Response of Streamflow and Spring Discharge from Precipitation Recharge Events in Icehouse Canyon Watershed, Eastern San Gabriel Mountains, California

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Icehouse Canyon watershed lies in the eastern San Gabriel Mountains of Southern California within a natural region of Angeles National Forest. Icehouse Creek is an important tributary of the San Antonio watershed that provides drinking water supplies to residents of Mount Baldy Village and the city of Upland. Surface flow in the creek during dry periods is controlled by discharge from landslide and alluvial deposits in addition to deep-seated fractures and fault zones in crystalline rock. We utilized a velocity flow probe, V-notch weirs, and pressure transducers to measure streamflow in Icehouse Creek and discharge from associated perennial springs at approximately bi-weekly intervals between July 2014 and December 2015. Pressure transducers were installed at selected gauging stations in order to obtain a continuous record of surface-flow over long periods of time. Coincident with the discharge study, we have monitored precipitation at 5 rain gauges located between 4,600 and 6,200 ft elevation beginning December 2014. Our general objective is to record the watershed’s response to precipitation recharge events.

Hydrographs comparing precipitation data with discharge over the observation period yielded interesting preliminary results that provide an important baseline for documenting hydrology during the end of an extended 4-year drought period. Precipitation totals for individual storm events varied from 0.1 to 1.9 inches, which appear to be low compared to typical storm events occurring in Icehouse Canyon. Hydrographs for selected gauging stations along Icehouse Creek reveal different responses to precipitation recharge events. The stations located in areas with bedrock exposure appear to be more responsive. Comparison of two springs discharging from Cedar landslide along Icehouse Trail suggest that Spring #1 is more responsive to rain events while Spring #2 discharge remains relatively constant during minor storm events. It’s possible that Spring #1 is dominated by near-surface drainage from landslide material while Spring #2 may be fed by deeper bedrock fractures. Measurements of precipitation will continue during the rainy season to record heavy storm events from the El Nino phenomenon. Significant recharge events following 4 years of extended drought conditions are expected, which should provide an interesting contrasting data set.
PROJECT OBJECTIVES

Career Pathway

Presently, I’m a graduate student in the Geological Sciences Department at California State Polytechnic University in Pomona working towards completing a Master’s thesis project involving water resources planning and watershed management. I decided to pursue a graduate degree in the field of Geology to focus my research studies specifically on groundwater resources, which play a critical role in modern society. After completing the Master’s program in Geology, I plan to continue my education by pursuing a Ph.D. program in Hydrology and Water Resources in order to further develop my research skills and enhance my understanding of water related issues affecting regions such as Southern California. Furthermore, my long-term career goals include working as a professional Hydrologist for federal government organizations such as the U.S. Forest Service, U.S. Environmental Protection Agency, and U.S. Geological Survey. My overall career goal is to assist these organizations and other water agencies by contributing to the ongoing effort of improving the nation’s water supply and water quality issues. The knowledge and skills acquired through this research project has helped me become better prepared for these specific career paths.

Background and History

The study area is located within the eastern San Gabriel Mountains of Southern California in a natural region of the Angeles National Forest known as Icehouse Canyon. This place is situated north-east of Mt. Baldy Village, a small community where many visitors stop to dine and rest after exploring the great outdoors. Upon arriving at the parking lot near the canyon, a detailed map created by the U.S. Forest Service is located at the entrance of the main trail. The map of the region shows Icehouse Canyon Trail running parallel to Icehouse Creek, which spans a total distance of approximately 4.4 miles, beginning in Icehouse Trailhead near the parking lot and ending at Icehouse Saddle (Robinson, 1977). Figure 1 displays a satellite image from Google earth showing the general location of the study area. The rectangle outlined in red zooms into the study area to give a closer view of Icehouse Canyon. Figure 2 presents a Google earth satellite image illustrating the delineation of Icehouse Canyon watershed outlined in blue. The watershed area and perimeter were estimated using the measuring tool in Google earth Pro (2015), which yielded 45,714 ft for the perimeter and 126,608, 188 ft² for the watershed area. The main trail in Icehouse Canyon passes through steep and rugged terrain, which gradually increases in elevation from 4,920 ft to approximately 7,580 ft at its peak. Moreover, this forest region of the Cucamonga Wilderness is home to wildlife such as deer, black bear, mountain lions, big horn sheep, and coyotes.

