Michalski Nielsen
ASSOCIATES LIMITED

July 18, 2024

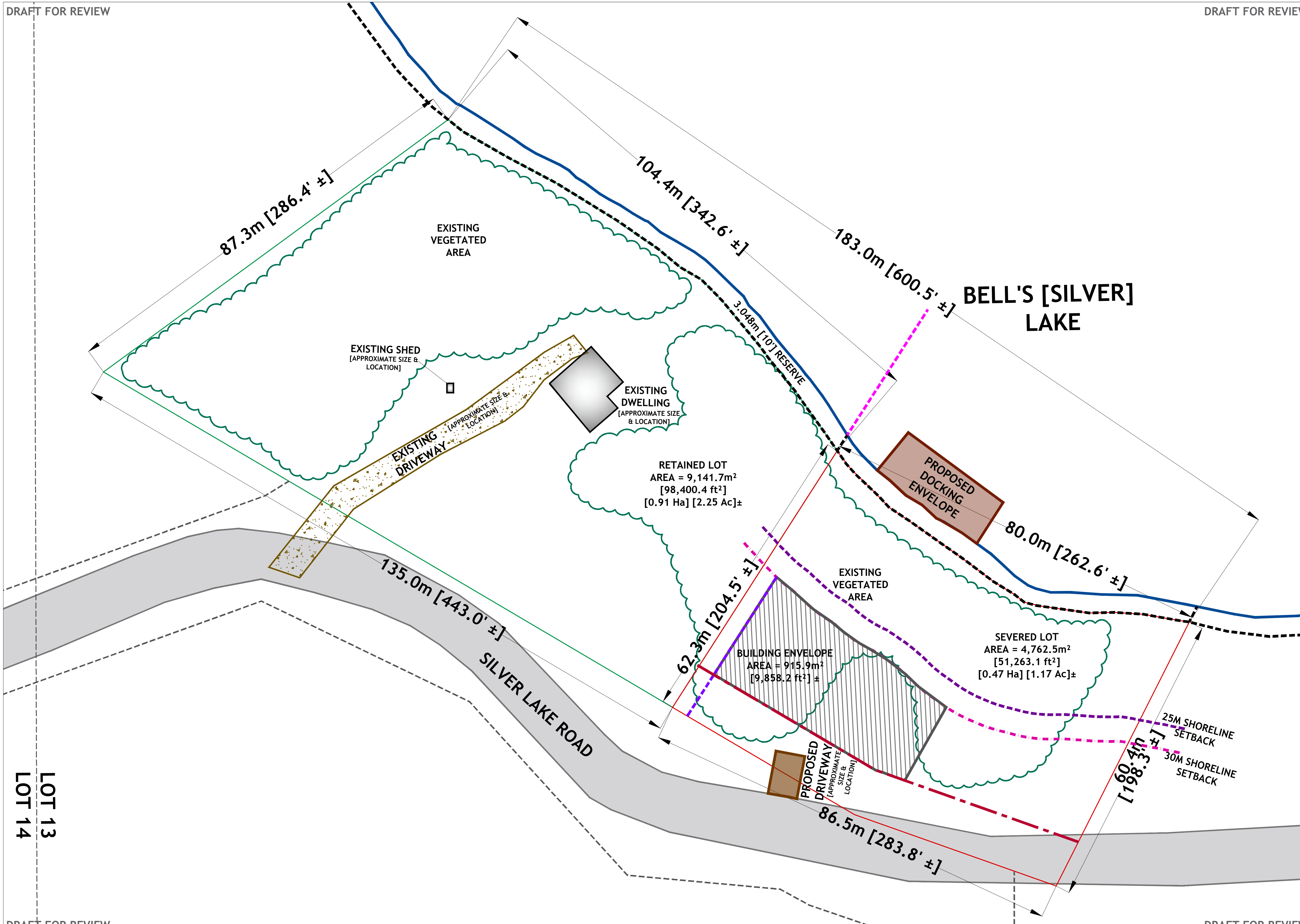
Ryan Lloyd
Planscape
108 Kimberley Avenue
Bracebridge, On
P1L 1Z8

Re: Scoped EIS and Lake Capacity/Water Quality Impact Assessment in Relation to a Proposed Severance of an Existing Cottge Lot at 184 Silver Lake Road, Municipality of Magnetawan, with Shoreline Frontage on Bells Lake (also known as Silver Lake) (Brandon and Ashley Cordua); Our File 0624

Dear Mr. Lloyd:

Thank you for asking Michalski Nielsen Associates Limited to provide this Scoped Environmental Impact Statement and Lake Capacity/Water Quality Impact Assessment in relation to the above-noted severance proposal. In this regard, the subject property, which is shown in background mapping and aerial photography that is included in **Appendix A**, has 183 m (600.5') of straight line frontage on Bells Lake. Per the Severance Sketch prepared by Planscape and included in the body of this report, the property currently contains a cottage and associated amenity area towards its western end, with the eastern approximately two thirds of the property being vacant. The owners would like to sever a cottage lot from the eastern portion of these lands, having a shoreline frontage of 80 m (262.6'). the Municipality of Magnetawan has provided a resolution of support, subject to the owners obtaining an Environmental Impact Study to: review deer wintering habitat and any other natural heritage features; establish a suitable building site and dock envelope; and recommend environmental mitigation measures. As part of this work, the municipality has also requested that there be a demonstration that the creation and build-out of this lot will not impact on the water quality of Bells Lake, referencing this requirement as a Lake Capacity/Water Quality Impact Assessment. It is the purpose of this report to address these two sets of requirements.

As brief background, I am an Ecologist and surface water specialist with 35 years of experience in assessing the impacts of land use change on the natural environment. A particular focus of my firm's work is on recreational lakes in Ontario. I routinely evaluate the impacts of new cottage lot creation/cottage development on lake water quality, fisheries resources, deer wintering habitat, Species at Risk, and other natural heritage values. I also routinely address topographic and other physical constraints in the assessment of such development opportunities. In the pages which follow, I first provide overview information on the setting of the subject lands and environmental constraints/environmental policy direction



SEVERANCE SKETCH

184 SILVER LAKE ROAD
PARTS 8 TO 13 PLAN 42R-12527
PART OF LOT 13, CONCESSION 14
GEOGRAPHIC TOWNSHIP OF SPENCE
TOWNSHIP OF MAGNETAWAN
DISTRICT OF PARRY SOUND

CORDUA

DISCLAIMER
THIS DRAWING IS FOR ILLUSTRATION PURPOSES ONLY.

BASE MAPPING CREATED FROM SCANNED PLAN 42R-12527 & 42R-2703 and MNRF AIR PHOTO & MAKE A TOPOGRAPHIC MAP

ALL INFORMATION CONTAINED WITHIN IS APPROXIMATE.

THIS IS NOT A PLAN OF SURVEY AND SHALL NOT BE TREATED AS SUCH.

PLANSCAPE
BUILDING COMMUNITY THROUGH PLANNING

SCALE	PROJECT NO.	DATE INITIATED	BY
1 : 750	167500	APRIL 30, 2024	JT

NO.	DATE	REVISIONS	BY
1.			
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BASE MAP SOURCE:
D.E. MAGEE O.L.S - 42R-12527 (1992)

of relevance to these lands. I then provide background information on the fishery and water quality of Bells Lake, followed by an explanation of winter deer habitat. This is followed by a detailed description of the proposed severed lot and its environmental constraints and opportunities, based on my site inspection. I then provide additional contextual information on a proactive approach that can be taken to protecting water quality on sensitive lakes, including the role that soils on the Precambrian Shield can play in retaining phosphorus from sewage disposal systems. This is followed by a review of Species at Risk potential in relation to the subject lands. Finally, I provide my summary comments on the appropriateness of the proposed severance application, together with detailed recommendations to ensure that the build-out of the proposed severed lot has appropriate consideration for water quality, natural heritage values and physical constraints associated with the subject property and Bells Lake.

1.0 Overview of Environmental Constraints/Environmental Policy Direction in Relation to the Subject Lands

Background mapping and aerial photography of the subject lands is included in **Appendix A**. This property is located at the southwest end of Bells Lake. It is noteworthy that the western portion of this lake tends to have very large lots, each with shoreline frontages of 60 m or more. This is in sharp contrast to the eastern portion of the lake, where there are many lots having shoreline frontages of between 25 m to 40 m, in a few cases being even less.

Bells Lake drains to the west, to Simmons Lake, with the outlet from Bells Lake being quite proximal to the subject property. Simmons Lake in turn drains through a long length of very marshy watercourse to Crawford Lake. Crawford Lake drains through Beaver Lake to Ahmic Lake, which forms part of the Magnetawan River chain of lakes.

There are no identified wetlands in close proximity of the subject lands, although there is a small, unevaluated wetland (appearing to be treed swamp), located a minimum 230 m to the south. There are no Provincially Significant Wetlands or Areas of Natural and Scientific Interest within several kilometers of these lands.

I have reviewed the Land Use schedules to the Municipality of Magnetawan's Official Plan (August 26, 2022; this being the version that appears on the municipality's website, which states that it has not yet been approved). Schedule A, Land Use, identifies the subject lands as being Shoreline Residential, with no Environmental Protection designations in any vicinity of those lands. Schedule B, Environmental Features, shows a very large area of Ministry of Natural Resources (MNR) identified Stratum 1 deer yard that encompasses all of Bells Lake and several small surrounding lakes, and which extends north to include large portions of lands surrounding Ahmic Lake, including lands north of that lake. This Stratum 1 deer yard measures over 50 km^2 in size, and is surrounded by an even broader area of Stratum 2 deer yard, with these combined deer yards occupying an area of over 160 km^2. Section 4.5.1.4 of the Municipality of Magnetawan's Official Plan addresses deer habitat, noting that MNR has identified large portions of the municipality as being Stratum 1 and Stratum 2 deer yards and that development in these areas must be sensitive to such habitat, including that vegetation removal is to be minimized. It additionally includes the following:

> Within the significant deer habitat areas shown on Schedule B new lots should avoid areas of dense conifer cover or be of a sufficient size to provide a suitable development area including access and services, outside the most significant deer wintering habitat areas described above. The minimum lot size shall be 90 metres frontage and 90 metres depth.
>
> Exceptions to the minimum lot size requirements may be considered by the Municipality where more than one legal detached dwelling that is structurally sound exists as of the approval of this Plan, it is demonstrated to the appropriate approval authority that each dwelling can be adequately serviced, and a site evaluation has been completed by a qualified biologist that documents habitat conditions and demonstrates that winter deer habitat is not present on the property.
>
> Where deer habitat is located within shoreline areas, development shall be situated in locations that will not result in the removal of significant amounts of shoreline vegetation or affect shoreline habitat. Site-specific zoning and site plan control will be used to site development in the most appropriate areas to ensure minimal impact on the natural habitat.

Further background information on deer wintering habitat is included in Section 3.0 of this report, with Section 4.0 describing site conditions and their relation to such habitat. Section 7.0 provides summary comments and recommendations which include attention to the protection of such habitat.

Schedule B to the Official Plan shows areas that have been identified through an earlier municipal downloading exercise completed by MNR in 1996 as being Type 1, or more critical, fish habitat, with no such habitat having been identified within the nearshore of Bells Lake. Given the small size of this lake, it is quite possible that MNR never completed surveys on it to type fish habitat. Section 4.5.1.5 of the Municipality of Magnetawan Official Plan notes that areas of unidentified fish habitat should be assumed to be Type 1 habitat and treated as such, unless otherwise demonstrated not to be through a site-specific fish habitat assessment. Section 2.0 of the present report provides additional background information on the fishery of Bells Lake, with Section 4.0 providing a detailed assessment of fish habitat conditions across the nearshore of the proposed severed lot. Section 7.0 of this report provides summary comments and recommendations which include attention to the protection of such habitat.

Section 4.3.1 of the Municipality of Magnetawan's Official Plan identifies Bells Lake as one being "near capacity" from a development standpoint. It states:

> In the case of lakes that are ***near capacity***, ongoing monitoring of these lakes shall occur in consultation with MECP. Applications for land use changes (including lot creation), which would result in a more intensive use on lakes that are near capacity, shall include supplemental technical information related to stormwater runoff and/or septic/servicing design. The scope of such technical information shall be at the discretion of the Municipality.

With respect to septic design, that section of the report describes one of criteria that is acceptable to the Ministry of Environment, Conservation and Parks (MECP) as being the presence of native soils with specific chemical characteristics, as demonstrated through site-specific soil investigations by a qualified professional.

Concerns relating to lake capacity all revolve around the introduction of additional phosphorus into lakes where water quality has been impacted by existing development. Increased amounts of this plant nutrient can result in excessive aquatic plant and algae growth, a reduction in water clarity, nuisance algae blooms, and a deterioration of aesthetic conditions (collectively referred to as eutrophication). A substantial focus of this report relates to existing water quality in Bells Lake (Section 2.0), the potential influences of existing development on lake water quality (also Section 2.0), existing site conditions, including our site-specific examination of soil conditions (Section 4.0), employing other proactive tools, including the use of Precambrian Shield Soils of specific characteristics in the protection of water quality (Section 5.0), and our site-specific recommendations regarding development of the proposed severed lot to ensure it does not increase phosphorus loads to Bells Lake (Section 7.0). Collectively, this information constitutes the Lake Capacity/Water Quality Impact Assessment component of this report.

Section 4.5.1.3 of the Municipality of Magnetawan Official Plan addresses the protection of Endangered and Threatened species, an important consideration in contemplation of any land use changes through this municipality, as well as in other jurisdictions of the province. Section 6.0 of this report includes a review of Species at Risk potential for the subject lands, together with our assessment of the potential impacts of a severance/additional development on such habitat. Section 7.0 provides summary comments and recommendations, which includes attention to the protection of such habitat.

Section 4.7 of the Municipality of Magnetawan Official Plan provides details on the information that should be included in an Environmental Impact Study (EIS). It is noted that such advice applies to a broad spectrum of development applications, of very different scales and having very different potential to have adverse impacts on the natural environment. The present report has considered the municipality's requirements for an EIS, and has scoped that work in accordance with the specific attributes of the subject property and adjacent lands, the attributes of Bells Lake, and the nature and scale of this proposed application, being to create only one additional cottage lot. The recommendations provided in Section 7.0 of this report provide for a robust level of protection for the natural environment qualities of the subject property, adjacent lands and Bells Lake.

2.0 Overview of Bells Lake

The MNR's Lake Fact Sheet for Bells Lake, also known as Silver Lake, is provided in **Appendix B**. It is a very small lake of only 41 ha (0.41 km^2) in size. It is also reasonably shallow, with a mean depth of 6.7 m and a maximum depth of 13 m. The volume of the lake is 287 ha·m.

In accordance with MNR's Fact Sheet, Bells Lake has a very small external watershed of only 80 ha (0.8 km^2). A review of the Water Quality Resources of Ontario report (MNR 1984) indicates the following values for the area in which it is located:

mean annual precipitation	900 mm
mean annual evaporation (from lake)	650 mm
mean annual evapotranspiration (from external watershed)	500 mm

From this information, the mean annual flow through Silver Lake is estimated to be 42.25 ha·m. This would imply it has a very long turnover time (the time required to replenish the entire lake volume), of 6.8 years.

There is very little information available through MNR on the fishery of Bells Lake, limited to that from a now very dated 1979 lake survey. The lake is said to support Smallmouth Bass, together with Cisco (Lake Herring), Pumpkinseed (a sunfish), White Sucker and Brown Bullhead. Although Cisco can be considered a coldwater species, the fishery is really one that is typical of a warmwater lake.

There is considerable development on Bells Lake, particularly towards its eastern end, where, as described in Section 1.0 of this report, lot sizes are generally very small. Based on our review of background mapping and aerial photography of the lake, there are approximately 55 shoreline lots around the lake, although the locations of a few of the existing cottages suggests that some lots have been merged. We have identified 41 developed cottages around the lake, with approximately 5 more lots which are vacant and appear developable, for a total of about 52 lots. Based on this lake having a shoreline perimeter of 3.5 km, this would equate to an average shoreline width per lot of only 67 m. There are only a few lots on this lake, including the subject lot, which could be severed to create an additional lot, meaning that future development potential on this lake is very limited.

On such a small, shallow lake with a small watershed and correspondingly very high turnover time, and with it having extensive shoreline development, Ontario's Lakeshore Capacity Model would predict that phosphorus levels in this lake would be quite elevated. However, data that has been collected through the province's Lake Partner Program indicates the very opposite, with recorded spring phosphorus levels that were measured between 2003 and 2022 ranging from 3.1 µg/L to 8.5 µg/L, averaging just 5.2 µg/L. These are very low phosphorus levels, making this lake an oligotrophic (very low nutrient level) lake; with oligotrophic lakes being those having spring phosphorus levels of up to 10 µg/L, Bells Lake is considered to have exceptionally low phosphorus levels, at the lowest end of what we see in Ontario. Oligotrophic lakes like this are prized for their high water clarity and good aesthetics. The Lake Partner Program data also indicates that phosphorus levels in this lake have been very stable over the past two decades, which is very good to see.

That Bells Lake has such exceptionally good and stable water quality points to it having very good quality soils in its watershed. In this regard, and as described further in Section 5.0 of this report, many lakes on the Precambrian Shield have a natural protection against increased phosphorus levels that is afforded to them by the soils in their watersheds, with such soils having a well defined 'B' horizon that have very high levels of iron and aluminum, metals that have a high capacity to bind with phosphorus. Where such soils are present in a sewage disposal bed, as an underlay of that bed, and/or within lands downgradient of that bed, the metals in these soils immobilize phosphorus, first through adsorption, and then through the creation of permanent and immobile mineral complexes. It is very typical in such situations for a sewage disposal bed to be able to adsorb and/or permanently mineralize the entire load of phosphorus in sewage effluent over the lifespan of the bed, thereby ensuring that no sewage-related phosphorus ever enters the lake. Such soils can be identified visually during the collection of soil cores, evidenced by a rich orange-brown colour that extends through the 'B' horizon; as further described in Section 5.0, our work on this property included the collection and visual examination of soils in the general area where a sewage disposal bed would be installed on the lot to be severed, and did confirm the presence of very good quality 'B' horizon soils.

3.0 Overview of Deer Wintering Habitat

As previously noted, the subject property is located within a very large Stratum 1 winter deer yard, surrounded by an even larger area of Stratum 2 deer yard, the combined sizes of which constitute approximately 40% of the geographic area of the Municipality of Magnetawan.

In Central Ontario, White-tailed Deer are at the northern fringe of their continental range. In largest part, this relates to deer being poorly adapted to our winters, and in particular heavy snow. One of the adaptations deer have made to survive winter is to "yard up" in areas where there is an abundance of conifers, including hemlock, cedar, pine and spruce. As described in the Ministry of Natural Resources' (MNR's) publication "Deer Conservation in Winter" (undated), such trees catch snow in their branches, reducing the depth of snow beneath. Deer can then pack accumulated snow into a network of trails, allowing them to move easily between food and cover. The shelter provided in areas of heavy conifer cover also reduces winds and moderates temperatures. The MNR's document "Forest Management Guidelines for the Provision of White-tailed Deer Habitat" (Voight, Broadfoot and Baker, August, 1997) includes the following in its description of winter deer yards:

- primary concern is habitat that provides adequate coniferous cover interspersed with sufficient winter food;
- for cover, hemlock and cedar are the best interceptors of snow and often grow in association with the preferred browse species. In the absence of these trees, spruce, pine or balsam may be utilized;
- yards should include an interspersion of heavy conifer with areas where conifer are intermixed with deciduous vegetation; and
- for browse, suitable species include cedar, hemlock, viburnums, Red Maple, Striped Maple, Mountain Maple, Red-osier Dogwood, Sugar Maple, Beaked Hazel, Yellow and White Birch, cherry, Ground Yew, White Pine and lichens. To be accessible to deer, such browse should be within 30 m of areas of suitable cover.

Stratum 2 yards are those areas where deer move to as snow depth begins to build, but typically don't provide the same quality of cover as Stratum 1, or core winter habitat, where deer will congregate once snow depths exceed about 0.5 m.

MNR first identifies potential areas of deer yarding based on a review of aerial photographs and local knowledge. These areas are then typically flown in a grid pattern in order to examine the density of deer tracks. These surveys are completed in the late winter as that is when snow cover is generally deepest, and therefore when deer have been concentrated into areas of good cover for a considerable period of time (and therefore when evidence of tracks is generally most abundant and obvious). MNR flies deer yards using 1 km grid scales, interpreting information on track densities to approximate the boundaries of Stratum 1 and Stratum 2 yards.

It is important to note that not only are identified deer yards based on an interpretation of best available information, they are also generally mapped at a broad level. The present circumstance is no exception. The quality of habitat typically varies considerably across identified deer yards, and good portions of such yards may be quite poorly suited to the winter needs of deer. **In considering individual applications for land use change, it is therefore important that thought be given to the site-specific attributes of areas to be impacted by such changes. It is equally important to consider the scale of the proposed works and associated amount of vegetation disturbance that will be required, and in particular whether such works will impact on vegetation providing good winter cover for deer.**

It is also important to note that deer do habituate to the presence of humans, particularly in situations where a substantial human presence (i.e., roads, homes, cottages, businesses) has already been established. Therefore, even within areas having good winter cover characteristics, the creation and development of a new cottage lot that is very proximal to already established uses is much less likely to impact deer behaviours/use of an area than are entirely new land uses.

4.0 Site Conditions

As evident from the mapping included in **Appendix A**, the subject lands slope from approximately 320 metres above sea level (masl) at Silver Lake Road, down to about 305 metres at the lake shoreline, representing an average slope of ±22%.

As can be seen from the aerial photography included in **Appendix A**, the subject lands contain conifer-dominated forest within ±30 m of the shoreline, with a deciduous dominated, mixed forest towards Silver Lake Road.

Our site inspection of the subject property was completed on April 10, 2024, under snow and ice free conditions and at a time of year that was fully appropriate for its intended purposes. It is noted that a site inspection this early in the season provided a good opportunity to observe for evidence of winter deer use, based on the presence of scat and browse (stems of small trees and shrubs which have been eaten by deer). It also occurred at a time of year when vernal pools (areas of seasonal ponding) are most evident. Although occurring early in the year, before aquatic vegetation is well established, it did provide an opportunity to see the remnants of such vegetation from the previous year.

The proposed retained lot is shown in the attached Severance Sketch. **Photograph 1** provides a view of this lot, which contains a small cottage, a small associated amenity area, and a dock. A majority of the proposed retained lot remains well treed.

Photograph 2 provides a view of Bells Lake from the subject lands. The westerly portion of the lake has a low density of development. As is also evident from this photograph, there is considerable conifer cover within the riparian area around this portion of the lake, generally considered to be those lands extending to a distance of 30 m back from the shoreline. Eastern Hemlock makes up the majority of the conifer cover, with there also being some Eastern White Cedar; both of these species afford good winter cover opportunities for deer.

The proposed severed lot is shown on the attached Severance Sketch. It has well drained conditions throughout, containing no wetlands or vernal pool features. While the easterly portion of this property has some rockier terrain, with limited bedrock exposure, this proposed lot does not contain any rock barrens. Nor were any rock barrens ro wetlands seen on adjacent lands, including on the proposed retained lot to the west, on the cottage property to the east, or on the opposite side of Silver Lake Road to the south.

Photographs 3 to **6** provide views of the recommended building envelope on the proposed severed lot, which is also shown on the Severance Sketch. This is located on the western side of this proposed lot, a minimum 30 m back from the shoreline, taking advantage of the well drained, gentle to moderate terrain in the area. It consists of Sugar Maple dominated deciduous forest, with some American Beech and with scattered Eastern Hemlock. Slopes are ±15% across this area, making it an easy location to build on, as well as to install a sewage disposal bed (note that the building envelope has been sized such that the sewage disposal can be located within it). Conditions in this area are preferable to the western portion of the lot, where slopes are more uneven and often steeper, and where ground conditions are rockier.

Photograph 7 shows a small ridge, containing some exposed rock, on the left side of the photo (note that this area of rockier soils remains well treed, so is not a rock barren). A small area of ephemeral drainage, created by localized flows carried through a culvert beneath Silver Lake Road, runs along the east edge of this ridge (this is not a watercourse, with the very seasonal drainage dissipating a short distance below the culvert). The presence of these features creates a logical divide between the proposed lots. The proposed retained lot is to include the ridge, creating a visual divider between the two lots. The boundary of the proposed severed lot is in immediate vicinity of the culverted drainage.

On the proposed severed lot, we are recommending a 30 m structural setback from the shoreline, both as part of a precautionary approach to the protection of water quality and because slopes steepen within 30 m of the shore. With regards to the latter, the pink flagging tape on **Photograph 8** shows the 30 m setback from the lake in front of the proposed building envelope. **Photographs 9** and **10** provide views of the steeper nature of the shoreline riparian area, with the pink flagging showing the 30 m setback also being evident in **Photograph 10**. As is clear from these photographs, the 30 m shoreline riparian area is dominated by Eastern Hemlock, with some Eastern White Cedar, particularly closer to the shoreline. The riparian zone also contains some Sugar Maple, beginning 10 m back from the shore. **Lands within 30 m**

Photograph 1. **View of existing cottage on proposed retained lot (April 10, 2024).**

Photograph 2. **View of Bells Lake from subject lands; this portion of lake is quite undeveloped (April 10, 2024).**

Photographs 3 and 4. **Views of recommended building envelope on proposed severed lot, set back a minimum 30 m from the shoreline on moderate sloping, well-drained land (April 10, 2024).**

Photographs 5 and 6. Additional views of recommended building envelope on proposed severed lot (April 10, 2024).

Photograph 7. **A small rock ridge creates a logical divide between proposed retained land, to left, and proposed severed land, to right. Note that recommended building envelope on the proposed severed lot avoids area of ephemeral drainage created by localized culverted runoff (not a watercourse) (April 10, 2024).**

Photograph 8. **Recommended 30 m cottage setback on proposed severed lot is shown with flagging tape. The slope increases within the riparian zone down to the lake (April 10, 2024).**

Photographs 9 and 10. Additional views of shoreline riparian zone, which can be easily traversed with a pathway (April 10, 2024).

of the shoreline of the proposed severed lot, and generally along the western portion of the lake, generally provide quite good winter cover for deer; this conifer cover will reduce the snow depth on the ground and provide shelter against winds, allowing deer to move more easily and expend less energy during the height of the winter. **This portion of the proposed severed lot provides much better opportunities as winter cover for deer than does the deciduous dominated lands beyond 30 m of the shore**.

It is noted that evidence of winter deer use of the property, through the presence of scat and browse, was very light, which may in part be due to the winter of 2023/2024 being less harsh than in many years (and with deer not needing to "yard up" as much). Regardless, it is our opinion that a majority of the conifer cover within 30 m of the shoreline on the proposed severed lot is important to retain, as further addressed in our recommendations in Section 7.0 of this report.

As previously noted, we have sized the building envelope on the proposed severed lot such that it can include the septic envelope. Soils were probed throughout this building envelope, and ranged from a depth of 0.29 m to 0.64 m (average of 0.44 m) to refusal on cobble/boulder or hard pan (dense sand). These soil depths are very typical of this very broad area of Ontario on the Precambrian Shield, where bedrock is generally close to surface and where the overburden contains a considerable amount of boulder and cobble, together with compacted soils at depth. The western portion of the proposed severed lot has better soil depths than the eastern portion of the lot, contributing to the rationale for us having only identified the western portion of the lot for a building envelope.

A soil core was taken within the western portion of the proposed building envelope, at a distance of 50 m from the shoreline, with that profile shown in **Photograph 11** and described in **Table 1**. There is a very well developed and deep 'B' horizon, which is very well drained over the top ~60%, with some seasonal moisture in the lower ~40%. That 'B' horizon is well mineralized to depth, with its orange-brown colour being indicative of the presence of abundant iron and aluminum, and signifying its high capacity to adsorb and permanently mineralize phosphorus (see Section 5.0 of this report for further discussion of the importance of soils with these properties in immobilizing phosphorus and preventing it from reaching the lake). While no laboratory analyses were completed of the soils from this property, we are confident from our examination of them that they have a high phosphorus retention capacity.

As is very typical of sewage disposal systems on the Precambrian Shield, a raised bed would be required to ensure an adequate depth (0.9 m) of well-drained soils, with an opportunity to use either imported soils or to salvage additional 'B' horizon soils for that purpose.

To assess fisheries constraints, a transect survey was completed across the nearshore of the proposed severed lot, using chest waders to examine nearshore slopes, substrate conditions and other elements of fish habitat. Onshore conditions were also recorded. **Figure 1** shows the locations of the six transects that were surveyed, with **Table 2** summarizing our findings. **Photographs 12 – 14** provide views of nearshore conditions. Nearshore slopes across the shoreline frontage of the proposed severed lot were in the range of 1:4 to 1:9, meaning that a water depth of 1 m (more than adequate for boat mooring on such a small lake) was encountered 4 m to 9 m offshore. Substrates consist of firm sand in the very nearshore, generally

Photograph 11. Soil profile from one of several areas within proposed building envelope that would be suitable for a sewage disposal bed (April 10, 2024).

Photograph 12. Shoreline and nearshore of proposed severed lot, from east to west (April 10, 2024).

Table 1. Soil Characteristics in General Location of Proposed Sewage Disposal Bed.

Depth (m)	Soil Characteristics
0.00 – 0.03	Humic layer; comprised of decomposing leaves
0.03 – 0.10	‘A’ horizon; organic-rich, dark brown coloured, silty sand
0.10 – 0.42	‘B^1’ horizon; orange-brown coloured, medium textured sand with some silt and minor gravel; well drained; well mineralized
0.42 – 0.65	‘B^2’ horizon; orange-brown coloured, medium textured sand; seemingly well drained, but damp under early spring conditions; no mottling of soils seen, suggesting that dampness is very seasonal; remains well mineralized to depth
0.65	Refusal on hard pan

Ontario

Ministry of Natural Resources and Forestry

Make-a-Map: Natural Heritage Areas

Figure 1. Shoreline Transects, 184 Silver Lake Road

Map created:7/15/2024

Legend

- Assessment Parcel
- ANSI
- Earth Science Provincially Significant/sciences de la terre d'importance provinciale
- Earth Science Regionally Significant/sciences de la terre d'importance régionale
- Life Science Provincially Significant/sciences de la vie d'importance provinciale
- Life Science Regionally Significant/sciences de la vie d'importance régionale
- Evaluated Wetland
- Provincially Significant/considérée d'importance provinciale
- Non-Provincially Significant/non considérée d'importance provinciale
- Unevaluated Wetland
- Conservation Reserve
- Provincial Park
- Natural Heritage System

0.0 | 0 | 0.02 | 0.0 Kilometres

Absence of a feature in the map does not mean they do not exist in this area.

This map should not be relied on as a precise indicator of routes or locations, nor as a guide to navigation. The Ontario Ministry of Natural Resources and Forestry(OMNRF) shall not be liable in any way for the use of, or reliance upon, this map or any information on this map.

Table 2. Description of nearshore and shoreline conditions.

