DUNCAN CANYON/LONG CANYON
PAIRED WATERSHED STUDY

To
Placer County Water Agency
Auburn, California

By
WRC Environmental
Chuck Watson
John H. Humphrey

December 20, 2002

TABLE OF CONTENTS

List of Figures

List of Tables

INTRODUCTION

The primary purpose of the paired watershed study was to determine why unexpected flow differences are evident when comparing Duncan Canyon and Long Canyon streamflow records. Although Long Canyon has nearly twice the area of Duncan Canyon, and apparently similar elevation ranges and slope aspects, the mean annual flows are similar, instead of Long Canyon being greater as expected. The secondary purpose of the paired watershed study was to assess the influence of vegetative management on watershed hydrology and find a procedure to allow resource management decision-making. The Precipitation-Runoff Modeling System of the U.S. Geological Survey was selected for the technical hydrologic analyses

LITERATURE REVIEW

Research for over 70 years has demonstrated that removal of forest cover from watersheds can significantly change hydrology. The earliest study found in the literature was for the Wagon Wheel Gap watershed in Colorado in 1928 (Ref 21). It found significant increases in annual yield and snowmelt runoff due to tree removal. Kettelmann did a summary of water yield improvement studies in the Sierra Nevada in 1982 (Ref. 5). James (Ref. 3) showed the importance of interception storage losses. A summary of hydrologic effects due to logging in British Columbia was done in 1988 (Ref. 14) and again in 1996 (Ref. 8) for the Sierra Nevada. In general, these studies showed annual water yield increases of 10-30% and forest recovery periods of 10 years for the Pacific coast to 30 years for the Rocky Mountains.

The Precipitation-Runoff Management System (PRMS) has seen widespread use in the western United States. It was first applied in 1983 by its USGS author Leavesley (Ref. 7) in northern Colorado. Ref 11 (1986) provided a further application for snowmelt studies for Parachute Creek in Colorado. It was used to simulate the effects of forest management on streamflow in the Oregon Coast Range (Ref. 12). PRMS was favorably compared to other models of snowmelt runoff in 1986 by the WMO (Ref. 22). Techniques for estimating model parameters were developed in Ref. 2 for eastern Montana. Another paper providing guidance for selection of model parameters was written by Troutman (Ref 15). An excellent comparison of several snowmelt runoff simulation models, including PRMS, was done by Tarboton (Ref. 13), in 1991 using excellent Central Sierra Snow Laboratory data. A relatively nearby study on Camp Creek in Placerville used PRMS to evaluate the influence of land clearing due to urbanization (Ref. 10). Marron (Ref 9) applied PRMS to simulations of snowmelt on the East Fork Carson River. PRMS simulations of the Lake Tahoe Basin were made in 1999 by Jeton (Ref. 4).

DATA COLLECTION

Description of Paired Watersheds

Figure 1. *Duncan Canyon/Long Canyon Watersheds* shows the location of the paired watersheds in the northern Sierra Nevada. They are located in the Middle Fork of the American River approximately 15 miles west of Lake Tahoe

The watersheds involved in the study are both drained by third order streams and range in size from 9.9 sq mi (Duncan Canyon) to 18.0 sq mi (Long Canyon) and range in elevation from 4100 to 7400 ft. This is an elevation range which exhibits significant changes in total precipitation, snowfall, snow accumulation, snowmelt and annual yield.

Nearly all of the marketable timber on the Long Canyon watershed was removed from the early 1960s to the present. In contrast, only 10% (most of Section 8) of the Duncan Canyon watershed was selectively logged in the 1980s.

Topographic Maps

Figure 2 shows Duncan Canyon topography and Figure 3 shows Long Canyon topography. This topography comes from U.S. Geological Survey maps: Greek Store, Bunker Hill, Duncan Peak and Royal Gorge.

Aerial Photography

Scanned aerial photography rectified to digital orthoquads was obtained from the NRCS. This aerial photography was flown in 1993. Printed aerial photography for 1996 was obtained from the U.S. Forest Service. Additional non-rectified aerial photography was obtained on May 3, 2000 and May 30, 2000.

Soils

Soils mapping was obtained from soil surveys published by the USDA. Forest Service, El Dorado National Forest (Ref 17.) and Tahoe National Forest (Ref. 18).

Hydrogeology

Field investigations were made to determine the sources and sinks of base flow in the watersheds. Figures 4, 5, and 6 show Duncan Canyon bedrock geology, surficial geology and geomorphology and baseflow features. Figures 7, 8, and 9 show Long Canyon bedrock geology, surficial geology and geomorphology and baseflow features.

Climatologic Data

Climatological data were obtained from the Internet sites of the National Climatic Data Center (ref. 19), California Data Exchange Center (Ref. 1) and Mesowest (Ref. 23). Data requirements for the modeling were daily precipitation, daily maximum-minimum temperature and daily pan evaporation. Figure 10 shows locations of climatological stations in the Yuba, Bear and American River watersheds. The nearest long-term representative climatic station was located at Blue Canyon.

Snow Survey Data

Daily snow pillow data and monthly snow course data locations in the vicinity of the paired watersheds, obtained from CDEC, are also shown on Figure 10. This data is used for determining model calibration of snowpack accumulation. Figure 11 shows data availability for the 1980-2000 period.

Hydrologic Data

Hydrologic data were obtained from the Internet at the U.S. Geological Survey web site. (Ref. 20). The availability of daily flow data is shown as a graph on Figure 12.

Synoptic Measurements

A reconnaissance of the watersheds was made on April 25, 2000 to investigate the flow measurement sites. Synoptic measurements of flow were made on May 5, 2000 and June 5, 2000 to approximately coincide with aerial photographic flights assessing snowpack coverage.

METHODOLOGY

Description of Precipitation-Runoff Modeling System (PRMS) Computer Program

The Precipitation-Runoff Modeling System (PRMS) was published in 1983 by the U.S. Geological Survey. (See Ref. 6. for User's Manual). The PRMS is a modular-design, deterministic, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate and land use on streamflow, sediment yields, and general basin hydrology. Basin response to rainfall and snowmelt can be simulated to evaluate changes in water-balance relationships, flow regimes, flood peaks and volumes, soil-water relationships, and ground-water recharge. To reproduce the physical reality of the hydrologic system as close as possible, each component of the hydrologic cycle is expressed in the form of know physical laws or empirical relationships that have some physical interpretation based on measurable watershed characteristics. Snowmelt is simulated using formulas developed by the U.S. Army Corps of Engineers at the Central Sierra Snow Laboratory (Ref. 16).

PRMS components are designed around the concept of partitioning a watershed into units on the basis of slope, aspect, vegetation type, soil type, and precipitation distribution. Each unit is considered homogeneous with respect to its hydrologic response and is called a hydrologic-response unit (HRU).

Database for PRMS Models

A U.S. EPA program called Annie, which is also used by other Federal hydrologic computer programs, structures the database for the PRMS. The database was loaded for the years 1949-2001 and consisted of daily precipitation, maximum air temperature and minimum air temperature as recorded at Blue Canyon NWS/CDEC weather station. For most months, daily evaporation was based on Tahoe City. Winter pan evaporation data was obtained from Hetch Hetchy Dam. Daily solar radiation data was based on a textbook algorithm for clear sky solar radiation adjusted for cloudiness at Blue Canyon. Interested parties can be supplied with a CD with the Database.

Description of PRMS Model Input Files

Model input files are exactly structured values input as cards (records or lines) and columns. There are approximately 40 records and 200 input values. Three records repeat for each discrete HRU. Reference 6, the users manual, describes them. Interested parties can be supplied with a CD with all the Duncan Canyon/Long Canyon input and output files.

Comparison of Duncan Canyon and Long Canyon

Using existing data, a comparison was made of annual runoff of Duncan Canyon compared to Long Canyon for 1960 to 1992. In 1992 the Long Canyon stream gage was discontinued. Partial records were available, for some months of the year, at North Fork Long Canyon and South Fork Long Canyon, but there was no way to reproduce annual runoff values consistent with the lower elevation gage which was discontinued in 1992. Duncan Canyon daily stream flow data were available through 2001. Figure 13 shows the ratio for 1960 to 1992. For most years, Duncan has significantly higher runoff than Long Canyon, in spite of its smaller drainage area (10 sq miles vs. 18 sq miles). The wide fluctuations in the ratio reveal that the high flow rating curves for both gages, but more likely Long Canyon since it was in a poor location, were seriously in error. PRMS modeling results eventually determined that the 1960-1965 record for Long Canyon could not be supported by precipitation data. Probably since the Long Canyon gage location was damaged in the February 1986 flood event, the 1987-1992 records could also not be supported by the precipitation data. It was also likely that high flows recorded by the Long Canyon stream gage were seriously underestimated in all years.

For this reason a comparison was made between the two gage records for 1966 to 1986. (See Figure 14). Wide fluctuations still exist, but at least the trend is upwards which is consistent with what is expected from the hydrologic effects of forest removal.

The comparisons in Figures 13 and 14 clearly show one reason why Long Canyon has less runoff per square mile than Duncan Canyon. Figure 15 shows hypsometric aspect curves (accumulated area vs. elevation for north, south and east-west aspects) for Duncan and Long Canyons. These curves show that for critical runoff producing zones above 6000 feet, Duncan Canyon has nearly twice the area of Duncan Creek. As we shall see, the PRMS model confirms that runoff from higher elevations in Duncan Creek can compensate for its lower area. For north slopes, the percentage of watershed area is slightly lower for Duncan (48% vs. 54%), but heavily weighted toward lower elevations in Long Canyon, with the average elevation of north slopes 1000 ft higher in Duncan. For south slopes, the percentage of the watershed is similar at 20%, but also weighted toward lower elevations in Long Canyon, with the average elevation of south slopes

1000 ft higher in Duncan. For east-west slopes, the percentage of the watershed is higher for Duncan (31% vs. 21%) and the average elevation of east-west slopes is 500 ft higher in Duncan.

Geographic Information Systems (GIS) Procedures

Arcview Spatial Analyst was used to digitally map elevation zones, aspect zones, available soil moisture capacity zones, and forest canopy cover. The elevation and aspect zones came from the U.S. Geological Survey topographic mapping. The available soil moisture capacity zones were based on available water capacity (inches per inch) and depth to bedrock for the soil types. (References 17, 18, Tables 6 and 7). The available soil moisture zones were digitized. Forest canopy cover was based on the May 2000 aerial photography and digitized. Figures 22 and 23 show existing forest canopy cover.

Description of Hydrologic Response Units

The elevation zones were at 500 ft intervals. Aspect zones were North (300-60 deg), East-West (60-120 deg, 240-300 deg) and South (120-240 deg). In addition, slopes less that 10 degrees were assigned to the East-West Zone. The average north and south aspect was determined to have approximately 30 degrees of slope. Figures 16 and 17 show elevation zones and Figures 18 and 19 show aspect zones.

Available soil moisture capacity was estimated by converting the soil type available soil moisture capacity (inch/inch) times the depth to bedrock. Low values were less than 2 inches, moderate values were 2 to 6 inches, and high values were greater than 6 inches. Figures 20 and 21 show available soil moisture capacity zones.

Forest canopy cover was determined from the May 2000 aerial photography. Areas were classified as unforested, partially forested, forest, and brush/rock. It was found that brush and rock areas corresponded to low moisture capacity soil types. These classifications were grouped into three for the PRMS model: Unforested/brush/ rock (average 10% canopy), Partial Forest Canopy (average 30% canopy) and Forest (average 90% canopy).

These zones and classifications are listed in Table 1 below. There were 162 defined HRUs. Many of these HRUs are not represented in the Duncan/Long PRMS models since they have no or little area. Both watersheds were modeled with approximately 50 HRUs. The larger 162 number of HRUs was defined and modeled to allow extension of the PRMS results to other watersheds.

Table 1. Description of Hydrologic Response Units (HRUs)

Elevation Zones	*Aspect Zones*	*Available Soil Moisture Zones*	*Forest Canopy Cover Zones*
4500-5000	East/West	Low (1")	Rock/Unforested/Brush
5000-5500	North	Moderate (4")	Partial Forest Canopy
5500-6000	South	High (8")	Closed Forest Canopy
6000-6500			
6500-7000			
7000-7500			

Description of Wet, Normal and Dry Years

In order to translate the PRMS model results into a workable tool for resource managers, model runs were made for representative wet, normal and dry years. These representative years were selected from the Duncan Canyon annual flow frequency distribution (Figure 24). With the further selection criteria that they occurred in the last 10 years, where much better calibration data existed, and they had normal distributions of winter and spring snowmelt runoff. From Figure 24, year 1992 was selected as a dry year at approximately the annual runoff 10th percentile. Year 2000 was selected as an average year at approximately the 50^{th} percentile. Year 1998 was selected as a wet year at approximately the 90^{th} percentile. Figure 25 shows how daily flows for the representative water years compare. The obvious difference in the water year types occurs during the spring snowmelt season, which peaks in April in a dry year, May in a normal year, and June in a wet year.

Calibration Procedures for PRMS Models

Calibration of Duncan Canyon and Long Canyon PRMS models was a complicated process. The first phase of the calibration procedure was to compare snowpack accumulation in the model to observed snowpacks at similar elevations. Precipitation, temperature adjustments and snow/rain threshold temperatures were adjusted until a best fit was obtained. In the second phase, model results were compared to observed annual runoff, and adjustments were made to precipitation elevation zones multipliers to account for differences between the watershed elevation zone and Blue Canyon. Finally a third phase involved adjustments in evaporation and solar radiation to account for differences in forest canopy.

Vegetation Management Alternatives

Vegetative management considered in PRMS models comprised simulation of general timber harvesting practices. Model parameters described unforested areas (0-10% canopy) , partially forested areas (20-40% canopy), mature forest (90-100% canopy) , rock areas and brush areas. Model alternatives for Duncan and Long Canyon left the natural areas of brush and rock unchanged. The different forest canopy values were tested on all elevation zones, all aspects and moderate and high available moisture capacity. Low available moisture capacity was always associated with rock and brushy areas.

As described earlier, the unforested alternative had 10% canopy, the partial forest 30% canopy and the forest 90% canopy. This is a gross simplification since canopy values due to timber harvesting have differing canopy cover at initiation, and then gradually recover over a 25-year period. Some regrowth areas show a similar recovery rate, but eventually have a nearly level dense canopy of young trees, which is not like natural old growth forest. It was sometimes quite difficult to determine from the aerial photography the degree of canopy recovery since timber removal.

The model parameters which reflect differences in forest canopy cover are interception storage, upper soil zone depth (litter layer), condensation-convective melt due to wind differences, and seasonal differences in solar radiation transmission to the ground. The PRMS model cannot differentiate between clearing size or tree height. For example, a complete forest canopy of high mature trees may have greater interception evaporation and transpiration losses than a complete forest canopy of small trees. But, a level, dense regrowth may have much higher interception evaporation losses that natural forest. In another example, certain size clearings may be efficient at redistributing snow and then maintaining shade.

At any rate, higher values of interception storage are assigned to the highest values of canopy covers. Lower upper zone soil storage is assigned to unforested areas to account for loss of duff. Lower wind speeds are assigned to the higher values of canopy covers. Transpiration losses vary directly with canopy cover. Solar radiation transmission varies with the monthly average noon solar elevation, with partial canopies effectively blocking solar radiation in winter months, and relatively ineffective in late spring months.

Investigation of vegetative management alternatives began with comparisons of HRUs for various elevation zones and aspects. Specific vegetative management alternatives were then developed for Duncan Canyon.

RESULTS

Base Flow Analysis

Introduction:

The PRMS model is mainly focused on the precipitation, vegetation, soil moisture storage, and soil drainage influences on streamflow regimes. For watersheds with complicated geologic conditions the PRMS model does not consider the implications of springs and seeps controlled by geology and groundwater processes. Therefore the PRMS modeling outputs ignore deep and long-term water storage in groundwater features and the implications of groundwater discharges on streamflows. Therefore strictly speaking the PRMS model as applied to these small watersheds has a minimum flow resolution that is terminated once moisture in the soil mantle has drained to field capacity. In conjunction with the PRMS model, an understanding of non-soil baseflow sources is necessary to fully understand overall watershed process and function of these geologically complicated watersheds.

To provide this more thorough evaluation and understanding of watershed process and function this project included a detailed field program designed to determine specific source areas of baseflow origin and to provide a field check against the modeling outputs.

The following is a general discussion of the geologic and geomorphologic conditions in the two watersheds as they may influence watershed process and function. Also there is a description of the spatial baseflow source features and baseflow regimes of the two watersheds, and a discussion of the relationships between the PRMS modeling application and the fieldwork on baseflow sources.

A) Watershed geology; **(see Figures 4 and 7)**

Both watershed are located in the 4000-7500 foot elevation zone of the west slope of the Sierra Nevada which is a zone of general metamorphic and granitic crystalline basement bedrock with a sequence of nearly horizontally bedded extrusive volcanic units, superjacent and overlying the basement rocks. Prior to the initiation of the volcanic burial of the area, the crystalline basement bedrock surfaces were eroded into a complex surface topography. The extrusive volcanic sequences, of rhyolite ash and andesitic lahars and a variety of mudflow units of variable composition, buried the crystalline terrain over a period of about 40 million years. The volcanic material burial process was a very long period of sequences of discrete flow deposition events separated by long periods of erosion and small-scale relief and terrain development. This process first filled and buried the preexisting terrain of the crystalline basement bedrock surfaces then created a board and nearly continuous surface of extruded volcanic material. In the study area only a few scattered hilltops of the crystalline bedrock, such as Little Bald Mountain and Duncan Peak, remained above the buried terrain.

The long period of volcanic flow deposits and intervals of surface erosion, that included the development of small scale local relief, stream system development, sediment transport and deposition, and the subsequent burial by additional volcanic flow events has led to a deep volcanic material depositional unit of very high variability. This sequence has resulted in a thick unit of nearly flat-lying volcanic materials but within which there is a complex of low relief bedding planes of varying extent, slopes and aspects, and permeabilities.

Since the cessation of the volcanic extrusive activities, about 5 million years ago, the Sierra has undergone progressive uplift on its eastern margin and the rotation of the nearly level volcanic depositional units into a gentle SW slope to the Sierra foothills. During the uplift the modern stream system of the Sierra developed and have downcut into the terrain over a period of about 5 million years. At the downstream end of the two watersheds, the downcutting is on the magnitude of about 1200-1500 ft.

The general geologic situation in both watersheds is somewhat similar in that the crystalline basement bedrock is exposed along the central watercourse through the downstream portions of the watersheds with much of the sideslopes and upper headwater portions of the watershed composed of various volcanic superjacent materials.

- <u>Duncan Canyon</u>: The majority of the Duncan Canyon watershed is predominantly superjacent series extrusive volcanic material. Although not mapped separated the lower rhyolite ash Valley Springs Formation occupies the lower slopes of the superjacent area and is buried by the overlying andesitic Mehrton Formation upslope and in the upper watershed above about elevation 5960 feet. In the downstream portion of the watershed the bedrock is dominated by the strongly metamorphosed Soo Fly Formation which is notable by it very hard chert dominated mineralogy. This unit is highly contorted and rotated and has very steep to near vertical bedding surface dips. A few outcrops of granite exist; however they are generally small in extent. They typically are positioned east of the Soo Fly Formation material. The locations of the basement crystalline bedrock units indicate that they may underlie the superjacent volcanic through much of the watershed at an elevation of about 5200 to 6000 feet and may increase in elevation gradually toward the east. This however is uncertain, as the buried crystalline bedrock erosional surface is unknown.

- <u>Long Canyon</u>: In the Long Canyon watershed the basement crystalline bedrock is composed entirely of granitic series intrusive units buried by the superjacent volcanic series. The granites occur in the downstream two thirds of the watershed and while limited to the lower elevations along the valley bottom as in Duncan Canyon, due to more extensive erosion, they occupy a wider portion of the watershed cross-section. Although not differentiated on the map, these granitics are predominantly silica rich granites in downstream two thirds of their exposure and mafic rich (and more resistant to weathering) gabbro in the upstream one third. Similar to the Duncan Canyon watershed, these basement crystalline rocks underlie the superjacent volcanic material throughout the rest of the watershed. The buried crystalline erosional surface is also unknown in the Long Canyon watershed but some granite exposures high on the canyon slopes along Nevada Point Ridge indicate that the pre-burial crystalline terrain surface is highly variable.

The identification of these exposures during the fieldwork on this project has lead to modifications of existing area geology maps of the granitic boundary along the north-facing slope of Nevada Point Ridge. The exposures are very limited in extent, and the geologic field mapping in this area was not thorough, so the modifications made on the geology maps for this project should be considered provisionary if used for any other purposed than as part of the PRMS modeling effort.

The superjacent series includes both rhyolitic ash Valley Springs Formation, just above the crystalline bedrock, and the andesite extrusive volcanic Mehrton Formation overlying the rhyolite material. Different from Duncan Canyon, there is as small unit of Ione Formation along the NF Long Canyon, which is a deposit of auriferous (gold baring) gravels. This unit has been heavily mined and is now mostly an open gravel pit.

B) Watershed geomorphology; **(see Figures 5 and 8)**

In spite of the overall similar bedrock geology, the two watersheds vary in some geomorphic parameters that have significant implications to baseflow.

- Duncan Canyon: The dominate geomorphologic features of Duncan Canyon includes extensive colluvial slopes with a moderate to relatively thick soil mantel, extensive areas of relatively impervious bedrock, a relatively broad valley setting upstream of the crystalline bedrock channel control and a highly incised channel in the crystalline bedrock reach.

- Geometry: The watershed ranges in elevation from about 5250 to about 7430 ft. The stream density of the watershed is ___/square mile based on USGS defined stream courses. It has a channel dissection ratio of about 2.7 (27.1 miles of modeled channel in 10 square miles). The dissection ratio described the possible channels in a unit of terrain based on a fine-grained assessment of topographic crenellations. In this study the total watershed channel segment lengths that provide this ratio is based on a "flow accumulation grid model" that defines a potential channel when there is 22.2 or more acres of flow contribution area to a point of flow concentration as defined by a 30 meter DEM. Although this assessment develops estimates of "potential channels" it may reasonably provide a relative measure of the degree of watershed erosion conditions and a better estimate of channel density when considering higher magnitude runoff events.

- Features; The crystalline basement bedrock exposures along the downstream channel reaches in the watershed are more resistance to erosion than the rhyolite and andesite units along upstream channel reaches. As a result the downstream channel reaches are noted primarily by bedrock incision conditions while upstream channel reaches are notable by broad low slopes adjacent to the channel along with terraces and deep colluvial slopes. This condition most likely results from an erosion-resistance nick-point at the upstream edge of the crystalline bedrock. This unit is more resistant to erosion and arrests the channel downcutting erosional rates of upstream channel reaches, which allows for a different balance between channel downcutting and slope retreat that leads to a wider valley condition. The terraces probably relate to episodic downcutting "events" driven by longer-term climatic patterns

Downstream from Robinson Flat is a small area of glaciation that include some scoured terrain and some lateral moraines. The source of this glacier was probably the north slope of Little Bald Mountain although clear evidence of this was not observed in the field.

Along the north-facing slope of Red Star Ridge there are several topographic features of apparent accelerated erosion, which have the expression of landslide scarps. Based on observations of features similar to these in other portions of the NF/MF watershed, they appear to be progressive small-scale landslide failures and progressive slope retreat in flat-bedded andesite materials when water sapping occurs at lower slope positions. These failures are not thought to be massive in scale because no substantial debris fields have been observed leading to the conclusion that the local export of debris materials occurs at greater rates than slope failures. In the Duncan Canyon watershed only small portions of these features appear to be active and may mostly be in a recession state, transitioning toward more typical colluvial processes.

The rest of the watershed geomorphology is driven by hillside erosion, colluvial processes, and rarely small scale landslides resulting from discrete springs and seeps.

- Long Canyon; The dominate geomorphologic features of Long Canyon includes extensive colluvial slopes with a soil mantel of thin to moderate thickness, areas of relatively impervious bedrock, and a wide valley setting due to glacier shed-jumping from the Rubicon Canyon glacier.

- Geometry; The watershed ranges in elevation from about 4160 to about 7230 ft. The stream density of the watershed is ___/square mile based on USGS defined stream courses. It has a channel dissection ratio of about 2.9 (51.4 miles of modeled channel in 18 square miles).

- Features; The dominate geomorphologic feature from a baseflow perspective are the consequences of glacier shed-jumping from the Rubicon to SF Long Canyon and from SF Long Canyon to NF Long Canyon. The glacier jumping into SF Long Canyon appears to have occurred in two separate events and at two locations. These events have both modified the topography of the watershed and introduced till and moraine material. The shed-jumps also entered the receiving watersheds at mid elevations damming the watershed. The character and distribution of sediment derived from these glacial processes are of primary importance in the distribution of baseflow source areas and baseflow regimes.

Similar to Duncan Canyon, the upstream portion of the main stem CF Long Canyon is a open valley setting with riparian terraces with a relatively low channel gradient and has a "hanging valley" nature when compared to overall channel profiles through the watershed. In Duncan Canyon this feature was attributed to downstream harder bedrock along the channel. In SF Long Canyon this is attributed to the greater downcutting downstream that occurred during the periods when the glaciers jumped from the Rubicon Canyon.

C) Channel and baseflow features: **(see Figures 6 and 9)**

The sources of baseflows in the two watersheds and the overall baseflow regimes are primarily related to geologic and geomorphic features however there are also significant baseflow sources that are related to general soil moisture drainage that support the findings of the PRMS model outputs.

- Duncan Canyon; The baseflow regime in Duncan Canyon have three main source types. First, along the main channel at elevations 6400 to about 6800 feet is a reach in which many seeps and small areas of concentrated springs were observed very late in the baseflow season even when the field season was at the end of a low water year precipitation regime. This source had the widely distributed characteristics that could be explained by general soil moisture drainage rather than discrete geologically controlled groundwater discharge springs. The highest elevation occurrence of fish, indicating constant and reliable flows, was at about elevation 6600 feet.

