A preliminary report on the evaluation of changes in water quality in a stream following the implementation of agricultural best management practices[1]

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BACKGROUND

Otsego Lake (Otsego County, NY), of glacial origin, forms the headwaters of the Susquehanna River. It is a deep (50.5 m max) dimictic waterbody of 4,167 acres having a catchment of 46,482 acres. The lake serves as the potable water supply of Cooperstown and it is noted for its cold water fishery, which includes native lake trout and whitefish as well as stocked brown trout and Atlantic salmon. The lake provides many recreational opportunities and it provides an aesthetic backdrop for the historically preserved Village of Cooperstown, which depends heavily upon a tourist-based economy (Harman et al. 1997).

Though historically considered oligomesotrophic, research over the last 30 years by the Biological Field Station (BFS) has documented trends toward increasing eutrophy. These changes are reflected in decreased water clarity, increased algal production, and increased rates of summer oxygen depletion. As the lake's production is limited by phosphorus, it is assumed that enrichment of this nutrient is responsible for the aforementioned changes. Reducing inputs of phosphorus is the primary objective of the recently adopted "A Plan for the Management of the Otsego Lake Watershed" (OLWC 1998).

The bulk of the phosphorus and sediment entering Otsego Lake are derived from drainage basins being actively farmed (Albright 1996). Most notably, Shadow Brook, which drains 4,720 ha (11,660 ac), 46% of which is farmed, is the largest contributor of phosphorus and sediments to the lake. It also has the highest rates of export of those pollutants (loading on a per-area basis), with the exception of a small urban stream at the south end of the lake. This does not imply that agricultural practices are wholly to blame. This area is naturally more fertile than other regions of the watershed. However, conventional agricultural practices have long been recognized to accelerate rates of nutrient and sediment loss from the land to adjacent waters (i.e., Omernik 1976; 1977; Sonzogni et al. 1980; Beaulac and Reckhow 1982). This not only accelerates eutrophy in receiving waters but negatively impacts agricultural production. Various agricultural Best Management Practices (BMPs) have been developed which are designed to reduce the export of nutrients and sediment from the land, thereby improving local water quality.

Through the 1996 USDA Farm Bill, the Environmental Quality Incentive Program (EQIP) was established to assist crop and livestock producers with establishing measures to address environmental and conservation issues on farms (USDA 1996). The Otsego County Natural Resources Conservation Service received $887,000 EQIP funds between 1996-2001 to

[1]Funding for this study was provided by the Otsego County Conservation Association.

implement agricultural BMPs on farms in the "Susquehanna Lakes" watershed (the area draining into the Susquehanna River above Milford, NY). The Otsego County Conservation Association (OCCA) provided the non-Federal 25% match for projects undertaken (otherwise a responsibility of the farm owner).

INTRODUCTION

A unique opportunity exists for long-term evaluation of the effectiveness of the BMPs implemented in the Shadow Brook basin as related to changes in water quality. As part of a United States Environmental Protection Agency (USEPA) funded Phase I Diagnostic Feasibility study, the BFS developed a two-year precipitation based nutrient budget on Otsego Lake in the early 1990s (Albright 1996). A component of that work involved the establishment of a constant monitoring station near the mouth of Shadow Brook. Flow and loadings of total phosphorus, suspended sediment and nitrite+nitrate nitrogen where quantified.

Although local implementation of agricultural BMPs began in 1996, the first projects undertaken in the Shadow Brook basin were not completed until 1999, when four were constructed. One project each was finished in 2000 and 2001. Three contracts are currently under construction (Pullano 2001). To date, $288,000 in Federal funding has been spent on such projects throughout the watershed; a local match of almost $100,000 has been provided by the OCCA. Approximately $70,000 was provided by New York State Department of Agriculture and Markets, resulting in $458,000 being spent on projects on farms in the watershed.

In order to access changes in water quality in Shadow Brook following the initiation of BMP implementations, the BFS was funded by the OCCA to re-evaluate nutrient and sediment delivery by that stream. Data collection began in 1999 and continues to date.

METHODS

All methodologies employed were identical to those used in monitoring between 1991-93 (hereafter referred to as "pre-BMP") (Albright 1996). The "mid-BMP" period (December 1999 to July 2001) was a time during which BMPs were being implemented. The "post-BMP" period, July 2001 through January 2003, saw additional BMP construction. It was anticipated that enough time had elapsed since the commencement of construction that water quality changes might be realized during that period.

