REPORTS:

Evaluating phosphorus migration from septic systems near Otsego Lake

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INTRODUCTION

The introduction of phosphorus into lakes from septic systems is a major concern. While that source is generally a small component of the total phosphorus load, the impacts can be substantial because it is in a soluble form, readily available to algae. Because most of near-lake septic system usage is seasonal, it is added to lakes at the height of the algal growing season (Harman, et al., 1997). Conversely, most non-point sources of phosphorus are not easily taken up by algae and are introduced into lakes during spring runoff events, which precede the onset of the first algal blooms (Albright, 1996). It has long been known that excessive phosphorus loading leads to eutrophication (i.e. Vollenweider, 1968), reflected by higher plant and algae growth, lower water clarity, lower concentrations of dissolved oxygen in the hypolimnion and the potential loss of potability. Previous research by the Biological Field Station has focused on sampling for fecal coliform bacteria (Herring, 2000; Green, 2001), the rationale being that chronic "hot spots" might indicate failing systems. However, it is now recognized that functioning systems, having adequate percolation rates, can contribute substantial amounts of phosphorus (Ptacek, 1998; Baker et al., 1998; Zanini et al., 1998). More extensive research is necessary in order to verify the extent of this locally. More importantly, technologies are described that can efficiently intercept that phosphorus, preventing its reaching ground or surface waters (Baker et. al, 1998).

BACKGROUND

A septic system consists of a septic tank and an absorption drain field, or leach field (Figure 1). The sludge, scum, and water are separated in the tank and the effluent then moves through a pipe into the drain field where the organic component is removed through bacterial decomposition (Braem, Mlay, 1986). Between 20 and 30% of the total phosphorus from raw wastewater is separated out in the form of sludge, which accumulates in the bottom of the septic tank (Day, 2001). Additional phosphorus will be taken up by the soil by geochemical processes, such as adsorption and mineralization. However, soils are limited in their retentive capacity and the development of phosphorus plumes in the water table down grade of septic systems has been documented following the saturation of soils by phosphorus (Ptacek, 1998; Baker et al., 1998; Zanini et al., 1998) (see Figure 1). A phosphorus plume is a zone around the infiltration pipe of a septic system having a significantly higher phosphorus concentration than the

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surrounding area. Concentrations are highest immediately below the tile bed and extend, gradually decreasing, down grade (Robertson et al. 1998). The extent of phosphorus removal (or, conversely, the extent of plume migration) depends on the soil type, slope, percolation rate, depth to bedrock and to the water table, and the system's age and design.The less effective the system and the less suitable the soils, the further and faster the phosphate migrates. Ptacek (1998) has shown migration rates in excess of 1 to 2 m per year on various site characteristics.

Extensive research has been conducted through the University of Waterloo, Ontario, Canada dealing with defining plumes and measuring rates of phosphorus migration through the soil (Ptacek, 1998; Zanini, et al. 1998; Robertson, et al. 1998; Baker et al. 1997; 1998). They have been able to determine appropriate soil conditions for maximum efficiency of onsite septic systems. Zanini et al. (1998) found that both fine-grained non-calcareous sediments and coarse-grained calcareous sand have a high ability to immobilize phosphorus, though the processes were likely different.

Several studies have shown that it is possible to measure phosphorus plumes around leach fields using both soils and groundwater. These methods are effective on systems that would typically be considered functional. Generally, plumes are defined by sampling for phosphorus in soils or groundwater in a three dimensional grid down grade from a system's leach field. Soil samples can be retrieved by corers. Ground water samples (which probably better reflect migrating phosphorus) are generally collected by installing a field of piezometers (pipes perforated near their tip which are driven into the ground below the water table). Accumulated groundwater can be retrieved using a hand-operated vacuum pump. Without septic contamination, ground water can be expected to have phosphorus levels below detection (< .005 mg/l) (Ptacek, 1998).

Work by Zanini et al. (1998) involved the collection of sediment cores to determine the phosphorus plumes around four different septic systems in Ontario, Canada. They collected three cores from each site and determined the amount of total phosphorus in each sample. By knowing the phosphorus concentrations, they could determine the migration dynamics for each site. They found phosphorus accumulation within a narrow sediment zone close to the infiltration pipes appears to be a common occurrence at septic system sites and inferred that since they are so close to the pipes, the reaction must be occurring rapidly. They also found that the phosphorus precipitation is associated with iron and aluminum sediments.

Ptacek (1998) tested a 16-year old septic system to determine the rate of migration of soluble phosphorus and its release to a nearby wetland. This system was suspect because of elevated phosphorus concentrations in ponds adjacent to the tile bed. Twenty-seven groundwater collected samples indicated elevated concentrations of dissolved phosphate (> 3.0 mg/l as P) near the tile bed. These levels are comparable to those near most other septic systems (Ptacek, 1998). Ptacek (1998) was able to conclude that phosphate attenuation was controlled by a combination of adsorption and precipitation reactions.

