CRWR Online Report 09-01

Effectiveness of Natural Vegetated Areas for Stormwater Treatment: Monitoring of the Falconhead West Development

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August 2009

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This document is available online at:

http://www.crwr.utexas.edu/online.shtml

Acknowledgements

The authors would like to acknowledge the financial support provided by Don Walden and the Falconhead West Limited Partners, which made this study possible. In addition, we would like to thank Greg Ketchum for providing assistance in the installation and maintenance of the stormwater sampling locations.

Abstract

Urban development activity leads to increased non-point source pollution in the form of stormwater runoff. Stormwater Best Management Practices (BMPs) are used to mitigate the effect of non-point source pollution. Vegetative filter strips (VFS) are a non-structural BMP that use sedimentation, infiltration, filtration, and biological uptake to treat stormwater pollutants. Two natural VFS with single-family residential contributing drainage areas were monitored from June 2008-June 2009. The VFS are located on the Glen Rose Formation common to the Hill Country of central Texas. Runoff volumes and quality are compared before and after natural VFS treatment. Volume reduction by infiltration was found as the most successful VFS treatment mechanism. Average volume and peak flow rate reductions ranged from 75-97% and 45-97% respectively. Removal effectiveness of total suspended solids, nutrients and metals was found to vary with influent concentration. Performance of 18 natural VFS was qualitatively reviewed during the monitoring period. Rainfall intensity and contributing drainage area stabilization were found to affect VFS performance.

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Chapter 1: Introduction

Overview

Increased development in the Central Texas Hill Country has led to water quality stress on the Highland Lakes. Urban stormwater runoff carries pollution from human activity, namely nutrients and toxic substances, to receiving waters and is one of the contributors to nonpoint source pollution in the Highland Lakes. The Highland Lakes Watershed Ordinance prescribes multiple stormwater Best Management Practices (BMPs) for mitigating the effects of urban stormwater runoff. Vegetative filter strips (VFS) are an available BMP that include areas designed to receive stormwater runoff in distributed overland sheet flow. The filter strips use sedimentation, infiltration, filtration and biological uptake to remove pollutants and improve runoff quality. The Lower Colorado River Authority (LCRA) Water Quality Management Technical Manual allows these VFS to be naturally occurring or engineered for increased performance. This study examines the effectiveness of natural VFS which potentially provide low cost, nonstructural BMP treatment.

Hydrology of the Glen Rose Formation

The Hill Country of Central Texas is primarily underlain by the Glen Rose Formation, most prominently seen in the typical stair-stepped terrain (Woodruff and Wilding, 2007). This terrain consists of alternating terraced ledges (treads) and steep recessive slopes (risers), which are illustrated in Figure 1.

Previous mismanagement of stormwater BMPs limited VFS to the tread portions of the landscape. However, Woodruff and Wilding (2007) provide counterintuitive results, finding the terrain risers exhibit the highest infiltration and water retention and lowest runoff and erosion; whereas the treads contain the lowest infiltration and water retention and yield the highest runoff volumes. Results show that the thickest and most diverse soil is found on the steepest parts of the landscape, the risers, which typically exceed 20% slope and at times exceed 30%. Water infiltration was found to directly correlate with soil thickness, which correlates directly with local terrain slope. Infiltration and stair-stepped hydrologic data can be seen in Figure 2.

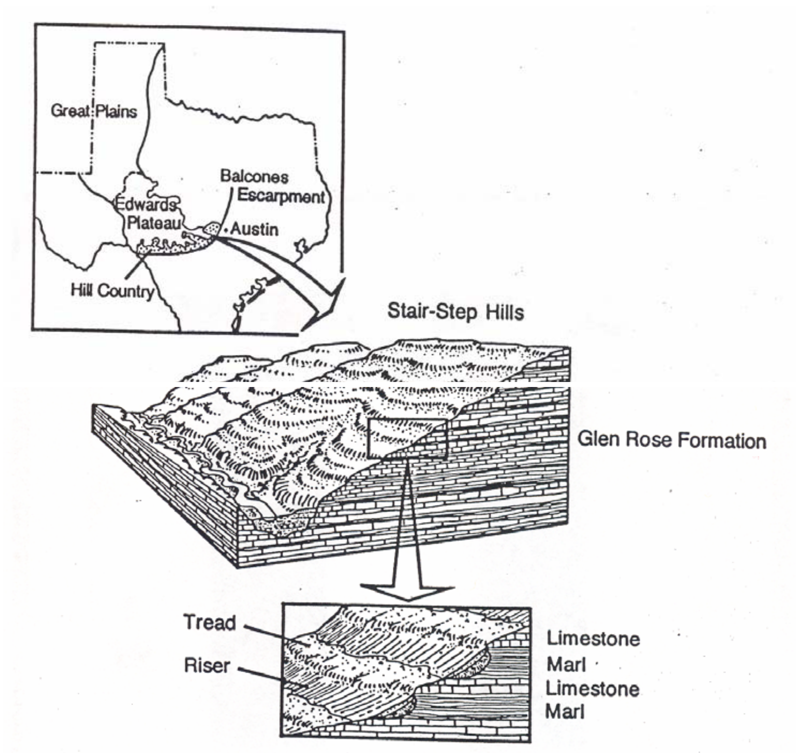
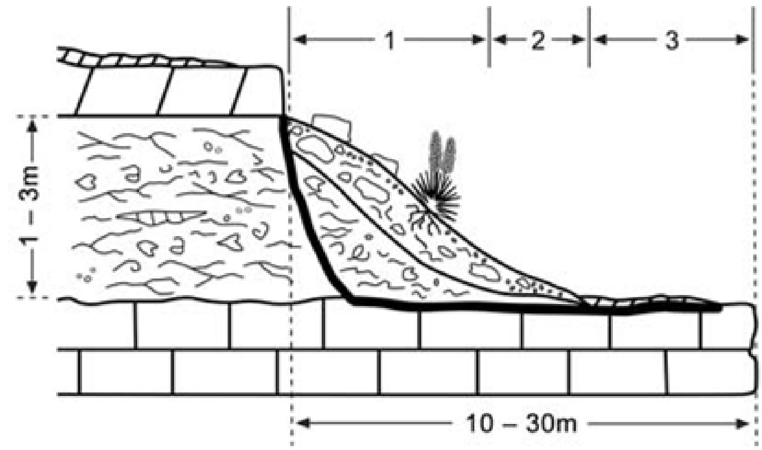


Figure 1: Stair-Step Hills of the Glen Rose Formation (Woodruff, 1992 via LCRA, 2007)

Accurate knowledge of the hydrologic properties of the Glen Rose Formation presents opportunities for environmental design to mitigate adverse impacts of development on surface and groundwater. As a steward of the Colorado River, the LCRA has recently updated the Water Quality Management Technical Manual (effective July 1, 2007) to include the advanced knowledge of hill slope hydrology reported by Woodruff and Wilding (2007). Previous design guidelines limited natural vegetative filter strip area slope to 10%. However, the most recent technical manual includes a "Terrace Slope Option" to take advantage of potential treatment benefits of the naturally occurring stair-stepped topography. This option allows for riser slopes to be steeper than 20% provided the overall slope is less than 20%. Risers are also required to be stable and capable of functioning as flow spreaders.



Micro-topographic position

Property*	1 Upper/Mid Riser	2 Riser/Tread	3 Tread
Infiltration rate (cm/hr)	11.3	5.1	3.0
CWRD (cm)**	9.0	5.0	2.5
Runoff (%)	5	27	31
Eroded sediment (kg/ha/yr)	55	1675	315
Hydrologic soil group	A	B or C	D
Hydrological curve number	45	60	85

*Mean values with standard errors up to 40% of the mean, 95% confidence level.
**CWRD is cumulative water retention difference (plant available water) between soil water potentials of -0.33 and -15 atmospheres tension, expressed as cm water/unit area/soil depth.

Figure 2: Hydrologic and Soil Properties of Stepped Landforms (Woodruff and Wilding, 2007)

The aim of this study is to examine the effectiveness of natural vegetative filter strips for urban stormwater treatment on risers of the Glen Rose Formation. VFS site descriptions, construction materials, sampling and observation procedures are discussed in Chapter 3: Material and Methods. Results of this study include hydrologic data, event mean concentrations, analysis of VFS treatment, and qualitative review of the VFS systems. Conclusions are made on natural VFS effectiveness for stormwater treatment and recommendations presented for future VFS application. Calculations of runoff coefficients and peak flow rate reductions are shown in Appendices A and B respectively. Appendices also include event mean concentrations and hydrographs of each monitored storm event. Finally, a map of all VFS in the monitored development and quarterly pictorial observations are presented in Appendices E and F respectively.

Chapter 2: Literature Review

INTRODUCTION

This chapter provides a review of available literature on previous VFS studies and the applicability of this BMP on the stair step topography of the Glen Rose Formation. The LCRA 2007 Water Quality Management Technical Manual limits the use of VFS to drainage areas under 3 acres or as part of a BMP treatment train. Only recently are natural VFS beginning to be recognized as a standalone BMP for treating urban stormwater runoff. VFS have been traditionally used for treating agricultural runoff. Agencies are also finding that VFS can be effectively and conveniently placed along roadways for runoff treatment (Barrett et al., 1998; Line and Hunt, 2009). Under appropriate conditions both agricultural and roadway vegetative filter strips have resulted in greater than 85% sediment reduction for filter strips at least 30 ft. in flow length (Barrett et al., 1998; Han et al., 2005; Mickelson et al., 2003; Robison et al., 1996). Previous studies primarily exist on engineered VFS with specified slope, lengths, and vegetated cover.

VEGETATED FILTER STRIPS AND LEVEL SPREADERS

Daniels and Gilliam (1996) examined the effectiveness of vegetated filter strips for treating agricultural runoff in North Carolina. VFS sites included engineered grass filter strips and grass buffers with natural riparian vegetation filters in series. Filters strip sites where sheet flow dominated resulted in the following reductions: 30-60% total sediment, 50-70% total phosphorus and 35-60% total Kjeldahl Nitrogen. VFS effectiveness was observed to vary with erosiveness of the watershed and storm intensity. Daniels and Gilliam (1996) note that concentrated inflows need to be dispersed to reduce energy and flow velocity.

Dilhalla et al. (1986) also found runoff flow regime to be the most influential component affecting the performance of VFS. The filter strips require inflow in the form of overland sheet flow to take full advantage of treatment mechanisms. As such, a level flow spreader is commonly used to convert concentrated runoff inflow into shallow overland sheet flow and distribute it uniformly across the VFS.

An early study of level spreader-vegetative filter strip (LS-VFS) combination is reported by Franklin et al. (1992). Level flow spreaders were used to enhance a forested filter zone (FFZ) by dispersing flow laterally across entire filter zone. Nutrient and sediment concentration reductions include: 75% ammonia nitrogen, 32% total phosphorus, and 47% total suspended solids. FFZ infiltration reduced runoff volumes by 36% percent on average leading to further reductions in total nutrient and sediment loads.

Limited quantitative studies exist to examine the effectiveness of level spreader-vegetative filter strip combination with urban stormwater runoff influent. Yu et al. (1993) performed a field test on a 4 ha. commercial watershed with approximately 100% impervious cover. A concrete flow spreader was used with 21 and 45 m engineered grass buffer strips at 6% slope. The level spreader-grass buffer system resulted in the percent mass removal of the following: 54-84% TSS, (27)-20% NO_3+NO_2, 25-40% TP, (16)-50% lead, 47-55% zinc (numbers in parenthesis indicate negative removal rate). Negative removal, or addition of pollutant, existed only at the 21 m grass buffer strip and is hypothesized to have occurred due to hill slope soil erosion. Yu et al. (1993) concludes that removal efficiency increases as filter strip flow length increases and that filter strip length is an important design parameter, particularly for removal of soluble pollutants whose primary reduction is through infiltration.

Line and Hunt (2009) monitored the performance of a level flow spreader-grass filter strip from a heavily traveled two-lane highway contributing watershed. The 17.1 m engineered grass filter strip was graded below surrounding terrain at a 5.2% longitudinal slope and was installed with Bermuda grass sod. The 14 storm events monitored resulted in an average reduction in runoff volume and peak flow rate of 49% and 23% respectively. Results showed mass load reduction in total suspended solids and total phosphorus of 83% and 48% respectively. Line and Hunt (2009) conclude that level spreader-grass filter strips are an attractive option for linear highway stormwater treatment when appropriately designed and constructed.

Winston and Hunt (2009) examined level spreader-vegetated buffer systems in two North Carolina urban watersheds (70-89% impervious cover). Each watershed level spreader-vegetative buffer system included one 7.6 m wide grassed buffer and one 15.2 m wide half grassed half wooded buffer. This study found that runoff percentage volume reduction ranged between 70-90% and that percent volume reduction decreased as rainfall increased. Peak flow reduction was substantial and resulted in an order of magnitude reduction for small storm events. Water quality improvements resulted in reductions between 68-80% by mass of TKN, TN, TP, and TSS, largely from the volume reductions, which exceeded 70%.

In summary, prior published studies indicate that:

- Runoff flow regime is the most influential component to VFS performance (Dilhalla et al., 1986; Daniels and Gilliam, 1996), and that level spreaders are commonly used to create overland sheet flow.
- LS-VFS reduced mass loads of runoff by: 47-83% TSS and 25-80% total phosphorus (Franklin et al., 1992; Yu et al., 1993; Line and Hunt, 2009; Winston and Hunt, 2009).
- LS-VFS provided 36-90% volume reduction (Franklin et al., 1992; Line and Hunt, 2009; Winston and Hunt, 2009) and 23% average peak flow rate reduction (Line and Hunt, 2009).
- VFS treatment studies exist primarily on engineered VFS and only grass buffer strips have been studied with runoff from urban areas.

These results show promise in LS-VFS application for management of urban stormwater runoff. LS-VFS promote infiltration and reduce impervious surfaces, two criteria of Low Impact Development (Winston and Hunt, 2009). Recommended design guidelines prescribe slope to be as flat as possible while allowing for drainage, normally in the range of 0.02-0.08 (Han et al., 2005). However, Woodruff and Wilding (2007) find the Glen Rose Formation riser/tread landforms provide hydrologic buffer zones along locally steep hillsides. These buffer zones result from significant water retention, enhanced erosion abatement, nutrient uptake by plants, and bioremediation of waters cycled through these environmental buffers. Vegetative filter strip design requirements commonly include a variety of planted or indigenous vegetation as long as dense ground cover is achieved. This study will examine natural VFS and their application as a stormwater BMP on the Glen Rose Formation.

Chapter 3: Materials and Methods

SITE DESCRIPTION

Two natural VFS monitoring sites are located in the Falconhead West Development in the City of Bee Cave, TX. This single family residential development is approximately 3 miles west along State Highway 71 from the S.H. 71 and RM 620 intersection and can be seen below in Figure 3. The contributing drainage area to both monitoring sites is contained within the unique stair step topography of the Glen Rose Formation and part of the Highland Lakes (Lake Travis) watershed.

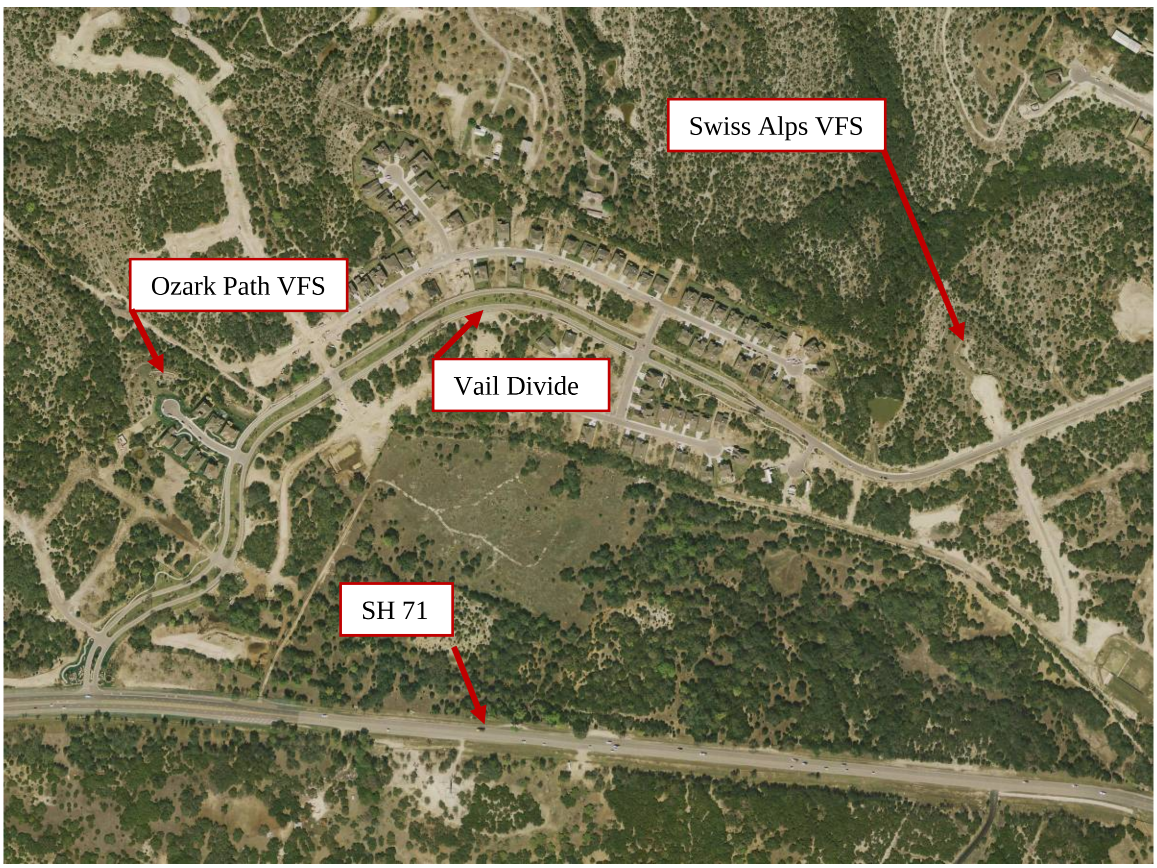


Figure 3: Falconhead West Development and Monitoring Sites (Landiscor, 2009)

Each monitoring site includes a single residential development contributing drainage area. The first monitoring location is located at the end of the cul-de-sac, Ozark Path, and the second at the end of future Swiss Alps Court (henceforth referred to as Ozark Path and Swiss Alps, respectively). BMP and sampling sites construction was completed and monitoring began in June 2008 and continued through June 2009.

OZARK PATH

The Ozark Path monitoring site has a contributing drainage area of 0.8 acre. This area includes a portion of developed lots but is predominantly from the street and cul-de-sac. Contributing drainage area and outfall location is shown in Figure 4. Stormwater runoff from this area drains to an 18 in. concrete storm drain.

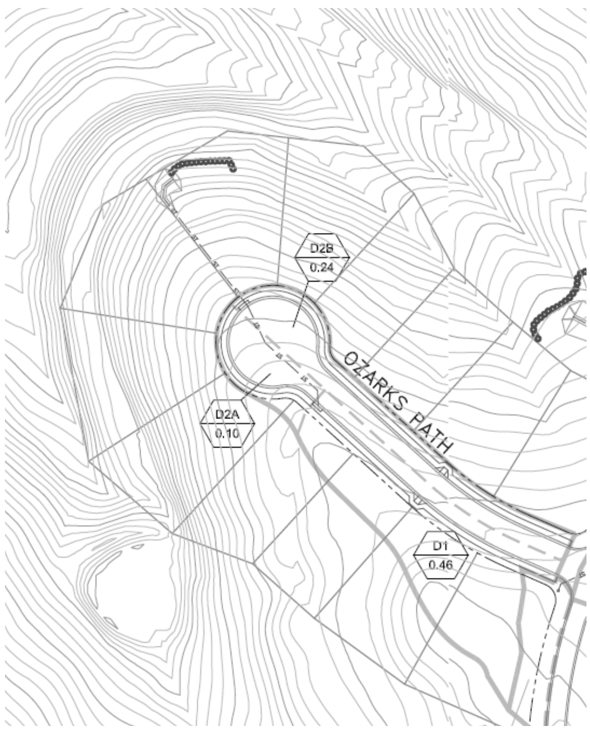


Figure 4: Ozark Path Contributing Drainage Area

Flow rate is measured at the outfall of this storm drain using an ISCO 4230 Bubbler Flow Meter that measures flow depth. Manning's equation is used with a 0.0195 longitudinal storm sewer slope, corresponding pipe dimensions, and a concrete roughness coefficient of 0.012 to convert measured depth into flow rate. Total volumes for storm events are calculated by integrating the flow rate hydrograph over the storm event duration.

Water quality samples are taken using an ISCO 3700 Portable Sampler. Flow weighted composite samples are drawn through a Teflon coated suction line. A stainless steel strainer is attached to the inflow of the sample tubing to prevent debris from clogging the sample line.

SWISS ALPS

During the study period the Swiss Alps site had a contributing drainage area of 0.42 acre primarily from Vail Divide Drive. The contributing drainage area and outfall location for Swiss Alps can be seen in Figure 5. The drainage area runoff is discharged from an 18 in. concrete storm drain that terminates with an outfall at 0% slope. Because Manning's equation cannot be applied to a 0% slope an ISCO 4250 Area Velocity Meter was used to monitor the flow rate. The ISCO 4250 uses corresponding pipe dimensions and area-velocity measurements to determine the flow rate. An ISCO 3700 Portable Sampler setup is used to obtain flow weighted composite runoff samples. An ISCO 674 tipping bucket rain gauge is located onsite and used to measure rainfall for both locations. Rainfall and runoff rates at both sites were continuously collected every two minutes.

Figure 5: Swiss Alps Contributing Drainage Area

LEVEL SPREADERS AND DOWNSLOPES

Ozark Path and Swiss Alps storm drain outfalls are each dispersed across a 130 ft. level spreader during storm events. However, it should be noted that qualitative monitoring showed that only a portion of the level spreader length was effective at distributing runoff into sheetflow. These level spreaders are a rock berm design and comprised of 3”-5” open graded rock encased in woven wire sheathing and can be seen in Figures 6 and 7. The level spreader is designed to convert a concentrated inflow into a uniform exit sheetflow to distribute across the VFS. LCRA 2007 defines sheetflow as a flow depth less than 0.2 feet with a velocity less than one foot per second during the 1-year, 3-hour storm.

Figure 6: Ozark Path Level Spreader

Figure 7: Swiss Alps Level Spreader

The rock berm level spreaders generate sheetflow upslope of a natural VFS approximately 70 ft. in flow length. The last portion of the natural VFS is a Glen Rose Formation riser with slopes greater than 30%. Following the initial abstraction and infiltration along the natural VFS remaining runoff is collected at the toe of the risers with 8 in. PVC collection pipes shown in Figures 8 and 9. The collection pipes are installed flush with the ground level across the natural VFS with a longitudinal slope of approximately 0.5% to direct water to the monitoring collection box. Sod was placed and manicured directly upslope of the collection pipes to stabilize soil and attempt a water tight connection between the ground and collection pipes. Runoff flows into a collection box with a 1.5 ft. H-flume outfall at Ozark Path and 1.0 ft H-flume at Swiss Alps. These H-flume outfalls are equipped with both the ISCO 4230 bubbler flow meter and ISCO 3700 automatic sampler. Total flow volume was again calculated by integrating the flow rate hydrograph over the entire storm event and automatic samplers programmed to collect flow weighted composite samples. All flow meters, samplers and rain gauges are powered by a solar panel and marine deep cycle 12 volt battery.

Figure 8: Ozark Path Downslope Collector

Figure 9: Swiss Alps Downslope Collector

SAMPLING PROCEDURE

Prior to each predicted rain event collection pipes and flumes were cleaned out to remove any dirt, leaves, grass, or debris that had accumulated during the antecedent dry period. Ten liter capacity sample bottles were collected at the conclusion of each rain event and transported for analysis to Environmental Laboratory Services, a NELAC certified laboratory of the Lower Colorado River Authority (LCRA). Samples were delivered to the laboratory after rain events as soon as possible as permitted by operating hours.

Runoff volume and quality was compared between upstream and downstream of the natural VFS. The mass balance approach was used to calculate pollutant loads removed by the VFS: Mass In – Mass Out = Mass Removed. The analysis parameters and methods are shown below in Table 1.

Table 1: Parameters and Analysis Methods by Environmental Laboratory Services

Parameter	Units	Method (USEPA, 2003)	Practical Quantification Limit
Total Suspended Solids	mg/L	E160.2	1
Total Kjeldahl Nitrogen	mg/L	E351.2	0.02
Nitrate and Nitrite as N	mg/L	E353.2	0.02
Total Phosphorus	mg/L	E365.4	0.02
Dissolved Phosphorus	mg/L	E200.8	0.02
Total Copper	mg/L	E200.8	2
Dissolved Copper	mg/L	E200.8	1
Total Zinc	mg/L	E200.8	5
Dissolved Zinc	mg/L	E200.8	4

Natural VFS treatment success is determined primarily based on two of the above analysis parameters, total suspended solids (TSS) and total phosphorus (TP). These parameters are chosen as success metrics based upon the primary concerns of the regulatory authorities. The monitoring site drainage area ultimately discharges to Lake Travis, one of the Highland Lakes. Lake Travis is classified as mesotrophic (TCEQ, 2008), signifying moderate nutrient concentrations and is one of the clearest lakes in Texas. As such, the LCRA's primary concerns include sedimentation and eutrophication, which is phosphorus limited. Thus, TSS and TP are extremely relevant pollutants and crucial to maintaining Lake Travis and downstream receiving waters health and ecological balance.

The Falconhead West Development includes a total of 18 LS-VFS systems (including Ozark Path and Swiss Alps). During the sampling period a qualitative monitoring review was conducted on all LS-VFS systems. Photographs were taken every three months to document BMP status and performance. Progressing time series photos of all sites can be found in Appendix E with analysis summarized in the Qualitative Monitoring results section.

HYDROLOGIC UNCERTAINTIES

One of the major sources of uncertainty associated with the natural VFS monitoring is in flow measurements. Area velocity flow meters, as used at the upstream of Swiss Alps, are not the ideal choice of monitoring equipment because of the uncertainty introduced from each of the two parameters (flow area and velocity) that must be measured. Both sites storm drain inflow pipe incurs a 90 degree bend upstream from the measurement location. This sharp turn increases hydraulic turbulence and uncertainty in the flow measurement. Additionally, sediment accumulation can occur near the outfall of the storm drain systems, creating a backwater effect. Backwater would violate use of Manning's equation under uniform flow to calculate normal depth and lead to upstream flow overestimation.

The major source of downstream collector uncertainty is introduced in capturing 100% of the overland runoff flow. Losses are expected to occur between the uneven terrain and PVC collection pipe. Site construction included installing the collection pipe as flush with the ground as possible and placing sod directly upslope to stabilize soil and create a seal to the collector pipes. Even with these measures, some runoff flow was observed to escape between the collection pipe and ground surface. Lost flow is expected to be particularly apparent during a low intensity storm with shallow, low velocity runoff and leads to underestimation of downstream flow measurements. H-flume flow monitors also produce uncertainty due to contractual obligations forcing H-flume sizing to be capable of measuring the 2-year storm event. Midway through the monitoring period the Ozark Path site downstream collector box experienced cracks due to weathering that required additional re-sealant.

In conclusion, multiple parameters existed during sampling that would indicate uncertainty in upstream flow measurements and downstream flow measurements, so reported volumes should be considered the minimum volume. However, from inspection of rainfall runoff correlation results, these upstream and downstream uncertainties appear to be systematic and not overwhelming in comparison to total runoff generated. Runoff reductions resulting from infiltration are a primary treatment mechanism. Recognizing measurement uncertainties, volumetric reduction results should be considered as the upper limit of potential volumetric reduction.

Chapter 4: Results

HYDROLOGIC DATA AND SAMPLES

During the monitoring period central Texas has been in a Stage 4 “exceptional” drought crisis (USDA, 2009). Available storm events (or lack thereof) presented a major data collection hurdle. Since the natural VFS monitoring began in June 2008, 12 storm events were captured for upstream (untreated) inflow samples. From the sampled events a total of 10 paired samples (including both upstream and downstream) were collected, 7 at Ozark Path and 3 at Swiss Alps. Fewer downstream samples were collected at the Swiss Alps site due to smaller volumes discharged from the VFS.

Monitored storm event dates, rainfall, runoff volumes, and sample data are presented in Table 2. Runoff volumes depicted by (-) indicate that flow volumes were not measured due to site vandalism or other damage to monitoring equipment. Rainfall on 1/28/2009 depicted in brackets was calculated by interpolation from runoff coefficient graphs. Interpolation was required due to zero recorded rainfall, likely because the tipping bucket rain gauge was frozen.

The first sample collected at the Ozark Path site was not used to determine system performance. The sample was discarded after discovery that the downstream collection point included a larger drainage area than strictly the contributing drainage area of the upstream natural VFS, making influent and effluent comparisons impossible. This discrepancy was corrected by installing silt fences to steer adjacent drainage area runoff away from downstream collection, thus isolating the monitoring site drainage area and confirming that both sampling locations incorporated the same contributing drainage area.

Construction began in the Swiss Alps drainage area midway through the sampling period. Ground clearing and land development activities created further monitoring challenges. Disturbed ground cover and additional storm drain installation led to large variance in runoff quality and volume. These changes to the contributing watershed effectively broke the monitoring location into two distinct sites, Swiss Alps pre and post-construction.