In summer 1999, an automated water monitoring station was re-established near the mouth of Shadow Brook (Figure 1). A Sigma 800SL™ programmable automated water sampler was used. A pressure transducer type integral flowmeter provided for sampling initiation and, along with data logging capabilities, for constant hydrological monitoring. Because the pressure transducer was situated in an open channel, stream gauge-to-flow relationships were established and programmed into the sampler. This was accomplished by manually measuring flow over a wide range of gauge heights using a Marsh-McBirney^{TM} portable water flow meter. The station was inoperable until higher-end conditions were encountered in October 1999. Manual readings were intermittently conducted to ensure validity of the sampler. The stream channel was modified during extremely high flows encountered in a 28 February 00 snow melt event such that the established gauge-to-flow relationship was invalidated and had to be re-established.

Because the vast majority of phosphorus and sediment export occurs in conjunction with runoff events, efforts were focused accordingly. The sampler was programmed to initiate a sampling regime upon a rise in gauge height. A series of discrete samples (typically 24-48) was

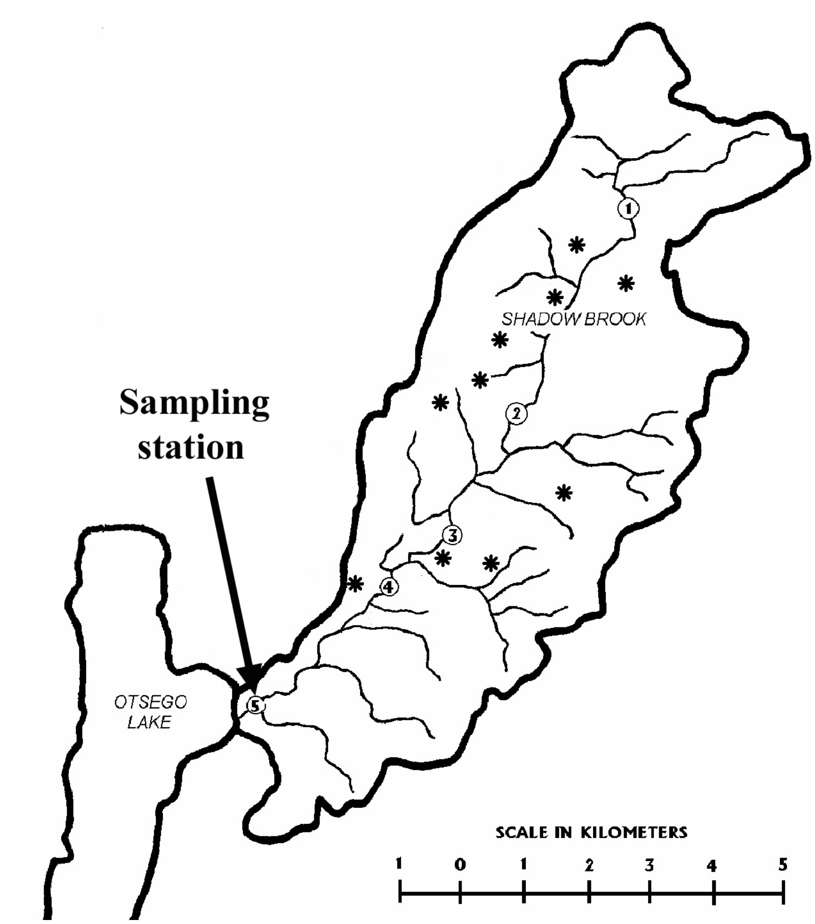

Figure 1. Shadow Brook drainage basin showing locations of BMPs (asterisks), constant monitoring station and summer time weekly sampling stations (1-5).

collected during each runoff event (defined here as a discharge increase from base flow conditions by at least a factor of three and having a duration of at least 0.5 days). Sampling intensity was greatest during the ascending phase of the hydrograph to address the “first flush” phenomenon. This situation is reflected by quicker responses in flow and nutrients during the earlier stages of an event (Livingston and Cox 1985; Beaulac and Reckhow 1982). Upon return to the lab, samples were composited in a flow- and time-weighted manner. Additional samples were collected weekly throughout the growing season along the stream (indicated by sites 1-5, Figure 1) (Collins and Albright 2000; Miner 2001; Parker 2002; Meehan 2003; 2004). Total phosphorus was measured by persulfate digestion followed by the single reagent ascorbic acid technique (APHA 1989); suspended sediments were measured using the gravimetric method (APHA 1989). Internal quality assurance measures were employed.