Robertson, et al. (1998) used piezometers to collect ground water samples below the leach fields of ten different mature (6 to ten years old) septic systems in central Canada. As many as 500 piezometers were used at a particular site to ensure that the boundaries of the plumes were precisely determined. Phosphorus concentrations down grade of the systems revealed a plume zone (Figure 2). When piezometers were placed outside of that zone, the concentration of phosphorus was below detection (Robertson, 1998).

In 1995, a survey of the septic systems around Otsego Lake (Figure 3) was conducted. The main objective of the survey was to determine the location, age, distance from the lake, type of usage, and the last time these tanks were pumped and inspected. There was a 50% response rate to the survey, having an even distribution of responses around the lake. The survey indicated that inspection and testing of the systems is not being done and that 40% are over 25 years old (McIntyre, 2001). The average lifespan of most new septic systems is 15 to 30 years (Day, 2001). Operation and maintenance of septic systems is largely unregulated, unless in obvious failure, and is left to the judgment of the owner (Green, 2001). According to the EPA, regular pumping of the tanks is necessary; they recommend pumping every three to five years (Braem and Mlay, 1986). It is recommended by the Public Health Service's *Manual of Septic-Tank Practice* that tanks be inspected every year (Mandel, 1993). The survey conducted in 1995 on the septic systems adjacent to Otsego Lake showed that 41% of the surveyed systems have never been pumped (McIntyre, 2001). If systems are not pumped regularly, they will not operate as efficiently as they should, which will lead to more nutrients being passed out in the effluent.

The soil types throughout the Otsego Lake Watershed have “severe limitations” in their ability to provide suitable septic tank absorption fields (Dept. of Geology, 1994). These are based upon both hydrological factors (including permeability, high water table and susceptibility to flooding) and geological ones (such as slope and depth to bedrock).

There are two areas with high concentrations of near-lake parcels, one on the northwest side of Otsego Lake that runs for 2.3 miles north of 5-mile point, and another on the northeast side for about 0.4 miles south of Hyde Bay (Figure 3). It is estimated that 40% of these parcels are within 100 feet of the lake (McIntyre, 2001). A severe rating is given to the soils in those areas because of their poor capability of removing nutrients from effluent. There are three main soil types represented here. The first is Manlius, which is very poor for septic system use due to the shallow to moderate depth to bedrock, low water capacity and moderate soil permeability (Stein, 2001). The next is Honeoye, which is also poor for septic systems regardless of slope. There is low percolation because the soil is too dense for the water to move through it (Stein, 2001). The water moves laterally on top of the bedrock down grade. Because the water only comes in contact with a small portion of the soil, nutrients are not being removed. The Honeoye soils represented near Otsego are on steep slopes, compounding the problem. The third type of soil, Howard, is not suitable for septic systems because the soil has low water retention, so water moves through the soil too quickly for the soil to remove all of the nutrients, especially if the soil is on a slope. (Stein, 2001).

LAKE MANAGEMENT

In 1998, the Otsego Lake Watershed Council prepared a management plan for Otsego Lake and its watershed (OLWC, 1998). The main concern addressed in that document related to ongoing eutrophication, which to date has been well documented (i.e. Harman et al, 1997; Albright, 1999; 2000; 2001). Because algal production in Otsego is limited by phosphorus, the management plan focuses primarily on curtailing inputs of that nutrient. The potential importance of septic systems as a phosphorus source was recognized in the management plan. The plan recommends the inspection of all systems within 500 feet of the lake. Those systems not in compliance would have one year to be upgraded.

It has been estimated that 3-5% of total phosphorus entering Otsego lake is due to septic systems (Albright, 1996). However, it is worth noting the importance of the fate of different forms of phosphorus. Unlike most derived from the watershed (either from natural or human induced sources), most phosphorus coming from septic systems is in a soluble reactive form. That fraction is immediately available to plants and algae, and would effectively fertilize a lake by orders of magnitude more than an equal amount entering from a fluvial source. Research on the Upper Saranac Lake has demonstrated this issue (Martin, 2001). That lake's watershed is near pristine, and cottages near the shore are relatively sparse. Beginning in the 1950s, the lake began showing signs of eutrophy, including declining transparencies and eventually the internal release of phosphorus following the loss of dissolved oxygen in the hypolimnion. The only substantial anthropogenic input of phosphorus was from a fish hatchery which discharged into a tributary of the lake; that accounted for only about 5% of the lake's total phosphorus budget but it was in a soluble form. Following that realization, the hatchery reduced its phosphorus output by 90% and in the ensuing years many trophic indicators suggest improvement.

