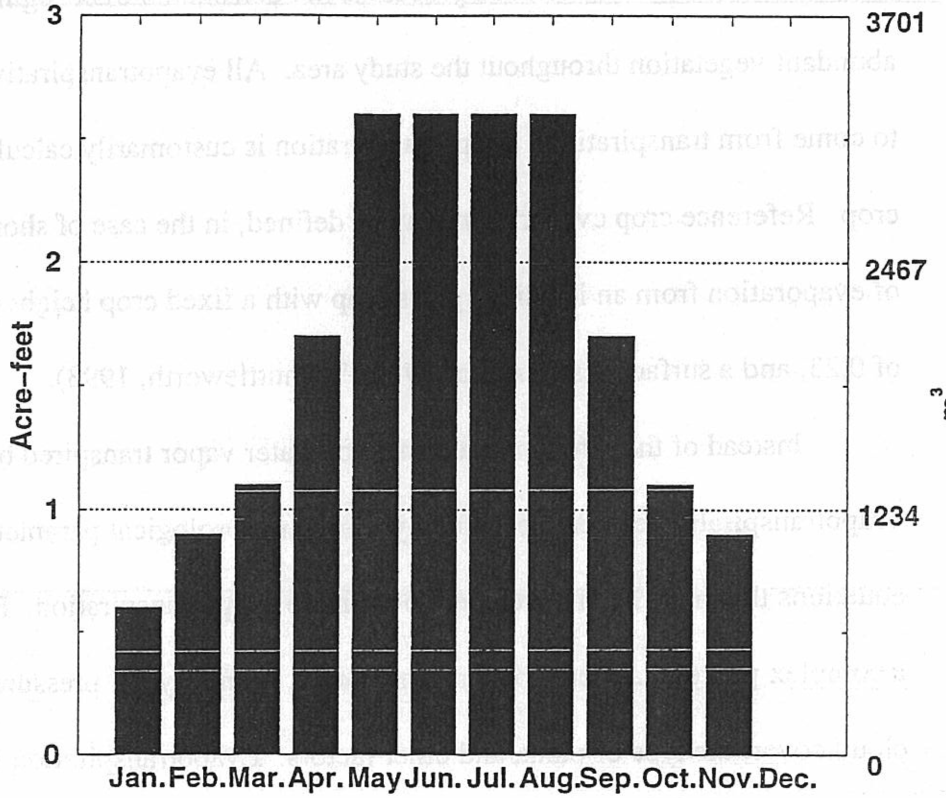

Figure 4.9, Mean monthly domestic water use

<u>Evapotranspiration</u>

Evaporation is the conversion of water from the liquid state into the gas state. Evaporation not only occurs from bodies of water, but also can take place from soil and plants. Transpiration is defined as "that part of the total evaporation which enters the atmosphere from the soil through the plants" (Shuttleworth, 1993). The combined total of evaporation and transpiration is referred to as evapotranspiration. There is no surface water storage in Upper Sabino Creek basin, and the surface area of Sabino Creek is too small to be considered significant for evaporation. While some evaporative losses may occur directly from the soil, this process is not considered to be significant due to the abundant vegetation throughout the study area. All evapotranspirative losses are assumed to come from transpiration. Evapotranspiration is customarily calculated for a reference crop. Reference crop evaporation may be defined, in the case of short grass, as "the rate of evaporation from an idealized grass crop with a fixed crop height of 0.12 m, an albedo of 0.23, and a surface resistance of 69 s/m" (Shuttleworth, 1993).

Instead of the direct measurement of water vapor transpired by plants, evapotranspiration can be measured by using meteorological parameters, as inputs into equations that have been developed to estimate evapotranspiration. Evapotranspiration is a complex process, affected by air temperature, humidity, air pressure, wind speed, and cloud cover, the type of plant, and other factors. Evapotranspiration is difficult to quantify, and the most accurate methods rely on all of the above parameters. For this study however, the only available parameters were daily minimum and daily maximum temperature.

The temperature values were adjusted from the elevation at which they were measured to the mean basin elevation of 8,015 ft. (2,443 m.). The same lapse rate used for snowmelt calculations (-0.0038 °F / foot change in elevation) was applied. Reference crop evaporation was then estimated using the Hargreaves equation (Hargreaves and Samani, 1985; Shuttleworth, 1993):

$$Erc = 0.0023\, So\, (\delta T)^{0.5}\, (T + 17.8) \qquad (6)$$

where *Erc* is the reference crop evaporation (mm/day), *So* is the water equivalent of extraterrestrial radiation (mm/day) (the equivalent energy necessary to evaporate the same amount of water in one day), δT represents the difference between mean monthly maximum and minimum temperatures, and *T* is the temperature (°C).

The value of *So* can be estimated if the relative positions of the earth and sun and the amount of daylight are known. These can be calculated if the latitude and the day of the year are known. The solar declination (δ) [angular distance of the Sun north or south of the Earth's equator] is given by:

$$\delta = 0.4093 \sin (2\pi/365\ J - 1.405) \qquad (7)$$

where *J* is the day of year number (Shuttleworth, 1993). The sunset hour angle (ωs) [the difference between local solar time and solar noon] is given by the equation:

$$\omega s = \arccos(-\tan \phi \tan \delta) \qquad (8)$$

where ϕ is the latitude (in radians) (Shuttleworth, 1993). The relative distance between the earth and the sun (*dr*) is given by:

$$dr = 1 + 0.033 \cos (2\pi / 365\ J) \qquad (9)$$

(Shuttleworth, 1993). Once these parameters are known, the extraterrestrial solar radiation (So) can be estimated by:

$$\mathrm{So} = 15.392\ dr\ (\omega s \sin \phi\ \sin \delta + \cos \phi \cos \delta \sin \omega s\ ) \qquad (10)$$

(Shuttleworth, 1993).

The reference crop characteristics previously described do not correspond to the vegetation at the study site, which is primarily forest. The evapotranspiration estimates

~~were further revised so that they would be more representative of the vegetation present at~~ the study site. In a forest environment, approximately 20 percent of the precipitation may be intercepted by the forest canopy (Shuttleworth, 1993) where it evaporates more quickly than normal because of the turbulent action of wind. However, forest transpiration rates are generally lower (80% of reference crop evaporation) (Shuttleworth, 1993). It is necessary to consider both processes when attempting to estimate evapotranspiration in a forest environment. A monthly evapotranspiration estimate for a forest environment suggested by Shuttleworth (1993) is:

$$Eforest = 0.8Erc + \alpha P \qquad (11)$$

where α represents interception loss (assumed to be 0.2), and P is precipitation (mm). Aside from the ski runs of Mt. Lemmon Ski Valley and central Summerhaven, the entire study area is forested.

Daily temperature records from the stations in Table 2.1 were used with Equations 8-12 to determine monthly potential evaporation. Monthly precipitation data from the same stations were used with Equation 13 to account for the effect of the forest canopy. Table 4.8 gives the monthly potential evapotranspiration estimates for the study area.

Table 4.8 Mean monthly potential evapotranspiration

Month	Evapo-transpiration, inches	Evapo-transpiration, acre-ft	Evapo-transpiration, cm	Evapo-transpiration, m^3
January	1.4	239	3.6	294,687
February	1.8	295	4.5	364,025
March	2.8	474	7.2	585,294
April	4.1	677	10.3	835,790
May	5.4	908	13.8	1,120,077
June	6.2	1,034	15.7	1,276,181
July	5.8	962	14.6	1,187,009
August	4.9	816	12.4	1,007,122
September	3.9	652	9.9	804,768
October	2.8	473	7.2	583,902
November	1.8	301	4.6	371,108
December	1.3	224	3.4	275,792
Annual	**42.2**	**7,055**	**107.2**	**8,705,755**

Groundwater

Groundwater is most readily available in the alluvial sediments in the channel of Sabino Creek (Scheruder and Laine, 1974). Although water may not be flowing in the creek, it is usually present in the deposits beneath the channel itself. The driller's log from the U.S.F.S. well in Upper Sabino Canyon near Dead Fir Spring indicates that the depth of the alluvium is 40 feet at that location (A.D.W.R., 1983). Assuming a depth of 40 feet along the entire 3-mile length of the stream and a porosity of 30%, the volume of alluvium available for storage is 190,080 ft^3, or 4.36 acre-ft (5,378 m^3). While the water in the alluvium is readily accessible, this unit should not be considered to be a viable source of water since over-exploitation could cause the creek to go dry.

No data are available on the hydraulic properties of the fractured rock units that underlie the study site. Schreuder and Laine (1974) found that the time lag between a

~~precipitation event and an increase in spring flow was approximately one week,~~ suggesting a connection with groundwater flow in the bedrock system. The driller's log for the Forest Service well indicates a 10-foot thick zone of fractured granite at a depth of 75 to 85 feet, but does not indicate that water was encountered in this unit. Figure 4.10 is a plot of mean monthly groundwater pumpage by the U.S. Forest Service. The well withdraws groundwater from the alluvium along the bed of Sabino Creek. Groundwater withdrawals peak during the periods of high demand during the summer months, and decline for the remainder of the year. Due to insufficient pumping records it was impossible to correlate stream discharge with well pumping.

Another component of the groundwater system is underflow along Sabino Creek. Underflow is that water that flows in the channel of a stream, beneath the streambed. The gaging station at Marshall Gulch never measures underflow, even though it is occurring. If the depth of alluvium is estimated to be 20 feet and the width of the alluvial channel is estimated to be 10 feet, the discharge through the alluvium on a monthly basis can be estimated by solving Darcy's law (Bear, 1972):

$$Q = -K A \, dh/dl \qquad (12)$$

where: Q equals discharge [L^3/T], K is the hydraulic conductivity [L/T], A is the cross-sectional area (200 ft^2) [L^2], and dh/dl is the hydraulic gradient [L/L].

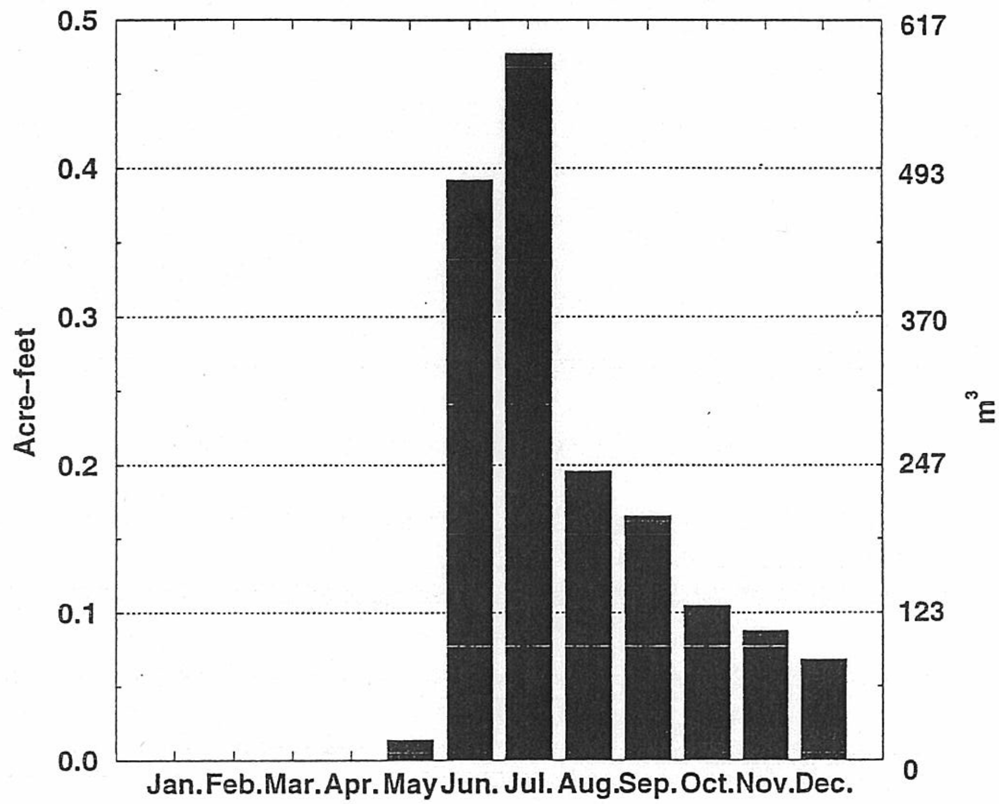

Figure 4.10, Mean monthly groundwater pumping, 1989-1991

There are no data available on the hydraulic conductivity of the alluvium of Sabino Creek. Anderson and Freethey (1992) note that the mean hydraulic conductivity value used to model the alluvium of the Tucson Basin was 86.6 ft/day. The hydraulic gradient is equivalent to the stream gradient of 0.1. Solving equation (14) above using these values estimates underflow to be 1,732 ft^3/day or 1.2 acre-ft/month, which is a small fraction of monthly discharge. Although this figure undoubtedly varies on a diurnal basis, without further study it is impossible to make a more accurate estimate of underflow.

CHAPTER 5
RESULTS

This chapter presents the results of a monthly water budget analysis for Upper Sabino Creek Basin based on an analysis of 48 years of hydrologic data. For each month of the year, the mean value for each component of the water budget was determined. Because precipitation is the largest contributor, and evapotranspiration accounts for the greatest loss of water from the system. The implications of this study as a source of information about mountain-front recharge to the Tucson Basin are addressed at the conclusion of this chapter.

<u>Monthly Water Budget</u>

As described in Chapter 3, the water budget approach assumes that there is a balance among the hydrologic processes so that all the terms in equation (2), when summed are equal to zero, giving:

$$P + M - R - U - D + W - G - E + \Delta S = 0 \qquad (13)$$

This assumes that the storage term (ΔS) reflects changes in soil moisture and groundwater. Water input from precipitation was subdivided into rain and snow, based on the following procedure:

1. The daily elevation of the freezing point of water was determined based upon temperature data from the sources in Table 2.1. If no data were available, the elevation was extrapolated from temperature data collected at the Tucson airport, using a lapse rate of -0.0038 °F/ft.

2. The areal percentage of the basin with a temperature below freezing was determined based on the elevation distribution in Figure 1.3.

3. Daily rainfall and/or SWE volumes were estimated based upon the relative areas of the basin above or below freezing.

4. The proportion of rain and/or snow (as a percentage of total monthly precipitation) was determined for each month of record. If no data were available, mean values were used.

Snowpack storage is not included in this balance, but is accounted for separately. Snowmelt was limited by the SWE available for each month.

On an annual basis, the change in storage (ΔS) must be equal to zero if there is no net gain or loss in storage (steady-state conditions). When the monthly water budget was calculated using the methods described in Chapter 4, the mean annual change in storage was -3.7 ac-ft, with a standard deviation of over 1,500 ac-ft. This discrepancy indicated that a component of the water budget was either over- or underestimated.

Since precipitation, snowmelt, and runoff are based on observed values and potential evapotranspiration was based solely on estimated values, it appeared likely that evapotranspiration was the component in question. The potential evapotranspiration values for each month were adjusted until the annual change in storage was zero. By reducing the potential evapotranspiration values by an average of slightly more than 56%, it was possible to bring the change in storage to zero for every year, with the exceptions of 1983, 1985, and 1990. The potential evapotranspiration adjustment factor for each month can be found in the monthly water balance presented in Appendix A.

After adjusting evapotranspiration for the 48 years of record, the mean change in storage was -48.4 ac-ft, with a standard deviation of 380.3 ac-ft. Although the mean change in storage is higher than before potential evapotranspiration was reduced, the standard deviation is only 25% of the unadjusted standard deviation. Furthermore, these values are dominated by the extreme rainfall event of October 1983. If the annual change in storage for 1983 is not used to calculate the average, the mean change in storage for 47 years of record falls to 6.2 ac-ft, with a standard deviation of 37.0 ac-ft, only 2.5% of the unadjusted standard deviation. After adjusting for evapotranspiration, the mean annual change in storage is approximately one tenth of one percent of the total annual mass flux.

All components of the water balance were averaged to find the mean value for each month of the year. These values were then input to equation (15) and the storage term was adjusted to bring the system into balance. Tables 5.1 - 5.3 list the monthly volumes for the hydrologic processes operating in upper Sabino Creek basin; and Table 5.4 shows the total inputs, outputs, and final balances. A month-by-month water balance for the time period 1950 - 1997 is presented in Appendix A.