Table 2: Hydrologic Monitoring Data

		Runoff (m^3)					
				Pre-construction		Post-construction	
Event Date	Rainfall (in)	Ozark Path1	Ozark Path2	Swiss Alps1	Swiss Alps2	Swiss Alps1	Swiss Alps2
7/23/2008	0.12	1.26	0.407	3.392	0		
7/24/2008	1.92	13.617	28.776	41.956	3.602		
8/16/2008	0.77	12.18	20.662	23.709	1.806		
8/19/2008	1.4	15.504	49.561	65.347	0.731		
8/26/2008	1.05	12.101	49.629	37.154	0.147		
10/7/2008	0.44	19.146	0.142	14.385	0		
10/14/2008	0.34	3.614	0.302	10.911	0		
10/15/2008	1.11	16.363	8.505	43.114	0.009		
1/6/2009	0.41	66.509	-	3.674	-		
1/28/2009	[0.53]	18.489	-	13.948	-		
2/9/2009	0.46	85.169	-	39.294	0		
2/11/2009	0.48	15.918	-			6.769	0.407
3/12/2009	2.13	981.464	12.809			98.216	3.161
3/25/2009	0.41	117.312	0.103			16.542	0.01
3/26/2009	0.13	64.937	0			7.392	0
4/2/2009	0.49	201.935	0.662			20.267	0.009
4/11/2009	0.22	62.787	0			5.096	0
4/18/2009	1.69	250.771	9.402			143.172	33.53
4/27/2009	0.67	180.771	0.071			32.128	0.001
5/16/2009	0.67	146.703	1.317			28.779	0

Sample collected
Paired sample for statistical analysis

Water Quality Analysis

Runoff was measured for total suspended solids, total and dissolved nutrients and metals. Pollutant average concentration upstream and downstream of the natural VFS along with statistical significance can be seen in Table 3. A two-tailed unequal variance Student's T-test was performed on upstream and downstream pollutant event mean concentrations. A paired T-test is presented subsequently for TSS and TP for all available paired samples. Student's T-test is designed for small sample sizes where the standard deviation is unknown. The T-test assumes that the difference in paired sample arrays is normally distributed and returns the probability associated that the difference in population means could be attributed to randomness.

Table 3: Influent and Effluent Event Mean Concentrations

		Ozark Path 1	Ozark Path 2	T-test probability
# of Events Sampled		12	7	
Total Suspended Solids	(mg/L)	76.30	73.20	0.94
Total Kjeldahl Nitrogen	(mg/L)	1.18	2.15	0.26
Total Phosphorus	(mg/L)	0.18	0.21	0.73
Nitrate and Nitrite as N	(mg/L)	0.38	0.22	0.05
Dissolved Phosphorus	(mg/L)	0.08	0.04	0.16
Total Copper	(µg/L)	4.50	2.70	0.14
Total Zinc	(µg/L)	21.56	16.85	0.43
Dissolved Copper	(µg/L)	2.76	1.48	0.03
Dissolved Zinc	(µg/L)	3.96	3.98	0.99

		PreSwiss Alps 1	PreSwiss Alps 2	T-test probability	PostSwiss Alps 1	PostSwiss Alps 2	T-test probability
# of Events Sampled		6	0		6	3	
Total Suspended Solids	(mg/L)	225.33	-	-	1149.67	540.57	0.20
Total Kjeldahl Nitrogen	(mg/L)	1.86	-	-	2.39	1.81	0.46
Total Phosphorus	(mg/L)	0.18	-	-	0.30	0.23	0.58
Nitrate and Nitrite as N	(mg/L)	0.48	-	-	0.43	0.34	0.61
Dissolved Phosphorus	(mg/L)	0.02	-	-	0.04	0.06	0.75
Total Copper	(µg/L)	4.46	-	-	7.13	7.93	0.85
Total Zinc	(µg/L)	22.17	-	-	34.93	125.50	0.50
Dissolved Copper	(µg/L)	2.15	-	-	1.16	3.30	0.47
Dissolved Zinc	(µg/L)	2.60	-	-	2.00	9.44	0.27

No samples were captured at the downstream Swiss Alps site before construction began on the contributing drainage area. Ozark Path treatment of nitrate/nitrite as nitrogen and dissolved copper are the only differences in concentrations found statistically significant by the unequal variance T-test. The Swiss Alps site contradicts the dissolved copper reduction significance with downstream dissolved copper concentrations approximately three times that of the upstream. However, the downstream increase in concentration is primarily from one highly concentrated effluent event that also resulted in both zinc and copper increasing in downstream concentrations at the Swiss Alps site. Other constituents include variable degrees of increase or decrease of pollutant concentration, although none are found statistically significant. Receiving water body primary concerns include sedimentation and phosphorus limited eutrophication. Total suspended solid and total phosphorus concentrations are highlighted in Table 3 with paired T-test, percent removal, and pollutant load reduction further investigated in the following sections.

Variation in antecedent dry periods, drainage area stabilization, storm durations and intensities lead to large variability in performance of natural VFS. The LCRA Water Quality Management Technical Manual guidelines are based on the design of BMPs to remove 70% of the TSS and TP incremental increase caused by development. However, Strecker et al. (2001) advocates that runoff effluent quality is a more robust measure of BMP performance than percent removal. Percent removal of pollutants is strongly dependent on influent concentrations and discourages source controls (Strecker et al. 2001). As such, the effectiveness of treating urban stormwater runoff with natural vegetative filter strips will be analyzed as both pollutant percent removal and with regards to final effluent quality.

Paired sample influent and effluent EMC for TSS and total phosphorus along with mean, median, and two tailed paired T-test significances are presented in Table 4. Both site locations are within the same single family residential development. However, the Ozark Path site is located on a cul-de-sac with 100% completed lot construction and stabilized landscaping. During the sampling period the Swiss Alps site incurred ongoing dirt work that created a contributing drainage area more representative of a construction site than a stable urban watershed. This disturbance in ground cover and activity led to major increases in pollutant load, particularly total suspended solids. The site landscaping and ground cover stability variation created large differences in influent concentrations between the two monitoring sites. Although limiting repeatability, this site deviation allowed for observation of natural VFS performance under a large variation of influent pollutant concentrations and loads.

Table 4: Paired Sample Event Mean Concentrations

Ozark Path EMC (mg/L)						
Date	**TSS1**	**TSS2**	**T-Test**	**TP1**	**TP2**	**T-Test**
10/15/2008	22.0	23.0		0.142	0.067	
2/11/2009	390	202		0.414	0.545	
3/12/2009	58.8	27.9		0.126	0.062	
3/25/2009	124	37.6		0.093	0.100	
4/17/2009	36.7	69.0		0.114	0.386	
4/27/2009	34.3	97.6		0.078	0.123	
5/16/2009	7.4	55.3		0.186	0.191	
Mean	**96.2**	**73.2**	**0.520**	**0.165**	**0.211**	**0.356**
Median	**36.7**	**55.3**		**0.126**	**0.123**	

Post-Construction Swiss Alps EMC (mg/L)						
Date	**TSS1**	**TSS2**	**T-Test**	**TP1**	**TP2**	**T-Test**
2/11/2009	1480	445		0.321	0.239	
3/12/2009	445	16.7		0.193	0.048	
4/17/2009	1650	1160		0.461	0.406	
Mean	**1192**	**541**	**0.078**	**0.325**	**0.231**	**0.072**
Median	**1480**	**445**		**0.321**	**0.239**	

The more stabilized cleaner influent site, Ozark Path, did not exhibit consistent decreases in concentration for either TSS or TP. However, it is important to note that the untreated influent runoff at Ozark Path had lower TSS and TP concentrations than the LCRA Technical Manual estimates for developed watersheds, shown in Table 5, and for some events, even lower concentrations than that expected in undeveloped watersheds.

Table 5: LCRA Expected Concentrations

Constituent	Predevelopment Conditions	Developed Conditions
TSS (mg/L)	48	130
TP (mg/L)	0.08	0.26

The Swiss Alps monitoring location included a drainage area approximately half the size of Ozark Path. As such, larger more intense storm events were required to collect samples below the VFS, leading to fewer paired sample events. The Swiss Alps high pollutant influent concentrations led to substantial reductions in downstream TSS and TP EMCs. Although the observed EMC reductions are larger when the influent concentrations are higher, both sites exhibit significant reduction between upstream and downstream runoff volumes. This large runoff reduction coupled with EMC reduction (although variable) generates a substantial load reduction in observed constituents.

RUNOFF COEFFICIENTS

Monitored hydrologic data was used to calculate runoff coefficients upstream and downstream of the VFS. Hydrologic monitoring upstream of both VFS began in January 2008 before downstream equipment was installed. This additional rainfall-runoff data was used in runoff coefficient calculations. During the second half of the monitoring period sediment accumulation occurred near the Ozark Path upstream sampling location. Sediment deposition was a common occurrence observed to varying degrees at most storm drainage outfalls. However, the deposited sediment and debris created a backwater effect at the Ozark Path location. The Ozark Path site bubbler flow meter measures flow rate with Manning's equation, which assumes no backwater present. Backwater effects led to drastically overestimated upstream runoff volume measurements for the latter period at upstream Ozark Path. As such, this monitoring data was not employed to calculate runoff coefficient values.

Initial runoff volumes monitored at the downstream Ozark Path site were also not used to determine the site runoff coefficient. As previously noted, these runoff volumes were discarded after discovery that the downstream collection point included a larger drainage area than strictly the contributing drainage area of the upstream natural VFS, making hydrologic flow comparisons inappropriate. Silt fences were installed to isolate and confirm matching drainage areas. Both downstream flow monitoring locations were temporarily offline due to site vandalism or other damage to monitoring equipment.

Runoff coefficients were calculated by dividing the summation of runoff volumes, converted to inches by dividing by the contributing drainage area, by the summation of corresponding rainfall, and are shown in Table 6. Values used for runoff coefficient calculation are presented in Appendix A.

Table 6: Monitored Runoff Coefficients

	Ozark Path1	Ozark Path2	Swiss Alps1	Swiss Alps2
Runoff Coefficient	**0.190**	**0.047**	**0.721**	**0.020**

Infiltration along the natural VFS on the Glen Rose Formation risers led to an average of 75% and 97% runoff reduction at Ozark Path and Swiss Alps monitoring sites respectively. Runoff volume reduction is a key treatment parameter of VFS. Other BMP controls are effective at settling out pollutants such as TSS. However, to reduce the discharge of soluble pollutants, such as dissolved phosphorus, reduction in runoff volume is the most practical approach. Although many nutrients are adsorbed onto the sediment and are thus removed with settling, volume reduction makes VFS an attractive option and is often recommended for use in combination with other BMPs (LCRA, 2007).

Each monitoring location rainfall and runoff results for individual events are presented in Figures 10-13. Distinctions between upstream and downstream runoff ratios can be seen in the slope of the regression line. Larger runoff ratios occur upstream of the VFS with the 1:1 rainfall to runoff ratio presented for comparison. Initial abstraction is also evident at both downstream locations. Approximately 0.4 in. of initial abstraction occurs in both VFS before the downstream collectors observe any flow. This initial abstraction makes capturing paired upstream and downstream samples only possible for moderate to large storm events.

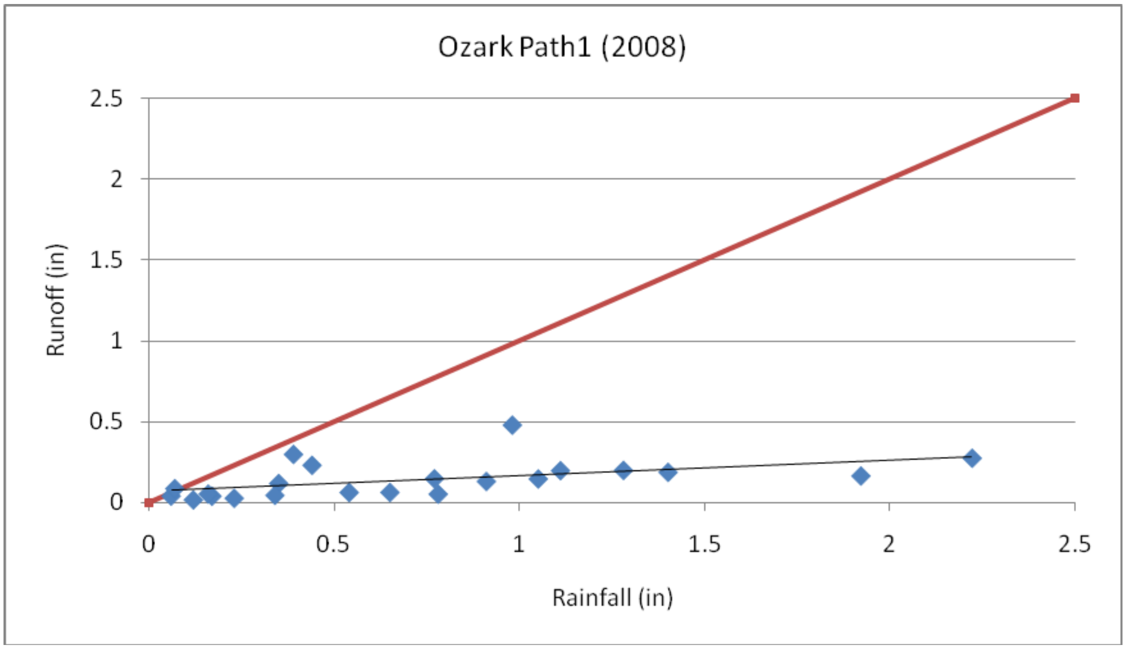


Figure 10: Ozark Path Upstream Rainfall-Runoff; Runoff = 0.10 × Rainfall + 0.07

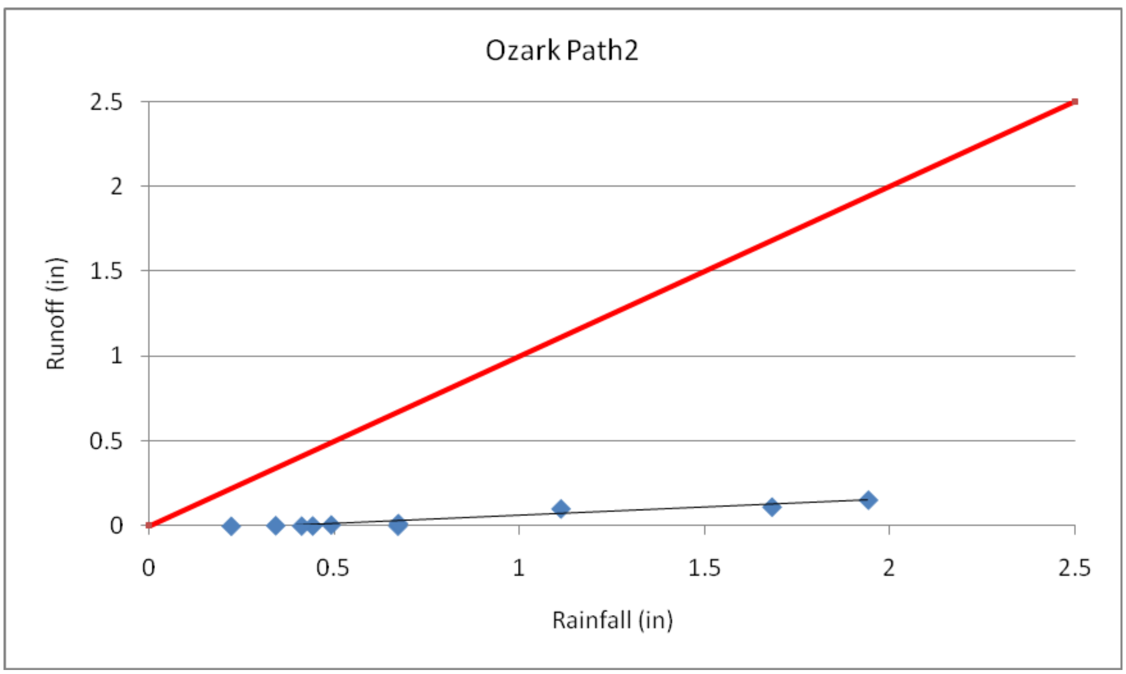


Figure 11: Ozark Path Downstream Rainfall-Runoff; Runoff = 0.10 × Rainfall - 0.04

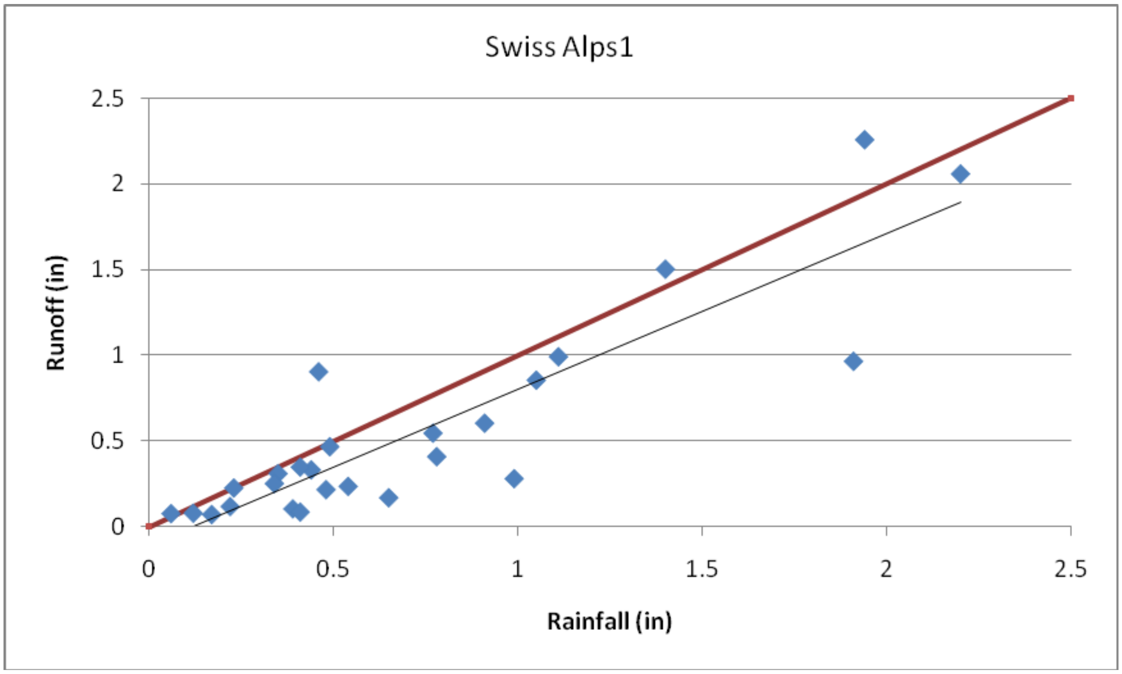


Figure 12: Swiss Alps Upstream Rainfall-Runoff; Runoff = 0.91 × Rainfall - 0.01

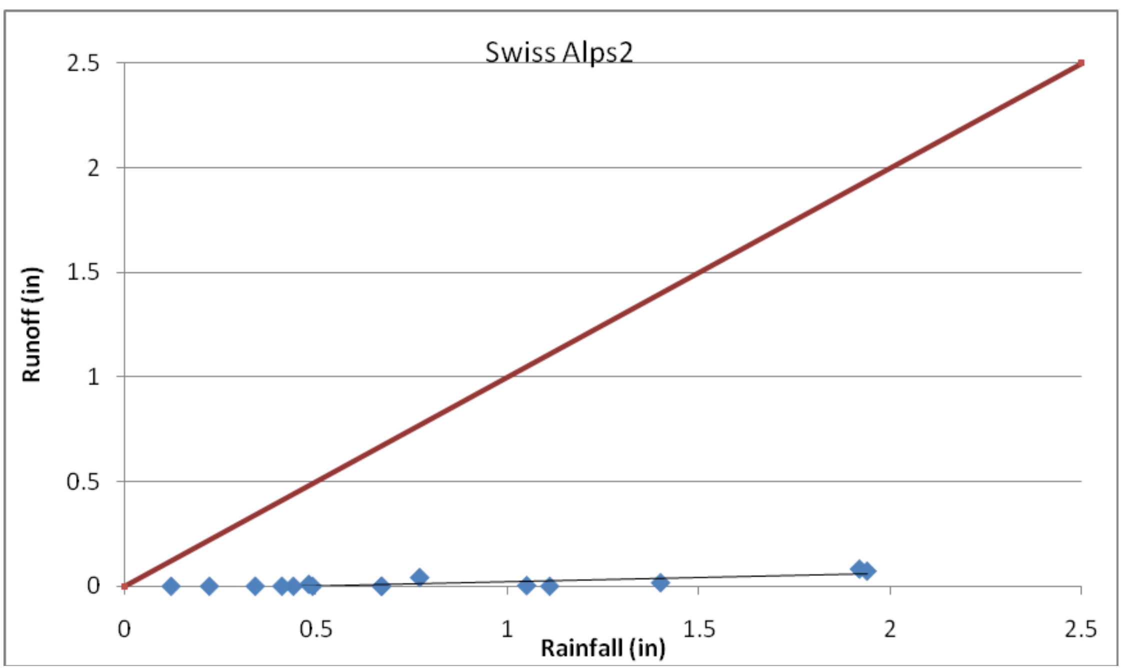


Figure 13: Swiss Alps Downstream Rainfall-Runoff; Runoff = 0.04 × Rainfall - 0.02

PEAK FLOW RATE AND RAINFALL INTENSITY

Variation in rainfall intensity and antecedent moisture conditions also affect the VFS performance. Runoff volumes downstream of VFS correlate positively with rainfall intensity as well as total rainfall. In addition to volume reduction, significant peak flow rate abatement was observed with natural VFS treatment. Peak flow rates were reduced by 45% and 97% on average at Ozark Path and Swiss Alps respectively. Storms events when both Ozark Path upstream and downstream flow measurements were accurate limited available data for peak flow rate calculation. Available Ozark Path data included subsequent storm events that created wetter than average antecedent moisture conditions and biased peak flow rate reduction calculations, which are predicted to be larger in reality. Peak flow rates and reduction percentages are presented in Appendix B.

ANNUAL POLLUTANT LOADS

Table 7 shows the LCRA Nonpoint Source Pollution Control Technical Manual method for estimating annual pollutant load. These calculations are made with a rainfall to runoff coefficient (Rv). Rv represents the total average annual runoff divided by the total average annual rainfall for a watershed with corresponding level of impervious cover (LCRA, 1998). The relationship between runoff coefficient and impervious cover is based on field runoff flow measurements conducted by the City of Austin for a range of watersheds in the Austin area.

Table 7: Annual Pollutant Load Calculation (LCRA, 1998)

L = A * RF * Rv * 0.2266 * C L = Annual pollutant load (lbs) A = Contributing drainage area (acres) RF = Average annual rainfall volume (inches) Rv = Runoff coefficient 0.2266 = Unit conversion factor C = Average annual pollutant concentration (mg/L)

LCRA load calculations assume different TSS and TP event mean concentrations for developed and pre-developed conditions. Table 8 compares LCRA concentrations with observed monitored values. The LCRA TSS and TP event mean concentrations were derived with local data from the City of Austin's Stormwater Monitoring Program (1988) along with additional USEPA and other nationwide reports in determining appropriate stormwater runoff pollutant concentrations.

Table 8: TSS and TP Concentrations

	LCRA Concentrations		Ozark Path		Swiss Alps Pre-Construction		Swiss Alps Post-Construction	
	Post-Developed	Pre-Developed	Untreated	Treated	Untreated	Treated	Untreated	Treated
TSS (mg/L)	130	48	76.3	73.2	225.3	-	1149.7	540.6
TP (mg/L)	0.26	0.08	0.18	0.21	0.18	-	0.30	0.23

The LCRA prescribes BMP design standards to reduce the *incremental* increase in TSS and TP load caused by development. Non-shore locations within Travis County require 70% reduction of the incremental load increase. Table 9 presents site parameters for LCRA annual pollutant load estimation. Comparisons between LCRA predicted pre-development pollutant load, post development (with and without VFS treatment), and monitored pollutant loads (with and without VFS treatment) are shown in Table 10. Percent removal of incremental load caused by development is compared between LCRA's design standards and monitored natural VFS stormwater treatment.

Table 9: Parameters for LCRA Annual Pollutant Load Calculation

	Ozark Path	Swiss Alps
Drainage Area (acres)	0.8	0.42
Rainfall (inches)	32	32
Runoff Coefficient (undeveloped)	0.049	0.049
Runoff Coefficient (68,60% impervious)	0.506	0.424
Unit Conversion	0.2266	0.2266

Table 10: Predicted and Monitored Annual Pollutant Load and Percent Removal

Annual Pollutant Load (lbs) (with 32 in. of rainfall)										
Pre-Development (LCRA, 1998)	LCRA (1998)									
	Ozark Path		Swiss Alps							
	TSS	TP	TSS	TP						
	13.6	0.023	7.2	0.012						
Post Development (untreated)	LCRA				Monitored Upstream					
	Ozark Path		Swiss Alps		Ozark Path		Pre-Swiss Alps		Post-Swiss Alps	
	TSS	TP	TSS	TP	TSS	TP	TSS	TP	TSS	TP
	381.6	0.763	167.9	0.336	84.1	0.200	494.8	0.397	2524.5	0.659
Post Development (with VFS treatment)	LCRA				Monitored Downstream					
	Ozark Path		Swiss Alps		Ozark Path		Swiss Alps		Post-Swiss Alps	
	TSS	TP	TSS	TP	TSS	TP	TSS	TP	TSS	TP
	110.4	0.222	48.2	0.097	20.1	0.058	-	-	32.7	0.014
Percent Removal of Additional Load	**0.70**	**0.70**	**0.70**	**0.70**	**0.72**	**0.67**	**-**	**-**	**0.99**	**0.98**

Both monitoring locations achieve lower pollutant effluent loads than expected with LCRA design standards. As previously noted the Swiss Alps site experienced influent pollutant concentrations much greater than a typical single-family residential area. The combination of major pollutant concentration and runoff volume reductions achieved 98% and 99% reductions in TP and TSS respectively. However, even with the increased influent concentrations the Swiss Alps VFS still produced lower effluent loads than assumed by LCRA with 70% removal.

Ozark Path achieved annual pollutant load reductions of 72% in TSS and 67% in TP. TP at the Ozark Path site is the only occurrence below the LCRA 70% removal of TSS and TP additional load. The lower percent removal of additional pollutant is due to the clean untreated influent at this site. TSS and TP influent concentrations at Ozark Path were cleaner than LCRA developed site predictions by 41% and 31% respectively. The relatively clean influent led to lower percent removal of additional load while still achieving post-treatment annual effluent loads below those expected with LCRA design standards. Runoff volume reduction was the primary treatment mechanism in achieving the load reductions. In summary, the two monitoring sites studied presented runoff coefficients and influent concentrations below LCRA predictions (Ozark Path) and above LCRA predictions (Swiss Alps). However, both sites achieve lower pollutant effluent loads than required by LCRA design standards.

QUALITATIVE MONITORING

Every three months a qualitative review was conducted of the 18 LS-VFS systems in the Falconhead West Development. This review was helpful in identifying trends of BMP performance and required maintenance. Over the monitoring and inspection period multiple flow level spreaders became increasingly filled with sediment and debris. Three level spreaders incurred breaks in the woven wire sheathing containing the rock berm. Figure 14 shows a break in the rock berm wire cage of system M. Breaks in the wire basket can indicate that concentrated inflow to the level spreader is not dissipating into shallow sheetflow but was staying concentrated in the break location. A map of all LS-VFS systems and time series photo documentation are presented in Appendix E and F respectively.

Figure 14: Break in Rock Berm Wiring of System M

Even in cases when woven wire cages were not broken significant downstream erosion was apparent at multiple sites. Figure 15 presents erosion downslope of the level spreader of system T. The erosion can be an indication of level spreaders not functioning appropriately, due to faulty construction or placement on a non-uniform grade. A level spreader field evaluation by Hathaway and Hunt (2009) found similar results with lack of maintenance and buffer topography as the leading causes of level spreader system malfunctions. Even when spreaders are functioning properly variable topography along the natural VFS can cause flow to re-concentrate causing increased erosion and short circuiting of the VFS, reducing the potential VFS treatment performance.

Figure 15: Downslope Erosion on System T

Sediment deposition behind the level spreaders indicates that this area provides pretreatment prior to the natural VFS. However, as the level spreaders approach sediment capacity runoff will eventually circumnavigate the flow spreader and enter the VFS in concentrated flow. Figure 16 illustrates sediment accumulation in LS-VFS system V.

Figure 16: Sediment Accumulation in System V

These observations are evidence of the need for maintenance access of LS-VFS systems. Most LS-VFS systems in the reviewed residential development are isolated behind continuous residential fences of developed lots, shown in Figure 17. Maintenance access to the level spreaders should be considered during design to provide opportunities for sediment removal, berm repair, and other activities.

Figure 17: Lack of Maintenance Access to LS-VFS Systems

Chapter 5: Conclusions

The results show that natural vegetated filter strips (VFS) perform well in areas of relative high slopes characteristic of many locations on the Glen Rose Formation. Natural VFS treatment reduced TSS and TP pollutant loads by 72-99% and 67-99% respectively and achieved lower than predicted LCRA annual pollutant load discharges. Results indicate the primary treatment mechanism for load reduction of constituents is volume reduction by infiltration. Ozark Path and Swiss Alps experience 75% and 97% average runoff volume reduction respectively. Infiltration is the most practical treatment mechanism of BMPs to reduce soluble pollutants and includes the ancillary benefit of increased groundwater recharge.

