FIELD PERFORMANCE OF INSTRUMENTATION FOR MONITORING EFFECTS OF TIMBER HARVESTING ON WATER QUALITY

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By
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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

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presented by Eric M. Hollabaugh,

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and hereby certify that, in their opinion, it is worthy of acceptance.

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Field Performance of Instrumentation for Monitoring Effects of Timber Harvesting on Water Quality

Abstract:

Water samples from ephemeral streams and associated hillsides are being collected to quantitatively determine the impact of Regenerative Oak Clear Cutting (ROCC) on water quality and sediment and nutrient transport in ephemeral channels in the Missouri Ozarks. The concept of a threshold event is introduced and defined as the amount of precipitation necessary under a specific set of environmental conditions to create collectable flow in the ephemeral channels. Precipitation and antecedent soil moisture were monitored and found to have the most significant influence on the amount of runoff. A model was developed relating precipitation, soil moisture, and the number of water samples collected following each recorded precipitation event. An automatic flow monitoring and water sampling unit was installed to collect water samples and measure the flow response of a forested ephemeral watershed. Stream gauge and discharge hydrographs were recorded for one ephemeral channel during two significant flow events and a water balance performed on an ephemeral drainage basin revealed approximately 20% of moisture exits as channel flow.

Performance of all equipment is evaluated. Over 200 pieces of equipment have collected nearly 360 channel water samples and over 210 hillslope water and sediment samples. Although performing well overall, equipment has been prone to damage from wildlife and environmental factors. Work for this thesis was performed between May 2005 and August 2006.

Chapter 1 – Introduction

1.1 Overview

Public perception that timber harvesting negatively impacts water quality and increases erosion has driven research to investigate whether the Missouri Department of Conservation's (MDC) current best management timber harvest practices are effective. The Conservation Department, Missouri Department of Natural Resources (MDNR), United States Department of Agriculture Forest Service (USDA), and the Institute for Interdisciplinary Geotechnics (I^2G) are collaborating to quantitatively determine the impact of a practice called Regenerative Oak Clear-Cutting (ROCC) on surface water quality in the southeast Missouri Ozark highlands. Regenerative Oak Clear-Cutting involves clearing entire stands of forest to meet the goals of MDC's management plan, including the elimination of diseased trees and re-establishing the native pine forests. The Institute for Interdisciplinary Geotechnics was charged with the task of monitoring sedimentation and water quality changes as a result of clear-cutting over a seven-year period. During a 2-4 year period prior to harvest, background data were collected. After the harvesting, post-harvest water quality data will be collected for an additional 2-3 years, depending on the harvest schedule. Water and sediment samples are being collected using monitoring equipment discussed in this thesis.

Best management practices (BMP) are precautions taken before and during timber harvesting to minimize detrimental environmental impacts. Missouri Department of Conservation's current BMP include maintaining a streamside management zone (SMZ) (Fig. 1.1) along the length of some perennial and ephemeral streams. A streamside management zone is a strip of vegetation left undisturbed to act as a buffer and retain

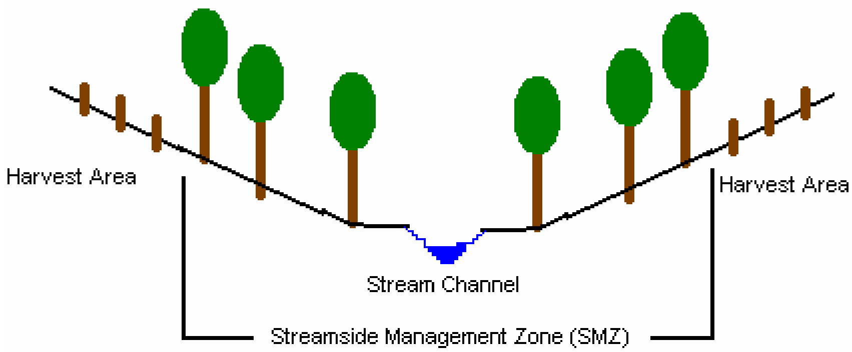

Figure 1.1 – Streamside Management Zone (SMZ).

erosional materials traveling downslope before they reach the ephemeral stream and are removed from the research site. The width of the SMZ varies with sideslope inclination. Sites with steeper sideslopes have wider SMZ's in an effort to retard the velocity of surface runoff traveling downslope to the ephemeral stream channel. Buffer widths are currently approximated by:

$$\text{Buffer Width (ft)} = (2 \times \text{Sideslope \%}) + 25 \text{ feet} \qquad \text{Eq. 1.1}$$

Streamside management zones are not applied to every first order ephemeral stream. Micro-features such as small gullies and concavities in the landscape could be classified as first order ephemeral streams, but often are not deemed large enough to necessitate applying a SMZ. District foresters have the final determination on which streams have SMZ's applied during harvesting.

1.2 Overall Objectives

The foremost objective of the project is to determine if the Missouri Department of Conservation's current BMP are effective in preventing sediment and nutrients eroded from hillsides after clear-cutting from entering the ephemeral channel. A related objective is to determine if other precautions should replace or be used in addition to streamside management zones to better protect water quality.

1.3 Specific Objectives

In support of the overall project objectives, the principal focus of the component of the project described in this thesis is to evaluate the performance of the equipment developed and installed at the research sites to monitor water quality. The equipment includes manual devices designed and installed by the research team such as rising stage water samplers and hillslope sediment monitors, along with automated water sampling and gauging equipment, electronic soil moisture gauges, and precipitation gauges. Subtasks include selecting the appropriate equipment and modifying it to accommodate field conditions, installation of these devices, evaluating instrument performance, and making necessary modifications and retrofits to equipment currently in the field.

A second objective is to define a set of threshold conditions necessary to create flow in the ephemeral drainageways. These data are necessary to better understand the hydrology of forested ephemeral Ozark watersheds and as an aide in determining when a water sample collection trip must be made. A related goal is to analyze data gathered from the automated flow monitoring system to provide insight into flow response in the ephemeral channels after precipitation and supply additional information about the complex and dynamic ephemeral hydrologic system.

Another task in this project is to ensure that each piece of equipment is functioning properly throughout the duration of the study. Equipment maintenance is critical to maximize the number of water and sediment samples obtained, helping to more accurately determine the impact of ROCC on water quality within research sites in the Missouri Ozarks.

1.4 Methodology

Research sites were selected in the Current River and Angeline conservation areas, located in the southeast Missouri Ozarks as shown in Fig. 1.2.

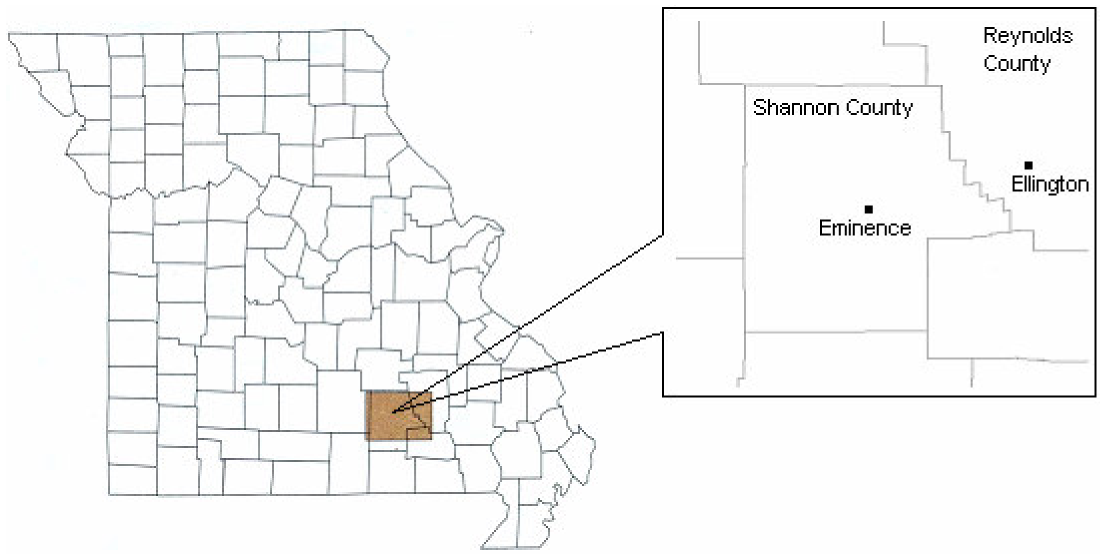

Figure 1.2 – Shannon and Reynolds Counties, Missouri, USA.

Each site consists of at least one first order ephemeral stream and its corresponding drainage basin. An ephemeral stream is a stream that periodically does not transport water. Criteria were developed to determine which sites would be most suitable for instrumentation and harvesting. Of approximately 100 sites considered, more than 50 sites were visited and 15 were selected for instrumentation. Sites were selected based on accessibility and harvest schedule, as well as watershed and channel features such as slope, shape, and size. Several additional criteria were also considered and are listed in Appendix A.

Two instrumentation regimes were implemented when installing equipment on the research sites, “intensive” and “extensive” monitoring. Of the 15 sites, four were selected for intensive instrumentation. These sites are the most heavily instrumented sites of the study. They have both more individual instruments, as well as a wider array of equipment types. All electronic or automated instruments are located on intensively monitored sites. Intensively monitored sites make it possible to observe small changes within each site. The remaining 11 sites were selected for a less rigorous instrumentation program and are referred to as extensive sites. Extensively instrumented sites allow the comparison of changes among all of the research sites.

Of the 15 sites, five are maintained as control sites and will not be harvested. The other 10 sites will be clear-cut after adequate pre-harvest data is collected. Among the four intensively monitored sites, three will be harvested while the remaining one will act as a control site and remain unharvested. With the exception of one site, all sites were scheduled to be harvested on only one aspect extending from the channel to the ridgetop (Fig. 1.3); however, current discussions are considering harvesting both aspects of sites scheduled to be harvested.

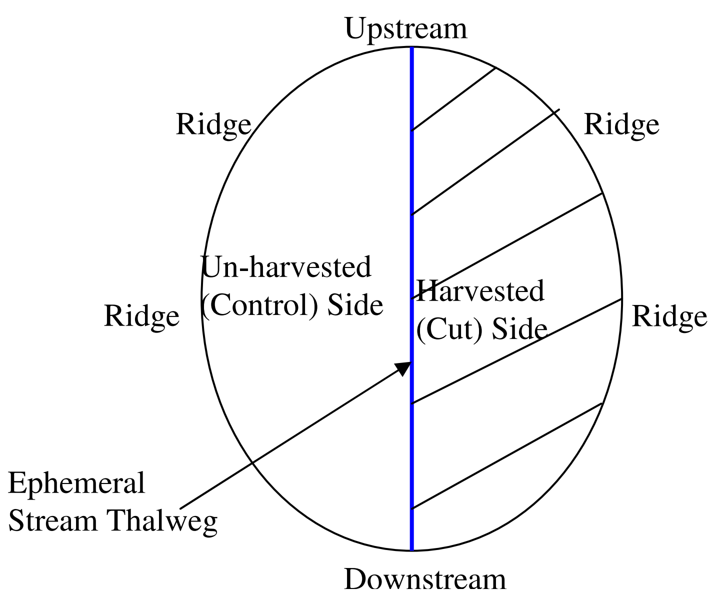

Figure 1.3 – Plan view of typical harvested site layout.

Depending on the harvesting schedule, the manual equipment will collect data for one to three years before each site is harvested. Electronic equipment will collect pre-harvest data for one to two years. After timber harvesting occurs, data collection will resume with all equipment for approximately three additional years.

1.5 Scope

The scope of this thesis includes the maintenance of 90 rising stage water samplers and 69 hillslope sediment monitors installed prior to May 2005. It covers installation and maintenance of two electronic soil moisture sensors and precipitation gauges, and an automated flow monitoring and water sampling device from May 2005 through August 2006. The dataset used during the analysis ended August 15, 2006. Performance of all equipment is evaluated and comparisons and contrasts made between manual and automated water sampling equipment. Data obtained from research equipment will be used to establish a threshold event and create a hydrograph for forested ephemeral drainageways in the southeast Missouri Ozark highlands.

1.6 Thesis Outline

Relevant literature is reviewed and presented in Chapter 2. Various equipment types are described in Chapter 3, Methods and Materials. Chapter 4 includes a presentation of results and discussion of instrument performance. Conclusions and practical implications of the findings are presented in Chapter 5. Recommendations are also made in Chapter 5. Chapter 6 contains a list of relevant references.

Chapter 2 – Literature Review

2.1 Introduction

The primary goals of the overall research project are to determine the impact of regenerative oak clear-cutting on upland ephemeral watersheds in the southeast Missouri Ozarks on sediment and nutrient transport and to review the efficacy of the Missouri Department of Conservation's current Best Management Practices as they apply to timber harvesting. Specific means necessary to achieve the main goals, including water sampling equipment performance analysis and maintenance, channel flow and hillside hydrology characteristics of ephemeral drainage basins, and defining a threshold event, are the focus of this thesis. Previous research related to these topics is reviewed in this chapter.

2.2 Water Sampling Equipment

Collecting both pre-harvest and post-harvest water quality data is necessary to determine the impact of clear-cutting within the research sites. For this purpose, various instruments have been installed to collect data from both the ephemeral channels and adjacent hillsides. Finlayson (1981) introduced a rising stage water sampler design for use in a study similar to the current research. He stated that stream channel water sampling techniques should be designed to collect runoff during peak flow, when the majority of erosion and sediment transport occurs. This can be achieved with an instrument capable of collecting samples from several flow depths of increasing magnitude.

A study similar to the current project was performed in the southeastern Missouri Ozarks. Settergren et al. (1980) instrumented two low order watersheds to investigate the factors influencing changes in overland flow and sediment transport. One site was clear-cut and the other remained uncut to act as a control. Their instrumentation regime included 20 hillslope sediment traps distributed between the sites. The traps were placed on various topographic features within the sites, including varying slope aspects, inclines, and locations. The instruments were also positioned beneath varying amounts of vegetative cover. These parameters are listed for each device in Table 2.1. Slope aspect describes the principle direction the slope is facing. In the northern hemisphere, a south facing slope receives more sunlight than a northern aspect and will typically be warmer and drier, thus reducing the amount of expected runoff. The slope treatment refers to whether the timber on the research site will be harvested or remain uncut. Slope position is important because lower portions typically receive less sunlight and more runoff and are wetter than areas higher in the landscape. Also, as slope percentage increases the slope gets steeper, allowing less moisture infiltration and increasing the amount and velocity of overland flow. The slopes represented in Table 2.1 are similar to the range of slopes encountered for this research study. Vegetative cover reduces the volume of surface flow through several mechanisms. The canopy can intercept a portion of the precipitation before it reaches the forest floor. In addition, vegetation increases the soil's ability to absorb moisture, both through vegetative uptake of moisture and the loosening the soil structure via the root systems of the vegetation. The larger vegetative coverages presented in Table 2.1 are typical of the current research sites during periods of heavy vegetation. Lower vegetation levels are similar to those encountered during the winter months. The design of hillslope sediment monitors used during the current MDC project was modeled after the design created by Settergren et al. (1980). Both the original and current designs can be seen in Figure 2.1.

Table 2.1 – Sediment trap location variables (Settergren et al. 1980).

Trap Number	Aspect	Treatment	Slope Position	Slope (%)	Average Cover (%)
1	South	Uncut	Middle	24	90
2	South	Uncut	Lower	1	100
3	South	Uncut	Upper	30	89
4	South	Uncut	Middle	24	96
5	South	Cut	Upper	13	51
6	South	Cut	Upper	18	71
7	South	Cut	Middle	20	66
8	South	Uncut	Middle	22	62
9	North	Cut	Upper	14	52
10	North	Cut	Middle	12	66
11	North	Cut	Upper	15	75
12	North	Cut	Lower	24	32
13	North	Cut	Upper	25	99
14	North	Uncut	Middle	30	99
15	North	Uncut	Middle	27	90
16	North	Cut	Lower	43	100
17	North	Control	Lower	29	96
18	North	Control	Middle	22	99
19	South	Control	Middle	22	99
20	South	Control	Lower	13	95

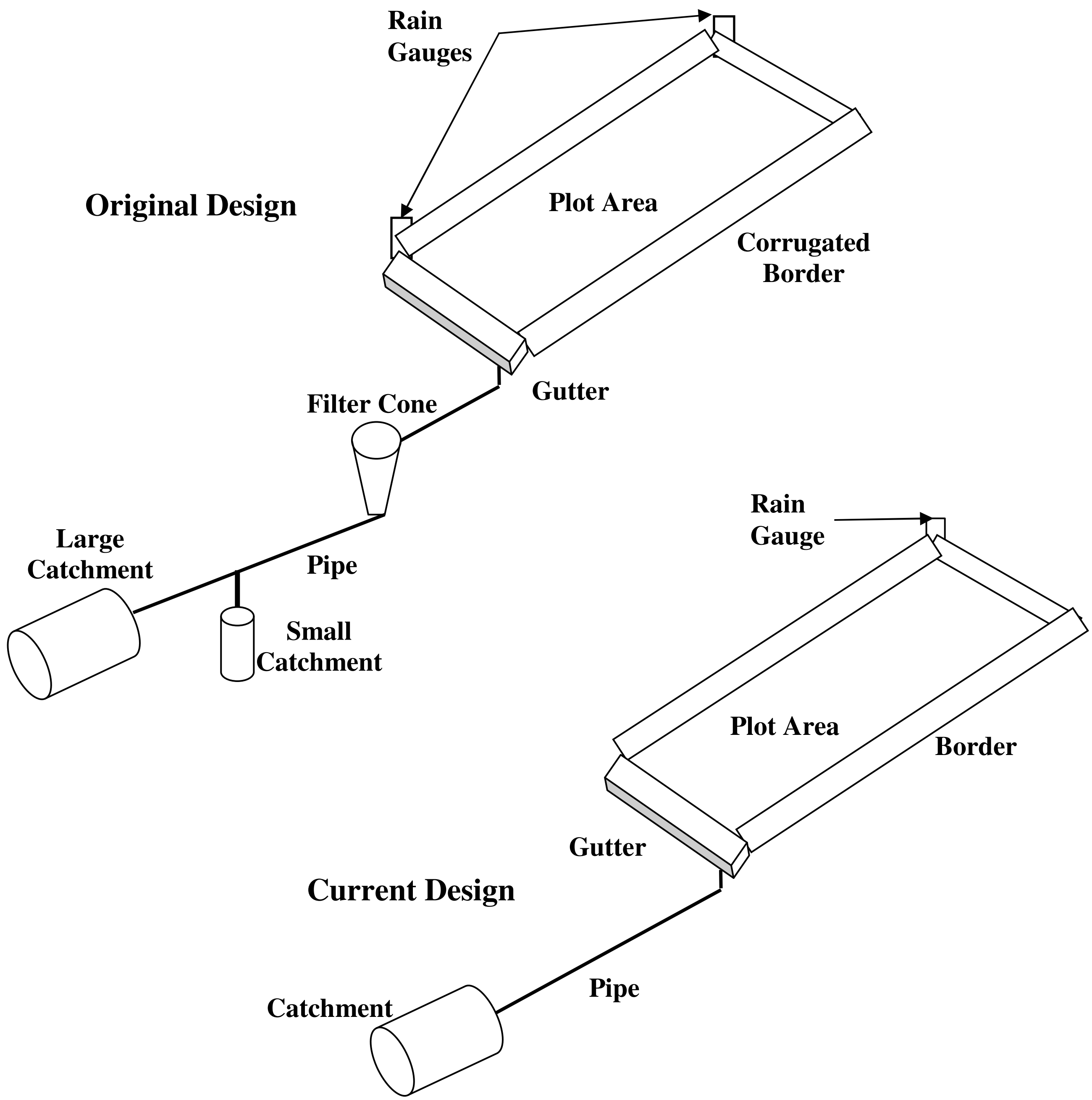

Figure 2.1 – Original (Settergren et al, 1980) and current (Bunger, 2005) sediment trap designs.

The instruments were monitored for 20 storm events between March and October 1979. A series of linear regression analyses were performed relating surface runoff and sediment yield with various parameters. No significant correlations were found. The results are presented in Table 2.2.

Table 2.2 – Runoff and sediment yield correlations with monitored variables (Settergren at al. 1980).

		r^2	
Variable	**Units**	**With Runoff**	**With Sediment**
Runoff	cm	-	0.388
Sediment Yield	kg/ha	0.388	-
Total Precipitation	cm	0.181	0.014
Maximum 5 Minute Intensity	cm/hr	0.07	0.109
Maximum 30 Minute Intensity	cm/hr	0.204	0.12
Maximum 1 Hour Intensity	cm/hr	0.196	0.07
Maximum 2 Hour Intensity	cm/hr	0.223	0.06
Average Storm Intensity	cm/hr	0	0.001
Throughfall	cm	0.219	0.025
Days Since Last 0.1 Inch Precipitation	days	0	0
Total Precipitation Last 72 Hours	cm	0.002	0.009
Percent Bare	%	0.05	0.061
Percent Cover	%	0.05	0.061
Slope Percent	%	0.044	0.034
Slope Position	Low, Mid, or Hi	0.001	0.019

Work has also been done with automated and electronic equipment. In 2000, the United States Geological Survey (USGS) (Graczyk et al, 2000) conducted a study in Wisconsin comparing the results of automated water sampling to those from manual siphon samplers. In the study, three drainage basins, two perennial streams and one ephemeral stream, ranging in size from 5.7 – 18.3 square miles were outfitted with several siphon samplers and an Isco® automatic water sampler at the downstream gauging location. The siphon samplers were installed at three distinct elevations in the channel to be able to sample different stages and times during the rising limb of flow. The automatic sampler was programmed to take samples at specific gauge increments, matching those of the manual samplers. In all, 41 pairs of samples were analyzed for suspended solids, and 47 pairs for various nutrients including total phosphorous and ammonia nitrogen. Results are presented in Figure 2.2 and Table 2.3. Overall the paired samples contained similar amounts of the constituents, with the automatic sampler showing a slightly smaller range in values. When compared to an equal concentration line in Figure 2.2, a weak trend of increasing concentration in the siphon samplers is possible.

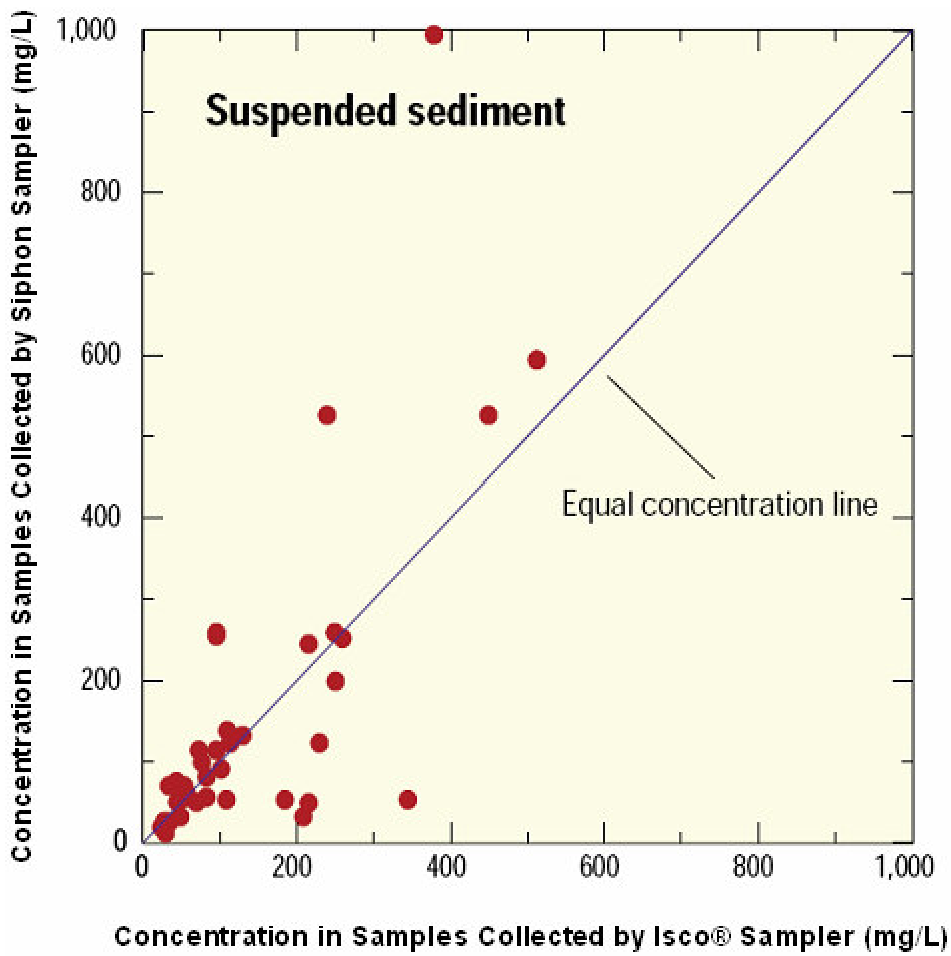

Figure 2.2 – Concentration of suspended solids from paired samples from manual and automatic water samplers (Graczyk et al, 2000).

Table 2.3 – Constituent concentrations from paired samples from manual and automatic water sampling (Graczyk et al, 2000).

	Concentration (mg/L)					Difference in concentration (Siphon - ISCO) (mg/L, %)				
Constituent and Method	**Minimum**	**Maximum**	**Standard Deviation**	**Mean**	**Median**	**Maximum Negative Difference**	**Maximum Positive Difference**	**Standard Deviation**	**Mean Difference**	**Median Difference**
Total phosphorus										
Siphon Sampler	0.1	4.17	0.73	0.6	0.41	-2.16	1.08	0.43	-0.05 (23%)	-0.03 (7%)
ISCO Sampler	0.13	3.58	0.73	0.65	0.41					
Ammonia nitrogen										
Siphon Sampler	0.02	4.16	0.67	0.39	0.22	-2.09	1.49	0.43	-0.07 (7%)	-0.02 (8%)
ISCO Sampler	0.05	3.25	0.68	0.46	0.22					
Suspended sediment										
Siphon Sampler	12	526	193	155	75	-291	287	133	14.0 (-41%)	5.0 (4%)
ISCO Sampler	23	449	120	141	95					

Soil moisture probes and rain gauges are necessary to determine the impact the measured quantity has on generation of surface runoff and channel flow in the ephemeral watersheds. Previous work with this equipment was done by Bobba (2004), near Hannibal, Missouri during his master's thesis project. Bobba instrumented an engineered soil plot with ECH_2O EC-20 soil moisture probes, ECHO® Temp air temperature sensors, and ECRN50 rain gauges. Each of these devices was connected to an ECHO® data logger to control measurement intervals and store recorded data. Bobba installed 23 soil moisture probes at depths ranging from 6 to 160 inches below the soil surface. The probes recorded volumetric water content of the soil for a period of 11 months. During this time, the probes provided nearly constant data. However, at some point, two of the probes experienced an unknown malfunction and provided faulty data. In addition, some data was lost due to wildlife activity and battery discharge. The two probes installed nearest the surface were at depths of 6 and 9 inches. Both of these probes clearly showed the wetting of the soil after precipitation and then the subsequent desiccation.

The ECHO® precipitation gauges also functioned well (Bobba, 2004), providing rainfall measurements similar to official weather stations in the area. The air temperature sensors clearly showed both daily and seasonal temperature fluctuations.

2.3 Channel Flow and Hillside Hydrology Characteristics

Knowledge of the dynamic and complex relationships existing among the various components of the ephemeral hillslope hydrological cycle is necessary to estimate stream response during and following precipitation events. In 1933, Horton simplified the system when he compared the soil to a sieve capable of separating rainfall into two basic components. Simply put, Horton stated that soil splits precipitation into surface flow and subsurface flow.

The current research focuses on surface flow. Surface flow is comprised of all water that does not infiltrate into the soil and can be estimated by subtracting the infiltration rate of water into the soil from the rainfall intensity (Horton, 1933). Kirkby and Chorley (1967) have suggested that surface flow does not occur until the local surface soil layers have become completely saturated, regardless of the infiltration rate of the soil. They also state that for all but the largest storms, little overland flow may be expected to occur over watersheds having a significant vegetation and litter layer, while surface runoff is common where vegetation is sparse and soils are thin (Kirkby and Chorley, 1978). Because overland flow does not occur until the soil is saturated, the area contributing to overland flow changes with the saturation of the soil. At the beginning of a precipitation event, typically only moist soil located near convergent topography low on the hillside produces overland flow. As the precipitation continues, the area of saturated soil increases and advances up the hillside, increasing the source area contributing to overland flow. The peak in a discharge hydrograph is associated with the maximum contribution area (Kirkby and Chorley, 1978).

2.4 Summary

The complex and dynamic nature of the hydrological cycle present on the research sites, combined with the rough terrain, unpredictable environment, and soil variability, make identifying the effects of timber clear-cutting on runoff quantity and quality in ephemeral watersheds difficult. This is demonstrated by the small correlation values from the Settergren et al study in 1980. This section will outline the relevance of previous research to the current MDC timber harvesting project, as well as describe similarities and differences between the prior research presented in this chapter and the ongoing research discussed in this thesis.

Previous research has provided ideas for design of water sample collection equipment and shown that the various types of equipment in use on this project can provide reliable data. Finlayson's (1981) rising stage water sampler was redesigned for increased durability and easier installation in the rough Ozark terrain (Bunger, 2005). The sediment trap design presented by Settergren et al (1980) was able to be used after several modifications to account for the rocky soil and steep slopes of the research sites (Bunger, 2005). The Settergren at al (1980) study was similar to the present research in that ephemeral basins were instrumented with sediment traps in an effort to determine the controlling factors influencing overland flow and sediment transport following clear-cutting in the Ozarks. The Settergren at al (1980) study was also distinctly different in that it only examined two watersheds, did not investigate water quality in the stream channels, and did not gather any pre-harvest background data.

The comparison between manual siphon water samplers and automatic Isco® samplers showed that both instruments are capable of providing consistent, comparable constituent concentrations (USGS, 2000). It also illustrated that the Isco® unit can function in the natural environment of an ephemeral watershed. Because the design of the manual siphon sampler allows only a single water sample to be collected in each device, it was necessary to install several siphon samplers to obtain samples from different depths of flow.

Bobba (2005) showed that the ECHO® equipment is able to provide precipitation, soil moisture, and air temperature data over extended periods of time. However, the soil used in his research was an engineered artificial soil, dissimilar to the natural rocky soils present in the Missouri Ozarks. In addition, Bobba installed both the rain gauges and air temperature sensors in an open area, without cover provided by vegetation. On the MDC research sites, the instruments are located underneath the forest canopy for much of the year. Bobba's research also revealed that the ECHO® instruments may experience maintenance issues associated with wildlife activity and battery discharge. Care must be taken to properly protect the equipment from damage and ensure fresh batteries are installed frequently.

Data gathered by Horton (1933) and Kirkby and Chorley (1967, 1978), illustrate the relationships of precipitation intensity and condition of moisture in the soil to the generation of overland flow. Surface flow is most likely only during heavy precipitation when soils become saturated or the maximum infiltration rate is exceeded. Therefore, water samples in hillslope sediment traps are unlikely except in extreme events.

Previous research relating to the current MDC timber harvest project has provided valuable insight into possible instrumentation, as well as observations about the numerous interactions among the components of the hydrologic system of a forested ephemeral drainageway. With the knowledge gained from prior work, a broad and effective water sampling and data gathering system can be established for the current timber harvesting impact study. In addition, data from the current research will help advance the understanding of the complex nature of the forested ephemeral hillslope hydrology.

Chapter 3 – Methods and Materials

3.1 Introduction

The instrumentation for this project focused on two distinct areas within the ephemeral watersheds, the ephemeral stream channel and the hillslopes adjacent to the stream channel. Each region was outfitted with instrumentation designed to collect data from the particular land feature. Several types of devices were installed on each feature to obtain as much relevant data as possible. The equipment included both custom designed and fabricated items as well as automated and electronic equipment purchased from suppliers. Stream channel instrumentation included rising stage water samplers, crest gauges, and an Isco® automatic stream gauging station and water sampling unit. Hillslope equipment included hillslope sediment trap monitors and controls, silt fences, manual rain gauges, soil moisture probes, and electronic tipping bucket rain gauges.

3.2 Stream Channel Instrumentation

Four different types of devices were installed in the ephemeral drainageways. Manual equipment includes the rising stage water samplers and stream crest gauges. On one intensive site, the manual equipment has been supplemented with additional automated equipment to gather more data and obtain insight into the relative effectiveness of each type of device. Automated equipment included an Isco® 6712 water sampler coupled with an Isco® 4150 flow logger, low flow area velocity sensor, and Isco® 674 tipping bucket rain gauge.

3.2.1 Rising Stage Water Samplers

The rising stage water samplers were designed to collect water samples during flow events from depths of zero, three, and six inches above the stream thalweg. The lowest inlet tube was mounted flush with the channel thalweg and the other two inlets are positioned at three inches and six inches above the channel bottom. The water is gravity-fed through flexible plastic tubing to 500 milliliter plastic bottles for sample collection. The length of tubing depends on the slope of the channel and elevation difference required to force water into the collection bottles. Figures 3.1 and 3.2 show a typical rising stage water sampler installed in the stream channel and a schematic drawing.

Figure 3.1 – Rising stage water sampler seen facing downstream.

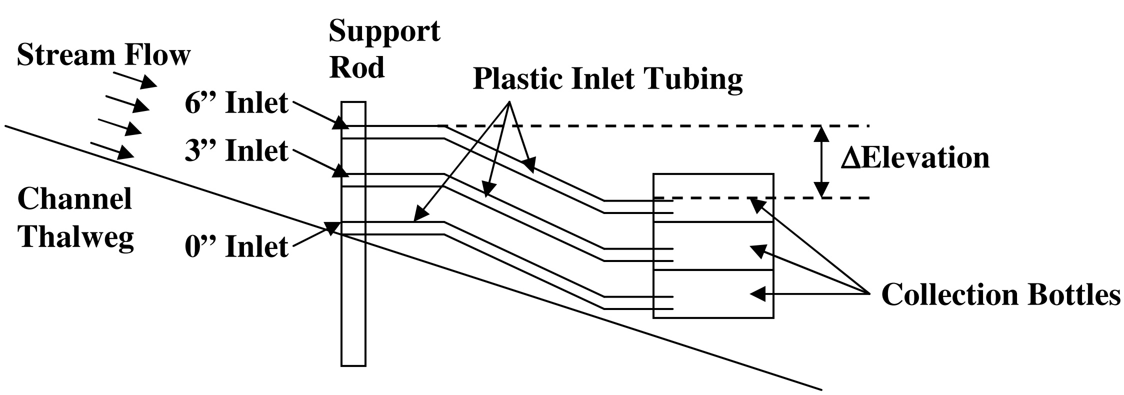

Figure 3.2 – Rising stage water sampler schematic.

Between three and ten rising stage water samplers are installed on each site. Intensively monitored sites have more samplers per site than the extensive sites. The samplers were initially installed at an upper, middle, and downstream location on each site. The uppermost samplers were installed at the highest point where a visibly discernable stream channel became apparent. The downstream samplers were positioned just below the downstream limit of the planned harvest area, while the middle samplers were installed approximately mid-length along the channel. Upon analysis after initial precipitation events, additional rising stage samplers were deemed necessary. The additional samplers were installed in many smaller "feeder" streams just upstream of their confluence with the main ephemeral channel to determine the impact of flow from the sidestreams. A typical rising stage water sampler layout can be seen in Figure 3.3.

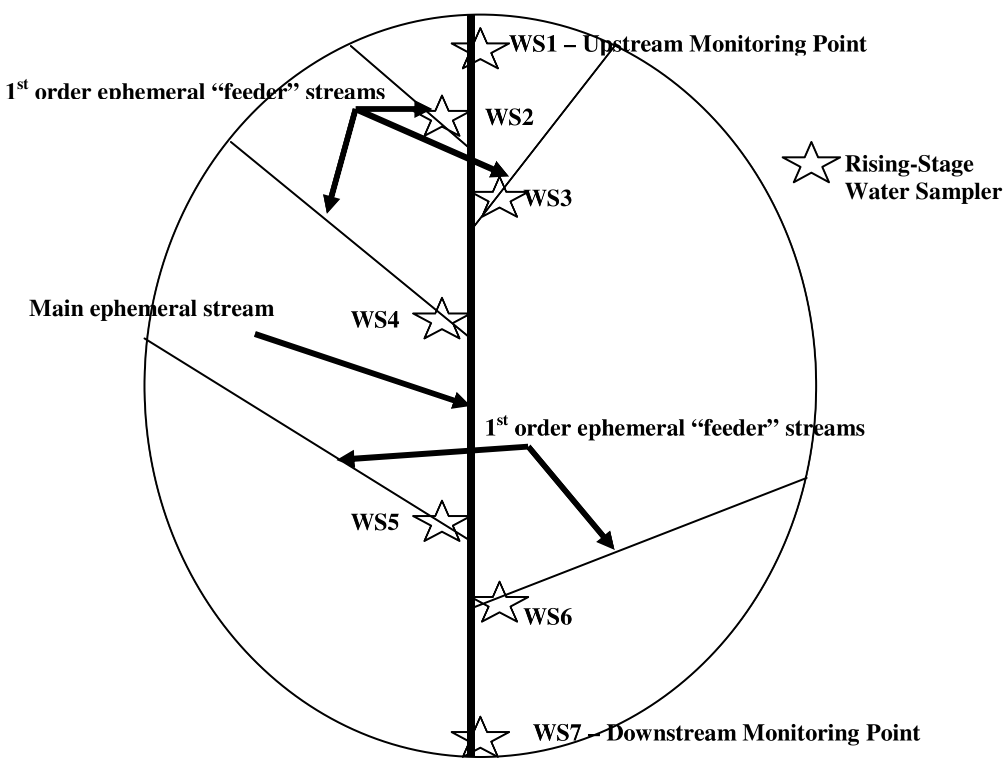

Figure 3.3 – Typical plan view of rising stage water samplers.

To this point the rising stage samplers have functioned effectively, collecting over 350 water samples. The water samplers have proved to be reliable and robust and have collected samples from each of the 15 research sites. However, many challenges associated with the environment and installation difficulty have reduced the potential number of samples collected. These obstacles and the overall performance of the rising stage water samplers will be discussed in Chapter 4.

3.2.2 Stream Crest Gauges

The stream crest gauges are designed to record the maximum flow depth in the ephemeral channel for the period between each sampling event. This depth, in conjunction with the cross sectional area of the stream at the crest gauge, allows the volume of flow to be estimated. The device consists of a two foot length of two inch diameter PVC piping mounted vertically in the channel thalweg. Small holes are drilled through the pipe near its base and covered with a screen. A mixture of small bits of cork coated in chalk dust is contained in the bottom of the pipe. A schematic of a crest gauge can be seen in Figure 3.4.

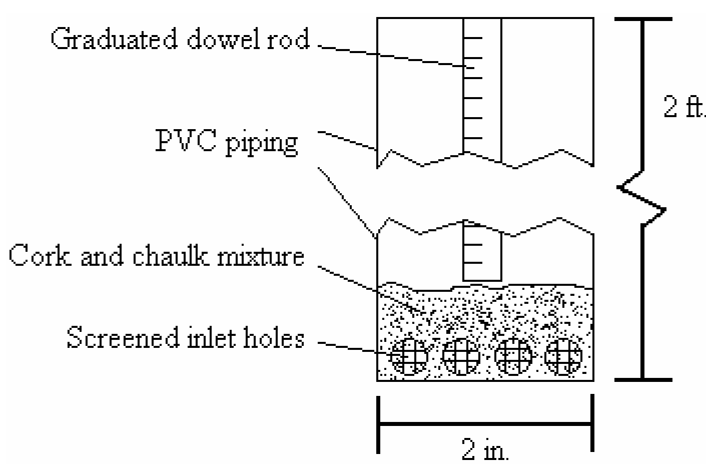

Figure 3.4 – Crest gauge schematic.

As the water level rises, the pipe fills with water and the cork mixture floats inside the pipe. Peak flow depth is determined by observing the height of chalk left on a graduated dowel rod suspended inside the pipe. The crest gauges are positioned just downstream of the downstream rising stage water sampler on each site.

3.2.3 Automated Water Sampling Equipment

In addition to the rising stage water samplers, an automated flow monitoring system and water sampler were installed on one intensive site in March 2006 to supplement the data from the manual samplers and gather additional information regarding flow in the ephemeral channel. The devices selected for this purpose are manufactured by Isco® and include the model 6712 water sampler, model 4150 flow logger, and model 674 rain gauge.

3.2.3.1 Isco® 6712 Water Sampler

The Isco® 6712 water sampler, seen in Figure 3.5, is capable of collecting up to 24 water samples and storing them internally until they can be retrieved. Because the sampler is situated to the side of the ephemeral stream channel (Fig. 3.6), the samples are collected via a flexible plastic tube attached to a stainless steel strainer mounted in the base of the channel thalweg. A peristaltic pump operated by a programmable controller provides the suction necessary to collect samples. The peristaltic pump is ideal for both maintenance purposes and maintaining sample quality. In a peristaltic pump, the fluid never contacts any internal pump parts and therefore the pump is less likely to clog and the sample is less likely to become contaminated.

To enhance its versatility, the sampler can be programmed to collect samples when a specified series of trigger conditions are met. The conditions can include many

Figure 3.5 – Isco® 6712 automatic water sampler.

Figure 3.6 – Isco® automatic water sampler installed in security box.

different combinations of time, date, precipitation, flow depth, and flow rate. All parameters of interest are monitored, and when the programmed conditions are met, a flow logger signals the water sampler to collect a sample.

Because flow in the ephemeral channels is intermittent, and every precipitation event does not result in flow, flow depth was selected as the trigger condition to ensure the sampler only attempts to collect samples when there is flow in the channel. The flow logger is programmed to activate the sampler when flow in the channel reaches depths of 0.1, 0.2, 0.3, and 0.5 feet (1.2, 2.4, 3.6, and 6.0 inches). Due to programming limitations, only four depths could be input to trigger the sampler and entry units were required to be to the nearest tenth of a foot. These depths were chosen because they most closely mimic the sampling heights of the rising stage water samplers.

3.2.3.2 Isco® 4150 Flow Logger and Area Velocity Sensor

An Isco® 4150 flow logger (Fig. 3.7) is connected to the automatic water sampler. The flow logger serves as an instrument control and interface device, as well as a data storage unit. It is connected to the sampler, rain gauge, and area velocity sensor, and can be attached to a laptop computer for programming and data downloading.

Figure 3.7 – Isco® 4150 area velocity flow logger and area velocity sensor.

The area velocity sensor is mounted beside the sample collection strainer in the channel thalweg. Both the area velocity sensor and sample collection strainer can be seen in the lower right of Figure 3.6. The area velocity sensor measures both the depth and velocity of flow in the ephemeral stream. Flow depth is measured with a pressure transducer that is accurate to ± 0.008 ft/ft over the range from 0.033 to 5.0 feet (Isco, 2006).

The area velocity sensor uses a Doppler ultrasonic method to measure flow velocity. High frequency sound waves are propagated from the sensor nose and the reflections from small particles and air bubbles suspended in the water are measured (Fig. 3.8). The Doppler effect causes the reflected waves to vary in frequency according to the velocity of the object from which they are reflected. Waves reflected from objects moving away from the sensor return at a lower frequency. The opposite is true of particles moving toward the sensor. The average flow velocity can be determined from the difference in reflected frequency from incident frequency. Using this method, the sensor is accurate to within ± 0.1 ft/sec over the range from -5.0 to 5.0 ft/sec, and to within 2.0% above 5.0 ft/sec (Isco, 2006). With these data, and the cross-sectional channel area at the sensor mounting location, the flow logger also computes and records flow volumes and discharge rates.

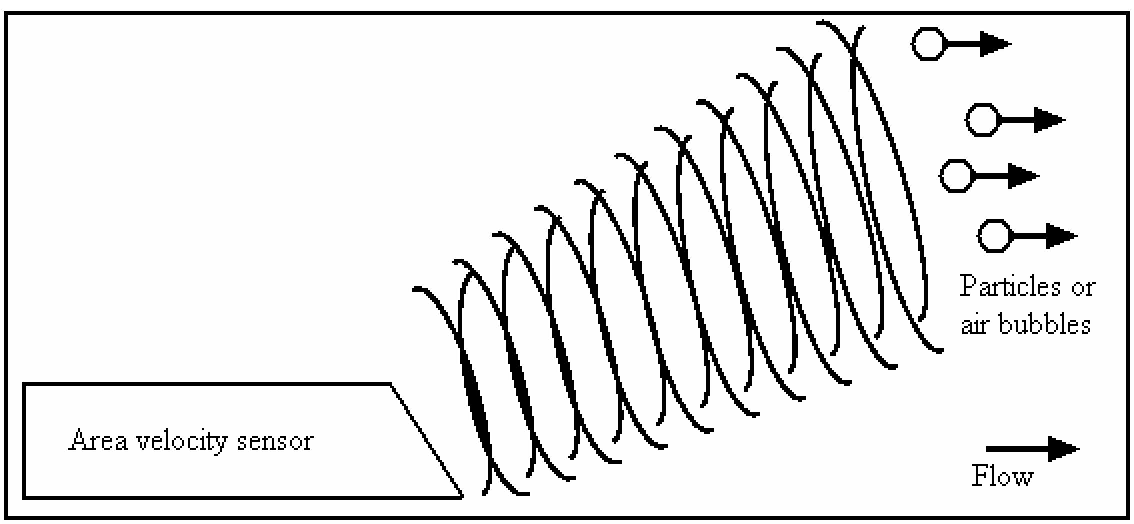

Figure 3.8 – Schematic of Doppler ultrasonic method used to measure flow velocity.

Both the automatic sampling unit and the flow logger are stored within a large steel security box (Fig. 3.6) to deter vandals and prevent damage from wildlife. The power supply, a 12 volt deep-cycle marine battery, is also stored within the security box. Access for the sampling tube, area velocity sensor, and rain gauge is through a small hole cut near the base of the box. The empty space remaining around the tubing and wires passing through the outlet was filled with expansive foam to prevent wildlife from entering the box. As an additional precaution against wildlife damage, all exposed wires and tubing were run through a length of hard plastic tubing.

3.2.3.3 Isco® 674 Rain Gauge

An Isco® model 674 rain gauge (Fig. 3.9) is mounted on top of the security box to collect an additional measurement of local precipitation beneath the canopy. Its dual tipping mechanism has a precision of 0.01 inches. A bubble level provides a means to ensure the device is properly mounted. Level installation is critical for accurate function of the tipping mechanism. Precipitation data is transmitted to the flow logger for storage until it can be downloaded onto a laptop computer.

Figure 3.9 – Isco® 674 rain gauge.

3.3 Hillslope Instrumentation

3.3.1 Overview

While flow in the channel is of obvious importance, some of the main influences of the stream water quality are the conditions on the surrounding hillslopes. For this reason, several different types of equipment were designed and installed on the hillslopes adjacent to the ephemeral stream in an effort to quantify the effect of runoff directly from the hillsides into the channel. Equipment installed on the sideslopes include hillslope sediment monitors, hillslope monitor control devices, silt fences, soil moisture sensors, manual and electronic precipitation gauges, and ambient temperature sensors.

3.3.2 Hillslope Sediment Monitors

The hillslope sediment monitors are designed to collect surface water runoff from the hillside and the sediment load carried by the water. The design (Fig. 3.10) consists of a trapezoidal area of approximately 40 square feet enclosed by aluminum flashing on the uphill and side edges (Bunger, 2005). The lower end is formed by a four foot piece of roof guttering laid flush with the ground surface to collect surface flow. The guttering is angled slightly downhill to direct water into an inlet pipe in the lower corner. Here the water is transported through a four foot length of one inch diameter PVC piping and into a catchment constructed from a four foot length of six inch diameter PVC piping capped at both ends. A design modification applied after initial installation to prevent surface flow from escaping beneath the guttering includes a two-foot wide strip of impermeable plastic sheeting to bridge gaps between the forest floor and the guttering.

The research sites have between four and six hillslope monitors. Generally, four devices are installed on the aspect scheduled to be harvested, with one hillslope monitor

Figure 3.10 – Hillslope sediment monitor and manual rain gauge.

placed on the side which is not going to be harvested to serve as a control. On the Current River sites, the hillslope monitors are installed in clusters with several devices located near one another. On sites in the Angeline conservation area, the monitors are installed on various micro-features of the terrain such as small concavities and convexities. This was done in order to try to capture the effect of landform on runoff and sediment quantity. In addition, hillslope monitors were installed on various slopes to determine the effect of ground slope on overland flow and sediment transport.