During the pre-BMP period (1 January – 31 December 91 and 1 May 92 - 31 April 93), 820 samples were collected which represented 21 and 31 runoff events, respectively. Between 15 December 99 and 26 July 01, 912 water samples were collected during 38 runoff events. An additional 24 samples representing baseline conditions at the same site were collected, as well as 64 samples along the main branch of the stream (see Figure 1). Between January 02 and December 03, 532 samples representing 23 runoff events were collected, and 83 samples were collected from the stream sites.

To evaluate changes in water quality before and after the initiation of BMPs, methods similar to those of Grabow et al. (1998) were employed. For each storm event monitored, total flow volume (m^3), total phosphorus volume (kg) and total suspended sediment volume (kg) were determined and converted to runoff (flow) and export rates (total phosphorus and sediment), giving units/day/ac. Because runoff was not expected to have been significantly influenced by the agricultural projects, this function was used to describe event intensity. Conversely, it was anticipated that total phosphorus and suspended sediment export would change as a result of the projects. Therefore, after correcting for skewness (by applying logarithmic transformations), regression analysis was applied to compare runoff and total phosphorus (and suspended sediment) export for both the pre-, mid- and post BMP data sets. The rationale was that the data set represented by the line having the lower y intercept and/or the lower slope would deliver less phosphorus (or sediment) loading for a storm of a given intensity. This process was conducted twice, once with the entire data set and once after outliers were omitted from the mid- and post-BMP data set following procedures described by Longabucco et al. (1999). During those five events, mean runoff was significantly higher (between 165-400%) than any events encountered in the pre-BMP phase. Three of these points fell above the regression line and two below it.

Meteorological data were provided by Hollis (1994), Hurley (1999; 2000), Nelson (1999; 2000), Blechman (2003) and McIntyre (2001).

RESULTS AND DISCUSSION

Appendices 1 through 3 provide an overview of each pre-, mid- and post-BMP storm event monitored, respectively. The information provided includes the start date of each event, the event duration, the total water volume delivered as well as the loads of total phosphorus and suspended sediment, the runoff rate and the export rates of total phosphorus and suspended sediment.

Figure 2 compares log-transformed runoff and total phosphorus export rates (A) and suspended sediment export rates (B) for storm events during the pre- and post- BMP project implementation timeframes using the entire data sets. Figure 3 compares the same data with the removal of outliers. It is expected that this figure most accurately describes the relationship between runoff and phosphorus/sediment export rates.

Comparisons between the both the complete data sets and those with outliers removed indicate no significant changes in either the y-intercept or the slope of the regression lines. Therefore, no changes in water quality have been documented over the scope of this study.

The main challenge in ascribing water quality changes to changes in land-use practices is overcoming meteorological variability. Here, mean event runoff was used to describe runoff intensity. While presumably the single best measure of intensity, there are a number of factors that make it only marginally adequate. One such factor involves the shape of the hydrograph. An event having relatively homogeneous runoff might have a mean runoff similar to that of another event having a very high runoff peak for a short duration, though the latter event would be expected to transport much more phosphorus and sediment due to its erosional nature. Another issue is the duration since the antecedent runoff event. Longer intervals between storms would allow for more transportable material to accumulate in the watershed. That seems particularly true during periods of snow cover. Materials entrapped in the snow may or may not be transported as the snow melts, depending upon how quickly melting occurs and whether rainfall accompanies that melting.

There seems to be a paucity of available information which empirically documents improved water quality following the implementation of agricultural practices, despite the widespread acceptance that these projects are sound management tools. This is likely due, in part, to factors mentioned above. Also, the time and money involved in monitoring for success generally exceeds that involved in implementing the projects themselves.