This study also shows that filtration and particle settling are only strongly apparent with large influent concentrations (Swiss Alps), but that volume reduction is dependent on the underlying geology and is effective at all pollutant concentrations. In addition to volume reduction, VFS reduced peak flow rates by 45% and 97% at Ozark Path and Swiss Alps, respectively. Reductions in volume and peak flow rate make natural VFS an attractive option for both small and large storm events. Results also indicate that approximately the first 0.4 in. of rainfall is absorbed in initial abstraction and that runoff volume varies with rainfall intensity as well as total rainfall volume.

The qualitative review conducted showed that level spreader construction and VFS topography play a major role in treatment effectiveness and downslope erosion. Future LS-VFS systems should include available maintenance access and are recommended to include larger gauge wire sheathing for rock berm level spreaders. Filter strips should be sited in areas that are relatively smooth and level spreaders constructed across a level uniform grade to minimize the re-concentration of sheet flow. Poor design can lead to low treatment effectiveness and increase required maintenance.

Development activities' sharp increases on runoff volume, peak flow rates, and pollutant concentration have adverse impacts on surrounding ecology. Natural VFS assist in minimizing impervious cover and maintaining natural vegetation and habitats. Reduction in pollutant load, runoff volume and peak flow rate are the key components of Low Impact Development that the natural VFS design promotes. This study has shown that appropriately designed natural VFS are effective at treating stormwater from residential urban watersheds and should be a utilized BMP as development continues.

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Appendices

APPENDIX A: RUNOFF COEFFICIENT CALCULATION

		Runoff (m^3)			
Event Date	Rainfall (in)	Ozark Path1	Ozark Path2	Swiss Alps1	Swiss Alps2
1/31/2008	0.06	3.279		3.28	
2/15/2008	0.08	7.101		4.86	
3/3/2008	0.17	3.199		3.043	
3/6/2008	0.39	24.753		4.487	
3/10/2008	0.98	39.836		12.151	
3/18/2008	1.28	16.524		11.245	
4/17/2008	0.54	5.073		10.196	
4/25/2008	0.78	4.264		17.755	
4/27/2008	2.22	22.778		89.537	
5/4/2008	0.16	4.281		1.165	
5/10/2008	0.23	2.111	8.901	9.785	2.637
5/14/2008	0.35	9.716	8.565	13.452	5.119
5/15/2008	0.65	5.131	6.999	7.307	12.05
6/30/2008	0.91	10.801	22.551	26.231	5.444
7/23/2008	0.12	1.26	0.407	3.392	0
7/24/2008	1.92	13.617	28.776	41.956	3.602
8/16/2008	0.77	12.18	20.662	23.709	1.806
8/19/2008	1.4	15.504	49.561	65.347	0.731
8/26/2008	1.05	12.101	49.629	37.154	0.147
10/7/2008	0.44	19.146	0.142	14.385	0
10/14/2008	0.34	3.614	0.302	10.911	0
10/16/2008	1.11	16.363	8.505	43.114	0.009
1/6/2009	0.41	66.509	-	3.674	-
1/28/2009	0.53	18.489	-	13.948	-
2/9/2009	0.46	85.169	-	39.294	0
2/11/2009	0.48	15.918	1.276	6.769	0.418
3/12/2009	2.13	981.464	12.809	97.469	3.161
3/25/2009	0.41	117.312	0.103	16.542	0.01
3/26/2009	0.13	64.937	0	7.392	0
4/2/2009	0.49	201.935	0.662	20.267	0.009
4/11/2009	0.22	62.787	0	5.096	0
4/17/2009	1.69	250.771	9.402	143.172	33.53

4/27/2009	0.67	180.771	0.071	32.128	0.001
5/16/2009	0.67	146.703	1.317	28.779	0
∑ Runoff (m^3)		252.63	34.59	664.91	9.89
Runoff (in)		3.03	0.42	15.29	0.23
∑ Corresponding Rainfall (in)		15.95	8.78	21.21	11.47
Runoff Coefficient		**0.190**	**0.047**	**0.721**	**0.020**

APPENDIX B: PEAK FLOW RATE RESULTS

Event Date	Rainfall (in)	Ozark Path1 (L/s)	Ozark Path2 (L/s)	Peak Flow Reduction (%)	Swiss Alps1 (L/s)	Swiss Alps2 (L/s)	Peak Flow Reduction (%)
7/23/2008	0.12	0.758	0.013	0.98	1.614	0	1.00
7/24/2008	1.92	7.139	16.249	-1.28	37.408	7.027	0.81
8/16/2008	0.77	1.447	8.908	-5.16	13.985	0.152	0.99
8/19/2008	1.4	14.443	38.658	-1.68	41.155	0.677	0.98
8/26/2008	1.05	7.856	29.29	-2.73	24.162	0.247	0.99
10/7/2008	0.44	19.517	1.338	0.93	20.493	0	1.00
10/14/2008	0.34	1.206	0.598	0.50	9.136	0	1.00
10/15/2008	1.11	5.449	5.93	-0.09	23.208	0.009	1.00
1/6/2009	0.41	7.64	-		0.284	-	
1/28/2009	[0.54]	7.196	-		2.709	-	
2/9/2009	0.46	18.916	-		3.104	0	1.00
2/11/2009	0.48	7.725	1.425	0.82	5.446	0.512	0.91
3/12/2009	2.13	48.875	1.805	0.96	9.033	0.927	0.90
3/25/2009	0.41	64.417	0.103	1.00	12.035	0.007	1.00
3/26/2009	0.12	39.201	0	1.00	2.519	0	1.00
4/2/2009	0.49	63.406	0.491	0.99	7.928	0.009	1.00
4/11/2009	0.22	36.031	0	1.00	3.359	0	1.00
4/18/2009	1.68	22.931	3.24	0.86	35.995	2.263	0.94
4/27/2009	0.67	14.697	0.076	0.99	11.45	0.002	1.00
5/16/2009	0.67	32.758	0.672	0.98	11.171	0	1.00
Average				0.45			0.97

APPENDIX C: EVENT MEAN CONCENTRATIONS

Table C-1: Ozark Path1 Event Mean Concentrations

	TSS (mg/L)	TKN (mg/L)	Total P (mg/L)	NO_3^- and NO_2^- as N (mg/L)	Dissolved P (mg/L)	Total Cu (µg/L)	Total Zn (µg/L)	Dissolved Cu (µg/L)	Dissolved Zn (µg/L)
8/19/2008	95	0.646	0.138	0.09	0.055	2.59	8.15	1.69	2
10/7/2008	96	2.45	0.532	0.6	0.266	11.5	32	7.5	8.89
10/16/2008	22	0.48	0.142	0.47	0.069	2.23	10.3	1.7	2
1/6/2009	11.8	0.71	0.168	0.6	0.131	2.27	9.1	1.69	2
1/28/2009	15.6	0.824	0.092	0.55	0.057	2.63	13	2.53	4.72
2/9/2009	24	0.707	0.095	0.14	0.046	2.68	13	2.21	2
2/11/2009	390	2.86	0.414	0.26	0.06	11.6	49.8	4.14	4.27
3/12/2009	58.8	1.25	0.126	0.51	0.04	5.57	39.8	3.36	8.1
3/25/2009	124	1.2	0.093	0.33	0.025	3.81	29.7	1.92	5.12
4/17/2009	36.7	0.919	0.114	0.13	0.064	2.3	16.4	1.41	2
4/27/2009	34.3	0.935	0.078	0.49	0.021	3.74	29.8	2	4.45
5/16/2009	7.4	1.13	0.186	0.35	0.112	3.04	7.66	3	2

Table C-2: Ozark Path2 Event Mean Concentrations

	TSS (mg/L)	TKN (mg/L)	Total P (mg/L)	NO_3^- and NO_2^- as N (mg/L)	Dissolved P (mg/L)	Total Cu (µg/L)	Total Zn (µg/L)	Dissolved Cu (µg/L)	Dissolved Zn (µg/L)
10/16/2008	23	0.505	0.067	0.08	0.026	1	7.64	0.5	2
2/11/2009	202	5.95	0.545	0.19	0.111	5.77	33	2.32	4.49
3/12/2009	27.9	0.395	0.062	0.12	0.027	2.31	31.9	1.49	13.4
3/25/2009	37.6	0.976	0.1	0.31	0.046	2.4	11.6	1.37	2
4/17/2009	69	3.43	0.386	0.14	0.067	1	9.73	1.18	2
4/27/2009	97.6	1.28	0.123	0.18	0.024	2.87	10	1.36	2
5/16/2009	55.3	2.49	0.191	0.5	0.01	3.57	14.1	2.14	2

Table C-3: Swiss Alps1 (Pre-Construction) Event Mean Concentrations

	TSS (mg/L)	TKN (mg/L)	Total P (mg/L)	NO_3^- and NO_2^- as N (mg/L)	Dissolved P (mg/L)	Total Cu (µg/L)	Total Zn (µg/L)	Dissolved Cu (µg/L)	Dissolved Zn (µg/L)
8/19/2008	270	2.83	0.33	0.19	0.01	4.73	21.3	0.5	2
10/7/2008	682	3.04	0.359	0.44	0.01	6.76	33	2.07	2
10/16/2008	317	1.56	0.178	0.01	0.01	2.91	27.3	0.5	2
1/6/2009	25.6	0.723	0.082	0.83	0.034	6.03	15.9	4.09	2
1/28/2009	20.4	1.11	0.071	1.04	0.024	3.59	20.4	3.44	5.57
2/9/2009	37	1.89	0.064	0.35	0.029	2.75	15.1	2.31	2

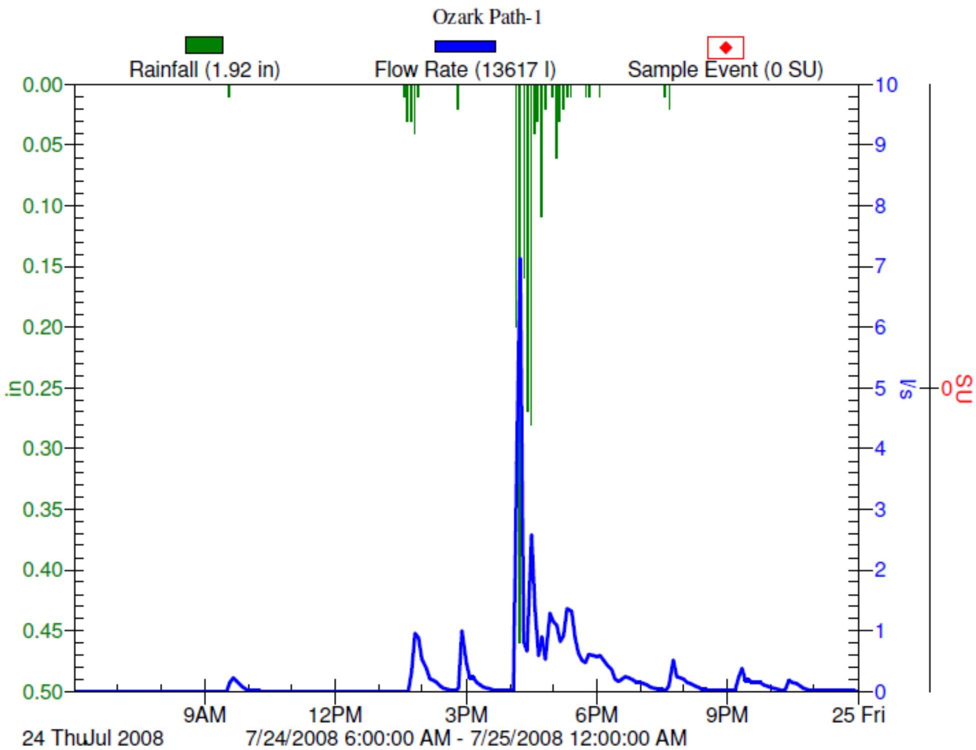
Table C-4: Swiss Alps1 (Post-Construction) Event Mean Concentrations

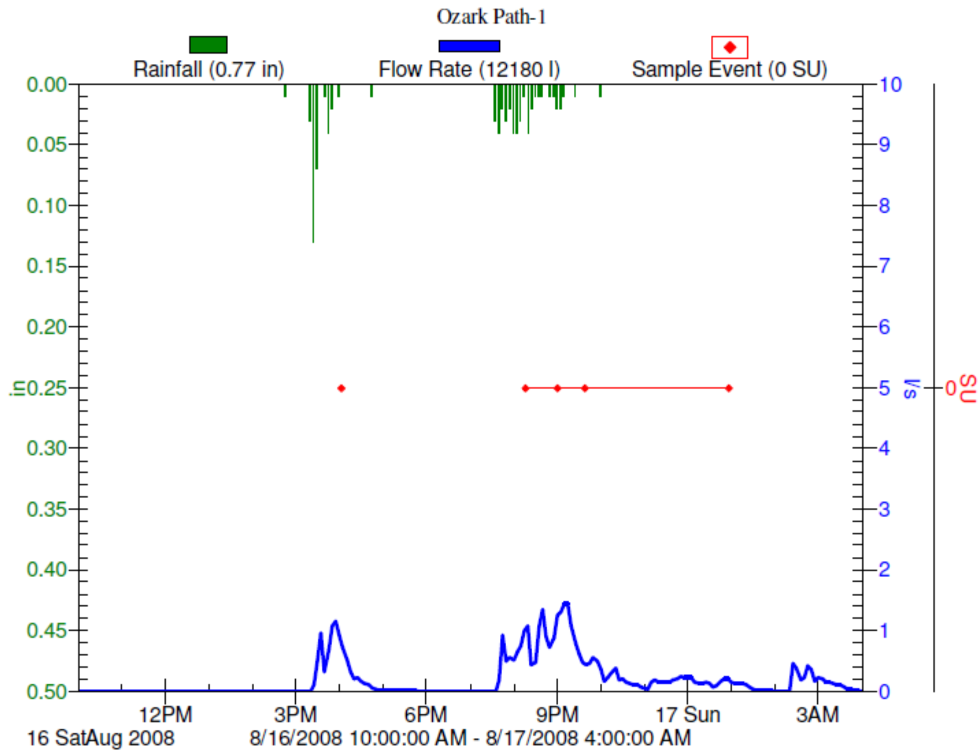
	TSS (mg/L)	TKN (mg/L)	Total P (mg/L)	NO_3^- and NO_2^- as N (mg/L)	Dissolved P (mg/L)	Total Cu (µg/L)	Total Zn (µg/L)	Dissolved Cu (µg/L)	Dissolved Zn (µg/L)
2/11/2009	1480	3.34	0.321	0.19	0.02	7.15	55.3	1.62	2
3/12/2009	445	2.07	0.193	0.57	0.023	6.46	37.2	1.56	2
3/25/2009	703	2.08	0.23	0.53	0.023	6.03	33.6	1.34	2
4/17/2009	1650	2.51	0.461	0.21	0.177	9.5	30.5	0.5	2
4/27/2009	1090	1.84	0.241	0.52	0.01	7.3	28.9	0.5	2
5/16/2009	1530	2.51	0.354	0.57	0.01	6.32	24.1	1.45	2

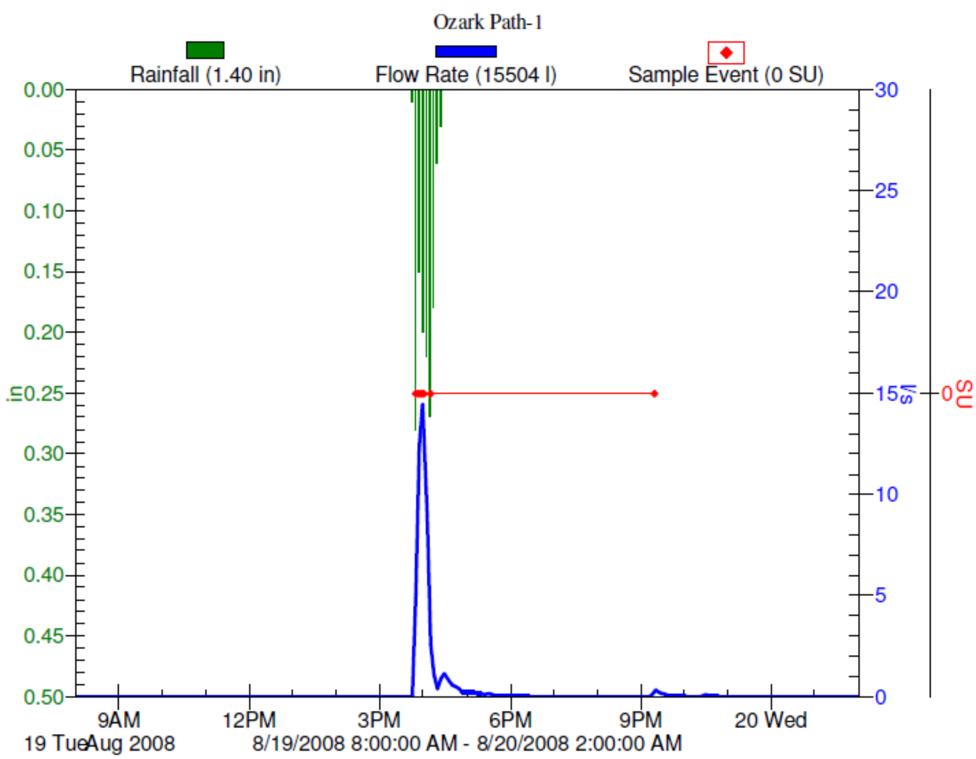
Table C-5: Swiss Alps2 (Post-Construction) Event Mean Concentrations

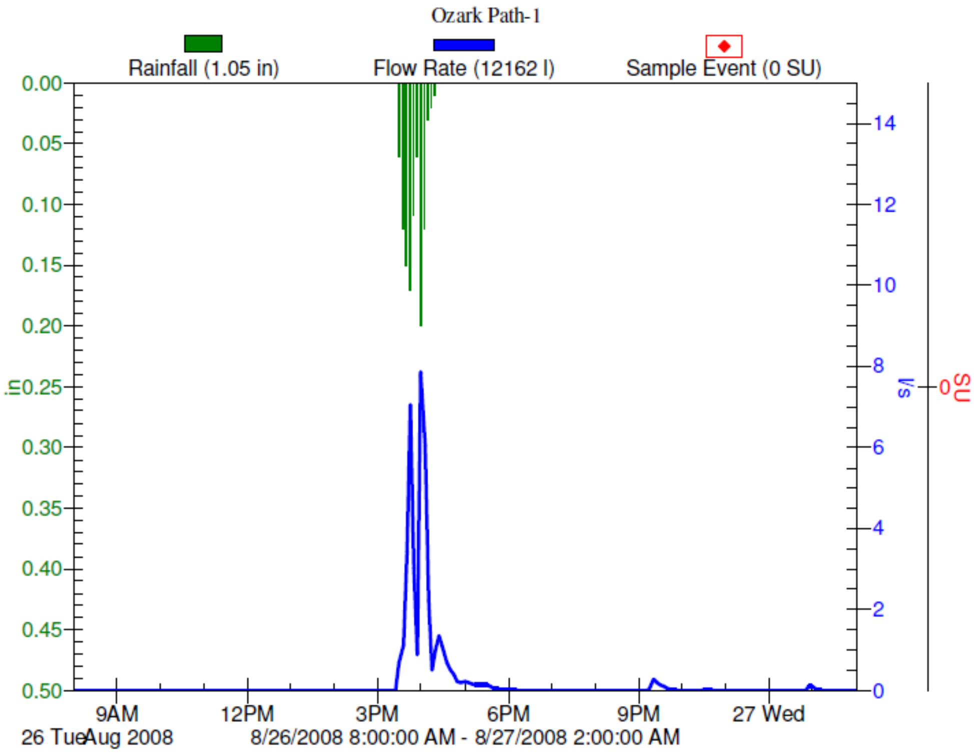
	TSS (mg/L)	TKN (mg/L)	Total P (mg/L)	NO_3^- and NO_2^- as N (mg/L)	Dissolved P (mg/L)	Total Cu (µg/L)	Total Zn (µg/L)	Dissolved Cu (µg/L)	Dissolved Zn (µg/L)
2/11/2009	445	2.78	0.239	0.63	0.021	14	345	8.05	18.6
3/12/2009	16.7	0.619	0.048	0.2	0.01	1	6.09	1.35	7.73
4/17/2009	1160	2.04	0.406	0.19	0.157	8.79	25.4	0.5	2

APPENDIX D: HYDROGRAPHS OF MONITORED STORM EVENTS




Ozark Path-1
Rainfall (0.77 in)
Flow Rate (12180 l)
Sample Event (0 SU)
in
l/s
SU
12PM
3PM
6PM
9PM
17 Sun
3AM
16 SatAug 2008
8/16/2008 10:00:00 AM - 8/17/2008 4:00:00 AM


Ozark Path-1
Rainfall (1.40 in)
Flow Rate (15504 l)
Sample Event (0 SU)
in
l/s
SU
9AM
12PM
3PM
6PM
9PM
20 Wed
19 TueAug 2008
8/19/2008 8:00:00 AM - 8/20/2008 2:00:00 AM


Ozark Path-1
Rainfall (1.05 in)
Flow Rate (12162 l)
Sample Event (0 SU)
in
l/s
SU
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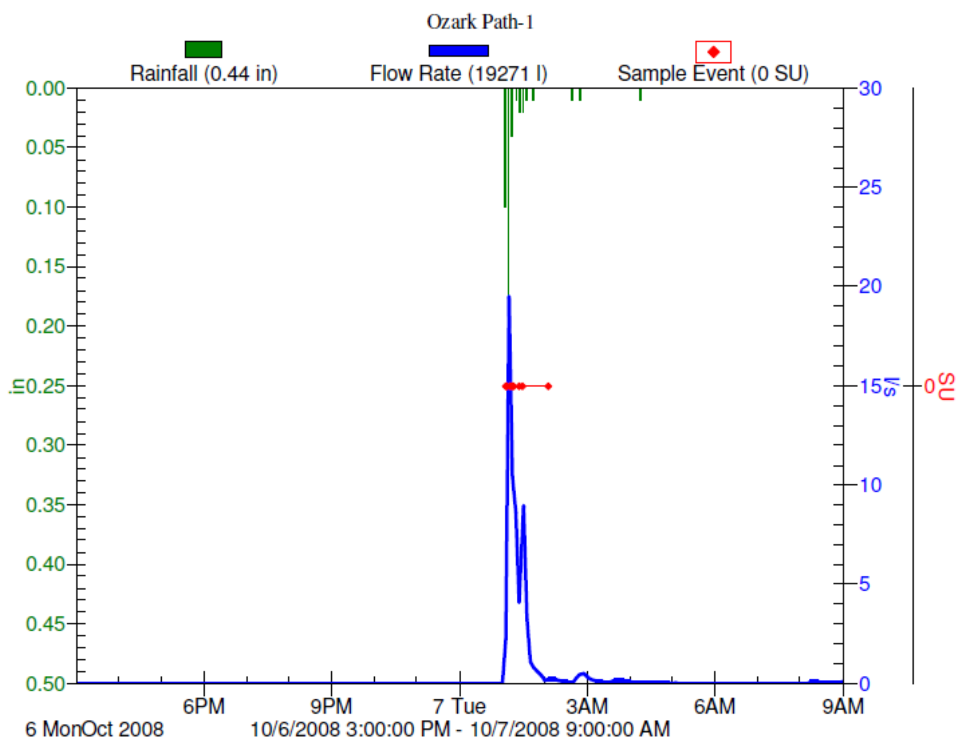
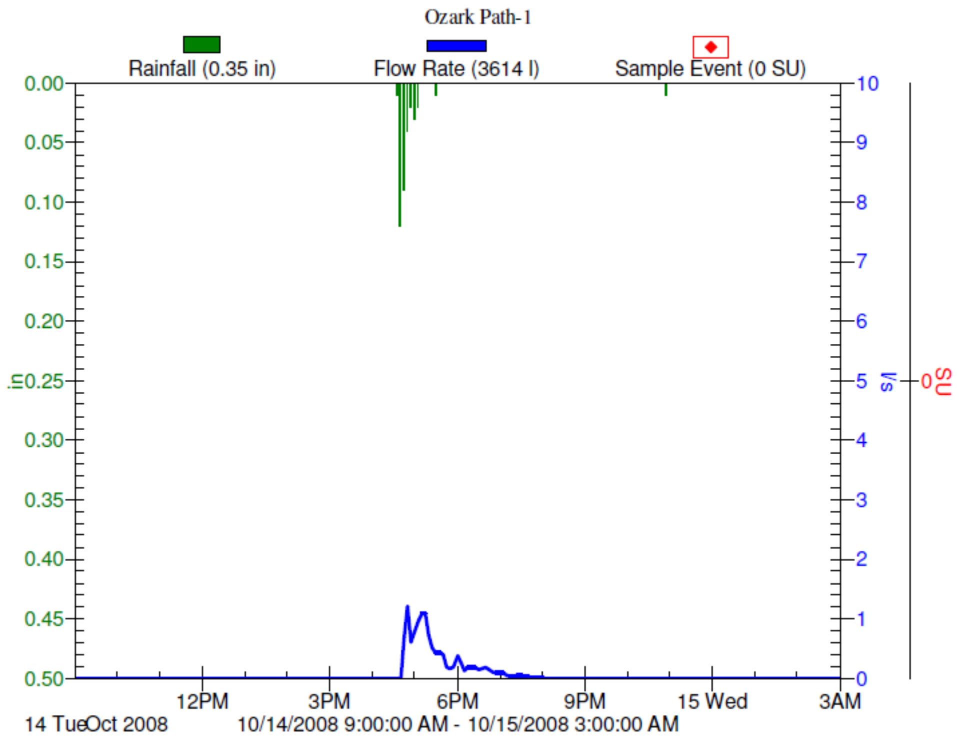
8/26/2008 8:00:00 AM - 8/27/2008 2:00:00 AM
9AM
12PM
3PM
6PM
9PM
27 Wed


Ozark Path-1
Rainfall (0.44 in)
Flow Rate (19271 l)
Sample Event (0 SU)
in
l/s
SU
6 Mon Oct 2008
10/6/2008 3:00:00 PM - 10/7/2008 9:00:00 AM
6PM
9PM
7 Tue
3AM
6AM
9AM


Ozark Path-1
Rainfall (0.35 in)
Flow Rate (3614 l)
Sample Event (0 SU)
in
l/s
SU
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9PM
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3AM
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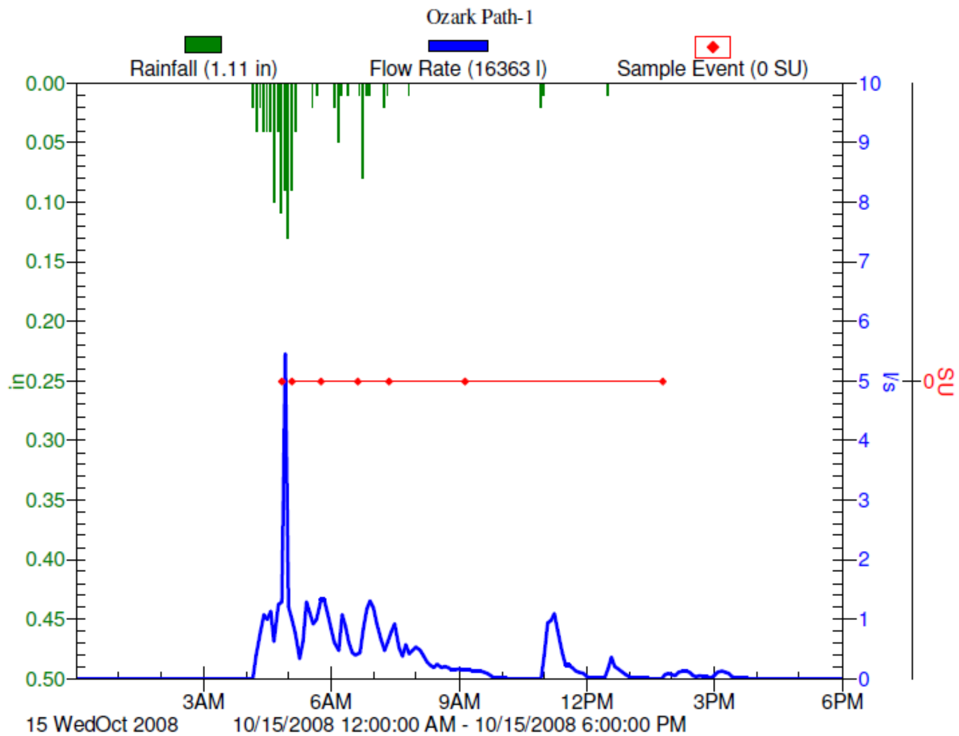
10/14/2008 9:00:00 AM - 10/15/2008 3:00:00 AM