3.3.3 Hillslope Monitor Control Device

After the design retrofits to the hillslope monitors in which the plastic sheeting was installed, it was noticed that sample frequency and volume increased significantly. It was hypothesized that the larger and more frequent samples were not a result of increased effectiveness in collecting runoff from the exposed hillslope monitor plot area, but rather primarily a function of precipitation falling directly onto the impermeable sheeting.

To test this theory, three hillslope monitor control devices were installed (Fig. 3.11). These devices resemble a typical hillslope monitor but have only an eight square foot plot area which is completely covered with the plastic sheeting. The lower portion, including the guttering, piping and catchment, is identical to that of a standard hillslope monitor (Fig. 3.10). This design provides data relating precipitation event size to the volume of sample per area of plastic sheeting. The hillslope monitor control device makes it possible to determine the volume of sample resulting from rainfall directly onto the sheeting. Data from these devices will help estimate the impact the plastic sheeting has on sample volumes in hillslope sediment monitors.

Figure 3.11 – Hillslope monitor control device.

3.3.4 Silt Fences

Silt fences are installed on five research sites to gather data about the quantity and rate of large debris and sediment moving down the hillslopes above the ephemeral drainageways. Each site with silt fences has two on each side of the channel for a total of four per site and twenty silt fences distributed among all sites. They are located on sites A27-1, A34-1, CR7-5b, CR7-5c, and CR7-6. The fences are constructed of a geotextile fabric approximately 1.5 feet tall by six feet wide attached to wooden stakes driven into the soil. A yardstick is attached to the central stake to record the depth of sedimentation and debris build-up. The silt fences were installed on similar topography as the hillslope sediment monitors. They were placed on various slopes and on both concavities and convexities to determine the impact of landform on the movement of overland sediment and forest litter. A typical silt fence example can be seen in Figure 3.12.

Figure 3.12 – Typical silt fence.

3.3.5 Rain Gauges

In order to get an accurate measure of local precipitation manual rain gauges (Fig. 3.13, 3.10) were installed at every hillslope monitor and hillslope monitor control. This allows quantification of precipitation penetrating through the forest canopy at the location of each of the hillslope monitors.

In addition to the manual gauges, ECH_2O® ECN electronic tipping bucket rain

Figure 3.13 – Manual rain gauge.

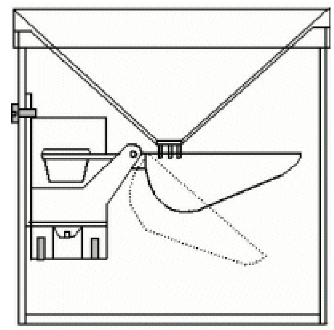

Figure 3.14 – Cutaway schematic of ECH_2O® ECN electronic tipping bucket rain gauge.

gauges (Fig. 3.14) with an accuracy of $\pm 2.0\%$ are located on sites Angeline 34-1 (A34-1) and Current River 7-5c (CR7-5c), two of the intensively monitored sites. The tipping bucket empties when a volume of one milliliter of water is collected. Each time the bucket tips, a signal is sent to an electronic data logger to be stored until it is able to be downloaded from the logger onto a laptop computer. Due to limited memory capacity of the data logger, data must be downloaded periodically to prevent new readings from replacing saved data. While only a specific amount of data can be stored in the logger at any one time, the length of time over which the device can record data depends on the method in which the data is programmed to be stored and how often readings are taken. In an effort to maximize both the amount of data collected and the length of time between downloads, the data loggers were programmed to take readings once per minute but only commit the hourly average to permanent memory. This configuration allows for up to four months of data to be stored before it must be downloaded.

Two sources of precipitation data available online are also used to supplement data from electronic rain gauges installed on the sites and to gauge when a sample collection trip is necessary. One source, a Remote Automated Weather Station, or RAWS (Fig. 3.15), is available from the National Oceanic and Atmospheric Administration (NOAA) (NOAA, 2006) (Appx. C). Data from this station is available from August 29, 2002 until present. The RAWS is located near Carr Creek just southeast of the intersection of Highway 106 and State Road HH approximately 13 miles east of Eminence, Missouri (37°10'50"N, 91° 7'5"W)(Fig. 3.15). The station is between two and five miles from all of the research sites located in the Current River Conservation Area.

Figure 3.15 – Typical Remote Automated Weather Station (RAWS).

The other online source is available from the United States Geological Survey (USGS) (USGS, 2006) (Appx. C). This data comes from a remote station located on the

Missouri Highway 19 bridge crossing the Jack's Fork River in Eminence, Missouri (Fig. 3.16). Both sources provide data in both tabular and graphical format.

3.3.6 ECH$_2$O® EC-20 Soil Moisture Probes

ECH$_2$O® EC-20 soil moisture sensors with an accuracy of $\pm 3\%$ (Fig. 3.17) are installed at the same locations as the tipping bucket rain gauges on two intensive sites, A34-1 and CR7-5c. The devices measure the dielectric constant of the soil. Because the dielectric constant depends on the moisture content of the soil, the rate of change of voltage across the buried probe can be converted to the volumetric water content of the soil (Decagon, 2006). The probe is programmed to collect data every 60 seconds and record the hourly average to memory. Three probes are spaced vertically on the hillside and buried to a depth of six inches at each location. The uphill probe is even with the top of the hillslope monitor, the center one is even with the guttering, and the downhill probe is approximately 10 feet downslope from the guttering. The data collected from these probes are stored in the same data logger as data from the rain gauge and also available for download to a computer.

The antecedent surface soil moisture level will provide data to help predict surface flow volumes for various size precipitation events and provide insight into the limiting conditions of a threshold event. For the purposes of this project, a threshold event is any combination of parameters which generates collectable flow, and thus water samples, in the ephemeral channels. These factors are numerous and can include soil moisture content, vegetative cover, soil type, ground slope, and temporal variations.

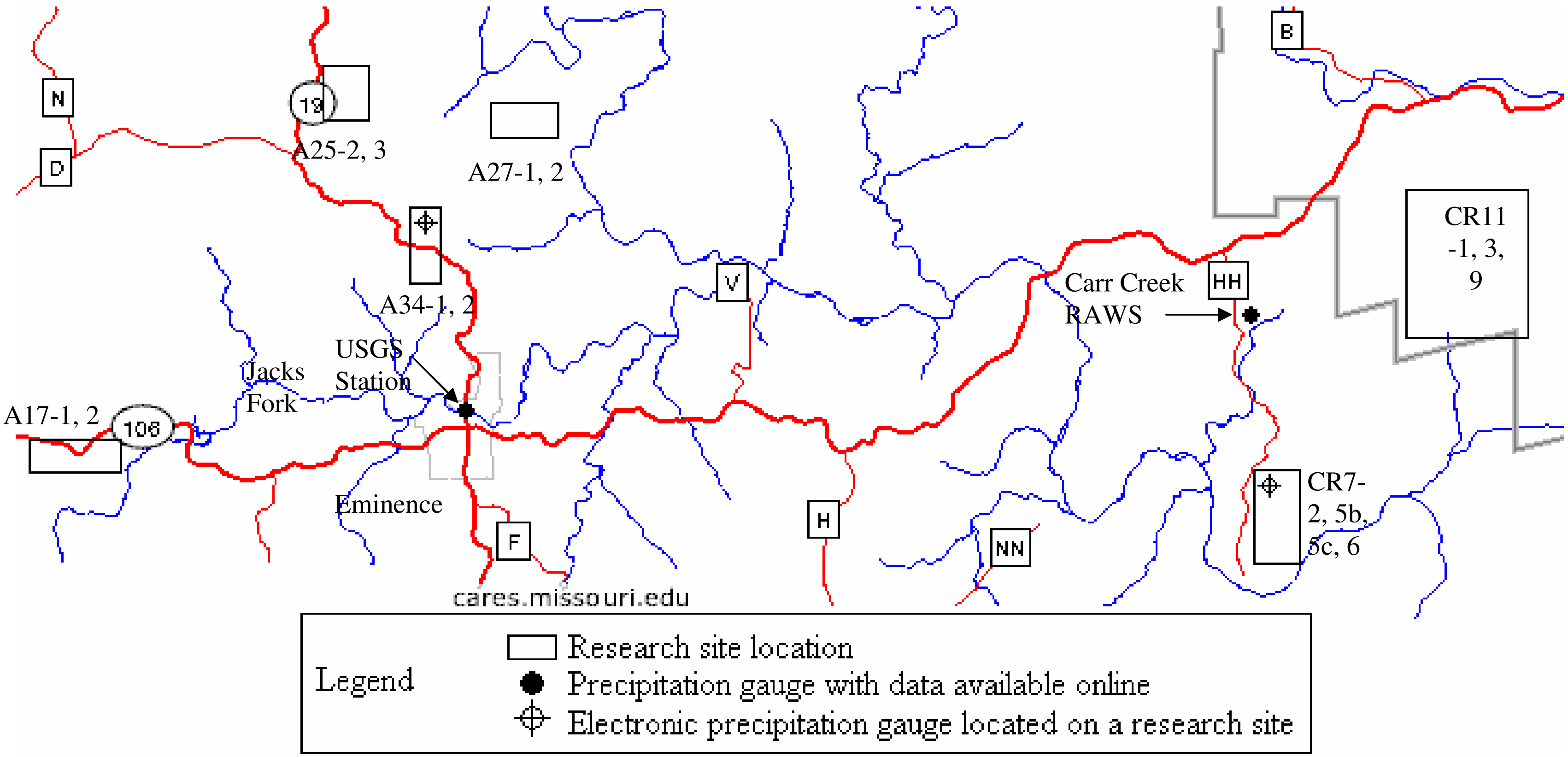

Figure 3.16 – Location of research sites and electronic and online precipitation gauges.

Figure 3.17 – ECH2O® EC-20 soil moisture probe.

3.3.7 ECH$_2$O® Air Temperature Sensors

The ECH$_2$O® temperature sensors (Fig. 3.18), also installed on A34-1 and CR7-5c, are attached to the same data logger as the rain gauge and soil moisture sensors. The temperature is monitored once per minute and the hourly average is recorded with an accuracy of ± 1ºC (1.8ºF). The actual probe is shielded within a protective housing to minimize effects from sun, rain, and wind. They provide data which can be used to

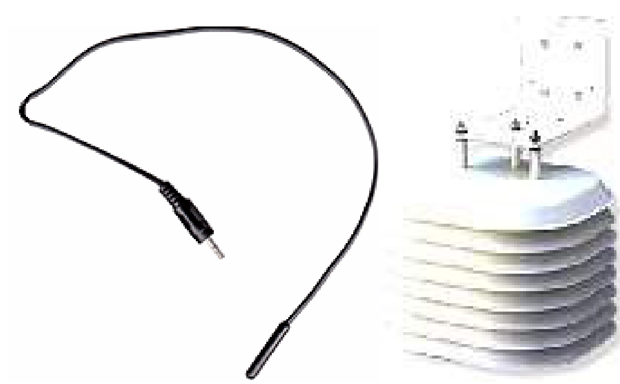

Figure 3.18 – Ambient air temperature sensor and protective housing.

evaluate the effects of temperature and evaporation on soil moisture content and other parameters.

3.4 Summary

In order to accurately quantify the effects of regenerative oak clear cutting on the effect of sedimentation and nutrient changes in forested ephemeral drainageways, a thorough and effective field data collection system must be created and maintained. This involves the design, installation, and maintenance of a large number and wide variety of instruments. This is necessary to cover both depth and breadth of data collection. Many pieces of each type of equipment are needed to create as large of a data set as possible. To date, over 200 pieces of equipment have been installed on the research sites. A variety of equipment types is important to provide data redundancy and to gather other information relative to the study. Eleven different types of instruments are currently installed to perform this function.

Simple, reliable manual sample collection equipment has been supplemented with automatic systems. Each device will be evaluated and compared to determine benefits and drawbacks, as well as provide insight into their relative effectiveness.

Chapter 4 – Results and Discussion

4.1 Introduction

Effectively monitoring changes in water quality and sediment transport resulting from clear-cutting timber requires that many high quality water samples be collected over an extended period of time. To collect as many samples as possible, and to assure high quality standards, the sampling equipment must be maintained in good working order and its performance evaluated. More than 270 pieces of field equipment have been installed on this project and have been in use for at least four precipitation events, and most have been in place for almost two years. This has allowed ample time to observe how well the equipment is functioning and what modifications, alterations, or retrofits may be necessary to improve performance. Performance of each type of equipment has been evaluated and is discussed in this chapter.

In conjunction with equipment maintenance and performance evaluations, it has been necessary to decide when a water sample collection trip is necessary. This requires selecting specific criteria to determine when to initiate a trip to the field. Due to the research sites being located approximately four hours driving time from Columbia, Missouri, it is neither economical nor practical to visit all sites after every precipitation event. In an effort to minimize the number of sampling trips, and maximize the number and quality of water samples collected, an effort has been made to determine quantitative limits for several factors influencing a threshold event. A threshold event is the amount of precipitation necessary under a given set of environmental conditions to produce flow, and thus water samples, in the ephemeral channels. Factors such as precipitation intensity and duration, as well as antecedent soil moisture content, have been investigated to determine their correlation with the amount of flow created in the ephemeral drainageways and the number of water samples collected.

4.2 Equipment Performance

Proper equipment performance is crucial to the success of the timber harvest project's overall goal of evaluating the effectiveness of the MDC's current best management timber harvesting practices; specifically the effectiveness of streamside management zones in preventing sediment and nutrients washed from the hillslopes from entering the ephemeral channel and being removed from the site. Each variety of instrument has been observed for a period ranging from five to thirty months. This has allowed enough time for each piece of equipment to be studied after at least four significant precipitation events. Most equipment has been exposed to between eight and eleven such events.

4.2.1 Stream Channel Instrumentation

Because of the distinctly different design and intended function of the various types of instrumentation, performance analyses have been separated into sections according to equipment location within the topography of the site. Instrumentation situated in the stream channel is discussed first, with an analysis of hillslope instrumentation to follow.

4.2.1.1 Rising Stage Water Samplers

The 91 rising stage water samplers have been performing well and have been effective at collecting and retaining water samples during flow events. From the installation of the first rising stage water samplers in October 2004, to the most recent sampling trip in July 2006, over 350 samples have been collected from the ephemeral drainageways.

Functionality of the instruments is reduced as the result of several different challenges. All soft construction materials, including the plastic inlets, mounting brackets, tubing, and sample bottles, are susceptible to damage by wildlife. Often, these materials contain teeth and chew marks which have damaged the instrument to the point where water samples can no longer be collected or retained.

The softer construction materials are also more prone to degradation and damage due to environmental factors such as solar radiation, temperature changes, and debris impact. In several cases, the plastic mounting brackets attaching the inlet ports to the support rod have been snapped after large flow events have forced heavy debris against the inlets. Sample bottles that have been in the field for an extended period of time have been subject to degradation from sunlight. The solar radiation (UV-B) severely weakens the plastic, causing it to become brittle. In some cases the bottles have become so brittle that they have cracked after being struck by debris during large flow events or shattered during routine sample collection.

On one site, the downstream rising stage water sampler was completely washed out during high a flow event. In an extreme case, a downstream water sampler was completely buried under a deposit of gravel and other debris over 16 inches deep. Because of its location in the center of the channel, and its vertical orientation, the inlet support rod is often the cause of a local debris dam. Sticks and leaves being washed downstream lodge against the support rod, increasing it frontal area. Additional debris then becomes caught and the size of the mass increases. Because of this, leaf litter often covers or clogs the tubing inlets. In many cases, the inlet positioned on the channel thalweg has become filled with sediment.

Despite all of these obstacles, the rising stage water samplers have performed well. With regular maintenance trips to maintain functionality of the devices, they reliably collect and store water samples during flow.

4.2.1.2 Stream Crest Gauges

The crest gauges functioned effectively in laboratory testing, but when subjected to use in the field, have not performed well. At this point in the project, the crest gauges have seen limited success.

The poor performance can be attributed to several factors. In nearly all of the crest gauges, the cork and chalk mixture has degraded and compacted into a solid mass that no longer floats freely within the vertical piping. The small apertures in the inlet screens are prone to clogging, preventing free movement of water into and out of the interior of the pipe. It has also been observed that, due to the moist environment, the wooden measuring dowel on nearly all of the crest gauges has rotted and become discolored, making it difficult to see both the graduation marks and any evidence of chalk left during flow events. Also, after exposure to just one or two flow events, a majority of the chalk dust had rinsed out of the gauges. Due to installation difficulties, and the location in the channel thalweg, about three have been washed out during high flows.

Initially, the crest gauges were monitored during each sample collection event. After multiple flow events without having observed a record of a maximum flow depth at any of the sites, monitoring of the crest gauges has been discontinued. The downstream rising stage water sampler can be used to obtain an estimate of maximum flow depth. If the only sample collected is from the inlet positioned on the channel thalweg, the deepest flow was less than three inches. If both the zero and three inch bottles contain a sample, the maximum flow depth was between three and six inches. If samples are retrieved from all bottles of the sampler, the water level was at least six inches or greater. Because the crest gauges presently in use have not performed well, a new method to determine maximum stream crest must be instituted. Either an alternate measurement method or a crest gauge of a different, more robust design will be used to monitor flow depths in the ephemeral channels.

4.2.1.3 Automated Flow Monitoring System

To supplement data coming from manual in-stream water samplers, several types of automated devices were installed on research site A34-1, an intensively monitored site. These instruments include an Isco® automatic water sampler, flow logger, area-velocity sensor, and tipping bucket rain gauge. The unit has provided important data regarding flow characteristics of the ephemeral stream such as stream response to precipitation and total discharge.

4.2.1.3.1 Automatic Water Sampler

On the first sampling trip after installation of the automatic water sampler (5/16/06), no samples were collected because of a mechanical error within the pump. A latch closing the pump housing was knocked loose during the installation process, and as a safety precaution, the pump will not activate if the latch is not fully secured. Because the pump would not activate, no samples were collected. However, the event log kept by the sampler revealed that it had received 14 trigger signals from the flow logger during the period of time since its installation. This indicates that, had the pump been operating correctly, 14 water samples would have been collected. The malfunction was corrected, and the pump was manually tested to ensure proper function.

4.2.1.3.2 Tipping Bucket Rain Gauge

On the same sampling trip (5/16/06), data was downloaded from the Isco® flow logger. The flow logger and area velocity sensor performed properly, collecting precipitation data (Fig. 4.1), as well as stream depth, velocity, and flow rate data. The monitoring period includes data from several distinct precipitation and flow events. Precipitation data from three sets of multiple events recorded by the Isco® are shown, as well as data collected at the ECHO® station located on A34-1. One set of events occurred on April 28-29, 2006, the second set occurred May 3-4, and the third set approximately six days later on May 9-10.

During the first event, occurring April 28-29, the Isco® rain gauge recorded a two day total accumulation of approximately 1.3 inches, while the A34-1 ECHO® station measured around 1.8 inches of rainfall. This precipitation was received as a slow, steady rain lasting about 36 hours on April 28-29.

For the second event, on May 3-4, the two day total recorded by the Isco® was just over two inches. The two day total measured at the ECHO® rain gauge was approximately three inches. At both devices, almost two inches of rain fell during a six hour period beginning around 21:00 on May 3 and extending until 03:00 the following morning. This served to create a somewhat intense precipitation event. However, data also show that nearly an inch of precipitation fell earlier during a two hour period beginning at 14:00 on the afternoon of May 3.

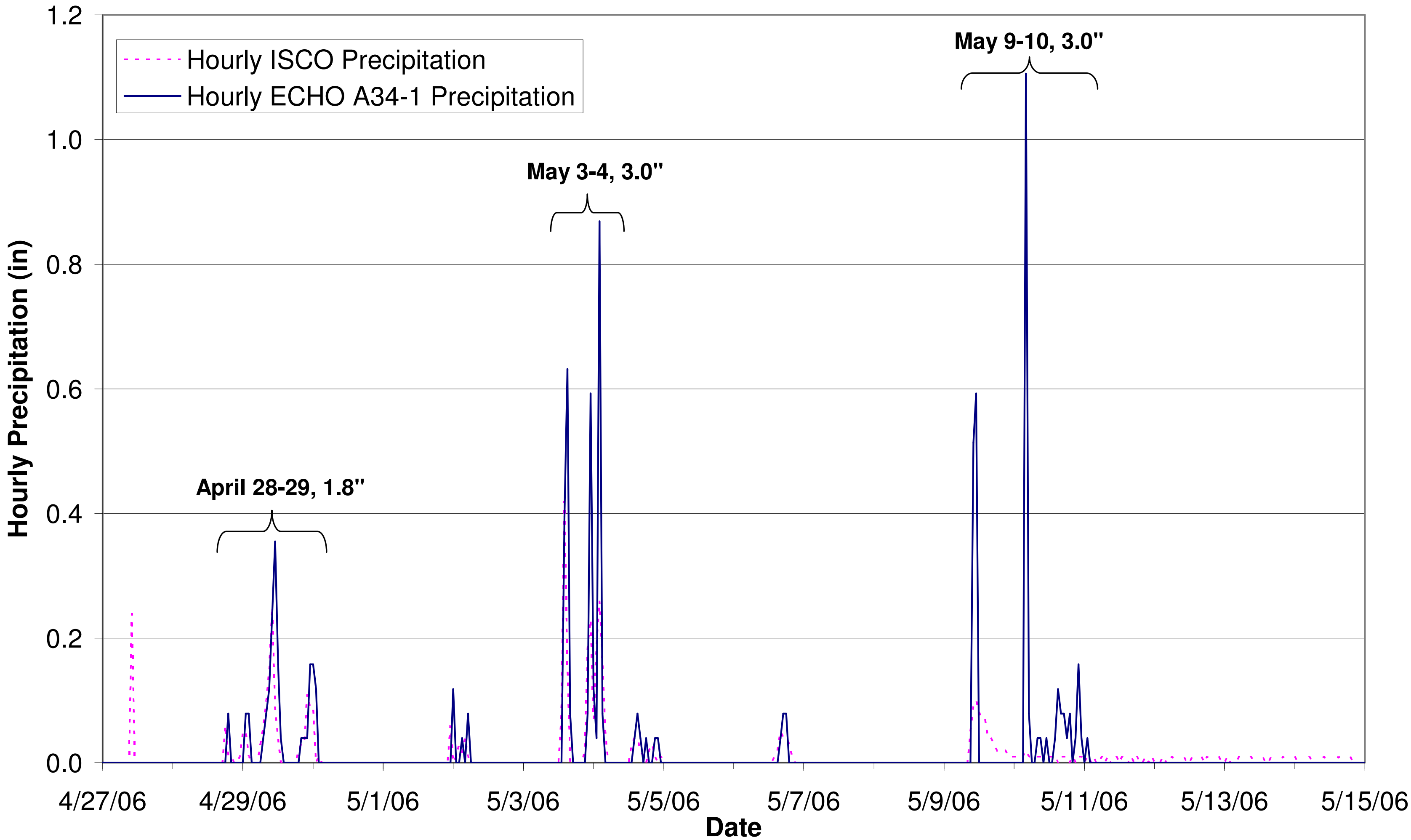

Figure 4.1 – Hourly precipitation data from Isco® rain gauge and ECHO® station on A34-1.

Five days later, on May 9-10, another set of precipitation events was recorded. During these events, approximately 0.8 inches of rainfall was measured by the ISCO® while just over three inches was measured at the A34-1 ECHO® station. Rainfall from this event was spread over nearly a 36 hour period, creating a longer duration, less intense precipitation event.

The Isco® rain gauge has recorded data similar to measurements from other sources. However, on both sampling trips after its installation (5/16/06, 7/19/06) the rain gauge was clogged with debris. Its hourly data is considered unreliable and will be disregarded. Precipitation data from extended periods are still considered somewhat accurate. The Isco® rain gauge data will be discussed in further detail later in the chapter.

4.2.1.3.3 Area Velocity Sensor – Flow Depth

Precipitation from the three events occurring from April 28-May 10 generated only two separate measurable flow events in the ephemeral channel on A34-1. Flow depths measured in the channel for the three precipitation events are shown in Figure 4.2. During the first precipitation event, on April 28-29, approximately 1.8 inches was recorded over 36 hours and no flow was measured in the ephemeral channel.

In the second event, on May 3-4, nearly three inches of rain fell over 13 hours, causing the depth to rise rapidly over a period of five hours to a peak value of 6.3 inches. Over the next 18 hours, the flow depth dropped almost constantly to around 3 inches. Flow continued to drop slowly and steadily over the subsequent three and half days.

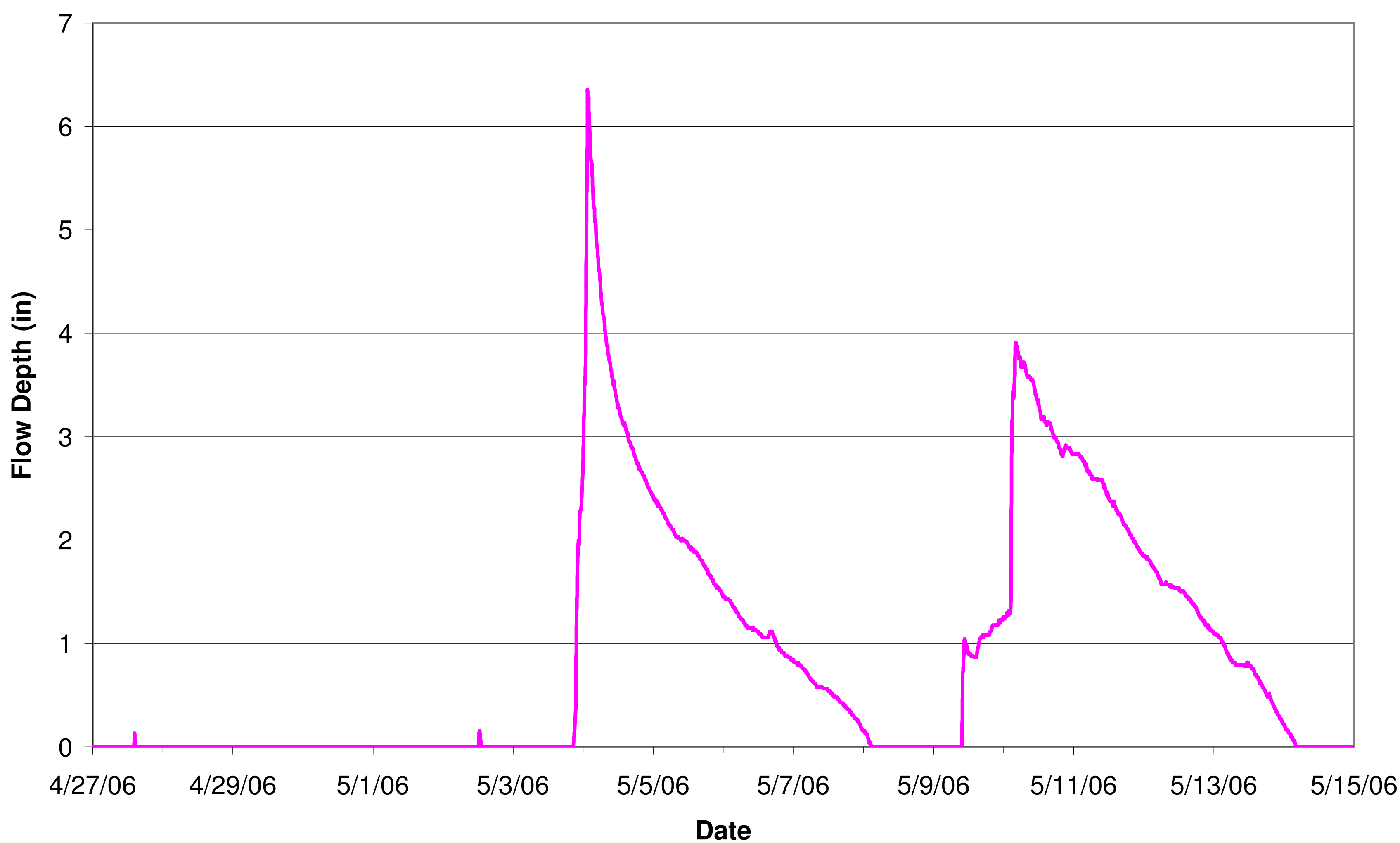

Figure 4.2 – Flow depth measured after three precipitation events from Isco® flow logger on A34-1.

The second flow event occurred slightly over a day after flow from the previous event ceased. Generating the second flow event was approximately 3 inches of rain occurring over 36 hours on May 9-10. During the flow event, the stream level rose quickly to around 1.0 inch where it remained nearly constant for approximately 15 hours. It then increased rapidly again to a maximum flow depth of 3.9 inches. The level then dropped at a near constant rate over the next four days.

When compared to data obtained from the rising stage water samplers from the same site and precipitation events, flow depth matched closely. The downstream rising stage sampler contained samples from all three inlet heights; 0, 3, and 6 inches, matching well with the maximum flow depth of just over six inches indicated by the Isco® flow logger.

4.2.1.3.4 Area Velocity Sensor – Flow Velocity

In Figure 4.3, stream velocity is plotted for the same monitoring period. The profiles are similar to those of the flow level. During the initial flow event, stream velocity increases rapidly to its maximum value of 2.52 ft/sec in 5.5 hours, then subsides steadily over a period of about two and a half days. The second event reaches a peak velocity of 2.15 ft/sec in 16 hours, with the decline extending over the next three days.

4.2.1.3.5 Area Velocity Sensor – Flow Rate

To calculate the unit flow rate, or discharge, of the stream both the depth and velocity of flow are needed. In addition, a cross-section of the channel and floodplain (Fig 4.4) at the location of the area velocity sensor must be measured and input so a cross sectional area of flow can be determined. At the position of the area velocity sensor and sample collection strainer, the channel is narrow in the thalweg, resulting in relatively

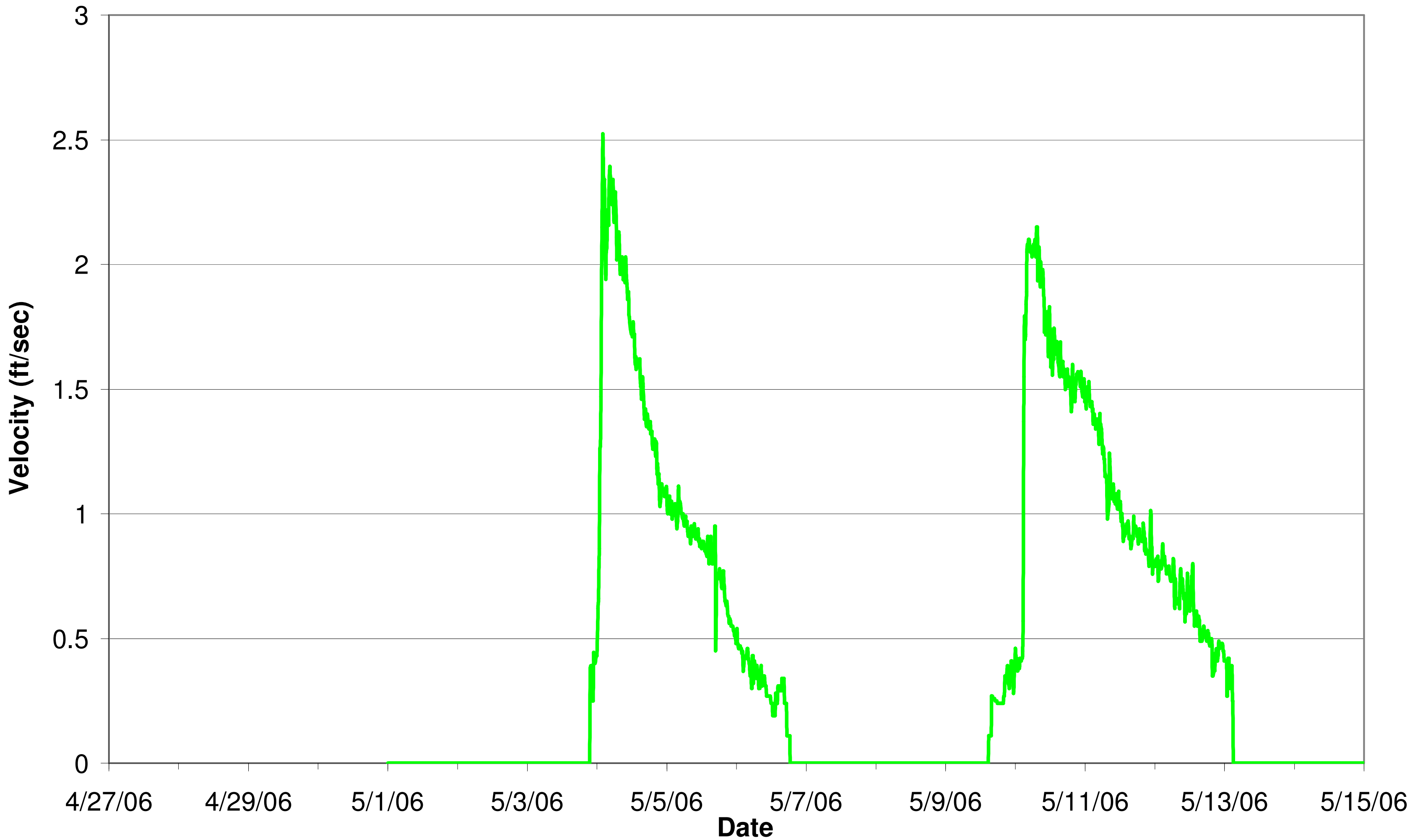

Figure 4.3 – Flow velocity measured after three precipitation events from Isco® flow logger on A34-1.

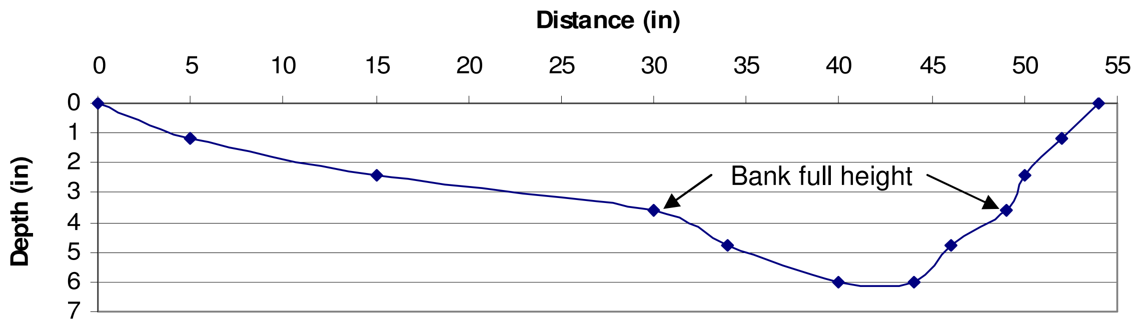

Figure 4.4 – Channel cross section at location of Isco® area velocity sensor.

low discharge for approximately the first three inches of flow depth. After the depth reaches bank full height (indicated by arrows in Fig. 4.4), it overflows onto a floodplain, increasing the area of flow dramatically. Once the flow has spilled onto the wider section of channel, stream discharge increases rapidly for small increases in flow level.

Figure 4.5 is a plot of flow rate in the ephemeral channel after each of the three precipitation events. After the initial precipitation event on April 28-29, no flow occurred in the channel. Following the May 3-4 event, discharge increased rapidly over a period of five hours to a maximum value of almost 3000 gallons per minute (gpm). It then dropped quickly over the next 20 hours to a level of about 300 gpm. From this point, the rate of decline in flow rate diminished and flow rate continued to drop for the next 18 hours. During the third precipitation event, discharge increased slowly for seven hours to about 50 gpm, at which point it increased rapidly to a maximum value of about 1000 gpm within the following two hours. Flow rate then dropped at a nearly constant rate over the next three days.

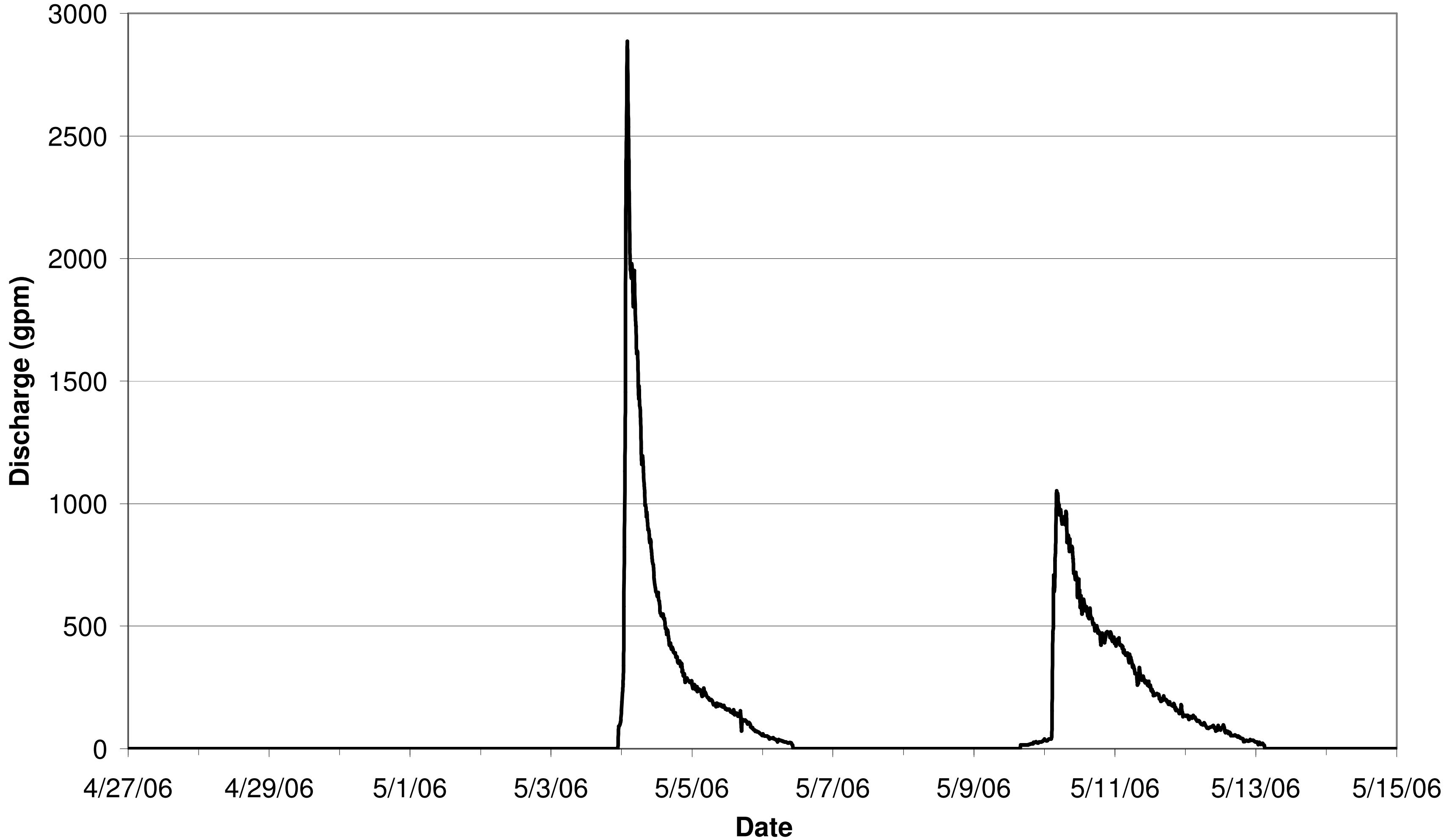

Figure 4.5 – Flow rate measured after three precipitation events from Isco® flow logger on A34-1.

4.2.1.3.6 Rain Gauge and Area Velocity Sensor – Combined Data

Data from the Isco® flow monitoring system was combined to generate a hydrograph for discharge, flow depth, and velocity in the ephemeral stream (Fig. 4.6). The shape of the plot is typical of flow response following precipitation. All three parameters peak quickly with the initial runoff, and then decline more slowly as runoff diminishes and moisture contained in the soil begins to drain.

Each parameter is related but shows a differently shaped curve. As flow depth increases, stream velocity will increase, but the two are not directly proportional. Obstacles such as rocks and branches in the channel, as well as the distance from the bank and depth at which the velocity is measured can influence the relationship between depth and velocity. Flow rate increases with both depth and velocity. Flow rate is directly proportional to changes in velocity, but because of the irregularly shaped channel cross section, its relation to depth is disproportional.

When the plots of stream depth, velocity, and discharge are overlaid, as in Fig. 4.6, it is noticed that even after discharge and velocity have dropped to zero, there continues to be measurable depth of flow in the ephemeral channel. After flow rate drops to zero following the first precipitation event, measurable channel depth continues for another 36 hours. When discharge from the second flow event ceases, flow level is able to be measured for the following 24 hours. It is uncertain why this occurs, but it is likely due to instrument measurement methods and equipment detection limits. The sensitivity of the area velocity sensor when measuring velocity is 0.1 ft/sec. If the velocity drops below this rate, the sensor may interpret it as zero. Because the Doppler method utilized by the area velocity sensor requires sufficient suspended particles or air bubbles to

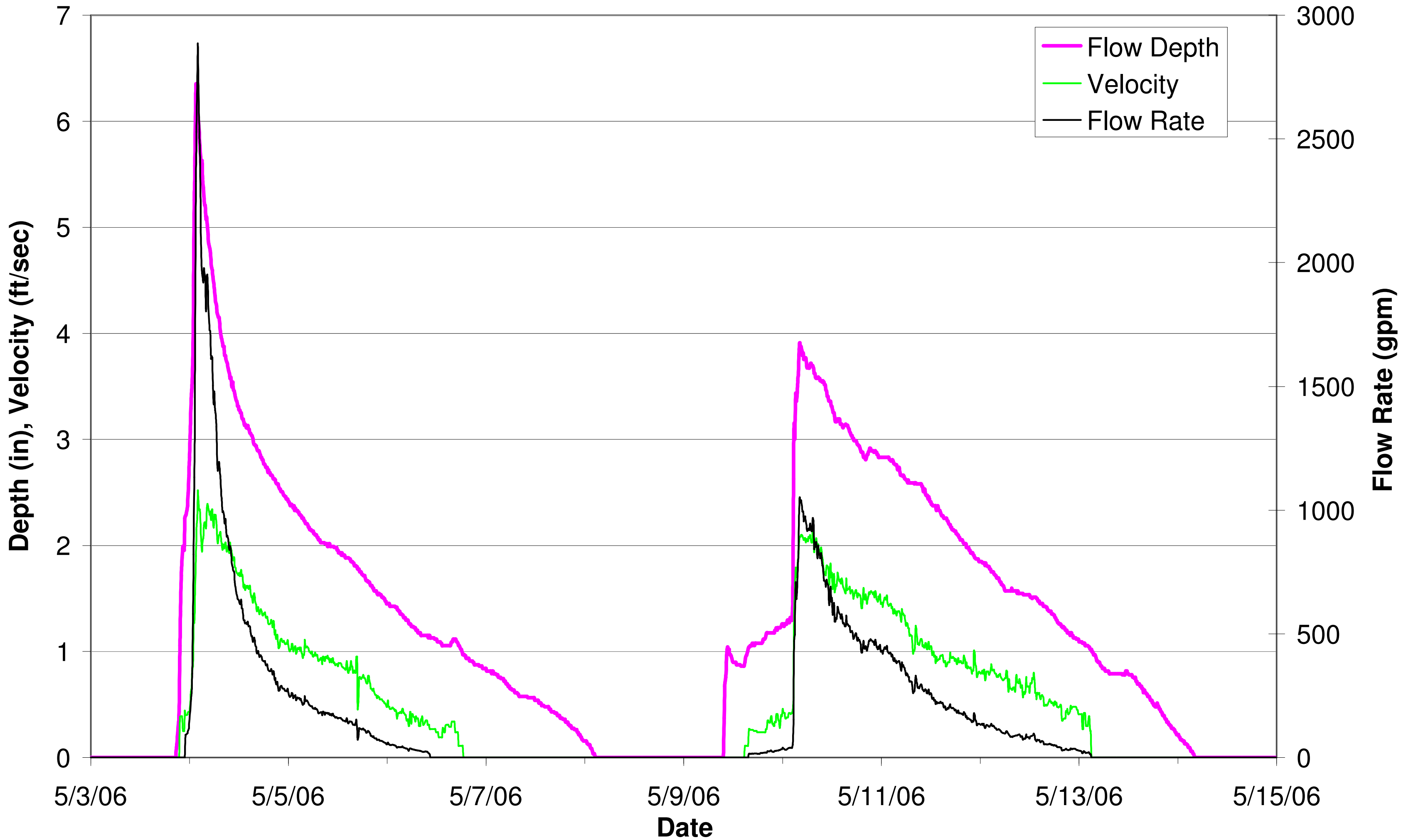

Figure 4.6 – Hydrograph of ephemeral stream on A34-1 for two precipitation events.

reflect transmitted sound waves, it is also possible that at low flow velocities, suspended particles drop out of suspension and the sensor is unable to function. Because depth is measured with a pressure transducer, it would be possible for the system to continue to measure flow levels even after it measures flow velocities of zero or is unable to measure velocities.

In Figure 4.7, the precipitation and flow depth data shown in Figures 4.1 and 4.2 are overlaid, illustrating the response of flow depth in the ephemeral stream after the precipitation events. The initial rainfall, on April 28-29 totaled about 1.8 inches. The antecedent soil moisture level at that time, expressed as a percent of total soil volume, or volumetric water content, was around 12 percent. Because a volumetric water content of 12% is relatively low, the soil had more capacity to absorb precipitation, and no flow response was seen in the ephemeral stream. The initial precipitation in the second set of events occurred between 14:00 and 16:00 on May 3 and totaled nearly one inch. No response was recorded in the ephemeral stream following the rainfall. Not until the larger precipitation event began several hours later, did flow in the channel begin. The delayed flow response within the ephemeral channel was the result of rainfall being absorbed into the soil instead of being diverted as overland flow. Because the antecedent soil moisture level was low prior to the 14:00 rainfall (Fig. 4.8), the soil had a larger capacity to absorb water before shedding it as runoff. The moisture content of the soil before the 14:00 precipitation event began was around 15 percent. During the precipitation the moisture content spiked to about 22 percent. It then began to drain and desiccate until the next event began around 21:00 the same evening. During the 21:00 event the soil moisture peaked around 24 percent. When the precipitation and soil

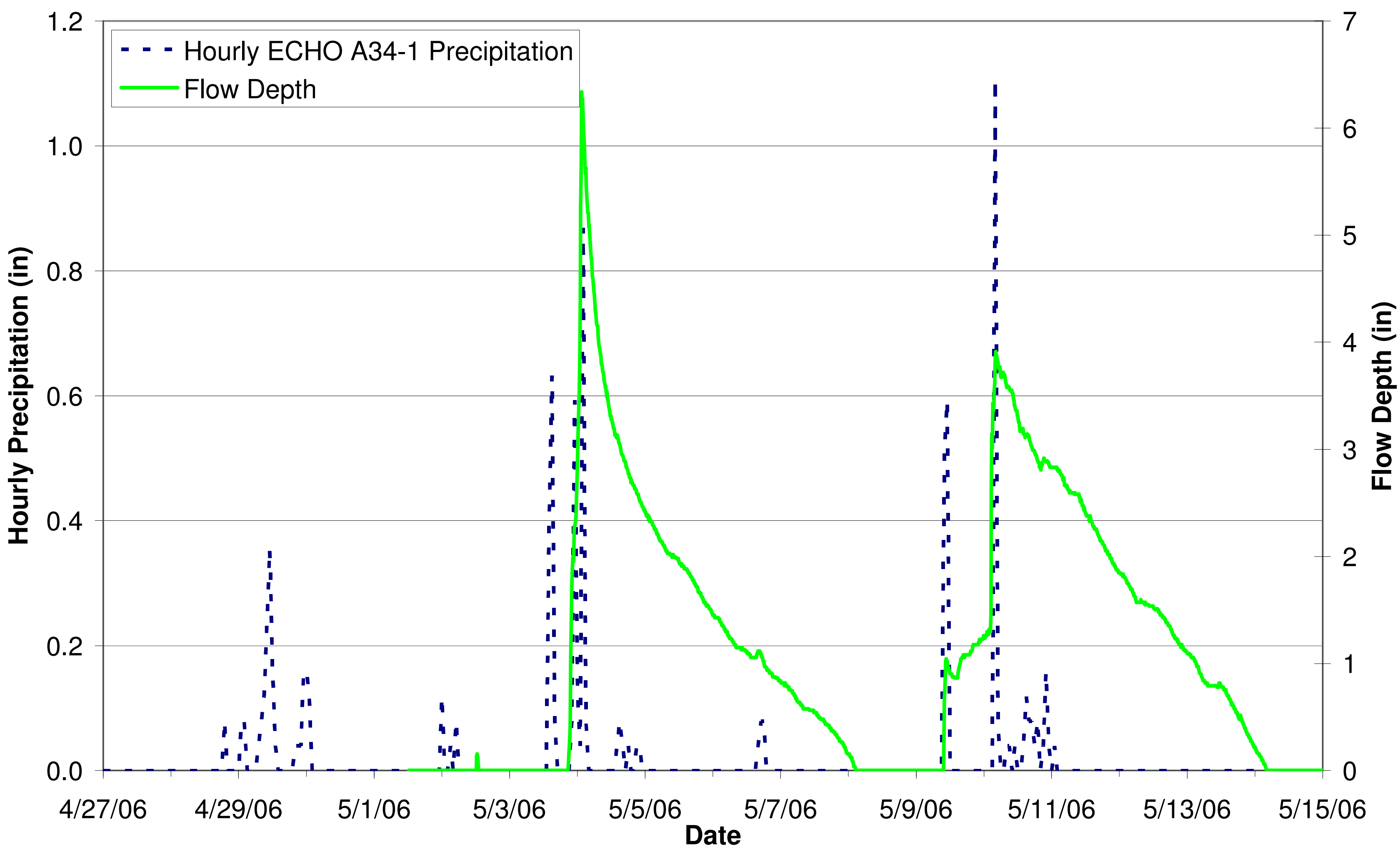

Figure 4.7 – Hourly precipitation and flow depth at A34-1 for three precipitation events.