Between about elevation 5900 to 6200 feet the main channel runs through the "hanging valley" setting with substantial elevated terraces. The terraces are positioned at the foot of broad colluvial slopes on andesite terrain. These terraces have many springs and seeps that also provide baseflow to the main channel. The likely water sources of these springs and seeps are the progressive downslope moisture movement from the valley sides and the surfacing of this water due to a reduction of slope angle near the stream. However the overall input of water in this reach appears to be balance by transpiration loss rates of the dense riparian thickets, and little net change in baseflow magnitude is apparent.

Below elevation of 5900 feet the main channel is controlled by crystalline bedrock. Over about a mile of channel, the base of the overlying volcanic material is within about 5-20 feet of the channel bed elevation and there are numerous baseflow sources that are both seeps and discrete, well-organized springs. In addition, discrete spring sources located at mid-slope elevations in the andesite material result in considerable inflow at tributaries and hillside flow-ways. From about elevation 5700 to 5500 feet, the baseflow magnitude increased from 2-3 fold due to these groundwater discharge sources.

Areas of accelerated erosion along the north slope of Red Star Ridge are vegetated by a dogwood/mixed brush complex that indicates higher late season soil moisture. However, if site visits to similar situations in the Long Canyon watershed apply to those in Duncan Canyon, these areas provide baseflow discharges but at very low magnitudes that may only be significant to the moisture regimes of the tributary channels, and provide essentially no contribution to the baseflow of the main stem.

Flows in Little Duncan Canyon are primarily supported by discharges from Robinsons Flat, discharges from the head cuts of "valley fill" channel incision processes (particularly NE of Little Bald Mountain), well organized bedrock groundwater discharge springs, and drainage of low terraces.

Scattered alder thickets indicate locations of high soil moisture due to geologically controlled seeps and springs. Some of this site provides baseflow discharges while others appear to transpire all available moisture.

- Long Canyon; Similar to Duncan Canyon, the baseflow regime in SF Long Canyon has three main source types. First, along the main channel at elevations 6300 to about 6420 feet is a reach in which many seeps and small areas of concentrated springs were observed very late in the baseflow season even when the field season was at the end of a low water year precipitation regime. This source had the widely distributed characteristics that could be explained by general soil moisture drainage rather than discrete geologically controlled groundwater discharge springs.

Between about elevation 5900 and 6300 feet the main channel runs through the “hanging valley” setting with substantial elevated terraces. The terraces are positioned at the foot of broad colluvial slopes of andesite terrain. These terraces have a few springs and seeps that provide almost no baseflow contribution to the main channel. However in this reach dense riparian thickets have high transpiration rates, deep fluvial channel materials. The overall low input of water, in this reach appears to lose baseflows due to both transpiration loss rates and deep flow through the channel sediments. Throthrough the downstream portions of this reach surface baseflows occur only in scattered locations.

From elevation about 5760 to 5900 feet, the channel gradient is steep and cuts through glacial moraine materials. At the head of this reach the baseflow are reestablished by the interception of deep channel material flows by the steeper channel gradients. The highest elevation occurrence of fish in this channel, indicating constant and reliable flows, was at about elevation 5800 feet.

From about elevation 5400 to 5760 feet the main stem traverses a reach of andesite bedrock, glacier outwash, and granite bedrock, over which baseflow are lost to deep percolation and apparently to groundwater recharge to the jointed granite unit. Baseflow, when observed are in small disconnected pools with extensive dry channel reaches.

Between about elevation 5200 and 5400 feet baseflows are reestablished in the main channel apparently due to moisture drainage from the large glacier moraine body in the Big Meadow area.

From elevation 5200 to the bottom of the watershed additional baseflow sources are mostly associated with small scattered hillside springs. These springs are located on glacial valley fill and ground till. The probably sources of this water may be derived from moisture draining of the thick ground till units but also may be through-flow water from buried groundwater discharge springs located along the moraine-buried boundary of the granite/superjacent units. These sources provide very low baseflow rates and evapotranspiration losses in this reach appear to roughly balance the inputs. Baseflow magnitude changes little over the reach.

Similar to Duncan Canyon there are areas of accelerated erosion along the north slope of Nevada Point Ridge that are vegetated by a dogwood/mixed brush complex that indicate higher late season soil moisture. However, site visits to some of these areas indicate that these areas provide baseflow discharges but at very low magnitudes which may only be significant to the moisture regimes of the tributary channels, and provide essentially no contribution to the baseflow of the main stem.

The baseflow regime in NF Long Canyon is notably different that of SF Long Canyon. Essentially all the baseflow in this system has its source in a short reach of channel between about elevation 4780 and 4900 feet. This area has an exposed granite/superjacent bedrock boundary and relatively thick deposits of “backwater” glacial moraine material resulting from the shed-jump into NF Long Canyon from SF Long Canyon. There is a 1200-foot reach with a dense pattern of seeps and springs from terrace, moraine, and weathered bedrock units.

Downstream of this reach there are a few baseflow inputs to the NF Long Canyon but they result in essentially no change in baseflow magnitude. The sources of these additional baseflow inputs are mostly mid-slope bedrock springs and seeps in the andesite and rhyolite units. There are baseflow inputs along the channel of the NF Long Canyon below elevation 4240 where the channel is incised into crystalline bedrock but these sources tend to cease flow early in the baseflow season.

D) Conclusions:

These field work results in two main conclusions. First the specific geologic and geomorphologic circumstances of these small watershed are primary driving factors in the sources of baseflows and a understanding of these features would be need to understand the baseflow portion of watershed processes and function. Second, the field work tends to confirm the PRMS model in that for extreme baseflow circumstances, soils moisture discharges near the headwaters are an important factor in the baseflow regime regardless of other geologic an geomorphic factors, and in spite of the small contributing watershed area to these headwater reaches. Therefore if baseflow management were a defined resource value, vegetation management above about 6200 feet along the main stem would be an important consideration.

Calibration of PRMS Models

The snowpack accumulation calibration was considered a key first step in the modeling. Simulating water available for runoff from the snowpack depends on more model parameters than runoff in the rainfall elevation zones. Snowpack generated runoff is also the most important to resource managers since it occurs when reservoirs, which were drawn down for winter flood control, can be re-filled. In addition, late spring and early summer runoff in the Sierra Nevada is almost always controlled by snowmelt, and agriculture interests without storage facilities can use this runoff.

Figures 26, 27 and 28 show the results of snowpack simulations for the 6250 ft zone for dry, normal and wet years. The snow course water contents marked by ex's. are closest to the elevation of the 6250 HRU. Average and wet years simulated well, although the dry year model simulated snowpack melted out two weeks early.

The second phase of the calibration was a comparison of Duncan Canyon annual yield with the PRMS model. Figure 29 shows the result of this comparison. For most years, including the representative years, model results are within 10% of observed. All of the years with larger errors had major winter floods, when the Duncan Canyon stream gage-rating curve was poorly calibrated. It is quite likely that the PRMS model results are more accurate than the stream gage record.

The final phase of calibration involved comparing observed and simulated daily flows for the representative years. Figures 30, 31 and 32 show PRMS Duncan Canyon model results for the representative years. The daily flow simulations are best in the dry and normal years. In the wet year 1998, differences are greatest above 200 cfs, where the data are least trustworthy. Model water storage compartment partitioning and base flow recession coefficients were assigned the Duncan Canyon and Long Canyon PRMS models based on observed base flow recession at the stream gages after storms and after spring snowmelt.

Figures 33, 34 and 35 show PRMS Long Canyon model results for the representative years. The only valid conclusion, which can be made from the figures, is that the Long Canyon stream gage records are very poor. In fact, the gage records for Long Canyon having too low flows above 50 cfs can partially explain the low ratios of annual yield of Long/Duncan.

Vegetation Management Alternatives

Individual HRU Response Patterns were compared for forest vs. no canopy. These comparisons would naturally show the greatest effects. Actual watersheds, unless very small, would not exhibit the magnitude of these changes. Figures 36 through 47 show the influence of removing forest cover for various elevations, aspects and representative years. On a percentage basis, the increases are the most significant in dry years and the least significant in wet years. Increases in yield range from 10 to 30%, consistent with the literature.

Vegetative management alternatives were tested for Duncan Canyon entire watershed. Figures 48,49 and 50 show the effect of complete coverage of partial canopy. All water year types show significant increases in spring snowpack melt runoff, but only minor differences in timing.

Similar comparisons of forest vs. no canopy were made for north aspects only. (See Figures 51, 52 and 53). Snowmelt runoff increases are lower than the entire watershed test, since north slopes comprise 43% of the watershed.

Comparisons for south slopes were also made. (See Figures 54, 55 and 56). Only 20% of Duncan watershed is a south slope, and most of those are rock/brush. Increases in annual yield are a few percent.

Partial canopy removal scenarios were simulated to show the effect of removing all remaining marketable timber in Duncan Canyon. Areas of brush, rock and Section 8, which were already had partial canopies, were excluded. (See Figures 57, 58 and 59). Significant increases in winter flood events and peak spring snowmelt occurred in all representative year types. Annual increases in yield varied from 10 to 20%.

Excel Spreadsheet of HRU Assessment Matrix

The PRMS HRU individual responses can be used to predict some hydrologic parameters for any watershed in the American River and Yuba River basins with elevation ranges (4500-7500 ft.) similar to the paired Duncan Canyon/Long Canyon watersheds. The individual HRU responses were used to construct a spreadsheet assessment matrix. Examination of the HRU simulations determined that annual runoff; snowpack April 1 water content, snowpack meltout date and mid-July base flow were useful and predictable hydrologic parameters for resource managers.

A spreadsheet model was set up to predict these four types of watershed response to vegetative management in individual HRUs. The area of the watershed determined for each HRU is entered in the spreadsheet. The percentage of existing canopy cover and a new percentage for the future are entered for each HRU (from 0 to 100% canopy cover).

The spreadsheet calculates the following watershed responses for the existing and the future condition. The conditions listed below are shown for wet, normal and dry years. Table 2 shows an example of the spreadsheet and its output.

1. Annual Runoff (acre feet/year)
2. Snowpack Maximum Water Content (Inches on April 1)
3. Snowpack Melt-Out Date (Julian day)
4. Summer Base Flow (cfs on July 1)

A CD with the HRU Assessment Matrix Excel spreadsheet is attached to this report.

REFERENCES

(1) California Department of Water Resources, California Data Exchange Center (CDEC) cdec.water.ca.gov

(2) Cary, L.E. *Techniques for estimating selected parameters of the U.S. Geological Survey Precipitation-Runoff Modeling System in eastern Montana and northeastern Wyoming.* U.S. Geological Survey, Denver, Colorado, WRIR 91-4068, 1991.

(3) James, E.D. and C.M. Brendecke, "The Redistribution and Sublimation Loss of Snow pack in the Alpine Watershed". *53rd Western Snow Conference*, 1985

(4) Jeton, A.E. *Precipitation-Runoff Simulations for the Lake Tahoe Basin, California and Nevada*, U.S. Geological Survey, Denver, Colorado, WRIR 99-4282, 1999.

(5) Kattelmann, R.C. "Water Yield Improvement in the Sierra Nevada Snow Zone, 1912-1982". *50th Western Snow Conference*, 1982.

(6) Leavesley, G.H., R.W. Lichty, B.M. Troutman, and L.G. Saindon. *Precipitation-Runoff Modeling System: User's Manual.* U.S. Geological Survey WRIR 83-4238, Denver, Colorado, 1983

(7) Leavesley, G.H., R.W. Lichty, B.M. Troutman and L.G. Saindon. "A Precipitation-Runoff Modeling System for Evaluating the Hydrologic Impacts of Energy Resources Development". *49th Western Snow Conference*, 1981

(8) Marvin, Sharah. "Possible Changes in Water Yield and Peak Flows in Response to Forest Management", *Sierra Nevada Ecosystem Project: Final Report to Congress*, University of California, Centers for Water and Wild land Resources Davis, California, Vol. III, 1996.

(9) Marron, James K. "Parameter Estimation for the Precipitation-Runoff Modeling System Using Snow Telemetry System Data." *54th Western Snow Conference*, 1986.

(10) McGurk, Bruce J. and Maureen L. Davis. Camp and Clear Creeks, El Dorado County: Chronology and Hydrologic Effects of Land-Use Change. *Sierra Nevada Ecosystem Project: Final Report to Congress*, University of California, Centers for Water and Wildland Resources Davis, California, Vol. III, 1996.

(11) Norris, J. Michael. *Application of the Precipitation-Runoff Modeling System to Small Basins in the Parachute Creek Basin, Colorado.* U.S. Geological Survey, Denver, Colorado, WRIR 86-4115, 1986.

(12) Risley, J.C. *Use of a precipitation-runoff model for simulating effects of forest management on stream flow in 11 small drainage basins, Oregon Coast Range,* U.S. Geological Survey, Denver, Colorado, WRIR 93-4181, 1994.

(13) Tarboton, David G., Mohammed J. Al-Adhami, David S. Bowles. "A Preliminary Comparison of Snowmelt Models for Erosion Prediction". *59th Western Snow Conference*, 1991.

(14) Toews, D.A., and D.R. Gluns. "Translating Snow Hydrology Research Results into Guidelines for Forest Managers: Gaps Between Theory and Practice". *56th Western Snow Conference*, 1988

(15) Troutman, B.M. "Errors and parameter estimation in precipitation-runoff modeling," *Water Resources Research*, 21(8), 1214-1222.

(16) U.S. Department of the Army, Corps of Engineers, North Pacific Division, *Snow Hydrology,* Central Sierra Snow Laboratory, Willamette Basin Snow Laboratory, NTIS PB 151660, 1956.

(17) U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. *Soil Survey Eldorado National Forest*, 1985.

(18) U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. *Soil Survey Tahoe National Forest*, 1985.

(19) U.S. Department of Commerce, National Weather Service, National Climatic Data Center. lwf.ncds.noaa.gov/oa/ncdc.html

(20) U.S. Department of Interior, Geological Survey, Reston, Virginia water.data.usgs.gov/ca/nwis/qw

(21) University of Utah, Cooperative Mesonets in the western United States. www.met.utah.edu/mesowest/

(22) Van Haveren, Bruce P. "Wagon Wheel Gap Watershed Experiment Revisited". *49th Western Snow Conference*, 1981

(23) WMO, *Intercomparison of models of snowmelt runoff: WMO Operational Hydrology Report No. 23, WMO Publication No. 646*, WMO, Geneva, 1986.

Figure 1.

Duncan Canyon / Long Canyon Watersheds

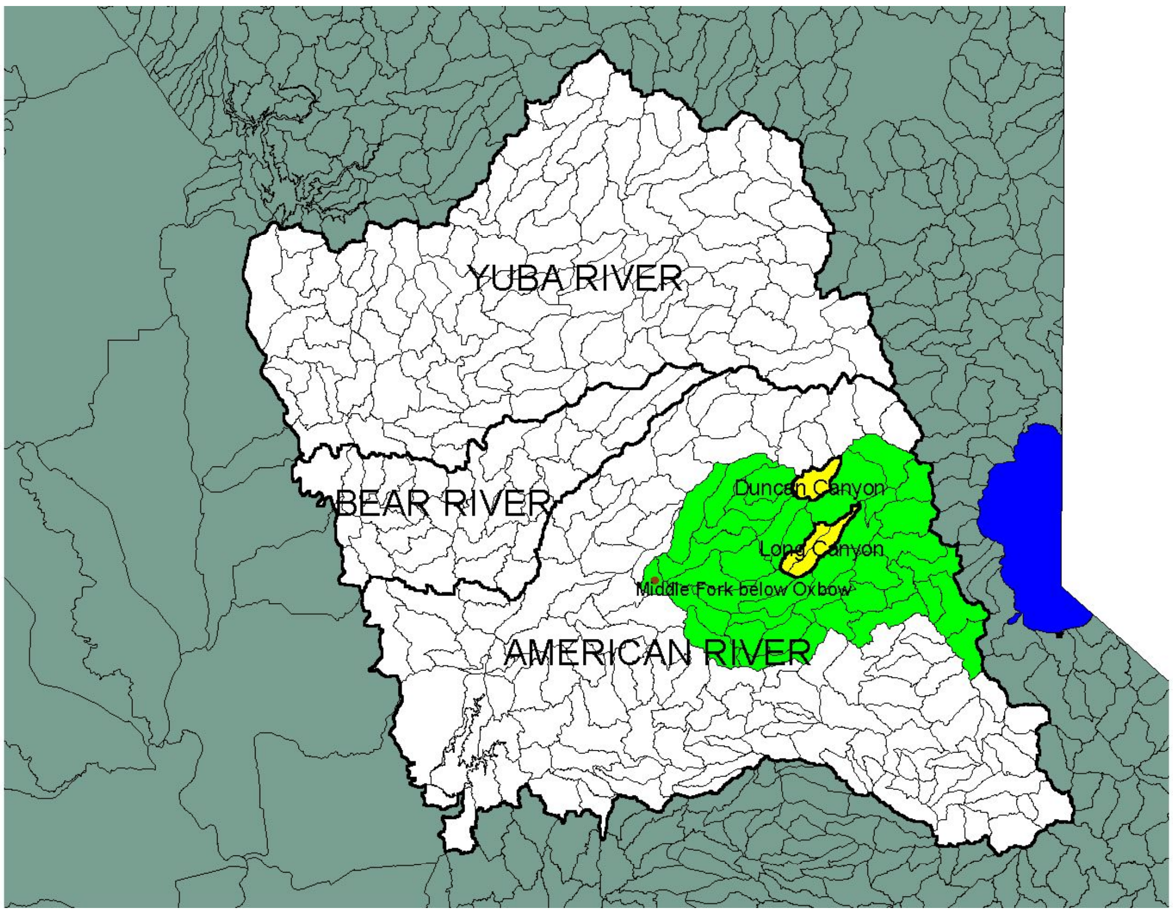


Figure 2.

Duncan Canyon Topography

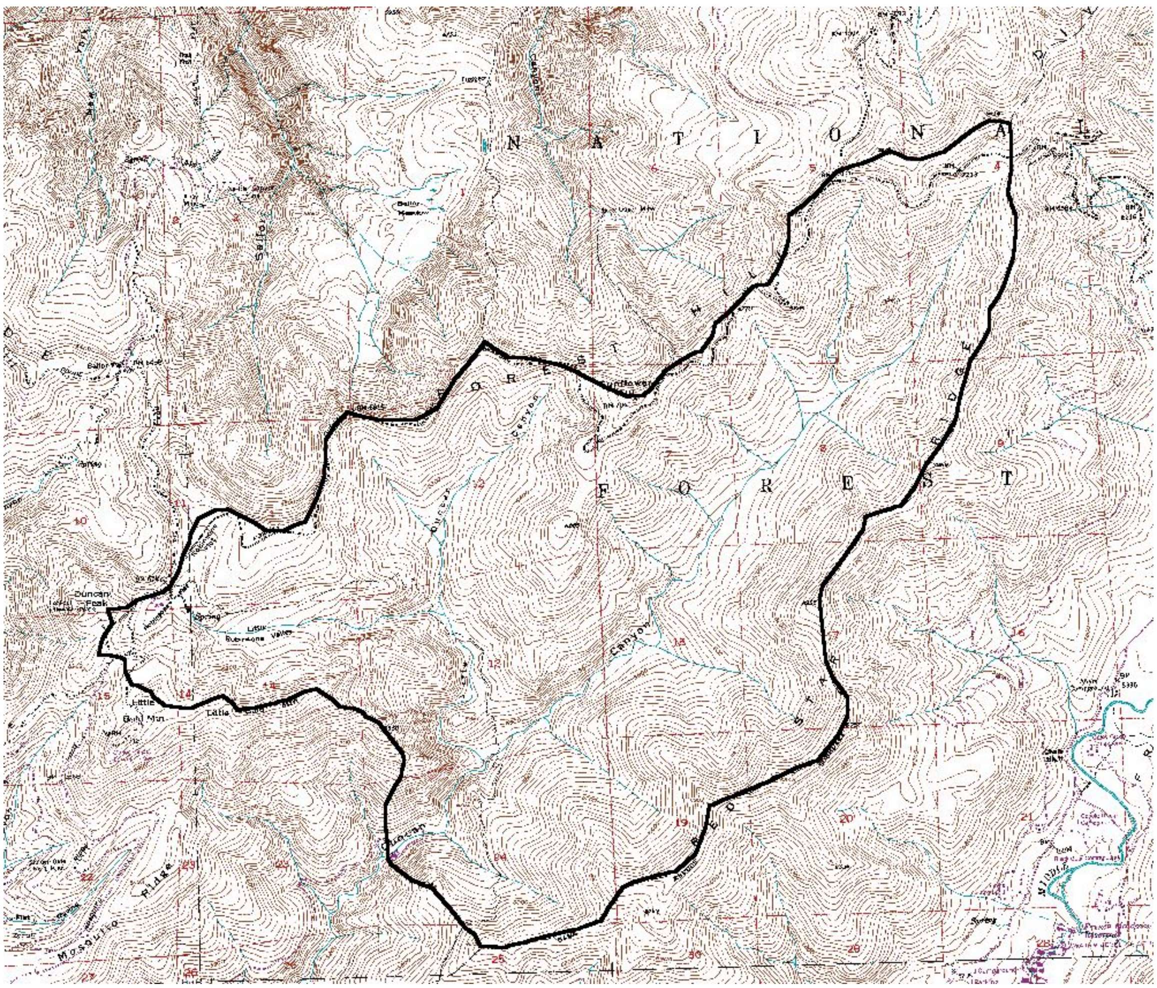


Figure 3.

Long Canyon Topography

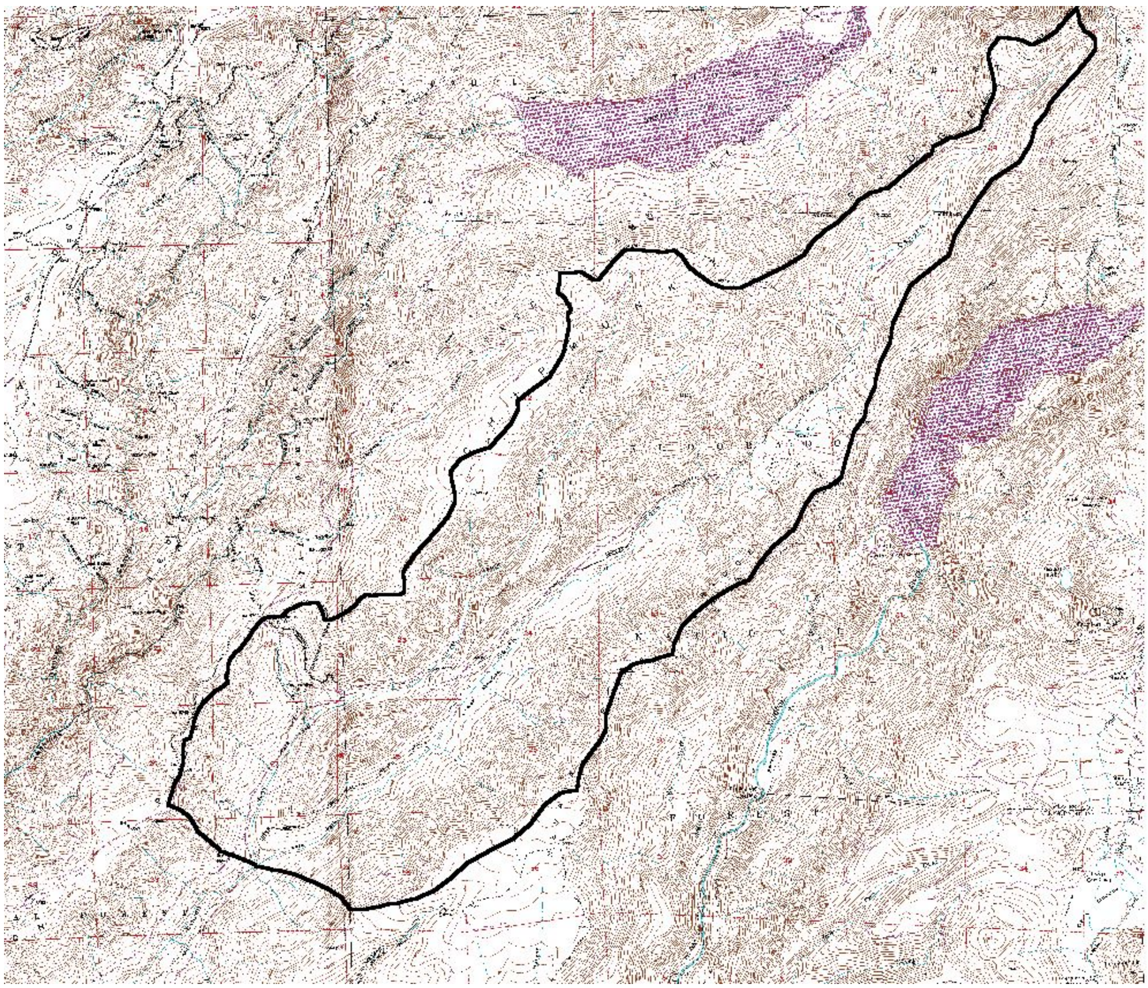


Figure 10.

