ANALYSIS OF BASEFLOW RECESSION IN ICEHOUSE CANYON, SAN GABRIEL MOUNTAINS, CA

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Contents

Abstract

Icehouse Canyon is a drainage system located in the eastern San Gabriel Mountains of Southern California. Spring runoff from several locations within the canyon have been measured periodically throughout a year to provide information for creation of hydrographs, which show the discharge of a stream or spring at a single location as a function of time. During periods of little to no rainfall, flow decays in the form of an exponential curve. Hydrographs of locations within Icehouse Canyon display this effect, known as baseflow recession. Baseflow recession is described by the equation: $Q = Q_o e^{-at}$, where **Q** is flow at some time **t** after the recession has started, $\mathbf{Q_o}$ is flow at the start of the recession, and **a** is the baseflow recession constant for the basin. Recession constants are a measure of the rate at which groundwater drains out of a basin after precipitation stops. One way to calculate "a" is to create graphs of ln Q versus time. This yields a straight line with slope equal to –a. Baseflow recession constants vary between locations because they are controlled by topography, temperature, sun angle, transpiration, soil makeup, and local geology. Baseflow recession recorded by Icehouse Canyon springs is compared to that of other drainage basins within the San Gabriel Mountains to determine hydrogeologic differences between them. Comparison of recession constants from year to year also provides a means of predicting future runoff levels at specific times following a particular magnitude of peak runoff. Flow data is then used to estimate the hydraulic conductivity of the Cedar Canyon landslide which is a large controlling factor of Icehouse Canyon's baseflow recession constant.

Introduction

Purpose and Objectives

The intent of this project is to measure the discharge of several springs in Icehouse Canyon during the course of a year to determine how stream discharge decays over time during periods of little recharge, resulting in the assignment of a baseflow recession constant for each location. Measurements are also taken from within nearby Icehouse Creek to determine the spring contribution to the creek. In addition, the measurements taken will be used to determine the hydraulic conductivity of the Cedar Canyon landslide material through which the springs discharge.

The information obtained from this year's field measurements and calculations will then be used as a comparison to data from previous years to determine the predictability of spring discharge rates. If the discharge rates prove to be predictable, or an average baseflow recession can be determined, then it will be feasible to make estimates in the future of how much water will be present at certain locations within Icehouse Canyon at various times during the year based on a given initial discharge and precipitation amount. The baseflow recession constants derived will also be compared with other drainage basins in the San Gabriel Mountains to discuss the differences between them that may be related to variations in geology, vegetation cover, and insolation (sun angle).

Site Description

Icehouse Canyon is a drainage system located in the eastern San Gabriel Mountains in San Bernardino County, California, north of the 210 Freeway and west of Interstate 15. The San Gabriel Mountains are part of the Transverse Ranges and are subsequently highly fractured and faulted from the many tectonic forces affecting this region (see also Nourse et al, 1994). Icehouse Canyon itself is located between Thunder Mountain to the northeast and Sugarloaf Peak to the southwest. It is part of the San Antonio drainage basin in the Angeles National Forest.

There are four main rock units found in the area of study: Quaternary alluvium seen as flood channel deposits, Quaternary talus deposits, Quaternary landslide deposits, and Mesozoic crystalline bedrock (Figure 1). The last unit presents an important feature for taking field measurements because it creates a water barrier due to its low permeability and porosity. The Quaternary landslide deposits also play an important role in this project because they represent the aquifer material which supplies water to the springs below. The main landslide in this area is the Cedar Canyon Landslide (Figure 2). The porosity and permeability of this material allows for the accumulation of precipitation in the form of groundwater and its ensuing release from springs when the water encounters the impermeable basement rock below.

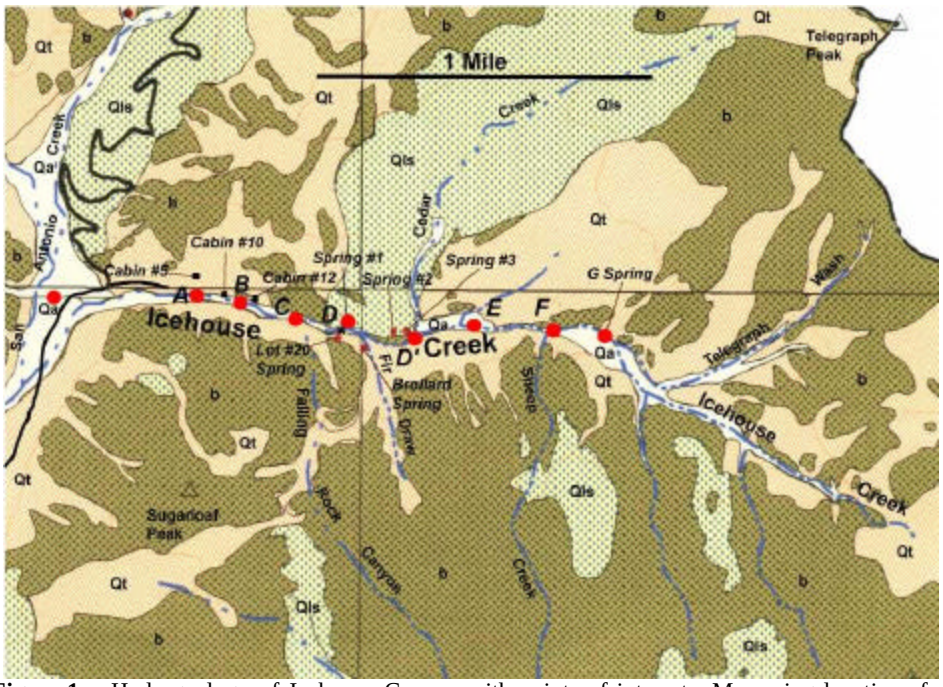

Figure 1. Hydrogeology of Icehouse Canyon with points of interest. Measuring locations for this project are outlined in yellow. Qal=Quaternary Alluvium, Qt=Quaternary Talus, Qls=Quaternary Landslide Deposits, B=Bedrock (Map by Dr. Jon Nourse, 2003)

Figure 2. View looking Northeast at Cedar Canyon Landslide. Icehouse Creek is located at the base of the landslide. Cedar Spring is shown here as the red circle (photo compliments of Daniel Heaton and Dr. Jon Nourse)

Previous Works in Icehouse Canyon and Other Watersheds

Previous research in Icehouse Canyon is fairly limited. Most of the research was conducted by Dr. Jon Nourse during the 1990s and consists of unpublished data. However, several senior theses have been completed in the areas surrounding Icehouse Canyon with one in particular that is more relevant to this project.

Melissa L. Pratt completed her senior thesis in 1995 on the "Hydrogeology of Icehouse Canyon-Southern California, Eastern San Gabriel Mountains". Her analysis went into detail about the regional geologic and tectonic setting of Icehouse Canyon within the San Gabriel Mountains, its climate and vegetation, and local geology. She also collected data from the stream at different gauge locations within Icehouse Creek to analyze the surface flow in the creek, including gaining/losing stream segments and the flow relationship with subsurface geology. Also completed in this research study was a water budget analysis which took into account precipitation and evapotransipiration, along with the comparison of this drainage unit with other years and San Antonio Canyon itself. Pertinent data from her research study will be used for comparison in this one.

Jessica Strand completed a senior thesis in 2006 on baseflow recessions, but her study was mostly limited to the San Dimas watershed located to the southwest of San Antonio Basin of which Icehouse Canyon is a part of. Strand's thesis, "Impact of Wildfires on Historical and Modern Analysis of Baseflow Recession in the San Dimas Watershed" was focused on finding the impacts of wildfires on the baseflow recession of the creeks within the San Dimas Watershed in order to see if these differences are predictable. She found that baseflow recession increases during the year following a fire. The conclusion was also drawn that since the current and historical data are so similar,

the San Dimas Watershed has not been impacted long-term by fire damage. In Strand's analysis, San Dimas Basin was compared to San Antonio Basin and some data from Icehouse Canyon is contained in her report. This data was utilized for historical flow data analysis in this report.

Much of the unpublished data utilized in the compilation of historical Icehouse Canyon flow data has been provided by Dr. Jon Nourse. He has measured flow periodically throughout Icehouse Canyon both by himself and with the assistance of his Groundwater Geology classes. Measurements also include several data sets for the major springs of interest in this study, especially Spring 1 and Spring 2. This data was extremely useful for baseflow recession constant comparisons and analysis.

Another senior thesis was completed in Icehouse Canyon in 1992 by Matt Cunningham of Pomona College. It describes "Seasonal Influences upon Icehouse Canyon Stream Chemistry". Water at Spring 1 was monitored during his study but no flow data was recorded that could be used in this discussion. In his study however, Cunningham comments on observing the general stream characteristics and baseflow recession pattern currently seen.

Van Vathanasin completed a senior thesis in 1999 for Cal Poly Pomona entitled "Hydrology and Water Budget of the San Dimas Experimental Forest, San Gabriel Mountains, California" in which he examined historical and recent hydrological data from the San Dimas Experimental Forest. His analysis focuses on precipitation, evaporation, and runoff data. One of the more profound findings of use for this project is the amount of evapotranspiration that the area experiences. Vathanasin found that San

Dimas Canyon loses about 80+% of its precipitation to evaporation from sun exposure and plant respiration.

Also of note is another senior thesis by Molly Blumer in 1996 of Claremont McKenna College on "Mapping the Watersheds of the Mt. San Antonio and Newport Bay Bioregions". This study includes the general geology, hydrogeology, and stream flow of the area, tracking water flow throughout the canyon, human impact on the area, flood control, and the consequences of channelization. No quantitative data is available for comparison in this study.

Hydrological Data

Spring and Stream Flow Data from Icehouse Canyon

Spring and Gauge Locations

There are various spots where flow measurements were taken for this project. Two measurement locations are down in the actual creek itself: one upstream before the influence of the springs (Gauge D'), and one downstream after water from the springs enters the creek (Gauge D). Other measurement locations are located at the springs themselves (Figure 3).

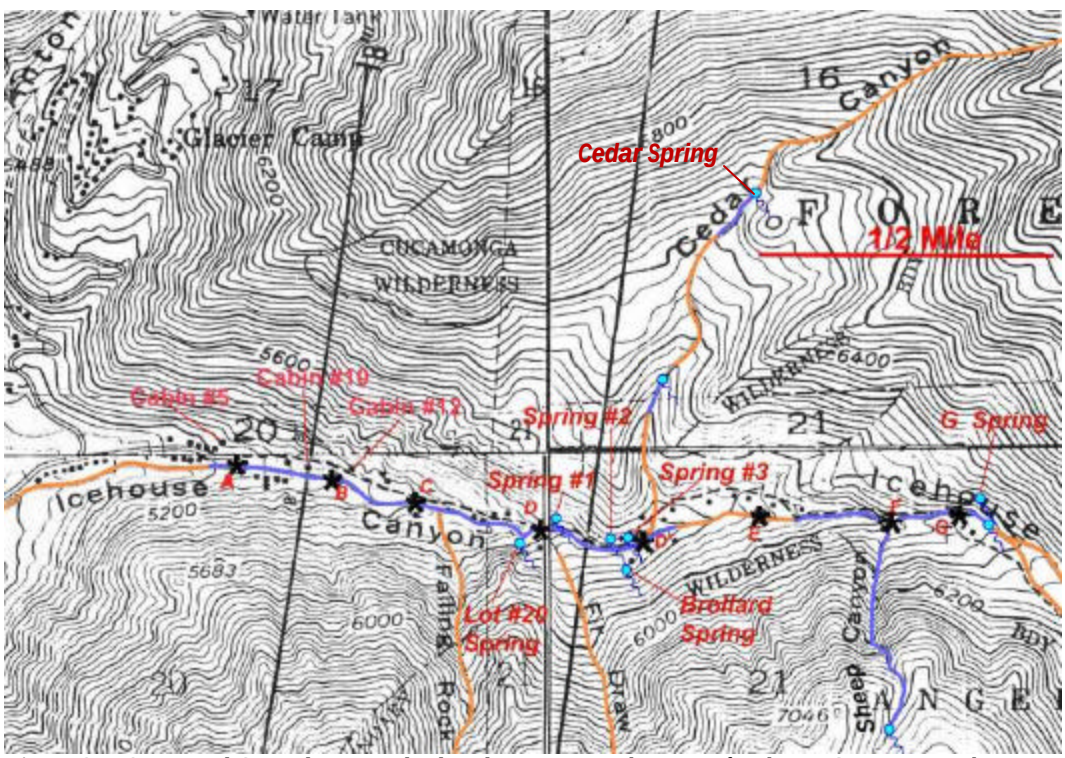

Figure 3. Spring and Gauge locations displayed on a topographic map of Icehouse Canyon. Map by Dr. Jon Nourse (2003)

Field Techniques

Several different measuring techniques were used to collect flow data, depending on the characteristics of the site. For the two gauges within the creek, locations were already chosen where the water flows over or near bedrock so that there is little to no groundwater flow and the measured value roughly represents the entire flow in that location. For Gauge D and D', as well as for Spring 1, a flow meter was utilized to determine the flow. The flow meter is made by Global Water and measures the velocity of running water. There is a propeller at the end of the meter that rotates as the water runs through it. An electrical signal created by a magnet at the end of this propeller registers the velocity. By setting the meter to record the average velocity for an area and multiplying by the cross sectional area of the weir, discharge volume is obtained in cubic feet per second (cfs). Locations were also chosen based on their cross sectional area. Places where the cross sectional area is easily approximated by using shapes such as triangles and rectangles were preferable. Flow is then channeled into these areas and loss estimated to add on to the end flow rate. At times, it was necessary to build dams or use boards to help channel the water into desired pathways. Gauge D (and at times, Gauge D') was not able to be approximated by one shape and so multiple shapes had to be used. Each one had its own cross sectional area and velocity associated with it. The resulting flow rates were then added together. Typical weir shapes for locations measured with the flow meter are as follows:

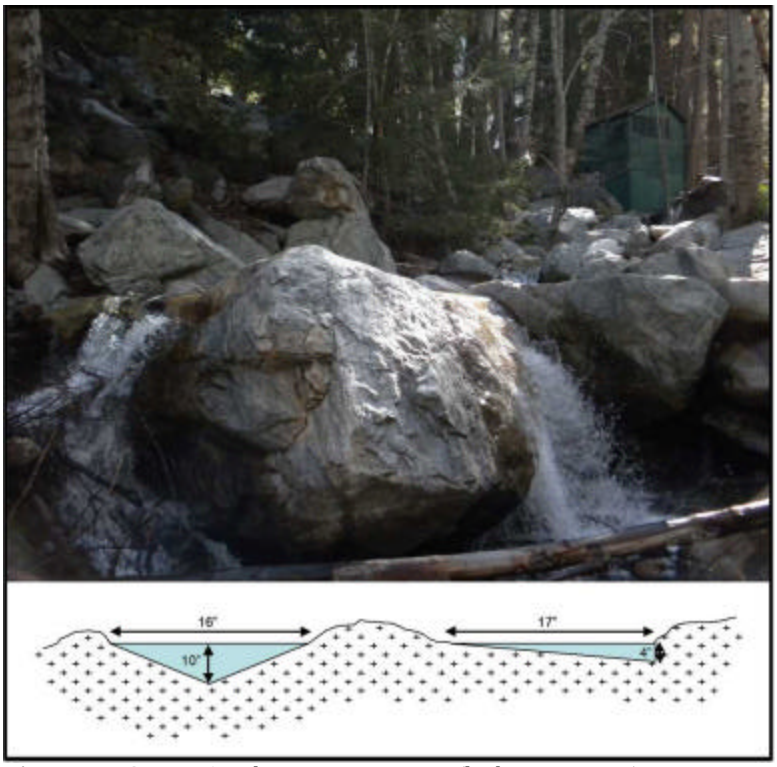

Figure 4a. Gauge D' with cross section areas (looking upstream)

