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Nonpoint source reduction to the nearshore zone via watershed management practices: Nutrient fluxes, fate, transport and biotic responses — Background and objectives

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ABSTRACT

Studies that evaluate the linkages between watershed improvement through Best Management Practices (BMPs) and downstream outcomes are few. Water quality of coastal waters is often impacted by soil and nutrient loss from watersheds in agriculture. Mitigation of these impacts is of concern in the Great Lakes, the Finger Lakes Region of New York State, and generally in water bodies of North America. In this issue, we report on hypothesis-based research at the watershed level evaluating the impact of BMPs on mitigation of nonpoint sources of nutrient and soil loss to streams and the nearshore zone of a lake. Specifically, we hypothesize not only reductions in nutrient and soil losses from watersheds but also a resultant decrease in metaphyton (filamentous algae), coliform bacteria, and macrophyte populations in the nearshore at stream mouths draining sub-watersheds where BMPs were introduced. Small experimental sub-watersheds, predominantly in agriculture (>70%), were selected to ensure that effects on downstream systems would not be confounded by other land use practices often observed in large watershed approaches. In this introductory paper, we provide background information on Conesus Lake, its watershed, and the Conesus Lake watershed project, a large multi-disciplinary study evaluating agricultural management practices. The series of papers in this volume consider the effect of BMPs designed to control nonpoint sources on water chemistry, metaphyton, macrophytes, and microbial populations in the coastal zone of a lake. Ultimately, this volume expands the basic understanding of the ability of BMPs to control nonpoint source pollution while contributing toward the goal of improving water quality of downstream systems including streams, embayments, and the nearshore of large lakes.

Introduction

Lake Ontario coastal waters are a valuable resource for drinking water and industrial usage, recreational boating, fishing and swimming, tourism, and wastewater processing and are a key asset in the economies of upstate New York and Ontario Province. Article 14 of the New York Ocean and Great Lakes Ecosystem Conservation Act 2006 states "… coastal ecosystems are critical to the state's environmental and economic security and integral to the state's high quality of life and culture." Yet in Lake Ontario, many of the bays, rivers and drowned river mouths, as well as the coastal zone of the south shore of Lake Ontario, are suffering from high turbidity, sedimentation, nutrient enrichment, and algal blooms that are often associated with agricultural land use (Makarewicz and Howell, 2007). Sediment loads, nutrient concentrations, and Cyanobacteria appear to be higher in the streams and embayments and at shoreside sites compared to offshore sites west of the Genesee River. Phosphorus (P) levels often exceed the New York State Department of Environmental Conservation (NYSDEC) Ambient Water Quality Guideline for P while in the Province of Ontario, total phosphorus (TP) levels do not generally exceed the Provincial Water Quality Objective. In the coastal zone there are many locations, such as embayments, river mouths, and locations near the shoreline, where TP will periodically, if not frequently, exceed the NYSDEC ambient guideline of 10 or 20 μg/L (T. Howell, Personal Communication, Ontario Ministry of the Environment).

Whether it be Lake Ontario or the Finger Lakes region of New York State (Fig. 1), public beaches are often closed or posted due to elevated levels of fecal pollution indicators and poor water quality. Elevated levels of fecal indicators may result from factors other than strictly poor water quality in a conventional sense (e.g., losses from farming operations, beach sediments, gulls). In Lake Ontario, water quality of the coastal zone is generally poorer than water from the offshore zone (Makarewicz and Howell, 2007). Structure and function of the littoral zone, whether it be a Finger Lake or a Great Lake, are complex, variable, and influenced by the proximity of the shoreline, localized sources of meso-scale variability (e.g., tributaries, land use in the watershed, embayments, geology, effluent pipes), and variations in the current regime (wind direction, upwellings, etc.), as