Climatological Stations and Snow Courses

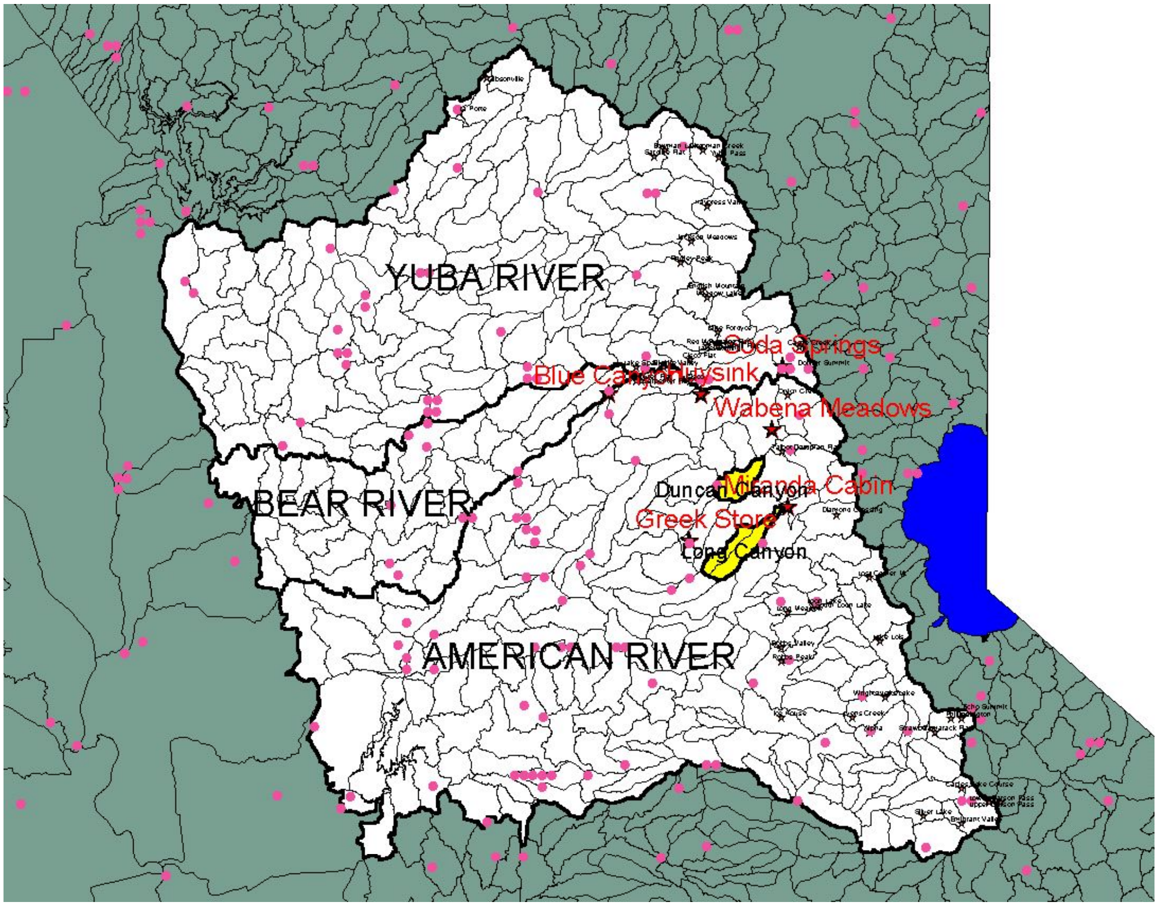


Figure 11.

Daily Snow Pillow and Monthly Snow Course Data

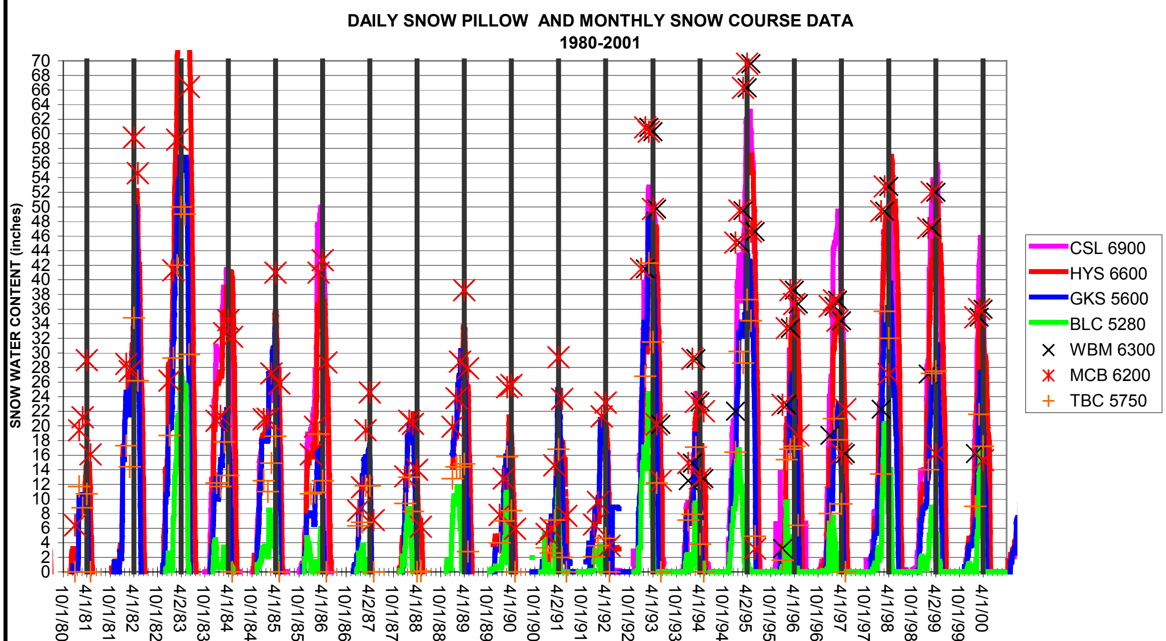


Figure 12.

Duncan Canyon and Long Canyon Daily Flow Data

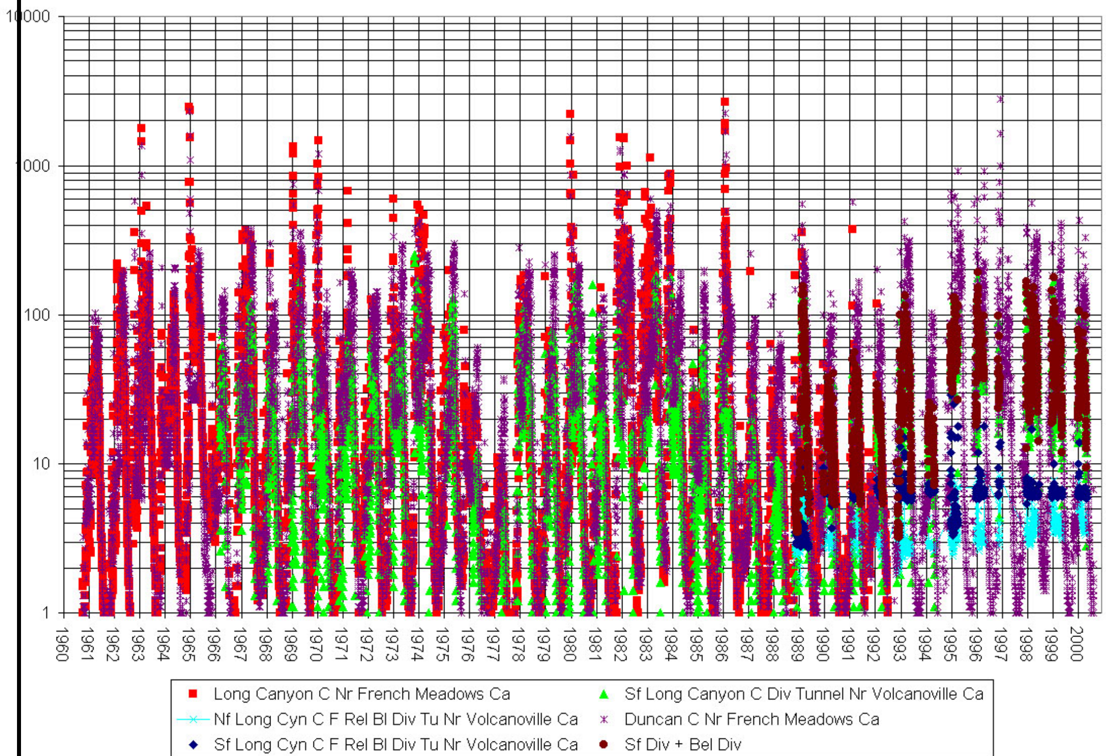
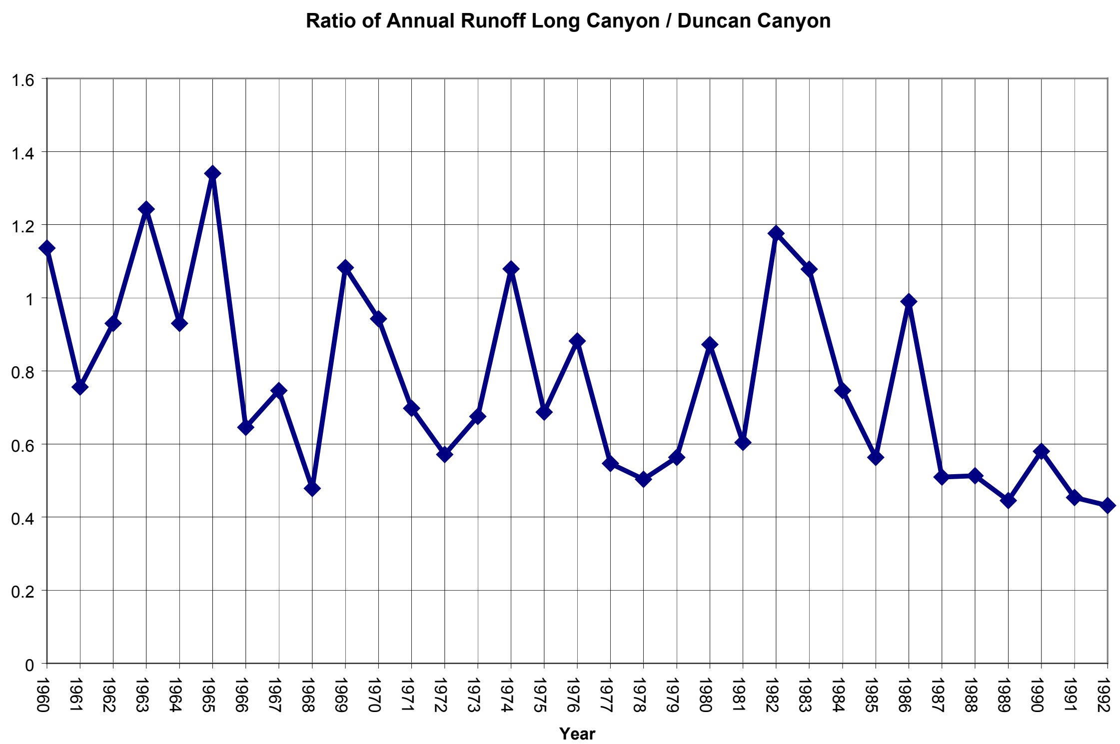


Figure 13.

Duncan Canyon / Long Canyon



Ratio of Annual Runoff 1960-1992

Figure 14.

Duncan Canyon / Long Canyon

Ratio of Annual Runoff 1966-1986

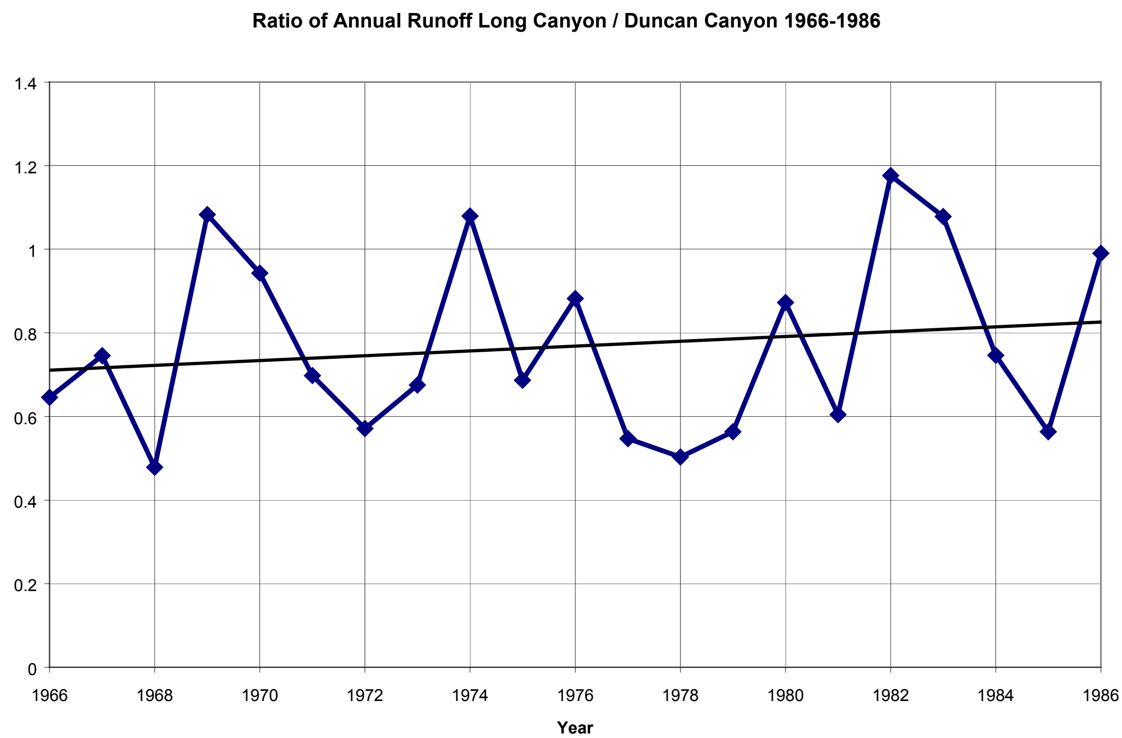


Figure 15.

Duncan Canyon / Long Canyon

Hypsometric Aspect Curves

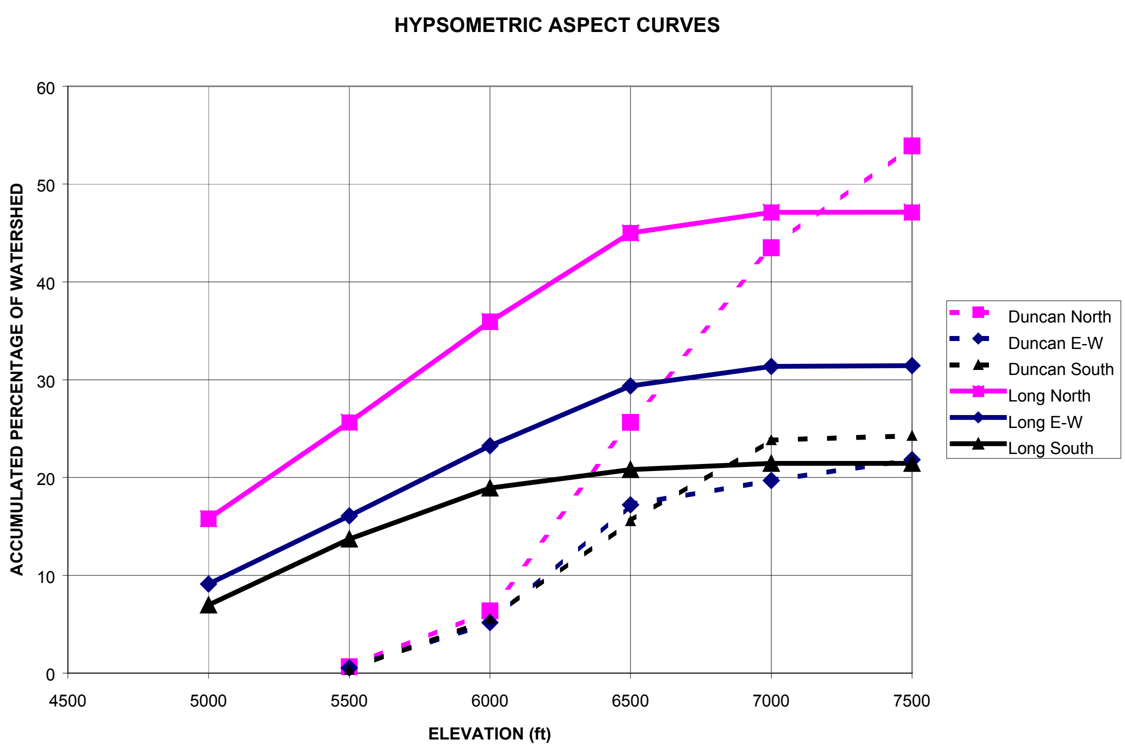


Figure 16.

Elevation Zones for Duncan Canyon

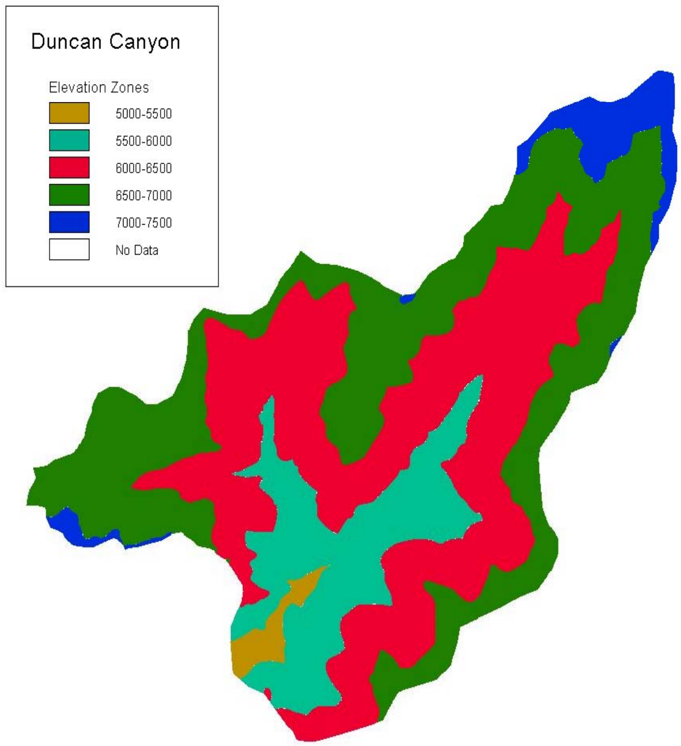


Figure 17.

Elevation Zones for Long Canyon

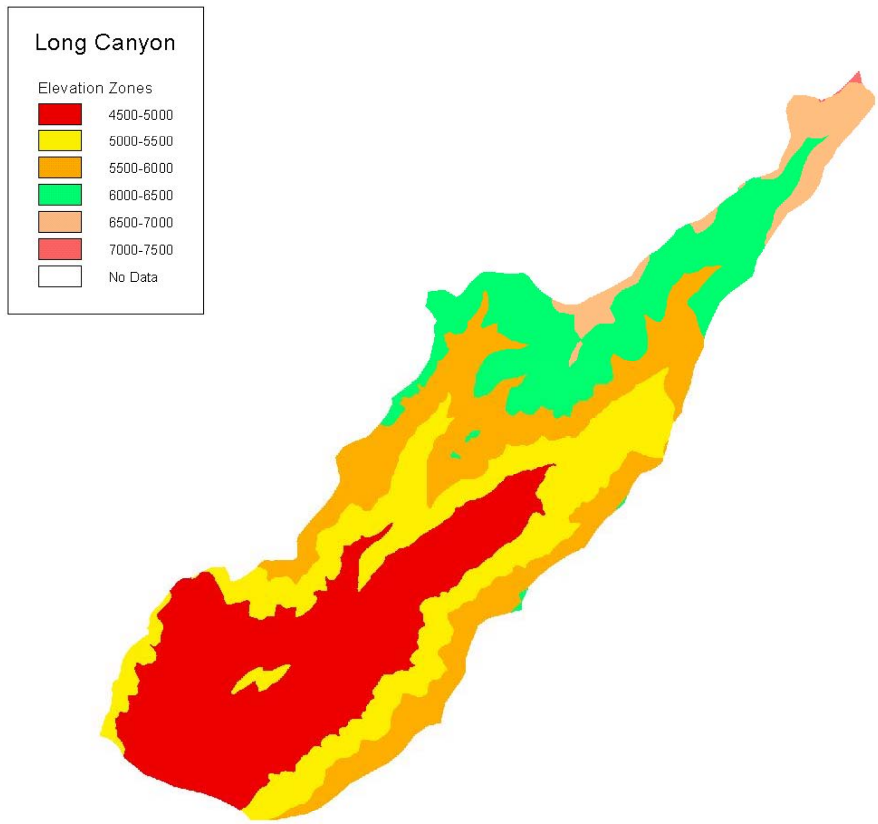


Figure 18.

Aspect Zones for Duncan Canyon

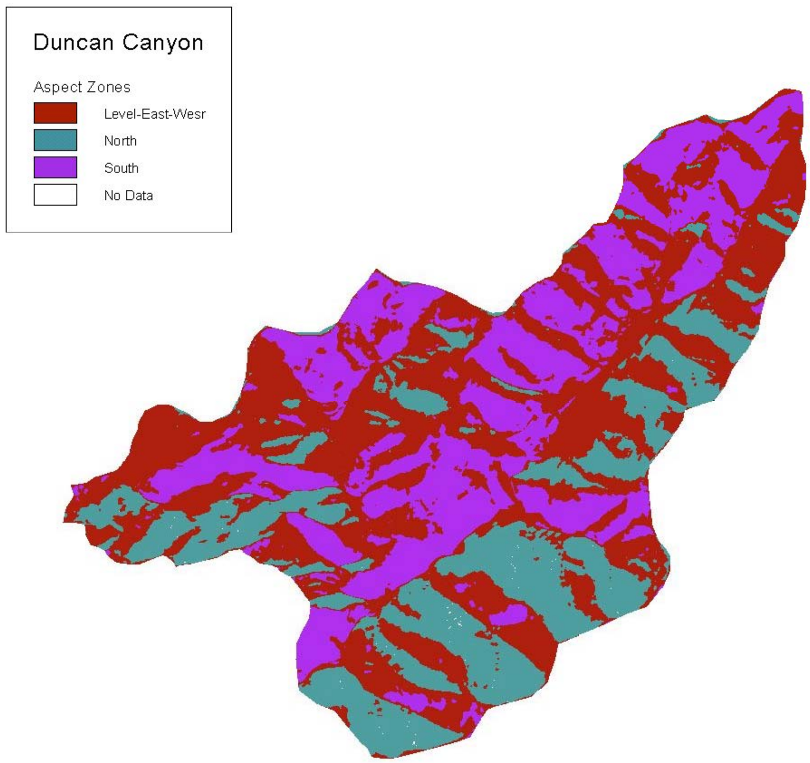


Figure 19.

Aspect Zones for Long Canyon

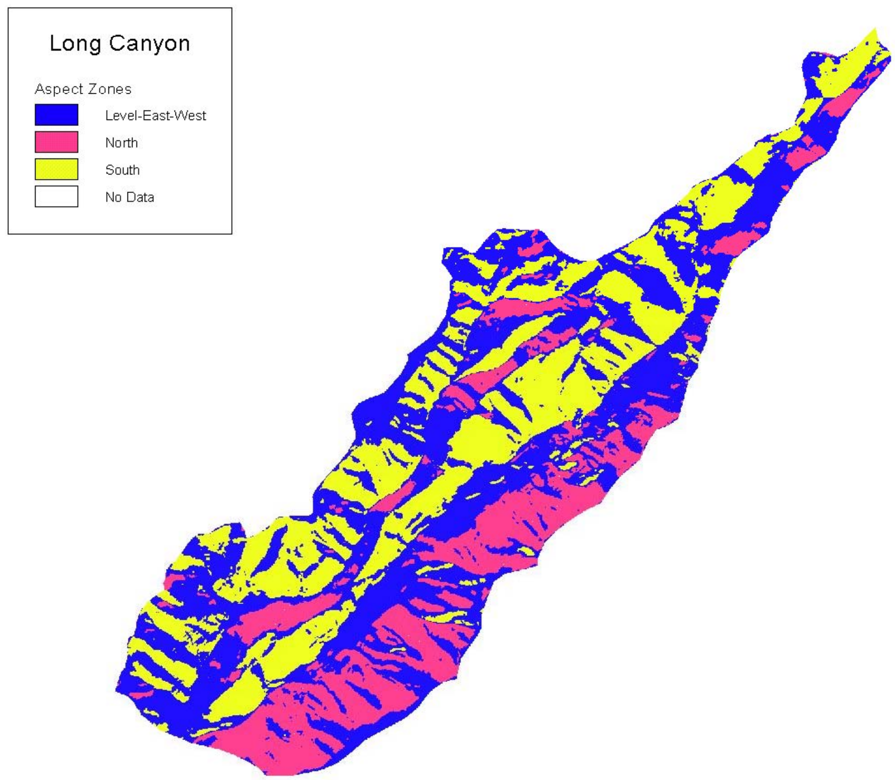


Figure 20.

Duncan Canyon

Available Soil Moisture Capacity Zones

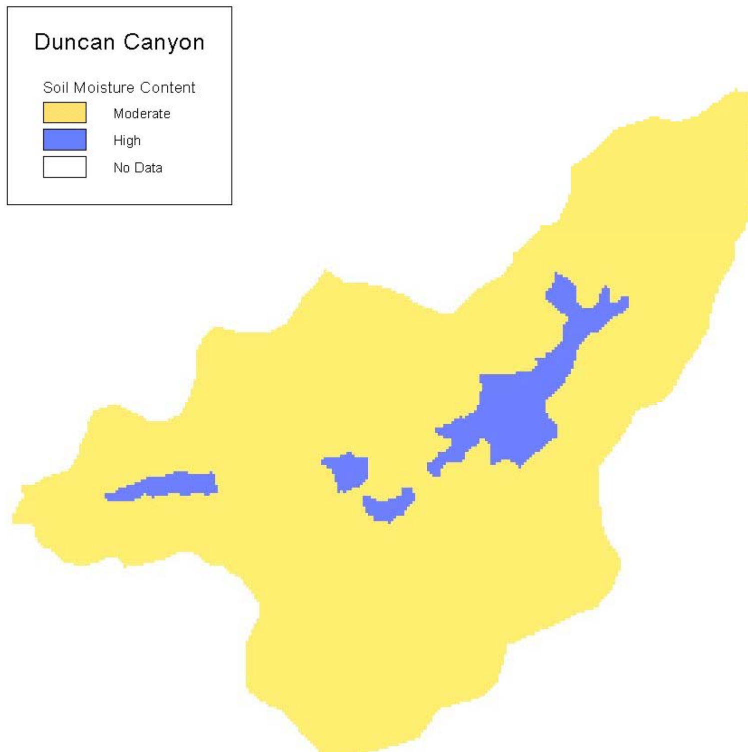


Figure 21.

