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# Comparison of Predicted and Observed Flood Flows in Pajarito Canyon Following the 2000 Cerro Grande Fire

Jake Meadows

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# Committee Approval

The Master of Water Resources Professional Project Report of **Jake Meadows,** entitled "Comparison of Predicted and Observed Flood Flows in Pajarito Canyon Following the 2000 Cerro Grande Fire" is approved by the committee:

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|---|---|---|
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## Abstract

In May 2000, the Cerro Grande fire devastated lands in and around Los Alamos National Laboratory (LANL) in northern New Mexico and dramatically increased stormwater runoff from the impacted areas. The purpose of this paper is to demonstrate the recovery of burned lands and the corresponding decrease in flood flows and floodplains over a 7-year period in Pajarito Canyon near Los Alamos. A secondary purpose was to evaluate the applicability of the U.S. Army Corps of Engineers hydrologic modeling tool, Hydrologic Engineering Center–Hydrologic Modeling System (HEC-HMS) in Pajarito Canyon by comparing computed runoff to stream gage runoff in Pajarito Canyon. An initial study completed by Wright Water Engineers for LANL in 2001 predicted increased flood flows and floodplains under post-Cerro Grande fire conditions on LANL lands and surrounding property.

Rainfall runoff calculations were made using the Natural Resources Conservation Service's curve number (CN) method. For calibration, a hydrograph output from HEC-HMS was compared to hydrographs from two gaging stations in Pajarito Canyon. The model predicted an average of 42 percent of the peak discharge in upper Pajarito Canyon and 24 percent of the total volume discharge for three calibration simulations. For the same calibrations it predicted 37 percent of the peak discharge and 18 percent of the volume discharge in Twomile Canyon. While underestimated, these values may have been skewed by precipitation measurements. To demonstrate the watershed's recovery through CN modification, a design storm with an average recurrence interval (ARI) of 100-year was used to model the watershed's response for conditions representative of both year 2000 and 2007. The model consistently under-predicted the hydrograph peak and discharge volume for the calibration simulations and given the magnitude of the underestimation it was expected that the design storm predictions were underestimated as well. Through evaluation of the variability of the model's predictions and the intense data requirements associated with HEC-HMS it was determined that HEC-HMS has limited applicability within Pajarito Canyon.

## Acknowledgements

The completion of this project would not have been possible without the support and encouragement of a long list of people. I would like to start by thanking my committee for the countless hours they committed to helping me and for their encouragement and sage advice whether in a meeting or over a cup of coffee. Dr. Bruce Thomson chaired my committee and always made time to meet with me and review my work. Dr. Julie Coonrod provided GIS expertise and experience with HEC modeling programs. LANL staff members Steven Rae and William Turney volunteered their time to assist me from the very beginning. I am honored to have worked with them and to have them as friends. Mike Saladen, my team leader at LANL, provided support and assistance throughout my time in graduate school. My mentor at LANL, Robin Reynolds, not only introduced me to the Water Resources Program but also offered all available resources and time to help me successfully complete it. Brad McKown helped with GIS data acquisition. Without his ability to answer my countless questions related to GIS I may never have finished. Greg Kuyumjian helped me understand many hydrologic concepts and gather stream gage data. Jeff Walterscheid and Sam Loftin assisted with field work and provided background information on the canyons and volunteered their experience gained from working on the Cerro Grande fire rehabilitation.

I would also like to thank my parents, Bill and Helen Meadows, for their support and for teaching me to always complete what I start.

# Acronyms and Abbreviations

| | |
|---|---|
| **ARI** | average recurrence interval |
| **BAER** | Burned Area Emergency Rehabilitation |
| **BART** | Burned Area Rehabilitation Tracking |
| **BMP** | best management practice |
| **CN** | curve number |
| **DEM** | digital elevation model |
| **HEC-HMS** | Hydrologic Engineering Center–Hydrologic Modeling System |
| **HSG** | hydrologic soil group |
| **LANL** | Los Alamos National Laboratory |
| **MET** | Meteorologic Tower (LANL site) |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NRCS** | Natural Resources Conservation Service |
| **PFRS** | Pajarito Flood Retention Structure |
| **SCS** | Soil Conservation Service |
| **TA** | technical area |
| **USACE** | United States Army Corps of Engineers |
| **USDA** | United States Department of Agriculture |
| **WWE** | Wright Water Engineers |

## Definitions

**ArcMap –** Geographic Information System application used for analyzing data and generating maps.

**Cubic feet per second** (cfs) **–** the rate of discharge representing a volume of 1 cubic foot passing a given point during 1 s and is equivalent to 7.48 gal. per s, 448.8 gal. per min, or 0.2832 cubic meters per s.

**Discharge –** the volume or water (or more broadly, the volume of fluid including suspended sediment) that passes a given point within a given period of time.

**Drainage area –** the area of a stream at a specified location, measured in a horizontal plane and enclosed by a topographic divide, from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point.

**Ephemeral stream –** surface water that flows only in direct response to precipitation or snowmelt in the immediate locality.

**Froude number –** a dimensionless parameter used to describe flow conditions. An index to the influence of gravity in flow situations where there is a liquid-gas interface.

**Gaging station –** a particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

**HEC-geoHMS –** a software package for use with the ArcView Geographic Information System to develop a number of hydrologic modeling inputs.

**Hydraulic radius –** flow area divided by wetted perimeter of a stream channel.

**Hydrology –** the science dealing with the properties, distribution, and circulation of natural water systems.

**Hyetograph –** a graph depicting precipitation versus time.

**Initial Abstraction –** all the water losses occurring before runoff begins, including interception, evaporation, and infiltration.

**Runoff curve numbers –** a factor used to calculate runoff, based on land cover and soils.

**Stream flow –** the discharge that occurs in a natural channel.

**Thalweg –** imaginary line connecting the lowest points of streambed elevation in a channel.

**Time lag –** The standard lag is defined as the length of time between the centroid of precipitation mass and the peak flow of the resulting hydrograph.

**Time of concentration –** time it takes runoff to travel from the hydraulically most distant point in the watershed to a design point or point of discharge.

**Total excess –** excess precipitation subject to direct runoff.

**Travel time** (Tt) **–** time it takes runoff to travel from one point to another point down slope along a hydraulic segment in a watershed.

**Water year –** the 12-mo period, October 1 through September 30. The water year is designated by the calendar year in which it ends.

Definitions were adapted from Buckley et al. (2005), LANL (2006), SCS (1986), USACE (2001), and USACE (2006).

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# 1.0 Introduction

Los Alamos is located in northern New Mexico at the top of Pajarito Plateau near the Jemez Mountains. Los Alamos is the site of Los Alamos National Laboratory (LANL) and was heavily impacted by the Cerro Grande fire of May 2000. Following the fire, the burned landscape around LANL was susceptible to potential floods that also impacted areas downslope of the burned areas. Extensive rehabilitation efforts were completed to help protect the land and structures. Studies were completed to analyze the potential effect of floods in the area. Initially, all canyons surrounding Los Alamos were modeled using computer software representing post-fire conditions to determine the estimated floodplain and flood velocities for 6-hr duration precipitation events with an average recurrence interval (ARI) of 2, 25, and 100-years. The purpose of this study is to demonstrate that modeling the hydrology of post-precipitation runoff from a 6-hr 100-year storm in Pajarito Canyon 7 years after the Cerro Grande fire will show reduced discharge at stream gages, reduced runoff velocities, and reduced floodplains, thus demonstrating hydrologic recovery resulting from the watershed's natural recovery and response to rehabilitation. This study encompassed a re-creation and evaluation of predicted and observed flood flows to determine the applicability and accuracy of modeling software for investigating hydrologic recovery of a post-burn watershed in New Mexico.

The study objectives were to

- research previous hydrologic and hydraulic modeling of stormwater runoff at Los Alamos,
- review literature on the Natural Resources Conservation Service's (NRCS) curve number (CN) method and investigate its applicability for runoff calculations,
- compare HEC-HMS predictive modeling results to observed runoff to determine the model's applicability to Pajarito Canyon,
- model hydrology of runoff and evaluate the results for 6-hr / 100-year design storm in Pajarito Canyon immediately after the Cerro Grande fire and after recovery (7 years), and
- discuss the results of this study to make recommendations for future work.

In May 2000, the Cerro Grande fire burned 47,650 acres in and around LANL. Following the fire, the potential was realized for greatly increased flood and debris flows in the burned sub-basins posing a variety of concerns to downstream areas and LANL's infrastructure (Buckley et al. 2005). For 5 years following the Cerro Grande fire, LANL staff members reported post-fire monitoring of rehabilitation. In 2001, a team of LANL and Wright Water Engineers (WWE) personnel combined their data with available runoff reports for input parameters for the hydrologic model. The modeling was completed in 2001 and employed U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) modeling software. The purpose of this floodplain analysis was to model the floodplain under post-Cerro Grande fire conditions on LANL property. In this report, the initial hydrologic simulations were re-created and accompanied with new data to calculate post-precipitation flood flows for Pajarito Canyon that are representative of 2007 field conditions. Calibration runs were completed for three separate storms as well to determine the accuracy of the model's calculations when compared to gaged runoff.

## 2.0 Background

*Hydrology* is the study of the occurrence and movement of water on and beneath the surface of the earth. Hydrologic modeling focused on stormwater runoff and was completed with the intent of generating a hydrograph, including a peak discharge and volume discharge. Hydrologic Engineering Center–Hydrologic Modeling System (HEC-HMS) is a program developed by the U.S. Army Corps of Engineers to model hydrologic behavior of watersheds. HEC-HMS (Version 3.1.0) was used to complete hydrologic modeling of Pajarito Canyon.

Pajarito Canyon was selected for analysis because of the severity of the burn within its drainage and the availability of accurate stream-gage data. Pajarito Canyon heads on the flanks of the Sierra de los Valles on U.S. Forest Service lands. Figure 1 shows LANL and Los Alamos County lands with Pajarito Canyon highlighted in green. The canyon crosses the central part of LANL before entering Los Alamos County lands near White Rock (LANL 2006). During the Cerro Grande fire, upper Pajarito Canyon experienced at least 50% high-severity burn, 10% moderate-severity burn, and 30% to 40% low-severity burn (WWE 2003).

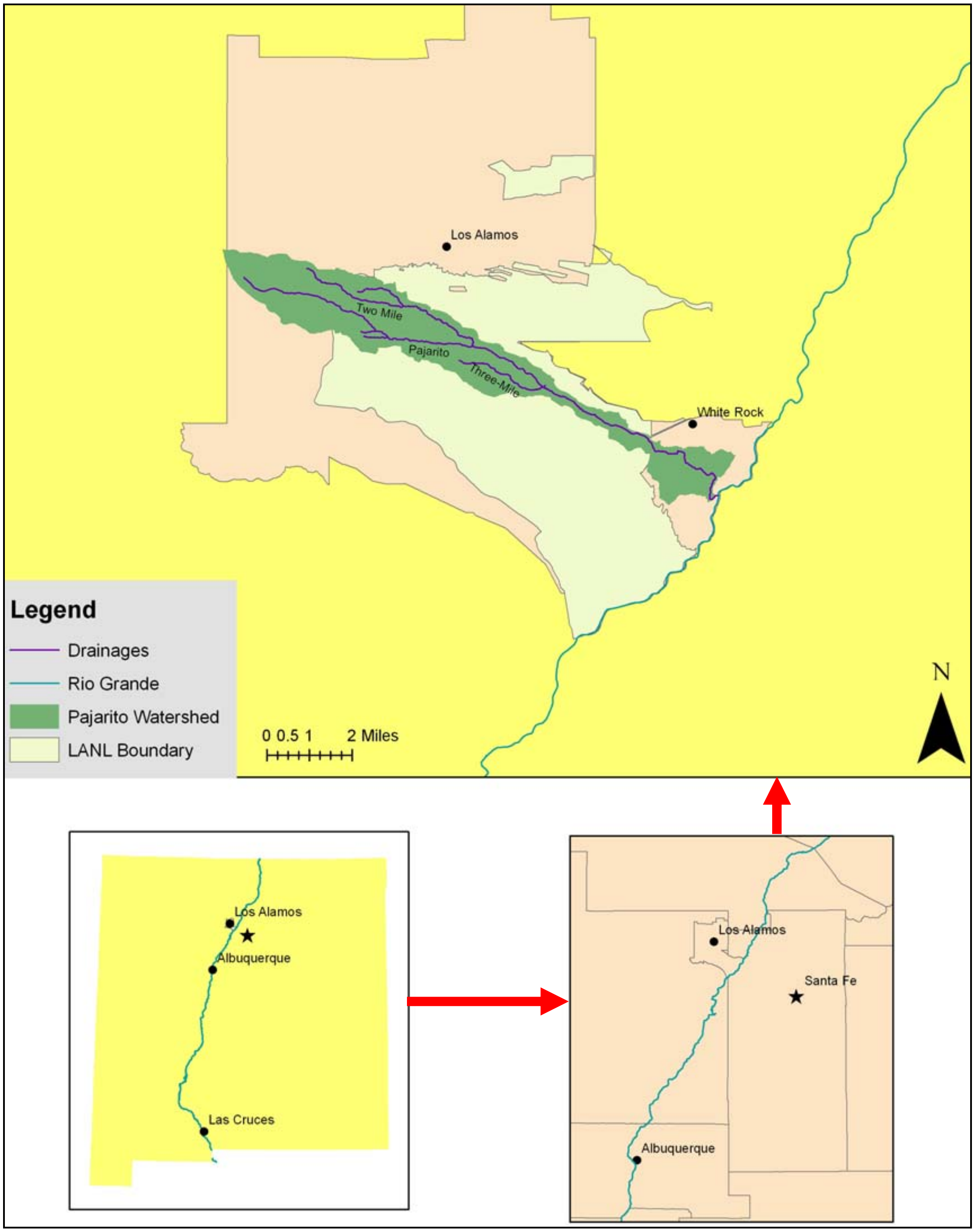


**Figure 1.** Pajarito Canyon and surrounding areas. Map shows New Mexico, Los Alamos County, and Los Alamos National Laboratory, and surrounding drainages. Pajarito Canyon and its tributaries are demarcated in green and purple, respectively.

Figure 2 shows the Cerro Grande burn area, and Appendix B presents a map with the burn intensities.

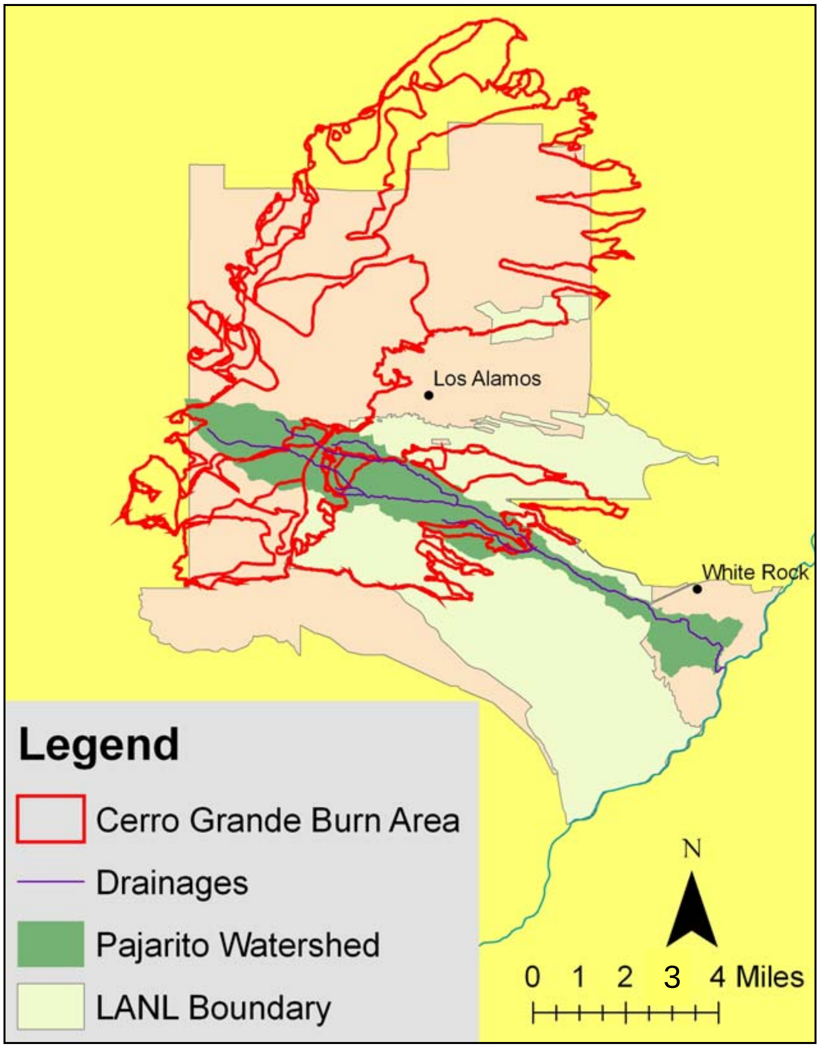


**Figure 2.** Cerro Grande fire burn area. The burn perimeter is highlighted in red.

The landscape in Pajarito Canyon has changed considerably since 2000. Much of the area has been revegetated, and the soils have more capacity to retain water than they did following the fire. It is widely accepted that rainfall runoff increases after a fire event because of the hydrophobic nature of burned soils, resulting in increased hydrograph peaks (McLin 2001). The intent of creating a hydrologic model within HEC-HMS was to depict the current hydrology of Pajarito Canyon and to reflect changes in rainfall-runoff relationships and changing landscape conditions.

Climate dynamics of Los Alamos contribute to a complex hydrologic modeling environment. The seasonal distribution as well as the intensity of precipitation events leads to rapid flows in many of the ephemeral streams. Yearly precipitation at Los Alamos averages 18.9 in., with 45% distributed between July and September in the form of intense afternoon and evening thunder showers from 1971-2000. The distribution and intensity of precipitation in the area cause sharp-peaked hydrographs and potential for flooding of low-lying areas. Understanding how the watersheds behave in the post-fire environment is important for managing stormwater and making decisions concerning development.

The probability for exceeding a specific precipitation event has been found to remain relatively constant with topographic relief and east to west movement in Los Alamos (Reneau et al. 2003). Reneau et al. (2003) also found that the probability of exceeding specific 15- or 30-min. rainfall amounts was similar across Los Alamos, regardless of east to west direction or elevation. While the probability of exceeding a specific amount of precipitation may remain the same, actual precipitation measurements for an individual event can vary greatly across observation stations located a few miles apart due to the nature of summer thunderstorms, the principle source of precipitation in summer months.

Figure 3 demonstrates the variability of precipitation across LANL and surrounding Los Alamos County and Forest Service lands. The storm depicted occurred on August 4, 2008 and precipitation distribution is shown in in. for each gaging station. The storm dropped 3.05 in. of rain at Technical Area-49 (TA-49) while only 0.03 in. at station e245.5. According to the National Oceanic and Atmospheric Administration (NOAA) Atlas 14, the 3.05 in. recorded at TA-49 corresponds to an ARI of approximately 190 years. Table 1 shows NOAA's precipitation frequency estimates for Los Alamos for storms ranging from an ARI of 1 to 100-years with durations ranging from 5 min. to 7 days.

There are 24 precipitation gages across LANL and surrounding lands. The stations have been divided by Thiessen polygons to help track precipitation. The polygons are also depicted in Figure 3. The Thiessen polygon method associates precipitation gages with a spatial area to allow for the collection of more refined precipitation data. The gages are equipped with 5 min. tipping buckets connected to existing runoff gaging stations which are equipped with data loggers. While there are now several precipitation gages in Pajarito Canyon for the storms used to calibrate the model in this study the only available source for precipitation data was the TA-06 Meteorological Tower (MET).

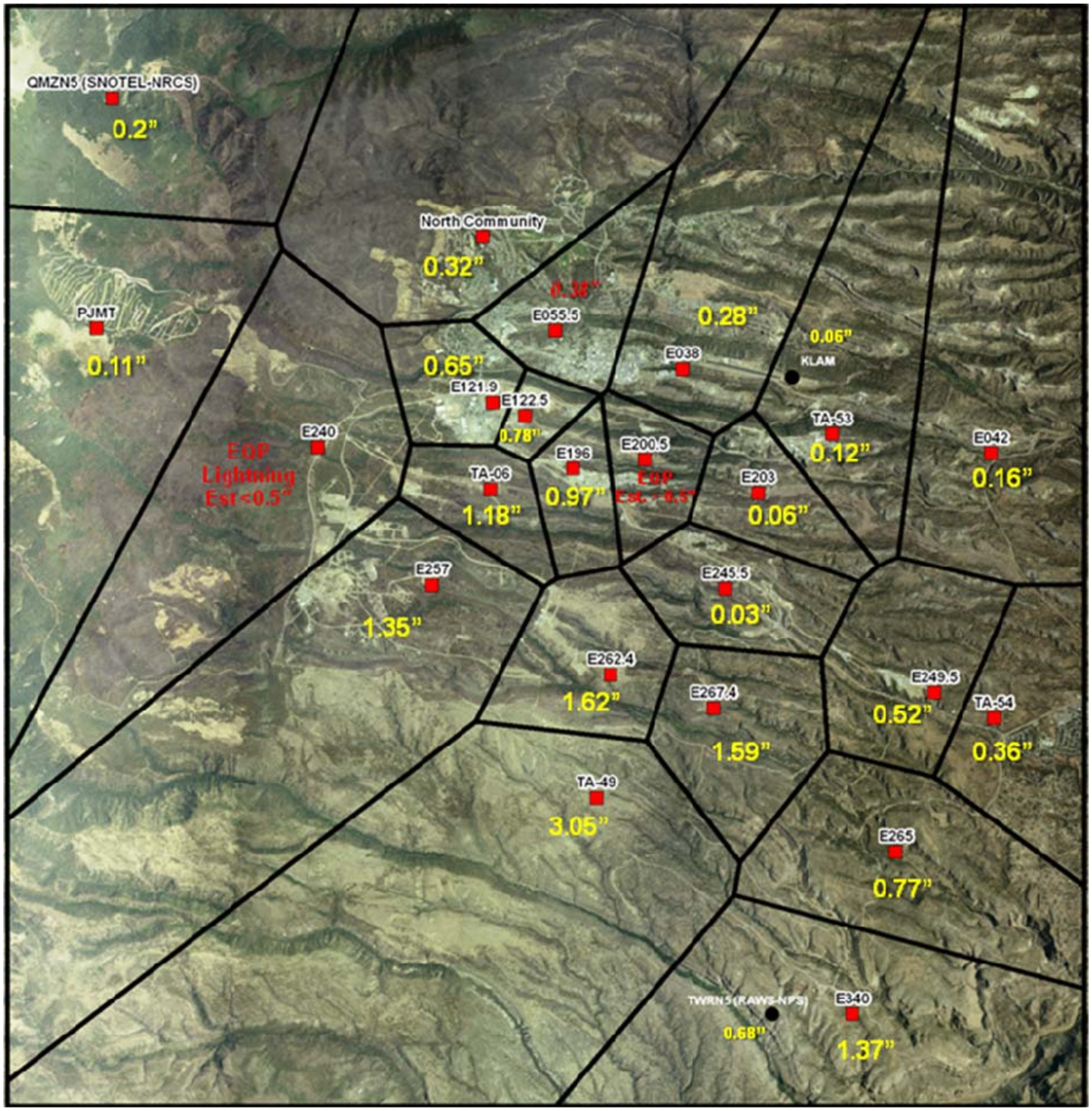


**Figure 3.** Precipitation gages. Thiessen polygons with precipitation recorded on August 4, 2008. Pajarito Canyon runs from left to right through the TA-06 MET.

**Table 1.** NOAA precipitation frequency estimates for Los Alamos, NM. From Bonnin et al. (2006).

| Precipitation Frequency Estimates (inches) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ARI (years)** | 5 min | 10 min | 15 min | 30 min | 60 min | 120 min | 3 hr | 6 hr | 12 hr | 24 hr | 48 hr | 4 day | 7 day |
| **1** | 0.21 | 0.33 | 0.4 | 0.54 | 0.67 | 0.79 | 0.9 | 1 | 1.14 | 1.37 | 1.59 | 1.89 | 2.28 |
| **2** | 0.28 | 0.42 | 0.52 | 0.7 | 0.87 | 1.01 | 1.1 | 1.3 | 1.44 | 1.71 | 1.99 | 2.36 | 2.85 |
| **5** | 0.37 | 0.56 | 0.7 | 0.94 | 1.17 | 1.33 | 1.4 | 1.6 | 1.81 | 2.14 | 2.46 | 2.92 | 3.5 |
| **10** | 0.44 | 0.67 | 0.83 | 1.12 | 1.39 | 1.59 | 1.7 | 1.9 | 2.1 | 2.47 | 2.85 | 3.37 | 4.01 |
| **25** | 0.54 | 0.82 | 1.01 | 1.37 | 1.69 | 1.94 | 2 | 2.2 | 2.51 | 2.92 | 3.36 | 3.97 | 4.71 |
| **50** | 0.61 | 0.93 | 1.15 | 1.55 | 1.92 | 2.22 | 2.3 | 2.5 | 2.82 | 3.27 | 3.76 | 4.44 | 5.23 |
| **100** | 0.69 | 1.05 | 1.3 | 1.75 | 2.17 | 2.52 | 2.6 | 2.8 | 3.15 | 3.63 | 4.16 | 4.92 | 5.76 |
| **200** | 0.77 | 1.17 | 1.45 | 1.96 | 2.42 | 2.84 | 3 | 3.2 | 3.49 | 3.99 | 4.57 | 5.4 | 6.29 |
| **500** | 0.88 | 1.34 | 1.66 | 2.23 | 2.77 | 3.27 | 3.4 | 3.6 | 3.95 | 4.48 | 5.12 | 6.05 | 6.99 |
| **1000** | 0.97 | 1.47 | 1.83 | 2.46 | 3.05 | 3.62 | 3.8 | 3.9 | 4.31 | 4.85 | 5.54 | 6.54 | 7.52 |

# 3.0 Modeling Approach

According to the NRCS's "Urban Hydrology for Small Watersheds" (1986), seven factors affect runoff: precipitation, soil permeability, watershed area, ground cover, antecedent moisture, watershed storage, and time parameters (time of concentration and travel time). Three of the factors can be affected by anthropogenic means: soil permeability, ground cover, and the time parameters. All the other factors are fixed but must still be considered in any watershed analysis. Consistent with the idea of being able to alter soil permeability and ground cover is the idea of modeling post-fire runoff. This study used an application of composite CNs representative of field conditions to analyze the changes in runoff characteristics following the Cerro Grande fire.

The NRCS hydrograph method was originally developed from observed data collected in small agricultural watersheds. The data were generalized as dimensionless hydrographs, and a best-approximate hydrograph was developed for general application.

Runoff CNs are a factor used to determine runoff based on land cover and soils. Multiple tables provide CNs for various cover types on different soils. Soils are classified into hydrologic soil groups (HSG) that indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The HSGs are one element used in determining CNs. As determined by Wright Water Engineers (WWE 2003), all soils within Pajarito Canyon fell under HSG C. Field work by WWE in 2003 revealed that the high hydrophobic character of the soil in Pajarito Canyon had disappeared in the 3 years after the fire, thus reducing the risk associated with high runoff potential following the Cerro Grande fire. The soils were mostly sandy with a high percentage of silt (WWE 2003).

The following text describes the method used by HEC-HMS for CN based runoff calculation, and the equations are from Chapter 5 of the HEC-HMS technical reference manual (USACE 2000).

> The SCS Curve Number (CN) model estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture, using the following equation:
>
> $$P_e = \frac{(P - I_a)^2}{P - I_a + S} \quad (5\text{-}3)$$
>
> Where $P_e$ = accumulated precipitation excess at time t; P = accumulated rainfall depth at time t; $I_a$ = the initial abstraction (initial loss); and S = potential maximum retention, a measure of the ability of a watershed to abstract and retain storm precipitation. Until the accumulated rainfall exceeds the initial abstraction, the precipitation excess, and hence the runoff, will be zero.
>
> From analysis of results from many small experimental watersheds, the SCS developed an empirical relationship for $I_a$ and S:
>
> $$I_a = 0.2\,S \quad (5\text{-}4)$$
>
> Therefore, the cumulative excess at time t is:
>
> $$P_e = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \quad (5\text{-}5)$$

Incremental excess for a time interval is computed as the difference between the accumulated excess at the end of and beginning of the period. The maximum retention, S, and watershed characteristics are related through an intermediate parameter, the curve number (commonly abbreviated CN) as:

$$S = \begin{cases} (1000 - 10\,CN)/CN & \text{(foot-pound system)} \\ (25400 - 254CN)/CN & \text{(SI)} \end{cases} \quad (5\text{-}6)$$

Since the sub-basins in Pajarito Canyon had spatially varying hydrologic properties both pre- and post-fire composite CNs were calculated by WWE to account for multiple soil types and varying vegetative cover. In 2003, WWE computed pre- and post-fire CNs for sub-basins in the Los Alamos area and used these as input to HEC-HMS to estimate potential increase in flood discharges for all areas affected by the Cerro Grande fire. In consideration of these CN determinations, sub-basins were identified to reflect as uniform a burn severity as practical. The pre-fire CNs were based on rainfall-runoff analysis by LANL for those sub-basins where data existed. Post-fire CNs were initially determined by area weighting the burn severity in each sub-basin using criteria specified by WWE (2003).

