Clean Water Legacy Project Final Report

Project Title: Evaluation of alternative surface-water monitoring protocols for use in agriculture TMDL load allocation and BMP evaluation.

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EXECUTIVE SUMMARY

Edge-of-field runoff driven by rainfall, snowmelt, or a combination of rain and snowmelt, produce discharge events that vary greatly in total volume. It is difficult, if not impossible, to accurately pre-program automated samplers so that both small and large events are sampled adequately. What often occurs is insufficient samples are collected during small runoff events, and sampler capacity is exceeded during large runoff events. To overcome this challenge, Pioneer Farm, in cooperation with the United States Geological Survey, has monitored runoff events in real-time via remote connections and adjusted the time between samples so that a much larger range of events can be monitored. Unfortunately, this method increases costs due to increased technician labor and increased sample handling and preparation.

The purpose this study was to evaluate two alternative methodologies for estimating discharge and collection samples for nutrient and sediment analysis. The first alternative system (2-part FWC) used an automated sampler that is capable of collecting samples based on two flow intervals simultaneously. This allows one sampler to be set to two flow-weight compositing intervals- one interval for small events and one for large events. The second system (SS Siphon) includes single-stage siphon samplers installed at multiple flume depths in association with an integrated stage sensor-datalogger. Samplers were installed at sites 2 and 8 at the University of Wisconsin-Platteville Pioneer Farm and snow and rainfall driven runoff events were monitored to determine accuracy and precision of alternative sampling techniques. Accuracy measurements are reported as relative percent accuracy and are calculated as a difference from results determined by our current system (referred to as EPA method).

Experimental results indicate that the 2-part FWC method was able to adequately sample both large and small events, but one of the replicate samplers produced significantly different total phosphorus load; however, the actual difference in loads was small – the sum of event loads equaled 10.1 kg for the EPA method and 10.9 kg for the 2-part FWC method. The nitrogen and phosphorus loads produced by replicate samplers were precise and strongly correlated to EPA method loads, which may indicate a sampler bias. Discharge estimates as well as suspended sediment concentration and load estimated by the 2-part FWC method did not differ significantly from EPA method. Due to reductions in equipment costs, required technician labor, and sample handling, the 2-part FWC method would cost slightly more than half that of the EPA method, assuming a three-year monitoring program.

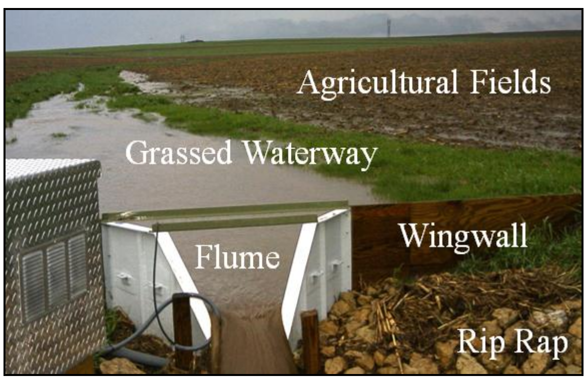
The SS Siphon method did not produce significant differences in any of the measured constituents (discharge, nutrient concentration, nutrient load, suspended sediment concentration, or suspended sediment load). However, the sum of event load suspended sediment from siphon samplers was 685 and 729 kg compared to 419 kg suspended sediment load determined by the EPA method. While this method relies on low cost equipment, technician time required for operation and maintenance is similar to the 2-part FWC method, therefore the cost of a multi-year monitoring project will be similar for the two methods.

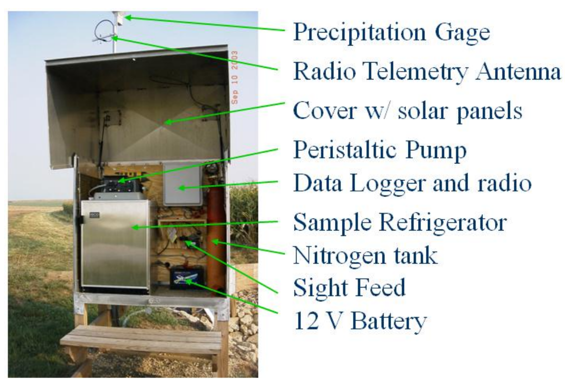
INTRODUCTION

This research project compared the current monitoring protocol used by UW-Platteville Pioneer Farm and UW-Extension Discovery Farms that meet EPA guidelines (EPA), with two alternate low-cost methods: 2-part flow-weighted automated sampling (2-Part FWC) and single-stage passive samplers (SS Siphon).

Pioneer Farm monitoring methods (a.k.a. EPA Method) utilize a pre-calibrated H-flume (Figure 1) with a pressure transducer stage recorder to determine flow. Samples are triggered based on time interval that is adjustable remotely via radio telemetry and internet communication. After collection, samples are cooled in the refrigerated sampler until retrieved by a technician. A detailed description of the current monitoring strategy at Pioneer Farm can be downloaded at the following website:http://pubs.usgs.gov/of/2008/1015/pdf/ofr_2008-1015.pdf