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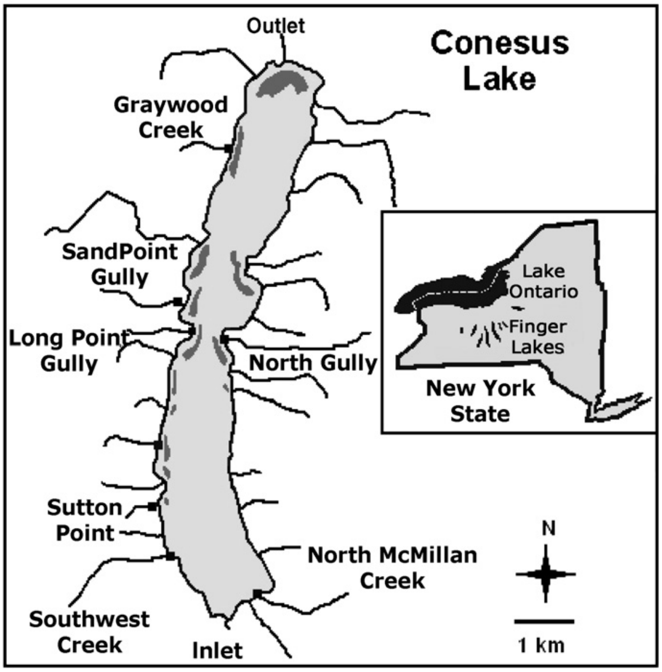

Fig. 1. Macrophyte beds in Conesus Lake (N 42° 46.784′, W 77° 43.068′), NY, USA. Squares represent stream discharge monitoring sites. Irregular areas near streams are GPS identified macrophyte beds. Adapted from D'Aiuto et al. (2006). Mean depth = 11.5 m, Maximum depth = 20.2 m (Forest et al., 1978).

well as by land use and nonpoint source loading. Nonpoint source impacts of agricultural practice on water quality of lakes via tributary-delivered loads of pollutants and the potential role of management practices to reduce impacts are the primary concerns of this volume.

Since the 1970s, environmental management at the watershed scale has emerged as a promising procedure to deal with water quality problems in general (Hawkings and Geering, 1989) and in particular with those associated with agricultural land use (Staver et al., 1989; Whitelaw and Solbe, 1989). Water pollution from areas of intense livestock production is caused by deficiencies in the management of animal manure (e.g., lack of appropriate storage facilities, no treatment of feedlot runoff, application problems) and milk house wastewater (e.g., direct discharge into water courses) and in inadequate fertilization processes caused by excessive or untimely field applications of manure or fertilizers in general (Cooper and Lipe, 1992; Clausen et al., 1992). Jones et al. (2004) have suggested that nonpoint sources (cropland) account for 60 to 70% of the variation in nutrient chemistry in Missouri reservoirs; that is, there is a positive correlation with increasing TP and total nitrogen with increasing cropland in a watershed. Similarly, Makarewicz et al. (2007) and D'Aiuto et al. (2006) have suggested that a positive correlation existed between percent cover of nearshore metaphyton (filamentous) with the amount of agricultural land use and that macrophyte standing crop is positively correlated with TP loading.

The demonstrated losses of soil and nutrients from agricultural activities in the watershed and the probable effects on downstream communities are serious issues locally, regionally, and nationally. Herein lies the growing dilemma for governmental leaders in agricultural areas: their most important economic industry (agriculture) may also be the cause of environmental degradation which heightens public concern. For farmers, this is further exacerbated by the high profile increase of governmental regulation on agricultural operations [e.g., Total Daily Maximum Loads (TDML), Concentrated Animal Feeding Operations (CAFO)]. The agricultural industry needs scientific evidence that farmers are capable of being part of the solution, not just part of the problem.

In P-limited lakes, theory states that nutrient reduction from impacted watersheds will improve water quality by reducing limiting nutrients thus decreasing phytoplankton, metaphyton, and macrophyte populations (Osgood, 1999). Best Management Practices (BMPs), if properly implemented, should lead to a reduction of nutrient and soil loss from the watershed and to nutrient declines in the water column of the lake. In Lake Erie for example, massive reductions in point loads of P led to significant improvements in water quality, reductions in phytoplankton populations, and reductions in nuisance algal species (Makarewicz and Bertram, 1991).