Transect	Nearshore slope	Substrates	Extent of aquatic vegetation	Other elements of cover	Nature of shoreline riparian area
A	1:8	Substantial amount of woody detritus over firm sand in the very nearshore; grading to soft silty sand about 5 m offshore	Scattered Pipewort and Floating-leaved Burreed	Very considerable amount of large logs and tree limbs	15% to 20% slopes to about 15 m back from shore, then steepening to 20% to 25%; hemlock dominated
B	1:6	Substantial amount of woody detritus over firm sand in the very nearshore; grading to soft silty sand about 3 m offshore	None seen	Very considerable amount of large logs and tree limbs	20% slopes to 20 m back from shore, steepening to about 30% further back; hemlock dominated
C	1:7	Substantial amount of woody detritus over firm sand in the very nearshore; grading to a medium firm sand about 5 m offshore	None seen	Very considerable amount of large logs and tree limbs	20% to 25% slopes to about 15 m from shore; steepening to about 30% further back; hemlock dominated
D	1:6	Substantial amount of woody detritus over firm sand in the very nearshore; grading to a medium firm sand about 4 m offshore	Some Pickerelweed to about 3 m offshore	Very considerable amount of large logs and tree limbs	±25% slopes to a distance of 30 m back from shore, then moderating; hemlock dominated
E	1:4	Substantial amount of woody detritus over firm sand in the very nearshore; grading to a medium firm sand about 4 m offshore	Moderate amount of Pipewort	Very considerable amount of large logs and tree limbs to 3 m offshore only, with scattered large woody material further offshore	±20% slopes, with good opportunities to install a very walkable pathway from a dwelling down to a dock; hemlock dominated
F	1:9	Substantial amount of woody detritus over firm sand in the very nearshore; grading to a medium firm sand about 7 m offshore	Some Pickerelweed to about 3 m offshore; moderate amount of Pipewort	Considerable amount of large logs and tree limbs to about 4 m offshore, with scattered large woody material further offshore	Somewhat hummocky terrain, with 20% to 30% slopes; hemlock dominated

Photographs 13 and 14. Additional views of shoreline riparian zone and nearshore of proposed severed lot (April 10, 2024).

transitioning quite quickly to soft, silty sand offshore. The entire shoreline frontage of the property is characterized by a large amount of fallen logs and large tree limbs in the very nearshore, providing very abundant cover for fish, and providing opportunities for Smallmouth Bass spawning (which fan out a nest over firm sand or sand and gravel substrates, almost always in areas where protection is afforded by cover such as logs and tree limbs). Recognizing that our survey was not completed when aquatic vegetation was abundant, there was nevertheless evidence of some such vegetation, particularly the emergent vegetation Pickerelweed (restricted to the very nearshore), the floating -leaved vegetation Floating-leaved Burreed (restricted to the eastern end of the proposed severed lot), and the submergent vegetation Pipewort (a short, grass form of submergent vegetation which also produces thin fruiting stalks that extend to surface in the late summer, but which provides very limited cover value for fish). In our opinion, **the entire nearshore of the proposed severed lots provides a protected environment which likely supports Smallmouth Bass and Pumpkinseed spawning, and which is undoubtedly also valuable for juvenile development. It additionally provides good feeding opportunities for a variety of fish. As such, it has characteristics which are quite consistent with what MNR has generally identified as Type 1 (more critical) fish habitat**. It is important that docking facilities minimize impacts on this habitat; this is to be ensured through the recommendations of Section 7.0 of this report. As part of such a strategy, we are recommending that the dock on the proposed severed lot be restricted to the general area centered on Transect E (see **Figure 1** and Severance Sketch). In this regard, nearshore slopes are steeper within this zone, allowing for an elevated and narrower boardwalk portion of the dock to extend across the most sensitive portion of the nearshore, within approximately 4 m of the shore, then to increase in dimension, should the owner choose, in the less constrained offshore area where there are good depths for mooring and boat access/egress, and where large woody material and aquatic vegetation are not present/much less abundant. Further, while a pathway to the shoreline could be constructed virtually anywhere across the shoreline area of the proposed severed lot, it is most easily installed within vicinity of transect E, where the riparian slopes are moderate and quite uniform.

5.0 Comments on a Proactive Strategy to Protect Water Quality, Including the Use of Native Soils in Septic Systems That Have a High Capacity to Retain Phosphorus

The science of water quality on our Precambrian Shield lakes has been advancing over the years, with the District of Muskoka having made important contributions to this. As with the Municipality of Magnetawan, the quality of the recreational lakes in Muskoka has been a very important driver of its economy, with cottage and tourism industries that have flourished because of the world class quality of its lakes. As such, it has been very important for the District to ensure the protection of its lakes through a proactive approach to both water quality monitoring and in its Official Plan policies. **The District of Muskoka has now collected over 40 years of water quality data**, with an emphasis on phosphorus concentrations, for the majority of the lakes within its jurisdiction. In concert with that work, its Official Plan has long implemented a framework of strategic initiatives to protect the water quality of its lakes under the umbrella of the Lake System Health Program, with the objectives of minimizing the impacts of human development on water resources, preserving environmental health and quality of life, and protecting its future as a premier recreational region. As stated in its current Official Plan, "the Lake System Health Program incorporates the best available science and responds to emerging water quality issues based on periodic review, which in turn guides District policies to achieve a holistic and balanced approach to managing Muskoka's watershed health and its shoreline development." Its Official Plan policies were updated in July 2016 to reflect the results of its most recent review of its approach to water quality protection; that review demonstrated that the modelling approach which the District had until then been using, which was based on the Province's Lakeshore Capacity Model, was not a good predictor of water quality. In this regard, the great majority of the District's lakes have had very stable water quality conditions over the past many decades, despite fairly extensive development within several of them. **That data demonstrated that a suite of best management tools the District had been employing to protect water quality as new development was occurring were being effective, and that the move-forward policy direction was better focused on the application of such best management practices.** At the same time, the District recognized that there were other stressors, and in particular those associated with changing climate, that must now be considered.

While the policies of the District of Muskoka are not applicable policy within the Municipality of Magnetawan, they are nevertheless important in showing how an evolving science-led approach to the protection of recreational lakes is very important. The District's current recreational water quality policies include a variety of best management practices which are applicable to new development (including both severances and vacant lot development) on all of its lakes. These include:

- preserving at least 75% of the shoreline frontage of lots in a natural state to a distance of at least 15 m back from the shore;
- requiring a minimum 30 m setback for leaching beds;
- requiring a minimum 20 m setback for dwellings; and
- requiring site-specific examination of development opportunities and constraints, and using various planning tools to ensure there is appropriate consideration of the locations of all development (including driveways and pathways), the retention of natural shoreline buffers, the retention of tree cover elsewhere within the lot, and the implementation of construction mitigation measures and long-term stormwater management measures to protect water quality.

Further, the District has identified three water quality indicators for its lakes which require additional attention and care to water quality. These include a long-term statistically significant increase in phosphorus concentrations, a long-term phosphorus concentration of ≥ 20 µg/L, or the occurrence of a blue-green algae bloom, as confirmed and documented by the Province and/or Health Unit. When one or more of these water quality indicators has been confirmed, there are additional protection requirements for new lot creation or development on vacant lots which include:

- increased building and leaching bed setbacks in consideration of site-specific conditions;
- a site-specific examination of soils to determine the most appropriate location for sewage disposal systems; and

- the use of soils in the construction of sewage disposal beds which have a demonstrated ability to effectively retain phosphorus, or alternatively the employment of equivalent septic phosphorus abatement technologies.

Having completed many water quality impact assessments within the District of Muskoka, and having seen from the water quality information for Bells Lake that soils within its watershed are clearly very effective in retaining phosphorus and in having provided for a high level of natural protection against water quality impacts, we believe that a similar proactive approach to the protection of water quality is important to the creation and build-out of the proposed severed lot, ensuring that it does not have any negative influence on the water quality of Bells Lake. The recommendations in Section 7.0 of our report include a proactive approach towards increased shoreline setbacks, the retention of the shoreline riparian area in a natural state, construction best management practices to protect water quality, long-term stormwater management, an increased setback for the sewage disposal bed, and the use of a large quantity of 'B' horizon soils which have a high degree of mineralization in the construction of the sewage disposal bed.

As some background on the benefits of using well-mineralized 'B' horizon soils in attenuating phosphorus, phosphorus modelling on Ontario cottage country lakes has traditionally assumed that a majority of new phosphorus loads to lakes which are under development comes from the sewage disposal systems of the new cottages. While the sources of new phosphorus associated with development are more complicated than that, the proper location and design of sewage disposal systems remains key.

There are two primary considerations in the design of more traditional septic systems to mitigate phosphorus impacts: first, the distance between the leaching bed and lake, with larger setbacks providing greater attenuation opportunities; and second, the composition of soils within and downgradient of the leaching beds, and their ability to immobilize phosphorus.

With respect to distance from the lake, the sewage treatment system on the proposed severed lot is, per the subsequent recommendations of Section 7.0 of this report, to be a minimum 50 m from Bells Lake, providing enhanced opportunities for the attenuation and permanent mineralization of phosphorus.

With respect to soils, research on existing and innovative small scale sewage treatment systems over the past 30+ years has greatly improved the knowledge base regarding the movement of phosphorus from septic tank tile field systems, and particularly the ability of 'B' horizon Precambrian Shield soils to negate this movement. For such soils, there is both a non-permanent adsorption process driven by soil hydraulics, as well as a permanent reaction resulting from precipitation by soil-related aluminum and iron. Regarding the latter, in acidic soils which are common throughout Precambrian Shield cottage country, aluminum and iron are the dominant ions that react with phosphorus. The first products formed are amorphous (shapeless) aluminum and iron phosphates, which gradually change into compounds that resemble crystalline variscite (an aluminum phosphate compound) and stregnite (an iron phosphate compound). Each of these reactions results in insoluble compounds of phosphate that do not move in the soil. This means the geochemical reactions are permanent, resulting in no mobilization to the lake environment. Because of the importance of this matter, **Appendix C** was prepared. It summarizes the research on the movement of phosphorus from small scale sewage treatment systems (producing less than 10,000 L/day of sewage), and the ability of Precambrian Shield 'B' horizon soils to negate the movement. Twenty-nine publications are cited; most of those that relate to Ontario's Precambrian Shield cottage country are from referenced journals, and all indicate that phosphorus is retained by soils. In virtually every case, the retention is substantial and permanent. The publication titled, "Limnology, plumbing and planning: Evaluation of nutrient-based limits to shoreline development in Precambrian Shield watersheds" constitutes a chapter in the **Handbook of Water Sensitive Planning and Design** (Lewis Publisher, CRC Press 2002); it is included in **Appendix D**. Its primary conclusion (which relies on long term data from lakes in the Muskoka River watershed) is that a key assumption which had long been made in Ontario water quality modeling, namely that 100% of phosphorus in septic systems within 300 m of a lakeshore is mobile, could not be substantiated scientifically, either on an empirical or mechanistic basis.

Of particular importance is the final entry in **Appendix C**, which summarizes phosphorus retention in a 20 year old septic system filter bed located in Precambrian Shield cottage country; its author is Dr. Will Robertson of the University of Waterloo, who has also served as the MECP's Scientific Advisor on matters relating to the mobility of sewage-related phosphorus and other contaminants in soils. The complete paper is included in **Appendix E**. The abstract in part reads as follows.

> "Septic systems in lakeshore environments often occur where thin soils overlie bedrock and, consequently, filter beds may be constructed of imported filter sand. The objective of this study was to assess the mobility of wastewater phosphorus in such a potentially vulnerable setting by examining a 20 year old domestic septic system located near Parry Sound . . . where the filter bed is constructed of imported non-calcareous sand. The groundwater plume is acidic (pH 6.0) and has a zone of elevated $P0_4$-P (up to 3.1± - 1.7 mg/L) below the tile lines, but no elevated $P0_4$-P is present beyond 5.0 m from the tile lines . . . the total mass of acid-extractable P (39 kg) is similar to the estimated total lifetime P loading to the system (33 kg). Microprobe images reveal abundant Fe and Al-rich mineral coatings on the sand grains that are increasingly P rich near the tile lines. Additionally, 6 years of monitoring data show that groundwater $P0_4$ concentrations are not increasing. This indicates that mineral precipitation, not adsorption, dominates P immobilization at this site. The example of robust long-term P retention opens up the possibility of improving P removal in on-site treatment systems by prescribing specific sand types for filter bed construction."

The research has also demonstrated that there are differences between phosphorus attenuation by soils in Precambrian settings (which are typically acidic and have low concentrations of calcium carbonate) and off-shield soils (which are basic and rich in calcium carbonate). To highlight this, information is presented in **Table 3** from two scientific publications and two reports prepared by Dr. Robertson. The three publications are summarized in **Appendix C**, while the two reports prepared for the MECP are included in **Appendix F**. The findings set out in **Appendix C** clearly show that Precambrian Shield non-calcareous soils are more effective than calcareous soils in retaining sewage-related phosphorus. **Table 3** additionally includes information collected in relation to the Branson tile field which has been monitored by our office, and which is discussed further below.

Table 3. Phosphorus reduction capabilities in calcareous and non-calcareous soils reported by Dr. W.D. Robertson, Department of Earth Sciences, University of Waterloo, and Michael Michalski, Michalski Nielsen Associates Limited.

Publication	Calcareous	Non-calcareous	Phosphate phosphorus (mg/L)		% Reduction
			Effluent (N)	Plume (N)	
1998[1]	Cambridge		6.4 (21)	4.9 (26)	23.4
	Camp Henry		11.8 (1)	1.1 (9)	90.7
	Long Point 1		6.2 (12)	2.8 (13)	54.8
	Long Point 2		7.1 (1)	4.8 (1.6)	32.4
	Langton		8.2 (6)	1.3 (10)	84.1
		Delawana	1.2 (3)	0.3 (15)	75.0
		Harp Lake	8.9 (2)	0.03 (3)	99.7
		Lake Muskoka	12.1 (10)	0.05 (27)	99.6
2003[2]	Cambridge		6.3 (4)	4.8 (7)	23.8
		Lake Joseph	6.3 (1)	0.06 (13)	99.0
		Lake Muskoka	13.0 (5)	0.016 (8)	99.9
2005[3]		Lake Joseph	1.2 (1)	<0.02 (6)	98.3
		Lake Muskoka	13.5 (10)	<0.02 (7)	99.8[5]
		Killarney	6.5 (1)	<0.02 (10)	99.7
			9.8 (1)	<0.02 (9)	99.8
		Sturgeon Bay	5.3 (1)	<0.02 (3)	99.6
			6.7 (1)	0.78 (3)	88.4
2006[4]		Sturgeon Bay	8.9 (1)	0.06 (10)	99.3
2006 - 2013		Branson (MNAL)	10.5 (26)	0.07 (126)	99.3

1 Robertson, W.D., S.L. Schiff, and C.J. Ptacek. 1998. Review of Phosphate Mobility and Persistence in 10 Septic System Plumes. **Ground Water**, 36: 1000-010.

2 Robertson, W.D. 2003. Enhanced Attenuation of Septic System Phosphate in Noncalcareous Sediments. **Ground Water**, 41: 48-56.

3 Robertson, W.D. 2005. 2004 Survey of Phosphorus Concentrations in Five Central Ontario Septic System Plumes. Report prepared for Ministry of the Environment. 7 pages plus table and figures.

4 Robertson, W.D. 2006. Phosphorus Distribution in a Septic System Plume on Thin Soil Terrain in Ontario Cottage Country. Report prepared for the Ministry of the Environment. 7 pages plus tables and figures.

5 Michael Michalski, Branson Property on South Kushog Lake.

Monitoring of Branson Tile Field: As alluded to above, one of the most promising technologies that is emerging consists of the use of 'B' horizon Precambrian Shield soils in constructing tile or filter beds. In this regard, the Branson matter is informative and important. As background, Mr. William Branson (now deceased) applied to the Land Division Committee, County of Haliburton, to sever a 3.5 ha parcel from about 24.3 ha which front on South Kushog Lake, a MNR designated at-capacity Lake Trout lake, generally meaning no further lot creation.

The single-lot application was appealed to the Ontario Municipal Board by MNR; the appeal was denied after an extended hearing. In permitting the application, the Board required ongoing monitoring of the tile field, which was to be constructed with 'B' horizon Precambrian Shield soil because of its high capability to retain phosphorus through mineralization or precipitation with aluminum and iron. The monitoring commenced in 2003, following five years of extended seasonal use by the landowners. Five permanent sampling wells were installed in the leaching bed when it was constructed, four in each of the corner areas, and one in the centre (**Figure 2**). The depth of the wells to bedrock ranged between 1.75 m and 2.0 m. As an objective, staff of the MECP determined prior to the monitoring commencing that phosphorus concentrations following treatment by the soils would need to be reduced by 90% relative to concentrations at the outlet of the septic tank (in the distribution box).

There are 26 sets of monitoring data collected between August 12, 2003 and September 23, 2016; the information is presented in **Table 4**. There are five critical results, as follows.

1. There was a very significant reduction in phosphorus, typically greater than 97%, and in 21 cases out of 26, greater than 99%.

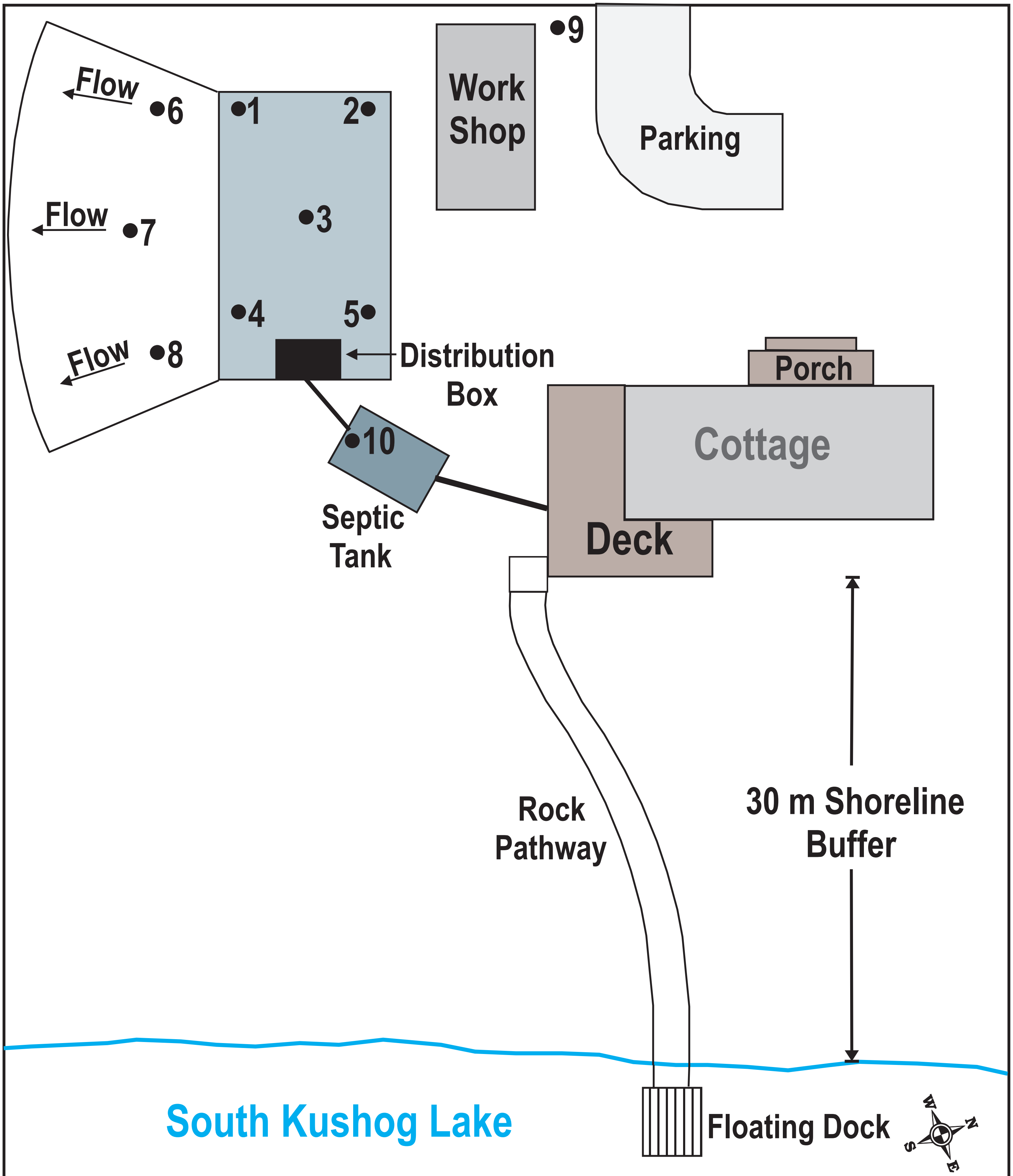
2. The MECP's objective of 90% reduction was achieved for all samples.

3. There was no evidence after 14 years of use that the soils are running out of their capability to retain phosphorus.

4. The findings are consistent with the scientific results reported by Dr. Robertson in his evaluations of the mobility of sewage-related phosphorus in soils (see **Tables 3** and **4** and related text above).

The extensive field research undertaken by Dr. Robertson and at the Branson site clearly demonstrates the substantial benefits of using 'B' horizon Precambrian Shield soils to irreversibly retain septic tank related phosphorus, resulting in near zero to zero impacts on downgradient surface waters.

Mitigation of Sewage Related Phosphorus Loadings: The proposed severed lot has appropriate locations for leaching beds which are well back from the lake and which have very good quality 'B' horizon soils that are well suited for phosphorus removal. There will be a need to add additional soil to increase the depth of soils over bedrock and/or depth of soils in the construction of the leaching bed. In the present instance, we believe that with a good depth of very good quality 'B' horizon soil already being present, this can simply be augmented with additional 'B' horizon soil that is salvaged on site, bringing the minimum



Project Name: 184 Silver Lake Road

Date Initiated: 2024

Filename: Silver Lake

Figure 2

Prepared For: Brandon and Ashley Cordua

Sketch of developed portion of Sanderson lot on western shore of South Kushog Lake, showing location of tile field sampling wells

Michalski Nielsen
ASSOCIATES LIMITED

Rev. No: 0

Drawn By: JN

Scale: Not to scale

Project Number: 0624

Table 4. Sewage related phosphorus reduction at Branson/Sanderson site, South Kushog Lake. Values for raw sewage and the samples from each piezometer are shown as milligrams of phosphorus per litre.

Date	Raw	Piezometer Numbers					Average % Reduction
		1 (NE)	2 (NW)	3 (Centre)	4 (SW)	5 (SE)	
August 12, 2003	9.1	0.04	1.30	0.02	0.01	0.02	97.0
December 2, 2003	9.2	0.36	0.05	0.07	0.03	0.05	98.8
June 10, 2004	10.9	0.2	–	0.01	0.03	0.07	99.4
May 16, 2005	9.5	0.04	0.02	0.01	0.01	0.01	99.8
May 31, 2005	8.7	0.02	0.13	0.005	0.01	0.01	99.6
August 26, 2005	10.4	0.85	0.06	0.06	0.06	0.04	97.9
November 11, 2005	9.6	0.01	0.17	0.02	0.02	0.01	99.6
November 14, 2005	9.6	0.01	0.01	0.01	0.01	0.01	99.9
April 18, 2006	11.4	0.007	0.011	0.012	0.008	0.007	99.9
October 11, 2006	8.5	0.005	0.052	0.005	0.056	0.017	99.7
May 17, 2007	13.9	0.011	0.042	0.006	<0.005	<0.005	99.9
May 22, 2007	10.1	0.012	0.051	0.011	<0.005	0.008	99.8
September 6, 2007	22.8	0.043	0.114	0.450	0.263	0.026	99.4
October 4, 2007	7.9	0.059	–	–	0.107	0.023	99.3
October 10, 2007	8.03	0.020	0.023	–	0.005	0.005	99.9
April 28, 2008	9.14	0.013	0.030	–	0.011	0.006	99.9
May 22, 2008	9.53	0.012	0.051	0.011	<0.008	0.008	99.9
June 6, 2008	8.60	0.020	0.012	0.019	0.006	<0.005	99.9
July 10, 2008	7.90	<0.005	0.008	<0.005	<0.005	0.005	99.9
November 3, 2008	9.60	0.008	0.018	0.010	<0.005	0.009	99.8
August 15, 2009	10.2	0.009	0.006	0.011	0.013	<0.005	99.9
November 12, 2009	13.7	0.156	0.660	0.070	0.064	0.175	98.4
June 26, 2010	14.6	0.235	0.144	0.295	0.082	0.328	98.4
October 17, 2011	9.9	0.222	0.041	0.102	0.008	0.028	99.5
November 2, 2011	11.6	0.022	0.022	0.122	0.023	0.026	99.6
September 23, 2016	9.7	0.016	0.020	0.055	0.018	0.034	99.7
Average	**10.5**	**0.091**	**0.125**	**0.082**	**0.033**	**0.037**	**99.3**

depth of such 'B' horizon soil to 0.6 m across the footprint of the sewage disposal bed (with any required amendments to this soil to be made as may be required by the septic inspector and/or septic installer. It will be very easy during site preparation for the cottage to salvage 'B' horizon soils from a depth of 0.1 m to 0.4 m below ground, to ensure these have a rich orange-brown colour, then to use these to augment the naturally occurring 'B' horizon soils in the location of the sewage disposal bed.

Note that in many similar studies that we have completed, we have recommended that naturally occurring 'B' horizon soils be augmented with those imported from an aggregate producer who has stockpiled such soils and determined their phosphorus retention capacity through laboratory testing. Although that option is available for this lot, and would allow for the quantification of phosphorus removal (and demonstration that all phosphorus loadings to the sewage disposal bed could be retained over the lifespan of that bed), we do not believe that is necessary to this particular circumstance, based on our visual assessment of the high quality of the native 'B' horizon soils on the proposed severed lot, together with the good soil depths on this lot, and with the opportunity to locate the sewage disposal system a considerable distance from the lake.

In summary, the exceptionally low phosphorus levels in Bells Lake, for a small lake with a very long turnover time and with quite extensive cottage development on it, provides very clear evidence that iron and aluminum rich soils in its watershed are affording it a high level of natural protection against phosphorus loads from the many existing cottages around the lake. These soils can be capitalized on in the build-out of the proposed severed lot.

Through the combination of moving the septic system to a distance of 50 m back from the shoreline on the proposed severed lot, and by augmenting the depth of the naturally occurring good quality 'B' horizon soils to ensure a minimum 0.6 m depth of such soils in the construction of the sewage disposal bed, Michalski Nielsen Associates Limited is confident that there will be no potential for phosphorus from the sewage disposal system on this proposed lot to ever migrate to Bells Lake. Further, and per the recommendations of Section 7.0 of this report, other potential sources of phosphorus associated with both short term and longer term aspects of the development of the proposed severed lot can be properly controlled.

6.0 Species at Risk Potential

A Species at Risk review has been completed for the subject lands. In this regard, a search of the MNR's Natural Heritage Information Centre (NHIC) database indicates that there is one known Species at Risk occurrences within the one kilometre square that includes these lands, as follows:

Snapping Turtle	(Special Concern).

A search over a broader 5 km radius of the property identified the following species within this locale:

Eastern Wood-pewee	(Special Concern);
Canada Warbler	(Special Concern);

Olive-sided Flycatcher	(Special Concern);
Bobolink	(Threatened); and
Lake Sturgeon	(Threatened).

As a further source of information on Species at Risk in this locale, we have consulted a list compiled by MNR of species known or presumed to occur in the Geographic Township of Spence, in which the subject lands are located. That list is provided in **Appendix G** and includes the following additional species:

Barn Swallow	(downlisted to Special Concern);
Blanding's Turtle	(Threatened);
Chimney Swift	(Threatened);
Eastern Hog-nosed Snake	(Threatened);
Eastern Meadowlark	(Threatened);
Eastern Ribbonsnake	(Special Concern); and
Whip-poor-will	(Threatened).

Note that it is only Threatened and Endangered species (and not Special Concern species) which receive species and habitat protection under the *Endangered Species Act*.

The nearshore of the subject property does have attributes that could support Snapping Turtle. As there have been no sightings of Blanding's Turtle within a 5 km radius of these lands, it is very unlikely to be encountered on Bells Lake and is therefore not considered relevant to this application.

Eastern Hog-nosed Snake is a habitat generalist, so can be found foraging in almost all habitat types. However the subject lands do not contain the micro-habitat features required by this species, including wetlands as a source of food, open sandy areas for gestation and rock barrens with good sun exposure and cover for thermoregulation.

Eastern Ribbonsnake is found around wetlands, particularly marshes. It is very unlikely to be found in proximity to the subject lands.

Lake Sturgeon have been identified in the Magnetawan River, but have no relevance to Bells Lake, which could not support this species.

Bobolink and Eastern Meadowlark are both grassland birds, found in hayfields, pasturelands and other grasslands, with no potential for them to be encountered within the subject lands.

Eastern Whip-poor-will are a ground nesting bird which require rock barrens or other reasonably sized openings in areas of otherwise forested habitat for breeding. No such habitat opportunities for that species occurs within the subject lands.

Barn Swallow capitalize on human-made structures, such as barns and delipidated buildings, for nesting. Similarly, Chimney Swift most often nest in chimneys and other man-made structures, and occasionally on cave walls and in hollow trees. Neither of these species have any relevance to the subject lands.

The other identified bird species are woodland birds which can be quite commonly encountered throughout the broader area. While these birds have some potential to occur within forested portions of the proposed severed lot, potential impacts to these birds can be addressed by minimizing the extent of tree removals, and to otherwise time such tree removals to avoid periods when these species may be nesting; recommendations to this effect are included in Section 7.0 of this report.

In addition to the above-noted species, several species of bats have recently been listed as Endangered in Ontario due to the devastating effects of a fungal disease on them. Although the decline in their populations is not a consequence of habitat loss, protection of their summer roosting and maternity habitat has formed part of an overall strategy to mitigate against further declines. Most of these bat species use crevices, peeling bark and cavities within mature and over-mature trees, and in particular hardwoods such as Red Oak, as summer roosting and maternity habitat. Potential impacts to bats can be addressed by minimizing the extent of tree removals, and to otherwise time such tree removals to periods when bats are not using them as roosting and maternity habitat, recommendations to this effect are included in Section 7.0 of this report.

7.0 Summary Comments and Recommendations

The subject property has extensive shoreline frontage, this being nearly three times the average frontage of lots on Bells Lake and over six times that of many existing lots; its severance into two shoreline lots will ensure both have a very considerable size and shoreline frontage, with such a severance having been demonstrated to be environmentally appropriate through the work completed as part of this report.

The proposed severed lot has abundant lands, particularly within its western half, that are very well suited for a dwelling, associated amenity area and a septic system; the general area that has been identified for these uses is shown in the Severance Sketch that is included in this report. This building envelope has very moderate slopes, and can be very easily accessed by a driveway off of Silver Lake Road. Further, it is proximal to the nearshore area we have identified as being most suitable for a dock, with terrain conditions between where the cottage will be located and this dock being well suited for a pathway that winds down to the shoreline, and which would have quite gentle grades.

From a deer wintering habitat perspective, it is only the shoreline riparian zone of the proposed severed lot, to a distance of 30 m back from the shoreline, that provides winter cover for deer. This portion of the property can be retained in a natural state. Further, a majority of the treed cover further back into this lot can also be retained, preserving opportunities for deer to browse across lands on the periphery of those providing good winter cover. Deer routinely use areas where there are cottages as part of their winter cover and there are no concerns that the careful development of the proposed severed lot will impact on the broader identified Stratum 1 deer yard, or on deer activity within the more localized area of good quality habitat that follows the western shoreline of Bells Lake.

On the matter of fish habitat, the very nearshore of the proposed severed lot does provide well-protected, functionally valuable fish habitat. This habitat is likely to support Smallmouth Bass spawning, together with other important spawning, juvenile development and feeding functions. It has conditions which are typical of those which MNR has identified as providing more critical, Type 1, fish habitat. With careful attention to the location and design of a shoreline structure, together with careful attention to the protection of the shoreline riparian zone, these important fish habitat attributes can be fully protected.

From a Species at Risk perspective, the proposed severed lot does not contain wetlands, vernal pools, watercourses, rock barrens or other features of particular value to such species. The nearshore of this proposed lot may support Snapping Turtle, but these values are easily protected, particularly given the protections which are to be provided to the nearshore and shoreline riparian areas in concert with the protection of fish habitat. This proposed lot otherwise generally has little potential to support most other Species at Risk, although, like any other property containing woodland within the Municipality of Magnetawan, does have some potential to support various forest-dwelling birds and bat species which have been so designated. Impacts on such species can be properly mitigated through a combination of limiting the overall extent of tree removals on the proposed severed lot, and through the timing of such tree removals to periods when birds are not nesting and when there is no roosting or maternity use by bats.