Ozark Path-1
Rainfall (1.11 in)
Flow Rate (16363 l)
Sample Event (0 SU)
in
l/s
SU
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6AM
9AM
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3PM
6PM
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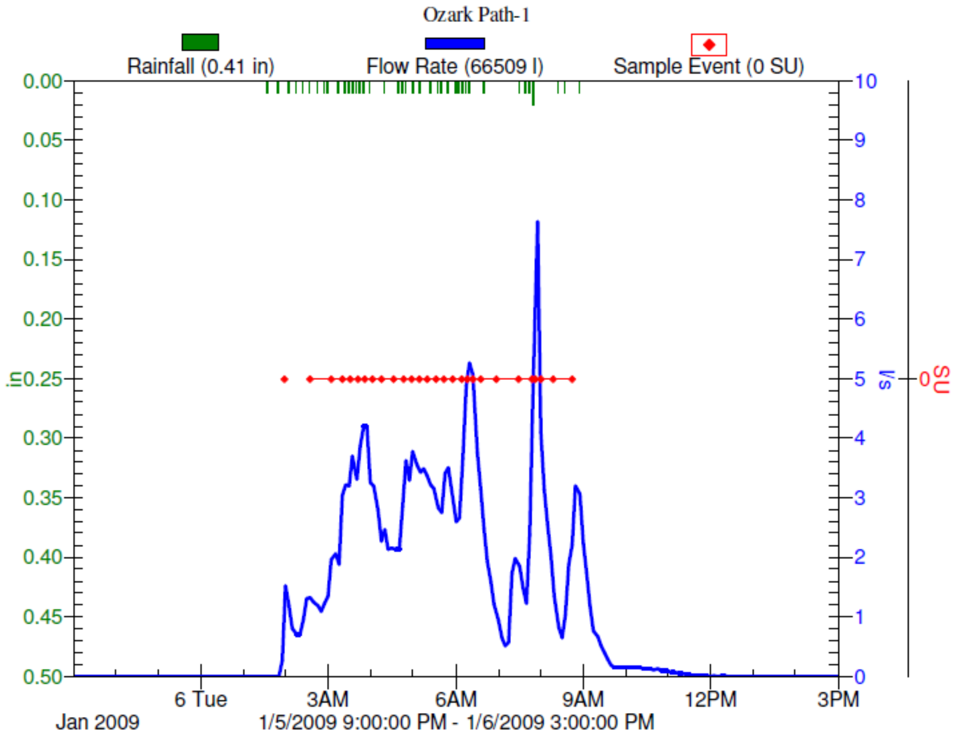
Ozark Path-1
Rainfall (0.41 in)
Flow Rate (66509 l)
Sample Event (0 SU)
in
l/s
SU
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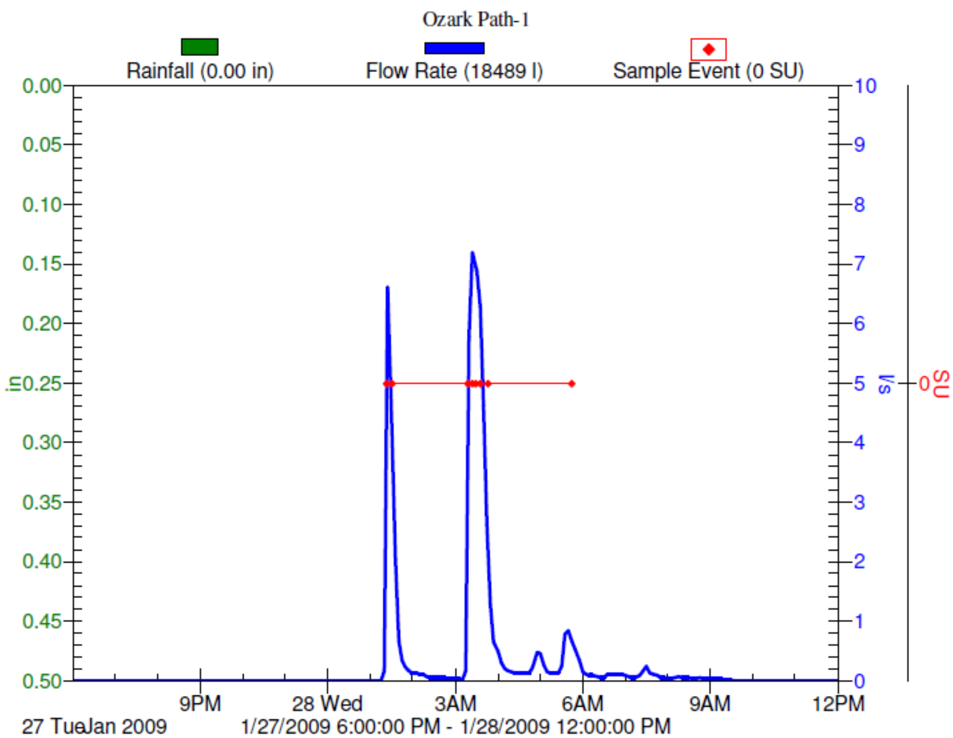
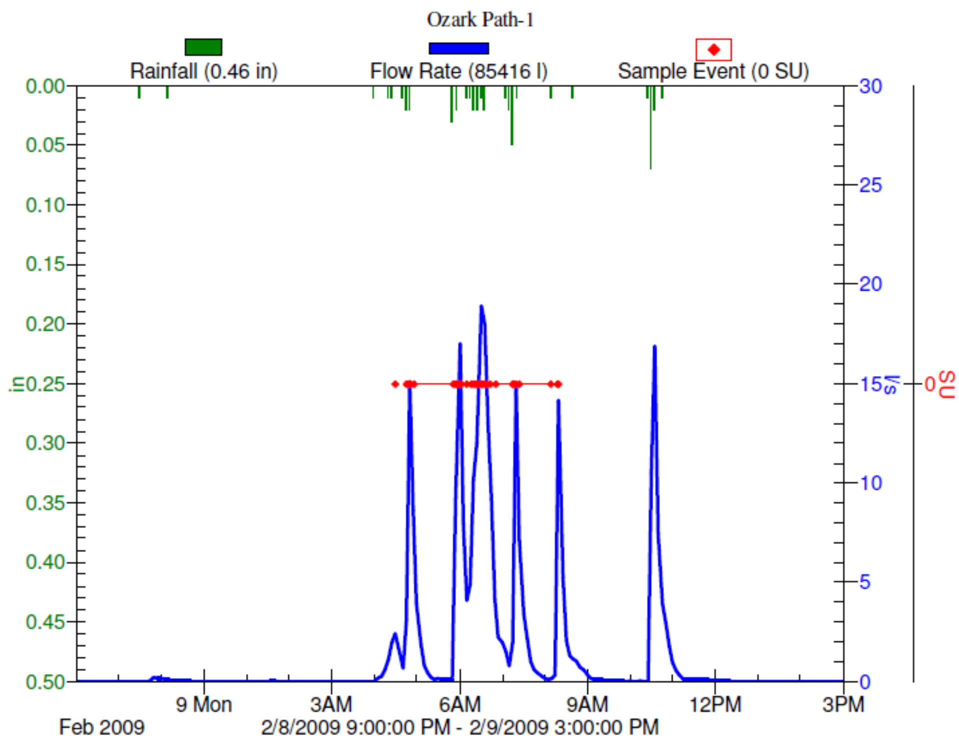
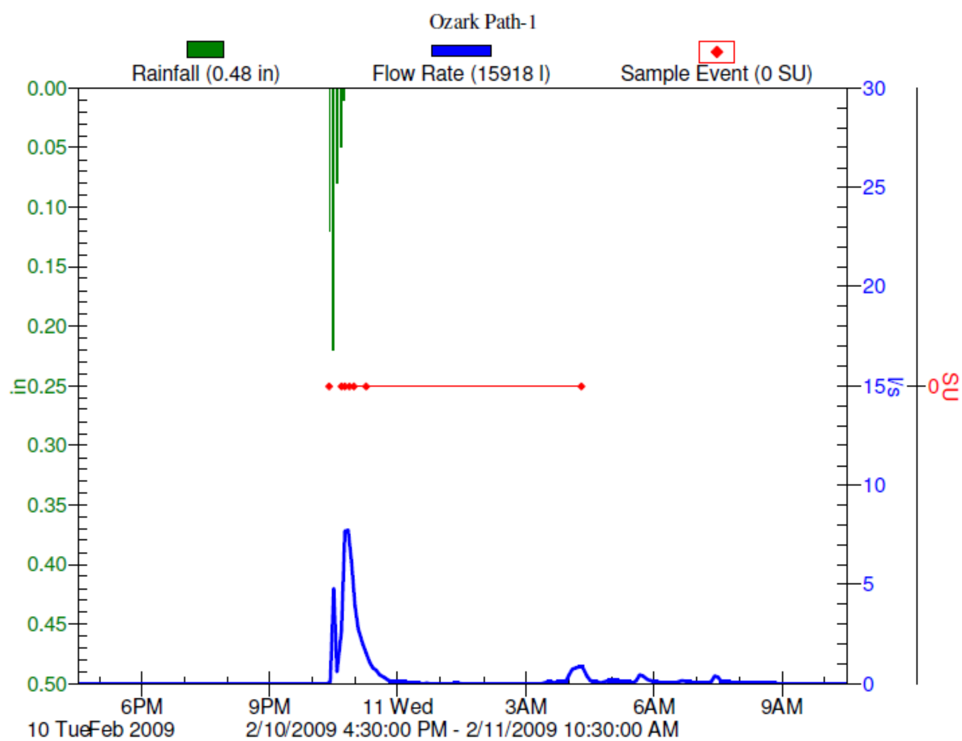
3AM
6AM
9AM
12PM
3PM
Jan 2009
1/5/2009 9:00:00 PM - 1/6/2009 3:00:00 PM


Ozark Path-1
Rainfall (0.00 in)
Flow Rate (18489 l)
Sample Event (0 SU)
in
l/s
SU
9PM
28 Wed
3AM
6AM
9AM
12PM
27 TueJan 2009
1/27/2009 6:00:00 PM - 1/28/2009 12:00:00 PM


Ozark Path-1
Rainfall (0.46 in)
Flow Rate (85416 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
l/s
30
25
20
15
10
5
0
SU
0
9 Mon
3AM
6AM
9AM
12PM
3PM
Feb 2009
2/8/2009 9:00:00 PM - 2/9/2009 3:00:00 PM


Ozark Path-1
Rainfall (0.48 in)
Flow Rate (15918 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
l/s
30
25
20
15
10
5
0
SU
0
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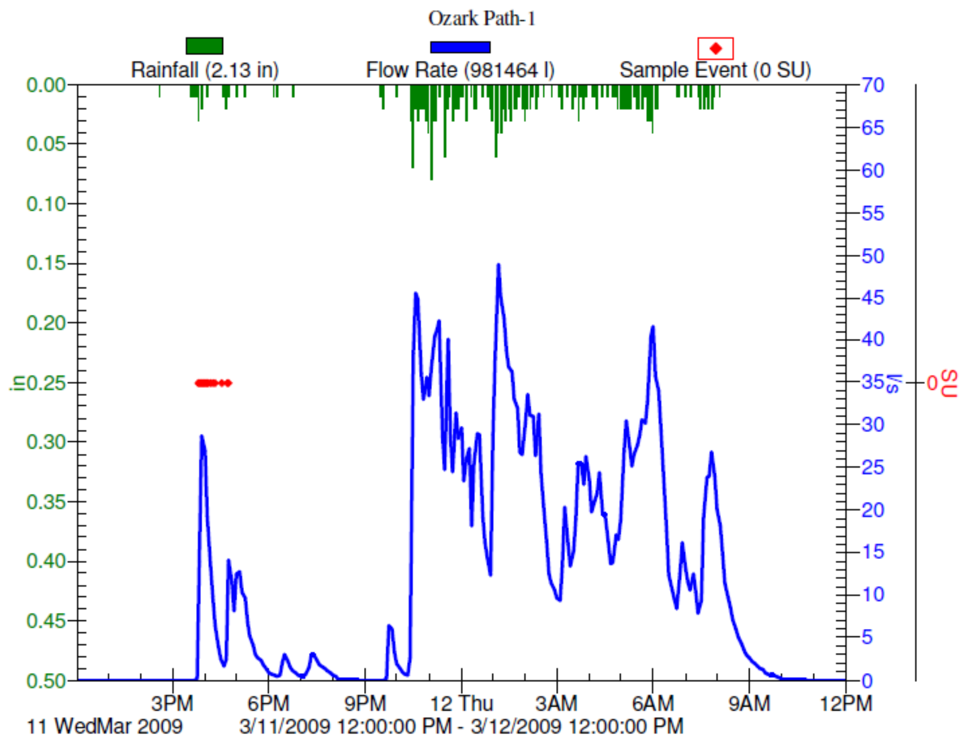
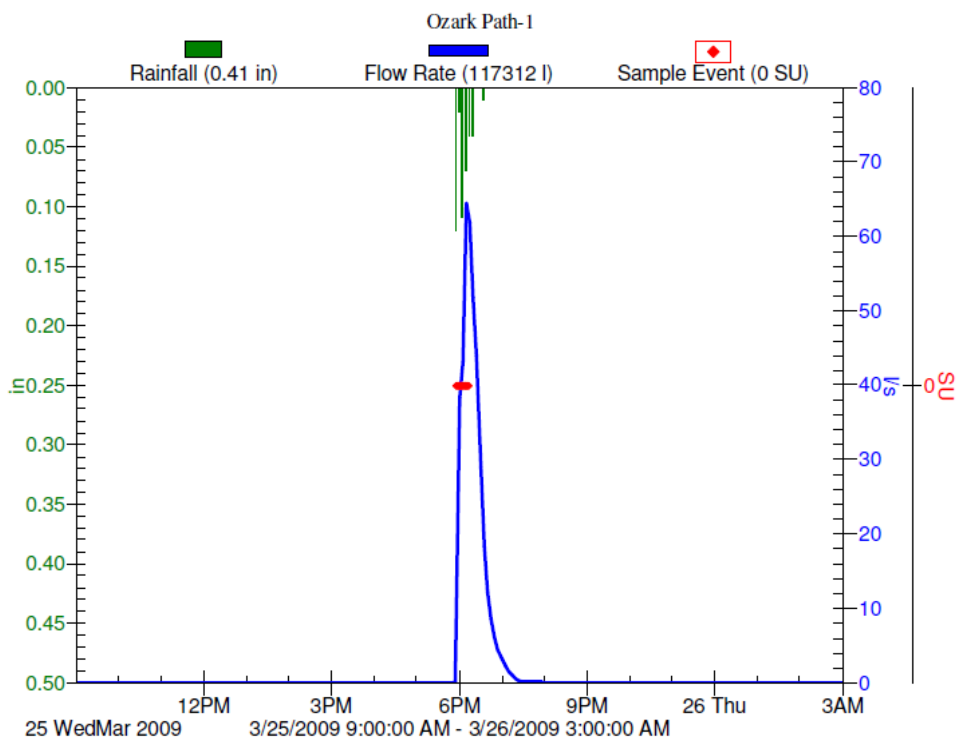
9PM
11 Wed
3AM
6AM
9AM
10 Tue Feb 2009
2/10/2009 4:30:00 PM - 2/11/2009 10:30:00 AM



Ozark Path-1
Rainfall (2.13 in)
Flow Rate (981464 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
l/s
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
SU
0
3PM
6PM
9PM
12 Thu
3AM
6AM
9AM
12PM
11 WedMar 2009
3/11/2009 12:00:00 PM - 3/12/2009 12:00:00 PM



Ozark Path-1
Rainfall (0.41 in)
Flow Rate (117312 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
l/s
80
70
60
50
40
30
20
10
0
SU
0
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3PM
6PM
9PM
26 Thu
3AM
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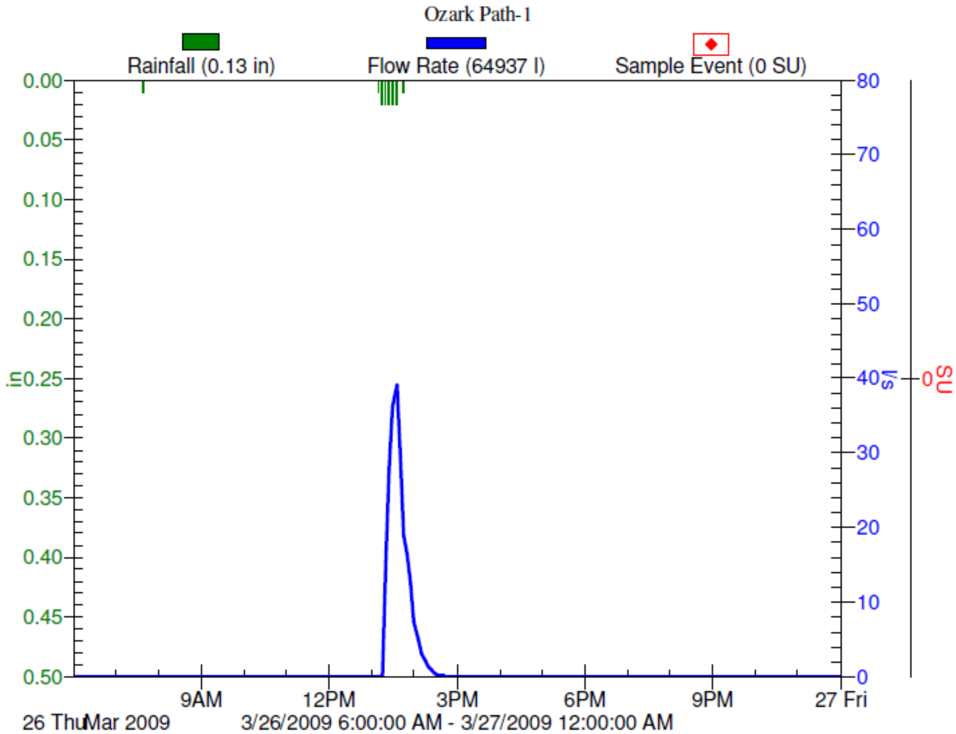
3/25/2009 9:00:00 AM - 3/26/2009 3:00:00 AM


Ozark Path-1
Rainfall (0.13 in)
Flow Rate (64937 l)
Sample Event (0 SU)
in
l/s
SU
26 Thu Mar 2009
9AM
12PM
3PM
6PM
9PM
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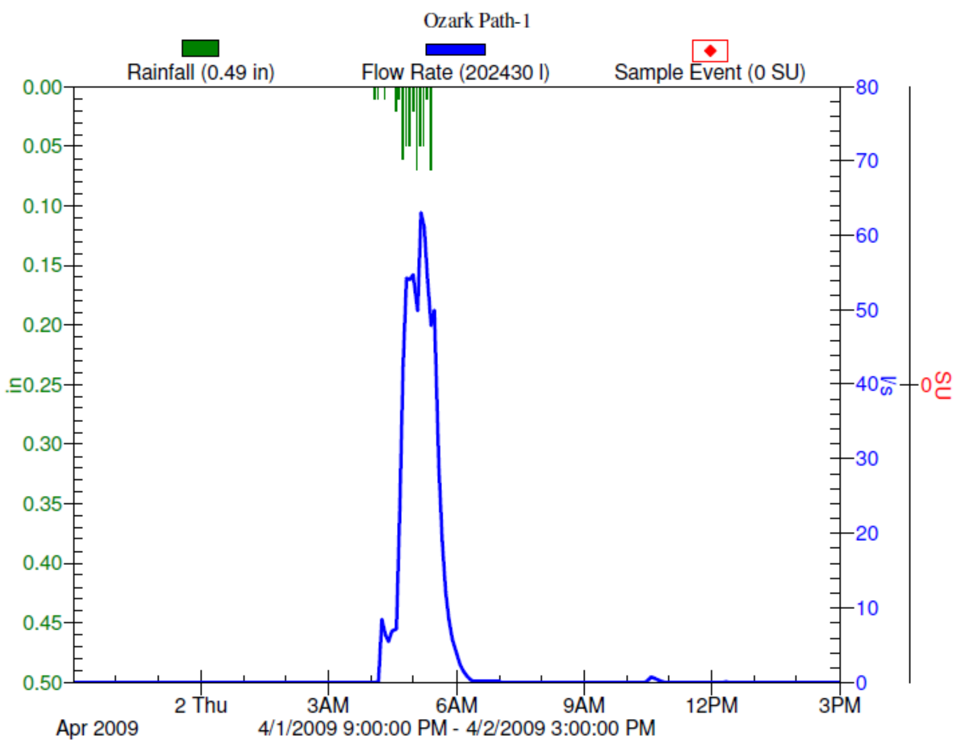
3/26/2009 6:00:00 AM - 3/27/2009 12:00:00 AM


Ozark Path-1
Rainfall (0.49 in)
Flow Rate (202430 l)
Sample Event (0 SU)
in
l/s
SU
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2 Thu
3AM
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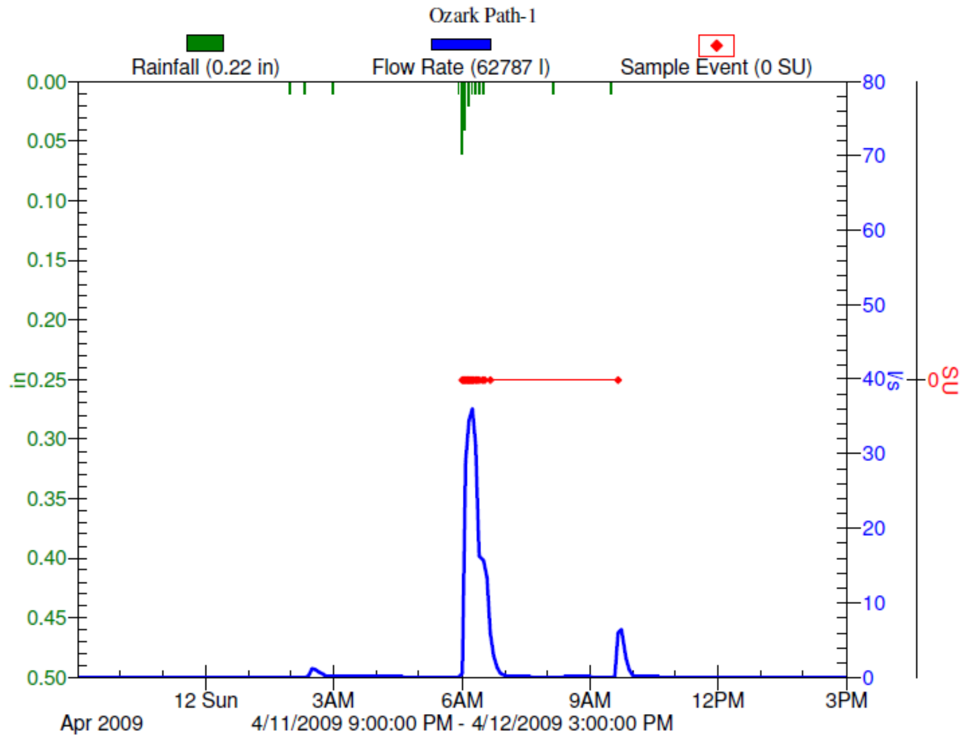
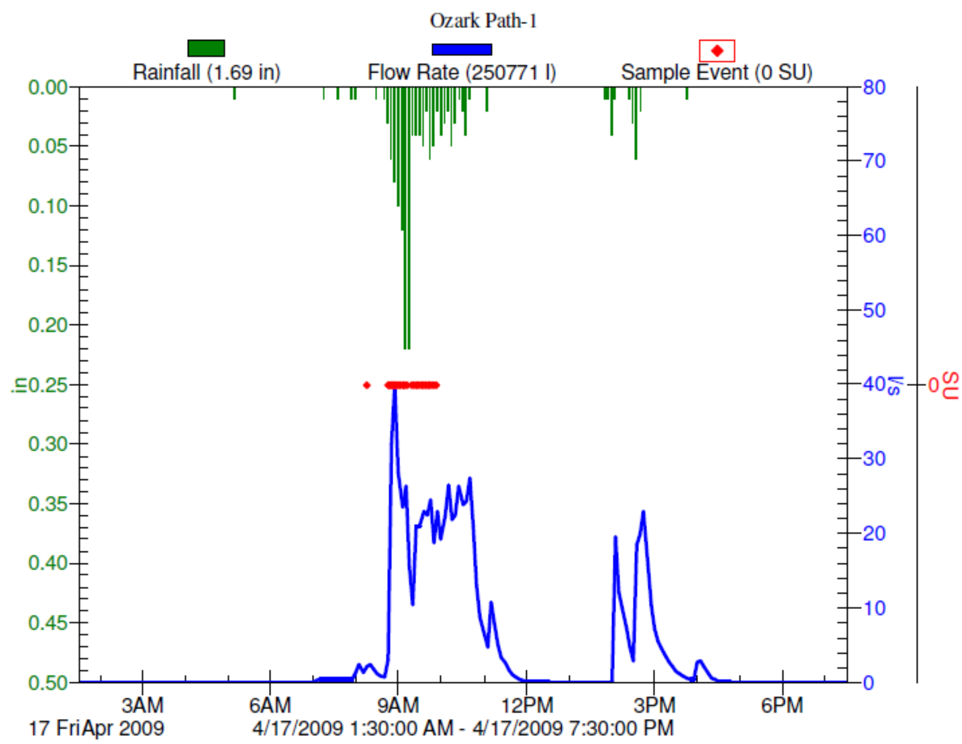
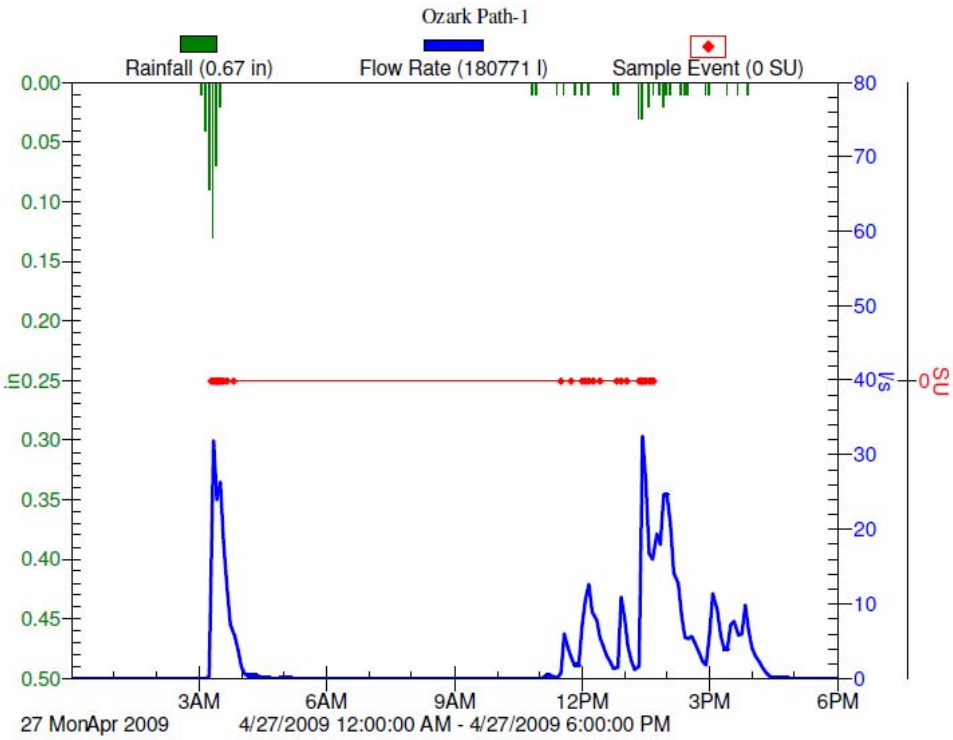

Ozark Path-1
Rainfall (0.22 in)
Flow Rate (62787 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
80
70
60
50
40
30
20
10
0
l/s
0
SU
12 Sun
3AM
6AM
9AM
12PM
3PM
Apr 2009
4/11/2009 9:00:00 PM - 4/12/2009 3:00:00 PM


Ozark Path-1
Rainfall (1.69 in)
Flow Rate (250771 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
80
70
60
50
40
30
20
10
0
l/s
0
SU
3AM
6AM
9AM
12PM
3PM
6PM
17 FriApr 2009
4/17/2009 1:30:00 AM - 4/17/2009 7:30:00 PM


Ozark Path-1
Rainfall (0.67 in)
Flow Rate (180771 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
in
0.25
0.30
0.35
0.40
0.45
0.50
80
70
60
50
40
30
20
10
0
l/s
0
SU
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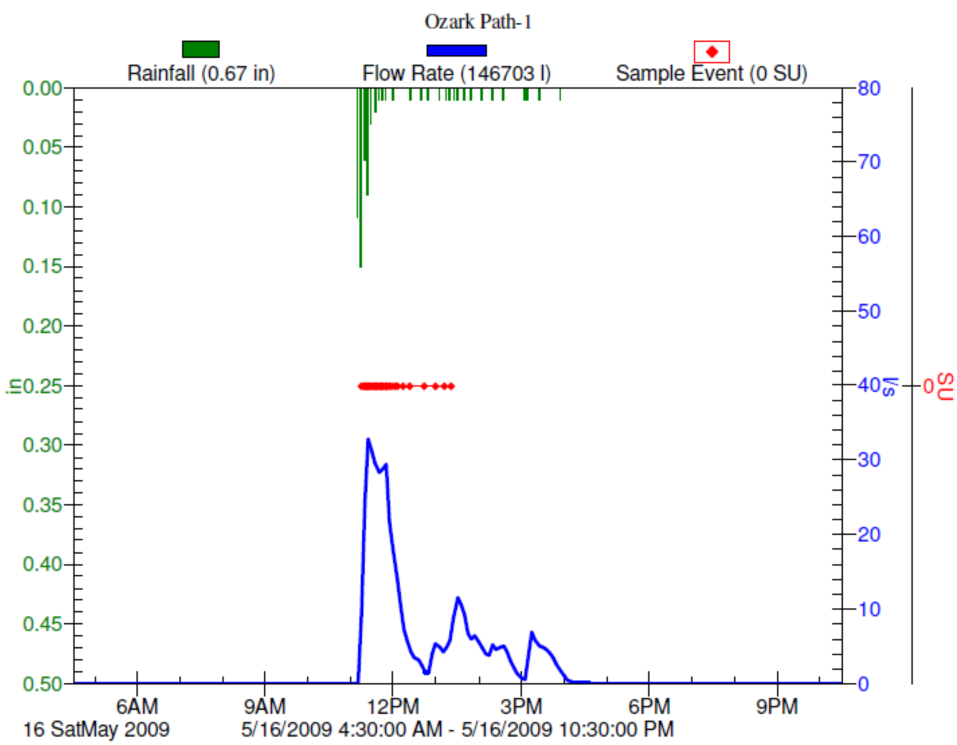
6AM
9AM
12PM
3PM
6PM
27 Mon Apr 2009
4/27/2009 12:00:00 AM - 4/27/2009 6:00:00 PM