One project currently underway attempts to evaluate water quality changes following BMP implementation in a small catchment in the West Branch of the Delaware River drainage basin (Longabucco et al. 1999). That project differs from the local one in that it compares water quality in a stream draining farmland managed with BMPs to a nearby, pristine “control” stream. Success in some facets is implied, though empirical documentation of that success is not currently possible because of a lack of statistical significance of the changes.

The amount of time necessary for land use changes to be manifested in water quality changes is unknown because similar research is lacking and that which is available is recent. While referred to as the "post-BMP" period, BMPs were in the process of being implemented throughout this study and are, in fact, still under construction. Furthermore, there are a number of potential agricultural projects that warrant attention for which monies are not currently available (Pullano 2001). Even upon the completion of all appropriate projects in the drainage basin, one would expect that some amount of time would be necessary before water quality changes become evident. Because the sampling station is at the bottom of a relatively large (11,660 ac) drainage basin, material accumulated in the watershed, and the stream itself, would need time to pass through the system before water quality reached its potential. The erosional nature of Shadow Brook's stream channel itself may be more responsible for high phosphorus and sediment transport than land use activities away from the stream corridor. If so, projects intended to stabilize the stream bank, such as the establishment of vegetation or the placement of hard substrate, may be an effective strategy there. Finally, for BMPs to effectively improve runoff quality, it is imperative that the farm operators manage the projects in conjunction with input from the assisting agencies.

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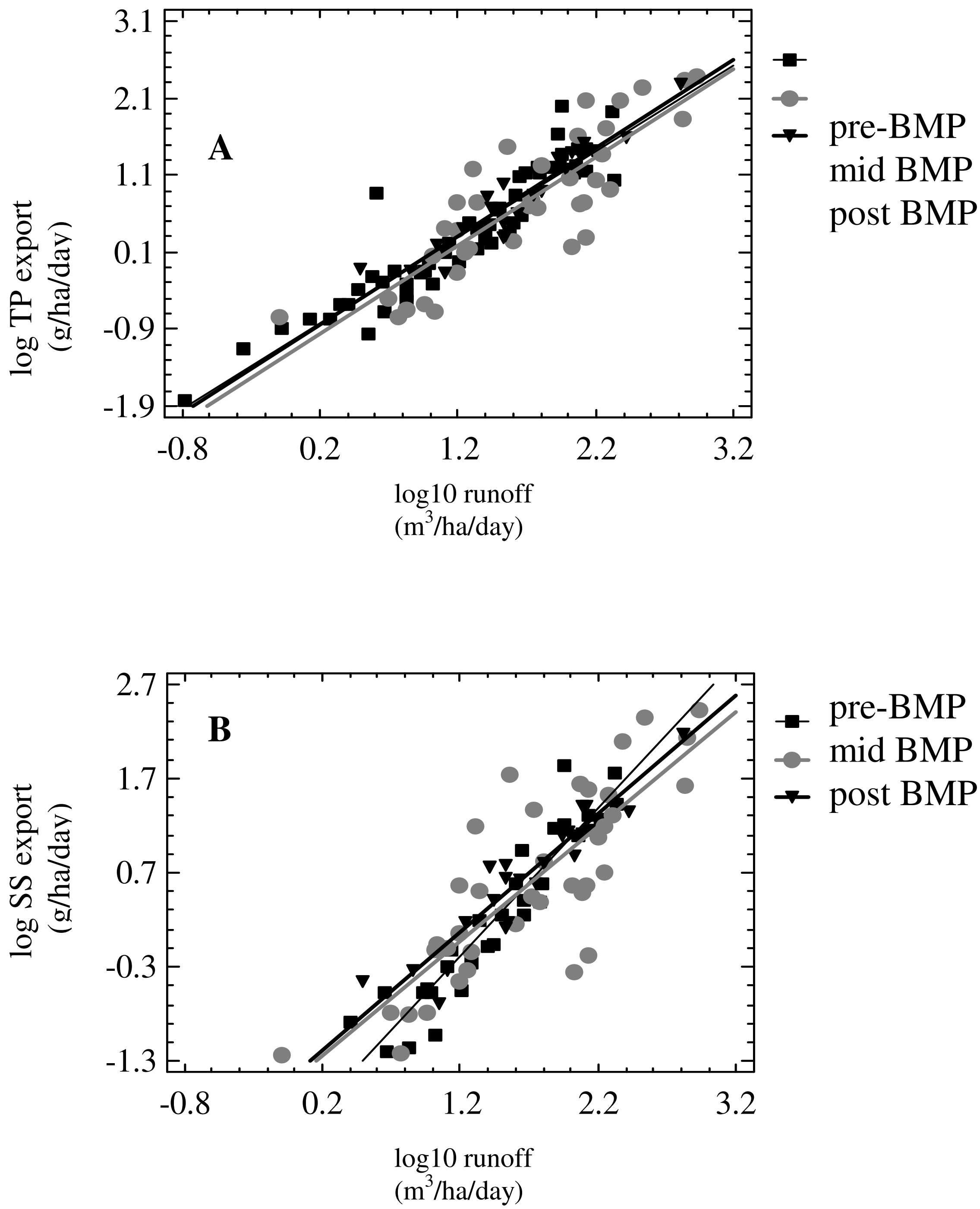