From a water quality perspective, the proposed severed lot can be developed with no concerns that it will negatively impact on the water quality of Bells Lake, which, despite the extensive development around good portions of the lake and the very long period that it takes for the entire volume of the lake to replenish itself through runoff/precipitation, has exceptionally low phosphorus levels. The excellent and stable water quality of Bells Lake is substantially a consequence of natural soil conditions within its watershed, with the well mineralized 'B' horizon soils found on the proposed severed lot likely being very characteristic of these, and having a high capacity to retain phosphorus. Through a combination of having a large setback for the septic system and by augmenting the depth of the naturally occurring 'B' horizon soils in the construction of the sewage disposal bed on the proposed severed lot, a very high level of water quality protection will be provided to Bells Lake. Further, other potential sources of phosphorus associated with both short term and long term aspects of the development of this proposed lot can be properly controlled, as part of a proactive and cautionary approach to the protection of water quality.

In accordance with the above, Michalski Nielsen Associates Limited recommends that the Municipality of Magnetawan permit this severance application, subject to the implementation of the following recommendations:

- **development of the severed lot be subject to site plan control;**
- **development of a cottage, associated amenity area and sewage disposal bed are all to generally occur within the building envelope that is identified on the Severance Sketch;**

- **the foundation of the dwelling is to be a minimum 30 m back from the shoreline, with a 5 m allowance (i.e., a minimum 25 m back from the shoreline) for decks, patios and hard landscaping;**
- **the sewage disposal bed is to be located a minimum 50 m back from the shoreline;**
- **lands within 25 m of the shoreline are to be retained as a natural buffer. Tree removals within this buffer are to be limited to the minimum requirements to create a pathway of no more than 2 m width down to a dock and shoreline amenity area; a clearing of no more than 5 m x 8 m (or another configuration totaling 40 m^2 or less) as a shoreline amenity area for such features as a deck, patio, fire pit and/or storage shed; limited limbing of trees to create view windows from the cottage down to the lake; and the removal of trees certified by an arborist to pose a legitimate safety hazard;**
- **there are to be minimal tree removals within the eastern portion of the lot that is located beyond the identified building envelope. By restricting tree removals to the building envelope, and to a very minimal number of trees within the adjacent riparian area, well our 75% of the natural vegetation of this lot will be retained, including the great majority of that contributing to winter deer cover and to the shoreline buffer that protects fish habitat, potential turtle habitat and water quality;**
- **tree removals to accommodate development on this lot should generally occur outside of the period of both breeding bird activity and bat roosting and summer maternity use. This allows for tree removals between October 1 and April 15. If select tree removals are to occur outside of this period, it is recommended that there first be a survey to ensure no breeding bird activity and no bat roosting opportunities/use in the trees being removed;**
- **the sewage disposal bed is to include additional rich orange-brown 'B' horizon soils that are salvaged from the building area (from a depth of 0.1 m to 0.4 m beneath the surface), bringing the depth of 'B' horizon soils within/beneath the bed to a minimum depth of 0.6 m;**
- **prior to any construction, sediment fencing is to be properly installed around the downgradient limits of all earthworks, including that associated with the construction of the cottage, any accessory buildings and the sewage disposal system. In doing so, it is recognized that shallow bedrock may limit opportunities to trench traditional sediment fencing in, with opportunities in such instances to either secure the base of such fencing in pea gravel or to use an alternate form of sediment and erosion control, such as Silt Soxx;**
- **sediment controls are to be inspected by the contractor at least twice per week and maintained in good condition over the entire period of construction;**
- **sediment controls are to be properly maintained until such time as all disturbed areas have been fully stabilized through landscaping or the reestablishment of vegetation;**
- **minimal grading and blasting is to be undertaken in association with construction of the cottage, any accessory structures, the sewage disposal system and associated amenity space/landscaped areas;**
- **roof leaders for the cottage and any accessory structures should drain to soakaway pits or gravel splash pads which infiltrate and/or broadly disperse any flows. Grading should encourage the broad dispersal of all runoff from the building area through the riparian zone, as opposed to encouraging any concentration of such flows; and**

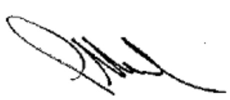
- **similarly, the driveway should be graded such that it broadly disperses runoff. In no instance should there be any channelization of flows from such areas towards Bells Lake;**
- **the dock should be located within the docking envelope identified on the Severance Sketch;**
- **the dock should consist of a gangway of no more than 1.3 m in width, extending to a distance of at least 5 m offshore, to a floating dock. The gangway, which can be pole-supported and/or suspended, should be at least 0.5 m above the water, minimizing its impacts on the shading of aquatic vegetation. With the floating dock component of this dock system being at least 5 m offshore, there will be minimal impacts on aquatic vegetation. A dock of this design will also keep boat slips to areas of greater water depths, and outside of the area of dense woody debris on the lakebed, allowing better access and egress for boats. Further a dock of this design will also protect turtles potentially using the very nearshore area; and**
- **apart from the installation of a shoreline structure, there is to be no disturbance of the shoreline or nearshore. Shoreline vegetation is not to be removed, woody material is not to be removed, beach creation is not to be permitted, and nearshore substrates are not to be altered.**

* * * *

In closing, I trust this report is complete and appropriately addresses the requirements of the Municipality of Magnetawan, but would be pleased to answer any questions staff may have.

Yours truly,

MICHALSKI NIELSEN ASSOCIATES LIMITED
Per:



Gord Nielsen, M.Sc.
Ecologist
President

APPENDIX A – BACKGROUND MAPPING AND AERIAL PHOTOGRAPHY

Ontario

Ministry of Natural Resources and Forestry

Make-a-Map: Natural Heritage Areas

184 Silver Lake Road, Magnetawan

Map created:4/3/2024

Notes:

Silver Lake is also known as Bells Lake

Legend

- Assessment Parcel
- ANSI
  - Earth Science Provincially Significant/sciences de la terre d'importance provinciale
  - Earth Science Regionally Significant/sciences de la terre d'importance régionale
  - Life Science Provincially Significant/sciences de la vie d'importance provinciale
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  - Provincially Significant/considérée d'importance provinciale
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- Unevaluated Wetland
- Conservation Reserve
- Provincial Park
- Natural Heritage System

0.6 0 0.32 0.6 Kilometres

Absence of a feature in the map does not mean they do not exist in this area.

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Make-a-Map: Natural Heritage Areas

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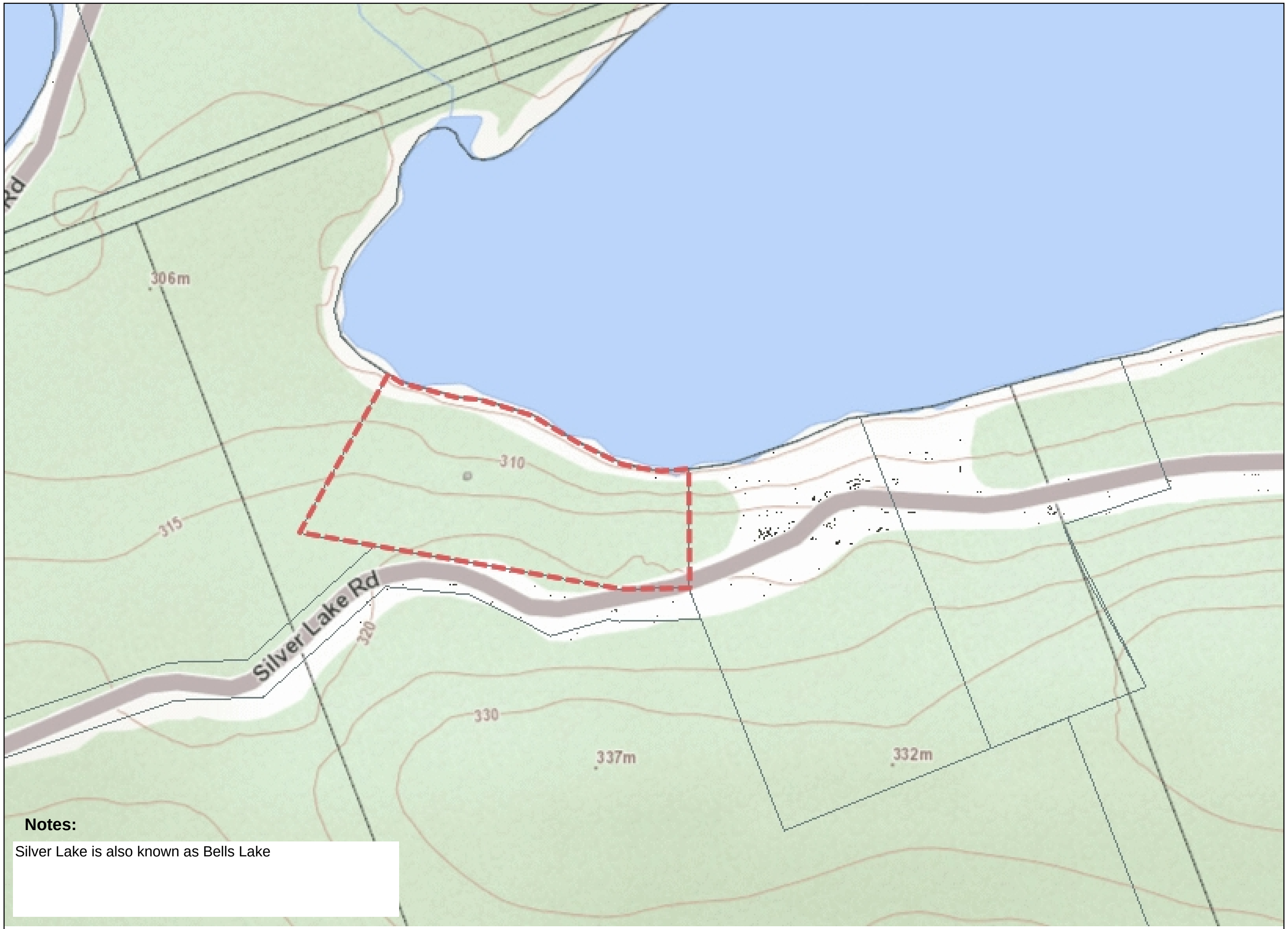

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0.2 0 0.08 0.2 Kilometres

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0.1 0 0.04 0.1 Kilometres

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Ministry of Natural Resources and Forestry

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0.0 0 0.02 0.0 Kilometres

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APPENDIX B – MNR'S LAKE FACT SHEET FOR BELLS LAKE

Lake Fact Sheet – Parry Sound District

Bells Lake

Location

Official Name: .... Bells Lake
Local Names: .... Silver Lake
County/District: .... Parry Sound
Geographic Twp: .... Spence
Municipality: .... Municipality of Magnetawan
MNR Admin. Area: .... Parry Sound
Lat./Long: .... 45.602 N 79.680 W
UTM (NAD83): 17 602900 5050500
Topographic Map (1:50,000): 031E12
Drainage Basin: .... Magnetawan River

Physical Features

Surface Area (ha): 41
Maximum Depth (m): 13
Mean Depth (m): 6.7
Elevation (m asl): 315
Perimeter (km): 3.5
Island Shoreline (km): 0
Volume (10^4 m^3): 287
Watershed (km^2): .... 0.8 (excludes area of lake)
Water Clarity (m): 4.8

Land Use and Development

Crown Land (%): 0
Provincial Parks: .... none
Shoreline Development: .... high; shoreline residential
Access: .... private
Water Level Management: .... not regulated

Fish Species

Major Fish Species: .... smallmouth bass
Other Fish Species: .... cisco, pumpkinseed, white sucker, Iowa darter, brown bullhead
Other Species: ....

Notes: E: extirpated, I: introduced – intentional or accidental, O: occasional, R: remnant, S: currently stocked, ?: status uncertain, 2009: year of first record or introduction if known, blank: presumed native

Parry Sound District office: (705) 746-4201
Bracebridge Area office: (705) 645- 8747

Bells Lake

Fisheries Management

Fisheries Management Zone: 15

Designation for Lake Trout Management: .... not designated

Fishing Regulation Exceptions .... no lake-specific exceptions

Current Stocking: .... none

Historic Stocking (last year stocked): .... none

Contaminants (species tested): .... no testing done

Summary of Fisheries Studies/ Reports

Synopsis

The only fisheries information available for Bells Lake is the 1979 lake survey. At that time smallmouth bass was the only major game fish species found to be present. It is quite possible that additional species have been illegally introduced since that time. Given that high level of development, the lake likely supports a modest fishery for bass and associated species.

Updated: 2020

Refer to Lake Fact Background Information document for explanation of content.

Parry Sound District office: (705) 746-4201
Bracebridge Area office: (705) 645- 8747

APPENDIX C – REVIEW OF TECHNICAL MATERIAL RELATING TO PHOSPHORUS UPTAKE CAPABILITIES OF PRECAMBRIAN SHIELD SOILS

Table 1. Sewage effluent, phosphorus and soils literature review, modified from Riverstone Environmental Solutions Inc. (2008).

Date	Author(s)	Summary
1976	Viraraghaven and Warnock[1]	Most groundwater samples below a septic tile field operating for three years showed phosphate concentrations lower than background levels.
1976	Reneau and Pettry[1]	No soluble phosphorus in a slowly moving water table below a four and fifteen year old septic system in sandy loam soils, and orthophosphate concentrations below 0.2 µg/L at points 3 m from the tiles.
1977	Sawhney and Starr[1]	Sampling tubes installed below and downgradient from a tile field showed that soil 15 cm – 30 cm from the tiles was removing most of the outflow phosphate after six years of use. Also showed that wetting/drying (alternate operation of two trenches) "regenerated" the soils phosphorus removal capacity.
1979	Reneau[1]	Studied transfer of effluent from 10 domestic septic tank systems all greater than 12 years old, to an agricultural tile drain. Varying soil phosphorus attenuation was found, with 99% removal within 8 m to 30 m from the outflows
1979	Jones and Lee[1]	Concluded, "no evidence for phosphate transport from septic tank effluent was found in any of the monitoring wells" after sampling 15 points within 10 m – 100 m from a four year old septic tile field.
1981	Aulenbach et al.[1]	According to the Scope Newsletter, "estimated 85% overall removal of phosphorus from sewage in septic tank systems (including soil retention and assuming 5% of systems failing) around Lake George, New York State."
1983	Gilliom and Parmont[1]	Concluded, "movement of more than 1% effluent phosphorus to the lake was rare" from a study of eight septic systems ranging between 20 and 40 years of age adjacent to a small lake.

Date	Author(s)	Summary
1988	Chen[1]	Found that, "of 45 groundwater sampling points situated 0 m to 3 m below the surface, and up to 100 m from 17 different septic tank systems situated near the shores of lakes in northern and eastern New York State, only four showed phosphate concentrations >0.1 mg P/L".
1988	Johnson and Atwater[1]	Showed, "96% to 99% removal of soluble phosphate with three different soil types (three loamy sands, three sands) in 3 m long channels.
1989	Alhajjar et al.[1]	Compared phosphorus contamination of groundwater for nine septic systems and concluded, "there was zero probability of more than 5% of phosphate reaching groundwater in all cases, with mean phosphate transfer < 0.1 mg P/L in all cases".
1989	Reneau, Hagedorn and Degan[1]	Concluded, "most field studies indicate that P contamination is limited to shallow groundwater adjacent to on-site waste water disposal systems and that P sorption continues under saturated conditions".
1991	Robertson et al.	On the Muskoka River near Bracebridge, from a septic system in operation for one year on a poorly buffered, carbonate-depleted sand aquifer, and in Cambridge from a septic system in operation for over twelve years on a carbonate-rich sand aquifer, tests showed high levels (about 10 mg/L) of phosphorus in the septic tank effluent, while concentrations were substantially attenuated immediately below the tile field, with no detectable phosphate phosphorus (<0.02 mg/L) observed in the groundwater zone.
1992	Wieskel and Howes[1]	Looked at nutrients from four different 10 – 75 year old septic tank systems situated close to Buttermilk Bay, Massachusetts, and concluded that approx 0.3% of the effluent phosphorus would reach the bay.

Date	Author(s)	Summary
1993	Wood	In research undertaken as part of a Master's of Science degree, phosphorus levels from a septic system installed in 1962 to serve a shoreline seasonal residence on Harp Lake, northeast of Huntsville were analysed. The septic system was located 0.66 metres above the water table and 15.8 metres from the shoreline of the lake. Between 1962 and 1992, there was no maintenance to either the tile field or the steel septic tank. Wood reported slightly elevated phosphorus in the groundwater of the terrestrial and aquatic zones, and most of the phosphorus from 30 years of use was found directly under the tile field (within 14 cm of the drains). Soil phosphorus concentrations below and downgradient from this horizon were at background levels.
1995	Robertson[1]	Reported further monitoring results from the Cambridge domestic septic tank site (see 1991 above). Phosphate levels stabilized at 1 mg P/L in the septic plume, and "analysis of dilution factors led to the conclusion that around 25% of septic tank effluent P continued to be attenuated in the vadose zone"; the attenuation is most likely the result of mineral precipitation, and higher attenuation values are obtained at lower pH levels (acidic waste water or soil conditions).
1995	Robertson and Blowes[1]	A septic tank system serving a seasonal cottage was studied for four years after installation in Sudbury. The native soil was poorly buffered silt, and an acid contamination plume developed in the ground, but with limited phosphate mobility. There was no phosphate migration significantly beyond the infiltration bed gravel layer over the study period.
1996 1999	Harmon et al.[1] Robertson and Harman[1]	These two studies looked at effluent plumes from three septic systems serving a 200-pupil school for nearly 50 years and a seasonal 200-person campsite for five and for 25 years (two outflows). Following this extended use, approximately 85% of phosphate was being retained in the first 30 cm past the tiles. Phosphate above background levels was detectable up to 75 m away from the older system (mobile groundwater), but not beyond. They concluded that over long periods of use of septic tanks, long-term migration of phosphorus in the groundwater zone may occur.

Date	Author(s)	Summary
1998	Zanini, Robertson *et* al.	Studies continued on the school plume (as above) and on three domestic septic tank systems also in Ontario: Cambridge (operational approx 20 years), Muskoka (10 years), and Harp Lake (30 years). Results showed high phosphorus removal within the first 10 cm – 30 cm of soil around infiltration pipes. Based on soil iron content, they estimated that it would take approximately 35 years to saturate the first 25 cm around the infiltration pipes.
1998	Robertson et al.	Studied phosphate distribution in ten mature septic system plumes, and revealed that in six cases (primarily those on calcareous sands, and south of the southern limit of the Precambrian Shield), relatively large plumes were present (>10 m in length), and phosphate concentrations of 0.5 mg/L to 5.0 mg/L were higher than normally found in uncontaminated aquatic ecosystems. At the other four sites, on acidic and on Precambrian Shield non-calcareous sands and silt- and clay-rich sediments, high phosphate concentrations occurred only within three metres of the infiltration pipes. Concentrations of phosphorus in the Precambrian Shield plumes appeared to be strongly controlled by mineral precipitation reactions that occur in close proximity to the infiltration pipes. Concluded that results open up the possibility of modifying septic system design to achieve improved phosphate attenuation.
1998	Ptacek[1]	Studied an effluent plume situated on sand and found, "phosphate concentrations higher than background (but low at <0.02 mg P/L) up to 60 m away from the septic tank in part of the soil groundwater (non-surface groundwater with low oxygen levels). This shows that septic tank outflows can contribute phosphate to surface waters where septic tanks are relatively close to surface waters (<100 m) and in sand substrate (rather than soil) over an impermeable layer".
2000	Robertson[1]	Research, "in a two-year field experiment using a lysimeter containing natural sandy soils, showed that septic tank effluent soluble phosphate levels were brought down below the detection limit (<0.005 mg P/L). Only around 0.2% of soil iron had been used, forming stable coatings on the soil particles, suggesting that the system would remain effective for many years".

Date	Author(s)	Summary
2003	Robertson	Robertson's fundamental conclusion that phosphorus is strongly attenuated in acidic soils remained consistent. The data show that under acidic conditions, permanent phosphorus attenuation is carried out by high levels of aluminum combining to produce an aluminum/phosphate complex on sand grains below the infiltration bed.
2005	Zhang	The author used path analysis and multiple regression to examine the relationships between phosphorus adsorption and levels of iron and aluminum in different soils and found that extractable (acidified aluminum ammonium oxalate) aluminum and iron were the two most important properties related to the adsorption of phosphorus in soil.
2002	Hutchinson	Presents results of a re-evaluation of nearly 25 years of data from over 125 lakes in the District Municipality of Muskoka. The assumption that 100% of the phosphorus entering a septic system will ultimately be expressed as increased trophic state in downgradient lakes, "has only been tested indirectly" and that, "recent investigations of septic system geochemistry and the mechanisms of phosphorus mineralization in soil suggest that this assumption is debatable where soils are present between a septic system and a waterbody and that 100% phosphorus export is, in fact, unlikely". Dr. Hutchinson recommends that the phosphorus contribution from sewage septic systems be reduced by 74% for those lakes with suitable soils in their catchments.

Date	Author(s)	Summary
Aug 2003 through Oct 10, 2008	Branson property (Michalski Nielsen Associates Limited)	In a site plan agreement with Mr. Branson and the County of Haliburton, monitoring was undertaken on concentrations of phosphorus in the sewage before entering the tile field, and concentrations after treatment. The concentrations after treatment were captured in five permanent sampling wells installed to bedrock when the tile field was constructed, four in each of the corner areas and one in the centre. The phosphorus capacity of soil used to construct the tile field ranged between 75 mg and 150 mg of phosphorus/100 grams of soil. Nineteen sets of results show a very significant reduction in total phosphorus (i.e., continuously greater than 99%).
2006	Paterson et al.	The position of the Ministry of Environment differs from the recent science regarding the sewage-related phosphorus attenuating ability of soils. This publication updates the approach in that it recognizes that phosphorus attenuation may occur in some watersheds and probably increases with distance from the lake's shoreline. The publication notes, "First, in watersheds (or portions of watersheds) with shallow (generally <3 m) or absent soils, and with exposed or fractured bedrock, the existing assumption of zero retention is applied . . . Second, at sites where deeper (generally >3 m), non-calcareous native soils are present, the modeller may use the coefficients outlined in Table 3. Here, the degree of attenuation increases with distance from the shoreline, with an assumption of zero export at distances of >300 m (Hutchinson 2002). Third, in cases where site-specific characteristics demonstrate that retention of septic system phosphorus may occur over the long term, attenuation factors may be developed for consideration by local planning authorities and plugged into the model.

Date	Author(s)	Summary
No date	Lacosse and Fanfan	Monitoring of the Ecoflow Biofilter followed by 12 inches of soil demonstrated that the former reduces total phosphorus by 12% on average. The combination of the biofilter and drain field provides an overall removal of 98% of the total phosphorus present in the septic tank effluent. The monitoring covered a period of 40 months, and no influence was noted with respect to soil permeability. It was concluded that the phosphorus fixation related to the adsorption on the surface of metallic elements, particularly iron and aluminum. The life span of the treatment train insofar as phosphorus retention is concerned was estimated to be about 20 years, without accounting for the contribution in iron, aluminum, humic and fulvic acids associated with the peat-based filtering media.

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2005	Zhang	The author used path analysis and multiple regression to examine the relationships between phosphorus adsorption and levels of iron and aluminum in different soils and found that extractable (acidified aluminum ammonium oxalate) aluminum and iron were the two most important properties related to the adsorption of phosphorus in soil.

2002	Hutchinson	Presents results of a re-evaluation of nearly 25 years of data from over 125 lakes in the District Municipality of Muskoka. The assumption that 100% of the phosphorus entering a septic system will ultimately be expressed as increased trophic state in downgradient lakes, "has only been tested indirectly" and that, "recent investigations of septic system geochemistry and the mechanisms of phosphorus mineralization in soil suggest that this assumption is debatable where soils are present between a septic system and a waterbody and that 100% phosphorus export is, in fact, unlikely". Dr. Hutchinson recommends that the phosphorus contribution from sewage septic systems be reduced by 74% for those lakes with suitable soils in their catchments.
Aug 2003 through Oct 10, 2008	Branson property (Michalski Nielsen Associates Limited)	In a site plan agreement with Mr. Branson and the County of Haliburton, monitoring was undertaken on concentrations of phosphorus in the sewage before entering the tile field, and concentrations after treatment. The concentrations after treatment were captured in five permanent sampling wells installed to bedrock when the tile field was constructed, four in each of the corner areas and one in the centre. The phosphorus capacity of soil used to construct the tile field ranged between 75 mg and 150 mg of phosphorus/100 grams of soil. Nineteen sets of results show a very significant reduction in total phosphorus (i.e., continuously greater than 99%).
2006	Paterson et al.	The position of the Ministry of Environment differs from the recent science regarding the sewage-related phosphorus attenuating ability of soils. This publication updates the approach in that it recognizes that phosphorus attenuation may occur in some watersheds and probably increases with distance from the lake's shoreline. The publication notes, "First, in watersheds (or portions of watersheds) with shallow (generally <3 m) or absent soils, and with exposed or fractured bedrock, the existing assumption of zero retention is applied . . . Second, at sites where deeper (generally >3 m), non-calcareous native soils are present, the modeller may use the coefficients outlined in Table 3. Here, the degree of attenuation increases with distance from the shoreline, with an assumption of zero export at distances of >300 m (Hutchinson 2002). Third, in cases where site-specific characteristics demonstrate that retention of septic system phosphorus may occur over the long term, attenuation factors may be developed for consideration by local planning authorities and plugged into the model.

Date	Author(s)	Summary
No date	Lacosse and Fanfan	Monitoring of the Ecoflow Biofilter followed by 12 inches of soil demonstrated that the former reduces total phosphorus by 12% on average. The combination of the biofilter and drain field provides an overall removal of 98% of the total phosphorus present in the septic tank effluent. The monitoring covered a period of 40 months, and no influence was noted with respect to soil permeability. It was concluded that the phosphorus fixation related to the adsorption on the surface of metallic elements, particularly iron and aluminum. The life span of the treatment train insofar as phosphorus retention is concerned was estimated to be about 20 years, without accounting for the contribution in iron, aluminum, humic and fulvic acids associated with the peat-based filtering media.

1 Information referenced from Scope Newsletter January 2006.

APPENDIX D – LIMNOLOGY, PLUMBING AND PLANNING: EVALUATION OF NUTRIENT-BASED LIMITS TO SHORELINE DEVELOPMENT IN PRECAMBRIAN SHIELD WATERSHEDS. DR. NEIL HUTCHINSON. IN: HANDBOOK OF WATER SENSITIVE PLANNING AND DESIGN (LEWIS PUBLISHERS, CRC PRESS 2002)

HANDBOOK OF
WATER SENSITIVE PLANNING and DESIGN

Edited by
Robert L. France, B.Sc., M.Sc., Ph.D.
Associate Professor of Landscape Ecology
Science Director of the
Center for Technology and Environment (CTE)
Graduate School of Design
Harvard University
Cambridge, Massachusetts

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chapter II.17

Limnology, plumbing and planning: Evaluation of nutrient-based limits to shoreline development in Precambrian Shield watersheds

Neil J. Hutchinson

Abstract

The concept of using water quality as a planning tool for recreational lakes has been in active practice in Ontario and parts of the United States for approximately 25 years. In practice, assumptions regarding anthropogenic loadings of phosphorus to a watershed (generally septic systems servicing shoreline development) are linked to estimates of natural phosphorus loading. The resultant model estimates total phosphorus concentration and the response of trophic status indicators such as water clarity and dissolved oxygen in specific lakes. Linking the model to a water quality objective allows planners to set capacities for anthropogenic phosphorus loads, and hence shoreline development such as cottages, resorts, or permanent homes. This chapter presents an example of how the concept can be applied in practice, based on the application of the author's experience to a test watershed in south-central Ontario. Practical examples are given to show the development and calibration of accurate trophic status models, the use of monitoring data to set ecologically valid water quality objectives and their translation into shoreline development capacities, and to show the strengths and weaknesses of the approach.

The availability of a scientifically based water quality model has overemphasized water quality as a planning tool and generated unrealistic expectations of a single-capacity determinant among the public. Recent advances in our understanding of the geochemistry of domestic septic systems indicates that less phosphorus may be mobile than was previously assumed. In addition, as alternative septic technologies for phosphorus abatement are developed a refocusing of capacity determinants will be required. A combination of land-use regulations and a scientifically based management program is recommended as an alternative to a single, phosphorus-focused approach. These could address stresses to the ecology of the riparian and littoral zones and acknowledge the importance of social determinants such as noise, crowding, powerboats, and the wilderness aesthetic. This would promote a diversity of planning approaches, shift the existing focus away from plumbing and septic systems, and provide a more holistic management program which protected more components of the lake system.

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located adjacent to shorelines and 2,700 kg/year of phosphorus are added from point source STPs in urban centers. The Lake Rosseau watershed also includes approximately 4,800 ha of agricultural land use. There are approximately 4,400 vacant shoreline lots across the watershed, which represents a substantial resource base of future development potential. Approximately 1,400 back lots (i.e., set back from the shoreline) exist, and about one third of these are vacant.

The Province of Ontario and various municipal governments in recreational areas have maintained water quality programs since the late 1970s, to manage recreational growth in recognition of the important economic link of tourism to water quality. These programs generally consist of four elements:

1. Policies to maintain water quality through limits to shoreline development
2. Predictive models linking shoreline development to water quality
3. Lake-specific policies, including development objectives based on water quality and,
4. Monitoring programs to track changes in water quality in lakes

This chapter describes a process for developing a water quality model, validating its predictions of water quality, and setting development objectives on the basis of water quality. Issues of water sensitive land-use planning with respect to rural lakes are also covered in Chapters II.1, II.12, II.13, II.14, and II.16.

The author has made use of water quality and land-use data for a set of lakes situated within the Muskoka River watershed. The concepts and observations herein are those of the author alone and are intended to guide technical practitioners of water quality planning in recreational lakes in Ontario and elsewhere. They are not presented as specific recommendations for water quality planning for lakes in the Muskoka River Watershed — but the Muskoka watershed is used as an example of how these models can be applied throughout the Precambrian Shield in Ontario and elsewhere.

The history and origins of lakeshore capacity planning in Ontario

The first lakeshore capacity planning initiatives in Ontario grew out of the efforts to control eutrophication of Lake Erie in the 1970s. Lake Erie was a large and visible example of the threats posed by enrichment of surface waters with the algal nutrient phosphorus and of the success of remedial programs that were centered on managing the lake's phosphorus budget. In the same era, the eutrophication of inland lakes was also documented in response to inputs of partially treated sewage effluent. Among these was Gravenhurst Bay on Lake Muskoka, which suffered a history of algal blooms until tertiary sewage treatment was implemented in 1972 (Michalski et al., 1975) and enhanced treatment and relocation of the outfall were implemented in May 1994.

The primary water quality concern in Ontario's cottage country is also nutrient enrichment. Excessive phosphorus input promotes the growth of algae, causing a loss of water clarity. The lake user sees this as "greener" water of less aesthetic appeal or as surface blooms of nuisance algal growth. Algae settle to the bottom of the lake, where their decomposition consumes oxygen, reducing the amount of cold, oxygen-rich habitat available for sensitive aquatic life such as lake trout (*Salvelinus namaycush*) and triggering remineralization of sediment-bound phosphorus. Residential or cottage development on a shoreline may increase the input of phosphorus to a lake. Domestic septic systems may be a significant component of the loading, but clearing of the shoreline, fertilizer application, and increased erosion are also important.