Table 5.1 Monthly water budget inflows, acre-feet

Month	Rainfall	Snowmelt	Septic return
January	226.4	285.3	0.6
February	370.3	140.3	0.9
March	340.4	43.0	1.1
April	125.3	15.2	1.7
May	121.2	0.0	2.6
June	115.3	0.0	2.6
July	720.2	0.0	2.6
August	864.0	0.0	2.6
September	415.3	1.4	1.7
October	280.4	92.3	1.1
November	136.5	208.7	0.9
December	128.3	410.4	0.6
Annual	**3,843.6**	**1,196.4**	**19.0**

Table 5.2 Monthly water budget outflows, acre-feet

Month	Runoff	Under-flow	M.L.W.C. use	U.S.F.S. use	Groundwater pumping	Evapotrans - piration
January	209.8	1.2	1.6	0.3	0.0	130.3
February	158.5	1.2	0.8	0.2	0.0	161.4
March	213.9	1.2	1.1	0.2	0.0	258.6
April	114.1	1.2	3.4	0.6	0.0	370.1
May	33.1	1.2	0.6	0.8	0.0	500.1
June	12.4	1.2	1.5	0.8	0.4	561.1
July	38.3	1.2	1.4	0.8	0.5	523.0
August	109.8	1.2	1.2	0.6	0.2	436.1
September	68.5	1.2	2.0	0.5	0.2	352.2
October	54.7	1.2	3.2	0.6	0.1	257.5
November	39.9	1.2	0.3	0.3	0.1	162.9
December	133.2	1.2	1.7	0.6	0.1	120.2
Annual	**1,186.0**	**14.4**	**18.7**	**6.2**	**1.5**	**3,833.5**

Table 5.3 Monthly water budget balance, acre-feet

Month	Inflows	Outflows	Δ Storage	Balance
January	512.3	343.1	-169.2	0.0
February	511.5	322.1	-189.4	0.0
March	384.5	475.0	90.5	0.0
April	142.2	489.4	347.2	0.0
May	123.8	535.7	411.9	0.0
June	117.9	577.0	459.1	0.0
July	722.8	564.7	-158.1	0.0
August	866.6	548.9	-317.7	0.0
September	418.4	424.5	6.1	0.0
October	373.8	317.2	-56.6	0.0
November	346.0	204.5	-141.5	0.0
December	539.3	256.9	-282.4	0.0
Annual	**5,059.1**	**5,059.1**	**0.0**	**0.0**

Precipitation Water input from precipitation is the greatest in the month of August, with a mean volume of 864 acre-feet. The least amount of rain falls in May and June, with volumes of 121 and 115 acre-feet, respectively.

Snowmelt The greatest volume of snowmelt, 410 acre-ft, is produced in December. Snowmelt volumes decline later in the season as the amount of snow-covered area is reduced. Stream discharge does not peak until March, suggesting that early snowmelt infiltrates through the soil and rock rather than simply draining into Sabino Creek. Later in the melt season, the combination of saturated soil and increasing temperatures produces a significant increase in runoff.

Runoff Runoff ranges from 214 acre-ft in March to 12 acre-ft in June. On an annual basis, runoff accounts for 25% of the total volume of water in the study area.

Spring runoff is supplied by snowmelt, while rainfall is the driving force behind runoff for the remainder of the year. Runoff is highly variable, and daily flow rates are often 1 cfs (2 acre-feet/day) or less.

Domestic Use Withdrawal of water ranges from over 3 acre-ft in April and October to less than one acre-ft in November. This reflects the filling of storage tanks rather than actual use, which peaks during the summer months. Virtually all of the water withdrawn by the M.L.W.C. is returned to the basin as septic field discharge. U.S. Forest Service pumping is negligible in terms of the water budget for the entire basin. Human use can and does have a very significant impact on the surface flow in Sabino Creek, however.

Both the M.L.W.C. and U.S.F.S. rely on springs that feed Sabino Creek for water supply purposes. By diverting spring flow for human consumption, the discharge in Sabino Creek can be diminished. Although nearly all of the water used by the M.L.W.C. is returned to the basin in the form of septic discharge, this water generally does not re-enter the creek at rates high enough to supplement discharge at a noticeable level.

Evapotranspiration Vegetation accounts for the greatest withdrawal of water from the study area at a rate of 3,834 acre-ft per year; it is more than runoff and human consumption combined. Evapotranspiration peaks during the month of June at 561 acre-ft and is at its lowest during December at 120 acre-ft. These values have been adjusted to bring the system into balance, as described previously. Potential evapotranspiration is approximately double the adjusted evapotranspiration.

Alluvial Underflow At present, there are not enough data to accurately estimate this component of the water budget. While it undoubtedly varies, for this study it is estimated to have a fixed value of 1.2 acre-feet per month.

Groundwater Recharge and Soil Moisture This component of the water balance was not directly measured. The greatest amount of water leaves the basin as groundwater recharge or soil moisture storage during the months of November through February. This suggests that surplus water during these months exits the basin as mountain-front recharge or is stored as soil moisture. The greatest amount of water enters the basin from soil moisture storage during the months of April through June. Input from this source of water is reduced in July through September as evapotranspiration peaks, using most of this water.

Mountain-Front Recharge

Increasing awareness about the depletion of aquifers in the Tucson basin and the ongoing controversy over the delivery of Central Arizona Project water to homes in the city of Tucson have inspired several studies on mountain-front recharge to the Tucson basin. Geochemical analyses of groundwater samples from the Tucson basin indicated high-altitude recharge, as well as contact with the gneissic basement rocks of the Santa Catalina Mountains (Mohrbacher, 1983). Mohrbacher (1984) also estimated recharge from the eastern half of the Santa Catalina Mountains to be 50 acre-ft per year per mile of mountain front (mmf).

Anderson *et. al.* (1991) developed an equation to predict mountain-front recharge from precipitation greater than 8 inches:

$$\log Qrech = -1.40 + 0.98 \log P \qquad (14)$$

where *Qrech* equals mountain-front recharge, and *P* is precipitation. Using the annual basin input of 5,040 acre-feet for the study area Equation 16 estimates recharge to be 169 acre-ft.

Recent work by Chavez *et. al.* (1994) is the most comprehensive insofar as it relates to the water budget of Sabino Creek Basin. Chavez *et. al.* developed an analytical model of seasonal streamflow and evapotranspiration in order to estimate mountain-front recharge from Sabino Creek. After model development and calibration, mountain-front recharge was estimated to be 13.5 acre-ft /year per mmf. However, this was for the summer period only. The results of this study which show excess moisture in the spring and the work by Keith (1980) indicate that most recharge occurs during the spring rather than the summer.

Estimates of mountain-front recharge based on the water budget for upper Sabino Creek basin have a large uncertainty, as they are based on assumptions about several other hydrologic processes in the basin. Chavez *et. al.* (1994) note that mountain-front recharge "cannot be estimated reliably by 'gross' water balance calculations." There are several miles and approximately 5,000 feet of elevation difference between the study area and the aquifers in the Tucson Basin. Any potential recharge leaving the study area still needs to work its way down through the entire Santa Catalina mountain range, suffering depletion from springs, gaining streams, and evapotranspiration.

CHAPTER 6
ANNUAL VARIABILITY

This chapter examines the variability of the hydrologic processes operating in the study area. Without some measure of variability, knowledge of the expected value (the mean) leaves many questions unanswered, especially for water management applications. For example, in a three-year period (1966 to 1968) the snow depth record from Bear Wallow contains both the highest (1966 and 1968) and lowest (1967) extremes on record. Variability is analyzed from two perspectives. The first method looks at the variability present within each data set. The second approach addresses the relationship between the data from Upper Sabino Creek Basin and global climatic variations, primarily the El Niño Southern Oscillation (ENSO) phenomenon.

Information on variability is important for several reasons. First, it allows one to relate current data (precipitation, for example) to previous experience as well as make predictions into the future. An understanding of variability will allow one to judge whether the current conditions are simply a natural fluctuation of the system or a component of a long-term trend. Secondly, information on variability will allow water managers to identify solutions to the common problems faced by all users in Upper Sabino Creek Basin as the result of climatic or hydrologic variations. Finally, an understanding of variability resulting from ENSO will allow water management agencies to better predict the amount of precipitation the basin will receive several months in advance.

Variability within Upper Sabino Creek Basin

One of the most widely used descriptors of variability is the coefficient of variation (CV). It is the ratio of the standard deviation to the absolute value of the mean, and provides a scale-independent measure of variability for the process of interest. The formula is:

$$CV = \frac{\sigma}{|\mu|} \tag{15}$$

where σ is the standard deviation and μ is the mean.

~~This chapter discusses the variability of those hydrologic processes for which~~ independent data exist (temperature, precipitation, snowfall, streamflow, and consumptive use) rather than those that are estimated from these data (snowmelt and evapo-transpiration). Reconstructed streamflow and estimated temperature data are not included, since they are based on measurements observed outside of Upper Sabino Creek Basin.

Temperature. Temperature records from the Catalina Mountains vary from year to year, but show no discernable long-term trends (though this may be due to the absence of a long-term temperature record at any one location). Figure 6.1 is a plot of the CV for each month for each site with temperature data listed in Table 2.1. The greatest CVs are found during the months of November and December. Ski Valley exhibits the greatest range (0.02 to 0.28) and Mt. Lemmon School has the smallest range of values. Ski Valley has the lowest CV (0.13).

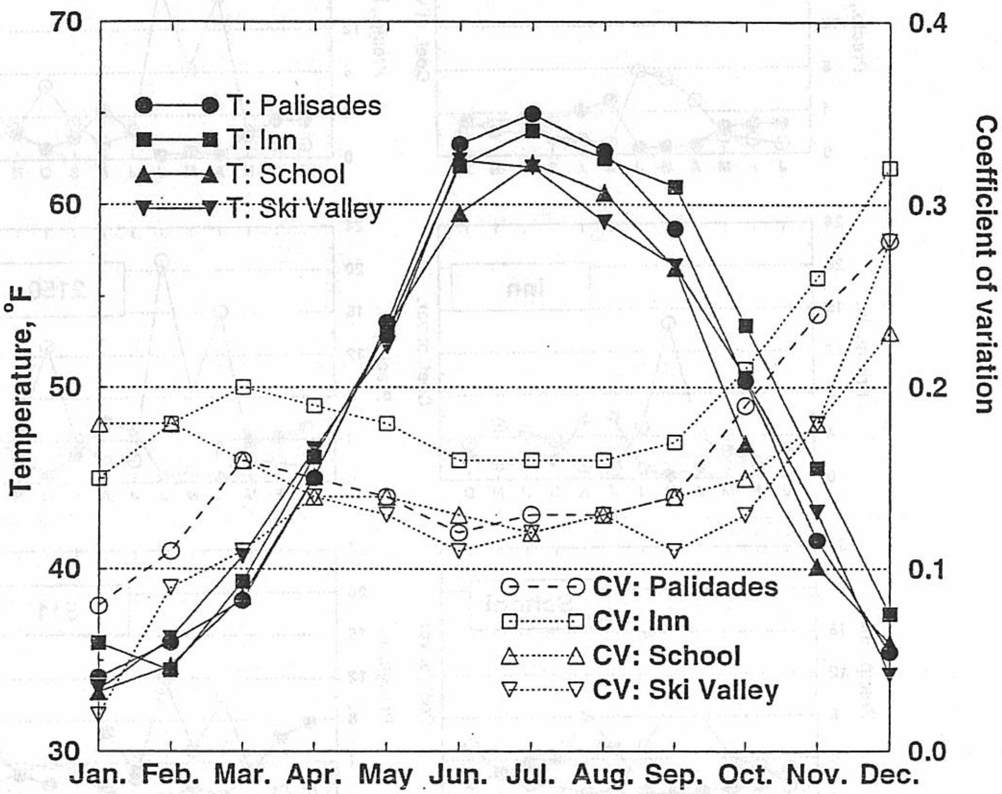

Figure 6.1, Coefficient of variation in average monthly temperatures

Precipitation. Coefficients of variation for the total monthly rainfall at each station range from 0.7 at the Mt. Lemmon School in August to 20.97 at ALERT station 2150 in June. ALERT station 2150 also exhibits the greatest variability over the course of a year. Precipitation recorded at Mt. Lemmon School exhibits the least variation, with a range of 8.82 between the minimum and maximum CVs. Figure 6.2 is a plot of monthly CV for each station and the mean rainfall for all stations.

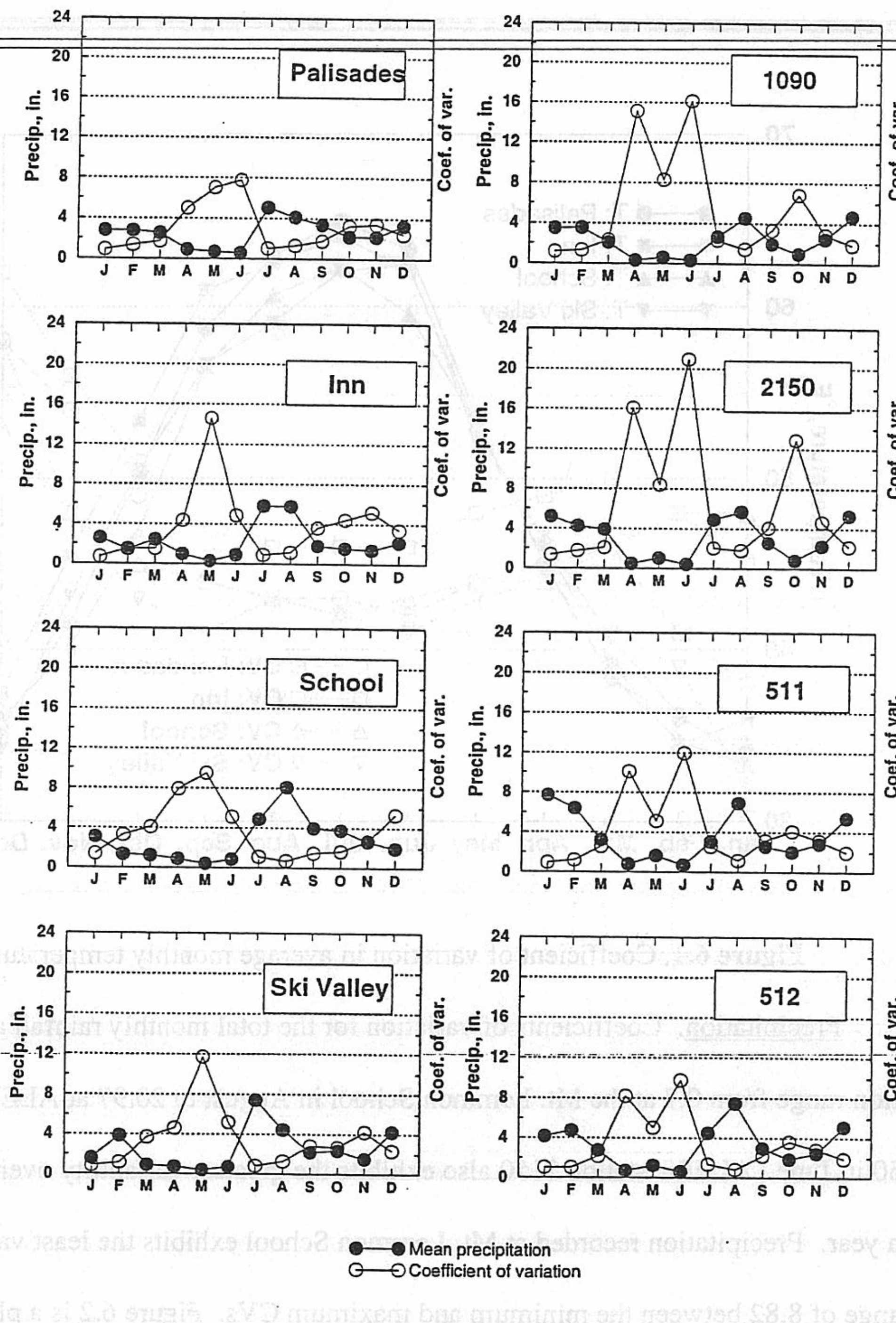

Figure 6.2. Coefficient of variation in monthly precipitation

CV is inversely proportional to precipitation: as mean precipitation increases, variation decreases. As Figure 6.2 shows, the months with the highest CVs (April, May, June) receive the least amount of rain. The variability of precipitation has implications for water management in upper Sabino Creek basin. High variability is not a significant concern in April since the majority of water in the basin during this month comes from snowmelt rather than rainfall. However, low rainfall in the months of May and June is important. All of the snow is generally melted, and precipitation does not significantly increase until July. Water collected in May and June often serves as the basis for summer supplies. With such high variability, water managers must take every opportunity to conserve water during these months.