Ozark Path-1
Rainfall (0.67 in)
Flow Rate (146703 l)
Sample Event (0 SU)
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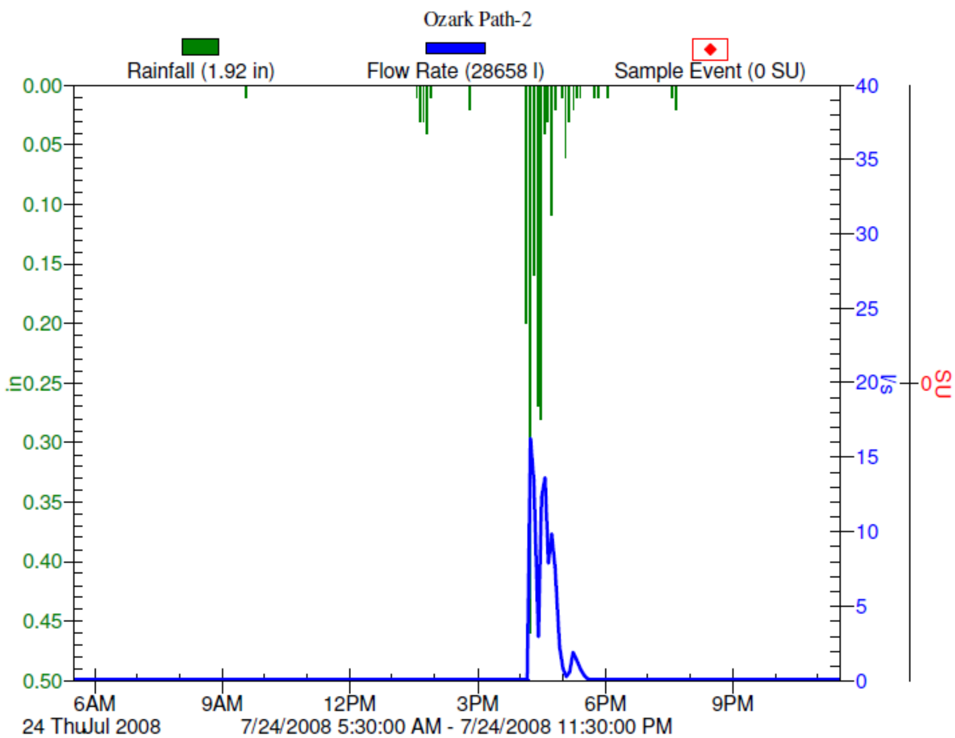
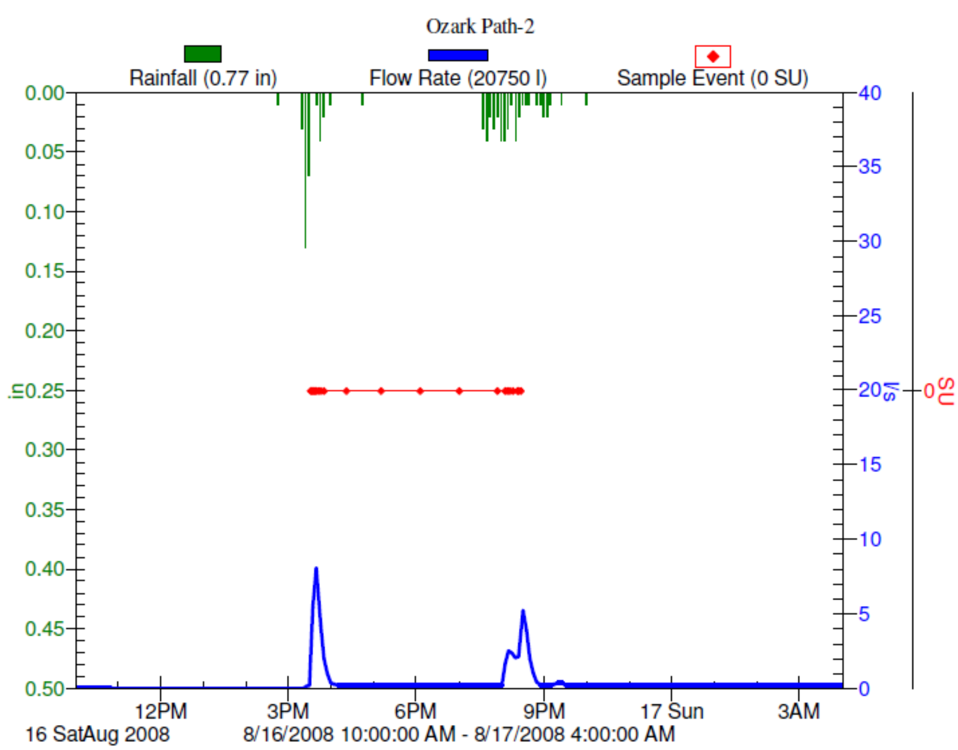
0.10
0.15
0.20
in
0.25
0.30
0.35
0.40
0.45
0.50
80
70
60
50
40
30
20
10
0
l/s
0
SU
6AM
9AM
12PM
3PM
6PM
9PM
16 Sat May 2009
5/16/2009 4:30:00 AM - 5/16/2009 10:30:00 PM


Ozark Path-2
Rainfall (1.92 in)
Flow Rate (28658 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
40
35
30
25
20
15
10
5
0
6AM
9AM
12PM
3PM
6PM
9PM
24 ThuJul 2008
7/24/2008 5:30:00 AM - 7/24/2008 11:30:00 PM


Ozark Path-2
Rainfall (0.77 in)
Flow Rate (20750 l)
Sample Event (0 SU)
in
l/s
SU
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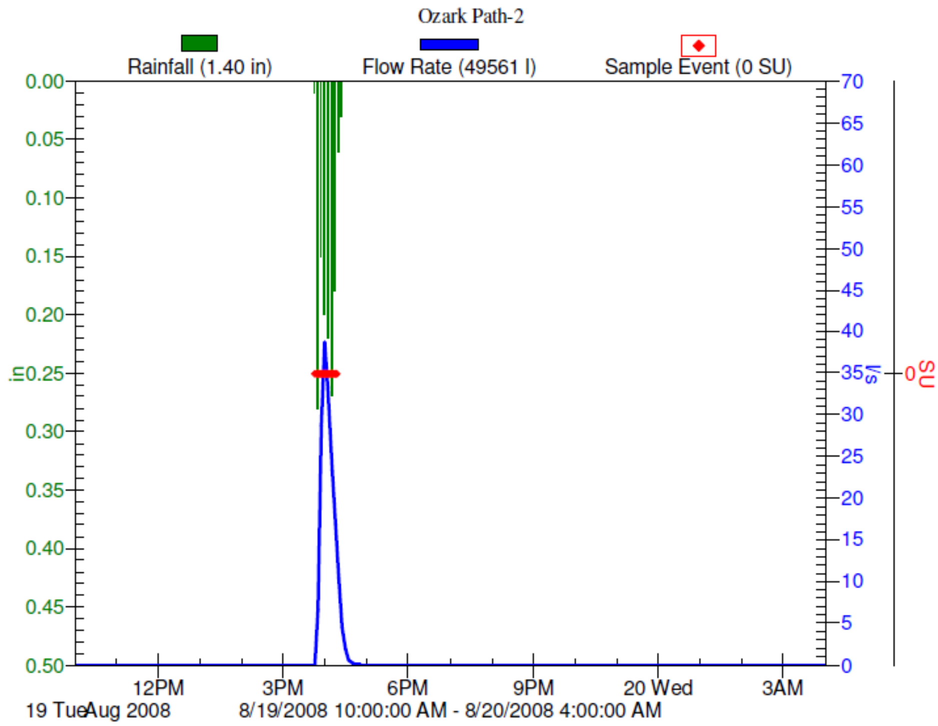
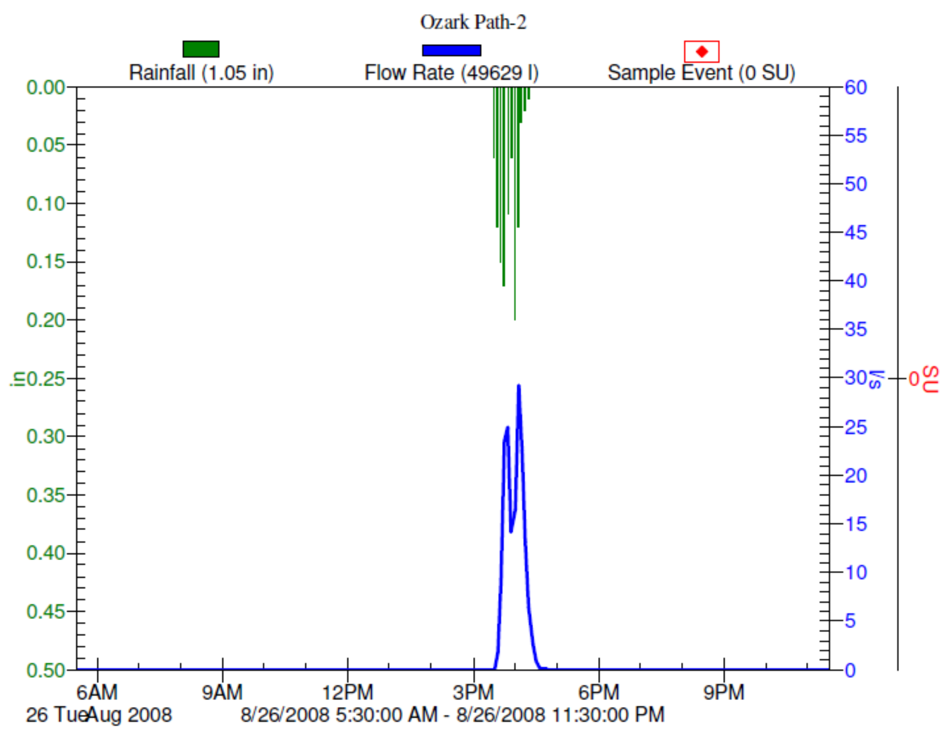
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
40
35
30
25
20
15
10
5
0
12PM
3PM
6PM
9PM
17 Sun
3AM
16 SatAug 2008
8/16/2008 10:00:00 AM - 8/17/2008 4:00:00 AM


Ozark Path-2
Rainfall (1.40 in)
Flow Rate (49561 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
12PM
3PM
6PM
9PM
20 Wed
3AM
19 Tue
Aug 2008
8/19/2008 10:00:00 AM - 8/20/2008 4:00:00 AM


Ozark Path-2
Rainfall (1.05 in)
Flow Rate (49629 l)
Sample Event (0 SU)
in
l/s
SU
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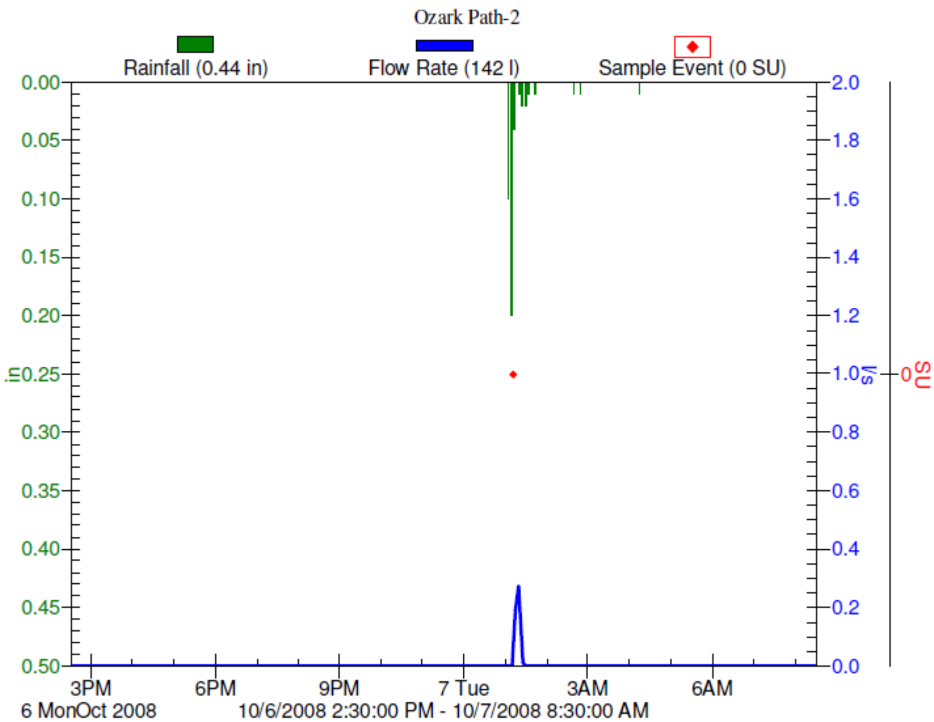
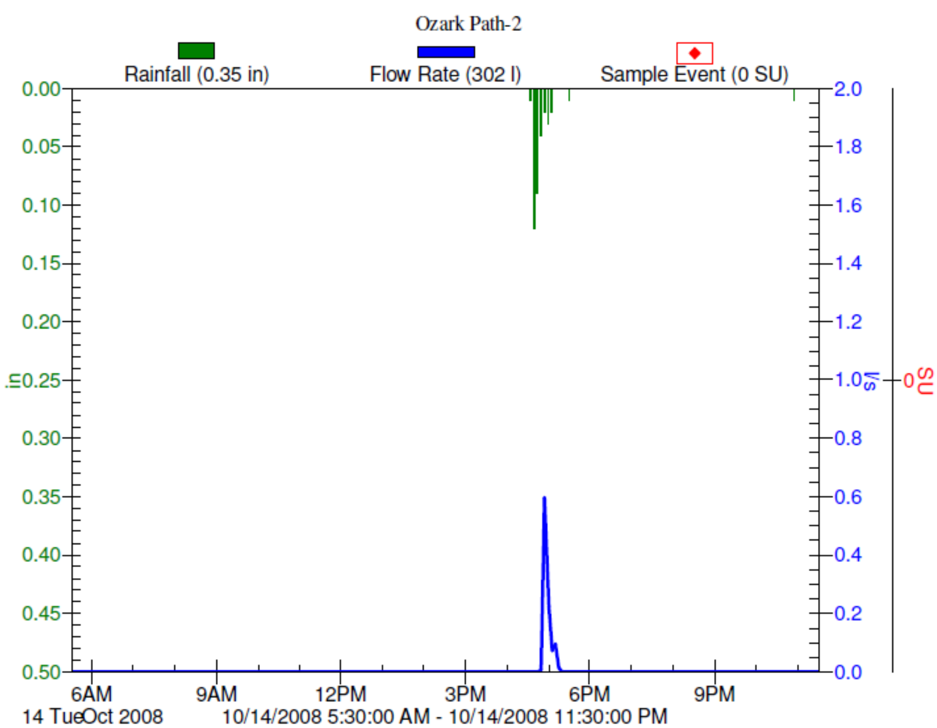
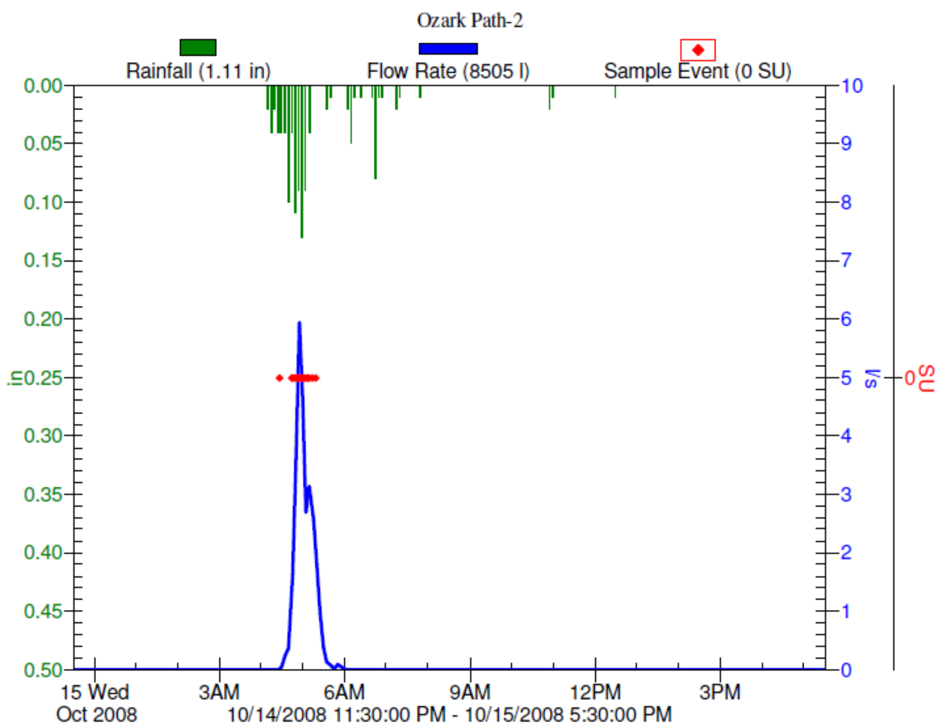
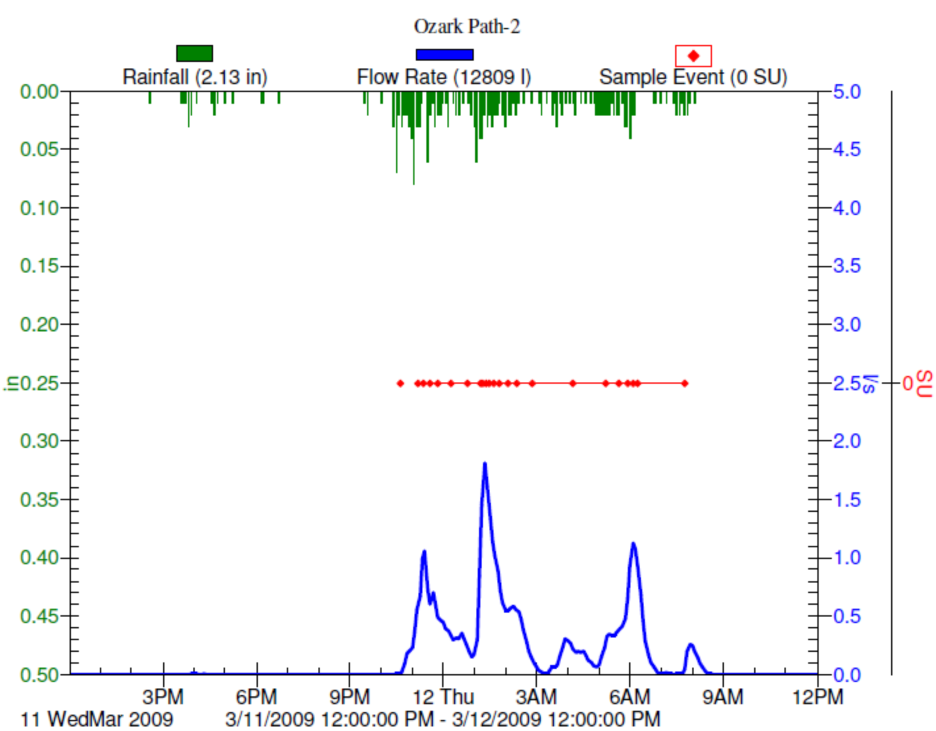
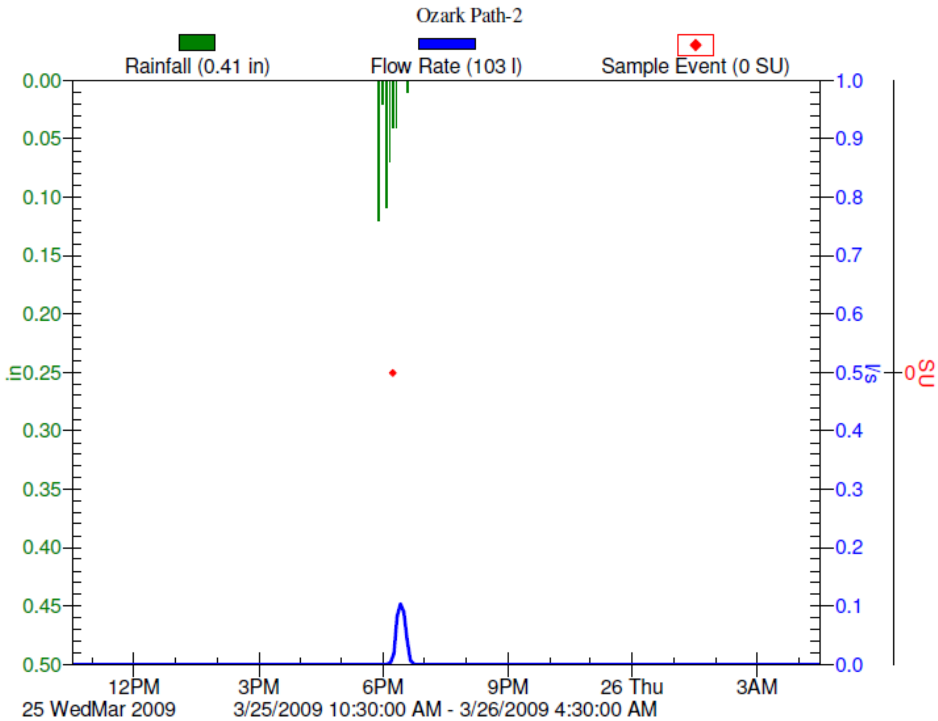
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
60
55
50
45
40
35
30
25
20
15
10
5
0
6AM
9AM
12PM
3PM
6PM
9PM
26 Tue
Aug 2008
8/26/2008 5:30:00 AM - 8/26/2008 11:30:00 PM

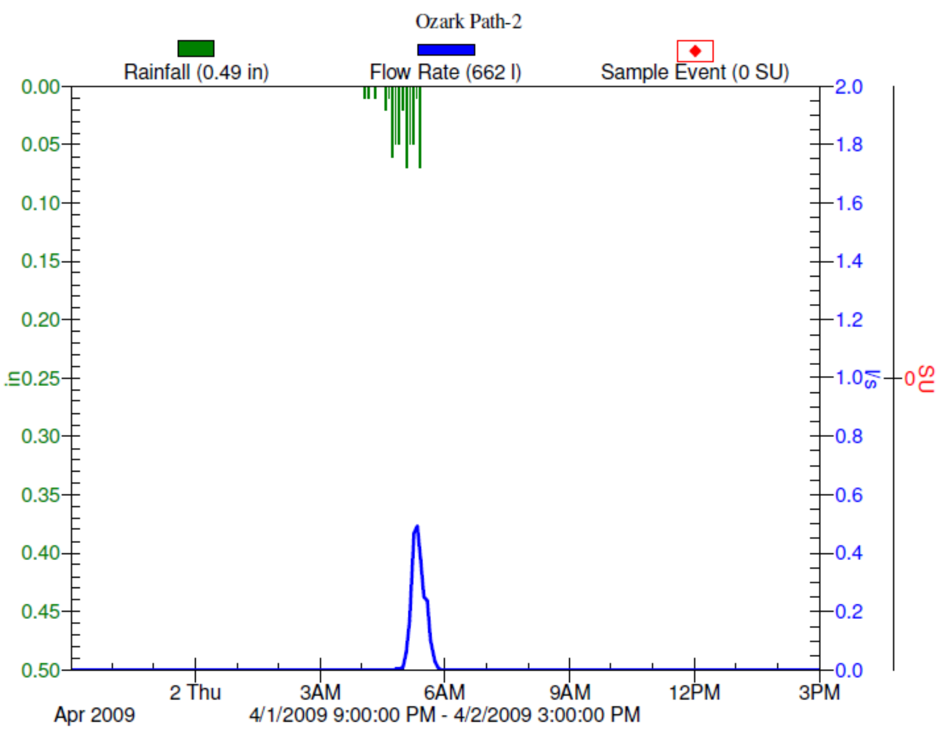

Ozark Path-2
Rainfall (0.44 in)
Flow Rate (142 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
3PM
6PM
9PM
7 Tue
3AM
6AM
6 Mon Oct 2008
10/6/2008 2:30:00 PM - 10/7/2008 8:30:00 AM

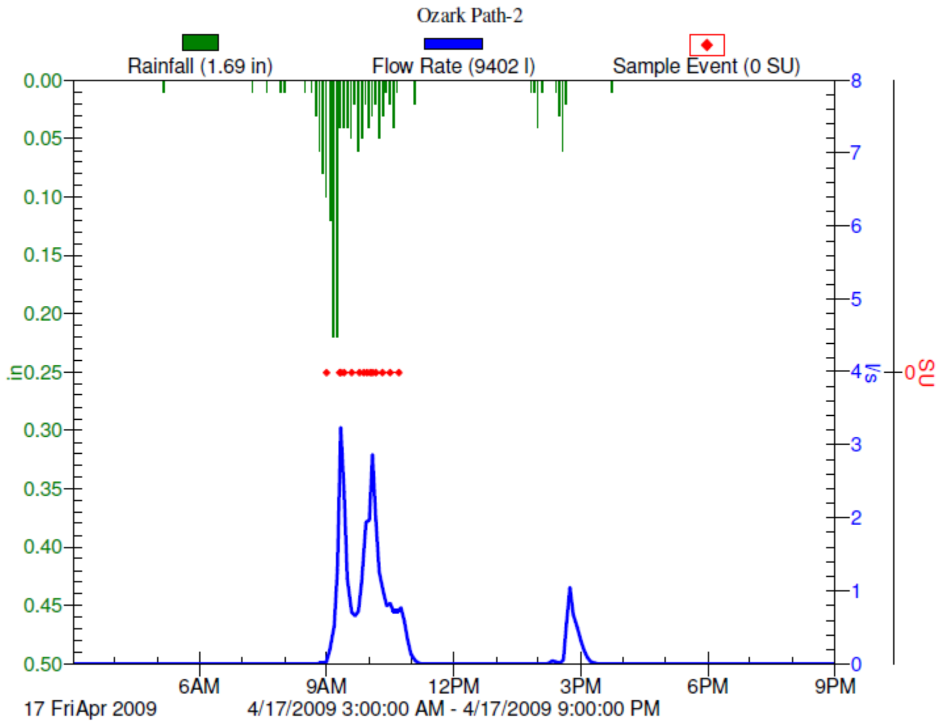

Ozark Path-2
Rainfall (0.35 in)
Flow Rate (302 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
6AM
9AM
12PM
3PM
6PM
9PM
14 Tue Oct 2008
10/14/2008 5:30:00 AM - 10/14/2008 11:30:00 PM

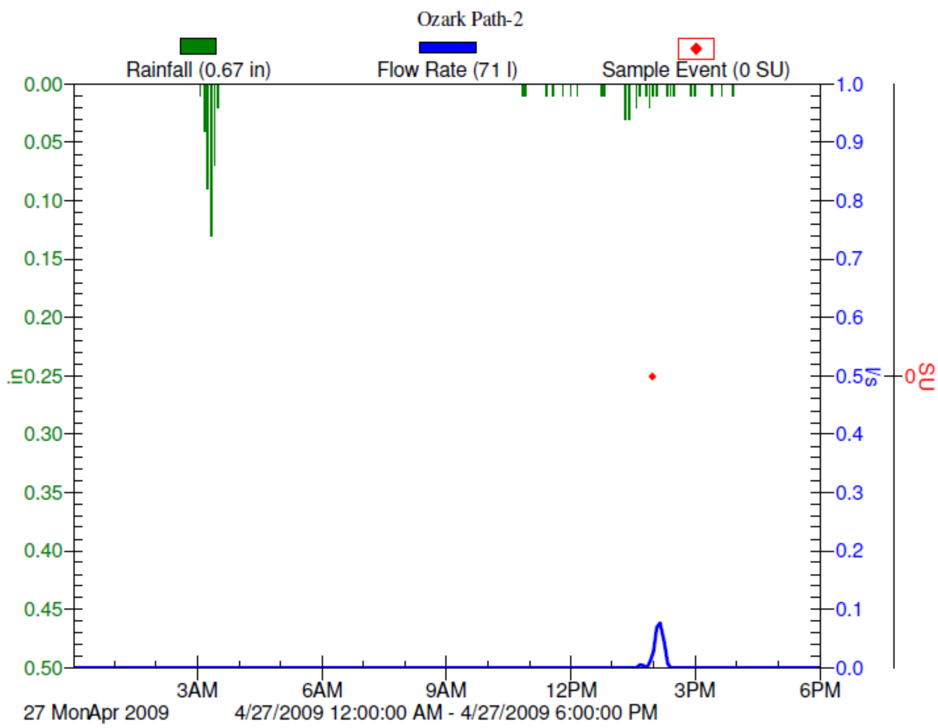

Ozark Path-2
Rainfall (1.11 in)
Flow Rate (8505 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
in
10
9
8
7
6
5
4
3
2
1
0
l/s
0
SU
15 Wed
Oct 2008
3AM
6AM
9AM
12PM
3PM
10/14/2008 11:30:00 PM - 10/15/2008 5:30:00 PM