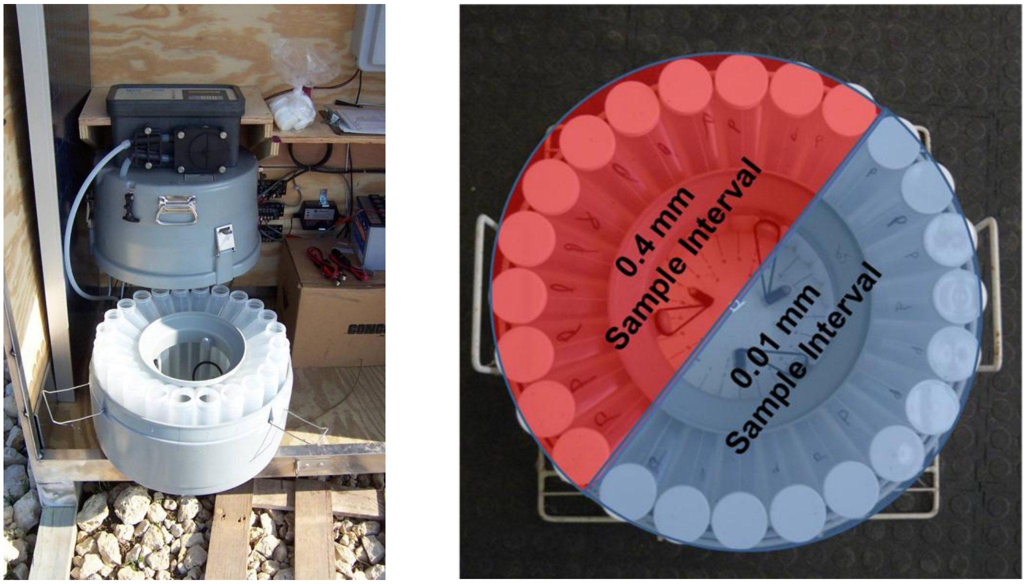
Figure 1. Flume-wing-wall installations at Pioneer Farm.





In contrast, the 2-Part FWC method does not have remote access. Instead the ISCO 6712 sampler has the capability to collect samples based on two flow intervals simultaneously. This allows one sampler with a 24 bottle carrousel to be set to two flow-weight compositing intervals: bottles 1-12 were set to 0.01 mm interval for small events, and sample bottles 13-24 were set to a 0.4 mm interval for large events (figure 2). Flow is determined using the H-flume instrumented with an ultrasonic flow meter. Samples collected by the 2-part sampler were not refrigerated.

Figure 2. Figure Surface-water monitoring equipment used for 2-Part FWC method.



The single-stage siphon sampler is a passive sampler, meaning that collects a sample without any external control or activation. The sample begins to collect when surface-water height in the flume exceeds the maximum height of the intake tube. This initiates a siphon and the sample bottle fills rapidly. Three siphon samplers are located along side each flume with their intake tube sample heights fixed inside the so that samples are collected at 0.2’, 0.5’, and 1.0’ stages (figure 3).

Figure 3. Surface-water monitoring equipment used for SS-Siphon method.

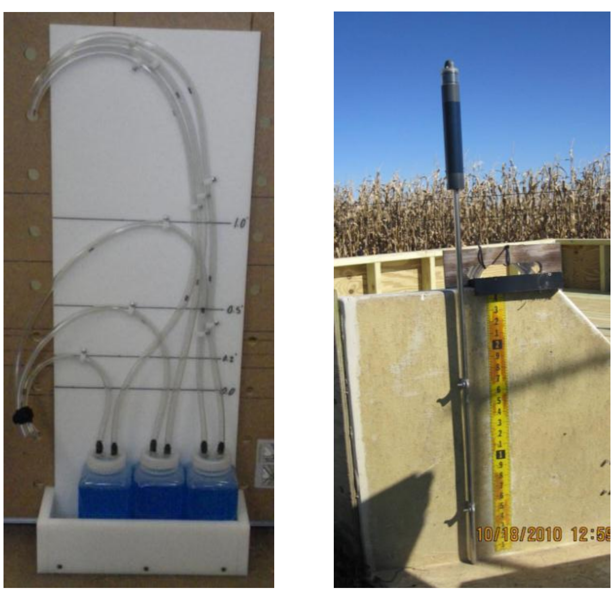
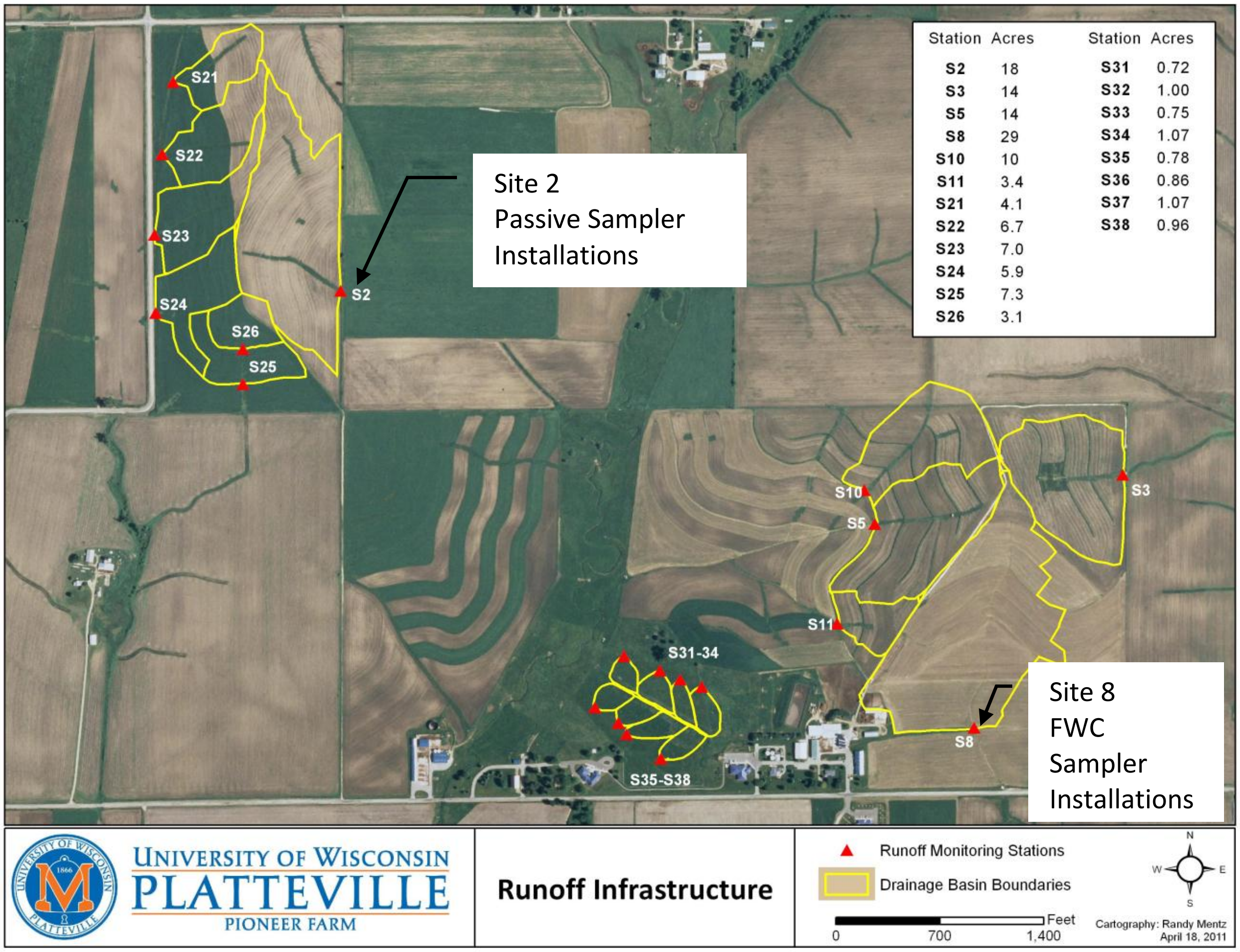


