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

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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 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 in the Otsego Lake watershed (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, $143,082 in Federal funding has been spent with a local match of approximately $50,000 provided by the OCCA. Approximately $70,000 was provided by New York State Department of Agriculture and Markets, resulting in $263,000 being spent on projects on farms that are wholly or partially in the Shadow Brook drainage basin.

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 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™ 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 collected during each runoff event (defined here as a discharge increase from base flow

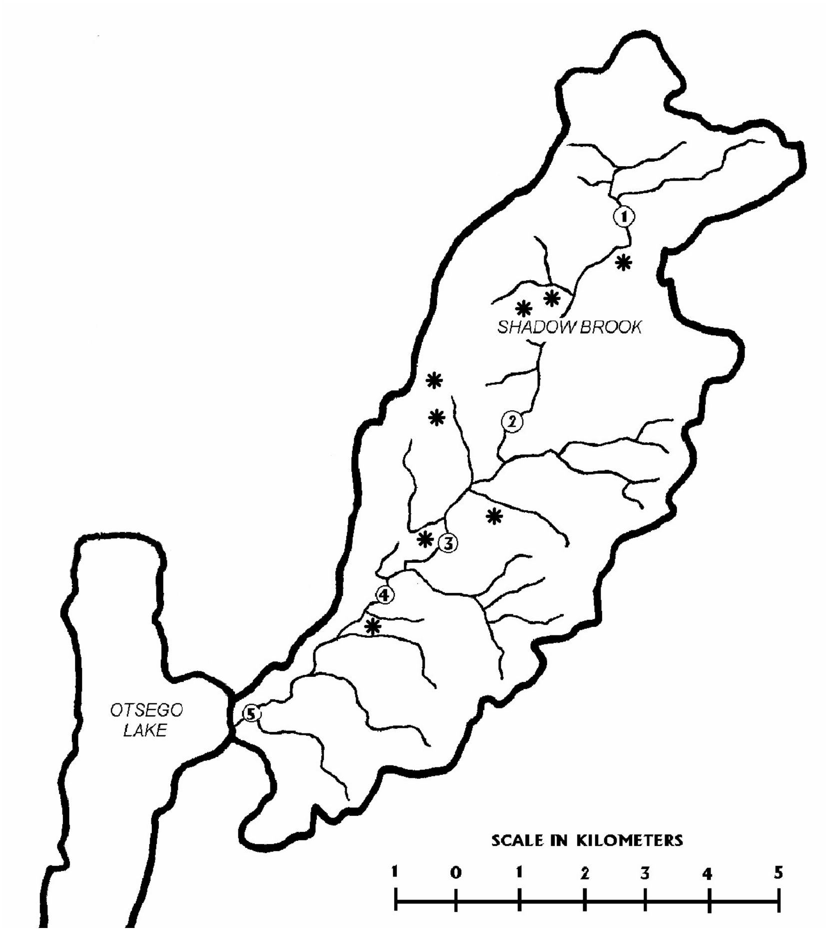

Figure 1. Shadow Brook drainage basin showing locations of BMPs (asterisks), constant monitoring station and summer time weekly sampling stations (1-5).

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- 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

Tables 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.