Figure 2. Comparison of regression lines of plots of log transformed total phosphorus export (g/ha/day) (**A**) and suspended sediment export (kg/ha/day (**B**) vs. log transformed runoff (m^3/ha/day) for pre-, mid and post BMP construction using all available storm event data.

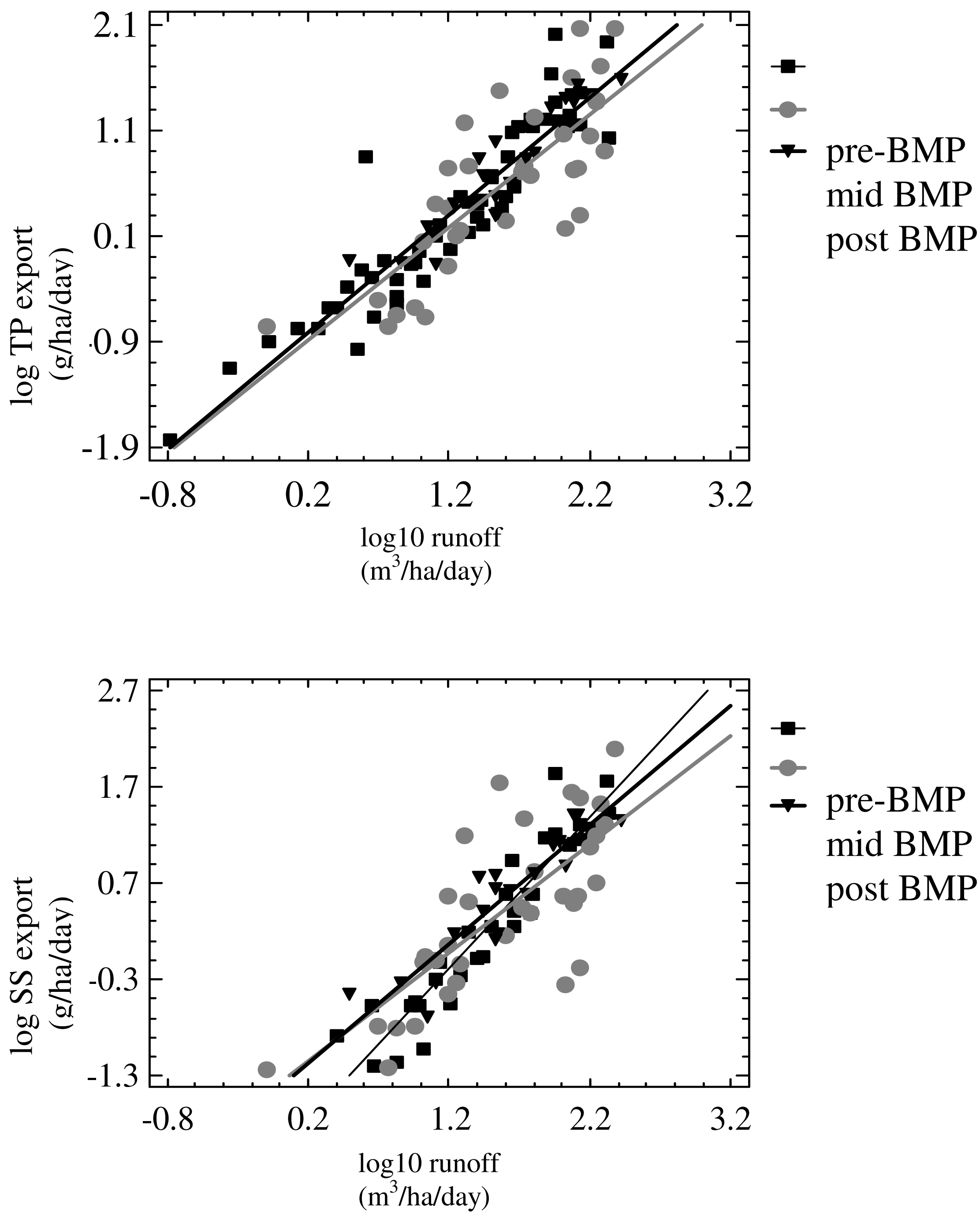

Figure 3. Comparison of regression lines of plots of log transformed total phosphorus export (g/ha/day) (**A**) and suspended sediment export (kg/ha/day (**B**) vs. log transformed runoff (m^3/ha/day) for pre-, mid and post BMP construction storm event data after removal of potential outliers.

Start date of event	Duration (days)	Flow volume (cubic meters)	T. phosphorus load (kg)	Sus. sediment load (kg)	Runoff m^3/ha/day	T. phosphorus export g/ha/day	Sus. sediment export kg/ha/day
2/5/1991	3.188	618551	105.39		41.1013	7.0029	
2/19/1991	2.042	807017	414.06		83.7193	42.9542	
3/2/1991	0.799	185095	51.32		49.0734	13.6062	
3/3/1991	1.5	779072	97.15		110.0233	13.7199	
3/25/1991	2.986	520338	32.64		36.9143	2.3156	
4/9/1991	1.958	231563	23.16		25.0527	2.5057	
4/21/1991	2.13	1195773	277.47		118.9235	27.5953	
4/30/1991	1.07	134703	14.08		26.6681	2.7875	
5/6/1991	1.02	104419	6.69		21.6859	1.3894	
5/30/1991	0.81	25924	1.32		6.7798	0.3452	
6/30/1991	1.46	5729	0.86		0.8312	0.1248	
7/7/1991	0.93	8187	0.73		1.8648	0.1663	
7/24/1991	2.14	1705	0.15		0.1688	0.0148	
8/3/1991	2.37	4937	0.79		0.4413	0.0706	
8/9/1991	1.02	10651	1.29		2.2120	0.2679	
9/15/1991	2.28	14554	1.82		1.3522	0.1691	
9/19/1991	1.02	18076	2.89		3.7541	0.6002	
10/2/1991	0.52	13556	1.78		5.5224	0.7251	
10/4/1991	2.21	31197	4.29		2.9903	0.4112	
10/15/1991	3.17	53554	1.63		3.5787	0.1089	
11/11/1991	1.25	39934	2.85		6.7675	0.4830	
11/22/1991	2.28	336906	47.37		31.3020	4.4012	