According to the WWE report, the objective of post-fire recovery is to return to the “natural” condition rather than “pre-fire” condition. The “pre-fire” condition—as represented by the pre-fire CN—does not equate to the “natural” condition. The “pre-fire” condition of the watershed contained dense vegetation which was susceptible to carrying a high intensity fire such as the Cerro Grande. Thus, the hydrologic characteristics have changed by varying degrees, resulting in an “unnatural’ hydrologic condition. In the specific case of the Cerro Grande fire, the overgrown pre-fire landscape is not expected to be the future condition because of recent changes in forest management practices and philosophy (WWE 2003).

The following approach for estimating post-fire CN was developed by WWE (2003): sub-basin recovery was based on a ratio of post-fire CN to pre-fire CN. With recovery of the watershed and in the absence of subsequent disturbances, such as another wildfire or a significant change in land use, this ratio decreases over time. As re-vegetation and other variables change, the sub-basin hydrology gradually moves its hydrologic response towards its “natural” condition (CN=1.1, which represents the pre-fire CN ratio of 1.0 plus 10%) (WWE 2003). Figure 4 demonstrates a graphic of the post-fire to pre-fire CN ratio. It is from

WWE (2003) and shows the “natural condition” as 1.1 times the pre-fire CN. More intense burn results in a higher post-fire CN ratio. With a high post-fire CN ratio, a longer recovery time to a “natural condition” can be expected. The curved lines provide a general representation of recovery.

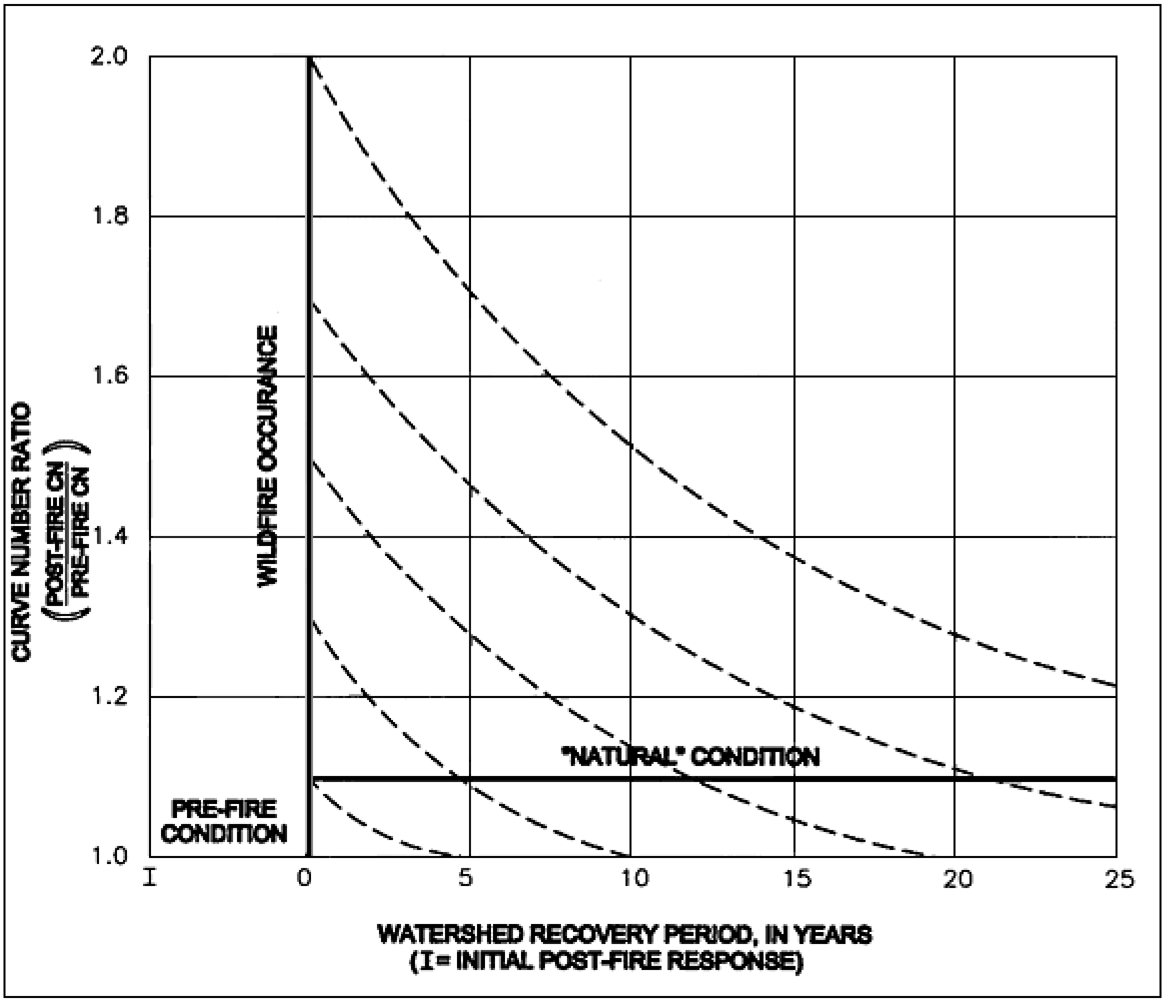


**Figure 4.** CN Ratio versus Watershed Recovery Period. From WWE (2003).

The sub-basins modeled in McLin et al. (2001) compared favorably to those generated through ArcMap calculations. When the sub-basins and associated data were used, it became possible to modify the CN in an attempt to demonstrate hydrologic recovery throughout Pajarito Canyon. The first step was to modify CNs for all sub-basins with high-burn intensity. In October 2007, the author spent 2 days in the field to gather vegetative cover data from high-intensity Burned Area Rehabilitation Tracking (BART) units. The areas selected were the focus of intense rehabilitation efforts and were in areas that could potentially contribute to high stormwater runoff volumes and velocities. The areas of interest were selected through review of the Cerro Grande fire reports and consultation with LANL staff involved with the Burned Area Emergency Rehabilitation (BAER) efforts. BART units were established by the BAER team, which is composed of U.S. Forest Service professionals who assist with land stabilization following a natural disaster such as wildfire on Forest Service lands.

In 2007, BART Units 2, 6, and 34 were selected for this study because of their proximity to the stream channel and were the focus of BAER efforts. To assist composite CN calculations, percent vegetative cover was measured at four randomly selected plots in each of the burn units. The percent cover was then averaged to represent the entire unit.

To further justify the CNs, previously used photographic monitoring locations were located and photographed to the maximum extent practicable. Transitions in personnel led to difficulties in locating all the photo points. To determine whether the areas were the same as previously used in photo documentation, staff walked through the area to locate the markers. Instances when the exact photo point could not be located, a close approximation was utilized.

The condition of Pajarito Canyon streambed is documented in the photographs in Appendix D. It should be noted that the vegetative cover varied greatly. Rehabilitated areas showed vegetation ranging from 15% to 80%. Unburned areas in the canyon bottom often had 100% vegetative cover. Different cover types were also evident. Previous research by Grove et al. (1998) has documented complications associated with using a composite CN to represent vastly different hydrologic conditions within the same sub-basin. A composite CN was generated with the understanding that it may not accurately reflect actual runoff conditions but was the best option given data gathering limitations.

The observations from the 2003 WWE report further documented the complex terrain and associated difficulties with developing a composite CN. Table 2 contains CNs for burned and unburned areas on and around LANL estimated by WWE. Wright Water Engineers found rock cover on steep slopes within Pajarito Canyon to be as great as 60%. In burned areas there was no canopy. A result of the change from canopy and vegetative litter to grass, the predominant cover type in areas of severe burn, has changed to one representative of herbaceous cover rather than the pre-fire cover type of piñon-juniper woods. Area-weighted 3-year post-fire CNs were calculated by WWE. The CN for upper Pajarito Canyon was 76 in 2003. Values calculated in 2007 and based on field observations combined with WWE's approach are presented in Table 3. Figure 5 contains a map of the sub-basins, each of the CNs were assigned to their specific sub-basin for calibration as well as year 2000 and year 2007 simulations.

**Table 2.** WWE's Estimated CNs for Los Alamos Watersheds

| Burn Severity | Estimated CN |
|---|---|
| Unburned | 55–75 |
| Low | 80–83 |
| Moderate, without hydrophobic soils | 87 |
| Moderate, with hydrophobic soils | 89 |
| High, without hydrophobic soils | 92 |
| High, with hydrophobic soils | 95 |

**Table 3.** Area-Weighted CNs for Pajarito Canyon

| Sub-basin | Original CN | Post Cerro Grande CN | 2007 Modified CN |
|---|---|---|---|
| 1 | 52 | 77 | 65 |
| 2 | 62 | 70 | 65 |
| 3 (A and B) | 61 | 69 | 64 |
| 4 | 70 | 65 | 63 |
| 5 | 67 | 65 | 63 |
| 6 | 72 | 72 | 72 |
| 7 | 73 | 73 | 73 |

**Note:** The 2000 values were developed by WWE and the 2007 values were based on data gathered during the 2007 field season.

# 4.0 Hydrologic Model Simulation Methods

HEC-HMS contains multiple components, each with separate data requirements to represent the watershed being modeled. HEC-HMS simulations were carried out under two separate circumstances, first to determine its accuracy through calibration and then to analyze the results from a design storm. Section 5.0 details the model calibration when run with actual precipitation data and compared to stream gage data. Section 6.0 contains the design storm simulations and comparisons of runoff changes from year 2000 versus year 2007 conditions.

The primary components of HEC-HMS are the basin model, the meteorologic model, control specifications, time-series data, and paired data. The basin model captures hydrologic properties of the watershed. For this study, Pajarito Canyon was divided into sub-basins calculated in ArcMap. The meteorologic model associates precipitation data with the basin model to represent precipitation within the sub-basins and facilitate runoff calculations. Time-series data was linked with the meteorologic model. For calibration, TA-06 MET data was entered in 15 min. intervals and for the design storm separate meteoroligic models were developed for each sub-basin. Paired data was used to model the Pajarito Flood Retention Structure (PFRS).

Figure 5 shows a schematic of the hydrologic model and its tributaries, including Twomile Canyon and Threemile Canyon. The following bullets provide a physical description of the basin locations within Pajarito Canyon. An additional area was included in sub-basin 3B to represent runoff from a 12.8 acre development within TA-03. This area is a tributary to Twomile Canyon and is gaged by a 12 in. Parshall flume at station E243.5.

- Sub-basin 1 is Pajarito above NM 501
- Sub-basin 2 is Pajarito below NM 501
- Sub-basin 3A is Twomile Canyon above Pajarito
- Sub-basin 3B is Twomile Canyon below Pajarito
- Sub-basin 4 is Pajarito between Twomile and Threemile Canyons
- Sub-basin 5 is Threemile Canyon
- Sub-basin 6 is Pajarito Canyon at White Rock
- Sub-basin 7 is Pajarito Acres

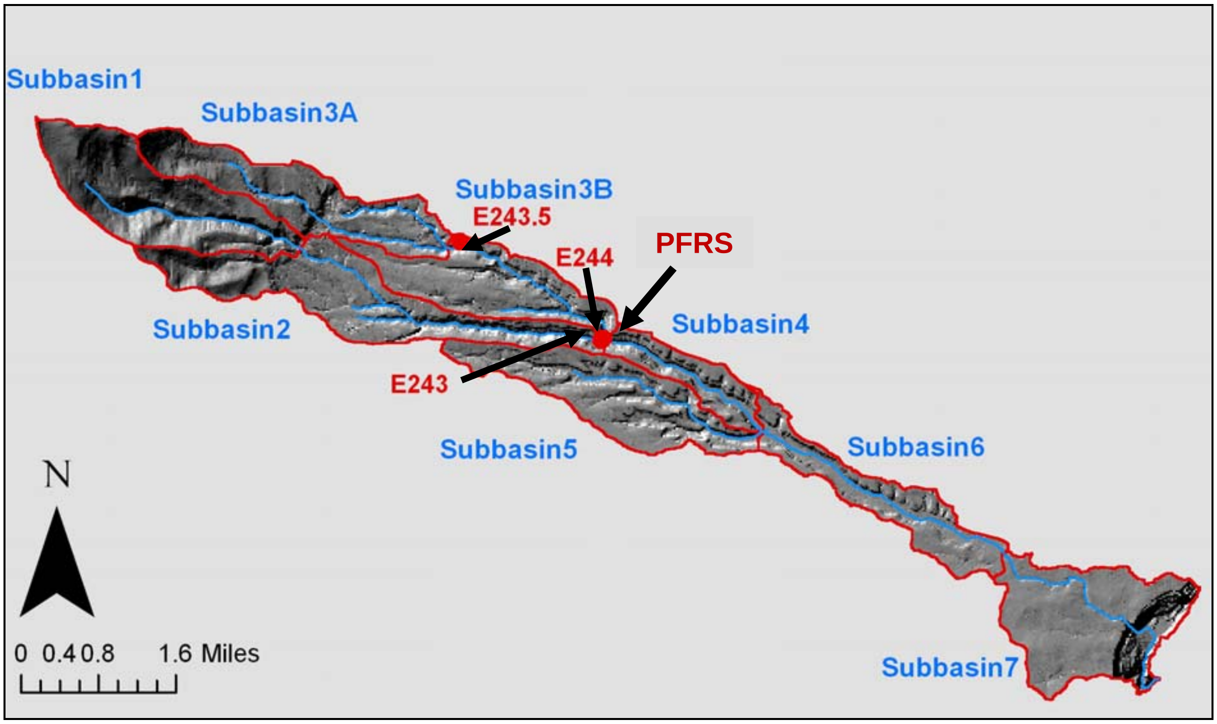


**Figure 5.** Sub-basins for HEC-HMS Pajarito Canyon model. Each sub-basin is outlined in red.

The data listed in Table 4 were entered manually into HEC-HMS. The sub-basin characteristics were consistent with those proposed by McLin (2001) for sub-basins 2 through 7. Rainfall runoff calculations were made using the NRCS's CN method described previously. Lag times for each sub-basin and channel routing methods followed previous research by McLin and WWE. Precipitation and gaging-station data verified the time lag input parameters. The hydrologic inputs for sub-basins 6 and 7 remained unchanged because they did not burn. Channel routing was completed using the Muskingum method with components derived from McLin (2001).

**Table 4** Hydrologic Input Parameters for Pajarito Canyon

| Sub-basin | CN | Area (square mi.) | Lag Time (min.) | Impervious Area (%) |
|---|---|---|---|---|
| 1 | 65 | 1.99 | 45 | 22 |
| 2 | 65 | 2.57 | 96 | 22 |
| 3A | 64 | 1.29 | 30 | 16 |
| 3B | 64 | 1.99 | 99 | 35 |
| 4 | 63 | 0.67 | 107 | 38 |
| 5 | 63 | 1.70 | 128 | 49 |
| 6 | 72 | 1.15 | 172 | 12 |
| 7 | 73 | 2.24 | 80 | 3 |

Challenges arose with manually entered model inputs because of the limited ways to represent culverts and other flow-altering devices (i.e., debris, logs) and erosion control best management practices (BMPs) (i.e., straw wattles). The impervious area was calculated from United States Department of Agriculture (USDA) soil surveys conducted in Pajarito Canyon. The impervious area was incorporated into the composite CN calculations. HEC-HMS also requires inputs for percent impervious areas – the values used in this model were urbanized areas and calculated from aerial photographs. Appendix G contains specific information on the soils for each of the sub-basins and their relative percent compositions.

The PFRS, as shown in Figure 6, was the primary flow control structure modeled in Pajarito Canyon. The PFRS was constructed following the Cerro Grande fire to mitigate the velocity of precipitation runoff. The PFRS rises to 69 ft above ground surface (total height is 118 ft) and has a 42-in. corrugated-metal pipe, allowing for a peak flow of 500 cubic feet per second (cfs). The PFRS was modeled as a reservoir and discharge-area tables from McLin (2001) facilitated function within HEC-HMS.

**Figure 6.** View of PFRS outlet

## 5.0 Hydrologic Model Calibration

Three separate calibration runs were completed to determine the model's accuracy in calculating peak discharge, discharge volume, and the general shape of the hydrograph, which characterizes the watershed's runoff behavior. Sub-basins 1, 2, 3A, and 3B were selected for calibration as they received the most intense burns within Pajarito Canyon and also have stream gages to allow for comparison of calculated runoff to gaged runoff.
Three storms were selected to calibrate sub-basins representing burned areas within Pajarito Canyon. Storms with return intervals of approximately 1-year, 10-years, and 100-years were chosen to analyze the model's predictions and to use them to validate its calculations for the design storm which is discussed in Section 6.0. Section 5.1 contains model simulations for a

storm that occurred on August 29, 2007. Section 5.2 contains model simulations for a storm that occurred on September 28-29, 2005. Section 5.3 contains model simulations for a storm that occurred on August 25, 2006.

The precipitation data collected at the TA-06 MET were used for precipitation measurements and contained precipitation data in 15-min. intervals for calibration runs. Gaging stations proximate to the MET were correlated with TA-06 data to derive local rainfall runoff. While the data for the TA-06 MET is high quality, given the spatial variation of precipitation events there was potential for the data to not capture localized precipitation for the entire sub-basins within upper Pajarito and Twomile Canyon.

Figure 7 shows sub-basins 1 and 2 which were used for calibrating upper Pajarito Canyon. They are gaged by station E243.

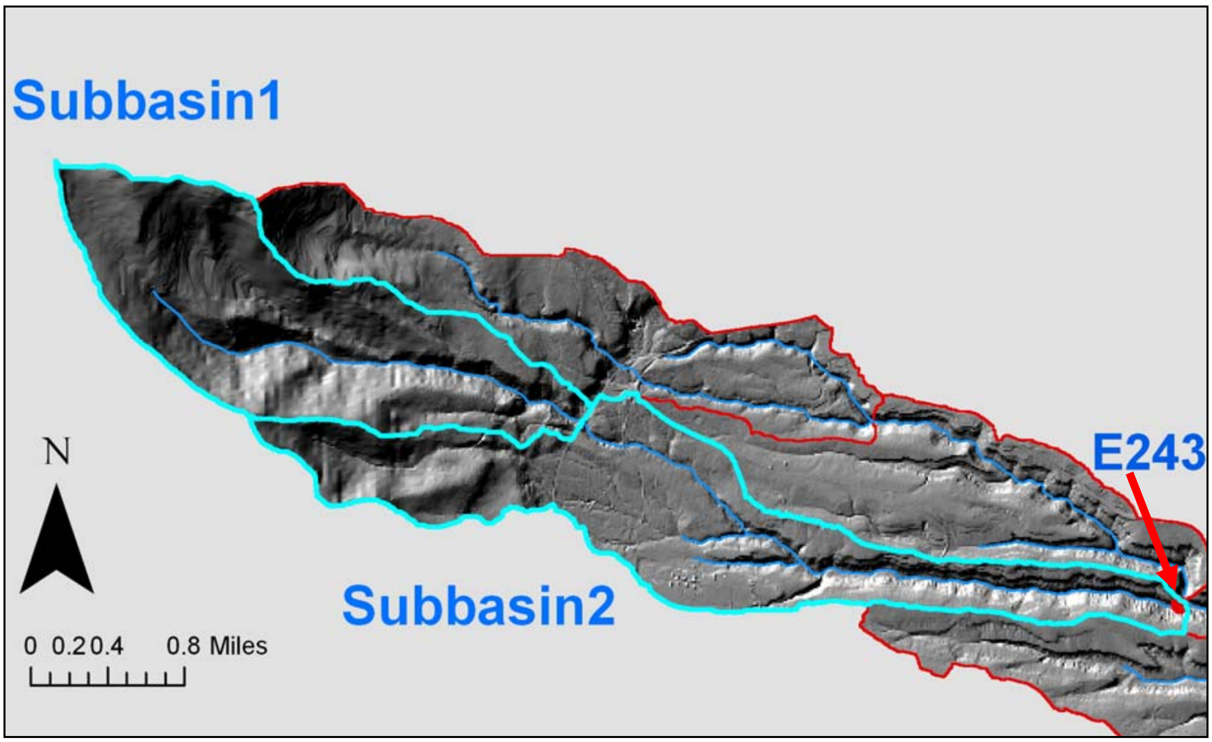


**Figure 7.** Sub-basins for calibrating upper Pajarito Canyon. Station E243 gaged runoff from the sub-basins which are highlighted in light blue.

Figure 8 shows sub-basins 3A and 3B which are gaged by station E244. Station E243.5 gages runoff from TA-3 and was linked with sub-basin 3B. A detailed description of the stream gage data quality is in Appendix E.

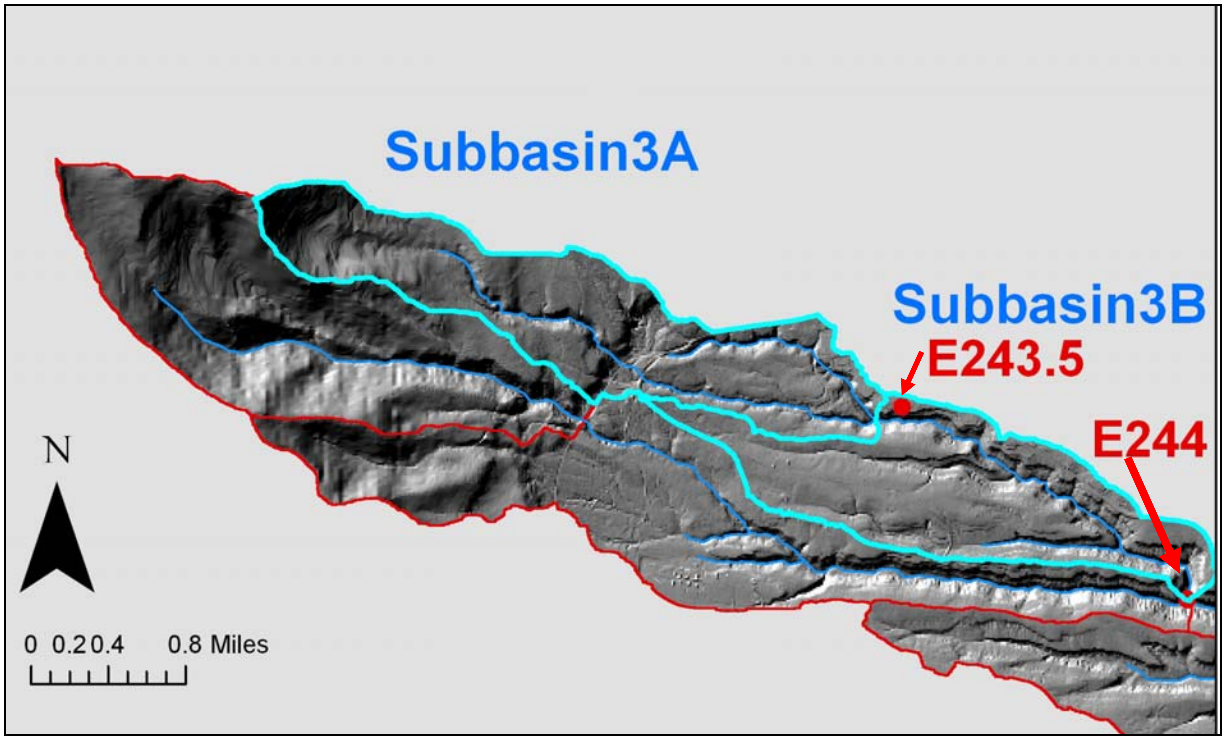


**Figure 8.** Sub-basins for calibrating Twomile Canyon. Gaging station E243.5 gages TA-3 runoff and E244 gage flow from sub-basins 3A and 3B as well as runoff that through station E243.5. Sub-basins 3A and 3B are highlighted in light blue.

## 5.1 August 29, 2007 Precipitation Event Calibration

The first calibration run represented a precipitation event from August 29, 2007 that dropped 0.99 in. of rain at the TA-06 MET. This storm corresponded to an ARI of approximately 1-year. Figure 9 shows percent precipitation versus percent time for the storm, demonstrating that the most intense precipitation occurred at the beginning of the storm when 0.58 in. of rain fell in 30 min. The storm dropped a calculated 241 acre-foot (AF) of equivalent precipitation into the drainage area for gaging station E243 and 174 AF of equivalent precipitation into the drainage area for gaging station E244. This storm was selected as it had two separate intensities which could be useful for determining the model's capacity for calculating accurate runoff for varying intensities within the same event.

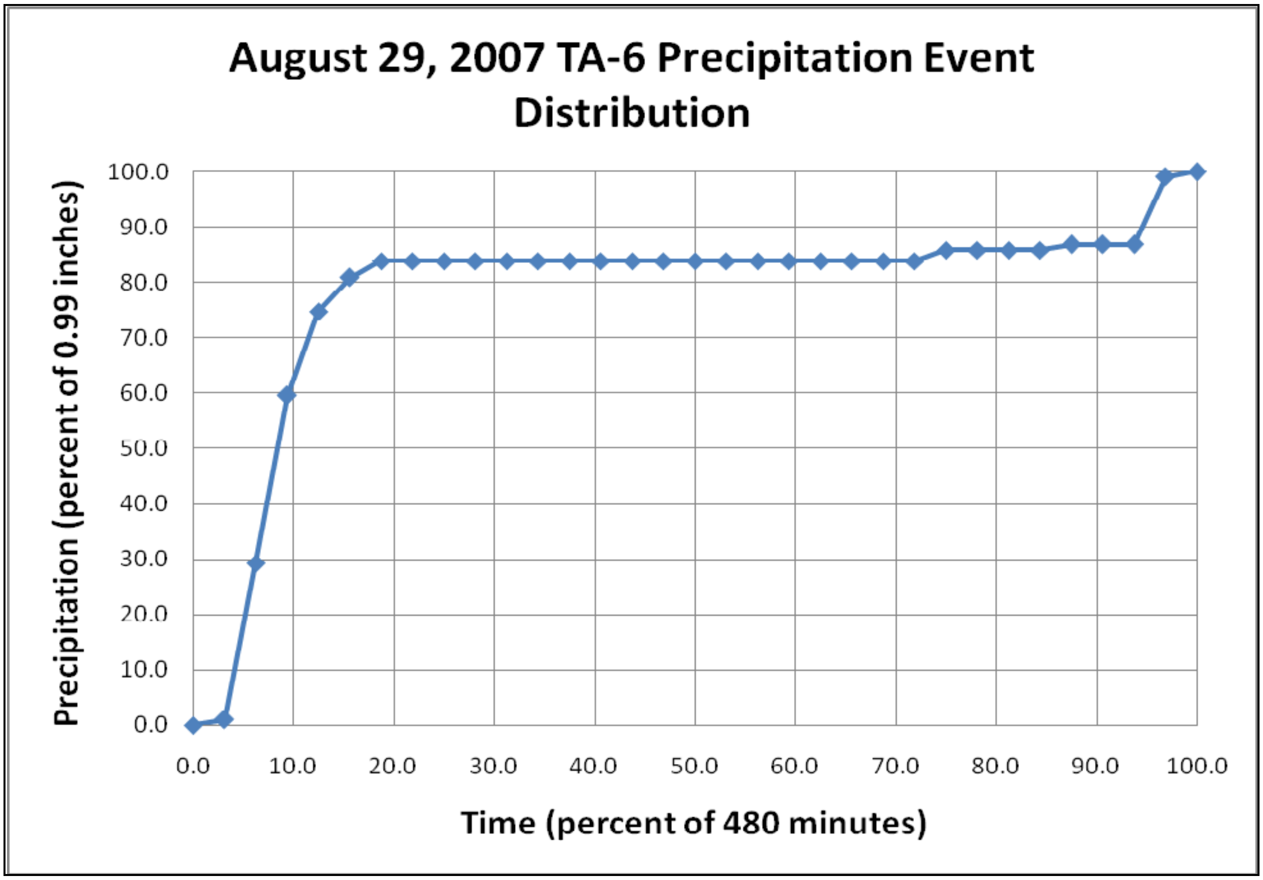


**Figure 9.** August 29, 2007 Precipitation distribution. Percent precipitation versus percent time for the August 29, 2007 storm at TA-06.

Figure 10 shows the HEC-HMS generated hydrograph for gaging station E243. The peak discharge observed at station E243 for upper Pajarito Canyon was 86.5 cfs while the model computed 25.8 cfs. The observed discharge volume for E243 was 7.6 AF while the model computed 5.5 AF, or 75 percent of the total runoff. While there was variation within the model's numerical predictions it was able to represent two separate peaks within the hydrograph.