In addition, the study area is filled with remains from pre-existing buildings that provide clues about the history of Icehouse Canyon. For instance, in 1921 a building known as the Icehouse Canyon Resort was built by a land owner named Roy Chapman (Robinson, 1977). This particular building was once located near the entrance of Icehouse Canyon Trail, however, today only two stone pillars that supported a large wooden sign still remain standing. The interior space of this building was frequently used for filming movies and TV shows for nearly fifty years (Robinson, 1977). It is also believed that around 1858, people from the city of Los Angeles were
supplied with ice cream made from blocks of ice cut from the mountains of San Antonio, which may explain the origin of the name “Icehouse Canyon”.

Figure 1. Satellite image from Google earth displaying the general location of the study area.

Figure 2. Google earth satellite image illustrating the delineation of Icehouse Canyon watershed in blue.
Project Description

The objective of this research project is to study the response of Icehouse Canyon watershed to recharge events by monitoring streamflow, spring discharge, and precipitation. The observation period occurred during an important transition phase from severe drought conditions to the El Nino season. Icehouse Creek is an important tributary of the San Antonio watershed that supplies drinking water sources to residents of Mt. Baldy Village and the city of Upland. Water quantity data and related baseflow recession curves produced by this research study, combined with analysis of historical records, will provide ground truth information to guide water resources planning; e.g., response of the watershed to precipitation recharge events and prediction of surface flow for future time periods. With the assistance of Cal Poly Pomona undergraduate students, a portable velocity probe was utilized to gauge several localities along Icehouse Creek at approximately biweekly intervals. Pressure transducers were installed at selected spring locations that feed the creek year-round in order to gather real-time continuous flow readings during storm events and to measure diurnal variations of spring discharge. Initially, I also planned to map the local talus and landslide deposits in relation to bedrock distribution to document groundwater sources and hydrogeologic mechanisms of many perennial springs in the canyon. This particular task is currently a working progress. Additionally, five all-weather rain gauges were installed at different elevations within the catchment area to measure precipitation levels from various storm events during the rainy season. Preliminary fieldwork in this study area was initiated late June 2014 for my Master’s thesis research project. Specific gauging sites were selected based on locations from previous work to compare and contrast the new results with historical records. Furthermore, the source of freshwater not only supplies drinking water for the public but also supports local plants and wildlife, which are essential to the long-term sustainability of the watershed itself.
Previous Work

Hydrogeologic Setting

In previous studies, the hydrogeologic characteristics of the study area were investigated. Figure 4 presents a hydrogeologic map of the study area developed in ArcGIS by Dr. Jonathan A. Nourse, professor of Geological Sciences at Cal Poly Pomona, from several years of detailed fieldwork observations. The hydrogeologic map shows various surface geological units including the following: Holocene alluvium (Qa), well-consolidated Quaternary landslide (Qls), poorly consolidated Holocene talus deposit (Qt), and nonporous crystalline bedrock (b). These geological units especially the Quaternary deposits have a major influence on the surface flow regulation of Icehouse Creek and tributaries associated with it. They also provide valuable information about aquifer properties such as porosity and permeability of the material composing these shallow groundwater systems. The Qls and Qt units in particular behave like sponges by absorbing rainfall and snowmelt during winter and spring months, then gradually releasing the stored groundwater to drainages such as Icehouse Creek during the summer and fall dry seasons (Nourse et al., 2010).

The hydrogeologic map also displays specific locations of gauging stations along Icehouse Creek with asterisk symbols and the locations of perennial springs using solid red circles. It appears that many of the perennial springs discharge near contact points between nonporous bedrock units and highly porous surface deposits. These springs (Spring #1, Spring #2, and Spring #3) correspond to locations where bedrock units act as barriers, which tend to force groundwater within the sediments to rise up to the surface (Nourse et al., 2010). In this research study, I have monitored the discharge from multiple springs including Spring #1, Spring #2, and East Cabin Spring. Furthermore, observations from previous studies indicate that the steep south facing wall of Icehouse Canyon prevents direct sunlight from reaching lower areas of the Canyon during the months of December and January, which tends to preserve ice and snow for longer periods of time due to low temperature conditions. One reason for continuous flow in Icehouse Creek is the persistence of snow on the south facing slope of the canyon that gradually melts during the months of April through July, which then feeds the springs during the dry season period (Nourse et al., 2010).
Surface Flow Records