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

Start date of event	Duration (days)	Flow volume (cubic meters)	T. phosphorus load (kg)	Sus. sediment load (kg)	Runoff cm/ac/day	T. phosphorus export g/ac/day	Sus. sediment export kg/ac/day
2/5/1991	3.188	618551	105.39	NA	16.6402	2.8352	NA
2/19/1991	2.042	807017	414.06	NA	33.8944	17.3904	NA
3/2/1991	0.799	185095	51.32	NA	19.8678	5.5086	NA
3/3/1991	1.5	779072	97.15	NA	44.5439	5.5546	NA
3/25/1991	2.986	520338	32.64	NA	14.9450	0.9375	NA
4/9/1991	1.958	231563	23.16	NA	10.1428	1.0144	NA
4/21/1991	2.13	1195773	277.47	NA	48.1472	11.1722	NA
4/30/1991	1.07	134703	14.08	NA	10.7968	1.1285	NA
5/6/1991	1.02	104419	6.69	NA	8.7797	0.5625	NA
5/30/1991	0.81	25924	1.32	NA	2.7448	0.1398	NA
6/30/1991	1.46	5729	0.86	NA	0.3365	0.0505	NA
7/7/1991	0.93	8187	0.73	NA	0.7550	0.0673	NA
8/9/1991	1.02	10651	1.29	NA	0.8956	0.1085	NA
9/15/1991	2.28	14554	1.82	NA	0.5475	0.0685	NA
9/19/1991	1.02	18076	2.89	NA	1.5199	0.2430	NA
10/2/1991	0.52	13556	1.78	NA	2.2358	0.2936	NA
10/4/1991	2.21	31197	4.29	NA	1.2107	0.1665	NA
10/15/1991	3.17	53554	1.63	NA	1.4489	0.0441	NA
11/11/1991	1.25	39934	2.85	NA	2.7399	0.1955	NA
11/22/1991	2.28	336906	47.37	NA	12.6729	1.7818	NA
12/8/1991	1.68	32185	56.57	NA	1.6430	2.8879	NA
5/2/1992	0.844	353813	401.78	274462	35.9528	40.8270	27.8895
5/5/1992	2.636	489115	37.39	47458	15.9135	1.2165	1.5441
5/31/1992	1.896	112116	11.29	4466	5.0714	0.5107	0.2020
6/6/1992	1	46079	4.2	1286	3.9519	0.3602	0.1103
7/5/1992	1.3	15656	1.63	804	1.0329	0.1075	0.0530
7/13/1992	1.049	22158	2.48	1321	1.8116	0.2028	0.1080
7/15/1992	2.133	136862	16.37	7522	5.5029	0.6582	0.3024
7/23/1992	1.333	379800	99.52	15476	24.4358	6.4030	0.9957
7/29/1992	0.25	22810	3.5	643	7.8250	1.2007	0.2206
7/31/1992	2.083	315471	46.15	17807	12.9889	1.9001	0.7332
8/17/1992	3.132	915910	200.72	56054	25.0803	5.4963	1.5349
8/29/1992	1.417	148088	17.31	10514	8.9630	1.0477	0.6364
9/10/1992	1.417	61072	4.72	1936	3.6964	0.2857	0.1172
9/22/1992	1.417	56008	4.51	1826	3.3899	0.2730	0.1105
10/9/1992	1.417	31260	1.45	419	1.8920	0.0878	0.0254
10/11/1992	1.583	50170	2.18	512	2.7181	0.1181	0.0277
10/16/1992	1.417	70520	3.2	649	4.2682	0.1937	0.0393
10/24/1992	1.417	108015	6.43	1842	6.5376	0.3892	0.1115
11/3/1992	4.476	522397	39.35	17171	10.0095	0.7540	0.3290
11/12/1992	1.667	219990	12.87	6666	11.3180	0.6621	0.3430
11/22/1992	2.365	854820	181.07	161561	30.9988	6.5662	5.8588
11/24/1992	4.007	859141	70.06	32991	18.3885	1.4995	0.7061
12/17/1992	1.25	264187	71.56	50988	18.1260	4.9098	3.4983
12/30/1992	1.66	707445	179.75	128047	36.5499	9.2867	6.6155
1/4/1993	1.667	363011	31.8	20183	18.6761	1.6360	1.0384
3/28/1993	2.674	2671016	132.56	337526	85.6676	4.2516	10.8255
3/30/1993	4.007	3099097	508.9	345652	66.3311	10.8922	7.3981
4/8/1993	1.667	1051537	219.87	162462	54.0991	11.3118	8.3583
4/10/1993	2.882	2857583	1161.95	768690	85.0367	34.5776	22.8749
4/16/1993	2.625	1388113	214.04	150610	45.3521	6.9931	4.9207
4/22/1993	1.715	1098584	116.56	115680	54.9377	5.8289	5.7849

Table 1. Characterization of storm events monitored prior to the onset of BMP implementation. Runoff describes event intensity, total phosphorus and suspended sediment exports describe the corresponding migration of those constituents.