Long Canyon

Available Soil Moisture Capacity Zones

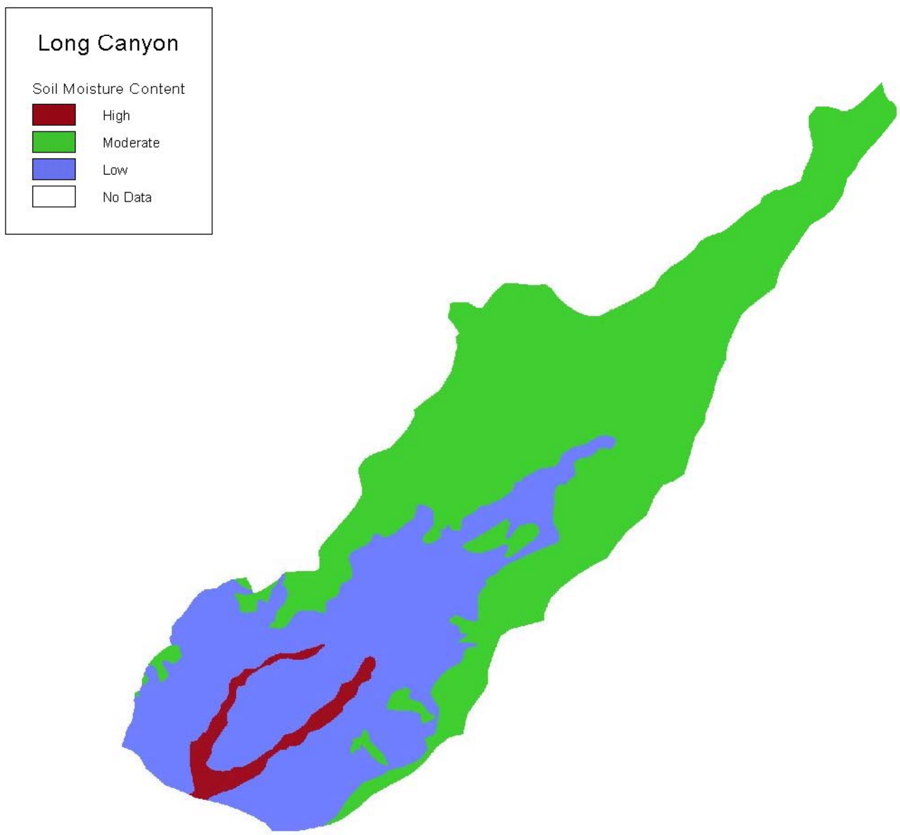


Figure 22.

Existing Canopy Cover for Duncan Canyon

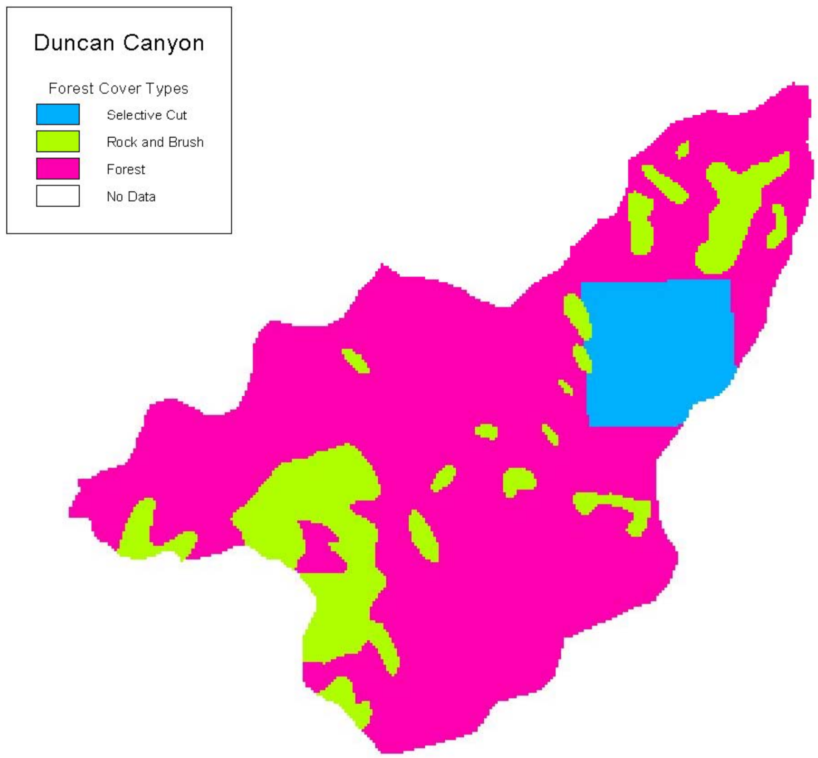


Figure 23.

Existing Canopy Cover for Long Canyon

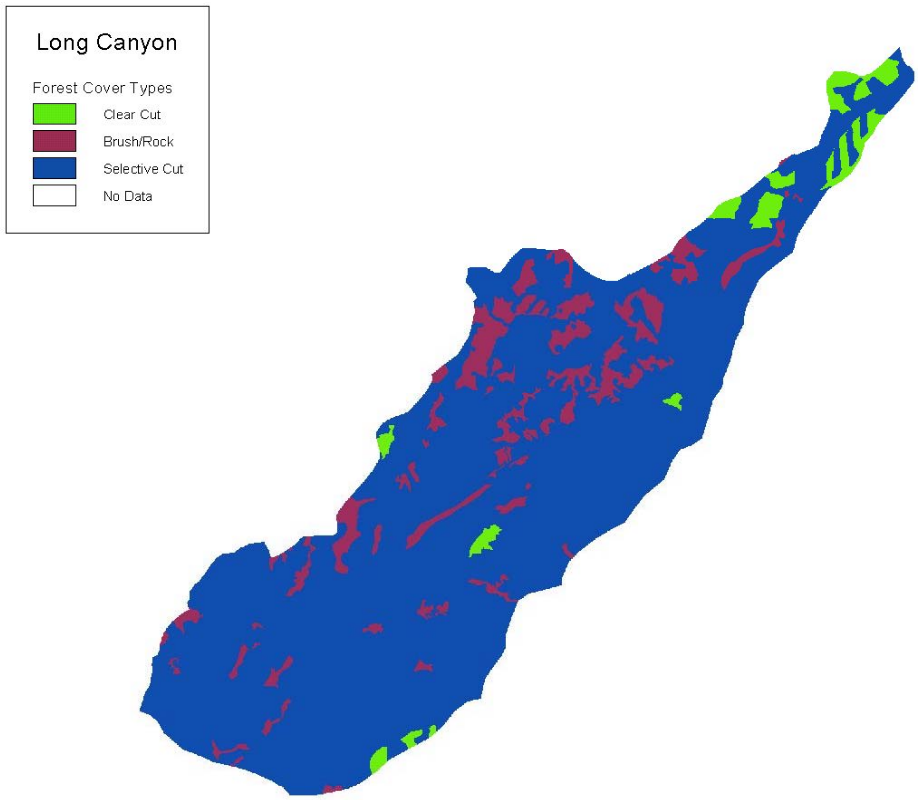


Figure 24.

Duncan Canyon

Annual Flow Frequency Distribution 1960-2000

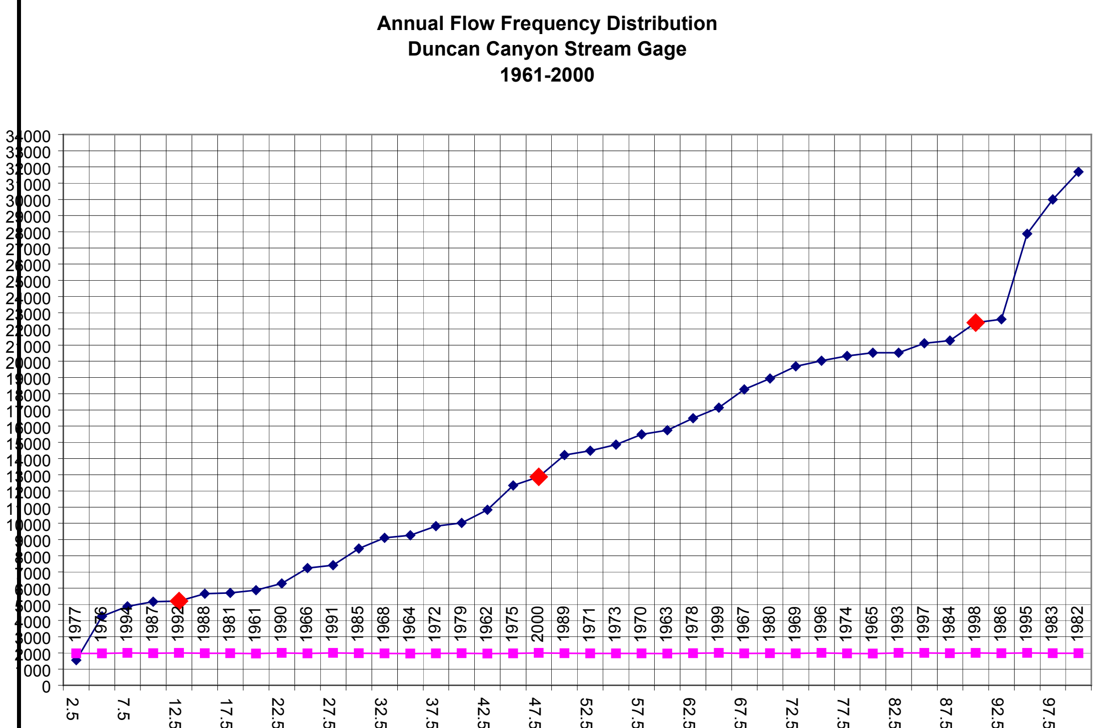


Figure 25.

Duncan Canyon

Daily Flows for Water Year Types 1992, 1998, 2000

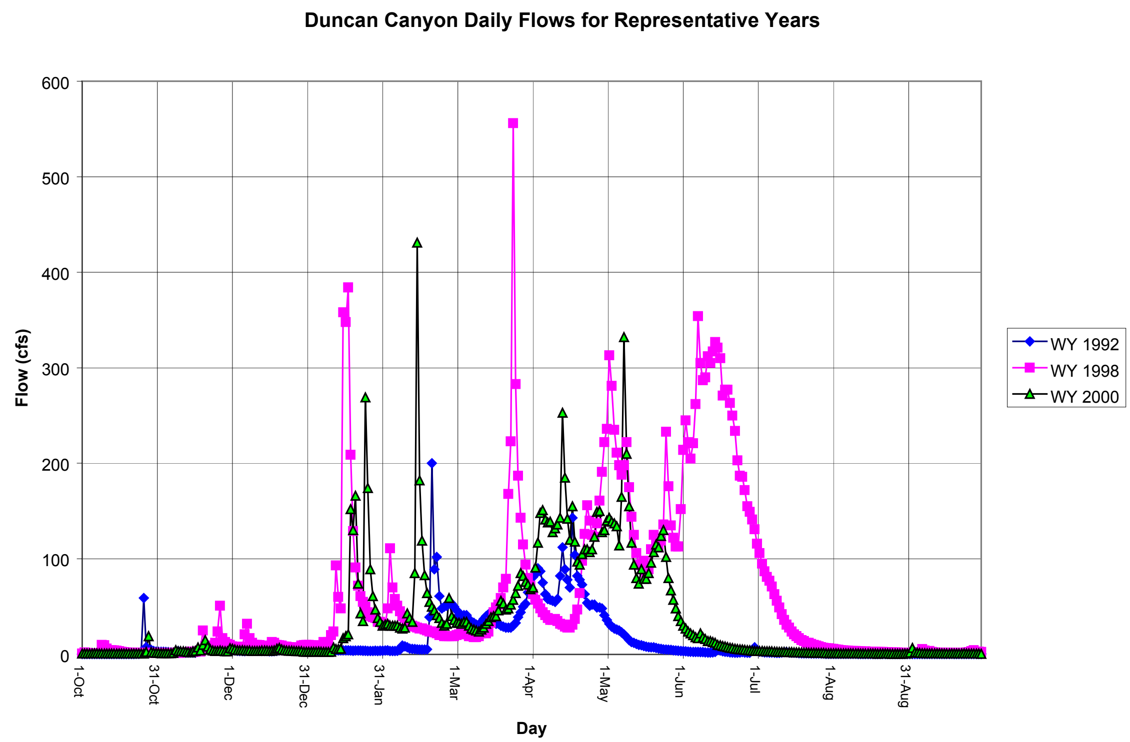


Figure 26.

6250 ft Elevation Snow vs. Snow Course and

Snow Pillow Data 1992

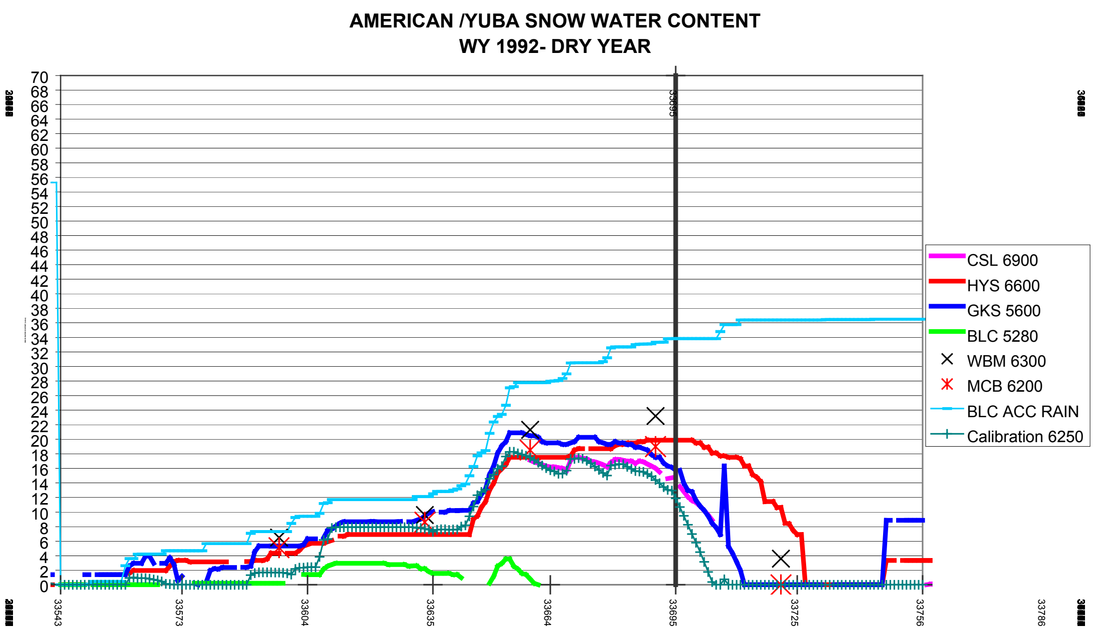


Figure 27.

6250 ft Elevation Snow vs. Snow Course and

Snow Pillow Data 1998

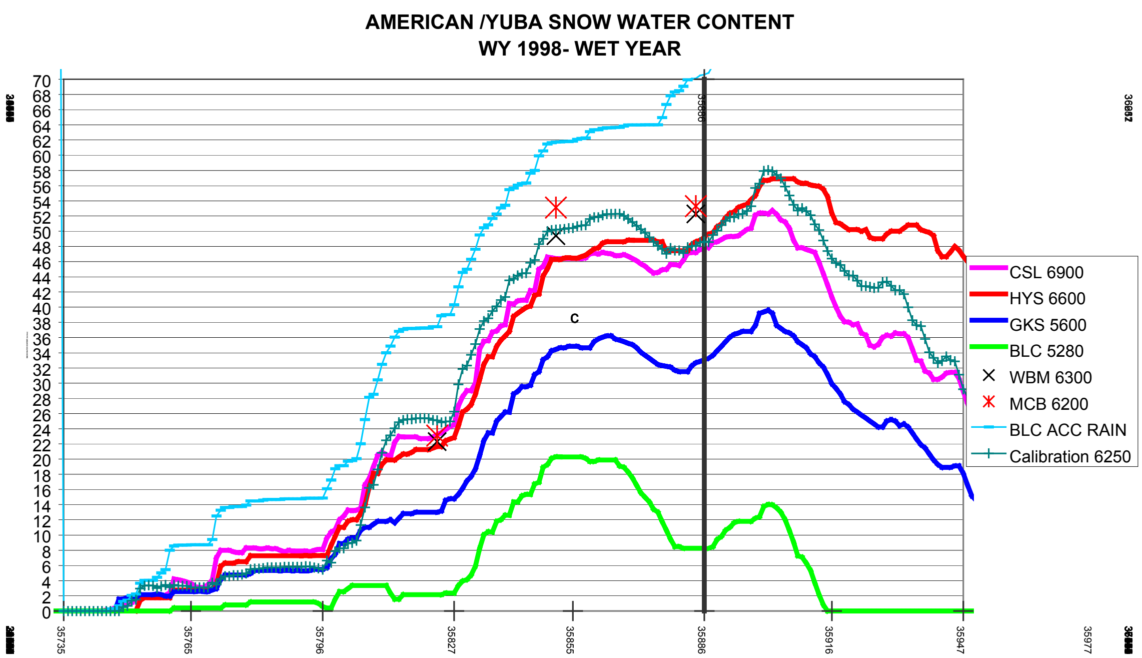


Figure 28.

6250 ft Elevation Snow vs. Snow Course and Snow Pillow Data 2000

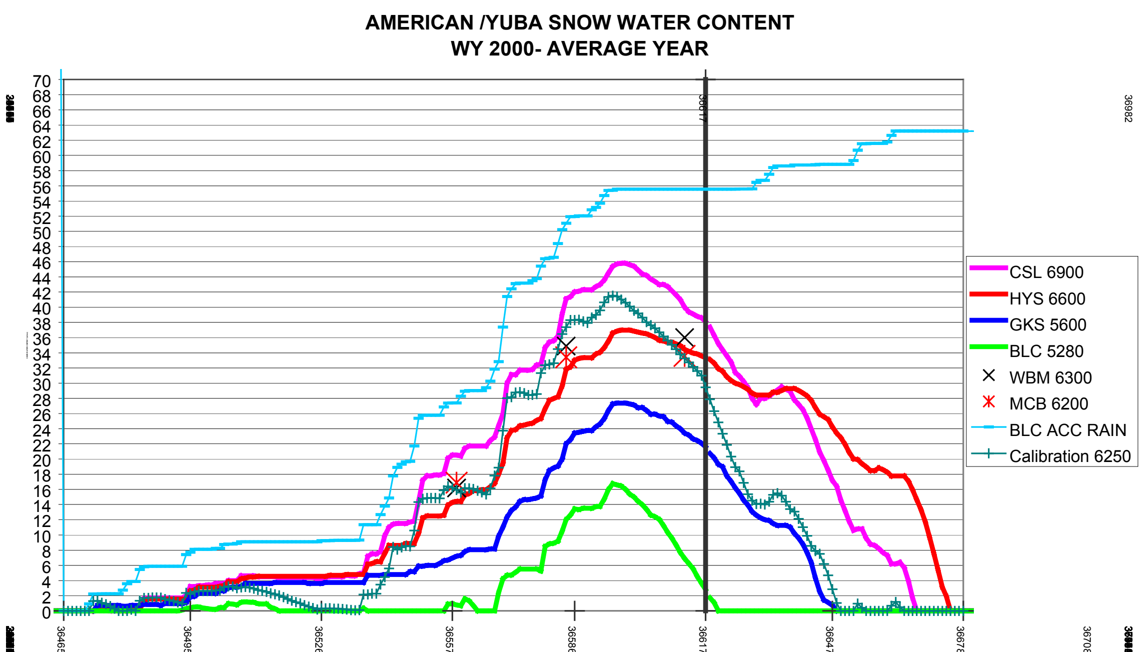


Figure 29.

Duncan Canyon Annual Yield

Simulated vs. Observed 1960-2000

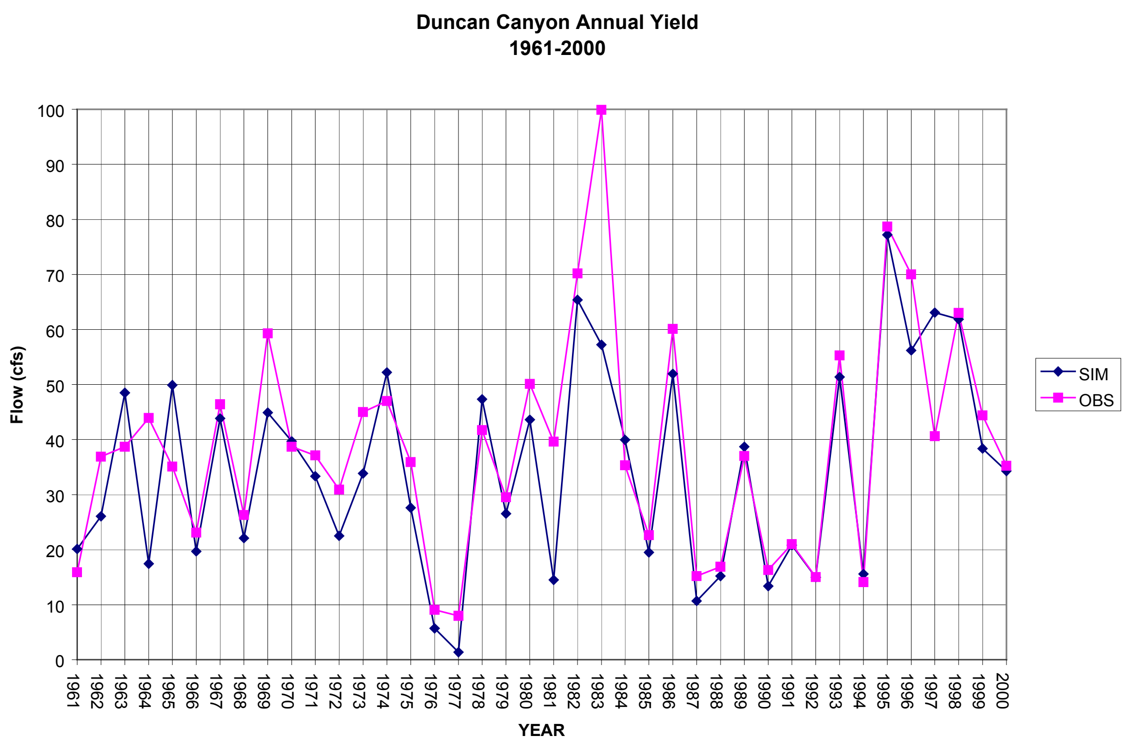


Figure 30.

Duncan Canyon Daily Simulated vs. Observed 1992

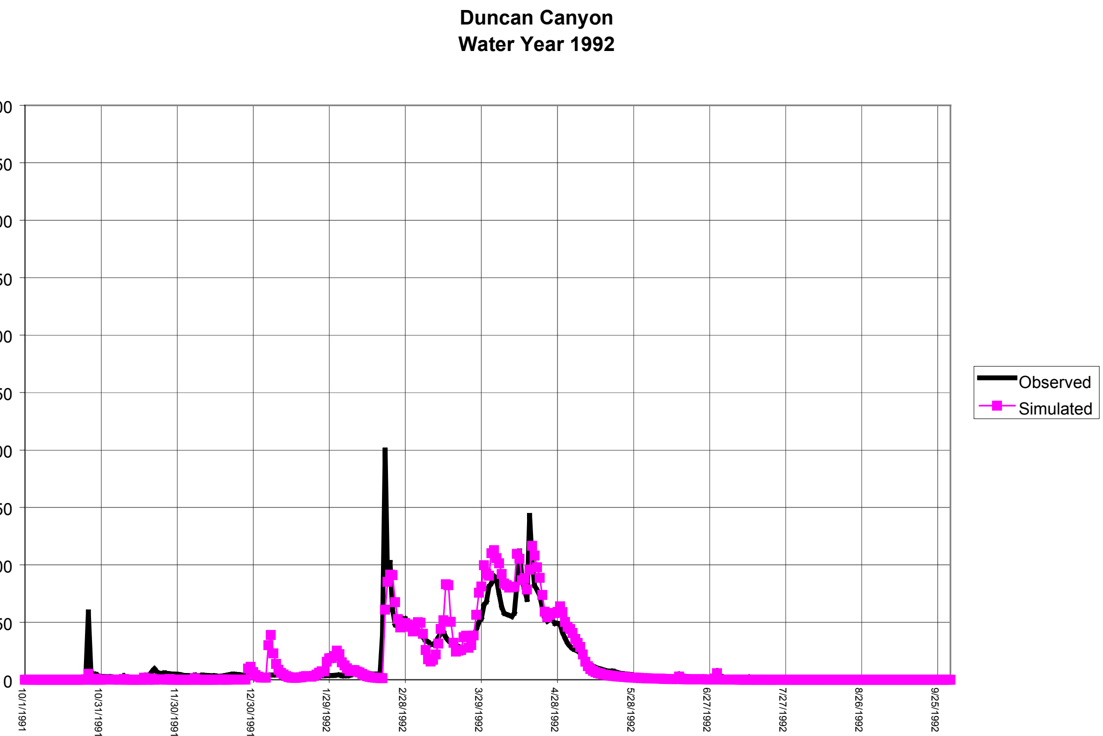


Figure 31.