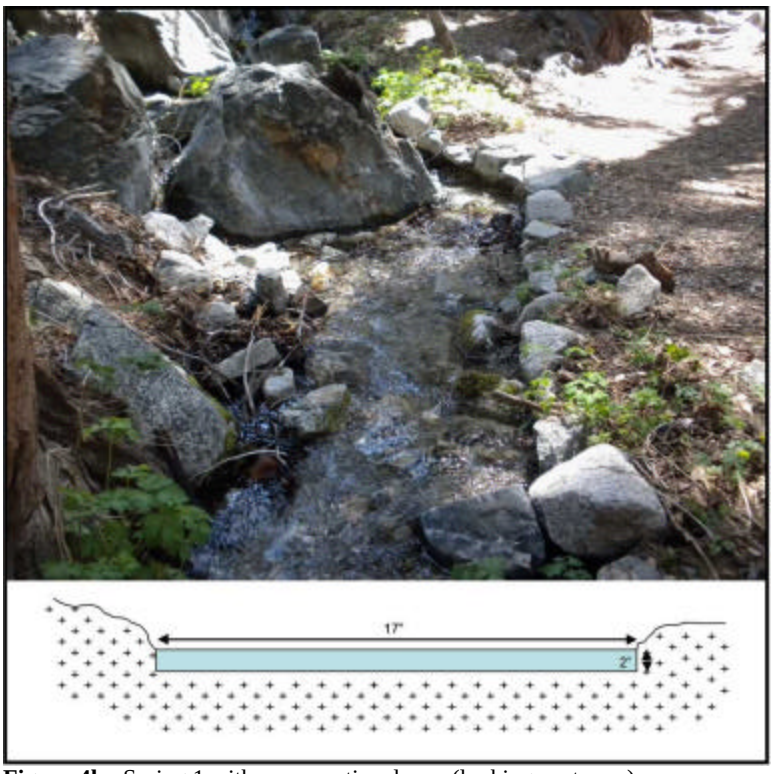

Figure 4b. Spring 1 with cross sectional area (looking upstream)

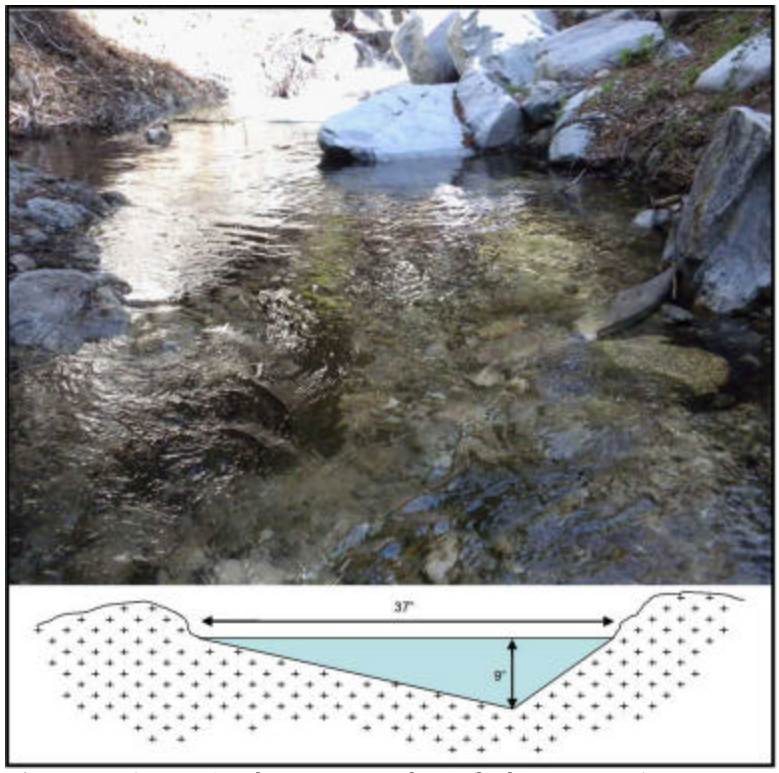

Figure 4c. Gauge D' with cross sectional area (looking upstream)

While these shapes are simplified versions of the actual configuration in the creek, they give a good estimate of cross sectional area.

Springs 2, 3 and the upper Cedar Spring are not conducive to measuring with the flow meter. At these locations, the water discharges directly out of the ground and there is no good place to measure the direct flow or determine a cross sectional area. Here, the majority of the flow was collected into cups and buckets to measure the volume with the help of boards used as flumes or reconfiguring rocks to channel the discharge. At Spring 2, both the discharge from above the trail where the water first comes out and below the trail where the water runs off the side (about 5 feet above the bedrock contact) are measured since the whole area is saturated (Figure 5a-b). The flow therefore increases from top to bottom, as seen in the data. Since the discharge above the trail is so spread out, the flow was collected from two or three different locations and then added together.

Estimates were also made as to how much flow was lost to reduce the error in the final calculations. For example, if an estimated ninety percent of the flow was caught in the measuring containers, an extra ten percent of the total discharge volume was added on to the final value.

While collecting the water, the length of time required to fill to a certain volume was recorded with the use of a stopwatch, and a rate (or volume per unit time) was obtained for each location. Two main containers were used to measure the volume of spring discharge. One consisted of a large measuring cup which measured volume in cups, and the other was a rectangular plastic bucket with vertical sides. Volumes obtained from the measuring cup were converted to cubic feet by multiplying the cup volume by a conversion factor. When water was captured in the bucket, the height of the water was measured in inches and then multiplied by the area of the bottom of the bucket to obtain volume. This value was then converted to cubic feet. Several measurements were taken in a row to find a better value than one single measurement would represent. Similar measuring procedures were performed at Spring 3 (Figure 6a-b) and Cedar Spring (Figure 7a).

Figure 5:

a) Using a measuring cup to measure discharge at Spring 2 Upper. Several areas of flow were measured at this spot and added together to obtain a total discharge for the upper part of the spring.

b) Measuring discharge at Spring 2 Lower by the "bucket technique". Field partner Anthony Hernandez times how long it takes to fill the bucket with a stopwatch.

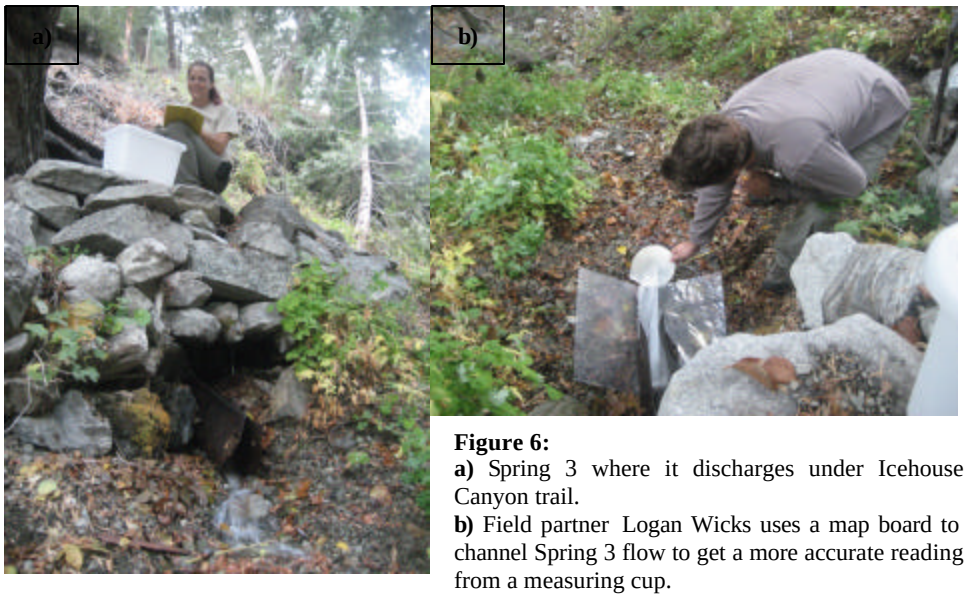

Figure 6:

a) Spring 3 where it discharges under Icehouse Canyon trail.

b) Field partner Logan Wicks uses a map board to channel Spring 3 flow to get a more accurate reading from a measuring cup.

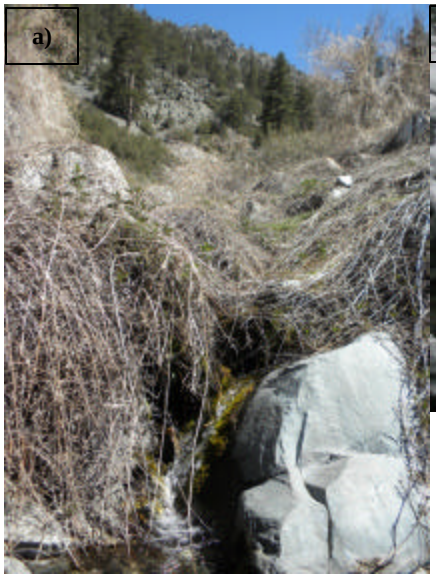

Figure 7:
a) Cedar Spring
b) Using the Flow Meter to measure stream flow at Gauge D

2008-2009 Flow Data

Field measurements for this study were collected roughly once every two to three weeks during the recession period and an average of once every month after rainfall commenced and a rise in discharge was seen. Cedar Spring was sampled less often (about once every month during recession and every couple of months after). This data was collected for the span of a year starting April 25th, 2008 and ending April 26th, 2009. Resulting flow values were plotted on graphs to show the recession exhibited by each location (see Appendix I). On top of these curves, rain data has been overlain to show the influence of precipitation and resulting aquifer recharge on the discharge of the springs and increased flow in Icehouse Creek.

Date	Gauge D Q (cfs)	Gauge D' Q (cfs)	Difference (cfs)	Spring 1 Q (cfs)	Spring 2 Upper Q (cfs)	Spring 2 Lower Q (cfs)	Difference (cfs)	Spring 3 Q (cfs)	Cedar Spring Q (cfs)
04/25/08	3.974	3.965	0.009	0.662	0.067	0.090	0.024		
5/23/2008	4.798	2.804	1.993	0.708	0.117				
06/02/08	4.120	1.923	2.196	0.510	0.067			0.044	
6/11/2008	3.443	1.750	1.694	0.574	0.051			0.022	
7/2/2008	2.944	1.630	1.313	0.428	0.041	0.066	0.025	0.017	0.043
7/20/2008	3.003	1.770	1.232	0.463	0.039	0.100	0.061	0.020	0.032
8/3/2008	2.519	1.268	1.252	0.311	0.036	0.090	0.054	0.024	
8/20/2008	2.710	1.618	1.093	0.261	0.031	0.095	0.064	0.020	0.027
9/7/2008	1.993	0.906	1.087	0.257	0.016	0.010	-0.006	0.035	
9/21/2008	2.616	0.947	1.669	0.231	0.026	0.025	0.000	0.023	0.016
10/02/08	1.897	0.784	1.113	0.359	0.025	0.079	0.054	0.023	
10/17/2008	1.489	0.873	0.616	0.156	0.025	0.077	0.052	0.022	
11/2/2008					0.024	0.066	0.043	0.018	
12/23/2008	1.440	0.891	0.549	0.225	0.024	0.069	0.046	0.018	
1/10/2009					0.022	0.065	0.043	0.019	0.024
2/20/2009	2.604	1.594	1.010	0.224	0.027	0.087	0.060	0.021	
4/26/2009	5.884	5.245	0.639	0.502	0.078	0.138	0.061	0.034	0.049

Table 1: Icehouse Canyon flow data collected during this study

Historical Flow Data from Icehouse Canyon

Historical data for Icehouse Canyon comes from a few different sources. Most of the data was collected by Dr. Nourse and his classes, and there is some older data that was used in Melissa Pratt's senior thesis. The available period of record was 1993 to 2000. Much of this data has been collected from other stream weirs in Icehouse Creek that were not used in this study. A table of the historical flow values for each location of interest is provided in Appendix II. Of the data that is available for the locations of interest in this project, the data points can be sporadic and spaced at large time intervals so that they do not show periods of recession well. By compiling all the information available and plotting them in graphs, a few periods of apparent recession can be picked out (example shown in Figure 8). These specific periods have been plotted separately on natural log of flow versus time graphs and the best fit lines for each period show the

baseflow recession constants. Related analysis will be described further in the discussion of baseflow recession constants.

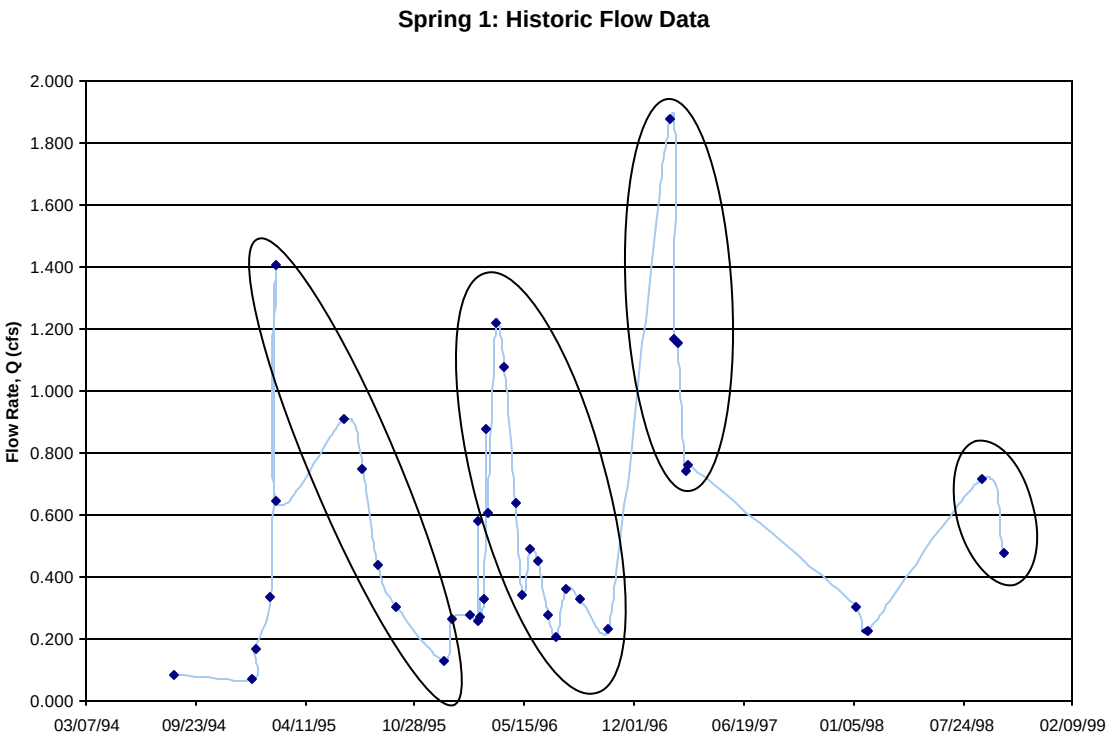

Figure 8. Historical flow measurements from Spring 1 are plotted as a function of time. Several strings of data provide recession curves (as circled here), which can then be plotted as natural logs to obtain baseflow recession constants for comparison.

Historical Flow Data from other Drainage Basins

Flow data from streams and springs in other drainage basins was provided by Dr. Nourse and by Jessica Strand's 2006 senior thesis. Comparison of flow records includes data from upper San Antonio Canyon and the three creeks studied by Strand in the San Dimas watershed. Data from San Antonio Canyon ranges from 1993 to 2007, with the most extensive datasets from 1993 to 1998. Sets of measurements that show decay are plotted to determine the baseflow recession constants for the various gauge stations in San Antonio Creek. In the case of the San Dimas creeks, baseflow recession constants

have been provided by Strand and the calculation of them is not necessary. Comparison of these baseflow recession constants with Icehouse Canyon will be discussed further.

Precipitation Data

Rain data for the area has been recorded and provided by Mrs. Pat Chapman at nearby Chapman Ranch (elevation = 4360 ft). Measurements date back to 1979, but are incomplete: e.g. the period of 1986 to 1992 is missing. Since all the historic data that the current measurements are being compared to date back only to 1993, only the rain data from 1993 to present has been displayed below in Figure 9 so that the average precipitation and deviation from mean is not impacted by the lost data.