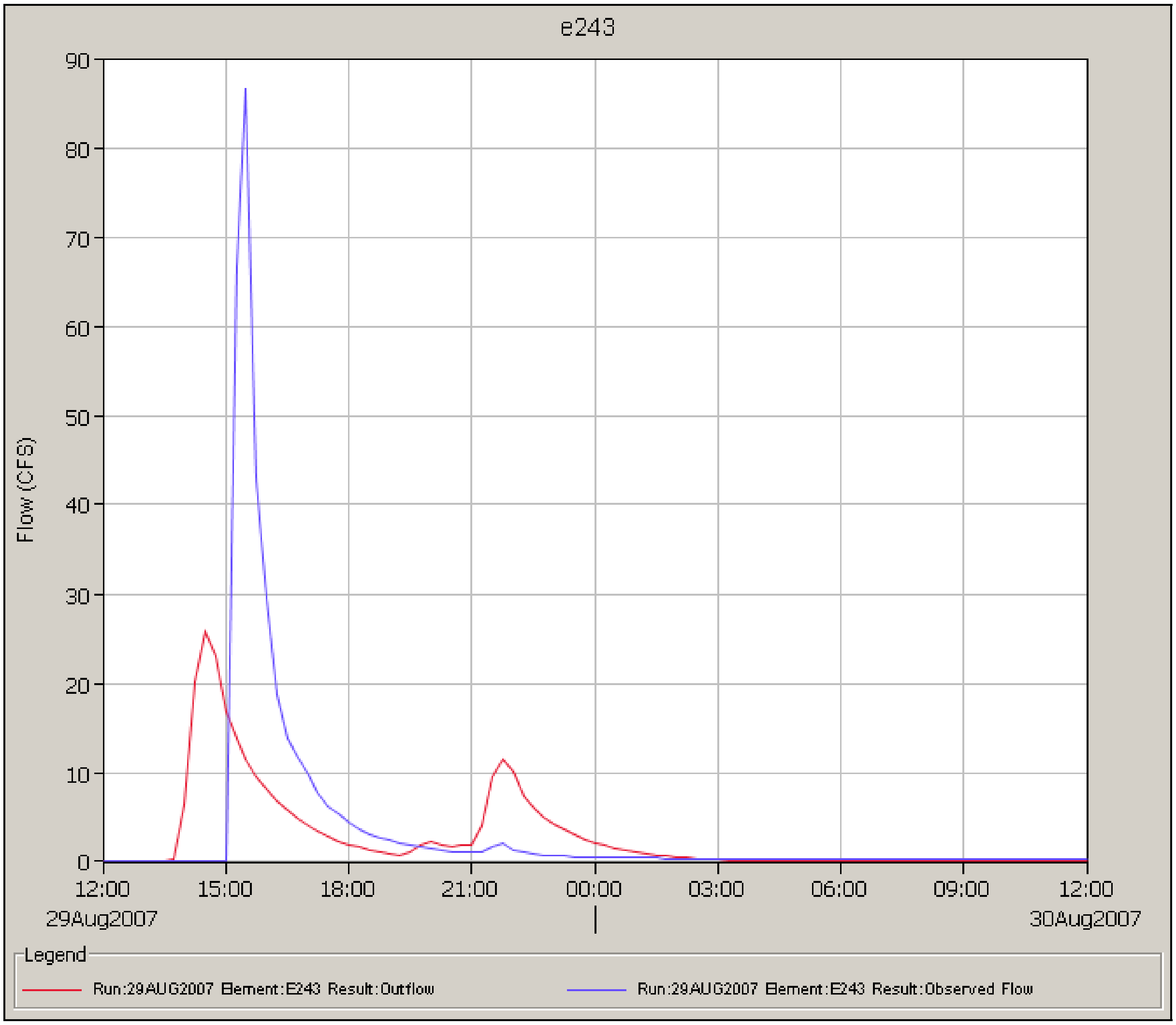


**Figure 10.** Discharge hydrograph for upper Pajarito Canyon. Station E243 discharge compared with estimated discharge for the August 29, 2007, precipitation event.

Figure 11 shows the hydrograph generated by HEC-HMS for gaging station E244. The peak discharge observed at station E244 was 32.0 cfs while the model computed 18.4 cfs. The observed discharge volume for E244 was 4.6 AF while the model computed 4.2 AF, corresponding to 91 percent of the total runoff. The model was able to represent both observed hydrograph peaks and the accuracy of the observed versus predicted discharge volumes was encouraging.

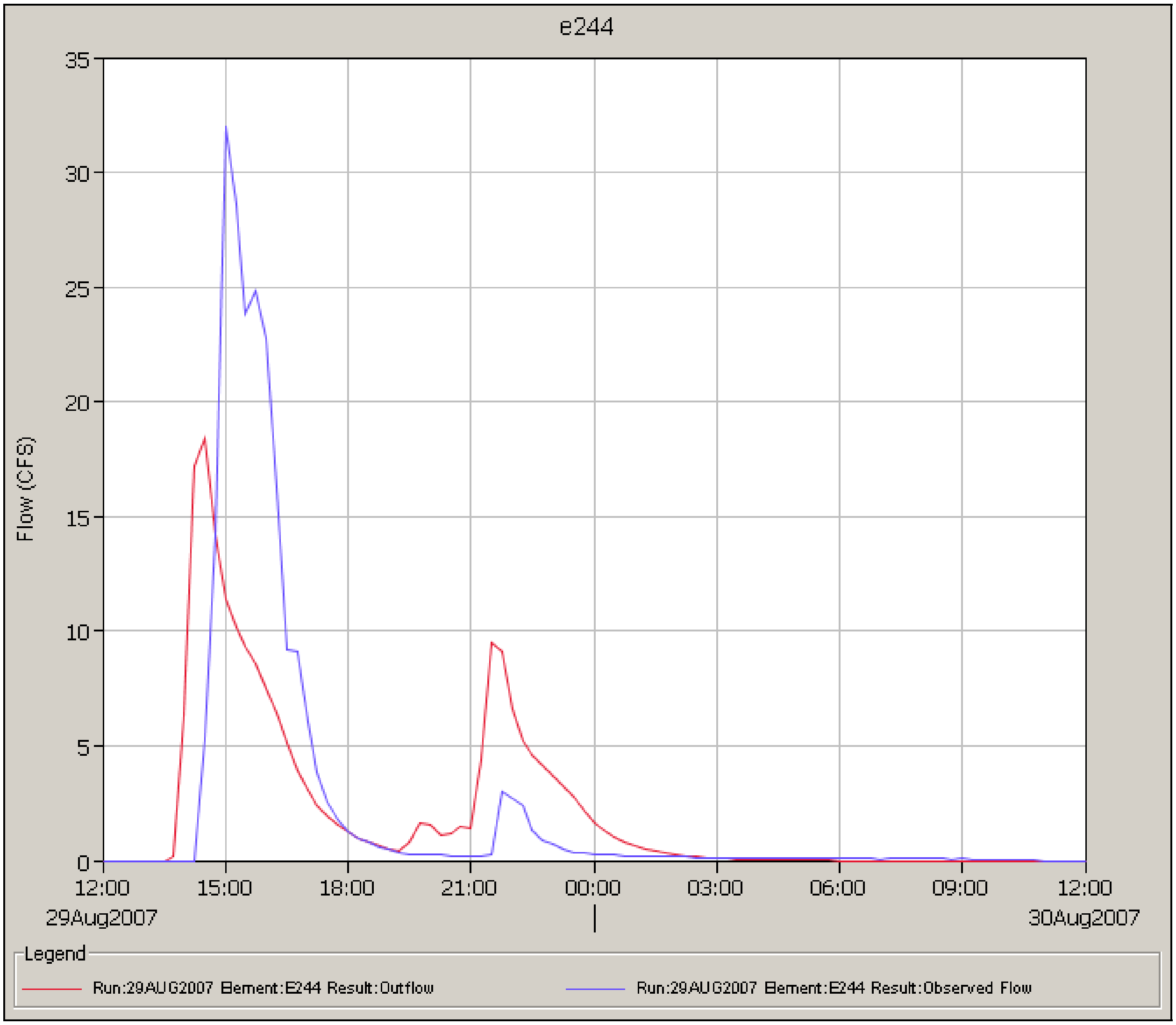


**Figure 11.** Discharge hydrograph for Twomile Canyon. Station E243 discharge compared with estimated discharge for the August 29, 2007 precipitation event.

Table 5 shows the observed and computed peak discharges, and the observed and computed discharge volumes for gaging stations E243 and E244. Of all three calibration runs the model was able to predict the peak discharge and volume discharge with the greatest accuracy for the August, 2007 event.

**Table 5.** August 29, 2007 Observed and Computed Discharge Data

| Hydrologic Element | Observed Peak Discharge (cfs) | Computed Peak Discharge (cfs) | Peak Discharge Difference (cfs) | Observed Discharge Volume (AF) | Computed Discharge Volume (AF) | Discharge Volume Difference (AF) |
|---|---|---|---|---|---|---|
| E243 | 86.5 | 25.8 | 60.7 | 7.3 | 5.5 | 1.8 |
| E244 | 32 | 18.4 | 13.6 | 4.6 | 4.2 | 0.4 |

## 5.2 September 28-29, 2005 Precipitation Event Calibration

The second calibration run was for a precipitation event on September 28-29, 2005 that dropped 2.36 in. of rain at the TA-06 MET. While the storm occurred two years prior to the CN modification, it was selected for calibration as it was the one of the few storms on record with a duration of 24-hr. The storm also had a relatively even precipitation distribution which limited biases associated with potential variation of precipitation related to spatial variability. The storm corresponded to an ARI of approximately 9-years.

Figure 12 shows percent precipitation versus percent time for the storm, demonstrating its intensity. The storm dropped a calculated 574 AF of equivalent precipitation in the drainage are for station E243 and 415 AF of equivalent precipitation in the drainage area for station E244. Of the three storms selected for calibration it was expected that the calculated precipitation total would be most accurate for this storm. There were several intensity peaks within the storm which are visible in the hydrographs. The model was able to represent these peaks, which was encouraging. However for both gaging stations it underestimated the hydrograph peak and discharge volume.

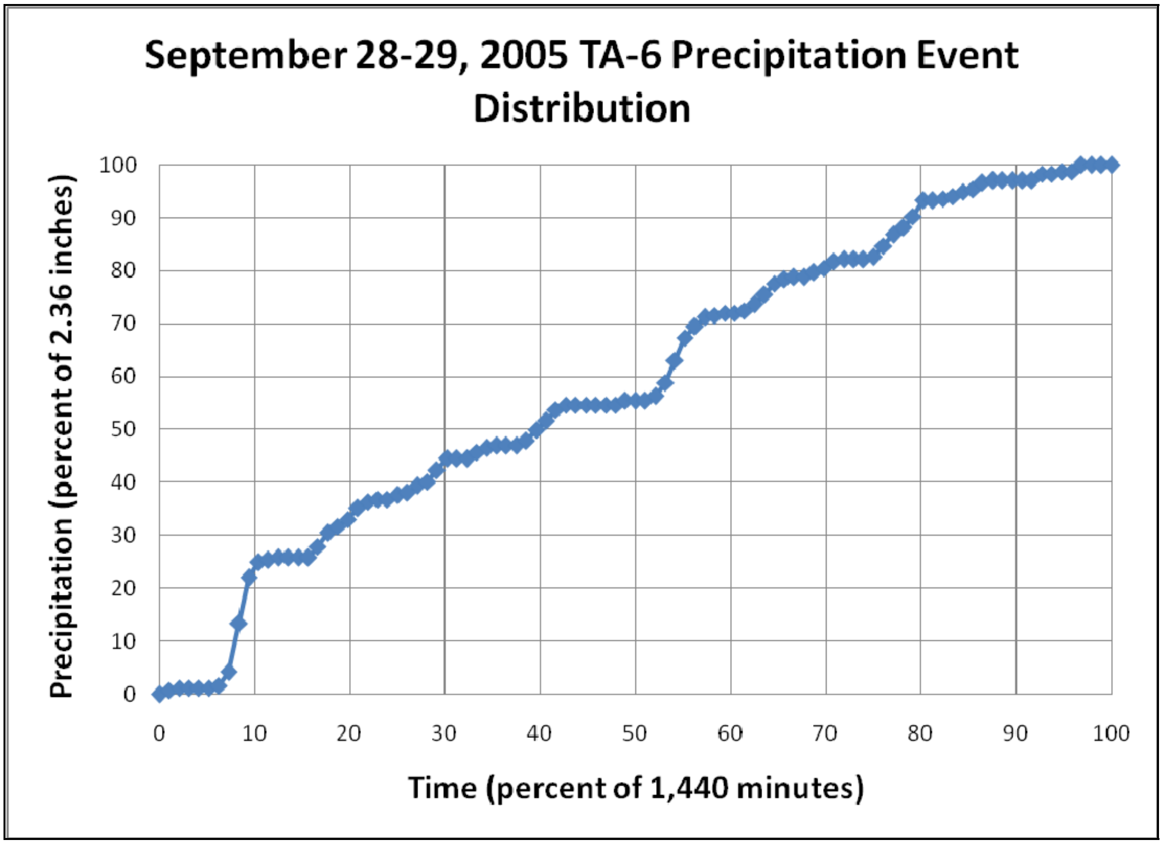


**Figure 12.** September 28-29, 2005 Precipitation distribution. Percent precipitation versus percent time for the September 28-29, 2005 storm at TA-06.

Figure 13 shows the hydrograph generated by HEC-HMS for gaging station E243. The peak discharge observed at station E243 was 46.7 cfs while the model computed 18.8 cfs. The observed discharge volume for E243 was 71 AF while the model computed 11.3 AF, corresponding to 16 percent of the total runoff. The model grossly underestimated discharge volume for the event at station E243. The general shape of the hydrograph was captured by the model, however. Several attempts were made to modify the CN and impervious area to get the model to match the gage’s runoff, but representative results were only attained with values far different from those observed in the field. For purposes of using defensible data the data gathered in the field was used.

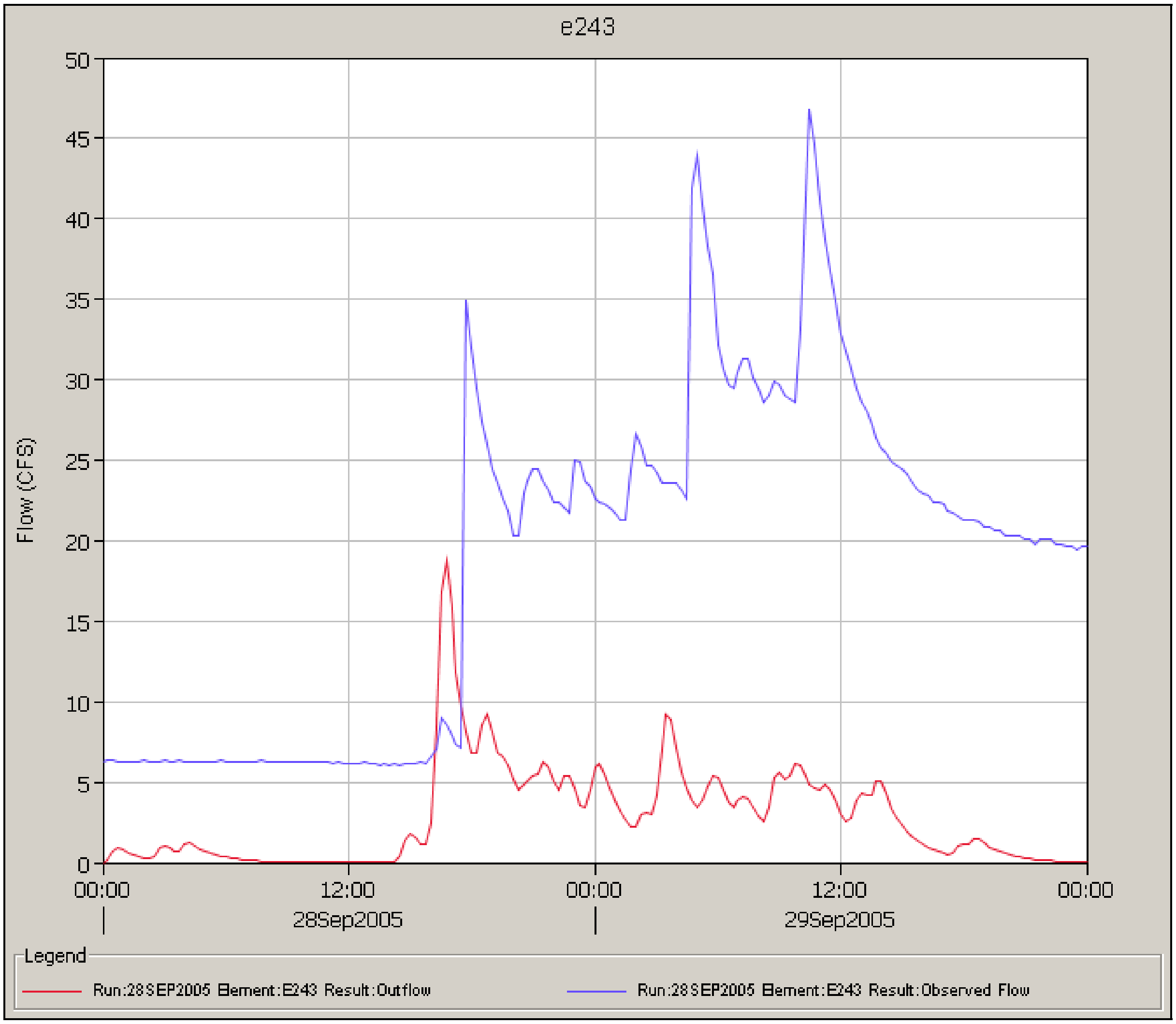


**Figure 13.** Discharge hydrograph for upper Pajarito Canyon. Station E243 discharge in blue compared with estimated discharge in red for the September 28-29, 2005, precipitation event.

Figure 14 is the hydrograph generated by HEC-HMS for gaging station E244. The peak discharge observed at station E244 was 29.8 cfs and the model computed 14.0 cfs. The observed discharge volume for E244 was 22.0 AF while the model computed 9.2 AF, equating to 42 percent of the total runoff. The model represented the first peak of the hydrograph accurately both in terms of peak magnitude and time, however it was unable to predict the remaining peaks, thus leading to underestimation of total discharge.

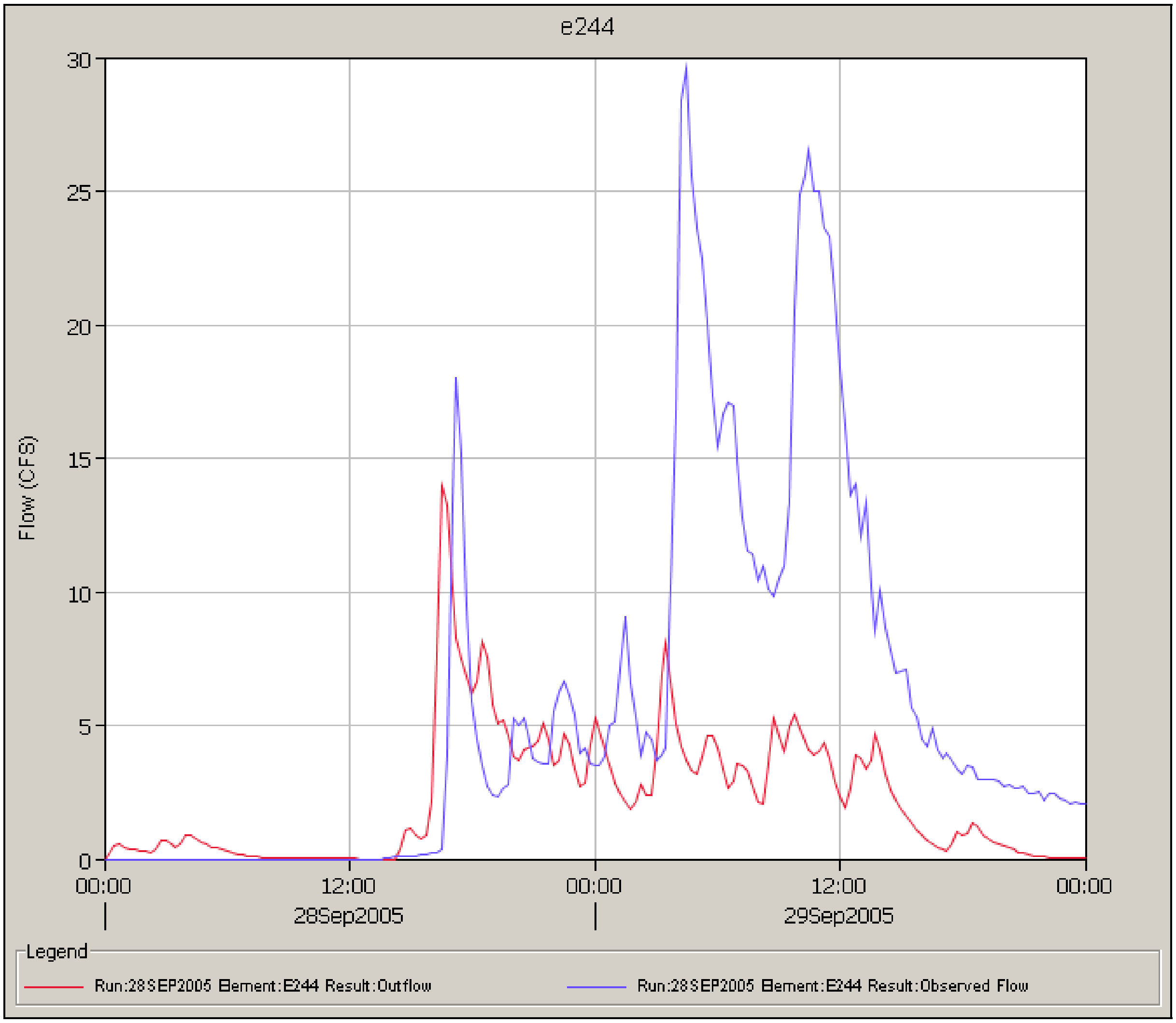


**Figure 14.** Discharge hydrograph for Twomile Canyon. Station E244 discharge in blue compared with estimated discharge in red for the September 28-29, 2005, precipitation event.

Table 6 provides the observed and calculated values for peak discharge, discharge volume and the difference between observed and computed values for the 2005 precipitation event calibration.

**Table 6.** September 28-29, 2005 Observed and Computed Discharge Data

| Hydrologic Element | Observed Peak Discharge (cfs) | Computed Peak Discharge (cfs) | Peak Discharge Difference (cfs) | Observed Discharge Volume (AF) | Computed Discharge Volume (AF) | Discharge Volume Difference (AF) |
|---|---|---|---|---|---|---|
| E243 | 46.7 | 18.8 | 27.9 | 71.0 | 11.3 | 59.7 |
| E244 | 29.8 | 14.0 | 15.8 | 22.0 | 9.2 | 12.8 |

## 5.3 August 25, 2006 Precipitation Event Calibration

Although the August 25, 2006 storm occurred only 6 years after the fire, it was selected for calibration because it was the best available representation of a 100-year intensity. The August 25, 2006 storm produced 2.01 in. of precipitation in 4.5 hr at the TA-06 MET. While the TA-06 measurements did not meet a 100-year ARI, unofficial data from a precipitation near the center of LANL, which was not available for use in calibration, showed the storm had an ARI of 100-years at its peak intensity. While the peak intensity of the storm was not centered over the TA-06 MET, record peak discharge was recorded in Twomile Canyon. Across LANL, new peak discharges were recorded at more than 20 stream gages (LANL 2006).

The storm generated peak runoff of 15.5 cfs in upper Pajarito Canyon (station E243) and 597 cfs in Twomile Canyon (station E244). The storm dropped a calculated 489 AF of equivalent precipitation into the drainage area for station E243 and 354 AF into the drainage area for gaging station E244. Given the proximity of the TA-06 MET and the spatial variability of precipitation it was not expected that the entire Pajarito watershed received this amount of precipitation. Figure 15 shows the relationship of percent precipitation versus percent time, 44 percent of the total precipitation fell within a 30 min. period.

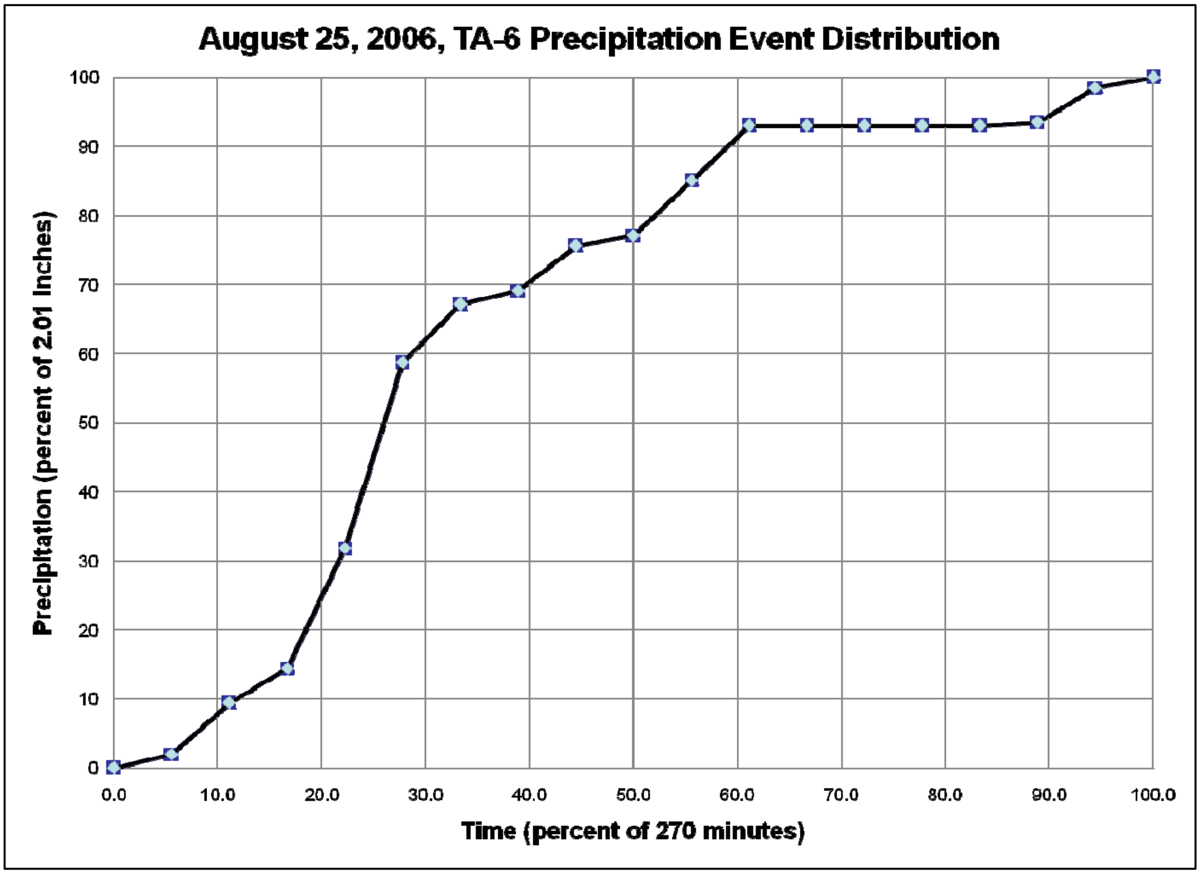


**Figure 15.** August 25, 2006 Precipitation distribution. Percent precipitation versus percent time for the August 25, 2006 storm at TA-06.

Figure 16 shows the hydrograph generated by HEC-HMS for gaging station E243. The peak discharge observed at station E243 was 15.5 cfs while the model computed 8.6 cfs. The observed discharge volume for E243 was 1.2 AF while the model computed 2.2 AF. The model overestimated the discharge volume by 1 AF for this location.