Previous work performed in Icehouse Canyon also involved the study of surface flow variations throughout Icehouse Creek and the monitoring of discharge from perennial springs. During the first upstream mile of Icehouse Creek, there are significant variations in surface flow occurring from one specific location to another along the main channel. Professor Dr. Jonathan A. Nourse lived in one of the cabins in Icehouse Canyon from 1990 to 1992, and during that time he observed consistent high-flow to low-flow segments along specific locations in the creek. As an effort to explain this behavior, Dr. Nourse decided to develop a detailed hydrogeologic map of the study area. After completing the study, he recognized that surface flow variations observed along the creek are generally governed by geologic factors such as porosity and permeability of the surface material which have a major influence on surface flow behavior (Nourse et al., 2010). To further investigate the relationship between surface flow variation and surface geology, Dr. Nourse utilized Icehouse Canyon as a study site for his Groundwater Geology laboratory course at Cal Poly Pomona. From 1993 to 2010, Dr. Nourse and many generations of Geology students performed hundreds of streamflow measurements throughout Icehouse Creek and various tributary springs (Nourse et al., 2010). The flow measurements performed on specific dates were taken at different gauging stations (Gauges H-G) along the main channel of Icehouse Creek. In addition, Spring #1 and Spring #2 were frequently monitored along with other local springs that were measured occasionally.
Figure 5 presents a graph of stream discharge against stream gauge location in Icehouse Creek showing upstream to downstream surface flow variations during dry periods between 1993 and 2010. The various curves with high peaks correspond to gaining segments where discharge increases in a downstream direction, which may be attributed to areas where a significant number of perennial springs are contributing groundwater to the creek. In contrast, the lowest points on the curves correspond to losing segments where discharge decreases in a downstream direction, which may be the result of infiltration due to water flowing over thick layers of alluvium material. Although the maximum and minimum values for each curve vary from one year to another, the graph generally exhibits similar curve patterns that are reproducible over different dry periods (Nourse et al., 2010).

![Graph showing upstream to downstream surface flow variations in Icehouse Creek during various dry periods](image)

**Figure 5.** Graph showing upstream to downstream surface flow variations in Icehouse Creek during various dry periods (Nourse et al., 2010).

**Baseflow Recession Records**

The surface flow measurements for Icehouse Creek and tributary springs collected from 1993 to 2010 were utilized to develop baseflow recession curves. By definition baseflow is considered as the background low-flow conditions in a stream or other body of surface water; it also represents the portion of streamflow derived from deep and shallow groundwater inputs (Hornberger et al., 1998). Baseflow conditions in a stream typically occur after recharge events such as rainfall or snowmelt stop contributing water to the stream system. During dry periods when storm events rarely occur, the baseflow recession curve often takes the shape of a negative exponential function. According to baseflow recession records from previous studies, several
perennial springs in Icehouse Canyon exhibit this behavior. The specific form of the equation for the baseflow recession curve is:

\[ Q = Q_0 e^{-ct}, \]  

(Equation 1)

where \( Q \) represents the discharge value at time \( t \) after recession begins, \( Q_0 \) is the discharge at the beginning of the recession period, \( t \) is the time measured from the beginning of the recession period, and \( c \) is the recession constant. The recession constant in particular measures the rate at which groundwater drains out of a basin after recharge events no longer occur (Carey, 2009). These recession constant values can be determined from long term flow records by plotting discharge data against time. The exponential equation resulting from this graph can be reduced to the simple equation of a straight line by taking the natural logarithm of both sides. This reduction then yields the equation below, which takes the form of a linear function.

\[ \ln Q = \ln Q_0 - ct \]  

(Equation 2)

Furthermore, after plotting flow data on a graph of \( \ln Q \) vs. time, a best fit line through the data points can be obtained for a particular recession period. The slope of this trend line represents the negative value of the baseflow recession constant (Carey, 2009). Moreover, obtaining baseflow recession constants for various gauging stations is important primarily because they can be utilized to estimate discharge values throughout a dry period, which is beneficial for water resources planning and watershed management.