Duncan Canyon Daily Simulated vs. Observed 1998

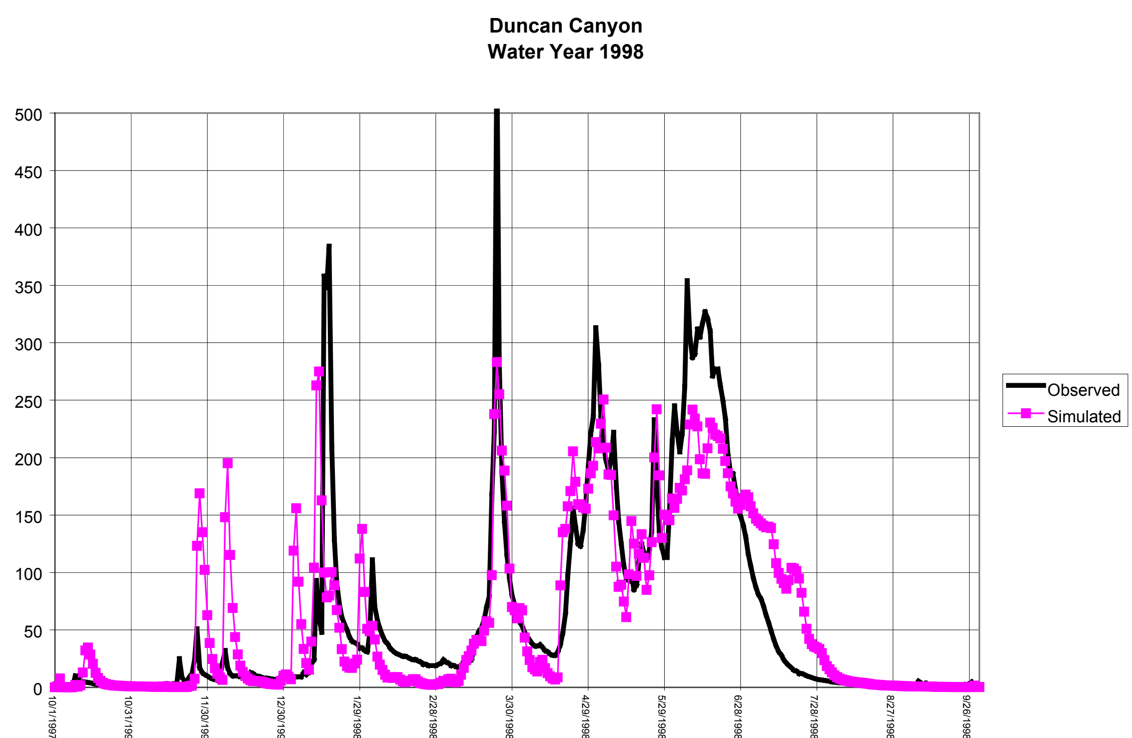


Figure 32.

Duncan Canyon Daily Simulated vs. Observed 2000

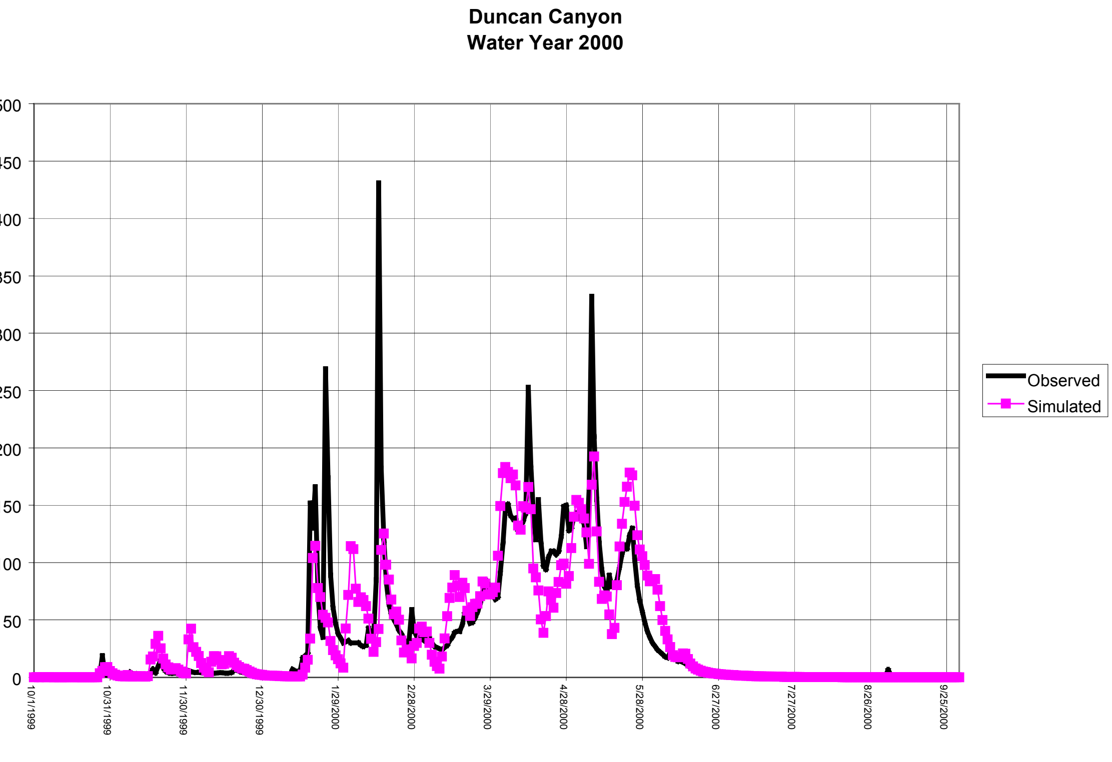


Figure 33.

Long Canyon Daily Simulated vs. Observed 1992

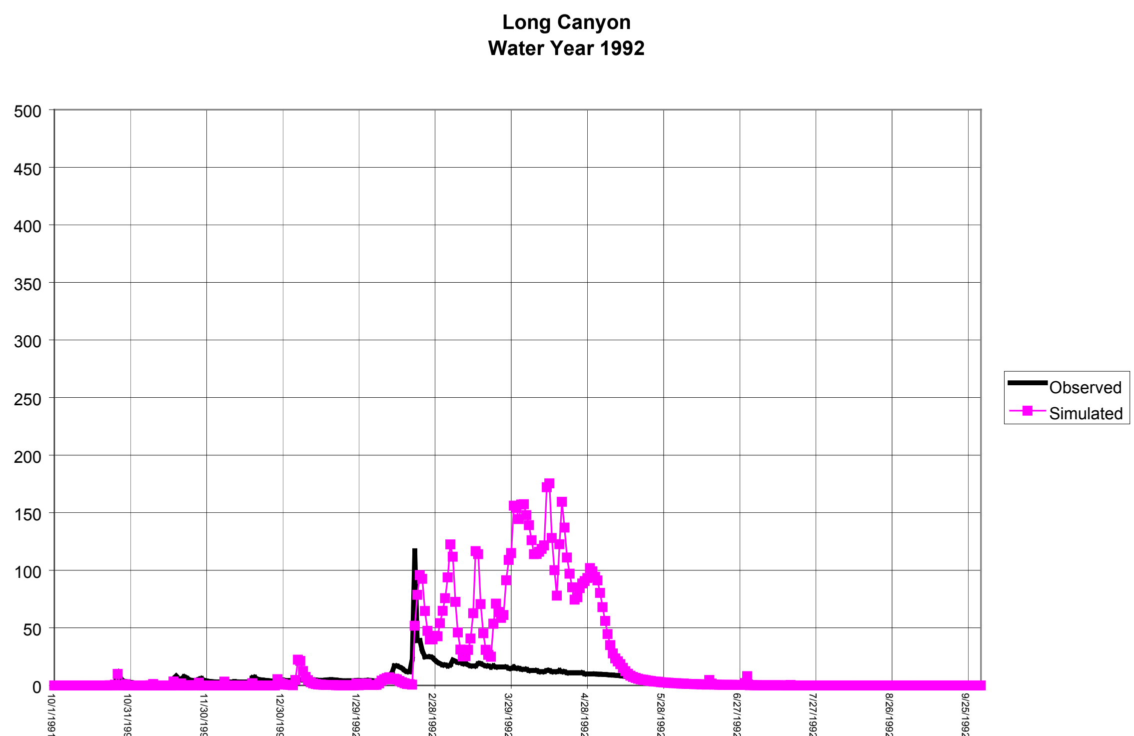


Figure 34.

Long Canyon Daily Simulated vs. Observed 1998

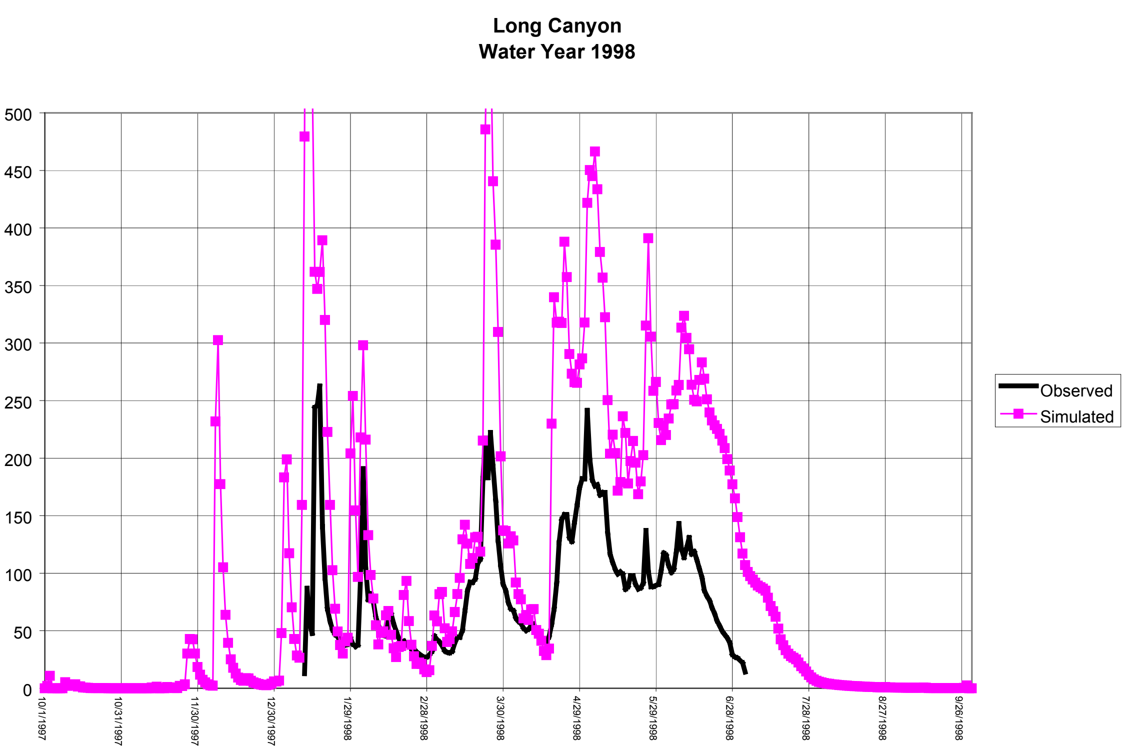


Figure 35.

Long Canyon Daily Simulated vs. Observed 2000

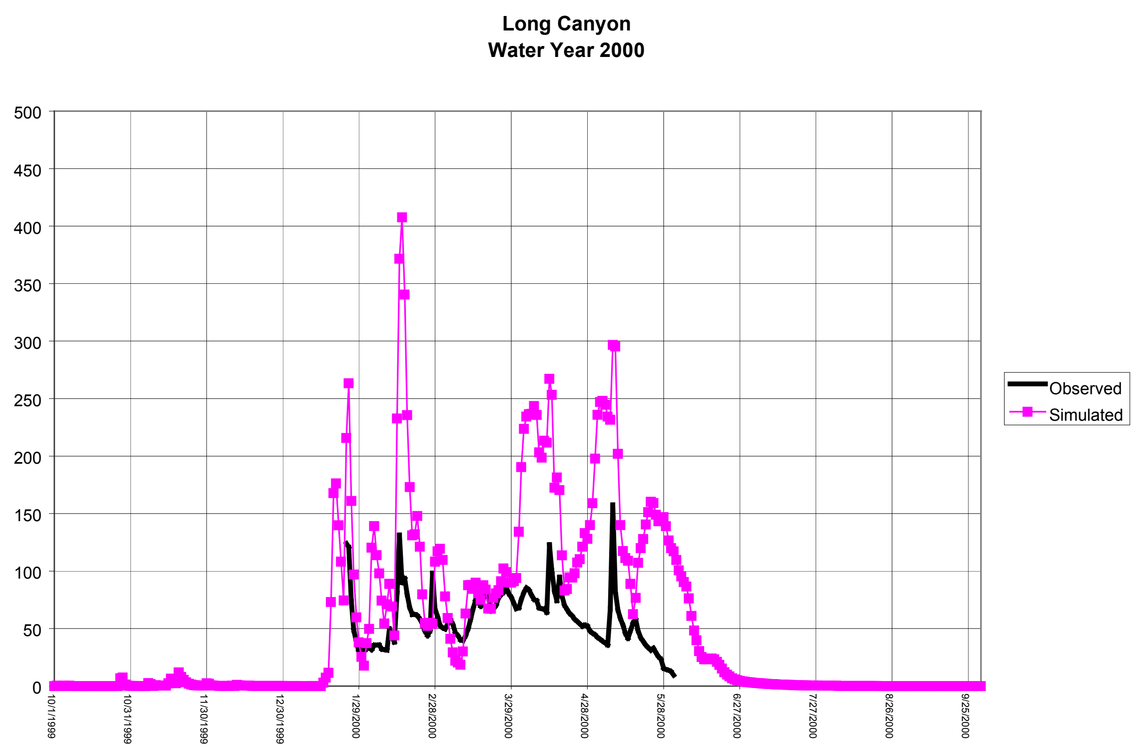


Figure 36.

1992 Elevation 7250, North, Accumulated,

Forest vs. No Canopy (#152 v. #148)

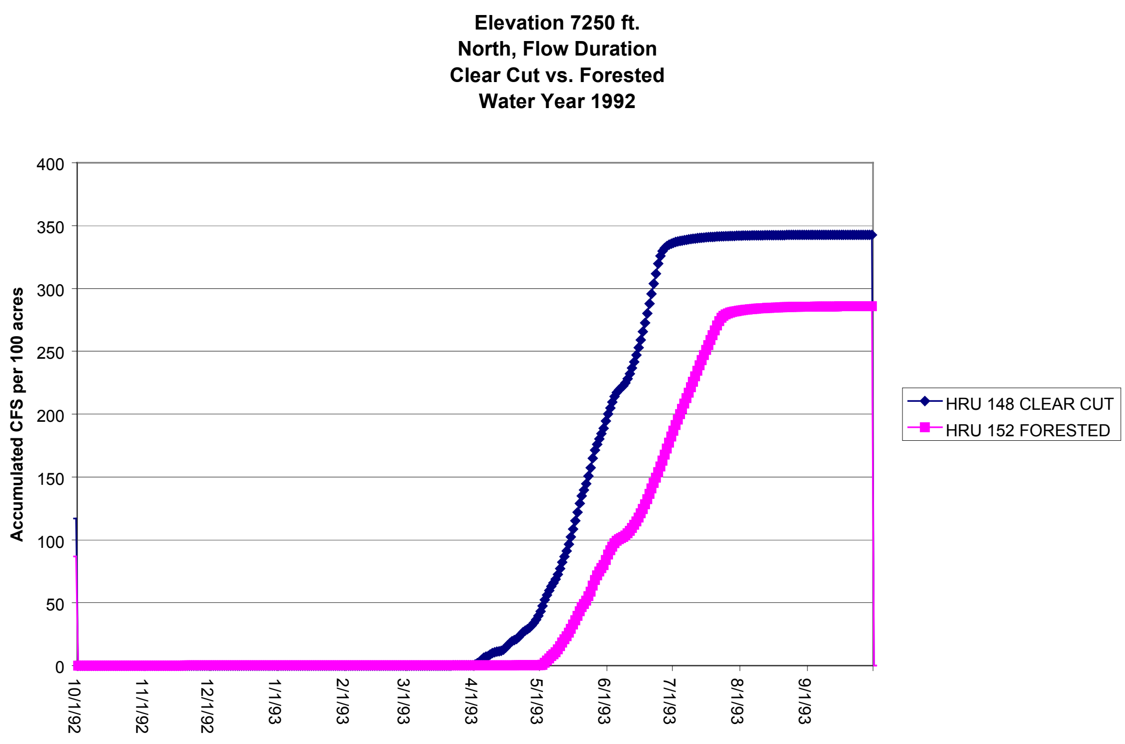


Figure 37.

1998 Elevation 7250, North, Accumulated,

Forest vs. No Canopy (#152 v. #148)

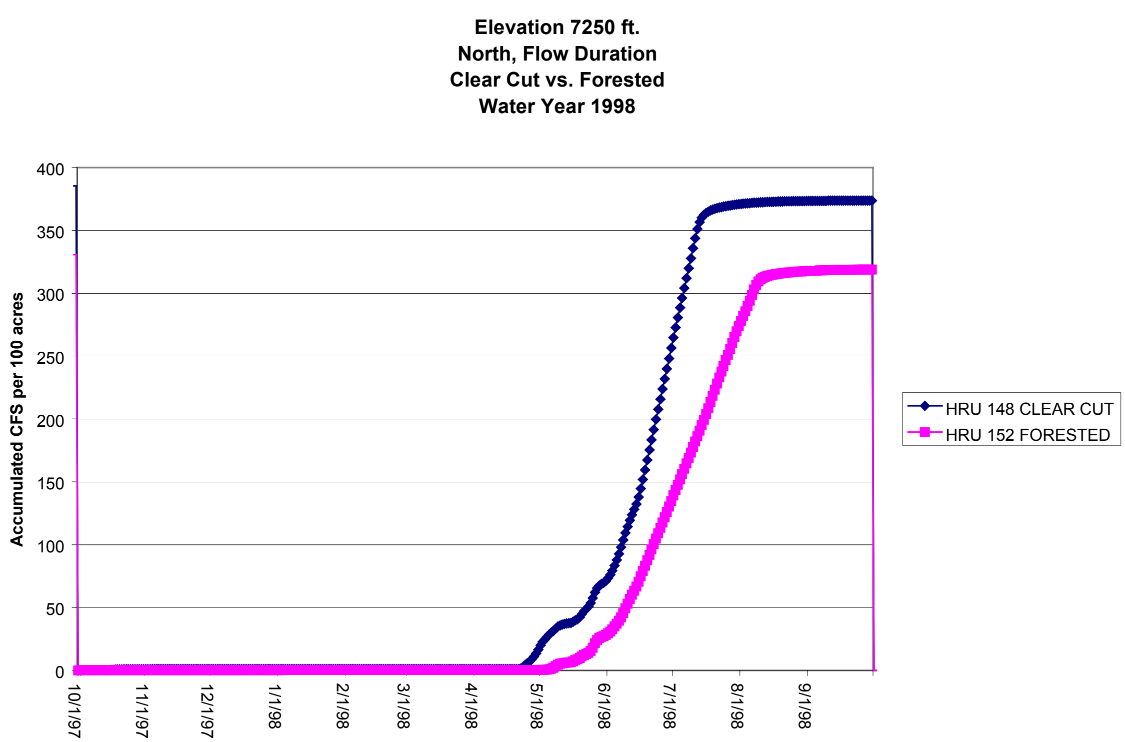


Figure 38.

2000 Elevation 7250, North, Accumulated,

Forest vs. No Canopy (#152 v. #148)

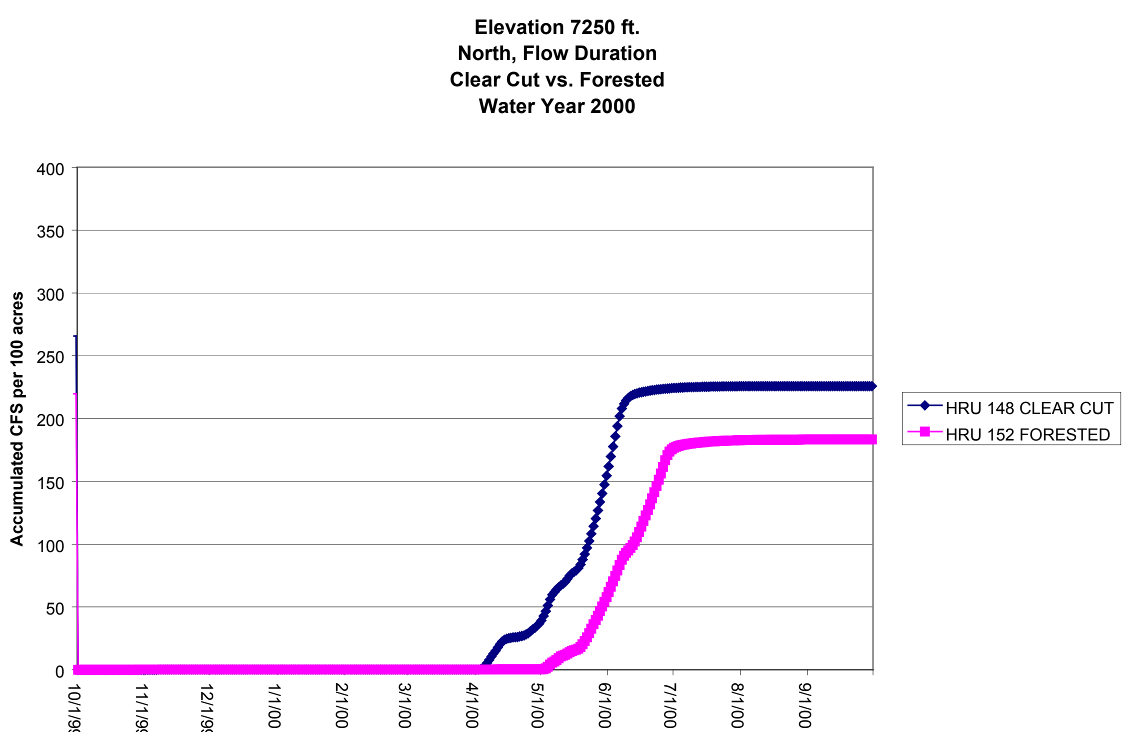


Figure 39.

1992 Elevation 4750, North, Accumulated,

Forest vs. No Canopy (#18 v. #13)

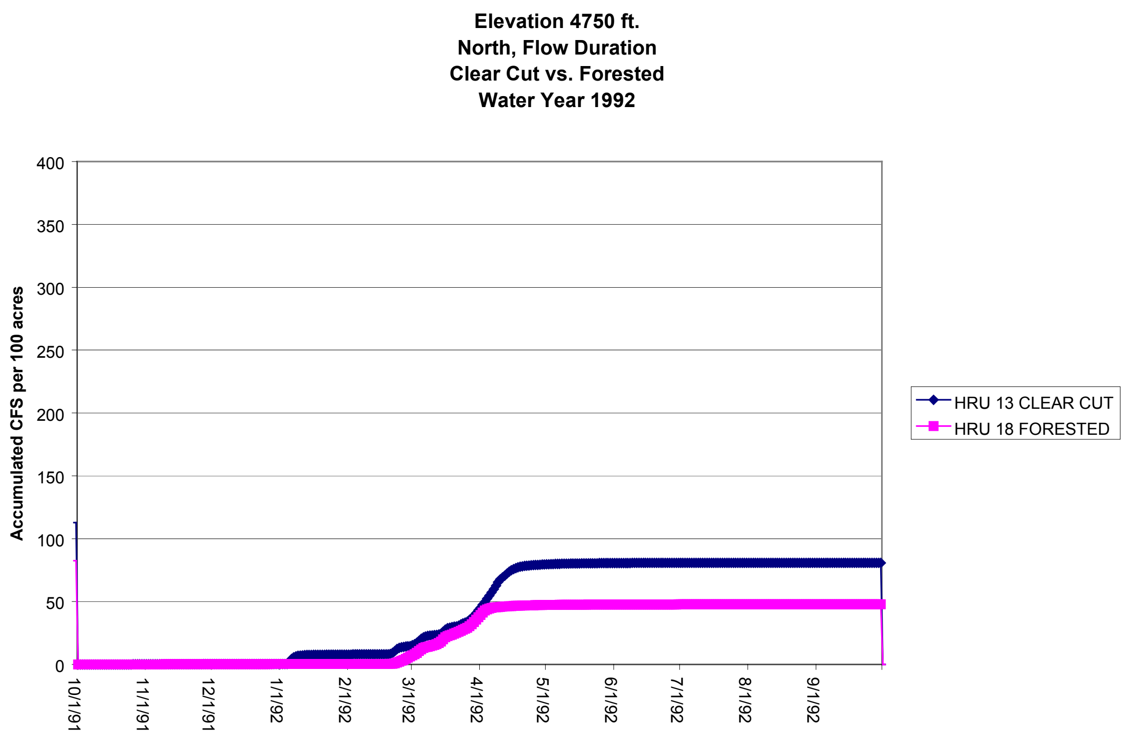


Figure 40.

1998 Elevation 4750, North, Accumulated,

Forest vs. No Canopy (#18 v. #13)

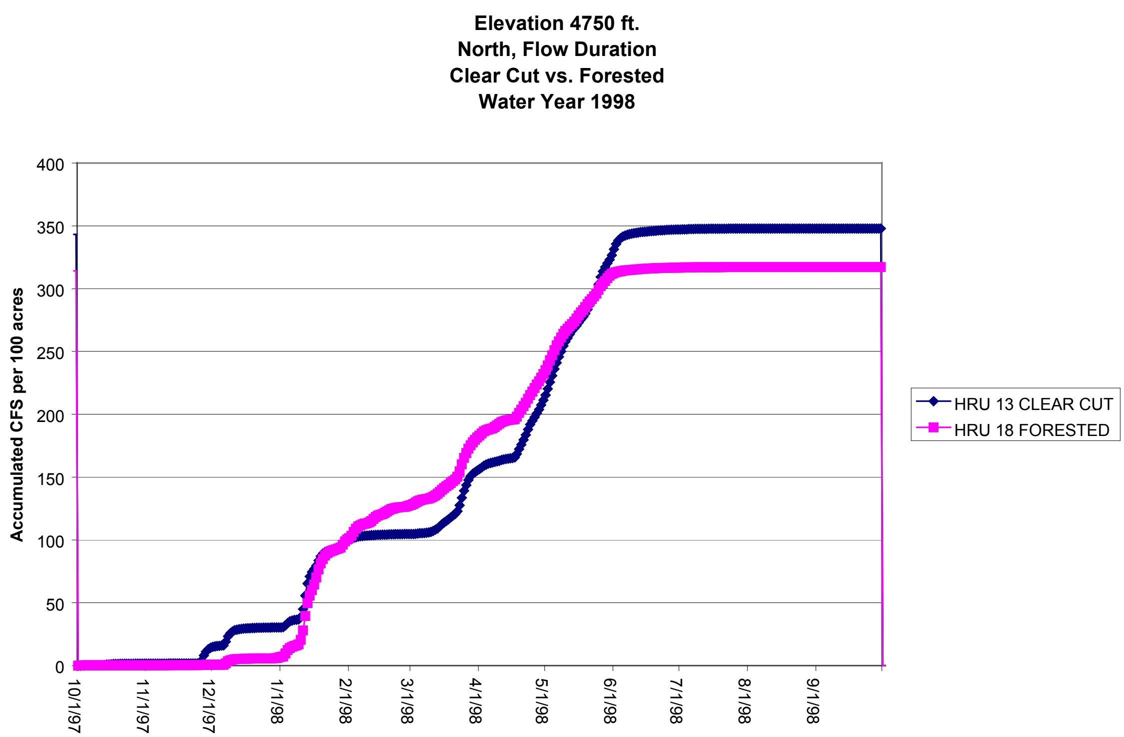


Figure 41.