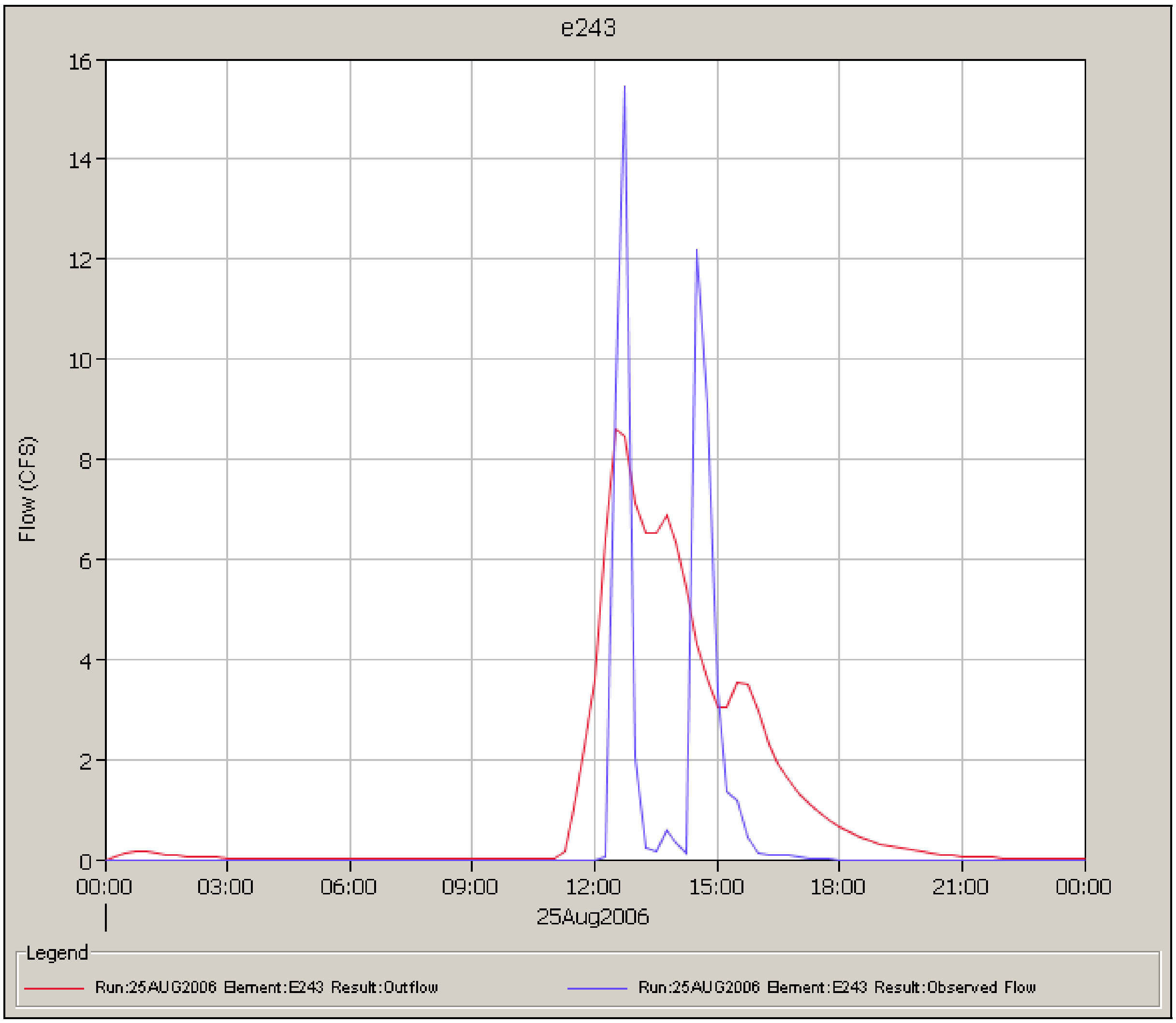


**Figure 16.** Discharge hydrograph for upper Pajarito Canyon. Station E243 discharge compared with estimated discharge for the August 25, 2006, precipitation event.

Flow at station E244 went from 1.3 cfs at 12:15 pm to 597 cfs at 12:45 pm, suggesting an extremely rapid runoff response to intense precipitation. Figure 17 shows the hydrograph generated by HEC-HMS for gaging station E244. The peak discharge observed at station E244 was 597 cfs while the model computed 36 cfs. The observed discharge volume for E244 was 100 AF while the model computed 9.1 AF equating to 9.1 percent of the total runoff. It was expected that the TA-06 precipitation data did not represent the actual precipitation that fell during the storm. There was also potential that debris could have interfered with the stream gage, thus altering flow measurement.

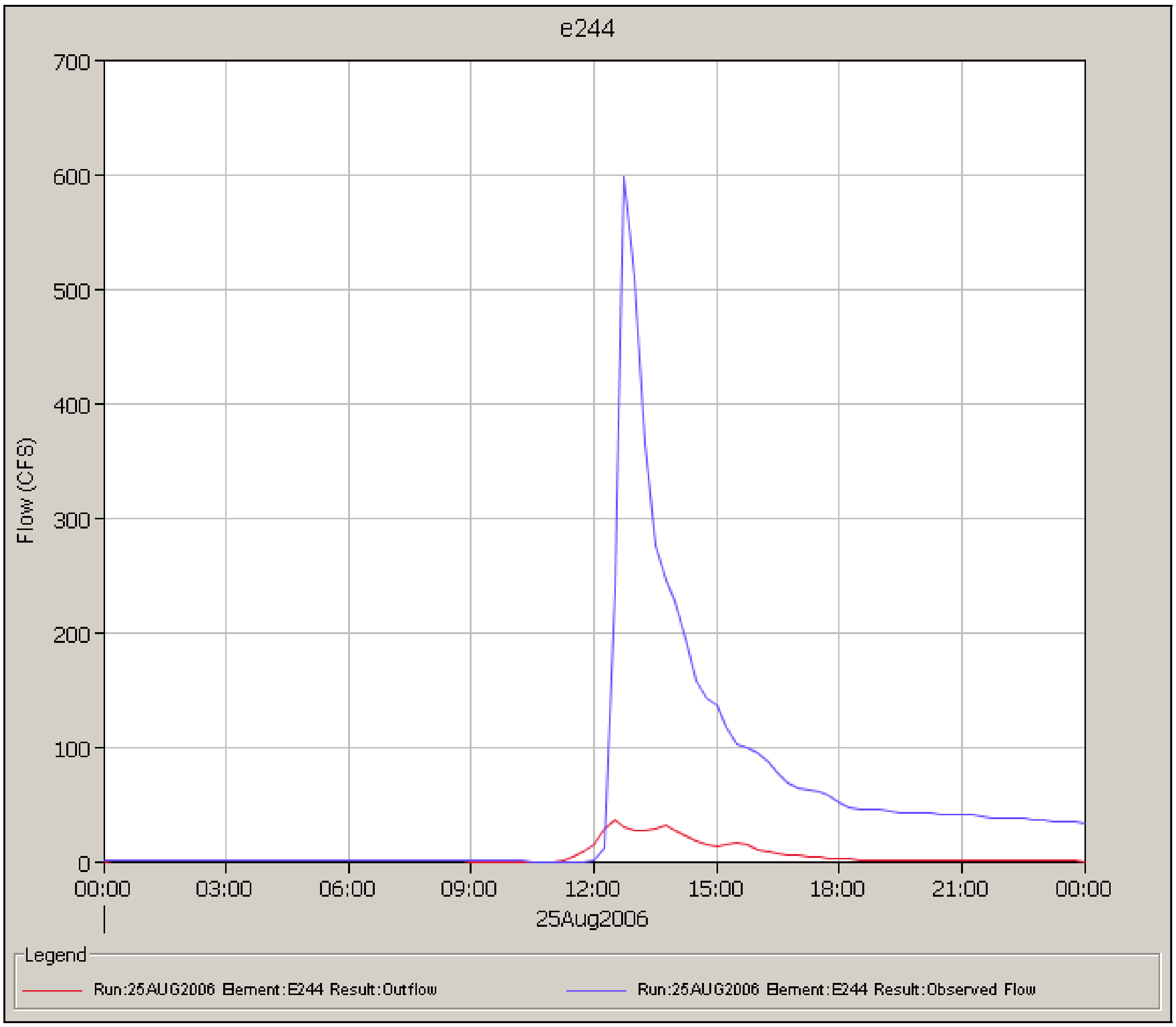


**Figure 17.** Discharge hydrograph for Twomile Canyon. Station E244 discharge compared with estimated discharge for the August 25, 2006, precipitation event.

Table 7 contains values for observed and computed peak discharge and discharge volume. The total discharge predicted for station E244 was dramatically less than the gaged flow. The calibration simulations contained variables that potentially influenced the difference between observed and estimated runoff. Contributing factors could be tied to various input parameters including precipitation data and field conditions variant from model inputs.

**Table 7.** August 25, 2006 Observed and Computed Discharge Data

| Hydrologic Element | Observed Peak Discharge (cfs) | Computed Peak Discharge (cfs) | Peak Discharge Difference (cfs) | Observed Discharge Volume (AF) | Computed Discharge Volume (AF) | Discharge Volume Difference (AF) |
|---|---|---|---|---|---|---|
| E243 | 15.5 | 8.6 | 6.9 | 1.2 | 2.2 | -1 |
| E244 | 597 | 36 | 561 | 100 | 9.1 | 90.9 |

The model predicted an average of 42 percent of the peak discharge and 24 percent of the total discharge volume at station E243. For station E244 it predicted an average of 37 percent of the peak discharge and 18 percent of the discharge volume. While these relationships show a general under-prediction of runoff it should be understood that actual precipitation may have varied greatly from what was observed at TA-06, potentially leading to variation and ultimately underestimation of runoff.

# 6.0 Hydrologic Model Design Storm Results

To analyze the runoff response of Pajarito Canyon 7 years after the Cerro Grande fire a design storm was used to facilitate precipitation within HEC-HMS in scenarios representative of both year 2000 and year 2007. The precipitation events used in the meteorological portion of the model had a 6-hr duration and an ARI of 100-years. Table 8 contains design storm intensities for each of the sub-basins in Pajarito Canyon. The intensities were distributed by methodology proposed by McLin (2001). The precipitation distributions used were separated for each sub-basin. The distribution factors can be found in Appendix G.

From reviewing NOAA's Precipitation Frequency Analysis it was determined the value used by McLin for sub-basin 1 (3.91 in.) was not consistent with a 6-hr storm with a 100-year ARI. The sub-basin 1 value was modified to 2.84 in. to remain consistent with NOAA's data.

**Table 8.** Design Storm Intensities

| **Pajarito Sub-basins** | **100-year 6 hr. Precipitation (in.)** |
|---|---|
| 1 | 2.84 |
| 2 | 2.73 |
| 3A and B | 2.73 |
| 4 | 2.10 |
| 5 | 2.27 |
| 6 | 1.86 |
| 7 | 1.59 |

**Note:** Precipitation intensities for sub-basins modeled in Pajarito Canyon.

Table 9 contains computed peak discharge and discharge volumes for all sub-basins as well as station E243, E243.5, and E244. Based on the calibration runs, the predicted peak discharge and discharge volumes for the station E243 and E244, 2007 simulations they were most likely underestimated from what actual flow from this storm may be.

**Table 9.** Modeled Discharges for 2000 and 2007 Conditions

| Hydrologic Element | Total Precipitation (AF) | 2000 Peak Discharge (cfs) | 2007 Peak Discharge (cfs) | 2000 Discharge Volume (AF) | 2007 Discharge Volume (AF) |
|---|---|---|---|---|---|
| Sub-basin 1 | 301 | 134 | 51 | 19.5 | 8.1 |
| Sub-basin 2 | 374 | 183 | 76 | 22.5 | 10.5 |
| Sub-basin 3A | 187 | 97 | 36 | 10.6 | 4.6 |
| Sub-basin 3B | 289 | 66 | 27 | 10.4 | 6.7 |
| Sub-basin 4 | 75 | 38 | 15 | 9.0 | 3.6 |
| Sub-basin 5 | 205 | 21 | 16 | 7.8 | 6.1 |
| Sub-basin 6 | 114 | 17 | 7 | 5.7 | 3.3 |
| Sub-basin 7 | 190 | 18 | 12 | 6.2 | 3.4 |
| E243 | 675 | 194 | 82 | 39.9 | 17.7 |
| E243.5 | 3 | 13 | 13 | .94 | .94 |
| E244 | 480 | 130 | 54 | 27 | 12.3 |

Figure 18 shows the computed hydrograph for the design storm comparing discharge and watershed response for upper Pajarito Canyon. Following the CN modification a reduction in peak discharge and discharge volume was observed. The hydrograph peaks occurred at approximately the same time under both conditions, however. Since the calibration runs underestimated runoff for 2007 conditions, it was expected that calculations would also be underestimated for 2000 conditions. Limited availability of stream gage data precluded extensive calibration for year 2000 simulations. The CNs used for year 2000 were from previous research at LANL. Without calibration data to use for comparison it was not possible to determine the magnitude by which the year 2000 predictions may have been underestimated.

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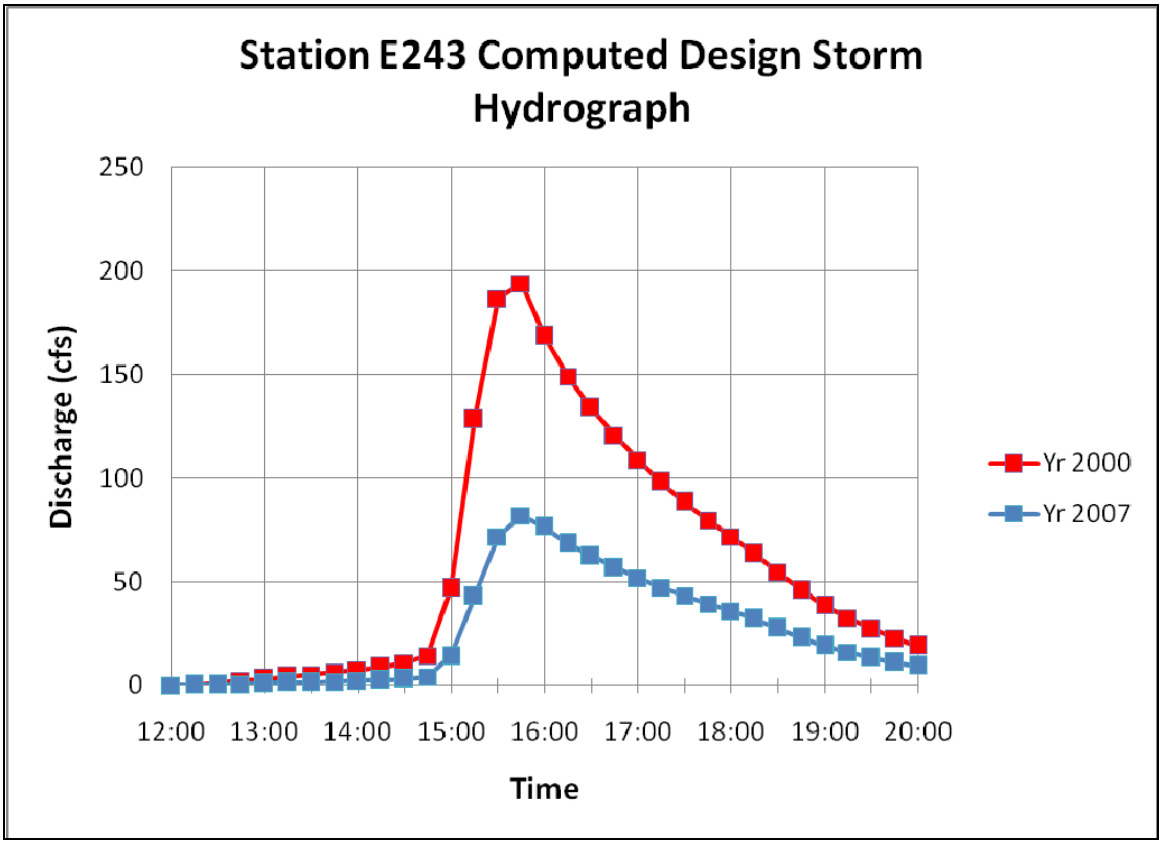


**Figure 18.** Upper Pajarito Canyon design storm hydrograph. Hydrograph depicting computed values for upper Pajarito Canyon (Sub-basins 1 and 2) with year 2000 values in red and year 2007 values in blue.

Figure 19 shows the computed hydrograph for the design storm comparing discharge and watershed response for Twomile Canyon for both year 2000 and year 2007 conditions. The model predicted a similar response for both simulations, denoted by the general shape of the hydrograph. CN modification resulted in a reduced peak and discharge volume for the 2007 simulation.

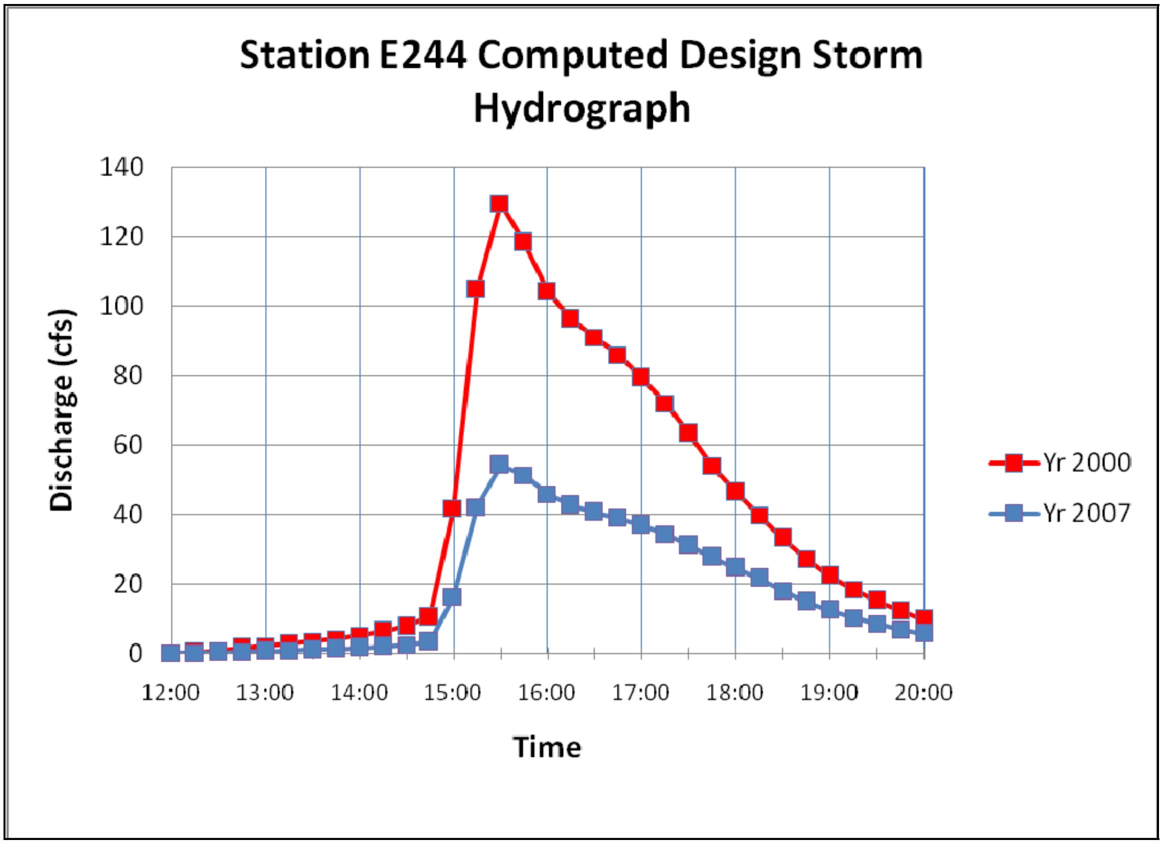


**Figure 19.** Twomile Canyon design storm hydrograph. Hydrograph depicting computed values for Twomile Canyon (Sub-basins 3A and 3B) with year 2000 values in red and year 2007 values in blue.

# 7.0 Discussion

As a reflection of the CN modification, each of the sub-basins exhibited reduced runoff for the design storm. For the sub-basins of particular interest (1, 2, 3A, and 3B), the predicted peak runoff was reduced significantly from 2000 to 2007 conditions. This change is of interest because those four sub-basins are upstream of the PFRS. The reduction was also expected as the sub-basins recovered from the burn they have greater capability to retain water through infiltration and interception following precipitation. From the driving equations from HEC-HMS as the CN decreases (supported by field work and previous research) the total maximum retention (S factor in HEC-HMS equations) increases, thus exhibiting decreased peak flows. Precipitation intensity also plays a significant role in determining runoff. Through consultation with LANL staff it was learned that prior to the fire

Pajarito Canyon and its tributaries were heavily vegetated and did not demonstrate the rapid runoff response observed following the fire.

Appendix C shows a sequence of photos from BART Unit 2 which was burned in 2000 and was a focal point of the BAER efforts. The first photo was taken in July, 2000 immediately following the installation of straw wattles. Photographs were taken from the same point in 2001, 2003, 2005, and 2007. There was significant visual evidence of recovery from the burn as a result of BAER efforts and natural succession. Many trees that burned in the fire also fell during that time. Trees can act as flow obstructions once on the ground surface. While difficult to quantify, the full effect of the rehabilitation efforts versus natural recovery the cumulative effect of the vegetative recovery is represented by CNs.

Because the CN method is empirical, there is inherent risk in using CNs to evaluate the watershed's response to fires, especially in areas like Los Alamos that are dominated by convective storms, which have not been sufficiently tested by the method (WWE 2003). Others have found this method to fit the data well despite its supposed lack of sound theoretical support (Steenhuis 1995). Grove et al. (1998) found that significant errors in runoff estimates can occur when composited rather than distributed CNs are used. This problem is avoided, however, when average runoff depths are calculated using distributed CNs because the true CN value is used to determine the runoff depth for all areas. Thus, CN compositing will always underestimate runoff depths compared to averaging of runoff calculated from distributed CN, regardless of any other factors (Grove et al. 1998). The results from the three calibration runs demonstrated a consistent underestimation of runoff by HEC-HMS. The underestimation was likely a product of using composited CNs and HEC-HMS's inability to represent weighted runoff.

According to Moglen (2000), building a spatially distributed runoff model from a model conceived in a lumped fashion, such as the SCS (NRCS in this study) method, can introduce biases in runoff prediction from the original lumped runoff estimates. While HEC-HMS is a lumped parameter model, the input parameters were derived from a spatial tool, and the results should be carefully scrutinized. Given a calibrated model, if a new approach systematically changes the answer in a single direction, the value of the new approach needs to be questioned (Moglen 2000). In the calibration runs for this model it was found that model could more accurately represent the gaged runoff, but only with inputs that weren't representative of field conditions. Consistent with the work of Moglen (2000) since the modifications changed the output in a positive direction this was determined to be a bias and the model may not compute representative results should those inputs be used under different conditions.

As supported by evidence from this project, compositing a CN can lead to variation in the model's response, including underestimation of runoff. When compared to gaged runoff computed discharge volumes were underestimated by an average of 76 percent for station E243 and 82 percent for station E244. Station E244's predictions were heavily influenced by the August 25, 2006 precipitation event, however. A possible solution to the model's underestimation would be to use a weighted runoff calculation. The primary advantage of weighting runoff is that it accounts for variability of high runoff areas and low runoff areas independently, rather than compositing them as a weighted CN does.

Multiple input parameter variations within the model may have caused differences in predicted results and observed values. A primary concern was the accuracy of localized rainfall-runoff relationships used in HEC-HMS. Pajarito Canyon may not respond in a linear manner for high-intensity or long-duration precipitation events. In addition, runoff calculations using the CN method is not a linear relationship, so a small CN corresponds to a large change in calculated runoff. The August 25, 2006 storm and runoff at station E244 supports this claim. Investigating this relationship by measuring localized precipitation, runoff, and vegetation may improve its definition.

A 100-year storm should correspond to a 100-year runoff (Jiang 2001). Using a 100-year event can assist the model's response as a majority of the precipitation should result in stream flow. This was not seen in the August 25, 2006 calibration, however, that was likely due to under-representation of the actual precipitation resulting from the spatial distribution of precipitation for that event. The CN method also often underestimates runoff for storms of low ARI. Distributed modeling techniques applied to the existing CN method allow for consideration of the orientation of high-runoff and low-runoff-producing areas when determining the runoff from a watershed (Moglen 2000).

Another potential influence is the initial abstraction ratio used. HEC-HMS automatically altered manually entered initial abstraction ratios for all sub-basins to between 0.1992 in. and 0.2009 in. Entered values ranged from 1.09 to 1.13 in. as calculated from the relationship $I_a = 0.2S$. This range implies a storage value much smaller than calculated, which could lead to miscalculation of the peak hydrograph and discharge volumes.

Additional research may focus on the application of using modified initial abstraction values in a weighted runoff scenario by applying an initial abstraction ratio of 0.05 and methods proposed by Jiang (2001). It was apparent that the CNs allowed modeled sub-basins 1, 2, 3A, and 3B to closely mimic the behavior of the watershed but the volume runoff was underestimated for all areas except those captured by gage E243.5. Using an initial abstraction ratio of 0.05 would reduce the retention volume, perhaps allowing for more accurate calculation of runoff volume.

Variation of a watershed's hydrologic characteristics greatly influences its runoff producing potential from storm to storm. An example of an influencing factor not included in the HEC-HMS model in this study is antecedent soil moisture. While the CN method allows for adjustment to account for antecedent soil moisture, this study found that without access to accurate soil moisture data, the CNs may not represent exact field conditions and runoff calculations can be influenced, leading to under- or over- prediction of runoff.

Other potential sources of variation within the calibration runs include un-gaged runoff not captured within the Geographic Information System (GIS) watershed layers. Gaging station E243.5 was included in the model and could serve as a representation of the contributions of other developed areas along Pajarito Canyon. For Water Year 2007 station E243.5 discharged 6.6 AF and from TA-06 calculations 20.8 AF of equivalent precipitation fell within its catchment area. This corresponds to 32 percent of precipitation resulting in runoff which would be expected from an urbanized area such as the E243.5 catchment. While the runoff contributions of developed areas along Pajarito Canyon likely behave in a hydrologically similar manner, their contributions should be quantified and included in future studies. Investigation was made into the effectiveness of modeling runoff in a smaller sub-basin by comparing computed results to gaged runoff at station E243.5. The model was able to predict discharge through station E243.5 with accuracy (85% of peak discharge and 100% of discharge volume for the 8/25/06 precipitation event). The model's response was likely assisted more by TA-3's developed setting and the absence of complex hydrologic characteristics found in many of the other drainages around LANL more than the reduction in sub-basin size. Since TA-3 didn't burn during the Cerro Grande fire, further evaluation into the model's capabilities in this area wasn't completed.

# 8.0 Conclusions

The results of this study indicated that with modified CNs HEC-HMS successfully demonstrated reduced peak discharges, velocities, and water surface elevations for year 2007 conditions when compared to year 2000. However, the calibration runs showed an underestimation of peak discharge and discharge volume for all simulations, leading to concerns regarding the use of a composited CN. Use of a weighed runoff scenario should be considered rather than a composited CN and it should be used in conjunction with a variable initial abstraction ratio as proposed by Jiang (2001).

Modeled results should always be validated with field data, if possible, to verify their accuracy and precision. If the results are not accurate, new input data should be considered, or an alternative modeling approach or software should be evaluated before predictions impacting future development are made. Following the calibration runs, it became apparent that HEC-HMS, when applied with composite CNs, under-estimated peak discharge and discharge volume for all three calibration simulations. As was discussed, the model predicted an average of 42 percent the peak discharge in upper Pajarito Canyon and 24 percent of the total volume discharge for three calibration events.  For the same calibration events it predicted 37 percent of the peak discharge and 18 percent of the volume discharge within Twomile Canyon. The most encouraging results were from station E244 for the August 27, 2007 event where the model was able to predict 91 percent of the discharge volume. The model was not able to replicate this accuracy for any of the other calibration storms, thus demonstrating poor accuracy and precision.  While more accurate results were obtained through modification of the input parameters, the decision was made to use field data rather than input values that could not be validated. Also evident was the fact that not all hydrologic properties of the watershed were accounted for, including antecedent soil moisture conditions. In the design storm simulation it was expected that the calculated runoff may be less than what would occur from an actual storm of equal magnitude.

Incorporating spatial variability into the NRCS runoff equation can lead to clear biases between the spatial and lumped results. The model did not weigh runoff because it relied on a composite CN to represent each sub-basin. It was not clear if using smaller sub-basins would aid with differentiating the drainage areas and improve runoff calculations. Simulations made with station E243.5 showed potential for HEC-HMS to accurately represent runoff in terms of peak discharge and discharge volume. The urbanized characteristics of the drainage to E243.5 likely assisted the model's response, however. TA-3 lacks the complex hydrologic characteristics that are present in much of Pajarito Canyon.

The location of the TA-06 precipitation station precluded use of exact localized precipitation data for the HEC-HMS calibration for Twomile and upper Pajarito Canyons. Given the high degree of spatial variability of precipitation, it was not possible to represent local precipitation patterns accurately without additional precipitation monitoring station data. While the data was not available for this study, the recent implementation of Thiessen polygon method has helped correct this with an expanded number of stations.

The data intensiveness of HEC-HMS leaves room for interpretation in the parameters in the model used. There also was no capacity to model specific spatial attributes of a watershed (i.e., impervious areas) within HEC-HMS without using smaller sub-basins. If smaller sub-basins were used, their behavior still may not be accurately quantified.

Input parameter variations also arose from complex terrain and associated ephemeral streams, especially under adverse conditions such as those resulting from a burn. Modeling of precipitation runoff over the steep, narrow extent of Pajarito Canyon was not effective and would not be possible without detailed information associated with precipitation, ground cover, CNs, and soil.

The complex hydrologic characteristics of Pajarito Canyon may not be represented accurately when the methods from this study are used. The complex and steep canyons complicate the representation of the watershed with weighted CNs.  Not all parts of Pajarito Canyon behave in a hydrologically consistent manner. Using average slopes and composite CNs may lead to inaccurate results which were visible in the model in this study**.** Since the CN method was developed in small agricultural watersheds in the northeast and it's applicability in a composited form may be limited in the southwest. Intense data requirements precluded quick and accurate analysis of runoff, thus limiting the applicability of the model for small scale studies where results could be required within a short timeframe. Furthermore, the application of HEC-HMS limits the modeler's ability to represent weighted runoff and variable initial abstraction ratios.  For these reasons it is not recommended to use HEC-HMS for making runoff calculations and stormwater management decisions in Pajarito Canyon.