Figure 6.3 is a plot of total basin precipitation for the period of record. The 1950's drought can be seen as an area of lower peaks while the high precipitation of the late 1980's is visible as well. Although individual stations report more rain during the summer months, Figure 6.3 shows that basin precipitation is generally higher in the later months of the year. This is due to the different types of precipitation events. Summer precipitation is generally isolated, and while an individual station may record significant rainfall, it is not necessarily evenly distributed throughout the basin. In contrast, winter rains, while lower in magnitude, are more widespread, and will therefore contribute more water overall to the basin. There is no discernible long-term trend: precipitation is the most variable hydrologic process in upper Sabino Creek basin.

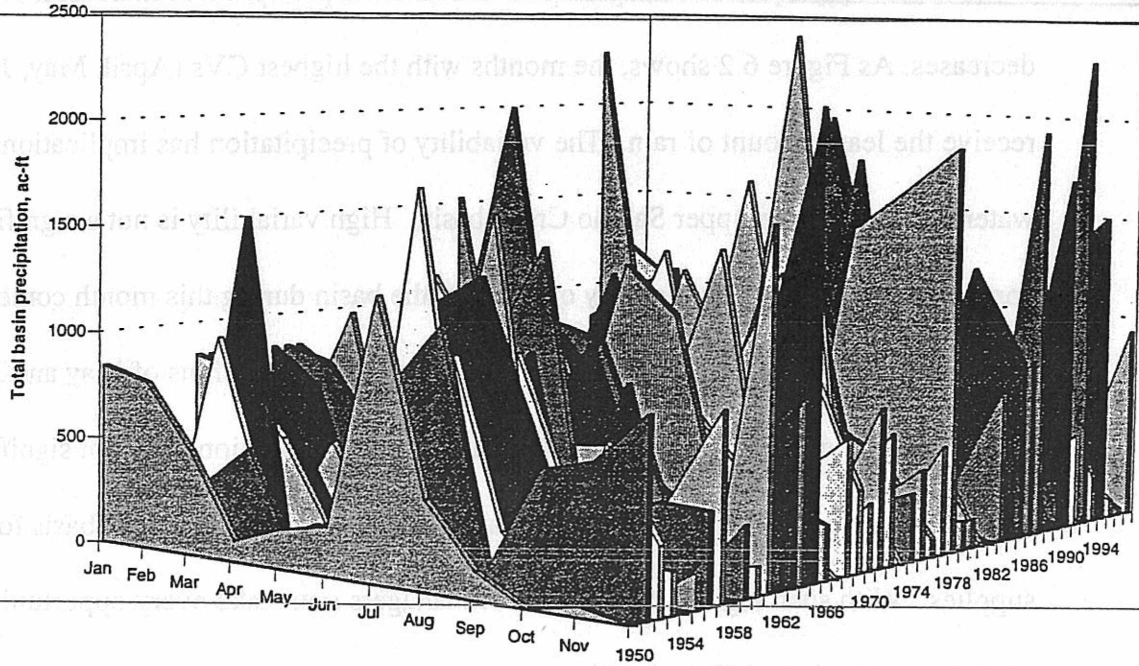

Figure 6.3, Total basin precipitation

Snowfall. In their study of snow in the Madrean province, Ffolliott *et. al.* (1996) noted that snow data "rarely approached the long-term average; a few values were indicative of extreme highs, and a relatively large number of values were below the long-term average." This is clearly represented in the snowfall record for upper Sabino Creek basin. **Figure 6.4** shows the monthly CV for each station recording snowfall.

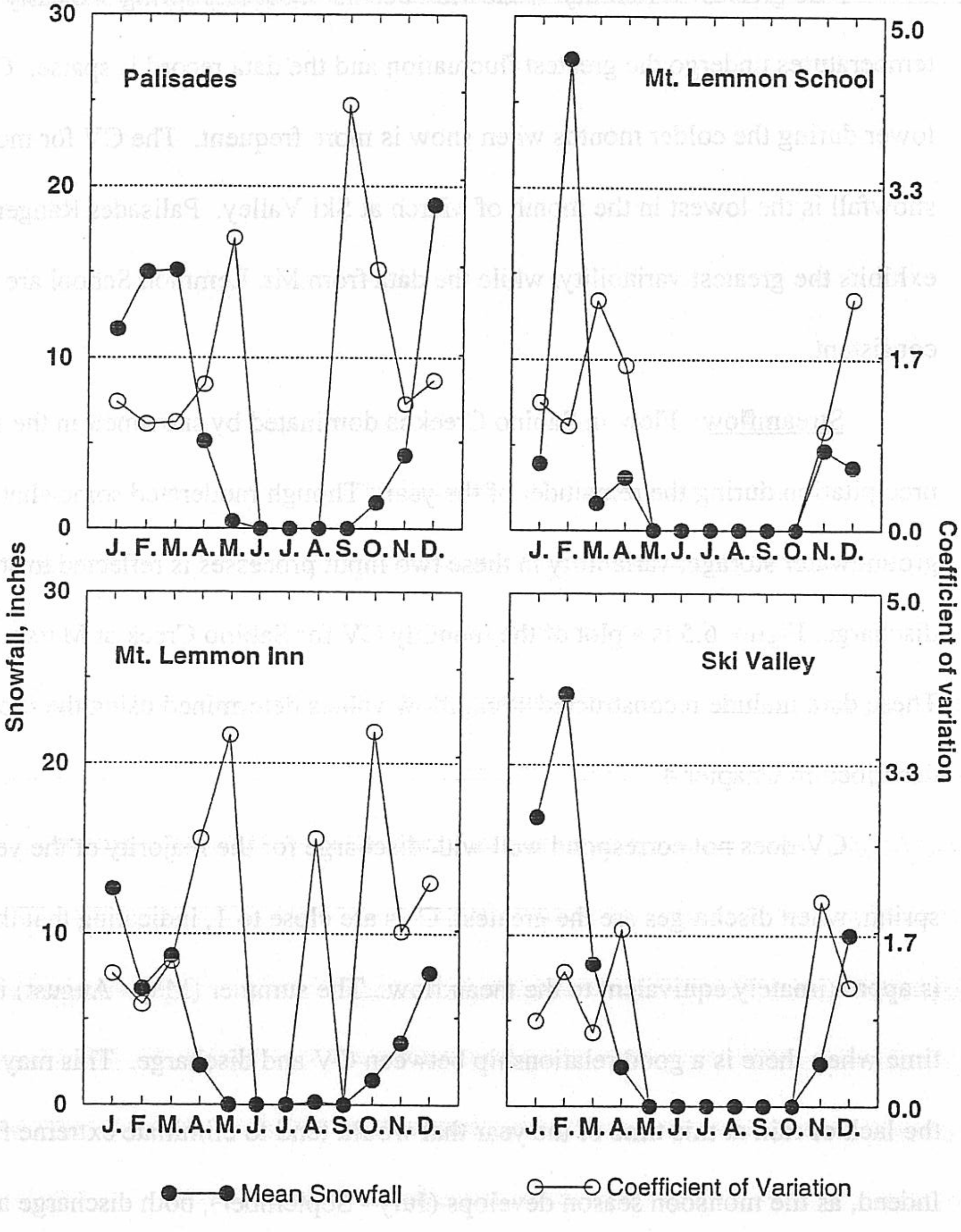

Figure 6.4, Coefficient of variation in monthly snowfall

The greatest variability in snowfall occurs in the late spring and early fall when temperatures undergo the greatest fluctuation and the data record is sparse. CVs are lower during the colder months when snow is more frequent. The CV for monthly snowfall is the lowest in the month of March at Ski Valley. Palisades Ranger Station exhibits the greatest variability, while the data from Mt. Lemmon School are the most consistent.

Streamflow. Flow in Sabino Creek is dominated by snowmelt in the spring and precipitation during the remainder of the year. Though moderated somewhat by soil and groundwater storage, variability in these two input processes is reflected in stream discharge. Figure 6.5 is a plot of the monthly CV for Sabino Creek at Marshall Gulch. These data include reconstructed streamflow values determined using the process described in Chapter 4.

CV does not correspond well with discharge for the majority of the year. In the spring, when discharges are the greatest, CVs are close to 1, indicating that the variability is approximately equivalent to the mean flow. The summer (May - August) is the only time when there is a good relationship between CV and discharge. This may be due to the lack of rain at this time of the year that would tend to eliminate extreme flow events. Indeed, as the monsoon season develops (July - September), both discharge and CV increase. The high CVs for the remainder of the year (September - December) may reflect both historical extreme flow events and the greater variability of precipitation.

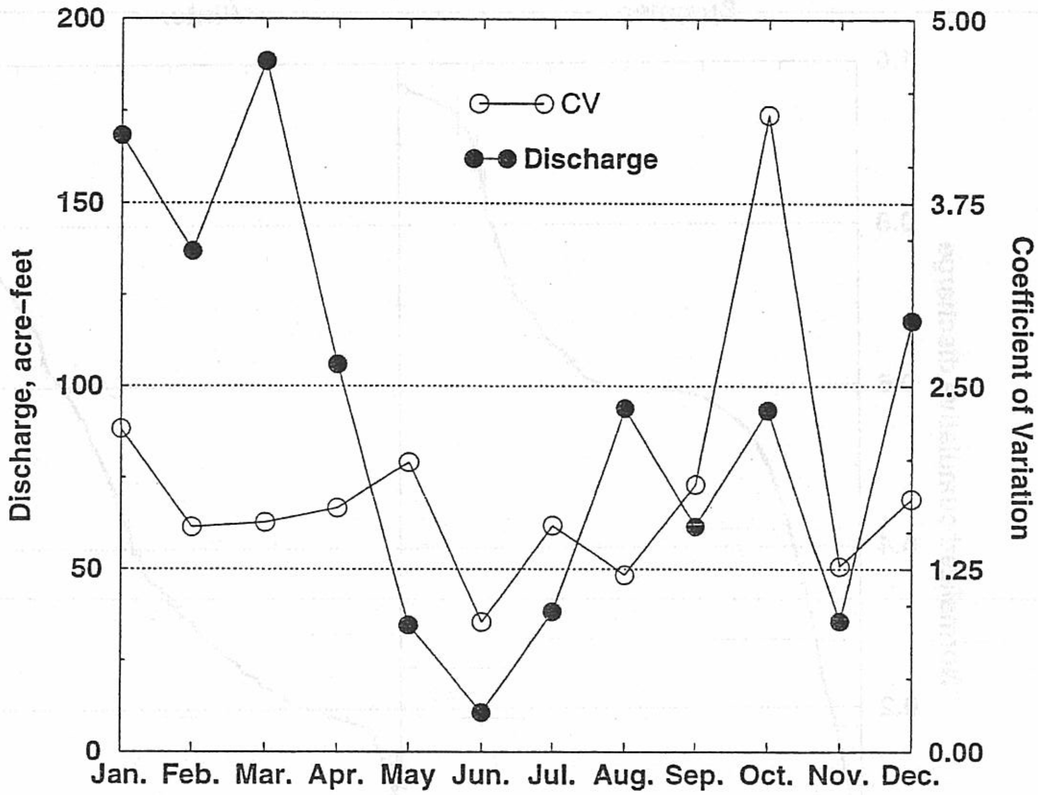

Figure 6.5. Monthly CV for streamflow

Plots of summer and winter cumulative daily discharge at Marshall Gulch are shown in Figure 6.6. The different shapes of the two curves indicate that different processes control streamflow during the year. In the summer, Sabino Creek reaches half of its cumulative discharge very quickly before leveling off for approximately one month. The latter portion of the summer is also a time of rapid rise, and may represent monsoon precipitation. The rise in cumulative winter discharge is much more uniform after the first month, and reflects winter precipitation and snowmelt.

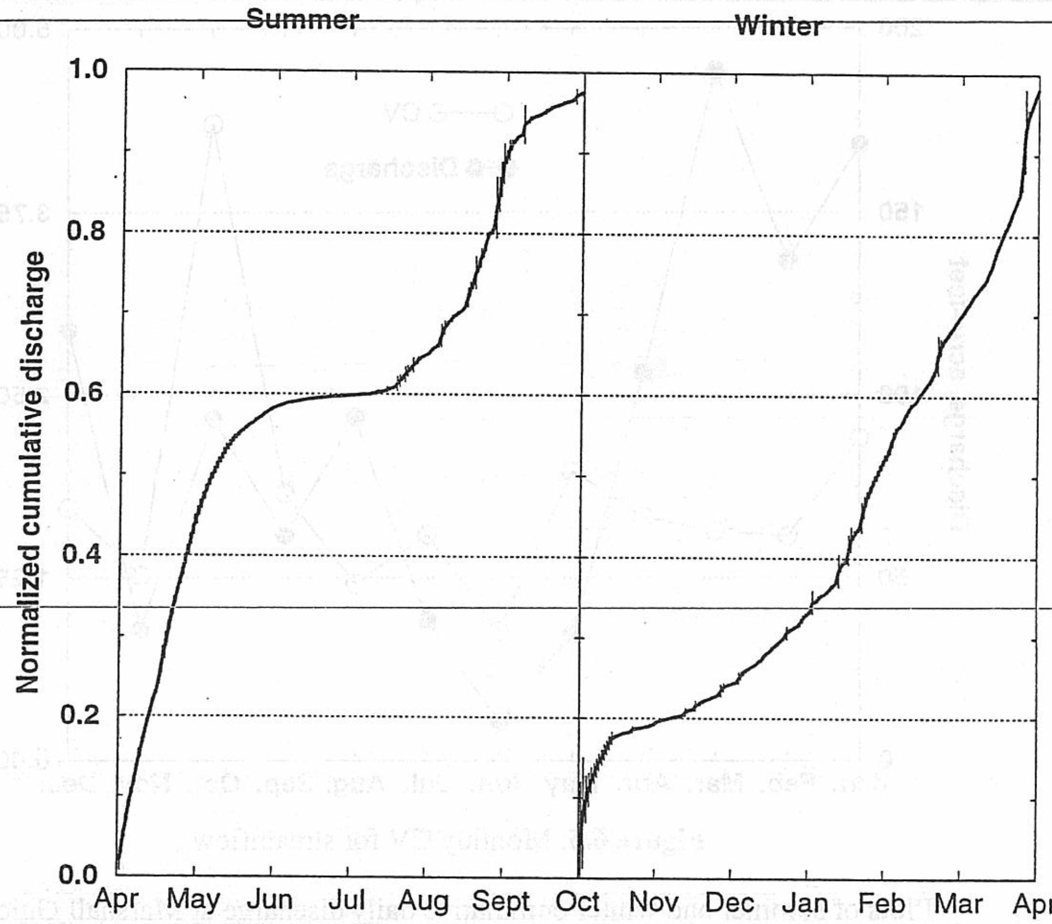

Figure 6.6, Cumulative mean discharge distribution

For the summer months, the standard deviation is less than the mean. For the winter months, the standard deviation is greater than the mean. This is likely due to the different mechanisms responsible for streamflow. Winter streamflow results from snowmelt and winter precipitation, neither of which is generally an extreme hydrologic process. In contrast, summer precipitation is derived from isolated monsoon storms, which are very short in duration but produce large quantities of rainfall.

Figure 6.7 is a plot of discharge for the period of record. The influence of abnormally high streamflows in October of 1983 and January of 1993 is quite apparent. The central portion of the graph (1974 – 1982) where the discharge is equal from year to year reflects the use of mean monthly discharge values, as no discharge was recorded at either the Marshall Gulch or Sabino Canyon gaging stations.