Start date of event	Duration (days)	Flow volume (cubic meters)	T. phosphorus load (kg)	Sus. sediment load (kg)	Runoff cm/ac/day	T. phosphorus export g/ac/day	Sus. sediment export kg/ac/day
12/15/1999	1.375	70115	1.388	5591.67	4.3733	0.0866	0.3488
1/3/2000	1.653	1036380	889.836	291740.97	53.7709	46.1677	15.1365
1/10/2000	1.368	415419	107.760	42696.76	26.0436	6.7557	2.6768
2/24/2000	0.917	235771	25.251	98198.62	22.0507	2.3616	9.1841
2/25/2000	2.875	2710319	108.413	269405.71	80.8507	3.2340	8.0366
2/28/2000[a]	1.833	2977612	1522.155	1930981.38	139.3180	71.2193	90.3477
3/7/2000	1.459	1078609	75.179	81327.12	63.4031	4.4192	4.7806
3/28/2000	1.305	1440104	710.259	758214.76	94.6422	46.6775	49.8291
3/29/2000	2.062	1145980	388.373	421147.65	47.6639	16.1533	17.5165
4/3/2000[a]	1.576	6284067	1836.204	1985765.17	341.9685	99.9232	108.0620
4/14/2000	2	1151261	49.734	28355.56	49.3680	2.1327	1.2159
4/21/2000	3	1846053	77.903	51227.97	52.7745	2.2271	1.4645
5/10/2000	1.743	485240	38.043	20501.39	23.8759	1.8719	1.0088
5/13/2000	1.994	1751578	474.327	316597.72	75.3366	20.4011	13.6171
5/18/2000	2	993123	13.904	4111.53	42.5867	0.5962	0.1763
5/24/2000	1.244	797238	11.401	3882.55	54.9628	0.7860	0.2677
6/2/2000	1.5	280097	12.520	9923.84	16.0147	0.7159	0.5674
6/6/2000	1.326	1081772	143.767	98008.54	69.9671	9.2986	6.3390
6/12/2000	0.834	698452	94.850	19654.44	71.8244	9.7538	2.0211
6/20/2000	1.493	722720	81.378	25779.42	41.5156	4.6747	1.4809
7/15/2000	1.826	452229	43.052	24569.60	21.2402	2.0221	1.1540
8/11/2000	0.993	102790	26.499	15110.13	8.8778	2.2887	1.3050
8/23/2000	1.993	97994	10.495	7006.57	4.2169	0.4516	0.3015
9/2/2000	2	47244	2.924	1535.43	2.0259	0.1254	0.0658
9/9/2000	1.243	90310	13.953	6517.67	6.2311	0.9627	0.4497
9/12/2000	1.577	141940	10.575	5417.85	7.7192	0.5751	0.2946
10/6/2000	1.993	86250	2.493	1552.50	3.7115	0.1073	0.0668
10/18/2000	1.993	170232	12.018	4426.03	7.3255	0.5172	0.1905
11/10/2000	1.993	62803	2.104	1444.47	2.7026	0.0905	0.0622
4/9/2001[a]	2	6319108	624.328	394944.25	270.9738	26.7722	16.9359
4/12/2001[a]	2	6569254	2060.118	1278376.83	281.7004	88.3413	54.8189
5/22/2001	1.993	343825	273.685	503359.80	14.7956	11.7773	21.6607
6/11/2001	1.993	192875	138.735	148031.56	8.2998	5.9701	6.3701
6/12/2001	1.243	92555	32.672	21611.59	6.3860	2.2543	1.4911
6/16/2001	1.993	145620	6.218	3240.05	6.2664	0.2676	0.1394
6/23/2001	0.993	59710	11.769	3742.03	5.1570	1.0164	0.3232
7/4/2001	0.493	1863	0.411	135.07	0.3241	0.0716	0.0235
7/26/2001	0.91	25407	0.765	260.42	2.3945	0.0721	0.0245

Table 2. Characterization of storm events monitored following BMP implementation. Runoff describes event intensity, total phosphorus and suspended sediment exports describe the corresponding migration of those constituents ([a] indicates potential outliers).