PROJECT APPROACH

Bucket Catch Method

In this research study, various methods were utilized to determine streamflow in Icehouse Creek and discharge values for perennial springs located within the canyon. These field methods include the following: 1) bucket catch method, 2) velocity-area method, 3) triangular v-notch weir method, and 4) the application of pressure transducers. The bucket catch method in particular was applied to areas of low to moderate flow conditions such as Spring #2 and East Cabin Spring gauging stations where the majority of surface flow could be captured with a container of appropriate size and shape. Three pitchers of different sizes (32 oz, 64 oz, 1 gal) made from clear plastic material were used to capture spring water. Moreover, the bucket catch method involved a simple procedure of measuring the amount of time (using a stopwatch) required to fill a container of known volume. Five consecutive measurements were recorded in a field notebook, and the average value was used to determine spring discharge. The discharge value was initially calculated in units of cubic feet per second using the equation below then converted to units of gallons per minute.

\[ Q = \frac{\text{Volume}}{\text{Time}} \]  

(Equation 3)
Velocity-Area Method

The velocity-area method was applied primarily along the main channel of Icehouse Creek for low to moderate flow conditions. The procedure for this particular method involved a detailed survey of the cross-sectional area of the main stream channel and measuring average stream velocity using a portable flow probe. For each gauging station located along the stream (A, B, C, Broullard, and D’) the width and depth were measured in centimeters using stainless steel rulers of different lengths. To account for a non-uniform stream bed, the depth was measured at multiple points across the main channel and an average value was computed. After determining the dimensions of the cross-sectional area, the average stream velocity was measured by moving a flow probe slowly and smoothly throughout the cross-sectional area of the stream channel until an average velocity reading stabilized in the display screen of the instrument. Additionally, the portable flow probe used is manufactured by Global Water, Inc. and is capable of measuring the average stream velocity to an accuracy of +/- 0.1 feet per second (Global Water, 2009). Streamflow values using this particular method can be determine from the equation below:

\[ Q = (\text{Average Velocity} \times \text{Cross-Sectional Area}) \]  

(Equation 4)

Thin Plate 90° V-notch Weirs

The third method implemented in this research study to determine discharge values involves the use of thin plate 90° V-notch weirs. These V-notch weirs were constructed from sheets of clear acrylic plastic material with different dimensions depending on the width and depth of the stream channel where gauging stations were selected. The central angle of the V-notch opening is equal to 90° and the weir plate itself was balanced vertically and horizontally during installation using a level. Two weirs were installed at gauging stations Spring #1 and East Cabin Spring to obtain flow measurements efficiently and accurately. Figure 6 shows a photograph of a V-notch weir installed at the Spring #1 gauging station. The proper field procedure for this method involves the measurement of water depth from the vertex point on the V-notch to the surface water level; this measurement is typically made at a location slightly upstream from the weir plate to avoid any influence from the withdrawal caused by the opening. The water depth value is commonly represented by the variable “h,” which is also referred to as the static head of the weir. Furthermore, once the water depth value is measured, then spring discharge was determined using the following empirical equation:

\[ Q = 2.47h^{2.5} \]  

(Equation 5)

where \( Q \) = discharge in cubic feet per second, and \( h \) = static head above the vertex of the notch in units of feet (Fetter, 1994). The overall goal from implementing this particular field method is to obtain more accurate values of discharge in order to improve the level of confidence in the hydrologic data.
Pressure Transducers

In this research project, one AquiStar PT2X Smart Sensor manufactured by Instrumentation Northwest Inc. was installed at the East Cabin Spring gauging station to monitor water temperature and pressure in real-time. These pressure transducers are integrated dataloggers with built-in pressure and temperature sensors. They are capable of measuring fluid pressure in pounds per square inch, temperature in degrees Celsius, and actual time. The data collected in the field utilizing this sensor can be viewed and exported into an Excel workbook using the provided control software from the manufacturer (Aqua4Plus). Figure 7 is a diagram illustrating how the pressure sensor communicates with a laptop computer to view and download the collected data. Currently, the pressure sensor is programmed to make one recording every hour for several consecutive weeks. The goal is to use the pressure data acquired with this sensor in combination with discharge data from the V-notch weir to monitor spring discharge continuously in real-time. Figure 8 is a photograph showing the current experimental setup at the East Cabin Spring gauging station.
Figure 7. Diagram illustrating how the PT2X Smart Sensor communicates with a laptop computer (Instrumentation Northwest Inc.)