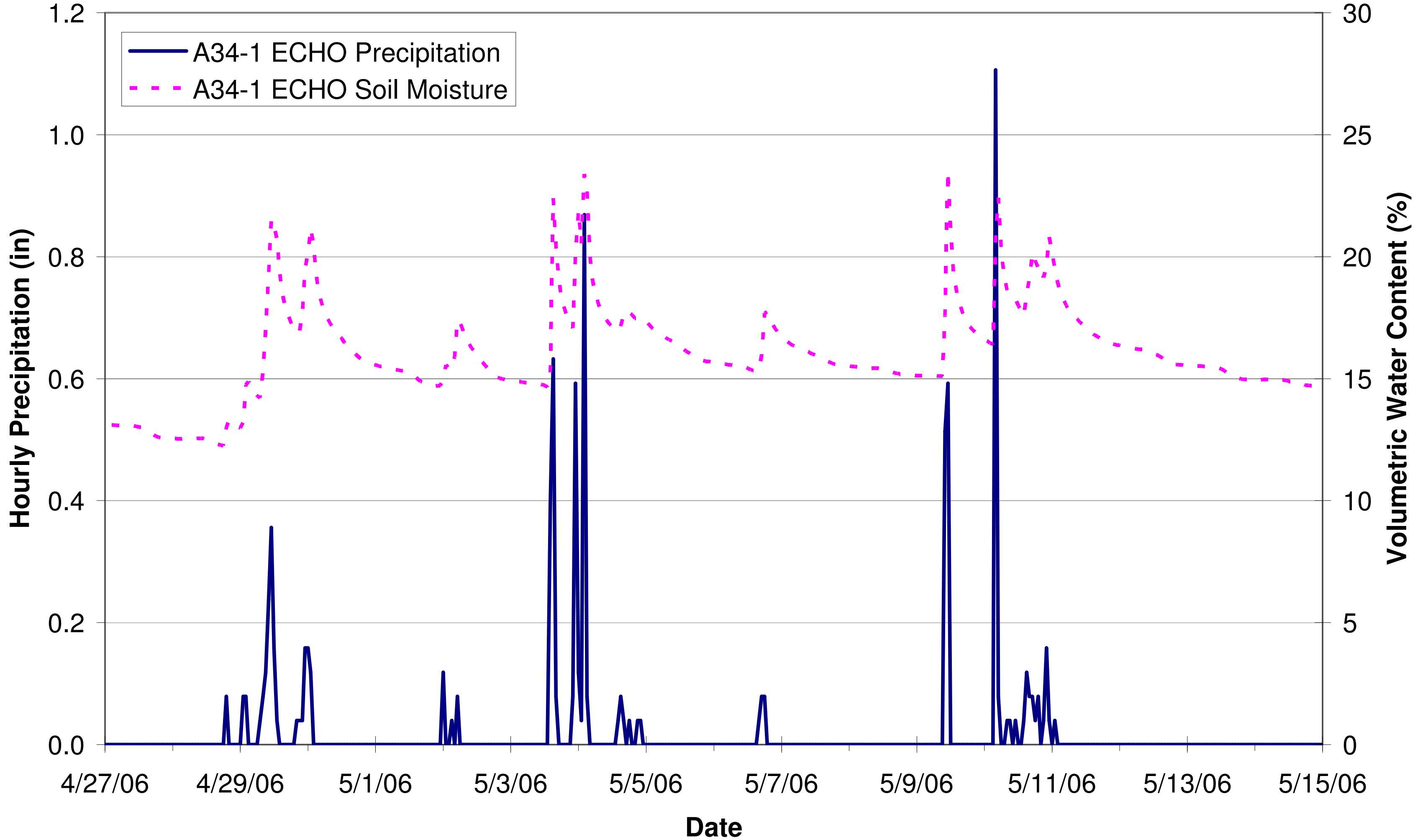

Figure 4.8 – Volumetric soil moisture content and hourly precipitation measured at A34-1 ECHO® station, April 27-May 15, 2006.

moisture data from Figure 4.8 is enlarged and overlaid with flow depth data from the Isco® in Figure 4.9, it can be seen that flow in the ephemeral channel did not begin until the rainfall event occurring around 21:00 on May 3. At that time, the soil was about 6% wetter than it had been prior to the 14:00 rainfall event and had less capability to absorb additional precipitation. When water cannot infiltrate into the soil, it is transported as overland flow and drains into the ephemeral stream. The commencement of flow in the ephemeral stream after the 21:00 precipitation event was rapid. Measurable flow is seen within minutes of the onset of rainfall. Flow depth peaks approximately five hours later after nearly two inches of additional precipitation. Stream depth and soil moisture content both peak at nearly identical times near the time of most intense precipitation. When soil moisture is at its maximum, all pore space in the soil is filled with water and the soil is considered saturated. Water infiltrates more slowly into saturated soils causing essentially all additional precipitation to be shed as overland flow. This causes flow depth to peak with soil moisture content.

4.2.1.4 Water Balance for Site A34-1

The presence of the Isco® automated flow monitoring system on A34-1 provides the capability to perform a rudimentary water balance for the ephemeral drainage basin. A water balance can be completed for the entire amount of time the Isco® unit has been installed. In addition, the analysis can be performed for each of the two separate flow events recorded by the Isco® and the contributing precipitation.

To do a proper water balance, all moisture input and output at the site during the period of interest must be included. Water input can be in the form of stream flow into the site, spring flow, and precipitation. The drainage basin for A34-1 has no known

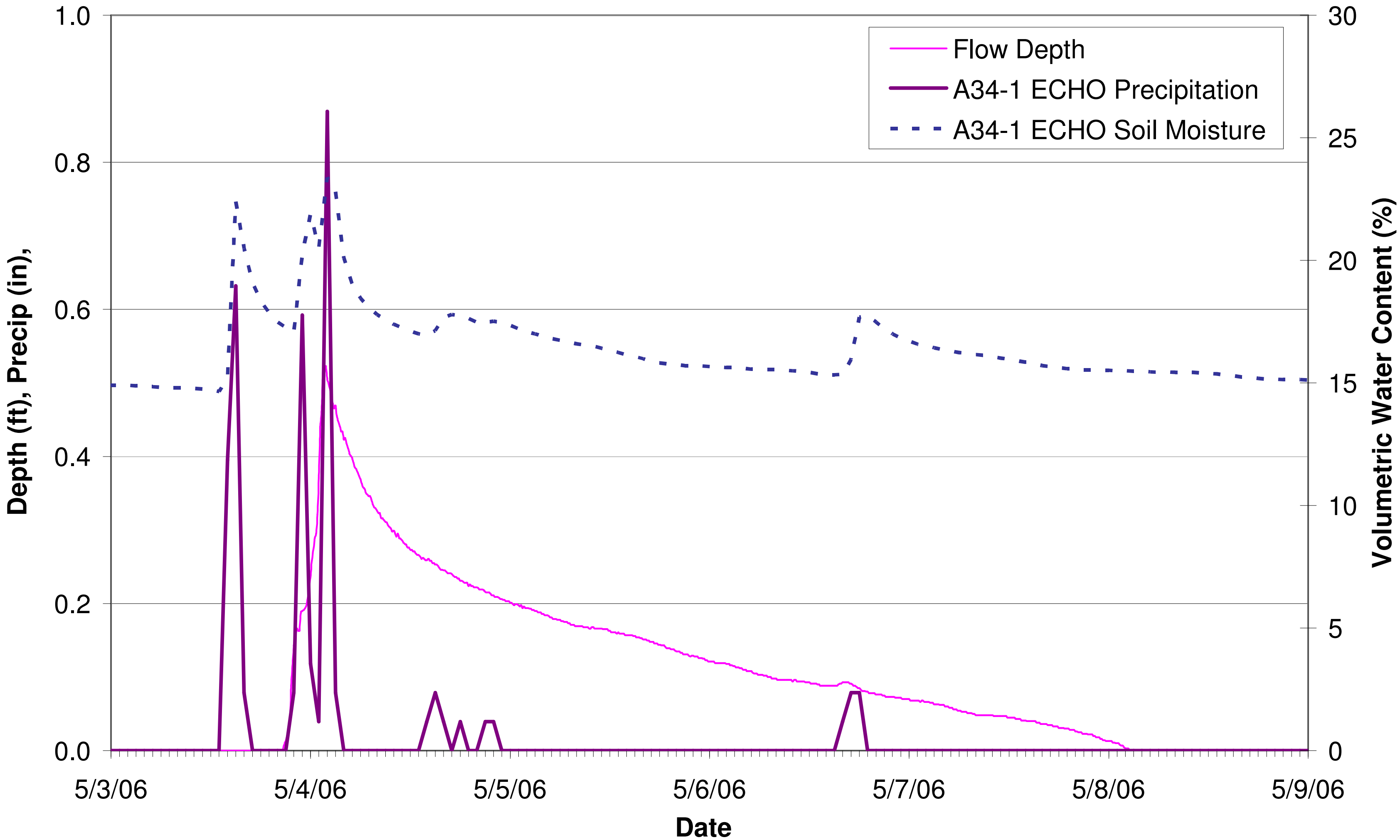

Figure 4.9 – Hourly precipitation and soil moisture from A34-1 ECHO® station and stream flow depth for precipitation events occurring May 3-4, 2006.

springs, and little to no stream flow from above the site because it is a first order stream. For this analysis, total moisture input will be assumed to come only from precipitation. Water output includes stream discharge, as well as moisture loss due to infiltration into the aquifer, evaporation, and transpiration. Data for infiltration, evaporation, and transpiration were unavailable so the only water output mechanism analyzed is total stream discharge. From the time the Isco® unit was installed on March 23, 2006, to the end of the data monitoring period included in this report, August 15, 18.2 inches of rainfall was measured by the A34-1 ECHO® station. During that same period, the only time at which any flow was measured exiting the site occurred during the period from April 28-May 14. With a site area of 30 acres (Mueller, 2006) (Appendix A), total volume of water input onto the site for the nearly five month period the Isco® has been monitoring flow in the ephemeral channel can be approximated as nearly 1.59 million ft^3. During the same period, the flow monitoring unit recorded about 379,000 ft^3 of water output through the channel. This equates to around 19%, or 3.5 inches, of the total precipitation input onto the site being removed as surface drainage.

Flow event specific analyses can also be performed. Water balance analyses were performed for two separate flow events. Because flow stopped for only a short time between the two events, the procedure was also applied to the combination of the two flow events. Data for these analyses, performed with data from the A34-1 ECHO station, as well as other data sources, are presented in Table 4.1. The alternate data sources included the RAWS, USGS station and three averages of the different sources. Table 4.1 also lists soil moisture readings from the A34-1 ECHO® and the RAWS for both the first day of the period and the average of the period. The precipitation data source listed

Table 4.1 – Water balance analyses from various data sources listing percent of moisture input at A34-1 exiting site as channel flow

Period	Days in Period	Precipitation Data Source	Precipitation In Period (in)	Mean Daily Precipitation (in)	Moisture Input (ft^3)	Average Soil Moisture (%)	Discharge (ft^3)	Discharge (in. of precipitation)	Discharge/ Moisture Input (%)
April 28-May 8	11	RAWS	3.8	0.35	411,000	31	200,000	1.9	48.7
April 28-May 8	11	USGS	4.8	0.44	521,000	-	200,000	1.9	38.4
April 28-May 8	11	A34-1 ECHO	5.4	0.49	582,000	16	200,000	1.9	34.4
April 28-May 9	11	USGS, ECHO	5.1	0.47	552,000	-	200,000	1.9	36.3
April 28-May 8	11	Average	4.7	0.43	505,000	23	200,000	1.9	39.7
May 9-May 14	6	RAWS	2.4	0.41	263,000	33	179,000	1.7	68.1
May 9-May 14	6	USGS	2.5	0.42	273,000	-	179,000	1.7	65.4
May 9-May 14	6	A34-1 ECHO	3.1	0.52	336,000	17	179,000	1.7	53.3
May 9-May 14	6	USGS, ECHO	2.8	0.47	305,000	-	179,000	1.7	58.7
May 9-May 14	6	Average	2.7	0.45	291,000	25	179,000	1.7	61.6
April 28-May 14	17	RAWS	6.3	0.37	674,000	32	379,000	3.5	56.3
April 28-May 14	17	USGS	7.4	0.43	794,000	-	379,000	3.5	47.7
April 28-May 14	17	A34-1 ECHO	8.5	0.5	919,000	16	379,000	3.5	41.3
April 28-May 14	17	USGS, ECHO	8	0.47	856,000	-	379,000	3.5	44.3
April 28-May 14	17	Average	7.4	0.44	796,000	24	379,000	3.5	47.7
Mar 23-Aug 15	146	RAWS	17.3	0.12	1,861,000	23	379,000	3.5	20.4
Mar 23-Aug 15	146	USGS	16.9	0.12	1,822,000	-	379,000	3.5	20.8
Mar 23-Aug 15	146	A34-1 ECHO	18.2	0.13	1,961,000	10	379,000	3.5	19.3
Mar 23-Aug 15	146	USGS, ECHO	17.6	0.12	1,892,000	-	379,000	3.5	20
Mar 23-Aug 15	146	Isco	14.8	0.1	1,590,000	-	379,000	3.5	23.8
Mar 23-Aug 15	146	Average (w/o Isco)	17.5	0.12	1,881,000	-	379,000	3.5	20.2
Mar 23-Aug 15	146	Average (w/ Isco)	17.6	0.12	1,892,000	17	379,000	3.5	20

as “USGS, ECHO” is the average precipitation data from the USGS station in Eminence and from the ECHO® station on A34-1. They were selected to be averaged because of their relatively close proximity to one another. The data source listed as “Average” is the average of the USGS, A34-1 ECHO®, and RAWS for precipitation data, and is the average of the A34-1 ECHO and the RAWS for soil moisture data. For the period from March 23 through August 15, precipitation data from the Isco® rain gauge is also included as a comparison. This period includes average values both with and without the Isco® precipitation data. The results for the ratio of channel discharge to precipitation input range from about 34%-70% for the individual flow events, with results for the combined events near 45%. For the entire measured period from March 23-August 15, about 20% of precipitation exited the site as surface flow. In general, as the length of the measured period increased, the proportion of moisture exiting as overland flow decreased (Fig. 4.10). It is important to note that all precipitation and flow data were collected during a period of heavy vegetation and canopy coverage. Data may be significantly different during times of more sparse vegetative cover.

The results calculated using the RAWS precipitation data are 3.5% to 10% greater than other sources for all periods other than March 23-August 15. This is the effect of smaller precipitation measurement at the RAWS during these periods. The RAWS is almost 14 miles from A34-1 and the highly variable nature of storms in the region deposited less precipitation at the RAWS location during the shorter periods. When examined for the long period, the RAWS data is much more similar to precipitation data from other sources, resulting in channel flow percentages nearly identical to other sources. During the long period, from March 23-August 15, the Isco® data provides the

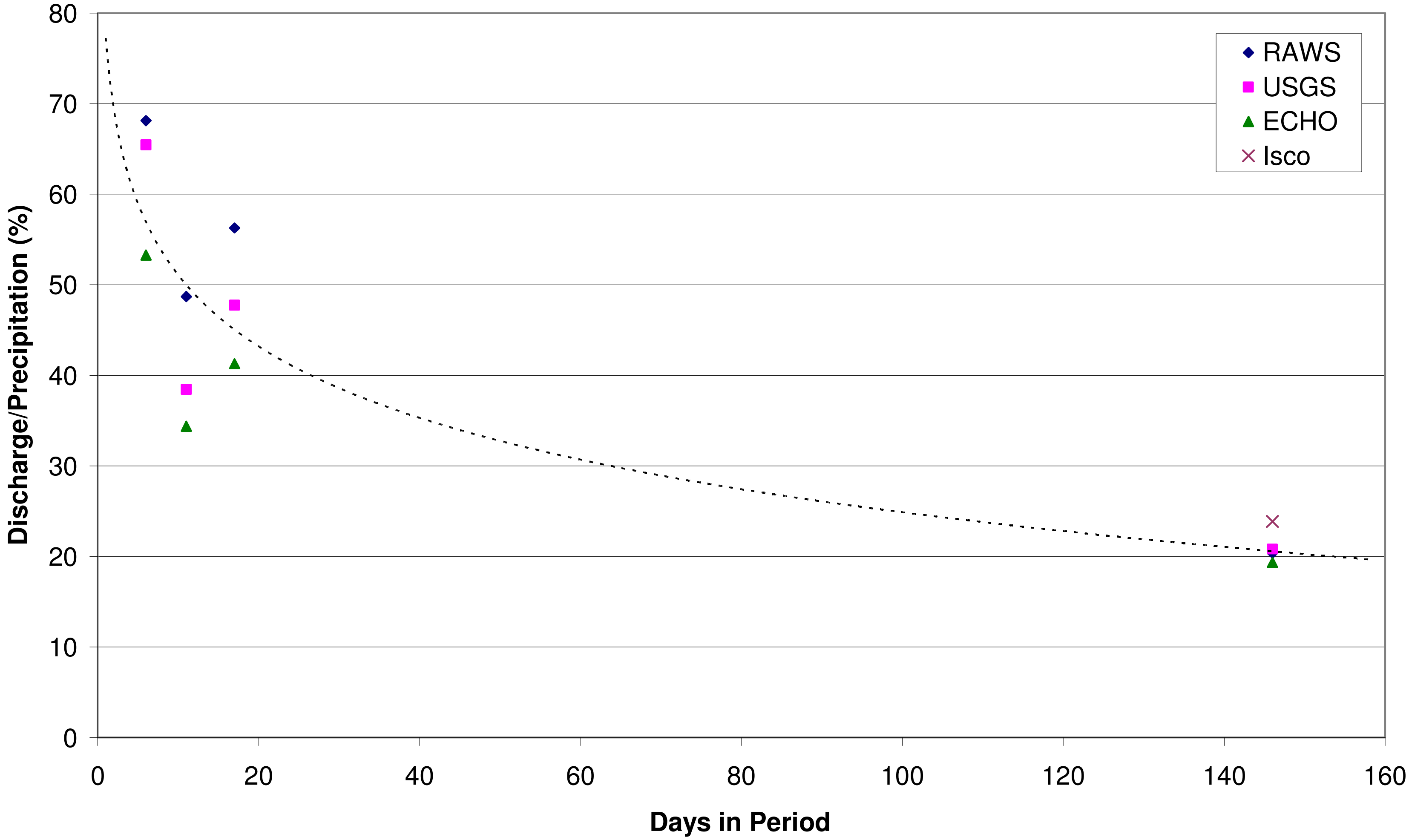

Figure 4.10 – Proportion of moisture exiting A34-1 as channel flow vs. the number of days in the measured period.

outlying result, 3% higher than the next highest. As mentioned earlier, the Isco® precipitation gauge has been prone to clogging and providing inaccurate measurements. Isco® precipitation data will be discussed in more detail later in the chapter.

The proportion of moisture leaving the drainage basin as surface runoff is a function of both precipitation and soil moisture. As the average daily precipitation for the period being analyzed increases, the percent of water discharged through the ephemeral channel increases (Fig. 4.11). The relative amount of moisture exiting as surface flow also increases with the average soil moisture value for the period in question (Fig. 4.12). In both plots, strong correlation values are present in the RAWS data, while the values are slightly smaller for data from the A34-1 ECHO® station. Coefficients of correlation are presented on the charts.

Settergren (1972), in a study of a forested karst watershed in southeast Missouri, estimated that approximately 22% of rainfall is lost to deep seepage. This indicates the remaining 78% of moisture is lost to other mechanisms, including channel flow. The water balance estimated channel flow as 20% of moisture input. Because of the complexity of a water balance, many possibilities exist to explain variations in moisture losses. Soil type, specifically grain size and permeability govern the rate at which water can be absorbed into the soil. Smaller grain sizes and lower permeability prevent water from easily entering the soil and cause more to be diverted as surface runoff. Antecedent soil moisture also plays a role. A dry soil is more readily capable of absorbing moisture and generates less overland flow. Other factors, including slope, time of year, amount and type of vegetative cover, and the presence or absence of karst features all influence the proportion of water leaving the site as surface runoff.

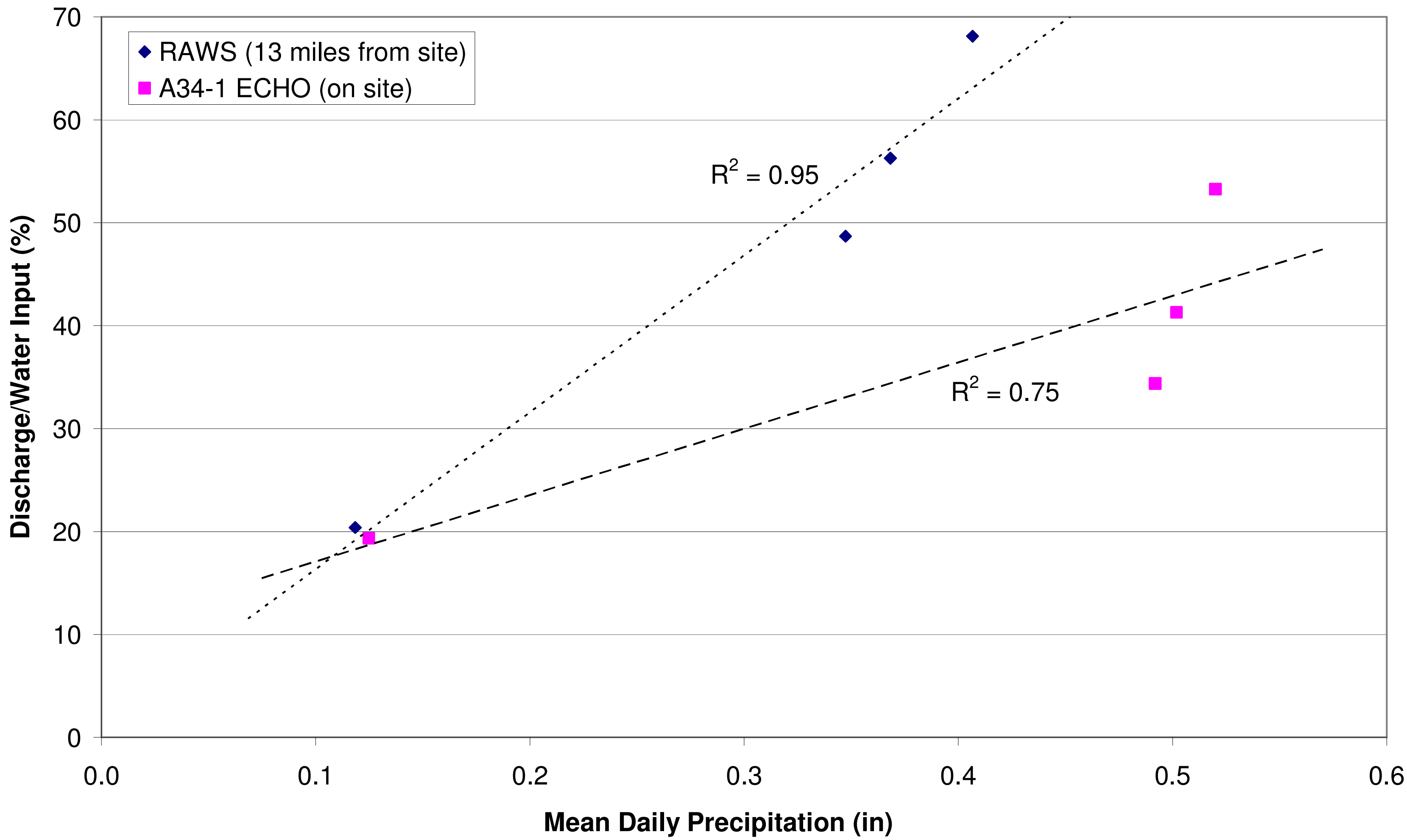

Figure 4.11 – Stream discharge as a proportion of moisture input on A34-1 vs. average daily precipitation over four time periods.

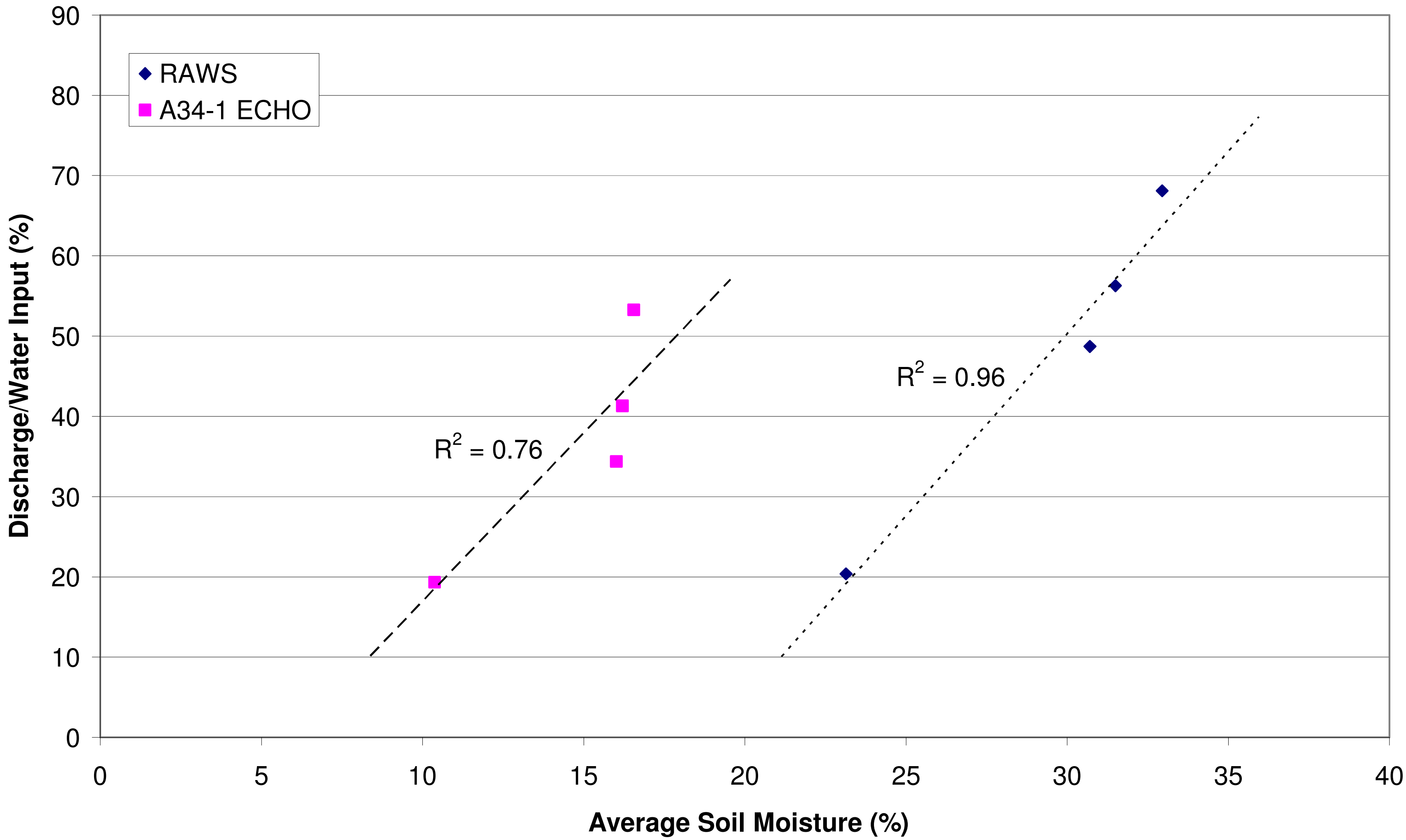

Figure 4.12 – Stream discharge as a proportion of moisture input on A34-1 vs. average soil moisture values over four time periods.

4.2.2 Hillslope Instrumentation

Equipment located on the hillsides above the ephemeral drainageways has different purposes than instrumentation positioned in the channels, as well as different challenges associated with it. The performance of the various pieces of hillslope equipment is presented in the following paragraphs.

4.2.2.1 Hillslope Sediment Monitors

The 69 hillslope monitors have been functioning with varying success, but have collected over 200 samples between October 2004 and July 2006. Many factors, the largest of which may be the soil and environmental conditions encountered at the test sites, influence the performance. The soil in the Missouri Ozarks is extremely rocky, making it difficult to maintain a flush contact between the soil surface and the rigid metal guttering of the hillslope sediment monitor. In addition, the rocky surface and steep slopes made work and installation difficult, further reducing the ability to establish a watertight seal between the guttering and forest floor. After it was noticed that gaps were forming beneath the guttering, plastic sheeting was added to reduce the amount of surface flow escaping the plot area. This solution worked well to limit the escape of overland flow, but also added new complications.

As seen in Figure 4.13, the number of hillslope samples collected after the addition of the plastic sheeting increased dramatically. It is believed the impermeable membrane artificially increases the volume of sample collected. Instead of the sample being exclusively runoff from the plot area, much of it now comes from precipitation falling directly on the plastic. In an effort to evaluate this hypothesis, and quantify how

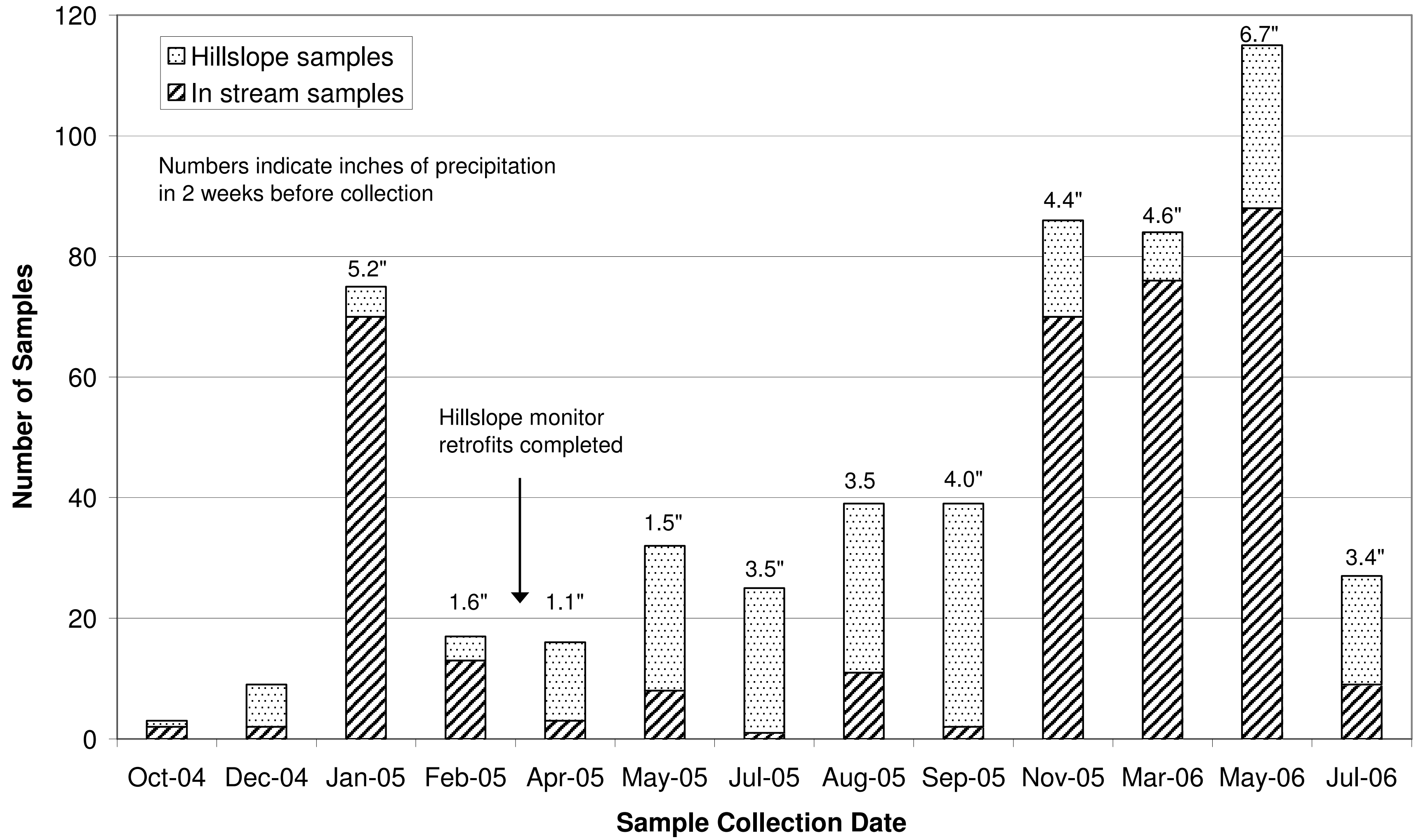

Figure 4.13 – Number of hillslope monitor and in-stream water samples collected during each sampling event.

much of the sample volume results from precipitation falling directly onto the plastic, hillslope monitor controls were introduced.

4.2.2.2 Hillslope Sediment Monitor Control Devices

Three hillslope monitor control devices were installed in June 2005. They were installed on three different sites distributed geographically throughout the region of the research sites. They are located on A17-1, A34-1 and CR7-5b (Fig. 4.14).

The hillslope monitor control devices have been functioning as intended. Sample volumes for the six most recent sampling events are presented in Table 4.2. The control devices have been in place for several significant precipitation events, and in most cases the catchments have been nearly or completely full.

Table 4.2 – Hillslope monitor control device sample volumes.

Sampling Event Number	Sampling Date	Antecedent Soil Moisture (%) [1]	Precipitation Total (in) [2]	Site	Volume Collected (gal) [3]
5	7/15/2005	18.0	1.6	A17-1 A34-1 CR7-5b	4.3 5.4 no data
6	8/22/2005	15.0	3.3	A17-1 A34-1 CR7-5b	4.9 5.9 5.1
7	9/18/2005	16.0	3.6	A17-1 A34-1 CR7-5b	5.4 5.6 5.6
8	11/18/2005	28.0	4.3	A17-1 A34-1 CR7-5b	5.4 5.4 5.6
9	3/15/2006	29.0	4.7	A17-1 A34-1 CR7-5b	no data no data no data
10	5/16/2006	29.0	7.0	A17-1 A34-1 CR7-5b	no data 2.2 4.7
11	7/19/2006	11.0	2.4	A17-1 A34-2 CR7-5b	no data 5.1 4.4

1. RAWS volumetric water content of the soil before precipitation leading to sample collection.
2. Average cumulative precipitation from online and electronic sources in the 14 days prior to sample collection.
3. Maximum catchment volume is 5.9 gallons.

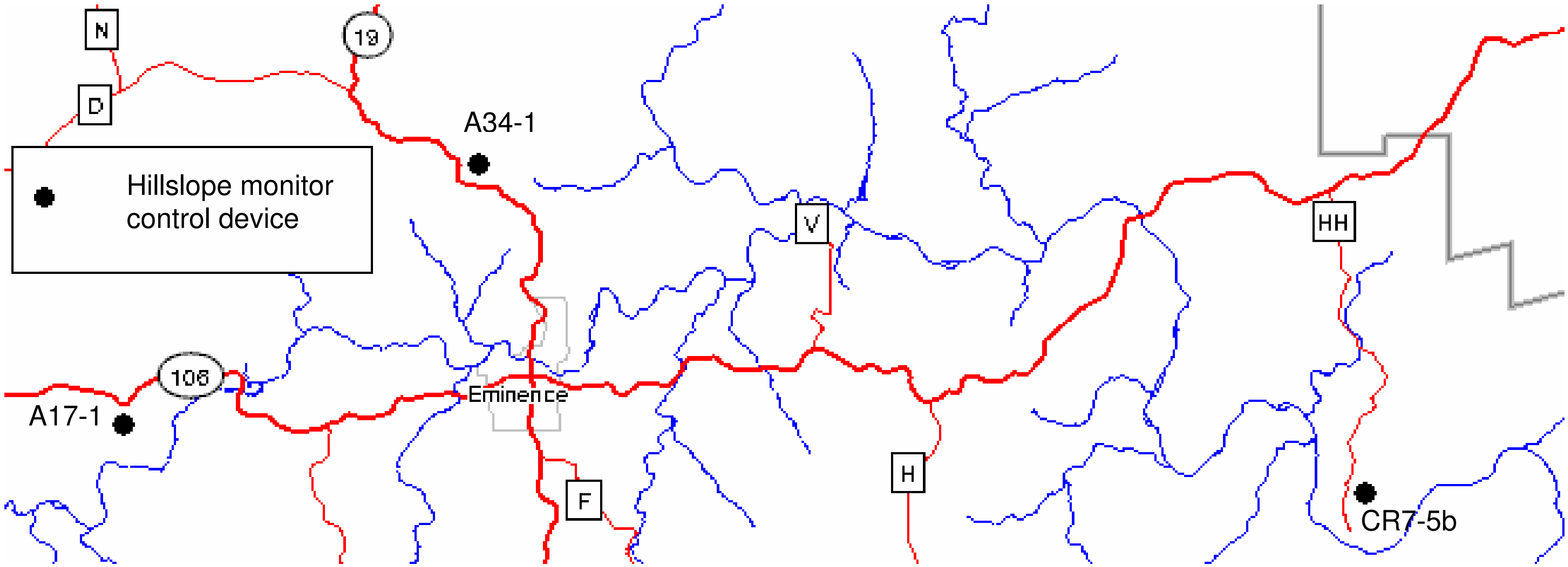

Figure 4.14 – Location of hillslope monitor control devices.

The plot area of the hillslope control devices consists of eight square feet covered with plastic sheeting. The theoretical precipitation event magnitudes necessary to fill the catchment for various areas of plastic sheeting are shown in Figure 4.15. With the

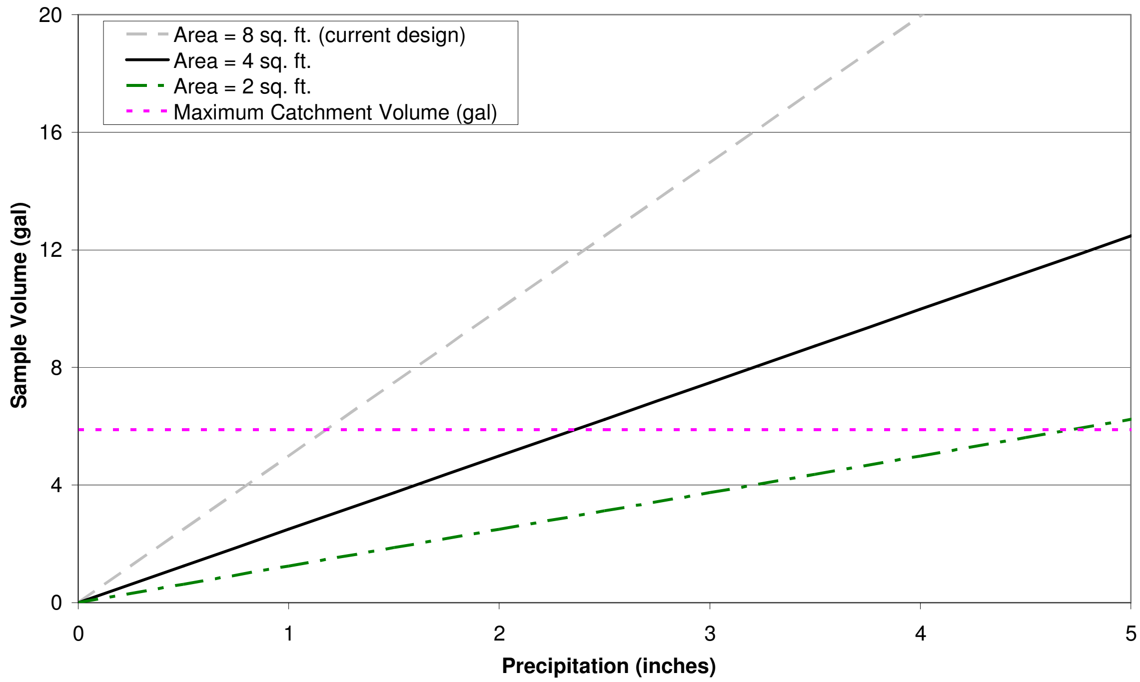

Figure 4.15 – Catchment volume vs. precipitation event size for various areas of plastic sheeting.

current design, a rainfall of one inch should fill the 5.9 gallon catchment assuming no water is lost to leakage or other mechanisms. However, although all of the precipitation events in Table 4.2 are larger than one inch, not all of the catchments were full all of the time. This is due to several factors. The sample volumes near the maximum volume of 5.9 gallons are reduced slightly due the inclination of the catchments. Because the catchments are positioned on a sloped surface, the entire volume cannot be utilized without spillover. This is illustrated in Figure 4.16. Sample volumes significantly less than 5.9 gallons are the result of leaks within the apparatus.

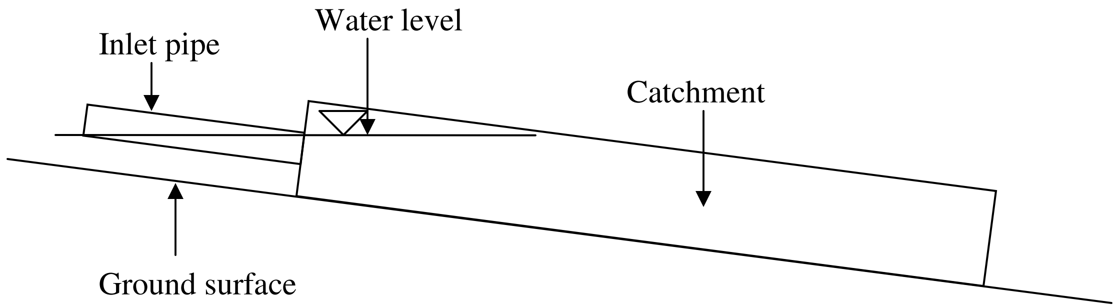

Figure 4.16 – Catchment volume reduction resulting from inclination.

Because the entire sample generated from precipitation events larger than one inch cannot be retained, a retrofit is in order to enable the device to accommodate larger precipitation events. During precipitation events larger than one inch, it is not possible to determine exactly how much influence the sheeting area has on sample volume because not all of the sample can be retained. If the water volume created by the plot area combined with rainfall amount is larger than the available catchment volume, some of the sample volume is lost due to overflow. A modification to make the plot area smaller or the catchment larger will eliminate this defect and allow larger precipitation events to be analyzed. According to Fig. 4.15, if the plot is reduced to dimensions of four feet by six inches, creating an area of two square feet, the catchment will be able to retain the entire sample volume for precipitation events of almost five inches. This should be sufficient for most cases because single rainfall events larger than five inches have rarely been observed during the monitoring period of the timber harvest project.

4.2.2.3 Silt Fences

The silt fences are intended to give an estimate of the overall quantity of sediment and forest litter moving down the hillslope. Because of the design, neither the quantity of overland flow passing through the geotextile, nor the area from which the forest litter is coming is taken into account. No discernible sediment has been observed collecting behind the fences, indicating that there is currently little significant overland sediment transport. The majority of the debris retained by the fences is forest litter such as leaves, twigs, and pine cones. Since their installation in early 2005, between 3 and 9 inches of debris has collected behind the fences.

4.2.2.4 Rain Gauges

The manual rain gauges have been functioning well during the warmer months, providing measurements of precipitation penetrating the forest canopy at the site of each hillslope sediment trap. Data obtained from manual rain gauge readings are compared to online and electronic sources in Table 4.3. The data is presented graphically in Figure 4.17. Online and electronic data shown are the maximum, minimum, and average of all online and electronic sources, including both ECHO® stations, both online sources, and the Isco® system, from nine sampling events between April 2005 and July 2006. The data from manual rain gauges were averaged across all 15 research sites for each of the sampling events. Events 1 and 2 were excluded because reliable readings of manual rain gauges could not be located. All online and electronic sources were averaged to create a more representative comparison with the manual readings because the manual gauges are spread across all of the research sites. Mean readings from the two methods differed by 1% to 87% or 0.1 to 3.0 inches. Most of the mean manual data are larger than corresponding data from the electronic sources. This is likely the effect of a longer accumulation time. The precipitation readings from the manual gauges accumulate precipitation beginning when they are emptied during the previous sampling event. The electronic data are the summation of the two weeks just prior to the sampling event.

Table 4.3 – Manual, online, and electronic rain gauge readings for all sampling events from April 2005 – July 2006.

		Precipitation (in)					
		Online and Electronic [1]			Manual (all sites)		
Event [2]	Date	Max	Min	Mean	Max	Min	Mean
3	4/15/05	1.1	1.0	1.1	2.5	0.0	1.0
4	5/18/05	1.5	1.1	1.3	4.0	0.0	1.7
5	7/15/05	6.3	0.1	1.8	4.4	1.6	3.3
6	8/22/05	5.0	1.5	3.3	4.5	2.6	3.9
7	9/18/05	4.1	2.6	3.1	4.8	2.2	3.6
8	11/18/05	5.8	0.6	4.3	5.0	4.0	4.5
9	3/15/06	5.5	4.2	4.7	n/a	n/a	n/a
10	5/16/06	8.6	4.6	7.0	4.8	2.8	4.1
11	7/19/06	4.4	1.1	2.5	4.3	2.5	3.6

1. Data presented for online and electronic sources are the maximum, minimum, and mean of the 14 day precipitation accumulation prior to sample collection.
2. Events 1 and 2 are excluded due to lack of reliable manual rain gauge data.