In reference to watersheds and lakes, the “Phosphorus Paradigm” is that P reduction will reduce algae and macrophyte populations and will improve water clarity and quality. However, the evidence for a connection between nutrient reductions by BMPs and reductions of nuisance plant growth is not as strong as it is generally believed (Osgood, 1999). Most examples of successful restoration of lakes suffering from overloads of P represent “point” source reduction or control: that is, sewage effluent that has been treated or diverted (Moss et al., 1997). Dealing with nonpoint sources has proven to be more difficult. Phosphorus in runoff usually comes from multiple sources such as storm sewers, fertilized lawns, or agricultural fields. In addition, the treatment or management practice is normally a low-tech approach resulting only in a partial reduction in P compared to much higher rates of removal for point source loading. As a result, it is not possible to totally eliminate the limiting nutrient P. Unlike point sources which technically could be turned off or reduced to a regulatory standard, nonpoint sources can only be turned down and with great difficulty because of the large spatial component.

The assumption of the “Phosphorus Paradigm” that we can obtain the same results from reduction of nonpoint loading as point source loading has to be critically reviewed (Osgood, 1999). The proposed BMPs being tested in this study selectively target nutrient and erosion management such as animal waste handling (lagoons, timing of manure spreading) and erosion prevention (terracing, buffer strips). Clearly, several studies have shown the “local” effectiveness of BMP implementation in reducing nutrient loss, soil loss, and bacteria counts (Cook et al., 1996; Meals 1996, 2001; Gilliam, 1995). For example, with livestock operations a >90% reduction in P loss to immediate downstream locations was achieved by capturing and storing manure in a lagoon (Gilliam, 1995). Phosphorus export from cornfields was 1500% higher where manure was spread in the winter rather than in the spring (Meals, 1996). It follows that seasonal timing of manure spreading is critical to reducing P losses and other nutrients, such as nitrate, from a watershed to downstream systems.

However, from a watershed perspective, local effects did not always translate to ecosystem or watershed-wide reductions in nutrients and soil loss (Meals, 1996). In fact, BMPs introduced in small portions of watersheds in the Finger Lakes within the Lake Ontario watershed have not effectively demonstrated a connection between nutrient and erosion reduction and visual or measurable nearshore, offshore, or lake-wide reductions of nutrients, metaphyton, or aquatic plant populations (Bosch et al., 2001). This inability to demonstrate mitigation of stresses caused by nutrient enhancement in downstream systems is the result of confounding factors inherent in nonexperimental evaluations and/or the use of very large watersheds where a single manipulation (i.e., a BMP) of a small area will not provide a large enough reduction in nutrients to affect significant change in downstream nutrient concentration, nutrient loading, and metaphyton and macrophyte population size. In the Finger Lakes Region of New York, the lack of demonstrable evidence of the success of selected BMPs on reducing nuisance species of lake plants has inhibited the ability of managers and planners to convince the agricultural community to voluntarily initiate expensive changes through BMPs (P. Kanouse, Personal Communication, Livingston County Soil and Water Conservation District). In some cases within the Finger Lakes Region, individual farmers fail to recognize that some

Table 1
Nutrient and soil loss from selected Conesus Lake watersheds during events in autumn, 2000.

Watershed	Percent agriculture	Watershed area (ha)	Event loading data (g/ha/day, TSS = kg/ha/d)				
			NO_3	TP	SRP	TSS	TKN
Graywood Gully	74	33.8	1,202	34.7	30.7	1,651	3.7
Sand Point Gully	83	325	54.9	5.4	3.2	1,310	4.1
Cottonwood Gully	75	76	180	9.1	3.8	3,749	3.3
Sutton Point Gully	76	62.2	43.5	1.0	0.7	77.0	3.1
Long Point Gully	86	622.5	590	11.1	6.4	1,807	21.4
North McMillan Creek	12	2045	9.5	0.43	N.D.	426	5.64

NO_3 = nitrate, TP = total phosphorus, SRP = soluble reactive phosphorus, TSS = total suspended solids, and TKN = total Kjeldahl nitrogen.

agricultural practices are leading to major losses of soil and nutrients from their fields.