Figure 4. Pioneer Farm aerial map with sampler installations identified.



Research was conducted for this project at sites 2 and 8 at the University of Wisconsin-Platteville Pioneer Farm. Both of these sites were managed and operated in conjunction with the United States Geological Survey for the duration of this study as described in the USGS Open File report 2008-1015 Methods for data collection, sample processing, and data analysis for edge-of-field, streamgaging, subsurface-tile, and meteorological stations at Discovery Farms and Pioneer Farm in Wisconsin, 2001-7. In addition to the USGS-PF samplers, two passive samplers were installed at site 2 and two FWC samplers were installed at site 8, allowing for direct comparison of event mean concentration and load data as well as an evaluation of operation and maintenance requirements for the alternative methods.

More specifically, the comparisons will be based on the following.

1. **Relative error** of event loads (N, P, and sediment) calculated by 2-part flow-weight composite and single-stage sampling strategies. The relative error will indicate how closely the alternative method

compares to the EPA approved method. For example, a relative error of 90% would indicate that the alternative method calculated a load that was 10% less than the actual load.

2. **Precision** of 2-part flow-weight composite and single-stage sampling methods. The precision, or coefficient of variation (CV), will indicate how well the alternative methods are able reproduce load estimates. If sampling methods are imprecise (have a large CV) they may not be useful in evaluating BMPs. In the proposal it was indicated that the precision evaluation would be based on standard deviation; however, the large variations in mean values makes that comparison difficult. The CV is a ratio of the standard deviation to the sample mean; therefore events with large differences in sample means can be directly compared.

3. **Costs** of alternative methods including: equipment, operation, and maintenance.

Tables in the following pages contain event monitoring results for discharge, total nitrogen, total phosphorus, and suspended sediment. Section 1 lists event concentration and load data for the EPA and FWC methods; describes error and precision of these estimates; and discusses cost of operation and maintenance. Section 2 is similar the first section, but focuses on the single-stage siphon sampler results. The third and final section presents recommendations for future research.

It is important to note that not all runoff events that occurred during the experiment are included in this analysis. There were occasions when events were missed due to equipment failure or operator error. Failures occurred on all systems- including the USGS-PF operated sites. For example, large runoff events washed out the flume on site 8, sampler lines froze on site 2, batteries failed on site 8, and aquarod data was overwritten during runoff events of long duration. While failures were more frequent with the FWC and SS-Siphon samplers when compared to the USGS-PF samplers, PF technicians have been operating these systems for 8 years and are much more familiar with these systems. For this reason, the comparisons on the following pages are based on events for which data was available from both sampling systems. If all events were included, the observed differences may be more a result of operator experience than inherent capabilities of sampling equipment.

SECTION 1. TWO-PART FLOW WEIGHT COMPOSITE SAMPLING

Table 1. Event discharge data for FWC sampling methods.

	Discharge			Relative Error		Precision	
Date	EPA	FWC-A	FWC-B	A	B	s.d.	CV
	(cf)	(cf)	(cf)	(%)	(%)		
1/24/2010	1,449	1,380	775	4.8	46.5	427.8	0.40
3/5/2010	55,300	51,400	50,400	7.1	8.9	707.1	0.01
3/9/2010	82,100	86,000	84,900	-4.8	-3.4	777.8	0.01
3/11/2010	9,700	11,200	11,200	-15.5	-15.5	0.0	0.00
6/5/2010	66	90	78	-36.4	-18.2	8.5	0.10
6/15/2010	766	702	703	8.4	8.2	0.7	0.00
6/23/2010	570	784	731	-37.5	-28.2	37.5	0.05
7/7/2010	11,800	12,900	12,300	-9.3	-4.2	424.3	0.03
7/23/2010	17,000	18,300	17,900	-7.6	-5.3	282.8	0.02
12/30/2010	12,100	13,500	13,600	-11.6	-12.4	70.7	0.01
2/14/2011	86,600	83,600	85,600	3.5	1.2	1414.2	0.02
2/20/2011	35,800	36,800	36,700	-2.8	-2.5	70.7	0.00
3/1/2011	11,400	15,700	14,700	-37.7	-28.9	707.1	0.05
3/7/2011	12,200	12,700	13,600	-4.1	-11.5	636.4	0.05
Total	336,851	345,056	343,187	-2.4	-1.9		0.00
intercept		-883	-651				
Slope		1.01	1.01				
r squared		0.99	1.00				
Obs P		0.33	0.40				