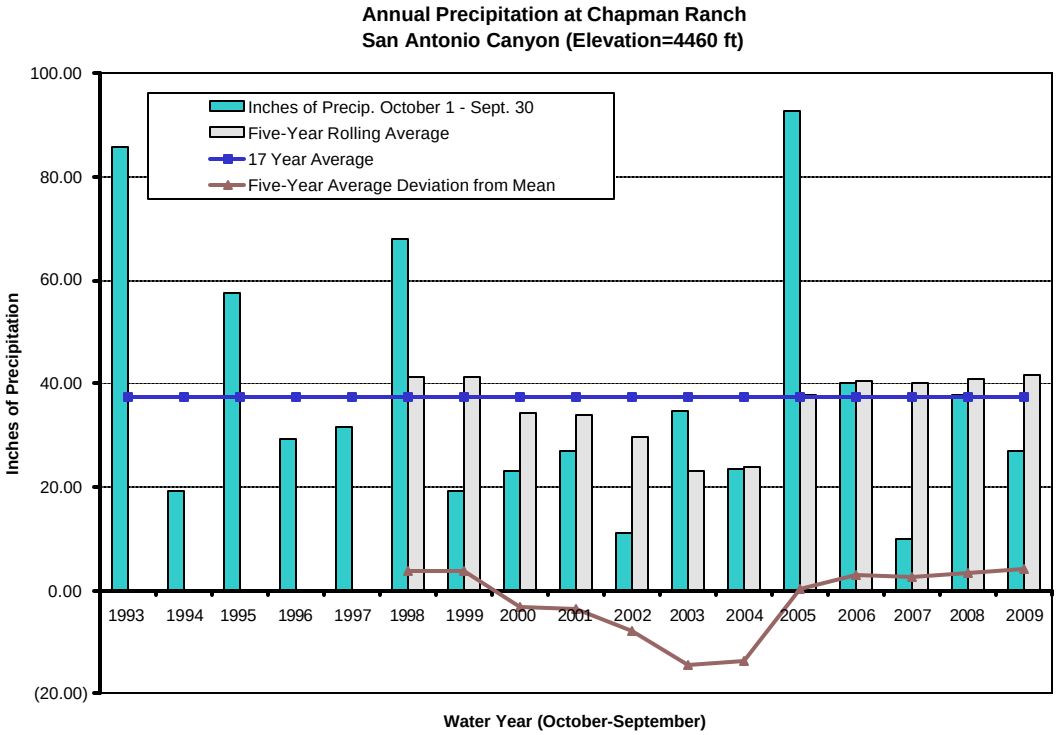

Figure 9. Graph of annual precipitation from nearby Chapman Ranch from 1993 to Present.

As seen from Figure 9, precipitation for last year (the water year October 1, 2007 to September 30, 2008) was just about average. This is useful since the baseflow recession of springs studied from late spring to early fall of 2008 is reflective of the recharge experienced by the aquifer from last year's precipitation. Therefore, the recession seen in this study has a better chance of representing an average recession because it follows a year of average precipitation. Precipitation values for 2009 are still incomplete since the rain season lasts from October 1st of the year before to September 30th. Therefore, when this data has been compiled, there are still 4 months left in which precipitation could increase. However, late spring and summer rain is rare and usually mild so it is likely that the precipitation value for 2009 will stay below average. This may have repercussions on next year's recession values, as discussed later.

Analysis and Discussion

Baseflow Recession Constant

The baseflow recession constant is a measure of the rate at which groundwater drains out of a basin after precipitation stops. Usually, in periods of little to no rainfall, this decay is seen over time in the form of an exponential curve. The springs in Icehouse Canyon all display this effect. The shape of the baseflow recession curve relates to certain characteristics of the drainage basin that may include: geology, vegetation, sunlight exposure, temperature, and slope of the ground. The main influence of baseflow recession is debatable. Thus, it will change for each location depending on the site characteristics. This allows the comparison of different basins and locations within the same drainage basin to be compared and analyzed. In general, the baseflow recession curve is given by the equation:

$$\mathbf{Q = Q_0 e^{-at}}$$

where

- Q is the flow at some time, t, after the recession has started and is measured in volume per time. For this study, units of cubic feet per second (cfs) are used.
- Q_0 is the flow at the start of the recession (also measured in cfs).
- A is the recession constant for the basin with units of time^{-1} (days^{-1} used here).
- t is the time since the start of the recession at which Q is taken, with units of time (days). The graphs shown here of the flow decay show t as the x value in the equations for the best fit curves.

Manipulating this equation gives:

$$
\begin{aligned}
Q &= Q_0 e^{-at} \\
\ln Q &= \ln[Q_0 e^{-at}] \\
\ln Q &= \ln Q_0 + \ln(e^{-at}) \\
\ln Q - \ln Q_0 &= -at \\
\mathbf{\ln Q} &= \mathbf{\ln Q_0 - at}
\end{aligned}
$$

which is the equation for a straight line in the form of:

$$y = b - mx$$

so that, when the data is plotted on a graph as the natural log of the flow versus time, a straight line for the period of recession is obtained. The slope of this line is equal to the negative value of the baseflow recession constant.

Baseflow Recession Constant Comparisons

2008-2009 Icehouse Canyon Data

Recent data for the two gauges (D and D') as well as the four springs monitored in this study were plotted as ln(Q) versus time. These results are displayed in Figure 10 with the baseflow recession constants tabulated in Table 2 for comparison. Additional hydrographs showing the recession of the individual locations are provided in Appendix III.

When plotted on a natural log graph, relative discharges of the different locations can also be compared to each other. Locations with high discharge are located highest on the graph while locations with relatively low discharge are displayed lower on the graph.

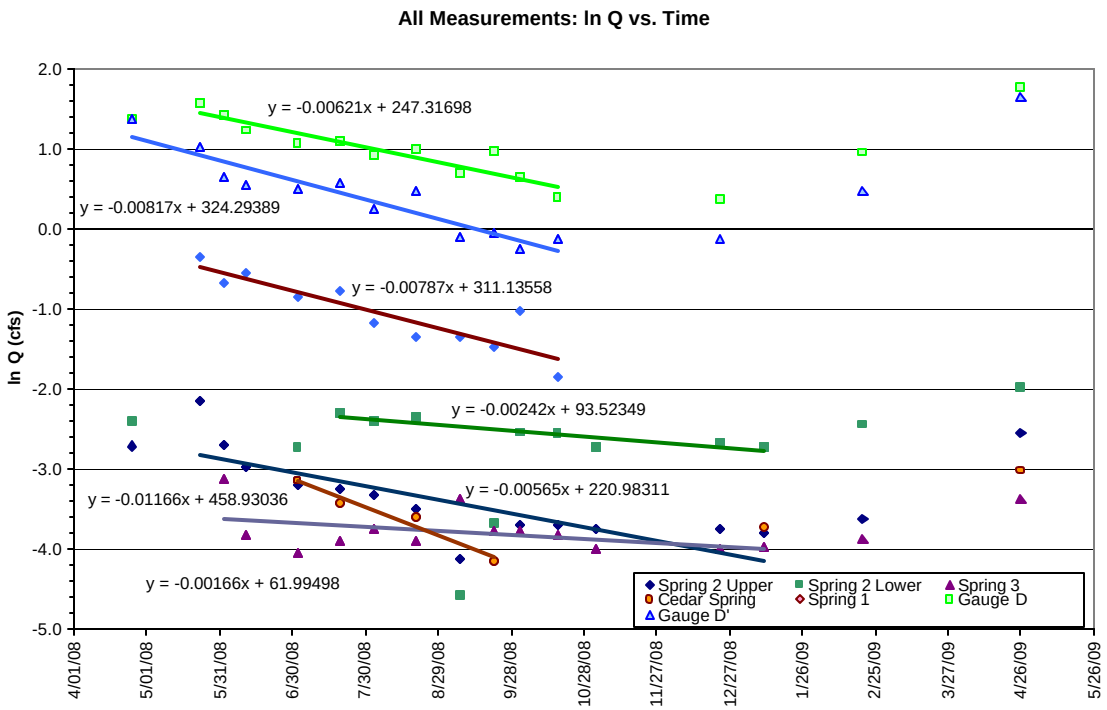

Figure 10. Natural log plot of measurement locations showing the baseflow recession

Location	Baseflow Recession Constant (days^{-1})
Gauge D	0.00621
Gauge D'	0.00817
Spring 1	0.00787
Spring 2 Upper	0.00565
Spring 2 Lower	0.00242
Spring 3	0.00166
Cedar Spring	0.01166

Table 2. Baseflow recession constants for Icehouse Canyon locations

Time Variability of Recent Data and Historical Data

Historical data for areas of interest in Icehouse Canyon have been plotted below with current data on natural log graphs after picking out sets of data that exhibit recession, as explained previously. In order to display all the data next to each other in one graph, the years of the data have been normalized. This consolidates the data into a one-year

reference frame while maintaining the respective seasonal relationship of the data points. Plots showing the historic baseflow recession as a function of true time are provided in Appendix IV. Data availability varies and some of the baseflow recession lines have been determined with only a few data points. The error in baseflow recession constant is therefore higher and the obtained value is less accurate that those calculated with more extensive data, but they at least provide a range of baseflow recession constants with which to compare to other years. Some examples of these types of lines are the two most recent historical recession constants for Spring 1 and the only available historical data points indicative of a recession for Spring 3. There was not enough historical data to construct graphs for Gauge D' or for Cedar Spring.

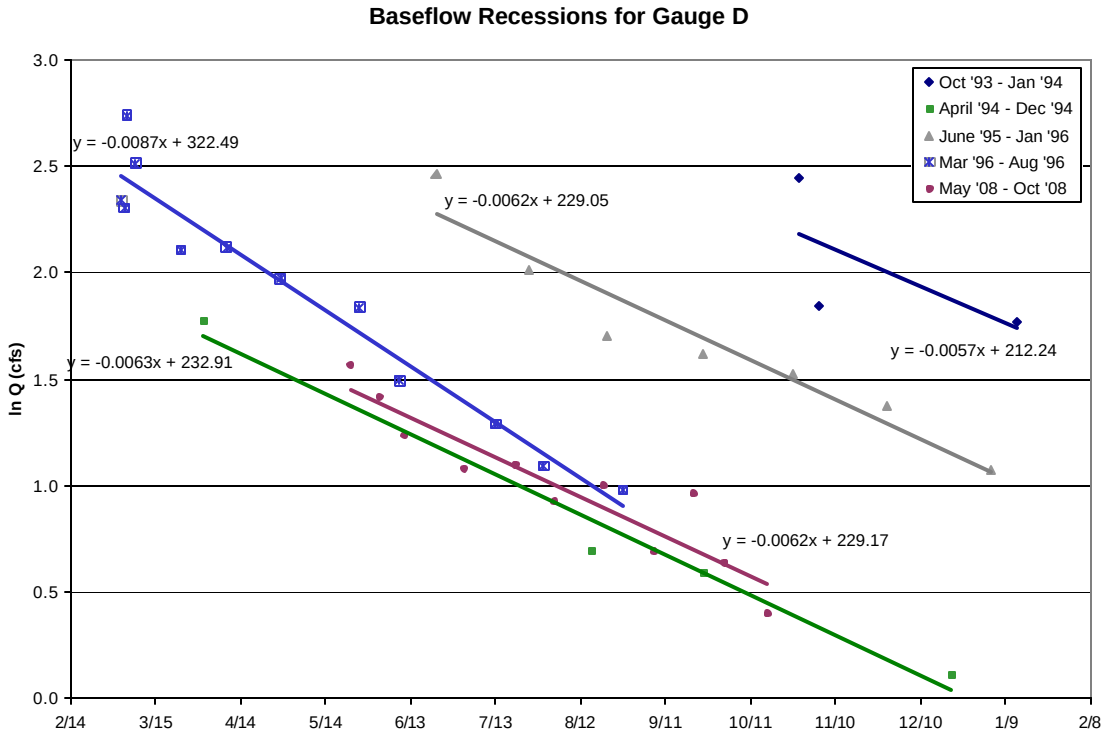

Figure 11a. Comparison of historic baseflow recession values for Gauge D in Icehouse Canyon. Recent data is shown in maroon.

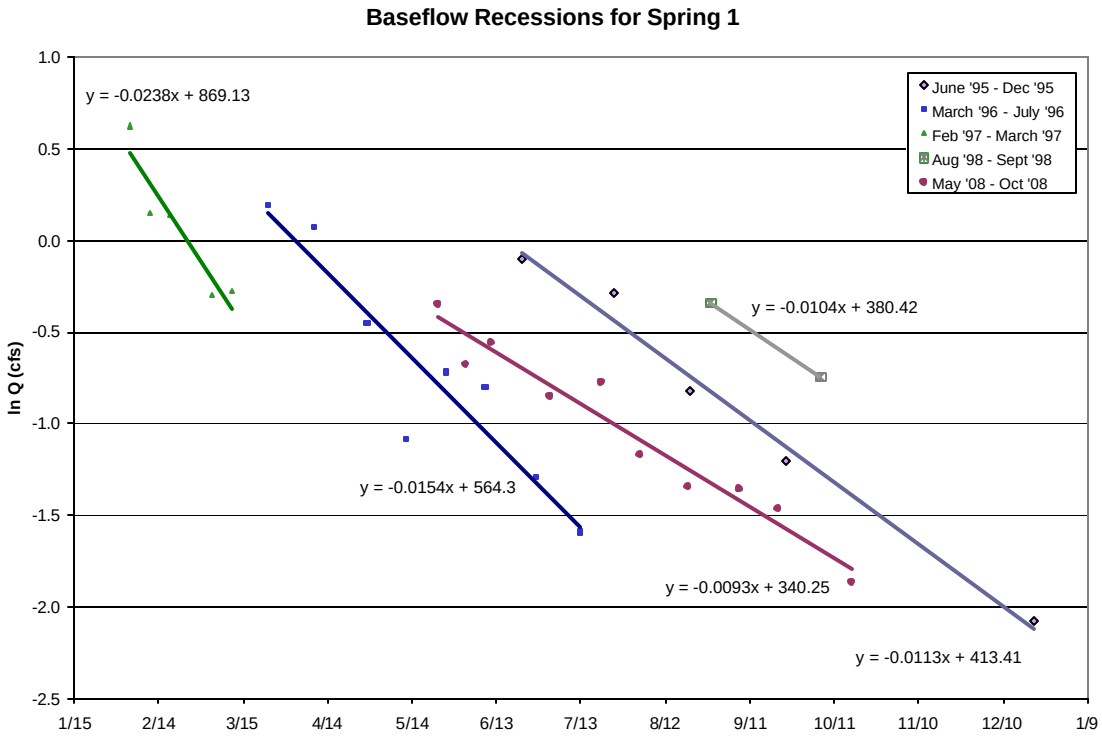

Figure 11b. Comparison of historic baseflow recession values for Spring 1 in Icehouse Canyon. Recent data is shown in maroon.

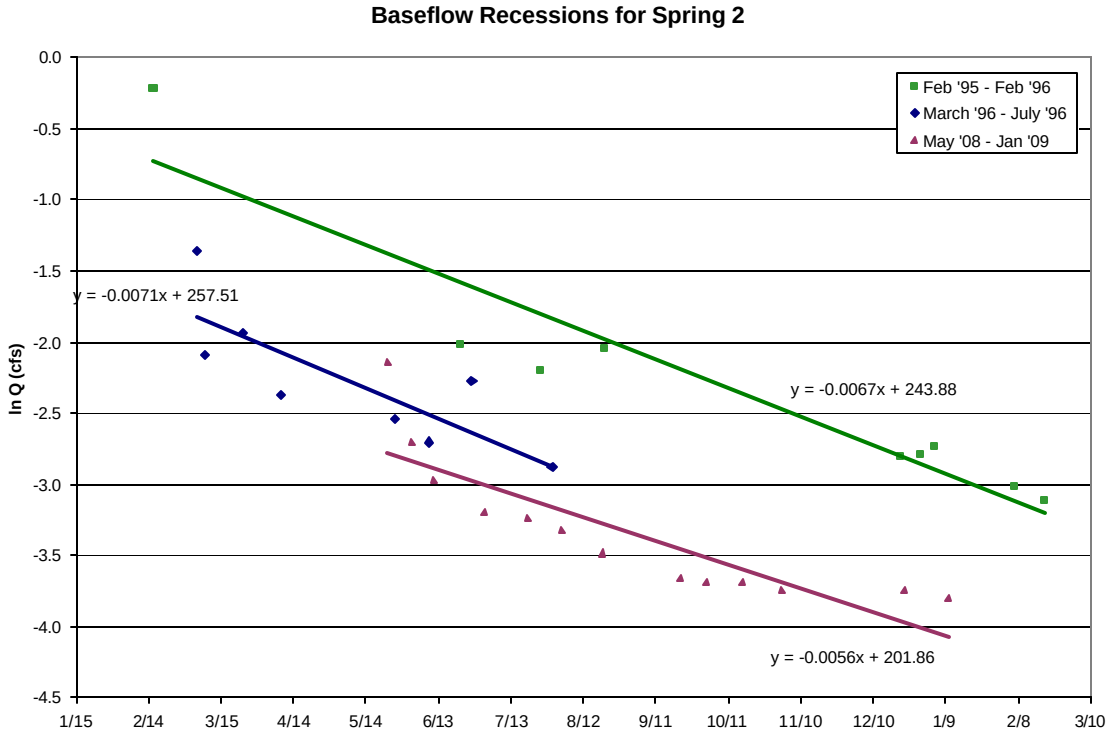

Figure 11c. Comparison of historic baseflow recession values for Spring 2 in Icehouse Canyon. Recent data is shown in maroon.