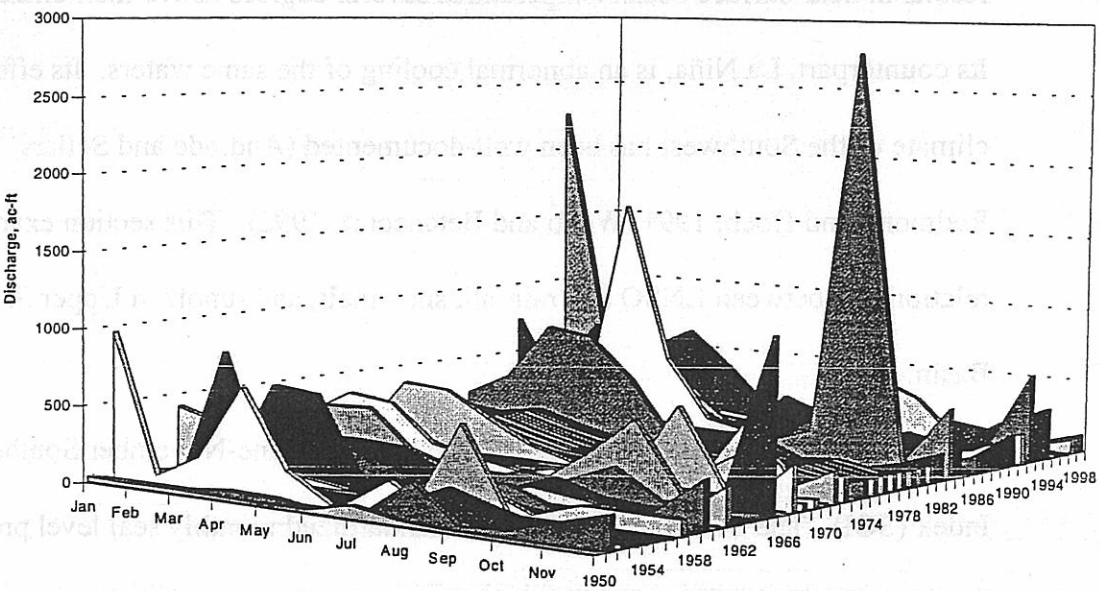

Figure 6.7, Monthly discharge, Sabino Creek at Marshall Gulch

Consumptive Use. The coefficient of variability in the domestic use of water is approximately 1.8 during the months of May and October (when the storage tanks are re-filled) and less than one between June and September (the months of greatest use). The period of record for groundwater pumping from the U.S. Forest Service well in Upper Sabino Canyon is only for 19 discontinuous months in a three-year period. This is not a long enough time period from which to derive meaningful values for variability.

Climatic Variability

The El Niño Southern Oscillation (ENSO) phenomenon has been described by many researchers (Rasmusson and Carpenter, 1982; Cane, 1983; Rasmusson, 1984; Ramage, 1986) and is currently the subject of on-going research. El Niño is the term given to a periodic warming of the eastern Pacific often noticed in late December. It results in near-surface ocean temperatures several degrees above their climatic average. Its counterpart, La Niña, is an abnormal cooling of the same waters. Its effect on the climate of the Southwest has been well-documented (Andrade and Sellars, 1988; Redmond and Koch, 1991; Webb and Betancourt, 1992). This section examines the relationship between ENSO and rainfall, snowmelt, and runoff in Upper Sabino Creek Basin.

The ENSO phenomenon is quantified by the June-November Southern Oscillation Index (SOI). The SOI is defined as the "standardized monthly seal level pressure departure from average at Tahiti minus the standardized monthly departure at Darwin, Australia" (Redmond and Koch, 1991). A negative SOI value indicates a weak pressure gradient between the eastern South Pacific and Indonesia: El Niño. A reverse in the pressure gradient (positive SOI values) indicates La Niña conditions. Values between -0.5 and 0.5 are considered to be neutral, and indiciatve of neither El Niño nor La Niña. Figure 6.8 is a plot of the SOI for the time period 1950 - 1997.

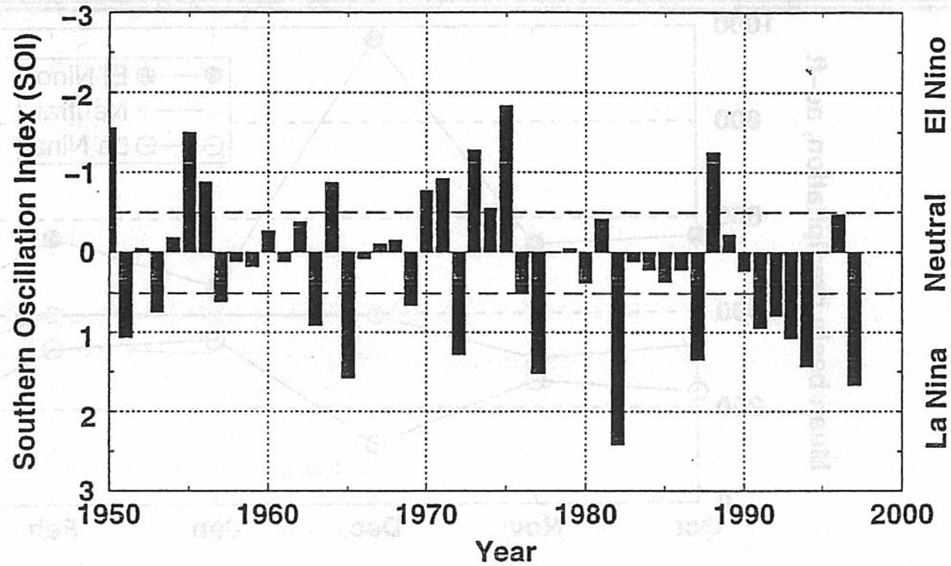

Figure 6.8, Southern Oscillation Index, 1950-1997

For the time period covered by this thesis (1950-1997), there are 10 El Niño years, 15 La Niña years, and 23 neutral years.

ENSO is a time-lagged phenomenon (Redmond and Koch, 1991). Its effects may not be apparent until the following winter or summer. In order to determine the effect of ENSO upon the hydrologic processes operating in upper Sabino Creek basin, comparisons were made between the water budget components of precipitation, snowmelt, and discharge for El Niño, La Niña, and neutral winters.

<u>Precipitation</u>. Monthly basin precipitation totals (rainfall and snowfall) were calculated for the winters following El Niño, La Niña, and neutral summers. Figure 6.9 shows the difference in mean monthly precipitation to Upper Sabino Creek basin.

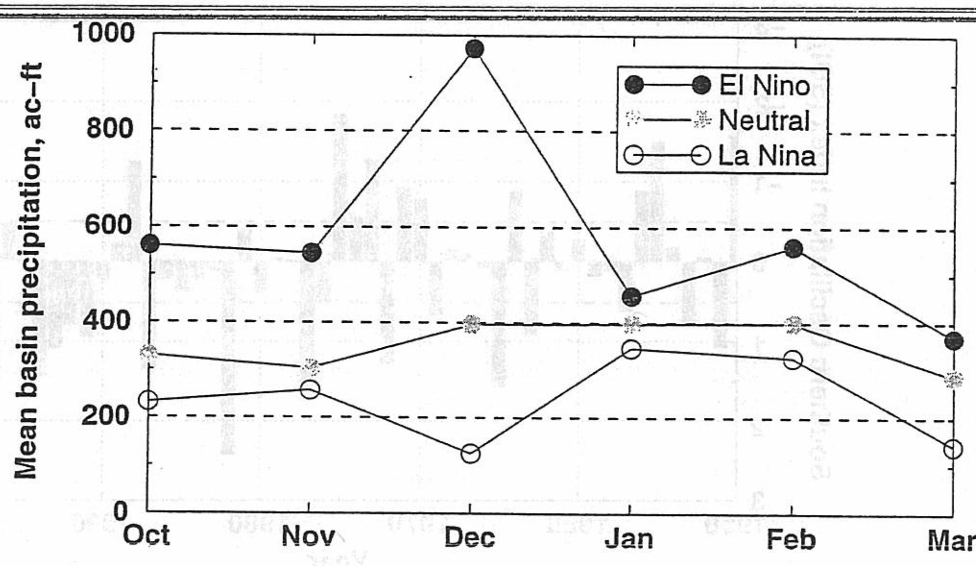

Figure 6.9, Mean monthly precipitation for El Niño, neutral, and La Niña winters

The months following strong El Niño events have significantly more precipitation than neutral years or La Niña years. Additionally, El Niño winters show an increase in December precipitation that is reversed for Decembers following strong La Niña years.

Figure 6.10 shows the total winter precipitation for all years plotted against the SOI value for the preceding summer. El Niño winters exhibit the highest mean precipitation (3,317 ac-ft), and also have a high standard deviation (1,573 ac-ft). In neutral winters, the mean precipitation drops approximately 1,000 ac-ft to 2,524 ac-ft, but the standard deviation is within 98% of El Niño winters. La Niña winters have both the lowest mean precipitation (2,056 ac-ft) and the lowest standard deviation (970 ac-ft). There is a decreasing trend with increasing SOI, both within each category and among the data set as a whole.

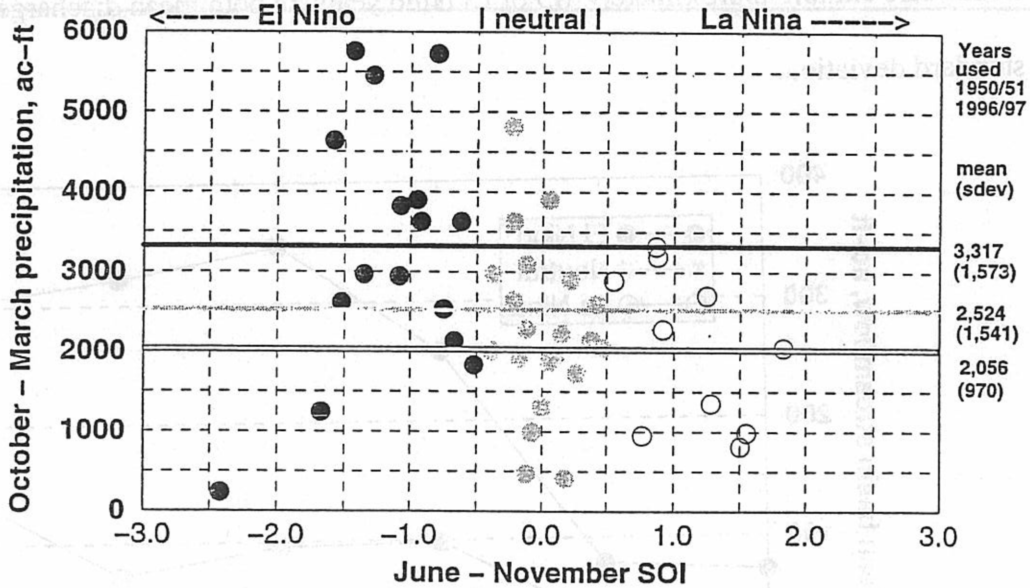

Figure 6.10, Southern Oscillation Index and October – March precipitation

Streamflow. The same approach was used to compare streamflow. The data used for this analysis included both recorded and reconstructed data. Mean monthly discharge data for the months following various SOI summers are plotted in Figure 6.11. The difference between El Niño and La Niña years is most apparent between December and March. El Niño discharge is approximately three times greater than neutral years, and La Niña discharge is generally less than one quarter of that in neutral years.

Figure 6.12 shows the variability in winter streamflow against SOI. Like precipitation, the mean and standard deviation are highest for El Niño years (1,287 ac-ft and 993 ac-ft, respectively). In neutral years, the mean is approximately 2/3 lower than El Niño years (798 ac-ft) and the standard deviation is actually higher than the mean. La

Niña years exhibit approximately 1/3 of El Niño years, in both mean discharge and standard deviation.

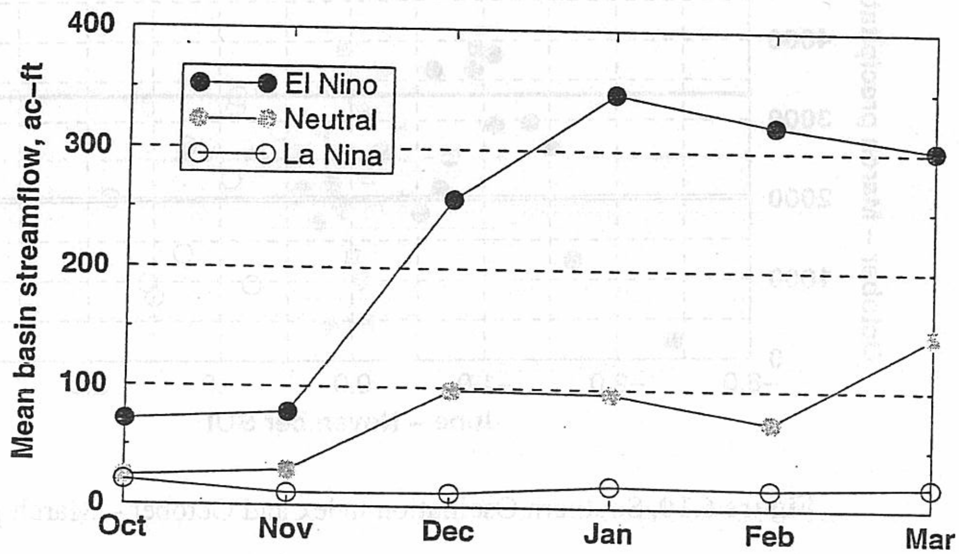

Figure 6.11, Mean monthly streamflow for El Niño, neutral, and La Niña winters

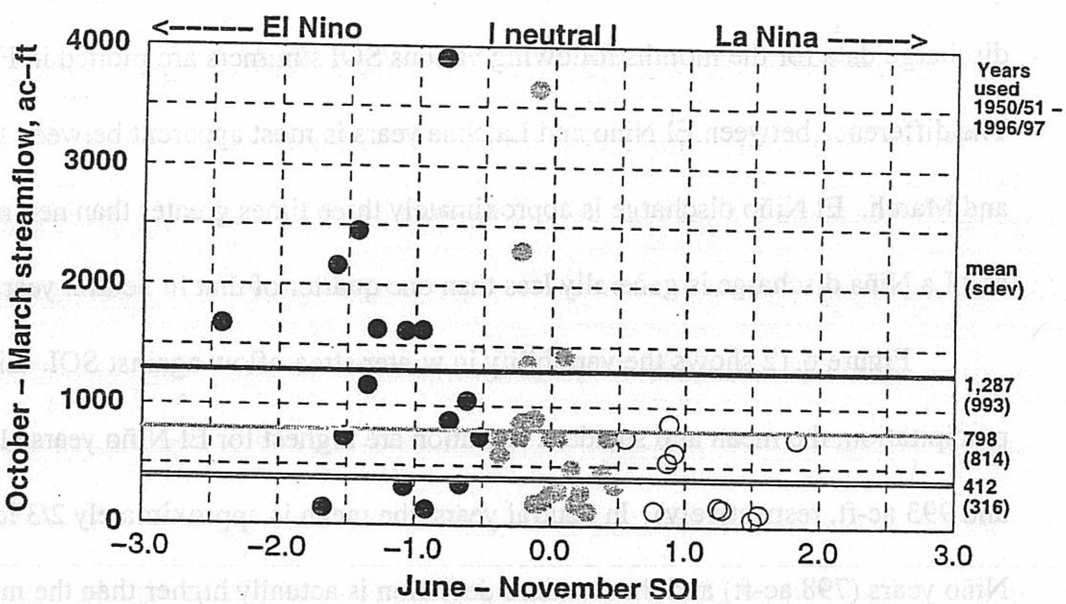

Figure 6.12, Southern Oscillation Index and October – March streamflow

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Two hydrologic processes dominate the hydrology of Upper Sabino Creek Basin: precipitation and evapotranspiration. Together, these two processes account for approximately 56% of the mean monthly mass entering or leaving the basin. Groundwater recharge and soil moisture storage account for 19%. Streamflow, while important for aesthetic and regulatory reasons, is a relatively minor component of the hydrology of the basin at 9% of the mean monthly mass flux. Snowfall and snowmelt each account for 9%, and the remaining processes account for less than 1%of the mean monthly mass flux. Consumptive use is negated by recharge to the basin through septic systems and domestic use. More data must be collected to better understand the annual water cycle in the study area and the implications for mountain-front recharge to the Tucson Basin.

The variability of the process operating within upper Sabino Creek basin (as measured by CV) is the greatest for precipitation and the least for temperature. Streamflow is less variable than precipitation, but the standard deviation can be up to five times the mean value. The high variability of these processes makes an understanding of their operation especially important for water managers.

One approach towards understanding this variability is an examination of ENSO data. Using readily available data, water managers can make qualitative assumptions regarding the amount of precipitation or streamflow expected in the coming months. This will be an invaluable tool that can be used to prepare for times of drought.

Recommendations

Measurements and Data Collection Many of the calculations in this study are based on estimated values, as there are insufficient data on many hydrologic processes in the study site. In order to create a more realistic water budget for Upper Sabino Creek basin, more data must be collected. In particular, future work on the water budget of Upper Sabino Creek basin should include efforts to better quantify soil moisture and groundwater fluxes. At present, there are no recent soil moisture data available. Soil moisture should be regularly monitored at various elevations, slope aspects, and soil types on a long-term basis.