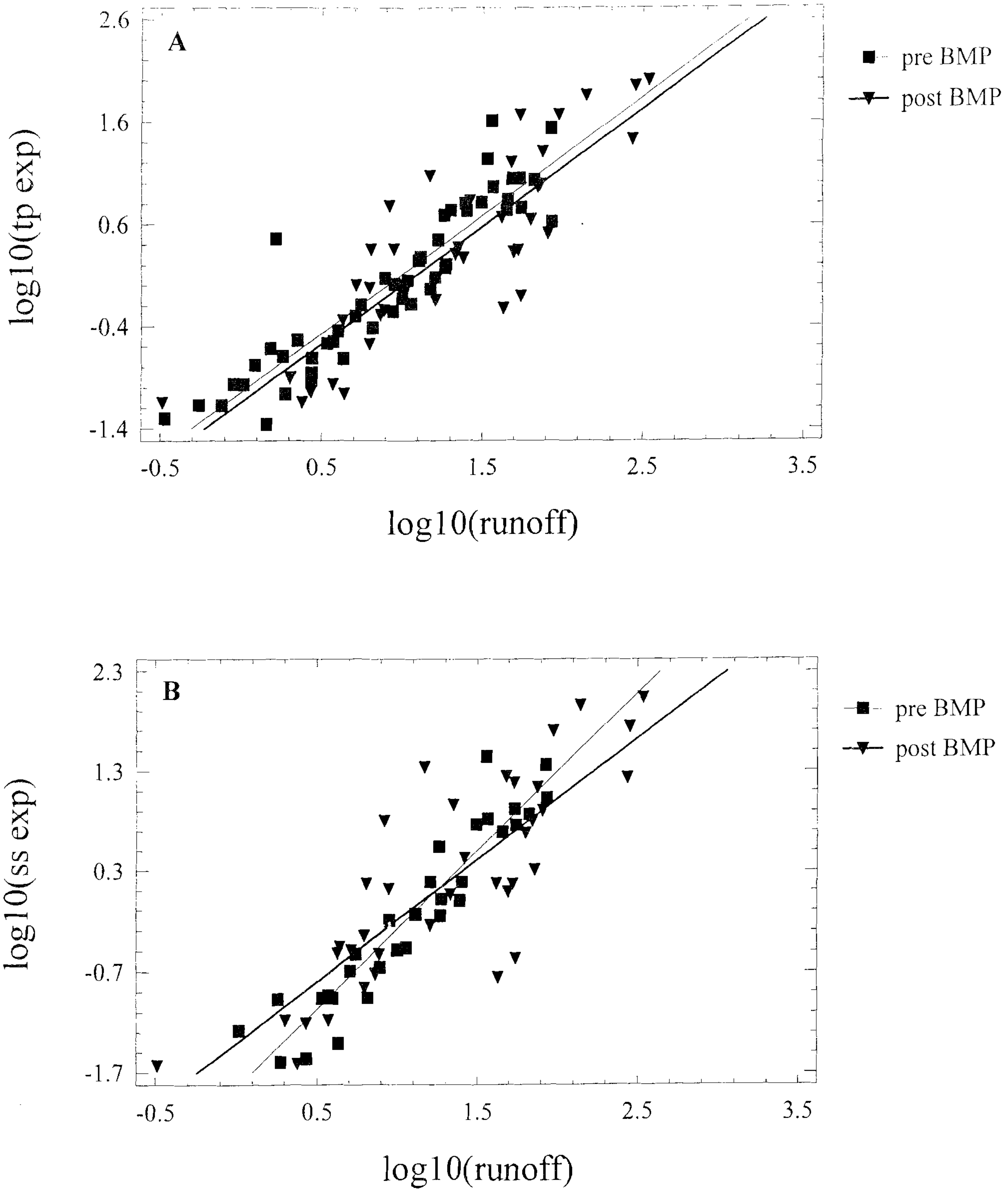

Figure 2. Comparison of regression lines of plots of log transformed total phosphorus export (g/ac/day) (**A**) and suspended sediment export (kg/ac/day) (**B**) vs. log transformed runoff (m^3/ac/day) for pre- and post BMP implementation using all available storm event data.