2000 Elevation 4750, North, Accumulated,

Forest vs. No Canopy (#18 v. #13)

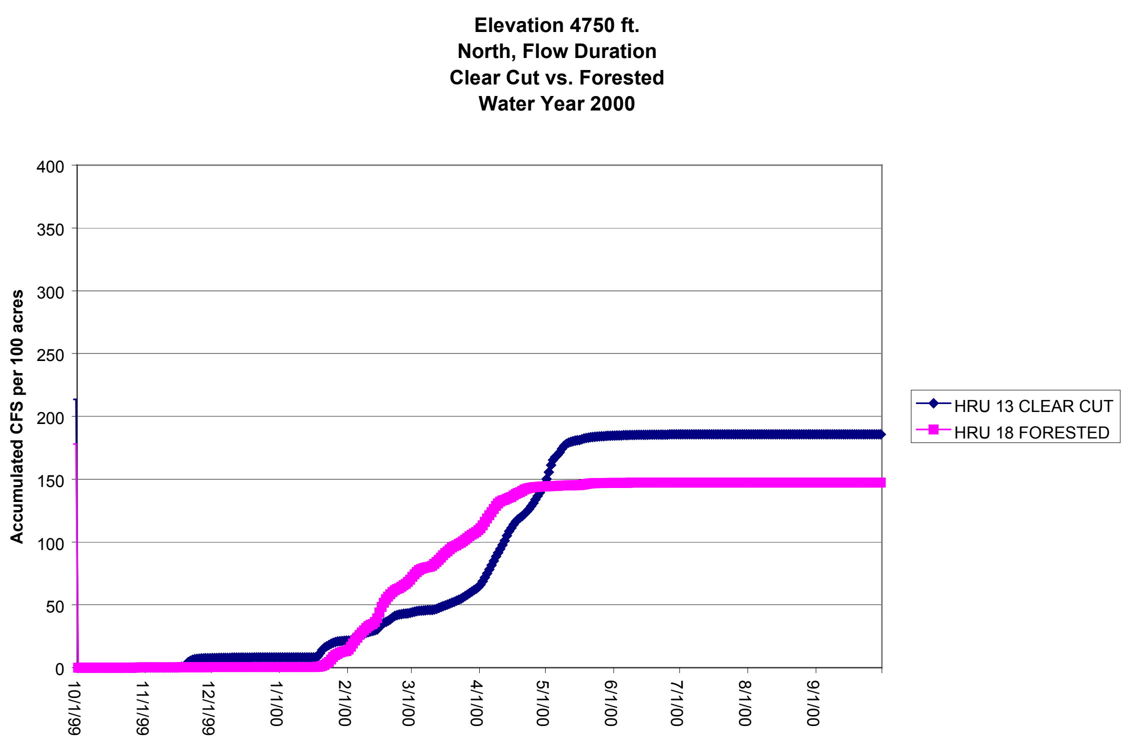


Figure 42.

1992 Elevation 7250, South, Accumulated,

Forest vs. No Canopy (#162 v. #157)

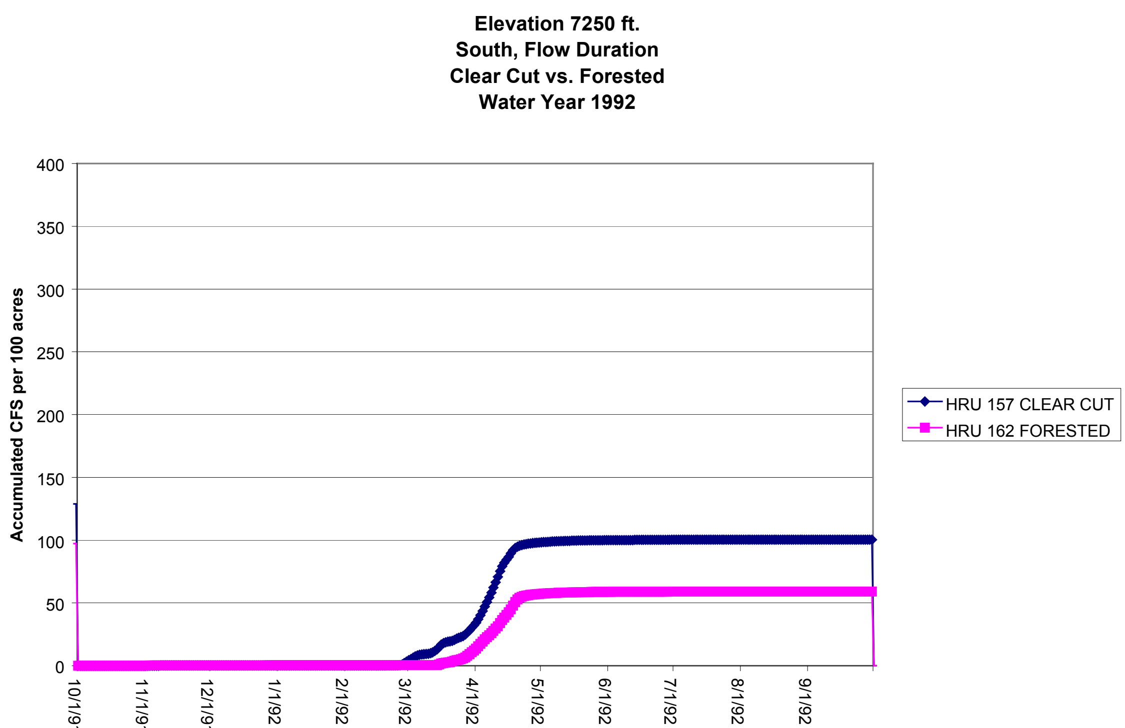


Figure 43.

1998 Elevation 7250, South, Accumulated,

Forest vs. No Canopy (#162 v. #157)

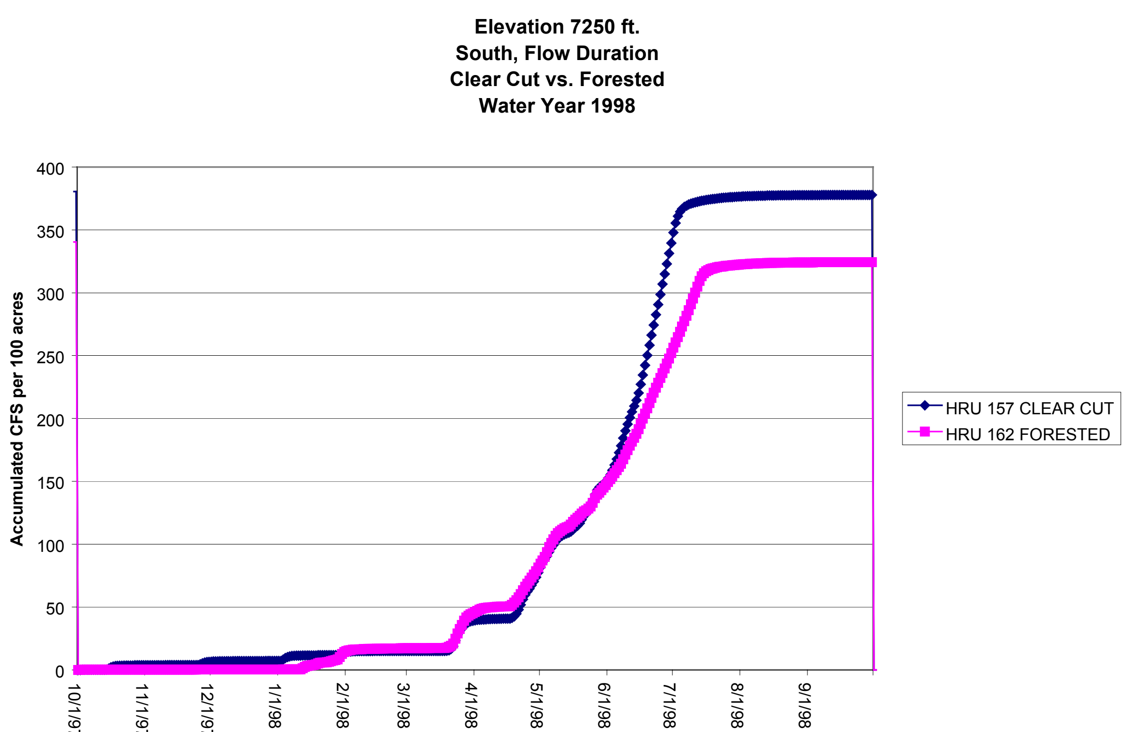


Figure 44.

2000 Elevation 7250, South, Accumulated,

Forest vs. No Canopy (#162 v. #157)

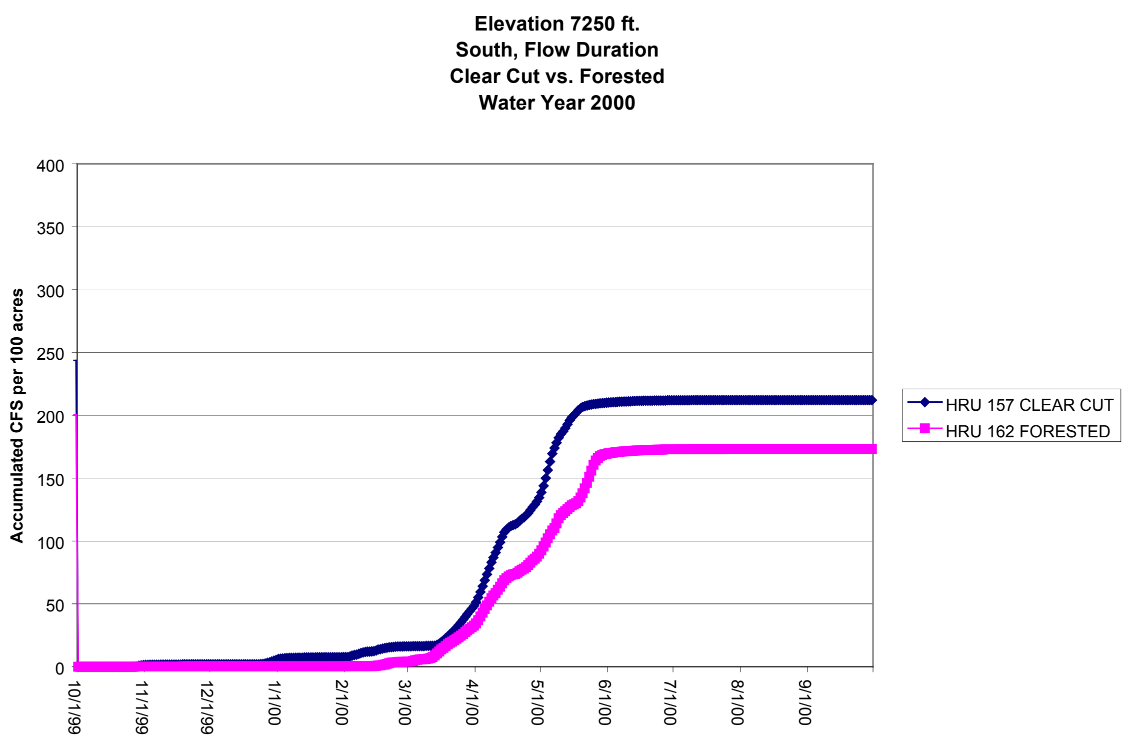


Figure 45.

1992 Elevation 4750, South, Accumulated,

Forest vs. No Canopy (#27 v. #22)

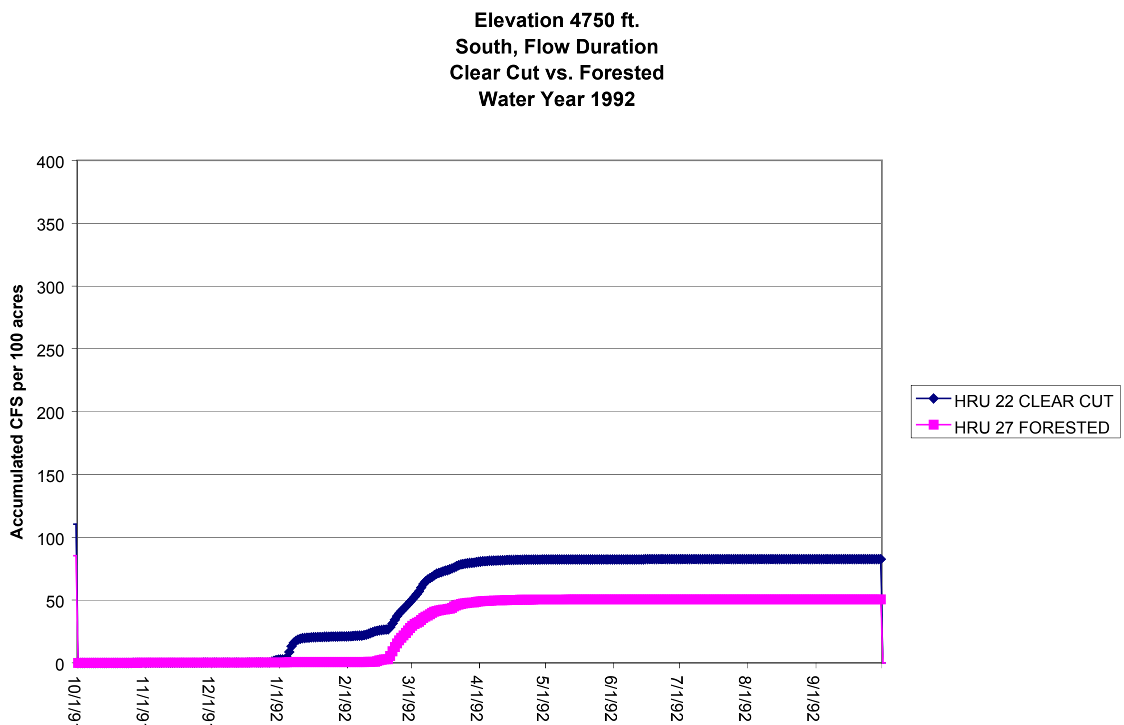


Figure 46.

1998 Elevation 4750, South, Accumulated,

Forest vs. No Canopy (#27 v. #22)

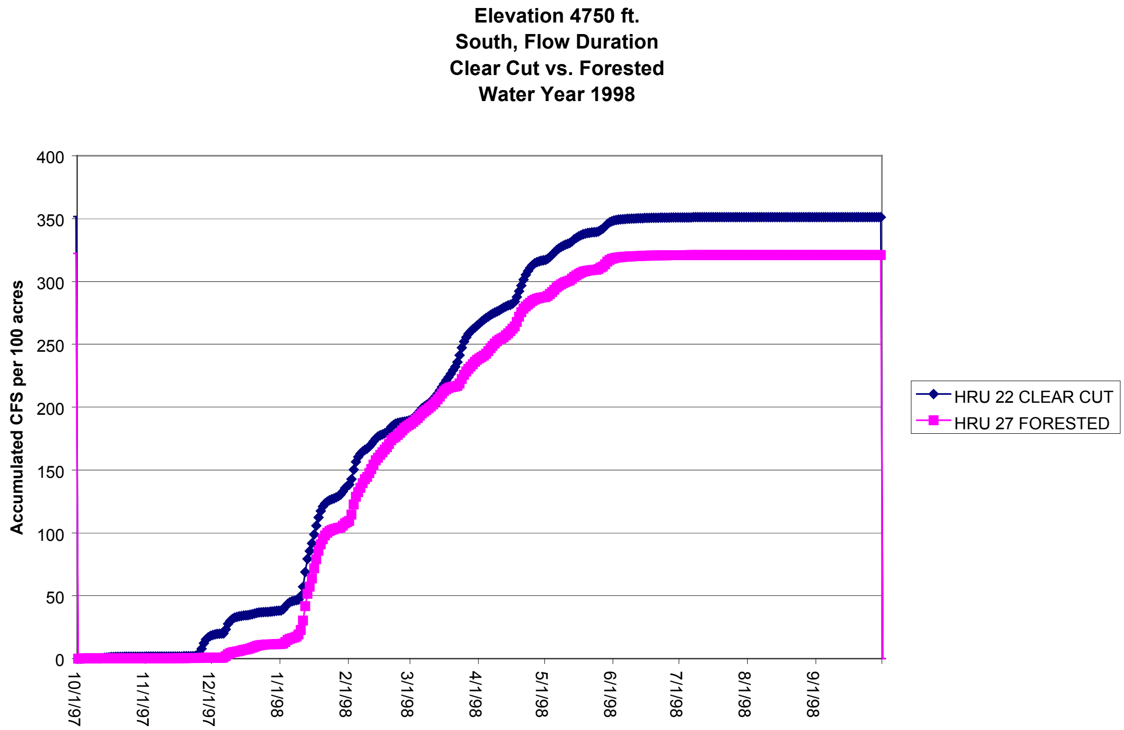


Figure 47.

2000 Elevation 4750, South, Accumulated,

Forest vs. No Canopy (#27 v. #22)

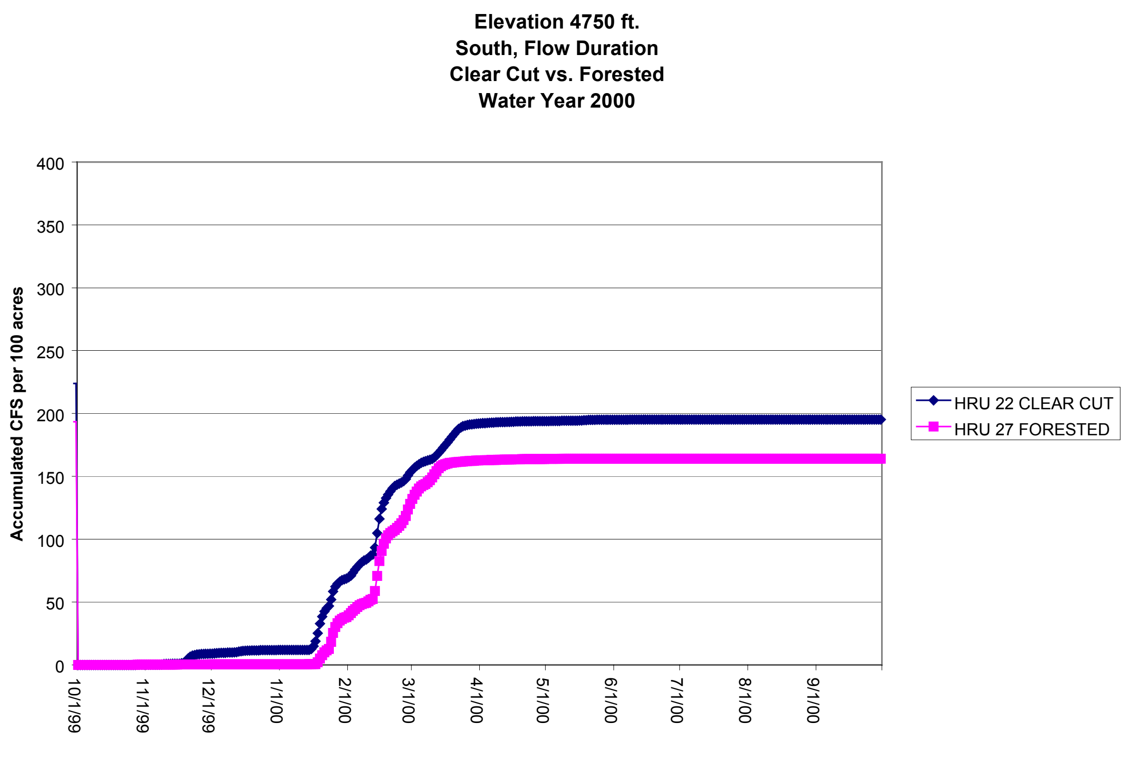


Figure 48.

Duncan Canyon Daily Flows 1992, Forested vs. No Canopy

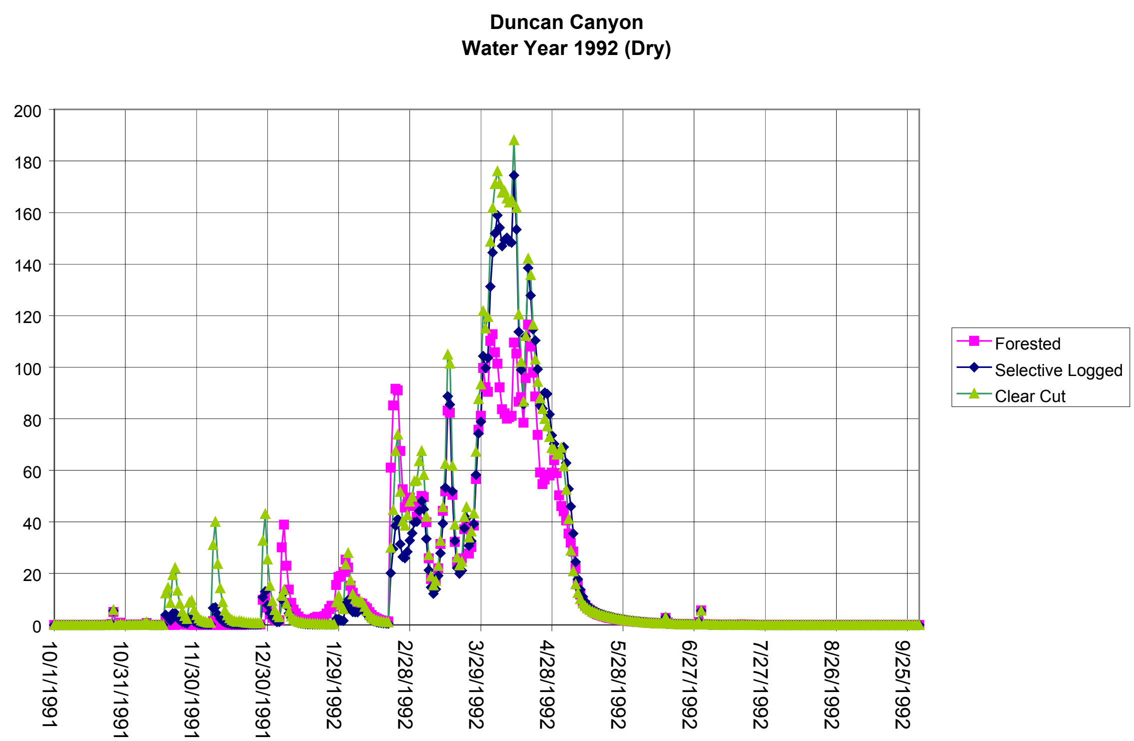


Figure 49.

Duncan Canyon Daily Flows 1998, Forested vs. No Canopy

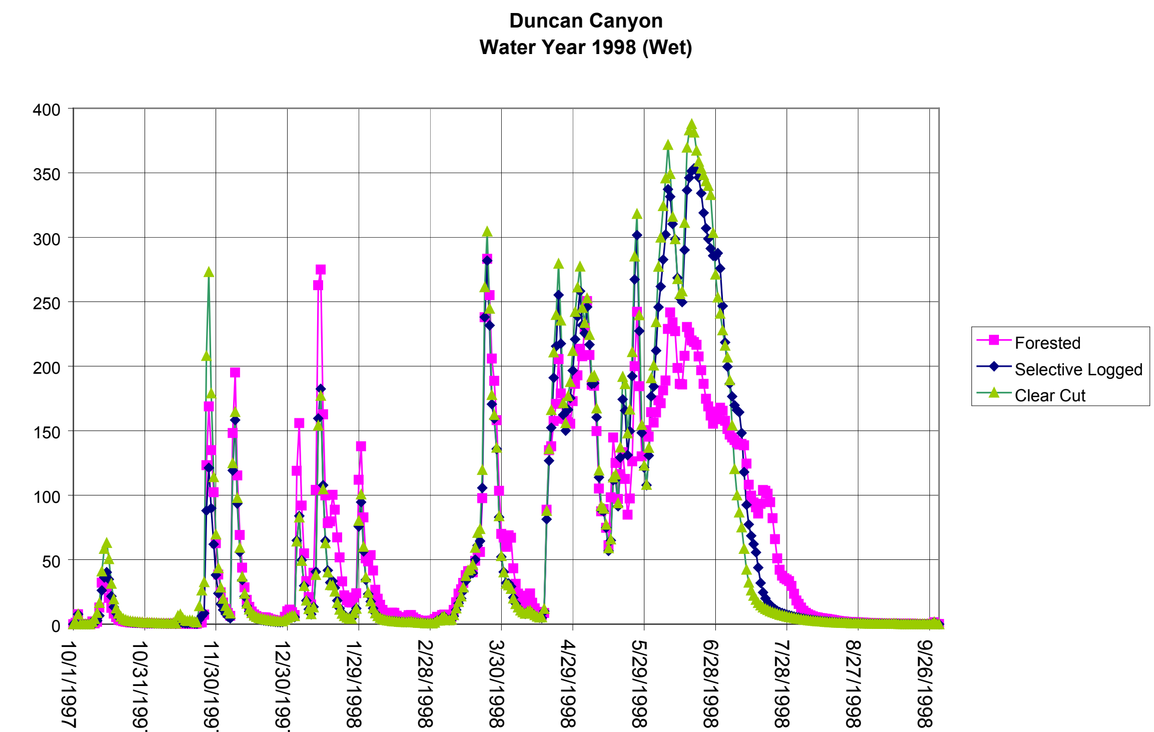


Figure 50.