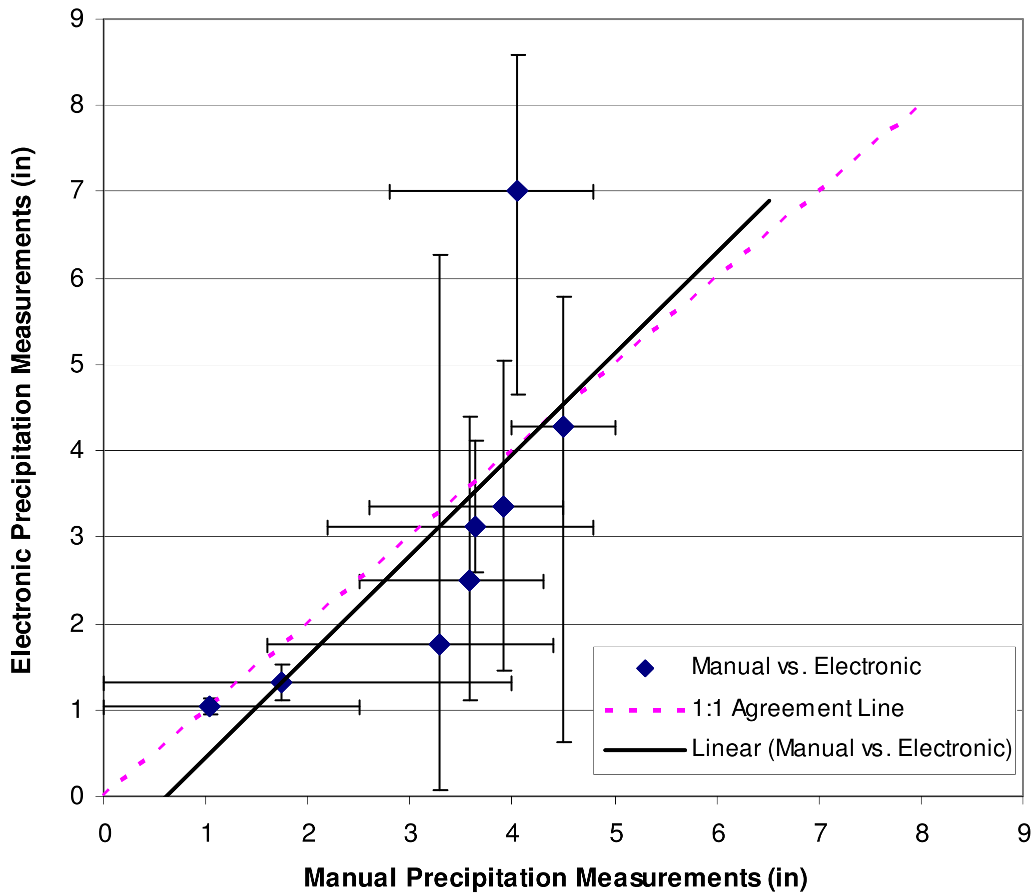

Figure 4.17 – Comparison of precipitation measurements from manual and electronic sources.

The two week period was selected to adequately capture the individual precipitation events leading to stream flow and resulting in the need to make a sample collection trip. On a few occasions, an extra 1-3 days were included to capture a specific significant (>1.0 in) precipitation event. Often, the flow was the result of an extended period of precipitation, and it was necessary to examine the entire two weeks prior to the sampling event to capture all relative precipitation. Other times, a sample collection trip was necessary after just a few intense, closely spaced precipitation events, but was unable to be made immediately due to scheduling conflicts.

Although data from the manual rain gauges have generally matched well with other sources, there are challenges associated with them. Occasionally a rain gauge will be tipped over by wildlife activity. Over the winter months, if they are not emptied, they often freeze, causing the plastic to crack. This renders them useless until they are replaced during a subsequent sampling or maintenance trip. In an effort to reduce this drawback, more robust, "weather-proof" rain gauges were installed on all hillslope monitors and control devices. However, even the robust rain gauges were still prone to cracking during freezing weather. As noted above, the manual rain gauges collect precipitation the entire time between sampling trips. This also allows ample time for debris such as acorns, leaves, and insects to collect in the gauge. The solids in the gauge reduce the accuracy by increasing the apparent liquid volume, sometimes significantly in the case of acorns and large insects. An additional drawback of the extended collection period is enough time for evaporation to reduce the volume water contained in the gauge. However, despite these challenges, the manual rain gauges have provided precipitation data at the location of each hillslope sediment monitor and control device.

The ECHO® automated rain gauges have been installed on two sites, A34-1 and CR7-5c, since August 2005. They have functioned reliably and have provided useful measurements of local precipitation. Figure 4.18 is a plot of daily precipitation totals measured at site A34-1, shown vertically upwards, compared to measurements from CR7-5c, shown vertically downward. Precipitation events are almost always detected on the same days, though the amount of precipitation recorded at each site varies. This is due to the relative location of the sites. Site locations can be seen in Figure 4.19. Relative distances between all research sites and precipitation data sources are listed in Table 4.4. The two sites with ECHO® data stations are approximately 15 miles apart. Because weather in the region is highly variable and storm events are frequently extremely localized, 15 miles of separation can cause each site to receive significantly different amounts of rainfall.

An additional consideration when comparing precipitation measurements from the different devices is their location relative to overhead cover. Both the RAWS and USGS stations are located in an open area, without vegetative or canopy cover. During much of the year, the ECHO® stations and the manual gauges are beneath a heavy forest canopy, which can divert and capture precipitation, altering rainfall measurements.

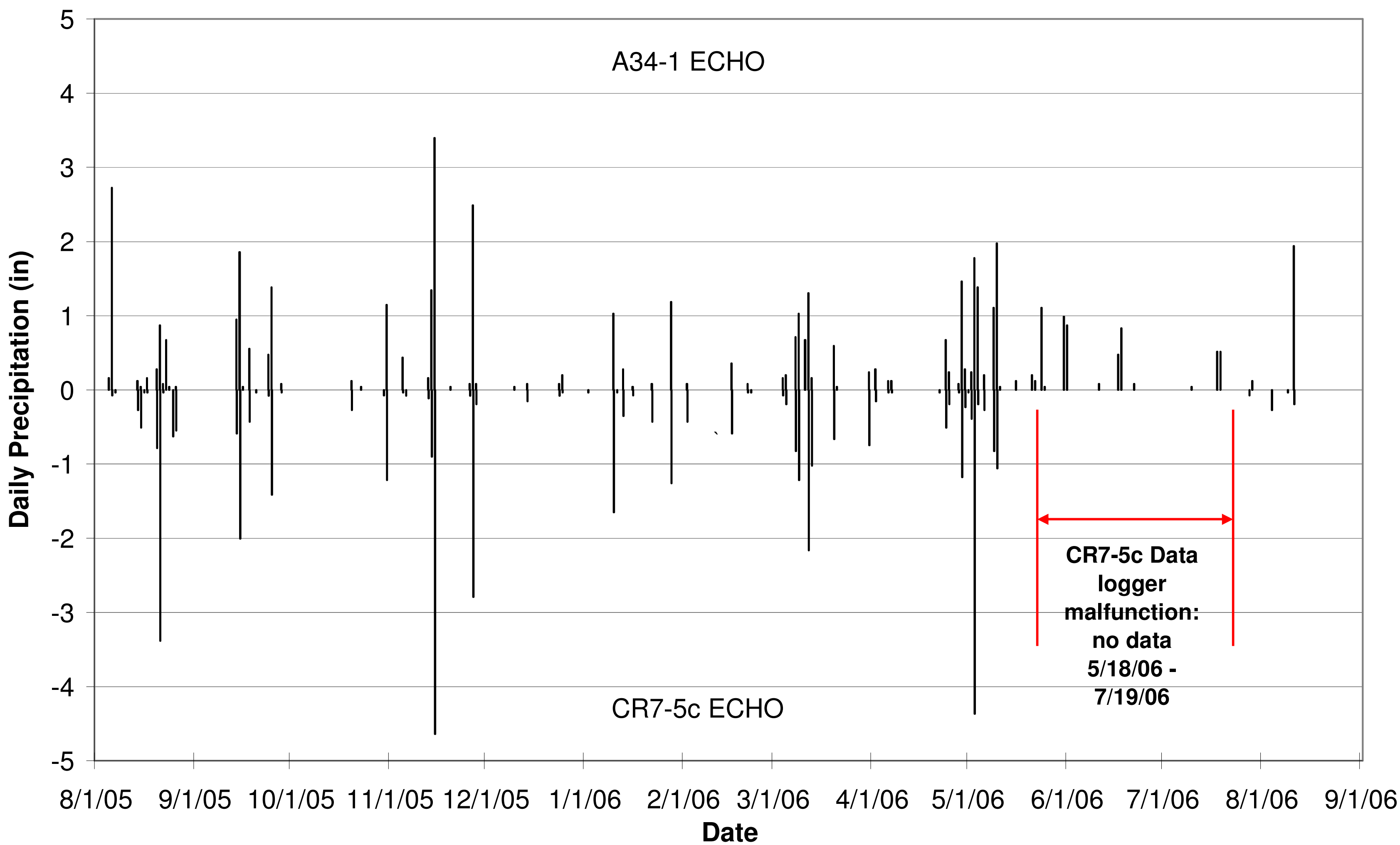

Figure 4.18 – Daily precipitation at ECHO® stations on A34-1 (shown as positive) and CR7-5c (shown as negative).

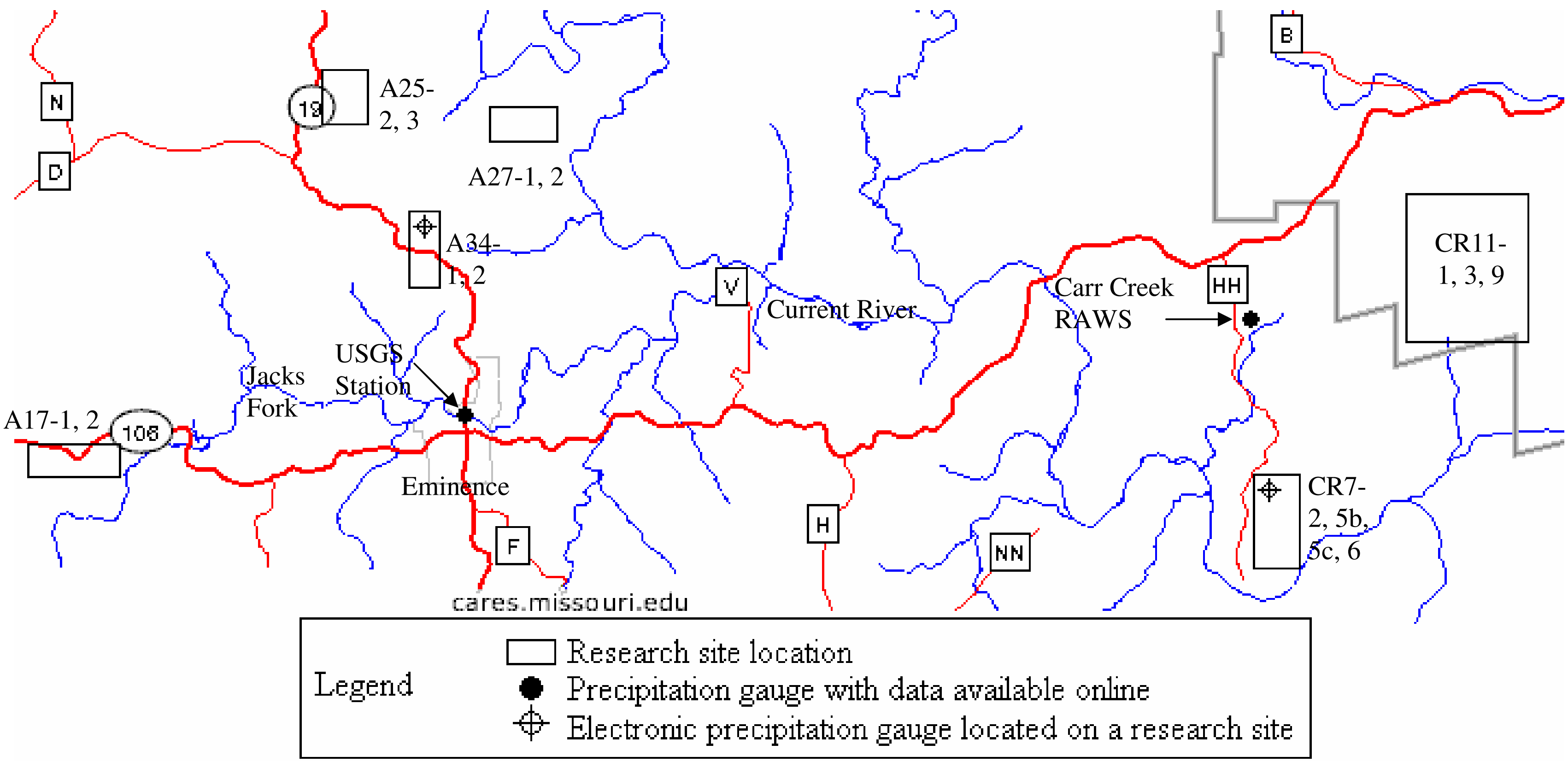

Figure 4.19 – Location of research sites and electronic and online precipitation gauges.

Table 4.4 – Relative distance between research sites and precipitation data sources.

Location	Relative distance between locations in miles							
	A17-1, 2	A25-2, 3	A27-1, 2	A34-1, 2	CR7-2, 5b, 5c, 6	CR11-1, 3, 9	RAWS	USGS
A17-1, 2	-	8	9	7	20	23	20	7
A25-2, 3	8	-	2.5	2.5	17	18	16	6
A27-1, 2	9	2.5	-	2.5	14	15.5	12.5	5
A34-1, 2	7	2.5	2.5	-	14.5	16.5	13.5	3
CR7-2, 5b, 5c, 6	20	17	14	14.5	-	4.5	3.5	13
CR11-1, 3, 9	23	18	15.5	16.5	4.5	-	3	16
RAWS	20	16	12.5	13.5	3.5	3	-	13
USGS	7	6	5	3	13	16	13	-

All sites are within 7 miles of an online precipitation data source and within 7 miles of an ECHO® station installed on a research site. All sites are within 3 miles of an online source or an ECHO® station. The entire research area extends approximately 23 miles east to west and 8 miles north to south, totaling just less than 185 square miles.

Precipitation data available online is used to supplement data from manual and electronic gauges installed on the research sites. Daily precipitation data from the Remote Automated Weather Station (RAWS) located 13 miles east of Eminence, Missouri (shown vertically upward) and the USGS weather station in Eminence (shown vertically downward) are presented in Figure 4.20. The precipitation monitoring period begins in July 2004 when the first equipment was installed in the field (Bunger, 2005). Precipitation is generally observed on the same days, however magnitudes differ between locations. The largest difference in daily accumulation between the two locations during the monitoring period is 2.9 inches, with all but 10 days having less than one inch difference. Spatial separation of 13 miles and high variability of storms in the region contribute to different precipitation measurements.

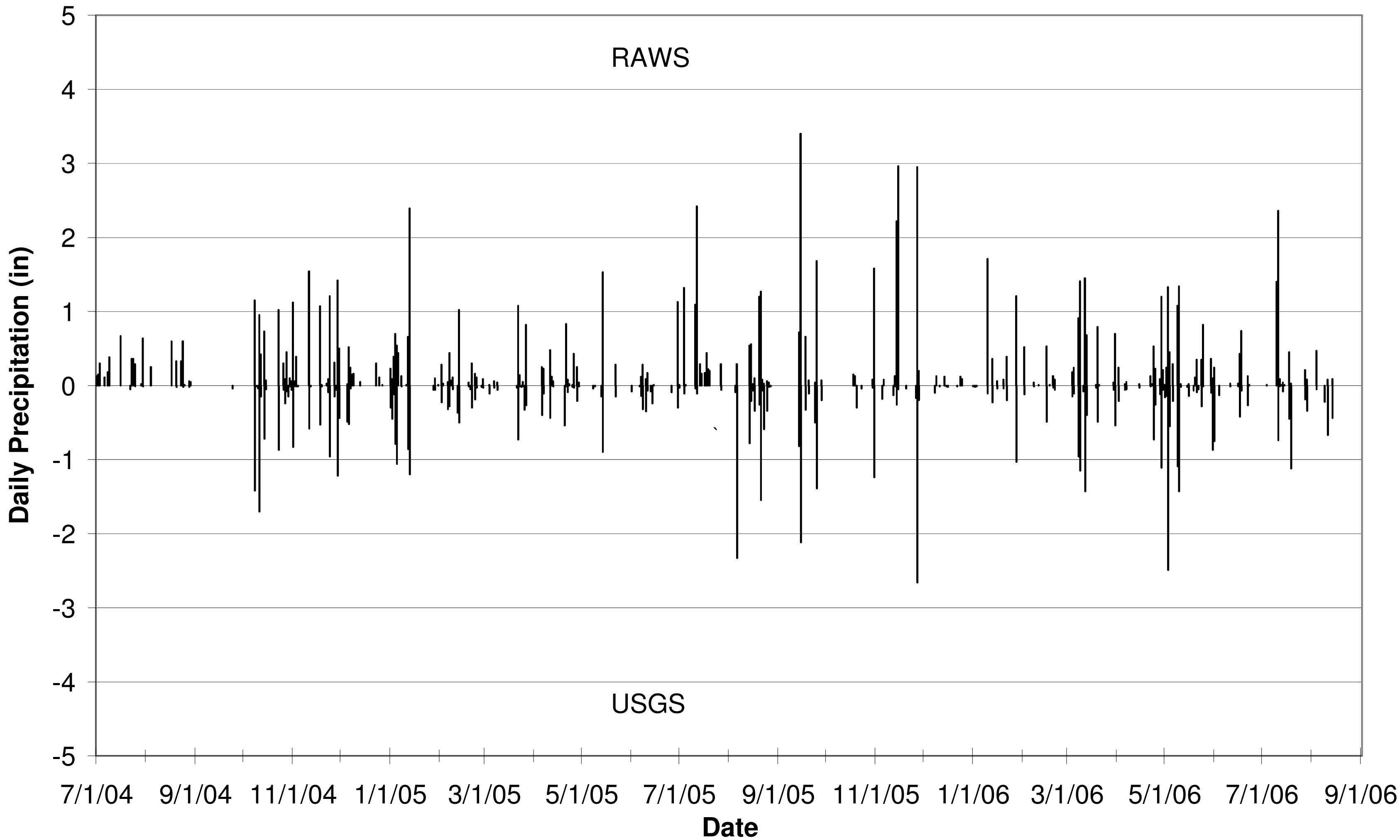

Figure 4.20 – Daily precipitation data from RAWS (shown as positive) and USGS (shown as negative) online sources.

In Figure 4.21, monthly precipitation totals are compared from both ECHO® stations and both online sources. The ECHO® precipitation data are available beginning in July 2005. It can be seen that for most months, all gauges recorded similar accumulations. Monthly accumulations from each gauge, along with the maximum and minimum measured totals, range, and mean are presented in Table 4.5. All months except for four (Jul 2004, Jul 2005, Nov 2005, Jul 2006) show less than 3 inches difference in total accumulation. The largest monthly accumulation difference is 6.3 inches in July 2005 and the smallest range is 0.04 inches in September 2004.

Table 4.5 – Monthly precipitation totals and statistics for all online and ECHO® sources.

	Monthly Precipitation Totals (in)				Statistics (inches)			
Date	RAWS	USGS	A34-1	CR7-5c	Max	Min	Range	Mean
Jul-04	3.59	0.07	n/a	n/a	3.6	0.1	3.5	1.8
Aug-04	2.23	0.06	n/a	n/a	2.2	0.1	2.2	1.1
Sep-04	0.00	0.04	n/a	n/a	0.0	0.0	0.0	0.0
Oct-04	5.34	5.56	n/a	n/a	5.6	5.3	0.2	5.5
Nov-04	7.75	4.91	n/a	n/a	7.8	4.9	2.8	6.3
Dec-04	1.56	1.05	n/a	n/a	1.6	1.1	0.5	1.3
Jan-05	5.69	4.91	n/a	n/a	5.7	4.9	0.8	5.3
Feb-05	2.70	2.38	n/a	n/a	2.7	2.4	0.3	2.5
Mar-05	2.20	1.60	n/a	n/a	2.2	1.6	0.6	1.9
Apr-05	2.80	1.87	n/a	n/a	2.8	1.9	0.9	2.3
May-05	1.81	1.25	n/a	n/a	1.8	1.3	0.6	1.5
Jun-05	1.80	1.68	n/a	n/a	1.8	1.7	0.1	1.7
Jul-05	6.62	0.35	1.07	0.59	6.6	0.4	6.3	2.2
Aug-05	4.20	6.66	5.17	6.38	6.7	4.2	2.5	5.6
Sep-05	6.64	5.47	5.33	4.60	6.6	4.6	2.0	5.5
Oct-05	1.94	1.61	1.30	1.57	1.9	1.3	0.6	1.6
Nov-05	8.54	3.70	8.02	8.85	8.9	3.7	5.2	7.3
Dec-05	0.46	0.15	0.40	0.28	0.5	0.2	0.3	0.3
Jan-06	3.81	1.69	2.61	3.85	3.9	1.7	2.2	3.0
Feb-06	1.32	0.71	0.51	1.10	1.3	0.5	0.8	0.9
Mar-06	6.42	5.40	5.10	6.92	6.9	5.1	1.8	6.0
Apr-06	2.74	2.64	3.24	2.44	3.2	2.4	0.8	2.8
May-06	6.87	7.72	6.72	7.16	7.7	6.7	1.0	7.1
Jun-06	1.69	1.66	2.33	n/a	2.3	1.7	0.7	1.9
Jul-06	4.69	2.93	1.19	n/a	4.7	1.2	3.5	2.9

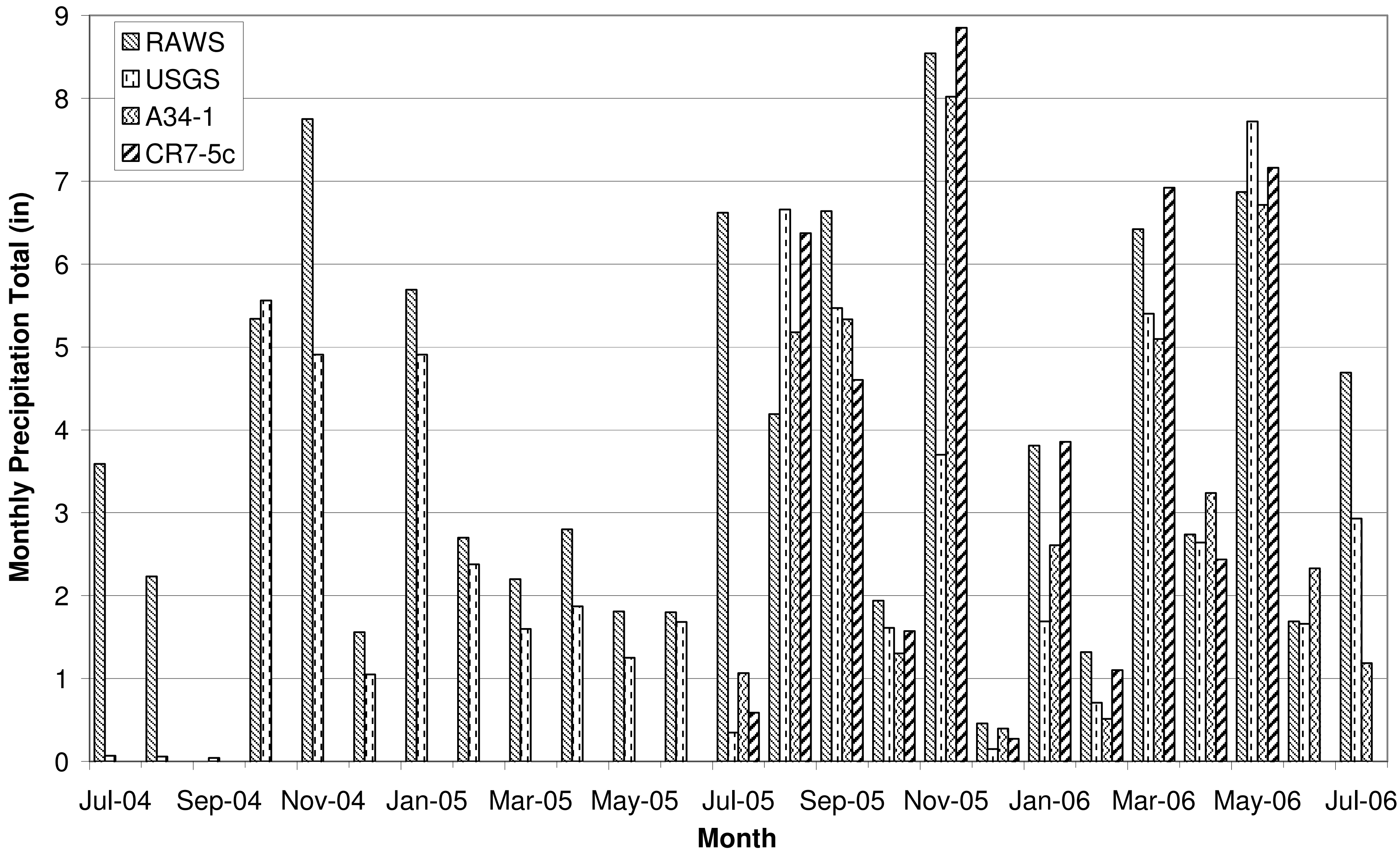

Figure 4.21 – Monthly precipitation totals from both online and ECHO® sources.

In addition to precipitation data measured during the monitoring period, historical climactic data for the region from 1904-2002 were obtained for comparison purposes. Historical precipitation and temperature data from official weather stations surrounding the region were averaged to create an estimate of historical data for the Eminence area. The data were measured at stations located in Rolla, Farmington, Doniphan, and Mountain Grove, Missouri (Fig. 4.22). The average annual precipitation since 1904 is plotted in Figure 4.23. The average annual precipitation from 1904-2002 was 42.7 inches. RAWS measurements for 2003-2005 were both above and below the historical

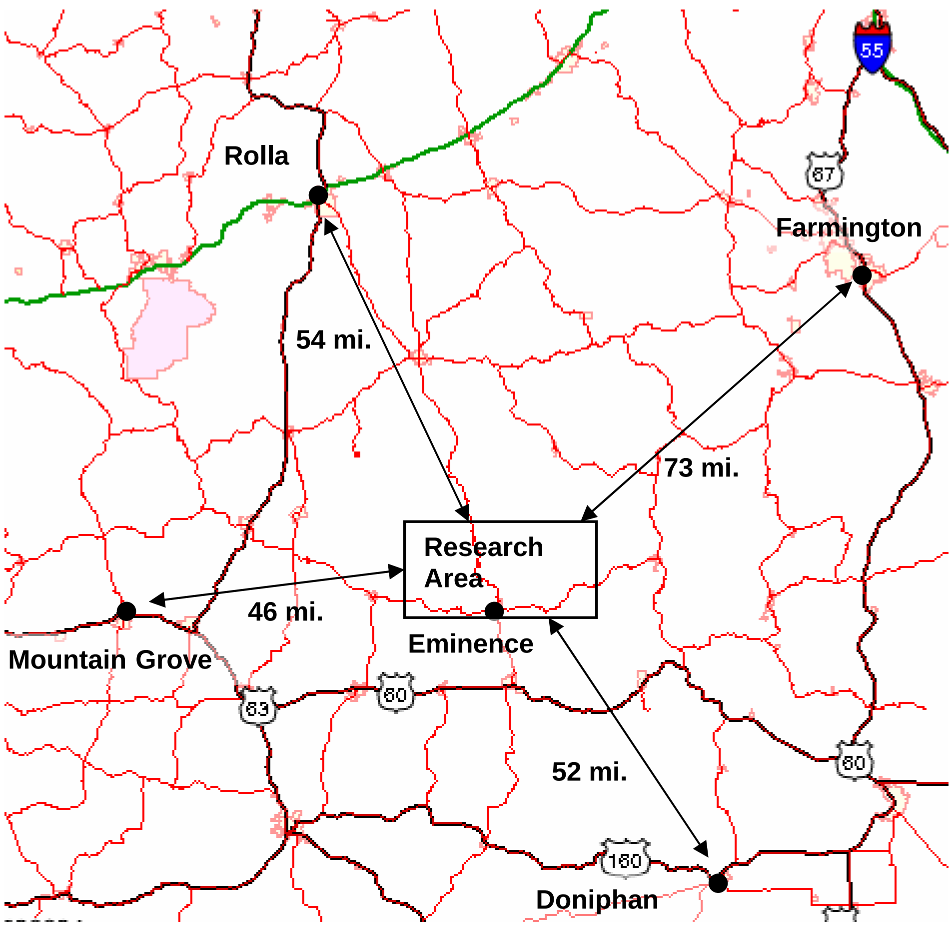

Figure 4.22 – Location of official weather stations providing historical climactic data for region surrounding Eminence, MO. (http://ims.missouri.edu/moims/step1.aoi/countylist .asp)

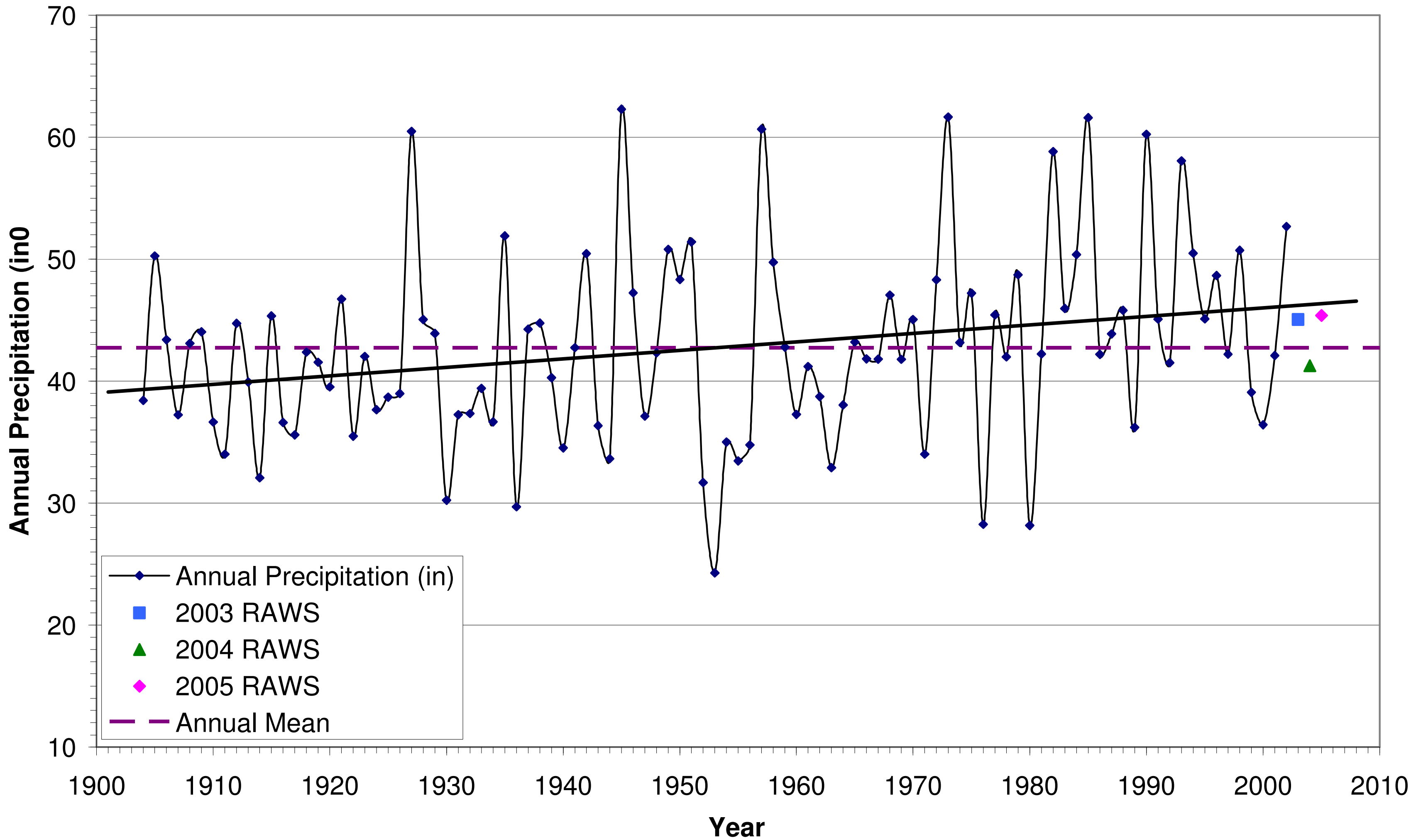

Figure 4.23 – Average annual precipitation 1904-2002 from official weather stations and annual totals from RAWS from 2003-2005.

average and within 2% of the average. A linear trend of the data shows a slight increase in the yearly rainfall total of about 7 inches since 1904. All RAWS totals were less than the value projected by the trend line.

Monthly historical data are analyzed as well (Fig 4.24). Along with the monthly averages are the maximum and minimum historical monthly measurements and monthly accumulations measured by the RAWS and ECHO® stations during the monitoring period. The RAWS data includes data from January 2003 thru July 2006, while the ECHO® data begins in July 2005 and ends July 2006. Historically, May is the wettest month, recording an average of 4.7 inches of rainfall. February is the driest month, averaging only 2.5 inches of precipitation per month. March through June is typically the wettest season, with an average of 4.2 inches per month. December through February is the driest period, averaging about 2.7 inches monthly. The smallest monthly total was 0.11 inches and occurred in January 1986. The largest, 12.9 inches, was measured in December 1982.

Measurements made at the RAWS and ECHO® locations fall both above and below the historical averages. No strong trends are seen relating precipitation amount to temporal variation. For the months of April and June, typically wetter months, both the RAWS and ECHO® readings are less than measurements from August and September, two generally drier months. In addition, November, a month which typically receives moderate precipitation, had nearly twice the historical average of precipitation. For nearly all months, the ECHO® data are a more extreme value than the RAWS readings. This is partially the result of the RAWS data being averaged over two years, while the ECHO® measurements incorporate only one year.

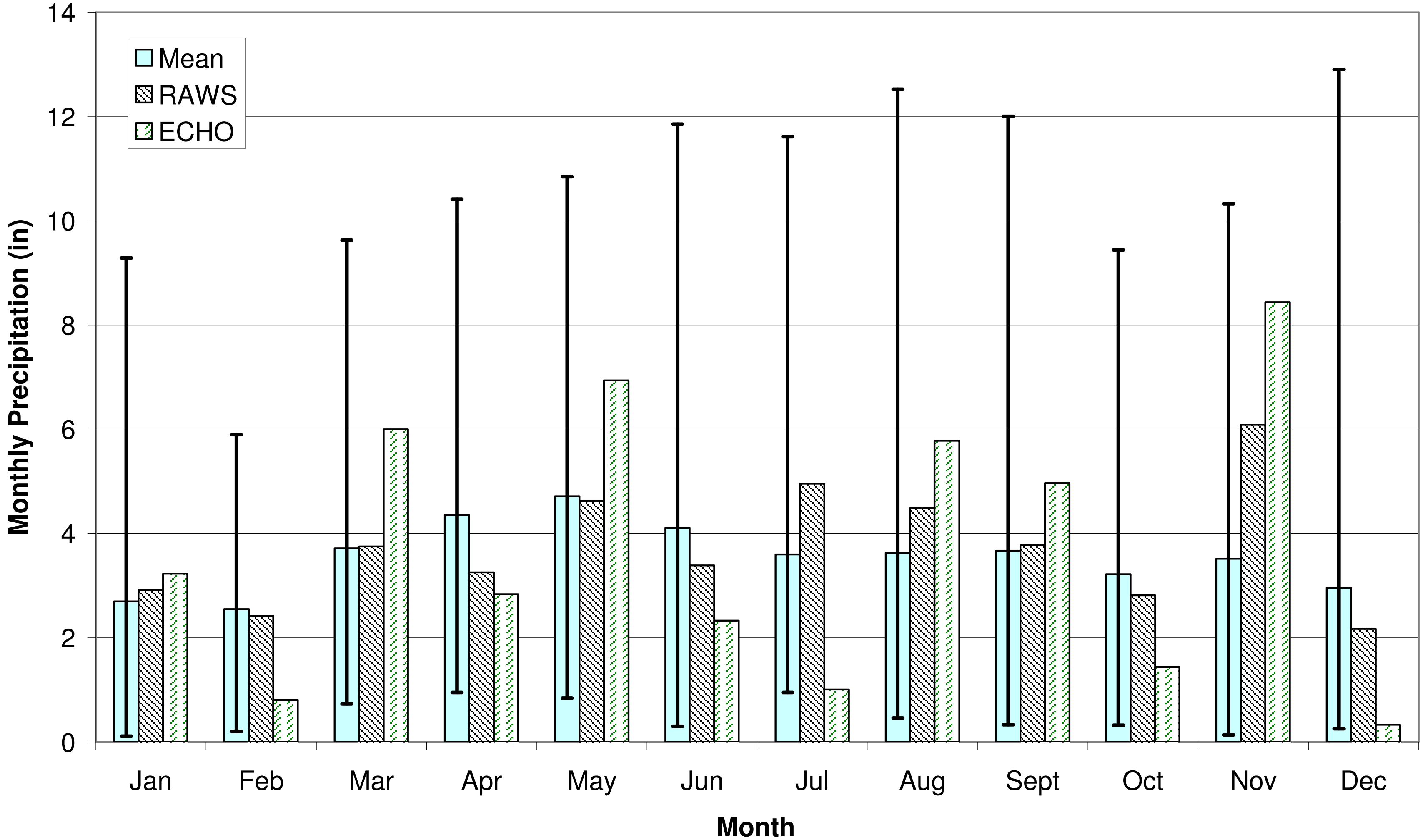

Figure 4.24 – Average historical monthly precipitation since 1904 and monthly totals from the RAWS and ECHO® stations during the monitoring period (Jul 2004-Aug 2006, RAWS, Jul 2005-Aug 2006, ECHO®).

As mentioned previously, the Isco® rain gauge has been clogged on all sampling trips since its installation in March 2006. The instrument was designed for use in a more open environment where debris is less likely to clog the inlet funnel. Although the funnel is guarded with a metal screen, its ¼ inch openings allow enough litter into the funnel to slow or completely block the flow of precipitation into the gauge. On both the 5/16/06 and 7/19/06 sampling trips, water was ponded in the inlet funnel.

When the flow is slowed or blocked, the gauge cannot provide accurate measurements of precipitation relative to time. Figures 4.25(a) and 4.25(b) illustrate the effect of slowed drainage into the rain gauge. Figure 4.25(a) is hourly precipitation data from the A34-1 ECHO® station and Isco® gauge, as well as data from the RAWS available online, from April 27 - May 15, 2006. In Figure 4.25(b) the vertical scale has been enlarged to make small precipitation amounts more visible. For a period of time after installation, the rain gauge appears to perform properly. Until the precipitation events occurring May 9-10, the Isco® rain gauge measures precipitation amounts similar to those recorded by the A34-1 ECHO® station. During this time, both the Isco® and ECHO® also closely match data retrieved online from the RAWS. During the May 9-10 events, the Isco® gauge shows significantly smaller measurements than other instruments. Additionally, after the initial precipitation on May 9, the Isco® data show tiny, consistent, precipitation readings of 0.01 inches every one to six hours extending over the next five days. This small, extended event is not seen in the ECHO® or RAWS data. These small consistent readings are the result of water trapped in the inlet funnel slowly leaking through the debris plug.

In Figure 4.26, precipitation data from the same three sources are shown over a longer time period. The same small, extended "precipitation events" not seen in the ECHO® or RAWS data are present in the Isco® rainfall data. From after the 5/16/06 sampling trip, when the debris clogging the funnel was removed, until a precipitation event around June 1, the Isco® gauge measured precipitation amounts similar to those seen in the ECHO® and RAWS data. After the June 1 rainfall, the Isco® data again show numerous measurements of 0.01 inches of precipitation every few hours continuing for about 7 days. Similar trend are shown after precipitation events on June 18 and July 10. On both these dates, precipitation is recorded at both the A34-1 ECHO® station and RAWS location, but the Isco® measured just small consistent increments. The small prolonged readings are measured as water slowly filters through the build-up of debris in the inlet cone. Because most of the precipitation appears to eventually percolate through the barrier, accumulated precipitation totals of one day or greater are similar to measurements made at other locations. When the inlet funnel is clogged and the funnel begins to overflow, the total precipitation measured at the Isco® becomes smaller than that recorded at other locations. Only precipitation measurements from durations less than one day are significantly affected by the clogged inlet funnel of the Isco® rain gauge.

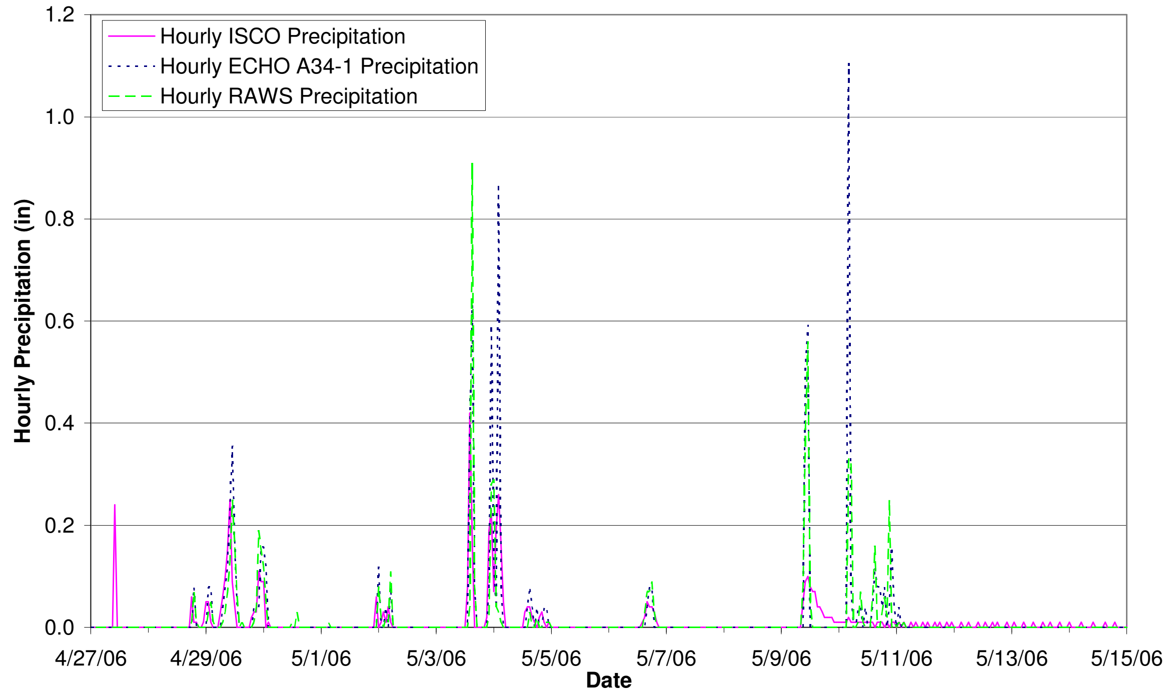

Figure 4.25(a) – Hourly precipitation data from April 27 – May 15, 2006 from A34-1 ECHO® station, Isco® gauge, and RAWS.

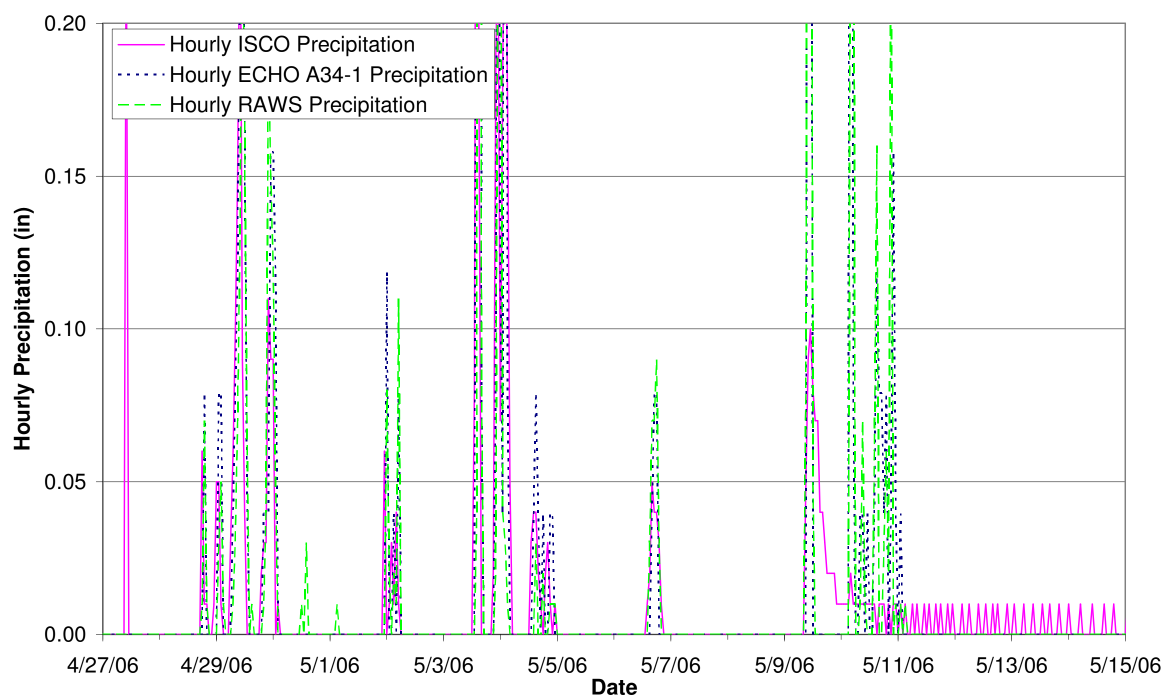

Figure 4.25(b) – Hourly precipitation data from April 27 – May 15, 2006 from A34-1 ECHO® station, Isco® gauge, and RAWS for an enlarged vertical axis.

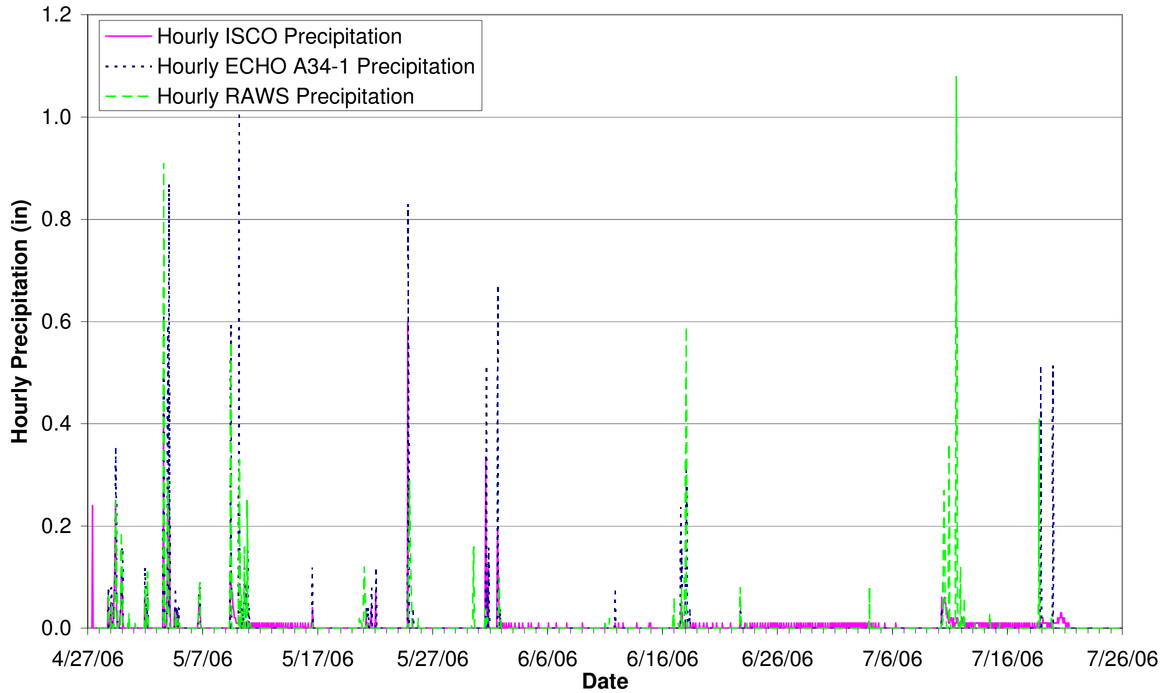

Figure 4.26(a) – Hourly precipitation data from April 27 – July 26, 2006 from A34-1 ECHO® station, Isco® gauge, and RAWS.