The table above presents corrected (see the quality assurance project plan for a description of correction methods) discharge data for the project. The comparative analysis for the flow-weight composite (FWC) sampling technique included 14 events starting with the January 24th, 2010 event. Events monitored include snowmelt, rainfall, and events driven by combinations of rain and snowmelt discharge.

Both FWC samplers (A and B) provided relatively accurate, precise estimates of event discharge. However, for events of less than 12,000 cubic feet the relative error could be large (46.5% maximum). Regression analysis indicates good correlation between the EPA discharge and FWC sampler A (r^2 = 0.99) and FWC B sampler (r^2 = 1) and a slope of near 1 for both samplers. The coefficient of variation (CV, ratio of standard deviation to mean) for discharge measurements, with the exception of the 1/24/2011 event, was less than 0.10- indicating a high precision of discharge estimate.

The ultrasonic stage sensors used as part of the FWC method consistently exhibited more within variation than those recorded by the Sutron bubble sensor used in the EPA method (data not shown). These issues were more pronounced during snowmelt events. The manufacturer's minimum operating temperature for this sensor was 32^o F. Alternative sensors available for this system may perform better under snowmelt conditions.

Table 2. Total nitrogen concentration and load data for FWC sampling methods.

	Concentration			Error		Prec.	Load			Error		Prec.
Date	EPA	A	B	A	B	CV	EPA	A	B	A	B	CV
	(mg/L)	(mg/L)	(mg/L)	(%)	(%)		(kg)	(kg)	(kg)	(%)	(%)	
1/24/2010	3.6	4.2	3.8	-16.5	-3.3	0.09	0.15	0.17	0.08	-10.7	44.8	0.47
3/5/2010	7.0	10.2	9.9	-44.5	-41.1	0.02	11.00	14.80	14.20	-34.5	-29.1	0.03
3/9/2010	4.3	4.7	5.0	-9.7	-16.9	0.04	10.00	11.50	12.10	-15.0	-21.0	0.04
3/11/2010	8.9	8.2	6.6	8.5	25.6	0.15	2.45	2.60	2.11	-6.1	13.9	0.15
6/5/2010	3.8	4.9	4.6	-30.2	-22.8	0.04	0.01	0.01	0.01	-77.3	-44.7	0.14
6/15/2010	3.8	5.2	5.6	-37.2	-48.7	0.06	0.08	0.10	0.11	-26.2	-36.0	0.05
6/23/2010	4.5	4.6	4.6	-2.0	-4.0	0.01	0.07	0.10	0.10	-40.3	-33.3	0.04
7/7/2010	6.1	4.3	4.3	29.3	29.3	0.00	2.03	1.57	1.49	22.7	26.6	0.04
7/23/2010	1.1	1.4	1.3	-30.0	-19.1	0.06	0.53	0.74	0.67	-40.5	-25.7	0.08
12/30/2010	1.5	1.6	2.0	-11.0	-35.6	0.14	0.50	0.62	0.76	-24.2	-52.6	0.15
2/14/2011	4.2	5.6	5.7	-33.3	-36.2	0.01	10.30	13.30	13.90	-29.1	-35.0	0.03
2/20/2011	3.1	3.2	3.0	-3.6	1.0	0.03	3.11	3.31	3.16	-6.4	-1.6	0.03
3/1/2011	4.8	5.1	5.1	-7.1	-6.9	0.00	1.54	2.27	2.11	-47.4	-37.0	0.05
3/7/2011	5.7	5.6	5.0	3.0	13.2	0.08	1.98	2.00	1.92	-1.0	3.0	0.03
Totals							43.75	53.10	52.72	-21.4	-20.5	0.01
intercept		1	1					0	0			
slope		0.79	0.78					0.78	0.76			
r squared		0.75	0.62					0.99	0.99			
Obs P		0.15	0.40					0.07	0.09			

Total nitrogen concentrations estimated by the EPA method ranged from 1.1 to 7.0 mg/l. Estimates of total nitrogen concentration generated by the FWC samplers were generally higher the EPA estimates- relative percent error as large as 44.5%. This lead to increased load estimates for the FWC samplers- sum of loads for all events was about 9 kg higher. However, the FWC samplers produced consistent (precise) results- CV values for concentration were less than 0.15.

While concentrations estimates for FWC methods were not significantly different from the EPA estimates, load values for both samplers were significantly different from EPA load estimates at the 10% significance level. Regression analysis of total nitrogen load estimates indicates a strong correlation between both FWC methods and the EPA method, and that the FWC method predicts higher total nitrogen load (slope = 0.78 and 0.76). The CV data indicates that the two FWC samplers produced comparable total nitrogen load estimates (CV < 0.15, excluding 1/24/10 event).

These results (low CV, high r^2, and slope of 0.78) may indicate a systematic sampler, field method, or laboratory method error. For example, results may be due to differing sample intake velocities which select preferentially for specific particle sizes or differing sample collection points within the H-flume. Alternatively, errors may be introduced by Pioneer Farm compositing and sub-sampling methods, UWSP churn splitting methods, or the time-based sampling scheme utilized.