Duncan Canyon Daily Flows 2000, Forested vs. No Canopy

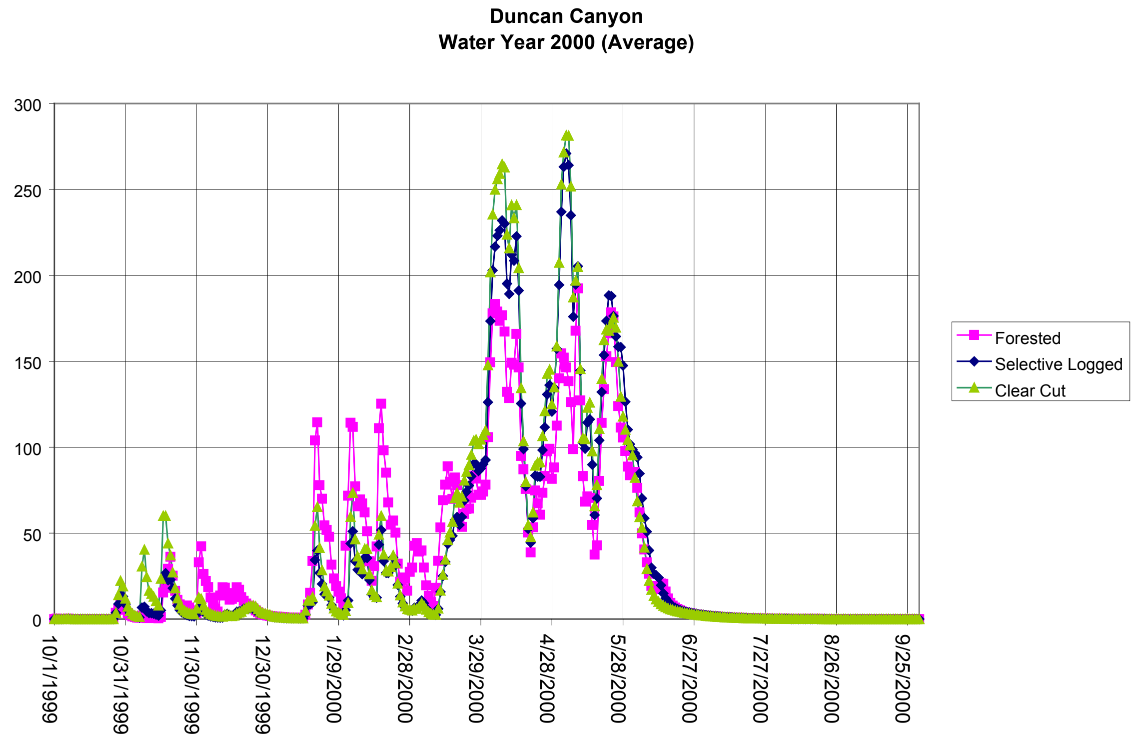


Figure 51.

Du

No

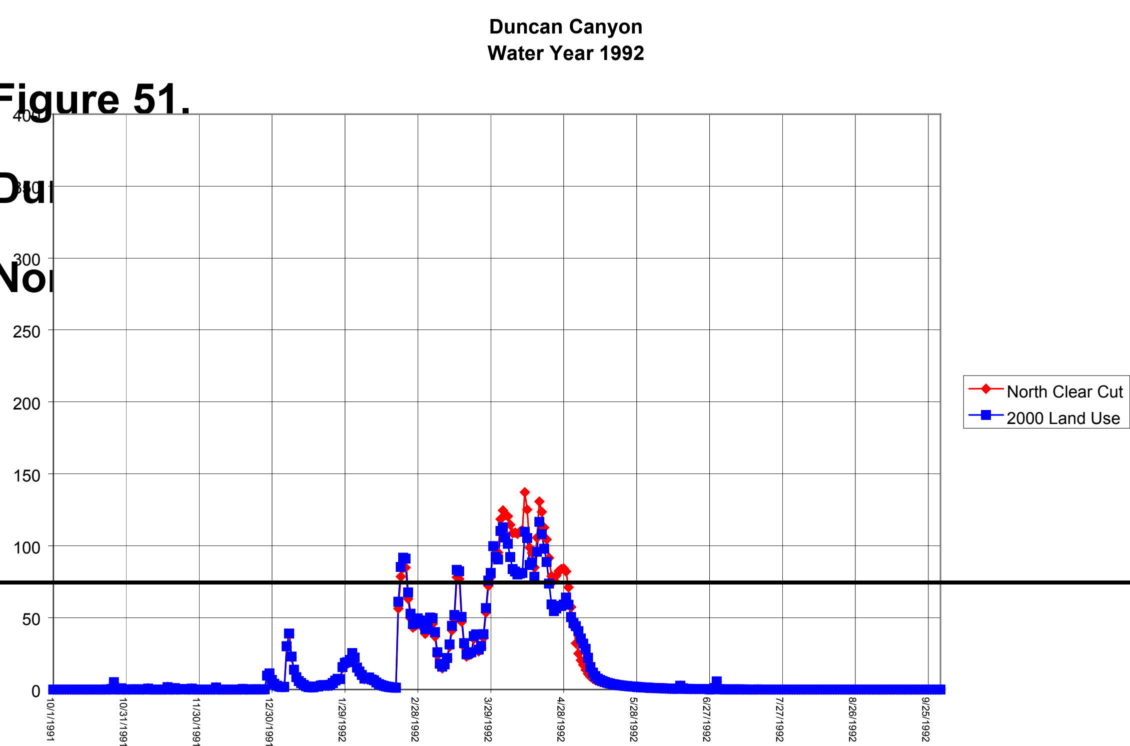


Figure 52.

Duncan Water Year 1998

North No Canopy vs. 2000 Land Use

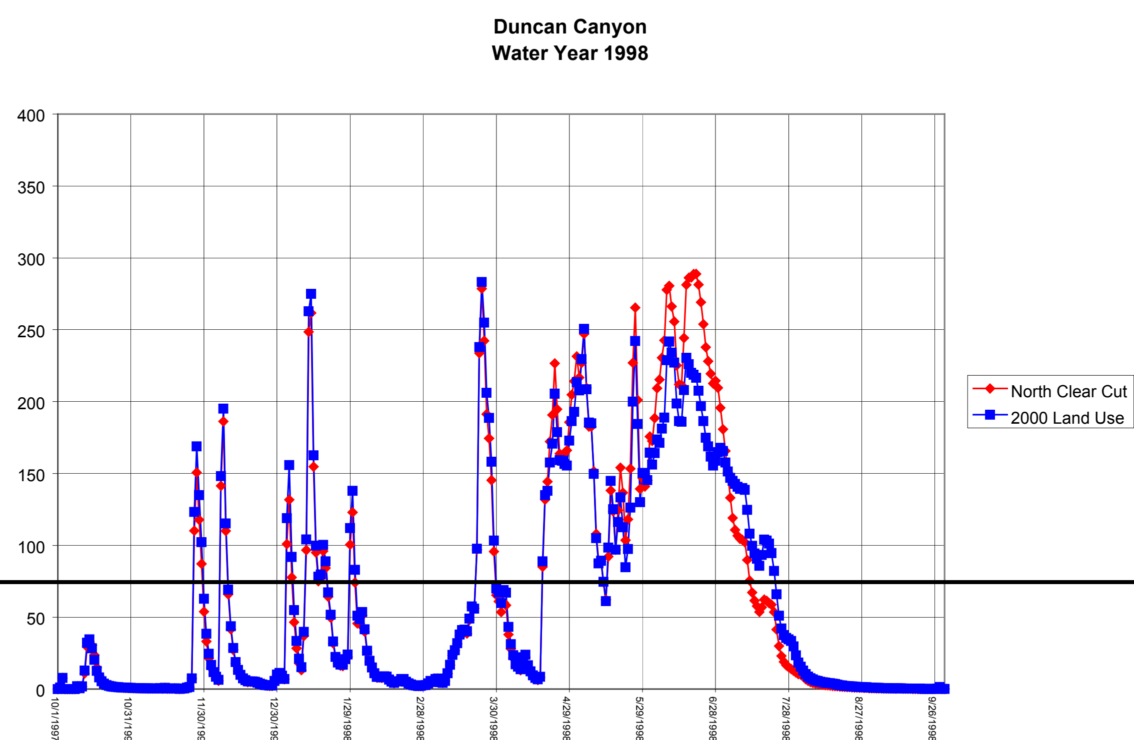


Figure 53.

Duncan Water Year 2000

North No Canopy vs. 2000 Land Use

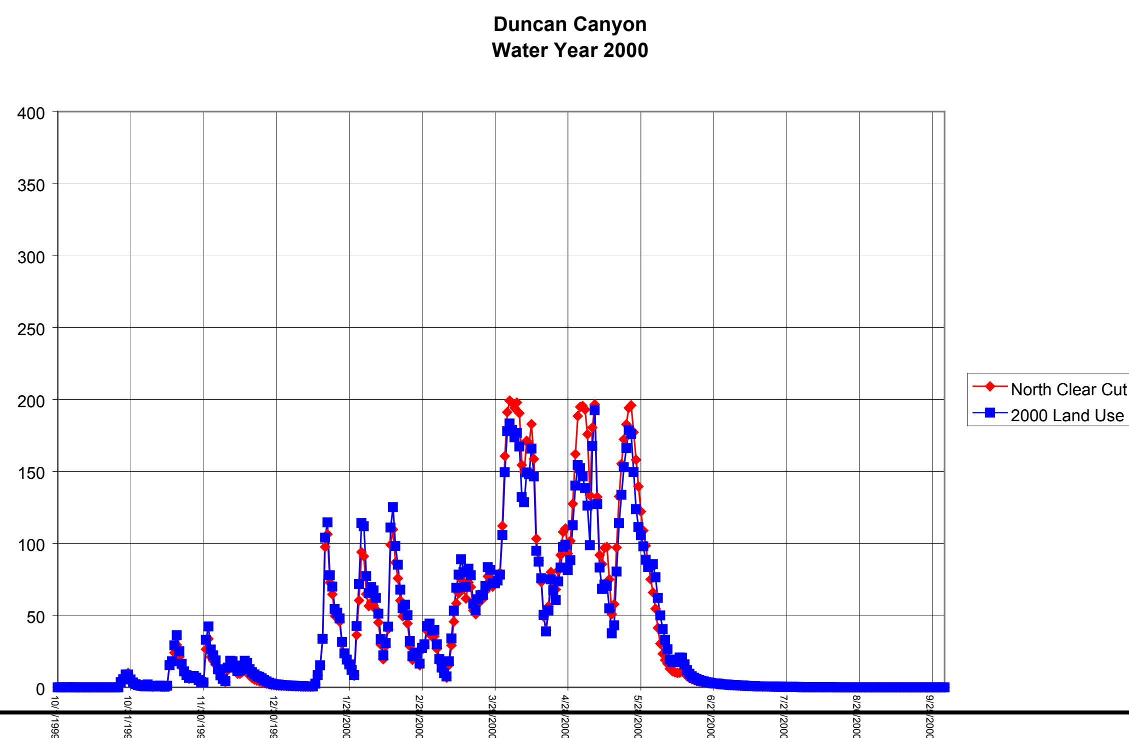


Figure 54.

Duncan Water Year 1992

South No Canopy vs. 2000 Land Use

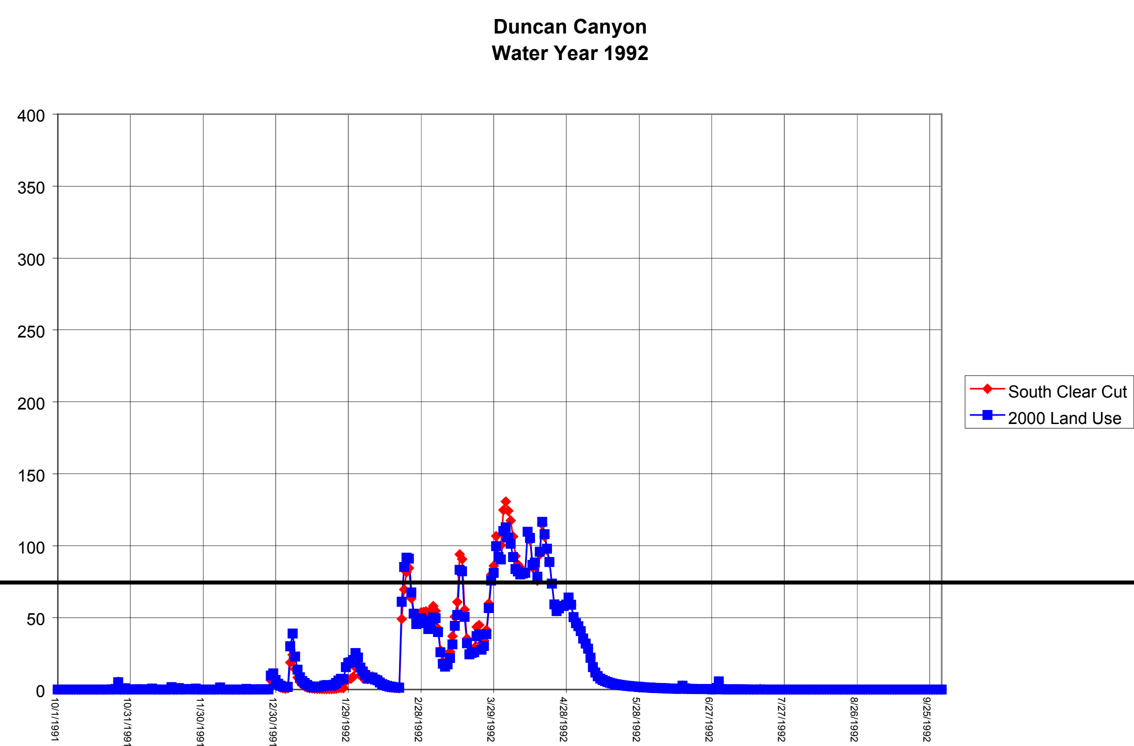


Figure 55.

Duncan Water Year 1998

South No Canopy vs. 2000 Land Use

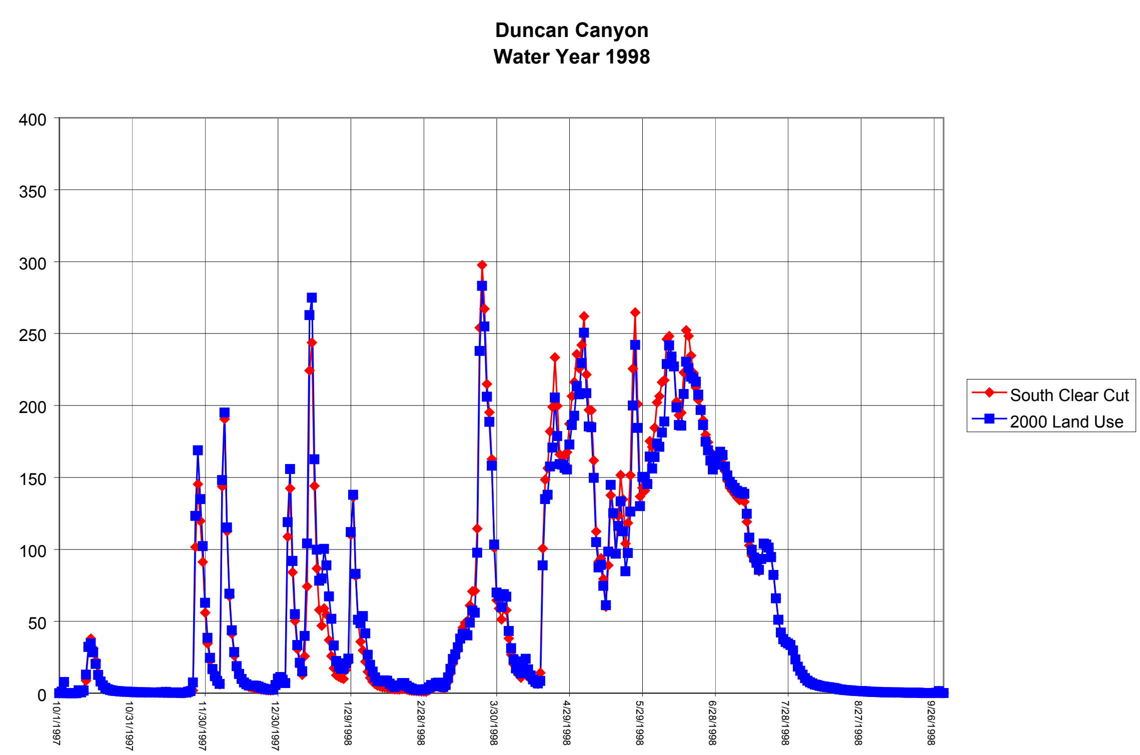


Figure 56.

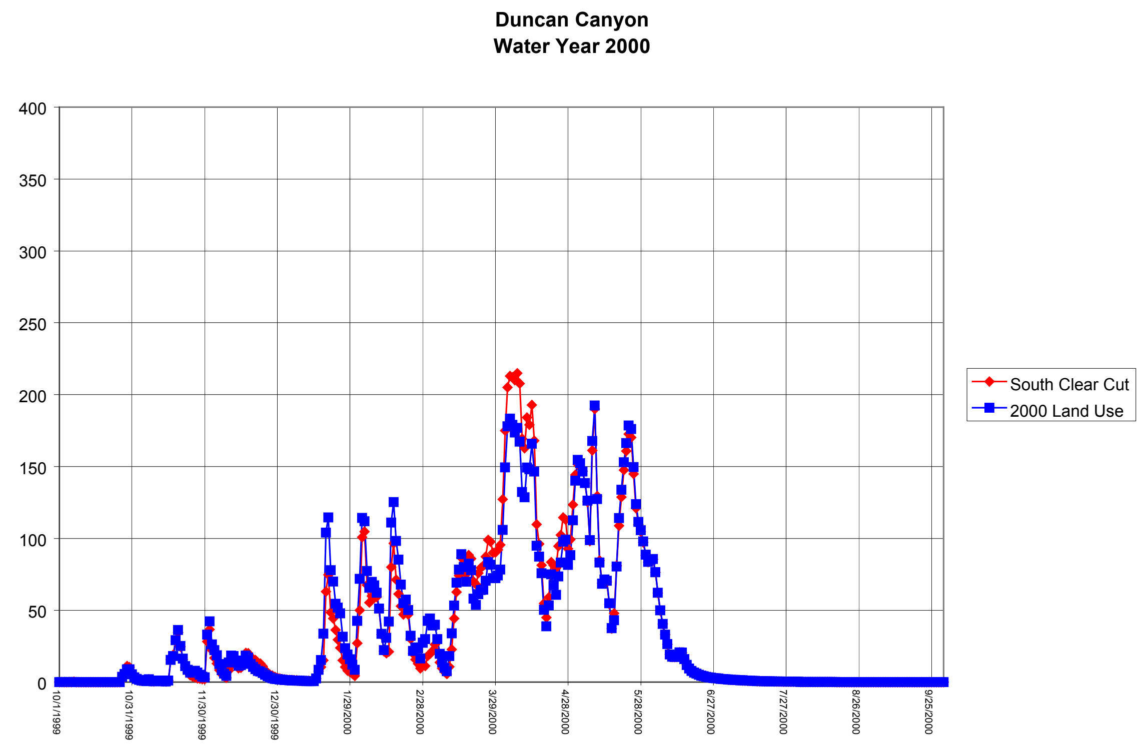
Duncan Water Year 2000

South No Canopy vs. 2000 Land Use

Fig

Du

Par


Duncan Canyon
Water Year 2000
400
350
300
250
200
150
100
50
0
10/1/1999
10/31/1999
11/30/1999
12/30/1999
1/29/2000
2/28/2000
3/29/2000
4/28/2000
5/28/2000
6/27/2000
7/27/2000
8/26/2000
9/25/2000
South Clear Cut
2000 Land Use

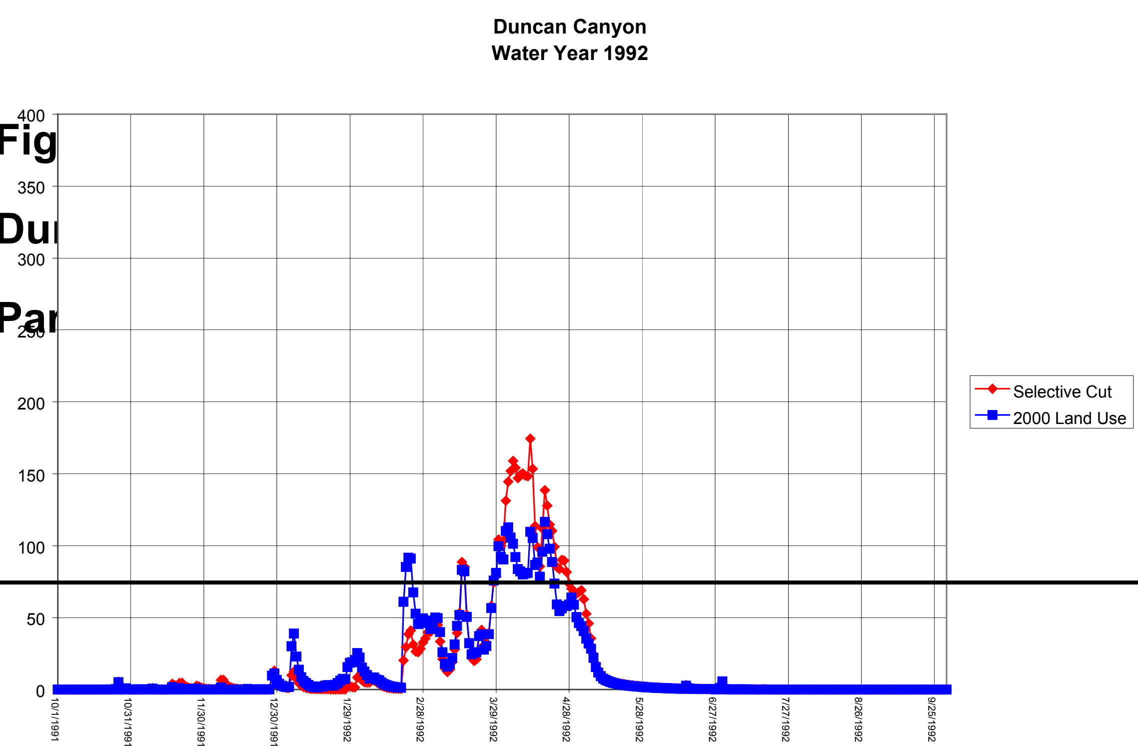

Duncan Canyon
Water Year 1992
400
350
300
250
200
150
100
50
0
10/1/1991
10/31/1991
11/30/1991
12/30/1991
1/29/1992
2/28/1992
3/29/1992
4/28/1992
5/28/1992
6/27/1992
7/27/1992
8/26/1992
9/25/1992
Selective Cut
2000 Land Use

Figure 58.

Duncan Water Year 1998

Partial Canopy vs. 2000 Land Use

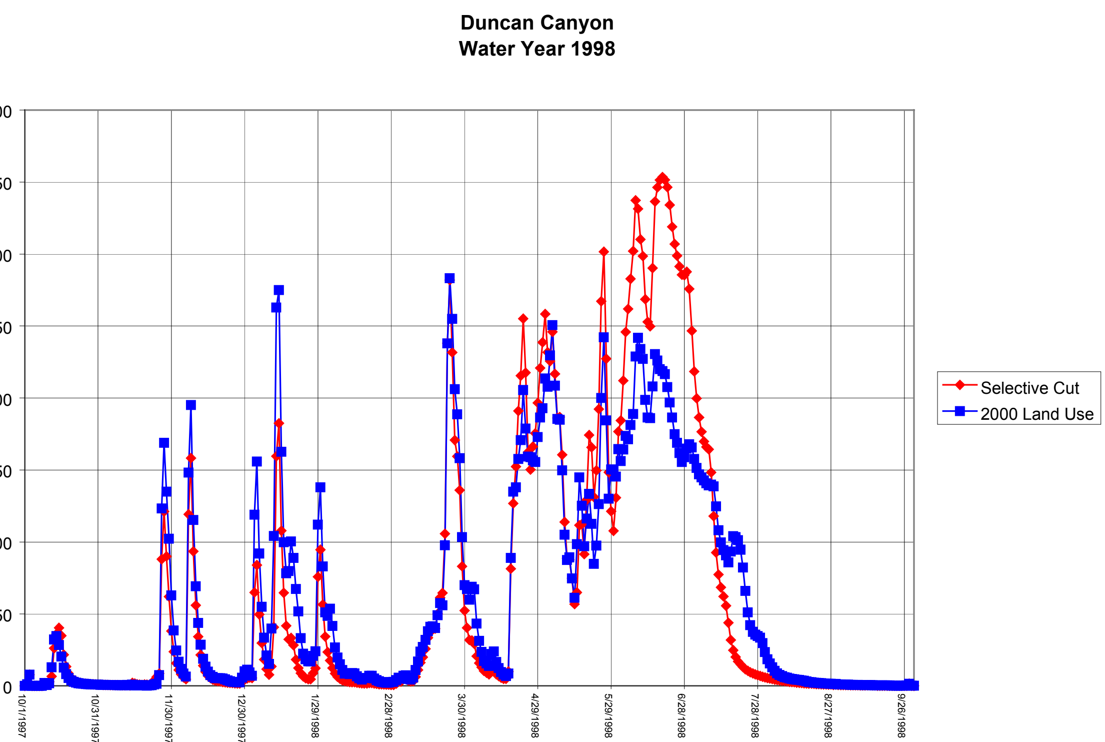

Duncan Canyon
Water Year 1998
400
350
300
250
200
150
100
50
0
10/1/1997
10/31/1997
11/30/1997
12/30/1997
1/29/1998
2/28/1998
3/30/1998
4/29/1998
5/29/1998
6/28/1998
7/28/1998
8/27/1998
9/26/1998
Selective Cut
2000 Land Use

Fig
Du
Par

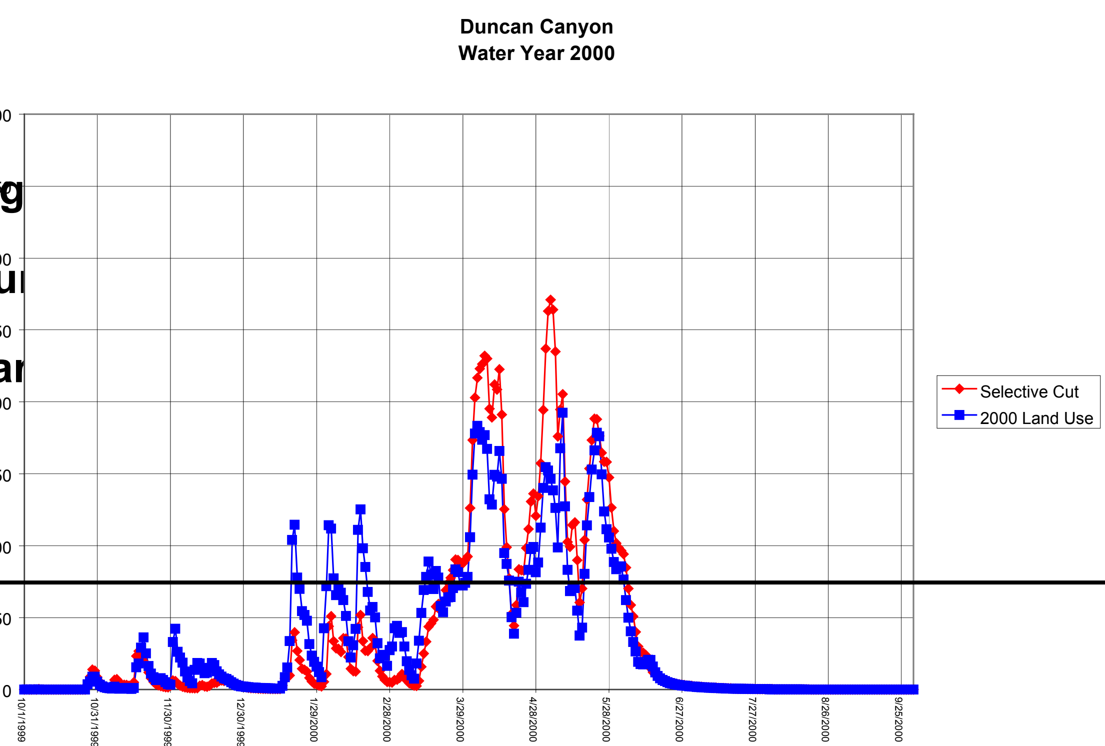

Duncan Canyon
Water Year 2000
400
350
300
250
200
150
100
50
0
10/1/1999
10/31/1999
11/30/1999
12/30/1999
1/29/2000
2/28/2000
3/29/2000
4/28/2000
5/28/2000
6/27/2000
7/27/2000
8/26/2000
9/25/2000
Selective Cut
2000 Land Use

Table 2.