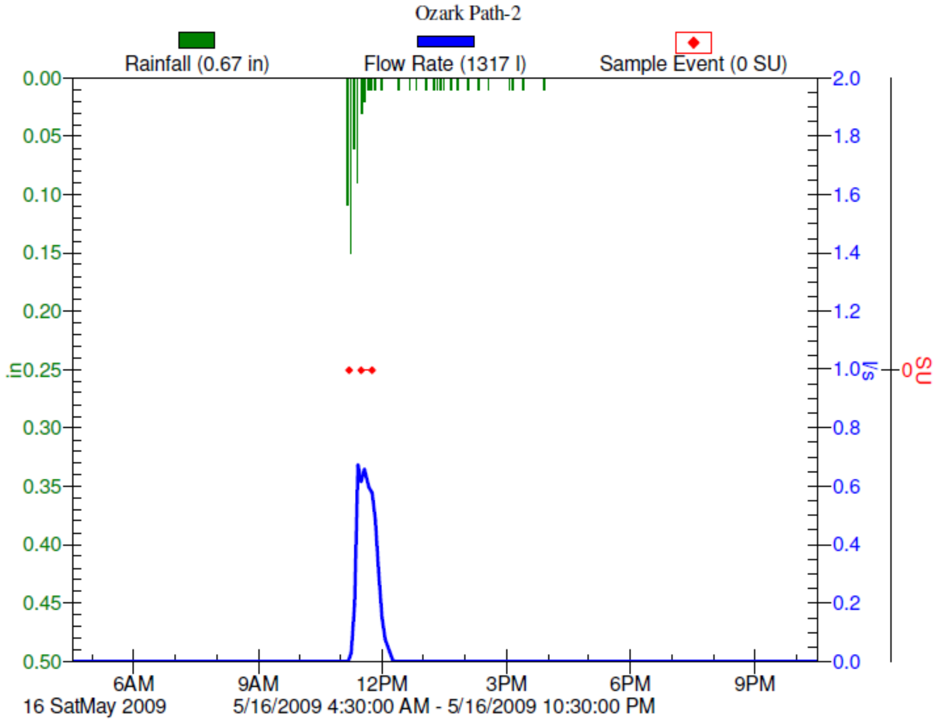

Ozark Path-2
Rainfall (2.13 in)
Flow Rate (12809 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
in
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
l/s
0
SU
3PM
6PM
9PM
12 Thu
3AM
6AM
9AM
12PM
11 WedMar 2009
3/11/2009 12:00:00 PM - 3/12/2009 12:00:00 PM


Ozark Path-2
Rainfall (0.41 in)
Flow Rate (103 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
12PM
3PM
6PM
9PM
26 Thu
3AM
25 WedMar 2009
3/25/2009 10:30:00 AM - 3/26/2009 4:30:00 AM

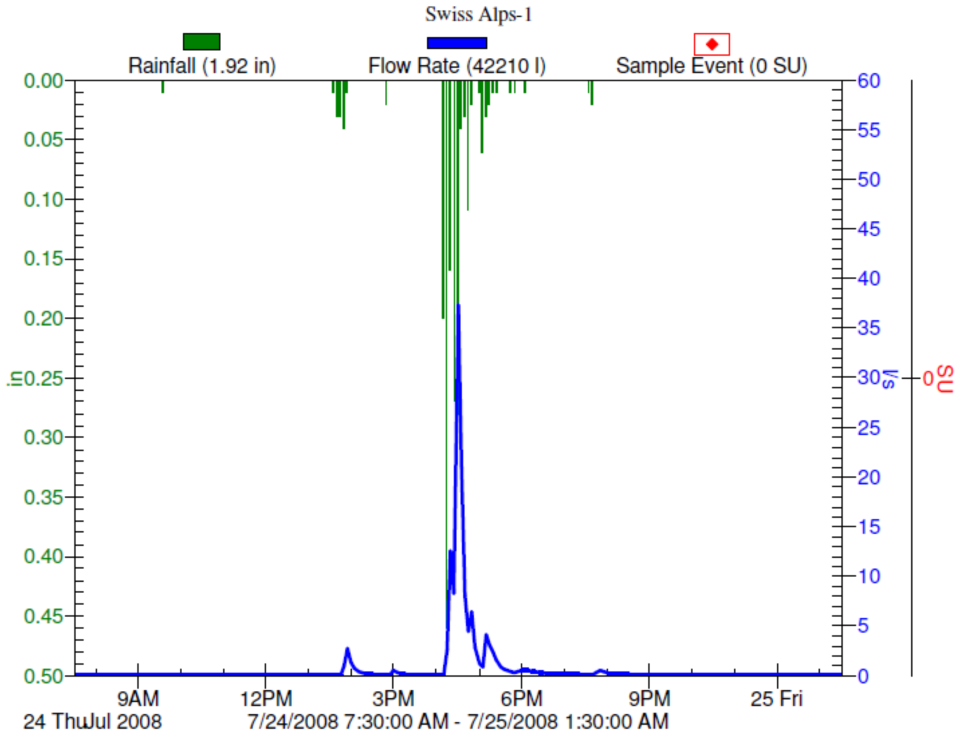

Ozark Path-2
Rainfall (0.49 in)
Flow Rate (662 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2 Thu
3AM
6AM
9AM
12PM
3PM
Apr 2009
4/1/2009 9:00:00 PM - 4/2/2009 3:00:00 PM


Ozark Path-2
Rainfall (1.69 in)
Flow Rate (9402 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
in 0.25
0.30
0.35
0.40
0.45
0.50
8
7
6
5
4 l/s
3
2
1
0
0 SU
6AM
9AM
12PM
3PM
6PM
9PM
17 Fri Apr 2009
4/17/2009 3:00:00 AM - 4/17/2009 9:00:00 PM

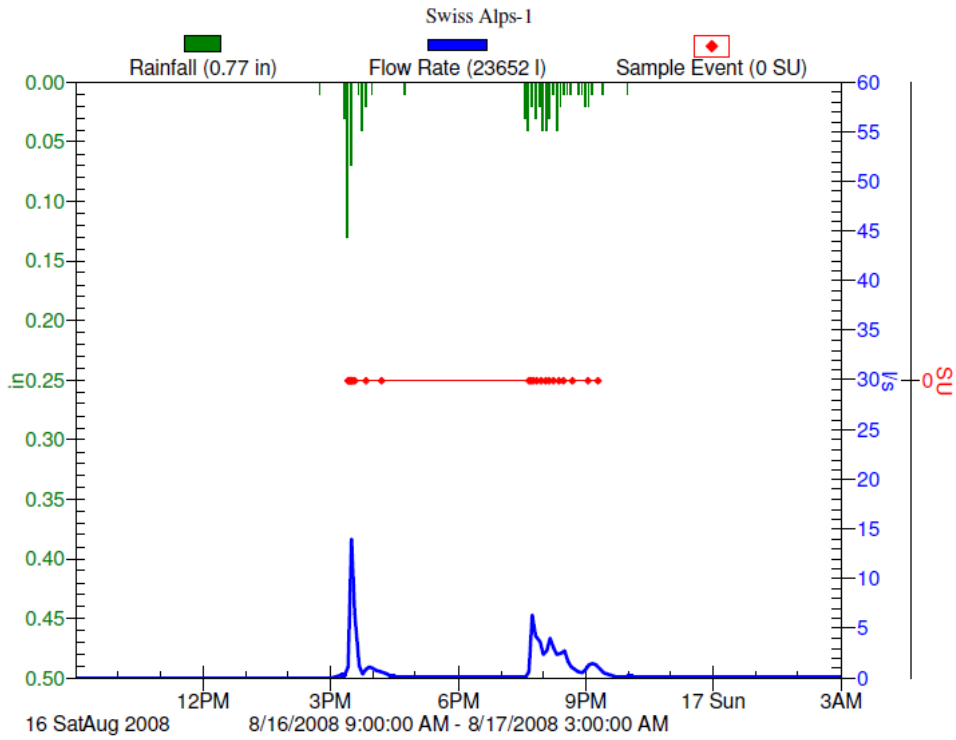

Ozark Path-2
Rainfall (0.67 in)
Flow Rate (71 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
in 0.25
0.30
0.35
0.40
0.45
0.50
1.0
0.9
0.8
0.7
0.6
0.5 l/s
0.4
0.3
0.2
0.1
0.0
0 SU
3AM
6AM
9AM
12PM
3PM
6PM
27 Mon Apr 2009
4/27/2009 12:00:00 AM - 4/27/2009 6:00:00 PM

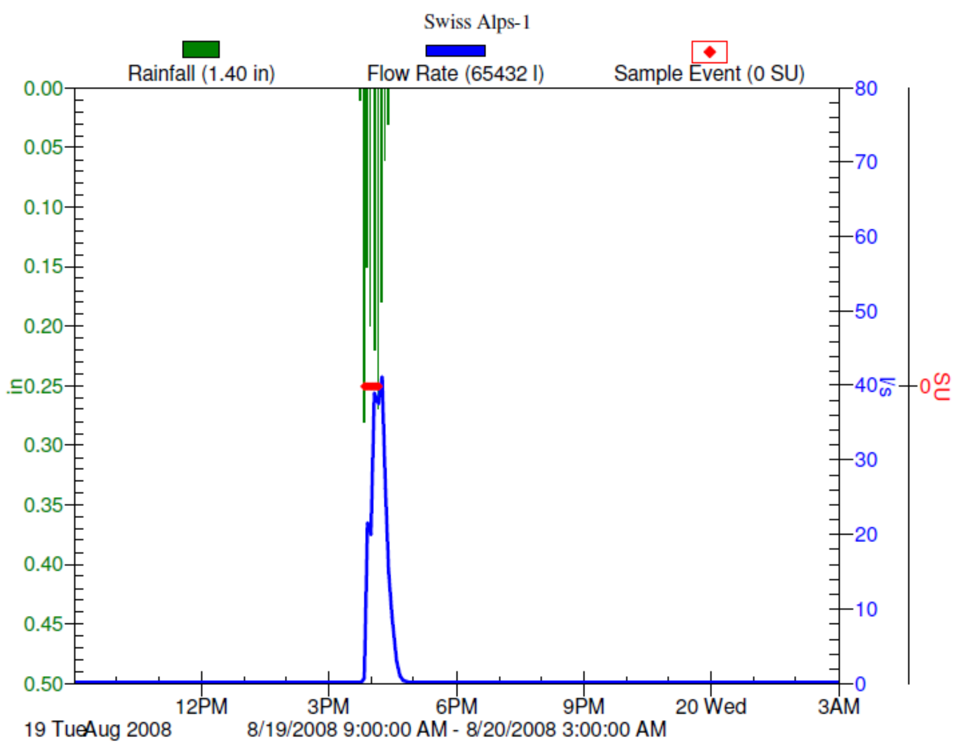


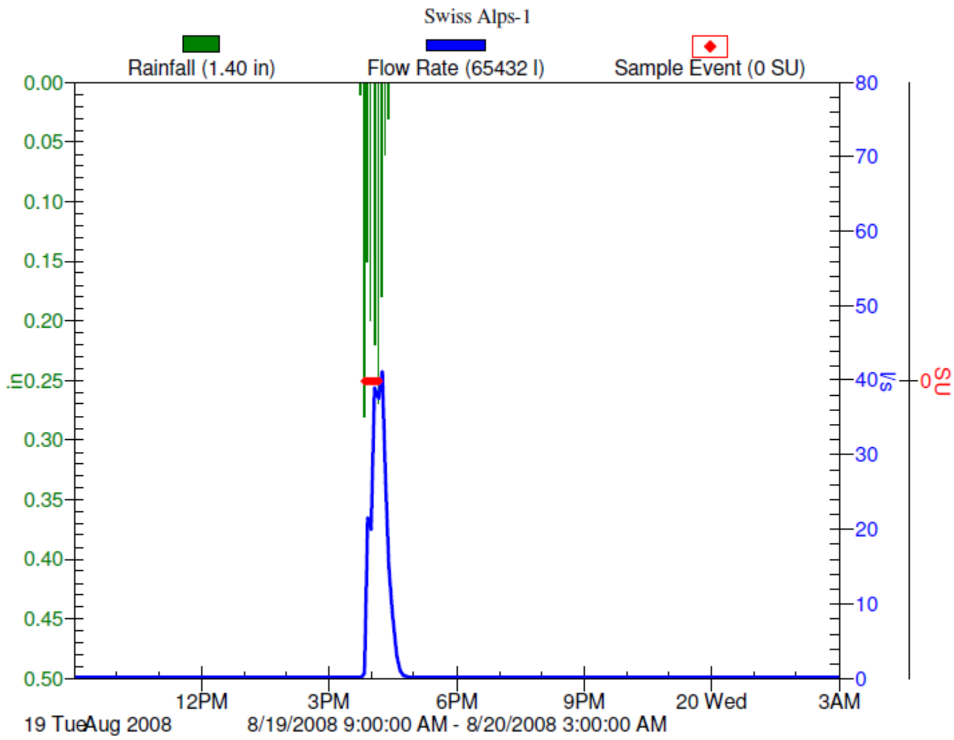
Ozark Path-2
Rainfall (0.67 in)
Flow Rate (1317 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
in
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
l/s
0
SU
6AM
9AM
12PM
3PM
6PM
9PM
16 SatMay 2009
5/16/2009 4:30:00 AM - 5/16/2009 10:30:00 PM



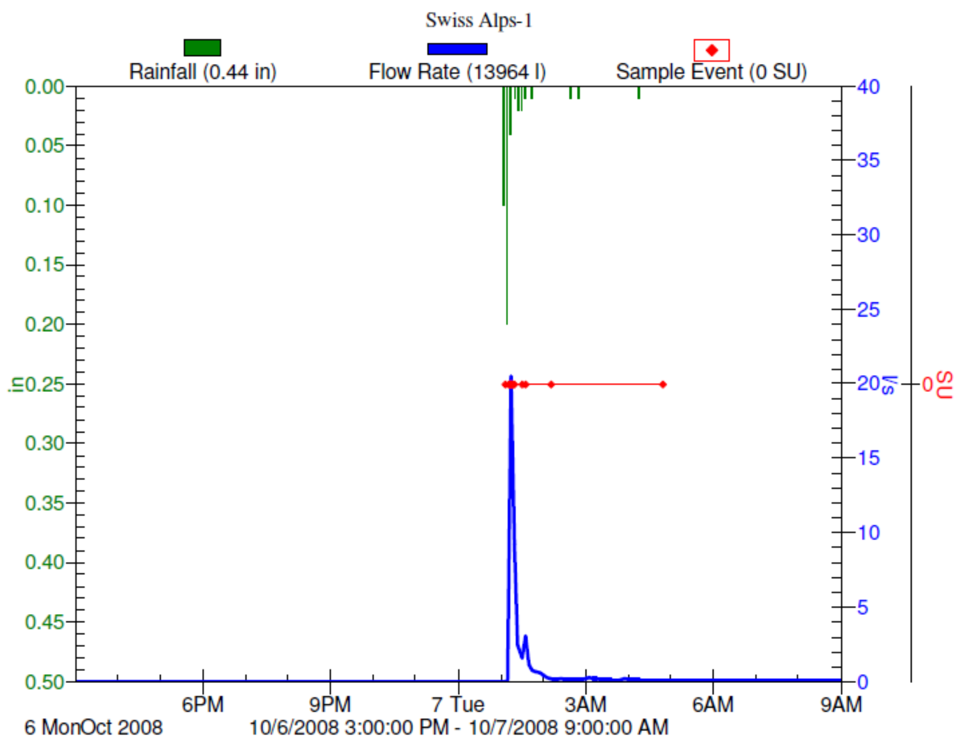
Swiss Alps-1
Rainfall (1.92 in)
Flow Rate (42210 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
in
60
55
50
45
40
35
30
25
20
15
10
5
0
l/s
0
SU
9AM
12PM
3PM
6PM
9PM
25 Fri
24 ThuJul 2008
7/24/2008 7:30:00 AM - 7/25/2008 1:30:00 AM


Swiss Alps-1
Rainfall (0.77 in)
Flow Rate (23652 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
60
55
50
45
40
35
30
25
20
15
10
5
0
l/s
0
SU
12PM
3PM
6PM
9PM
17 Sun
3AM
16 Sat Aug 2008
8/16/2008 9:00:00 AM - 8/17/2008 3:00:00 AM

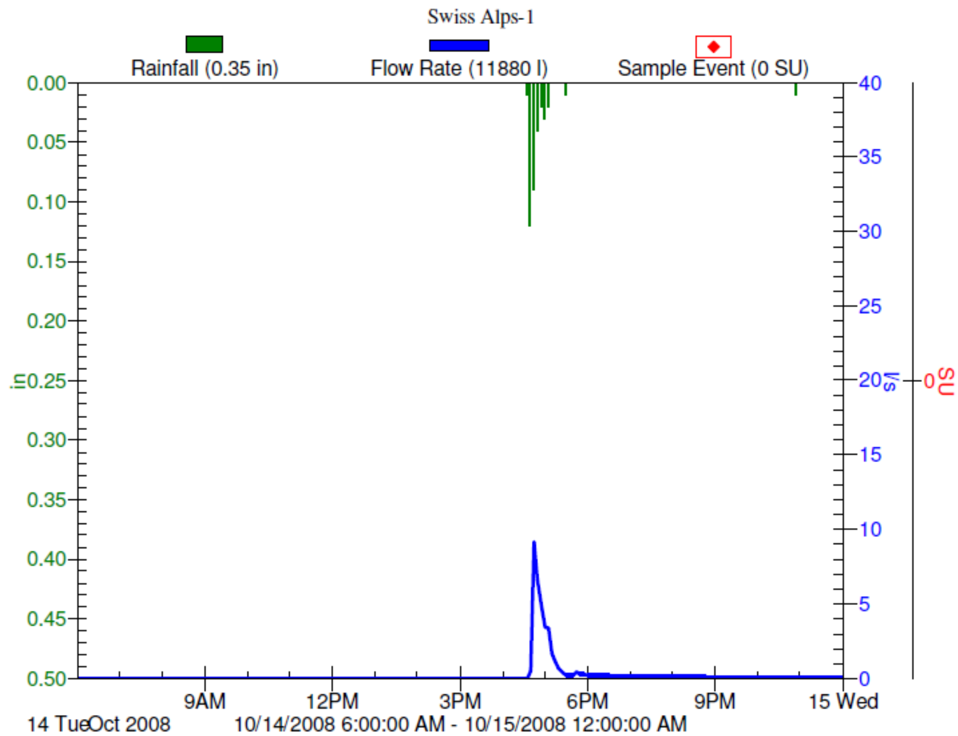

Swiss Alps-1
Rainfall (1.40 in)
Flow Rate (65432 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
80
70
60
50
40
30
20
10
0
l/s
0
SU
12PM
3PM
6PM
9PM
20 Wed
3AM
19 Tue Aug 2008
8/19/2008 9:00:00 AM - 8/20/2008 3:00:00 AM

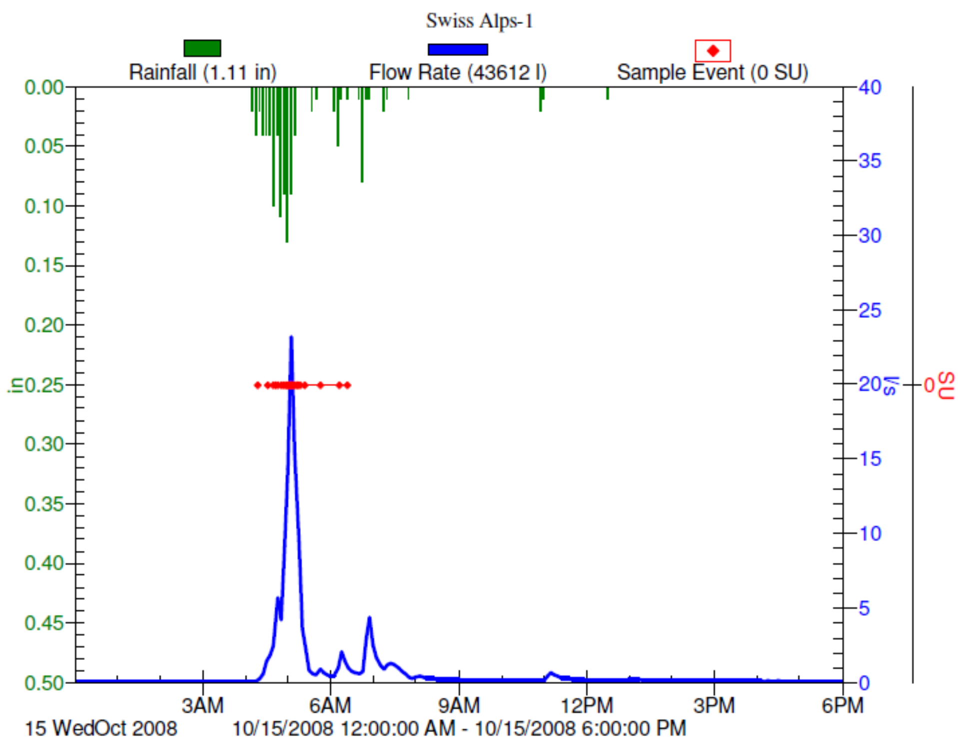


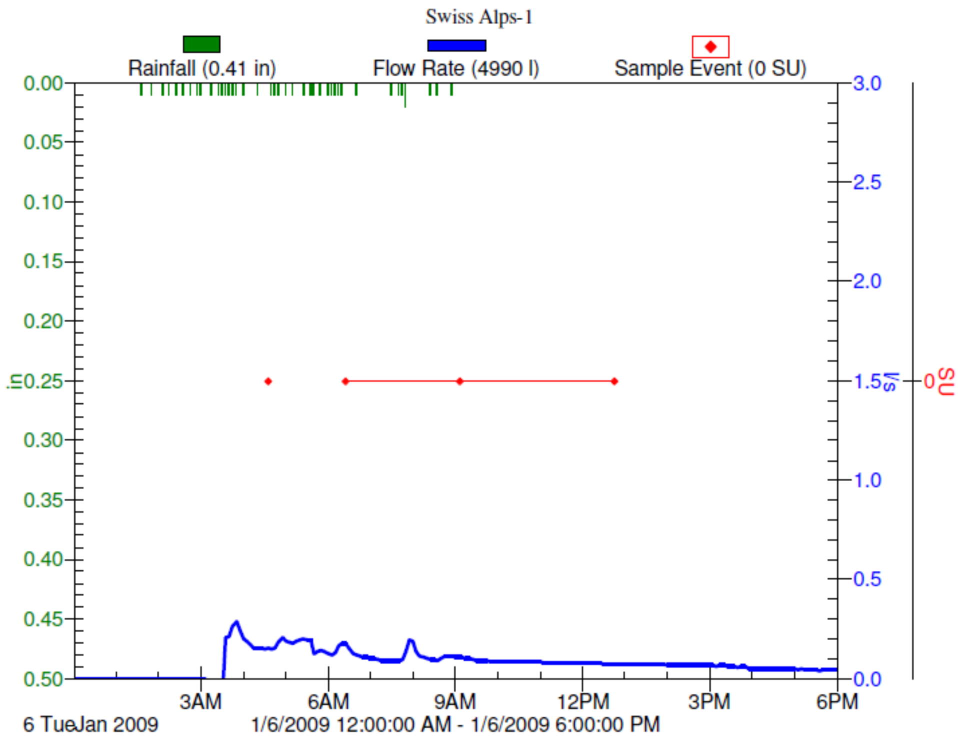
Swiss Alps-1
Rainfall (1.40 in)
Flow Rate (65432 l)
Sample Event (0 SU)
in
l/s
SU
19 Tue Aug 2008
8/19/2008 9:00:00 AM - 8/20/2008 3:00:00 AM



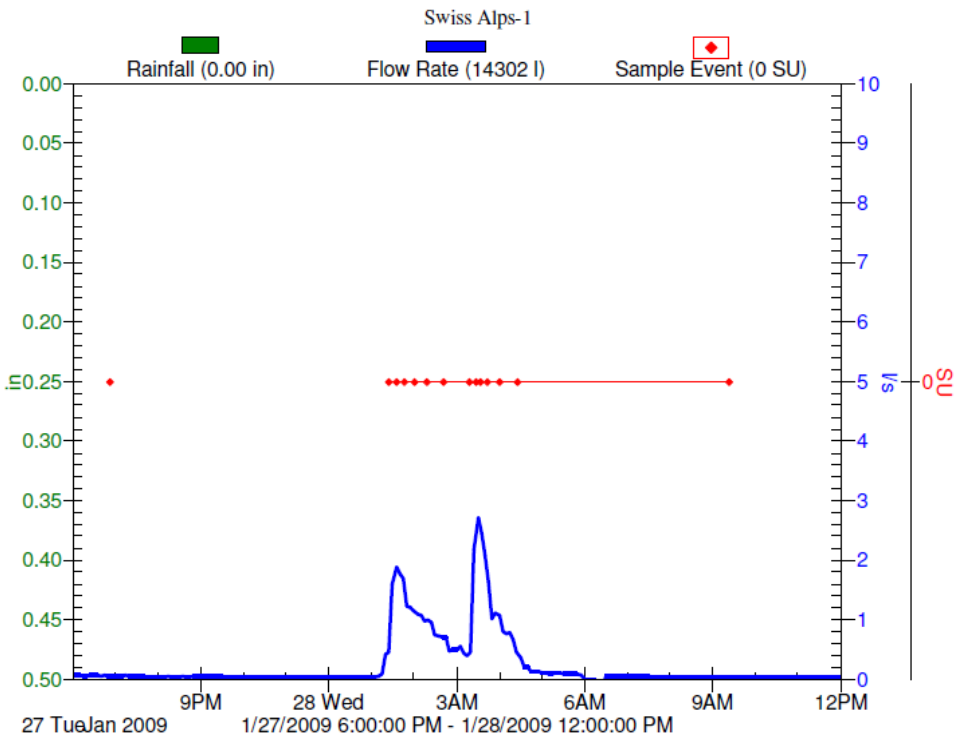
Swiss Alps-1
Rainfall (0.44 in)
Flow Rate (13964 l)
Sample Event (0 SU)
in
l/s
SU
6 Mon Oct 2008
10/6/2008 3:00:00 PM - 10/7/2008 9:00:00 AM


Swiss Alps-1
Rainfall (0.35 in)
Flow Rate (11880 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
40
35
30
25
20
15
10
5
0
9AM
12PM
3PM
6PM
9PM
15 Wed
14 TueOct 2008
10/14/2008 6:00:00 AM - 10/15/2008 12:00:00 AM

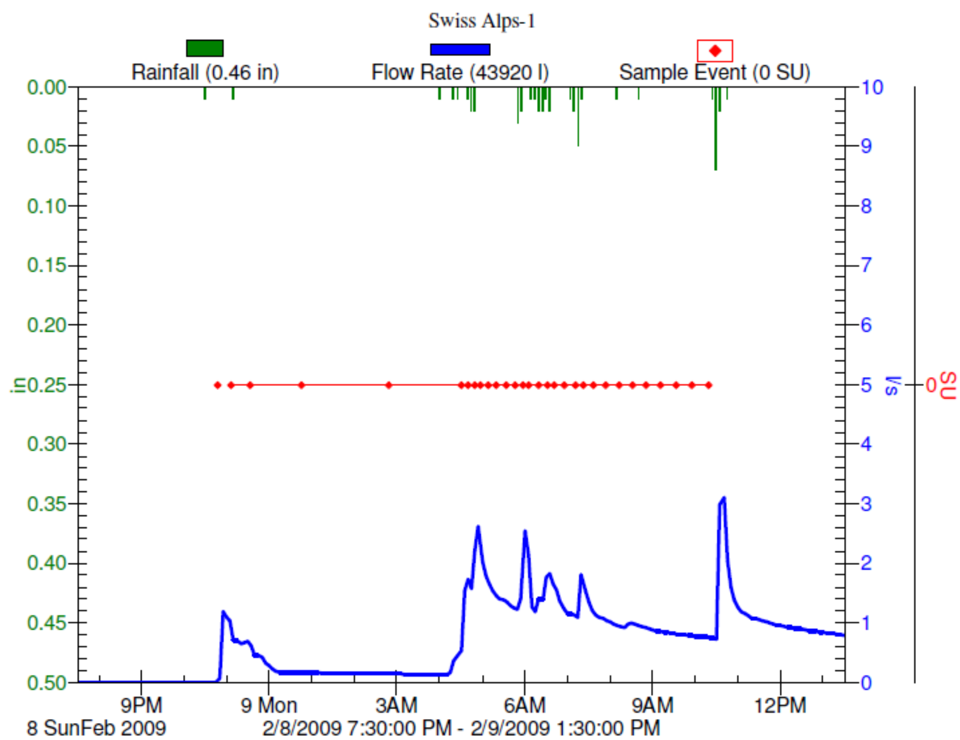

Swiss Alps-1
Rainfall (1.11 in)
Flow Rate (43612 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
40
35
30
25
20
15
10
5
0
3AM
6AM
9AM
12PM
3PM
6PM
15 WedOct 2008
10/15/2008 12:00:00 AM - 10/15/2008 6:00:00 PM