Table 3. Total phosphorus concentration and load for FWC sampling methods.

	Concentration			Error		Prec.	Load			Error		Prec.
Date	EPA	A	B	A	B	CV	EPA	A	B	A	B	CV
	(mg/L)	(mg/L)	(mg/L)	(%)	(%)		(kg)	(kg)	(kg)	(%)	(%)	
1/24/2010	0.9	1.1	1.0	-22.1	-14.3	0.05	0.04	0.04	0.02	-15.9	39.0	0.44
3/5/2010	1.3	1.5	1.5	-11.9	-11.5	0.00	2.08	2.16	2.11	-3.8	-1.4	0.02
3/9/2010	1.5	1.5	1.5	0.7	0.7	0.00	3.49	3.63	3.58	-4.0	-2.6	0.01
3/11/2010	2.3	2.0	1.8	13.9	21.8	0.07	0.63	0.62	0.57	0.5	9.4	0.07
6/5/2010	2.3	2.2	2.3	4.9	1.4	0.03	0.00	0.01	0.00	-29.8	-16.7	0.08
6/15/2010	1.8	2.6	2.6	-45.5	-46.6	0.01	0.04	0.05	0.05	-33.4	-34.7	0.01
6/23/2010	1.8	1.8	1.9	-5.1	-5.7	0.00	0.03	0.04	0.04	-44.7	-35.8	0.04
7/7/2010	1.7	1.5	1.6	14.4	10.9	0.03	0.58	0.55	0.54	6.2	7.4	0.01
7/23/2010	0.9	1.0	1.0	-12.2	-9.7	0.02	0.42	0.51	0.49	-21.1	-15.9	0.03
12/30/2010	0.5	0.5	0.6	-2.0	-14.1	0.08	0.17	0.19	0.22	-14.3	-28.6	0.08
2/14/2011	0.6	0.8	0.8	-21.6	-24.5	0.02	1.58	1.86	1.95	-17.7	-23.4	0.03
2/20/2011	0.4	0.5	0.4	-7.6	0.5	0.05	0.43	0.47	0.44	-10.5	-1.9	0.06
3/1/2011	0.9	1.0	1.1	-7.6	-13.6	0.04	0.30	0.45	0.44	-48.0	-45.4	0.01
3/7/2011	1.0	0.9	0.9	4.7	10.7	0.05	0.34	0.34	0.34	0.9	0.3	0.00
Total							10.12	10.92	10.78	-7.8	-6.5	0.01
intercept		0	0					0	0			
slope		0.89	0.87					0.95	0.95			
r squared		0.83	0.80					1.00	0.99			
Obs P		0.39	0.46					0.03	0.12			

Event total phosphorus concentrations and loads estimated by the FWC method were very similar to loads determined by the EPA method; however, due to the small magnitude of concentrations, the relative error in percentage terms is large. As was the case with total nitrogen, FWC total phosphorus concentrations were consistently higher than EPA concentrations and resulted in significantly higher loads for FWC sampler A (observed p value = 0.03), even though the difference between the sum of event loads was only 0.8 kg, or 7.8%. Concentration values estimated by the FWC samplers were also very precise- the maximum CV was 0.08 for the 3/1/2011 event.

Table 4. Suspended sediment concentration and load for FWC sampling method.

	Concentration			Error		Prec.	Load			Error		Prec.
Date	EPA	A	B	A	B	CV	EPA	A	B	A	B	CV
	(mg/L)	(mg/L)	(mg/L)	(%)	(%)		(kg)	(kg)	(kg)	(%)	(%)	
1/24/2010	5.0	19.0	3.0	-280	40	1.03	0.21	0.74	0.07	-261	68	1.18
3/5/2010	8.0	26.0	26.0	-225	-225	0.00	12.50	37.80	37.10	-202	-197	0.01
3/9/2010	15.0	1.0	13.0	93	13	1.21	34.90	2.44	31.30	93	10	1.21
3/11/2010	17.0	11.0	14.0	35	18	0.17	4.67	3.49	4.46	25	4	0.17
6/5/2010	364.0	181.0	214.0	50	41	0.12	0.68	0.46	0.47	32	30	0.02
6/15/2010	305.0	359.0	332.0	-18	-9	0.06	6.62	7.14	6.61	-8	0	0.05
6/23/2010	85.0	132.0	121.0	-55	-42	0.06	1.37	2.93	2.50	-114	-82	0.11
7/7/2010	332.0	182.0	190.0	45	43	0.03	111.00	66.50	65.90	40	41	0.01
7/23/2010	33.0	74.0	105.0	-124	-218	0.24	15.90	38.40	53.30	-142	-235	0.23
12/30/2010	3.0	1.0	1.0	67	67	0.00	1.03	0.38	0.39	63	62	0.02
2/14/2011	6.0	5.0	8.0	17	-33	0.33	14.70	11.80	19.40	20	-32	0.34
2/20/2011	1.0	11.0	5.0	-1000	-400	0.53	1.01	11.50	5.19	-1039	-414	0.53
3/1/2011	1.0	16.0	14.0	-1500	-1300	0.09	0.32	7.13	5.81	-2128	-1716	0.14
3/7/2011	64.0	33.0	20.0	48	69	0.35	22.10	11.80	7.70	47	65	0.30
Total							227.01	202.51	240.20	10.8	-5.8	0.12
intercept		6	-2					0	0			
slope		1.12	1.18					1.17	1.06			
r squared		0.74	0.80					0.61	0.61			
Obs P		0.48	0.47					0.73	0.85			

Suspended sediment concentrations estimated by the 2-part FWC samplers varied dramatically from EPA method estimates and among FWC samplers A and B but were not significantly different than EPA method concentrations (observed p = 0.48 and 0.47). Relative error values were as high as 1,500% (3/1/2011 event), and CV values were as high as 1.21. When the sum of event loads are compared the bias tends to average out and estimates from FWC samplers are within 10.8 (FWC-A) and -5.8 (FWC-B) percent of the EPA load. The slope of regression lines (1.12 and 1.18) indicate that concentrations estimated by the FWC samplers tend to be lower than concentrations determined by EPA methods. It is not too surprising that suspended sediment data exhibits the greatest error and least precision, since the within event concentration of suspended sediment varies much more than concentration of total nitrogen or total phosphorus.