Trophic status models and shoreline development policy

One of the significant breakthroughs achieved by the Dillon–Rigler model and its variants was their perceived ease of use and the accuracy of their predictions of water quality. Although the model is conceptually simple, its application can be complex. The model is supported by the results of approximately 25 years of detailed measurements on calibrated watersheds in south-central Ontario, and these calibrations must be validated periodically. The model was originally developed and calibrated on headwater lakes but, in practice, it is used in a watershed context (Dillon and Rigler, 1975; Dillon et al., 1986). Watershed modeling is conceptually straightforward, and the calculations eased by the use of personal computers, but implementation of policy in a watershed context, often between municipal government boundaries, is very complex. The model must be supported by monitoring programs to ensure the validity of its predictions. The management endpoints, both for water quality and development capacity, must be substantiated and defensible. Finally, implementation of a water quality program must be done by policy that is clear, fair to all resource users, and defensible. Therefore, the conceptual simplicity of the model may not be carried through into its application. This is reflected in four requirements for managing shoreline development by trophic status:

1. An accurate and defensible model based on sound inputs and data sources and defensible assumptions (The model must be able to distinguish natural sources of phosphorus [which are not manageable] from anthropogenic sources of phosphorus [which are the intent of the management program])
2. A process of model calibration and operation to validate predictions against measured water quality
3. Water quality end points, expressed as both water quality and allowable limits of development (as either anthropogenic phosphorus load or number of lots or development units)
4. An implementation strategy, formal planning instruments, and a process to guide implementation and ensure fair allocation of capacity

Technical basis of the models

The water quality models used in Ontario are all mass balance models that predict the trophic status of lakes at steady state with their phosphorus and hydrologic loadings. In summary phosphorus loading from the atmosphere and from the watershed as a function of soils and geology is linked with the lake's water load. Phosphorus loss from the water column is modeled as a settling velocity, specific to whether the hypolimnion is oxic or anoxic. The result is a prediction of "natural" or "background" phosphorus concentration. Human influence is added in the form of phosphorus loading from septic systems servicing shoreline residences, as a function of a per-capita phosphorus contribution of 800 gm/year, a count of the number of shoreline residences and estimates of their usage (as capita years per year, Dillon et al., 1986). A schematic of model operation is given in Figure II.17.2.

Although the mass balance principles of phosphorus loading and expression are generic, the resultant predictions of phosphorus and chlorophyll "*a*" concentration, Secchi depth transparency and hypolimnetic oxygen in the Ontario models were all derived from regression relationships specific to the Muskoka–Haliburton region of central Ontario (Hutchinson et al., 1991; Dillon et al., 1994). Phosphorus export coefficients for the natural landscape will also change as a function of wetlands, soil types, geology, and land use with confidence. In addition, assumptions guiding anthropogenic loading estimates and watershed implementation are open to some debate on both empirical and mechanistic grounds and should be addressed before beginning any management exercise.

Model validation

The accuracy of predictions made by a trophic status model must be confirmed against measurements of water quality in the subject lakes before the models can be used with confidence in policy setting. This requires:

1. Establishment of a water quality monitoring program to determine existing levels of phosphorus in lakes for comparison against present-day model predictions
2. Maintenance of the monitoring program for the long term to determine any trends in water quality
3. Calibration of natural phosphorus loadings and basic model operation in undeveloped lakes, with no human phosphorus sources
4. Calibration of the model on developed lakes to determine if assumptions on anthropogenic phosphorus sources are valid
5. A process to resolve inaccuracies in model predictions and to update the model on the basis of monitoring results

Model validation must also meet the requirements of the planning process it supports. The intent of a lake management program is to achieve stable and predictable water quality. This must occur in concert with the requirements for a stable and consistent planning and policy environment. Water quality programs should set stable targets for a minimum of 20 years — time to resolve new steady states in water quality in a monitoring program and to provide a stable economic and planning environment, without jeopardizing the resource through over-allocation of development.

Monitoring programs

The monitoring program supporting a lakeshore capacity policy must strike a balance between practical implementation, accuracy, and expense. Ontario's water quality models were developed on the basis of an intensive, long-term research program on a small number of study lakes which was undertaken by the provincial Ministry of the Environment in the Muskoka and Haliburton regions of Ontario. The program was based on dedicated laboratory procedures and analytical staff, long-term personnel, and routine scientific review. In contrast, a municipal program may have to be implemented with limited financial support, summer or term staff, a variety of commercial or government laboratory analyses, lack of in-house expertise, and staff who manage water quality only as one aspect of their career. None of these, on its own, jeopardizes the integrity of a water quality program, but all represent the potential for error and the need for stable policy support. The water quality program must, therefore, be supported by a cost-effective monitoring program that can be maintained for the long-term.

The water quality model is based on predictions of total phosphorus, and so the best comparisons of model accuracy are obtained by measuring total phosphorus directly. Published water quality relationships for Muskoka–Haliburton lakes (Clark and Hutchinson, 1992) suggest that long-term trends in water quality can be determined by making one phosphorus measurement each year at the time of spring overturn, when the lake is completely mixed from top to bottom, thus reducing program costs. Accordingly, an effective water quality monitoring program may consist of:

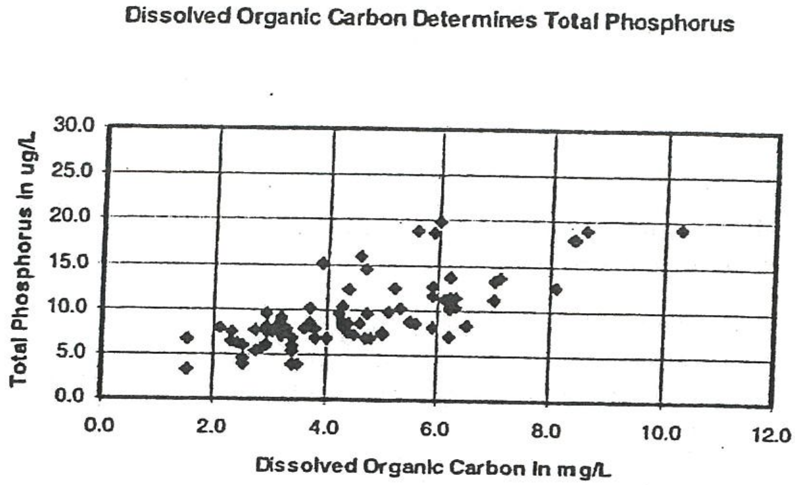

Figure II.17.3 Influence of dissolved organic carbon (DOC) on average long-term total phosphorus concentrations in Precambrian Shield lakes.

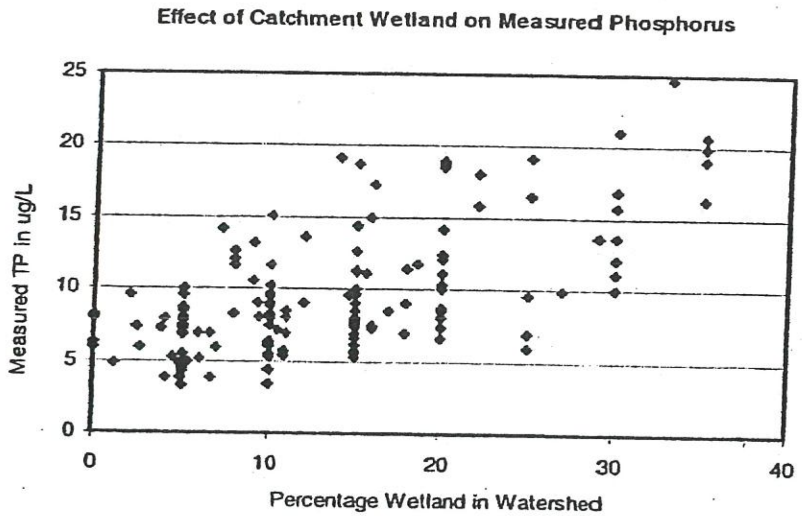

Figure II.17.4 Relationship of average long-term measured phosphorus in Precambrian Shield lakes with wetland area in catchment.

$$\text{kg TP/year} = \text{catchment area (km}^2) * (3.05 + (0.54 * \%\ \text{wetland}))$$

This relationship is driven by the export of phosphorus with dissolved organic carbon from wetlands in the catchments of the lakes. This is shown for lakes of the Muskoka River watershed in Figure II.17.3. Total phosphorus concentrations were significantly related ($p < 0.000001$, $r^2 = 0.39$) to the amount of wetland in the catchments of lakes in the Muskoka River watershed (Figure II.17.4.). Natural phosphorus loading from all catchments containing wetland can therefore be estimated from wetland area.

Phosphorus retention in shallow lakes. Both the Dillon–Rigler and Lakeshore Capacity Study models were developed and calibrated for use in lakes that are deep enough to

Figure II.17.5 Quaternary Geology of Muskoka, Ontario (from Barnett et al., 1991). Pink areas (1) denote igneous and metamorphic bedrock, which is exposed or covered with thin drift. Blue areas (24) are glaciolacustrine deposits of clay and silt. Remaining colors are glaciolacustrine deposits of outwash and till, sand and gravel (18, 23, 25) or organic peat and muck (32).

et al., 1971; Isenbeck-Schroter et al., 1993) and direct observations made in septic systems (Willman et al., 1981; Zanini et al., 1997; Robertson et al., 1998) all show strong adsorption of phosphate on charged soil surfaces and mineralization of phosphate with Fe and Al in soil. The mineralization reactions, in particular, appear to be favored in acidic and mineral-rich groundwater in Precambrian Shield settings (Robertson et al., 1998), such that over 90% of septic phosphorus may be immobilized. The mineralization reactions appear to be permanent (Isenbeck-Schroter et al., 1993), and direct observations suggest that most septic phosphorus may be stable within 0.5 m of the tile drains in a septic field on the Precambrian Shield (Robertson et al., 1998).

The mechanistic and geochemical evidence is supported, in part, by trophic status modeling. Dillon et al. (1994) reported that only 26% of the potential loading of phosphorus from septic systems around Harp Lake, Muskoka, could be accounted for as measured phosphorus in the lake. The authors attributed the variance between measured and modeled estimates of phosphorus to retention of septic phosphorus in thick tills in the catchment of Harp Lake. Although the Muskoka watershed is frequently characterized as an area of thin to no soils over bedrock, this description is in no way universal. The central corridor of the watershed (in which Harp Lake is located) occupies a glacial outwash plain of alluvial sands and gravels, and many catchments contain substantial soil deposits. Western and southwestern Muskoka represent the more typical topography of thin soils and granite ridges and outcrops (Figure II.17.5). Even in these areas, however, tile fields are often, by necessity, built on imported fill and so some attenuation is possible.

Revisions to trophic status models should use the findings of these recent studies to improve the positive bias (i.e., overprediction of measured phosphorus) in the model by accounting for a 74% retention of septic phosphorus for those lakes with suitable soils in their catchments (Dillon et al., 1994). The positive bias is apparent in model results for all developed lakes, but most pronounced in heavily developed lakes. All of the study lakes

Table II.17.1 Usage of Shoreline Residences in the District Municipality of Muskoka

Zone 1: Outlying area	0.82
Zone 2: Close to major highway	1.23
Zone 3: Close to major urban center	2.09
Resort unit usage	1.23
Trailer and camp sites	0.41

All values are given in capita years per year for each residential type.

Revised per-capita phosphorus contribution. The original Dillon–Rigler and Ontario models used a figure of 800 gm/C/year as an estimate of per-capita contributions of phosphorus to septic systems from human waste and household cleaning products. This figure was originally derived, in part, from measurements of total phosphorus in septic tanks (Dillon et al., 1986) made between 1965 and 1980. Phosphorus concentrations ranged from 5 to 21.8 mg/L, with a mean of 13.2 mg/L. More recent research conducted by the Ontario Ministry of the Environment. (Gartner Lee Limited, 2002, in preparation) found a range of 4.3 to 13.3 mg/L of total phosphorus in septic tanks serving shoreline residences and an overall average of 8.2 mg/L. The more recent values reflect the limitation of phosphate in laundry detergent in the early 1970s and represent 62% of the phosphorus concentrations used in Ontario's Lakeshore Capacity Study. Strict application of the reduced concentration produces an estimate of 500 gm/C/year (i.e., 800 * 0.62). No figure will be completely accurate, however, and so 100 gm/year was added to the measured value in order to maintain a protective and conservative approach to estimating phosphorus loadings. A water quality model should therefore consider a per-capita phosphorus contribution of 600 gm/year to the septic system.

Shoreline development also adds phosphorus to a lake from the conversion of a forested landscape by clearing and lawn planting, and hardening of soils. Previous Ontario models did not include a contribution from these sources. A model should account for this clearing by including an estimate of 2000 m^2 for the average size of the developed portion of each shoreline lot and an increased export coefficient of 17 $mg/m^2/year$ (= 34 gm/lot/year) from those areas.

Validation of cottage usage figures. The final requirement for estimating human phosphorus loadings from shoreline development is to obtain estimates of the number of days that residences are used in a year. Seasonally occupied residences will be occupied for fewer days per year than permanent homes, and different usage figures apply to resort units or trailer sites. In the 1970s, the Ontario Lakeshore Capacity Study estimated seasonal and permanent usage of shoreline residences figures as 0.89 and 2.55 capita years/year, respectively, on the basis of a cottage survey conducted in the Muskoka–Haliburton region of Ontario (Downing, 1986). Twenty years later, the District Municipality of Muskoka (1995) undertook a similar study and determined that the overall lot usage had not changed substantially (Table II.17.1). Usage figures did not support the commonly held perception that large numbers of cottages were converting from seasonal to permanent use to accommodate retirees or "telecommuters." Only two lakes had high proportions of permanent residents, and these were close to a major urban center (the town of Huntsville). Regionally specific lot usage surveys should accompany development of lake trophic status models to ensure accuracy.

Table II.17.2 Summary Statistics Showing the Percentage Agreement between Modeled and Measured Estimates of Water Quality in the Muskoka Watershed Model

	All Lakes		D.I. < 1.21		D.I. ≤ 1.11	
	+Error	–Error	+Error	–Error	+Error	–Error
Average error	14.74	–0.84	5.89	–0.28	2.83	–0.28
Median error	8.08	–0.51	2.81	–0.28	2.34	–0.28
No. lakes	120	3	47	1	32	1
No. > 40% error	9	0	1	0	0	0

overestimate was 8.1% in 120 lakes. The average overestimate of 14.7% included 9 lakes for which the bias exceeded 40%. The criterion of 40% was chosen as the mean coefficient of variation in measured phosphorus concentration for all lakes. Model errors in excess of 40% were considered unacceptable as they were outside the range of natural variance in water quality. These errors only occurred as a result of positive bias, however, as an indication that not all of the potential human phosphorus load modeled was actually expressed in the lake.

Model accuracy was further expressed by comparison of model error with the proportion of the total phosphorus load contributed by human sources. These sources were described using the "development index" (DI), which was the ratio of total phosphorus load to potential anthropogenic phosphorus load for each lake. A DI of 1.0 represents a lake with no anthropogenic loading, a DI of 1.5 denotes a 50% increase, 2.0 a doubling, and so on.

For 32 "undeveloped" lakes (DI < 1.11) the average overprediction was <3%. Positive bias increased with development intensity such that median and average error were 2.8 and 5.9%, respectively, for 47 moderately developed lakes (DI < 1.21, Table II.17.2). A scatterplot comparison of measured and modeled phosphorus concentrations (Figure II.17.7) shows a) the good correspondence between the two and (b) the tendency for the model to overpredict phosphorus concentration. The positive bias persisted, even after accounting for attenuation of septic phosphorus (see Model Validation section above).

The absolute difference between measured and modeled phosphorus was <1 μg/L for 75 lakes (Figure II.17.8), and error for 77% of the lakes was within 2 μg/L. All of these errors represent positive bias, however, such that the model has a strong tendency to overestimate phosphorus concentrations in developed lakes.

The positive model bias was related to the estimate of phosphorus loads from shoreline development. Median and average positive bias increased with the intensity of development (DI, Table II.17.2), but negative model bias did not change. Positive bias in excess of 10% was confined to developed lakes. The trend to overprediction appeared on undeveloped and sparsely developed lakes but was less than 5% and likely reflected model variance.

The positive bias was reduced by accounting for the retention of phosphorus in soils (see Model Validation). Average and median errors were 9.7 and 5.7%, respectively, for the 66 lakes in which 74% phosphorus retention was assumed on account of the soil characteristics. Error only exceeded 40% on two of these lakes. For lakes where retentive soil mantles were not assumed in the model, average and median error increased to 21.2 and 13.0%, respectively, and 8 lakes had positive bias above 40%. This suggests that some retention may be occurring around all lakes and not just those with thick soil mantles in their catchments.

In spite of the positive bias in model results, it is clear that shoreline development has influenced the phosphorus concentrations in lakes to some extent. Phosphorus concentrations have increased with development, but by far less than predicted on the basis of an

Setting water quality objectives and development limits

The intent of a water quality program is to use the monitoring and modeling exercises to support water quality-based shoreline development capacities. Some review of approaches to setting phosphorus objectives is therefore warranted.

Surface-water management in Ontario

The Ontario Ministry of the Environment (MOE) manages environmental quality primarily through two pieces of provincial legislation: The Environmental Protection Act and The Ontario Water Resources Act. Policies and procedures for management of surface water quality that arise from this legislation are elaborated in implementation documents such as *Water Management: Policies, Guidelines, Provincial Water Quality Objectives of the Ministry of Environment and Energy* (OMEE, 1994). The goal of surface water management in Ontario is *"to ensure that the surface waters of the province are of a quality which is satisfactory for aquatic life and recreation"* (OMEE, 1994).

Ontario established Provincial Water Quality Objectives (PWQOs) in the 1970s in order to meet this goal. The first objectives were mostly adopted from other agencies, such as The International Joint Commission, but were later developed in Ontario (OMEE, 1992).

> *"Provincial Water Quality Objectives (PWQOs) are numerical and narrative ambient surface water quality criteria. They are applicable to all waters of the province (e.g., lakes, rivers and streams) except in those areas influenced by MOEE approved point source discharges. In specific instances where groundwater is discharged to surface waters, PWQOs may also be applied to the groundwater. PWQOs represent a desirable level of water quality that the MOEE strives to maintain in the surface waters of the province. In accordance with the goals and policies in Water Management (OMEE, 1994), PWQOs are set at a level of water quality which is protective of all forms of aquatic life and all aspects of the aquatic life cycle during indefinite exposure to the water. The Objectives for protection of recreational water uses are based on public health and aesthetic considerations"* (OMEE, 1994).

Two policies are used to interpret the water management goal and application of the PWQOs to specific water bodies (OMEE, 1994).

> *"Policy 1: In areas which have water quality better than the Provincial Water Quality Objectives, water quality shall be maintained at or above the Objectives. Although some lowering of water quality is permissible in these areas, degradation below the Provincial Water Quality Objectives will not be allowed, ensuring continuing protection of aquatic communities and recreational uses.*
>
> *Policy 2: Water quality which presently does not meet the Provincial Water Quality Objectives shall not be further degraded and all practical measures shall be taken to upgrade the water quality to the Objectives."*

Municipal responsibilities for water quality in recreational lakes

The planning system in Ontario is established in the Planning Act, which provides the legislative jurisdiction for municipalities to monitor and regulate land use subject to policy

The 1979 PWQO was given the status of "guideline" to reflect the uncertainty about the effects of phosphorus and to acknowledge the difference between managing toxic and nontoxic pollutants.

> *"Current scientific evidence is insufficient to develop a firm objective at this time. Accordingly, the following phosphorus concentrations should be considered as general guidelines which should be supplemented by site-specific studies:*
>
> *To avoid nuisance concentrations of algae in lakes, average total phosphorus concentrations for the ice-free period should not exceed 20 µg/L;*
>
> *A high level of protection against aesthetic deterioration will be provided by a total phosphorus concentration for the ice-free period of 10 µg/L or less. This should apply to all lakes naturally below this value;*
>
> *Excessive plant growth in rivers and streams should be eliminated at a total phosphorus concentration below 30 µg/L."*

Total phosphorus and the PWQO development process

There are several shortcomings with Ontario's existing PWQO for total phosphorus and the province has been reviewing its approach to phosphorus management. The approach is derived from that first proposed in Hutchinson et al. (1991), and elements of it are summarized in this section. These can be considered in cases where a municipality wishes to derive its own phosphorus objectives to assist with managing shoreline development.

Phosphorus as a pollutant

Development of a water quality objective for total phosphorus is distinctly different from that for toxic substances. Most aquatic pollutants are directly toxic to some target tissue, such as the fish gill, even if some of them are required nutrients at trace amounts, i.e., copper or zinc. As a result, the health of aquatic organisms, and hence the ecosystem, declines rapidly at concentrations slightly above ambient levels (Figure II.17.9). Phosphorus, on the other hand, is a major nutrient. Concentrations can increase substantially with no direct toxic effects. In fact, the first response of the aquatic system is increased productivity and biomass. Beyond a certain point, however, indirect detrimental effects become apparent, which ultimately decrease system health.

The first detrimental responses of a lake to enrichment (i.e., water clarity, algal blooms) are aesthetic and of concern mostly to humans. Assessment of aesthetic impacts is highly subjective; perceived changes in water clarity are based largely on what one is used to (Heiskary and Walker, 1988). The development of a phosphorus objective must therefore acknowledge an element of subjectivity in dealing with human concerns. The objective-development process may also consider that aesthetic impacts begin where a change in water clarity is first noticeable to the human eye, or where the mean water clarity first exceeds natural variation. Unfortunately, human perception of water clarity has not been established. Existing guidelines are based on trophic status classification schemes. They do not consider other water clarity influences such as inorganic turbidity or dissolved organic carbon or how lake users perceive changes in water clarity.

Finally, trophic status indicators such as water clarity, chlorophyll *"a,"* or dissolved oxygen cannot be managed directly, but only through management of phosphorus. In addition, there may be delays of up to decades between the addition of phosphorus sources

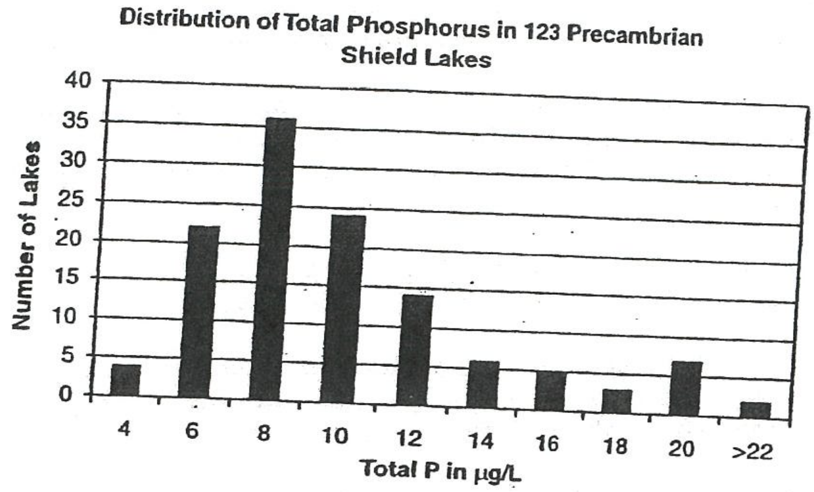

Figure II.17.10 Distribution of total phosphorus measurements in 123 lakes in the Muskoka River watershed, 1990–1998.

sustain a greater change than the low-phosphorus lake but would be restrained to a much lower load.

In summary, the existing two-tiered numeric objectives overprotect some lakes and do not protect others adequately. Allocation of phosphorus loadings is unnecessarily restricted in some lakes and overly generous in others. Neither biotic nor aesthetic attributes are adequately protected. Over time the diversity of trophic status presently represented in Ontario will decrease as lakes converge on one of two numeric objectives.

Environmental baselines and measured water quality

An emerging concern in environmental assessment is the need for a standard baseline for comparison against environmental change. Inland lakes respond quickly to point source phosphorus inputs. Detection of change is much more difficult, however, for nonpoint sources such as leachate from domestic septic systems.

The incremental nature of shoreline development (no lake is ever developed all at once) results in a slow and gradual increase in trophic status. The high degree of seasonal and annual variance in phosphorus levels in lakes (Clark and Hutchinson, 1992) means that changes may not be detectable without an intensive monitoring program, based on many samples and a precise and replicable analytical method.

Human observers may not notice a slow increase in trophic status over a generation. Environmental change that occurs over one generation becomes the status quo for the next. Over a long period, therefore, any assessment baseline based on measurements of total phosphorus will increase.

Any phosphorus objective that relies exclusively on measured water quality will therefore suffer from:

- Detection problems due to natural variance and analytical problems
- The lag time between addition of phosphorus to a watershed and its expression in a lake
- Failure to detect incremental changes in water quality
- Human perceptual conditioning, which reduces the apparent change in water quality over time

already being expressed in the lakes, and new development was added every year. Measured phosphorus concentrations were therefore higher than the natural baseline but potentially lower than their final, steady-state levels. The natural variability in phosphorus concentrations, and the lag time before the expression of septic-derived phosphorus (as discussed above), prevents the use of measured values as a planning baseline. Modeled, predevelopment baselines of phosphorus concentrations, validated against local lakes which are not yet developed, are therefore recommended as the starting point for objective development.

A model-based objective has two additional advantages. First, the modeled response of the watershed to future changes is instantaneous. It applies new development directly against capacity, without the intervening decades it takes for phosphorus to move to a lake and be expressed as a measured change in water quality (this approach, however, also requires assumptions on the ultimate mobility of phosphorus, which may not be valid (see Calibrating Anthropogenic Phosphorus Sources)). Second, the trophic status model is based on entire watersheds and so allows explicit consideration of downstream phosphorus transport in the assessment.

One disadvantage of the model-based baseline, however, lies with the inevitable changes in scientific understanding of lakes and watersheds. Any baseline derived from a water quality model is therefore subject to change as improved understanding or refinement produces changes in export coefficients, atmospheric deposition, or quantification of in-lake dynamics. For this reason, a modeling exercise must begin with locally validated coefficients and calibration of the water quality model. Model improvements should also be implemented within a defined schedule of Official Plan review, so that scientific understanding is incorporated at a schedule consistent with measured responses of lakes and the planning process.

The merits of a proportional increase

The second component of the objective is a proportional increase from the modeled predevelopment baseline. The proportional increase accommodates regional variation in natural or "background" water quality through the use of one numeric objective for all lakes. It is, in fact, a broader, yet simpler, application of the regionally specific, multitiered objectives proposed in other jurisdictions as a means of accommodating regional variation in background water quality (e.g., Heiskary and Walker, 1988).

One consideration is to adopt an allowable phosphorus increase of 50% above the modeled predevelopment level from anthropogenic phosphorus sources (Hutchinson et al. 1991). This approach is being considered by the Province of Ontario. Under this proposal, a lake modeled to a "predevelopment" phosphorus concentration of 4 µg/L would be allowed to increase to 6 µg/L from shoreline development or other human activities. Predevelopment concentrations of 6, 10, or 12 µg/L would increase to 9, 15, or 18 µg/L, respectively. A cap at 20 µg/L would still be maintained to protect against nuisance algal blooms.

There are numerous advantages to this approach.

1. Each waterbody would have its own water quality objective, but this could be described with one number (i.e., predevelopment plus 50%).
2. Development capacity and ultimate phosphorus status would be proportional to a lake's original trophic status.
3. As a result, each lake would maintain its original trophic status classification. A 4-µg/L lake would be developed to 6 µg/L and therefore maintain its distinction as oligotrophic. A 9-µg/L lake would be developed to 13.5 µg/L, would maintain its mesotrophic status, and development would not be unnecessarily constrained to 10 µg/L.

Background + 50%. The Province of Ontario has considered a revised water quality objective for total phosphorus in surface waters which is based on a 50% increase in anthropogenic loadings above the modelled natural background. Although the figure of 50% can be debated, it does reflect the merits of a proportional increase and a modelled baseline, as discussed previously. Municipalities must consider Provincial Policy, and so an objective of "Background + 50%" is used here to illustrate the implications of a potential Provincial Water Quality Objective.

"Filters" and water quality objectives

A water quality objective is not the only determinant of development capacity for lakes. Other physical factors can be considered as "filters," additional constraints to development that will modify any numeric objective developed for water quality. They apply equally to any water quality objective. Review of water quality objectives against other development filters helps to determine which aspects of a lake are most limiting to development and to place the water quality objective in the context of other capacity determinants.

Perimeter filter. The first such filter is shoreline perimeter, or the availability of waterfront lots based on physical constraints to development. The amount of lakeshore is limiting for any lake; some Ontario municipalities, for example, require a minimum lot frontage of 200 ft for new lots. Other municipalities may adopt larger or smaller lot sizes as a response to narrow embayments or other biophysical limits. Sensitive wetland areas, steep topography, or lack of soil may impose additional physical constraints that exclude portions of a lakeshore from development or require larger lot frontages.

In many cases, particularly lakes at the low end of the watershed, perimeter may be a more restrictive development limit than water quality. Total shoreline perimeter for each lake in the model can be determined using a geographic information system (GIS). The perimeter is then divided into 200-ft lots to provide an estimate of maximum shoreline available for development. This presents an overestimate, however, as steep shorelines or other physical constraints to development may further reduce the number of developable lots. These must be assessed on a lake-by-lake basis.

Crown land filter. A second physical filter possibly reducing development potential is consideration of "Crown" land. Many lakes in Ontario are surrounded by "Crown" land, publicly owned land managed by the province in the name of Her Majesty, the Queen. These lands are not developed at present and cannot be subdivided by private interests unless their status is revised by the province. This has been an uncommon occurrence in southern Ontario and is unlikely to occur in the immediate planning horizon. Modeling of all lakes in a watershed to the water quality objective of "Background + 50%" (including Crown land lakes) thus overestimates their ultimate phosphorus loading. In a watershed-based water quality model, the phosphorus loading from these lakes is accumulated in the anthropogenic load for downstream lakes, thus restricting future development. Because Crown lands are unlikely to be developed (and any consideration will involve extensive consultation between the Crown and municipal governments), the potential future load from shoreline development on these lakes can be removed from the modeling exercise as an additional limit or "filter" on development.

Vacant lot filter. Many lakes contain vacant lots on their shorelines. These lots have been legally created but have not yet been developed. Owners of these lots retain the legal right to build on them at any time in the future and so their potential phosphorus load must be subtracted from the future development capacity to account for their ultimate development. The 123 monitored lakes that are used in this exercise contain 4,400 vacant

In many cases, significant urban development and shoreline development potential may be located in the upper watershed. The trophic status of downstream lakes could, therefore, in the strictest sense, prevent any further development upstream.

In the practical sense, the watershed manager must determine the balance between protecting recreational water quality through watershed-based planning and the strictest approach, which would limit all development upstream of a capacity lake. Watershed-based planning remains an attractive concept, but quantitative advice on its implementation limits its utility.

Implications of watershed-based phosphorus limits

One approach to watershed-based planning is to first assess its implications:

1. Will the standards of water quality protection be reduced if development is not limited upstream of a lake that has reached capacity?
2. Does the added protection of a watershed-based approach translate into measurable or predictable improvements in water quality?

The implications can be assessed by running the watershed model in two scenarios:

1. In the first, future development is added to every lake in the watershed up to the limits prescribed by the "Background + 50%" or any other objective. These total future loads to upstream lakes are added to the downstream loading before downstream capacities are set. This approach represents true watershed-based planning.
2. In the second scenario, all lakes are developed to their individual limits, based on the difference between present day development and development to "Background + 50%" without accounting for the additional load from future upstream development. The phosphorus from this future development is then added to the downstream lakes, which are already at their own, independent capacity limits. This approach represents the implications of ignoring watershed-based planning.