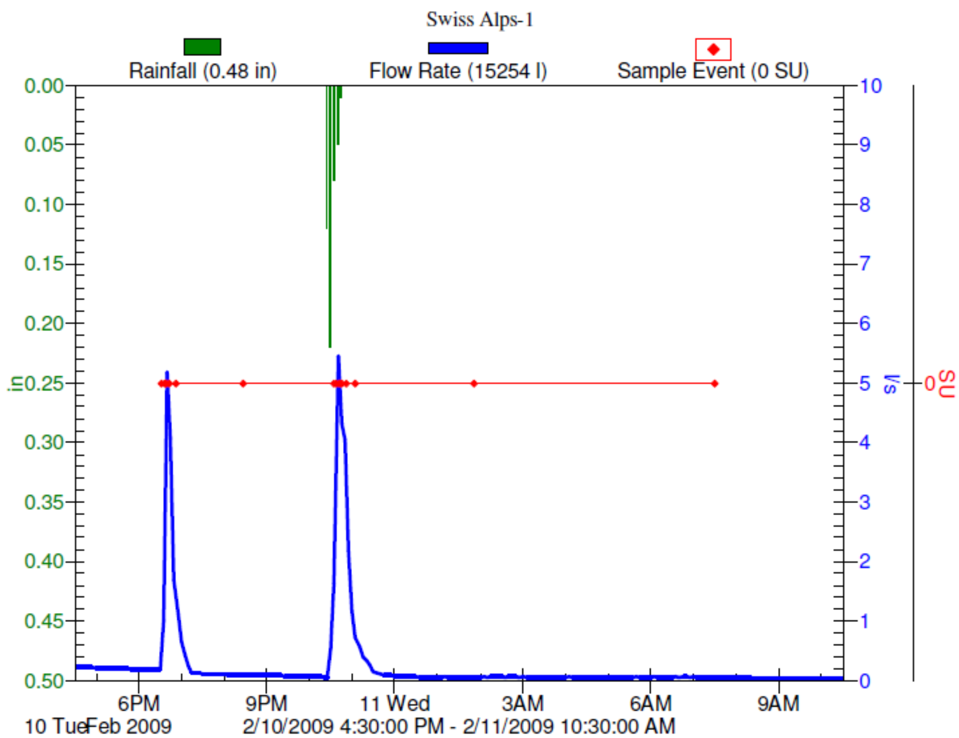


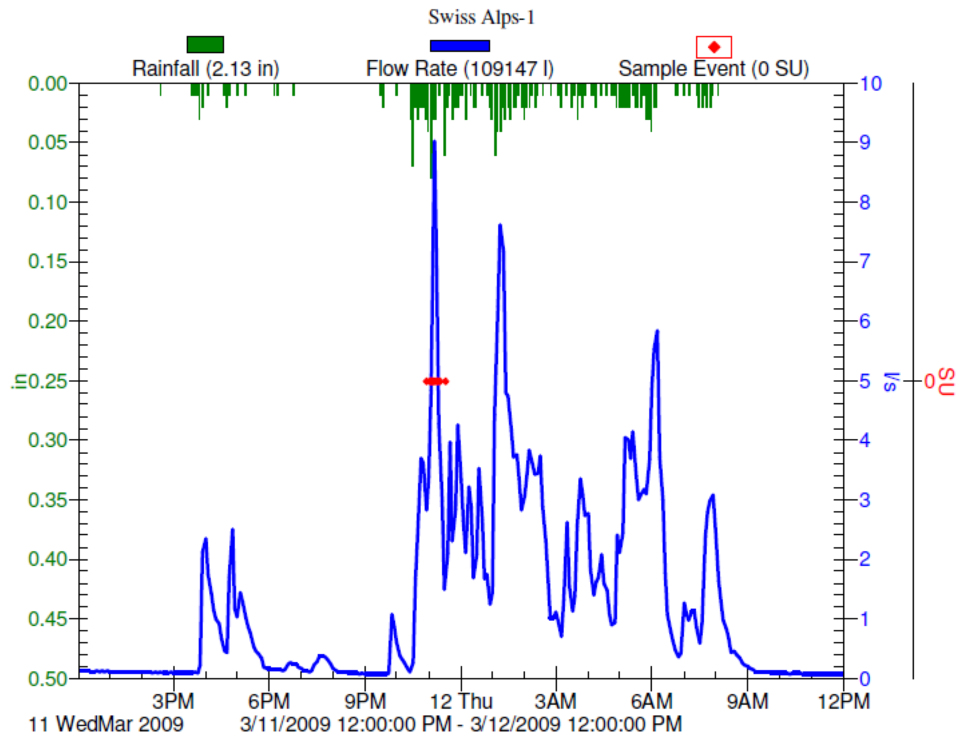
Swiss Alps-1
Rainfall (0.41 in)
Flow Rate (4990 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
in 0.25
0.30
0.35
0.40
0.45
0.50
3.0
2.5
2.0
1.5 l/s
1.0
0.5
0.0
0 SU
3AM
6AM
9AM
12PM
3PM
6PM
6 TueJan 2009
1/6/2009 12:00:00 AM - 1/6/2009 6:00:00 PM

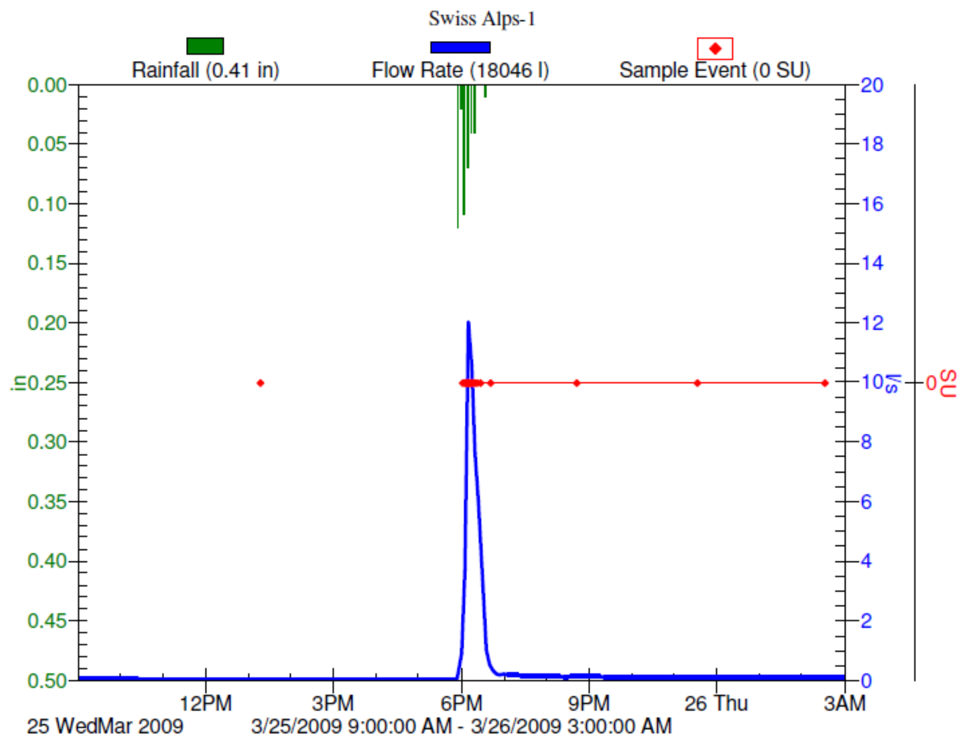


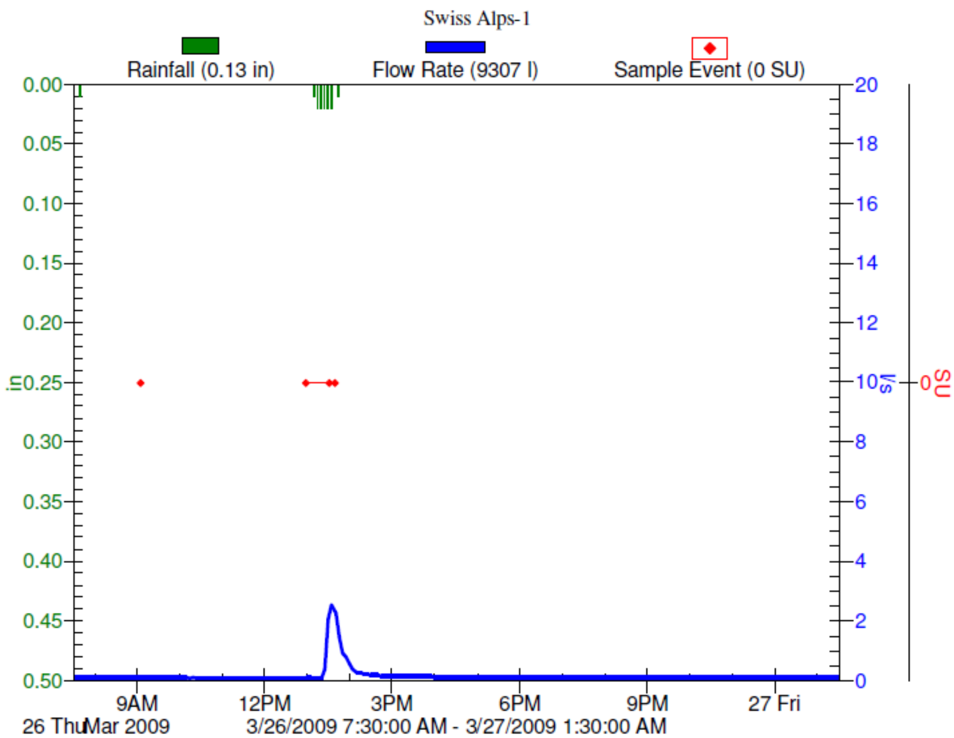
Swiss Alps-1
Rainfall (0.00 in)
Flow Rate (14302 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
in 0.25
0.30
0.35
0.40
0.45
0.50
10
9
8
7
6
5 l/s
4
3
2
1
0
0 SU
9PM
28 Wed
3AM
6AM
9AM
12PM
27 TueJan 2009
1/27/2009 6:00:00 PM - 1/28/2009 12:00:00 PM

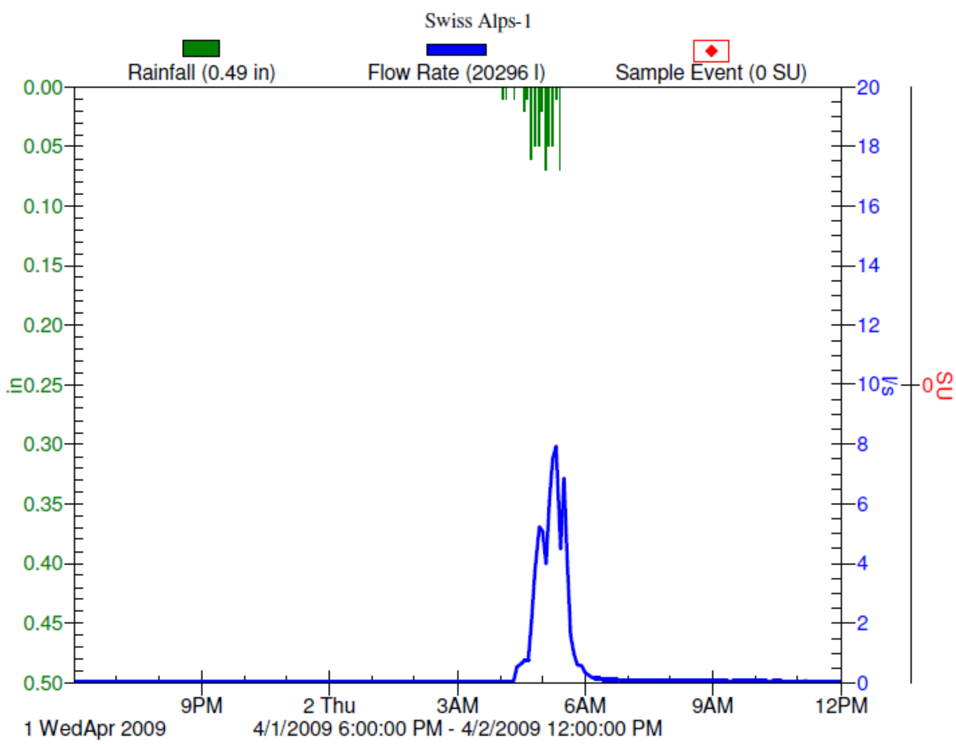

Swiss Alps-1
Rainfall (0.46 in)
Flow Rate (43920 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
l/s
10
9
8
7
6
5
4
3
2
1
0
SU
0
9PM
9 Mon
3AM
6AM
9AM
12PM
8 Sun Feb 2009
2/8/2009 7:30:00 PM - 2/9/2009 1:30:00 PM

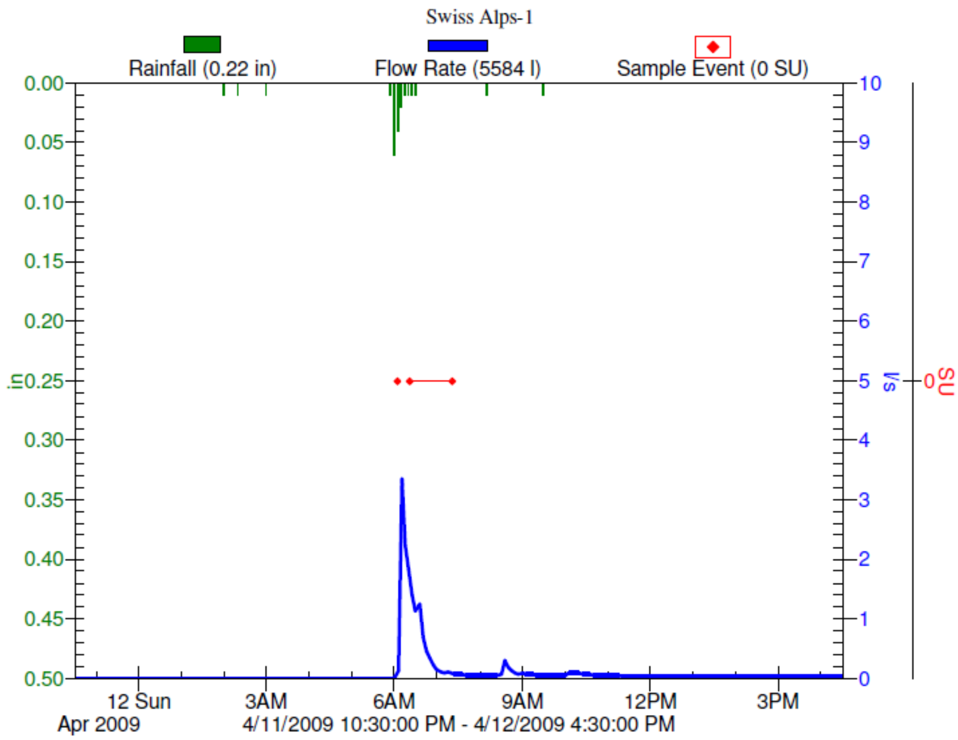

Swiss Alps-1
Rainfall (0.48 in)
Flow Rate (15254 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
l/s
10
9
8
7
6
5
4
3
2
1
0
SU
0
6PM
9PM
11 Wed
3AM
6AM
9AM
10 Tue Feb 2009
2/10/2009 4:30:00 PM - 2/11/2009 10:30:00 AM

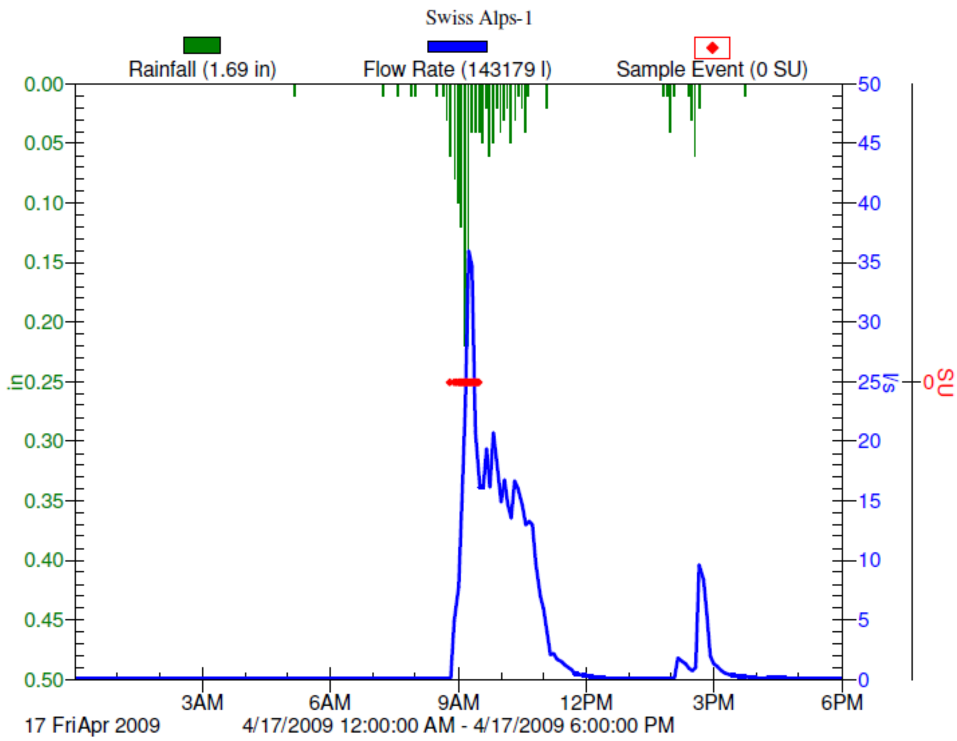

Swiss Alps-1
Rainfall (2.13 in)
Flow Rate (109147 l)
Sample Event (0 SU)
in
l/s
SU
11 WedMar 2009
3/11/2009 12:00:00 PM - 3/12/2009 12:00:00 PM

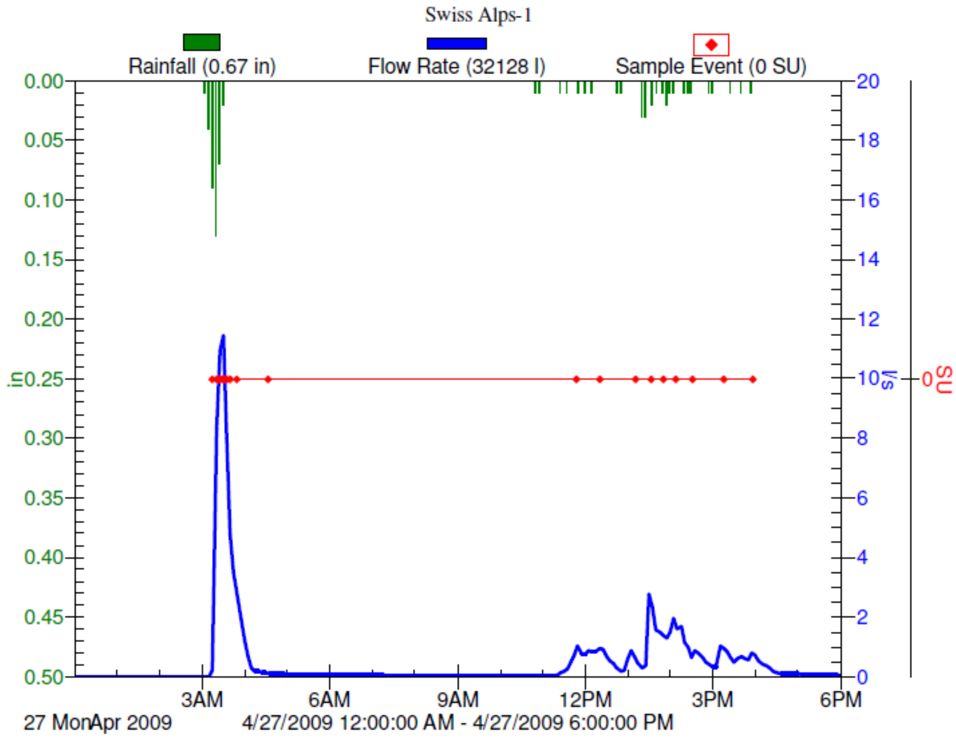

Swiss Alps-1
Rainfall (0.41 in)
Flow Rate (18046 l)
Sample Event (0 SU)
in
l/s
SU
25 WedMar 2009
3/25/2009 9:00:00 AM - 3/26/2009 3:00:00 AM

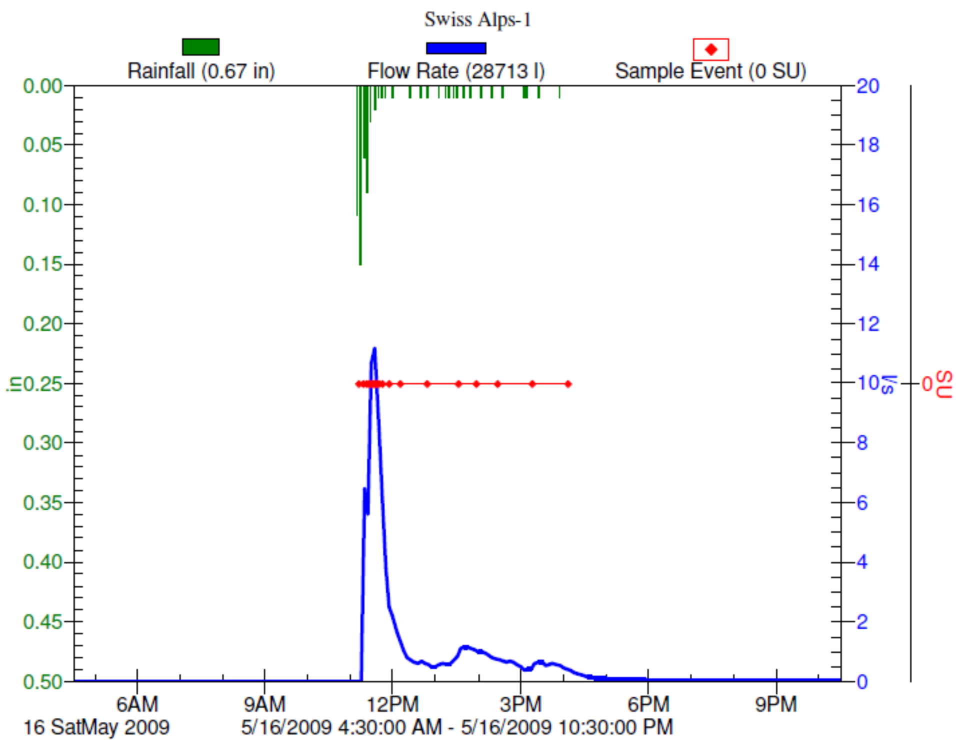

Swiss Alps-1
Rainfall (0.13 in)
Flow Rate (9307 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
in
20
18
16
14
12
10
8
6
4
2
0
l/s
0
SU
9AM
12PM
3PM
6PM
9PM
27 Fri
26 Thu Mar 2009
3/26/2009 7:30:00 AM - 3/27/2009 1:30:00 AM

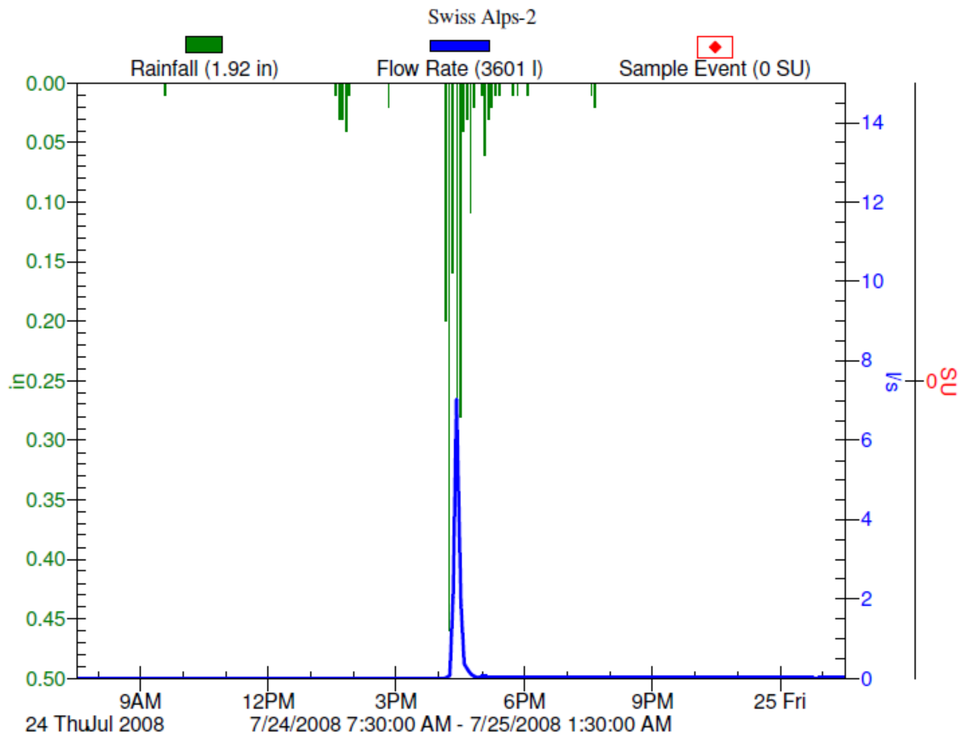

Swiss Alps-1
Rainfall (0.49 in)
Flow Rate (20296 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
in
20
18
16
14
12
10
8
6
4
2
0
l/s
0
SU
9PM
2 Thu
3AM
6AM
9AM
12PM
1 Wed Apr 2009
4/1/2009 6:00:00 PM - 4/2/2009 12:00:00 PM

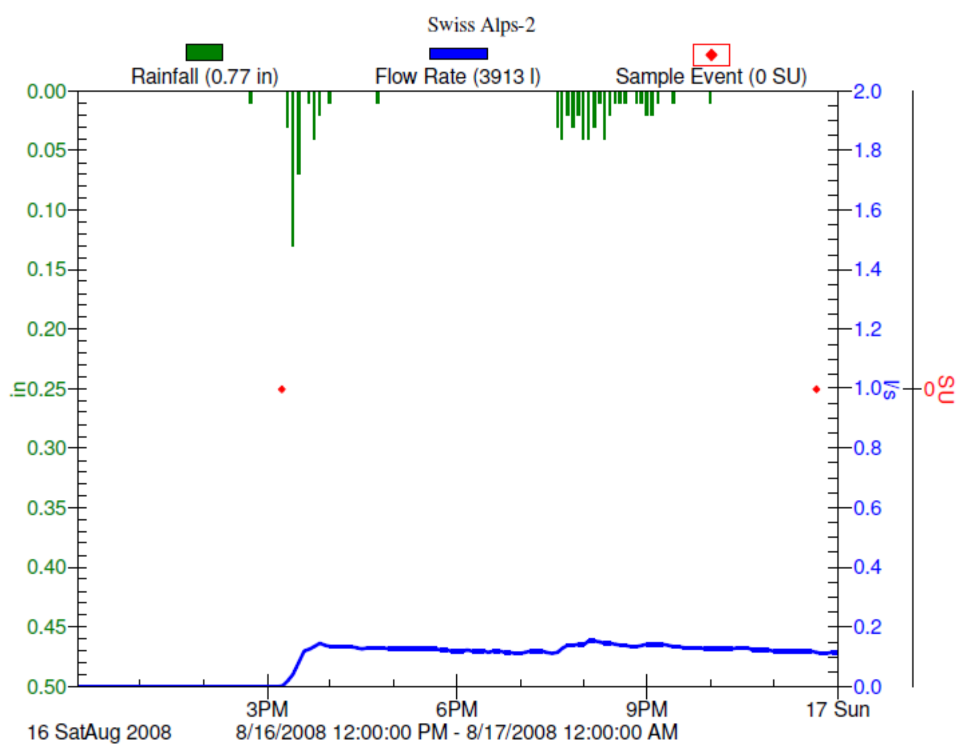

Swiss Alps-1
Rainfall (0.22 in)
Flow Rate (5584 l)
Sample Event (0 SU)
in
l/s
SU
12 Sun
3AM
6AM
9AM
12PM
3PM
Apr 2009
4/11/2009 10:30:00 PM - 4/12/2009 4:30:00 PM

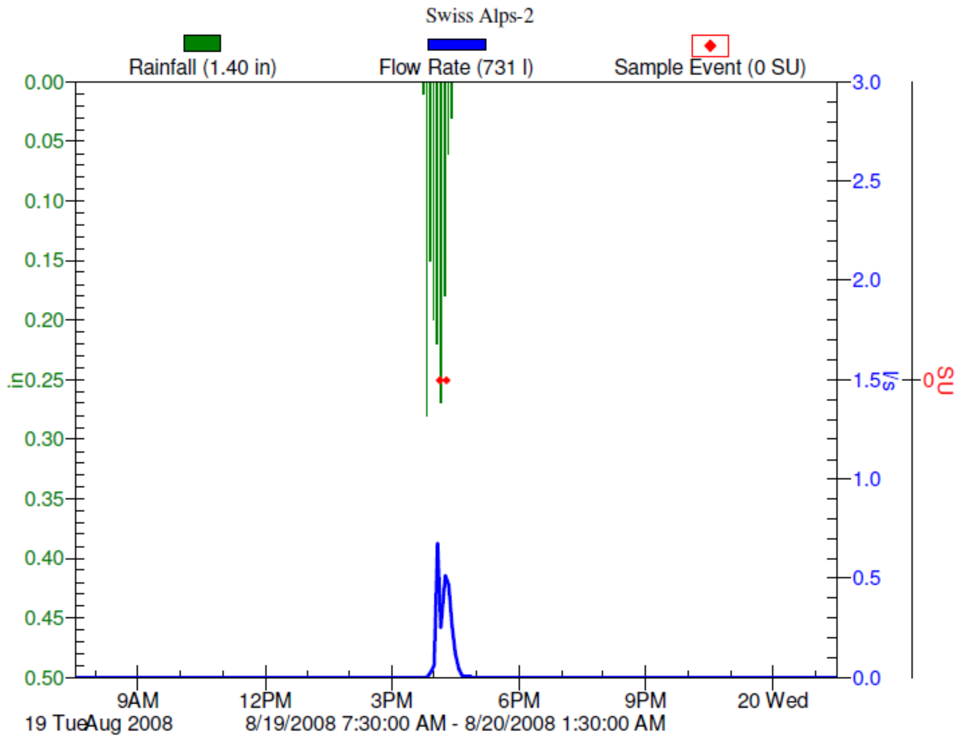

Swiss Alps-1
Rainfall (1.69 in)
Flow Rate (143179 l)
Sample Event (0 SU)
in
l/s
SU
3AM
6AM
9AM
12PM
3PM
6PM
17 FriApr 2009
4/17/2009 12:00:00 AM - 4/17/2009 6:00:00 PM