Ecosystem experiments are critically needed to improve environmental management practices and policies (Carpenter, 1998). Ecosystem experiments are a powerful tool for evaluating and predicting impacts of environmental change (Carpenter et al., 1995). The small watershed approach allows evaluation of land use management techniques. The assumption is that as water passes through the terrestrial ecosystem, it may be altered in chemical composition by management practices that reflect or can be attributed to known biological and geochemical processes (Carpenter et al., 1995). Such large-scale experiments have significant advantages over small artificial systems (e.g., lysimeters, plot analysis) (Carpenter, 1996; Carpenter et al., 1995). The fundamental problem with learning from small-scale experiments is that results must be translated across scales to draw conclusions about ecosystems (Carpenter, 1998) and can lead to spurious results (Schindler, 1998). Even interpolation from small watershed experiments, such as employed in the Conesus Lake Watershed Study, across diverse landscapes is a challenge. The scale of ecosystem experimentation is especially useful in environmental management because it is very difficult to convince managers or other stakeholders to change policies using complex arguments and extrapolations (Lee, 1993).

Here, background information is provided on Conesus Lake, its watershed, and a multi-disciplinary project conducting longer-term (1 Sep 2002 to 31 Aug 2007) hypothesis-based research at the watershed level designed to evaluate management practices associated with nonpoint sources of nutrient and soil pollution to downstream systems. Research at Conesus Lake had demonstrated that loss of nutrients and soils from some watersheds in agriculture is high compared to other areas with less agriculture (Table 1). Furthermore, the location and abundance of large macrophyte beds and metaphyton at the mouths of creeks in this Finger Lake appear to be a function of high nutrient loads from watersheds associated with agricultural land use (Figs. 1 and 2, D'Aiuto et al., 2006).

Our general hypothesis is that BMPs [see Herendeen and Glazier (2009) for a complete description of BMPs] implemented in experimental watersheds will lead to reductions in nutrient loads, metaphyton growth and abundance, fecal pollution as inferred from indicator bacteria, and reductions in the size and biomass of macrophyte beds in the nearshore near the mouths of streams draining managed watersheds. The extensive localized growth of metaphyton and macrophyte beds at the mouth of streams draining agriculturally dominated sub-watersheds offers an opportunity to experimentally test the effects of nutrient and soil BMPs implemented in small sub-watersheds on biota at the base of affected watersheds rather than on phytoplankton populations in the offshore of the lake. Since management plans were introduced into only 5 of 18 sub-watersheds, the effects from BMPs implemented on a few small sub-watersheds within the catchment are not expected to affect the phytoplankton of the offshore community. Before improvements are observed in the offshore, management plans would need to be introduced to other sub-watersheds to overcome the cumulative impacts from the 15 non-managed sub-watersheds.

The study site

Conesus Lake and its watershed

The Conesus Lake watershed is located in a broad glacial valley and is part of the Genesee River basin that drains into Lake Ontario. Approximately 9800 people live in the seven municipalities within the 180.5-km^2 watershed of Conesus Lake. Conesus Lake was one of the first lakes in New York State to have a perimeter sewer system, which was completed in 1972 with 26 pumping stations and a processing treatment plant that releases treated effluent into a stream draining away from the lake. The general climatic conditions can be described as humid continental with warm dry summers and cold snowy winters. Average yearly precipitation is approximately 80.5 cm. Conesus Lake is fed by 18 tributaries and a number of smaller streams and rivulets (Forest et al., 1978). The terrain in the watershed is characterized by gentle slopes at the northern outlet and southern inlet areas. Steep hilly slopes characterize the flanks and southern portion of the watershed. Elevation ranges from 249 m above sea level at the lakeside to about 549.9 m above sea level at the southern edge of the basin along the divide between the headwaters of the Conesus Inlet and South McMillan Creek (Forest et al., 1978). From the middle third of the lake to the southern end of the watershed, the lake and valley are flanked by steep slopes exceeding 45%.