Figure 8. Photograph of a pressure transducer placed inside a graduated measuring tube at the East Cabin Spring gauging station.
Stage-Discharge Relationship

The U.S. Geological Survey is able to obtain a continuous record of discharge in real-time for various gauging stations by applying the stage-discharge relation method. This method involves the following steps: obtaining a continuous record of stage (water depth) for a specific gauging station, measuring discharge periodically at this gauging station, establishing and maintaining a relationship between stage and discharge, and applying this relationship to the stage record (USGS Water Science School). For the East Cabin Spring location, water level pressure data recorded with the pressure transducer was converted into water depth values using the hydrostatic equation. Also, the discharge at this gauging station was measured periodically using the V-notch weir. From this information, it was possible to develop a graph of stage versus discharge, which is also known as a rating curve. Rating curves show the relationship between stage and discharge in graphical form and are useful for determining discharge values for any corresponding stage measurement. This allows a continuous record of discharge to be obtained through the application of a rating curve. Furthermore, obtaining a continuous record of spring discharge can be useful for studying seasonal and diurnal variations, which is beneficial for water resources management.

Measuring Precipitation

Storm events occurring within Icehouse Canyon watershed were documented by measuring and recording the amount of precipitation produced from each storm event using rain gauges. Five all-weather rain gauges were purchased from Forestry Suppliers and installed between 4,600 and 6,200 ft in elevation within the watershed area. The specific locations for these rain gauges were carefully selected in open areas to prevent tree branches or large bushes from interfering with the capture of precipitation during storm events. Figure 9 is a photograph of one of the rain gauges installed near the cabin 5 location. The rain gauge consists of a funnel for capturing rainfall, an inner tube for measuring inches of water, and an outer tube for overflow. By obtaining long-term precipitation records, the orographic effect (i.e. the variation in precipitation with increasing elevation) in Icehouse Canyon may be determined. Additionally, the orographic trend can then be extrapolated linearly to higher elevations in order to estimate average annual precipitation for Icehouse Canyon watershed (Nourse et al., 2010). The average annual precipitation of the study area is important for developing water budget analysis and water resources management.
PROJECT OUTCOMES

Icehouse Creek Hydrographs

Streamflow for selected gauging stations (A, B, C, Broullard, and D’) along Icehouse Creek was measured at approximately biweekly intervals using the velocity-area method. The measured streamflow values for these gauging stations were plotted against time to examine the response following precipitation recharge events. Figure 10 shows multiple hydrographs plotted in various colors for selected gauging stations along Icehouse Creek. Collectively, these hydrographs appear to follow a similar decreasing pattern in streamflow beginning at a specific time period. For example, the peak streamflow value for most of the hydrographs except gauging station B (dark blue line) occurred around January 10, 2015. From this specific point, all the hydrographs begin to decline gradually over time indicating a decrease in streamflow. This particular period of declining streamflow is referred to as the baseflow recession period, which will be discussed in more detail in the following sections. Additionally, the highest streamflow values were observed at gauging station C represented by the light blue line. At this gauging station there is significant bedrock exposure, which may be acting as a barrier to groundwater flow thereby allowing it to rise to the surface at this specific location. Previous studies have also reported high streamflow values at this gauging station along Icehouse Creek. The lowest streamflow values were recorded at gauging stations A and B (light and dark green lines). At these particular locations there may be thicker layers of alluvium material, which is allowing water to infiltrate beneath the surface resulting in loss of streamflow. This explanation can be tested by performing
a geophysical investigation in order to determine the thickness of the alluvium layer. Geophysical methods such as seismic refraction and electrical resistivity are capable of detecting bedrock at depth. The surface and subsurface geology of the study area appear to be governing surface flow behavior along Icehouse Creek. However, further research is necessary in order to gain more information about the subsurface geology at different gauging stations, which may have a significant influence on the surface flow behavior observed in the creek.

Figure 10. Stream hydrographs for selected gauging stations along the main channel of Icehouse Creek.