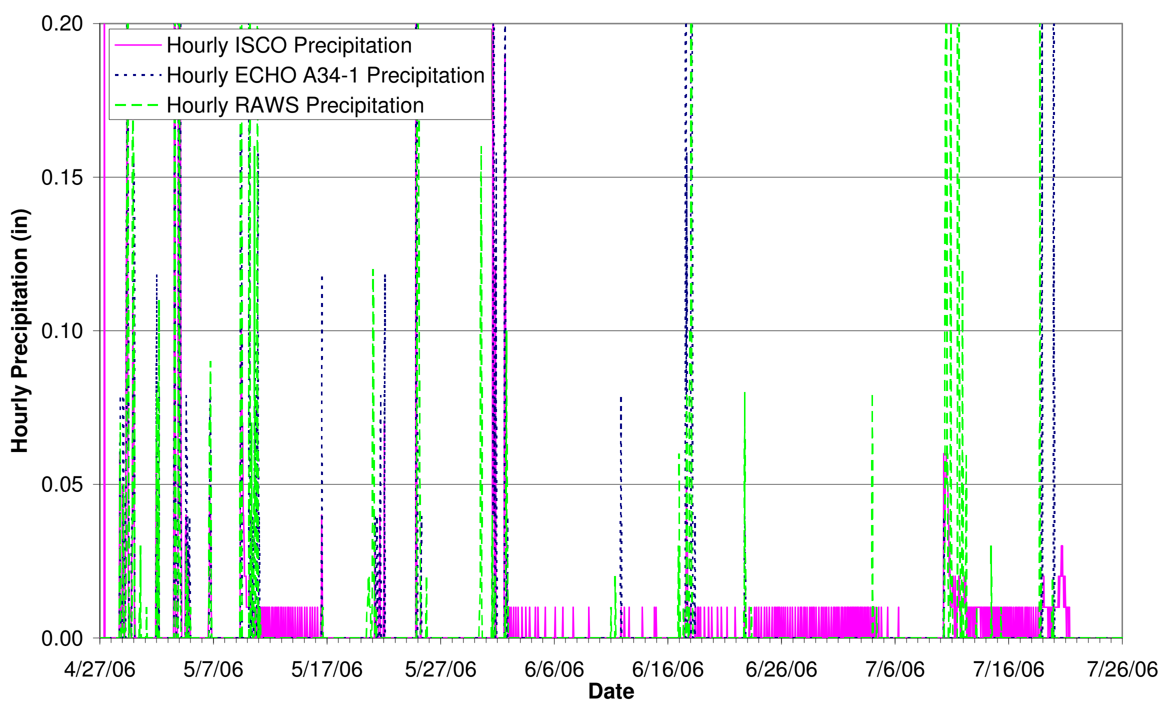

Figure 4.26(b) – Hourly precipitation data from April 27 – July 26, 2006 from A34-1 ECHO® station, Isco® gauge, and RAWS for an enlarged vertical axis.

4.2.2.5 Soil Moisture Sensors

The soil moisture sensors are performing well. They were installed in June 2005 and have been providing consistent data. Volumetric water contents from each of the three probes installed on both A34-1 and CR7-5c are presented in Fig. 4.26. Probe 1 is installed 15 feet uphill from the guttering of the corresponding hillslope sediment monitor. Probe 2 is buried even with the guttering and Probe 3 is positioned 15 feet downslope. No correlation can be seen relating soil moisture magnitude to probe position on the hillslope. On A34-1, Probe 2, located in the middle, measures consistently higher moistures than Probe 3. At CR7-5c, the opposite is true.

It can also be observed that on both sites, at some point, one of the probes appears to malfunction. On A34-1, around early November 2005, Probe 1 begins to deviate from the pattern shown by the other two probes (Point 1, Fig. 4.27(a)). It begins with a large upward jump not seen in Probes 2 and 3, followed by sporadic peaks and valleys. During this time, Probes 2 and 3 continue to match well. For this reason, it is believed Probe 1 is providing faulty data. From the point where the large spike occurs in November 2005, data from Probe 1 has been disregarded.

On site CR7-5c, a different malfunction occurred for a portion of the monitored period. Beginning in mid-November 2005, and extending to mid-March 2006, Probe 1 failed to record any soil moisture data (Point 1, Fig. 4.27(b)). For the same period, the remaining probes show normal wetting and drying patterns. In mid-March, Probe 1 began providing data again (Point 2, Fig. 4.27(b)). Because this data matches well with data from the Probes 2 and 3, it is believed the data is reliable. It is unclear why Probe 1 stopped recording data, or why is began working again. Further investigation is needed

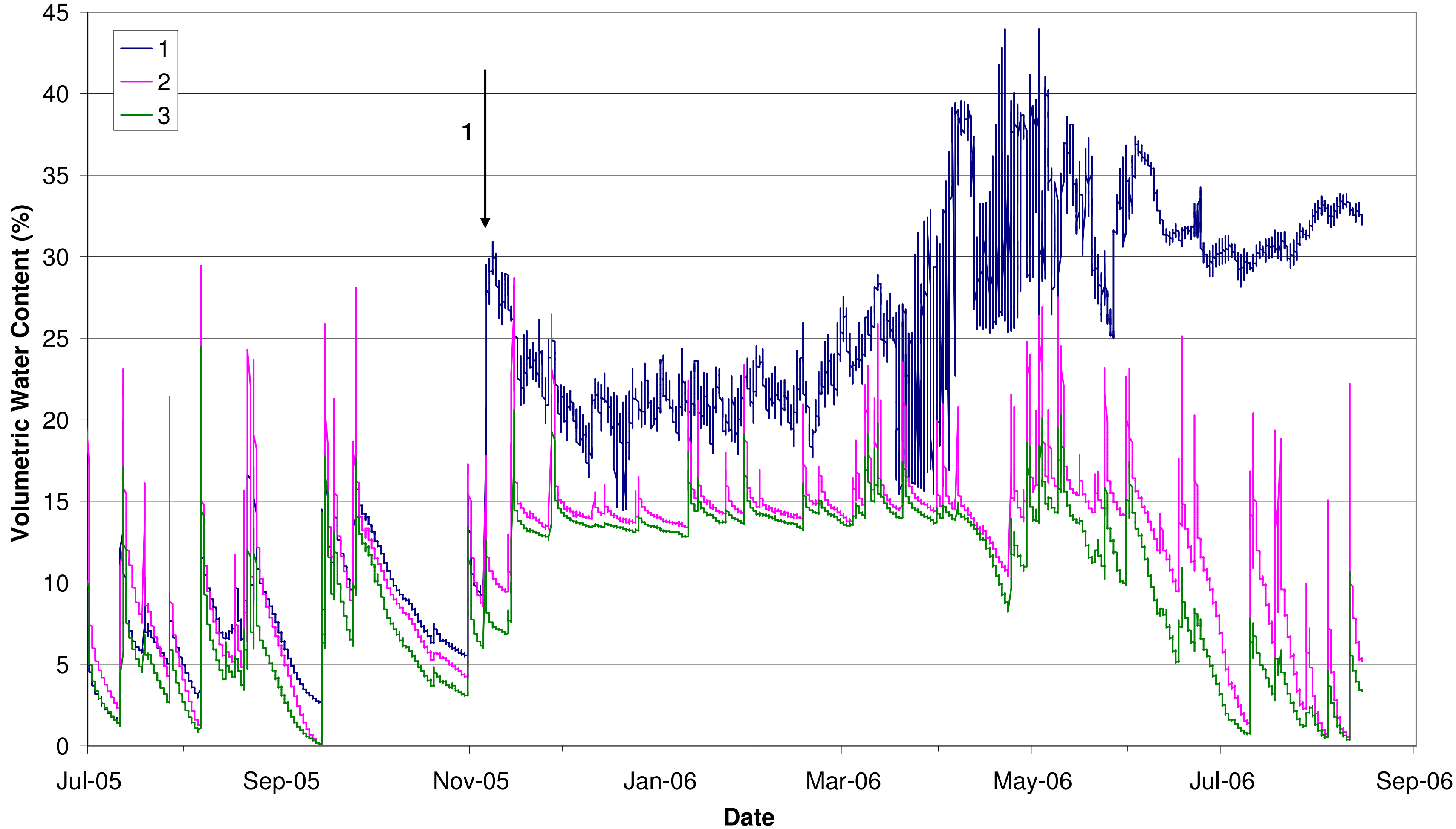

Figure 4.27(a) - ECHO® soil moisture data from A34-1 from July 1, 2005 thru August 15, 2006.

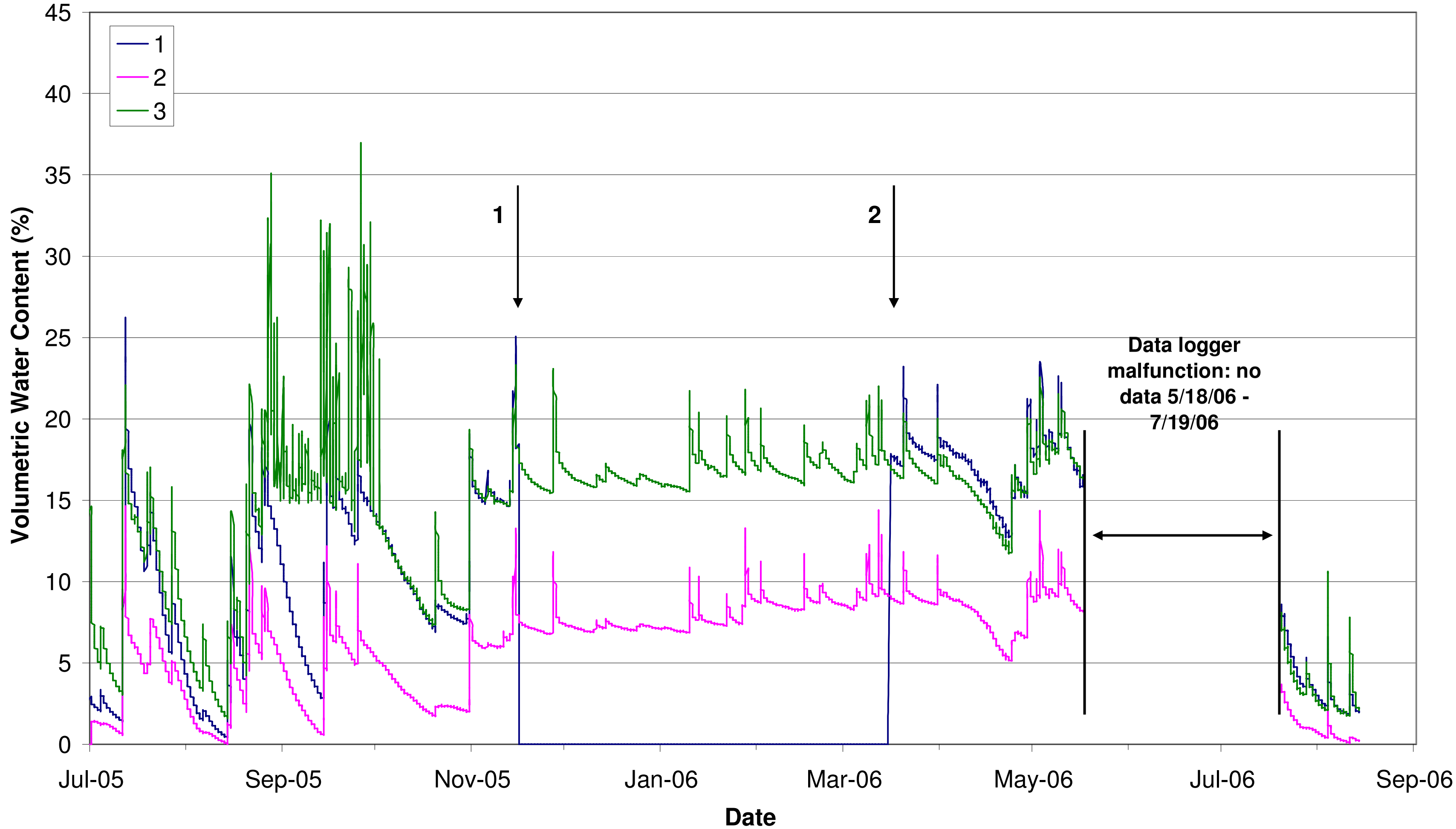

Figure 4.27(b) – ECHO® soil moisture data from CR7-5c from July 1, 2005 thru August 15, 2006.

to determine the possible effects of probe installation, subsequent disturbance, and other mechanisms on soil moisture readings.

In addition to the Probe 1 malfunction on CR7-5c, the entire data logger froze up and had to be reset on the 7/19/06 sample collection trip. When the logger was reset, all data recorded since the last sampling trip on 5/18/06 was lost. The reason for the logger malfunction is not known and will require further investigation.

On each site where the soil moisture probes are installed, all functional probes show similar responses to changes in soil moisture within the site. Spikes in moisture content are observed at nearly identical times. Although the precise magnitudes differ slightly among the working probes within a site, the wetting and drying patterns are nearly the same. More investigation is needed to determine the reason for the differences shown among the individual probes. Although the precise reason is uncertain, the differences are likely influenced by slight variations in local topography, variation in soil texture and density near the probes, and possibly nearby vegetation.

Because of variability among probes within a site, and the need to have a single set of values for comparison purposes, soil moisture data from each site has been averaged. For this thesis, when ECHO® soil moisture values from a particular site are referred to, it is the average value of all properly functioning probes within that site.

Soil moisture data from the two ECHO® stations installed on research sites are also being supplemented with data available online from the RAWS. When the data from all sources are compared (Fig. 4.28), similar trends are shown. However, the precise magnitudes and rates of change differ somewhat among the three sources. The data from the ECHO® sources show similar trends and match closely regarding soil moisture

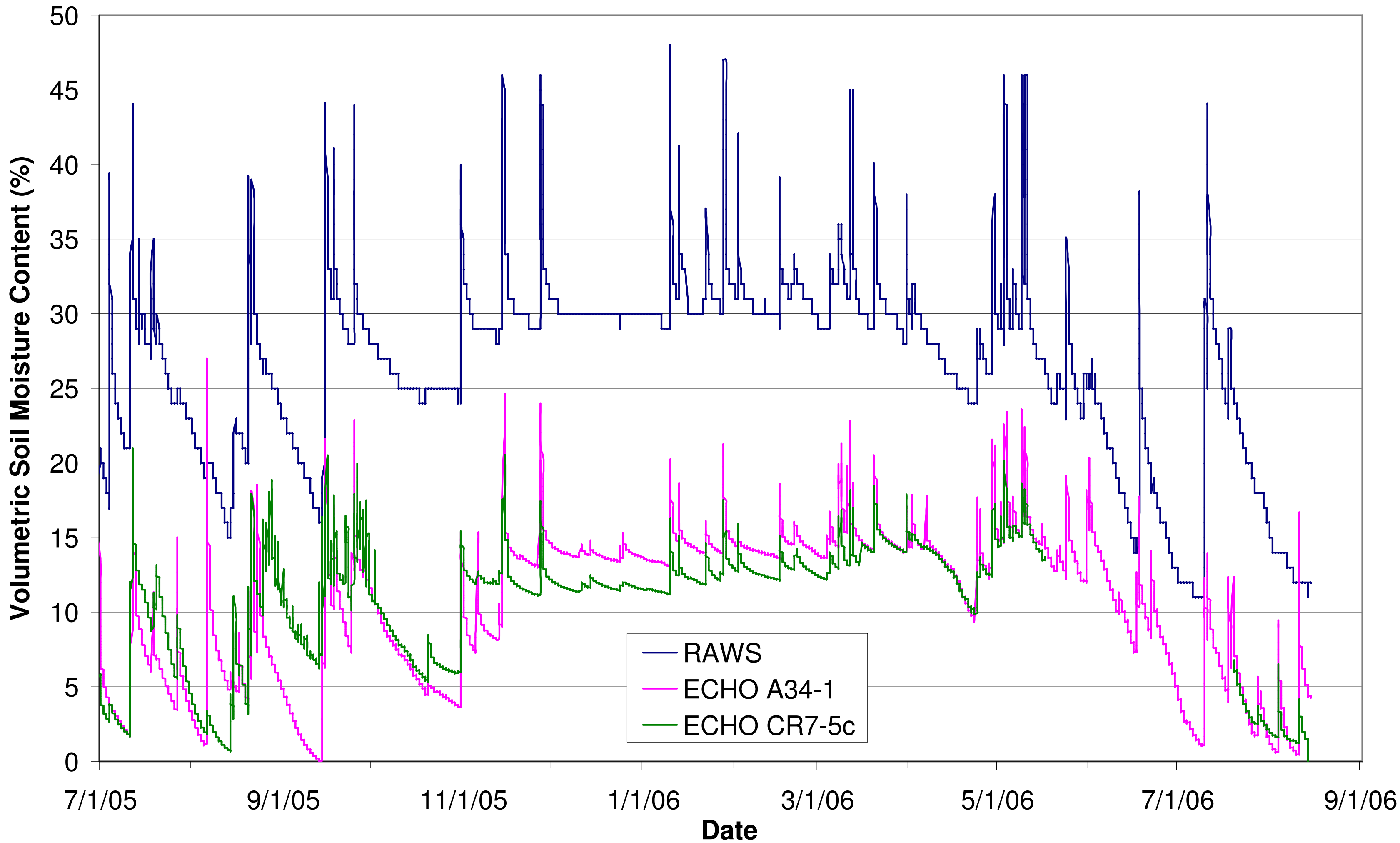

Figure 4.28 – Volumetric water content from RAWS and ECHO® stations.

magnitude. The RAWS data are consistently greater than the ECHO® data. The cause for the discrepancy between the RAWS data and values recorded at ECHO® stations is uncertain, but likely due to several factors. One influence is different vegetative cover at the various equipment locations. Both the ECHO® stations are located on a hillside beneath heavy forest canopy. The protection of the canopy, and moisture uptake of associated vegetation could result in lower measured water contents. The RAWS is located in an open field on a hilltop. Another possible contributing factor is the variety of equipment used to measure the soil moisture content, as well as installation depth of the equipment. The ECHO® probes sense changes in the dielectric constant of the soil at a depth of six inches. It is not known what type of device is used to measure the RAWS data, or how deep it is buried. Other possible factors include large variability in soil types and landscape among the locations.

Despite difficulties associated with some of the moisture probes and data loggers, the ECHO® soil moisture equipment has provided high quality data illustrating the rapid response of volumetric water content of the soil during precipitation events and the subsequent drying of the soil. An example of hourly precipitation and soil moisture data collected at the ECHO® station on A34-1 is presented in Figure 4.29. The precipitation data includes three hourly totals of greater than 0.5 inches in close succession with several smaller events in the following days. For each individual rainfall event, an increase in soil moisture content can be seen to follow almost immediately. Even small rainfall amounts of less than a tenth of one inch cause a moisture response in the soil. In each case, the moisture level peaks within an hour of the time of highest precipitation intensity. The increasing, or wetting, portion of the moisture curve is steep, usually

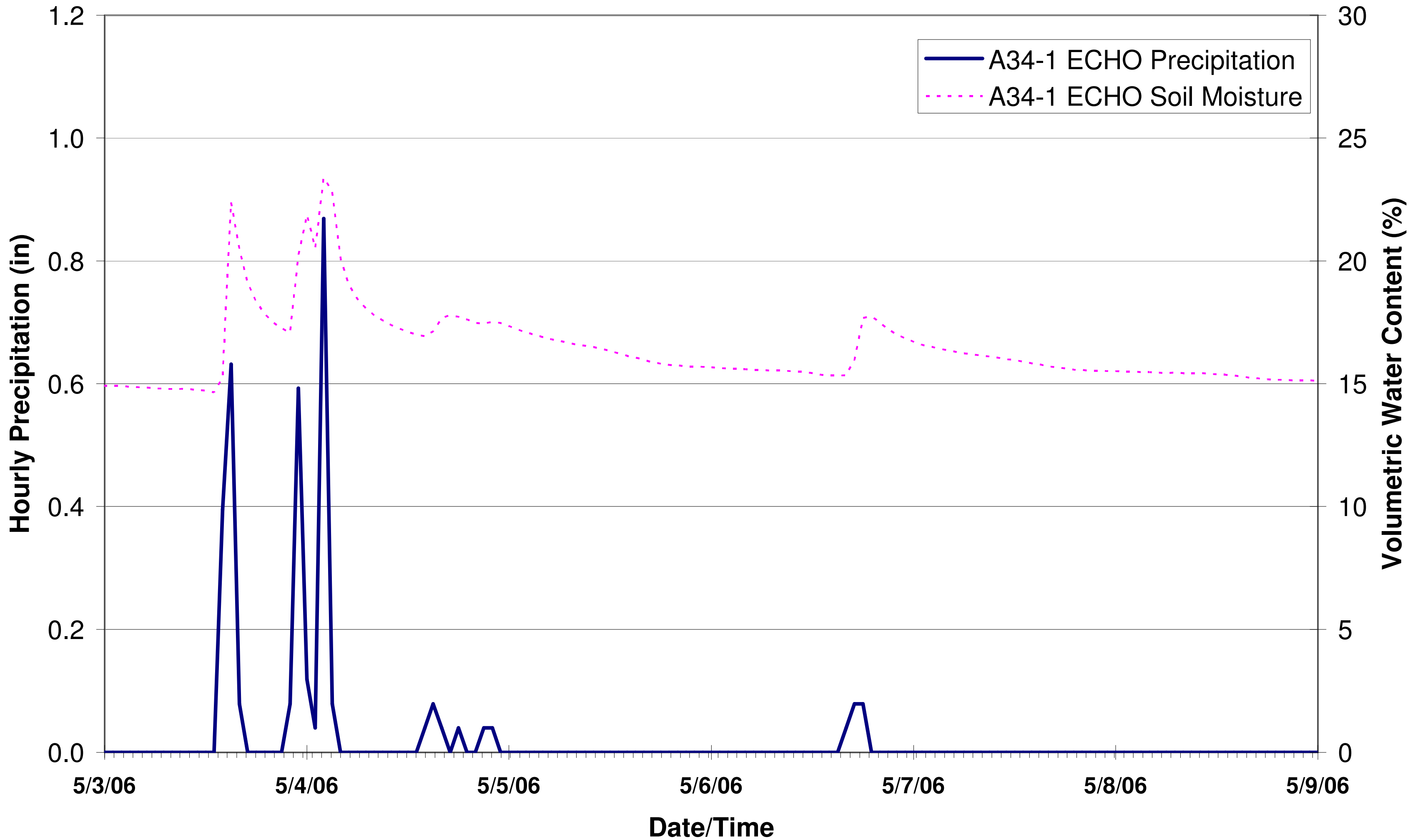

Figure 4.29 – Hourly precipitation and soil moisture data from the A34-1 ECHO® station May 3 – May 8, 2006.

taking less than three hours to reach its maximum value. Following the peak, the initial portion of the drying curve is also relatively steep as moisture drains from the soil due to gravity. When all water capable of being gravity drained has been removed from the soil, the dominant method for moisture removal is evaporation, causing the secondary portion of the drying curve to be more gradual.

4.2.2.6 Air Temperature Sensors

The ECHO® temperature sensors installed on A34-1 and CR7-5c have been performing well. Daily temperatures and monthly averages are plotted in Fig. 4.30. Daily temperature fluctuations on both sites are apparent, as well as seasonal variations.

Air temperature data is also available from the RAWS. Monthly averages from both ECHO® stations and the RAWS from July 2005 thru July 2006 are plotted in Fig. 4.31. Maximum and minimum temperatures for each month are also shown. The absolute high and low temperatures recorded at any of the locations during the monitoring period are 102°F and 4°F respectively. The average temperature for the entire monitoring period was 56°F. The average monthly temperatures recorded at the RAWS location are slightly higher than both EHCO® stations for the entire monitoring period. This is likely due to the location of the stations. The open field location of the RAWS puts the temperature sensor housing in direct sunlight. Both of the ECHO® stations are completely or partially shaded for the entire year. The direct sunlight at the RAWS location likely increases the measured temperature within the protective housing. The difference between the RAWS measurements and ECHO® measurements is slightly larger during the summer months, when solar radiation is most intense and would cause larger temperature differences. In addition, the forest canopy is thickest during this time,

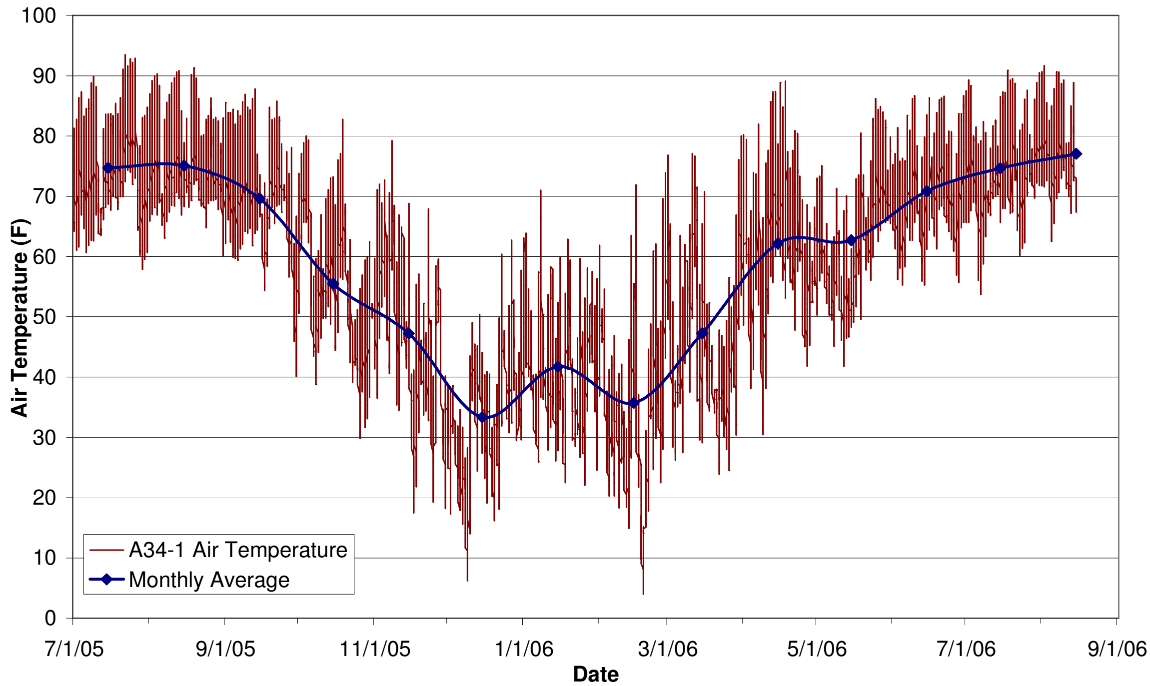

Figure 4.30(a) - Daily temperature variation and monthly averages from the ECHO® station on A34-1 from July 1, 2005 thru August 15, 2006.

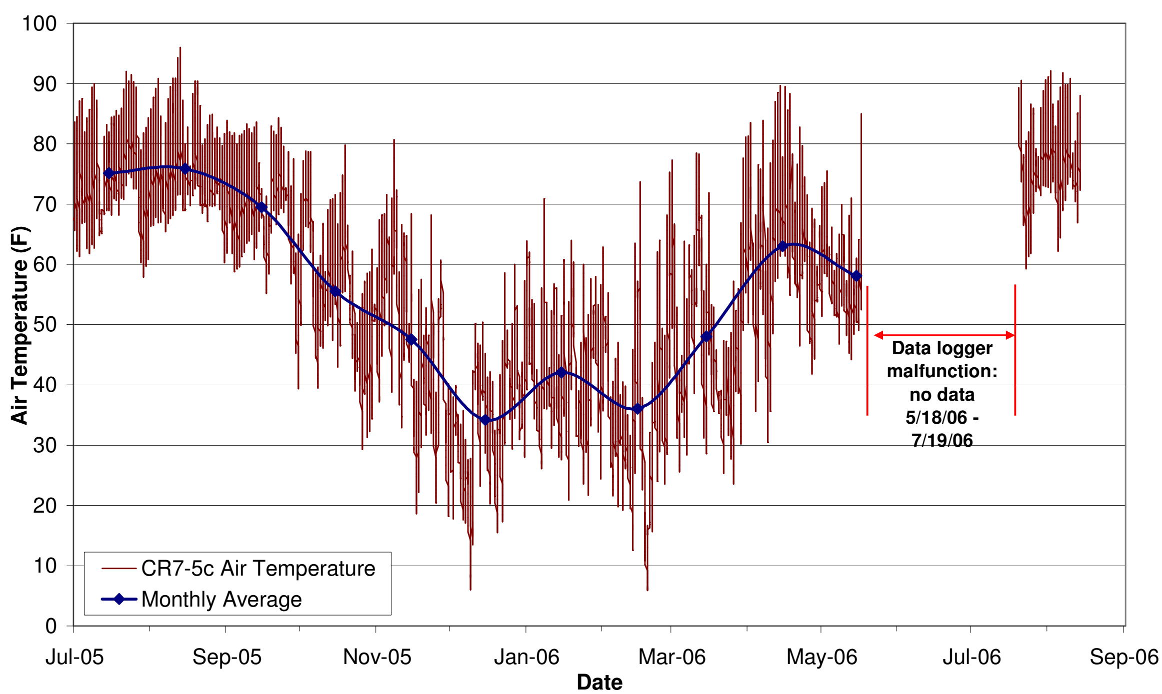

Figure 4.30(b) – Daily temperature variation and monthly averages from the ECHO® station on CR7-5c from July 1, 2006 thru August 15, 2006.

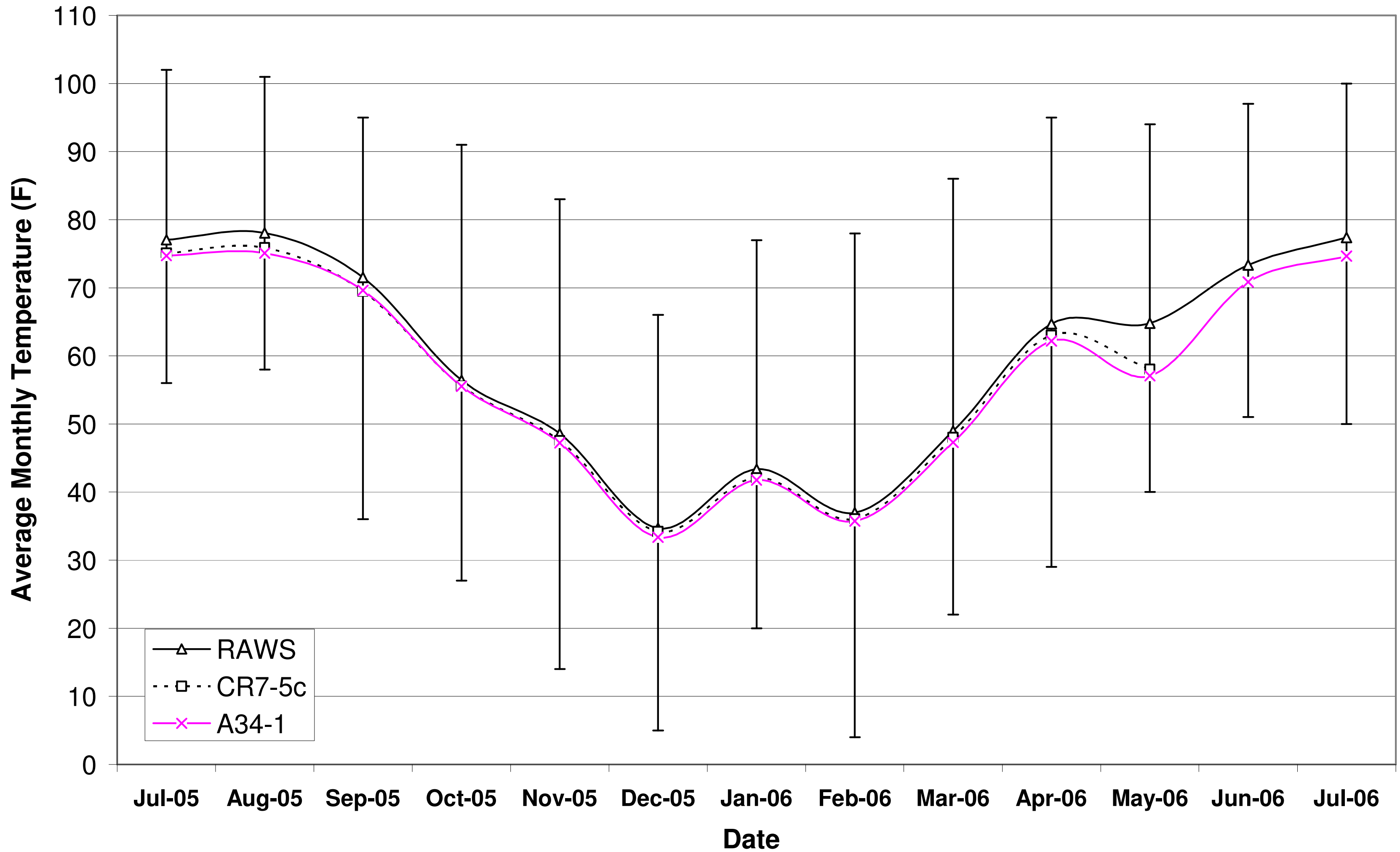

Figure 4.31 – Monthly temperature averages from the RAWS and ECHO® stations.

providing maximum shading of the ECHO® stations. During the winter months, when the canopy has fallen, and sunlight is less intense, temperature measurements between the RAWS and ECHO® stations are smaller.

In Figure 4.32, average monthly temperatures from the four official weather stations mentioned previously from 1904-2002 are plotted with maximum and minimum monthly averages. Monthly averages measured by the RAWS and ECHO® stations during the monitoring period are also presented. RAWS data is from January 2003 thru July 2006 and ECHO® data is the average of readings at A34-1 and CR7-5c from July 2005-July 2006. Historically the highest monthly average temperature was 99°F in July 1980 and the lowest was 7°F in January 1918. Data from the monitoring period reveal that the temperature has been slightly milder than average, showing both warmer than average winters and cooler than average summers.

4.3 Threshold Precipitation Event

As a secondary objective of instrument performance, and key component to obtaining the maximum number of high quality samples, criteria must be established to determine when water sample collection must be performed. Because the research sites are located nearly four hours driving time from Columbia, Missouri, it is neither practical nor economical to visit each site after all precipitation events. In addition, depending on environmental conditions, it is not necessary to make a sample collection trip following all precipitation events. Thus, quantitative limit conditions influencing the frequency and quantity of flow in low order ephemeral streams in the Missouri Ozarks must be set. These limits will be referred to collectively as a threshold event. A threshold event is any combination of parameters which generates collectable flow, and thus water samples, in

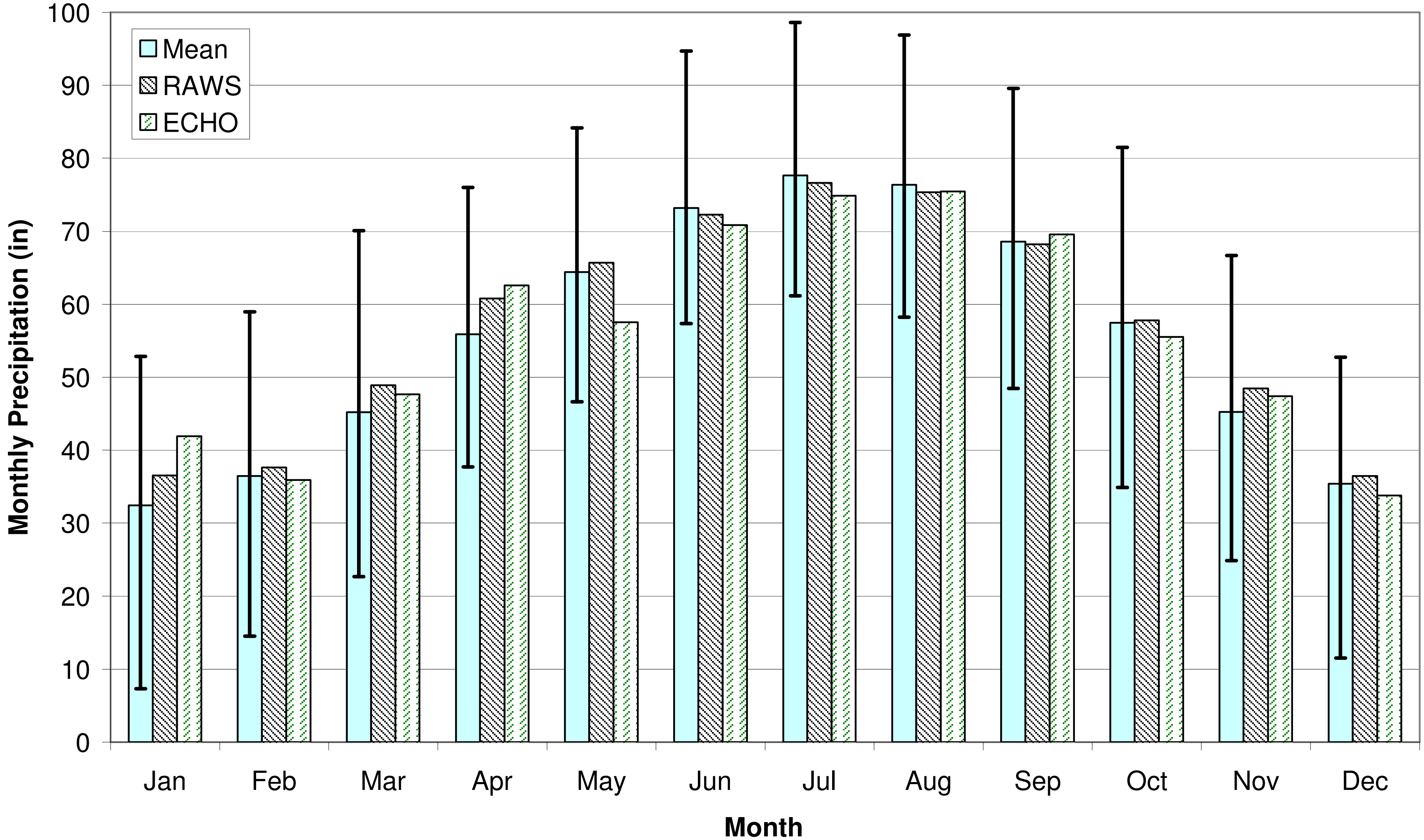

Figure 4.32 – Monthly average temperatures for the Eminence region from 1904-2002 and monthly average temperatures from RAWS and ECHO® stations measured during monitoring period.

the ephemeral channels. Parameters affecting a threshold event are many and varied and include precipitation amount and intensity, antecedent soil moisture content, vegetation, soil type, ground slope, and losing or gaining karst features. The effect of many of these factors will be examined in this section.

4.3.1 Precipitation

Total precipitation is the most obvious, and probably the most significant, factor influencing the generation of flow in the ephemeral channels. Without precipitation, only a gaining karst feature such as a spring could generate flow. However, because no known springs are present on any of the research sites, precipitation is the only mechanism for water input to the sites.

In order to examine the effect of precipitation on channel flow and quantity of samples collected, a specific length of time over which precipitation is measured must be selected. The two week time period immediately prior to the initial day of the sample collection trip was chosen. This time period encompasses the majority of the precipitation responsible for creating flow, and represents the rainfall being captured and collected in water samplers. It was necessary to extend the time period to two weeks because on several occasions it was not possible to organize and perform sample collection in a timely manner. For some of the sampling events, the two week period was extended by one to three days to include a significant (>1.0 inch) precipitation event.

When the rainfall accumulation in the two weeks prior to sample collection is compared to the number of samples collected (Fig. 4.33), a definite correlation is present. As the rainfall total increases, relatively strong correlations are seen in both the number of total and in-stream samples collected. Coefficient of determination (r^2) values for total and in-stream samples are 0.64 and 0.57, respectively. The number of hillslope samples collected is relatively constant for all precipitation amounts, resulting in an insignificant correlation for the number of hillslope sediment monitor samples ($r^2 = 0.03$). The nearly constant number of hillslope sediment monitor samples is likely influenced by the plastic sheeting on the instruments. The sheeting is impermeable and collects all rainfall, enabling it to collect samples regardless of amount of precipitation or other factors such as soil moisture content. The trend lines for total and in-stream samples are almost parallel because the total number of samples trend line represents the in-stream number increased by the relatively constant number of hillslope samples.

Rainfall values are the average of daily totals obtained from the USGS and RAWS sources available online. These two sources are used because the data can be remotely accessed from Columbia before a sample collection trip is made. Although precipitation data is available from instruments installed on the research sites, it is not available until after a field trip is made and the data is collected. To be able to predict when a sample collection trip must be made, the data must be available in Columbia prior to leaving.

In Figure 4.33, the lowest average two week precipitation total for which any in-stream samples were collected was 1.1 inches. The best linear fit of the in-stream samples indicates that approximately 1.9 inches would be necessary for any in-stream samples to be collected. This accumulation was measured prior to the April 15, 2005 sample collection trip in which 3 in-stream samples were collected.

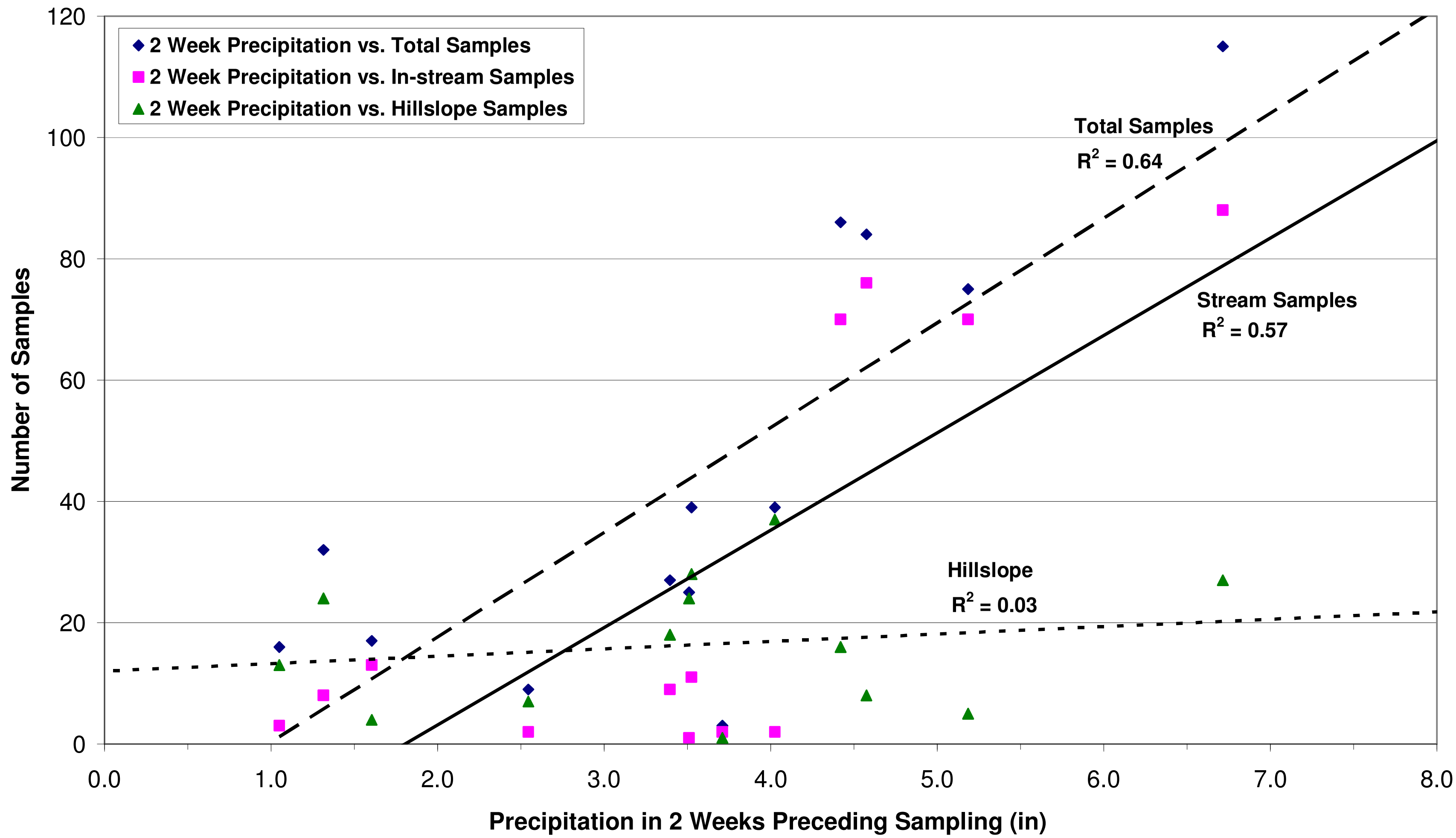

Figure 4.33 – Number of total, in-stream, and hillslope samples vs. average 2 week precipitation sum prior to sampling from USGS and RAWS sources available online.

4.3.2 Antecedent Soil Moisture

Another key element in predicting flow in the ephemeral channels is the soil moisture content prior to precipitation. The amount of water already present in the soil plays a significant role in determining how much of the rainfall is able to infiltrate into the soil, and thus how much must be shed as overland flow. For high antecedent moisture contents, the pore space of the soil is largely occupied by water and additional moisture is unable to enter the soil. When the moisture content is low, the soil can more readily absorb precipitation, preventing water from flowing into the ephemeral channels.

In Figure 4.34, the total number of water samples collected on each trip is plotted against the antecedent soil moisture content. The precipitation values are the average accumulation recorded at two online sources (RAWS, USGS) for the two weeks prior to the sampling date. Because soil moisture data is not available from the USGS station, the data for soil moisture is from only the RAWS. The soil moisture value was taken just before the beginning of the precipitation events necessitating the sample collection trip. The soil moisture value is not exactly two weeks prior to the sampling date, but is within the two week period. To get an accurate representation of the soil moisture condition prior to the rainfall which caused flow in the channels, the value was chosen at the soils' driest point, immediately preceding the onset of precipitation. In all cases it was equal to or within 3% of the driest condition of the soil within the two week period before sample collection. A linear regression of the data is also shown. While the correlation between the number of samples and antecedent moisture content is insignificant ($r^2 = 0.22$), with the exception of three sampling events where the preceding precipitation accumulation was small (<1.7 in.), there is a definite overall increase in the total number of samples

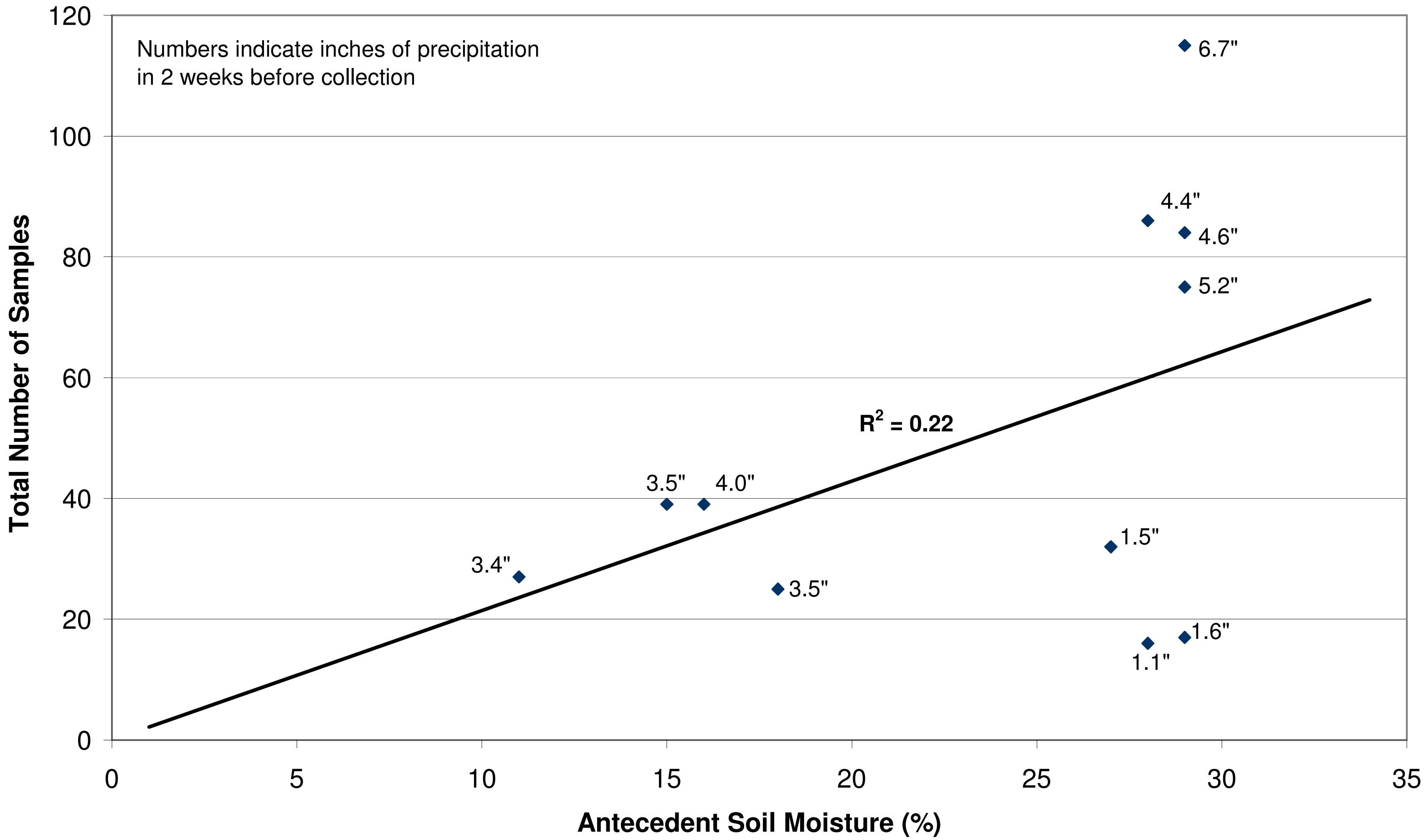

Figure 4.34 – Total number of samples collected during each sampling event vs. antecedent soil moisture content.

with an increase in antecedent soil moisture. However, it must be noted that the number of samples also depends heavily on the amount of precipitation preceding the sampling trip.