The soils of the Conesus Lake watershed are mostly derived from locally-occurring shale and sandstone bedrock material that has been reworked by glacial action (Bloomfield, 1978). Towards the north of the watershed, limestone materials transported by the glaciers from the central NY limestone belt influence the soil. This influence is less as one moves south, and in general, soils are more agriculturally productive to the north of the watershed compared with the south (Stout, 1970). The soils vary widely in other

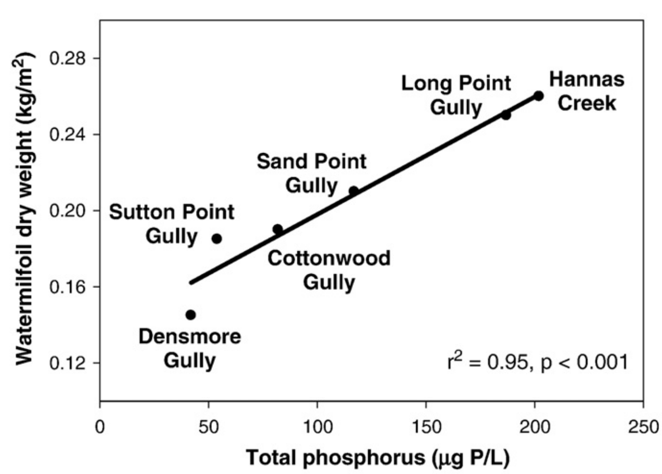

Fig. 2. Relationship between average stream event total phosphorus concentration and stream mouth Eurasian watermilfoil biomass in Conesus Lake, fall 2000.

properties of significance to land use management and water quality impacts. Many of the soils are highly susceptible to erosion, presenting the risk of sediment or sediment-borne nonpoint source pollution. Other soils are poorly drained, which make them likely to be important surface runoff generation areas. They are also risk zones for generation of nonpoint source pollution. Where soils of poor drainage exist, drainage tiles have often been installed (see Noll and Magee, 2009). Overall, the soils of this watershed present a diverse and complicated mosaic of management imperatives — they prescribe land use decisions at the field scale.

In 1999 about half of the entire land use within the Conesus Lake watershed was and continues to be in agriculture. Much of the agriculture (>70%) is concentrated in the western sub-watersheds of the lake (Fig. 3, SOCL, 2001). The deep, glacially-derived limestone soils that dominate the watershed are productive and support field crops (mostly corn), an occasional vineyard, and livestock. The vast majority of the livestock operations are in dairy operations while field crops are mostly for livestock feed. The lake is also a source of drinking water to ~15000 residents inside and outside of the watershed boundaries. As a recreational attraction, the lake is heavily used for swimming, boating, fishing, and aesthetic enjoyment. Economically, lake-based tourism is substantial but agriculture is predominant (SOCL, 2001).