The results of this exercise show that the implications of allocating development capacity independently of downstream transport are not significant for most lakes. Figure II.17.11 shows little overall deviation between watershed-based and independent allocations of development to the limits of the "Background + 50%" objective for lakes in the Muskoka River watershed. Lakes where the two development outcomes do not differ are shown as a straight 1:1 relationship. Departure from the 1:1 relationship, where the figure shows points above the 1:1 line, represent the degree to which the final water quality exceeds or "overshoots" the "background + 50%" objective because of upstream loading. The maximum deviation is 4.4 μg/L, in which a lake that should be at 11.1 μg/L ends up at 15.5 μg/L. (Figure II.17.11 shows one point with a very high deviation. This lake has already exceeded its objective as a result of upstream agricultural inputs.)

The ultimate, post-development phosphorus concentrations remained within 20% of the "Background + 50%" objective in 93% of the lakes modeled (Figure II.17.12). Water quality in 12 of the 376 modeled lakes could overshoot the objective by 40% or more as a result of downstream phosphorus transport. The water quality in these individual lakes would still be better, however, than that allowed if all were developed to Ontario's present-day Provincial Water Quality Objectives of 10 or 20 μg/L. The implications of exceeding the revised objective are therefore minor, and less than those of adhering to the present objective.

Setting development objectives

The objective-setting approach must protect water quality as well as assess the implications of model assumptions to policy for shoreline development. Development and calibration of the model for the Muskoka River watershed produced accurate estimates of water quality of the subject lakes, after accounting for reduced phosphorus loading to septic systems and the role of soils in attenuating phosphorus migration from shoreline septic systems to lakes. An objective of "Background + 50%" was tested to correspond to provincial initiatives and filters were developed to compare water quality and other determinants of development capacity. The resultant development capacities can then be summarized for each lake, each subwatershed, and the entire watershed. The capacities can then be compared with existing development density to provide insight into the degree of social stability and public expectations of policy.

Development objectives are best expressed as a phosphorus load in policy, so that the model can be used to compare resort, point source, or other development loadings against objectives. For ease of interpretation at the implementation stage that load can be converted to "Seasonal Residential" development using the occupancy figures for individual lakes (see "Validation of cottage usage" figures), or to any other type of development.

For this exercise, water quality objectives were stated as the total allowable anthrpogenic phosphorus load in kg. Objectives were set for each of the 376 lakes, bays, or rivers in the Muskoka River watershed as an index of potential development load, and for the 123 "monitored" lakes as an index of the loading of those lakes that are currently managed.

Although some jurisdictions may wish to optimize the allocation of future development to each lake, optimization was not attempted in this exercise. Certain popular lakes may well benefit from the adoption of stricter upstream controls on development, in order to maintain development opportunities in the popular lakes. Optimization would involve reducing the development capacity upstream of highly desired lakes, in order to maximize development of preferred locations. There is a near-infinite number of optimization strategies inherent in a large watershed, and optimization would involve a variety of stakeholders with different interests. Optimization could be considered on a case-by-case basis where there is a need to reallocate development opportunities.

Reconciliation of model accuracy and assumptions with objectives

Although the Muskoka River watershed model produced a very good correspondence between measured water quality and modeled estimates on average, there were many lakes in which a large discrepancy between measured and modeled phosphorus concentrations remained in the final model. The objective of a 50% increase in phosphorus against background was used here to illustrate a potential starting point for setting development limits. For this exercise, the 50% increase was modified, based on the agreement of the modeled estimate of phosphorus concentrations with phosphorus measurements for individual lakes, to accommodate the observed (versus the theoretical) expression of phosphorus in lakes. Where water quality measurements do not exist, the model should be assumed to be accurate.

The logic of reconciling objective development with model accuracy can be summarized as follows.

Criterion #1. If the measured phosphorus concentration exceeds the modeled "Background + 50%" objective and the modeled total phosphorus exceeds "Background + 50%,"

Then no additional development is allocated (accurate model, lake at capacity).

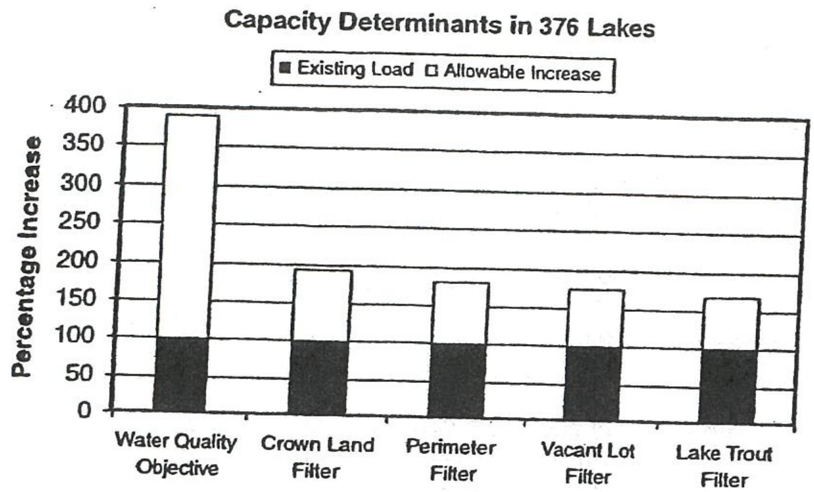

Figure II.17.13 Comparison of development constraints ("filters") in 525 lakes in the Muskoka River watershed.

Value of nutrient-based water quality objectives

Phosphorus is the nutrient limiting the growth of algae in the nutrient-poor lakes of the Precambrian Shield. When the phosphorus load to a lake increases because of anthropogenic sources and water quality declines, the recreational value of a lake will be diminished. In many municipalities on the southern Precambrian Shield in Ontario, lake-based recreation and tourism are the foundations of the local economy. A mechanism that allows local decision makers to define and understand the carrying capacity (whether based on water quality or otherwise) of the lakes within a municipality will ensure that further development does not unduly stress the natural resources upon which the area depends.

The intent of water quality-based development policies is to protect water quality from eutrophication induced by overdevelopment. It is therefore surprising that water quality is not always the strongest limitation on development capacity in lakes. The Muskoka River example was tested with a "Background + 50%" water quality objective and filters that limited development based on

1. Physical limits of available shoreline ("perimeter")
2. The presence of undevelopable Crown Lands
3. Vacant lots that were already committed to development
4. The presence of lake trout in lakes

Water quality alone did not represent the most significant restriction on shoreline development potential.

The exercise of modeling and monitoring an entire watershed is complex and costly. Water quality-based development limits are a worthy exercise in cases where the effort produces a substantial improvement in water quality protection; for example, if large point sources or urban areas are present. Biophysical and regulatory concerns may constrain development capacity far more, however, than water quality. Consideration of Crown Land and the physical shoreline limits may also reduce development capacity below that allowable under a very conservative phosphorus water quality objective of "Background + 50%." Lake trout habitat may be the most conservative filter and result in the lowest estimate of development capacity.

Managers are encouraged to consider and implement a broader spectrum of management approaches, in addition to phosphorus-based development capacities.

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APPENDIX E – PHOSPHORUS RETENTION IN A 20-YEAR-OLD SEPTIC SYSTEM FILTER BED

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TECHNICAL REPORTS

GROUNDWATER QUALITY

Phosphorus Retention in a 20-Year-Old Septic System Filter Bed

W. D. Robertson*

Septic systems in lakeshore environments often occur where thin soils overlie bedrock and, consequently, filter beds may be constructed of imported filter sand. The objective of this study was to assess the mobility of wastewater phosphorus (P) in such a potentially vulnerable setting by examining a 20-yr-old domestic septic system located near Parry Sound, ON, Canada, where the filter bed is constructed of imported noncalcareous sand. The groundwater plume is acidic (pH 6.0) and has a zone of elevated PO –P (up to 3.1 ± 1.7 mg L) below the tile lines but no elevated PO –P is present beyond 5 m from the tile lines. Elevated concentrations of desorbable P (up to 137 mg kg) and acid-extractable P (up to 3210 mg kg) occur in the filter sand within 1 m below four of seven tile lines present and the total mass of excess acid-extractable P (39 kg) is similar to the estimated total lifetime P loading to the system (33 kg). Microprobe images reveal abundant Fe and Al-rich authigenic mineral coatings on the sand grains that are increasingly P rich (up to 10% w/w P) near the tile lines. Additionally, 6 yr of monitoring data show that groundwater PO concentrations are not increasing. This indicates that mineral precipitation, not adsorption, dominates P immobilization at this site. This example of robust long-term P retention opens up the possibility of improving P removal in on-site treatment systems by prescribing specific sand types for filter bed construction.

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*Corresponding author (wroberts@sciborg.uwaterloo.ca)

5585 Guilford Rd., Madison, WI 53711 USA

A PREVIOUS REVIEW of phosphate (PO) behavior in 10 septic system plumes in Ontario (Robertson et al., 1998) revealed that six sites on sands had distinct groundwater PO plumes, extending >10 m away from the tile beds, with PO –P concentrations (1–6 mg L) that were much greater than threshold levels necessary to stimulate algal growth and eutrophication in lakes (~0.03 mg L ; Dillon and Rigler, 1974). In the United States, wastewater–PO plumes with similar concentrations have been mapped for distances of several hundred meters (Bussey and Walter, 1996). Long-term wastewater disposal could thus be of concern if these sites were located in lakeshore settings. However, the previous review also revealed that at some sites substantial P immobilization occurred within the first 1 to 2 m of subsurface flow. Electron microprobe studies indicated this was the result of mineral precipitation reactions that were likely promoted by redox changes occurring in close proximity to the infiltration pipes (Zanini et al., 1998). The sites where P immobilization was most complete (>99%) were those on noncalcareous sediments where sewage oxidation reactions led to the development of acidic conditions. Additional investigations at other acidic septic system sites in Ontario showed similarly robust P immobilization (Robertson, 2003). The three acidic sites in the latter study (Muskoka, Lake Joseph, and Nobel) all had relatively deep water tables (3–5 m). However, these were considerably in excess of the minimum depths required for tile bed construction in Ontario (0.7 m below the tile lines, OMOE, 1982). Efficient P removal at these sites could be related to the thorough effluent oxidation that occurs, but this may not be the case at all sites. In landscapes such as central Ontario's "cottage county," on-site wastewater disposal often occurs in lakeshore settings that have relatively thin soils that overlie bedrock that is noncalcareous in many areas and usually fractured. At these sites, septic system filter beds may be constructed of filter sand that is imported to the site to provide the minimum regulatory vadose zone thickness or a minimum thickness of permeable sediment overlying bedrock (0.9 m below tile lines, OMOE, 1982). At sites with thinner vadose zones, wastewater oxidation may be less complete. Also, laboratory studies have shown that P retained in filter-bed sediments can be remobilized if the water content of the sediment increases, which might occur as a result of seasonal water table fluctuations (Zurawsky et al., 2004). The fate of wastewater P in these potentially more vulnerable settings has so far received little attention.

Dep. of Earth and Environmental Sciences, Univ. of Waterloo, Waterloo, ON, Canada N2L 3G1. Assigned to Associate Editor Paul DeLaune.

Abbreviations: EDX, energy dispersive X-ray; PVC, polyvinyl chloride.

This study assessed wastewater-P retention in a typical central Ontario lakeshore setting where thin soils overlie bedrock and the septic system filter bed is constructed of imported sand. The objective was to test the hypothesis that seasonal shallow water table conditions that occur periodically in these settings might cause enhanced P mobility because of possible solubilization of P solids accumulated in the filter bed or because wastewater oxidation becomes less complete at these times. We are unaware of previous studies that have assessed long-term (decadal) P mobility in such settings. Furthermore, detailed sediment assays have allowed the total mass of excess P retained in the filter bed to be quantified and compared with the estimated total lifetime-P loading to the septic system over 20 yr of operation. Similar mass balances have not been presented in previous studies.

Materials and Methods

Site Description

The study site is located in central Ontario, near the town of Parry Sound (45°20′30″ N, 80°00′30″ W), and has a septic system of conventional design, which treats wastewater from a single-family residence located on the shoreline of a soft water lake. The septic system consists of a concrete septic tank and gravity-fed filter bed, 15 by 10 m in area, with seven, 15-m-long infiltration pipes of 10-cm-diameter perforated polyvinyl chloride (PVC) pipe (Fig. 1). Fractured granitic bedrock outcrops at the site and silty soils up to 2 to 3 m in thickness occur in pockets between the bedrock outcrops. The filter bed infills an area between two outcrops (Fig. 1) and consists of up to 1.4 m of silt-free, medium-coarse sand (Fig. 2, 3), imported from a local sandpit. The sand has d grain diameter of 0.22 ± 0.05 mm (n = 5), is noncalcareous (acid-extractable Ca = 0.43 ± 0.06% w/w, n = 5), and has substantial acid-extractable Fe (2.1 + 0.4% w/w, n = 5) and Al (0.59 ± 0.09% w/w, n = 5) contents, which presumably reflect the presence of oxyhydroxide minerals, such as ferrihydrite and gibbsite. The infiltration pipes are surrounded for a radius of 15- by 2-cm-diameter filter gravel.

The residence has been permanently occupied by two persons since the septic system was commissioned in 1990. Although water usage records are not available, the residence has an automatic dishwasher, clothes laundering facilities, etc. and is thus assumed to have water consumption and wastewater generation in an amount typical of residences in Ontario (267 L d per capita, Environment Canada, 2010). The septic tank effluent has concentrations of nitrogen (total Kjeldahl nitrogen, 81 ± 20 mg L ; NH –N, 59 ± 12 mg L), total phosphorous (7.5 ± 0.4 mg L), PO –P (7.5 ± 1.1 mg L), and Cl (63 ± 19 mg L , Table 1) that are typical of domestic wastewater (Robertson et al., 1998; Hinkle et al., 2008).

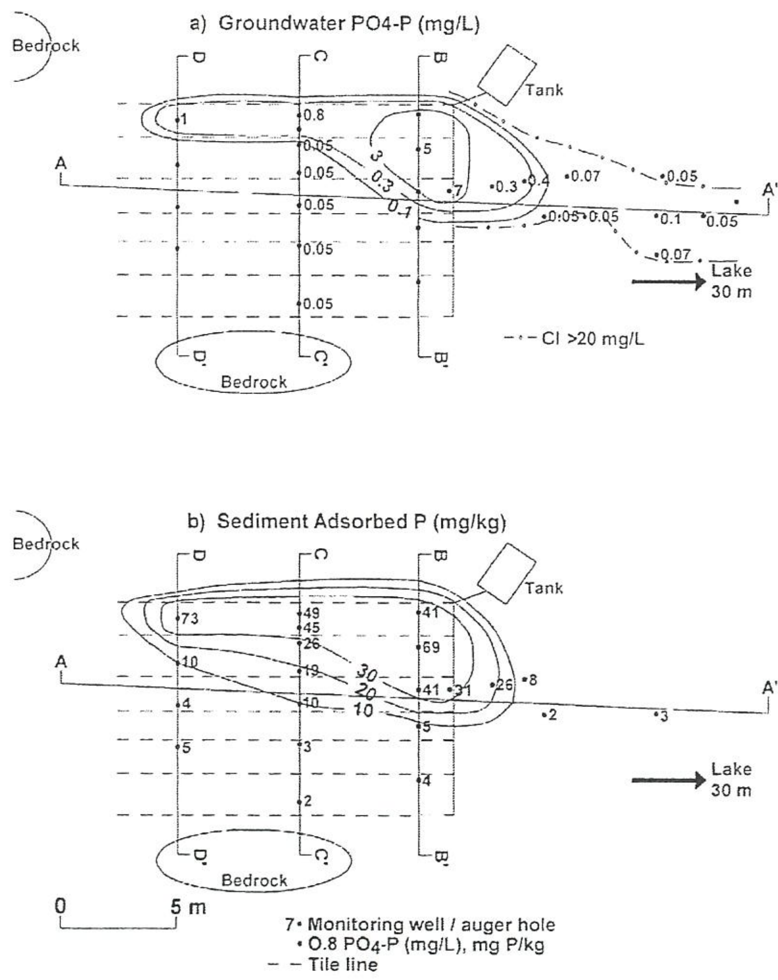

Fig. 1. Parry Sound site showing septic tank, filter-bed tile lines, and groundwater monitoring network: (a) groundwater plume outlined by maximum Cl values >20 mg L and maximum groundwater PO –P concentrations measured during years 16 to 19 of tile bed operation (2005–2008) and (b) mean desorbable-P concentration of the filter bed sand, years 17 to 18.

Sample Collection and Analyses

Multidepth monitoring wells were constructed of 1.3-cm-diameter PVC pipe with short, 5-cm-long, slotted, and screened tips, to which 0.6-cm-diameter polyethylene sampling tubes were attached at varying depths. These were installed manually using a 5-cm-diameter soil auger and sediment samples were retained at 10-cm depth increments in most cases. Installations were completed by backfilling the auger hole with the spoil material.

Groundwater samples were collected using a peristaltic pump, during three to seven sampling events per year, over the 6-yr period from 2006 to 2011, and were filtered (0.45 μm) inline before atmospheric exposure. Samples were acidified to pH <2 with HCl immediately after collection for cation, metals, PO , and NH analyses, or were left untreated for analysis of other ions. Measurements of pH and Eh were completed inline before atmospheric exposure, using field-portable meters. The Eh readings were checked against Zobell's solution (Nordstrom, 1977) and pH readings were checked against buffers of pH 4 and 7. Nitrate and Cl were analyzed by ion chromatography, using a Dionex ICS-90 (Dionex). This provided a detection limit of <0.05 mg L for NO –N and <0.5 mg L for Cl. Ammonium was analyzed colorimetrically, using a Seal AQ2 spectrophotometer (Seal Analytical), which provided a detection limit of 0.02 mg N L . Phosphate was analyzed colorimetrically, using Seal Autoanalyser 3 (Seal Analytical), which provided a detection limit of 0.05 mg L P. Cations were analyzed by inductively coupled plasma, mass spectrometry, whereas total Kjeldahl nitrogen, total suspended sediment, and 5-d biological oxygen demand were measured using standard methods. Regression fits of PO temporal trends were obtained using Dplot software.

Sediment acid-extractable P, Ca, Fe, and Al concentrations were analyzed by leaching with an aqua regia solution of concentrated HCl and HNO for 2 h at 95°C, followed by ICP elemental analysis (PerkinElmer). This method liberates elements associated with carbonate, hydroxide, and sulfide minerals but not silicate minerals. Sediment readily desorbable, plant available, P concentrations were measured by leaching with a 0.5M NaHCO solution (McBride, 1994).

Morphology and chemical composition of the media grains were examined by scanning electron microscopy with energy dispersive X-ray (EDX) analysis. These analyses were conducted using a Leo 440 microprobe with Quartz Zone EDX system (Carl Zeiss Microscopy).

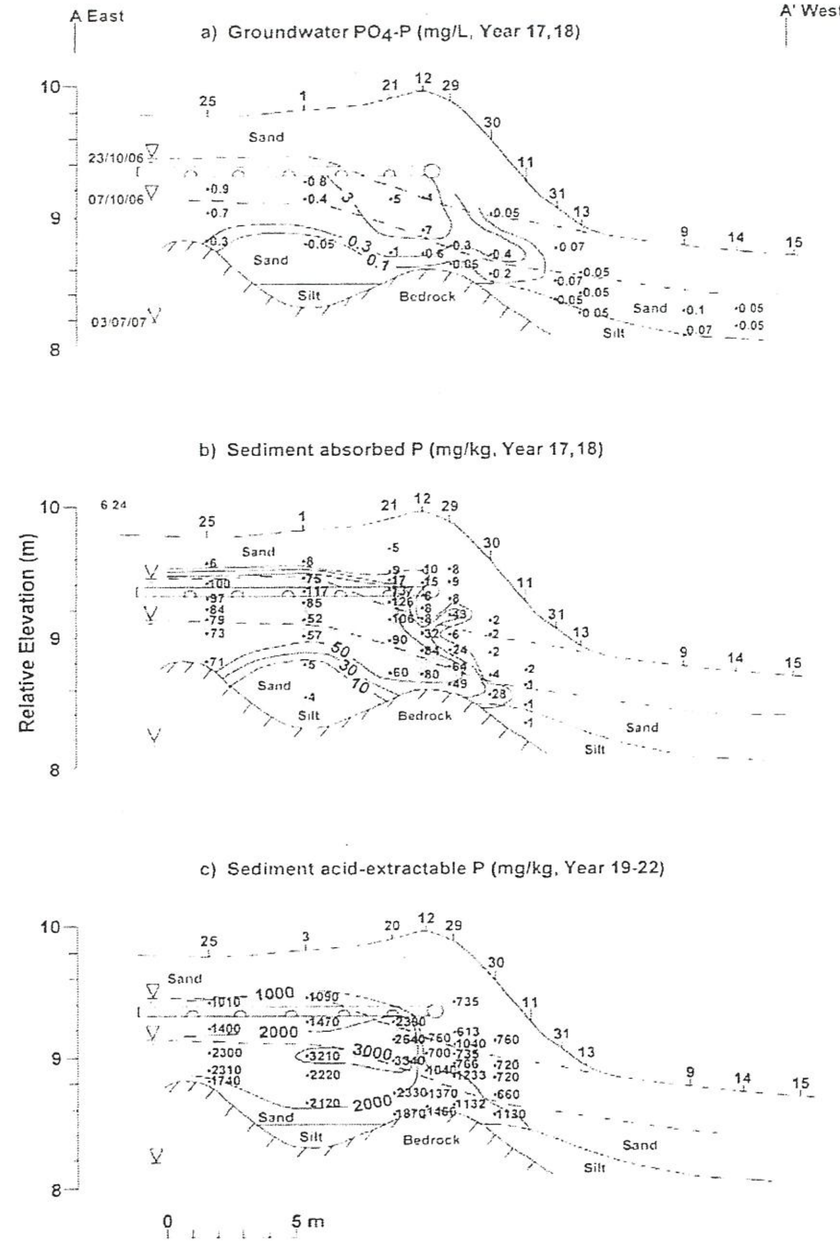

Fig. 2. Plume-core transect showing: (a) maximum groundwater PO –P concentrations measured during years 17 to 18 (2006–2007), (b) desorbable P in the filter-bed sand, years 17 to 18, and (c) acid-extractable P in the filter-bed sand, years 19 to 22. Dots in Fig. 5a represent the approximate locations of the well screens (5 cm length). PO –P values indicated as 0.05 mg L are detection limit values.

Results and Discussion

Groundwater Conditions

The water table below the filter bed varies seasonally, from ~0.4 m below surface during major precipitation/recharge events, to >1.8 m during dry periods in the summer (Fig. 2) when all of the monitoring wells are typically dry. Consequently, sampling episodes targeted shallower water table conditions in fall (October, November) and spring (April, May), after snowmelt.

Groundwater flow is toward the shoreline of a soft water lake, located 30 m down gradient from the edge of the tile bed (Fig. 1). The mean horizontal hydraulic gradient measured below the tile bed during eight monitoring events from 2006 to 2008, when the water table was relatively shallow, was 0.028 (range 0.020–0.034). Vertical gradients could not be measured using the existing monitoring network. The hydraulic conductivity of the filter sand is estimated at 0.048 cm s , based on the Hazen equation (Freeze and Cherry, 1979), using the mean d grain size diameter of 0.22 mm. Using these parameters and assuming effective porosity of 0.35 in the saturated zone, the Darcy equation yields an extremely fast horizontal average linear groundwater velocity of 3.3 m d . This velocity pertains specifically to the shallow water table periods. However, yearly average values are likely much lower.

Plume Development

The above estimate of horizontal velocity (3.3 m d) indicates that groundwater traverses the entire 15-m length of

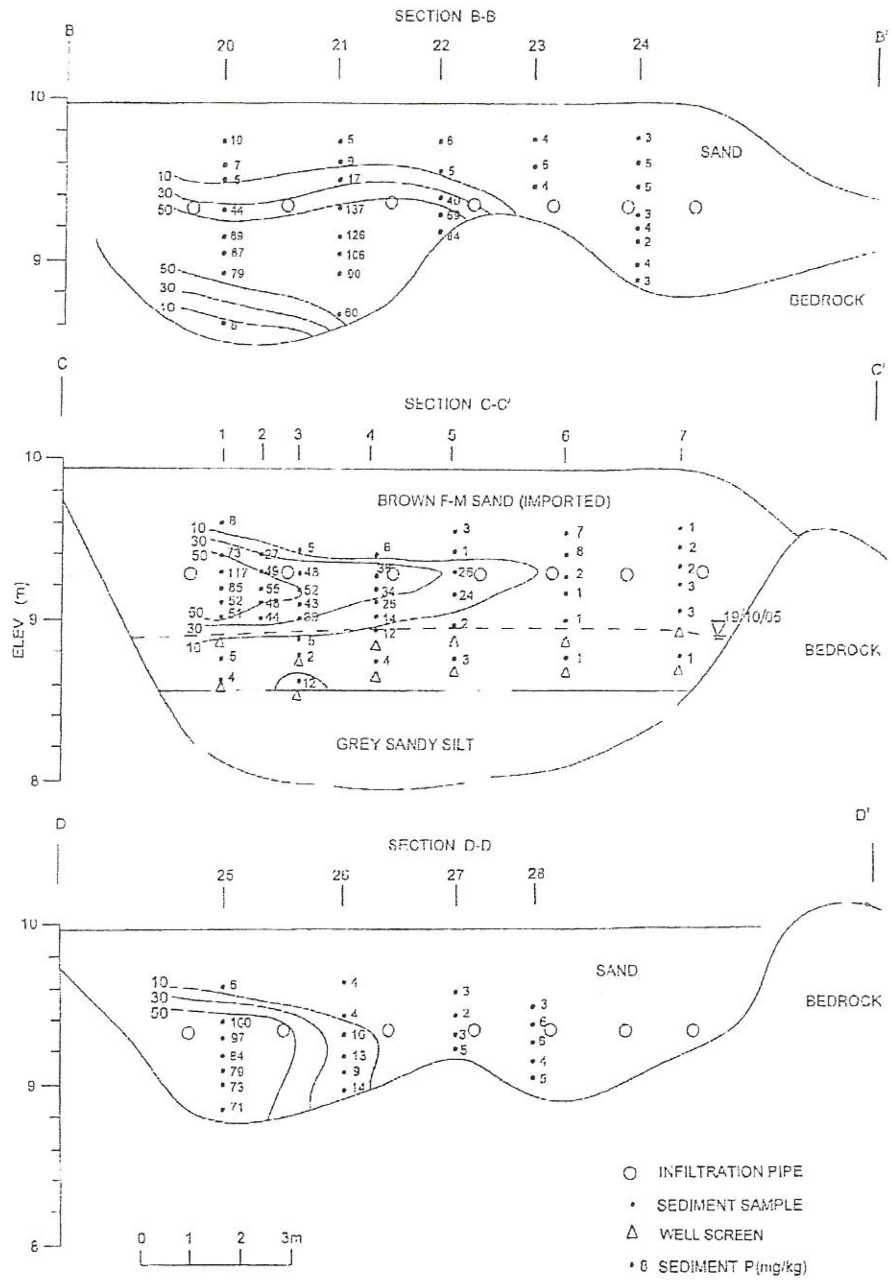

Fig. 3. Depth distribution of desorbable P in the filter-bed sand along transects B, C, and D in year 17 (2006).

the filter bed in ~5 d during shallow water table conditions. This is when most monitoring was undertaken. Considering the estimate of effluent loading to the tile bed (530 L d) and area of the tile bed that is in active use (80 m , see following section), wastewater loading is estimated at 0.66 cm d . Again, assuming saturated porosity of 0.35 in the groundwater zone, the effluent vertical (downward) velocity near the water table would be 1.9 cm d . This leads to a vertically thin wastewater plume that is only ~20 cm in thickness at the down-gradient edge of the tile bed during the shallow water table periods when most of the monitoring was done. The multidepth groundwater monitoring network encompasses a greater vertical depth of ~1 m, and consequently, most monitoring points only intermittently encounter the wastewater plume—depending on the seasonal position of the water table. Parameters, such as Cl, vary greatly—from >20 mg L within the plume to <2 mg L in the background groundwater. Consequently, large standard deviation values, typically 50 to 100% of the mean values, occur at most monitoring locations (Table 1). Lower Cl values indicate that the plume core is diluted by a factor of three to six, compared with the septic tank effluent (Table 1). This dilution is likely caused by the fluctuating depth position of the plume, rather than being the result of hydrodynamic dispersion, and illustrates the difficulty in monitoring small-scale contaminant plumes under such fluctuating water table conditions.

Figure 1a shows the outline of the groundwater plume during years 16 to 19 of tile bed operation, based on the occurrence of Cl values >20 mg L , which are shown to extend down gradient toward the lake. A distinct PO zone is also present (Fig. 1a) but is limited to an area within 5 m of the tile bed. Several monitoring points in the PO zone (well 12–1.2) and near its down-gradient edge (wells 30–0.9 and 31–0.5) were targeted for more frequent sampling (up to 25 sampling episodes during 2005–2011, years 16–21). Wastewater parameters at these three points are compared with the septic tank effluent values in Table 1. Seasonal and longer-term temporal trends of PO –P and pH at these locations are shown in Fig. 4 and 5. Nitrogen occurred predominantly as NH in septic tank effluent. However, in the monitoring wells, nitrogen occurred primarily as NO (Table 1). This demonstrated that relatively thorough oxidation of the wastewater did generally occur, despite the shallower water table conditions that were present during some sampling events. The mean PO –P value in the proximal monitoring point (well 12–1.2) was 3.1 mg L , which is 41% of the effluent mean value of 7.5 mg L . In contrast, mean values at the two down-gradient locations (wells 30–0.9 and 31–0.5) were much lower at 0.22 and <0.06 mg L , respectively, which was only <1 to 3% of the effluent value.

Desorbable Phosphorus

Figure 1b shows the area of desorbable P enrichment in plan view, whereas Fig. 2b and 3 show concentrations of desorbable P

Table 1. Means and standard deviations of wastewater parameters in the septic tank effluent and in the plume monitoring wells at increasing distances from the tile tiles, 2005–2011.

		Monitoring wells		
Parameter†	Tank	12–1.2	30–0.9	31–0.5
Distance (m)	0.0	0.5	3.7	5.6
EC (μS cm)	1456 ± 314	370 ± 305	217 ± 118	164 ± 82
pH	6.8 ± 0.4	6.0 ± 0.3	6.0 ± 0.3	5.9 ± 0.2
Eh (mV)	52 ± 33	417 ± 36	381 ± 34	–‡
BOD (mg L)	147 ± 10	–	–	–
Alk (mg L)	410	–	–	–
Cl§ (mg L)	63 ± 19	21 ± 13	17 ± 9	11 ± 9
PO –P§ (mg L)	7.5 ± 1.1	3.1 ± 1.7	0.22 ± 0.14	<0.06 ± 0.05
TP (mg L)	7.5 ± 0.4	–	–	–
NO –N§ (mg L)	0.2 ± 0.1	24 ± 22	9.5 ± 8.7	2.9 ± 3.3
NH –N (mg L)	59 ± 12	1.1 ± 2.8	0.02 ± 0.01	<0.01
TKN (mg L)	81 ± 20	–	–	–
Ca (mg L)	5.0 ± 2.3	0.97 ± 0.31	1.7 ± 1.3	4.2 ± 1.2
Fe (mg L)	0.31 ± 0.13	0.20 ± 0.01	0.20 ± 0.02	0.94 ± 0.06
Al (mg L)	0.34 ± 0.01	0.63 ± 0.03	0.22 ± 0.02	0.20 ± 0.03
Mn (mg L)	0.04 ± 0.03	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.02

† EC = electrical conductivity; BOD = 5-d biological oxygen demand; alk = alkalinity; TP = total phosphorus; TKN = total Kjeldahl nitrogen.

‡ No data available.