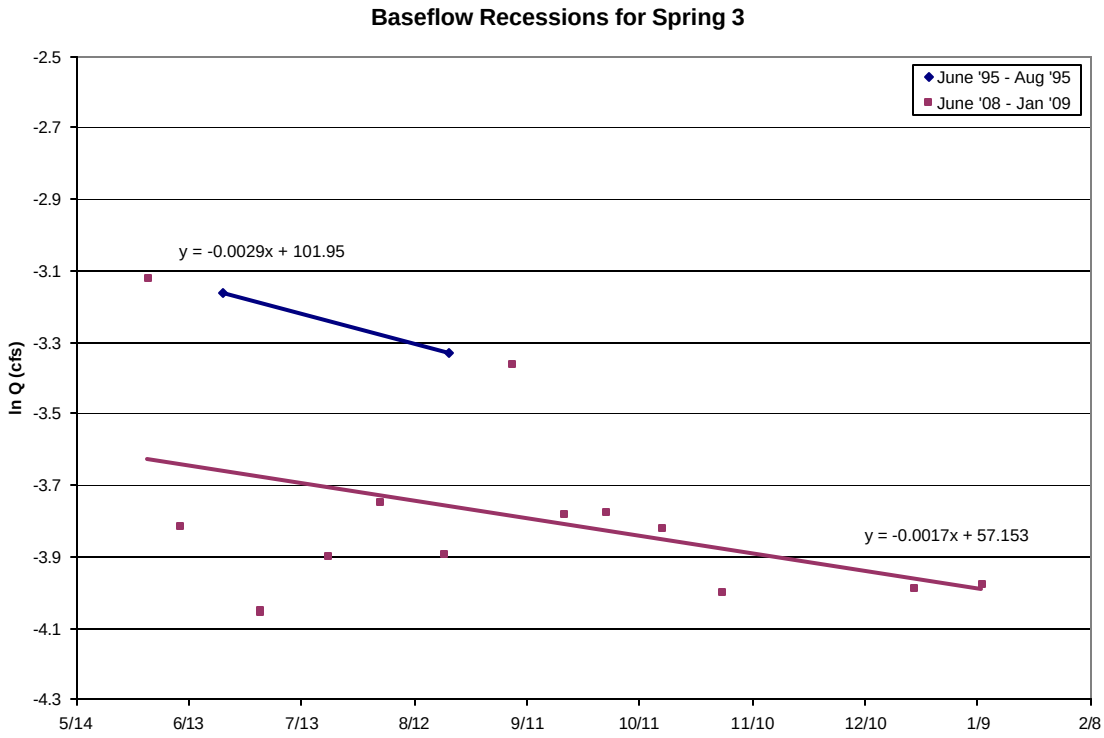

Figure 11d. Comparison of historic baseflow recession values for Spring 3 in Icehouse Canyon. Recent data is shown in maroon.

Year of Recession	Gauge D	Spring 1	Spring 2	Spring 3
’93 – ‘94	0.0057			
’94 – ‘95	0.0063			
’95 – ‘96	0.0062	0.0113	0.0067	0.0029
’96 – ‘97	0.0087	0.0154	0.0071	
’97 – ‘98		0.0238		
’98 – ‘99		0.0104		
’08 – ‘09	0.0062	0.0093	0.0056	0.0017
Average Baseflow Recession (days^{-1}):	**0.00662**	**0.01404**	**0.00647**	**0.0023**
Standard Deviation	0.00119	0.00592	0.00078	0.00085

Table 3. Summary of historic baseflow recession values for locations within Icehouse Canyon

Icehouse Canyon Compared with Other Drainages

Location	Baseflow Recession ($days^{-1}$)	Standard Deviation
Wolfskill Creek (San Dimas Drainage)	**0.0190**	
Middle Fork (San Dimas Drainage)	**0.0320**	
East Fork (San Dimas Drainage)	**0.0246**	
Upper San Antonio Canyon Average	**0.0185**	0.0053
Icehouse Canyon Average	**0.0081**	0.0014

Table 4. Summary of baseflow recession values for streams within the San Dimas drainage basin and San Antonio drainage basin (including Upper San Antonio Canyon and Icehouse Canyon)

Average baseflow recession values have been put together for the upper part of San Antonio Canyon and Icehouse Canyon in general by averaging several stream baseflow recession values. Historical data for each location was compiled, averages for each location found, and then representative stream locations were chosen where baseflow recession values were comparative and where consistent flow was experienced.

After comparing Icehouse Canyon to other drainage basins in the San Gabriel Mountains (Table 4), it is clear that Icehouse Creek typically has a lower baseflow recession constant. Again, there are many factors that control the baseflow recession values, but there are some noticeable differences between Icehouse Canyon and other drainage areas like upper San Antonio Canyon that influence the differences seen. San Antonio Canyon is a good drainage area to compare Icehouse Canyon to because both have similar hypsometric integrals, meaning that the distribution of elevation across the drainage areas are about the same. The areas of the two watersheds are also comparable. Upper San Antonio Canyon contains 4.71 square miles while Icehouse Canyon contains 3.91 square miles. Also, both canyons receive about the same amount of precipitation so this factor is constant between the two.

One of the larger influences on baseflow recession between the two canyons is the amount of sun exposure each canyon receives. Icehouse Canyon trends east-west and therefore has more shade than the north-south trending San Antonio Canyon which is more exposed to the sun. This sun exposure, in combination with the amount of vegetative cover, increases the evapotranspiration found in the area. As mentioned previously, Vathanasin's 1999 senior thesis found that evapotranspiration values can surpass 80% (see also Nourse et al., 1999). This drastically reduces the amount of rainfall that is recharged and available for groundwater discharge. Similar comparisons are seen in Strand's 2006 study of the creeks in the San Dimas Watershed. The north-south trending creeks were also found to have a higher baseflow recession value than the east-west trending creeks.

The soil coverage of an area also has a huge impact on baseflow recession. Porous material, such as the many talus and landslide deposits found in Icehouse Canyon, create good aquifers by absorbing precipitation and storing the water. It is then released at a much slower rate than the bedrock which principally surrounds San Antonio Canyon (Figure 12).

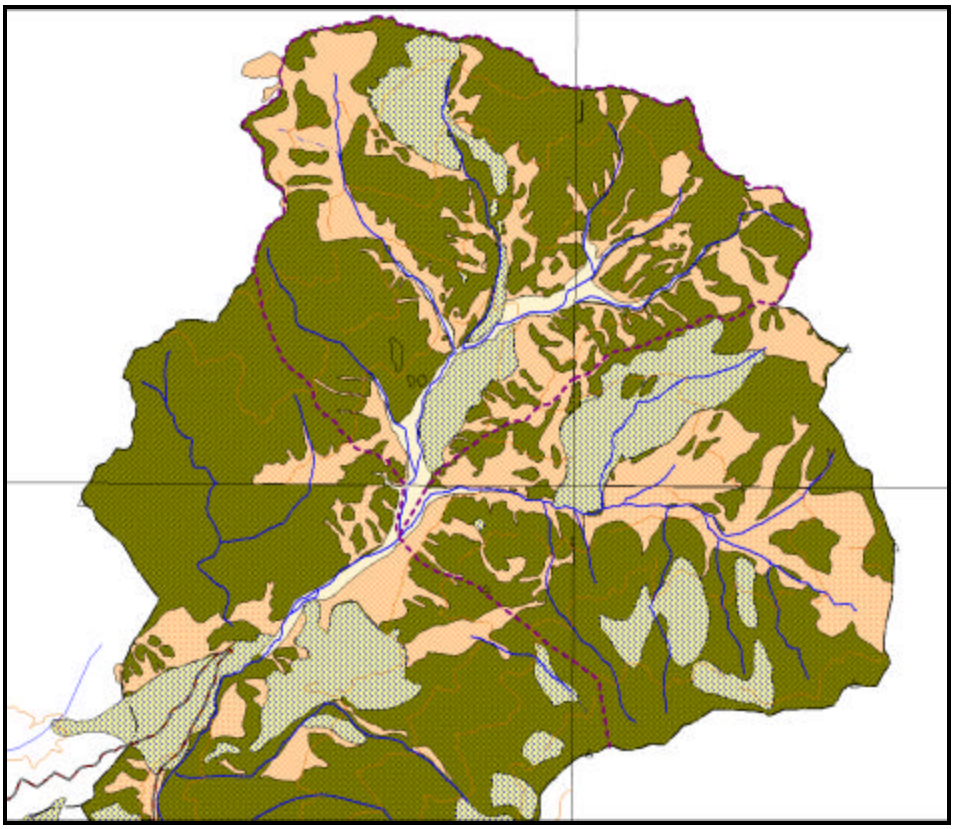

Figure 12. Geology of the upper part of the San Antonio Drainage Basin. White=Quaternary Alluvium, tan=Quaternary Talus, green stippled=Quaternary Landslide Deposits, olive green=Bedrock (Map by Dr. Jon Nourse, 2003).

Possible Controls of Baseflow Recession Constants in Icehouse Canyon

Several patterns and relationships between the measurement locations in Icehouse Canyon are recognizable from Figure 10. An attempt to explain the differences in baseflow recession values between the locations is given here.

From the graph, it is seen that Gauge D' decays more quickly than Gauge D. That is, the slope representing the baseflow recession constant for Gauge D' is steeper than that of Gauge D. This relationship is most likely due to the location of the gauges themselves. Gauge D, which is situated downstream of the spring locations, is experiencing recharge from these springs while D' is not. Therefore, the added source of

water from the above landslide provides a more constant flow of water than what is being released upstream of Gauge D'.

When the two baseflow recessions from Spring 2 are compared, it can be noted that the lower part of Spring 2 decays at a slower rate than the upper part of Spring 2. As the year progresses without recharge to the aquifer in the form of precipitation, the water table drops from loss due to evapotranspiration and spring discharge. The lowering of the water table will affect the upper part of Spring 2 more than the lower part. Thus, the water supply for the lower part of Spring 2 is more constant than for the upper part of Spring 2. The water table does not need to be as high to produce discharge, even in the dry season.

Spring 3 has a fairly constant discharge and does not exhibit much of an exponential recession. This indicates that the aquifer supplying this spring may be from a different source than the other springs that is less influenced by seasonal variations and additions or lack of recharge water.

Cedar Spring decays much faster than any of the other locations. This is not surprising as it is located much higher up in the recharge area. Subsequently, the aquifer it discharges from is closer to bedrock and shallower, providing less storage so that the supply of water during periods of little to no recharge therefore drops off at a quicker rate than those areas with larger groundwater reservoirs feeding them, such as the springs below at the toe of the landslide deposit.

It appears that the amount of precipitation received in the recharge area before recession begins is also a control on the baseflow recession constant. Upon plotting historical baseflow recession constants against precipitation data (Figure 13), an inverse

relationship is seen for Icehouse Canyon. Recession constants are plotted against the precipitation values that control each recession (i.e. the previous year's precipitation data). More precipitation in a given year results in lower baseflow recession values, meaning that the discharge from gauges and springs drops off at a slower rate as the recession progresses. Less precipitation in a given year results in higher baseflow recession values, meaning that the discharge drops off at a steeper rate.

This may not necessarily be the case for other drainage basins. When similar San Antonio Canyon data is plotted, some of the measuring locations show a direct proportional relationship to the precipitation while other locations provide no clear relationship between discharge and precipitation. The reason for this difference is most likely due in main part to the geology differences between the canyons. Because upper San Antonio Canyon does not have as many large landslide and talus deposits as are found in Icehouse Canyon, precipitation would tend to discharge more rapidly from San Antonio Canyon while it would be collected within the porous materials surrounding Icehouse Canyon and released at a slower rate.

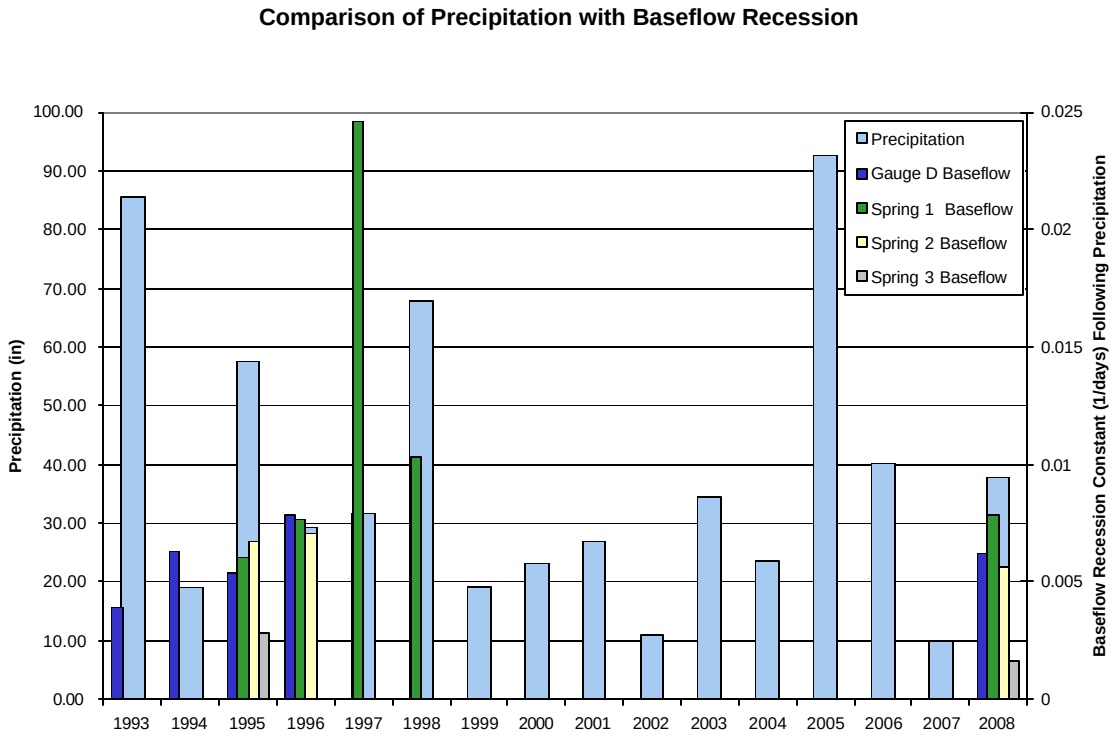

Figure 13. Historical Icehouse Canyon Precipitation plotted against precipitation for that year.

As mentioned before, the recession rates measured during this study follow a year of average rainfall and therefore may represent a more average recession constant. This year's precipitation has been below average so far, and is likely to remain so. Therefore, based on the overall trends seen here, one could predict that recession values for 2009 will be higher than the values seen here in the 2008 study.

Stream Gain and Spring Influence in Icehouse Canyon

Measurements taken in Icehouse Creek, both upstream of the springs, and downstream, show how the creek flow increases downstream. Since both of the measuring locations are situated on or close to bedrock (D rests on an unknown but presumably shallow thickness of alluvium), alluvial contributions of groundwater flow to

the observed flow gain can be ruled out. Instead, this difference in upstream versus downstream flow represents the discharge from the springs located in between the two gauges. Gain in stream flow due to spring influence at any given time during this study is plotted in Figure 14.