Streams

In the Conesus Lake catchment, sub-watersheds with a large percentage of land in agricultural practices are losing large amounts of soil and nutrients (soluble P, nitrate, and organic nitrogen), especially during hydrometeorological events (Makarewicz et al., 1999, 2001, 2007; SOCL, 2001). Segment analysis, a process of subdividing a stream into segments and performing water analyses above and below the segment (Makarewicz and Lewis, 1999), demonstrated that the nonpoint sources are of agricultural origin in several sub-watersheds (Makarewicz, 1992, 1993, 1994). Average concentrations of TP during baseline flow in six streams draining agriculturally dominated catchments (60 to 80% of the land use) ranged from 41.9 to 245.3 μg P/L in 2000 (Makarewicz et al., 2001). In contrast, summer epilimnetic lake TP concentrations ranged from 15.0 to 38.3 μg P/L. During hydrometeorological events, levels of tributary TP ranged a magnitude higher (258 to 1313 μg P/L) than during nonevents as materials were washed off the landscape and carried downstream (Makarewicz et al., 2007). The mass loss from the watershed, that is, the loading into the lake from the watershed of nitrate (up to 1800 g N/ha/day) and TP (up to 34 g P/ha/day) during hydrometeorological events, was high (Makarewicz et al., 2001). A concentration gradient, high to low, existed from the tributary to the nearshore zone and on into the offshore region of the lake (Makarewicz et al., 2007). The distribution of nutrient-enriched water from streams into the nearshore of the lake is determined by the nature of the entry plumes of streams and lake circulation (Trexler et al., 2006). Li et al. (2007) have documented the flow regimes in and around two creeks in Conesus Lake. This three-dimensional, macrophyte-drag hydrodynamic model demonstrates that nutrient-laden stream water is focused as a result of currents, local bathymetry, and prevailing winds into a macrophyte bed where metaphyton are prevalent. The plume development at stream mouths in Conesus Lake during storm events is site-dependent and may either be current or wind driven. The nutrient-laden stream water draining sub-watersheds predominantly in agriculture has a major impact on nearshore metaphyton biomass and production (D'Aiuto et al., 2006, Makarewicz et al., 2007) and probably on macrophytes (Fig. 2) and cumulatively on the offshore region of the lake. Also, the stream water draining the sub-watersheds carried microbial populations into the lake. Somarelli et al. (2007) assessed the

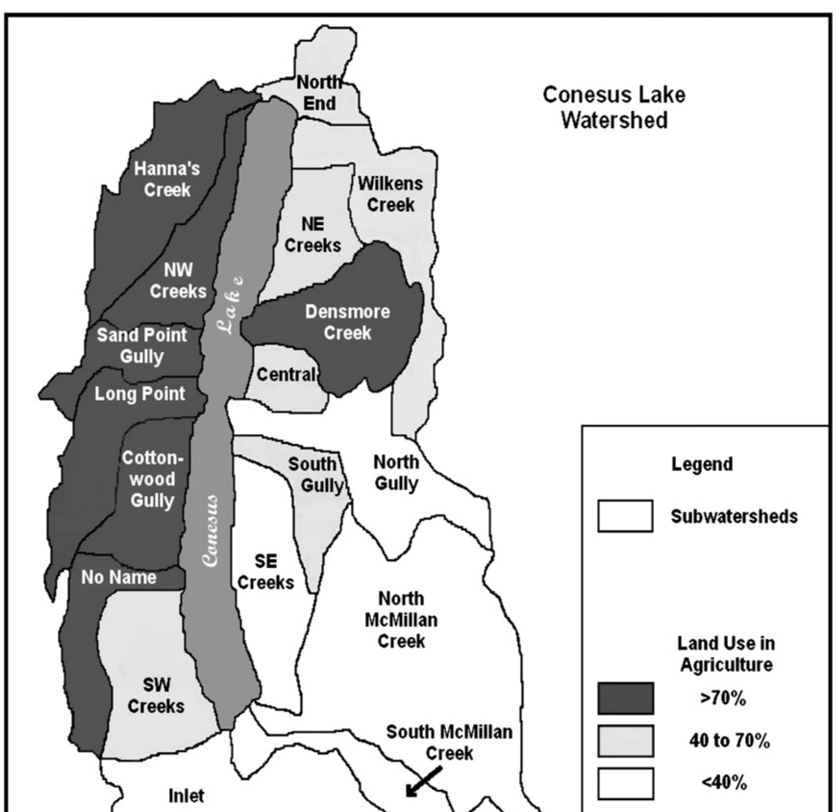

Fig. 3. Percentage of land in the Conesus Lake watershed in agriculture.

sources of bacteria contamination to streams within the Conesus Lake watershed using Rep-PCR. Surprisingly, geese were the dominant source of each of the sub-watersheds (44.7–73.7% of the total sources), followed by cows (10.5%–21.1%), deer (10.5–18.4%), humans (5.3–12.9%), and unidentified sources (0.0–11.8%) during the 2 years sampled.