# 9.0 Future Work

Further investigation for this project should include demonstrating different calculation techniques with the intent of demonstrating how weighting runoff rather than CNs alters calculated flow. Future work could also include expanding the sub-basins within ArcMap to account for contributing areas not included within the predefined watershed area. Developed areas along Pajarito Road have diverted stormwater runoff into Pajarito Canyon. These additional drainage areas add to the watershed's area, and because they are largely impervious, they contribute increased discharge volume and potentially increase runoff velocity. Aside from station E243.5, which is gaged, the overall contributions of these areas to Pajarito Canyon are not completely quantified.

Another area of interest for future research could include developing a runoff model that captures more accurately the hydrologic characteristics of Pajarito Canyon. This may require the use of GIS and finite element modeling capabilities to model small sub-basins to generate more representative results. An additional factor to consider would be to represent hydrologic factors not depicted in this study including the effect of down timber and BMPs on runoff. The results of this exercise could be used to analyze potential stormwater runoff from proposed construction sites to assist LANL managers and contractors with stormwater management.  By improving the understanding of localized rainfall- runoff relationships planning appropriate management techniques can be achieved with greater success.

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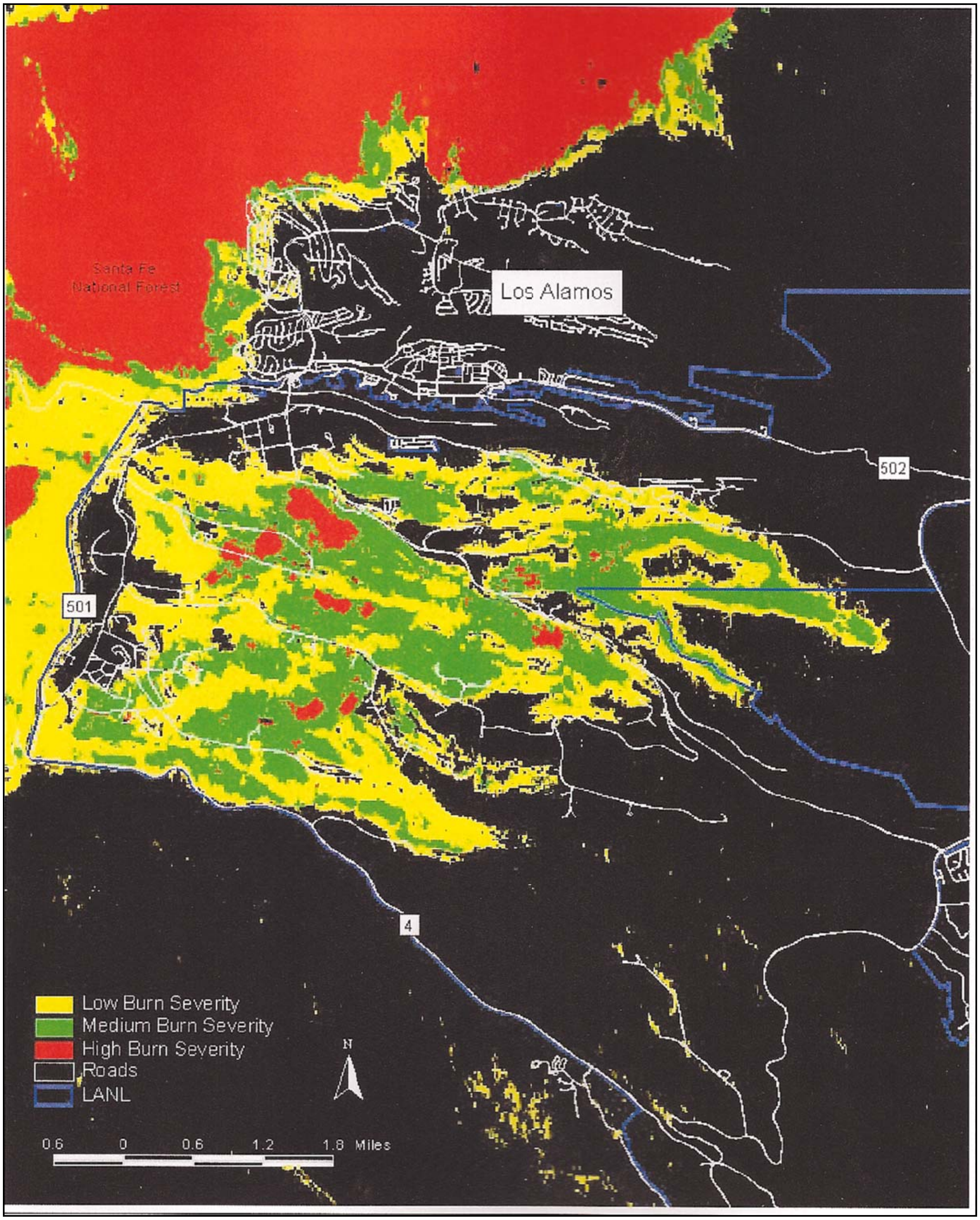
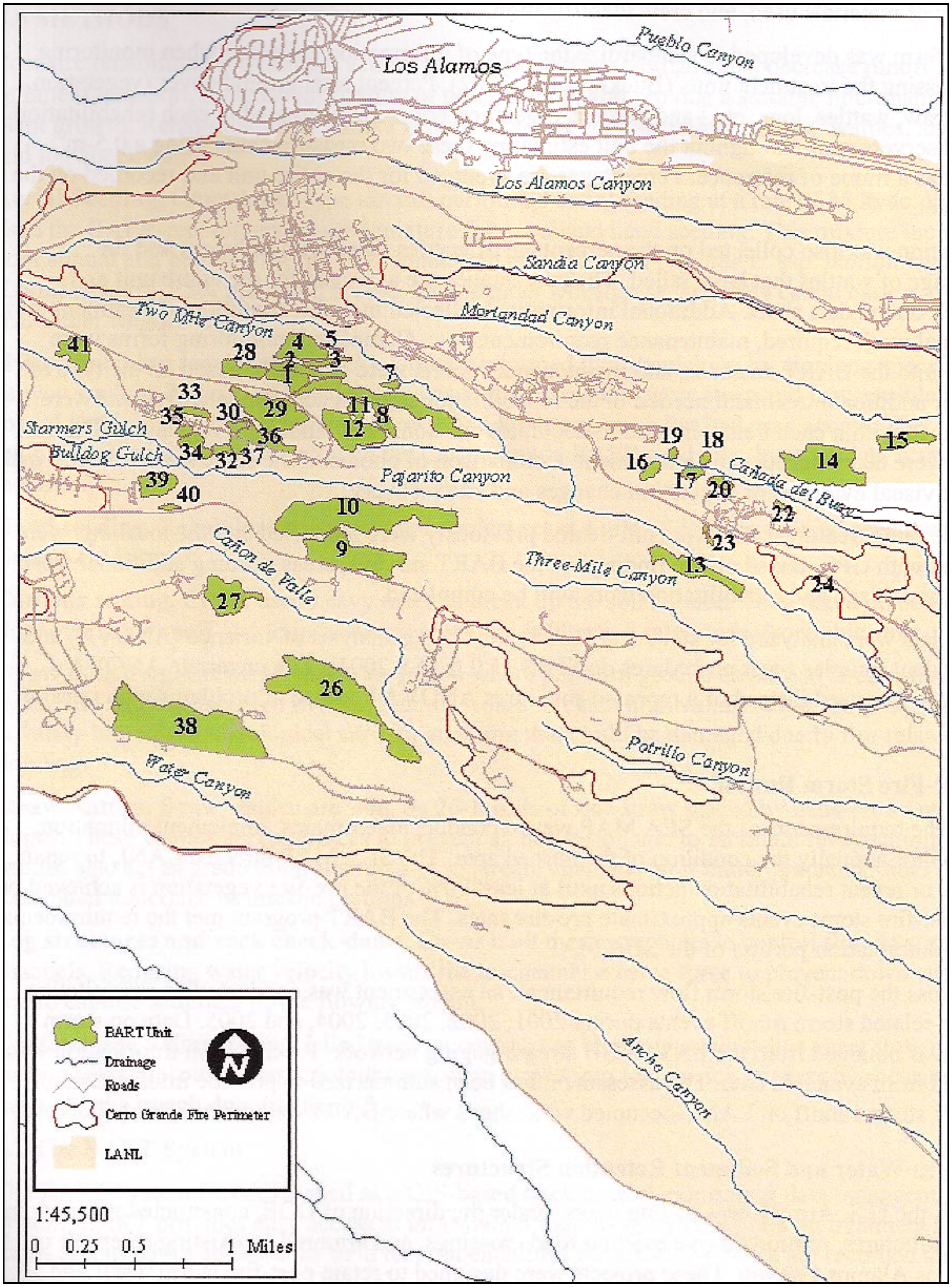
**Appendix A.** Cerro Grande Fire Burn Intensities (from Buckley et al. 2005)



**Appendix B.** Cerro Grande Fire BART units (BART units for the Cerro Grande Fire rehabilitation from Buckley et al. 2005).



**Appendix C:** BART Unit 2 Photographs. BART Unit 2 Photo 1 taken in July,2000 (from Buckley et al. 2005). All photographs were taken from the same photo point with the first photo from 2000 and ranging through 2007.

BART Unit 2, 2000

BART Unit 2, 2001

BART Unit 2, 2003

BART Unit 2, 2005

BART Unit 2, 2007

**Appendix D.** Vegetation and watershed photographs. Vegetation and watershed photographs of BART units analyzed for vegetative cover and hydrologic modeling.

BART Unit 2, 2007.

BART Unit 6 – Channel Bottom, 2007.

Upper reaches of BART Unit 6, 2007.

BART Unit 6, 2007.

BART Unit 34, 2007.

BART Unit 34, 2007.

**Appendix E.** Gaging Station Information. Gaging Stations in Pajarito Canyon used for model calibration from 2006 Surface Water Data at Los Alamos National Laboratory (Romero, Ortiz, and Kuyumjian, 2006).

**E243 Pajarito above Twomile (used for calibrating upper Pajarito Canyon)**

Sutron data logger (5 min. interval) with cellular phone and speech modem housed in a NEMA shelter on left bank. Bubble gage is sensing device and outside staff is reference gage. An ISCO-brand automatic sampler is stage-triggered by the data logger. Porcelain staff gage was available for outside reference until August 24. A steel post was installed 9/1/06 on left bank to existing datum and was used as a reference point of 2.56 gage until gage reconstruction was accomplished in April 2006. No provision for direct measurement of flows above wading stage.

**Field Work.** The station was visited twenty five times in 2006 for the purpose of making a discharge measurement and/or servicing the instrumentation. Field inspections for the gage are available on request.

**Datum Correction.** None from levels. On September 1 at same site, a datum correction of 1.0 ft lower due to the scour in channel after the flood of August 24, 2005.

Gage-Height Record. The data logger gage height record was complete and satisfactory for the water year.

**Rating.** The channel is straight for 150 feet above and below the gage. It is trapezoidal with the bed fairly well armored with large gravel and some cobbles. Banks are fairly well vegetated with grasses and should remain stable at all flows. Once it is well developed, the rating should be stable.

Rating 3 was redrawn based on low measurements and slope area of flood in 2005. Rating “back out” to left at top, but that is hydraulically most likely the case. Because rating 3 was never used for high flows, some of the upper points were just edited.

**Discharge.** Computed rating 3 with shift at low flow applied by “V” diagrams. Estimated zero flow in winter from icing of bubbler orifice. Stream was frozen dry.

**Remarks** This station was originally at a site downstream about 0.5 mile. With the building of the Pajarito Flood Control Structure it had to be moved. That site was never rated and although gage height record is available for 1998-2002. Record good, except for estimated daily discharges which are poor.

**E244 - Twomile above Pajarito (used for calibrating Twomile Canyon)**

**Equipment.** Sutron 8210 data logger (5 min. interval) with cellular phone and speech modem housed in a NEMA shelter. Stage sensor is milltronics sonic probe. ISCO samplers are housed in a separate shelter and are activated by stage through the data logger. An outside staff gage is available for reference. Wading measurements can be in the vicinity of the gage. No provision for measurement above wading stages.

**Field Work.** The station was visited twenty five times in 2006 for the purpose of making a discharge measurement and/or servicing the instrumentation. Field inspections for the gage are available upon request.

**Datum Correction.** None from levels. Some corrections applied as datums, but they are actually "pen" corrections. Gage reset by levels after destruction by flood in August 2006.

**Rating.** The channel at the gage is straight for about 150 feet above gage and 50 feet below gage. Channel expands quite a bit below gage. Bed material is coarse sand and gravel. Banks are grassy with some small trees and outcrops affecting roughness at higher flows.

Rating 1 was continued in use with large -.45 shift at extreme los flows. Measurements 10, 11 defined the shifts. Shift diagrams distributed them by time/stage and no shift was used above 10 cfs.

Peak of record occurred on August 25, 2006 confirmed b flood mark. Rating 1 was extended by log plotting to 6.5 ft. stage.

Rating No. 1 is good to fair.

**Discharge.** Discharge was computed by applying Rating No. 1 using variable shift diagrams. Some periods have large shifts on lower end because of dry condition varying the PZF. Periods of lost record were estimated using weather records and comparison with E243 which is just downstream on Pajarito Canyon.

Remarks. Records fair, except for estimated daily discharges, which are poor. This station was operated at a site 200 feet downstream but never rated. It had to be moved because that site is backwater from Pajarito Flood Control structure which was built in 2000 just after the Cerro Grande Fire.

**Appendix F.** Design Storm Distribution. Precipitation intensity distribution for the design storm in each of the sub-basins for Pajarito Canyon from McLin (2001).

| Time | Distribution | Time | Distribution |
|---|---|---|---|
| 12:00:00 PM | 0 | 3:05:00 PM | 0.824356 |
| 12:05:00 PM | 0.001612 | 3:10:00 PM | 0.854579 |
| 12:10:00 PM | 0.003267 | 3:15:00 PM | 0.873203 |
| 12:15:00 PM | 0.004968 | 3:20:00 PM | 0.886734 |
| 12:20:00 PM | 0.006716 | 3:25:00 PM | 0.897403 |
| 12:25:00 PM | 0.008515 | 3:30:00 PM | 0.906237 |
| 12:30:00 PM | 0.010369 | 3:35:00 PM | 0.913792 |
| 12:35:00 PM | 0.01228 | 3:40:00 PM | 0.920401 |
| 12:40:00 PM | 0.014253 | 3:45:00 PM | 0.926285 |
| 12:45:00 PM | 0.016292 | 3:50:00 PM | 0.931592 |
| 12:50:00 PM | 0.018403 | 3:55:00 PM | 0.93643 |
| 12:55:00 PM | 0.020589 | 4:00:00 PM | 0.940878 |
| 1:00:00 PM | 0.022859 | 4:05:00 PM | 0.944998 |
| 1:05:00 PM | 0.025218 | 4:10:00 PM | 0.948836 |
| 1:10:00 PM | 0.027674 | 4:15:00 PM | 0.95243 |
| 1:15:00 PM | 0.030236 | 4:20:00 PM | 0.955812 |
| 1:20:00 PM | 0.032915 | 4:25:00 PM | 0.959005 |
| 1:25:00 PM | 0.035722 | 4:30:00 PM | 0.962031 |
| 1:30:00 PM | 0.038671 | 4:35:00 PM | 0.964907 |
| 1:35:00 PM | 0.041779 | 4:40:00 PM | 0.967649 |
| 1:40:00 PM | 0.045063 | 4:45:00 PM | 0.970268 |
| 1:45:00 PM | 0.048548 | 4:50:00 PM | 0.972776 |
| 1:50:00 PM | 0.05226 | 4:55:00 PM | 0.975183 |
| 1:55:00 PM | 0.056233 | 5:00:00 PM | 0.977496 |
| 2:00:00 PM | 0.06051 | 5:05:00 PM | 0.979723 |
| 2:05:00 PM | 0.065145 | 5:10:00 PM | 0.981871 |
| 2:10:00 PM | 0.070206 | 5:15:00 PM | 0.983945 |
| 2:15:00 PM | 0.075786 | 5:20:00 PM | 0.985951 |
| 2:20:00 PM | 0.08201 | 5:25:00 PM | 0.987892 |
| 2:25:00 PM | 0.089059 | 5:30:00 PM | 0.989774 |
| 2:30:00 PM | 0.097201 | 5:35:00 PM | 0.9916 |
| 2:35:00 PM | 0.106863 | 5:40:00 PM | 0.993374 |
| 2:40:00 PM | 0.118788 | 5:45:00 PM | 0.995098 |
| 2:45:00 PM | 0.134449 | 5:50:00 PM | 0.996775 |
| 2:50:00 PM | 0.15747 | 5:55:00 PM | 0.998408 |
| 2:55:00 PM | 0.201581 | 6:00:00 PM | 1 |
| 3:00:00 PM | 0.742916 | | |

**Appendix G.** Soil Types in Pajarito Canyon. Soil types found in Pajarito Canyon expressed as a percentage. Complete soil survey data was not available for Sub-basin 1, and therefore Sub-basin 2 data was used.

| Soil Type | Sub-basin 2 | Sub-basin 3A | Sub-basin 3B | Sub-basin 4 | Sub-basin 5 | Sub-basin 6 | Sub-basin 7 |
|---|---|---|---|---|---|---|---|
| Rock outcrop | 22 | 16 | 35 | 38 | 49 | 11.8 | 3 |
| Carjo loam, 1 to 9 percent slopes | 43 | 12 | 25 | | 18 | | |
| Tocal very fine sandy loam, 3 to 8 percent slopes | 23 | 50 | 29 | | | | |
| Mirand-Alanos complex, 5 to 40 percent slopes | 8 | 22 | | | | | |
| Cajete-Cypher association, 8 to 50 percent slopes | 3 | | | | | | |
| Hackroy-Nyjack association, 1 to 5 percent slopes | 1 | | 6 | 27 | 6 | 31.0 | |
| Totavi loamy sand, 0 to 5 percent slopes | | | 1 | 24 | 8 | 30.5 | |
| Rock outcrop-Hackroy complex, 1 to 8 percent slopes | | | 3 | 11 | 19 | 26.5 | |
| Rock outcrop-Prieta complex, 3 to 15 percent slopes | | | | | | 0.1 | 89 |
| Penistaja-Hagerman association, 1 to 5 percent slopes | | | | | | | 8 |

**Appendix H.** 8/29-8/30/2007 Pajarito Canyon stream gage data. Discharge data was used for model calibration.

| Date | Time | Station E243 Discharge (cfs) | Station E243.5 Discharge (cfs) | Station E244 Discharge (cfs) |
|---|---|---|---|---|
| 8/29/2007 | 12:00 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:05 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:10 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:15 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:20 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:25 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:30 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:35 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:40 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:45 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:50 | 0.03 | 0 | 0 |
| 8/29/2007 | 12:55 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:00 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:05 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:10 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:15 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:20 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:25 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:30 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:35 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:40 | 0.03 | 0 | 0 |
| 8/29/2007 | 13:45 | 0.03 | 1.06 | 0 |
| 8/29/2007 | 13:50 | 0.03 | 3.12 | 0 |
| 8/29/2007 | 13:55 | 0.03 | 3.85 | 0 |
| 8/29/2007 | 14:00 | 0.04 | 5.84 | 0 |
| 8/29/2007 | 14:05 | 0.05 | 10 | 0 |
| 8/29/2007 | 14:10 | 0.05 | 10.77 | 0 |
| 8/29/2007 | 14:15 | 0.05 | 9.06 | 0 |
| 8/29/2007 | 14:20 | 0.05 | 6.46 | 0.04 |
| 8/29/2007 | 14:25 | 0.05 | 3.33 | 1.06 |

| | | | | |
|---|---|---|---|---|
| 8/29/2007 | 14:30 | 0.04 | 1.89 | 5.3 |
| 8/29/2007 | 14:35 | 0.04 | 1.59 | 10.9 |
| 8/29/2007 | 14:40 | 0.04 | 1.61 | 13.75 |
| 8/29/2007 | 14:45 | 0.04 | 1.46 | 14.11 |
| 8/29/2007 | 14:50 | 0.04 | 1.23 | 18.63 |
| 8/29/2007 | 14:55 | 0.04 | 1.12 | 26.82 |
| 8/29/2007 | 15:00 | 0.04 | 0.94 | 32.01 |
| 8/29/2007 | 15:05 | 0.03 | 0.66 | 32.82 |
| 8/29/2007 | 15:10 | 8.7 | 0.45 | 30.78 |
| 8/29/2007 | 15:15 | 66.51 | 0.3 | 28.6 |
| 8/29/2007 | 15:20 | 108.69 | 0.2 | 26.69 |
| 8/29/2007 | 15:25 | 100.87 | 0.12 | 25.21 |
| 8/29/2007 | 15:30 | 86.55 | 0.07 | 23.8 |
| 8/29/2007 | 15:35 | 61.68 | 0.04 | 23.27 |
| 8/29/2007 | 15:40 | 48.47 | 0.02 | 24.32 |
| 8/29/2007 | 15:45 | 43.06 | 0.01 | 24.85 |
| 8/29/2007 | 15:50 | 37.06 | 0 | 25.4 |
| 8/29/2007 | 15:55 | 32.86 | 0 | 25.04 |
| 8/29/2007 | 16:00 | 29.57 | 0 | 22.77 |
| 8/29/2007 | 16:05 | 25.56 | 0 | 20.93 |
| 8/29/2007 | 16:10 | 21.56 | 0 | 19.05 |
| 8/29/2007 | 16:15 | 18.73 | 0 | 16.28 |
| 8/29/2007 | 16:20 | 16.77 | 0 | 13.3 |
| 8/29/2007 | 16:25 | 15.56 | 0 | 10.59 |
| 8/29/2007 | 16:30 | 13.89 | 0 | 9.22 |
| 8/29/2007 | 16:35 | 12.83 | 0 | 8.56 |
| 8/29/2007 | 16:40 | 12.57 | 0 | 8.86 |
| 8/29/2007 | 16:45 | 11.62 | 0 | 9.14 |
| 8/29/2007 | 16:50 | 10.93 | 0 | 8.64 |
| 8/29/2007 | 16:55 | 10.7 | 0 | 7.84 |
| 8/29/2007 | 17:00 | 9.66 | 0 | 6.03 |
| 8/29/2007 | 17:05 | 8.65 | 0 | 4.6 |
| 8/29/2007 | 17:10 | 8.1 | 0 | 4.15 |
| 8/29/2007 | 17:15 | 7.74 | 0 | 3.87 |
| 8/29/2007 | 17:20 | 7.24 | 0 | 3.47 |
| 8/29/2007 | 17:25 | 6.58 | 0 | 3.11 |
| 8/29/2007 | 17:30 | 6.13 | 0 | 2.58 |

| | | | | |
|---|---|---|---|---|
| 8/29/2007 | 17:35 | 5.99 | 0 | 2.21 |
| 8/29/2007 | 17:40 | 5.85 | 0 | 2.05 |
| 8/29/2007 | 17:45 | 5.44 | 0 | 1.83 |
| 8/29/2007 | 17:50 | 5.04 | 0 | 1.51 |
| 8/29/2007 | 17:55 | 4.79 | 0 | 1.38 |
| 8/29/2007 | 18:00 | 4.44 | 0 | 1.29 |
| 8/29/2007 | 18:05 | 4.09 | 0 | 1.14 |
| 8/29/2007 | 18:10 | 3.98 | 0 | 1.03 |
| 8/29/2007 | 18:15 | 3.67 | 0 | 0.95 |
| 8/29/2007 | 18:20 | 3.38 | 0 | 0.86 |
| 8/29/2007 | 18:25 | 3.19 | 0 | 0.82 |
| 8/29/2007 | 18:30 | 3.1 | 0 | 0.8 |
| 8/29/2007 | 18:35 | 2.93 | 0 | 0.76 |
| 8/29/2007 | 18:40 | 2.68 | 0 | 0.69 |
| 8/29/2007 | 18:45 | 2.68 | 0 | 0.59 |
| 8/29/2007 | 18:50 | 2.61 | 0 | 0.56 |
| 8/29/2007 | 18:55 | 2.45 | 0 | 0.54 |
| 8/29/2007 | 19:00 | 2.38 | 0 | 0.52 |
| 8/29/2007 | 19:05 | 2.38 | 0 | 0.47 |
| 8/29/2007 | 19:10 | 2.3 | 0 | 0.39 |
| 8/29/2007 | 19:15 | 2.09 | 0 | 0.35 |
| 8/29/2007 | 19:20 | 2.03 | 0 | 0.34 |
| 8/29/2007 | 19:25 | 1.97 | 0 | 0.33 |
| 8/29/2007 | 19:30 | 1.91 | 0 | 0.3 |
| 8/29/2007 | 19:35 | 1.85 | 0.39 | 0.3 |
| 8/29/2007 | 19:40 | 1.73 | 0.65 | 0.27 |
| 8/29/2007 | 19:45 | 1.67 | 0.39 | 0.25 |
| 8/29/2007 | 19:50 | 1.61 | 0.22 | 0.28 |
| 8/29/2007 | 19:55 | 1.5 | 0.12 | 0.28 |
| 8/29/2007 | 20:00 | 1.46 | 0.07 | 0.26 |
| 8/29/2007 | 20:05 | 1.41 | 0.04 | 0.26 |
| 8/29/2007 | 20:10 | 1.36 | 0.02 | 0.26 |
| 8/29/2007 | 20:15 | 1.32 | 0.01 | 0.24 |
| 8/29/2007 | 20:20 | 1.32 | 0 | 0.22 |
| 8/29/2007 | 20:25 | 1.27 | 0 | 0.21 |
| 8/29/2007 | 20:30 | 1.17 | 0 | 0.21 |
| 8/29/2007 | 20:35 | 1.17 | 0 | 0.21 |

| | | | | |
|---|---|---|---|---|
| 8/29/2007 | 20:40 | 1.13 | 0.01 | 0.2 |
| 8/29/2007 | 20:45 | 1.08 | 0.03 | 0.18 |
| 8/29/2007 | 20:50 | 1.08 | 0.05 | 0.17 |
| 8/29/2007 | 20:55 | 1.04 | 0.03 | 0.18 |
| 8/29/2007 | 21:00 | 1.01 | 0.02 | 0.19 |
| 8/29/2007 | 21:05 | 1.04 | 0.02 | 0.18 |
| 8/29/2007 | 21:10 | 1.13 | 0.16 | 0.17 |
| 8/29/2007 | 21:15 | 1.17 | 0.25 | 0.19 |
| 8/29/2007 | 21:20 | 1.17 | 0.18 | 0.21 |
| 8/29/2007 | 21:25 | 1.17 | 0.12 | 0.21 |
| 8/29/2007 | 21:30 | 1.74 | 0.08 | 0.23 |
| 8/29/2007 | 21:35 | 2.38 | 0.05 | 0.26 |
| 8/29/2007 | 21:40 | 2.3 | 0.04 | 0.66 |
| 8/29/2007 | 21:45 | 1.97 | 0.03 | 3.01 |
| 8/29/2007 | 21:50 | 1.73 | 0.02 | 4.65 |
| 8/29/2007 | 21:55 | 1.56 | 0.01 | 3.72 |
| 8/29/2007 | 22:00 | 1.36 | 0.01 | 2.73 |
| 8/29/2007 | 22:05 | 1.17 | 0.01 | 2.37 |
| 8/29/2007 | 22:10 | 1.04 | 0.01 | 2.5 |
| 8/29/2007 | 22:15 | 1.01 | 0 | 2.37 |
| 8/29/2007 | 22:20 | 0.97 | 0 | 1.87 |
| 8/29/2007 | 22:25 | 0.9 | 0 | 1.58 |
| 8/29/2007 | 22:30 | 0.86 | 0 | 1.36 |
| 8/29/2007 | 22:35 | 0.86 | 0 | 1.11 |
| 8/29/2007 | 22:40 | 0.83 | 0 | 0.97 |
| 8/29/2007 | 22:45 | 0.76 | 0 | 0.86 |
| 8/29/2007 | 22:50 | 0.76 | 0 | 0.82 |
| 8/29/2007 | 22:55 | 0.7 | 0 | 0.78 |
| 8/29/2007 | 23:00 | 0.67 | 0 | 0.69 |
| 8/29/2007 | 23:05 | 0.67 | 0 | 0.59 |
| 8/29/2007 | 23:10 | 0.62 | 0 | 0.5 |
| 8/29/2007 | 23:15 | 0.62 | 0 | 0.48 |
| 8/29/2007 | 23:20 | 0.59 | 0 | 0.47 |
| 8/29/2007 | 23:25 | 0.56 | 0 | 0.39 |
| 8/29/2007 | 23:30 | 0.54 | 0 | 0.34 |
| 8/29/2007 | 23:35 | 0.51 | 0 | 0.37 |
| 8/29/2007 | 23:40 | 0.51 | 0 | 0.38 |