4.3.3 Precipitation and Antecedent Soil Moisture

Both the quantity of precipitation and level of antecedent soil moisture play a major role in creating flow in the ephemeral channels. Therefore it is appropriate to attempt to determine the combined effect of these two important parameters on the amount of flow generated in the channels and the number of samples collected.

When the two week precipitation accumulation is plotted against the antecedent soil moisture content (Fig. 4.35), little correlation is expected or observed. The soil moisture before the rainfall should be completely independent of the ensuing precipitation. A coefficient of correlation value of 0.002 for this plot supports the hypothesis. However, when the total number of water samples collected is included at each data point, general contour lines can be formed. For low values of antecedent soil moisture, or for small accumulations of precipitation, fewer samples are likely to be collected. When both antecedent moisture and rainfall accumulation are high, more samples are possible. The shaded regions of the graph represent the number of samples which may be expected for a given combination of soil moisture and precipitation. For antecedent soil moisture values of less than 20% and two week precipitation amounts less than about 4 inches, fewer than 40 samples should be expected. When soil moisture is greater than about 27%, and the rainfall total is more than 4.5 inches, 80 or more samples are possible. Other combinations are possible to generate between 40 and 80 samples. In addition, other combinations may generate an expected number of samples less than 40 or

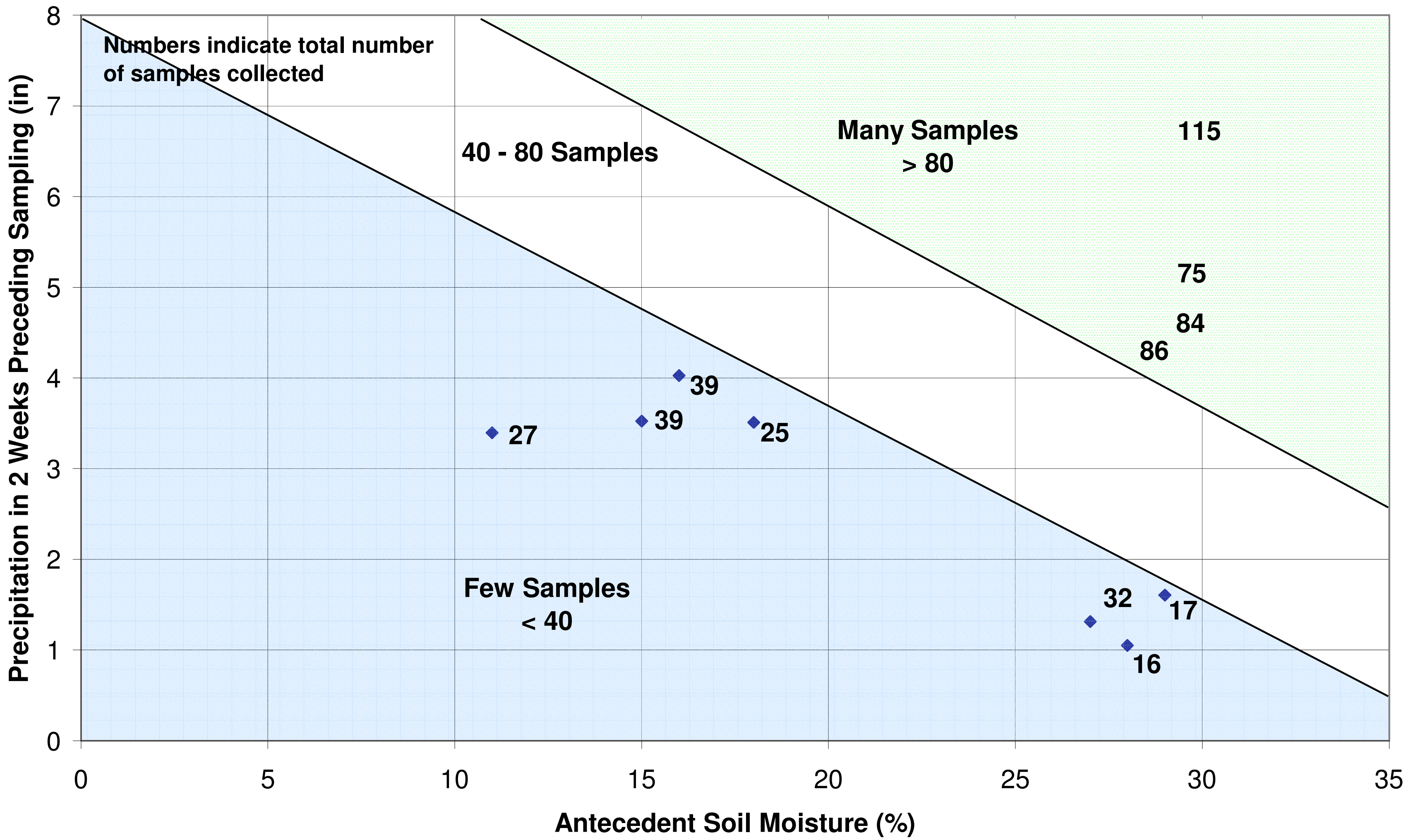

Figure 4.35 – Two week precipitation accumulation vs. antecedent soil moisture data from Carr Creek RAWS content with total number of samples collected are beside data points and expected sample number contours.

greater than 80. For less than 40 samples to be expected, the soil may either be dry (less than 5% volumetric water content), or the rainfall total may be small (less then about 1 inch). Extreme events may also produce more than 80 samples. If the antecedent moisture level is greater than 35% or the two week precipitation is larger than 8 inches, at least 80 samples are likely to be collected. These predictions are valid only if all sites are visited and a large majority (>90%) of samplers are functioning properly.

Because three variables are present, precipitation, soil moisture, and total number of samples, it is difficult to include all of them on one plot. One way to reduce the number of variables is to normalize one with respect to either of the others. This essentially combines two variables into one, leaving only two remaining variables. Figure 4.36 is a graph of the total number of samples normalized with respect to the antecedent soil moisture content plotted against the two week precipitation accumulation. Normalizing the total number of samples with respect to antecedent moisture creates the effect of estimating the total number of samples assuming the initial moisture content was identical in all cases. When this combined variable is plotted against total rainfall, a strong correlation ($r^2 = 0.85$) is seen. This is another possible way to predict the number of samples which may be expected to be collected given the antecedent moisture level and two week precipitation accumulation. With a known rainfall total, the equation

$$y = 0.6 * x \qquad \text{Eq. 4.1}$$

may be used to find the y, the normalized value, where x is the two week precipitation accumulation in inches. If this value (y) is multiplied by the antecedent moisture content in percent, the expected number of total samples can be predicted. More simply,

$$\text{total number of samples} = 0.6 * (\text{2 week rainfall}) * (\text{antecedent moisture}) \qquad \text{Eq. 4.2}$$

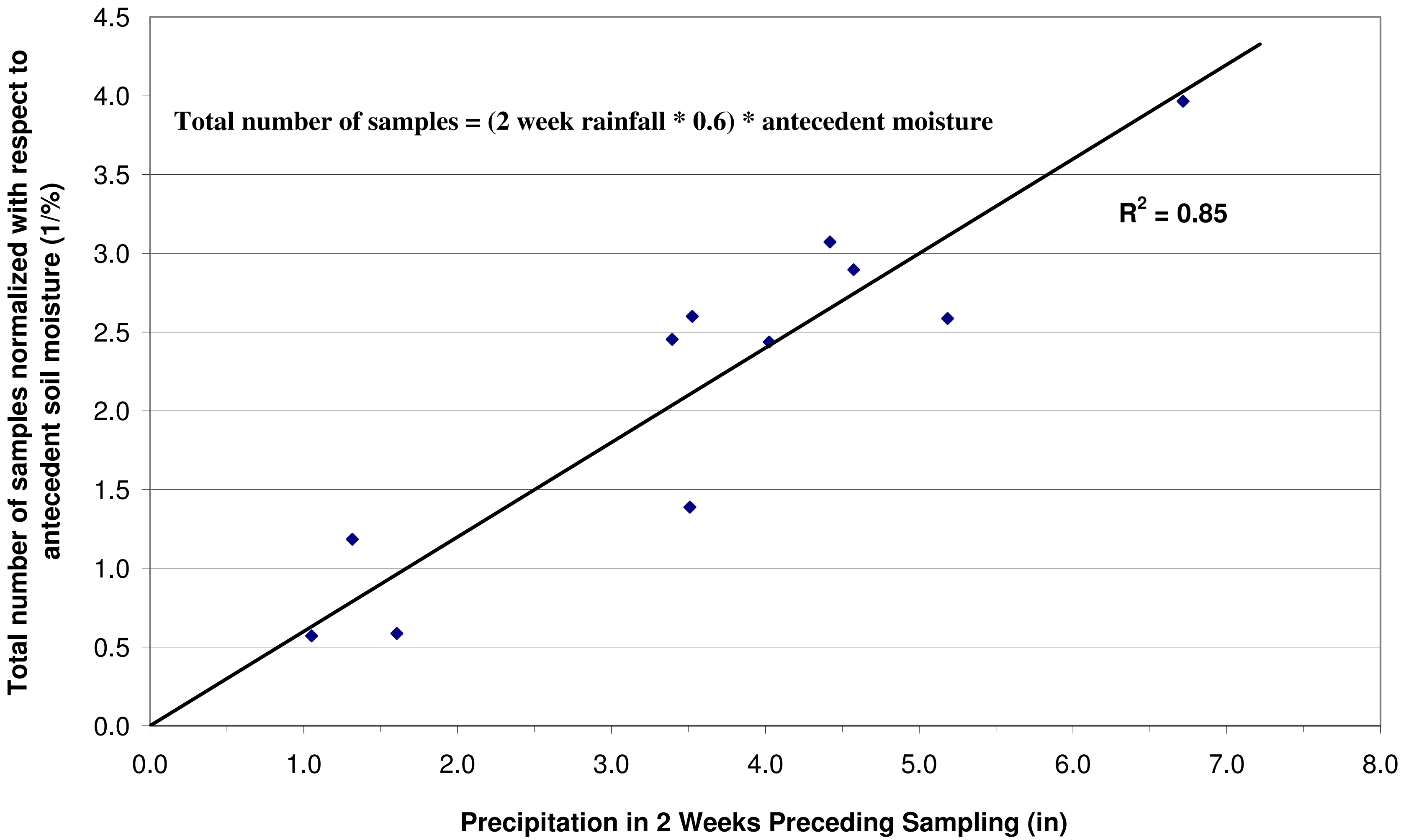

Figure 4.36 – Total number of samples normalized with respect to antecedent soil moisture vs. two week precipitation accumulation.

Other combinations of normalized parameters were tried, but none showed a coefficient of correlation greater than 0.86. Figure 4.35 can be used to provide an estimate of the total number of samples to be expected within a given range for specific precipitation and soil moisture conditions. Equation 4.1 can be used to provide a similar, and possibly more accurate, estimate. Analysis of total number of samples collected on future sample collection trips is necessary to test the models. In addition, data collected during future sampling will serve to refine the models and increase their accuracy.

4.3.4 Other Parameters Influencing the Threshold Event

While the two most significant parameters affecting the generation of flow and water samples in ephemeral channels are precipitation and antecedent soil moisture, several other factors play a role. These include parameters such as vegetation, soil type, ground slope, ground cover, and losing or gaining karst features.

4.3.4.1 Vegetation

Amount and type of vegetative cover can influence how much surface runoff is created during precipitation. The relative influence of vegetation is also related to the temporal variations and the growth state of the plant life. Heavy ground cover during the spring season requires significant amounts of moisture. During this period, vegetative uptake of moisture is greater and the soil generally has a larger capacity to absorb water because of the constant withdraw from vegetation. During the winter months, when vegetation in the region is in a dormant state, moisture needs are greatly reduced, lessening a water removal mechanism, and increasing the overall soil moisture content. In addition, the root systems of forest vegetation keep the soil porous and highly permeable, increasing the rate of water infiltration (Stuart, 2006).

4.3.4.2 Soil Type

Soil type also plays a role in determining how much overland flow is generated. Considerable variation in soil depths, fragipan (zone of higher bulk density) occurrence, drainage class, soil family classification, base saturation, and degree of rock outcropping exists within the region. Despite the degree of variation in properties the soils are closely related to bedrock lithology and landscape position and are formed primarily in loess, hillslope sediments, residuum, or gravelly alluvium. The soils can be generally classified as either ultisols or alfisols (Mueller et al, 2005). Soils which are loosely compacted or are primarily of large grain sizes are able to absorb moisture more quickly than tightly compacted or small grained soils. Small grained soils such as silts and clays, which have a lower permeability, will shed more water and create an increased amount of surface flow.

4.3.4.3 Slope

The slopes of the hillsides above the ephemeral drainageway also control the amount of surface runoff. Seventy-nine percent of total land area lies on slopes between 10 – 30 percent (Mueller et al, 2005). A shallow slope drains more slowly and allows more time for water to infiltrate into the soil before reaching the channel. A steep-sided channel sheds water more rapidly and generates more overland flow.

4.3.4.4 Ground Cover

It is the presence of an intact forest floor on the soil surface that protects soil (Stuart, 2006). The forest floor, comprised of the litter layer, underlying organic humus, and fibrous roots, serves to absorb impact energy of rain droplets. After filtering through the forest floor, the water does not contain enough energy to move soil particles and erode the soil. With no protective litter layer, rain droplets can hit exposed soil with enough force to compact it slightly. In addition, tiny soil particles can become dislodged and clog pores in the soil. Both the compaction of the soil surface, and clogging action reduce the infiltration rate and increase surface flow (Stuart, 2006).

4.3.4.5 Karst Geology

The heavy presence of karst geology in the region of the research sites often controls, or at least plays a significant role, in the surface hydrology as well. The many sinkholes, losing streams, and springs in the area cause streams to disappear below ground mid-length and re-emerge elsewhere. The research sites are situated high in the landscape, and are essentially above the influence of springs, but are likely susceptible to losing features such as sinkholes and losing streams. Sinkholes and losing streams remove water through subsurface conduits and reduce the amount of surface flow. It is unknown precisely how much, if any, water is lost to such features on the research sites. Settergren (1972), in a study on deep seepage in karst regions, estimated that around 22% of the annual precipitation budget is lost to subsurface flow.

4.4 Summary

Despite many and varied obstacles, the majority of monitoring equipment has been functioning reliably. Each piece of equipment has challenges associated with it, but many have been overcome and the rest are being examined. Since the completion of instrument installation in October 2004, to the July 19, 2006 sample collection trip, a total of over 560 water samples has been collected. Electronic equipment has and continues to provide essential detailed data regarding precipitation, soil moisture, and flow characteristics of the ephemeral channels. The Isco® automated flow monitoring system has provided a hydrograph of flow response in an ephemeral drainageway for several precipitation and flow events. As of the July 19, 2006 sampling trip, no water samples have been collected in the Isco® automatic water sampler.

Precipitation and soil moisture data acquired from the Remote Automated Weather Station and United States Geological Survey station available online has been combined with sample collection data to set quantitative limits for a threshold event. Analyzing these data provides a means to know when a sample collection trip is necessary, as well as the prediction of the total number of water samples which may be expected to be retrieved.

This research has provided insight into the dynamic and complex hydrologic processes present in a forested ephemeral watershed. Both precipitation and soil moisture content play a significant role in influencing the amount of overland flow. Soil, vegetation, and geology characteristics also play a role in determining the infiltration rate of moisture into the soil. These parameters, as well as many others, combine to control a complex and dynamic hydrologic system.

Chapter 5 – Conclusions and Recommendations

5.1 Summary

Two years into the project, significant progress has been made. All sites are fully instrumented with the manual equipment and two intensive sites are also outfitted with additional electronic equipment. While maintenance and environmental challenges are always present, efforts are being made to increase both the quantity and quality of samples collected. Already, over 560 water samples have been collected from both in-stream bottle samplers and sediment traps combined. Over a year of reliable precipitation and soil moisture data from both ECHO® stations has been collected, as well as over two years from the Remote Automated Weather Station and United States Geological Survey stations. Data retrieved from the RAWS were analyzed to define a threshold event, and will continue to be examined in an effort to increase the precision of the models. This knowledge will make it possible to estimate the amount of surface and channel flow to expect for a given precipitation amount and to determine more closely when to expect water samples in the instruments and how many are likely to be collected.

The ISCO® automated flow monitoring system has been installed for just over five months and has already provided valuable insight into the response of an ephemeral drainageway during and after precipitation. The hydrograph of stream gauge, discharge, and velocity was created from data recorded during flow events. In addition, four water balance analyses revealed the approximate proportion of water influx exiting an ephemeral drainage basin as surface flow to be between 20% and 60% depending on the level of antecedent soil moisture.

5.2 Practical Implications

Water samples from ephemeral streams and associated hillsides are being collected to quantitatively determine the impact of Regenerative Oak Clear Cutting (ROCC) on water quality and sediment and nutrient transport in ephemeral channels. Much information relative to the MDC timber harvest project, and other similar projects, was learned during the course of this research. Modified from previous designs to accommodate the Ozark terrain and environment, both the rising stage bottle samplers and hillslope sediment traps have collected numerous water samples and have enabled the determination of background levels of constituents of interest. Instruments intended to remain in an environment where wildlife damage is possible should be designed to either withstand or deter such damage. The same is true for damage from environmental factors. Because some damage is unavoidable, routine maintenance trips are needed to allow equipment to continue to perform as intended and provide data from post-harvest periods.

The installation of the plastic sheeting retrofit on the hillslope sediment monitors has increased the number of water samples collected in the devices. Hillslope sediment monitor control devices were installed in an effort to quantify the effect of the sheeting on increased sample frequency and size. Continued observation is necessary to determine the degree to which the plastic sheeting affects sample collection in the hillslope sediment monitors.

Water balance analyses performed on site A34-1 reveal that the proportion of moisture exiting the site as channel flow varies significantly with precipitation intensity and duration, soil moisture levels, and the length of time over which the data is monitored. Generally, for longer lengths of time, the channel flow fraction decreases (Table 5.1). This is can be attributed to a significantly larger amount of precipitation occurring during the longer period, but occurring at a slower rate and allowing nearly all additional water to be lost to infiltration or evapo-transpiration. Thus, a nearly identical volume of channel flow is measured over both the long and short time periods, decreasing the relative amount of channel flow for longer time periods.

Table 5.1 – A34-1 water balance results.

Days in Period	Discharge/Precipitation (%)
6	53 - 68
11	34 - 49
17	41 - 56
146	19 - 24

Overland flow and water sample collection on the research sites are unlikely unless heavy precipitation is received or antecedent soil moisture levels are high. The analysis of precipitation and soil moisture data in relation to overland and channel flow and the expected number of water samples will help determine when a sample collection trip is necessary. A plot has been created relating contours of the total number of samples collected to both precipitation and antecedent soil moisture levels (Fig. 5.1). The shaded regions of the graph represent the number of samples likely for a given combination of soil moisture and precipitation. Generally, for antecedent soil moisture levels below 20%, and precipitation less than 4 inches, fewer than 40 samples may be expected. If soil moisture exceeds 27%, and precipitation is greater than 4.5 inches, upwards of 80 samples are likely. Other combinations can produce between 40 and 80 samples, as well as less than 40 or more than 80. The plot provides a general estimate of the total number of water samples which may be expected given certain conditions.

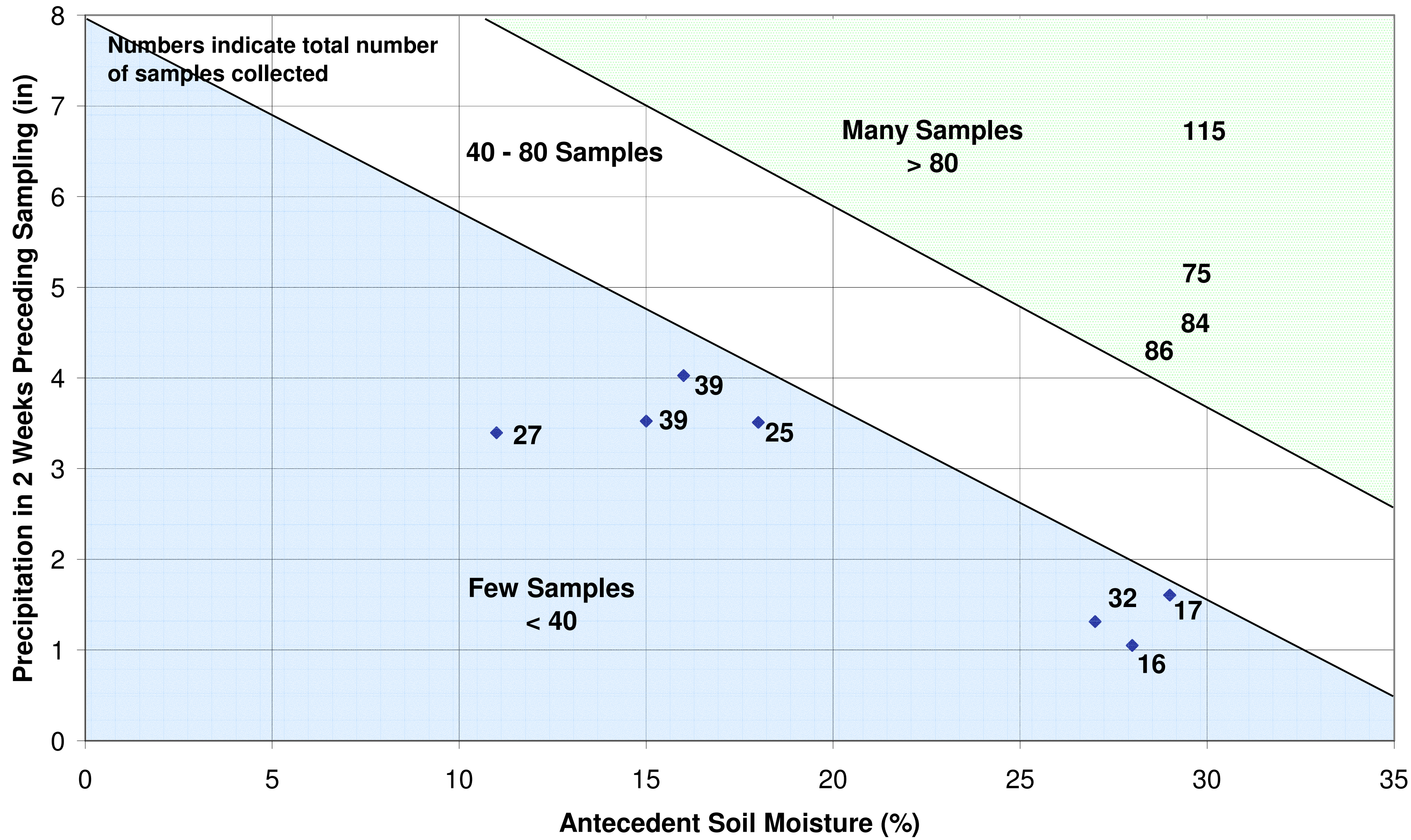

Figure 5.1 – Two week precipitation accumulation vs. antecedent soil moisture data from Carr Creek RAWS content with total number of samples collected are beside data points and expected sample number contours.

A sample collection trip should be made whenever antecedent soil moisture is at least 20% and more than 3.0 inches of precipitation was measured in the previous two weeks. This combination of parameters is estimated to yield approximately 30-40 total water samples. At this number of samples, the time and effort necessary to visit every instrument on each research site is judged to be worthwhile.

5.3 Conclusions

The efforts to create and maintain an effective sample collection program have been largely successful. Many types of equipment were designed, fabricated, and installed in large numbers and have proven to be capable of collecting and storing water samples in the rugged Ozark environment. The overall performance of each instrument variety is summarized below.

- Rising Stage Water Samplers – These devices have collected over 350 water samples during channel flow. Other than damage issues associated with wildlife, the rising stage water samplers have been both effective at sample collection and rugged enough to withstand most environment factors. Routine maintenance trips would allow these devices to function at an even higher level.
- Stream Crest Gauges – The crest gauges did not function well after installation in the field due to the harsh environment. A new, more reliable design is necessary to collect stream crest data.
- Hillslope Sediment Monitors – The hillslope sediment monitors have collected over 200 water samples. While their efficiency was increased after the plastic sheeting retrofit, the plastic seems to have falsely increased the number and

quantity of samples collected. Another modification is required to reduce the area of the plastic sheeting.

- Hillslope Sediment Monitor Control – The control hillslope monitors work well at collecting water samples. Before they can serve their intended purpose, the size of the plastic covered plot area needs to be reduced to enable the catchment to accommodate large precipitation events.
- Silt Fences – The silt fences are able to retain both sediment and forest debris moving downhill. The amount of sediment retained has been small, while significant amounts of forest litter have collected behind the fencing. Forest litter moves relatively freely downhill while little overland transport of sediment exists.
- ECHO® Precipitation Gauges – On both A34-1 and CR7-5c, the electronic precipitation gauges have consistently provided measurements similar to both the RAWS and USGS stations. No malfunctions have been observed.
- ECHO® Soil Moisture Probes – Out of six probes installed, four have provided constant, reliable soil moisture data. Two of the probes sustained unknown malfunctions during the monitoring period. One has since begun to function properly again.
- ECHO® Air Temperature Sensors – The temperature sensors have provided constant temperature readings consistent with values from the RAWS and official weather stations in the region.
- EHCO® Data Logger – The data loggers for the ECHO® devices have performed well except when the CR7-5c device froze up and required a reset. Both the

memory and battery life has been sufficient for the frequency of field trips during the project. Data retrieval is quick and simple.

- Isco® Area-Velocity Sensor – During the flow events on A34-1, the area-velocity sensor exhibited excellent performance. Both flow depth and velocity were able to be measured. The device is ideally suited to measure both low and high intermittent flow.
- Isco® Precipitation Gauge – The Isco® precipitation gauge is prone to clogging, making small time-rate precipitation measurements unreliable. If the inlet funnel does not overflow, total precipitation measurements are similar to data from other sources.
- Isco® Automatic Water Sampler – Little data is available on the performance of the water sampler. It has currently collected no samples due to an unsecured latch during the only recorded flow events. However, data indicate the sampler had initiated the sampling sequence 14 times during the flow event.

A second focus of this research has been to identify a threshold event to provide the ability to determine when a water sample collection trip must be made. Results indicate that two parameters, precipitation and antecedent soil moisture, are most significant in generating stream flow. A sample collection trip should be made whenever antecedent soil moisture is at least 20% and more than 3.0 inches of precipitation was measured in the previous two weeks. The number of water samples likely to be collected increases with both precipitation and soil moisture. The opposite is true as well. Figure 4.35 and Equation 4.2 can be used to estimate the total number of samples likely to be present for known values of precipitation and antecedent soil moisture. Precipitation and soil moisture data available online from the Carr Creek RAWS should be used to predict the total number of samples expected on a sampling trip. More sample collection trips are needed to both test and enhance the models.

5.4 Recommendations

- During maintenance, broken plastic mounting brackets attaching inlet tubing to steel post on rising stage bottle samplers should be replaced with metal brackets.
- Rising stage sampler sample bottles should be replaced yearly if they have not retained a sample in the previous 12 months.
- To reduce the likelihood that a rising stage sampler is washed away in large flow events, the mounting stake should be installed as securely as possible into the thalweg and the area exposed to flow should be reduced by removing as much of the unneeded upper portion of the stake as possible.
- Consider orienting inlets perpendicular to flow direction to help prevent clogging.
- A new design is needed for the downstream crest gauges.
- The area of exposed plastic sheeting on hillslope sediment monitors should be as small as possible to reduce the influence of precipitation falling directly on the impermeable surface. Only the amount necessary to adequately bridge gaps between the forest floor and collection guttering should be used.
- The plot area of the hillslope sediment monitor control devices should be reduced from eight to two square feet.
- Manual rain gauges should either be placed upside down during the winter months to prevent cracking due to freezing when full, or replaced each spring.

- A small amount of environmentally safe oil should be added after each time manual rain gauges are emptied to slow evaporation.
- Manual rain gauges should be securely fastened to a piece of re-bar driven into the soil to prevent weather or animal activity from displacing them.
- The cause of the malfunction in the failed ECHO® moisture probes needs to be investigated.
- The reason the ECHO® data logger on CR7-5c froze up and had to be reset needs to be investigated.
- The cause of the difference in moisture probe readings within a single site needs to be investigated.
- A method to prevent the Isco® precipitation gauge from clogging should be investigated.
- Insect poison needs to be kept inside the Isco® security box to prevent nesting and possible equipment damage.
- If equipment maintenance is not performed during sample collection trips, necessary repairs should be noted and a maintenance trip taken every 6 months.
- A sample collection trip should be made whenever antecedent soil moisture is at least 20% and more than 3.0 inches of precipitation was measured in the previous two weeks.
- Use Figure 4.35 and Equation 4.2 to predict the total number of samples expected on a sampling trip using precipitation and soil moisture data available online before leaving for the field.

5.5 Summary

The MDC timber harvest project is approximately two years into a planned seven year study. A water sampling and data collection system has been designed and implemented and has successfully collected over 560 pre-harvest background water samples. One year of precipitation, soil moisture, and air temperature data has been recorded from one site in each of the research conservation areas. Precipitation and soil moisture data online from an official station within the research area have been retrieved and analyzed for their relationship with surface and channel flow and the number of water samples collected. Limits have been established estimating the number of samples likely to be collected for specific levels of precipitation and soil moisture. A gauge and discharge hydrograph was created for one ephemeral watershed outfitted with an automatic flow monitoring and water collection system. The data gave insight into the flow response of an ephemeral hydrological system. A water balance was performed on the same site to determine the proportion of moisture being removed from the site as channel flow.

The water samples gathered in the past two years have been analyzed and have provided background water quality levels for constituents of interest (Smith, 2006). The first few research sites are scheduled to be harvested soon (Appx. D). When harvesting is complete, the instrumentation will begin to provide the first glimpse of post-harvest data. Precipitation, soil moisture, and hydrograph data will continue to provide additional insight into the dynamic and complex hydrological cycle of the forested ephemeral watersheds in the Missouri Ozarks.

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Appendices

Appendix A

Table A.1 – Site characteristics (Mueller, 2006).

Site	Site Area (ac)	Relief (m)	Drainage Density (km^{-1})	Geology (Percent)				Site Area Per Slope Classification (ha)					Site Aspect Classification (Percent)			
				Rd[1]	UG[2]	LG[3]	EM[4]	0% - 10%	10% - 20%	20% - 30%	30% - 40%	40% - 50%	336.5 - 66.5	66.5 - 156.5	156.5 - 246.5	246.5 - 336.5
A17-1	25	55	6.7	89.2	11.3	0.0	0.0	2.0	3.5	2.6	1.4	0.5	42.1	20.9	36.6	0.8
A17-2	29	61	4.4	66.9	33.1	0.0	0.0	1.3	3.2	3.9	3.4	0.0	35.6	32.0	31.1	1.2
A25-2	37	67	5.2	20.7	79.0	0.0	0.0	1.0	4.2	8.3	1.3	0.0	51.1	32.5	0.0	16.1
A25-3	41	61	7.3	49.0	51.0	0.0	0.0	3.4	7.5	5.6	0.1	0.0	58.8	29.3	5.0	6.9
A27-1	31	73	5.4	0.0	84.7	15.2	0.0	0.9	3.2	7.1	1.4	0.0	23.5	23.1	0.8	52.5
A27-2	26	73	6.3	0.0	78.4	21.5	0.0	0.5	3.2	5.4	1.4	0.0	53.4	27.5	0.0	19.0
A34-1	30	61	5.7	68.0	31.8	0.0	0.0	1.7	4.4	5.8	0.2	0.0	27.8	43.8	0.1	28.0
A34-2	44	61	4.6	68.7	31.5	0.0	0.0	1.5	3.8	8.6	4.0	0.0	26.4	24.8	47.7	1.3
CR7-2	40	98	4.5	0.0	41.8	34.1	24.5	1.9	3.7	7.1	3.3	0.4	45.2	53.5	1.3	0.4
CR7-5b	10	61	6.7	0.0	90.4	10.4	0.0	0.1	0.8	3.2	0.1	0.0	73.9	26.9	0.0	0.0
CR7-5c	12	49	10.0	0.0	88.3	12.8	0.0	0.3	1.4	3.2	0.2	0.0	44.2	21.3	0.0	35.5
CR7-6	46	91	6.4	0.0	45.3	46.2	8.3	1.8	4.7	9.5	2.4	0.0	43.0	51.8	0.1	5.0
CR11-1	36	55	6.0	0.0	70.9	29.5	0.0	2.5	5.8	6.1	0.1	0.0	50.3	42.8	0.0	7.3
CR11-3	14	61	7.8	0.0	59.1	40.8	0.0	0.3	2.2	3.2	0.1	0.0	0.0	46.0	53.9	0.0
CR11-9	14	49	8.7	0.0	78.3	21.6	0.0	0.9	2.7	2.2	0.0	0.0	0.9	45.8	46.0	7.2

1. Roubidoux sandstone formation
2. Upper Gasconade dolomite formation
3. Lower Gasconade dolomite formation
4. Eminence dolomite formation

Appendix B

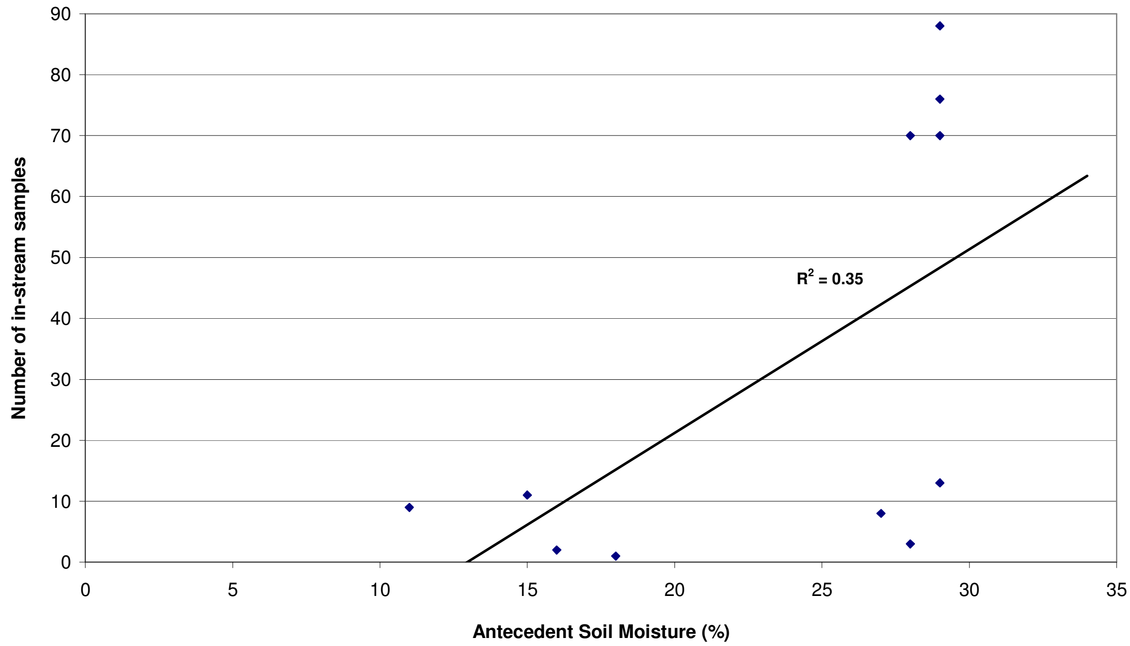

Figure A.1 – Number of in-stream samples vs. RAWS antecedent soil moisture.

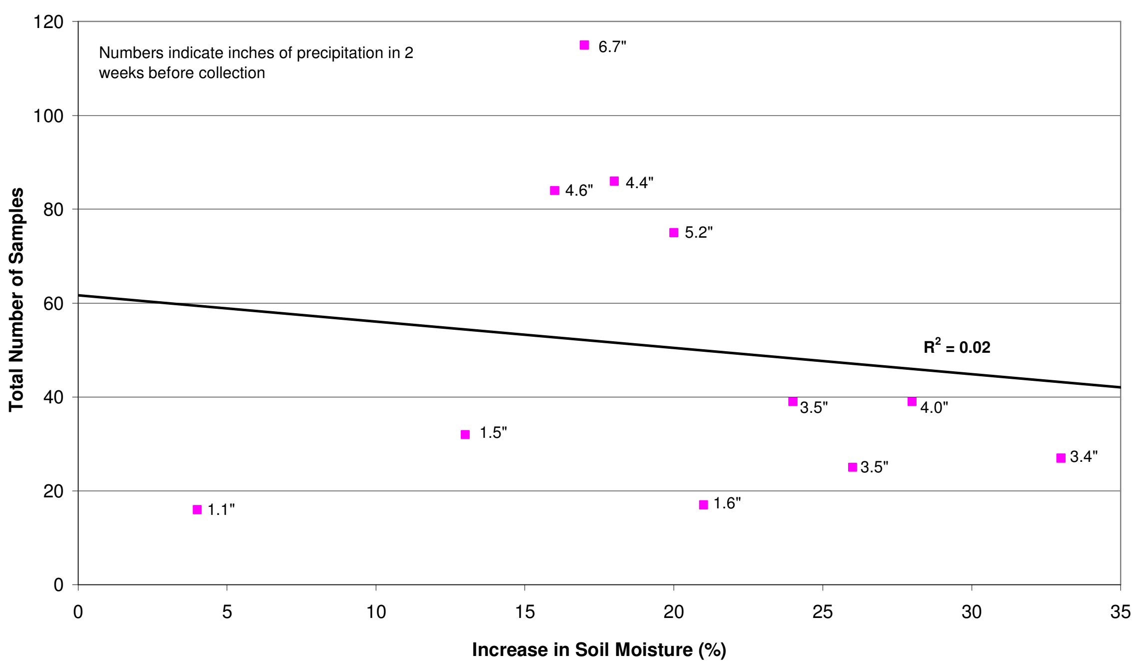

Figure A.2 – Total number of samples vs. increase in RAWS soil moisture during 2 weeks preceding sample collection.

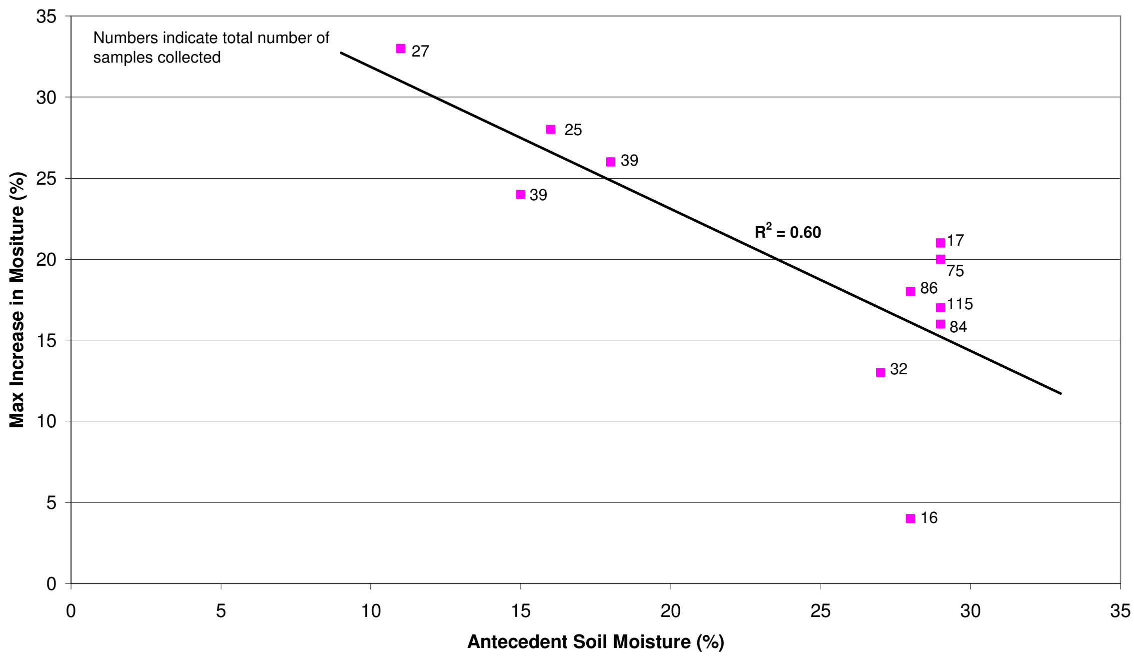

Figure A.3 – Maximum increase in RAWS soil moisture in 2 weeks prior to sampling vs. RAWS antecedent soil moisture.

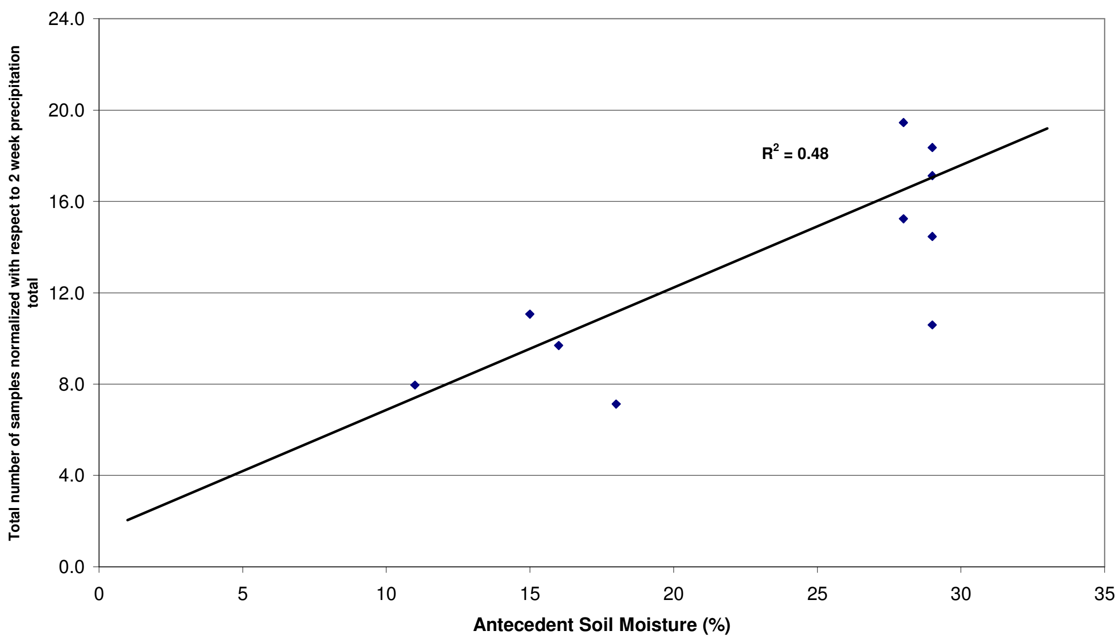

Figure A.4 – Total number of samples normalized with respect to 2 week precipitation total vs. antecedent soil moisture.

Table A.2 – Two week precipitation totals preceding sample collection from all sources.

		Two Week Precipitation Total (in) Precipitation Data Source					
		Online		ECHO		Isco	Manual
Event	**Date**	**RAWS**	**USGS**	**A34-1**	**CR7-5c**	**A34-1**	**Mean**
1	1/15/05	5.58	4.79	n/a	n/a	n/a	n/a
2	2/19/05	1.69	1.52	n/a	n/a	n/a	n/a
3	4/15/05	1.14	0.96	n/a	n/a	n/a	1.0
4	5/18/05	1.53	1.10	n/a	n/a	n/a	1.7
5	7/15/05	6.43	0.59	0.08	0.1	n/a	3.3
6	8/22/05	3.77	3.28	1.46	5.04	n/a	3.9
7	9/18/05	4.13	2.94	2.84	2.60	n/a	3.6
8	11/18/05	6.97	1.87	6.48	7.00	n/a	4.5
9	3/15/06	4.87	4.29	4.24	5.51	n/a	n/a
10	5/16/06	6.17	7.26	8.45	8.58	4.64	4.1
11	7/19/2006	4.39	2.40	1.07	0.00	1.93	

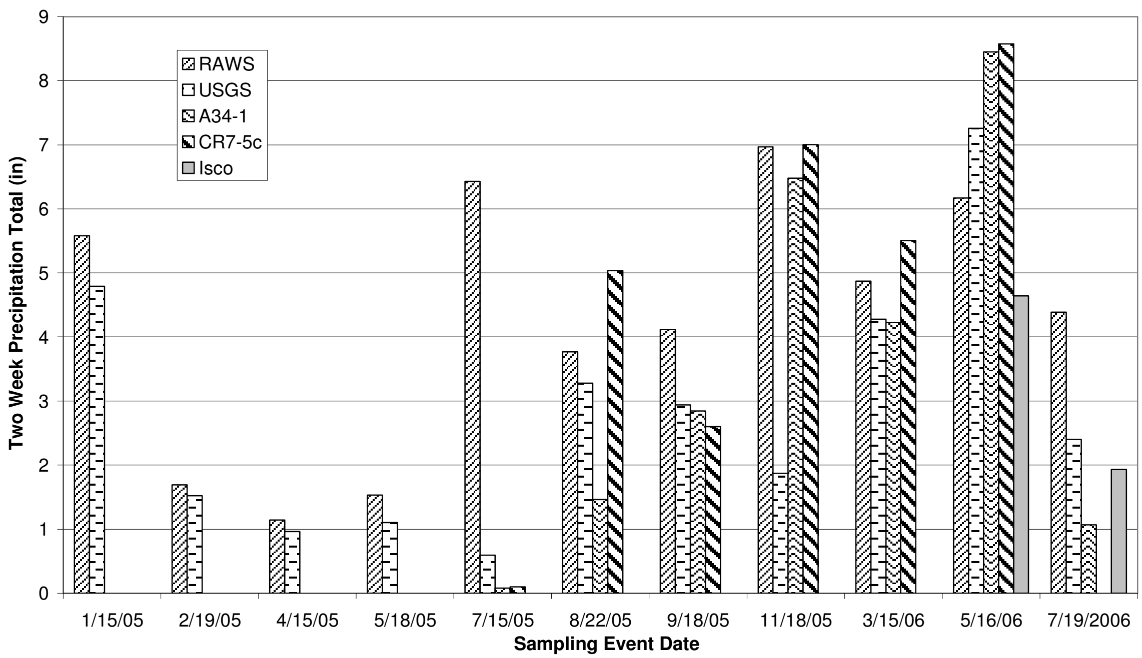

Figure A.5 – Two week precipitation total preceding sample collection from all sources.