The nearshore

In recent years, shoreline biomass of metaphyton and aquatic macrophytes has increased (Bosch et al., 2000, 2001). Field spatial analysis using GPS technology discovered that metaphyton and macrophyte [especially Eurasian milfoil (*Myriophyllum spicatum*)] beds are strongly associated with the mouth of the streams draining many of the sub-watersheds (Fig. 1, Bosch et al., 2000, 2001). In fact, a direct positive relationship exists between P and macrophyte biomass with higher concentrations of P in water draining the watershed being associated with greater macrophyte biomass (Fig. 2). In a series of field microcosm experiments, a 130 to 200% increase in growth of metaphyton occurred in water from six watersheds heavy in agriculture, compared to metaphyton grown in lake water (D'Aiuto, 2004; D'Aiuto et al., 2006). This major increase in metaphyton growth is attributed to elevated levels of dissolved P (~35 μg P/L) from watersheds dominated by agriculture compared to lake levels of 4.0 μg P/L. Metaphyton, which are the responsive algal type to nutrient inputs (Havens et al., 1999), are used as one indicator of BMP-induced change in nutrient retention in our watershed manipulations (Makarewicz et al., 2007).

The offshore

Despite the construction of a 28.6-km perimeter sanitary sewer completed in the early 1970s, Conesus Lake water quality has degraded in recent years (Makarewicz, 2001; SOCL, 2001; Makarewicz et al., 1991, 1999, 2001) due to “top-down” and “bottom-up” mechanisms. Phytoplankton populations have doubled from 2–4 μg/L in the 70 s to 7–8 μg/L of chlorophyll in the 90s due in part to the accidental introduction of alewives (*Alosa pseudoharengus*) that eliminated large herbivorous populations of zooplankton (Makarewicz, 2001). *Daphnia pulex*, which are effective grazers of smaller phytoplankton, were removed by the invasive alewives leading to major increases of phytoplankton in the 20- to 70-μm range. Simultaneously, watersheds with a large percentage of land in agricultural practices are losing large amounts of soil and nutrients (Makarewicz et al., 1999, 2001, 2007; SOCL, 2001) that are believed to stimulate the growth of pelagic phytoplankton communities (SOCL, 2001). Water clarity has decreased from secchi disk depths of 6–7 m in the 60 s to less than 3 m in the 90 s. Lake-wide manifestations of this degradation include higher than normal turbidity, blooms of algae in the open lake, and potentially harmful levels of fecal pollution as inferred from *Escherichia coli* and other coliform bacteria (SOCL, 2001). The cumulative flux of nutrients into the nearshore and offshore from the 18 creeks that drain the watershed, especially those from agriculturally dominated sub-watersheds, and the introduction of an invasive species, the alewive, appear to have had a negative impact on the trophic status of Conesus Lake. A bathymetric map of Conesus Lake may be found in Forest et al. (1978).

The Experiment

The use of experimental watersheds has been a successful method of accounting for environmental variability (Bishop et al., 2005). As annual variation and long-term trends in weather and nutrient export occur naturally in undisturbed watersheds (e.g., Esterby, 1996; Moog and Whiting, 2002), these effects must be separable from BMP effects when performing an evaluation of treatments (Bishop et al., 2005). At Conesus Lake, small sub-watersheds (Table 1) were chosen because they were predominantly in agriculture (over 70%, Fig. 3), are farmed by only one or two landowners, and thus impacts from other potential changes in land use are minimized. The five sub-watersheds targeted for nutrient and soil BMPs were Graywood Gully (74% in agriculture), Sand Point Gully (83%), Cottonwood Gully (75%), Long Point Gully (86%), and Sutton Point Gully (76%). Management practices were not introduced at North McMillan Creek (12% in agriculture) or North Gully (46%). Details on how watersheds were selected and management practices introduced are discussed in Herendeen and Glazier (2009). Monitoring of streams draining the watershed occurred for 5 years. Based on our previous work (Makarewicz et al., 1991, 1999; Makarewicz, 1992, 1993, 1994, 2001), we knew that these watersheds are event responsive; that is, over 80% of the soil and nutrient loss occurs in less than six or seven major precipitation events each year. Precipitation events, as runoff, sweep soil and nutrients from the landscape into drainage tiles and streams. Thus stream monitoring included instantaneous measurements of event and nonevent discharge and analyte chemistry (Makarewicz et al., 2009).