The precipitation data collected from one particular rain gauge (Cabin 5 RG) was used to develop hyetographs, which display the amount of rainfall for each storm event over time. This specific rain gauge was selected because it provided a larger data set to work with. The hyetographs were plotted in conjunction with stream hydrographs in order to examine the streamflow response from precipitation recharge events occurring within Icehouse Canyon watershed. Figure 11 shows hyetographs and stream hydrographs for various gauging stations along Icehouse Creek. The black bars on the x-axis represent storm events and the open circles displayed in different colors depict individual discharge values. Additionally, the open circles boxed in red indicate points where discharge values increased significantly due to precipitation recharge events. After carefully analyzing these graphs, it appears that the gauging stations along Icehouse Creek respond differently to precipitation recharge events. Some gauging stations appear to be more responsive than others. For example, gauging station A (Graph A) only responded to two storm events that occurred on January 10 and July 19 of 2015. This particular gauging station did not show any response to other storm events that occurred within the observation period. In contrast, gauging station C (Graph C) responded to four storm events during the same observation period. This would suggest that gauging station C is more sensitive to precipitation recharge events in comparison to station A, and therefore it is more responsive. The response behavior for each gauging station may be explained by examining the surface geology of the study area. For instance, gauging station A is located in an area where alluvium
material is abundant and no bedrock exposure is present. A thicker layer of alluvium material at that location allows surface runoff to infiltrate beneath the surface, and therefore, no response is observed. The highly porous and permeable alluvium material essentially allows surface runoff to flow beneath the surface as shallow groundwater. At gauging station C, there is significant bedrock exposure at the surface and probably a thinner layer of alluvium material present. The bedrock exposure allows surface runoff from storm events to flow near the surface oppose to beneath the surface, which may explain the higher sensitivity to recharge. Bedrock exposure is also present at other gauging stations including Brouillard and D’, and their hydrographs (Graph D and E) show a similar response in comparison to station C. The response of streamflow from precipitation recharge events appears to be influenced by surface and subsurface geology along Icehouse Creek. Locations with significant bedrock exposure are more responsive to storm events, and locations with the presence of abundant alluvium material appear to be less responsive.
The streamflow data for each gauging station along Icehouse Creek was plotted separately to develop individual hydrographs. These hydrographs presented in Figure 12 were carefully analyzed in order to determine the baseflow recession period for each gauging station, which is represented by a red line with arrows at both ends. Baseflow recession periods typically occur.

**Figure 11.** Hyetographs and stream hydrographs for selected gauging stations along Icehouse Creek. Each graph is labeled with a capital letter to distinguish between the different stations.

**Baseflow Recession Hydrographs**

The streamflow data for each gauging station along Icehouse Creek was plotted separately to develop individual hydrographs. These hydrographs presented in Figure 12 were carefully analyzed in order to determine the baseflow recession period for each gauging station, which is represented by a red line with arrows at both ends. Baseflow recession periods typically occur.
after rainy seasons when precipitation recharge no longer contributes water to the watershed. This recession period results from a gradual decrease in groundwater input to the stream system (Hornberger et al., 1998). Furthermore, Figure 12 also shows graphs of $\ln Q$ versus time labeled in capital letters (B, D, F, H, and J). These graphs were developed by plotting the natural log of streamflow values against time and applying trend lines through the data points. By plotting the data in this way, linear equations for these graphs were determined, which are related to the baseflow recession periods. Baseflow recession curves are useful because they may be utilized to estimate streamflow values during dry periods, which is beneficial for water resources planning (Hornberger et al., 1998).

The baseflow recession hydrographs developed for each gauging station along Icehouse Creek reveal that 4 of the 5 baseflow recession periods started around January 10 of 2015. In contrast, the baseflow recession period for gauging station B started over a month later sometime in late February. At this particular gauging station, local aquifers may be contributing groundwater to the stream for longer periods of time, which would explain the delayed start of a recession period. Moreover, the graphs of $\ln Q$ versus time in Figure 12 correspond to the baseflow recession hydrographs. The data points for these related graphs were plotted in identical colors to distinguish between the different gauging stations. These particular graphs show different slopes for the trending lines of each gauging station. For example, the slope for gauging station C (Graph F) appears to be steeper in comparison to the other stations. The value of the slope for these trend lines is equal to the recession constant ($c$) of the baseflow recession equation, which is related to the rate that groundwater drains out of a basin. As a result, the variation in slope values for the different gauging stations may indicate that groundwater is not draining at a constant rate along Icehouse Creek.
Spring Hydrographs