Information on groundwater conditions, aquifer extent, and hydrogeologic properties is very limited. Without more details on the hydraulic properties of the bedrock, it is difficult to estimate groundwater storage or the potential for mountain-front recharge. While it would not be cost-effective to conduct a large-scale drilling program for the sole purpose of defining aquifer properties; the installation of several piezometers in different geologic units could help determine hydraulic properties and groundwater fluxes. Additionally, data from future drilling projects will be very helpful to future researchers studying upper Sabino Creek basin.

There is also limited information on groundwater-surface water interactions. The installation of a series of piezometers in the alluvium of Sabino Creek would allow one to better quantify the underflow component of the water budget. Regular monitoring of the discharge of Sabino Creek at multiple sites in the study area will indicate areas of stream gain or loss. Continuous discharge measurement of Sabino Creek at Marshall Gulch must be maintained so that discharge may be more accurately described. The flow rate of springs should be consistently measured and recorded.

Water Management Demands on Sabino Creek could be reduced through water conservation measures plus the construction of storage facilities. The amount of water used by both the M.L.W.C. and the U.S.F.S. from June through November is approximately 3.1 million gallons (9.66 acre-feet). The existing storage capacity is approximately 900,000 gallons. The development of an additional 2.2 million gallons of storage capacity (for a total of 3.1 million gallons) would allow the M.L.W.C. and the U.S.F.S. to meet their demands without drawing water from springs that feed Sabino Creek. The flow of Sabino Creek would be unimpeded by domestic consumption during the months of the year when its natural flow is the lowest.

The M.L.W.C. and Forest Service also need to resolve issues related to in-stream flow on Sabino Creek. The current application (filed by the Forest Service) seeks the right of 0.9 cfs at Marshall Gulch (or the natural flow, whichever is greater). Discharges of 0.9 cfs or greater have only been measured for 35% of dates on record (see Figure 2.9, flow exceedence chart) and the adoption of 0.9 cfs could initiate a situation where the M.L.W.C. was unable to meet customer demands for water. While the enhancement of storage capacity would help minimize the impact of this situation, lowering the in-stream flow rate to a more frequently observed value should also be evaluated. A rate of 0.1 cfs or higher is observed 75% of the time; 0.2 cfs or higher is observed approximately 50% of the time.

Another issue between the M.L.W.C. and the U.S. Forest Service is the operation of the Forest Service's well situated approximately 40 feet from Sabino Creek. Water pumped from this well is used to supply Forest Service water needs at Palisades and other locations in the Santa Catalina Ranger District. If it returns to Sabino Creek at all, it does so below the Marshall Gulch gaging station. While the overall impact of this well on the hydrology of the basin is minimal; during a drought, pumping could diminish the flow of the M.L.W.C.'s springs. It is likely that the well has some impact on creek flow due to its proximity, but at present there are not enough data available to quantitatively estimate the effects of pumping. Increased pumping in dry periods could deplete the flow of Sabino Creek making it more difficult for the M.L.W.C. to meet its supply needs if the proposed in-stream flow right is approved.

More data collection is needed to better understand the variability present in the natural processes operating in upper Sabino Creek Basin. The information presented here will hopefully provide a comprehensive view of the hydrology of upper Sabino Creek and allow decision-makers to have a basis for their policy.

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APPENDIX 1, MONTHLY WATER BUDGET 1950 – 1997

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1950	1	*327.73*	512.60	512.60	*37.49*	128.02	673.62	0.00	673.62	0.513
1950	2	*584.98*	194.99	194.99	*33.01*	176.89	568.87	0.00	568.87	0.517
1950	3	*418.99*	68.21	68.21	*30.60*	283.81	171.58	0.00	171.58	0.527
1950	4	*84.83*	11.57	11.57	*20.42*	421.61	-346.83	0.00	-346.83	0.539
1950	5	*182.68*	0.00	0.00	*18.47*	550.83	-387.82	0.00	-387.82	0.550
1950	6	227.76	0.00	0.00	*18.80*	564.52	-356.75	0.00	-356.75	0.552
1950	7	1286.83	0.00	0.00	*88.47*	504.43	692.73	0.00	692.73	0.547
1950	8	413.23	0.00	0.00	*34.56*	472.94	-95.47	0.00	-95.47	0.544
1950	9	128.78	0.00	0.00	*18.93*	366.57	-257.93	0.00	-257.93	0.535
1950	10	0.00	0.00	0.00	*18.42*	309.67	-329.29	0.00	-329.29	0.529
1950	11	0.93	45.58	45.58	*18.41*	188.72	-161.82	0.00	-161.82	0.518
1950	12	0.00	0.00	0.00	*18.43*	151.25	-170.89	0.00	-170.89	0.515
1951	1	175.82	294.73	294.73	*18.52*	142.66	308.16	0.00	308.17	0.579
1951	2	145.80	11.80	11.80	*18.46*	165.52	-27.58	0.00	-27.58	0.588
1951	3	234.24	82.96	82.96	*20.17*	282.95	12.87	0.00	12.88	0.630
1951	4	517.86	0.00	0.00	*46.60*	397.21	72.85	0.00	72.85	0.666
1951	5	57.17	0.00	0.00	*41.93*	640.69	-626.66	0.00	-626.65	0.734
1951	6	0.00	0.00	0.00	0.65	752.71	-754.58	0.00	-754.57	0.762
1951	7	868.65	0.00	0.00	27.35	786.96	53.13	0.00	53.13	0.771
1951	8	1168.24	0.00	0.00	253.69	624.59	288.75	0.00	288.76	0.730
1951	9	131.77	0.00	0.00	26.08	516.57	-412.09	0.00	-412.09	0.701
1951	10	583.82	13.12	13.12	42.74	334.51	218.48	0.00	218.49	0.646
1951	11	472.80	186.14	186.14	138.05	182.28	337.41	0.00	337.42	0.594
1951	12	38.13	845.09	845.09	221.36	131.41	529.25	0.00	529.26	0.575

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1952	1	34.88	597.24	597.24	957.82	126.63	-453.53	0.00	-453.53	0.500
1952	2	50.21	0.00	0.00	55.74	132.15	-138.87	0.00	-138.87	0.498
1952	3	852.87	147.52	147.52	205.88	174.09	619.21	0.00	619.21	0.483
1952	4	278.29	0.00	0.00	685.69	268.37	-676.97	0.00	-676.97	0.446
1952	5	0.00	0.00	0.00	194.98	361.93	-558.10	0.00	-558.10	0.399
1952	6	158.34	0.00	0.00	20.63	385.06	-248.55	0.00	-248.55	0.384
1952	7	744.33	0.00	0.00	13.41	376.04	353.67	0.00	353.67	0.390
1952	8	1030.96	0.00	0.00	43.62	349.75	636.40	0.00	636.40	0.406
1952	9	284.50	0.00	0.00	10.06	309.69	-36.45	0.00	-36.45	0.427
1952	10	0.00	0.00	0.00	1.33	255.57	-258.10	0.00	-258.10	0.451
1952	11	157.16	573.11	573.11	9.44	139.32	580.31	0.00	580.31	0.496
1952	12	103.65	214.70	214.70	25.59	110.59	180.98	0.00	180.98	0.505
1953	1	48.76	0.84	0.84	41.06	136.94	-129.60	0.00	-129.60	0.489
1953	2	160.78	48.43	48.43	21.62	135.43	50.96	0.00	50.96	0.490
1953	3	100.48	459.08	459.08	194.98	212.76	558.01	203.69	354.32	0.455
1953	4	0.00	0.00	203.69	55.93	264.35	-525.18	-203.69	-321.49	0.429
1953	5	85.13	0.00	0.00	15.03	306.63	-237.74	0.00	-237.74	0.403
1953	6	48.72	0.00	0.00	3.89	365.32	-321.68	0.00	-321.68	0.355
1953	7	1751.83	0.00	0.00	200.83	351.09	1198.71	0.00	1198.71	0.369
1953	8	112.06	0.00	0.00	21.22	312.95	-223.31	0.00	-223.31	0.399
1953	9	0.00	0.00	0.00	0.77	299.16	-301.14	0.00	-301.14	0.408
1953	10	7.85	4.28	4.28	0.00	228.04	-217.11	0.00	-217.11	0.448
1953	11	30.66	194.16	194.16	0.00	159.97	63.65	0.00	63.65	0.479
1953	12	45.06	150.85	150.85	0.30	109.98	84.43	0.00	84.43	0.500

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1954	1	213.59	197.42	197.42	1.86	146.17	261.79	0.00	261.79	0.587
1954	2	139.47	0.00	0.00	14.28	198.36	-74.37	0.00	-74.37	0.603
1954	3	1553.44	0.00	0.00	861.42	211.62	479.20	0.00	479.20	0.607
1954	4	0.00	0.00	0.00	60.10	313.70	-375.00	0.00	-375.00	0.635
1954	5	160.09	0.00	0.00	13.13	628.42	-482.66	0.00	-482.66	0.711
1954	6	369.05	0.00	0.00	2.22	725.44	-359.81	0.00	-359.81	0.732
1954	7	1222.24	0.00	0.00	53.61	702.55	464.88	0.00	464.88	0.727
1954	8	1369.95	0.00	0.00	181.49	567.27	619.99	0.00	619.99	0.697
1954	9	726.23	0.00	0.00	88.26	475.67	161.09	0.00	161.09	0.676
1954	10	27.91	0.00	0.00	24.79	334.97	-333.06	0.00	-333.06	0.641
1954	11	0.00	0.00	0.00	9.00	227.23	-237.44	0.00	-237.44	0.611
1954	12	0.00	0.00	0.00	6.57	116.85	-124.62	0.00	-124.62	0.578
1955	1	174.99	94.29	94.29	16.86	81.96	169.27	0.00	169.27	0.496
1955	2	0.00	90.65	90.65	54.94	113.47	-78.96	0.00	-78.96	0.478
1955	3	16.27	0.00	0.00	67.24	194.08	-246.25	0.00	-246.25	0.419
1955	4	*84.83*	11.57	11.57	20.83	259.95	-185.58	0.00	-185.58	0.343
1955	5	*182.68*	0.00	0.00	6.23	280.20	-104.95	0.00	-104.95	0.284
1955	6	*84.47*	0.00	0.00	2.44	280.78	-199.95	0.00	-199.95	0.261
1955	7	*613.77*	0.00	0.00	14.34	277.02	321.21	0.00	321.21	0.302
1955	8	1640.30	0.00	0.00	559.93	223.31	855.86	0.00	855.86	0.392
1955	9	14.97	0.00	0.00	40.07	251.62	-277.92	0.00	-277.92	0.357
1955	10	57.02	0.00	0.00	4.96	212.87	-162.00	0.00	-162.00	0.402
1955	11	2.86	9.54	9.54	4.28	146.22	-139.30	0.00	-139.30	0.456
1955	12	0.00	169.79	169.79	5.61	114.40	48.57	0.00	48.57	0.477

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1956	1	0.85	101.20	101.20	5.20	135.77	-40.12	0.00	-40.12	0.559
1956	2	414.47	61.12	61.12	23.60	66.70	384.09	0.00	384.09	0.549
1956	3	0.00	0.00	0.00	17.45	226.79	-245.44	0.00	-245.44	0.572
1956	4	113.74	0.00	0.00	6.55	358.63	-252.64	0.00	-252.64	0.590
1956	5	0.00	0.00	0.00	1.59	593.73	-596.52	0.00	-596.52	0.620
1956	6	110.84	0.00	0.00	0.00	505.79	-396.16	0.00	-396.16	0.609
1956	7	*613.77*	0.00	0.00	22.37	587.80	2.40	0.00	2.40	0.619
1956	8	*1008.04*	0.00	0.00	6.92	469.85	530.07	0.00	530.07	0.605
1956	9	*415.45*	0.00	0.00	1.61	351.84	60.80	0.00	60.80	0.589
1956	10	*182.01*	51.34	51.34	0.14	238.43	-6.42	0.00	-6.42	0.574
1956	11	*169.30*	264.80	264.80	0.02	160.93	271.96	0.00	271.96	0.563
1956	12	254.68	169.79	169.79	0.50	134.79	287.98	0.00	287.98	0.559
1957	1	*327.73*	512.60	512.60	417.12	133.42	288.58	0.00	288.58	0.572
1957	2	*584.98*	194.99	194.99	332.03	200.32	246.42	0.00	246.42	0.587
1957	3	*418.99*	68.21	68.21	114.05	319.73	52.22	0.00	52.22	0.612
1957	4	*84.83*	11.57	11.57	51.97	516.05	-472.82	0.00	-472.82	0.651
1957	5	*182.68*	0.00	0.00	11.39	672.13	-502.04	0.00	-502.04	0.678
1957	6	*84.47*	0.00	0.00	1.07	764.66	-682.47	0.00	-682.47	0.694
1957	7	*613.77*	0.00	0.00	5.18	638.39	-31.00	0.00	-31.00	0.673
1957	8	*1008.04*	0.00	0.00	137.24	505.60	364.00	0.00	364.00	0.649
1957	9	*415.45*	0.00	0.00	12.58	356.07	45.60	0.00	45.60	0.620
1957	10	*182.01*	51.34	51.34	109.43	239.25	-116.53	0.00	-116.53	0.596
1957	11	*169.30*	264.80	264.80	111.27	136.97	184.66	0.00	184.66	0.573
1957	12	*221.70*	631.00	631.00	107.11	121.02	623.38	0.00	623.38	0.569

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1958	1	*327.73*	512.60	512.60	25.19	121.17	692.77	0.00	692.77	0.496
1958	2	*584.98*	194.99	194.99	84.69	154.21	539.87	0.00	539.87	0.483
1958	3	*418.99*	68.21	68.21	608.13	229.94	-352.08	0.00	-352.08	0.449
1958	4	*96.40*	0.00	0.00	576.60	313.04	-794.44	0.00	-794.44	0.403
1958	5	*182.68*	0.00	0.00	66.25	376.55	-261.32	0.00	-261.32	0.351
1958	6	*84.47*	0.00	0.00	12.04	380.72	-309.49	0.00	-309.49	0.346
1958	7	*613.77*	0.00	0.00	22.61	354.24	235.72	0.00	235.72	0.372
1958	8	*1008.04*	0.00	0.00	50.30	321.59	634.94	0.00	634.94	0.397
1958	9	14.97	0.00	0.00	8.39	175.90	-170.51	0.00	-170.51	0.474
1958	10	408.88	0.00	0.00	94.55	227.22	85.91	0.00	85.91	0.451
1958	11	0.91	34.75	34.75	34.31	145.94	-145.80	0.00	-145.80	0.486
1958	12	0.00	0.00	0.00	15.49	138.88	-155.57	0.00	-155.57	0.489
1959	1	11.05	17.29	17.29	6.09	138.61	-117.55	0.00	-117.55	0.477
1959	2	0.00	0.00	0.00	20.01	143.00	-164.21	0.00	-164.21	0.475
1959	3	0.00	0.00	0.00	15.67	211.82	-228.69	0.00	-228.69	0.435
1959	4	0.00	0.00	0.00	*18.52*	278.55	-298.27	0.00	-298.27	0.384
1959	5	0.00	0.00	0.00	*18.37*	314.25	-333.82	0.00	-333.82	0.343
1959	6	110.84	0.00	0.00	*18.37*	329.04	-237.77	0.00	-237.77	0.317
1959	7	1013.96	0.00	0.00	*128.32*	321.62	562.83	0.00	562.83	0.331
1959	8	1476.41	0.00	0.00	*133.32*	300.61	1041.28	0.00	1041.28	0.361
1959	9	14.97	0.00	0.00	*24.77*	269.72	-280.71	0.00	-280.71	0.392
1959	10	360.95	324.56	324.56	*91.72*	222.66	369.93	0.00	369.93	0.428
1959	11	0.00	41.86	41.86	*78.91*	165.93	-204.18	0.00	-204.18	0.462
1959	12	0.00	334.68	334.68	*320.71*	121.60	-108.83	0.00	-108.83	0.485