12/8/1991	1.68	32185	56.57		4.0583	7.1331	
5/2/1992	0.844	353813	401.78	274462	88.8034	100.8427	68.8871
5/5/1992	2.636	489115	37.39	47458	39.3065	3.0048	3.8138
5/31/1992	1.896	112116	11.29	4466	12.5264	1.2614	0.4990
6/6/1992	1	46079	4.2	1286	9.7612	0.8897	0.2724
7/5/1992	1.3	15656	1.63	804	2.5511	0.2656	0.1310
7/13/1992	1.049	22158	2.48	1321	4.4746	0.5008	0.2668
7/15/1992	2.133	136862	16.37	7522	13.5922	1.6258	0.7470
7/23/1992	1.333	379800	99.52	15476	60.3564	15.8153	2.4594
7/29/1992	0.25	22810	3.5	643	19.3279	2.9657	0.5448
7/31/1992	2.083	315471	46.15	17807	32.0825	4.6933	1.8109
8/17/1992	3.132	915910	200.72	56054	61.9483	13.5759	3.7913
8/29/1992	1.417	148088	17.31	10514	22.1385	2.5878	1.5718
9/10/1992	1.417	61072	4.72	1936	9.1300	0.7056	0.2894
9/22/1992	1.417	56008	4.51	1826	8.3730	0.6742	0.2730
10/9/1992	1.417	31260	1.45	419	4.6732	0.2168	0.0626
10/11/1992	1.583	50170	2.18	512	6.7137	0.2917	0.0685
10/16/1992	1.417	70520	3.2	649	10.5424	0.4784	0.0970
10/24/1992	1.417	108015	6.43	1842	16.1478	0.9613	0.2754
11/3/1992	4.476	522397	39.35	17171	24.7234	1.8623	0.8127
11/12/1992	1.667	219990	12.87	6666	27.9554	1.6355	0.8471
11/22/1992	2.365	854820	181.07	161561	76.5671	16.2186	14.4712
11/24/1992	4.007	859141	70.06	32991	45.4196	3.7038	1.7441
12/17/1992	1.25	264187	71.56	50988	44.7713	12.1271	8.6408
12/30/1992	1.66	707445	179.75	128047	90.2782	22.9382	16.3403
1/4/1993	1.667	363011	31.8	20183	46.1299	4.0410	2.5648
3/28/1993	2.674	2671016	132.56	337526	211.5989	10.5015	26.7389
3/30/1993	4.007	3099097	508.9	345652	163.8378	26.9037	18.2733
4/8/1993	1.667	1051537	219.87	162462	133.6249	27.9402	20.6450
4/10/1993	2.882	2857583	1161.95	768690	210.0406	85.4067	56.5009
4/16/1993	2.625	1388113	214.04	150610	112.0196	17.2729	12.1541
4/22/1993	1.715	1098584	116.56	115680	135.6962	14.3974	14.2887