§ n = 7–25.

along transect A, which follows the plume centerline and along sections B, C, and D, which are transverse sections through the filter bed at increasing distances from the septic tank. Desorbable P is distinctly enriched in the sand below the first four tile lines (30–137 mg kg), compared with background values of <6 mg kg . Enrichment is strongest at 0.5- to 1-m depth, which is immediately below the tile lines. The remaining three tile lines show no evidence of P enrichment. This highly variable P distribution demonstrates that effluent has discharged only through the first four tile lines (closest to the septic tank) over the entire operating life of the system. Consistent with this, thicker grass cover was noted over first and second tile lines. Irregular loading is not unexpected for a gravity-fed tile bed such as this.

Acid-Extractable P

Figure 2 also shows the distribution of acid-extractable P along the plume centerline transect, A-A′. Similar to desorbable P, acid-extractable P is considerably enriched (1010–3340 mg kg) in a zone that extends up to 1 m below the tile lines, compared with background values of ~700 mg kg , with maximum values occurring 20 to 40 cm below the tile line. The zones of elevated acid-extractable P, desorbable P, and groundwater P are all roughly in the same location (Fig. 2).

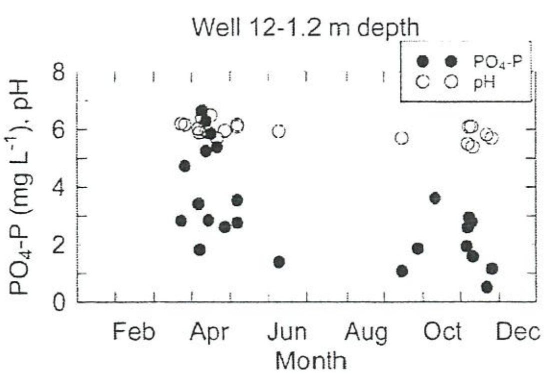

Fig. 4. Seasonal trends of PO –P and pH in well 12–1.2 m depth, during 6-yr period from 2006 to 2011. Values are from individual sampling events. Well is located below the down gradient edge of the tile lines.

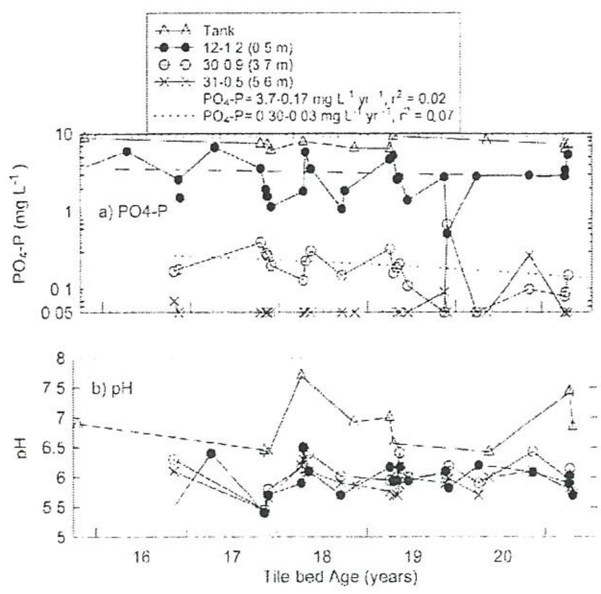

Fig. 5. Longer-term trends of groundwater: (a) PO –P and (b) pH during years 16 to 22 of tile bed operation (2005–2011). Shown are monitoring locations below the tile lines (well 12–1.2 m depth, 0.5 m below the tile lines) and at increasing distances down gradient of the tile lines (well 30–0.9, 3.7 m down gradient; and well 31–0.5, 5.6 m down gradient). See Fig. 2 for well locations. Dashed and dotted lines are linear regression fits of the well 12–1.2 and 30–0.9 data, respectively.

PO_4 Temporal Trends

The plume PO –P concentrations show considerable seasonal variability (Fig. 4), with peak concentrations >5 mg L occurring consistently in April, immediately after spring snowmelt. The larger PO –P concentrations do not appear to be associated with lower pH values that might result from snowmelt (Fig. 4). Rather, lowest pH values in well 12–1.2 occurred in the fall (pH 5.4–5.5, November, 2006 and 2007, Fig. 5b) and were associated with relatively low PO –P values (1.6–2.6 mg L , Fig. 5a). This suggests that the observed spring PO –P increase is more likely the result of the shallower water table conditions that occur in April as a result of the added recharge from snowmelt. This may then promote the reductive dissolution of ferric oxyhydroxide mineral coatings (e.g., Zurawsky et al., 2004) that are present on the sand grains and contain P (see below). However, despite these seasonal PO –P increases, down-gradient migration of the P plume has apparently remained limited.

There is no evidence of longer-term increasing PO –P concentration trends at any of the monitoring points (Fig. 5). This is in contrast to distinct increasing PO –P trends observed in the fontal portion of another septic system plume in Ontario (Long Point site), where the aquifer sand was calcareous (6.3% w/w Ca), plume pH values were near neutral, and reversible sorption was apparently the principal P attenuation mechanism in the groundwater zone (Robertson, 2008). The differing temporal behavior at Parry Sound points to a different attenuation mechanism, one that is robust and has considerable long-term sustainability.

Phosphorus Mass Balance

The Parry Sound site has been the permanent residence of two occupants since the septic system was commissioned in 1990. Assuming per capita water use at the typical Ontario residential rate of 267 L d (534 L d total) and considering the mean septic tank PO –P concentration of 7.5 mg L (n = 12, Table 1), PO –P loading to the tile bed was estimated at 1500 g yr or a total of 33 kg P over 22 yr of use to 2011. Figure 6 shows the total excess acid-extractable P mass at each coring location, calculated on an areal basis (g m). For this calculation, the mean excess concentration at each location was calculated as the mean concentration of all samples from the core (n = 4–7) minus the mean background concentration. The background concentration was calculated as the mean value from core 30 (798 mg kg , n = 5, Fig. 2c), which lies outside of the main zone of P accumulation. Total excess mass was then calculated by multiplying the excess concentration at each location by the cored depth for which acid-extractable sample data were available (0.3–1.4 m) and assuming bulk density of the filter-bed sand of 1.5 g cc . Considering the anomalous area represented by the 1000-g m contour in Fig. 6 (~ 25 m) and mean value of the three cores from within this zone (1557 g m), 39 kg of excess acid-extractable P was estimated to be retained in the filter-bed sediments. The total mass of excess desorbable P in the filter-bed sand, calculated in a similar manner, but this time considering the somewhat larger anomalous area (80 m) represented by the 10-mg kg contour shown in Fig. 1 (11 coring locations with mean desorbable P of 43 g m), is much less at only 3.4 kg. These calculations show that the excess P mass retained in the filter-bed sand as a result of sewage loading is most effectively represented by the acid-extractable-P assay and this P mass (39 kg) is similar to the estimated total lifetime P loading to the system of 33 kg. The desorbable-P assay, although it represented only a small fraction (9%) of the total excess P mass present, showed a much greater degree of relative enrichment in the anomalous area (up to 25 times greater than the background concentration). This assay is thus a more sensitive indicator of sediment-P accumulation and consequently can be useful in mapping the location of such zones.

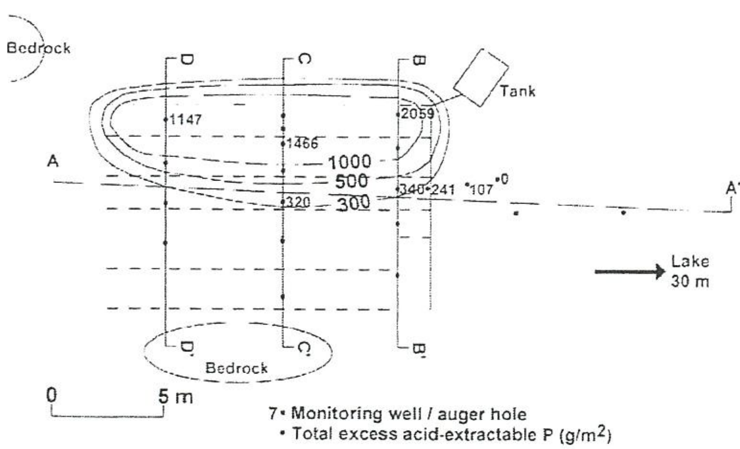

Fig. 6. Total mass of excess acid-extractable P measured in the filter-bed sand, years 19 to 22 (2008–2011).

Mechanisms of Phosphorus Retention

The mass of excess acid-extractable P retained in the filter bed (39 kg) was 11 times greater than the excess desorbable P mass (3.4 kg); thus, adsorption is likely not the principal mechanism causing P retention at this site. Electron microprobe images of sand samples from below the tile lines (Fig. 7, 8) show the ubiquitous presence of secondary mineral coatings on most of the sediment grains. These coatings exhibit considerable thickness (5–100 μm) and appear to develop most prominently on quartz grains (Fig. 7, 8). The morphology of the coatings appear similar both below the center of the tile lines (Fig. 7a) and slightly farther down gradient at the tile bed edge (Fig. 7b). Iron and Al, the principal cations, occur in roughly similar amounts in both samples (10–21% w/w, Fig. 7). These coatings appear to represent the precipitation of authigenic ferric and Al oxyhydroxide minerals onto the sand grain surfaces. Iron from the septic tank effluent (0.17 mg L , Table 1), which presumably occurs as Fe (II), could provide a source of Fe (III) for such mineral precipitates when oxidation occurs in the unsaturated zone. Likewise, Al present the septic tank effluent (0.34 mg L , Table 1) could also provide a source of Al for these mineral coatings. Phosphorus was intimately associated with these secondary coatings and occurs uniformly throughout their thickness as indicated by the electron dot maps shown in Fig. 8. The P content of the coatings was greatest close to tile lines (9.9% w/w P, 0.7 m depth, Fig. 7a) and decreased somewhat to 3.2% w/w P at slightly greater depths (1.2 m depth, Fig. 7b). This behavior suggests that P is incorporated as a component of the mineral precipitate but in a proportion that varies depending on the porewater-P concentration, which is greatest close to the infiltration pipes. Previous microprobe studies of sludge from sewage treatment plants, where Fe reagents were used to control P, have noted similar Fe–P precipitates with P contents that vary as a function of the effluent-P concentration (He et al., 1996). Thus, P immobilization at Parry Sound appears analogous to processes that are used in conventional sewage treatment, except that Fe (and Al) are delivered naturally by the system in this case. The source of these cations could be from the effluent itself, as mentioned above, or dissolution of pre-existing oxyhydroxide coatings present on the sand grains. Reductive dissolution of ferric hydroxide coatings could occur in local reducing zones that may be present immediately adjacent to the tile lines, as has been suggested previously (Zanini et al., 1998), or from seasonally transient reducing zones that may develop when the water table is shallow (e.g., Zurawsky et al., 2004).

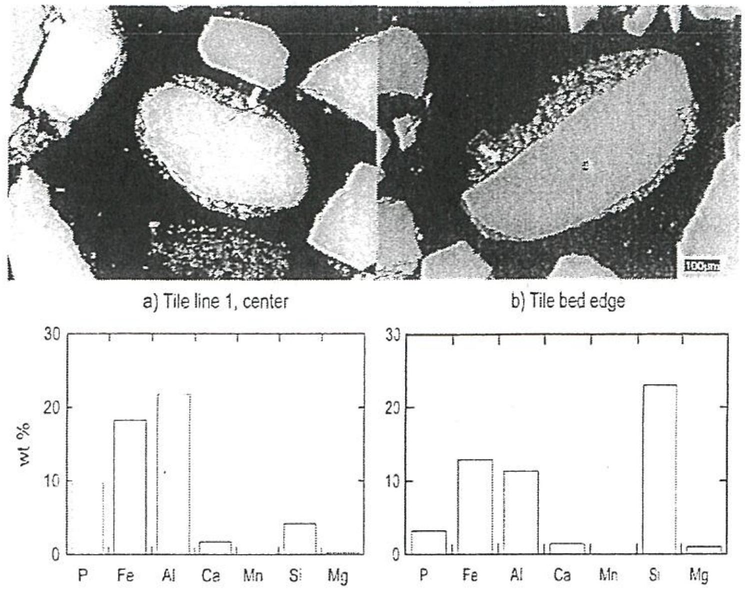

Fig. 7. Backscattered electron images of filter sand from: (a) below the center of tile line 1 (core 1; 0.7 m depth) and (b) below the down-gradient edge of the tile lines (core 12-1.2 m depth), showing quartz grains with secondary mineral coatings and bar graphs showing elemental composition of coatings at the locations indicated by the arrows.

The variable composition of the mineral coatings shown in Fig. 7 suggests that these may represent amorphous precursors to more crystalline mineral phases, such as strengite (FePO ·2H O) or variscite (AlPO ·2H O). Previous microprobe studies of P solids from septic system filter beds have also noted the presence of Fe–Al–P coatings with variable compositions (Zanini et al., 1998; Robertson, 2003). Predicting aqueous-phase PO concentrations in equilibrium with such solids is uncertain. Nonetheless, solubility curves presented previously for variscite, in equilibrium with gibbsite (AlOH ·H O) (Robertson et al., 1998), indicated an equilibrium PO –P concentration of 0.4 mg L at pH 6.0, which is close to the mean concentration in the mid-distance monitoring point at this site (0.2 mg L , well 30–0.9, Table 1). Groundwater in the more proximal well 12–2 has a greater mean PO –P concentration of 3.1 mg L (Table 1), suggesting supersaturation with respect to variscite. Likewise, solubility curves presented previously for strengite in equilibrium with ferrihydrite (FeOH ·2H O) (Robertson et al., 1998) suggest an equilibrium PO –P concentration of 0.3 mg L at pH 6.0. These comparisons support the likelihood of mineral precipitation reactions that involve P occurring within the filter-bed sediments.

Acidity Generation

Previous septic system investigations in Ontario showed that sites exhibiting greatest P attenuation were those on noncalcareous sands where acidic groundwater plumes were present (pH 4.0–5.7, Robertson et al., 1998; Robertson, 2003). Similarly, the filter bed sand at Parry Sound has a low calcium carbonate mineral content (Ca = 0.43% w/w) and acidic conditions do occur in the plume (mean pH 6.0, Table 1). Considering oxidation of just the NH –N present in the septic tank effluent (Eq. [1]):

NH + 2O → NO + 2H + H O [1]

(mean of 59 mg L or 4.2 mM), 8.4 mM of acidity would be generated, which would require 4.2 mM of alkalinity (420 mg L as CaCO) to neutralize. This is greater than the alkalinity available in the effluent (410 mg L as CaCO , Table 1) and oxidation of other constituents (e.g., reduced S, organic N) will cause further acid generation (Wilhelm et. al., 1996). Thus, thorough oxidation of the effluent in the vadose zone at this site consistently generates acidic porewater that then persists in the plume (Fig. 5b) because of the lack of carbonate mineral buffering

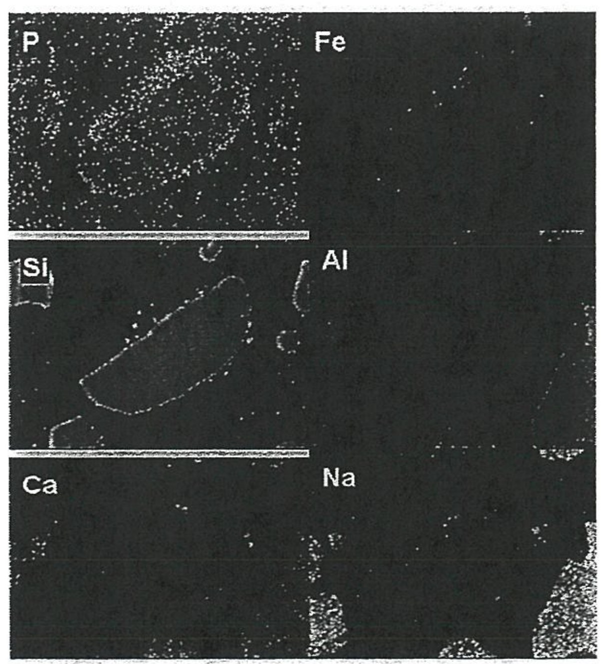

Fig. 8. Elemental dot maps showing distribution of P, Fe, Al, Ca, Na, and Si in the sediment grains shown in Fig. 7b.

capacity. Under acidic conditions, Al and Fe concentrations can increase as a result of gibbsite and ferrihydrite dissolution, which can then promote the precipitation of Al–P and Fe–P minerals, such as variscite and strengite or their amorphous precursors (Zanini et al., 1998; Robertson, 2003). The occurrence of Al, Fe, and P as major components of these mineral coatings (3.3–22% w/w, Fig. 7, 8) supports this reaction pathway.

Conclusions and Implications

Mapping of excess phosphorus accumulation in this 20-yr-old septic system filter bed shows that almost all of the sewage loading occurred in the first four of seven tile lines present. The excess acid-extractable P mass that is retained within ~1 m of the tile lines (39 kg) can account for essentially all of the sewage P loading that occurred over the life of the system (33 kg). Monitoring of the groundwater plume during years 16 to 22 showed that, although elevated mean PO –P values of up to 3.1 mg L were present below the tile bed, no detectable PO –P (<0.05 mg L) was present beyond 5 m from the edge of the tile bed. Temporal trends of PO –P showed seasonal variability with maximum concentrations occurring shortly after snowmelt in April. However, there is no evidence of increasing longer-term concentrations at any of the monitoring points. This filter bed, which consists of Fe- and Al-rich, noncalcareous sand imported to the site, has retained essentially all of the wastewater P loaded to the system over several decades of operation. Phosphorus retention at this site is considerably more robust than at some other septic system sites that are on calcareous sands, where distinct P plumes >10 m in length are present (e.g., Robertson et al., 1998; Robertson, 2008). The noncalcareous sand used at the Parry Sound site has allowed acidic conditions (mean pH 6.0) to persist in the plume, which appears to enhance P retention. Similar robust P retention has been observed previously at other sites on noncalcareous sands (Robertson, 2003). This observation of long-term P retention opens up the possibility of improving natural attenuation of P during on-site wastewater disposal by prescribing specific sand types for filter bed construction.

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APPENDIX F – 2004 SURVEY OF PHOSPHORUS CONCENTRATIONS IN FIVE CENTRAL ONTARIO SEPTIC SYSTEM PLUMES (2005), AND, PHOSPHORUS DISTRIBUTION IN A SEPTIC SYSTEM PLUME ON THIN SOIL TERRAIN IN ONTARIO COTTAGE COUNTRY (2006), PREPARED BY DR. ROBERTSON, DEPARTMENT OF EARTH SCIENCES, UNIVERSITY OF WATERLOO

2004 Survey of Phosphorus Concentrations in Five Central Ontario Septic system Plumes

Report Prepared for:
Ontario Ministry of the Environment
Dorset Research Centre,
Dorset, ON

Prepared by;
W.D. Robertson
Dept. of Earth Sciences
University of Waterloo

February 16, 2005

Introduction

During the 1990s, University of Waterloo personnel undertook detailed studies of phosphate (PO_4) mobility in a number of septic system groundwater plumes in Ontario, and noted a subset of sites where P attenuation was distinctly greater. At these sites acidic conditions (pH 3.5-5.9) had developed as a result of an absence of carbonate mineral buffer capacity in the sand, groundwater Al concentrations were elevated (up to 24 mg/L), and PO_4 consistently remained < 0.1 mg L P which was < 2 % of the septic tank effluent values. PO_4 attenuation resulted indirectly from the elevated Al concentrations (Fig. 1) which promoted the precipitation of Al+P minerals such as variscite ($Al(PO_4).2H_2O$) (Robertson et al., 1998; Zanini et al.,1998; Robertson et al., 2003). At other sites where carbonate mineral rich sands were present and neutral pH conditions existed, PO_4 concentrations in proximal plume zones routinely reached much higher values of 1-5 mg/L P or about 50-75% of the septic tank effluent value (e.g. Cambridge site, Fig.1). In consideration of the dramatically higher P attenuation indicated at the acidic sites, three of these sites, Muskoka, Lake Joseph, and Killarney all located in Ontario cottage country, were resampled in 2004 to confirm the persistence of the previously indicated high levels of P attenuation. Additionally, sampling was undertaken at two new sites located on Sturgeon Bay, near Pointe au Baril, ON.

Sampling

Resampling of the previously installed groundwater monitoring networks was undertaken at the Muskoka, Lake Joseph and Killarney sites during April-October, 2004. In addition, groundwater monitoring was undertaken at two new sites on Sturgeon Bay, near Pointe au Baril, ON. Here P loading from septic systems has come under scrutiny because of the recent occurrence of toxic blue-green algae blooms in Sturgeon Bay and because of the relatively high density of lakeshore septic systems present (Scheifer, 2003; Joy, 2003). Sampling procedure followed best available practices and was generally similar to that used previously at these sites (Robertson et al., 1998). Samples for major ions (Ca, Cl, K, Mg, Na, NH_4, NO_3), trace metals (Al, Fe, Mn), phosphorus (PO_4, TP) and TKN analyses were collected filtered (0.45 um) in two 50-500 ml plastic containers using a peristaltic pump and 8 mm dia. tubing. Immediately prior to sampling, piezometers were purged repeatedly and during sampling, field measurements of electrical conductivity (EC) and pH were obtained. One of the sample containers was acidified (pH <2) in the field with HCl, while the second container remained untreated. Additionally, a third sample was collected from a number of piezometers to allow an intralab comparison of PO_4 values (MOE, Resources Road Lab, Etobicoke, ON, vs University of Guelph, Soil and Nutrient Lab, Stone Road, Guelph, ON). The third sample, which was analyzed at the Guelph lab, was also filtered and acidified (HCl) in the field. After the initial sampling episodes, two of the sites (L.Joseph, Sturgeon Bay) were revisited in the Fall of 2004 for additional check sampling.

RESULTS

Lake Joseph Site

The Lake Joseph septic system has been in operation for more than 15 years and services a seasonal use recreational resort. The tilebed area is graded and slightly elevated and is constructed of local sands. A relatively thick (> 5 m) sand aquifer underlies the site.

Lake Joseph site results in 2004 (Fig. 2, Table1) were generally similar to previous results in 1998 (Table 6). High values of Cl (17-129 mg/L), Na (31-74 mg/L) and NO_3 (1-17 mg/L as N) demonstrated that the plume core zone remained intact in the downgradient piezometers (nests 13, 20 and 21, Fig.2). Moderately acidic pH values occurred (5.9-6.1) that were similar to previous values (5.8, Table 6). Moderately low Al values were present (0.02-0.03 mg/L, Table 1), that were also similar to previous values (Fig.1). PO_4 values (0.02-0.32 mg/L, Table 1) were also generally similar to previous values (0.01-0.15, Fig.1, Fig.7), except for one higher value (1.39 mg/L P) that repeat sampling in October suggested was an erroneous value. Note that U of G lab values in five of the plume core piezometers were significantly higher (0.06-0.09 mg/L P) than the MOE lab values (<0.02 mg/L P). Previous results (Fig.1, Table 6) support the validity of the U of G results. The lower MOE values are possibly the result of the use of the unacidified sample bottle for PO_4 analysis, which may have allowed P to combine with trace levels of Fe and precipitate out in the sample bottle.

The 2004 sample results suggest the Lake Joseph plume remains in a condition of steady state with respect to PO_4 concentrations and P levels remain generally consistent with values expected in the moderately acidic pH regime encountered. Plume P values remain < 2 % of the septic tank effluent value. However, a modestly higher PO_4 value was noted in piezometer 13-4.5 which should be confirmed with additional sampling.

Muskoka Site

The Muskoka septic system has serviced a two person permanent residence since 1988. The tile bed area is graded and slightly raised and is constructed with local sand. A relatively thick (>5 m) sand aquifer underlies the site.

Muskoka site results in 2004 (Fig.3, Table 2) were generally similar to previous results in 1995 (Table 6, Fig. 7). High values of Cl (26-36), Na (31-49 mg/L) and NO_3 (34-42 mg/L as N) demonstrated that the plume core zone remained intact in the downgradient piezometers (nests 29, 32 and 13, Fig.3). Quite acidic pH values occurred (4.4-5.6) that were similar to previous values (4.3, Table 6). Moderately high Al values were present (up to 1.6 mg/L, Table 2), that were also similar to previous values (Table 2, Fig.1). PO_4 values (<0.02 mg/L P, Table 2) were also similar to previous values (<0.1, Table 6, Fig.1, Fig.6).

The 2004 sample results suggest the Muskoka plume remains in a condition of steady state with respect to PO_4 concentrations and P levels remain generally consistent with values expected in an acidic plume. Plume P values remain < 2 % of the septic tank effluent value.

Killarney Site

The Killarney septic system has serviced a seasonal use family cottage since 1987. The tile bed has been trenched into natural sandy silt sediments present at the site, which overly bedrock at 1-2 m depth.

Killarney site results in 2004 (Fig. 4, Table 3) were not similar to previous results in 1995 (Table 6). High 1995 Cl values of up to 34 mg/L and Na of up to 31 mg/L (Table 6) were not reproduced in any of the piezometers resampled in 2004 (1-7 mg/L, Table 3). Other previous sampling (e.g.1990) had also confirmed the presence of elevated Cl levels in the plume core zone at those times (e.g.10-30 mg/L, Robertson and Blowes, 1995). Although the 2004 sampling was undertaken in May when dilution from spring runoff may have reduced solute concentrations, previous sampling in the spring (eg.May, 1990, Robertson and Blowes, 1995) had suggested that such dilution was limited to the shallowest piezometers only (<1 m depth) . This evidence suggests that the plume core zone has shifted and is no longer encountered by the monitoring network. This could occur as a result of irregular and spatially transient loading to the tile bed as a result of natural 'aging' from biomat formation, or it could be the result of other effects such as leaks in the septic tank or in the distribution piping. Although solute concentrations were unexpectedly low in the monitoring network, a number of piezometers had EC values in the range of 200-300 uS, which is still elevated compared background (83 uS, Table3). This indicates that the dispersed plume was probably still encountered in some of the piezometers during the 2004 sampling. These piezometers had modestly acidic pH values (~6.0), slightly elevated Al concentrations (0.07-0.22 mg/L) and PO_4 <0.05 mg/L, except for one of the deeper piezometers (0.11 mg/L, Fig.4). The increased P value in deeper piezometer leaves open the possibility that other areas of high P may be present in plume core zone which remained unsampled.

Sturgeon Bay

The three Sturgeon Bay septic systems studied, all have raised tile beds that were constructed with imported filter sand overlying thin (<2 m) natural sediments of sand to clay, overlying bedrock. The C and T sites are permanent two person residences, while the SN site is a seasonal use family cottage that neighbours the C site.

Sturgeon Bay results (Table 4) show that the initial monitoring networks installed through and immediately downgradient of the tile beds at the C and T sites (Fig. 6), were successful in encountering the plume core zones at both sites. Cl concentrations in the monitoring networks were high (>36 mg/L) and were similar to the tank values. Much higher Cl values at site C (1480 mg/L) were the result of salt inputs from a water treatment apparatus (Fe and sulfide removal). Site T exhibits slightly acidic conditions (pH 6.2-6.6), whereas Site C has near neutral pH (6.9) similar to the septic tank effluent value. Dominance of NH_4 over NO_3 in the plume water at Site C, indicates that the effluent has not been completely oxidized in the tile bed, thus pH remains similar to the effluent. The imported filter bed material consists of fine to medium sand at all three sites (Fig. 8). The sand is nonclacareous ($CaCO_3$ equiv. content < 1%) and has a relatively high Fe content ((9-66 mg/kg, Table 5), thus these plumes have the potential to develop acidic conditions if they are well oxidized. The high Fe content of the filter sand, probably also contributes to the elevated Fe levels found in the plumes (up to 8 mg/L, Table 4). PO_4 concentrations analyzed at the MOE lab are all low (<0.02 mg/L), whereas significantly higher values are reported in three of the U of G analyses (0.08-2.2 mg/L). It is likely that the lower MOE values are the result of the use of the unacidified sample bottle for P analyses. If significant Fe is present, as was the case here, P will be lost by precipitation with Fe in the sample bottle unless acidification has occurred.

Conclusions

1) There is no evidence to suggest that the previously indicated high rates of PO_4 attenuation (>98 %) at the Muskoka and Lake Joseph sites do not continue to persist. Continued acidic pH values and modestly elevated Al concentrations support the likelihood of continued P attenuation by precipitation as the mineral variscite ($AlPO_4.2H_2O$).
2) The apparent loss of the plume core zone at the Killarney site, highlights the difficulty of identifying plume core zones at smaller flux seasonal use septic systems and highlights the necessity of including conservative plume tracers (e.g. Cl, Na) in any sampling investigation of such plumes.
3) At the Sturgeon Bay site, PO_4 concentrations were variable but generally lower than values reported previously in a sceening survey of ~ 40 septic systems located on Sturgeon Bay (Joy, 2003). However, the sampling undertaken in the current study was not sufficiently broadbased nor of sufficient detail to establish if these results were representative of general conditions throughout the bay. The current study did, however, identify several samples with elevated PO_4 concentrations (up to 2.2 mg P/L)
4) The filter bed sand used at the C, T and SN sites on Sturgeon Bay is noncalcareous ($CaCO_3$ <1 %) and should be conducive to the development of acidic conditions and substantial P attenuation if the effluent is well oxidized. However, the C site effluent does not appear to be well oxidized (NH_4 dominates over NO_3) and pH has remained neutral. One possibility is that the high Cl and Na concentrations from the water treatment apparatus, has interfered with oxidation reactions. The T site is modestly acidic (6.2-6.6) and the effluent is more highly oxidized (NO_3 dominates over NH_4) but oxidation was still incomplete as indicated by high Fe(II) concentrations of up to 8 mg/L. PO_4 concentrations at site T were as high as 2.2 mg/L but were highly variable and some much lower values (<0.05 mg/L P) also occurred in the plume core zone. Further work needs to be done to conclusively establish the degree of PO_4 attenuation at these two sites.
5) The importance of effluent oxidation suggests that septic system plume studies should routinely include sampling for redox indicators, particularly the redox pair NH_4/NO_3 and Fe.
6) The similarity of NH_4 and TKN values at all of the sites demonstrates that reduced forms of N in septic system plumes are almost entirely dominated by NH_4 rather than organic N. Thus, in most cases, TKN analyses are unnecessary.
7) Significantly higher PO_4 concentrations observed in a number of the acidified samples compared to the unacidified samples, highlights the necessity of filtering and acidifying groundwater samples for P analysis immediately after their collection. If left unacidified, Fe oxidation reactions (conversion of Fe(II) to Fe(III)) and P stripping will usually begin in the sample bottle within a few minutes of atmospheric exposure.

Recommendations for Future Work

1) Although the present study generally confirmed the previous high degrees of PO_4 attenuation, several piezometers did exhibit higher P concentrations (Killarney and L. Joseph). These piezometers should be checked with additional sampling.
2) The two sites on Sturgeon Bay have plumes that are migrating in very thin sand layers (0.1-0.5 m thick) overlying lacustrine clay (impermeable). It is very likely that these thin, shallow flow systems experience seasonally variable saturation (less saturated during the summer) and consequently varying redox conditions that could greatly influence P mobility. Sporadically high P values were observed in these plumes. Furthermore, it could be argued that such thin, shallow flow systems are more typical of Ontario cottage country sites than are the thicker aquifer systems present at Muskoka and L. Joseph. More detailed studies of P mobility and P mass distribution in the subsurface should be undertaken at these two sites. This should involve expanding the monitoring networks, undertaking comprehensive geochemical sampling under both high and low water table conditions, and quantifying P mass solid phase distribution within the tile bed sediments.

References:

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Zanini, L., W.D. Robertson, C.J. Ptacek, S.L. Schiff and T. Mayer. 1998. Phosphorus characterization in sediments impacted by septic effluent at four sites in central Canada. J. Contam. Hydrol. 33:405-429.

Figure List

Table 1. Lake Joseph septic system site, summer camp with ~ 85 persons; sampled August 10, 2004[1].