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|---|---|---|---|---|
| 8/29/2007 | 23:45 | 0.51 | 0 | 0.34 |
| 8/29/2007 | 23:50 | 0.51 | 0 | 0.32 |
| 8/29/2007 | 23:55 | 0.51 | 0 | 0.3 |
| 8/30/2007 | 0:00 | 0.49 | 0 | 0.28 |
| 8/30/2007 | 0:05 | 0.49 | 0 | 0.26 |
| 8/30/2007 | 0:10 | 0.49 | 0 | 0.25 |
| 8/30/2007 | 0:15 | 0.46 | 0 | 0.26 |
| 8/30/2007 | 0:20 | 0.46 | 0 | 0.26 |
| 8/30/2007 | 0:25 | 0.46 | 0 | 0.24 |
| 8/30/2007 | 0:30 | 0.46 | 0 | 0.24 |
| 8/30/2007 | 0:35 | 0.46 | 0 | 0.24 |
| 8/30/2007 | 0:40 | 0.46 | 0 | 0.22 |
| 8/30/2007 | 0:45 | 0.46 | 0 | 0.21 |
| 8/30/2007 | 0:50 | 0.49 | 0 | 0.2 |
| 8/30/2007 | 0:55 | 0.49 | 0 | 0.2 |
| 8/30/2007 | 1:00 | 0.46 | 0 | 0.2 |
| 8/30/2007 | 1:05 | 0.44 | 0 | 0.18 |
| 8/30/2007 | 1:10 | 0.42 | 0 | 0.18 |
| 8/30/2007 | 1:15 | 0.44 | 0 | 0.18 |
| 8/30/2007 | 1:20 | 0.44 | 0 | 0.16 |
| 8/30/2007 | 1:25 | 0.42 | 0 | 0.16 |
| 8/30/2007 | 1:30 | 0.44 | 0 | 0.16 |
| 8/30/2007 | 1:35 | 0.44 | 0 | 0.16 |
| 8/30/2007 | 1:40 | 0.41 | 0 | 0.16 |
| 8/30/2007 | 1:45 | 0.39 | 0 | 0.16 |
| 8/30/2007 | 1:50 | 0.41 | 0 | 0.16 |
| 8/30/2007 | 1:55 | 0.41 | 0 | 0.16 |
| 8/30/2007 | 2:00 | 0.39 | 0 | 0.16 |
| 8/30/2007 | 2:05 | 0.39 | 0 | 0.16 |
| 8/30/2007 | 2:10 | 0.39 | 0 | 0.16 |
| 8/30/2007 | 2:15 | 0.39 | 0 | 0.16 |
| 8/30/2007 | 2:20 | 0.37 | 0 | 0.16 |
| 8/30/2007 | 2:25 | 0.35 | 0 | 0.16 |
| 8/30/2007 | 2:30 | 0.37 | 0 | 0.15 |
| 8/30/2007 | 2:35 | 0.37 | 0 | 0.14 |
| 8/30/2007 | 2:40 | 0.37 | 0 | 0.14 |
| 8/30/2007 | 2:45 | 0.37 | 0 | 0.14 |

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|---|---|---|---|---|
| 8/30/2007 | 2:50 | 0.37 | 0 | 0.14 |
| 8/30/2007 | 2:55 | 0.37 | 0 | 0.14 |
| 8/30/2007 | 3:00 | 0.35 | 0 | 0.13 |
| 8/30/2007 | 3:05 | 0.35 | 0 | 0.12 |
| 8/30/2007 | 3:10 | 0.35 | 0 | 0.12 |
| 8/30/2007 | 3:15 | 0.35 | 0 | 0.12 |
| 8/30/2007 | 3:20 | 0.35 | 0 | 0.12 |
| 8/30/2007 | 3:25 | 0.35 | 0 | 0.13 |
| 8/30/2007 | 3:30 | 0.35 | 0 | 0.13 |
| 8/30/2007 | 3:35 | 0.35 | 0 | 0.12 |
| 8/30/2007 | 3:40 | 0.35 | 0 | 0.13 |
| 8/30/2007 | 3:45 | 0.33 | 0 | 0.13 |
| 8/30/2007 | 3:50 | 0.33 | 0 | 0.12 |
| 8/30/2007 | 3:55 | 0.35 | 0 | 0.12 |
| 8/30/2007 | 4:00 | 0.35 | 0 | 0.11 |
| 8/30/2007 | 4:05 | 0.35 | 0 | 0.11 |
| 8/30/2007 | 4:10 | 0.33 | 0 | 0.12 |
| 8/30/2007 | 4:15 | 0.35 | 0 | 0.11 |
| 8/30/2007 | 4:20 | 0.37 | 0 | 0.11 |
| 8/30/2007 | 4:25 | 0.33 | 0 | 0.11 |
| 8/30/2007 | 4:30 | 0.32 | 0 | 0.1 |
| 8/30/2007 | 4:35 | 0.32 | 0 | 0.1 |
| 8/30/2007 | 4:40 | 0.32 | 0 | 0.1 |
| 8/30/2007 | 4:45 | 0.32 | 0 | 0.1 |
| 8/30/2007 | 4:50 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 4:55 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 5:00 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 5:05 | 0.32 | 0 | 0.1 |
| 8/30/2007 | 5:10 | 0.32 | 0 | 0.1 |
| 8/30/2007 | 5:15 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 5:20 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 5:25 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 5:30 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 5:35 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 5:40 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 5:45 | 0.3 | 0 | 0.08 |
| 8/30/2007 | 5:50 | 0.3 | 0 | 0.08 |

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|---|---|---|---|---|
| 8/30/2007 | 5:55 | 0.32 | 0 | 0.08 |
| 8/30/2007 | 6:00 | 0.3 | 0 | 0.08 |
| 8/30/2007 | 6:05 | 0.3 | 0 | 0.09 |
| 8/30/2007 | 6:10 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 6:15 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 6:20 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 6:25 | 0.32 | 0 | 0.09 |
| 8/30/2007 | 6:30 | 0.3 | 0 | 0.09 |
| 8/30/2007 | 6:35 | 0.28 | 0 | 0.08 |
| 8/30/2007 | 6:40 | 0.28 | 0 | 0.08 |
| 8/30/2007 | 6:45 | 0.3 | 0 | 0.08 |
| 8/30/2007 | 6:50 | 0.32 | 0 | 0.07 |
| 8/30/2007 | 6:55 | 0.3 | 0 | 0.07 |
| 8/30/2007 | 7:00 | 0.28 | 0 | 0.07 |
| 8/30/2007 | 7:05 | 0.28 | 0 | 0.08 |
| 8/30/2007 | 7:10 | 0.28 | 0 | 0.09 |
| 8/30/2007 | 7:15 | 0.28 | 0 | 0.08 |
| 8/30/2007 | 7:20 | 0.3 | 0 | 0.07 |
| 8/30/2007 | 7:25 | 0.3 | 0 | 0.08 |
| 8/30/2007 | 7:30 | 0.28 | 0 | 0.09 |
| 8/30/2007 | 7:35 | 0.28 | 0 | 0.09 |
| 8/30/2007 | 7:40 | 0.3 | 0 | 0.09 |
| 8/30/2007 | 7:45 | 0.3 | 0 | 0.1 |
| 8/30/2007 | 7:50 | 0.28 | 0 | 0.1 |
| 8/30/2007 | 7:55 | 0.28 | 0 | 0.1 |
| 8/30/2007 | 8:00 | 0.3 | 0 | 0.1 |
| 8/30/2007 | 8:05 | 0.3 | 0 | 0.1 |
| 8/30/2007 | 8:10 | 0.28 | 0 | 0.1 |
| 8/30/2007 | 8:15 | 0.28 | 0 | 0.11 |
| 8/30/2007 | 8:20 | 0.28 | 0 | 0.11 |
| 8/30/2007 | 8:25 | 0.3 | 0 | 0.1 |
| 8/30/2007 | 8:30 | 0.3 | 0 | 0.1 |
| 8/30/2007 | 8:35 | 0.27 | 0 | 0.1 |
| 8/30/2007 | 8:40 | 0.27 | 0 | 0.08 |
| 8/30/2007 | 8:45 | 0.28 | 0 | 0.07 |
| 8/30/2007 | 8:50 | 0.27 | 0 | 0.08 |
| 8/30/2007 | 8:55 | 0.28 | 0 | 0.09 |

| | | | | |
|---|---|---|---|---|
| 8/30/2007 | 9:00 | 0.3 | 0 | 0.08 |
| 8/30/2007 | 9:05 | 0.27 | 0 | 0.08 |
| 8/30/2007 | 9:10 | 0.3 | 0 | 0.08 |
| 8/30/2007 | 9:15 | 0.32 | 0 | 0.07 |
| 8/30/2007 | 9:20 | 0.3 | 0 | 0.07 |
| 8/30/2007 | 9:25 | 0.28 | 0 | 0.07 |
| 8/30/2007 | 9:30 | 0.27 | 0 | 0.07 |
| 8/30/2007 | 9:35 | 0.27 | 0 | 0.08 |
| 8/30/2007 | 9:40 | 0.27 | 0 | 0.04 |
| 8/30/2007 | 9:45 | 0.27 | 0 | 0.02 |
| 8/30/2007 | 9:50 | 0.27 | 0 | 0.05 |
| 8/30/2007 | 9:55 | 0.28 | 0 | 0.06 |
| 8/30/2007 | 10:00 | 0.3 | 0 | 0.05 |
| 8/30/2007 | 10:05 | 0.3 | 0 | 0.05 |
| 8/30/2007 | 10:10 | 0.27 | 0 | 0.06 |
| 8/30/2007 | 10:15 | 0.27 | 0 | 0.05 |
| 8/30/2007 | 10:20 | 0.27 | 0 | 0.04 |
| 8/30/2007 | 10:25 | 0.27 | 0 | 0.04 |
| 8/30/2007 | 10:30 | 0.28 | 0 | 0.03 |
| 8/30/2007 | 10:35 | 0.27 | 0 | 0.02 |
| 8/30/2007 | 10:40 | 0.25 | 0 | 0.03 |
| 8/30/2007 | 10:45 | 0.25 | 0 | 0.04 |
| 8/30/2007 | 10:50 | 0.25 | 0 | 0.03 |
| 8/30/2007 | 10:55 | 0.25 | 0 | 0.01 |
| 8/30/2007 | 11:00 | 0.24 | 0 | 0 |
| 8/30/2007 | 11:05 | 0.24 | 0 | 0 |
| 8/30/2007 | 11:10 | 0.25 | 0 | 0 |
| 8/30/2007 | 11:15 | 0.25 | 0 | 0 |
| 8/30/2007 | 11:20 | 0.25 | 0 | 0 |
| 8/30/2007 | 11:25 | 0.25 | 0 | 0 |
| 8/30/2007 | 11:30 | 0.24 | 0 | 0 |
| 8/30/2007 | 11:35 | 0.23 | 0 | 0 |
| 8/30/2007 | 11:40 | 0.23 | 0 | 0 |
| 8/30/2007 | 11:45 | 0.23 | 0 | 0 |
| 8/30/2007 | 11:50 | 0.24 | 0 | 0 |
| 8/30/2007 | 11:55 | 0.25 | 0 | 0 |
| 8/30/2007 | 12:00 | 0.24 | 0 | 0 |

**Appendix I.** 8/29/2007 TA-06 precipitation data. Precipitation data was used for model calibration.

| Date | Time | Precipitation (in.) |
|---|---|---|
| 8/29/2007 | 13:45 | 0.01 |
| 8/29/2007 | 14:00 | 0.28 |
| 8/29/2007 | 14:15 | 0.3 |
| 8/29/2007 | 14:30 | 0.15 |
| 8/29/2007 | 14:45 | 0.06 |
| 8/29/2007 | 15:00 | 0.03 |
| 8/29/2007 | 15:15 | 0 |
| 8/29/2007 | 15:30 | 0 |
| 8/29/2007 | 15:45 | 0 |
| 8/29/2007 | 16:00 | 0 |
| 8/29/2007 | 16:15 | 0 |
| 8/29/2007 | 16:30 | 0 |
| 8/29/2007 | 16:45 | 0 |
| 8/29/2007 | 17:00 | 0 |
| 8/29/2007 | 17:15 | 0 |
| 8/29/2007 | 17:30 | 0 |
| 8/29/2007 | 17:45 | 0 |
| 8/29/2007 | 18:00 | 0 |
| 8/29/2007 | 18:15 | 0 |
| 8/29/2007 | 18:30 | 0 |
| 8/29/2007 | 18:45 | 0 |
| 8/29/2007 | 19:00 | 0 |
| 8/29/2007 | 19:15 | 0 |
| 8/29/2007 | 19:30 | 0.02 |
| 8/29/2007 | 19:45 | 0 |
| 8/29/2007 | 20:00 | 0 |
| 8/29/2007 | 20:15 | 0 |
| 8/29/2007 | 20:30 | 0.01 |
| 8/29/2007 | 20:45 | 0 |
| 8/29/2007 | 21:00 | 0 |
| 8/29/2007 | 21:15 | 0.12 |
| 8/29/2007 | 21:30 | 0.01 |

**Appendix J.** 9/28-9/29/2005 Pajarito Canyon stream gage data. Discharge data was used for model calibration.

| Date | Time | Station E243 Discharge (cfs) | Station E243.5 Discharge (cfs) | Station E244 Discharge (cfs) |
|---|---|---|---|---|
| 9/28/05 | 0:00 | 6.3 | 0 | 0 |
| 9/28/05 | 0:05 | 6.3 | 0 | 0 |
| 9/28/05 | 0:10 | 6.3 | 0 | 0 |
| 9/28/05 | 0:15 | 6.38 | 0 | 0 |
| 9/28/05 | 0:20 | 6.38 | 0 | 0 |
| 9/28/05 | 0:25 | 6.38 | 0 | 0 |
| 9/28/05 | 0:30 | 6.38 | 0 | 0 |
| 9/28/05 | 0:35 | 6.3 | 0 | 0 |
| 9/28/05 | 0:40 | 6.3 | 0 | 0 |
| 9/28/05 | 0:45 | 6.3 | 0 | 0 |
| 9/28/05 | 0:50 | 6.3 | 0 | 0 |
| 9/28/05 | 0:55 | 6.3 | 0 | 0 |
| 9/28/05 | 1:00 | 6.22 | 0 | 0 |
| 9/28/05 | 1:05 | 6.22 | 0 | 0 |
| 9/28/05 | 1:10 | 6.3 | 0 | 0 |
| 9/28/05 | 1:15 | 6.3 | 0 | 0 |
| 9/28/05 | 1:20 | 6.3 | 0 | 0 |
| 9/28/05 | 1:25 | 6.3 | 0 | 0 |
| 9/28/05 | 1:30 | 6.3 | 0 | 0 |
| 9/28/05 | 1:35 | 6.3 | 0 | 0 |
| 9/28/05 | 1:40 | 6.3 | 0 | 0 |
| 9/28/05 | 1:45 | 6.3 | 0 | 0 |
| 9/28/05 | 1:50 | 6.3 | 0 | 0 |
| 9/28/05 | 1:55 | 6.3 | 0 | 0 |
| 9/28/05 | 2:00 | 6.38 | 0 | 0 |
| 9/28/05 | 2:05 | 6.38 | 0 | 0 |
| 9/28/05 | 2:10 | 6.3 | 0 | 0 |
| 9/28/05 | 2:15 | 6.3 | 0 | 0 |
| 9/28/05 | 2:20 | 6.3 | 0 | 0 |
| 9/28/05 | 2:25 | 6.3 | 0 | 0 |
| 9/28/05 | 2:30 | 6.3 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| 9/28/05 | 2:35 | 6.3 | 0 | 0 |
| 9/28/05 | 2:40 | 6.3 | 0 | 0 |
| 9/28/05 | 2:45 | 6.3 | 0 | 0 |
| 9/28/05 | 2:50 | 6.3 | 0 | 0 |
| 9/28/05 | 2:55 | 6.3 | 0 | 0 |
| 9/28/05 | 3:00 | 6.38 | 0 | 0 |
| 9/28/05 | 3:05 | 6.38 | 0 | 0 |
| 9/28/05 | 3:10 | 6.3 | 0 | 0 |
| 9/28/05 | 3:15 | 6.3 | 0 | 0 |
| 9/28/05 | 3:20 | 6.3 | 0 | 0 |
| 9/28/05 | 3:25 | 6.3 | 0 | 0 |
| 9/28/05 | 3:30 | 6.3 | 0 | 0 |
| 9/28/05 | 3:35 | 6.55 | 0 | 0 |
| 9/28/05 | 3:40 | 6.63 | 0 | 0 |
| 9/28/05 | 3:45 | 6.38 | 0 | 0 |
| 9/28/05 | 3:50 | 6.3 | 0 | 0 |
| 9/28/05 | 3:55 | 6.3 | 0 | 0 |
| 9/28/05 | 4:00 | 6.3 | 0 | 0 |
| 9/28/05 | 4:05 | 6.38 | 0 | 0 |
| 9/28/05 | 4:10 | 6.38 | 0 | 0 |
| 9/28/05 | 4:15 | 6.3 | 0 | 0 |
| 9/28/05 | 4:20 | 6.38 | 0 | 0 |
| 9/28/05 | 4:25 | 6.3 | 0 | 0 |
| 9/28/05 | 4:30 | 6.22 | 0 | 0 |
| 9/28/05 | 4:35 | 6.3 | 0 | 0 |
| 9/28/05 | 4:40 | 6.3 | 0 | 0 |
| 9/28/05 | 4:45 | 6.3 | 0 | 0 |
| 9/28/05 | 4:50 | 6.3 | 0.005 | 0 |
| 9/28/05 | 4:55 | 6.3 | 0.008 | 0 |
| 9/28/05 | 5:00 | 6.3 | 0.008 | 0 |
| 9/28/05 | 5:05 | 6.3 | 0.003 | 0 |
| 9/28/05 | 5:10 | 6.3 | 0 | 0 |
| 9/28/05 | 5:15 | 6.3 | 0 | 0 |
| 9/28/05 | 5:20 | 6.3 | 0 | 0 |
| 9/28/05 | 5:25 | 6.3 | 0 | 0 |
| 9/28/05 | 5:30 | 6.3 | 0.005 | 0 |
| 9/28/05 | 5:35 | 6.3 | 0.008 | 0 |
| 9/28/05 | 5:40 | 6.3 | 0.003 | 0 |

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|---|---|---|---|---|
| 9/28/05 | 5:45 | 6.38 | 0 | 0 |
| 9/28/05 | 5:50 | 6.47 | 0 | 0 |
| 9/28/05 | 5:55 | 6.38 | 0 | 0 |
| 9/28/05 | 6:00 | 6.3 | 0 | 0 |
| 9/28/05 | 6:05 | 6.3 | 0 | 0 |
| 9/28/05 | 6:10 | 6.3 | 0 | 0 |
| 9/28/05 | 6:15 | 6.3 | 0 | 0 |
| 9/28/05 | 6:20 | 6.38 | 0 | 0 |
| 9/28/05 | 6:25 | 6.38 | 0 | 0 |
| 9/28/05 | 6:30 | 6.3 | 0 | 0 |
| 9/28/05 | 6:35 | 6.3 | 0 | 0 |
| 9/28/05 | 6:40 | 6.3 | 0 | 0 |
| 9/28/05 | 6:45 | 6.3 | 0 | 0 |
| 9/28/05 | 6:50 | 6.3 | 0 | 0 |
| 9/28/05 | 6:55 | 6.22 | 0 | 0 |
| 9/28/05 | 7:00 | 6.22 | 0 | 0 |
| 9/28/05 | 7:05 | 6.3 | 0 | 0 |
| 9/28/05 | 7:10 | 6.3 | 0 | 0 |
| 9/28/05 | 7:15 | 6.3 | 0 | 0 |
| 9/28/05 | 7:20 | 6.3 | 0 | 0 |
| 9/28/05 | 7:25 | 6.3 | 0 | 0 |
| 9/28/05 | 7:30 | 6.3 | 0 | 0 |
| 9/28/05 | 7:35 | 6.3 | 0 | 0 |
| 9/28/05 | 7:40 | 6.3 | 0 | 0 |
| 9/28/05 | 7:45 | 6.38 | 0 | 0 |
| 9/28/05 | 7:50 | 6.38 | 0 | 0 |
| 9/28/05 | 7:55 | 6.3 | 0 | 0 |
| 9/28/05 | 8:00 | 6.3 | 0 | 0 |
| 9/28/05 | 8:05 | 6.3 | 0 | 0 |
| 9/28/05 | 8:10 | 6.3 | 0 | 0 |
| 9/28/05 | 8:15 | 6.3 | 0 | 0 |
| 9/28/05 | 8:20 | 6.3 | 0 | 0 |
| 9/28/05 | 8:25 | 6.3 | 0 | 0 |
| 9/28/05 | 8:30 | 6.3 | 0 | 0 |
| 9/28/05 | 8:35 | 6.3 | 0 | 0 |
| 9/28/05 | 8:40 | 6.3 | 0 | 0 |
| 9/28/05 | 8:45 | 6.3 | 0 | 0 |
| 9/28/05 | 8:50 | 6.3 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| 9/28/05 | 8:55 | 6.22 | 0 | 0 |
| 9/28/05 | 9:00 | 6.22 | 0 | 0 |
| 9/28/05 | 9:05 | 6.3 | 0 | 0 |
| 9/28/05 | 9:10 | 6.3 | 0 | 0 |
| 9/28/05 | 9:15 | 6.3 | 0 | 0 |
| 9/28/05 | 9:20 | 6.3 | 0 | 0 |
| 9/28/05 | 9:25 | 6.3 | 0 | 0 |
| 9/28/05 | 9:30 | 6.3 | 0 | 0 |
| 9/28/05 | 9:35 | 6.3 | 0 | 0 |
| 9/28/05 | 9:40 | 6.3 | 0 | 0 |
| 9/28/05 | 9:45 | 6.3 | 0 | 0 |
| 9/28/05 | 9:50 | 6.22 | 0 | 0 |
| 9/28/05 | 9:55 | 6.22 | 0.009 | 0 |
| 9/28/05 | 10:00 | 6.22 | 0.011 | 0 |
| 9/28/05 | 10:05 | 6.22 | 0.008 | 0 |
| 9/28/05 | 10:10 | 6.22 | 0.008 | 0 |
| 9/28/05 | 10:15 | 6.22 | 0.008 | 0 |
| 9/28/05 | 10:20 | 6.3 | 0.003 | 0 |
| 9/28/05 | 10:25 | 6.3 | 0 | 0 |
| 9/28/05 | 10:30 | 6.3 | 0 | 0 |
| 9/28/05 | 10:35 | 6.22 | 0 | 0 |
| 9/28/05 | 10:40 | 6.3 | 0 | 0 |
| 9/28/05 | 10:45 | 6.3 | 0 | 0 |
| 9/28/05 | 10:50 | 6.14 | 0 | 0 |
| 9/28/05 | 10:55 | 6.22 | 0 | 0 |
| 9/28/05 | 11:00 | 6.3 | 0 | 0 |
| 9/28/05 | 11:05 | 6.3 | 0 | 0 |
| 9/28/05 | 11:10 | 6.22 | 0 | 0 |
| 9/28/05 | 11:15 | 6.14 | 0 | 0 |
| 9/28/05 | 11:20 | 6.22 | 0 | 0 |
| 9/28/05 | 11:25 | 6.3 | 0 | 0 |
| 9/28/05 | 11:30 | 6.22 | 0 | 0 |
| 9/28/05 | 11:35 | 6.14 | 0 | 0 |
| 9/28/05 | 11:40 | 6.14 | 0 | 0 |
| 9/28/05 | 11:45 | 6.14 | 0 | 0 |
| 9/28/05 | 11:50 | 6.14 | 0 | 0 |
| 9/28/05 | 11:55 | 6.14 | 0 | 0 |
| 9/28/05 | 12:00 | 6.14 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| 9/28/05 | 12:05 | 6.22 | 0 | 0 |
| 9/28/05 | 12:10 | 6.22 | 0 | 0 |
| 9/28/05 | 12:15 | 6.14 | 0 | 0 |
| 9/28/05 | 12:20 | 6.22 | 0 | 0 |
| 9/28/05 | 12:25 | 6.22 | 0 | 0 |
| 9/28/05 | 12:30 | 6.14 | 0 | 0 |
| 9/28/05 | 12:35 | 6.14 | 0 | 0 |
| 9/28/05 | 12:40 | 6.22 | 0 | 0 |
| 9/28/05 | 12:45 | 6.22 | 0 | 0 |
| 9/28/05 | 12:50 | 6.14 | 0 | 0 |
| 9/28/05 | 12:55 | 6.14 | 0 | 0 |
| 9/28/05 | 13:00 | 6.14 | 0 | 0 |
| 9/28/05 | 13:05 | 6.14 | 0 | 0 |
| 9/28/05 | 13:10 | 6.14 | 0 | 0 |
| 9/28/05 | 13:15 | 6.14 | 0 | 0 |
| 9/28/05 | 13:20 | 6.14 | 0 | 0 |
| 9/28/05 | 13:25 | 6.14 | 0 | 0 |
| 9/28/05 | 13:30 | 6.06 | 0 | 0 |
| 9/28/05 | 13:35 | 5.98 | 0 | 0 |
| 9/28/05 | 13:40 | 6.06 | 0 | 0 |
| 9/28/05 | 13:45 | 6.14 | 0 | 0.02 |
| 9/28/05 | 13:50 | 6.22 | 0 | 0.03 |
| 9/28/05 | 13:55 | 6.22 | 0 | 0.05 |
| 9/28/05 | 14:00 | 6.06 | 0 | 0.06 |
| 9/28/05 | 14:05 | 5.98 | 0 | 0.07 |
| 9/28/05 | 14:10 | 6.06 | 0 | 0.07 |
| 9/28/05 | 14:15 | 6.14 | 0 | 0.08 |
| 9/28/05 | 14:20 | 6.06 | 0 | 0.08 |
| 9/28/05 | 14:25 | 6.06 | 0 | 0.09 |
| 9/28/05 | 14:30 | 6.06 | 0 | 0.09 |
| 9/28/05 | 14:35 | 6.06 | 0 | 0.09 |
| 9/28/05 | 14:40 | 6.14 | 0 | 0.1 |
| 9/28/05 | 14:45 | 6.14 | 0 | 0.1 |
| 9/28/05 | 14:50 | 6.22 | 0 | 0.1 |
| 9/28/05 | 14:55 | 6.22 | 0 | 0.11 |
| 9/28/05 | 15:00 | 6.14 | 0 | 0.11 |
| 9/28/05 | 15:05 | 6.14 | 0 | 0.12 |
| 9/28/05 | 15:10 | 6.14 | 0 | 0.13 |

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| 9/28/05 | 15:15 | 6.14 | 0 | 0.13 |
| 9/28/05 | 15:20 | 6.22 | 0 | 0.14 |
| 9/28/05 | 15:25 | 6.3 | 0 | 0.15 |
| 9/28/05 | 15:30 | 6.22 | 0 | 0.16 |
| 9/28/05 | 15:35 | 6.14 | 0 | 0.17 |
| 9/28/05 | 15:40 | 6.14 | 0 | 0.17 |
| 9/28/05 | 15:45 | 6.14 | 0 | 0.18 |
| 9/28/05 | 15:50 | 6.22 | 0 | 0.2 |
| 9/28/05 | 15:55 | 6.3 | 0 | 0.22 |
| 9/28/05 | 16:00 | 6.55 | 0 | 0.23 |
| 9/28/05 | 16:05 | 6.63 | 0 | 0.23 |
| 9/28/05 | 16:10 | 6.73 | 0 | 0.24 |
| 9/28/05 | 16:15 | 7.08 | 0 | 0.25 |
| 9/28/05 | 16:20 | 8.09 | 0 | 0.27 |
| 9/28/05 | 16:25 | 9.01 | 0 | 0.33 |
| 9/28/05 | 16:30 | 9.01 | 0 | 0.39 |
| 9/28/05 | 16:35 | 9.01 | 0 | 0.58 |
| 9/28/05 | 16:40 | 8.9 | 0 | 0.8 |
| 9/28/05 | 16:45 | 8.59 | 0 | 3.9 |
| 9/28/05 | 16:50 | 8.28 | 0 | 10.98 |
| 9/28/05 | 16:55 | 8.07 | 0 | 14.87 |
| 9/28/05 | 17:00 | 7.87 | 0 | 13.19 |
| 9/28/05 | 17:05 | 7.77 | 0 | 9.73 |
| 9/28/05 | 17:10 | 7.57 | 0 | 11.28 |
| 9/28/05 | 17:15 | 7.37 | 0 | 18 |
| 9/28/05 | 17:20 | 7.37 | 0 | 20.61 |
| 9/28/05 | 17:25 | 7.28 | 0 | 18.6 |
| 9/28/05 | 17:30 | 7.18 | 0 | 15.13 |
| 9/28/05 | 17:35 | 7.18 | 0 | 12.1 |
| 9/28/05 | 17:40 | 21.45 | 0 | 11.19 |
| 9/28/05 | 17:45 | 34.87 | 0 | 9.5 |
| 9/28/05 | 17:50 | 33.83 | 0 | 7.47 |
| 9/28/05 | 17:55 | 33.01 | 0 | 6.71 |
| 9/28/05 | 18:00 | 31.98 | 0 | 5.92 |
| 9/28/05 | 18:05 | 31.35 | 0 | 5.32 |
| 9/28/05 | 18:10 | 30.5 | 0 | 5.1 |
| 9/28/05 | 18:15 | 29.45 | 0 | 4.48 |
| 9/28/05 | 18:20 | 28.82 | 0 | 3.69 |