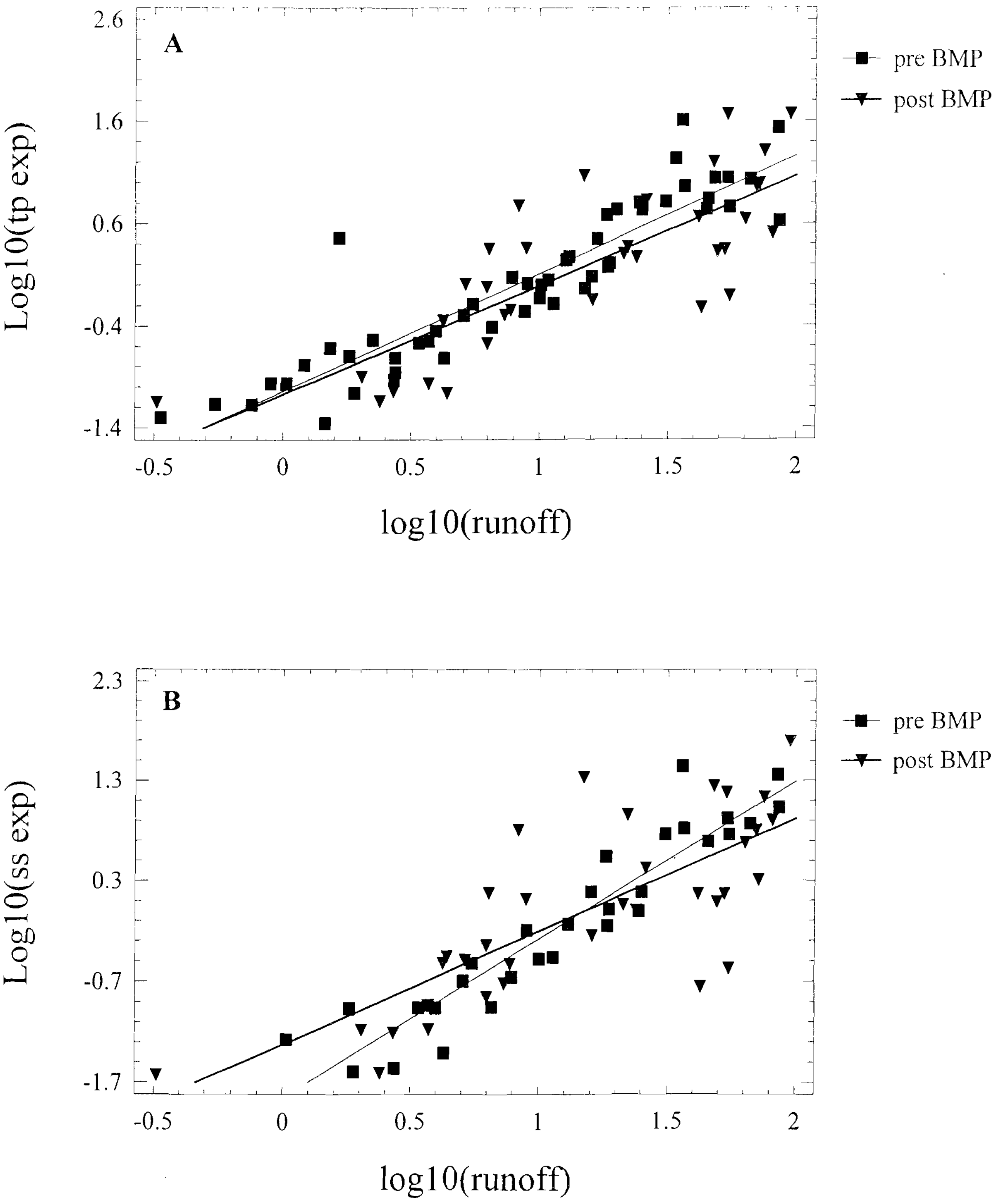

Figure 3. Comparison of regression lines of plots of log transformed log total phosphorus export (g/ac/day) (**A**) and suspended sediment export (kg/ac/day) (**B**) vs. log transformed runoff (m^3/ac/day) for pre- and post BMP implementation storm event data after having removed outliers.

Table 3 provides a statistical summary of the regressions performed. Included are correlation coefficients (r), which indicate the strengths of the relationships. The nearer that value is to 1.0 or –1.0 the stronger the relationship. During the post-BMP timeframe, both the y intercept and the slope of the regression lines comparing runoff and phosphorus export decreased, implying that phosphorus export is lower following BMP implementation over the range of event intensities studied. However, neither the y intercept nor the slope are different at any level of confidence. The slope of the regression line comparing runoff and suspended sediment export is lower following BMP implementation, though the y intercept increased. That would suggest lower sediment export during events of high intensity (i.e., elevated runoff), but higher exports during events of low intensity. Again, however, those differences are not statistically significant.

Pre-BMP	Log (runoff) vs log total phosphorus export	Log (runoff) vs log suspended sediment export
r	0.91	0.94
y intercept	-1.042	-1.853
slope	1.155	1.573
Post-BMP		
r	0.79	0.75
y intercept	-1.073	-1.326
slope	1.071	1.123

Table 3. Statistical summary of Pre- and post-BMP regressions between log (runoff) vs log (total phosphorus export) and log (runoff) vs log (suspended sediment export).

The strength of the relationships indicates that the export of both total phosphorus and suspended sediment are not as dependent upon runoff intensity as they had been since BMP implementation. This increased scatter about the regression line may indicate that BMPs are influencing water quality during some runoff events but not others. This may be due to some unrecognized attribute intrinsic to individual practices.

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 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. As with the local work, 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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