Swiss Alps-1
Rainfall (0.67 in)
Flow Rate (32128 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
20
18
16
14
12
10
8
6
4
2
0
l/s
0
SU
3AM
6AM
9AM
12PM
3PM
6PM
27 MonApr 2009
4/27/2009 12:00:00 AM - 4/27/2009 6:00:00 PM

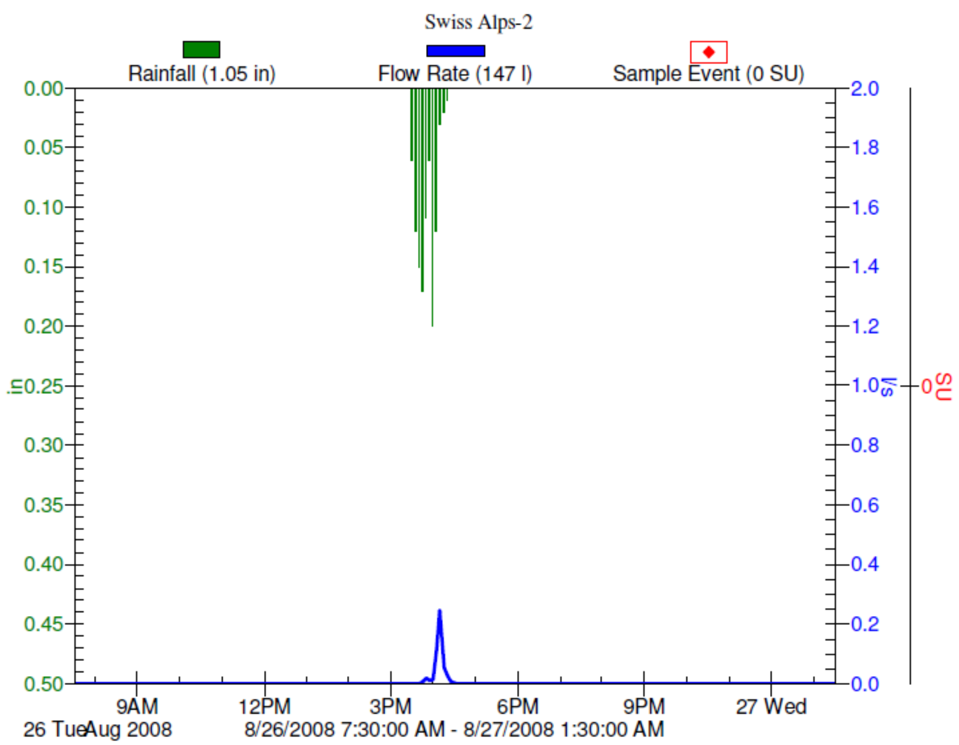

Swiss Alps-1
Rainfall (0.67 in)
Flow Rate (28713 l)
Sample Event (0 SU)
in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
20
18
16
14
12
10
8
6
4
2
0
l/s
0
SU
6AM
9AM
12PM
3PM
6PM
9PM
16 SatMay 2009
5/16/2009 4:30:00 AM - 5/16/2009 10:30:00 PM


Swiss Alps-2
Rainfall (1.92 in)
Flow Rate (3601 l)
Sample Event (0 SU)
in
l/s
SU
9AM
12PM
3PM
6PM
9PM
25 Fri
24 Thu Jul 2008
7/24/2008 7:30:00 AM - 7/25/2008 1:30:00 AM

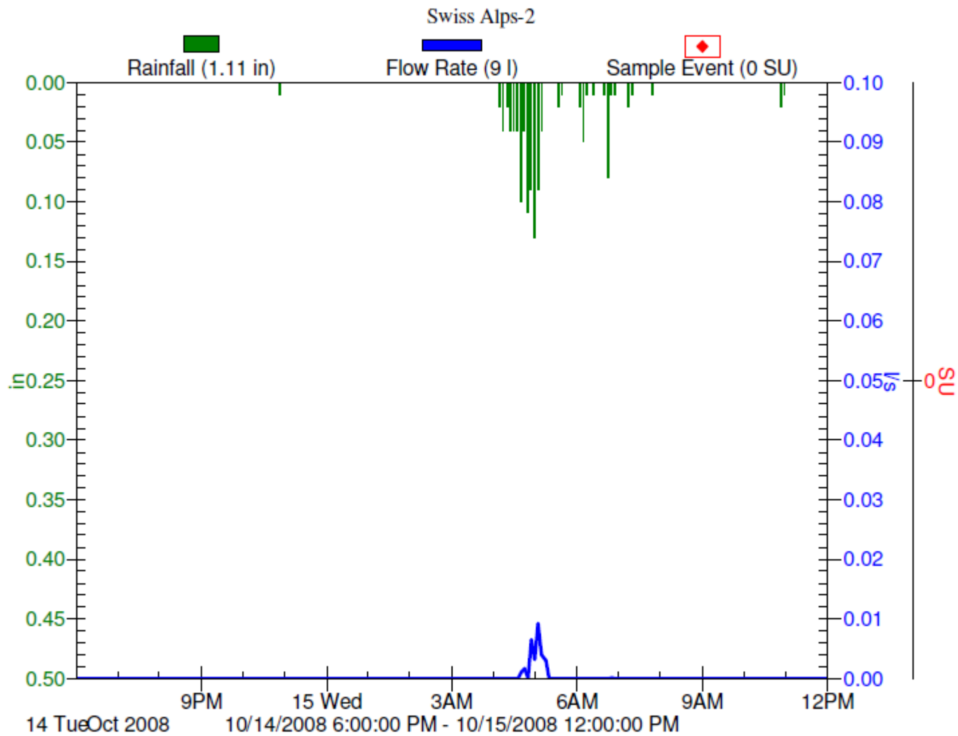

Swiss Alps-2
Rainfall (0.77 in)
Flow Rate (3913 l)
Sample Event (0 SU)
in
l/s
SU
3PM
6PM
9PM
17 Sun
16 Sat Aug 2008
8/16/2008 12:00:00 PM - 8/17/2008 12:00:00 AM

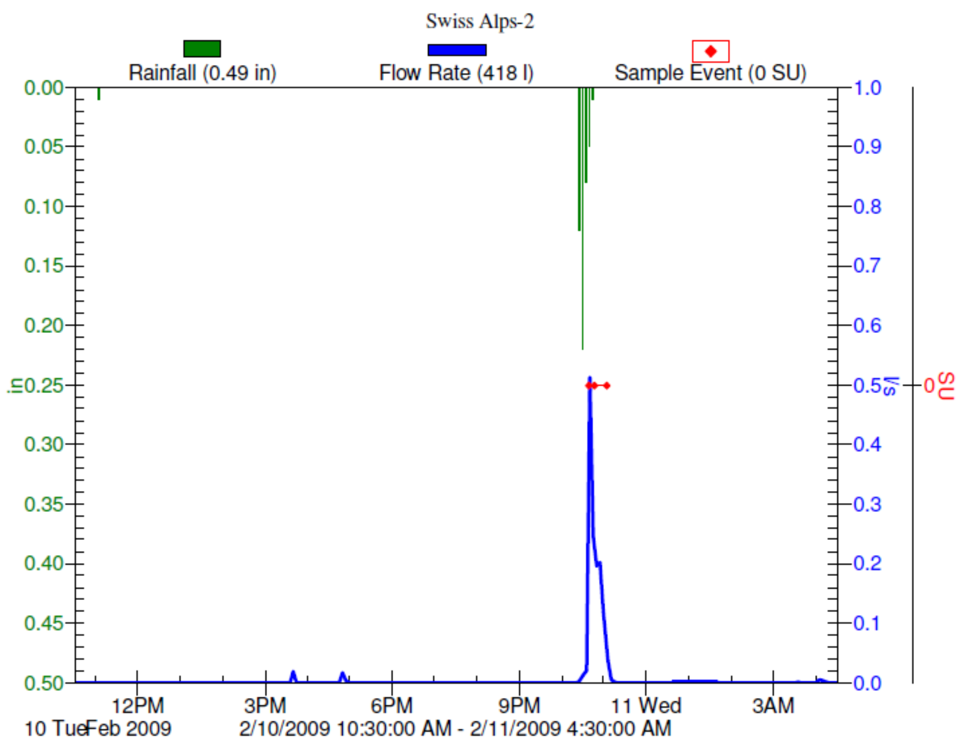


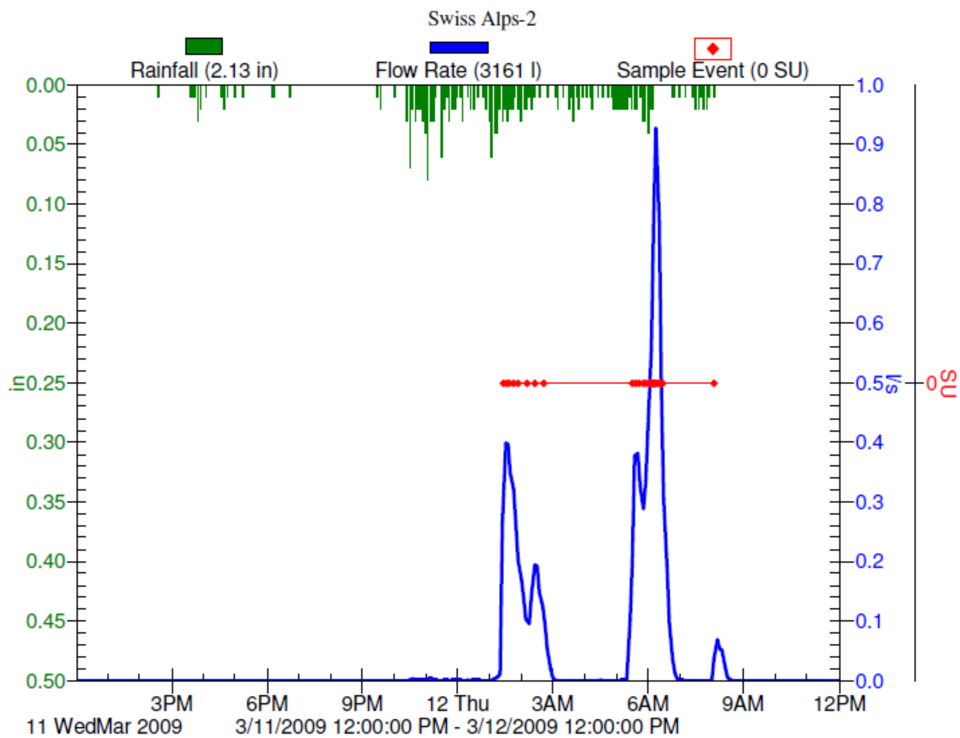
Swiss Alps-2
Rainfall (1.40 in)
Flow Rate (731 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
in
3.0
2.5
2.0
1.5
1.0
0.5
0.0
l/s
0
SU
9AM
12PM
3PM
6PM
9PM
20 Wed
19 Tue
Aug 2008
8/19/2008 7:30:00 AM - 8/20/2008 1:30:00 AM

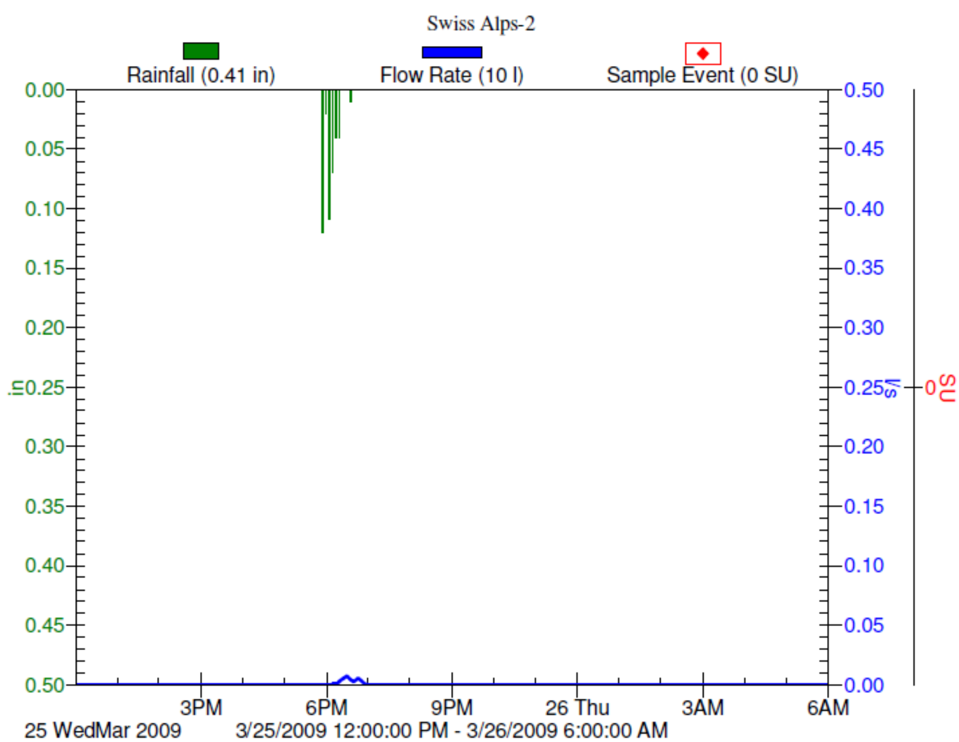


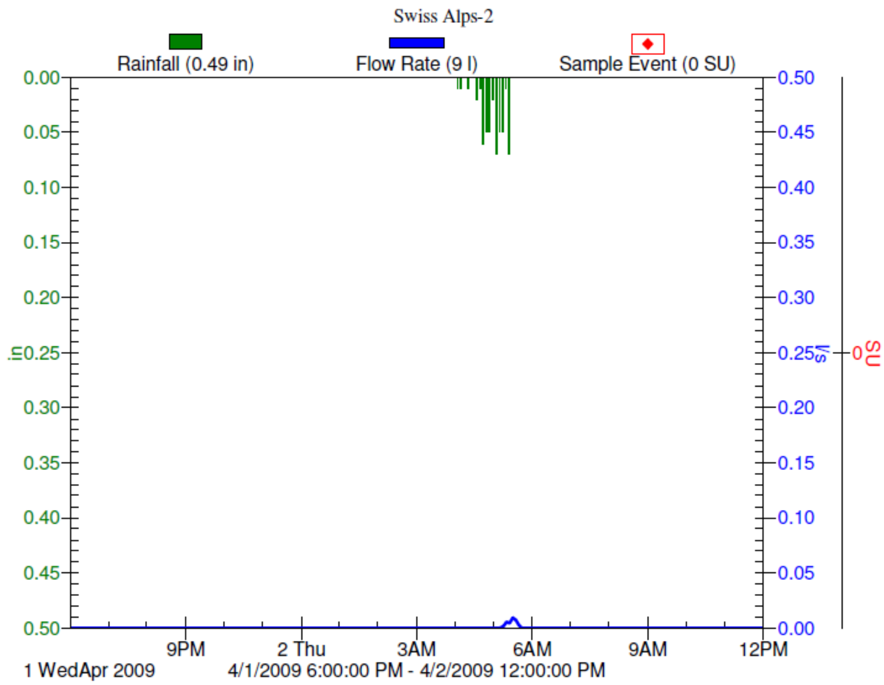
Swiss Alps-2
Rainfall (1.05 in)
Flow Rate (147 l)
Sample Event (0 SU)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
in
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
l/s
0
SU
9AM
12PM
3PM
6PM
9PM
27 Wed
26 Tue
Aug 2008
8/26/2008 7:30:00 AM - 8/27/2008 1:30:00 AM

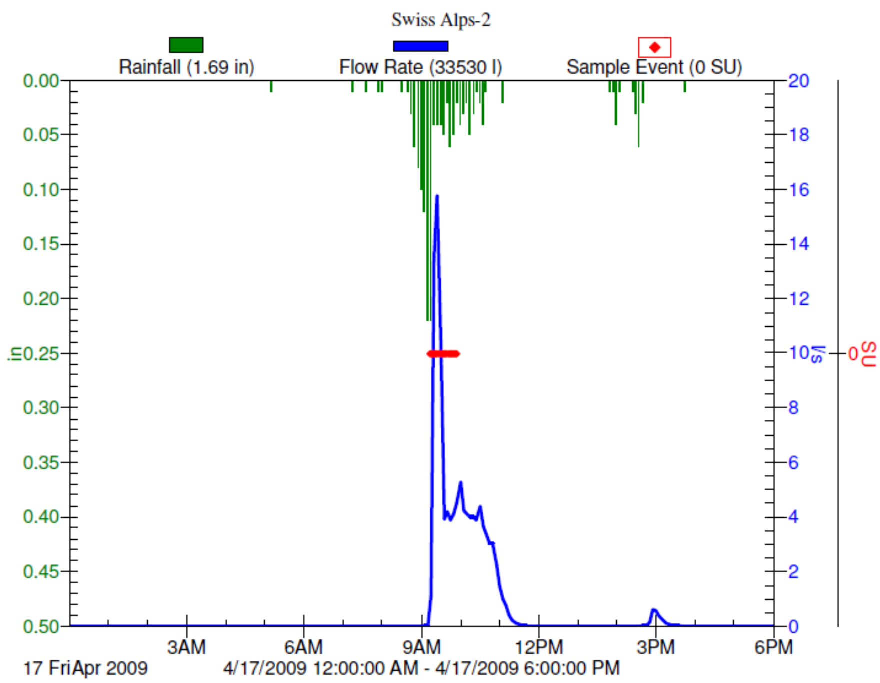

Swiss Alps-2
Rainfall (1.11 in)
Flow Rate (9 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
9PM
15 Wed
3AM
6AM
9AM
12PM
14 Tue
Oct 2008
10/14/2008 6:00:00 PM - 10/15/2008 12:00:00 PM


Swiss Alps-2
Rainfall (0.49 in)
Flow Rate (418 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
12PM
3PM
6PM
9PM
11 Wed
3AM
10 Tue
Feb 2009
2/10/2009 10:30:00 AM - 2/11/2009 4:30:00 AM

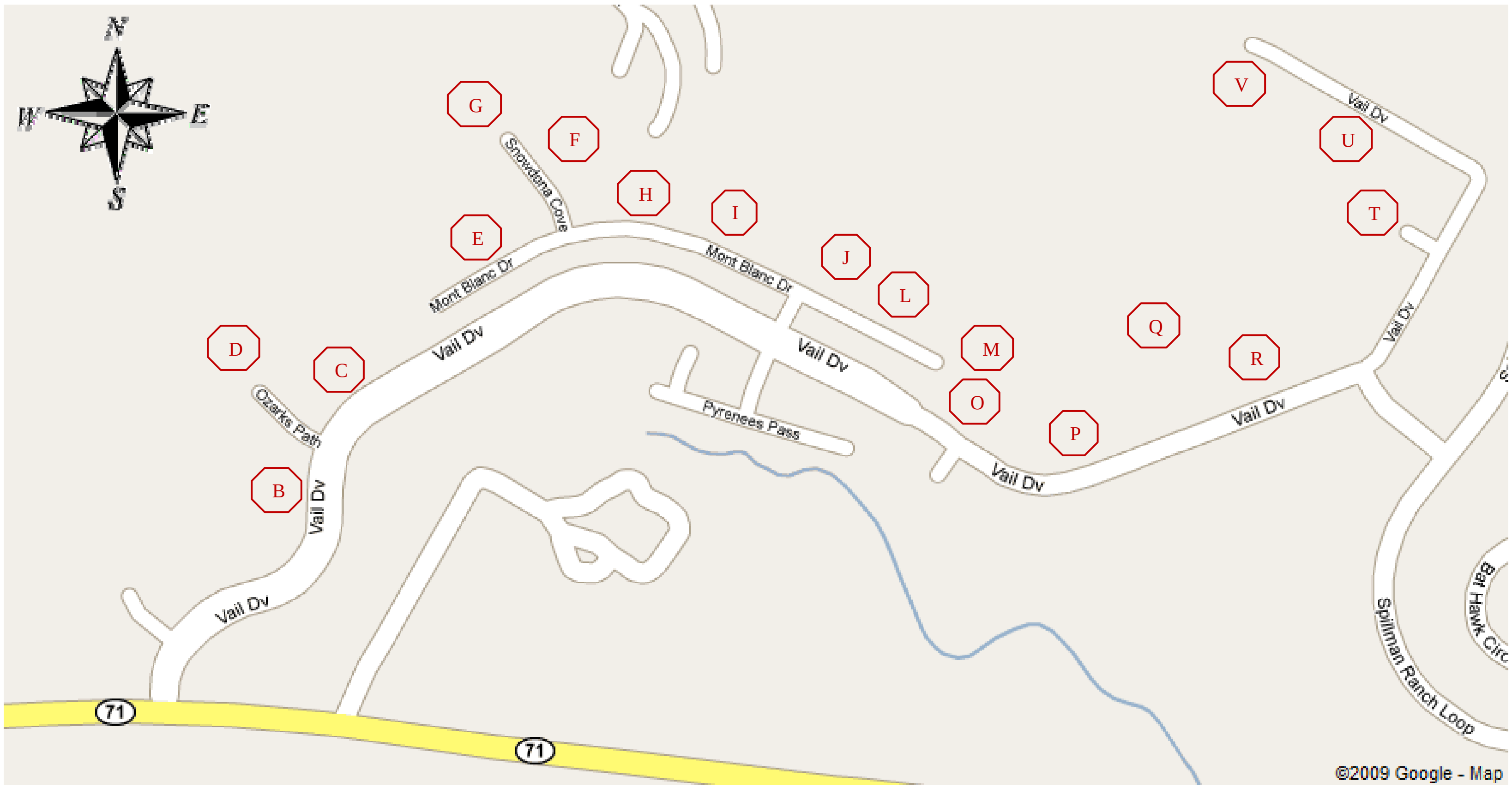

Swiss Alps-2
Rainfall (2.13 in)
Flow Rate (3161 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
3PM
6PM
9PM
12 Thu
3AM
6AM
9AM
12PM
11 WedMar 2009
3/11/2009 12:00:00 PM - 3/12/2009 12:00:00 PM


Swiss Alps-2
Rainfall (0.41 in)
Flow Rate (10 l)
Sample Event (0 SU)
in
l/s
SU
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
3PM
6PM
9PM
26 Thu
3AM
6AM
25 WedMar 2009
3/25/2009 12:00:00 PM - 3/26/2009 6:00:00 AM


Swiss Alps-2
Rainfall (0.49 in)
Flow Rate (9 l)
Sample Event (0 SU)
in
l/s
SU
9PM
2 Thu
3AM
6AM
9AM
12PM
1 WedApr 2009
4/1/2009 6:00:00 PM - 4/2/2009 12:00:00 PM


Swiss Alps-2
Rainfall (1.69 in)
Flow Rate (33530 l)
Sample Event (0 SU)
in
l/s
SU
3AM
6AM
9AM
12PM
3PM
6PM
17 FriApr 2009
4/17/2009 12:00:00 AM - 4/17/2009 6:00:00 PM

APPENDIX E: LS-VFS SYSTEMS MAP



APPENDIX F: QUARTERLY LS-VFS PICTORIAL OBSERVATION

System B

May 2008

July 2008

October 2008

January 2009

June 2009

System C

July 2008; Sediment Accumulation and Downstream Cage Break

January 2009, Downstream Wire Cage Break

October 2008

January 2009

June 2009

System D

May 2008

July 2008

October 2008

January 2009

June 2009

System E

May 2008

July 2008

October 2008

January 2009, Downslope Erosion

January 2009, Downslope Erosion

June 2009

System F

May 2008

July 2008

October 2008

January 2009

June 2009

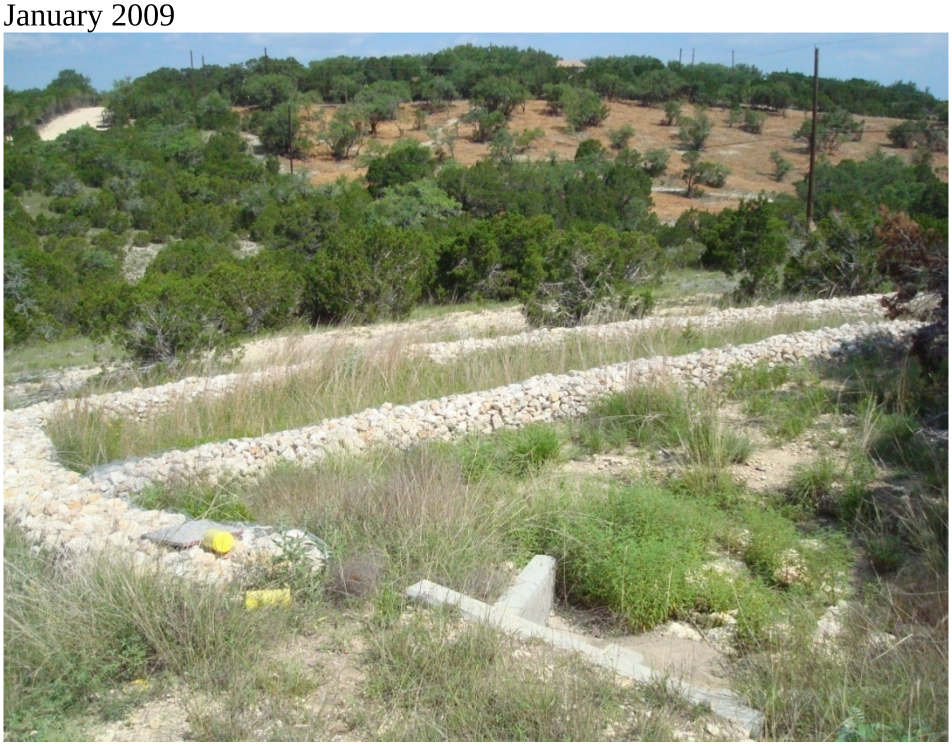
System G

May 2008

July 2008

October 2008

January 2009



June 2009

System H

July 2008

October 2008

January 2009, Downslope Erosion

June 2009

System J

May 2008

July 2008

October 2008

January 2009

June 2009

System L

May 2008

July 2008

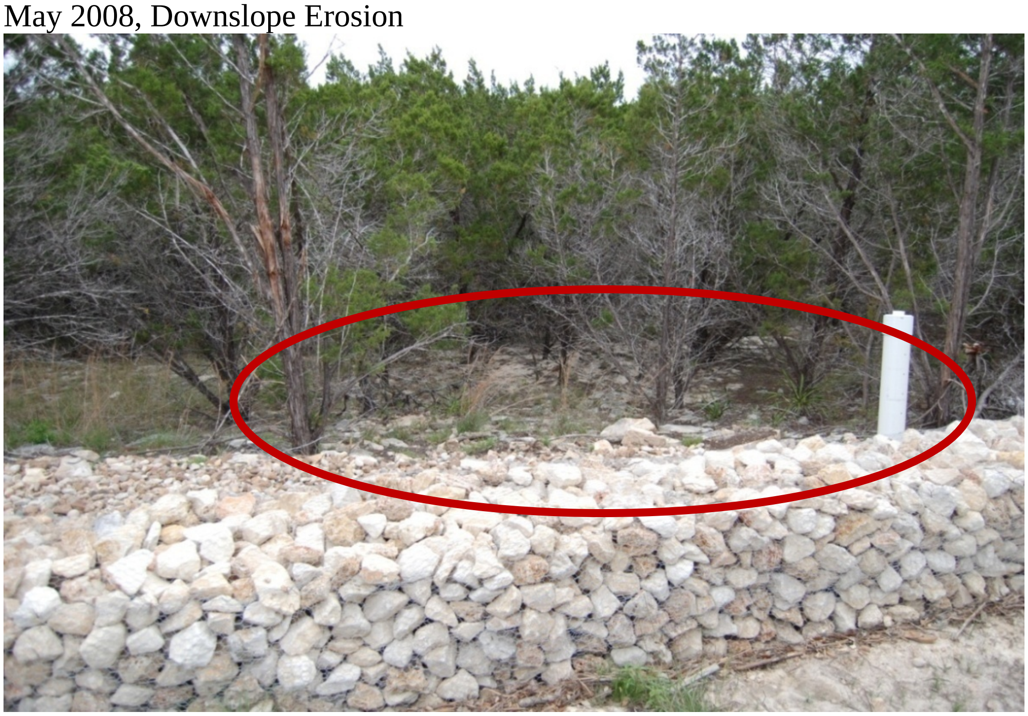
October 2008

January 2009

June 2009

System M

May 2008, Downslope Erosion



May 2008, Downslope Erosion

July 2008

October 2008

October 2008, Broken Wire Cage

January 2009, Broken Wire Cage

June 2009, Downslope Erosion

System O

May 2008

July 2008

October 2008

January 2009

June 2009

System P

May 2008

July 2008

October 2008

January 2009

June 2009

System Q

May 2008


July 2008

October 2008

January 2009

June 2009

System R

May 2008

July 2008

October 2008

January 2009

June 2009

System T

May 2008

May 2008, Downslope concentrated flow and erosion

July 2008, Sediment accumulation

October 2008, Broken wire cage

January 2009

June 2009

System U

May 2008

July 2008, Sediment accumulation

October 2008

January 2009

June 2009

System V

May 2008

July 2008, Sediment accumulation

October 2008, Sediment accumulation

January 2009, Sediment accumulation

June 2009