Table 5. Cost data for FWC sampling method.

EPA		2-Part Flow Weight Composite	
Equipment	**($)**		**($)**
Sampler	3,350	Sampler	3,350
Data Logger	1,500	Stage Sensor	1,670
Flume	1,000	Flume	1,000
Sampler Housing	5,000	Sampler Housing	200
Stage Sensor	1,000	Wing-wall	500
Radio	400		
Antennae	100		
Solar Panel	500		
Battery	70		
Wing-wall	500		
Generator	500		
Rain Gauge	300		
Camera	200		
Fuel Tank	200		
Total Equipment	**14,620**		**6,720**
Installation			
Materials	500	Materials	500
Labor	5,000	Labor	2,000
Earthwork	1,000	Earthwork	1,000
Total Installation	**6,500**		**3,500**
Operation			
Pioneer Farm Technician	10,000	Pioneer Farm Technician	10,000
Real-time Remote Monitoring	4,000		
Total Annual Operation	**14,000**		**10,000**
Maintenance			
Parts	1,000	Parts	200
Pioneer Farm Technician	3,000	Pioneer Farm Technician	500
Total Annual Maintenance	**4,000**		**700**

The table above compares cost for the EPA and 2-part FWC methods. The cost of equipment, installation, operation, and maintenance are lower for the 2-part FWC method. In the long-run most cost savings will be realized by eliminating the requirement for real-time remote monitoring of sites during events. Given the objective of having multiple samples collected from all runoff events, large or small, the EPA method requires that technicians monitor all events via remote connection and alter the time between sample collections to ensure adequate coverage of the hydrograph. The 2-part FWC sampler eliminates this need because it can collect two sets of flow-weighted samples simultaneously using to flow intervals. With this system multiple samples can be collected from large or small events. Given the data above, the total cost per site for a three-year monitoring program would cost $75,120 for the EPA method and $42,320 for the 2-part flow-weight composite sampler method.

SECTION 2. AQUAROD STAGE SENSOR-DATALOGGER AND SINGLE STAGE SIPHON SAMPLER

Table 6. Event discharge data for aquarod method.

	Discharge			Error		Precision	
Date	EPA	A	B	A	B	s.d.	CV
	(cf)	(cf)	(cf)	(%)	(%)		
3/9/2010	40,800	44,800		-9.8			
3/11/2010	5,800	7,710		-32.9			
6/26/2010	2,190	2,250	2,260	-2.7	-3.2	7.1	0.00
7/7/2010	5,280	5,350	5,210	-1.3	1.3	99.0	0.02
7/23/2010	3,270	3,000	3,120	8.3	4.6	84.9	0.03
7/24/2010	33,400	30,100	33,300	9.9	0.3	2262.7	0.07
8/8/2010	16,300	12,800	16,000	21.5	1.8	2262.7	0.16
8/9/2010	7,380	5,920	7,200	19.8	2.4	905.1	0.14
12/30/2010	1,060	898	1,460	15.3	-37.7	397.4	0.34
2/20/2011	13,000	17,900	11,400	-37.7	12.3	4596.2	0.31
3/1/2011	3,720	3,910	3,160	-5.1	15.1	530.3	0.15
Total	132,200	134,638		-1.8			
6/26 - 3/1	85,600		83,110		2.9		
intercept		417	204				
slope		0.95	1.01				
r squared		0.96	1.00				
Obs P		0.79	0.18				

The table above includes discharge estimates for the EPA method and the two aquarods (A and B). Due to limited inventory, we did not receive the second aquarod (B) until after the March 9th and 11th events.

Discharge estimated by the aquarod A and B were not significantly different from values produced by the EPA method (observed p value = 0.79 and 0.18). However, the percent relative error for events was often rather large- the average absolute percent relative error was 15% for aquarod A and 9% for aquarod B. The sum of event discharges for EPA and aquarods varied by less than 3% because the error in discharge estimates was not systematic and tended to balance over events. Discharge estimated by aquarods was imprecise when compared to other data- over half of the events had a CV > 0.14.

Table 7. Total nitrogen concentration and load for single-stage siphon sampler method.