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1960	1	239.21	441.10	441.10	*558.20*	29.86	91.04	0.00	91.04	0.145
1960	2	86.37	46.12	46.12	*148.44*	36.33	-53.48	0.00	-53.48	0.143
1960	3	37.41	0.00	0.00	*152.05*	68.01	-183.85	0.00	-183.85	0.137
1960	4	0.00	0.00	0.00	*47.09*	82.23	-130.52	0.00	-130.52	0.134
1960	5	66.07	0.00	0.00	*20.29*	107.50	-62.92	0.00	-62.92	0.128
1960	6	0.00	0.00	0.00	*18.39*	128.40	-147.98	0.00	-147.98	0.122
1960	7	421.41	0.00	0.00	*25.22*	121.67	273.31	0.00	273.31	0.124
1960	8	0.00	0.00	0.00	*22.16*	110.37	-133.74	0.00	-133.74	0.127
1960	9	245.57	0.00	0.00	*19.81*	90.71	133.85	0.00	133.85	0.132
1960	10	178.12	5.09	5.09	*18.41*	62.84	100.75	0.00	100.75	0.138
1960	11	91.48	0.00	0.00	*18.37*	45.04	26.86	0.00	26.86	0.142
1960	12	6.90	133.50	133.50	*18.42*	34.10	86.68	0.00	86.68	0.144
1961	1	*327.73*	512.60	497.27	*21.31*	0.00	833.15	15.33	817.82	0.539
1961	2	35.73	3.32	18.65	*20.74*	178.12	-176.35	-15.33	-161.02	0.599
1961	3	434.31	0.00	0.00	*25.09*	306.78	101.25	0.00	101.25	0.636
1961	4	6.05	0.00	0.00	*26.73*	435.81	-457.69	0.00	-457.69	0.670
1961	5	0.00	0.00	0.00	*18.39*	587.55	-607.14	0.00	-607.14	0.707
1961	6	60.90	0.00	0.00	*18.37*	742.57	-701.24	0.00	-701.24	0.741
1961	7	548.96	0.00	0.00	*18.37*	712.90	-183.51	0.00	-183.51	0.735
1961	8	558.91	0.00	0.00	*96.82*	600.00	-139.11	0.00	-139.11	0.709
1961	9	582.48	0.00	0.00	*58.77*	434.55	87.97	0.00	87.97	0.670
1961	10	0.00	123.76	123.76	*18.90*	304.69	-201.03	0.00	-201.03	0.636
1961	11	88.38	4.65	4.65	*30.26*	197.56	-135.99	0.00	-135.99	0.605
1961	12	292.94	1341.26	1341.26	*243.94*	134.73	1579.69	162.68	1417.01	0.585

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1962	1	0.00	650.54	487.86	*239.65*	120.76	-199.11	-162.68	-36.43	0.455
1962	2	115.06	115.06	277.74	*199.13*	122.26	70.21	0.00	70.21	0.454
1962	3	354.94	2.92	2.92	*169.28*	130.55	56.84	0.00	56.84	0.447
1962	4	0.00	0.00	0.00	*146.48*	213.95	-361.63	0.00	-361.63	0.342
1962	5	0.00	0.00	0.00	*27.90*	229.48	-258.58	0.00	-258.58	0.288
1962	6	0.00	0.00	0.00	*18.38*	229.72	-249.31	0.00	-249.31	0.253
1962	7	552.19	0.00	0.00	*22.24*	228.74	300.01	0.00	300.01	0.246
1962	8	294.16	0.00	0.00	*18.80*	230.50	43.66	0.00	43.66	0.266
1962	9	858.00	0.00	0.00	*48.66*	221.35	586.79	0.00	586.79	0.323
1962	10	6.07	0.00	0.00	*19.99*	198.95	-214.07	0.00	-214.07	0.369
1962	11	0.00	418.63	418.63	*20.20*	156.45	240.77	0.00	240.77	0.422
1962	12	0.97	129.63	129.63	*29.00*	116.00	-15.59	0.00	-15.59	0.459
1963	1	*327.73*	512.60	512.60	*46.69*	137.57	654.86	0.00	654.86	0.594
1963	2	670.84	0.00	0.00	*252.41*	159.02	258.21	0.00	258.21	0.602
1963	3	89.47	0.00	0.00	*71.51*	307.09	-290.34	0.00	-290.34	0.651
1963	4	254.09	0.00	0.00	*46.84*	455.65	-249.60	0.00	-249.60	0.695
1963	5	0.00	0.00	0.00	*22.13*	643.00	-666.33	0.00	-666.33	0.745
1963	6	*84.47*	0.00	0.00	*18.38*	846.66	-781.77	0.00	-781.77	0.793
1963	7	*613.77*	0.00	0.00	*18.52*	743.17	-149.12	0.00	-149.12	0.769
1963	8	*1008.04*	0.00	0.00	*128.55*	557.84	320.45	0.00	320.45	0.723
1963	9	*415.45*	0.00	0.00	*38.21*	405.41	-29.37	0.00	-29.37	0.681
1963	10	*182.01*	51.34	51.34	*18.40*	273.25	-59.50	0.00	-59.50	0.641
1963	11	*169.30*	264.80	264.80	*20.60*	142.11	270.20	0.00	270.20	0.596
1963	12	*221.70*	631.00	631.00	*20.89*	108.31	722.30	0.00	722.30	0.583

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1964	1	*327.73*	512.60	512.60	*19.46*	139.07	680.59	0.00	680.59	0.609
1964	2	*584.98*	194.99	189.55	*19.55*	191.97	572.68	5.44	567.25	0.632
1964	3	*418.99*	68.21	73.65	*36.34*	354.10	90.12	-5.44	95.56	0.696
1964	4	*84.83*	11.57	11.57	*37.05*	566.44	-508.29	0.00	-508.29	0.766
1964	5	*204.60*	0.00	0.00	*19.21*	881.51	-697.32	0.00	-697.32	0.856
1964	6	*84.47*	0.00	0.00	*18.37*	920.32	-855.42	0.00	-855.42	0.866
1964	7	*613.77*	0.00	0.00	*120.51*	755.32	-263.26	0.00	-263.26	0.822
1964	8	*1008.04*	0.00	0.00	*92.87*	595.11	318.86	0.00	318.86	0.775
1964	9	*415.45*	0.00	0.00	*219.86*	366.23	-171.84	0.00	-171.84	0.700
1964	10	*182.01*	51.34	51.34	*43.28*	284.40	-95.53	0.00	-95.53	0.670
1964	11	*169.30*	264.80	264.80	*26.22*	158.70	247.98	0.00	247.98	0.618
1964	12	*221.70*	631.00	631.00	*43.51*	126.57	681.42	0.00	681.42	0.603
1965	1	*245.76*	594.57	438.18	*87.23*	159.71	748.59	156.39	592.19	0.585
1965	2	506.82	183.08	339.47	*171.05*	153.83	207.43	-156.39	363.83	0.583
1965	3	234.14	36.14	36.14	*170.39*	263.42	-164.73	0.00	-164.73	0.611
1965	4	392.99	0.00	0.00	*153.92*	403.35	-165.48	0.00	-165.48	0.643
1965	5	0.00	0.00	0.00	*26.49*	591.70	-619.38	0.00	-619.38	0.683
1965	6	21.31	0.00	0.00	*18.37*	668.87	-667.12	0.00	-667.12	0.699
1965	7	696.18	0.00	0.00	*18.37*	700.12	-23.50	0.00	-23.50	0.705
1965	8	500.74	0.00	0.00	*33.95*	582.94	-117.35	0.00	-117.35	0.682
1965	9	32.25	0.00	0.00	*22.78*	438.99	-430.72	0.00	-430.72	0.651
1965	10	0.00	0.00	0.00	*18.48*	329.98	-349.66	0.00	-349.66	0.627
1965	11	27.98	1000.72	1000.72	*57.88*	196.65	772.97	0.00	772.97	0.594
1965	12	3.92	2059.65	2059.65	*1121.82*	131.60	808.95	0.00	808.95	0.577

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1966	1	122.70	366.16	366.16	*235.05*	119.89	132.71	0.00	132.71	0.532
1966	2	250.95	760.66	629.74	*355.13*	130.13	656.08	130.92	525.16	0.531
1966	3	45.05	0.00	130.92	*373.33*	244.24	-704.65	-130.92	-573.73	0.524
1966	4	9.68	0.00	0.00	*128.50*	348.01	-468.03	0.00	-468.03	0.517
1966	5	0.00	0.00	0.00	*32.44*	459.87	-493.50	0.00	-493.50	0.509
1966	6	341.04	0.00	0.00	*18.84*	525.04	-204.04	0.00	-204.04	0.505
1966	7	504.61	0.00	0.00	*34.05*	509.34	-39.97	0.00	-39.97	0.506
1966	8	1360.66	0.00	0.00	*235.05*	432.97	691.44	0.00	691.44	0.511
1966	9	1144.93	0.00	0.00	*495.18*	348.00	300.55	0.00	300.55	0.517
1966	10	190.18	0.00	0.00	*43.94*	261.14	-116.09	0.00	-116.09	0.523
1966	11	0.00	366.18	366.18	*52.93*	173.84	138.21	0.00	138.21	0.528
1966	12	80.44	177.50	177.50	*25.47*	123.98	107.30	0.00	107.30	0.531
1967	1	83.62	0.00	0.00	*22.97*	119.67	-60.22	0.00	-60.22	0.466
1967	2	9.30	0.00	0.00	*20.89*	139.67	-152.46	0.00	-152.46	0.452
1967	3	91.34	0.00	0.00	*24.56*	200.30	-134.72	0.00	-134.72	0.396
1967	4	224.57	0.00	0.00	*33.16*	222.35	-32.15	0.00	-32.15	0.368
1967	5	183.21	0.00	0.00	*19.03*	254.80	-91.82	0.00	-91.82	0.294
1967	6	27.71	0.00	0.00	*18.37*	256.81	-248.66	0.00	-248.66	0.265
1967	7	727.49	0.00	0.00	*94.33*	256.77	375.19	0.00	375.19	0.264
1967	8	281.33	0.00	0.00	*33.35*	253.12	-6.33	0.00	-6.33	0.302
1967	9	741.78	0.00	0.00	*68.86*	235.48	436.24	0.00	436.24	0.347
1967	10	475.46	0.00	0.00	*41.47*	201.39	231.40	0.00	231.40	0.395
1967	11	85.39	133.56	133.56	*19.21*	145.49	53.06	0.00	53.06	0.447
1967	12	0.00	0.00	0.00	*300.61*	67.71	-369.52	0.00	-369.52	0.501

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1968	1	137.69	256.29	256.29	*256.05*	111.49	25.24	0.00	25.24	0.475
1968	2	426.04	35.14	35.14	*418.61*	144.36	-102.99	0.00	-102.99	0.453
1968	3	387.86	11.30	11.30	*384.65*	181.15	-167.85	0.00	-167.85	0.423
1968	4	214.89	0.00	0.00	*141.05*	222.33	-149.69	0.00	-149.69	0.381
1968	5	39.13	0.00	0.00	*76.17*	265.21	-303.45	0.00	-303.45	0.297
1968	6	8.53	0.00	0.00	*29.17*	267.91	-289.75	0.00	-289.75	0.263
1968	7	421.97	0.00	0.00	*28.52*	267.56	124.69	0.00	124.69	0.281
1968	8	541.43	0.00	0.00	*60.13*	258.29	221.81	0.00	221.81	0.321
1968	9	177.38	0.00	0.00	*41.93*	236.63	-102.37	0.00	-102.37	0.362
1968	10	226.49	6.92	6.92	*18.93*	205.33	7.94	0.00	7.94	0.400
1968	11	355.52	79.12	79.12	*39.98*	134.83	258.62	0.00	258.62	0.460
1968	12	0.00	628.54	628.54	*49.02*	100.52	477.80	0.00	477.80	0.483
1969	1	102.42	343.02	343.02	*211.76*	127.47	105.01	0.00	105.01	0.557
1969	2	257.56	49.27	49.27	*71.79*	144.54	89.30	0.00	89.30	0.559
1969	3	142.47	41.46	41.46	*84.04*	222.31	-123.62	0.00	-123.62	0.570
1969	4	40.65	0.00	0.00	*55.60*	391.17	-407.32	0.00	-407.32	0.591
1969	5	199.22	0.00	0.00	*28.70*	430.30	-260.97	0.00	-260.97	0.596
1969	6	0.00	0.00	0.00	*18.37*	505.19	-524.76	0.00	-524.76	0.605
1969	7	643.60	0.00	0.00	*31.64*	586.41	24.35	0.00	24.35	0.614
1969	8	849.31	0.00	0.00	*66.28*	526.90	254.93	0.00	254.93	0.608
1969	9	506.35	0.00	0.00	*31.01*	395.74	78.40	0.00	78.40	0.592
1969	10	63.46	8.58	8.58	*18.54*	241.95	-189.65	0.00	-189.65	0.572
1969	11	483.58	473.39	473.39	*44.62*	155.46	755.69	0.00	755.69	0.561
1969	12	96.44	292.11	292.11	*66.66*	122.06	198.63	0.00	198.63	0.556

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1970	1	0.00	0.00	0.00	*26.76*	120.28	-148.24	0.00	-148.24	0.508
1970	2	120.87	0.00	0.00	*24.47*	150.09	-54.89	0.00	-54.89	0.500
1970	3	562.92	35.18	35.18	*158.53*	190.96	247.42	0.00	247.42	0.488
1970	4	108.41	0.00	0.00	*49.38*	257.24	-199.41	0.00	-199.41	0.467
1970	5	16.01	0.00	0.00	*29.61*	377.43	-392.23	0.00	-392.23	0.422
1970	6	74.60	0.00	0.00	*18.55*	416.35	-361.50	0.00	-361.50	0.404
1970	7	558.45	0.00	0.00	*21.73*	401.53	133.99	0.00	133.99	0.411
1970	8	681.22	0.00	0.00	*41.41*	359.95	278.66	0.00	278.66	0.429
1970	9	1428.74	0.00	0.00	*533.21*	289.61	604.71	0.00	604.71	0.456
1970	10	95.09	0.00	0.00	*21.17*	207.77	-135.04	0.00	-135.04	0.483
1970	11	3.40	19.25	19.25	*21.87*	156.84	-157.26	0.00	-157.26	0.498
1970	12	58.15	260.20	260.20	*19.19*	114.17	183.80	0.00	183.80	0.510
1971	1	0.00	102.92	102.92	*20.70*	146.05	-65.03	0.00	-65.03	0.581
1971	2	0.00	412.83	358.99	*24.47*	173.31	267.69	53.84	213.85	0.589
1971	3	0.00	0.00	53.84	*23.40*	316.96	-395.40	-53.84	-341.56	0.625
1971	4	139.39	0.00	0.00	*19.26*	417.11	-298.18	0.00	-298.18	0.648
1971	5	0.00	0.00	0.00	*18.41*	575.00	-594.61	0.00	-594.61	0.682
1971	6	0.00	0.00	0.00	*18.37*	718.06	-737.63	0.00	-737.63	0.710
1971	7	529.65	0.00	0.00	*33.69*	722.23	-227.47	0.00	-227.47	0.711
1971	8	1307.58	0.00	0.00	*198.55*	579.14	528.69	0.00	528.69	0.682
1971	9	830.47	0.00	0.00	*57.65*	451.26	320.37	0.00	320.37	0.655
1971	10	696.76	634.52	634.52	*240.63*	260.71	828.75	0.00	828.75	0.611
1971	11	0.00	203.85	203.85	*57.96*	191.09	-46.41	0.00	-46.41	0.593
1971	12	141.61	606.10	606.10	*217.78*	109.52	419.22	0.00	419.22	0.571