Spreadsheet of HRU Assessment Matrix, Part 1

Hydrologic Response Unit Runoff Program						***file name: hruprmsduncanlong.xls***		
(Assesses hydrologic response of land use changes on American River watersheds above 4000 ft)								
Input data required are areas of hydrologic response units for a watershed being evaluated								
Area Units								
Acres			x					
Square Miles								
Square Kilometers								
Name of Watershed				Test				
Excel File Name				Test.XLS				
Hydrologic Response Units (HRUs)								
(Input area and forest cover for each HRU in the watershed of interest)								
	Hydrologic Response				***Present***	***Future***		
	Units			***Area***	***Forest Cover***	***Forest Cover***		
HRU#	**Elevation**	**Aspect**	**Soil**	***Input***	***Input Percent***	***Input Percent***		
1	**4500-5000**	**North**	**B**	100	80	20		
2	**4500-5000**	**North**	**C**					
3	**4500-5000**	**North**	**D**					
4	**4500-5000**	**South**	**B**	20	70	30		
5	**4500-5000**	**South**	**C**					
6	**4500-5000**	**South**	**D**					
7	**4500-5000**	**E-W**	**B**					
8	**4500-5000**	**E-W**	**C**					
9	**4500-5000**	**E-W**	**D**					
10	**5000-5500**	**North**	**B**					
11	**5000-5500**	**North**	**C**					
12	**5000-5500**	**North**	**D**					
13	**5000-5500**	**South**	**B**					
14	**5000-5500**	**South**	**C**					
15	**5000-5500**	**South**	**D**					
16	**5000-5500**	**E-W**	**B**					
17	**5000-5500**	**E-W**	**C**					
18	**5000-5500**	**E-W**	**D**					
19	**5500-6000**	**North**	**B**					
20	**5500-6000**	**North**	**C**					
21	**5500-6000**	**North**	**D**					
22	**5500-6000**	**South**	**B**					
23	**5500-6000**	**South**	**C**					
24	**5500-6000**	**South**	**D**					
25	**5500-6000**	**E-W**	**B**					
26	**5500-6000**	**E-W**	**C**					
27	**5500-6000**	**E-W**	**D**					
28	**6000-6500**	**North**	**B**					
29	**6000-6500**	**North**	**C**					
30	**6000-6500**	**North**	**D**					
31	**6000-6500**	**South**	**B**					
32	**6000-6500**	**South**	**C**					
33	**6000-6500**	**South**	**D**					
34	**6000-6500**	**E-W**	**B**					
35	**6000-6500**	**E-W**	**C**					
36	**6000-6500**	**E-W**	**D**					
37	**6500-7000**	**North**	**B**	100	100	100		
38	**6500-7000**	**North**	**C**					
39	**6500-7000**	**North**	**D**					
40	**6500-7000**	**South**	**B**					
41	**6500-7000**	**South**	**C**					
42	**6500-7000**	**South**	**D**					
43	**6500-7000**	**E-W**	**B**					
44	**6500-7000**	**E-W**	**C**					
45	**6500-7000**	**E-W**	**D**					
46	**7000-7500**	**North**	**B**					
47	**7000-7500**	**North**	**C**					
48	**7000-7500**	**North**	**D**	100	100	100		
49	**7000-7500**	**South**	**B**					
50	**7000-7500**	**South**	**C**					
51	**7000-7500**	**South**	**D**					
52	**7000-7500**	**E-W**	**B**					
53	**7000-7500**	**E-W**	**C**					
54	**7000-7500**	**E-W**	**D**					

Table3.

Spreadsheet of HRU Assessment Matrix, Part 2

Sheet 2-RESULTS

Name of Watershed **Test**
Area of Watershed **320 Acres** Note: select correct units from D7,D8 or D9

	Wet Year		**Normal Year**		**Dry Year**	
	Present	***Future***	***Present***	***Future***	***Present***	***Future***
Annual Runoff (acre-feet)	**2353**	**2387**	**1006**	**1074**	**333**	**367**
Max. Snow Water Content (Inches)	**32.4**	**33.5**	**27.4**	**27.8**	**14.1**	**14.1**
Snow Meltout Date (Julian Day)	**160**	**156**	**139**	**135**	**121**	**117**
July Base Flow (cfs)	**1.06**	**1.06**	**0.15**	**0.15**	**0.05**	**0.05**

Figure 5.

Duncan Canyon Surficial Geology and Geomorphology

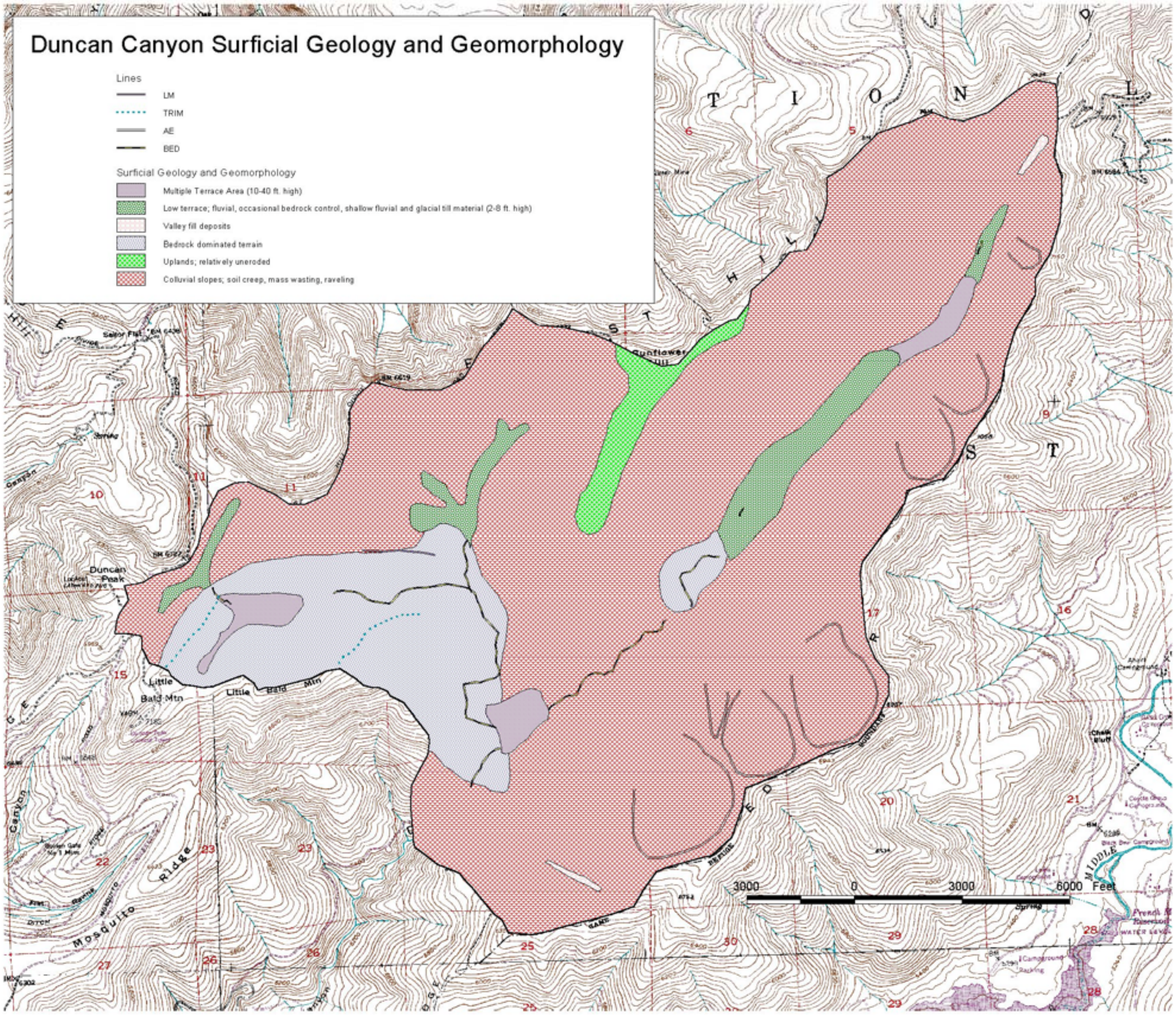


Figure 6.

Duncan Canyon Baseflow Features

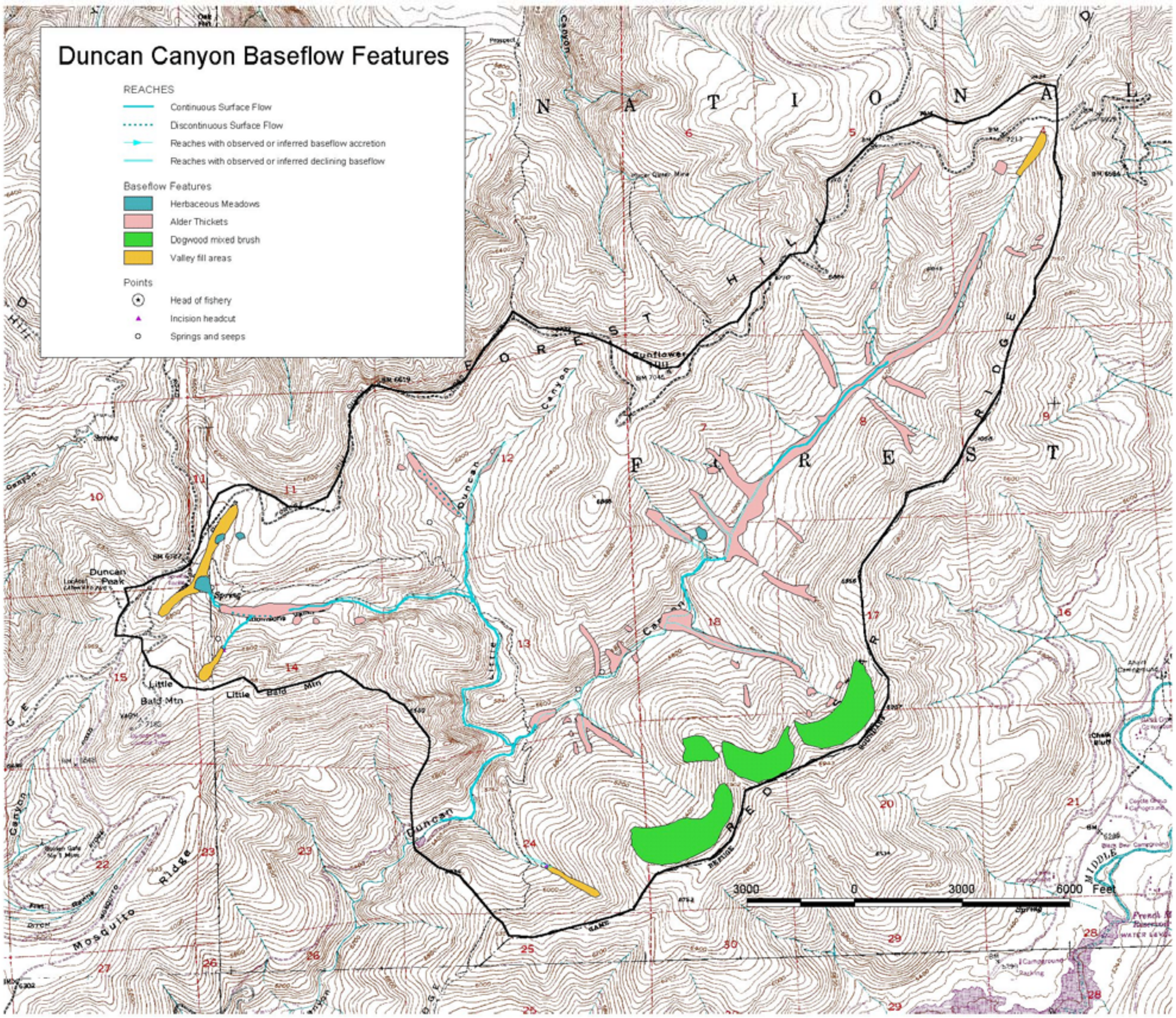


Figure 7.

Duncan Canyon Bedrock Geology

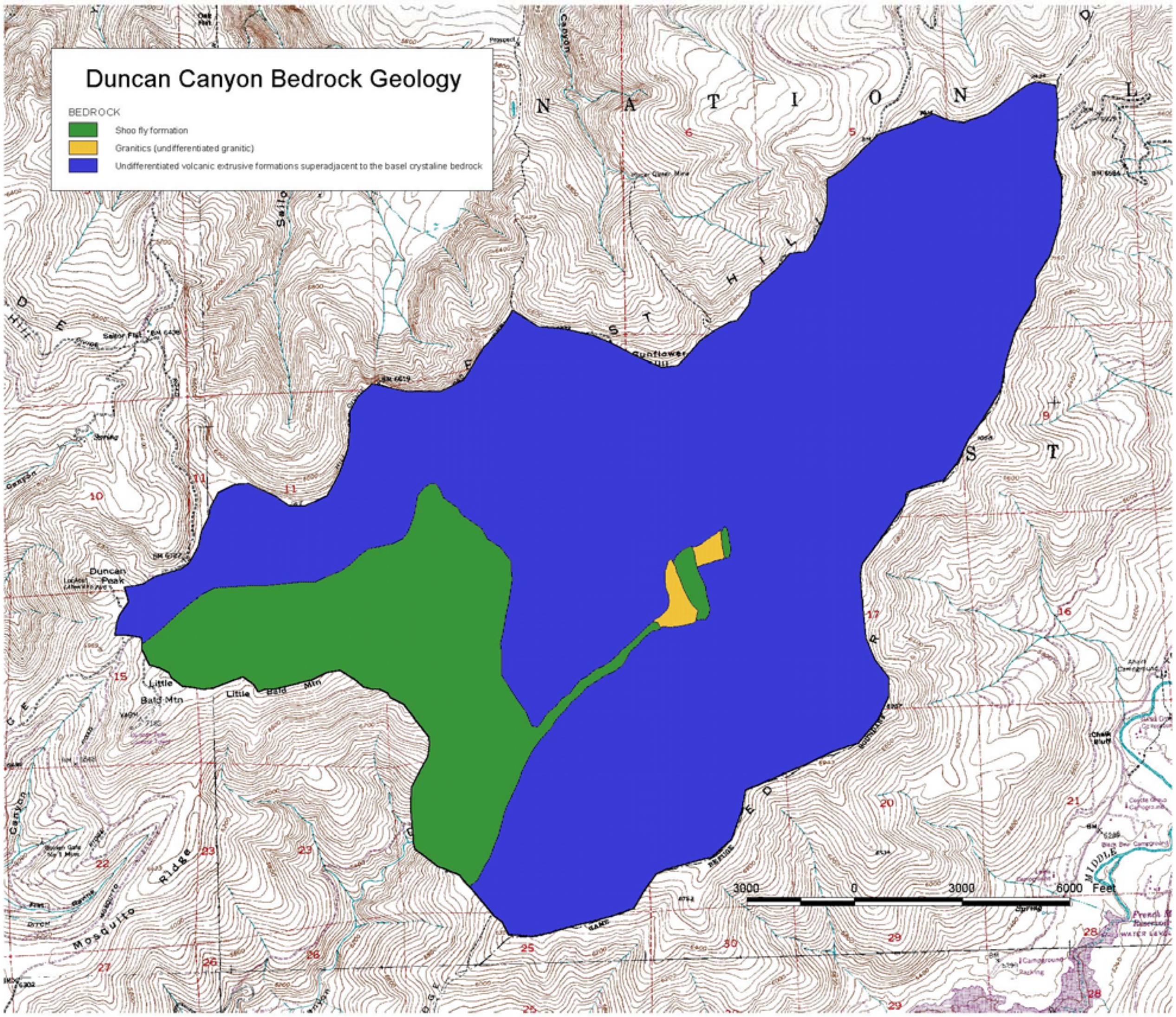


Figure 8.

Long Canyon Surficial Geology and Geomorphology

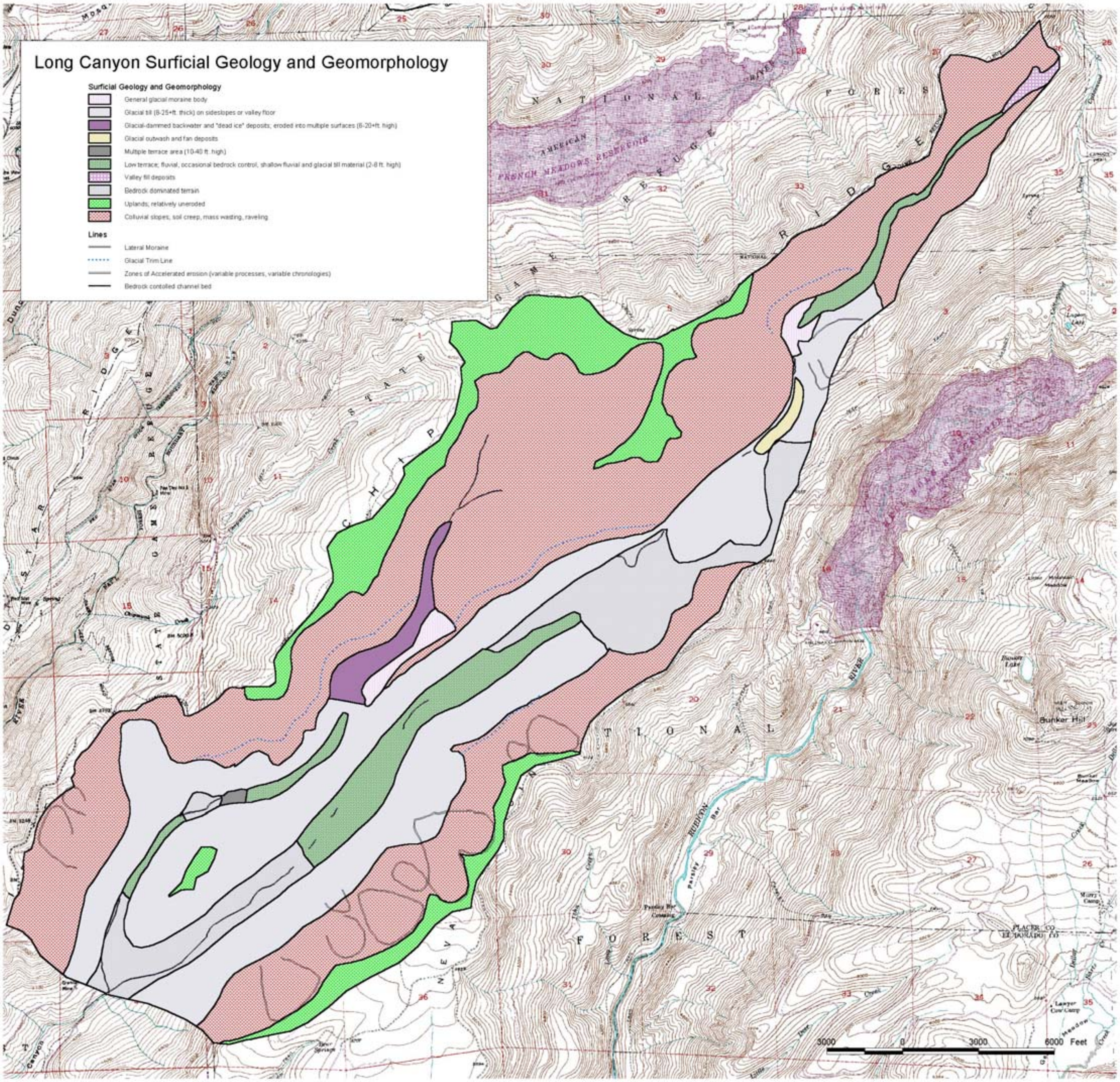


Figure 9.

Long Canyon Baseflow Features

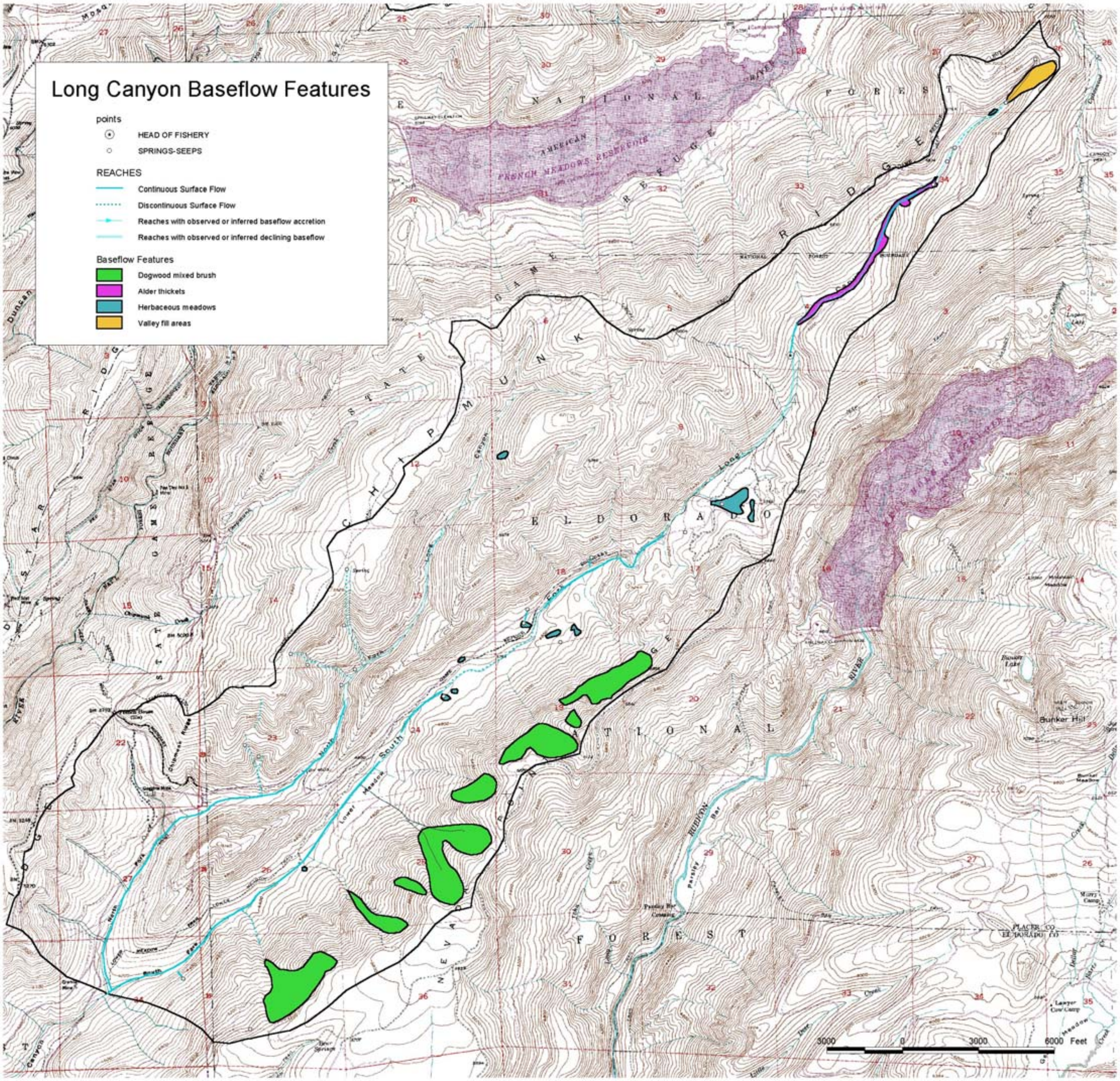


Figure 10.

Long Canyon Bedrock Geology