Appendix 1. Characterization of storm events monitored prior to BMP implementation (pre-BMP). Runoff desrcribes event intensity and total phosphorus and suspended sediment exports describe the corresponding transport of those constituents.

Start date of event	Duration (days)	Flow volume (cubic meters)	T. phosphorus load (kg)	Sus. sediment load (kg)	Runoff m^3/ha/day	T. phosphorus export g/ha/day	Sus. sediment export kg/ha/day
12/15/1999	1.375	70115	1.388	5591.67	10.8021	0.2139	0.8615
1/3/2000	1.653	1036380	889.836	291740.97	132.8142	114.0343	37.3872
1/10/2000	1.368	415419	107.760	42696.76	64.3278	16.6866	6.6116
2/24/2000	0.917	235771	25.251	98198.62	54.4652	5.8332	22.6848
2/25/2000	2.875	2710319	108.413	269405.71	199.7013	7.9881	19.8503
2/28/2000[a]	1.833	2977612	1522.155	1930981.38	344.1153	175.9118	223.1588
3/7/2000	1.459	1078609	75.179	81327.12	156.6056	10.9154	11.8081
3/28/2000	1.305	1440104	710.259	758214.76	233.7662	115.2935	123.0779
3/29/2000	2.062	1145980	388.373	421147.65	117.7299	39.8987	43.2657
4/3/2000[a]	1.576	6284067	1836.204	1985765.17	844.6621	246.8103	266.9132
4/14/2000	2	1151261	49.734	28355.56	121.9389	5.2678	3.0034
4/21/2000	3	1846053	77.903	51227.97	130.3531	5.5009	3.6173
5/10/2000	1.743	485240	38.043	20501.39	58.9736	4.6235	2.4916
5/13/2000	1.994	1751578	474.327	316597.72	186.0813	50.3908	33.6342
5/18/2000	2	993123	13.904	4111.53	105.1893	1.4726	0.4355
5/24/2000	1.244	797238	11.401	3882.55	135.7582	1.9413	0.6611
6/2/2000	1.5	280097	12.520	9923.84	39.5563	1.7682	1.4015
6/6/2000	1.326	1081772	143.767	98008.54	172.8187	22.9676	15.6574
6/12/2000	0.834	698452	94.850	19654.44	177.4063	24.0918	4.9922
6/20/2000	1.493	722720	81.378	25779.42	102.5436	11.5464	3.6577
7/15/2000	1.826	452229	43.052	24569.60	52.4634	4.9945	2.8503
8/11/2000	0.993	102790	26.499	15110.13	21.9281	5.6531	3.2234
8/23/2000	1.993	97994	10.495	7006.57	10.4158	1.1155	0.7447
9/2/2000	2	47244	2.924	1535.43	5.0040	0.3097	0.1626
9/9/2000	1.243	90310	13.953	6517.67	15.3909	2.3779	1.1108
9/12/2000	1.577	141940	10.575	5417.85	19.0665	1.4205	0.7278
10/6/2000	1.993	86250	2.493	1552.50	9.1675	0.2649	0.1650
10/18/2000	1.993	170232	12.018	4426.03	18.0939	1.2774	0.4704
11/10/2000	1.993	62803	2.104	1444.47	6.6753	0.2236	0.1535
4/9/2001[a]	2	6319108	624.328	394944.25	669.3052	66.1274	41.8316
4/12/2001[a]	2	6569254	2060.118	1278376.83	695.8001	218.2029	135.4027
5/22/2001	1.993	343825	273.685	503359.80	36.5450	29.0899	53.5020
6/11/2001	1.993	192875	138.735	148031.56	20.5006	14.7461	15.7342
6/12/2001	1.243	92555	32.672	21611.59	15.7735	5.5680	3.6831
6/16/2001	1.993	145620	6.218	3240.05	15.4779	0.6609	0.3444
6/23/2001	0.993	59710	11.769	3742.03	12.7379	2.5106	0.7983
7/4/2001	0.493	1863	0.411	135.07	0.8005	0.1768	0.0580
7/26/2001	0.91	25407	0.765	260.42	5.9144	0.1780	0.0606