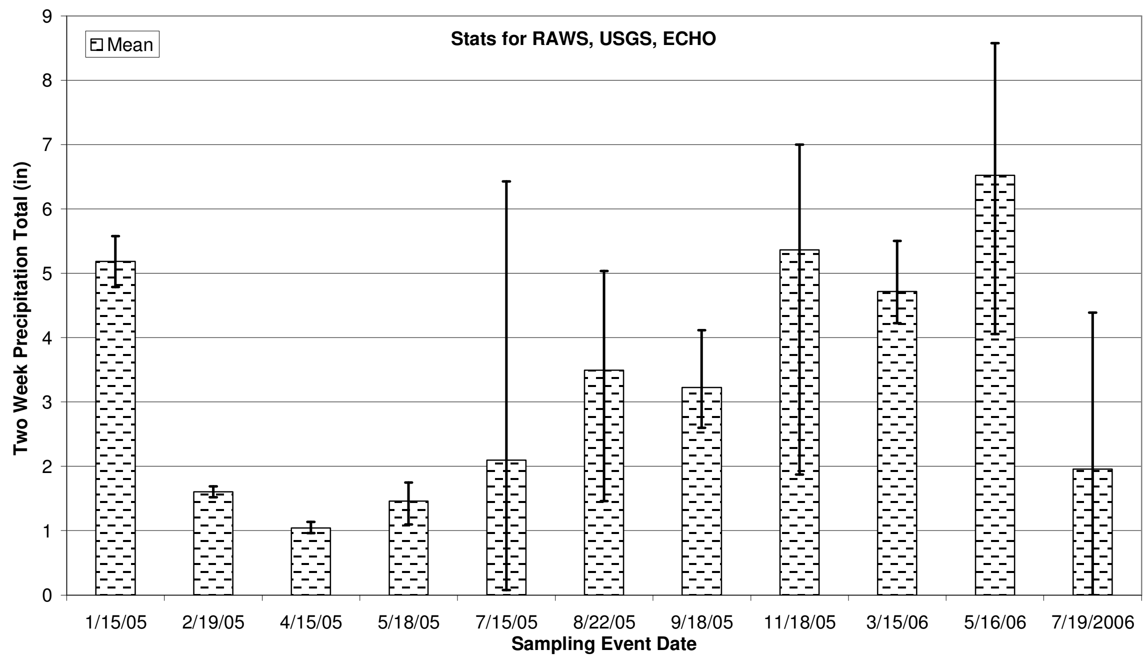

Figure A.6 – Mean, high and low values of two week precipitation totals preceding sample collection from electronic sources.

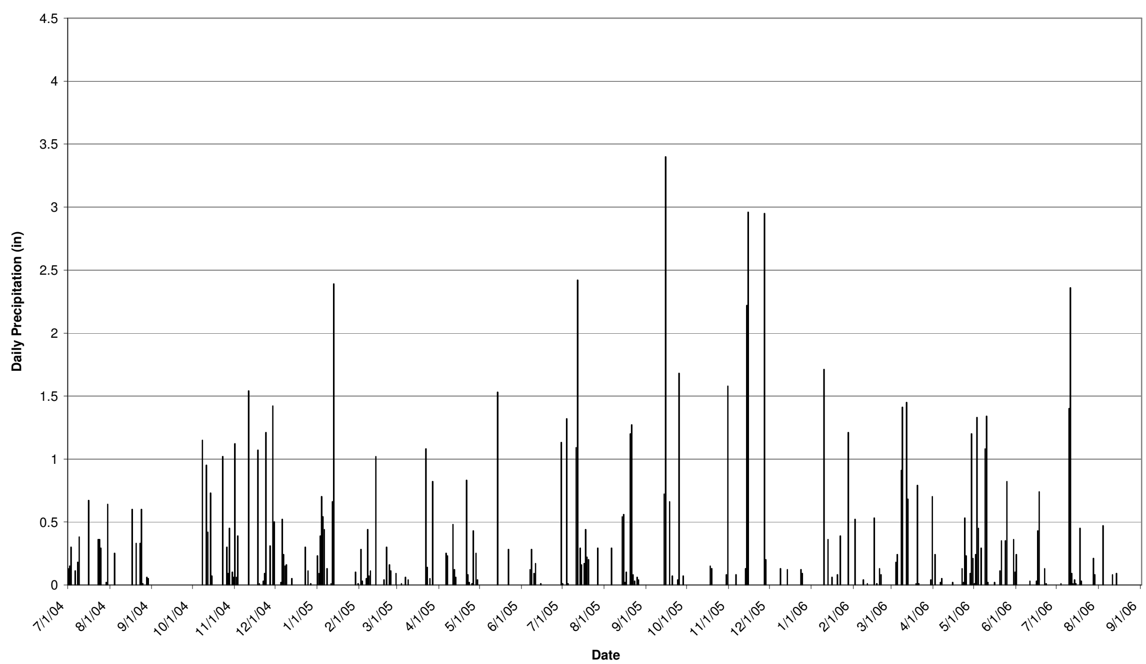

Figure A.7 – Daily precipitation totals from RAWS for the period July 2004-August 15, 2006.

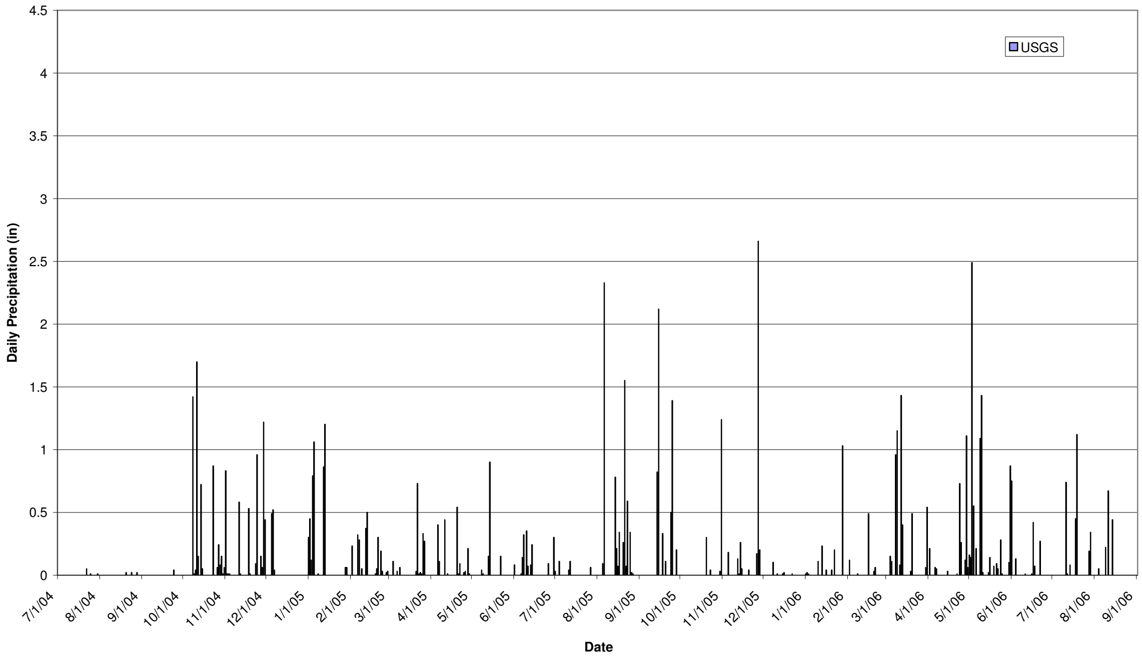

Figure A.8 - Daily precipitation totals from the USGS station for the period July 2004-August 15, 2006.

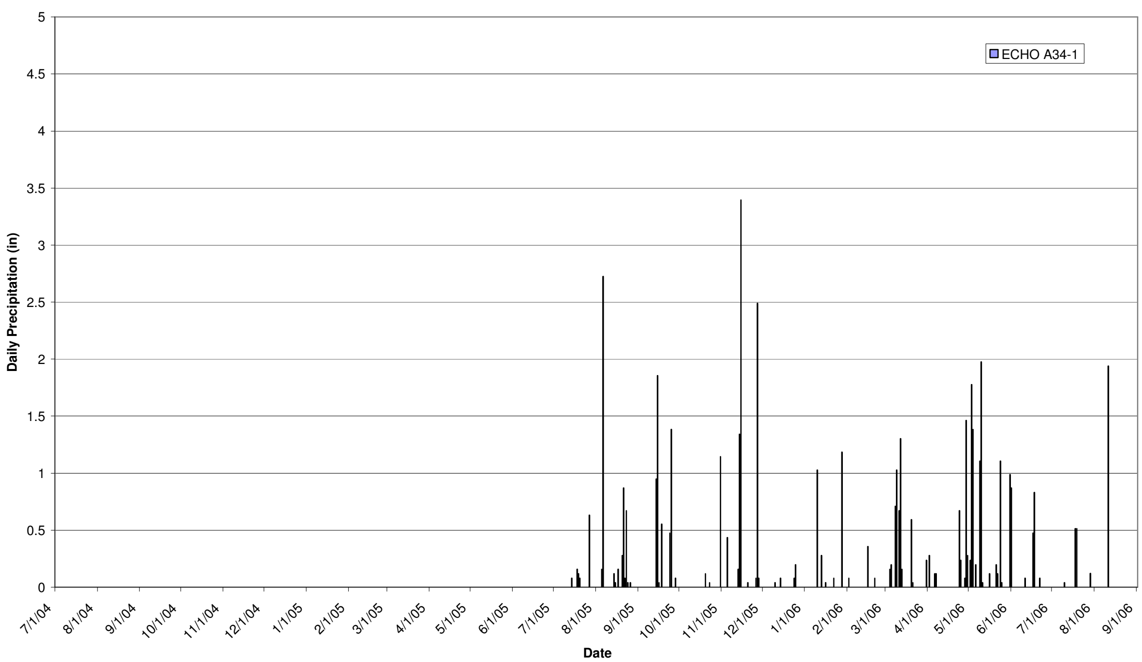

Figure A.9 - Daily precipitation totals from the A34-1 ECHO® station for the period June 22, 2005-August 15, 2006.

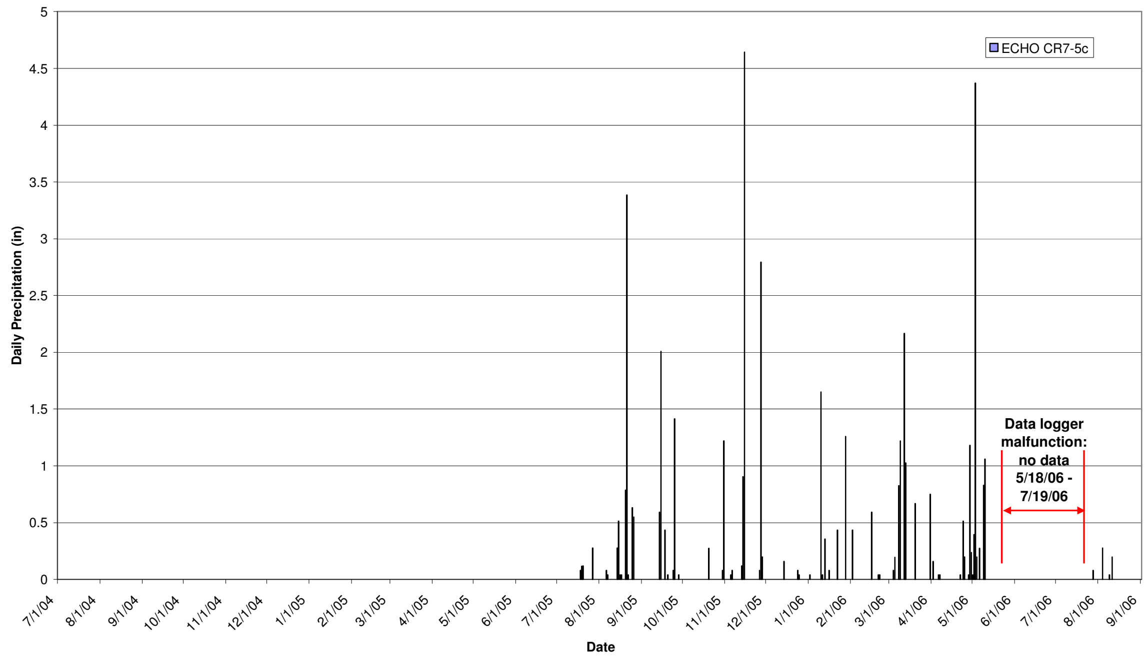

Figure A.10 - Daily precipitation totals from the CR7-5c ECHO® station for the period June 22, 2005-August 15, 2006.

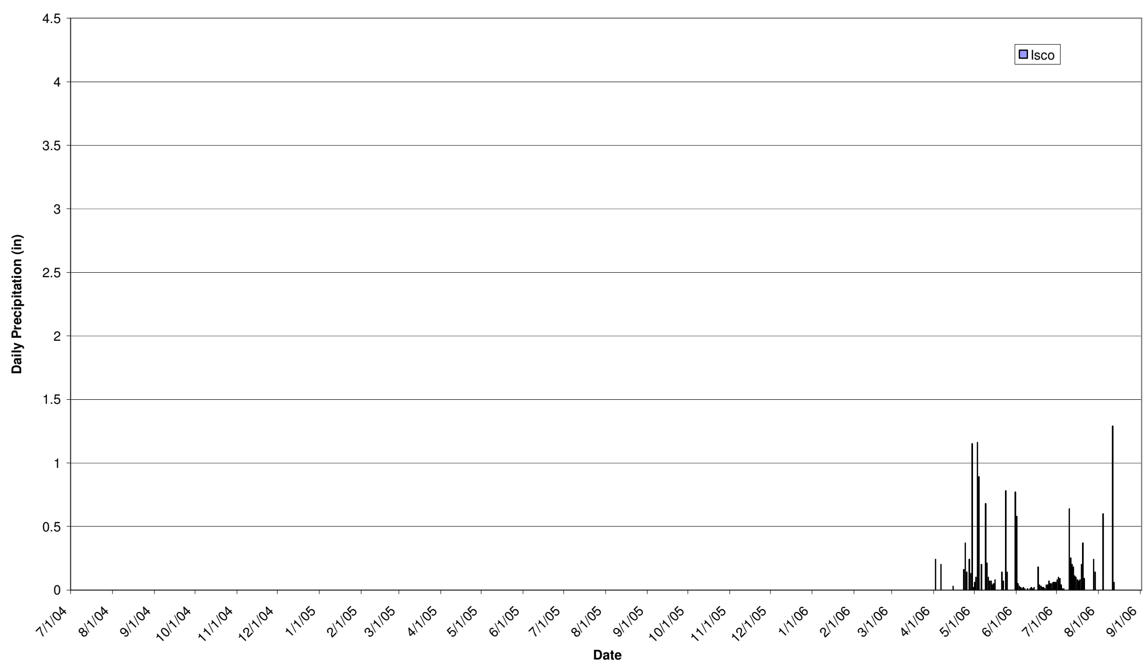

Figure A.11 - Daily precipitation totals from the Isco® for the period April 1, 2006-August 15, 2006.

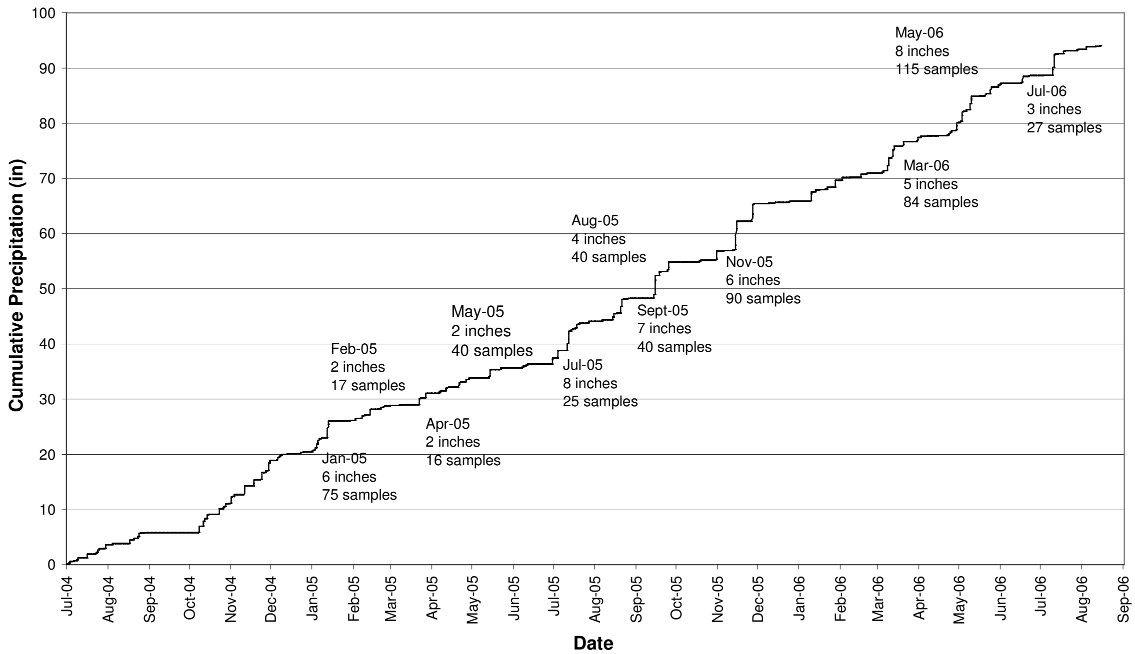

Figure A.12 – Cumulative precipitation from RAWS with sample collection dates, total number of samples collected, and approximate preceding precipitation for the period July 2004-August 15, 2006.

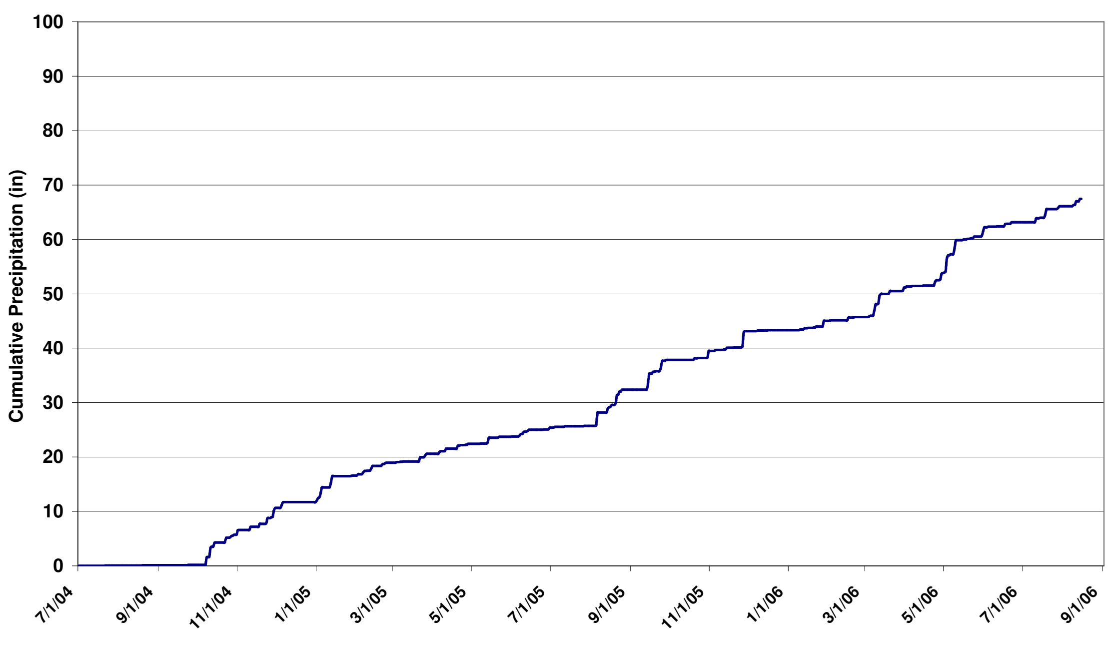

Figure A.13 – Cumulative precipitation from the USGS station for the period July 2004-August 15, 2006.

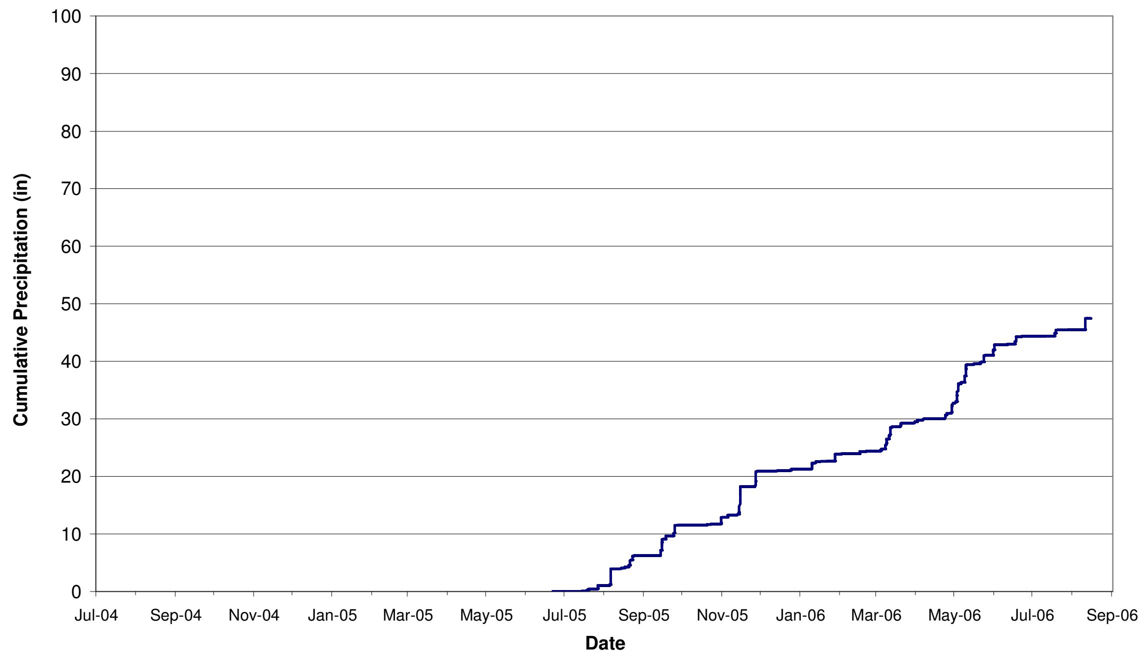

Figure A.14 – Cumulative precipitation from the A34-1 ECHO® station for the period June 22, 2005-August 15, 2006.

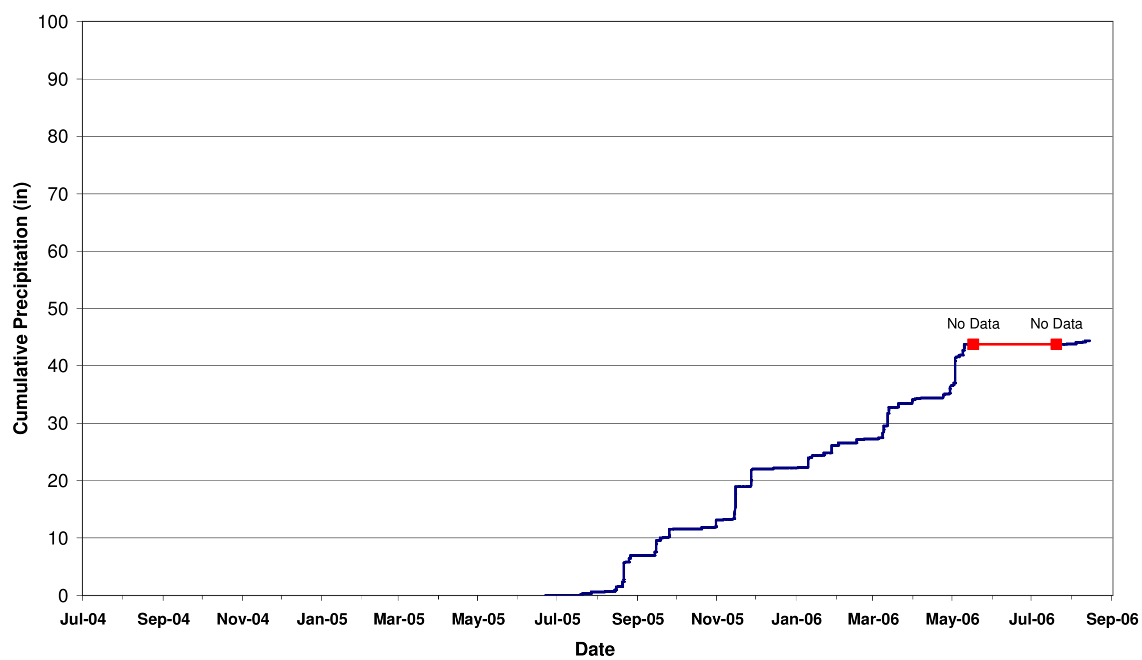

Figure A.15 – Cumulative precipitation from the CR7-5c ECHO® station for the period June 22, 2005-August 15, 2006.

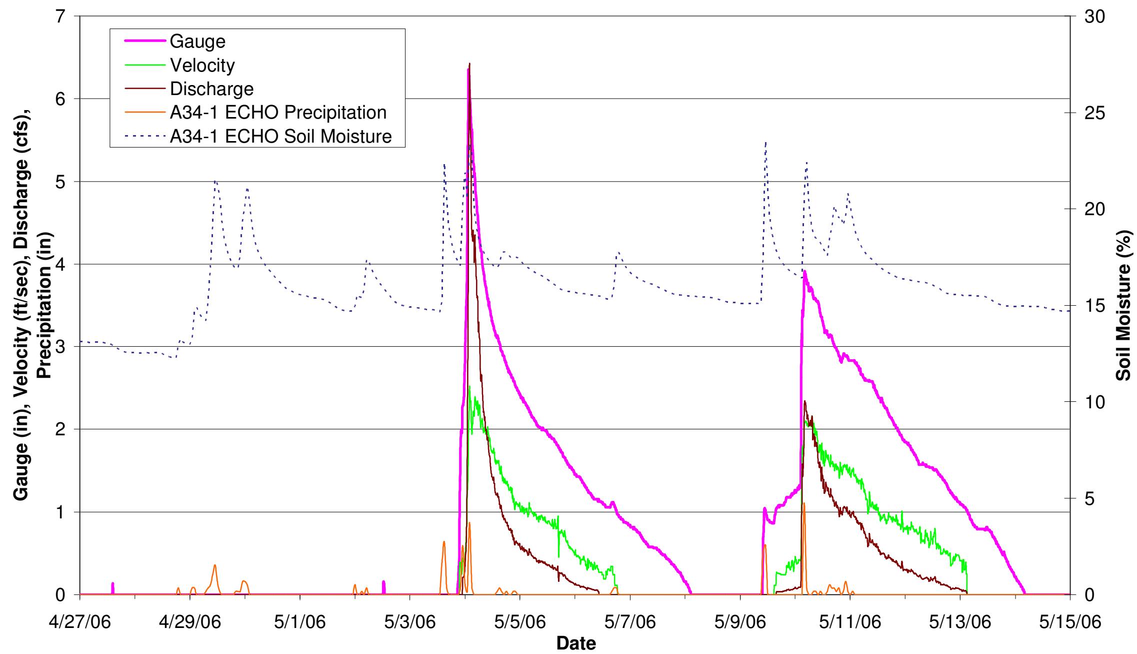

Figure A.16 – Gauge, velocity, discharge, precipitation, and soil moisture for the two flow events recorded by the Isco® on A34-1 between April 27, 2006 and May 15, 2006.

Table A.3 – Manual rain gauge readings for A17-1.

A17-1		Precipitation (in)					
Event	Date	1	2	3	4	5	control
3	4/15/05	n/a	n/a	n/a	n/a	n/a	n/a
4	5/18/05	0.4	1.2	3.0	0.8	0.5	n/a
5	7/15/05	n/a	n/a	n/a	n/a	n/a	n/a
6	8/22/05	4.1	4.5	4.5	4.1	4.3	4.3
7	9/18/05	3.8	3.5	3.2	3.5	4.0	3.6
8	11/18/05	4.7	4.5	4.5	4.7	n/a	4.5
9	3/15/06	n/a	n/a	n/a	n/a	n/a	n/a
10	5/16/06	n/a	n/a	n/a	n/a	n/a	n/a
11	7/19/06	n/a	n/a	n/a	n/a	n/a	n/a

Table A.4 - Manual rain gauge readings for A17-2.

A17-2		Precipitation (in)				
Event	Date	1	2	3	4	5
3	4/15/05	0.0	n/a	n/a	2.5	0.8
4	5/18/05	0.0	1.5	2.0	2.5	0.0
5	7/15/05	n/a	n/a	n/a	n/a	n/a
6	8/22/05	4.2	4.4	4.4	4.3	4.3
7	9/18/05	3.5	3.3	3.6	3.2	3.5
8	11/18/05	n/a	4.2	4.7	n/a	n/a
9	3/15/06	n/a	n/a	n/a	n/a	n/a
10	5/16/06	n/a	n/a	n/a	n/a	n/a
11	7/19/06	n/a	n/a	n/a	n/a	n/a

Table A.5 - Manual rain gauge readings for A25-2.

A25-2		Precipitation (in)				
Event	Date	1	2	3	4	5
3	4/15/05	n/a	n/a	n/a	n/a	n/a
4	5/18/05	1.8	3.0	3.6	2.5	0.8
5	7/15/05	3.1	3.7	4.0	2.4	2.1
6	8/22/05	4.2	4.4	4.2	4.0	3.3
7	9/18/05	3.6	2.2	2.9	2.4	2.7
8	11/18/05	4.5	4.8	4.2	4.3	4.8
9	3/15/06	n/a	n/a	n/a	n/a	n/a
10	5/16/06	4.2	n/a	3.7	4.5	n/a
11	7/19/06	3.6	n/a	n/a	4.3	n/a

Table A.6 - Manual rain gauge readings for A25-3.

A25-3		Precipitation (in)			
Event	Date	1	2	3	4
3	4/15/05	n/a	n/a	n/a	n/a
4	5/18/05	n/a	n/a	2.5	n/a
5	7/15/05	3.1	3.2	2.8	3.2
6	8/22/05	4.2	4.2	4.0	4.0
7	9/18/05	3.0	2.7	3.0	2.7
8	11/18/05	4.0	4.0	4.0	4.0
9	3/15/06	n/a	n/a	n/a	n/a
10	5/16/06	n/a	3.8	2.8	3.0
11	7/19/06	3.0	n/a	n/a	n/a

Table A.7 - Manual rain gauge readings for A27-1.

A27-1		Precipitation (in)				
Event	Date	1	2	3	4	5
3	4/15/05	n/a	n/a	n/a	n/a	n/a
4	5/18/05	n/a	2.8	n/a	2.6	n/a
5	7/15/05	2.4	2.0	2.3	3.0	n/a
6	8/22/05	2.6	3.5	3.3	3.2	3.2
7	9/18/05	3.2	3.7	3.6	3.9	3.8
8	11/18/05	n/a	n/a	n/a	n/a	n/a
9	3/15/06	n/a	n/a	n/a	n/a	n/a
10	5/16/06	3.8	n/a	4.2	3.8	n/a
11	7/19/06	n/a	n/a	n/a	n/a	n/a

Table A.8 - Manual rain gauge readings for A27-2.

A27-2		Precipitation (in)			
Event	Date	1	2	3	4
3	4/15/05	n/a	n/a	n/a	n/a
4	5/18/05	n/a	n/a	n/a	n/a
5	7/15/05	3.5	1.9	3.5	2.6
6	8/22/05	3.3	2.7	3.6	2.7
7	9/18/05	3.2	2.8	3.7	3.0
8	11/18/05	n/a	n/a	n/a	n/a
9	3/15/06	n/a	n/a	n/a	n/a
10	5/16/06	n/a	4.8	3.9	n/a
11	7/19/06	4.2	2.5	n/a	n/a

Table A.9 - Manual rain gauge readings for A34.1

A34-1		Precipitation (in)					
Event	Date	1	2	3	4	5	6
3	4/15/05	n/a	n/a	n/a	n/a	n/a	n/a
4	5/18/05	n/a	n/a	2.5	1.4	n/a	n/a
5	7/15/05	2.9	2.3	3.8	2.7	2.3	3.4
6	8/22/05	4.1	3.3	4.4	4.5	4.4	3.9
7	9/18/05	3.3	2.8	3.2	3.5	3.6	n/a
8	11/18/05	4.4	4.8	4.5	5.0	4.8	4.5
9	3/15/06	n/a	n/a	n/a	n/a	n/a	n/a
10	5/16/06	4.2	4.5	4.7	n/a	n/a	n/a
11	7/19/06	n/a	n/a	n/a	n/a	n/a	n/a

Table A.10 - Manual rain gauge readings for A34-2.

A34-2		Precipitation (in)				
Event	Date	1	2	3	4	5
3	4/15/05	n/a	n/a	n/a	n/a	n/a
4	5/18/05	n/a	1.2	n/a	1.2	n/a
5	7/15/05	4.0	3.3	3.0	2.9	n/a
6	8/22/05	4.1	4.0	n/a	4.3	n/a
7	9/18/05	4.1	3.3	3.3	4.1	4.3
8	11/18/05	4.5	5.0	5.0	4.8	4.5
9	3/15/06	n/a	n/a	n/a	n/a	n/a
10	5/16/06	n/a	3.8	n/a	n/a	n/a
11	7/19/06	n/a	n/a	n/a	n/a	n/a

Table A.11 - Manual rain gauge readings for CR7-2.

CR7-2		Precipitation (in)			
Event	Date	1	2	3	4
3	4/15/05	1.5	2.5	0.8	1.7
4	5/18/05	4.0	3.1	2.0	1.0
5	7/15/05	2.5	4.0	3.8	n/a
6	8/22/05	4.1	4.1	3.5	4.0
7	9/18/05	3.5	4.5	4.3	4.3
8	11/18/05	4.9	4.1	4.1	4.8
9	3/15/06	n/a	n/a	n/a	n/a
10	5/16/06	4.5	n/a	n/a	n/a
11	7/19/06	n/a	n/a	n/a	n/a

Table A.12 - Manual rain gauge readings for CR7-5b.

CR-75b		Precipitation (in)					
Event	Date	1	2	3	4	5	control
3	4/15/05	n/a	n/a	n/a	n/a	n/a	n/a
4	5/18/05	n/a	n/a	2.5	n/a	n/a	n/a
5	7/15/05	3.6	4.0	1.6	3.3	4.0	3.7
6	8/22/05	3.9	4.2	4.3	4.2	4.1	3.9
7	9/18/05	3.9	4.0	4.0	4.0	4.1	3.8
8	11/18/05	4.5	4.4	4.5	4.3	n/a	4.5
9	3/15/06	n/a	n/a	n/a	n/a	n/a	n/a
10	5/16/06	n/a	n/a	n/a	n/a	n/a	4.2
11	7/19/06	n/a	n/a	n/a	n/a	n/a	3.8

Table A.13 - Manual rain gauge readings for CR7-5c.

CR7-5c		Precipitation (in)				
Event	Date	1	2	3	4	5
3	4/15/05	0.7	1.2	n/a	n/a	n/a
4	5/18/05	0.5	2.0	2.8	n/a	3.0
5	7/15/05	4.3	3.5	4.2	2.9	4.2
6	8/22/05	4.1	4.5	4.0	4.1	4.1
7	9/18/05	3.9	3.9	3.9	n/a	4.0
8	11/18/05	4.1	4.5	4.0	n/a	4.8
9	3/15/06	n/a	n/a	n/a	n/a	n/a
10	5/16/06	n/a	n/a	n/a	n/a	n/a
11	7/19/06	n/a	n/a	n/a	n/a	n/a

Table A.14 - Manual rain gauge readings for CR7-6.

CR7-6		Precipitation (in)			
Event	Date	1	2	3	4
3	4/15/05	1.0	n/a	n/a	n/a
4	5/18/05	1.0	n/a	2.0	1.0
5	7/15/05	3.5	4.0	3.7	3.5
6	8/22/05	4.3	4.2	4.1	3.9
7	9/18/05	4.3	4.2	4.3	2.6
8	11/18/05	4.5	n/a	4.8	4.3
9	3/15/06	n/a	n/a	n/a	n/a
10	5/16/06	n/a	n/a	n/a	n/a
11	7/19/06	n/a	n/a	n/a	n/a

Table A.15 - Manual rain gauge readings for CR11-1.

CR11-1		Precipitation (in)				
Event	Date	1	2	3	4	5
3	4/15/05	0.0	2.0	2.1	2.4	n/a
4	5/18/05	1.0	3.0	3.0	n/a	n/a
5	7/15/05	3.8	3.7	n/a	4.0	3.4
6	8/22/05	3.3	3.7	3.9	3.5	3.1
7	9/18/05	4.0	4.0	n/a	4.1	4.1
8	11/18/05	n/a	n/a	n/a	n/a	n/a
9	3/15/06	n/a	n/a	n/a	n/a	n/a
10	5/16/06	4.1	n/a	n/a	n/a	n/a
11	7/19/06	n/a	n/a	n/a	n/a	n/a

Table A.16 - Manual rain gauge readings for CR11-3.

CR11-3		Precipitation (in)				
Event	Date	1	2	3	4	5
3	4/15/05	0.0	0.7	0.4	0.2	0.0
4	5/18/05	0.7	0.0	1.8	n/a	n/a
5	7/15/05	4.0	2.9	4.0	3.8	3.4
6	8/22/05	3.9	3.1	3.7	4.0	3.9
7	9/18/05	4.1	4.0	4.0	4.2	4.3
8	11/18/05	4.5	n/a	4.3	4.5	4.5
9	3/15/06	n/a	n/a	n/a	n/a	n/a
10	5/16/06	n/a	n/a	n/a	n/a	n/a
11	7/19/06	3.7	n/a	n/a	n/a	n/a

Table A.17 - Manual rain gauge readings for CR11-9.

CR11-9		Precipitation (in)			
Event	Date	1	2	3	4
3	4/15/05	0.6	0.9	1.0	0.8
4	5/18/05	0.0	n/a	0.0	3.0
5	7/15/05	2.9	3.2	4.4	4.0
6	8/22/05	3.3	3.5	4.0	4.0
7	9/18/05	3.5	3.7	4.8	3.6
8	11/18/05	5.0	4.1	n/a	5.0
9	3/15/06	n/a	n/a	n/a	n/a
10	5/16/06	n/a	n/a	n/a	4.6
11	7/19/06	n/a	n/a	n/a	n/a

Table A.18 – Monthly precipitation totals from all sources for the period January 2003-July 2006

	Monthly Precipitation Totals				
	inches				
Date	RAWS	USGS	A34-1	CR7-5c	Isco
Jan-03	0.33	n/a	n/a	n/a	n/a
Feb-03	4.19	n/a	n/a	n/a	n/a
Mar-03	2.01	n/a	n/a	n/a	n/a
Apr-03	4.25	n/a	n/a	n/a	n/a
May-03	3.98	n/a	n/a	n/a	n/a
Jun-03	5.99	n/a	n/a	n/a	n/a
Jul-03	4.91	n/a	n/a	n/a	n/a
Aug-03	7.07	n/a	n/a	n/a	n/a
Sep-03	4.70	n/a	n/a	n/a	n/a
Oct-03	1.16	n/a	n/a	n/a	n/a
Nov-03	1.98	n/a	n/a	n/a	n/a
Dec-03	4.49	n/a	n/a	n/a	n/a
Jan-04	1.81	1.89	n/a	n/a	n/a
Feb-04	1.49	1.05	n/a	n/a	n/a
Mar-04	4.37	4.14	n/a	n/a	n/a
Apr-04	3.24	5.83	n/a	n/a	n/a
May-04	5.82	0.54	n/a	n/a	n/a
Jun-04	4.07	0.00	n/a	n/a	n/a
Jul-04	3.59	0.07	n/a	n/a	n/a
Aug-04	2.23	0.06	n/a	n/a	n/a
Sep-04	0.00	0.04	n/a	n/a	n/a
Oct-04	5.34	5.56	n/a	n/a	n/a
Nov-04	7.75	4.91	n/a	n/a	n/a
Dec-04	1.56	1.05	n/a	n/a	n/a
Jan-05	5.69	4.91	n/a	n/a	n/a
Feb-05	2.70	2.38	n/a	n/a	n/a
Mar-05	2.20	1.60	n/a	n/a	n/a
Apr-05	2.80	1.87	n/a	n/a	n/a
May-05	1.81	1.25	n/a	n/a	n/a
Jun-05	1.80	1.68	n/a	n/a	n/a
Jul-05	6.62	0.35	1.07	0.59	n/a
Aug-05	4.20	6.66	5.17	6.38	n/a
Sep-05	6.64	5.47	5.33	4.60	n/a
Oct-05	1.94	1.61	1.30	1.57	n/a
Nov-05	8.54	3.70	8.02	8.85	n/a
Dec-05	0.46	0.15	0.40	0.28	n/a
Jan-06	3.81	1.69	2.61	3.85	n/a
Feb-06	1.32	0.71	0.51	1.10	n/a
Mar-06	6.42	5.40	5.10	6.92	n/a
Apr-06	2.74	2.64	3.24	2.44	2.68
May-06	6.87	7.72	6.72	7.16	3.63
Jun-06	1.69	1.66	2.33	n/a	1.52
Jul-06	4.69	2.93	1.19	n/a	3.08

Table A.19 – Monthly temperature measurements from all sources for the period January 2003-July 2006.

	A34-1				CR7-5c				RAWS			
month	**min**	**max**	**range**	**mean**	**min**	**max**	**range**	**mean**	**min**	**max**	**range**	**mean**
Jan-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	18	41	23	31
Feb-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	25	43	18	34
Mar-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	35	61	26	48
Apr-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	46	73	27	60
May-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	53	76	23	64
Jun-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	56	81	26	68
Jul-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	65	90	25	77
Aug-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	66	90	24	76
Sep-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	52	78	26	65
Oct-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	44	73	29	56
Nov-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	39	60	21	47
Dec-03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	29	49	20	38
Jan-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	23	45	23	34
Feb-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	25	49	24	38
Mar-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	39	64	25	51
Apr-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	45	72	27	60
May-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	58	81	24	69
Jun-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	60	86	26	72
Jul-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	64	89	25	75
Aug-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	59	87	28	72
Sep-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	54	86	32	69
Oct-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	50	73	23	61
Nov-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	41	60	19	50
Dec-04	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	25	50	24	36
Jan-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	29	47	18	38
Feb-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	32	54	22	42
Mar-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	33	60	27	47
Apr-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	45	72	26	59
May-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	48	81	33	65
Jun-05	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	61	91	30	75
Jul-05	58	94	36	75	58	92	34	75	56	102	46	77
Aug-05	60	91	31	75	60	96	36	76	58	101	43	78
Sep-05	40	88	48	70	39	84	45	69	36	95	59	72
Oct-05	30	83	53	56	29	80	51	56	27	91	64	56
Nov-05	18	79	62	47	18	81	63	48	14	83	69	49
Dec-05	6	63	57	33	6	60	54	34	5	66	61	35
Jan-06	22	71	49	42	21	71	50	42	20	77	57	43
Feb-06	4	74	70	36	6	75	69	36	4	78	74	37
Mar-06	24	80	56	47	24	81	58	48	22	86	64	49
Apr-06	31	89	59	62	31	90	59	63	29	95	66	65
May-06	42	75	33	57	44	76	31	58	40	94	54	65
Jun-06	55	87	31	71	data logger malfunction				51	97	46	73
Jul-06	54	91	37	75	data logger malfunction				50	100	50	77

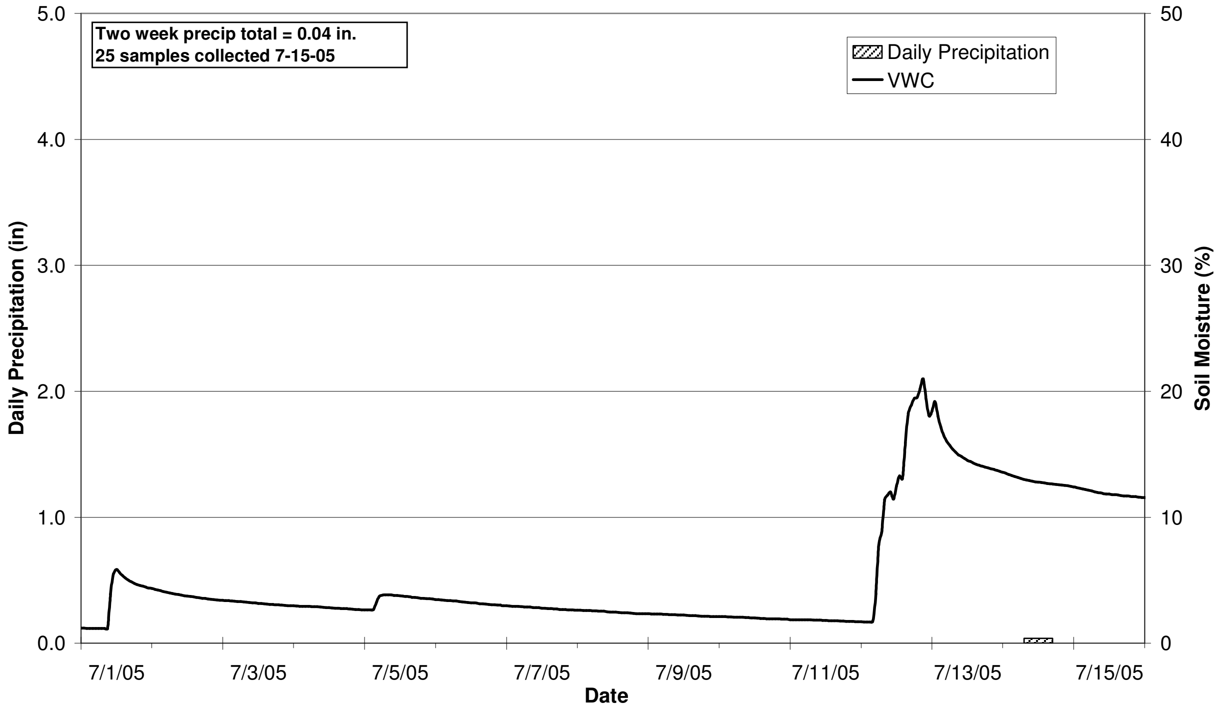

Figure A.17 – Average ECHO® soil moisture and daily precipitation for two weeks preceding sample collection on 7/15/05.

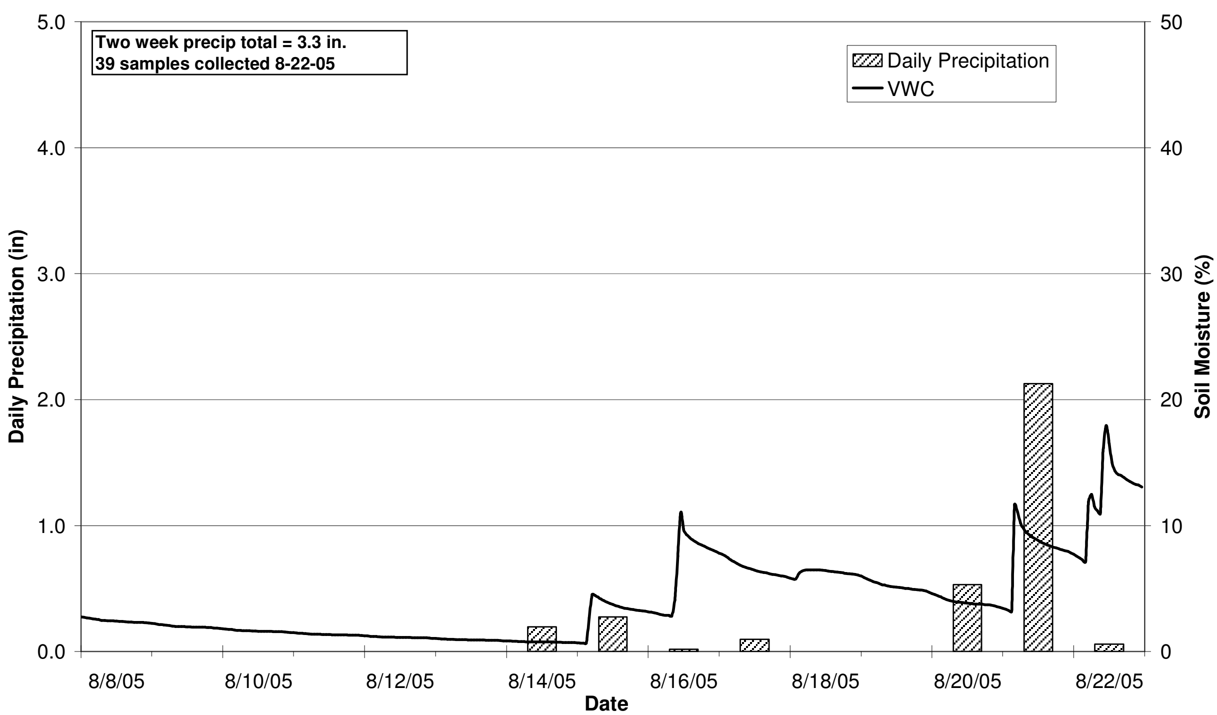

Figure A.18 – Average ECHO® soil moisture and daily precipitation for two weeks preceding sample collection on 8/22/05.