A study that serves as a useful guide was recently conducted in Delaware County on the Cannonsville Reservoir Basin (Day, 2001). A survey was conducted on soil conditions and a soil survey map was overlaid with a map of the septic systems. The soils were classified into four groups based on the soil's ability to support a septic system. In the basin, 80% of the soils were considered marginal to unsuitable for septic systems, which is similar to that in the Otsego Lake watershed. In order for effective wastewater treatment, Day (2001) suggested that special leach field designs are needed. This study looked at chemical properties, such as the absorption capacity of soils for phosphorus, potential phosphorus loading, and soil and moisture relationships. Different parameters of the systems themselves were also considered, such as the number, age, distance from watercourses, and non-residential systems (Day, 2001). Several conclusions were made using this information. The majority of the soils are inappropriate, and rehabilitation or replacement seemed necessary for most of the septic systems. It was estimated that 15-35% of the total phosphorus in the septic effluent was reaching the Cannonsville Reservoir is due to septic systems (Day, 2001).

Pilot studies

During the summer of 2001, a pilot study was conducted to attempt to refine protocols for future, more intensive research to determine phosphate levels in effluent below leach fields of septic systems near Otsego Lake. The system that was monitored was located within a high-risk area. Three piezometers were driven with a sledgehammer about 1 meter into the ground, just to the surface of the bedrock (Figure 4). They were placed across grade, with one directly down grade and the others one either side, to evaluate any differences in phosphorus concentrations. However, due to the extremely dry conditions that followed, water had not accumulated in the piezometers at the end of the study. They were left in place and will be tested in the future. Upon the establishment of reliable, reproducible methodologies, more intensive work with more piezometers at additional sites should be employed.

Mitigative technologies

Those workers who have documented phosphorus plume migration have also evaluated techniques to address that problem (Baker et al. 1997; 1998). Their intent was to develop permeable reactive mixtures that promote adsorption and precipitation of phosphorus. Initially, seven iron and six aluminum oxides were evaluated in batch experiments. Most of the iron oxide materials are byproducts of steel manufacturing. The reactive mixtures in the experiments were composed of 5% metal oxide, 45% high calcium limestone (providing suitable pH conditions and a constant calcium source, which allows for the formation of calcium/phosphorus minerals, as well as reactive surfaces necessary for phosphorus mineralization) and 50% silica sand (providing an inert media with a suitable porosity). Fifty g of each reactive mixture was placed in a 500 ml flask and 500 ml of 10 mg/l phosphate stock was added. Subsamples were removed intermittently over the next 10 hours and sampled for phosphate concentration.

Most reactive mixtures substantially reduced phosphorus concentrations during the trials. Most notable were iron oxide byproducts from steel production (“basic oxygen furnace” (BOF) oxide and BOF slag). These mixtures reduced phosphate concentrations to below detection (<0.01 mg/l) within one hour, giving a 99+% removal rate (Baker et al. 1997; 1998).

The most promising reactive mixtures tested in the batch experiments (including BOF oxide and activated aluminum oxide) were then tested for their ability to remove phosphorus over time. Flow-through columns were packed with reactive mixtures and a phosphate stock solution of ~3.3 mg/l P (similar to the concentration in septic tank effluent) was continuously passed through the columns for up to 4 years. The average residence time in the columns was about 1 day. For the BOF oxide, phosphorus retention was 99+% over the first 40 days and the mean retention throughout the monitoring was 90+%. Retention in the column with aluminum oxide was 99+% over the two years it was used. In order to estimate the potential longevity of the columns, solids were extracted from the columns after about one year and at the end of the trials. A mineralogical analysis of the materials indicated that the phosphate retentive capacities had diminished only slightly (Baker et al. 1998). While activated aluminum oxide out preformed BOF oxide, the former is considerably more expensive, while the latter is often a waste product.

Lastly, in order to test the mixtures under more realistic conditions, the reactive mixture was tested with effluent from a sewage treatment plant. A 0.5 m diameter x 05 m long cylinder was packed with mixture. Waste from the Waterloo treatment plant was passed through at a rate of 26 l/day for 133 days (retention time ~1.3 days). The treatment efficiency was 95+% over the experiment.

The above technologies can be applied to intercept phosphorus associated with septic system effluent (Baker et al. 1998). Reactive mixtures could be used in various ways (Figure 5): 1) Horizontal beds could be placed below conventional tile beds (5a), 2) A self-contained modular unit located in-line between a septic tank and the leach field could be packed with the mixture (5b), or 3) Where existing phosphorus plumes are migrating, trenches across grade could be packed with the mixture (5c).

CONCLUSION

Research has shown that phosphorus derived from septic systems can migrate through soils at rates that make contamination of nearby surface waters likely, even when conventional systems are located on suitable sites (Baker et al. 1997; 1998; Day 2001). Because conditions near Otsego Lake are generally considered unsuitable for standard systems based upon hydrological and geological conditions (Stein, 2001; Dept. of Geology, 1994), phosphorus loading to the lake undoubtedly is occurring. Local investigations should continue in order to quantify loading rates. At the same time, the feasibility of utilizing technologies that currently exist which could rectify this problem should be explored.

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