The overall objectives of the project were:

Objective 1: Implement a series of BMPs on individual farms in selected sub-watersheds with a goal of evaluating the impact of management plans on maintaining nutrients and soil on the landscape and of reducing losses of soil and nutrients to the downstream aquatic systems. The papers by Herendeen and Glazier (2009), Moran and Woods (2009), Makarewicz et al. (2009), Lewis and Makarewicz (2009), Zollweg and Makarewicz (2009), Noll and Magee (2009), and Noll et al. (2009) in this issue are directed at this objective.

Objective 2: Evaluate the effectiveness of agricultural management practices and strategies on bacteria, metaphyton, and macrophyte populations in the nearshore of Conesus Lake. Specifically, we hypothesize not only reductions in nutrient and soil concentrations and loading but also a decrease in metaphyton, bacteria, and macrophyte populations in the nearshore zone near stream mouths draining managed watersheds. The papers by Bosch et al. (2009a,b), Shuskey et al. (2009), and Simon and Makarewicz (2009a,b) in this issue address this objective. In related papers, Somarelli et al. (2007) identified wildlife as a major source of *Escherichia coli* in these agriculturally dominated watersheds, and Li et al. (2007) documented the flow regimes in the nearshore near two creeks draining from managed sub-watersheds of Conesus Lake.

Objective 3: Determine what physical and agricultural processes control/effect the biogeochemical cycling of nutrients through a watershed over time. Papers on winter manuring practices (Lewis and Makarewicz, 2009), on the impact of the “built environment” on extending a watershed beyond its topographic divide (Noll et al., 2009) on the fractionation of soil and sediments transported along a continuum from agricultural fields to nearshore lake sediments (Noll and Magee, 2009), and on the effect of antecedent hydrologic/meteorologic conditions on methodology for evaluating BMPs (Zollweg and Makarewicz, 2009) focus on this objective.

Objective 4: Experimentally evaluate the mode of nutrient uptake of the Eurasian milfoil. The hypothesis that Eurasian milfoil uptake of nutrients via leaves may provide a competitive advantage to this invasive species is tested in a series of experiments by Shuskey et al. (2009).

Objective 5: Develop a rigorous, physically-based GIS model of hydrology and nonpoint source pollution to analyze watershed processes and to evaluate management practices. The paper by Zollweg and Makarewicz (2009) deals with aspects of this issue.

Objective 6: Develop and implement an extension/education program that will demonstrate the link between watershed-specific agricultural management practices and water quality improvement, that will educate the agricultural community, and that will assist policymakers and managers in developing optimal strategies for water quality improvement. The papers by Herendeen and Glazier (2009) and Moran and Woods (2009) in this issue and by Glazier (2006), and Jacobs (2006a,b) in other sources comment on this final objective.

The series of manuscripts presented in this special edition should be of interest to people in the fields of watershed, soil, and aquatic science and restoration and conservation biology as well as to those in extension and planning who provide technical support to the agriculture community. In summary, a series of cultural and structural best management plans were voluntary and successfully implemented in several watersheds of Conesus Lake. Dramatic decreases in P, nitrogen, and soil loss from managed watersheds were realized. The greater the number of BMPs implemented, the greater the reduction of nutrient and soil loss to downstream systems. As a result of the BMPs introduced on the watersheds, significant reductions in metaphyton, macrophyte and microbial populations were observed in the nearshore of Conesus Lake.

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