	Concentration			Error		Prec.	Load			Error		Prec.
Date	EPA	A	B	A	B	CV	EPA	A	B	A	B	CV
	(mg/L)	(mg/L)	(mg/L)	(%)	(%)		(kg)	(kg)	(kg)	(%)	(%)	
3/9/2010	4.8	2.2	4.3	53.6	9.2	0.46	5.50	2.80	5.48	49.0	0.3	0.46
3/11/2010	8.2	5.6	5.4	31.3	34.6	0.03	1.34	1.23	1.17	8.6	13.0	0.03
6/26/2010	10.7	11.4	11.5	-6.1	-7.3	0.01	0.66	0.72	0.74	-9.3	-11.1	0.01
7/7/2010	4.9	7.9	7.8	-61.7	-59.2	0.01	0.73	1.19	1.15	-63.2	-57.7	0.02
7/23/2010	1.2	2.3	3.0	-90.8	-150	0.19	0.11	0.20	0.27	-75.7	-139	0.22
7/24/2010	1.2	2.0	2.0	-76.5	-77.4	0.00	1.09	1.73	1.92	-58.9	-76.4	0.07
8/8/2010	1.5	1.6	1.5	-4.7	3.3	0.06	0.69	0.57	0.66	17.8	4.7	0.10
8/9/2010	2.1	2.4	2.1	-10.3	3.8	0.10	0.45	0.39	0.42	11.5	6.1	0.04
12/30/2010	2.4	1.5	1.8	36.8	25.6	0.11	0.07	0.04	0.07	46.5	-2.4	0.44
2/20/2011	1.7	1.6	2.0	3.0	-20.1	0.15	0.62	0.83	0.66	-33.0	-5.8	0.16
3/1/2011	3.2	3.4	3.4	-5.6	-6.9	0.01	0.34	0.38	0.31	-11.2	9.5	0.15
Total							11.60	10.08	12.84	13.2	-10.6	0.17
intercept		1	0					-1	0			
slope		0.85	0.90					1.70	0.98			
r squared		0.76	0.79					0.80	0.97			
Obs P		0.99	0.56					0.61	0.22			

Total nitrogen concentrations and loads estimated by single-stage siphon samplers were not significantly different from EPA method derived concentrations (concentration observed p values = 0.99 and 0.56, load observed p values = 0.61 and 0.22); however, relative percent error values for event concentrations and loads were large. The error was not systematic. The sum of event loads estimated by siphon samplers was within 13.2% (sampler A) and -10.6% (sampler B). Total nitrogen concentration estimates generated by single-stage samplers were not as precise as those estimated by the FWC samplers listed in Table 2.

Table 8. Total phosphorus concentration and load for single stage siphon sampler method.

	Concentration			Error		Prec.	Load			Error		Prec.
Date	EPA	A	B	A	B	CV	EPA	A	B	A	B	CV
	(mg/L)	(mg/L)	(mg/L)	(%)	(%)		(kg)	(kg)	(kg)	(%)	(%)	
3/9/2010	1.0	1.0	1.0	-2.2	0.8	0.02	1.15	1.29	1.26	-12.2	-9.6	0.02
3/11/2010	1.0	1.1	1.1	-14.0	-14.0	0.00	0.16	0.24	0.24	-51.9	-51.9	0.00
6/26/2010	5.0	5.0	5.2	-1.1	-5.3	0.03	0.31	0.32	0.34	-4.2	-9.1	0.03
7/7/2010	1.7	2.5	2.4	-46.0	-40.6	0.03	0.25	0.37	0.35	-47.4	-38.7	0.04
7/23/2010	0.7	1.0	1.1	-41.7	-57.3	0.07	0.07	0.09	0.10	-30.4	-49.7	0.10
7/24/2010	0.6	0.8	0.8	-39.9	-38.2	0.01	0.56	0.71	0.77	-26.3	-37.7	0.06
8/8/2010	0.8	0.7	0.7	16.9	13.0	0.03	0.36	0.24	0.31	34.7	14.2	0.19
8/9/2010	0.8	0.7	0.7	7.8	9.5	0.01	0.17	0.13	0.15	26.0	11.8	0.12
12/30/2010	1.0	0.8	0.8	20.0	18.6	0.01	0.03	0.02	0.03	32.5	-11.9	0.35
2/20/2011	0.4	0.3	0.3	8.7	8.7	0.00	0.14	0.17	0.11	-21.4	18.6	0.28
3/1/2011	0.9	0.7	0.8	16.9	13.1	0.03	0.09	0.08	0.07	15.4	26.2	0.10
Total							3.29	3.65	3.73	-10.9	-13.5	0.02
intercept		0	0					0	0			
slope		0.93	0.91					0.85	0.86			
r squared		0.96	0.97					0.96	0.97			
Obs P		0.32	0.20					0.22	0.12			

Single-stage siphon samplers produced total phosphorus concentrations and loads that were not significantly different from EPA method estimates (observed $p > 0.12$), and were strongly correlated to EPA method values ($r^2 >$ 0.96). The relative percent errors for samplers A and B ranged from -57.3% to 20%; however, the magnitude of concentrations were low (< 5.2 mg/L). Siphon sampler total phosphorus concentration estimates were precise- the maximum CV was 0.07, and the sum of event loads for sampler A and B were within -10.9% and 13.5% of the EPA value.

Table 9. Suspended sediment concentration and load for single stage sampler method.

	Concentration			Error		Prec.	Load			Error		Prec.
Date	EPA	A	B	A	B	CV	EPA	A	B	A	B	CV
	(mg/L)	(mg/L)	(mg/L)	(%)	(%)		(kg)	(kg)	(kg)	(%)	(%)	
3/9/2010	14.0	25.0	18.0	-78.6	-28.6	0.23	16.20	31.70	22.80	-95.7	-40.7	0.23
3/11/2010	57.0	12.0	12.0	78.9	78.9	0.00	9.36	2.62	2.62	72.0	72.0	0.00
6/26/2010	1230.0	1394.0	1453.0	-13.3	-18.1	0.03	76.10	88.90	93.20	-16.8	-22.5	0.03
7/7/2010	519.0	882.0	1046.0	-69.9	-101.5	0.12	77.60	133.00	154.00	-71.4	-98.5	0.10
7/23/2010	92.0	404.0	318.0	-339.1	-245.7	0.17	8.51	34.40	28.10	-304.2	-230.2	0.14
7/24/2010	137.0	360.0	337.0	-162.8	-146.0	0.05	130.00	307.00	318.00	-136.2	-144.6	0.02
8/8/2010	115.0	120.0	147.0	-4.3	-27.8	0.14	53.00	43.40	66.80	18.1	-26.0	0.30
8/9/2010	168.0	156.0	152.0	7.1	9.5	0.02	35.10	26.10	31.00	25.6	11.7	0.12
12/30/2010	68.0	54.0	34.0	20.6	50.0	0.32	2.04	1.37	1.41	32.8	30.9	0.02
2/20/2011	23.0	30.0	31.0	-30.4	-34.8	0.02	8.49	15.20	10.00	-79.0	-17.8	0.29
3/1/2011	27.0	15.0	16.0	44.4	40.7	0.05	2.84	1.66	1.43	41.5	49.6	0.11
Total							419	685	729	-63.5	-74.0	0.04
intercept		-21	-10					12	11			
slope		0.78	0.72					0.43	0.41			
r squared		0.91	0.90					0.87	0.91			
Obs P		0.07	0.09					0.14	0.17			