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1972	1	0.00	0.00	0.00	*52.35*	158.32	-211.87	0.00	-211.87	0.572
1972	2	0.00	0.00	0.00	*27.01*	187.52	-215.73	0.00	-215.73	0.578
1972	3	0.00	0.00	0.00	*24.28*	351.41	-376.89	0.00	-376.89	0.609
1972	4	0.00	0.00	0.00	*18.51*	435.50	-455.21	0.00	-455.21	0.623
1972	5	90.72	0.00	0.00	*18.37*	589.88	-518.73	0.00	-518.73	0.649
1972	6	594.68	0.00	0.00	*20.29*	681.32	-108.13	0.00	-108.13	0.663
1972	7	309.28	0.00	0.00	*21.08*	670.37	-383.37	0.00	-383.37	0.661
1972	8	753.76	0.00	0.00	*22.68*	565.49	164.39	0.00	164.39	0.645
1972	9	527.31	0.00	0.00	*30.46*	425.57	70.08	0.00	70.08	0.622
1972	10	1973.66	458.39	458.39	*445.86*	267.35	1717.64	0.00	1717.64	0.593
1972	11	0.00	226.50	226.50	*77.45*	149.95	-2.10	0.00	-2.10	0.571
1972	12	206.14	414.24	414.24	*174.13*	125.13	319.92	0.00	319.92	0.566
1973	1	0.00	220.31	117.95	*70.54*	129.05	121.87	102.36	19.51	0.561
1973	2	304.70	859.40	503.90	*445.54*	156.38	1121.19	457.86	663.33	0.566
1973	3	718.90	70.65	124.92	*422.22*	210.37	1017.21	403.58	613.62	0.574
1973	4	81.31	0.00	403.58	*258.84*	363.20	-945.52	-403.58	-541.93	0.597
1973	5	425.13	0.00	0.00	*106.86*	579.72	-262.65	0.00	-262.65	0.628
1973	6	63.94	0.00	0.00	*27.23*	698.56	-663.04	0.00	-663.04	0.643
1973	7	934.09	0.00	0.00	*74.57*	529.56	328.76	0.00	328.76	0.621
1973	8	502.51	0.00	0.00	*33.51*	567.49	-99.69	0.00	-99.69	0.626
1973	9	117.72	0.00	0.00	*18.77*	441.44	-343.69	0.00	-343.69	0.609
1973	10	0.00	0.00	0.00	*18.37*	319.39	-338.96	0.00	-338.96	0.591
1973	11	0.00	430.36	430.36	*18.39*	186.03	224.75	0.00	224.75	0.570
1973	12	0.00	0.00	0.00	*18.37*	140.65	-160.22	0.00	-160.22	0.563

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation								
		Rainfall	Snowfall	Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
1974	1	23.14	547.73	547.73	*44.18*	144.87	380.62	0.00	380.62	0.573
1974	2	48.95	81.22	81.22	*22.45*	170.18	-63.66	0.00	-63.66	0.579
1974	3	179.84	42.89	42.89	*27.89*	309.29	-115.66	0.00	-115.66	0.608
1974	4	40.65	0.00	0.00	*21.13*	433.50	-415.17	0.00	-415.17	0.632
1974	5	0.00	0.00	0.00	*18.47*	646.48	-666.15	0.00	-666.15	0.669
1974	6	12.79	0.00	0.00	*18.37*	801.09	-807.86	0.00	-807.86	0.695
1974	7	846.44	0.00	0.00	*47.14*	657.30	140.80	0.00	140.80	0.671
1974	8	483.04	0.00	0.00	*42.07*	578.54	-138.77	0.00	-138.77	0.658
1974	9	1220.72	0.00	0.00	*39.24*	431.13	749.15	0.00	749.15	0.631
1974	10	496.44	754.17	754.17	*93.44*	307.57	848.39	0.00	848.39	0.607
1974	11	5.65	222.74	222.74	*35.69*	181.06	10.45	0.00	10.45	0.581
1974	12	1.96	322.92	322.92	*117.95*	127.87	77.86	0.00	77.86	0.569
1975	1	1.93	382.40	382.40	*168.39*	135.14	79.61	0.00	79.61	0.505
1975	2	98.19	85.91	85.91	*136.87*	141.06	-95.03	0.00	-95.03	0.503
1975	3	497.48	21.79	21.79	*188.40*	211.41	118.27	0.00	118.27	0.483
1975	4	449.13	0.00	0.00	*106.01*	265.05	76.87	0.00	76.87	0.466
1975	5	7.12	0.00	0.00	*34.70*	370.82	-399.61	0.00	-399.61	0.427
1975	6	0.00	0.00	0.00	*10.79*	424.41	-436.40	0.00	-436.40	0.404
1975	7	861.47	0.00	0.00	*38.33*	405.90	416.03	0.00	416.03	0.412
1975	8	299.03	0.00	0.00	*93.96*	385.78	-181.91	0.00	-181.91	0.421
1975	9	665.99	0.00	0.00	*61.66*	316.43	286.70	0.00	286.70	0.448
1975	10	262.22	0.00	0.00	*93.44*	246.04	-78.46	0.00	-78.46	0.472
1975	11	99.83	130.45	130.45	*35.69*	158.57	34.82	0.00	34.82	0.498
1975	12	43.98	382.12	382.12	*117.95*	127.85	179.11	0.00	179.11	0.506

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1976	1	102.92	0.00	0.00	*168.39*	138.66	-205.33	0.00	-205.33	0.568
1976	2	795.53	72.90	72.90	*136.87*	192.61	537.74	0.00	537.74	0.578
1976	3	50.97	107.94	107.94	*188.40*	276.35	-307.04	0.00	-307.04	0.594
1976	4	640.79	0.00	0.00	*106.01*	388.41	145.17	0.00	145.17	0.614
1976	5	184.99	0.00	0.00	*34.70*	589.52	-440.43	0.00	-440.43	0.646
1976	6	157.73	0.00	0.00	*10.79*	710.15	-564.41	0.00	-564.41	0.665
1976	7	1046.78	0.00	0.00	*38.33*	632.88	374.37	0.00	374.37	0.653
1976	8	684.75	0.00	0.00	*93.96*	570.38	19.22	0.00	19.22	0.643
1976	9	643.42	0.00	0.00	*61.66*	419.34	161.21	0.00	161.21	0.619
1976	10	466.82	121.03	121.03	*93.44*	285.07	208.13	0.00	208.13	0.595
1976	11	*169.30*	264.80	264.80	*35.69*	154.22	243.00	0.00	243.00	0.571
1976	12	1.97	87.82	87.82	*117.95*	142.28	-171.63	0.00	-171.63	0.568
1977	1	0.00	554.79	232.47	*168.39*	124.82	582.70	322.32	260.38	0.519
1977	2	46.49	0.00	322.32	*136.87*	162.22	-576.12	-322.32	-253.80	0.513
1977	3	112.09	10.53	10.53	*188.40*	222.30	-289.28	0.00	-289.28	0.502
1977	4	92.92	0.00	0.00	*106.01*	328.01	-342.29	0.00	-342.29	0.483
1977	5	8.89	0.00	0.00	*34.70*	399.06	-426.06	0.00	-426.06	0.468
1977	6	172.65	0.00	0.00	*10.79*	485.07	-324.41	0.00	-324.41	0.450
1977	7	*613.77*	0.00	0.00	*38.33*	445.96	128.28	0.00	128.28	0.458
1977	8	1714.54	0.00	0.00	*93.96*	415.59	1203.80	0.00	1203.80	0.465
1977	9	385.40	0.00	0.00	*61.66*	344.95	-22.40	0.00	-22.40	0.479
1977	10	*182.01*	51.34	51.34	*93.44*	223.16	-84.46	0.00	-84.46	0.502
1977	11	52.61	43.65	43.65	*35.69*	169.39	-110.01	0.00	-110.01	0.512
1977	12	219.70	296.20	296.20	*117.95*	136.49	260.25	0.00	260.25	0.517

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1978	1	639.49	331.80	331.80	*168.39*	253.61	548.09	0.00	548.09	1.000
1978	2	310.91	3.36	3.36	*136.87*	275.01	-98.81	0.00	-98.81	1.000
1978	3	*418.99*	68.21	68.21	*188.40*	544.48	-246.88	0.00	-246.88	1.000
1978	4	*84.83*	11.57	11.57	*106.01*	781.50	-792.30	0.00	-792.30	1.000
1978	5	458.92	0.00	0.00	*34.70*	886.51	-463.49	0.00	-463.49	1.000
1978	6	134.28	0.00	0.00	*10.79*	1117.76	-995.46	0.00	-995.46	1.000
1978	7	464.54	0.00	0.00	*38.33*	1034.00	-608.99	0.00	-608.99	1.000
1978	8	438.81	0.00	0.00	*93.96*	892.68	-549.03	0.00	-549.03	1.000
1978	9	143.52	0.00	0.00	*61.66*	701.57	-620.91	0.00	-620.91	1.000
1978	10	727.27	782.68	782.68	*93.44*	543.97	871.34	0.00	871.34	1.000
1978	11	923.20	785.01	785.01	*35.69*	296.10	1375.23	0.00	1375.23	1.000
1978	12	74.43	1842.21	1842.21	*117.95*	216.27	1581.22	0.00	1581.22	0.959
1979	1	239.74	1284.73	171.51	*168.39*	129.91	2338.20	1113.23	1224.97	0.602
1979	2	115.93	276.44	1354.79	*136.87*	176.99	1225.41	34.87	1190.53	0.622
1979	3	511.78	37.52	72.39	*188.40*	295.65	29.17	-34.87	64.05	0.668
1979	4	110.35	0.00	0.00	*106.01*	515.23	-512.09	0.00	-512.09	0.741
1979	5	*182.68*	0.00	0.00	*34.70*	831.66	-684.88	0.00	-684.88	0.830
1979	6	300.54	0.00	0.00	*10.79*	876.12	-587.57	0.00	-587.57	0.842
1979	7	522.14	0.00	0.00	*38.33*	856.51	-373.91	0.00	-373.91	0.837
1979	8	261.87	0.00	0.00	*93.96*	676.66	-509.95	0.00	-509.95	0.789
1979	9	148.36	0.00	0.00	*61.66*	549.61	-464.11	0.00	-464.11	0.752
1979	10	267.99	0.00	0.00	*93.44*	364.45	-191.11	0.00	-191.11	0.692
1979	11	84.54	2.28	2.28	*35.69*	183.38	-133.44	0.00	-133.44	0.624
1979	12	135.48	9.82	9.82	*117.95*	161.88	-135.73	0.00	-135.73	0.616

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1980	1	658.03	258.58	258.58	*168.39*	145.20	601.83	0.00	601.83	0.571
1980	2	1409.71	600.50	600.50	*136.87*	194.38	1677.76	0.00	1677.76	0.581
1980	3	472.23	0.75	0.75	*188.40*	255.78	27.59	0.00	27.59	0.594
1980	4	69.69	0.00	0.00	*106.01*	418.93	-456.45	0.00	-456.45	0.624
1980	5	*182.68*	0.00	0.00	*34.70*	685.03	-538.25	0.00	-538.25	0.669
1980	6	57.55	0.00	0.00	*10.79*	762.03	-716.47	0.00	-716.47	0.681
1980	7	448.26	0.00	0.00	*38.33*	696.91	-288.18	0.00	-288.18	0.670
1980	8	1137.72	0.00	0.00	*93.96*	571.57	470.99	0.00	470.99	0.650
1980	9	216.08	0.00	0.00	*61.66*	467.09	-313.87	0.00	-313.87	0.632
1980	10	*182.01*	51.34	51.34	*93.44*	257.47	-118.76	0.00	-118.76	0.594
1980	11	0.00	0.00	0.00	*35.69*	182.40	-219.29	0.00	-219.29	0.579
1980	12	37.35	106.31	106.31	*117.95*	151.43	-126.91	0.00	-126.91	0.572
1981	1	114.14	178.53	178.53	*168.39*	133.46	-10.38	0.00	-10.38	0.491
1981	2	475.59	158.53	158.53	*136.87*	161.56	334.48	0.00	334.48	0.480
1981	3	605.84	98.62	98.62	*188.40*	210.46	304.40	0.00	304.40	0.458
1981	4	132.88	18.12	18.12	*106.01*	299.83	-256.04	0.00	-256.04	0.410
1981	5	176.10	0.00	0.00	*34.70*	340.89	-200.69	0.00	-200.69	0.381
1981	6	110.84	0.00	0.00	*10.79*	378.47	-279.62	0.00	-279.62	0.346
1981	7	*618.52*	0.00	0.00	*38.33*	352.12	226.87	0.00	226.87	0.372
1981	8	564.44	0.00	0.00	*93.96*	331.04	138.24	0.00	138.24	0.389
1981	9	309.61	0.00	0.00	*61.66*	286.87	-40.12	0.00	-40.12	0.418
1981	10	66.25	18.68	18.68	*93.44*	210.29	-220.00	0.00	-220.00	0.458
1981	11	167.50	261.98	261.98	*35.69*	148.73	243.86	0.00	243.86	0.485
1981	12	0.00	0.00	0.00	*117.95*	121.85	-241.00	0.00	-241.00	0.496

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1982	1	682.85	466.58	466.58	*168.39*	125.01	854.84	0.00	854.84	0.544
1982	2	343.82	0.67	0.67	*136.87*	156.02	50.40	0.00	50.40	0.546
1982	3	541.57	52.16	52.16	*188.40*	242.07	162.06	0.00	162.06	0.549
1982	4	1.21	0.00	0.00	*106.01*	350.04	-456.04	0.00	-456.04	0.554
1982	5	116.89	0.00	0.00	*34.70*	458.38	-377.39	0.00	-377.39	0.558
1982	6	9.74	0.00	0.00	6.51	530.73	-528.70	0.00	-528.70	0.561
1982	7	728.18	0.00	0.00	15.78	523.73	187.48	0.00	187.48	0.561
1982	8	1381.16	0.00	0.00	176.98	468.37	734.60	0.00	734.60	0.559
1982	9	378.84	0.00	0.00	52.97	367.00	-42.34	0.00	-42.34	0.554
1982	10	115.55	23.98	23.98	7.92	256.57	-126.16	0.00	-126.16	0.550
1982	11	82.52	12.05	12.05	79.51	167.24	-153.37	0.00	-153.37	0.546
1982	12	0.00	0.00	0.00	188.04	116.14	-305.38	0.00	-305.38	0.544
1983	1	0.00	0.00	0.00	233.58	25.45	-260.23	0.00	-260.23	0.100
1983	2	0.00	0.00	0.00	391.06	29.46	-421.72	0.00	-421.72	0.100
1983	3	0.00	0.00	0.00	775.40	51.36	-827.96	0.00	-827.96	0.100
1983	4	0.00	0.00	0.00	732.10	70.58	-803.88	0.00	-803.88	0.100
1983	5	12.71	0.00	0.00	443.86	43.63	-475.98	0.00	-475.98	0.100
1983	6	0.00	0.00	0.00	30.48	96.57	-128.25	0.00	-128.25	0.100
1983	7	361.67	0.00	0.00	24.32	96.30	239.85	0.00	239.85	0.100
1983	8	1094.00	0.00	0.00	120.69	81.29	890.82	0.00	890.82	0.100
1983	9	762.18	8.98	8.98	222.51	64.74	482.71	0.00	482.71	0.100
1983	10	1170.83	0.00	0.00	2803.91	34.84	-1669.12	0.00	-1669.12	0.100
1983	11	180.47	38.14	38.14	67.78	26.63	123.01	0.00	123.01	0.100
1983	12	11.75	718.01	718.01	470.17	23.89	234.50	0.00	234.50	0.100

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1984	1	10.20	155.62	155.62	260.62	123.64	-219.64	0.00	-219.64	0.528
1984	2	0.00	0.00	0.00	28.12	157.50	-186.82	0.00	-186.82	0.524
1984	3	0.00	0.00	0.00	16.81	228.31	-246.32	0.00	-246.32	0.518
1984	4	219.00	0.00	0.00	37.19	297.91	-117.30	0.00	-117.30	0.511
1984	5	94.02	0.00	0.00	23.61	427.91	-358.70	0.00	-358.70	0.497
1984	6	421.42	0.00	0.00	5.59	485.40	-70.77	0.00	-70.77	0.491
1984	7	1490.27	0.00	0.00	128.84	447.40	912.83	0.00	912.83	0.495
1984	8	1168.24	0.00	0.00	222.93	411.84	532.27	0.00	532.27	0.499
1984	9	349.10	61.18	61.18	35.07	327.35	46.66	0.00	46.66	0.508
1984	10	280.92	32.11	32.11	17.72	227.61	66.50	0.00	66.50	0.518
1984	11	0.00	0.00	0.00	12.03	154.87	-168.10	0.00	-168.10	0.525
1984	12	152.81	67.59	67.59	348.78	61.04	-190.62	0.00	-190.62	0.533
1985	1	*327.73*	512.60	512.60	*168.39*	74.69	596.05	0.00	596.05	1.000
1985	2	*584.98*	194.99	194.99	*136.87*	180.63	461.27	0.00	461.27	1.000
1985	3	*418.99*	68.21	68.21	*188.40*	396.88	-99.29	0.00	-99.29	1.000
1985	4	*84.83*	11.57	11.57	*106.01*	584.08	-594.88	0.00	-594.88	1.000
1985	5	0.00	0.00	0.00	*34.70*	796.74	-832.64	0.00	-832.64	1.000
1985	6	0.00	0.00	0.00	*10.79*	851.79	-863.77	0.00	-863.77	1.000
1985	7	566.72	0.00	0.00	8.27	900.19	-342.94	0.00	-342.94	1.000
1985	8	876.88	0.00	0.00	23.82	829.89	21.98	0.00	21.98	1.000
1985	9	805.59	0.00	0.00	28.17	609.27	166.96	0.00	166.96	1.000
1985	10	341.12	237.62	237.62	52.83	446.72	77.99	0.00	77.99	1.000
1985	11	752.21	545.54	545.54	164.81	283.35	848.39	0.00	848.39	1.000
1985	12	*221.70*	631.00	631.00	40.58	208.35	602.58	0.00	602.58	1.000