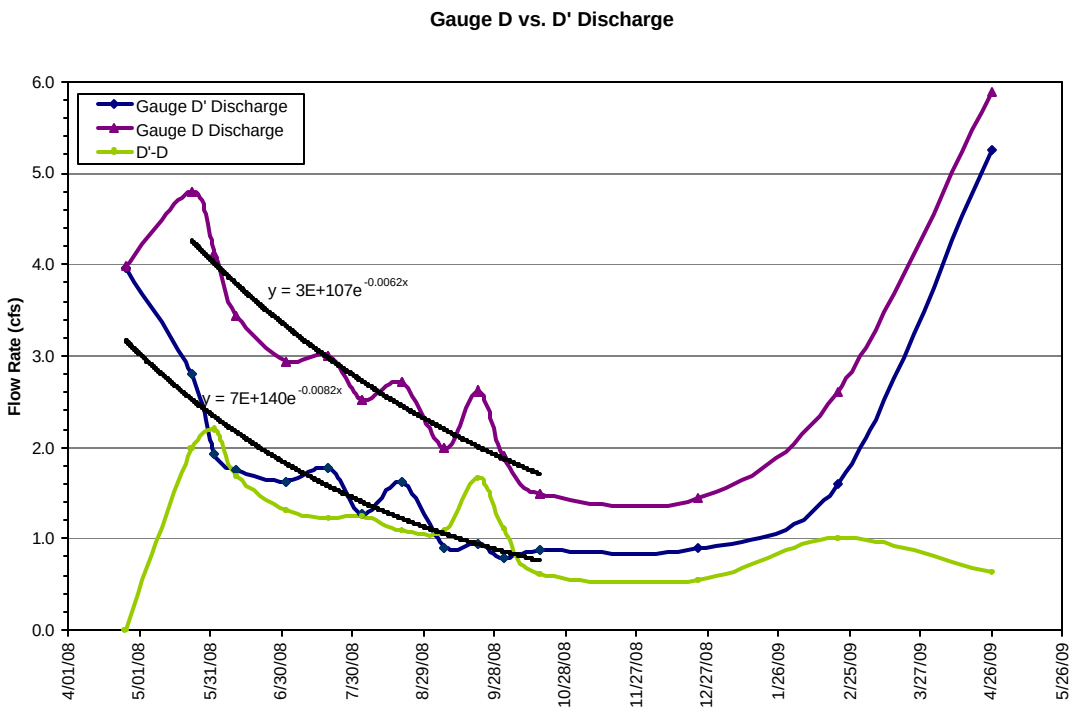

Figure 14. Flow gain relationship between upstream Gauge D' and downstream Gauge D. The green line represents the flow that is added between the two gauges.

There is one spring (Brollard Spring) situated on the other side of the canyon from the springs measured in this study (refer to Figure 3). Discharge of this spring was recorded at the end of the study. To determine the amount of effect Brollard Spring has on the flow in Icehouse Creek, the rate was compared to the gain in flow between Gauges D' and D. Dividing the flow rate of Brollard Spring by the difference of flow rates of D' and D (which represents the total added flow to the creek) gives the percentage of the total flow entering the creek from Brollard Spring. This value has been found to be 0.0313 or roughly 3% of the total increased flow between stream gauges. This

approximation assumes that the relationship seen at this one time measurement is consistent year-round and that the baseflow recession constant of Brollard Spring is comparable to that of the other springs and with that of the creek itself. Given that the baseflow recession constants of Springs 1, 2, and 3 have been seen to be highly variable (ranging from 0.0079 $days^{-1}$ to 0.0017 $days^{-1}$) and since the material that constitutes the reservoir for Brollard Spring is different from that of the other springs, this is probably not the case. However, since the contribution of Brollard Spring to Icehouse Creek is seen to be very low in comparison with the other springs during one of the highest discharge periods of the year, it can also be assumed that its contribution in drier parts of the year are just as insignificant, if not less.

The gain between the two stream gauges was also compared to the totaled rate of the springs that discharge directly into the creek (i.e. Spring 1, Spring 2 Lower, and Spring 3). Spring 2 Upper was excluded since it is accounted for in Spring 2 Lower, and Cedar Spring was excluded since the discharge seen there will still travel through the landslide material to the springs below. Subtracting out this total and the estimated 3% for Brollard Spring shows that the gain between Gauge D' and D cannot be accounted for solely by springs that were measured in this study. There was extra discharge unaccounted for in every data set except for the last one (which may plot differently due to differences in groundwater behavior during times of peak runoff). This extra unaccounted for flow could be due to measurement error in that spring discharge increases downward until it comes in contact with the bedrock (as seen at Spring 2). Therefore, some of the total flow from the springs may have escaped measurement. Also, not all water discharging from the landslide material comes from the springs. There were

several more wet spots consistently seen on the trail and doubtlessly more groundwater flow not visible from the surface.

When the extra flow is plotted with the stream gain between Gauges D' and D, it is seen that the value parallels the shape associated with this stream gain. The steam gain curve itself appears to be more affected by whatever is occurring between the two gauges. As seen in Figure 15, both Gauge D and the difference between D and D' peak around the end of September while Gauge D' does not. That the increased difference between the two gauges is due to spring influence explains why this increase in flow is not seen in Gauge D'. The similarity in shape between the stream gain and unaccounted for flow points to the conclusion that this extra flow is constant and is dependent on the same factors controlling flow differences in the creek, which is in turn related to the factors controlling spring discharge.

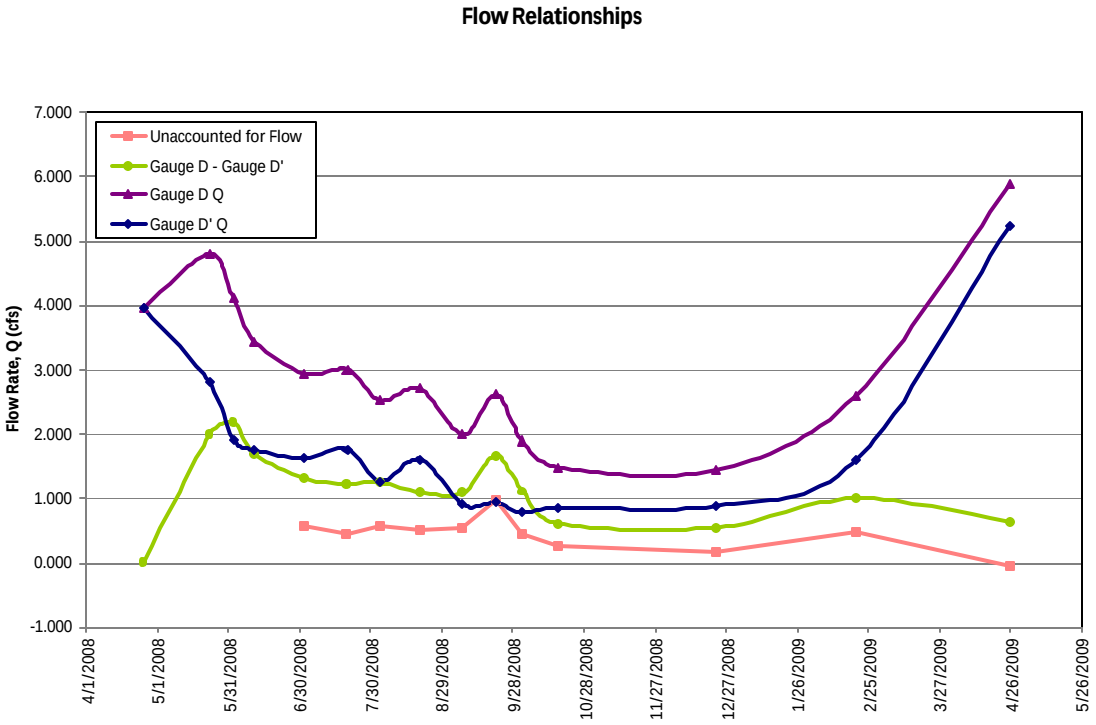

Figure 15. Gain relationship graph with added line (orange) representing flow that is left unaccounted for after totaling the measured contributions of the springs emptying into Icehouse Creek.

Hydraulic Conductivity of Cedar Canyon Landslide Material

An important aspect of unconsolidated materials, such as the landslide and talus deposits found in Icehouse Canyon, is that they exhibit different variations of grains with pore spaces in between that are often interconnected. The interconnection of pores allows for the movement of water, or permeation. The coefficient of this permeability, called hydraulic conductivity, is characteristic of different materials and depends on various factors such as grain size and pore space. Henry Darcy who studied movement of water through porous mediums in the mid 1800s established Darcy's Law which states that the discharge, Q, is proportional to the difference in water height (or hydraulic head) and inversely proportional to the flow length:

$$Q = -KA(h_A - h_B)/L$$

or

$$Q = -KA\,(dh/dl)$$

where dh/dl represents the hydraulic gradient and K is the hydraulic conductivity measured in length per time. Rearranging the equation gives:

$$\mathbf{K = \frac{-Q}{A(dh/dl)}}$$

The hydraulic conductivity of the Cedar Canyon Landslide material has been a subject of interest because this value will provide insight into how quickly water travels through the material. Through the information collected during this study, an estimate of the hydraulic conductivity has been conducted. Due to the complexities of the calculation for this area with the available data, many assumptions have to be made. The cross-sectional area, A, in this case will attempt to represent the saturated zone found

around Spring 2 since the height of water table can be seen here. Water discharges out of the spring from roughly 15 feet above the trail and comes in contact with the bedrock about 5 feet below the trail. Therefore, a height of 20 feet will be assumed. The overall shape of the cross-sectional area is assumed to be triangular with base of the triangle extending from the wet section of the trail to the west of Spring 2 to until just past Spring 3 to the east. This length is about 294.24 feet.

Hydraulic conductivity was conducted using the hydraulic gradient from both the upper Cedar Spring to Spring 2 and the lower Cedar Spring (refer to Figure 3 for location) to Spring 2. The value dh is taken to be the difference in elevation between the two springs and dl is the distance between them. The dh value for the elevation difference between Spring 2 and the upper Cedar Spring is 759 feet. Map distance between these two (which does not take elevation into account) is 3026.42 feet, so applying trigonometry yields a true length, dl, of 3120.14 feet. The elevation difference (dh) between Spring 2 and the lower Cedar Spring is 328 feet while the distance between the two (dl) is 1629.53 feet.

The first attempts at finding the hydraulic conductivity of the Cedar Canyon Landslide material utilized both the maximum and minimum flow rates (Q values) seen during the period of measurement. This has since been changed to include the maximum Q value seen during the 2008-2009 recession year as well as the maximum historic Q seen for flow through this cross-sectional area since it is more probable that this area is completely saturated with a high flow value, and a better value for the hydraulic conductivity will be achieved. This value is found by taking the stream gain between D' and D and subtracting out the flow that does not exit through the cross-sectional area

presented above. This includes Spring 1 and the small contribution of Brollard Spring. Flow values that seem questionable (either unusually high or low compared to surrounding values) were ignored in case if they contained large errors associated with the collection of the measurement. After calculating the total flow through the cross-sectional area, the highest Q value measured during this study is 1.62012 cfs from June 2, 2008 and the highest historical Q is 5.1943 cfs from June 22, 1995.

Using the hydraulic gradient from Spring 2 to the upper Cedar Spring as well as the highest 2008-2009 Q value and highest historical Q value, hydraulic conductivity values are 195.565 ft/day (or 0.0690 cm/s) and 627.008 ft/day (or 0.2213 cm/s), respectively. The hydraulic gradient for Spring 2 to the lower Cedar Spring yields conductivity values of 236.346 ft/day (or 0.08343 cm/s) and 757.754 ft/day (or 0.2675 cm/s) for the same flow rates.

When compared to a list of common hydraulic conductivity values from Freeze and Cherry, 1979, these four values range in the upper limit of silty sand, the mid limits of clean sand, and the lower limit of gravel. The area of the landslide being measured from the assigned cross-sectional area is the lower portion of the deposit, which may be more consolidated or cemented and would therefore have a lower value than a typical gravel. This slightly lower value, however, means that the deposit does not experience as much seepage as solely unconsolidated gravel would and so makes a more effective aquifer since it is able to hold onto its water better. The landslide deposit may therefore be one of the key contributors to Icehouse Canyon's comparatively low baseflow recession value.

Conclusions

This study has shown that the baseflow recession constant of an area can be reflective of the surrounding physical environment. The relationships between locations within Icehouse Canyon can be seen through the differences in their respective baseflow recession constants, such as the influence of spring discharge on the baseflow recession of Gauge D versus that of D'. In addition, the differences between drainage areas are also reflected in their baseflow recession constants, as illustrated in Strand's study of the San Dimas drainage basin and in the geographic and geologic differences between upper San Antonio and Icehouse Canyons.

Historical data for Icehouse Canyon shows that these baseflow recessions are fairly consistent as well, depending on slight seasonal variations such as precipitation. This relative constancy between values allows average recession values to be calculated and so the flow in an area can then be predicted for any time during recession based on the discharge at the start. This average baseflow recession value can be modified for a more accurate estimate based on the year's precipitation due to the inverse effect seen in Icehouse Canyon. For instance, since this year's precipitation has been below average, this year's baseflow recession values will likely be higher than average, and subsequently higher than last year's values.

The relatively high hydraulic conductivity values obtained for the Cedar Canyon landslide show that it is a good aquifer. It is able to retain its water to some degree but is still permeable enough to let it discharge from the ground. This discharge is responsible for sustaining flow in Icehouse Creek and maintaining the canyon's low baseflow recession.

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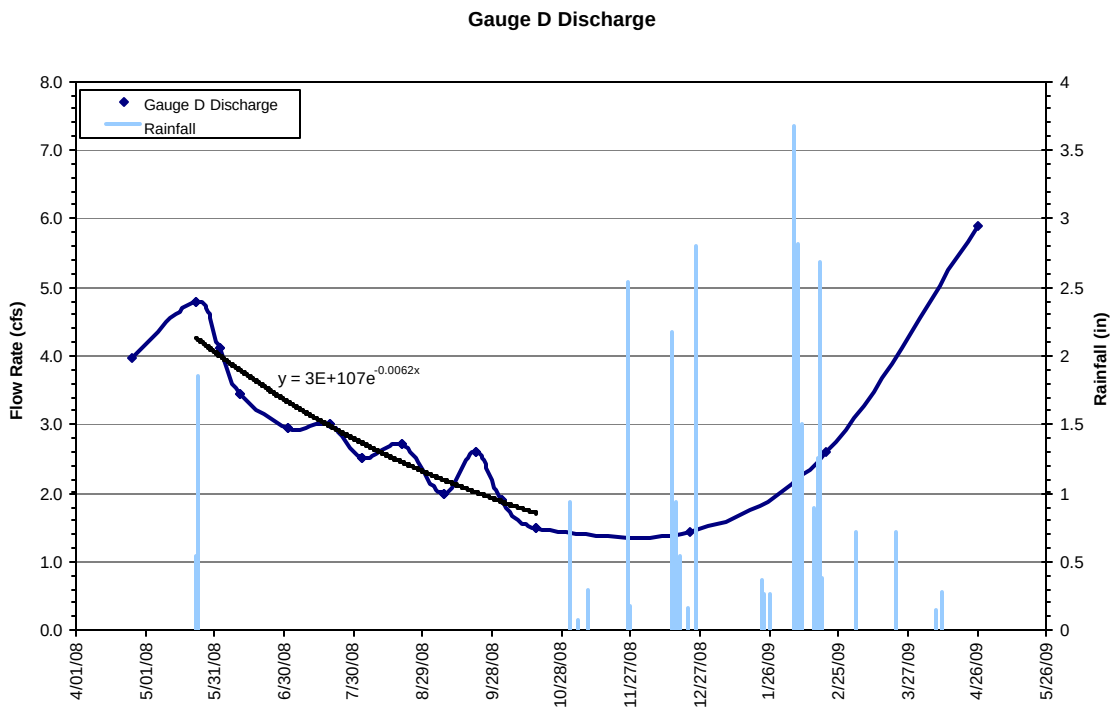
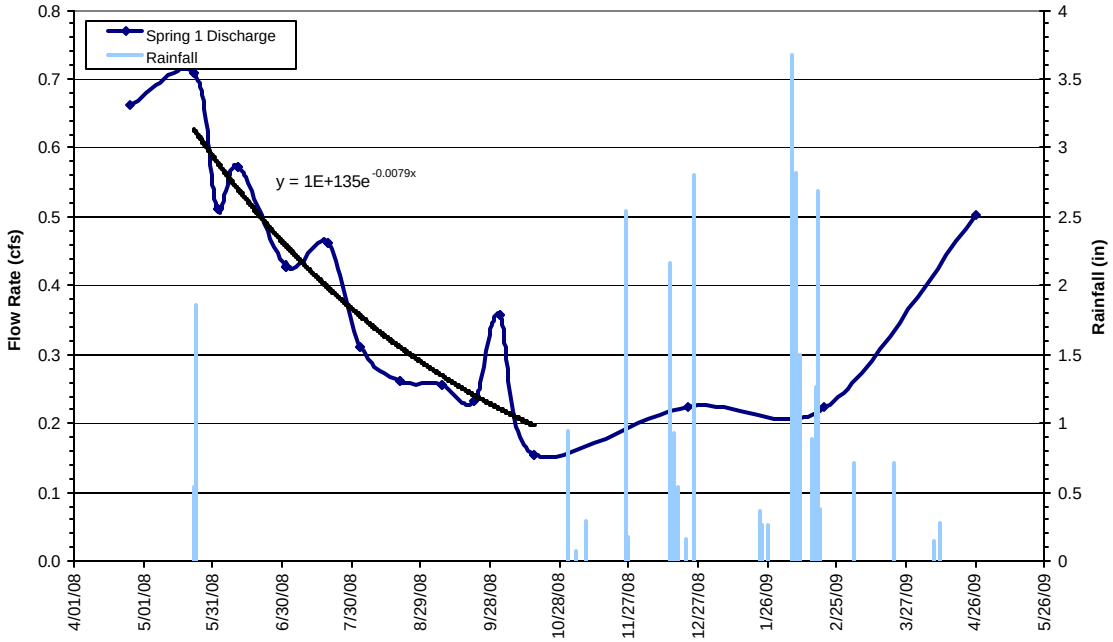
Appendices