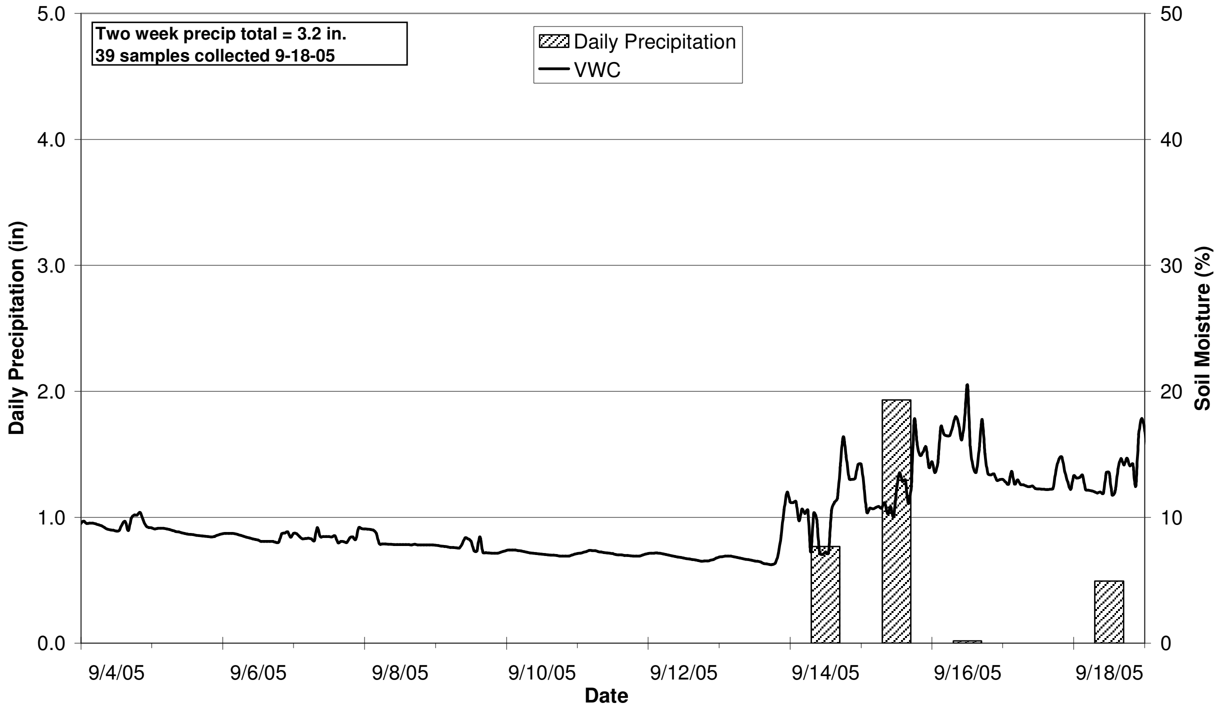

Figure A.19 – Average ECHO® soil moisture and daily precipitation for two weeks preceding sample collection on 9/18/05.

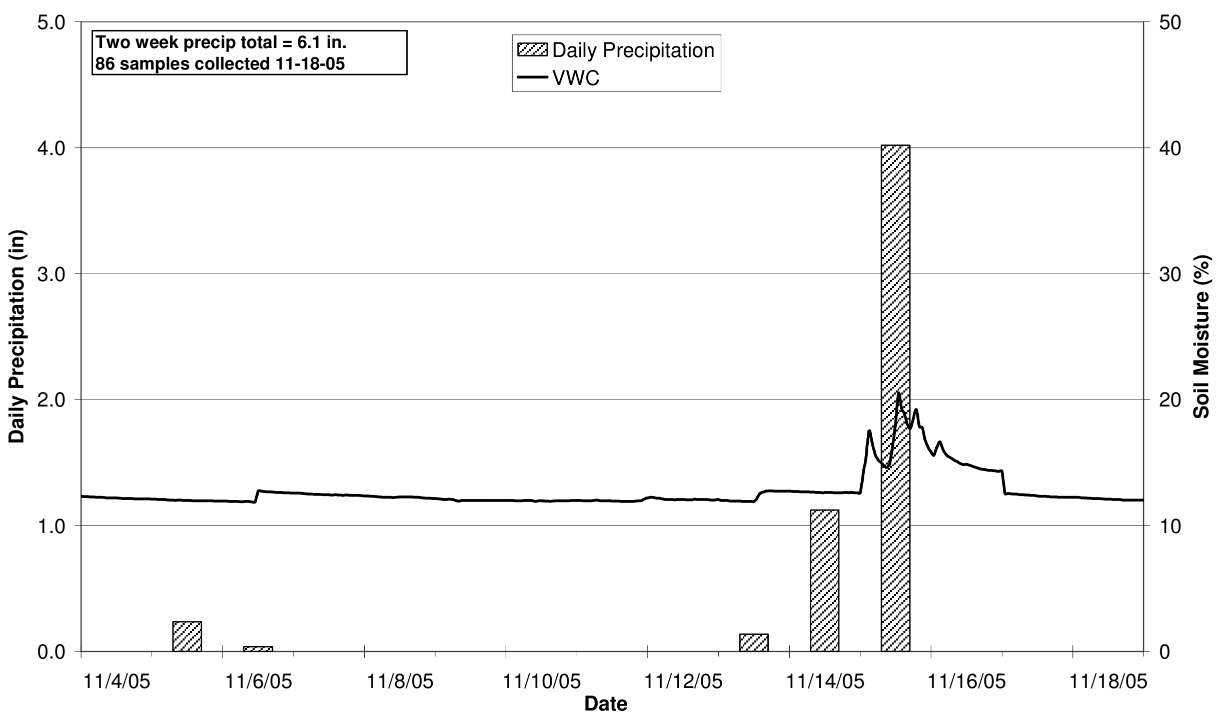

Figure A.20 – Average ECHO® soil moisture and daily precipitation for two weeks preceding sample collection on 11/18/05.

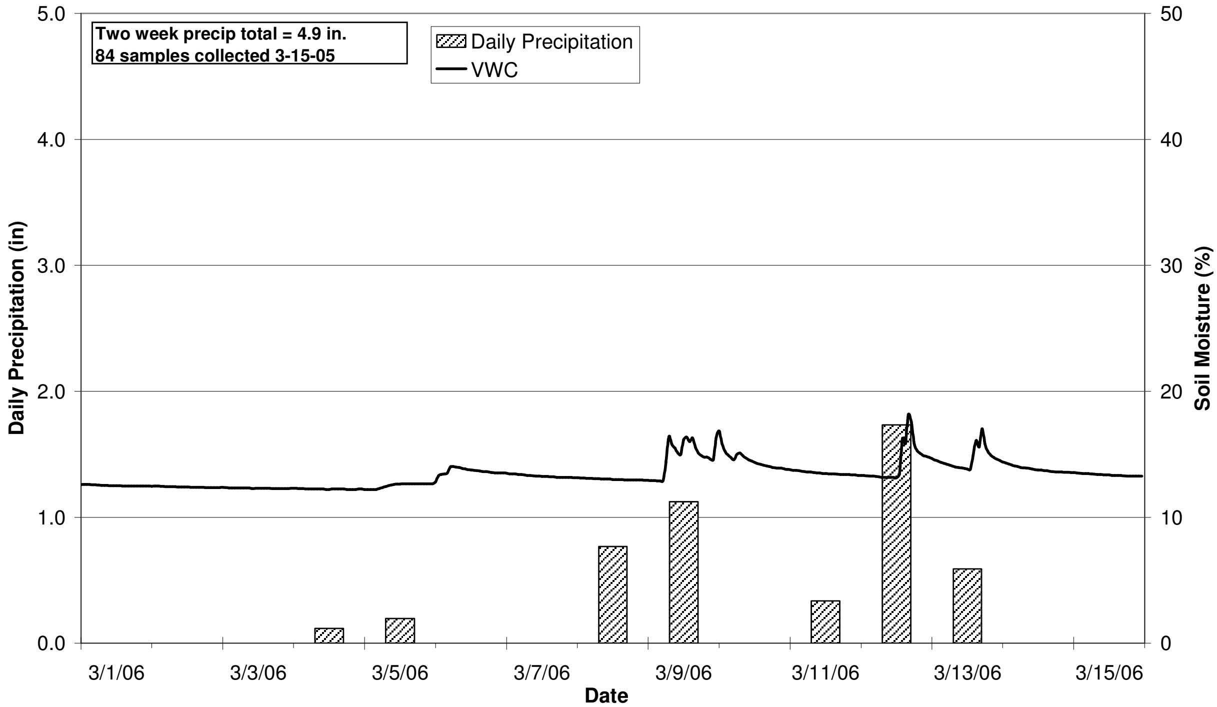

Figure A.21 – Average ECHO® soil moisture and daily precipitation for two weeks preceding sample collection on 3/15/06.

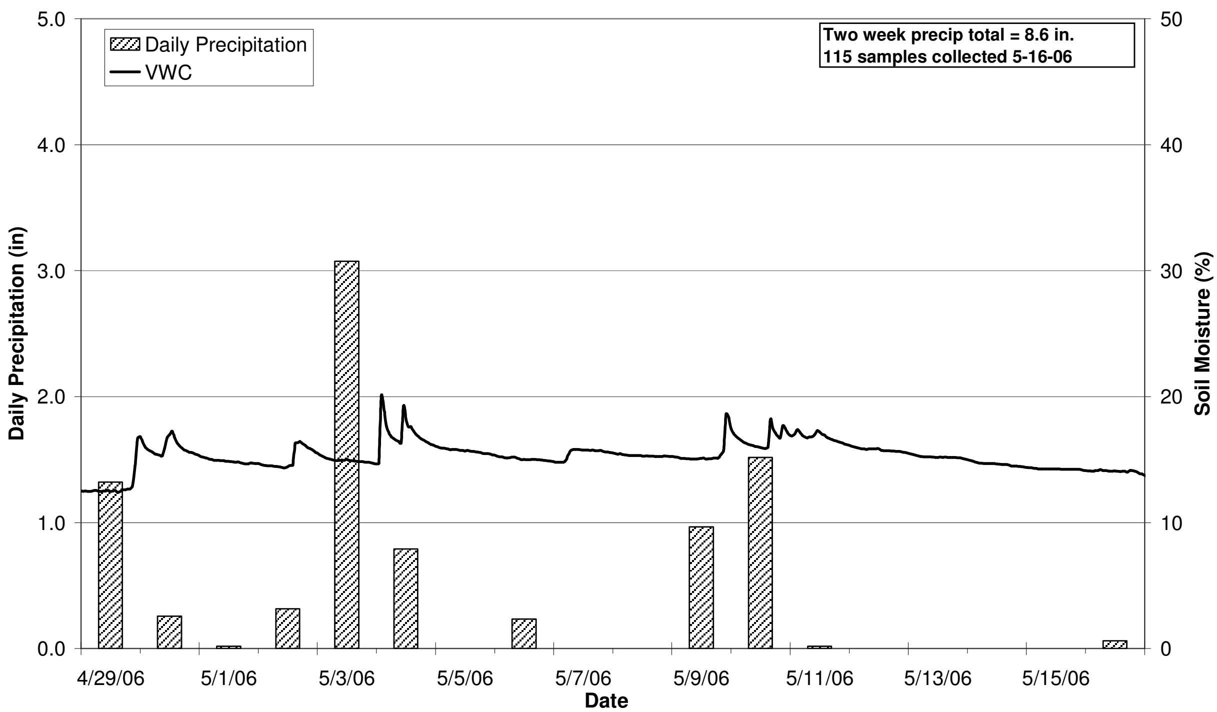

Figure A.22 – Average ECHO® soil moisture and daily precipitation for two weeks preceding sample collection on 5/16/06.

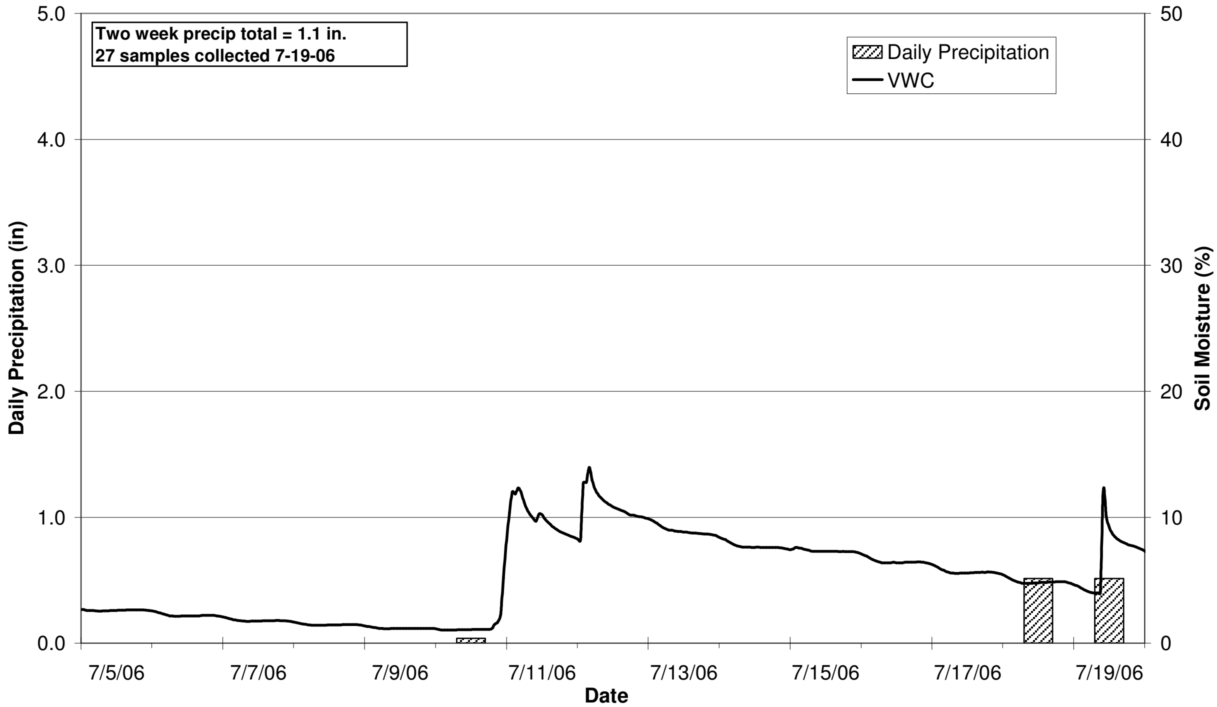

Figure A.23 – Average ECHO® soil moisture and daily precipitation for two weeks preceding sample collection on 7/19/06.

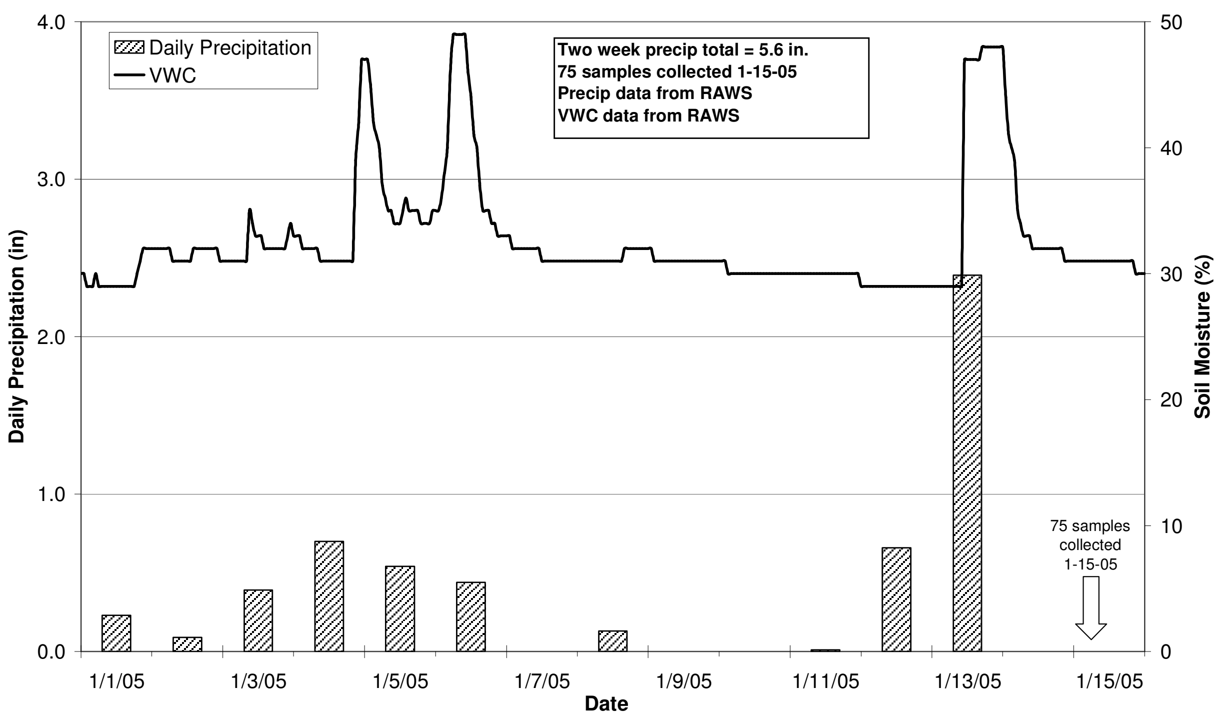

Figure A.24 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 1/15/05.

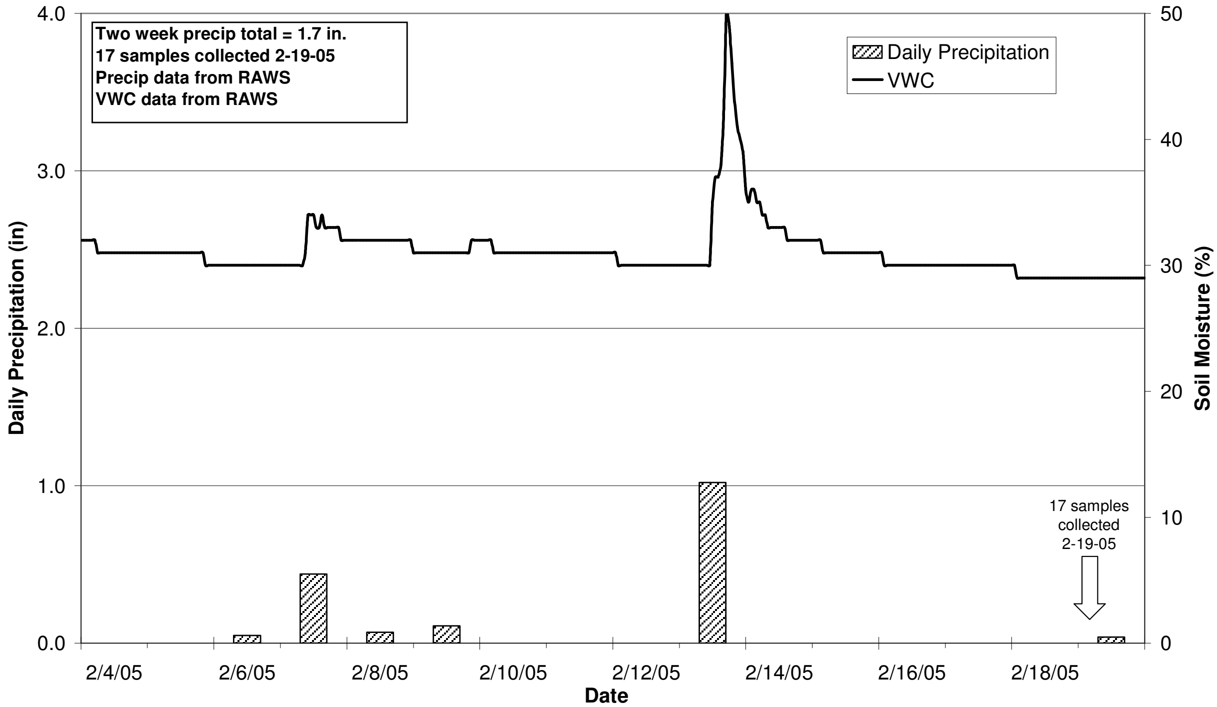

Figure A.25 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 2/19/05.

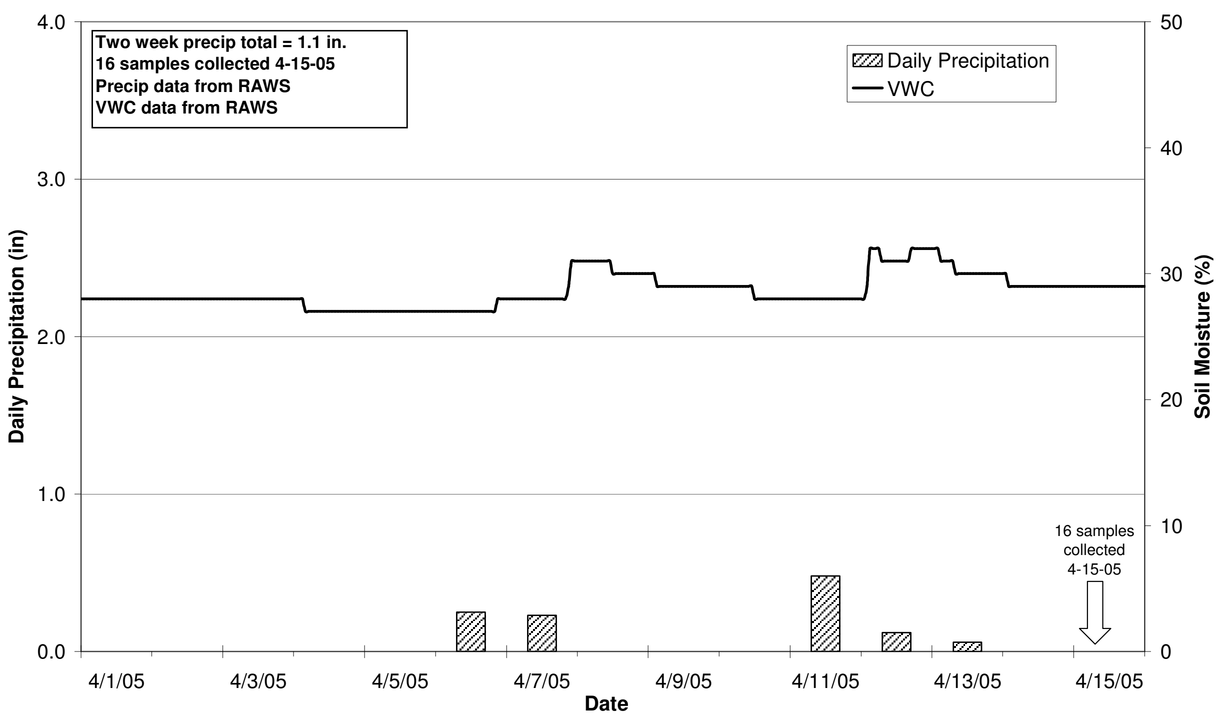

Figure A.26 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 4/15/05.

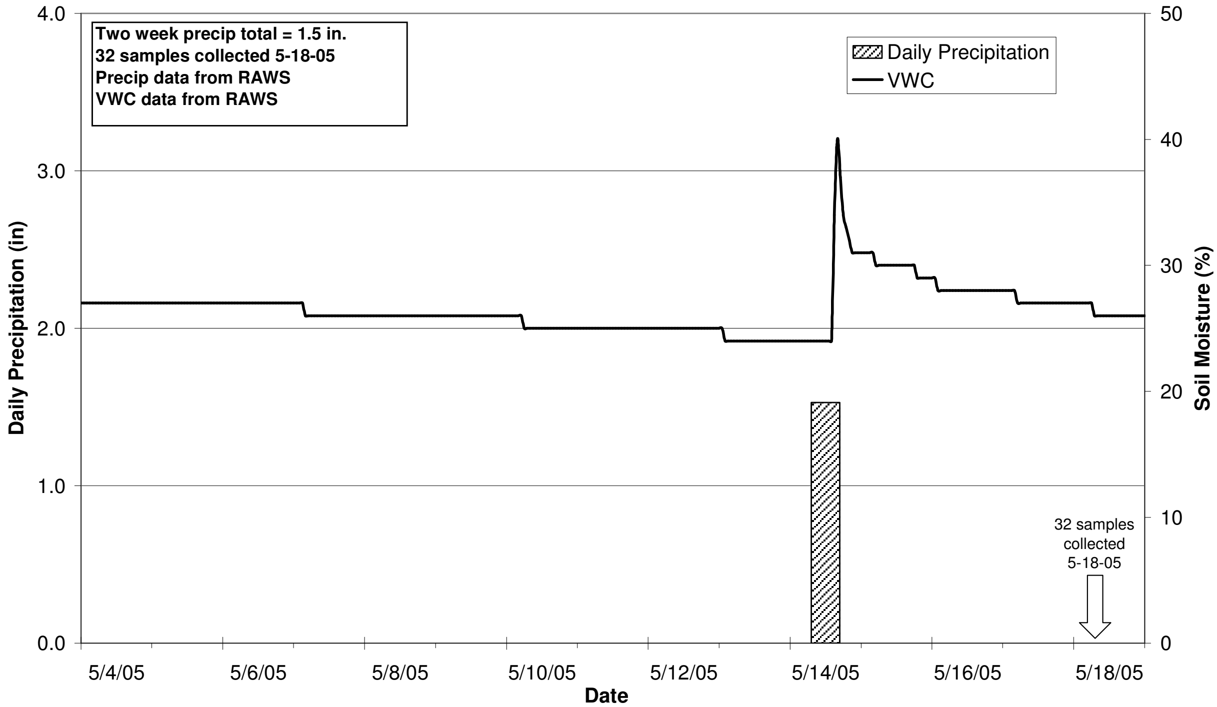

Figure A.27 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 5/18/05.

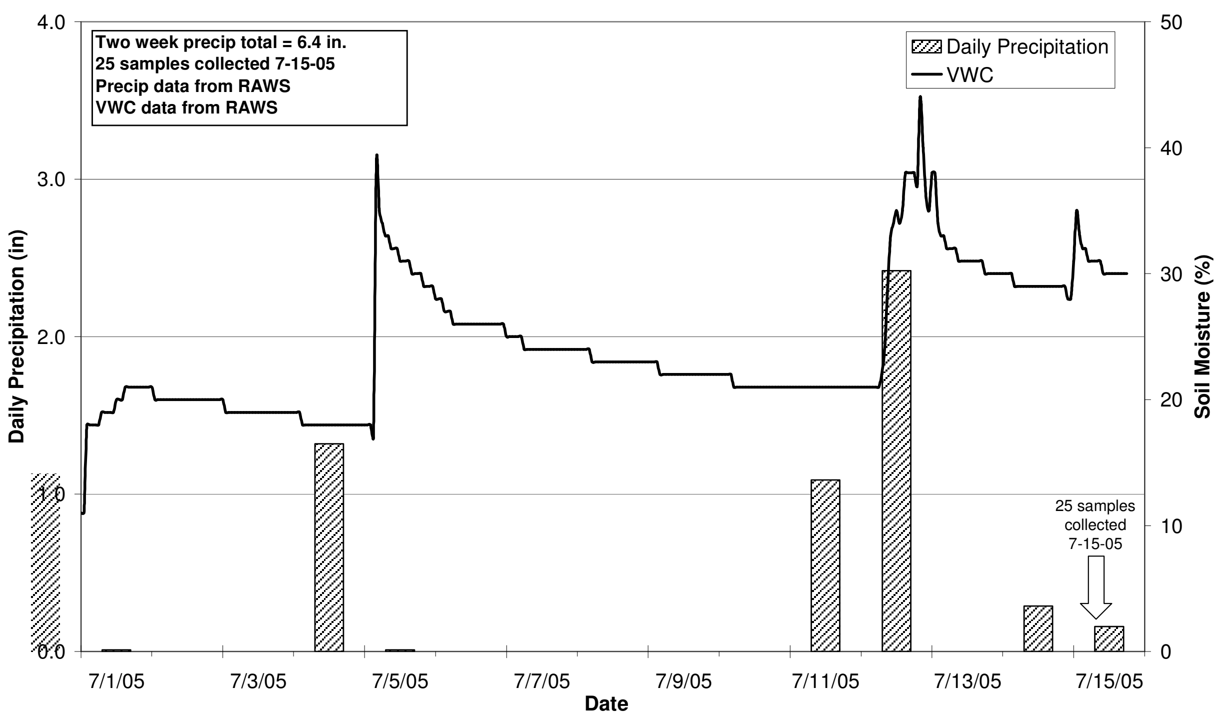

Figure A.28 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 7/15/05.

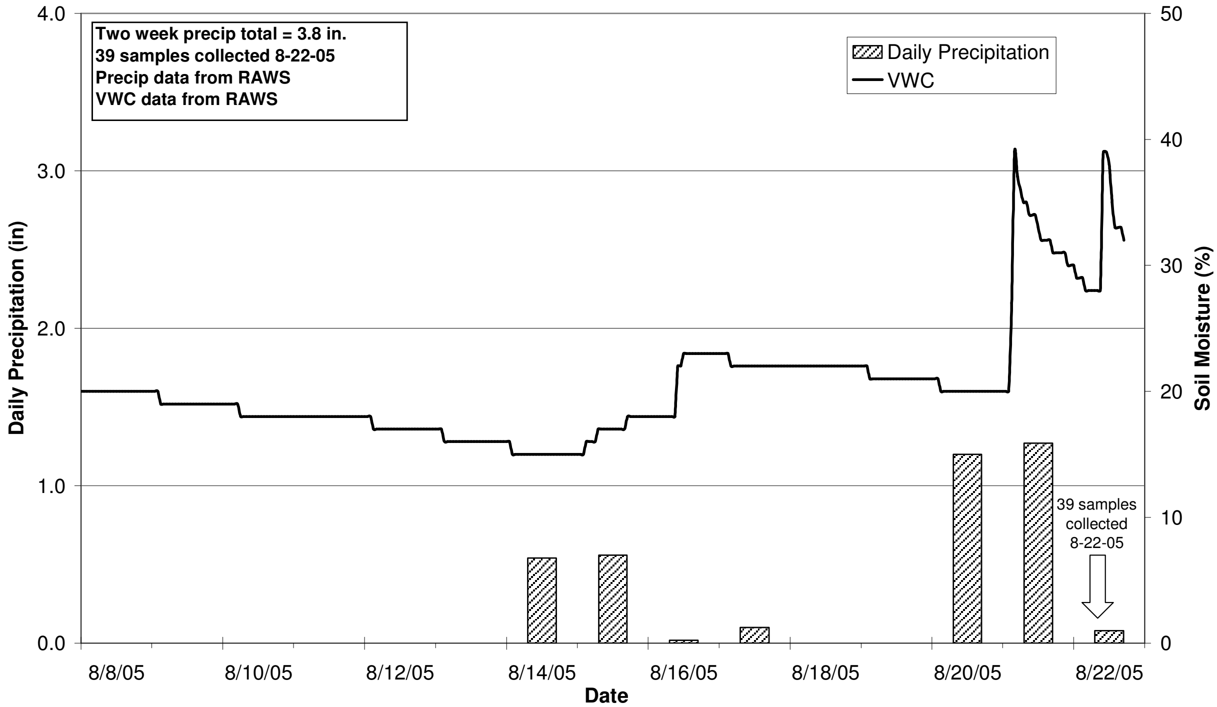

Figure A.29 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 8/22/05.

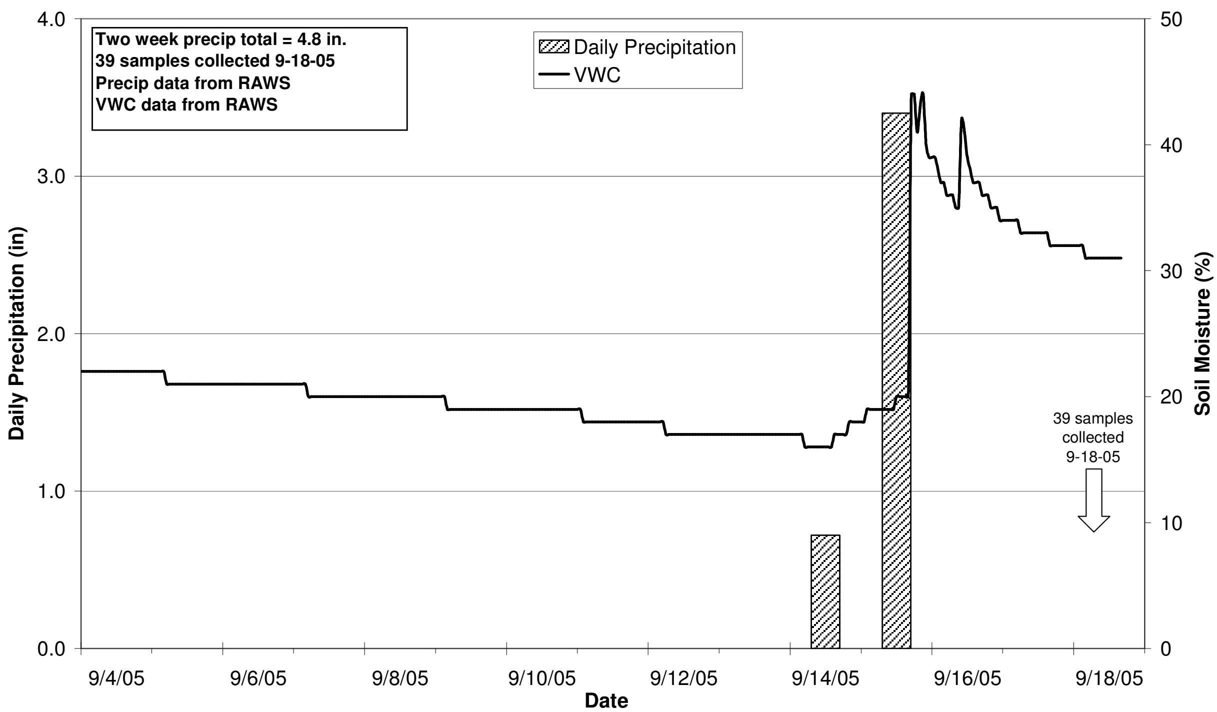

Figure A.30 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 9/18/05.

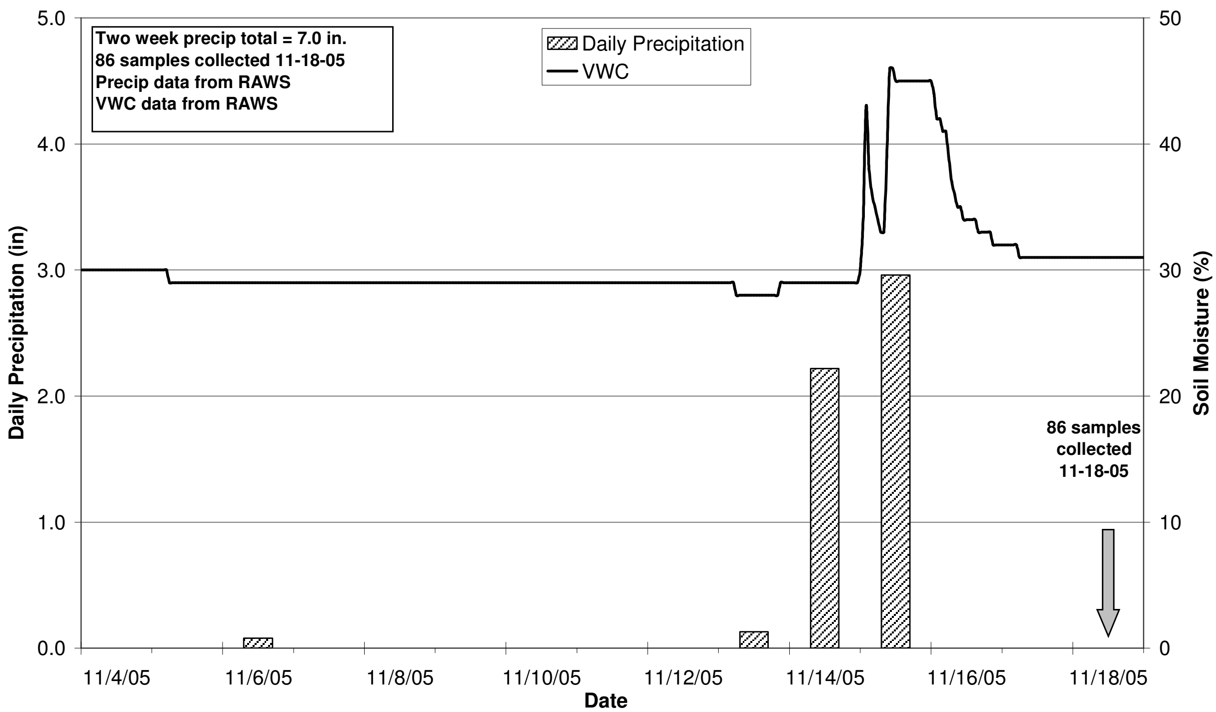

Figure A.31 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 11/18/05.

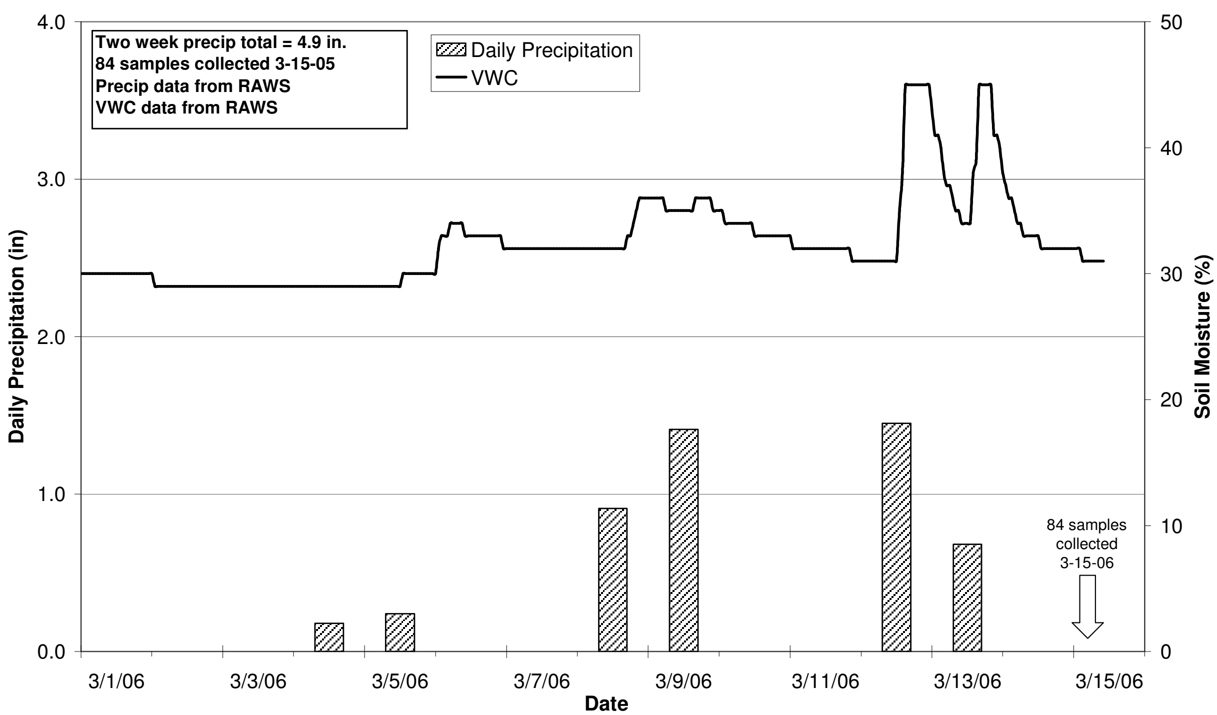

Figure A.32 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 3/15/06.

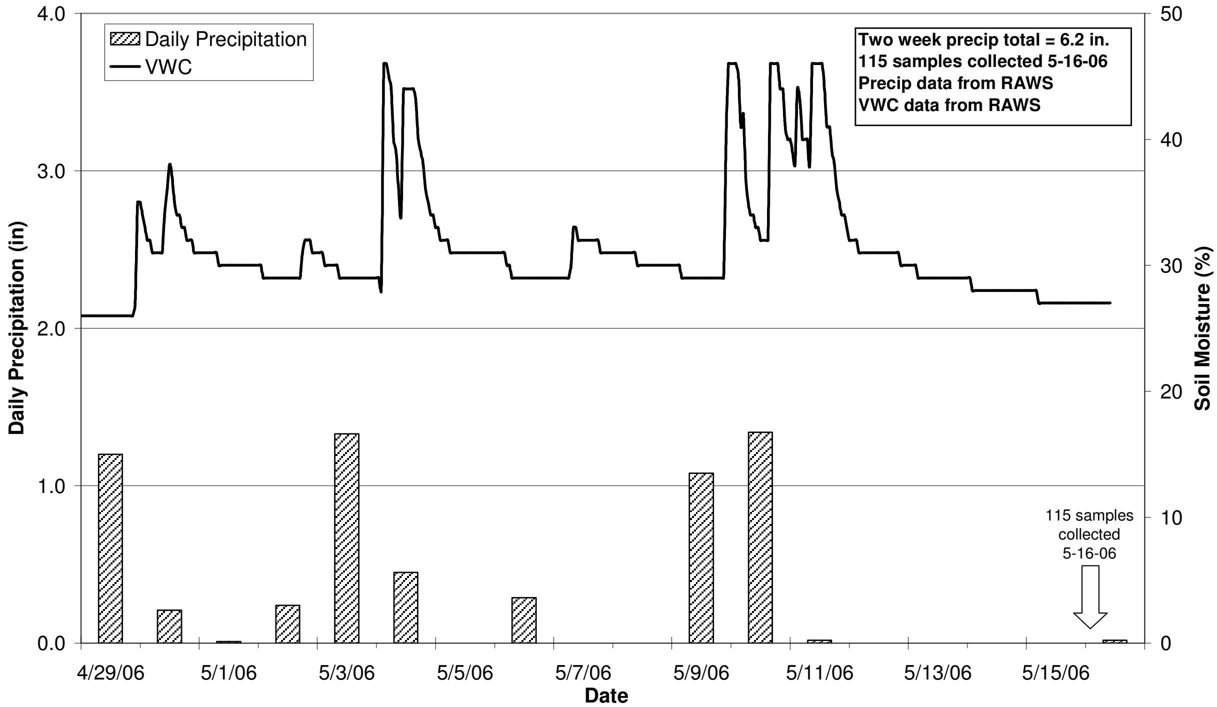

Figure A.33 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 5/15/06.

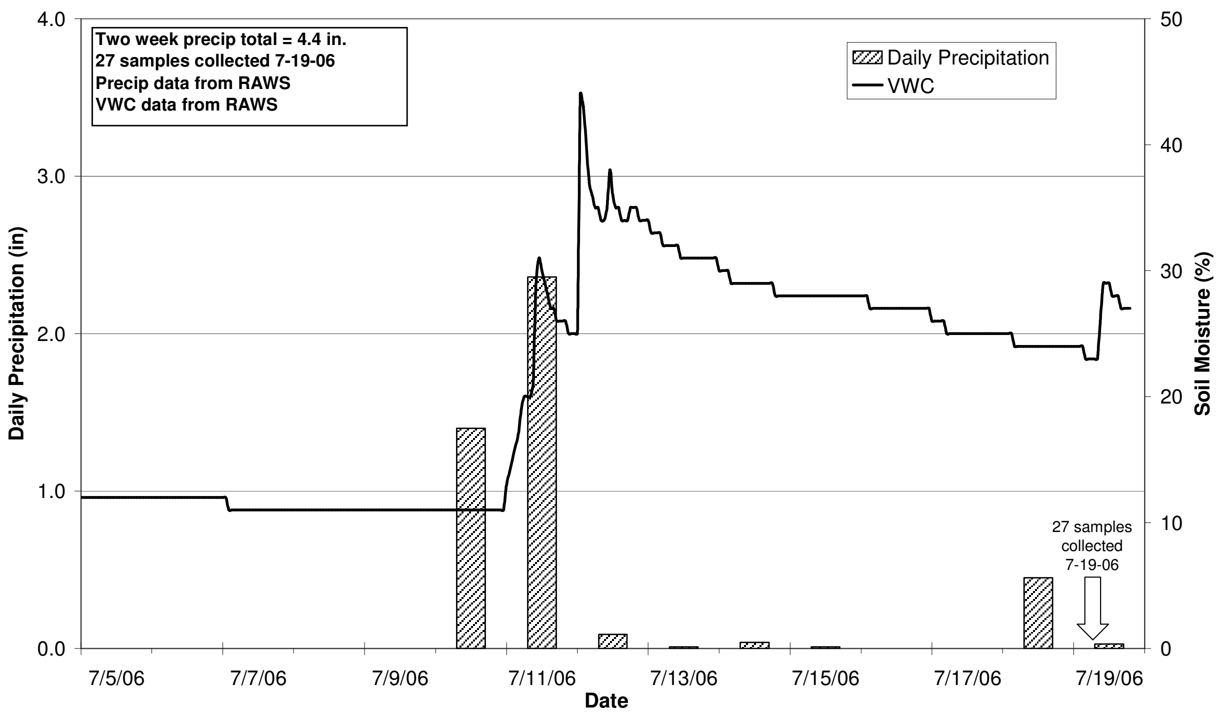

Figure A.34 – RAWS soil moisture and daily precipitation for two weeks preceding sample collection on 7/19/06.

Appendix C

To access weather data from Carr Creek RAWS:

1. A. Access website: http://raws.wrh.noaa.gov/cgi-bin/roman/past.cgi?stn=CRRM7&day26=2&month1=2&year1=2006

   B. Select date, time, and units of interest. Click "submit"

   C. Copy data of interest to a spreadsheet program for manipulation.

2. A. Access website: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?ndMCAR

   B. Select data of interest in left column.

   C. Select time period of interest (if required). Click "Submit Info"

To access weather data from USGS station in Eminence, MO:

1. Access website: http://waterdata.usgs.gov/mo/nwis/dv?cb_00045=on&format=html&begin_date=2006-06-09&end_date=2006-06-15&site_no=07066000&referred_module=sw

2. Select dates of interest. Click "Go"

Appendix D

Table A.20 – Anticipated harvest schedule as of August 2006.

Site	Treatment (Cut or Control)	Anticipated Harvest Date
A17-1	Cut	May-06
A17-2	Cut	May-06
A25-2	Control	NA
A25-3	Cut	Sep-08
A27-1	Cut	Sep-08
A27-2	Control	NA
A34-1	Cut	Oct-06
A34-2	Cut	Oct-06
CR7-2	Control	NA
CR7-5B	Cut	May-07
CR7-5C	Cut	May-07
CR7-6	Control	NA
CR11-1	Cut	May-07
CR11-3	Cut	May-07
CR11-9	Control	NA

Appendix E

Table A.21 – List of equipment on each site.

Site	Rising Stage Bottle Sampler	Stream Crest Gauge	Hillslope Sediment Monitor	Hillslope Sediment Monitor Control	Silt Fence	ECHO Station			ISCO		
						Moisture Probe	Rain Gauge	Temperature Sensor	Automatic Water Sampler	Stream Gauging Station	Rain Gauge
A17-1	5	1	5	1	-	-	-	-	-	-	-
A17-2	5	1	5	-	-	-	-	-	-	-	-
A25-2	7	1	5	-	-	-	-	-	-	-	-
A25-3	7	1	4	-	-	-	-	-	-	-	-
A27-1	7	1	5	-	-	-	-	-	-	-	-
A27-2	7	1	4	-	4	-	-	-	-	-	-
A34-1	10	1	6	1	4	3	1	1	1	1	1
A34-2	6	1	5	-	-	-	-	-	-	-	-
CR7-2	6	1	4	-	-	-	-	-	-	-	-
CR7-5b	7	1	5	1	4	-	-	-	-	-	-
CR7-5c	5	1	5	-	4	3	1	1	-	-	-
CR7-6	5	1	4	-	4	-	-	-	-	-	-
CR11-1	5	1	3	-	-	-	-	-	-	-	-
CR11-3	3	1	5	-	-	-	-	-	-	-	-
CR11-9	5	1	4	-	-	-	-	-	-	-	-
Total	**90**	**15**	**69**	**3**	**20**	**6**	**2**	**2**	**1**	**1**	**1**