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| 9/28/05 | 18:25 | 28.21 | 0 | 3.47 |
| 9/28/05 | 18:30 | 27.4 | 0 | 3.47 |
| 9/28/05 | 18:35 | 26.8 | 0 | 3.16 |
| 9/28/05 | 18:40 | 26.6 | 0 | 2.85 |
| 9/28/05 | 18:45 | 26.01 | 0 | 2.72 |
| 9/28/05 | 18:50 | 25.23 | 0 | 2.62 |
| 9/28/05 | 18:55 | 24.85 | 0 | 2.62 |
| 9/28/05 | 19:00 | 24.47 | 0 | 2.41 |
| 9/28/05 | 19:05 | 24.28 | 0 | 2.29 |
| 9/28/05 | 19:10 | 23.9 | 0 | 2.21 |
| 9/28/05 | 19:15 | 23.53 | 0 | 2.29 |
| 9/28/05 | 19:20 | 23.16 | 0 | 2.63 |
| 9/28/05 | 19:25 | 22.61 | 0 | 2.76 |
| 9/28/05 | 19:30 | 22.61 | 0 | 2.62 |
| 9/28/05 | 19:35 | 22.43 | 0 | 2.72 |
| 9/28/05 | 19:40 | 22.07 | 0 | 2.85 |
| 9/28/05 | 19:45 | 21.89 | 0 | 2.8 |
| 9/28/05 | 19:50 | 21.53 | 0 | 3 |
| 9/28/05 | 19:55 | 20.83 | 0 | 4.15 |
| 9/28/05 | 20:00 | 20.3 | 0 | 5.24 |
| 9/28/05 | 20:05 | 20.48 | 0 | 5.18 |
| 9/28/05 | 20:10 | 20.48 | 0 | 4.97 |
| 9/28/05 | 20:15 | 20.3 | 0 | 5.03 |
| 9/28/05 | 20:20 | 20.83 | 0 | 5.1 |
| 9/28/05 | 20:25 | 21.89 | 0 | 5.1 |
| 9/28/05 | 20:30 | 22.98 | 0 | 5.24 |
| 9/28/05 | 20:35 | 23.53 | 0 | 5.39 |
| 9/28/05 | 20:40 | 23.53 | 0 | 5.11 |
| 9/28/05 | 20:45 | 23.72 | 0 | 4.71 |
| 9/28/05 | 20:50 | 23.9 | 0 | 4.52 |
| 9/28/05 | 20:55 | 24.09 | 0 | 4.22 |
| 9/28/05 | 21:00 | 24.47 | 0 | 3.75 |
| 9/28/05 | 21:05 | 24.47 | 0 | 3.58 |
| 9/28/05 | 21:10 | 24.28 | 0 | 3.52 |
| 9/28/05 | 21:15 | 24.47 | 0 | 3.64 |
| 9/28/05 | 21:20 | 24.47 | 0 | 3.75 |
| 9/28/05 | 21:25 | 24.09 | 0 | 3.63 |
| 9/28/05 | 21:30 | 23.72 | 0 | 3.58 |

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| 9/28/05 | 21:35 | 23.34 | 0.104 | 3.47 |
| 9/28/05 | 21:40 | 23.16 | 0.263 | 3.52 |
| 9/28/05 | 21:45 | 23.16 | 0.201 | 3.58 |
| 9/28/05 | 21:50 | 22.79 | 0.08 | 3.81 |
| 9/28/05 | 21:55 | 22.43 | 0.03 | 4.74 |
| 9/28/05 | 22:00 | 22.43 | 0.006 | 5.53 |
| 9/28/05 | 22:05 | 22.25 | 0 | 5.99 |
| 9/28/05 | 22:10 | 22.25 | 0 | 6.3 |
| 9/28/05 | 22:15 | 22.43 | 0 | 6.22 |
| 9/28/05 | 22:20 | 22.43 | 0 | 5.55 |
| 9/28/05 | 22:25 | 22.25 | 0 | 5.79 |
| 9/28/05 | 22:30 | 22.07 | 0 | 6.62 |
| 9/28/05 | 22:35 | 22.07 | 0 | 6.62 |
| 9/28/05 | 22:40 | 21.89 | 0 | 6.46 |
| 9/28/05 | 22:45 | 21.71 | 0 | 6.14 |
| 9/28/05 | 22:50 | 22.25 | 0.015 | 6.14 |
| 9/28/05 | 22:55 | 23.72 | 0.103 | 6.14 |
| 9/28/05 | 23:00 | 25.04 | 0.448 | 5.41 |
| 9/28/05 | 23:05 | 25.62 | 1.727 | 4.9 |
| 9/28/05 | 23:10 | 25.43 | 4.179 | 4.53 |
| 9/28/05 | 23:15 | 24.85 | 6.561 | 3.98 |
| 9/28/05 | 23:20 | 24.66 | 6.429 | 3.92 |
| 9/28/05 | 23:25 | 24.28 | 6.081 | 4.15 |
| 9/28/05 | 23:30 | 23.72 | 5.926 | 4.15 |
| 9/28/05 | 23:35 | 23.53 | 4.385 | 3.97 |
| 9/28/05 | 23:40 | 23.34 | 2.567 | 3.8 |
| 9/28/05 | 23:45 | 23.34 | 1.436 | 3.58 |
| 9/28/05 | 23:50 | 23.16 | 1.082 | 3.36 |
| 9/28/05 | 23:55 | 22.79 | 1.049 | 3.36 |
| 9/29/05 | 0:00 | 22.61 | 1.033 | 3.52 |
| 9/29/05 | 0:05 | 22.43 | 1.026 | 3.52 |
| 9/29/05 | 0:10 | 22.43 | 1.019 | 3.52 |
| 9/29/05 | 0:15 | 22.43 | 1.013 | 3.52 |
| 9/29/05 | 0:20 | 22.25 | 1.006 | 3.47 |
| 9/29/05 | 0:25 | 22.07 | 1 | 3.58 |
| 9/29/05 | 0:30 | 22.25 | 0.993 | 3.8 |
| 9/29/05 | 0:35 | 22.07 | 0.986 | 4.41 |
| 9/29/05 | 0:40 | 21.89 | 0.98 | 5.03 |

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| 9/29/05 | 0:45 | 22.07 | 0.973 | 5.03 |
| 9/29/05 | 0:50 | 21.89 | 0.967 | 5.03 |
| 9/29/05 | 0:55 | 21.89 | 0.96 | 5.1 |
| 9/29/05 | 1:00 | 21.71 | 0.954 | 5.1 |
| 9/29/05 | 1:05 | 21.53 | 0.948 | 5.32 |
| 9/29/05 | 1:10 | 21.53 | 0.941 | 5.61 |
| 9/29/05 | 1:15 | 21.35 | 0.935 | 7.12 |
| 9/29/05 | 1:20 | 21.35 | 0.928 | 8.55 |
| 9/29/05 | 1:25 | 21.35 | 0.922 | 8.84 |
| 9/29/05 | 1:30 | 21.35 | 0.916 | 9.03 |
| 9/29/05 | 1:35 | 21.18 | 0.909 | 8.65 |
| 9/29/05 | 1:40 | 21.35 | 0.903 | 7.91 |
| 9/29/05 | 1:45 | 24.35 | 0.897 | 6.57 |
| 9/29/05 | 1:50 | 27 | 0.89 | 5.68 |
| 9/29/05 | 1:55 | 27 | 0.884 | 5.61 |
| 9/29/05 | 2:00 | 26.6 | 0.878 | 5.32 |
| 9/29/05 | 2:05 | 26.21 | 0.871 | 4.97 |
| 9/29/05 | 2:10 | 26.21 | 0.865 | 4.41 |
| 9/29/05 | 2:15 | 25.82 | 0.859 | 3.92 |
| 9/29/05 | 2:20 | 25.23 | 0.853 | 3.86 |
| 9/29/05 | 2:25 | 24.85 | 0.847 | 4.22 |
| 9/29/05 | 2:30 | 24.66 | 0.84 | 4.71 |
| 9/29/05 | 2:35 | 24.66 | 0.834 | 4.84 |
| 9/29/05 | 2:40 | 24.66 | 0.828 | 4.71 |
| 9/29/05 | 2:45 | 24.66 | 0.822 | 4.46 |
| 9/29/05 | 2:50 | 24.66 | 0.816 | 4.1 |
| 9/29/05 | 2:55 | 24.66 | 0.81 | 3.86 |
| 9/29/05 | 3:00 | 24.28 | 0.804 | 3.69 |
| 9/29/05 | 3:05 | 23.72 | 0.798 | 3.36 |
| 9/29/05 | 3:10 | 23.53 | 0.791 | 3.53 |
| 9/29/05 | 3:15 | 23.53 | 0.785 | 3.86 |
| 9/29/05 | 3:20 | 23.53 | 0.779 | 3.8 |
| 9/29/05 | 3:25 | 23.53 | 0.773 | 3.63 |
| 9/29/05 | 3:30 | 23.53 | 0.767 | 4.18 |
| 9/29/05 | 3:35 | 23.53 | 0.761 | 5.18 |
| 9/29/05 | 3:40 | 23.53 | 0.755 | 6.76 |
| 9/29/05 | 3:45 | 23.53 | 0.75 | 10.16 |
| 9/29/05 | 3:50 | 23.53 | 0.744 | 12.79 |

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| 9/29/05 | 3:55 | 23.72 | 0.738 | 13.87 |
| 9/29/05 | 4:00 | 23.53 | 0.732 | 16.61 |
| 9/29/05 | 4:05 | 23.34 | 0.726 | 19.5 |
| 9/29/05 | 4:10 | 23.53 | 0.72 | 23.95 |
| 9/29/05 | 4:15 | 23.16 | 0.714 | 28.4 |
| 9/29/05 | 4:20 | 22.61 | 0.708 | 29.37 |
| 9/29/05 | 4:25 | 22.61 | 0.703 | 30.17 |
| 9/29/05 | 4:30 | 22.61 | 0.697 | 29.58 |
| 9/29/05 | 4:35 | 30.36 | 0.691 | 28.2 |
| 9/29/05 | 4:40 | 39.62 | 0.685 | 27.25 |
| 9/29/05 | 4:45 | 41.86 | 0.679 | 25.58 |
| 9/29/05 | 4:50 | 43.7 | 0.674 | 24.14 |
| 9/29/05 | 4:55 | 44.4 | 0.668 | 23.44 |
| 9/29/05 | 5:00 | 43.93 | 0.662 | 23.62 |
| 9/29/05 | 5:05 | 43.01 | 0.657 | 23.62 |
| 9/29/05 | 5:10 | 41.86 | 0.651 | 22.59 |
| 9/29/05 | 5:15 | 40.95 | 0.645 | 22.42 |
| 9/29/05 | 5:20 | 40.28 | 0.64 | 22.09 |
| 9/29/05 | 5:25 | 39.39 | 0.634 | 20.76 |
| 9/29/05 | 5:30 | 38.29 | 0.629 | 20.12 |
| 9/29/05 | 5:35 | 37.21 | 0.623 | 20.44 |
| 9/29/05 | 5:40 | 36.99 | 0.618 | 19.37 |
| 9/29/05 | 5:45 | 36.57 | 0.612 | 17.38 |
| 9/29/05 | 5:50 | 34.67 | 0.607 | 17.09 |
| 9/29/05 | 5:55 | 33.22 | 0.601 | 15.74 |
| 9/29/05 | 6:00 | 32.19 | 0.596 | 15.45 |
| 9/29/05 | 6:05 | 31.35 | 0.591 | 16.66 |
| 9/29/05 | 6:10 | 31.14 | 0.585 | 16.8 |
| 9/29/05 | 6:15 | 30.71 | 0.58 | 16.66 |
| 9/29/05 | 6:20 | 30.07 | 0.574 | 16.1 |
| 9/29/05 | 6:25 | 29.86 | 0.569 | 16.53 |
| 9/29/05 | 6:30 | 29.65 | 0.564 | 17.09 |
| 9/29/05 | 6:35 | 29.65 | 0.559 | 16.38 |
| 9/29/05 | 6:40 | 29.65 | 0.553 | 16.24 |
| 9/29/05 | 6:45 | 29.44 | 0.548 | 16.95 |
| 9/29/05 | 6:50 | 29.65 | 0.543 | 17.23 |
| 9/29/05 | 6:55 | 30.07 | 0.538 | 16.53 |
| 9/29/05 | 7:00 | 30.5 | 0.532 | 15.03 |

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| 9/29/05 | 7:05 | 31.35 | 0.527 | 14.24 |
| 9/29/05 | 7:10 | 31.78 | 0.522 | 13.51 |
| 9/29/05 | 7:15 | 31.35 | 0.517 | 12.78 |
| 9/29/05 | 7:20 | 31.14 | 0.512 | 12.55 |
| 9/29/05 | 7:25 | 31.35 | 0.507 | 11.86 |
| 9/29/05 | 7:30 | 31.35 | 0.501 | 11.52 |
| 9/29/05 | 7:35 | 30.92 | 0.496 | 11.09 |
| 9/29/05 | 7:40 | 30.71 | 0.491 | 10.98 |
| 9/29/05 | 7:45 | 30.08 | 0.486 | 11.41 |
| 9/29/05 | 7:50 | 29.65 | 0.481 | 11.09 |
| 9/29/05 | 7:55 | 29.86 | 0.476 | 10.55 |
| 9/29/05 | 8:00 | 29.45 | 0.471 | 10.44 |
| 9/29/05 | 8:05 | 29.24 | 0.466 | 10.65 |
| 9/29/05 | 8:10 | 29.03 | 0.461 | 10.76 |
| 9/29/05 | 8:15 | 28.62 | 0.456 | 10.98 |
| 9/29/05 | 8:20 | 29.03 | 0.451 | 10.98 |
| 9/29/05 | 8:25 | 29.24 | 0.446 | 10.55 |
| 9/29/05 | 8:30 | 29.03 | 0.441 | 10.13 |
| 9/29/05 | 8:35 | 29.45 | 0.437 | 10.13 |
| 9/29/05 | 8:40 | 29.86 | 0.432 | 10.03 |
| 9/29/05 | 8:45 | 29.86 | 0.427 | 9.82 |
| 9/29/05 | 8:50 | 29.86 | 0.422 | 10.13 |
| 9/29/05 | 8:55 | 29.86 | 0.417 | 10.39 |
| 9/29/05 | 9:00 | 29.65 | 0.412 | 10.49 |
| 9/29/05 | 9:05 | 29.65 | 0.408 | 10.55 |
| 9/29/05 | 9:10 | 29.24 | 0.403 | 10.98 |
| 9/29/05 | 9:15 | 29.03 | 0.398 | 10.98 |
| 9/29/05 | 9:20 | 29.03 | 0.393 | 10.87 |
| 9/29/05 | 9:25 | 28.62 | 0.389 | 12.23 |
| 9/29/05 | 9:30 | 28.82 | 0.384 | 13.38 |
| 9/29/05 | 9:35 | 29.03 | 0.379 | 14.52 |
| 9/29/05 | 9:40 | 28.82 | 0.375 | 17.44 |
| 9/29/05 | 9:45 | 28.62 | 0.37 | 20.46 |
| 9/29/05 | 9:50 | 29.03 | 0.366 | 22.95 |
| 9/29/05 | 9:55 | 30.92 | 0.361 | 24.67 |
| 9/29/05 | 10:00 | 33.22 | 0.356 | 24.85 |
| 9/29/05 | 10:05 | 34.87 | 0.352 | 25.58 |
| 9/29/05 | 10:10 | 36.78 | 0.347 | 26.13 |

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| 9/29/05 | 10:15 | 41.24 | 0.343 | 25.57 |
| 9/29/05 | 10:20 | 44.87 | 0.338 | 26.32 |
| 9/29/05 | 10:25 | 46.06 | 0.333 | 26.68 |
| 9/29/05 | 10:30 | 46.77 | 0.329 | 26.5 |
| 9/29/05 | 10:35 | 46.05 | 0.324 | 26.87 |
| 9/29/05 | 10:40 | 45.58 | 0.319 | 25.95 |
| 9/29/05 | 10:45 | 44.64 | 0.315 | 25.03 |
| 9/29/05 | 10:50 | 43.47 | 0.31 | 24.85 |
| 9/29/05 | 10:55 | 42.78 | 0.306 | 25.03 |
| 9/29/05 | 11:00 | 41.19 | 0.301 | 25.03 |
| 9/29/05 | 11:05 | 39.83 | 0.297 | 24.32 |
| 9/29/05 | 11:10 | 39.39 | 0.293 | 23.96 |
| 9/29/05 | 11:15 | 38.73 | 0.288 | 23.62 |
| 9/29/05 | 11:20 | 38.07 | 0.284 | 23.27 |
| 9/29/05 | 11:25 | 37.64 | 0.279 | 23.79 |
| 9/29/05 | 11:30 | 36.78 | 0.275 | 23.28 |
| 9/29/05 | 11:35 | 36.13 | 0.271 | 22.24 |
| 9/29/05 | 11:40 | 35.71 | 0.267 | 21.91 |
| 9/29/05 | 11:45 | 34.87 | 0.262 | 21.09 |
| 9/29/05 | 11:50 | 34.66 | 0.258 | 19.97 |
| 9/29/05 | 11:55 | 34.04 | 0.254 | 19.18 |
| 9/29/05 | 12:00 | 32.81 | 0.25 | 18.42 |
| 9/29/05 | 12:05 | 32.81 | 0.245 | 17.38 |
| 9/29/05 | 12:10 | 32.81 | 0.241 | 16.8 |
| 9/29/05 | 12:15 | 31.77 | 0.237 | 16.24 |
| 9/29/05 | 12:20 | 31.14 | 0.233 | 15.54 |
| 9/29/05 | 12:25 | 31.14 | 0.229 | 14.51 |
| 9/29/05 | 12:30 | 30.71 | 0.225 | 13.62 |
| 9/29/05 | 12:35 | 30.07 | 0.221 | 12.91 |
| 9/29/05 | 12:40 | 29.86 | 0.217 | 13.15 |
| 9/29/05 | 12:45 | 29.45 | 0.213 | 13.99 |
| 9/29/05 | 12:50 | 29.03 | 0.209 | 13.62 |
| 9/29/05 | 12:55 | 28.82 | 0.205 | 12.9 |
| 9/29/05 | 13:00 | 28.62 | 0.201 | 12.09 |
| 9/29/05 | 13:05 | 28.21 | 0.197 | 11.63 |
| 9/29/05 | 13:10 | 27.8 | 0.194 | 12.94 |
| 9/29/05 | 13:15 | 28 | 0.19 | 13.39 |
| 9/29/05 | 13:20 | 27.6 | 0.186 | 11.87 |

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| 9/29/05 | 13:25 | 27.2 | 0.182 | 10.87 |
| 9/29/05 | 13:30 | 27.2 | 0.179 | 10.24 |
| 9/29/05 | 13:35 | 27 | 0.175 | 9.52 |
| 9/29/05 | 13:40 | 26.8 | 0.171 | 8.56 |
| 9/29/05 | 13:45 | 26.4 | 0.168 | 8.56 |
| 9/29/05 | 13:50 | 26.21 | 0.164 | 9.42 |
| 9/29/05 | 13:55 | 26.01 | 0.16 | 10.13 |
| 9/29/05 | 14:00 | 25.81 | 0.157 | 10.03 |
| 9/29/05 | 14:05 | 25.81 | 0.153 | 9.23 |
| 9/29/05 | 14:10 | 25.62 | 0.15 | 9.03 |
| 9/29/05 | 14:15 | 25.43 | 0.146 | 8.65 |
| 9/29/05 | 14:20 | 25.43 | 0.143 | 8.09 |
| 9/29/05 | 14:25 | 25.23 | 0.139 | 7.91 |
| 9/29/05 | 14:30 | 24.85 | 0.136 | 7.82 |
| 9/29/05 | 14:35 | 25.04 | 0.133 | 7.55 |
| 9/29/05 | 14:40 | 25.04 | 0.129 | 7.04 |
| 9/29/05 | 14:45 | 24.66 | 0.126 | 6.95 |
| 9/29/05 | 14:50 | 24.85 | 0.123 | 6.87 |
| 9/29/05 | 14:55 | 24.85 | 0.12 | 6.7 |
| 9/29/05 | 15:00 | 24.47 | 0.116 | 7.04 |
| 9/29/05 | 15:05 | 24.09 | 0.113 | 6.95 |
| 9/29/05 | 15:10 | 23.9 | 0.11 | 6.87 |
| 9/29/05 | 15:15 | 24.09 | 0.107 | 7.12 |
| 9/29/05 | 15:20 | 24.09 | 0.104 | 6.48 |
| 9/29/05 | 15:25 | 23.72 | 0.1 | 5.83 |
| 9/29/05 | 15:30 | 23.53 | 0.097 | 5.68 |
| 9/29/05 | 15:35 | 23.53 | 0.094 | 5.76 |
| 9/29/05 | 15:40 | 23.34 | 0.091 | 5.69 |
| 9/29/05 | 15:45 | 23.16 | 0.088 | 5.31 |
| 9/29/05 | 15:50 | 22.97 | 0.085 | 5.17 |
| 9/29/05 | 15:55 | 22.79 | 0.082 | 4.84 |
| 9/29/05 | 16:00 | 22.97 | 0.08 | 4.46 |
| 9/29/05 | 16:05 | 22.79 | 0.077 | 4.1 |
| 9/29/05 | 16:10 | 22.61 | 0.074 | 4.1 |
| 9/29/05 | 16:15 | 22.79 | 0.071 | 4.21 |
| 9/29/05 | 16:20 | 22.61 | 0.069 | 4.34 |
| 9/29/05 | 16:25 | 22.43 | 0.066 | 4.71 |
| 9/29/05 | 16:30 | 22.43 | 0.063 | 4.84 |

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| 9/29/05 | 16:35 | 22.43 | 0.061 | 4.52 |
| 9/29/05 | 16:40 | 22.43 | 0.058 | 4.27 |
| 9/29/05 | 16:45 | 22.43 | 0.056 | 4.1 |
| 9/29/05 | 16:50 | 22.25 | 0.053 | 3.86 |
| 9/29/05 | 16:55 | 22.25 | 0.051 | 3.8 |
| 9/29/05 | 17:00 | 22.25 | 0.048 | 3.74 |
| 9/29/05 | 17:05 | 21.89 | 0.046 | 3.92 |
| 9/29/05 | 17:10 | 21.71 | 0.044 | 4.09 |
| 9/29/05 | 17:15 | 21.89 | 0.041 | 3.98 |
| 9/29/05 | 17:20 | 22.07 | 0.04 | 3.86 |
| 9/29/05 | 17:25 | 21.89 | 0.038 | 3.8 |
| 9/29/05 | 17:30 | 21.71 | 0.037 | 3.69 |
| 9/29/05 | 17:35 | 21.53 | 0.035 | 3.63 |
| 9/29/05 | 17:40 | 21.53 | 0.034 | 3.52 |
| 9/29/05 | 17:45 | 21.53 | 0.033 | 3.36 |
| 9/29/05 | 17:50 | 21.35 | 0.031 | 3.25 |
| 9/29/05 | 17:55 | 21.35 | 0.03 | 3.1 |
| 9/29/05 | 18:00 | 21.35 | 0.028 | 3.15 |
| 9/29/05 | 18:05 | 21.35 | 0.027 | 3.36 |
| 9/29/05 | 18:10 | 21.35 | 0.026 | 3.41 |
| 9/29/05 | 18:15 | 21.35 | 0.024 | 3.52 |
| 9/29/05 | 18:20 | 21.35 | 0.023 | 3.27 |
| 9/29/05 | 18:25 | 21.35 | 0.021 | 3.16 |
| 9/29/05 | 18:30 | 21.35 | 0.02 | 3.41 |
| 9/29/05 | 18:35 | 21.18 | 0.019 | 3.36 |
| 9/29/05 | 18:40 | 21.18 | 0.017 | 3.15 |
| 9/29/05 | 18:45 | 21.18 | 0.016 | 2.95 |
| 9/29/05 | 18:50 | 21 | 0.014 | 2.95 |
| 9/29/05 | 18:55 | 20.82 | 0.013 | 3 |
| 9/29/05 | 19:00 | 20.82 | 0.012 | 2.95 |
| 9/29/05 | 19:05 | 20.82 | 0.01 | 3.05 |
| 9/29/05 | 19:10 | 20.65 | 0.009 | 3.1 |
| 9/29/05 | 19:15 | 20.82 | 0.007 | 3 |
| 9/29/05 | 19:20 | 20.82 | 0.006 | 3 |
| 9/29/05 | 19:25 | 20.65 | 0.005 | 3 |
| 9/29/05 | 19:30 | 20.65 | 0.003 | 3 |
| 9/29/05 | 19:35 | 20.48 | 0.002 | 2.95 |
| 9/29/05 | 19:40 | 20.48 | 0.001 | 2.9 |

| | | | | |
|---|---|---|---|---|
| 9/29/05 | 19:45 | 20.65 | 0 | 2.9 |
| 9/29/05 | 19:50 | 20.65 | 0 | 2.9 |
| 9/29/05 | 19:55 | 20.48 | 0 | 2.8 |
| 9/29/05 | 20:00 | 20.3 | 0 | 2.71 |
| 9/29/05 | 20:05 | 20.48 | 0 | 2.71 |
| 9/29/05 | 20:10 | 20.48 | 0 | 2.71 |
| 9/29/05 | 20:15 | 20.3 | 0 | 2.8 |
| 9/29/05 | 20:20 | 20.3 | 0 | 2.8 |
| 9/29/05 | 20:25 | 20.3 | 0.001 | 2.67 |
| 9/29/05 | 20:30 | 20.3 | 0.001 | 2.67 |
| 9/29/05 | 20:35 | 20.3 | 0 | 2.67 |
| 9/29/05 | 20:40 | 20.3 | 0.019 | 2.62 |
| 9/29/05 | 20:45 | 20.3 | 0.082 | 2.62 |
| 9/29/05 | 20:50 | 20.3 | 0.08 | 2.67 |
| 9/29/05 | 20:55 | 20.3 | 0.04 | 2.71 |
| 9/29/05 | 21:00 | 20.13 | 0.022 | 2.71 |
| 9/29/05 | 21:05 | 20.13 | 0.006 | 2.62 |
| 9/29/05 | 21:10 | 20.13 | 0 | 2.54 |
| 9/29/05 | 21:15 | 20.13 | 0 | 2.45 |
| 9/29/05 | 21:20 | 20.13 | 0 | 2.45 |
| 9/29/05 | 21:25 | 19.79 | 0 | 2.45 |
| 9/29/05 | 21:30 | 19.79 | 0 | 2.45 |
| 9/29/05 | 21:35 | 20.13 | 0 | 2.45 |
| 9/29/05 | 21:40 | 20.3 | 0 | 2.45 |
| 9/29/05 | 21:45 | 20.13 | 0 | 2.54 |
| 9/29/05 | 21:50 | 20.13 | 0 | 2.54 |
| 9/29/05 | 21:55 | 20.13 | 0 | 2.41 |
| 9/29/05 | 22:00 | 20.13 | 0 | 2.21 |
| 9/29/05 | 22:05 | 20.3 | 0 | 2.25 |
| 9/29/05 | 22:10 | 20.13 | 0 | 2.37 |
| 9/29/05 | 22:15 | 20.13 | 0 | 2.45 |
| 9/29/05 | 22:20 | 20.3 | 0 | 2.45 |
| 9/29/05 | 22:25 | 20.13 | 0 | 2.37 |
| 9/29/05 | 22:30 | 19.79 | 0 | 2.45 |
| 9/29/05 | 22:35 | 19.62 | 0 | 2.41 |
| 9/29/05 | 22:40 | 19.79 | 0 | 2.33 |
| 9/29/05 | 22:45 | 19.79 | 0 | 2.25 |
| 9/29/05 | 22:50 | 19.62 | 0 | 2.21 |

| | | | | |
|---|---|---|---|---|
| 9/29/05 | 22:55 | 19.62 | 0 | 2.21 |
| 9/29/05 | 23:00 | 19.62 | 0 | 2.21 |
| 9/29/05 | 23:05 | 19.96 | 0 | 2.21 |
| 9/29/05 | 23:10 | 19.96 | 0 | 2.13 |
| 9/29/05 | 23:15 | 19.62 | 0 | 2.09 |
| 9/29/05 | 23:20 | 19.45 | 0 | 2.09 |
| 9/29/05 | 23:25 | 19.28 | 0 | 2.13 |
| 9/29/05 | 23:30 | 19.45 | 0 | 2.13 |
| 9/29/05 | 23:35 | 19.62 | 0 | 2.13 |
| 9/29/05 | 23:40 | 19.62 | 0 | 2.09 |
| 9/29/05 | 23:45 | 19.62 | 0 | 2.09 |
| 9/29/05 | 23:50 | 19.62 | 0 | 2.13 |
| 9/29/05 | 23:55 | 19.45 | 0 | 2.09 |
| 9/30/05 | 0:00 | 19.62 | 0 | 2.05 |