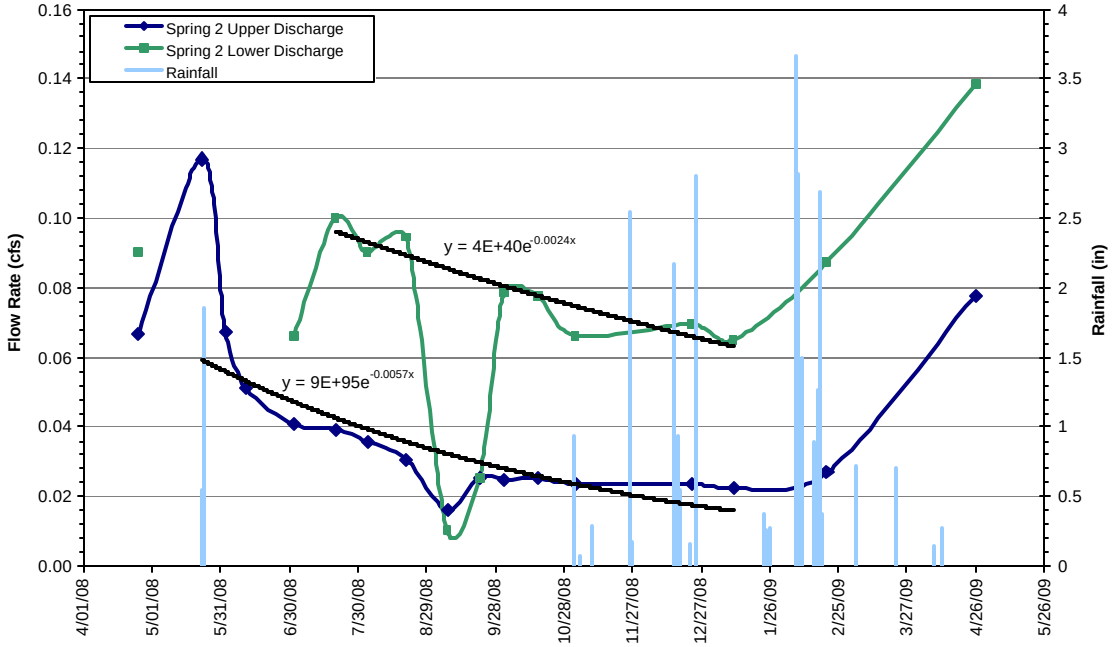
Appendix I: Icehouse Canyon Hydrographs (Flow Rate, Q vs. Time)

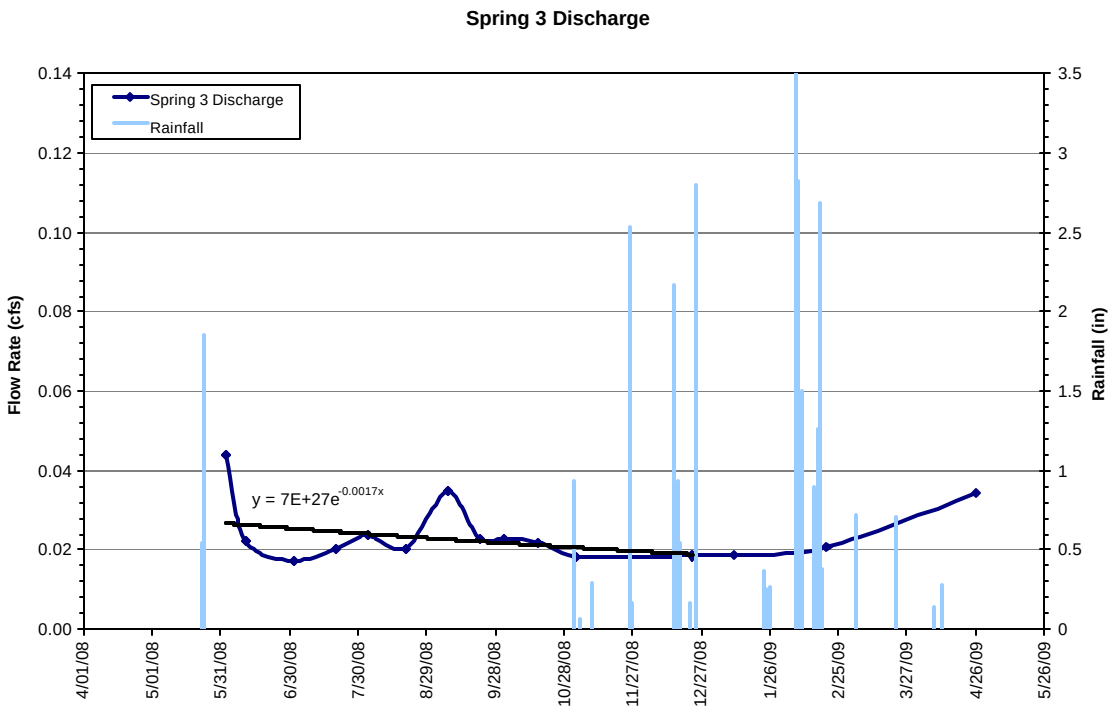


Spring 1 Discharge



Spring 2 Discharge




Spring 3 Discharge
Spring 3 Discharge
Rainfall
y = 7E+27e^-0.0017x
Flow Rate (cfs)
Rainfall (in)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
3.5
3
2.5
2
1.5
1
0.5
0
4/01/08
5/01/08
5/31/08
6/30/08
7/30/08
8/29/08
9/28/08
10/28/08
11/27/08
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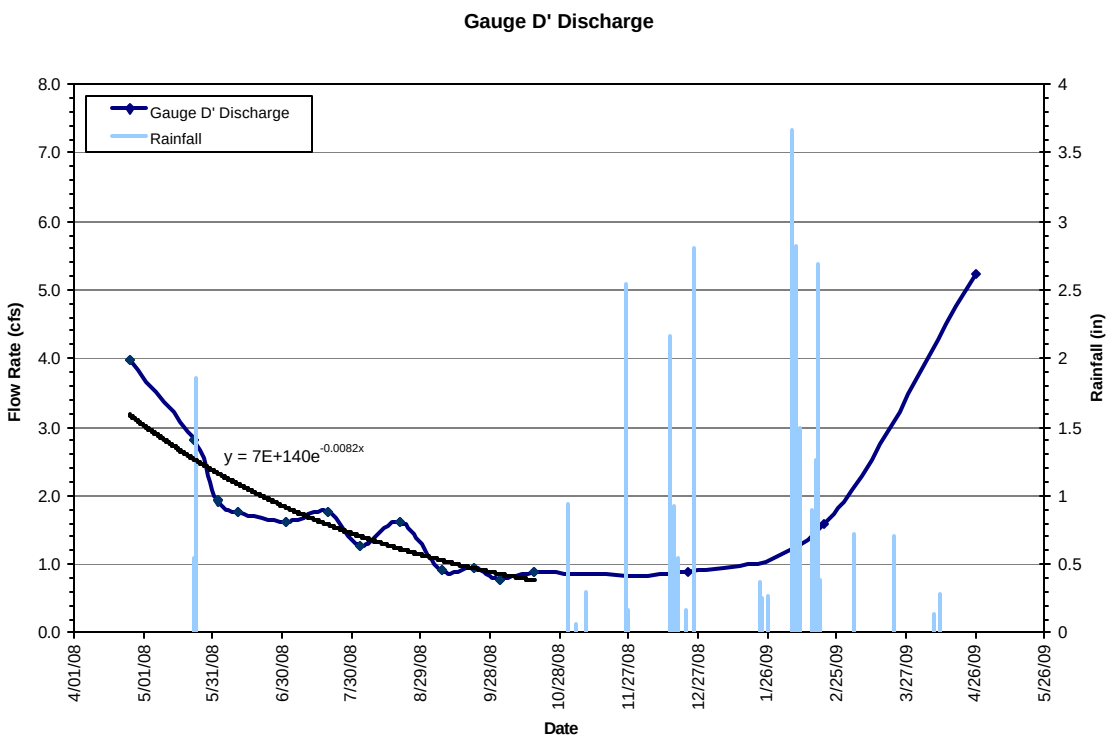
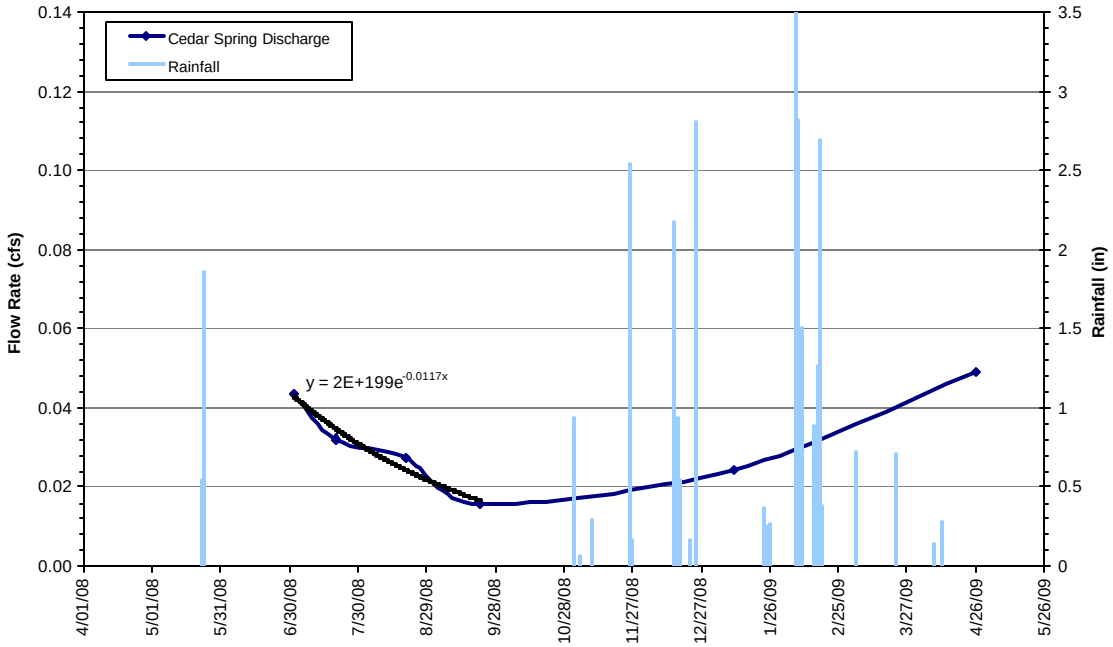
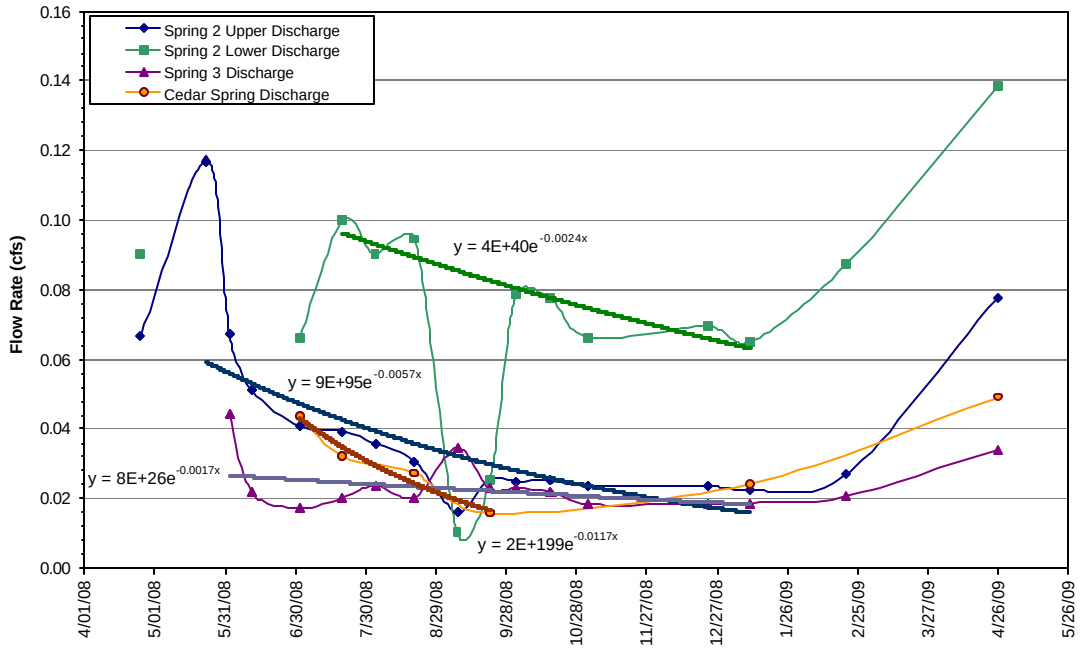
2/25/09
3/27/09
4/26/09
5/26/09


Gauge D' Discharge
Gauge D' Discharge
Rainfall
y = 7E+140e^-0.0082x
Flow Rate (cfs)
Rainfall (in)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4
3.5
3
2.5
2
1.5
1
0.5
0
4/01/08
5/01/08
5/31/08
6/30/08
7/30/08
8/29/08
9/28/08
10/28/08
11/27/08
12/27/08
1/26/09
2/25/09
3/27/09
4/26/09
5/26/09
Date

Cedar Spring Discharge



Spring 2, 3, and Cedar Spring Discharge



Appendix II: Historical Icehouse Canyon Data

Spring 1			
Date	Q (gpm)	Q (cfs)	ln Q
08/16/94	37.9	0.085	-2.469
01/05/95	31	0.069	-2.670
01/10/95	75	0.167	-1.787
02/07/95	150	0.335	-1.094
02/16/95	628	1.403	0.338
02/17/95	287.9	0.643	-0.442
06/22/95	406	0.907	-0.098
07/25/95	335	0.748	-0.290
08/21/95	197	0.440	-0.821
09/24/95	135	0.301	-1.199
12/21/95	56	0.125	-2.079
01/04/96	118	0.264	-1.334
02/06/96	123	0.275	-1.292
02/19/96	115	0.257	-1.359
02/20/96	259	0.578	-0.547
02/23/96	121.6	0.272	-1.304
03/03/96	145	0.324	-1.128
03/05/96	393	0.878	-0.130
03/08/96	270	0.603	-0.506
03/24/96	544	1.215	0.195
04/09/96	482	1.076	0.074
04/28/96	286	0.639	-0.448
05/12/96	151	0.337	-1.087
05/26/96	218	0.487	-0.720
06/09/96	201	0.449	-0.801
06/27/96	123	0.275	-1.292
07/13/96	91	0.203	-1.593
07/30/96	161	0.360	-1.023
08/26/96	145	0.324	-1.128
10/15/96	102	0.228	-1.479
02/04/97	839	1.874	0.628
02/11/97	521	1.164	0.151
02/18/97	516	1.152	0.142
03/04/97	332	0.741	-0.299
03/11/97	341	0.762	-0.272
01/10/98	135	0.301	-1.199
01/30/98	100	0.223	-1.499
08/28/98	319	0.712	-0.339
10/06/98	213	0.476	-0.743