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1986	1	0.00	0.00	0.00	12.36	130.37	-143.93	0.00	-143.93	0.521
1986	2	227.31	6.99	6.99	*136.87*	140.77	-44.54	0.00	-44.54	0.519
1986	3	8.13	0.00	0.00	*188.40*	222.57	-404.04	0.00	-404.04	0.507
1986	4	0.00	0.00	0.00	*106.01*	271.94	-379.15	0.00	-379.15	0.499
1986	5	*182.68*	0.00	0.00	0.88	328.20	-147.60	0.00	-147.60	0.490
1986	6	*84.47*	0.00	0.00	*10.79*	513.01	-440.52	0.00	-440.52	0.457
1986	7	*613.77*	0.00	0.00	*38.33*	430.18	144.06	0.00	144.06	0.473
1986	8	*1008.04*	0.00	0.00	*93.96*	378.69	534.19	0.00	534.19	0.482
1986	9	*415.45*	0.00	0.00	*61.66*	293.07	59.52	0.00	59.52	0.496
1986	10	*210.75*	22.60	22.60	*93.44*	210.45	-71.74	0.00	-71.74	0.509
1986	11	*157.40*	276.70	276.70	*35.69*	132.30	264.92	0.00	264.92	0.520
1986	12	*600.81*	251.90	251.90	*117.95*	104.72	628.83	0.00	628.83	0.524
1987	1	*467.73*	372.60	372.60	*168.39*	156.83	513.91	0.00	513.91	0.632
1987	2	*774.06*	5.91	5.91	*136.87*	218.70	423.20	0.00	423.20	0.663
1987	3	*487.19*	0.00	0.00	*188.40*	396.68	-99.09	0.00	-99.09	0.740
1987	4	*96.40*	0.00	0.00	*106.01*	690.05	-700.86	0.00	-700.86	0.846
1987	5	*182.68*	0.00	0.00	*34.70*	927.49	-780.71	0.00	-780.71	0.918
1987	6	*84.47*	0.00	0.00	*10.79*	1065.83	-993.35	0.00	-993.35	0.957
1987	7	*613.77*	0.00	0.00	2.27	859.97	-249.67	0.00	-249.67	0.899
1987	8	156.89	0.00	0.00	152.93	72.23	-69.48	0.00	-69.48	0.585
1987	9	601.65	0.00	0.00	21.98	528.38	50.09	0.00	50.09	0.790
1987	10	517.88	42.30	42.30	28.36	392.76	137.85	0.00	137.85	0.739
1987	11	150.74	12.49	12.49	22.49	199.81	-60.27	0.00	-60.27	0.654
1987	12	196.61	1768.77	1768.77	5.89	129.92	1828.37	0.00	1828.37	0.618

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1988	1	0.78	4.00	4.00	735.37	122.77	-854.56	0.00	-854.56	0.530
1988	2	189.37	27.58	27.58	234.94	159.71	-178.90	0.00	-178.90	0.527
1988	3	35.13	22.97	22.97	145.25	224.95	-313.31	0.00	-313.31	0.523
1988	4	322.65	0.00	0.00	141.26	282.76	-102.57	0.00	-102.57	0.518
1988	5	0.00	0.00	0.00	25.67	367.49	-394.36	0.00	-394.36	0.512
1988	6	477.45	0.00	0.00	2.92	373.96	99.37	0.00	99.37	0.511
1988	7	467.24	0.00	0.00	4.89	430.53	30.62	0.00	30.62	0.507
1988	8	1784.02	0.00	0.00	204.12	428.40	1150.30	0.00	1150.30	0.507
1988	9	180.29	0.00	0.00	9.58	344.11	-174.60	0.00	-174.60	0.513
1988	10	791.23	50.19	50.19	61.99	277.48	500.75	0.00	500.75	0.519
1988	11	110.99	451.64	451.64	11.94	197.00	352.50	0.00	352.50	0.525
1988	12	14.26	12.23	12.23	15.81	124.69	-115.22	0.00	-115.22	0.530
1989	1	89.14	395.86	395.86	25.83	149.23	308.74	0.00	308.74	0.597
1989	2	*740.97*	39.00	39.00	18.88	205.52	554.37	0.00	554.37	0.616
1989	3	11.62	0.00	0.00	31.85	334.89	-356.33	0.00	-356.33	0.657
1989	4	0.00	0.00	0.00	*21.92*	500.58	-523.69	0.00	-523.69	0.703
1989	5	201.59	0.00	0.00	1.29	707.22	-508.12	0.00	-508.12	0.755
1989	6	0.00	0.00	0.00	0.00	750.96	-752.16	0.00	-752.16	0.766
1989	7	2045.93	0.00	0.00	0.00	749.65	1295.08	0.00	1295.08	0.765
1989	8	867.36	0.00	0.00	*124.92*	580.68	160.56	0.00	160.56	0.724
1989	9	4.19	0.00	0.00	*18.41*	445.92	-461.33	0.00	-461.33	0.689
1989	10	690.81	12.30	12.30	*20.94*	331.67	349.30	0.00	349.30	0.656
1989	11	12.99	44.32	44.32	*18.37*	201.05	-163.31	0.00	-163.31	0.615
1989	12	34.29	230.59	230.59	*18.37*	148.42	96.89	0.00	96.89	0.596

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1990	1	253.58	236.84	236.84	*24.53*	251.89	212.80	0.00	212.80	1.000
1990	2	476.46	607.36	607.36	*92.36*	285.06	705.19	0.00	705.19	1.000
1990	3	297.81	0.00	0.00	*104.27*	462.98	-270.64	0.00	-270.64	1.000
1990	4	312.74	0.00	0.00	*32.13*	676.13	-396.72	0.00	-396.72	1.000
1990	5	38.52	0.00	0.00	*20.26*	854.78	-837.72	0.00	-837.72	1.000
1990	6	134.58	0.00	0.00	*18.37*	1105.07	-990.06	0.00	-990.06	1.000
1990	7	1988.25	0.00	0.00	*320.96*	953.62	712.47	0.00	712.47	1.000
1990	8	1039.03	0.00	0.00	207.86	830.78	-0.80	0.00	-0.80	1.000
1990	9	616.37	0.00	0.00	46.01	651.54	-82.38	0.00	-82.38	1.000
1990	10	75.22	0.00	0.00	7.38	381.70	-315.06	0.00	-315.06	1.000
1990	11	290.48	152.18	152.18	7.14	217.28	217.04	0.00	217.04	1.000
1990	12	1120.22	602.61	602.61	*218.26*	206.39	1296.98	0.00	1296.98	1.000
1991	1	516.74	183.21	183.21	*363.16*	105.86	229.73	0.00	229.73	0.445
1991	2	600.50	56.75	56.75	*102.02*	136.20	417.82	0.00	417.82	0.406
1991	3	1186.67	30.57	30.57	*1598.66*	171.08	-553.71	0.00	-553.71	0.339
1991	4	0.00	0.00	0.00	*496.36*	181.11	-678.67	0.00	-678.67	0.241
1991	5	0.00	0.00	0.00	*76.06*	131.80	-209.06	0.00	-209.06	0.127
1991	6	0.00	0.00	0.00	*19.70*	111.37	-132.27	0.00	-132.27	0.101
1991	7	276.02	0.00	0.00	10.23	152.85	111.75	0.00	111.75	0.160
1991	8	851.24	0.00	0.00	164.33	174.79	510.92	0.00	510.92	0.212
1991	9	189.89	0.00	0.00	9.96	179.00	-0.27	0.00	-0.27	0.310
1991	10	230.21	48.39	48.39	3.30	164.55	109.54	0.00	109.54	0.355
1991	11	40.55	200.66	200.66	65.21	117.11	57.69	0.00	57.69	0.431
1991	12	227.13	219.70	219.70	*210.19*	98.92	136.52	0.00	136.52	0.452

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1992	1	203.84	615.52	615.52	*240.14*	159.35	418.67	0.00	418.67	0.640
1992	2	978.75	14.37	14.37	686.90	241.00	64.02	0.00	64.02	0.682
1992	3	1118.80	0.00	0.00	422.96	428.89	265.75	0.00	265.75	0.766
1992	4	193.89	0.00	0.00	*218.21*	713.68	-739.19	0.00	-739.19	0.871
1992	5	828.69	0.00	0.00	*66.00*	984.02	-222.54	0.00	-222.54	0.956
1992	6	13.87	0.00	0.00	15.41	1093.16	-1095.89	0.00	-1095.89	0.988
1992	7	642.49	0.00	0.00	11.36	902.90	-272.98	0.00	-272.98	0.932
1992	8	1225.73	0.00	0.00	47.98	698.86	477.69	0.00	477.69	0.866
1992	9	277.50	0.00	0.00	10.79	449.40	-183.89	0.00	-183.89	0.774
1992	10	167.38	0.00	0.00	7.59	320.40	-161.81	0.00	-161.81	0.720
1992	11	11.97	48.98	48.98	8.52	184.71	-133.48	0.00	-133.48	0.654
1992	12	612.57	1690.47	1690.47	*598.01*	120.19	1583.64	0.00	1583.64	0.618
1993	1	1532.03	750.68	750.68	*2261.52*	118.73	-98.74	0.00	-98.74	0.460
1993	2	576.53	133.05	133.05	*585.26*	138.43	-15.32	0.00	-15.32	0.443
1993	3	202.71	0.00	0.00	445.45	209.19	-453.12	0.00	-453.12	0.361
1993	4	0.00	0.00	0.00	288.00	234.61	-523.81	0.00	-523.81	0.291
1993	5	83.29	0.00	0.00	45.58	223.73	-187.22	0.00	-187.22	0.208
1993	6	4.14	0.00	0.00	5.27	217.74	-220.07	0.00	-220.07	0.194
1993	7	148.47	0.00	0.00	9.16	234.59	-96.47	0.00	-96.47	0.248
1993	8	773.55	0.00	0.00	21.43	235.07	515.85	0.00	515.85	0.288
1993	9	171.10	0.00	0.00	2.65	211.42	-44.16	0.00	-44.16	0.357
1993	10	474.20	68.27	68.27	11.47	173.19	356.61	0.00	356.61	0.409
1993	11	214.05	605.78	605.78	40.94	120.46	657.23	0.00	657.23	0.458
1993	12	32.56	183.72	183.72	8.54	97.30	109.24	0.00	109.24	0.476

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1994	1	39.55	45.77	45.77	*24.83*	169.18	-109.90	0.00	-109.90	0.602
1994	2	658.45	5.22	5.22	*98.40*	205.95	358.12	0.00	358.12	0.614
1994	3	619.59	0.00	0.00	*133.21*	377.15	108.03	0.00	108.03	0.665
1994	4	66.68	0.00	0.00	*42.10*	608.71	-585.33	0.00	-585.33	0.726
1994	5	141.01	0.00	0.00	*19.33*	827.44	-706.97	0.00	-706.97	0.776
1994	6	125.70	0.00	0.00	2.58	946.21	-824.29	0.00	-824.29	0.802
1994	7	411.16	0.00	0.00	0.00	768.19	-358.23	0.00	-358.23	0.763
1994	8	711.39	0.00	0.00	3.65	604.49	102.05	0.00	102.05	0.725
1994	9	636.42	0.00	0.00	*83.81*	401.97	149.44	0.00	149.44	0.672
1994	10	138.88	80.93	80.93	*19.80*	272.52	-73.72	0.00	-73.72	0.635
1994	11	1145.62	122.63	122.63	*213.87*	154.96	898.22	0.00	898.22	0.597
1994	12	1011.88	508.07	508.07	*345.86*	130.33	1042.57	0.00	1042.57	0.588
1995	1	783.49	463.68	463.68	*520.31*	118.38	607.28	0.00	607.28	0.463
1995	2	1044.55	16.61	16.61	*989.61*	144.95	-74.60	0.00	-74.60	0.442
1995	3	441.14	0.00	0.00	*362.51*	205.76	-128.33	0.00	-128.33	0.378
1995	4	160.96	0.00	0.00	53.79	239.23	-133.26	0.00	-133.26	0.312
1995	5	85.75	0.00	0.00	26.88	241.25	-183.57	0.00	-183.57	0.235
1995	6	20.52	0.00	0.00	5.73	231.21	-217.62	0.00	-217.62	0.205
1995	7	381.54	0.00	0.00	*18.37*	243.64	118.34	0.00	118.34	0.247
1995	8	1045.28	0.00	0.00	*447.64*	241.72	354.72	0.00	354.72	0.302
1995	9	277.44	0.00	0.00	*317.70*	218.65	-260.11	0.00	-260.11	0.358
1995	10	35.75	1.82	1.82	*18.37*	180.03	-162.03	0.00	-162.03	0.409
1995	11	42.72	223.98	223.98	*18.37*	126.34	120.79	0.00	120.79	0.457
1995	12	53.77	30.87	30.87	*18.37*	106.68	-41.61	0.00	-41.61	0.472

Year	Month	Inputs, ac-ft			Outputs, ac-ft		ΔS			ET factor
		Precipitation		Snowmelt	Runoff	ET	Total	Snowpack	Soil/GW	
		Rainfall	Snowfall							
1996	1	24.35	3.67	3.67	*18.99*	153.26	-145.44	0.00	-145.44	0.559
1996	2	819.79	0.00	0.00	*126.63*	202.23	489.73	0.00	489.73	0.565
1996	3	77.17	0.00	0.00	*76.18*	339.36	-339.57	0.00	-339.57	0.582
1996	4	14.83	0.00	0.00	3.48	479.86	-469.72	0.00	-469.72	0.598
1996	5	8.64	0.00	0.00	0.23	679.71	-672.50	0.00	-672.50	0.620
1996	6	202.31	0.00	0.00	0.00	707.21	-506.11	0.00	-506.11	0.623
1996	7	1249.43	0.00	0.00	12.25	572.87	663.12	0.00	663.12	0.609
1996	8	1091.92	0.00	0.00	29.86	477.94	582.91	0.00	582.91	0.598
1996	9	840.98	0.00	0.00	47.99	328.24	463.56	0.00	463.56	0.581
1996	10	140.03	185.22	185.22	*30.64*	234.48	58.93	0.00	58.93	0.569
1996	11	137.37	32.74	32.74	*53.94*	157.22	-42.26	0.00	-42.26	0.560
1996	12	11.60	22.39	22.39	2.81	112.63	-82.65	0.00	-82.65	0.554
1997	1	498.75	362.79	362.79	20.05	152.31	687.97	0.00	687.97	0.578
1997	2	374.98	80.21	80.21	11.81	191.26	250.92	0.00	250.92	0.588
1997	3	207.46	0.00	0.00	*223.52*	393.44	-410.71	0.00	-410.71	0.632
1997	4	124.66	0.00	0.00	*43.74*	494.54	-414.82	0.00	-414.82	0.653
1997	5	70.70	0.00	0.00	*19.96*	755.22	-705.68	0.00	-705.68	0.701
1997	6	156.68	0.00	0.00	*18.37*	775.98	-638.87	0.00	-638.87	0.704
1997	7	499.30	0.00	0.00	*18.37*	691.74	-212.02	0.00	-212.02	0.689
1997	8	1348.78	0.00	0.00	*43.92*	518.30	785.36	0.00	785.36	0.657
1997	9	463.73	0.00	0.00	*23.26*	380.89	58.37	0.00	58.37	0.630
1997	10	94.31	19.58	19.58	*18.48*	241.20	-146.98	0.00	-146.98	0.599
1997	11	52.99	146.92	146.92	*18.37*	160.16	20.18	0.00	20.18	0.580
1997	12	316.36	613.28	613.28	*101.48*	100.68	726.28	0.00	726.28	0.566

Italics indicate estimated values. Estimation methods given below:

Precipitation: Mean monthly values

Streamflow: (1) Estimated from lower gage data, if available.
(2) Mean monthly value used