Appendix 2. Characterization of storm events monitored during BMP implementation (mid-BMP). Runoff desrcribes event intensity and total phosphorus and suspended sediment exports describe the corresponding transport of those constituents ([a] indicates potential outliers).

Start date of event	Duration (days)	Flow volume (cubic meters)	T. phosphorus load (kg)	Sus. sediment load (kg)	Runoff m^3/ha/day	T. phosphorus export g/ha/day	Sus. sediment export kg/ha/day
1/24/2002	1.5	241300	68.288	41744.90	34.0772	9.6439	5.8954
1/30/2002	0.58	153400	18.561	10277.80	56.0268	6.7792	3.7538
2/21/2002	1.29	216000	12.312	9180.00	35.4701	2.0218	1.5075
3/26/2002	1.51	762300	176.091	52598.70	106.9418	24.7035	7.3790
4/29/2002	1.45	230400	13.502	29491.20	33.6599	1.9726	4.3085
5/12/2002	1.41	578600	104.211	83511.27	86.9276	15.6564	12.5466
6/5/2002	1.45	582600	139.732	96478.56	85.1140	20.4140	14.0949
9/27/2002	0.87	12600	3.054	1421.28	3.0680	0.7435	0.3461
3/18/2003	1.95	1114000	214.775	229484.00	121.0177	23.3317	24.9297
3/21/2003[a]	2	6164900	1864.345	1371073.76	652.9718	197.4670	145.2209
3/24/2003	0.53	661200	95.705	56598.72	264.2746	38.2524	22.6219
4/10/2003	1.58	321800	30.233	30812.35	43.1447	4.0534	4.1311
5/11/2003	1.74	215100	55.248	48021.08	26.1872	6.7261	5.8463
6/1/2003	1.75	522400	62.857	52109.40	63.2359	7.6088	6.3078
6/11/2003	1.74	90800	12.475	1657.10	11.0544	1.5188	0.2017
6/21/2003	1.57	207800	34.997	18805.90	28.0378	4.7220	2.5374
7/21/2003	1.08	88500	12.874	7681.80	17.3587	2.5253	1.5067
9/23/2003	1.66	56500	5.619	3548.20	7.2101	0.7170	0.4528
9/29/2003	1.17	71000	3.694	2584.40	12.8550	0.6688	0.4679
10/15/2003	1.16	184600	16.298	7236.32	33.7110	2.9763	1.3215
10/27/2003	1.83	1120200	290.120	221799.60	129.6710	33.5834	25.6749
11/19/2003	1.49	853900	167.419	89488.72	121.4001	23.8022	12.7227
12/11/2003	1	457600	71.952	64613.12	96.9358	15.2419	13.6873

Appendix 3. Characterization of storm events monitored following BMP implementation (post-BMP). Runoff desrcribes event intensity and total phosphorus and suspended sediment exports describe the corresponding transport of those constituents ([a] indicates potential outliers).