The single-stage sampler suspended sediment concentrations differed significantly from EPA methods at the 10% significance level and relative error values were large- up to 339%. Siphon samplers often over predicted concentrations of suspended sediment- slope of regression lines were 0.78 (sampler A) and 0.72 (sampler B) (figure 5). However, the concentrations estimated by the siphon samplers correlated strongly with EPA method concentrations ($r^2 > 0.90$). This data may indicate sampler bias, which could be corrected.

Figure 5. Suspended sediment concentration for EPA and Siphon Sampler methods.

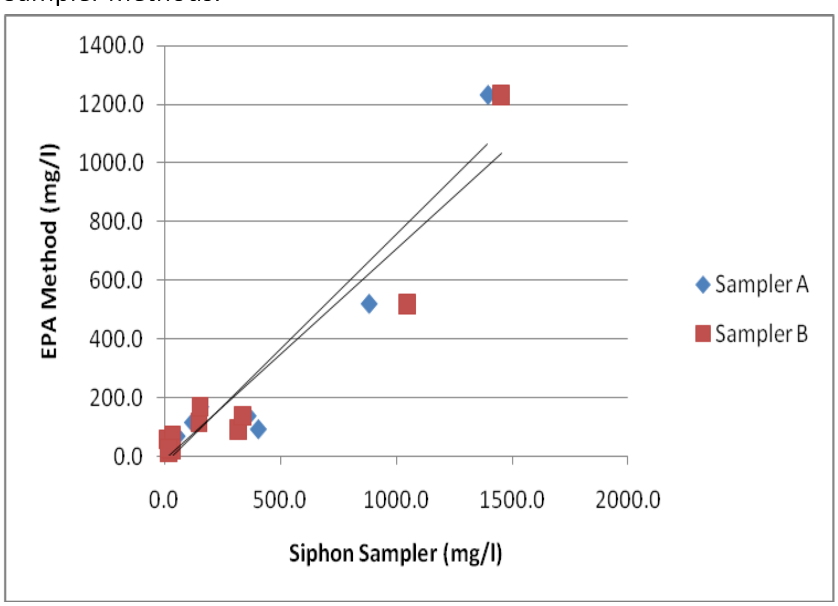


Table 10. Cost data for the single stage siphon sampler method.

EPA		Single-Stage Siphon	
Equipment	**($)**		**($)**
Sampler	3,350	Samplers	100
Data Logger	1,500	Stage Sensor	1,000
Flume	1,000	Flume	1,000
Sampler Housing	5,000	Wing-wall	500
Stage Sensor	1,000		
Radio	400		
Antennae	100		
Solar Panel	500		
Battery	70		
Wing-wall	500		
Generator	500		
Rain Gauge	300		
Camera	200		
Fuel Tank	200		
Total Equipment	**14,620**		**2,600**
Installation			
Materials	500	Materials	500
Labor	5,000	Labor	1,000
Earthwork	1,000	Earthwork	1,000
Total Installation	**6,500**		**2,500**
Operation			
Pioneer Farm Technician	10,000	Pioneer Farm Technician	10,000
Real–Time Remote Monitoring	4,000		
Total Annual Operation	**14,000**		**10,000**
Maintenance			
Parts	1,000	Parts	200
Pioneer Farm Technician	3,000	Pioneer Farm Technician	500
Total Annual Maintenance	**4,000**		**700**

The table above compares cost for the EPA and single-stage siphon sampler methods. The cost of equipment, installation, operation, and maintenance are lower for the single-stage sampler method. Due to the simplicity of the equipment, initial investment and installation cost is low for the single-stage siphon method ($2,600 + $2,500) compared to the EPA methods ($14,620 + $6,500). Additional cost savings can be realized by the elimination of remote real-time monitoring and reduced maintenance costs. Given the data above, the total cost per site for a three-year monitoring program would cost $75,120 for the EPA method and $37,200 for the single-stage siphon sampler method.

SECTION 3. SUGGESTIONS FOR FUTURE RESEARCH

1. As stated in the introduction, the events used for comparison purposes excluded missed events. It would be of interest to compare the systems using technicians that had no previous experience with any of the monitoring protocols. This would provide information regarding the learning curve associated with each of the methods. Missed events could then be included in the data set and the effect of missed events could be determined on annual yield and load estimates.
2. This experiment was conducted in one location for a relatively short period of time. A more reliable comparison would include a larger geographic area and longer period of record.
3. It is assumed that the EPA method is determining the "actual" concentration and load. However, there is variability in all measurement. Future studies should include multiple EPA protocols within the same site so that precision of this system can be quantified.
4. Lab studies that simulate runoff events using water with known sediment concentrations should be conducted and concentrations estimated with replicate EPA, 2-Part FWC, and Single-Stage Siphon sampling methods. With this data, accuracy and precision of all methods could be determined.