Hydrographs were developed for selected spring gauging stations in Icehouse Canyon including: Spring #1, Spring #2, and East Cabin Spring. The precipitation data from one particular rain gauge (Cabin 5 RG) was incorporated into the spring hydrographs in order to analyze the response from recharge events. Figure 13 shows three hydrographs (A, B, and C) for the selected spring locations and their unique responses to precipitation recharge events occurring within Icehouse Canyon watershed. After performing a careful analysis of these hydrographs, it appears that some springs are more responsive than others to recharge events. For example, when comparing two springs discharging from Cedar landslide along Icehouse Trail, the results suggest that Spring #1 is more responsive to rain events while Spring #2 discharge remains relatively constant following minor storm events. These different responses may indicate that Spring #1 is dominated by near-surface drainage from landslide material while Spring #2
may be fed by deeper bedrock fractures. This could explain the rapid response observed at
Spring #1 and the lack of response observed at the Spring #2 location. Furthermore, the
hydrograph for East Cabin Spring reveals that it is also responding to precipitation recharge
events. The response is indicated by increasing discharge values following storm events. This
particular spring may be discharging groundwater from a shallow aquifer, which would explain
the sensitivity to recharge events.

![Hydrograph for East Cabin Spring](image1)

![Hydrograph for East Cabin Spring](image2)
Rating Curve

Discharge and stage was measured periodically at the East Cabin Spring gauging station. Discharge values were determined using a thin plate V-notch weir and stage was measured directly using a clear plastic graduated cylinder. Additionally, stage was also determined from the pressure transducer measurements by converting pressure values to water depth values utilizing the hydrostatic equation. These measurements were performed on the same day in order to establish a relationship between stage and discharge at this particular gauging station. The objective of this method was to obtain a continuous record of discharge by measuring water level pressure in real-time with the pressure transducer. This method should provide valuable information regarding seasonal and long-term variations in spring discharge. Figure 14 (Graph A) shows a stage and discharge hydrograph for the East Cabin Spring station. The hydrographs appear to exhibit a similar pattern, which would be expected when comparing these two parameters. For example, as the spring discharge values increase, there is also a corresponding increase in stage values. This positive correlation is expected because higher discharge values in a stream would cause the water level to rise. Furthermore, Figure 14 (Graph B) shows a rating curve developed for the East Cabin Spring gauging station. The rating curve shows significant scatter in the data points, which may indicate a potential source of error. Typical stage-discharge rating curves show a positive correlation, however, this rating curve does display that relationship. Possible sources of error may come from the pressure transducer instrument or the V-notch weir. The most likely source of error is probably the V-notch weir, however, further investigation is necessary in order to make this determination.
Figure 14. (A) Stage and discharge hydrographs for East Cabin Spring gauging station. (B) Rating curve showing stage-discharge relationship.
CONCLUSIONS

The response of Icehouse Canyon’s watershed to precipitation recharge events was observed for a period of over one year during severe drought conditions in southern California. Various field methods were utilized to collect sufficient hydrologic data in order to analyze the watershed’s response in great detail. The fresh water supplies derived from this watershed contribute to drinking water sources for residents of Mount Baldy Village and the city of Upland. This water source also supports the wildlife and vegetation within the watershed area. Consequently, proper management and planning of this limited water resource is essential for long-term sustainability. Although important data was obtained through this research project, further research is necessary to determine long-term trends in streamflow and spring discharge within Icehouse Canyon watershed especially during historical drought conditions. As the human population continues to grow, greater demands will be placed on limited fresh water sources. Therefore, it is crucial to continuously monitor water quantity data not only in Icehouse Canyon but also in other watersheds throughout California.

This experiential learning internship has furthered my long-term career goals by providing me with an opportunity to gain valuable experience. The relevant and practical experience gained through this internship opportunity has contributed significantly to my preparation for career paths such as environmental hydrology with the U.S. Department of Agriculture and other federal government organizations. I would recommend other students pursuing similar fields to participate in this watershed management program in order to enhance their research capabilities and become better prepared for careers within the U.S. Forest Service or other agencies.
REFERENCES


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