	Tank	Plume							Transition/Background		
		x=3m[4]			x=10m		x = 20m				
		13-3.5[5]	13-4.0	13-4.5	20-4.3	20-4.5	21-4.1	21-4.4	20-5.1	21 4.7	3-3.5
Al mg/L		0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	
Ca	37	24	51	78	41	60	25	18	16	11	
Cl	88	46	99	129	86	87	41	17	16	23	
Fe	0.12	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.01	<0.4
K	7	7	8	9	8	8	6	4	4	1	
Mg	5	3	5	7	4	4	3	2	2	1	
Mn	0.05	0.02	0.07	0.30	0.18	0.12	0.02	0.01	0.01	0.02	
Na	67	61	67	73	63	64	47	31	29	15	
NH_4-N	11	0.76	0.84	<0.05	0.79	1.3	<0.05	<0.05	<0.05	<0.05	
NO_3-N	0.1	10	7	17	6	5	0.7	4	7	3	0.2
TKN		1.2	1.2	0.6	1.3	1.7	0.3	0.5	0.5	<0.05	
PO_4-P	1.2	<0.02	<0.02	0.25	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	
PO_4-P(2)		<0.05	<0.05	0.32	0.06	0.06	0.09	1.39	0.07	<0.05	<0.05
PO_4-P(3)		<0.05				0.06	0.09	0.09			
TP		<0.02	<0.02	0.29	<0.02	0.10	<0.02	0.16	<0.02	<0.02	
EC (uS)		407	500	576	605	618	388	237	234	150	
EC (3)	1367	949	992		899	875	866	548			
pH	6.8	5.9	5.9	5.9	6.0	5.9	6.1	6.1	6.3	6.1	

1) Sampled August 10, 2004, analyzed MOE lab, Toronto.
2) Sampled August 10, 2004, analyzed U of G. lab, Guelph.
3) Sampled October 26, 2004, analyzed U of G. lab, Guelph.
4) piezometer horizontal distance from the tile bed edge (0 = below tile bed).
5) piezometer numbering; first number is nest number (see map), second number is tip depth in metres.

Table 2. Muskoka septic system site, permanent 2 person residence; sampled April19, 2004[1].

	Plume							Transition/Background			
	x = 0m[2]			x = 0m		x = 6m					
	29-3	29-4	29-6	32-3	32-4	13-3	13-5	29-13	32-5	32-6	13-13
Al mg/L	0.26	0.01	0.07	0.97	0.74	0.06	1.6	0.04	0.05	0.04	0.07
Ca	43	43	45	34	44	44	34	15	11	8	15
Cl	36	32	31	26	26	29	38	11	9	9	15
Fe	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.01	0.01	0.01	0.01
K	11	11	11	10	10	9	12	4	5	4	5
Mg	5	5	5	4	5	4	5	2	2	2	2
Mn	0.06	0.04	0.04	0.06	0.07	0.02	0.09	0.15	0.02	0.06	0.07
Na	49	45	43	31	38	36	46	9	10	10	9
NH_4-N	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
NO_3-N	42	42	40	34	38	34	41	8	7	3	11
TKN	0.62	0.56	0.53	0.49	0.46	0.35	0.33	<0.05	<0.05	<0.05	<0.05
PO_4-P(1)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
TP (1)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
EC (uS)	550	604	610	519	520	614	607	182	190	151	182
pH	5.2	5.1	5.3	5.3	4.9	5.6	4.4	5.7	5.4	5.6	4.9

3) 1) Sampled April 19, 2004, analyzed MOE lab, Etobicoke .

4) 2) Piezometer horizontal distance from the tile bed edge (0 = below tile bed)

Table 3. Killarney septic system site, seasonal use cottage; sampled May 31, 2004[1].

	Tank[3]	Plume										Back
		x= 0m[4]	x = 0.6 m		x=1.2m			x = 1.7m		x = 2.0 m		
		62-1.0	61-0.8	61-1.9	60-1.0	60-1.3	60-1.9	9-1.3	9-1.9	21-1.9	DG-0.5	UG-0.5
Al mg/L	0.12	0.14	0.10	0.22	0.10	0.07	0.13	0.13	0.06	0.04	0.02	0.44
Ca	7	3	2	10	5	5	10	5	5	4	4	8
Cl	106	2	1	4	4	4	5	3	7	6	8	<
Fe	1.1	2.2	1.2	18.2	1.6	11	16	2.2	16	5.9	43[5]	0.46
K	45	3	2	4	1	5	3	2	2	2	1	0.4
Mg	2	2	2	9	3	4	6	4	4	3	1	1
Mn	0.09	0.21	0.11	1.4	0.25	0.58	1.0	0.28	0.86	0.50	0.64	0.21
Na	36	4	2	7	5	6	7	5	7	5	4	<1
NH_4-N	95	<0.05	0.5	9.1	0.4	14	6.9	2.0	4.3	3.6	<0.05	<0.05
NO_3-N	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
TKN	105	0.3	0.6	9.7	0.6	14	7.3	2.3	4.5	3.7	<0.05	<0.05
PO_4-P(1)	6.5	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PO_4-P(2)		<0.05			<0.05	<0.05	<0.05	<0.05	0.11			
TP	9.8	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.13	<0.02	<0.02	<0.02
EC (uS)	1126	86	65	280	118	285	288	150	192	150	149	83
pH	6.3	5.7	5.5	6.0	5.9	6.0	6.1	6.0	6.0	57	NM	6.3

1) Sampled May31, 2004, analyzed MOE lab, Toronto .
4) 2) Sampled May31, 2004, analyzed U of G. lab, Guelph.
3) 3) Sampled August 11, 2004, analyzed MOE lab, Toronto
4) 4) Piezometer horizontal distance from the tile bed edge (0 = below tile bed)
5) Result probably not representative (sampling problems due to low well yield)

Table 4. Sturgeon Bay septic systems, sites T (permanent 2 person residence) and C (permanent 2 person residence).

	Site T				Site C	
	Tank	Plume			Tank	Plume
		x=0m[4]	x = 4	x = 4		x = 0
		T1-1.5	T3-0.5	T5-0.5		C1-1.3
Al mg/L	0.04	0.13	0.06	0.26	0.003	0.82
Ca	6	13	5	8	47	21
Cl	57	45	40	36	1100	1480
Fe	0.39	7.7	0.60	6.6	0.02	7.6
K	13	6	8	5	18	13
Mg	2	2	3	2	8	4
Mn	0.22	0.39	0.53	3.7	0.04	0.96
Na	149	69	71	55	742	962
NH_4-N	43	4.4	0.5	3.6	71	31
NO_3-N	<0.1	22	16	2.3	<0.1	3.5
TKN	54	5.5	1.0	4.7	75	32
PO_4-P(1)	5.3	<0.02	<0.02	<0.02	7.6	<0.02
PO_4-P(2)	6.7	<0.05	2.2	0.08		0.16
PO_4-P(3)		0.07	<0.05			
TP (1)	6.8	<0.02	<0.02	<0.02	8.8	<0.02
EC (uS)	1090	370	434	406	4300	5500
EC (3)		438	613			
pH	7.1	6.2	6.6	6.6	6.9	6.9
pH (3)		6.2	6.3			

5) 1) Sampled August 12, 2004, analyzed MOE lab, Etobicoke .
6) 2) Sampled August 12, 2004, analyzed U of G. lab, Guelph.
3) 3) Sampled October 27, 2004, analyzed U of G. lab, Guelph
4) 4) Piezometer horizontal distance from the tile bed edge (0 = below tile bed)

Table 5. Carbonate mineral and leachable Fe mineral contents of the imported filter bed sand at the T, C and SN sites, Sturgeon Bay, ON. Grab samples collected with a soil auger and analyzed at the University of Guelph, Soil and Nutrient Lab. See Fig. 8 for accompanying grain size curves.

Site	Sample Depth (m)	$CaCO_3$ equiv. (wt %)	Fe (mg/Kg)
C1	1.1	0.8	66.4
C1	1.3	0.6	43.3
C2	0.7	0.5	44.5
T1	0.6	0.5	8.9
T1	1.0	0.9	33.5
SN	0.5	0.2	13.6

Table 6. Septic tank effluent and representative plume core samples in 2004 compared to samples obtained 6-9 years previously.

	Muskoka			Lake Joseph				Killarney			
	1995[1]		2004	1998[2]		2004		1995[1]		2004	
	Tank	32-3	32-3	Tank	13-4.0	Tank	13-4.5	Tank	61-0.8	Tank	60-1.3
Al mg/L	0.07	3.5	0.97				0.02	<0.1	0.08	0.12	0.07
Ca	10	34	34	37	46	37	78	11	10	7	5
Cl	41	36	26	166	178	88	129	89	34	106	4
Fe	0.14	0.03	0.03	0.16	0.03	0.12	0.02	0.88	18	1.1	11
K	12	15	10		9	7	9	43	18	45	5
Mg	3	4	4		3	5	7	6	5	2	4
Mn	0.02	0.37	0.06		0.04	0.05	0.30	0.10	0.42	0.09	0.58
Na	54	51	31	117	148	67	73	58	31	36	6
NH_4-N	34	0.1	<0.05	22	<0.1	11	<0.05	111	73	95	14
NO_3-N	<0.1	37	34	0.1	24	0.1	17	<0.1	<0.1	<0.05	<0.05
TKN			0.49				0.6			105	14
PO_4-P	6.7	0.08	<0.02	6.3	0.08	1.2	0.25	14.2	3.1	6.5	<0.02
TP			<0.02				0.29			9.8	<0.02
EC (uS)			519		1026	1367	576	1032	601	1126	285
pH	6.6	4.3	5.3	6.6	5.8	6.8	5.9	6.5	6.5	6.3	6.0

1) From Robertson et al., 1998.
2) From Robertson et al., 2003.

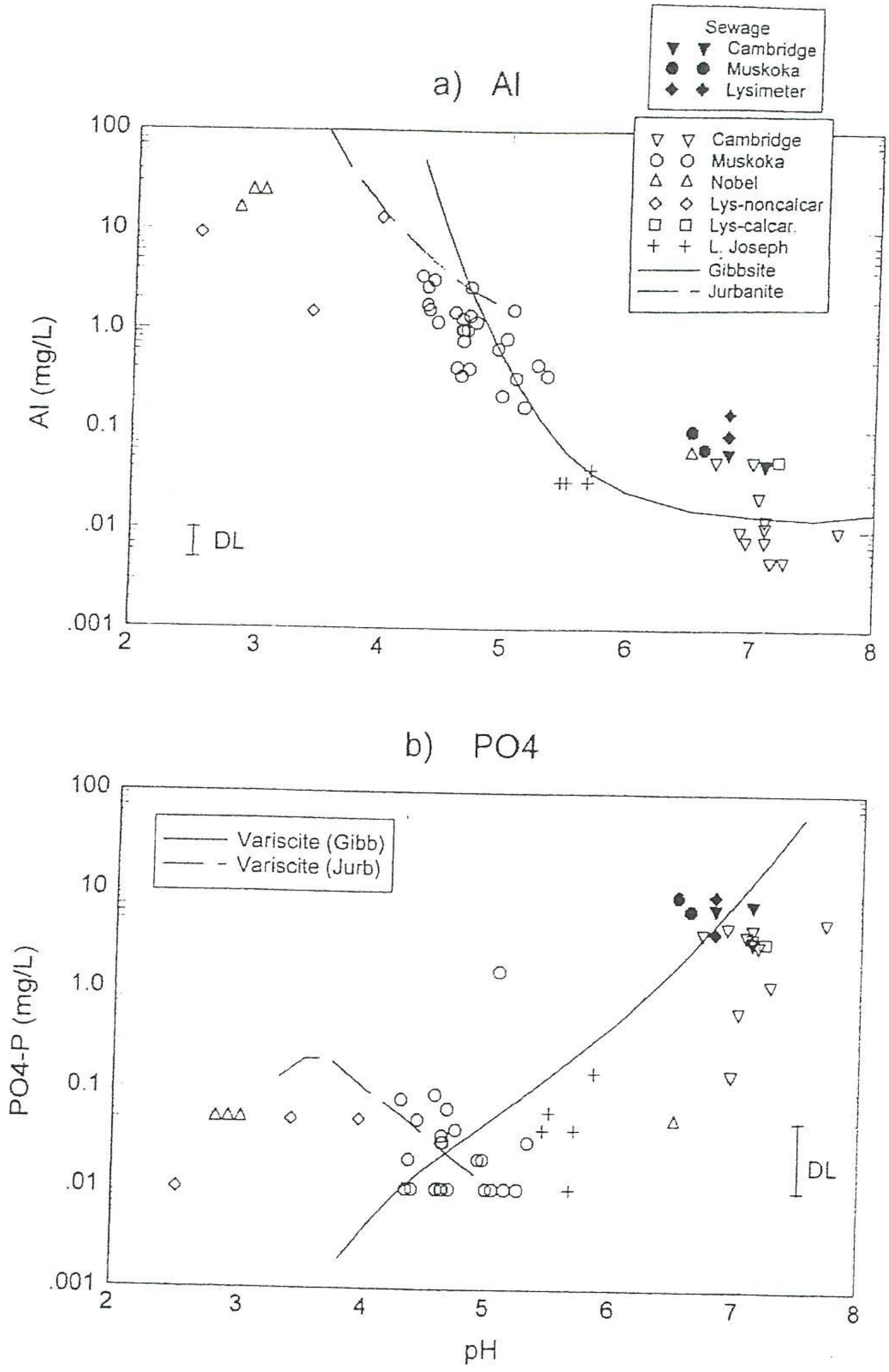


Fig. 1. Previous 1995-2000 data (from Robertson, 2003);

a) Al and b) PO_4 concentrations in the septic tank effluent, lysimeter effluent and the four septic system plumes, compared to the solubility of gibbsite, jurbanite and variscite Variscite curves assume equilibrium with gibbsite or jurbanite Solubility curves were calculated using the Muskoka plume water composition given by Robertson et al (1998) (Table 3) and the chemical equilibrium model PHREEQE (Parkhurst et al 1985), gibbsite (microcrystalline), $AL(OH)_3 + 3H^+ \rightarrow Al^{3+} + 3H_2O$, log K_{sp}= 9 35, PHREEQE database, jurbanite, $Al\,OH\,SO_4\,5H_2O \rightarrow Al^{3+} + OH^- + SO_4^{2-}$, log K_{sp} = -17 8 (Nordstrom, 1982); variscite, $AlPO_4\,2H_2O \rightarrow Al^{3+} + PO_4^{3-} + 2H_2O$, log K_{sp} = -21 (Stumm and Morgan, 1981)

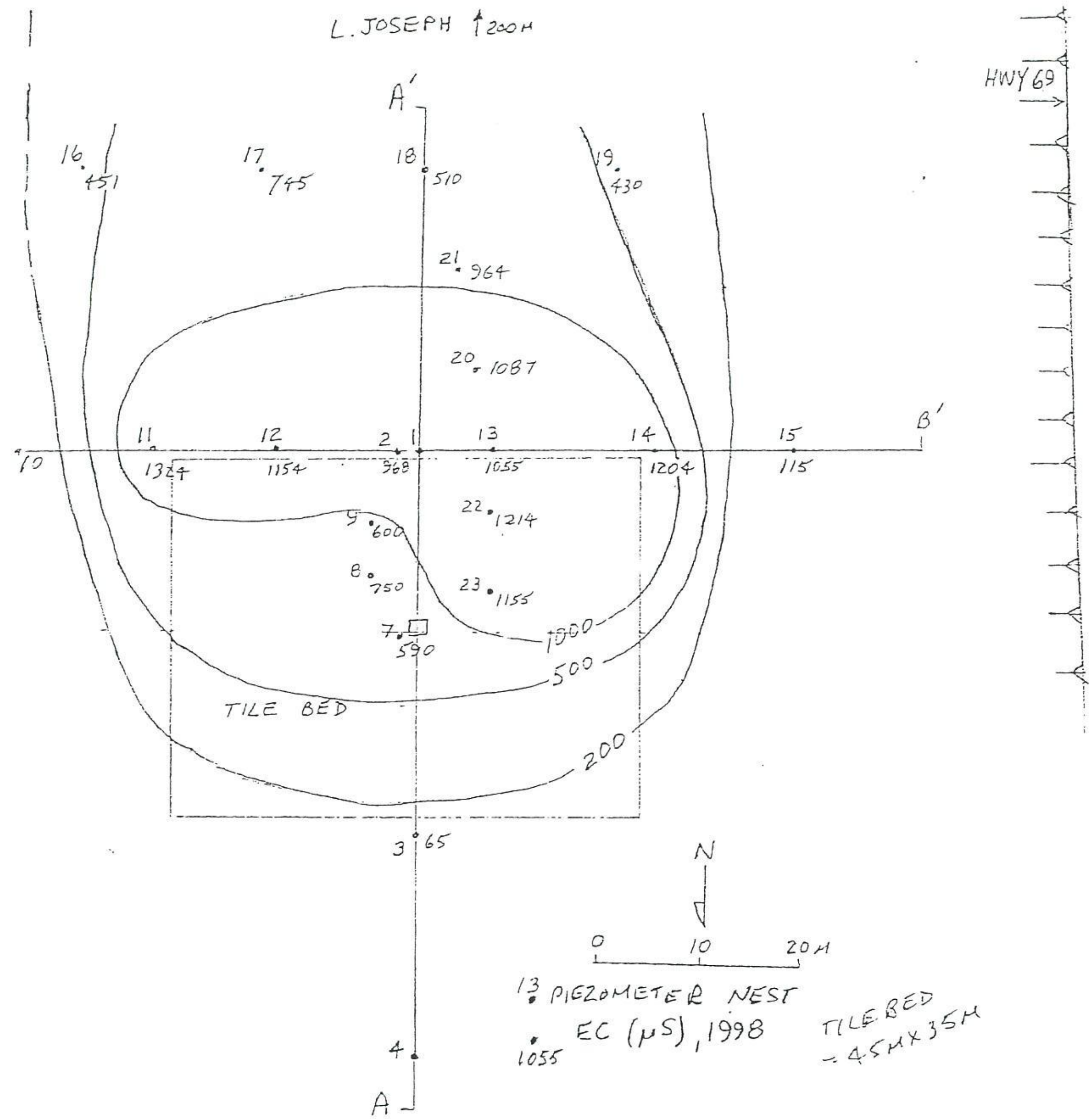


Fig. 2. Lake Joseph septic system site map

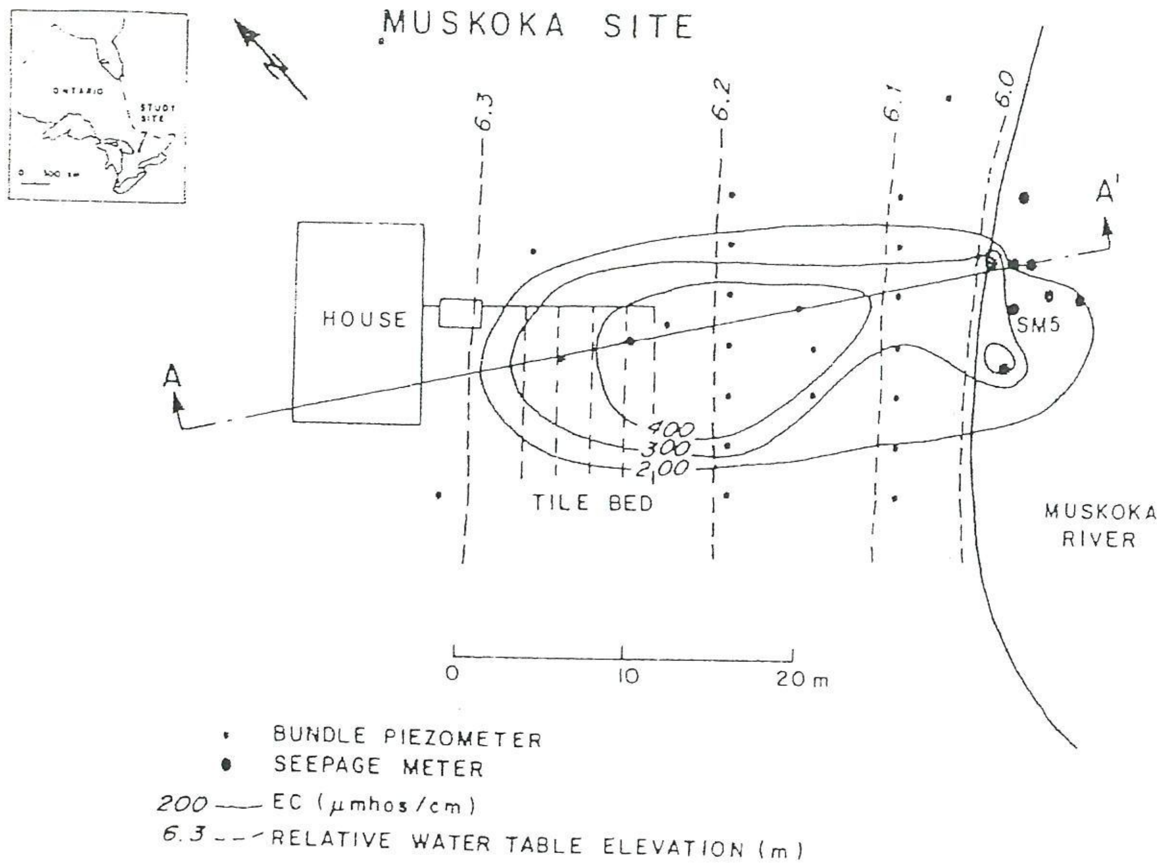


Fig. 3. Muskoka septic system site map (from Robertson et al., 1991)

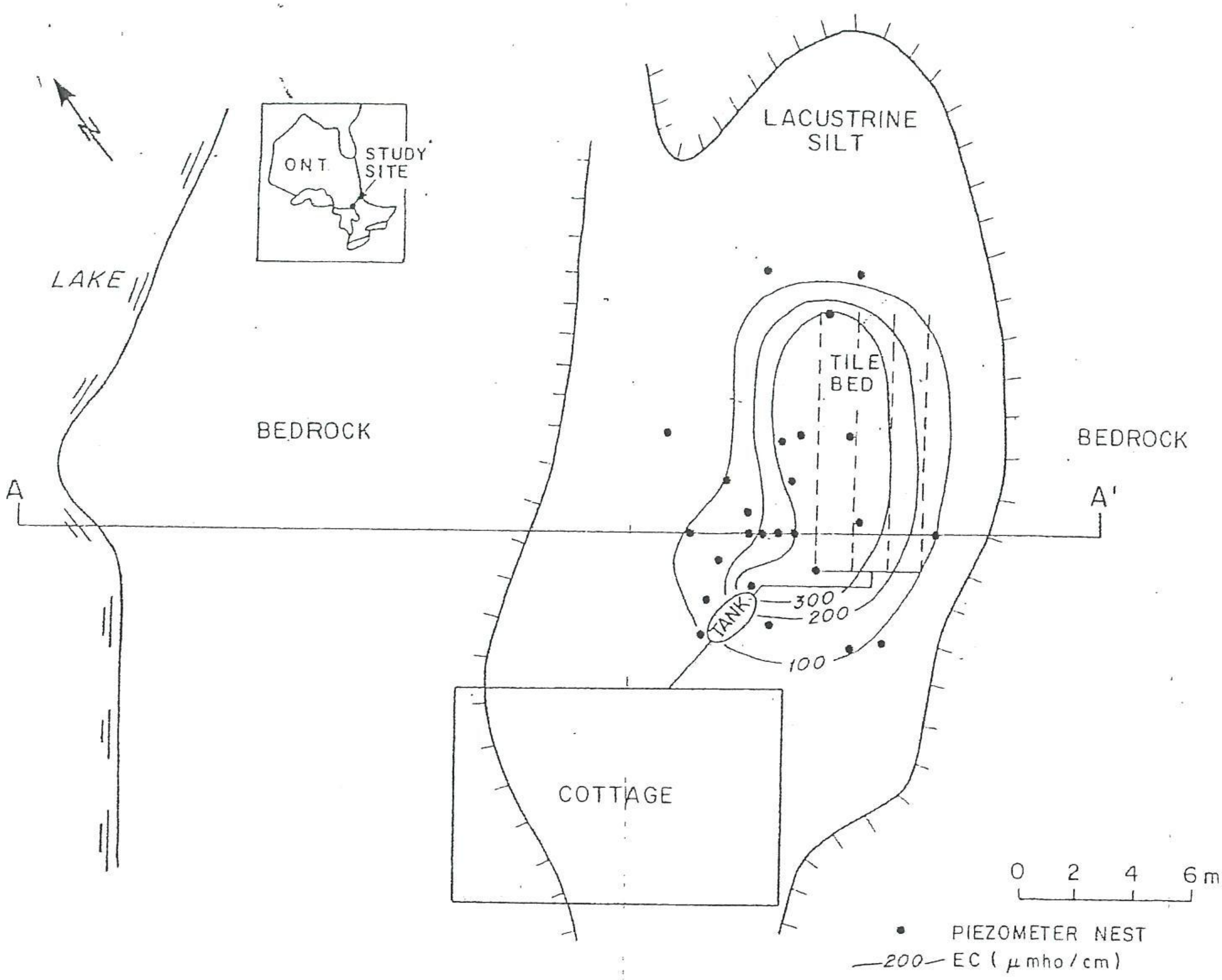
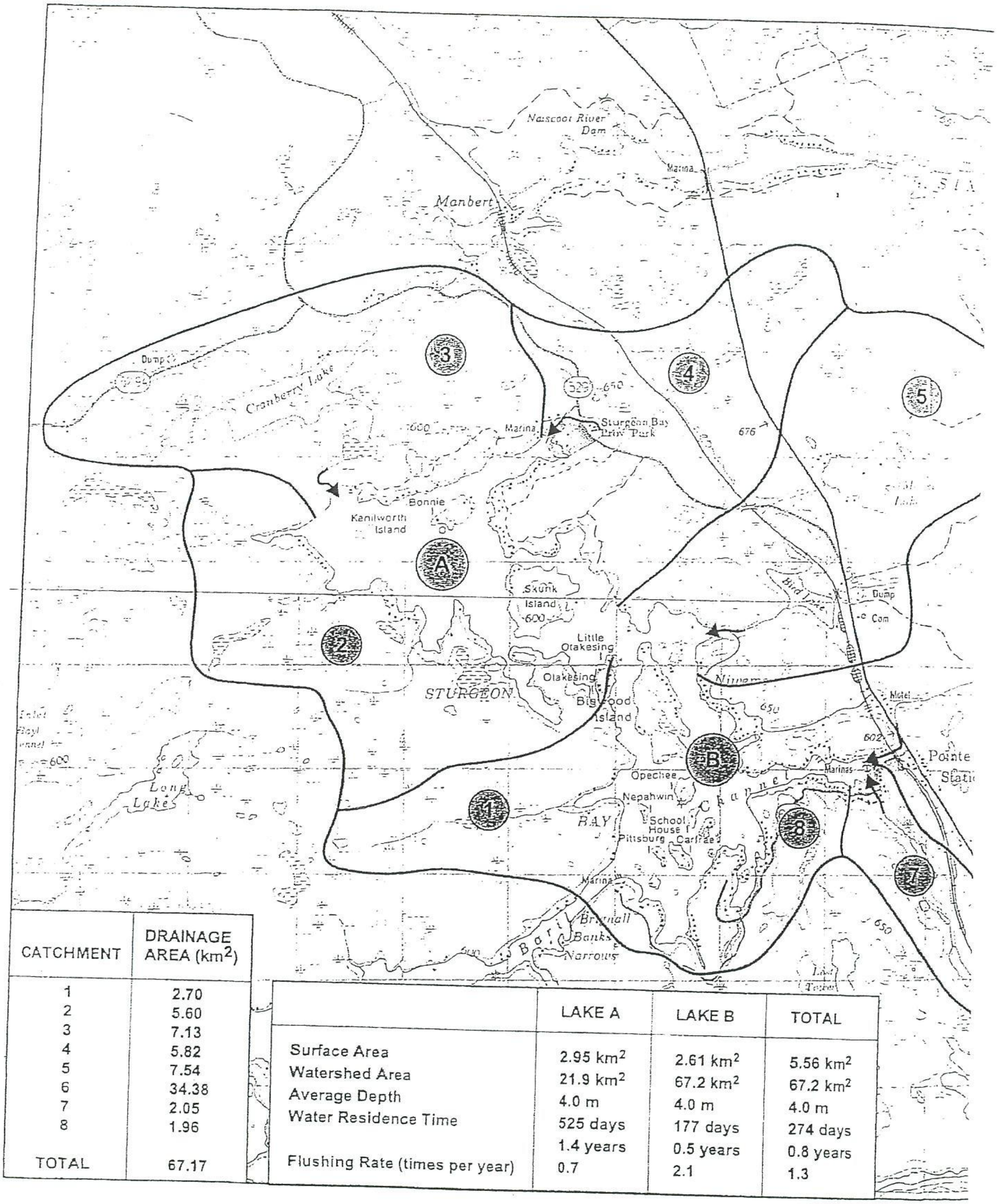


Fig. 4. Killarney septic system site map (from Robertson and Blowes, 1995)



CATCHMENT	DRAINAGE AREA (km^2)
1	2.70
2	5.60
3	7.13
4	5.82
5	7.54
6	34.38
7	2.05
8	1.96
TOTAL	67.17

	LAKE A	LAKE B	TOTAL
Surface Area	2.95 km^2	2.61 km^2	5.56 km^2
Watershed Area	21.9 km^2	67.2 km^2	67.2 km^2
Average Depth	4.0 m	4.0 m	4.0 m
Water Residence Time	525 days 1.4 years	177 days 0.5 years	274 days 0.8 years
Flushing Rate (times per year)	0.7	2.1	1.3

Fig. 5. Sturgeon Bay site map (from Schiefer, 2003)