**Appendix K**. 9/28-9/29/2005 TA-06 precipitation data. Precipitation data was used for model calibration.

| Date | Time | Precipitation (in.) |
|---|---|---|
| 9/28/05 | 14:30 | 0.02 |
| 9/28/05 | 14:45 | 0.01 |
| 9/28/05 | 15:00 | 0 |
| 9/28/05 | 15:15 | 0 |
| 9/28/05 | 15:30 | 0 |
| 9/28/05 | 15:45 | 0.01 |
| 9/28/05 | 16:00 | 0.06 |
| 9/28/05 | 16:15 | 0.22 |
| 9/28/05 | 16:30 | 0.2 |
| 9/28/05 | 16:45 | 0.07 |
| 9/28/05 | 17:00 | 0.01 |
| 9/28/05 | 17:15 | 0.01 |
| 9/28/05 | 17:30 | 0 |
| 9/28/05 | 17:45 | 0 |
| 9/28/05 | 18:00 | 0 |
| 9/28/05 | 18:15 | 0.05 |
| 9/28/05 | 18:30 | 0.06 |
| 9/28/05 | 18:45 | 0.03 |
| 9/28/05 | 19:00 | 0.03 |
| 9/28/05 | 19:15 | 0.05 |
| 9/28/05 | 19:30 | 0.03 |
| 9/28/05 | 19:45 | 0.01 |
| 9/28/05 | 20:00 | 0 |
| 9/28/05 | 20:15 | 0.02 |
| 9/28/05 | 20:30 | 0.01 |
| 9/28/05 | 20:45 | 0.03 |
| 9/28/05 | 21:00 | 0.02 |
| 9/28/05 | 21:15 | 0.05 |
| 9/28/05 | 21:30 | 0.05 |
| 9/28/05 | 21:45 | 0 |
| 9/28/05 | 22:00 | 0 |
| 9/28/05 | 22:15 | 0.03 |
| 9/28/05 | 22:30 | 0.02 |
| 9/28/05 | 22:45 | 0.01 |

| | | |
|---|---|---|
| 9/28/05 | 23:00 | 0 |
| 9/28/05 | 23:15 | 0 |
| 9/28/05 | 23:30 | 0.02 |
| 9/28/05 | 23:45 | 0.05 |
| 9/29/05 | 0:00 | 0.04 |
| 9/29/05 | 0:15 | 0.05 |
| 9/29/05 | 0:30 | 0.02 |
| 9/29/05 | 0:45 | 0 |
| 9/29/05 | 1:00 | 0 |
| 9/29/05 | 1:15 | 0 |
| 9/29/05 | 1:30 | 0 |
| 9/29/05 | 1:45 | 0 |
| 9/29/05 | 2:00 | 0.02 |
| 9/29/05 | 2:15 | 0 |
| 9/29/05 | 2:30 | 0 |
| 9/29/05 | 2:45 | 0.02 |
| 9/29/05 | 3:00 | 0.06 |
| 9/29/05 | 3:15 | 0.1 |
| 9/29/05 | 3:30 | 0.1 |
| 9/29/05 | 3:45 | 0.05 |
| 9/29/05 | 4:00 | 0.04 |
| 9/29/05 | 4:15 | 0.01 |
| 9/29/05 | 4:30 | 0.01 |
| 9/29/05 | 4:45 | 0 |
| 9/29/05 | 5:00 | 0.01 |
| 9/29/05 | 5:15 | 0.03 |
| 9/29/05 | 5:30 | 0.04 |
| 9/29/05 | 5:45 | 0.05 |
| 9/29/05 | 6:00 | 0.02 |
| 9/29/05 | 6:15 | 0.01 |
| 9/29/05 | 6:30 | 0 |
| 9/29/05 | 6:45 | 0.02 |
| 9/29/05 | 7:00 | 0.02 |
| 9/29/05 | 7:15 | 0.03 |
| 9/29/05 | 7:30 | 0.01 |
| 9/29/05 | 7:45 | 0 |
| 9/29/05 | 8:00 | 0 |
| 9/29/05 | 8:15 | 0.01 |

| | | |
|---|---|---|
| 9/29/05 | 8:30 | 0.05 |
| 9/29/05 | 8:45 | 0.05 |
| 9/29/05 | 9:00 | 0.03 |
| 9/29/05 | 9:15 | 0.05 |
| 9/29/05 | 9:30 | 0.07 |
| 9/29/05 | 9:45 | 0 |
| 9/29/05 | 10:00 | 0.01 |
| 9/29/05 | 10:15 | 0.01 |
| 9/29/05 | 10:30 | 0.02 |
| 9/29/05 | 10:45 | 0.01 |
| 9/29/05 | 11:00 | 0.03 |
| 9/29/05 | 11:15 | 0.01 |
| 9/29/05 | 11:30 | 0 |
| 9/29/05 | 11:45 | 0 |
| 9/29/05 | 12:00 | 0 |
| 9/29/05 | 12:15 | 0 |
| 9/29/05 | 12:30 | 0.03 |
| 9/29/05 | 12:45 | 0 |
| 9/29/05 | 13:00 | 0.01 |
| 9/29/05 | 13:15 | 0 |
| 9/29/05 | 13:30 | 0.03 |
| 9/29/05 | 13:45 | 0 |
| 9/29/05 | 14:00 | 0 |
| 9/29/05 | 14:15 | 0 |
| 9/29/05 | 14:30 | 0 |

**Appendix L.** 8/25/2006 Pajarito Canyon stream gage data. Discharge data was used for model calibration.

| Date | Time | Station E243 Discharge (cfs) | Station E243.5 Discharge (cfs) | Station E244 Discharge (cfs) |
|---|---|---|---|---|
| 8/25/2006 | 0:00 | 0 | 0.62 | 0.09 |
| 8/25/2006 | 0:05 | 0 | 0.45 | 0.07 |
| 8/25/2006 | 0:10 | 0 | 0.31 | 0.07 |
| 8/25/2006 | 0:15 | 0 | 0.22 | 0.07 |
| 8/25/2006 | 0:20 | 0 | 0.14 | 0.07 |
| 8/25/2006 | 0:25 | 0 | 0.1 | 0.09 |
| 8/25/2006 | 0:30 | 0 | 0.05 | 0.07 |
| 8/25/2006 | 0:35 | 0 | 0.02 | 0.07 |
| 8/25/2006 | 0:40 | 0 | 0.02 | 0.09 |
| 8/25/2006 | 0:45 | 0 | 0.01 | 0.09 |
| 8/25/2006 | 0:50 | 0 | 0.01 | 0.09 |
| 8/25/2006 | 0:55 | 0 | 0.01 | 0.09 |
| 8/25/2006 | 1:00 | 0 | 0 | 0.09 |
| 8/25/2006 | 1:05 | 0 | 0 | 0.09 |
| 8/25/2006 | 1:10 | 0 | 0 | 0.07 |
| 8/25/2006 | 1:15 | 0 | 0 | 0.07 |
| 8/25/2006 | 1:20 | 0 | 0 | 0.07 |
| 8/25/2006 | 1:25 | 0 | 0 | 0.06 |
| 8/25/2006 | 1:30 | 0 | 0 | 0.06 |
| 8/25/2006 | 1:35 | 0 | 0 | 0.06 |
| 8/25/2006 | 1:40 | 0 | 0 | 0.06 |
| 8/25/2006 | 1:45 | 0 | 0 | 0.06 |
| 8/25/2006 | 1:50 | 0 | 0 | 0.05 |
| 8/25/2006 | 1:55 | 0 | 0 | 0.05 |
| 8/25/2006 | 2:00 | 0 | 0 | 0.06 |
| 8/25/2006 | 2:05 | 0 | 0 | 0.07 |
| 8/25/2006 | 2:10 | 0 | 0 | 0.07 |
| 8/25/2006 | 2:15 | 0 | 0 | 0.06 |
| 8/25/2006 | 2:20 | 0 | 0 | 0.06 |
| 8/25/2006 | 2:25 | 0 | 0 | 0.06 |
| 8/25/2006 | 2:30 | 0 | 0 | 0.06 |
| 8/25/2006 | 2:35 | 0 | 0 | 0.06 |
| 8/25/2006 | 2:40 | 0 | 0 | 0.06 |

| | | | | |
|---|---|---|---|---|
| 8/25/2006 | 2:45 | 0 | 0 | 0.06 |
| 8/25/2006 | 2:50 | 0 | 0 | 0.06 |
| 8/25/2006 | 2:55 | 0 | 0 | 0.05 |
| 8/25/2006 | 3:00 | 0 | 0 | 0.05 |
| 8/25/2006 | 3:05 | 0 | 0 | 0.06 |
| 8/25/2006 | 3:10 | 0 | 0 | 0.06 |
| 8/25/2006 | 3:15 | 0 | 0 | 0.05 |
| 8/25/2006 | 3:20 | 0 | 0 | 0.05 |
| 8/25/2006 | 3:25 | 0 | 0 | 0.06 |
| 8/25/2006 | 3:30 | 0 | 0 | 0.05 |
| 8/25/2006 | 3:35 | 0 | 0 | 0.04 |
| 8/25/2006 | 3:40 | 0 | 0 | 0.04 |
| 8/25/2006 | 3:45 | 0 | 0 | 0.05 |
| 8/25/2006 | 3:50 | 0 | 0 | 0.05 |
| 8/25/2006 | 3:55 | 0 | 0 | 0.04 |
| 8/25/2006 | 4:00 | 0 | 0 | 0.04 |
| 8/25/2006 | 4:05 | 0 | 0 | 0.02 |
| 8/25/2006 | 4:10 | 0 | 0 | 0 |
| 8/25/2006 | 4:15 | 0 | 0 | 0.02 |
| 8/25/2006 | 4:20 | 0 | 0 | 0.04 |
| 8/25/2006 | 4:25 | 0 | 0 | 0.04 |
| 8/25/2006 | 4:30 | 0 | 0 | 0.05 |
| 8/25/2006 | 4:35 | 0 | 0 | 0.06 |
| 8/25/2006 | 4:40 | 0 | 0 | 0.05 |
| 8/25/2006 | 4:45 | 0 | 0 | 0.05 |
| 8/25/2006 | 4:50 | 0 | 0 | 0.06 |
| 8/25/2006 | 4:55 | 0 | 0 | 0.06 |
| 8/25/2006 | 5:00 | 0 | 0 | 0.05 |
| 8/25/2006 | 5:05 | 0 | 0 | 0.05 |
| 8/25/2006 | 5:10 | 0 | 0 | 0.06 |
| 8/25/2006 | 5:15 | 0 | 0 | 0.06 |
| 8/25/2006 | 5:20 | 0 | 0 | 0.06 |
| 8/25/2006 | 5:25 | 0 | 0 | 0.06 |
| 8/25/2006 | 5:30 | 0 | 0 | 0.06 |
| 8/25/2006 | 5:35 | 0 | 0 | 0.03 |
| 8/25/2006 | 5:40 | 0 | 0 | 0.03 |
| 8/25/2006 | 5:45 | 0 | 0 | 0.06 |
| 8/25/2006 | 5:50 | 0 | 0 | 0.06 |

| | | | | |
|---|---|---|---|---|
| 8/25/2006 | 5:55 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:00 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:05 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:10 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:15 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:20 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:25 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:30 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:35 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:40 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:45 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:50 | 0 | 0 | 0.06 |
| 8/25/2006 | 6:55 | 0 | 0 | 0.06 |
| 8/25/2006 | 7:00 | 0 | 0 | 0.06 |
| 8/25/2006 | 7:05 | 0 | 0 | 0.07 |
| 8/25/2006 | 7:10 | 0 | 0 | 0.07 |
| 8/25/2006 | 7:15 | 0 | 0 | 0.07 |
| 8/25/2006 | 7:20 | 0 | 0 | 0.09 |
| 8/25/2006 | 7:25 | 0 | 0 | 0.09 |
| 8/25/2006 | 7:30 | 0 | 0 | 0.09 |
| 8/25/2006 | 7:35 | 0 | 0 | 0.09 |
| 8/25/2006 | 7:40 | 0 | 0 | 0.09 |
| 8/25/2006 | 7:45 | 0 | 0 | 0.09 |
| 8/25/2006 | 7:50 | 0 | 0 | 0.09 |
| 8/25/2006 | 7:55 | 0 | 0 | 0.09 |
| 8/25/2006 | 8:00 | 0 | 0 | 0.09 |
| 8/25/2006 | 8:05 | 0 | 0 | 0.07 |
| 8/25/2006 | 8:10 | 0 | 0 | 0.07 |
| 8/25/2006 | 8:15 | 0 | 0 | 0.09 |
| 8/25/2006 | 8:20 | 0 | 0 | 0.09 |
| 8/25/2006 | 8:25 | 0 | 0 | 0.09 |
| 8/25/2006 | 8:30 | 0 | 0 | 0.09 |
| 8/25/2006 | 8:35 | 0 | 0 | 0.07 |
| 8/25/2006 | 8:40 | 0 | 0 | 0.06 |
| 8/25/2006 | 8:45 | 0 | 0 | 0.06 |
| 8/25/2006 | 8:50 | 0 | 0 | 0.06 |
| 8/25/2006 | 8:55 | 0 | 0 | 0.06 |
| 8/25/2006 | 9:00 | 0 | 0 | 0.06 |

| | | | | |
|---|---|---|---|---|
| 8/25/2006 | 9:05 | 0 | 0 | 0.06 |
| 8/25/2006 | 9:10 | 0 | 0 | 0.07 |
| 8/25/2006 | 9:15 | 0 | 0 | 0.09 |
| 8/25/2006 | 9:20 | 0 | 0 | 0.09 |
| 8/25/2006 | 9:25 | 0 | 0 | 0.09 |
| 8/25/2006 | 9:30 | 0 | 0 | 0.09 |
| 8/25/2006 | 9:35 | 0 | 0 | 0.09 |
| 8/25/2006 | 9:40 | 0 | 0 | 0.09 |
| 8/25/2006 | 9:45 | 0 | 0 | 0.09 |
| 8/25/2006 | 9:50 | 0 | 0 | 0.09 |
| 8/25/2006 | 9:55 | 0 | 0 | 0.07 |
| 8/25/2006 | 10:00 | 0 | 0 | 0.06 |
| 8/25/2006 | 10:05 | 0 | 0 | 0.05 |
| 8/25/2006 | 10:10 | 0 | 0 | 0.04 |
| 8/25/2006 | 10:15 | 0 | 0 | 0.04 |
| 8/25/2006 | 10:20 | 0 | 0 | 0.02 |
| 8/25/2006 | 10:25 | 0 | 0 | 0 |
| 8/25/2006 | 10:30 | 0 | 0 | 0 |
| 8/25/2006 | 10:35 | 0 | 0 | 0 |
| 8/25/2006 | 10:40 | 0 | 0 | 0 |
| 8/25/2006 | 10:45 | 0 | 0 | 0 |
| 8/25/2006 | 10:50 | 0 | 0 | 0 |
| 8/25/2006 | 10:55 | 0 | 0 | 0 |
| 8/25/2006 | 11:00 | 0 | 0 | 0 |
| 8/25/2006 | 11:05 | 0 | 0 | 0 |
| 8/25/2006 | 11:10 | 0 | 0 | 0 |
| 8/25/2006 | 11:15 | 0 | 0 | 0 |
| 8/25/2006 | 11:20 | 0 | 0 | 0 |
| 8/25/2006 | 11:25 | 0 | 1.76 | 0 |
| 8/25/2006 | 11:30 | 0 | 3.67 | 0 |
| 8/25/2006 | 11:35 | 0 | 6 | 0 |
| 8/25/2006 | 11:40 | 0 | 6.93 | 0 |
| 8/25/2006 | 11:45 | 0 | 5.6 | 0 |
| 8/25/2006 | 11:50 | 0 | 7.51 | 0 |
| 8/25/2006 | 11:55 | 0 | 8.2 | 0.04 |
| 8/25/2006 | 12:00 | 0 | 7.48 | 0.4 |
| 8/25/2006 | 12:05 | 0 | 6.48 | 0.91 |
| 8/25/2006 | 12:10 | 0 | 6.59 | 1.26 |

| | | | | |
|---|---|---|---|---|
| 8/25/2006 | 12:15 | 0.07 | 8.5 | 10.85 |
| 8/25/2006 | 12:20 | 2.29 | 6.03 | 83.14 |
| 8/25/2006 | 12:25 | 6.33 | 2.31 | 204.06 |
| 8/25/2006 | 12:30 | 9.44 | 0.89 | 236.06 |
| 8/25/2006 | 12:35 | 18.74 | 0.4 | 295 |
| 8/25/2006 | 12:40 | 25.04 | 0.2 | 504.21 |
| 8/25/2006 | 12:45 | 15.47 | 0.12 | 597.61 |
| 8/25/2006 | 12:50 | 5.31 | 0.07 | 564.01 |
| 8/25/2006 | 12:55 | 2.79 | 0.05 | 554.2 |
| 8/25/2006 | 13:00 | 2.06 | 0.05 | 509.81 |
| 8/25/2006 | 13:05 | 0.9 | 0.06 | 453.2 |
| 8/25/2006 | 13:10 | 0.31 | 0.12 | 415.18 |
| 8/25/2006 | 13:15 | 0.24 | 0.16 | 365.03 |
| 8/25/2006 | 13:20 | 0.17 | 0.24 | 313.4 |
| 8/25/2006 | 13:25 | 0.15 | 1.83 | 287.42 |
| 8/25/2006 | 13:30 | 0.15 | 3.42 | 275.91 |
| 8/25/2006 | 13:35 | 0.22 | 3.49 | 265.28 |
| 8/25/2006 | 13:40 | 0.51 | 3.68 | 254.29 |
| 8/25/2006 | 13:45 | 0.58 | 5.29 | 245.71 |
| 8/25/2006 | 13:50 | 0.37 | 6.46 | 240.78 |
| 8/25/2006 | 13:55 | 0.37 | 5.17 | 234.69 |
| 8/25/2006 | 14:00 | 0.35 | 3.15 | 226.79 |
| 8/25/2006 | 14:05 | 0.2 | 1.59 | 213.44 |
| 8/25/2006 | 14:10 | 0.12 | 0.77 | 200.49 |
| 8/25/2006 | 14:15 | 0.11 | 0.47 | 194.06 |
| 8/25/2006 | 14:20 | 0.13 | 0.33 | 185.26 |
| 8/25/2006 | 14:25 | 5.07 | 0.27 | 171.16 |
| 8/25/2006 | 14:30 | 12.19 | 0.74 | 157.19 |
| 8/25/2006 | 14:35 | 13.6 | 1.35 | 149.19 |
| 8/25/2006 | 14:40 | 11.23 | 1.41 | 144.94 |
| 8/25/2006 | 14:45 | 9.08 | 0.93 | 141.88 |
| 8/25/2006 | 14:50 | 7.03 | 0.43 | 139.98 |
| 8/25/2006 | 14:55 | 4.77 | 0.26 | 137.8 |
| 8/25/2006 | 15:00 | 3.35 | 0.63 | 136.12 |
| 8/25/2006 | 15:05 | 2.34 | 1.03 | 134.96 |
| 8/25/2006 | 15:10 | 1.76 | 0.77 | 130.36 |
| 8/25/2006 | 15:15 | 1.34 | 0.51 | 118.17 |
| 8/25/2006 | 15:20 | 1.18 | 1.12 | 107.75 |

| | | | | |
|---|---|---|---|---|
| 8/25/2006 | 15:25 | 1.24 | 1.45 | 104.25 |
| 8/25/2006 | 15:30 | 1.18 | 0.86 | 102.4 |
| 8/25/2006 | 15:35 | 0.97 | 0.43 | 100.99 |
| 8/25/2006 | 15:40 | 0.71 | 0.22 | 99.88 |
| 8/25/2006 | 15:45 | 0.43 | 0.11 | 98.98 |
| 8/25/2006 | 15:50 | 0.21 | 0.06 | 97.87 |
| 8/25/2006 | 15:55 | 0.16 | 0.04 | 96.43 |
| 8/25/2006 | 16:00 | 0.14 | 0.03 | 94.98 |
| 8/25/2006 | 16:05 | 0.13 | 0.01 | 93.41 |
| 8/25/2006 | 16:10 | 0.11 | 0.01 | 90.73 |
| 8/25/2006 | 16:15 | 0.1 | 0.01 | 87.22 |
| 8/25/2006 | 16:20 | 0.1 | 0 | 84.32 |
| 8/25/2006 | 16:25 | 0.1 | 0 | 81.89 |
| 8/25/2006 | 16:30 | 0.09 | 0.01 | 78.19 |
| 8/25/2006 | 16:35 | 0.09 | 0 | 73.41 |
| 8/25/2006 | 16:40 | 0.09 | 0 | 70.18 |
| 8/25/2006 | 16:45 | 0.08 | 0 | 68.43 |
| 8/25/2006 | 16:50 | 0.07 | 0 | 66.71 |
| 8/25/2006 | 16:55 | 0.07 | 0 | 65.01 |
| 8/25/2006 | 17:00 | 0.06 | 0 | 63.75 |
| 8/25/2006 | 17:05 | 0.05 | 0 | 63.05 |
| 8/25/2006 | 17:10 | 0.04 | 0 | 62.5 |
| 8/25/2006 | 17:15 | 0.03 | 0 | 61.95 |
| 8/25/2006 | 17:20 | 0.02 | 0 | 61.4 |
| 8/25/2006 | 17:25 | 0.02 | 0 | 60.85 |
| 8/25/2006 | 17:30 | 0.01 | 0 | 60.31 |
| 8/25/2006 | 17:35 | 0.01 | 0 | 59.54 |
| 8/25/2006 | 17:40 | 0.01 | 0 | 58.47 |
| 8/25/2006 | 17:45 | 0.01 | 0 | 57.38 |
| 8/25/2006 | 17:50 | 0 | 0 | 55.84 |
| 8/25/2006 | 17:55 | 0 | 0 | 53.82 |
| 8/25/2006 | 18:00 | 0 | 0 | 52.04 |
| 8/25/2006 | 18:05 | 0 | 0 | 49.49 |
| 8/25/2006 | 18:10 | 0 | 0 | 47.37 |
| 8/25/2006 | 18:15 | 0 | 0 | 46.69 |
| 8/25/2006 | 18:20 | 0 | 0 | 46.14 |
| 8/25/2006 | 18:25 | 0 | 0 | 45.86 |
| 8/25/2006 | 18:30 | 0 | 0 | 45.71 |

| | | | | |
|---|---|---|---|---|
| 8/25/2006 | 18:35 | 0 | 0 | 45.57 |
| 8/25/2006 | 18:40 | 0 | 0 | 45.42 |
| 8/25/2006 | 18:45 | 0 | 0 | 45.28 |
| 8/25/2006 | 18:50 | 0 | 0 | 45.14 |
| 8/25/2006 | 18:55 | 0 | 0 | 44.99 |
| 8/25/2006 | 19:00 | 0 | 0 | 44.85 |
| 8/25/2006 | 19:05 | 0 | 0 | 44.71 |
| 8/25/2006 | 19:10 | 0 | 0 | 44.37 |
| 8/25/2006 | 19:15 | 0 | 0 | 43.83 |
| 8/25/2006 | 19:20 | 0 | 0 | 43.31 |
| 8/25/2006 | 19:25 | 0 | 0 | 42.78 |
| 8/25/2006 | 19:30 | 0 | 0 | 42.47 |
| 8/25/2006 | 19:35 | 0 | 0 | 42.38 |
| 8/25/2006 | 19:40 | 0 | 0 | 42.28 |
| 8/25/2006 | 19:45 | 0 | 0 | 42.19 |
| 8/25/2006 | 19:50 | 0 | 0 | 42.1 |
| 8/25/2006 | 19:55 | 0 | 0 | 42 |
| 8/25/2006 | 20:00 | 0 | 0 | 41.91 |
| 8/25/2006 | 20:05 | 0 | 0 | 41.81 |
| 8/25/2006 | 20:10 | 0 | 0 | 41.72 |
| 8/25/2006 | 20:15 | 0 | 0 | 41.62 |
| 8/25/2006 | 20:20 | 0 | 0 | 41.54 |
| 8/25/2006 | 20:25 | 0 | 0 | 41.47 |
| 8/25/2006 | 20:30 | 0 | 0 | 41.4 |
| 8/25/2006 | 20:35 | 0 | 0 | 41.33 |
| 8/25/2006 | 20:40 | 0 | 0 | 41.26 |
| 8/25/2006 | 20:45 | 0 | 0 | 41.2 |
| 8/25/2006 | 20:50 | 0 | 0 | 41.13 |
| 8/25/2006 | 20:55 | 0 | 0 | 41.06 |
| 8/25/2006 | 21:00 | 0 | 0 | 40.88 |
| 8/25/2006 | 21:05 | 0 | 0 | 40.61 |
| 8/25/2006 | 21:10 | 0 | 0 | 40.33 |
| 8/25/2006 | 21:15 | 0 | 0 | 40.06 |
| 8/25/2006 | 21:20 | 0 | 0 | 39.79 |
| 8/25/2006 | 21:25 | 0 | 0 | 39.51 |
| 8/25/2006 | 21:30 | 0 | 0 | 39.24 |
| 8/25/2006 | 21:35 | 0 | 0 | 38.97 |
| 8/25/2006 | 21:40 | 0 | 0 | 38.7 |

| | | | | |
|---|---|---|---|---|
| 8/25/2006 | 21:45 | 0 | 0 | 38.44 |
| 8/25/2006 | 21:50 | 0 | 0 | 38.17 |
| 8/25/2006 | 21:55 | 0 | 0 | 37.9 |
| 8/25/2006 | 22:00 | 0 | 0 | 37.75 |
| 8/25/2006 | 22:05 | 0 | 0 | 37.66 |
| 8/25/2006 | 22:10 | 0 | 0 | 37.52 |
| 8/25/2006 | 22:15 | 0 | 0 | 37.39 |
| 8/25/2006 | 22:20 | 0 | 0 | 37.26 |
| 8/25/2006 | 22:25 | 0 | 0 | 37.13 |
| 8/25/2006 | 22:30 | 0 | 0 | 37 |
| 8/25/2006 | 22:35 | 0 | 0 | 36.87 |
| 8/25/2006 | 22:40 | 0 | 0 | 36.68 |
| 8/25/2006 | 22:45 | 0 | 0 | 36.44 |
| 8/25/2006 | 22:50 | 0 | 0 | 36.19 |
| 8/25/2006 | 22:55 | 0 | 0 | 35.95 |
| 8/25/2006 | 23:00 | 0 | 0 | 35.71 |
| 8/25/2006 | 23:05 | 0 | 0 | 35.47 |
| 8/25/2006 | 23:10 | 0 | 0 | 35.16 |
| 8/25/2006 | 23:15 | 0 | 0 | 34.89 |
| 8/25/2006 | 23:20 | 0 | 0 | 34.75 |
| 8/25/2006 | 23:25 | 0 | 0 | 34.61 |
| 8/25/2006 | 23:30 | 0 | 0 | 34.47 |
| 8/25/2006 | 23:35 | 0 | 0 | 34.34 |
| 8/25/2006 | 23:40 | 0 | 0 | 34.18 |
| 8/25/2006 | 23:45 | 0 | 0 | 34.01 |
| 8/25/2006 | 23:50 | 0 | 0 | 33.84 |
| 8/25/2006 | 23:55 | 0 | 0 | 33.67 |
| 8/26/2006 | 0:00 | 0 | 0 | 33.5 |

**Appendix M.** 8/25/2006 TA-06 precipitation data.

| Date | Time | Precipitation (in.) |
|---|---|---|
| 8/25/2006 | 11:15 | 0.04 |
| 8/25/2006 | 11:30 | 0.15 |
| 8/25/2006 | 11:45 | 0.1 |
| 8/25/2006 | 12:00 | 0.35 |
| 8/25/2006 | 12:15 | 0.54 |
| 8/25/2006 | 12:30 | 0.17 |
| 8/25/2006 | 12:45 | 0.04 |
| 8/25/2006 | 13:00 | 0.13 |
| 8/25/2006 | 13:15 | 0.03 |
| 8/25/2006 | 13:30 | 0.16 |
| 8/25/2006 | 13:45 | 0.16 |
| 8/25/2006 | 14:00 | 0 |
| 8/25/2006 | 14:15 | 0 |
| 8/25/2006 | 14:30 | 0 |
| 8/25/2006 | 14:45 | 0 |
| 8/25/2006 | 15:00 | 0.01 |
| 8/25/2006 | 15:15 | 0.1 |
| 8/25/2006 | 15:30 | 0.03 |