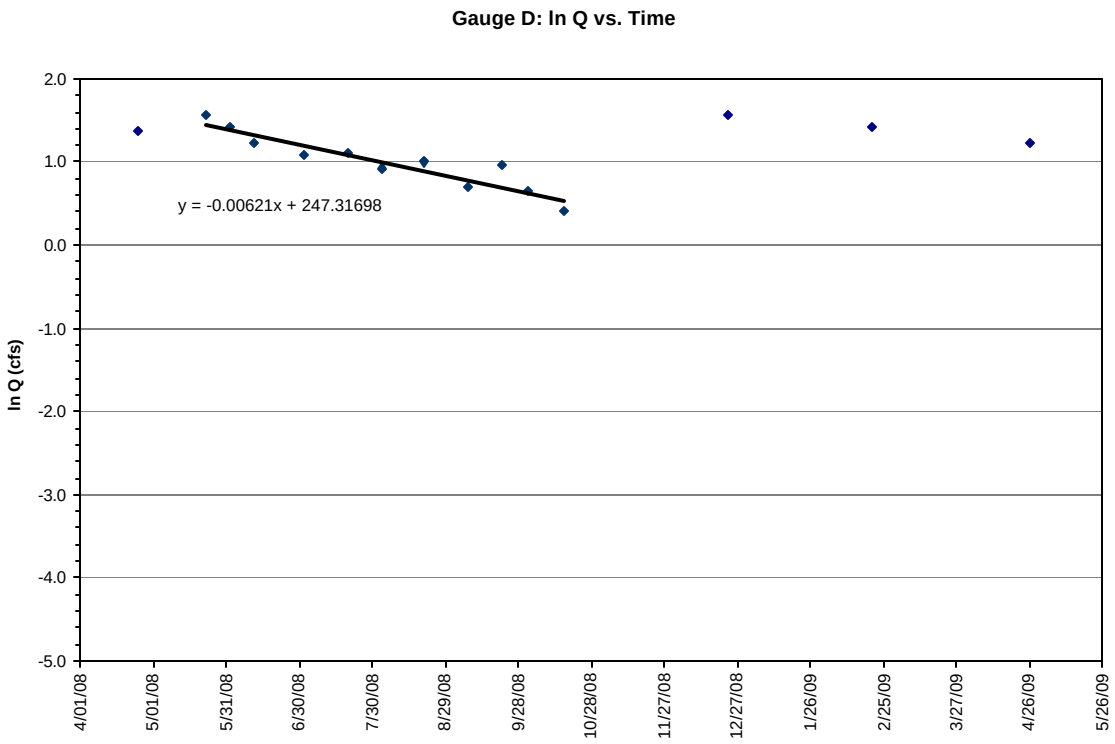
Spring 2			
Date	Q (gpm)	Q (cfs)	ln Q
1/13/1994	100	0.223	-1.499
12/21/94	30.2	0.067	-2.696
08/16/94	39.9	0.089	-2.418
12/21/94	60	0.134	-2.010
12/29/94	28	0.063	-2.772
1/5/1995	19.6	0.044	-3.129
01/10/95	43	0.096	-2.343
02/07/95	86	0.192	-1.650
02/16/95	360	0.804	-0.218
06/22/95	60	0.134	-2.010
07/25/95	50	0.112	-2.192
08/21/95	58	0.130	-2.044
12/21/95	27	0.060	-2.808
12/29/95	27.5	0.061	-2.790
01/04/96	29	0.065	-2.737
02/06/96	22	0.049	-3.013
02/19/96	20	0.045	-3.109
02/20/96	45	0.100	-2.298
02/23/96	50	0.112	-2.192
03/03/96	57	0.127	-2.061
03/05/96	115	0.257	-1.359
03/08/96	55	0.123	-2.097
03/24/96	65	0.145	-1.930
04/09/96	42	0.094	-2.367
05/26/96	35	0.078	-2.549
06/09/96	30	0.067	-2.703
06/27/96	46	0.103	-2.276
07/30/96	25	0.056	-2.885
10/15/96	27	0.060	-2.808
01/10/98	22	0.049	-3.013
01/30/98	100	0.223	-1.499

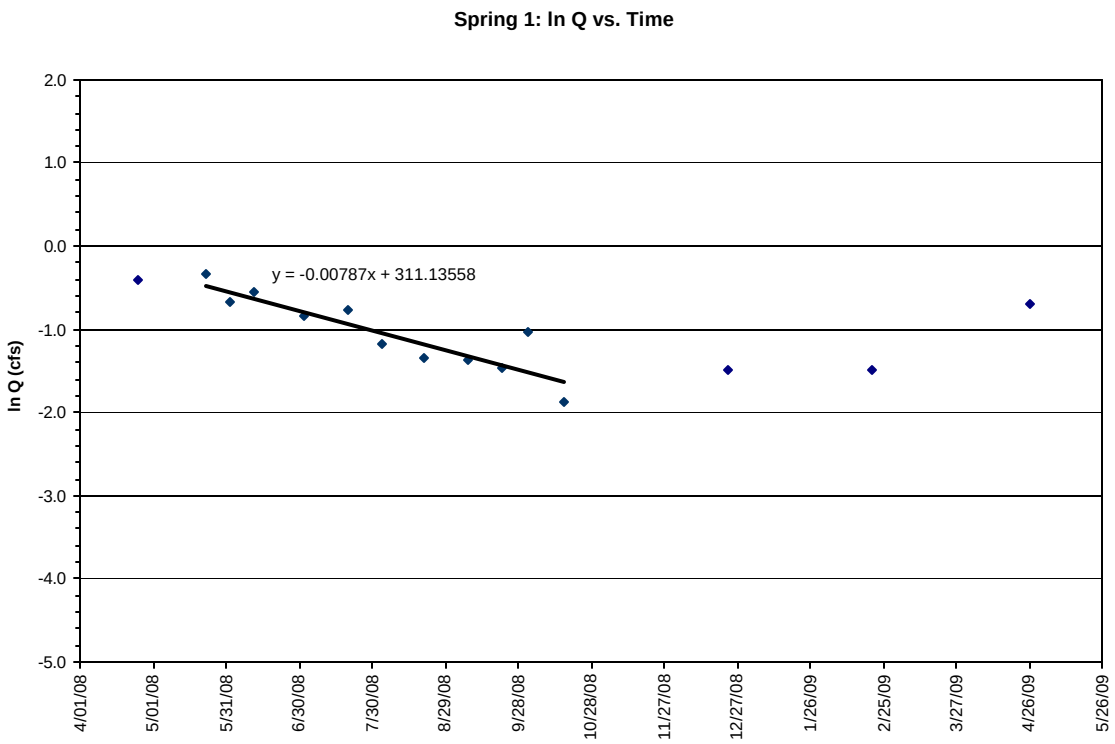
Spring 3			
Date	Q (gpm)	Q (cfs)	ln Q
06/22/95	19	0.042	-3.160
08/21/95	16	0.036	-3.332
04/09/96	10.6	0.024	-3.743

Gauge D			
Date	Q (gpm)	Q (cfs)	ln Q
02/13/93	28361.00	63.339	4.148
09/17/93	3904.54	8.720	2.166
10/28/93	5168.00	11.542	2.446
11/04/93	2834.37	6.330	1.845
01/13/94	2619.44	5.850	1.766
04/01/94	2641.83	5.900	1.775
08/16/94	895.54	2.000	0.693
09/25/94	805.98	1.800	0.588
12/21/94	501.50	1.120	0.113
01/05/95	729.86	1.630	0.489
06/22/95	5243.36	11.710	2.460
07/25/95	3358.26	7.500	2.015
08/21/95	2462.72	5.500	1.705
09/24/95	2252.27	5.030	1.615
10/26/95	2059.73	4.600	1.526
11/28/95	1773.16	3.960	1.376
01/04/96	1307.48	2.920	1.072
02/06/96	1423.90	3.180	1.157
02/23/96	14171.85	31.650	3.455
03/03/96	4643.35	10.370	2.339
03/04/96	4477.68	10.000	2.303
03/05/96	6940.40	15.500	2.741
03/08/96	5525.46	12.340	2.513
03/24/96	3689.61	8.240	2.109
04/09/96	3729.91	8.330	2.120
04/28/96	3223.93	7.200	1.974
05/26/96	2811.98	6.280	1.837
06/09/96	1997.04	4.460	1.495
07/13/96	1625.40	3.630	1.289
07/30/96	1334.35	2.980	1.092
08/27/96	1191.06	2.660	0.978
10/15/96	1088.08	2.430	0.888
01/10/98	1844.80	4.120	1.416
01/30/98	1450.77	3.240	1.176

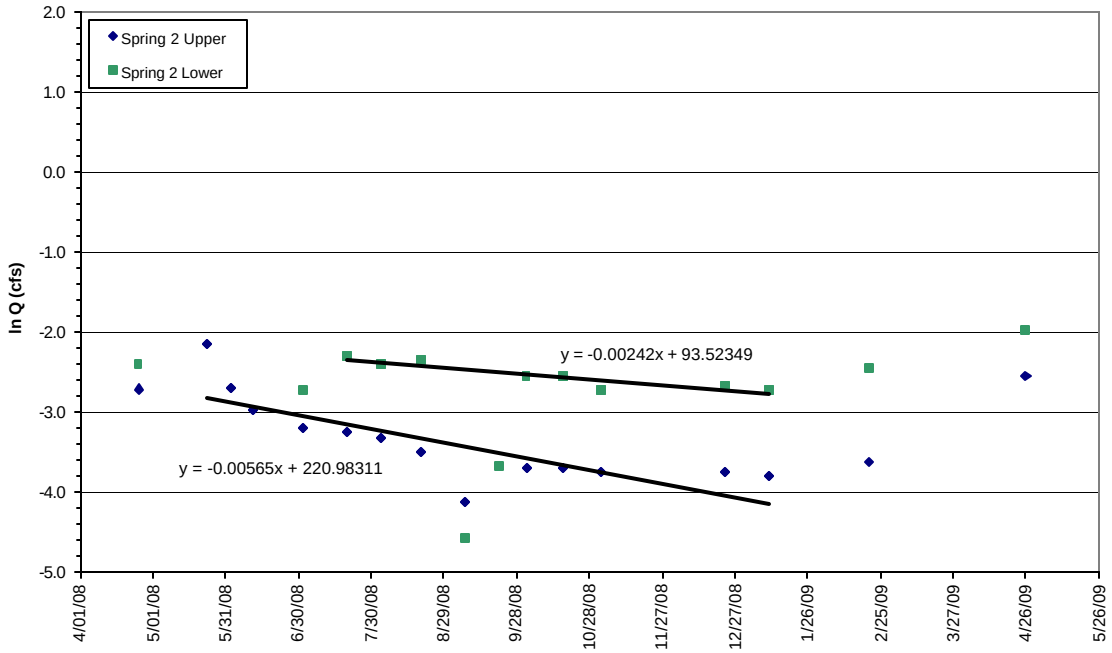
Gauge D'		
Date	Q (cfs)	ln Q
04/01/94	6.68	1.899
08/16/94	0.09	-2.408
12/21/94	0.94	-0.062
01/05/95	1.15	0.140
06/22/95	5.42	1.690
02/06/96	1.39	0.329
01/04/00	0.89	-0.117

Appendix III: Natural Log Plots of Icehouse Canyon Flow Rate (Baseflow Recession Graphs)

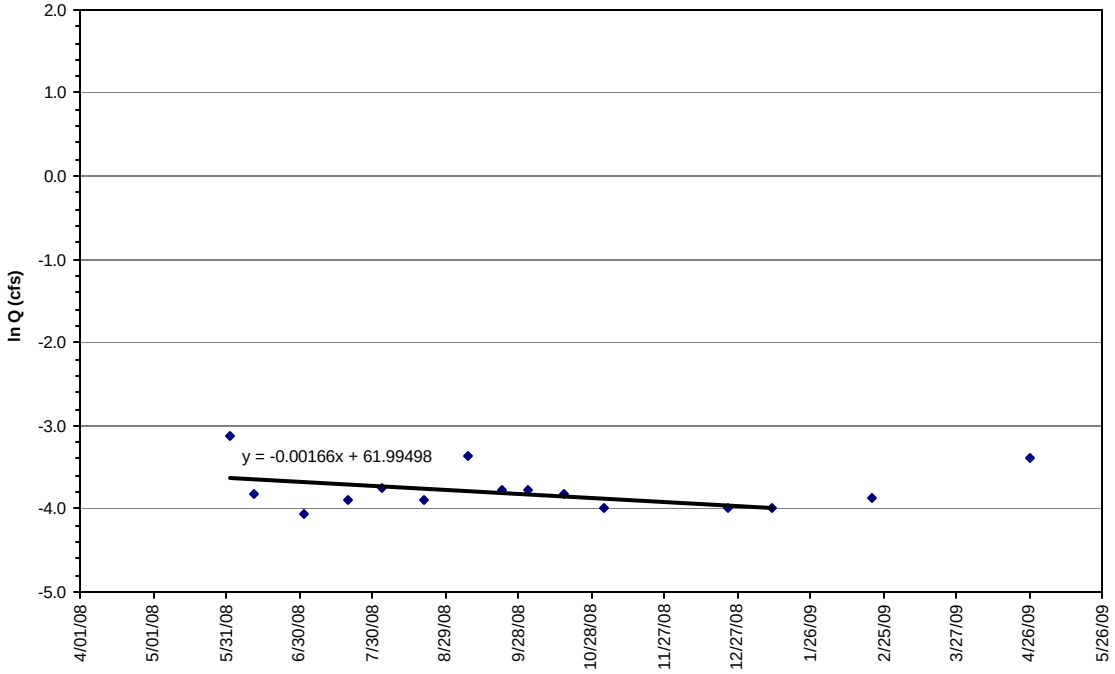


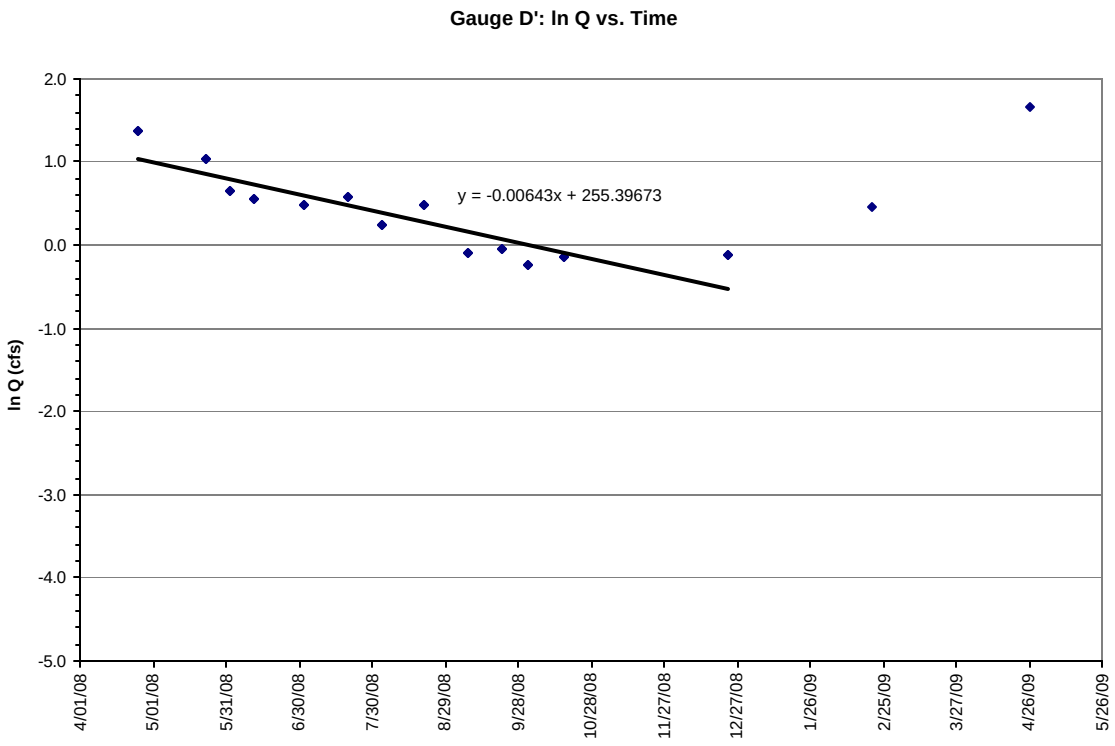


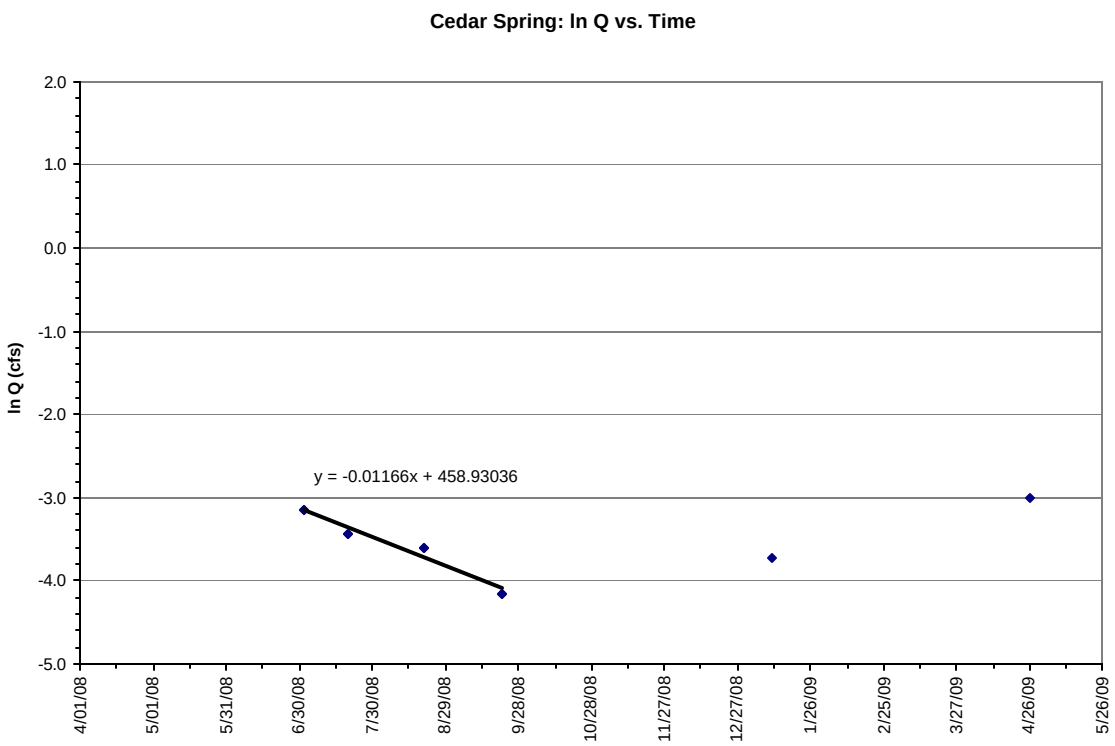
Spring 2: ln Q vs. Time



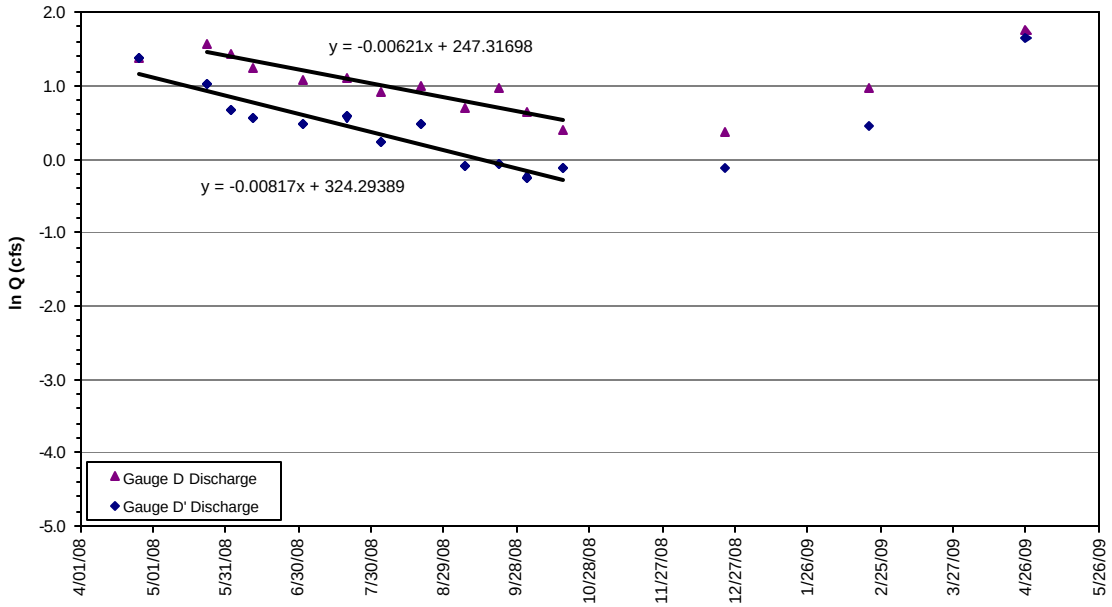
Spring 3: ln Q vs. Time



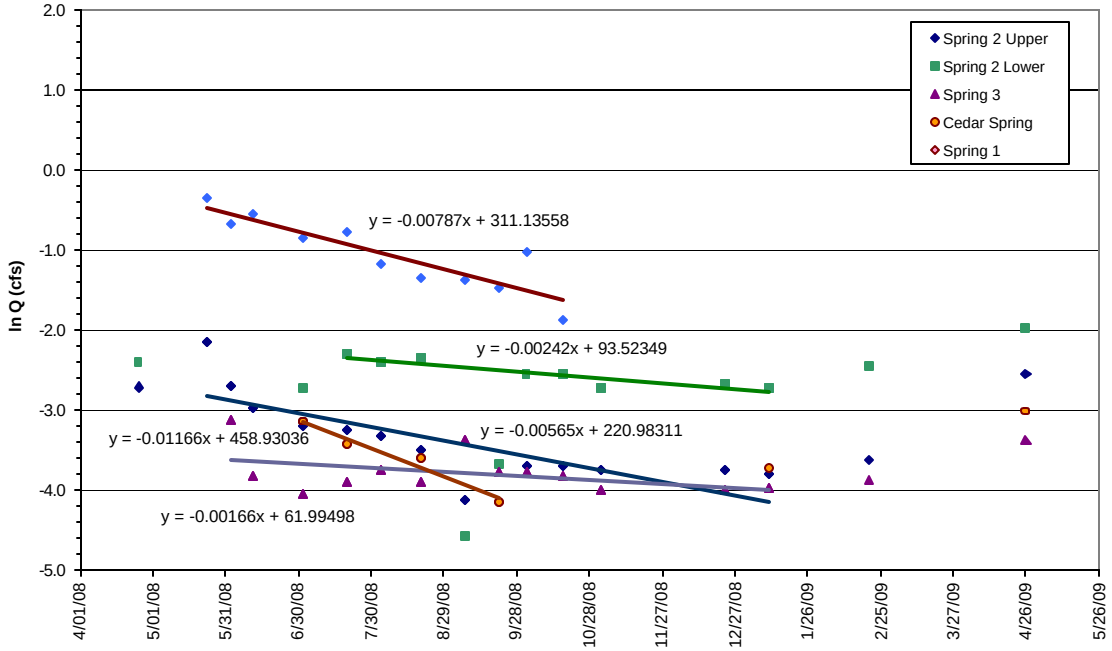

Gauge D': ln Q vs. Time
y = -0.00643x + 255.39673
ln Q (cfs)
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
4/01/08
5/01/08
5/31/08
6/30/08
7/30/08
8/29/08
9/28/08
10/28/08
11/27/08
12/27/08
1/26/09
2/25/09
3/27/09
4/26/09
5/26/09


Cedar Spring: ln Q vs. Time
y = -0.01166x + 458.93036
ln Q (cfs)
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
4/01/08
5/01/08
5/31/08
6/30/08
7/30/08
8/29/08
9/28/08
10/28/08
11/27/08
12/27/08
1/26/09
2/25/09
3/27/09
4/26/09
5/26/09

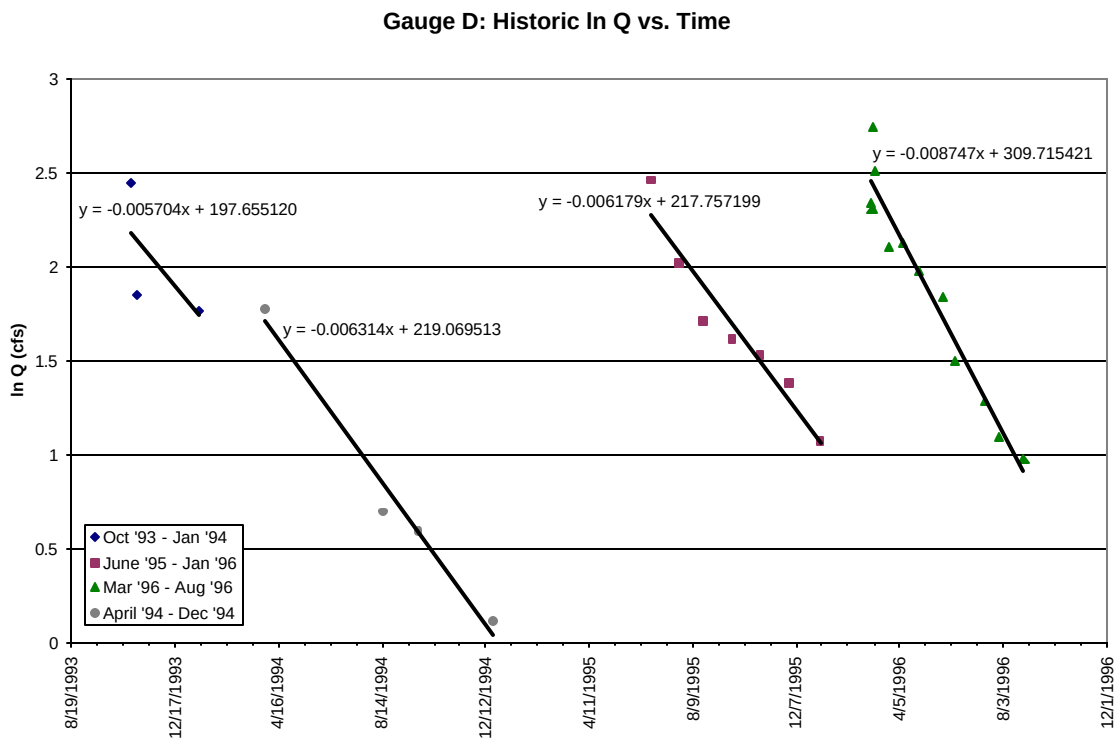
Gauge D: ln Q vs. Time

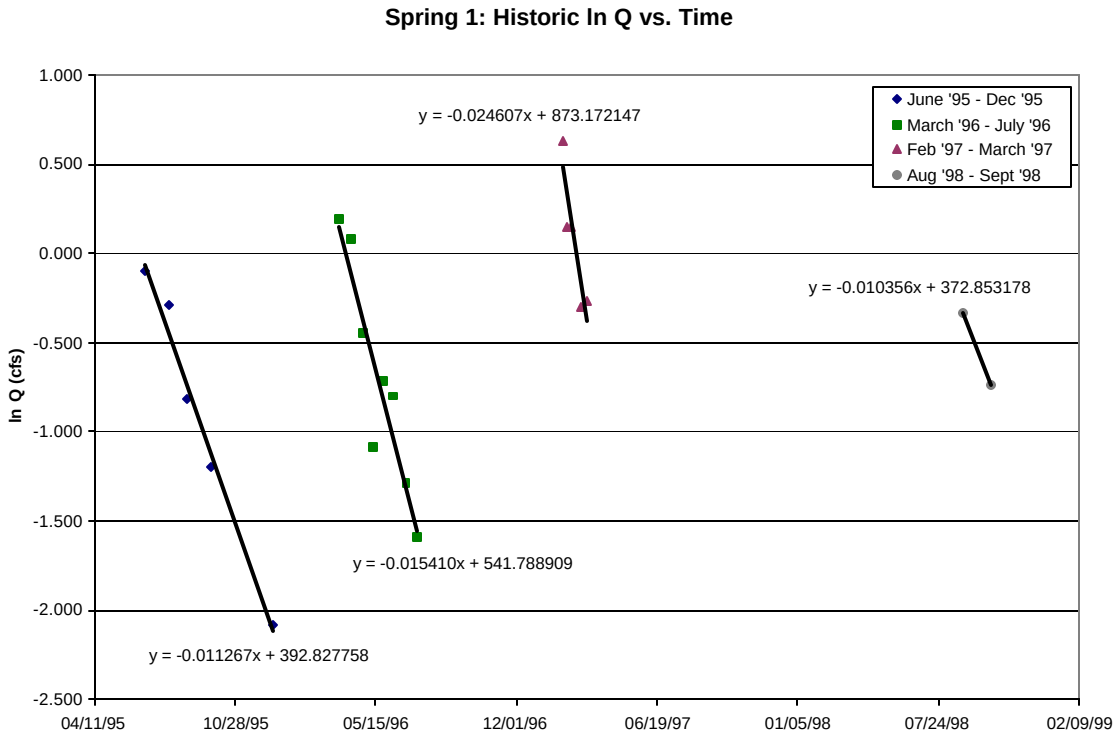


All Springs: ln Q vs. Time

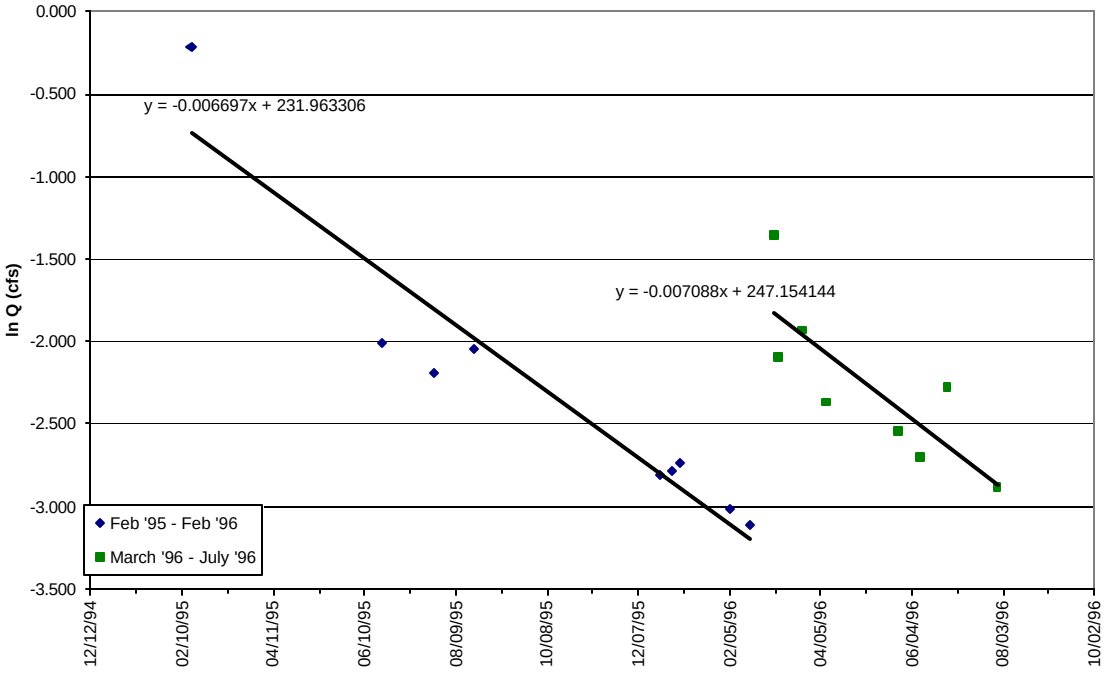


Appendix IV: Natural Log Plots of Historical Icehouse Canyon Flow Rate (Baseflow Recession Graphs)





Spring 2: Historic ln Q vs. Time



Spring 3: Historic ln Q vs. Time