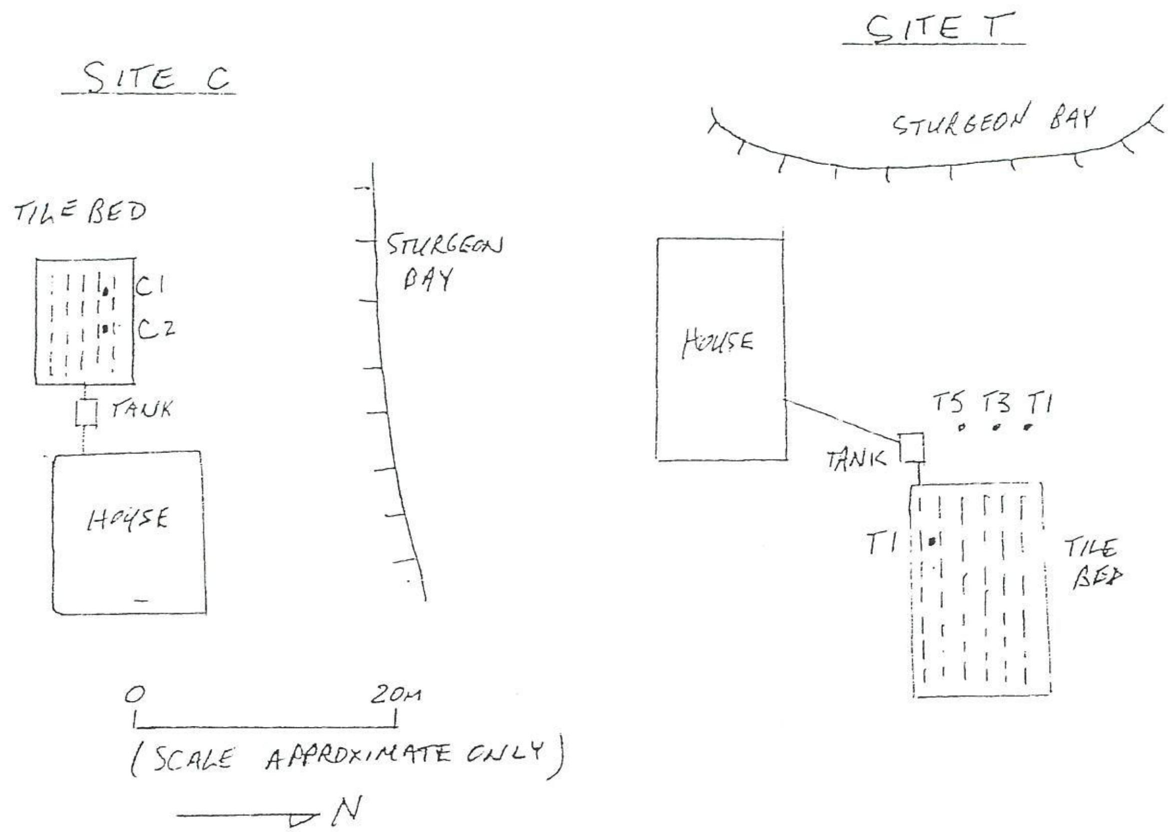


Fig. 6. Sturgeon Bay septic systems sites C and T

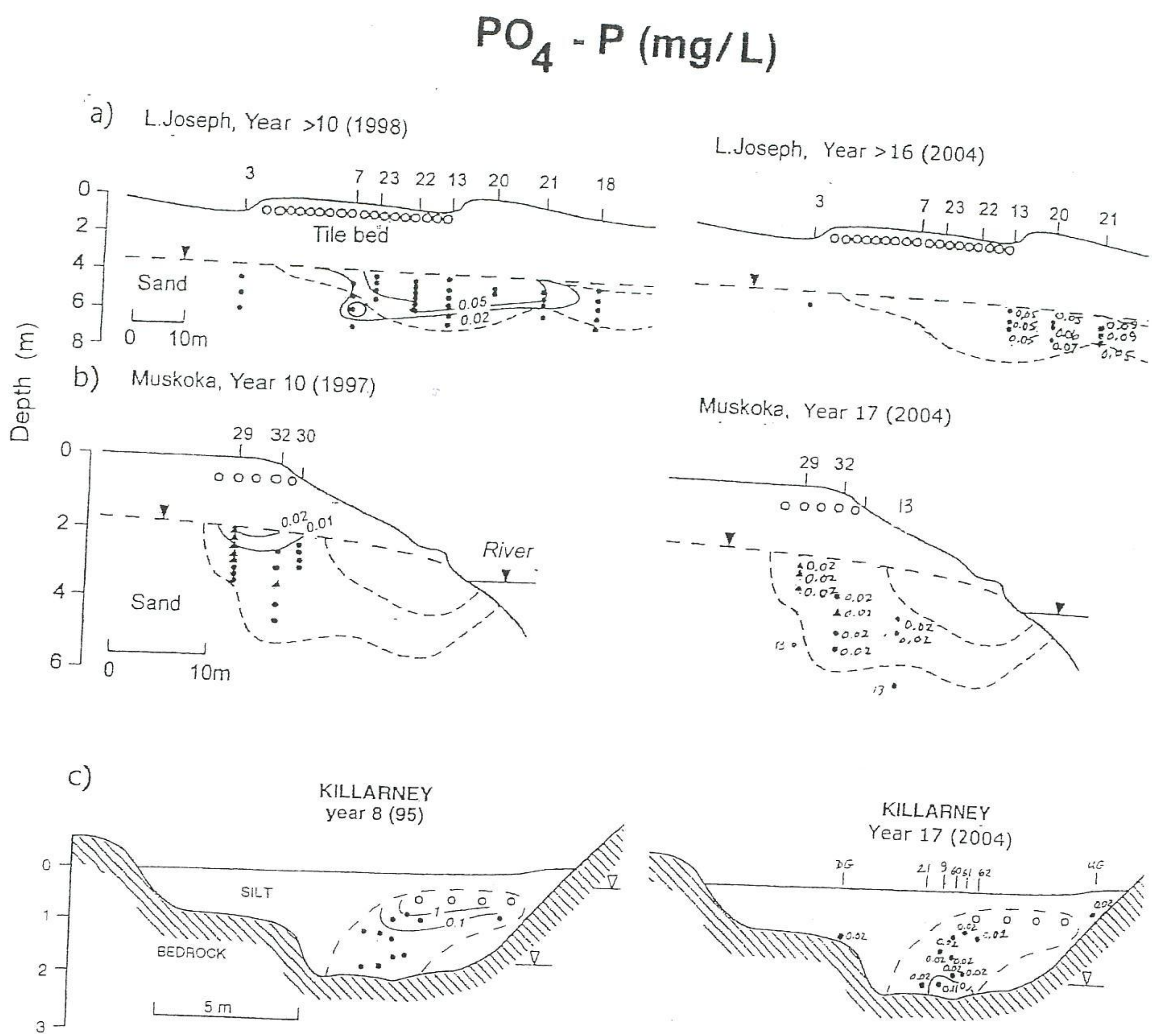


Fig. 7. 2004 PO_4 concentrations in the: a) Lake Joseph, b) Muskoka, and c) Killarney plumes, compared to concentrations observed 6-9 years prior. Earlier data from Robertson, (2003) and Robertson et al., (1998), respectively.

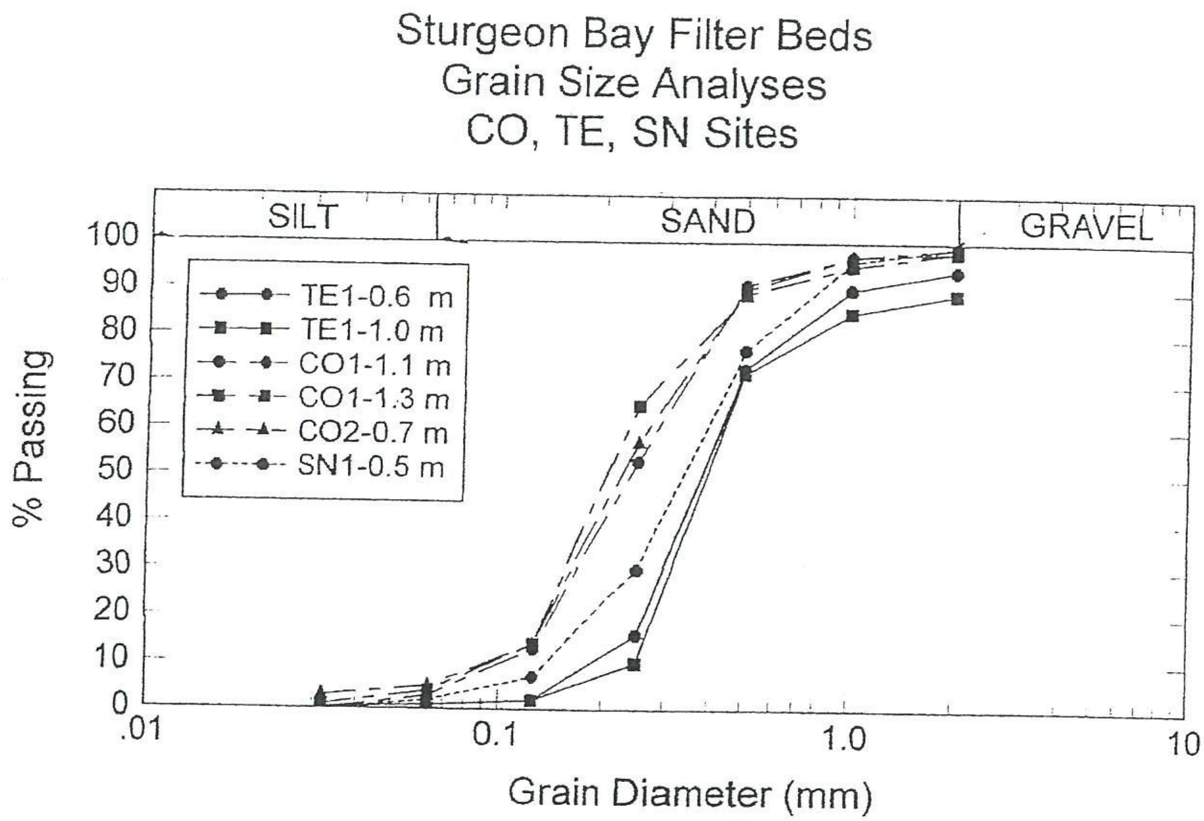


Fig. 8. Grain size distribution curves for the imported tile bed filter sand at the C, T and SN septic system sites on Sturgeon Bay.

Appendix A, Table A1. Sample analyses provided by MOE Resources Road Lab, Etobicoke, ON.

Note: <=W is no measurable response (zero); <T is a measurable trace amount, interpret with caution

Submission 22/04/04

Sample ID	Field ID	µg/L Aluminum	mg/L Calcium	mg/L Chloride	µg/L Iron	mg/L Potassium	mg/L Magnesium	µg/L Manganese	mg/L Sodium	µg/L NH3 + NH4	µg/L NO3	µg/L TKN	µg/L PO4	µg/L TP
										DL 0.05mg/L	0.05mg/L	0.05	0.02 mg/L	0.02
C115079-0001	BK13-3	82.1	44.4	29.2	18.5	8.55	4.15	21.1	36 <=W		34000	350 <=W		<=W
C115079-0002	BK13-5	1570	33.6	37.9	25.8	12.4	5	87.7	46 <=W		40500	330 <=W		<=W
C115079-0003	BK13-13	70.1	14.6	14.8	8.44	4.55	1.6	74.3	9.2 <=W		11000 <T	<=W		<T
C115079-0004	BK29-3	257	43.2	36	24.1	11.2	5.34	63.7	48.6 <=W		42000	620 <=W		<=W
C115079-0005	BK29-4	98	43.4	31.8	21.4	11	5.12	40.3	44.6 <=W		41500	560 <=W		<T
C115079-0006	BK29-6	73.2	45.2	31.4	17.2	11	5.18	38.3	43.2 <=W		40400	530 <=W		<T
C115079-0007	BK29-13	38.1	15	11.4	13.5	3.8	2.12	152	9 <=W		7850 <T	<=W		<=W
C115079-0008	BK32-3	989	33.8	25.8	28.2	10.4	4.25	60.3	31.4 <=W		34100	490 <=W		<=W
C115079-0009	BK32-4	736	43.8	20.4	27.2	10.3	5.01	65.3	38 <=W		38400	460 <=W		<=W
C115079-0010	BK32-5	48.5	11.1	9.3	14.3	5.05	1.62	15	10.2 <=W		7130 <T	<=W		<=W
C115079-0011	BK32-6	40.4	8.25	8.8	11.5	3.9	1.7	58	10 <=W		2760 <T	<=W		<=W
		Al	Ca	Cl	Fe	K	Mg	Mn	Na NH4		NO3	TKN PO4		TP

Submission 26/05/04

Sample ID	Field ID	µg/L Aluminum	mg/L Calcium	mg/L Chloride	µg/L Iron	mg/L Potassium	mg/L Magnesium	µg/L Manganese	mg/L Sodium	µg/L NH3 + NH4	µg/L NO3	µg/L TKN	µg/L PO4	µg/L TP
C115658-0001	JL9-1.3	131	5	2.5	2210	1.7	3.75	277	5.2	1990 <=W		2270 <=W		<T
C115658-0002	JL9-1.9	59.6	4.6	6.8	15700	1.55	3.45	862	6.6	4280 <=W		4490 <T		<T ← (130)
C115658-0003	JL21-1.9	38.7	4.4	6.1	5900	1.75	2.83	504	4.8	3830 <=W		3740 <=W		<T
C115658-0004	JL60-1.0	99.4	4.6	4	1640	1.7	3.12	246	5.4	440 <T		600 <=W		<T
C115658-0005	JL60-1.3	67	5.2	4.4	11000	4.75	4.4	576	6.2	14100 <T		14100 <=W		<T
C115658-0006	JL60-1.9	69.9	9.76	5.6	16000	3.15	5.9	1000	7.4	6870 <T		7330 <=W		<=W
C115658-0007	JL61-0.8	98.8	2.4	1.2	1240	1.85	1.75	107	2	460 <=W		630 <=W		<T
C115658-0008	JL61-1.9	223	10.3	4.4	18200	3.8	8.9	1430	7	9110 <T		9730 <=W		<T
C115658-0009	JL62-1.0	138	3.09	2	2160	2.6	1.88	211	3.6 <T	<T		300 <=W		<T
C115658-0010	JLUG-0.5	436	8.3 <T	<T	481	0.4	0.826	206 <T	<=W	<=W	<T	<=W		<=W
C115658-0011	JL-DG	17.5	4.2	7.5	42500	0.65	1.34	636	4.2 <T	<=W	<T	<=W		<=W
		Al	Ca	Cl	Fe	K	Mg	Mn	Na	NH3 NO3		TKN PO4		

*no sample for JL61-1.3

Submission 16/08/04

Sample ID	Field ID	µg/L Aluminum	mg/L Calcium	mg/L Chloride	µg/L Iron	mg/L Potassium	mg/L Magnesium	µg/L Manganese	mg/L Sodium	µg/L NH3 + NH4	µg/L NO3	µg/L TKN	µg/L PO4	µg/L TP
C118258-0001	TE-TANK	38.4	5.8	67.3	390	12.9	2.2	217	149	42900 <=W		53600	5330	
C118258-0002	CO-TANK	2.93	47	1100	20.1	18.2	8.25	38.4	724	70700 <=W		75400	7620	6 ← (6830, 6750, 100)
C118258-0003	CB20-4.5	17.9	60.2	66.9	12.6	8.35	4.06	120	63.6	1280	4780	1730 <T		
C118258-0004	CB20-5.1	20.8	16.4	15.8	9.22	4.35	1.6	8.38	29.4 <T		6570	540 <=W		<T
C118258-0005	JL-TANK4	123	6.63	108	1070	45.3	1.63	90	36.4	95200 (<=W)		105000	6530	8 ← (9760)
C118258-0006	CB21-4.7	8.33	10.8	22.9	6.43	1.4	1.45	18.5	15.4 <T		2750 <T	<T		<T
C118258-0007	CB13-3.5	26.9	24.4	46.4	22.3	7	3	15.3	61.8	760	10100	1210 <T		<T
C118258-0008	CB20-4.3	16.8	41.1	65.9	12.2	7.7	4.45	175	63.4	790	6273	1270 <T		<T
C118258-0009	CB3-3.5	10.2	15.4	19.3	1.58	2.5	1.44	1.55	1.8 <T		110 <T	<=W		<T
C118258-0010	TE5	202	6.38	35.7	6560	4.65	1.05	3670	55.4	3600	2275	4720 <=W		<T
C118258-0011	CB13-4.0	26.1	51	98.5	20.8	7.9	5.25	69.4	87.2	840	7290	1190 <T		<=W
C118258-0012	CO1-1.3	818	21.1	1480	7660	13	3.85	962	1010	30700	3485	31800 <T		<T
C118258-0013	CB21-4.4	21	17.6	17.2	20	4.4	1.65	5.18	31.2 <=W		4300	500 <T		← (160)
C118258-0014	CB21-4.1	23.3	25.3	41.1	17.1	5.6	3.2	15.8	46.8 <=W		729	320 <T		<T
C118258-0015	TE3	66.5	4.85	39.5	597	8.4	2.6	533	70.8	460	15663	1030 <=W		<T
C118258-0016	TE1	130	12.8	45.2	7650	5.8	1.8	387	88.8	4350	21633	5530 <=W		<T
C118258-0017	CB13-4.6	20.6	77.8	120	24	9.05	6.5	295	72.8 <T		17086	610	260	<T ← T
		Al	Ca	Cl	Fe	K	Mg	Mn	Na	NH4	NO2	TKN PO4		TP

Phosphorus Distribution in a Septic System Plume On Thin Soil Terrain in Ontario Cottage Country

Prepared for:

Ontario Ministry of the Environment

Dorset, ON

Prepared by:
W. D. Robertson[1]

1) Department of Earth Sciences, University of Waterloo
Waterloo, ON, N2L 3G1

*Corresponding author; Ph (519) 885 1211, Fax (519) 746 7484
Email, wroberts@uwaterloo.ca

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Summary

During 2005, detailed assessment of phosphorus (P) distribution was initiated at a lakeside septic system located near the community of Point aux Baril, ON (Sturgeon Bay site). The septic system is 14 years old and services a permanent two-person dwelling. This site is of particular interest because it is located on thin soil terrain, with abundant bedrock outcrop present, and is thus typical of much of Ontario cottage country. Such terrain is likely to have subsurface flow characteristics that are distinct from more typical sites on thicker overburden. However, detailed assessment of flow characteristics and P mobility in such terrain has remained virtually absent from the scientific literature because of the considerable difficulty in implementing effective groundwater monitoring networks in such terrain.

In the current study, a network of 14 multilevel monitoring wells was installed at the site, and was augmented with an assessment of sediment P content undertaken along a transect through the centre of the tilebed. The sediment cores revealed a distinct local zone of P enrichment restricted to one side of the tilebed, and limited to a narrow depth interval immediately below the infiltration pipes. Such irregular P distribution presumably reflects the irregular nature of sewage loading at the site, which is typical of gravity fed septic systems.

During groundwater sampling in summer and early fall, the water table below the tilebed was relatively deep (~ 1 m), thus the shallower monitoring wells were dry and samples could only be retrieved from the deepest monitoring wells. These were located below the zone of sediment P enrichment. These groundwater samples all returned nondetectable PO_4-P values (<0.05 mg/L), except for one well (TE12-1.1m depth, 3.8 mg/L P). During sampling undertaken during higher water table conditions however (Apr13/06, immediately after spring snowmelt), samples were also obtained from the shallower monitoring points that coincided with the zone of P enrichment. All of these samples had high PO_4-P concentrations (0.3-6.0 mg/L).

This evidence points to a scenerio where P is highly retained in the sediments, thus P mobility in the groundwater flowsystem is limited under normal water table conditions. However, this P appears subject to remobilization during high water table events, such as typically occur during spring snowmelt or during major rainfall events. Thus, the most likely potential for P loading to the adjacent lake at this site appears to be via a 'short circuiting' pathway involving periodic surface breakout at the toe of the tilebed, and then overland flow down to the lake.

Additional work should be done at this site to further assess this possibility. This should involve the installation of additional monitoring wells particularly in the shallow zone, further assaying of sediment P distribution, and additional sampling episodes targeting, particularly, high water table events.

Site Description

The Sturgeon Bay site consists of a permanent two-person dwelling with a conventional gravity-fed septic system that was installed in 1991 (14 years old) at the same time that the house was built. The dwelling has an automatic dish washer and clothes laundering facilities. The septic system consists of a concrete septic tank ~ 4000 L in size, with a typical gravel-trench and perforated-pipe tile bed, ~7m x 15m in area (Fig.1). The tile bed is located ~ 40 m from the edge of Sturgeon Bay, which is considerably in excess of the minimum Ontario setback distance of 15-20 m.

Stratigraphy

The tilebed is a 'raised bed' and is constructed of ~0.7m of imported fill material that consists of brown, medium-coarse, silt-free sand (Figs 2, 3). The imported fill overlies native sediment of variable thickness consisting of gray, sandy silt with abundant organic material present (paleo- soil horizon?). Bedrock outcrops throughout the property, including outcrops immediately adjacent to the tile bed (Fig. 4), and consists of rounded granitic gneiss hummocks that appear relatively unfractured. Overall, the overburden depth appears to be <2 m throughout most of the property.

Monitoring Network

A network of 14 multilevel monitoring wells was installed in area of the tile bed and for a distance of up to 15 m downgradient, toward Sturgeon Bay (Fig. 1). Each multilevel well consists of 2-4 depth-discrete sampling intervals (0.2-1.4 m depths, Table1). Wells are constructed of ½" PVC pipe, or ¼" polyethylene tubing, with short, 10-cm long, screened tips. These were installed by hand using a soil auger. Auger spoil material was backfilled around the wells and surface casing of 4" PVC pipe, with cap, was added to complete the installation. A sampling tube was also installed into the downstream compartment of the septic tank.

Sampling

The monitoring wells were sampled on three occasions, twice in the Fall of 2005 (Oct19 and Nov15), and once in the Spring of 2006 (Apr13, Table1). The latter event was timed to coincide with the end of the spring snowmelt when the water table position was expected to be close to the seasonal maximum. Sampling occurred for a variety of water quality parameters, including electrical conductivity (EC), pH, NO_3, NH_4, PO_4, and Cl. Samples were retrieved using ¼" tubing and a peristaltic pump and were filtered (0.45 um) prior to collection in two 20cc polyethylene vials. One bottle was immediately acidified with concentrated HCl for analysis of PO_4 and Fe, while the second bottle, for NO_3, NH_4 and Cl analysis, was untreated. EC and pH were measured in the field using portable meters and a flow-through cell that allowed measurement prior to atmospheric exposure. Buffers of pH 4 and 7 were used for calibration of pH.

Analytical Methods

Groundwater NO_3, and NH_4

Groundwater NO_3 and NH_4 was analyzed at the University of Guelph, Soil and Nutrient Laboratory. Both were analyzed colourimetrically; NO_3 using a cadmium reduction technique and NH_4 using the indophenol blue technique, with spectrophotometric quantification using a Technicon™ Auto Analyzer (Miller and Keeney, 1982).

Groundwater PO_4

Groundwater PO_4 was measured colourimetrically at the University of Guelph, Soil and Nutrient lab, using a Technicon Auto Analyzer (Reid, 1998).

Sediment Plant-Available P and Fe

Sediment plant available (loosely adsorbed) P and Fe was measured at the University of Guelph, Soil and Nutrient Lab. Available P was extracted from the sediment using a 0.5M sodium bicarbonate solution, after which P in solution was quantified colourimetrically, using a Technicon Auto Analyzer (Reid, 1998). Available Fe was extracted from the sediment using a surfactant solution (0.005M DTPA), after which Fe in solution was quantified by atomic adsorption (Varian™ spectrophotometer) (Carter, 1993).

Sediment Acid-Extractable Constituents

As part of this study, a single sediment core from the Sturgeon Bay site (TD1) was analyzed for acid-extractable cations and compared to similar cores taken from four other septic system sites in Ontario. For this purpose, new cores were retrieved in 2005, from the Cambridge, Long Point, and L. Joseph sites, which have been studied in detail previously (Robertson et al., 1991, 1998; Zanini et al., 1998; Robertson, 2003), whereas archived core samples from an earlier study (Wood, 1993) were used for the Harp L. site. All cores were dominated by similar-textured fine to medium sand. Sediment acid extractable cations and trace metals were analyzed using an Aqua Regia technique at Activation Laboratories, Ancaster, ON. This assay releases most constituents occurring as oxyhydroxide, carbonate, and sulfide phases but does not release silicate phases. The technique involves extraction with a concentrated HCl + nitric acid solution under heat (90 °C) for 2 hr, and then quantification of dissolved constituents by ICP/MS (Perkin Elmer, Sciex Elan 6100).

Results

Sediment Characteristics

The subtile sediments at Sturgeon Bay site consist of 0.7 m of medium-coarse, imported sand fill (Figs. 2 and 3), which is underlain by native sediment of variable depth, consisting of organic rich sandy silt. A thin layer of more permeable sand, ~10-20 cm in thickness, overlies the native silt in the area downgradient of the tilebed. It is uncertain if this sand layer is native or has been imported. The imported sand fill is noncalcareous (Ca, ~0.4 wt %) and has acid extractable Fe and Al contents (~25,000 mg/kg and 5,000 mg/kg respectively) typical of subtile sediments at several other septic system sites in Ontario (Harp L., L. Joseph, Cambridge, Long Point, Tables 2 and 3). Plant-available P shows a distinct but localized zone of enrichment on the north side of the tilebed (transect B-B'), at a depth of ~0.3-0.5 m, coincident with the depth of the infiltration pipes. Plant available P is highly enriched in this zone (up to 117 mg/kg) compared to background values of only 1-4 mg/kg (Table 2, Fig. 5).

Groundwater Composition

The septic tank had a Cl concentration of 46 mg/L (Table 1). Several of the monitoring wells underlying the tilebed had variable but elevated Cl (8-28 mg/L), and Cl was also elevated in the downgradient zone (Table 1), indicating that the septic system plume had been successfully captured by the monitoring network. However, dilution from precipitation or by mixing with background water was also indicated. Nitrogen concentrations in this zone were also variable but ranged up to 4 mg/L NH_4-N and up to 15 mg/L NO_3-N (Table 1), further indicating septic system impact. The pH of the plume water was slightly acidic (5.9-7.0, Table1). During low water table conditions (Oct. 19/05) all piezometers in the plume zone had PO_4-P below detection (<0.05 mg.L), with the exception of well 12-1.2 (Table 1). During high water table conditions however, the shallower piezometers, coincident with the zone of sediment P enrichment, all had elevated PO_4-P (0.3-6.0 mg/L, Table 1, Figs 3-5). It is possible that this shallow groundwater is also prone to surface breakout at the toe of the tilebed during high water table conditions.

Sediment Chemical Characteristics at Sturgeon Bay Site Compared to other Sites

Table 3 compares depth-discrete sediment characteristics at five septic system sites in Ontario including the Sturgeon Bay site. The other four sites have been described in detail previously (Robertson et al., 1991, 1998; Wood, 1993; Robertson, 2003). P mobility varies dramatically at these five sites, with two sites (Cambridge and Long Point) showing only minor P attenuation (<30 % in the proximal area), while the remaining three sites (Sturgeon Bay, L. Joseph and Harp L.) exhibit much higher P attenuation (>95% in the proximal area). It is thus of interest to compare the chemical composition of these sediments to determine if specific sediment characteristics can be used to predict P mobility. Of particular interest is the content of acid-leachable Fe, Al, and Ca, as this assay targets the concentrations of Fe and Al oxyhydroxide mineral species such as ferrihydrite, goethite, and gibbsite and Ca species such as calcite, all of which can act as adsorption sites for PO_4. Furthermore, dissolution of these minerals can supply cations that may promote the precipitation of P-minerals such as strengite, variscite, and hydroxyapatite. A Student's "t" test, assuming normal distribution, was thus undertaken to establish if significant differences occur between the sediments at the two P-mobile sites compared to the sediments at the three P-attenuated sites. Table 4 summarizes the parameters used for this statistical comparison (site mean values, standard deviations and number of samples):

Fe
Mean acid-extractable Fe values were very similar at all five sites (1.7-2.5 wt%, Table 4). None of these sites were different at a > 80% confidence level ($p > 0.2$). Thus, none of these sites were significantly different with respect to Fe content;

Al
Mean Al values showed some variation ranging from 0.13 wt% (Long Point) to 1.2 wt% (Harp, L. Joseph). Long Point was significantly lower at the >95% confidence level ($p<0.05$) compared to the three P-attenuated sites (Harp, L Joseph and Sturgeon Bay). Al content at the other P-mobile site however (Cambridge, 0.64 wt%), was not different at the >80 % confidence level ($p>0.2$), compared to the three P-attenuated sites. Thus, there was no significant difference between the Cambridge site and the three P-attenuated sites. The lower Al content of the Long Point site may not be typical of most Ontario sites because the sediments on Long Point are relatively young dune sands where soil formation processes have acted for only a short period of time;

Ca
Mean Ca concentrations showed major variations between the two P-mobile sites (5.0-6.3 wt%) and the three P-attenuated sites (0.23-0.43 wt %). The P-mobile sites were significantly higher at the 99% confidence level ($p<0.01$) compared to the P-attenuated sites.

Conclusions and Recommendations

1) The plant-available sediment P assay provided by the University of Guelph, appears to be an effective tool for revealing zones of sewage P immobilization below tilebeds.
2) Additional analyses of plant available P content should be undertaken at the Sturgeon Bay site to provide a 3-D picture of P distribution below the tilebed.
3) Zones of sediment P enrichment should be subjected to electron microprobe analyses to establish the morphology and cation composition of the P solids.
4) The monitoring well network should be expanded to better target the indicated zones of P enrichment.

5) Additional episodes of groundwater monitoring should be undertaken, targeting, particularly, high water table events.
6) There was no significant difference in the acid-extractable Fe content of any of the five septic system sites assessed, and the Al content at the Cambridge site was not significantly different than that of the three P-attenuated sites (L. Joseph, Harp and Sturgeon Bay). Thus, neither of these parameters appears useful for predicting P mobility at septic system sites.
7) Acid-extractable Ca content was significantly higher at the two P-mobile sites (5.0, 6.3 wt%, Cambridge, Long Point) compared to the three P-attenuated sites (0.23-0.43 wt%, Harp L., L. Joseph, Sturgeon Bay). Thus Ca content appears to be a useful parameter for predicting P mobility. This effect is indirect however. Low $CaCO_3$ content allows acidic conditions to develop and, subsequently, gibbsite ($Al(OH)_3$) dissolution and variscite ($AlPO_4.2H_20$) precipitation (Robertson, 2003). Also note, however, that calcareous sediments normally have a Ca-leached horizon associated with the soil zone (e.g. Cambridge site, 0.3 m depth, Table 3). Thus, sediment sampling for the purpose of predicting P mobility should target depth horizons that are coincident with the expected depth of tile line installation (e.g., ~0.5-1.5 m depth), rather than targeting surface soil samples.

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Table 1. Groundwater chemistry, Sturgeon Bay septic system site, 2004-06.

		EC (uS)			pH				PO_4-P (mg/L)		NO_3-N (mg/L)		NH_4-N (mg/L)		Cl (mg/L)	
Piezo	Depth (m)	1*	3	5	1	3	4	5	3	5	3	5	3	5	3	5
Tank		1090				6.9			8.9		0.05		64		46	
TD1	0.6			103				6.8		0.79		2		0.7		5
	0.8			179				7.3		0.32		0.02		3.2		2
	1.1	370	388	188	6.2	6.5	6.3	7.3	0.05	0.05	22	0.03	3.1	2.9	20	3
	1.4															
TD3	1.2		260	160		6.5		5.4	0.05	0.05	0.13	0.11	3.9	2.0	5	3
	1.45															
TD4	1.1		174	182		6.1		7.2	0.05	0.05	0.02	0.01	1.4	6.8	5	4
	1.25															
TD5	1.1		226	250		5.9		7.0	0.05	0.05	0.01	0.04	0.9	10	4	6
	1.3															
TD6	1.1		280	232		5.9		5.9	0.05	0.05	0.3	0.04	0.5	5.5	8	5
	1.3															
TD7	1.1		414	230		5.9		6.4	0.05	0.05	15	0.05	0.4	1.1	12	16
	1.3															
TD8	0.6		332			6.0			0.05		0.03		2.2		17	
	0.8															
TD9	0.6		258	203		6.1		6.7	0.10	0.05	0.25	3.9	0.1	0.3	8	9
	0.8															
TD10	0.6		407			5.9			0.05		2.5		0.8		23	
TD11	0.6								0.07		0.69		0.3		28	
	1.0		310	140		5.9		6.7		0.05		0.09		0.6		6
	1.2															
TD12	1.0			211				6.3		3.4		7.3		2.4		11
	1.2			158			5.6	6.5		6.0		0.04		0.2		2
	1.4			179				6.7		0.61		0.05		4.3		9
TD13	0.3			142			5.8	6.7		0.05		6.0		0.4		6
	0.5			142			5.9	6.6		0.05		0.6		0.5		6
	0.7			260			5.7	6.5		0.05		0.13		2.3		13
TD14	0.2															
	0.4			206				6.7		0.05		2.3		0.6		9
	0.6			275				7.0		0.05		0.10		8.8		20
TD15	0.2															
	0.3															
	0.5						6.0									

- sampling dates : 1) Aug12/04, 2) Oct27/04, 3) Oct19/05, 4)Nov15/05, 5) Apr13/06

Table 2. Sediment samples from Sturgeon Bay tile bed collected 10/05; Electrical Conductivity (EC), pH and PO_4-P content in porewater; plant available P and Fe, and acid leachable P, Fe, Al and Ca in solids.

Core	Depth	Porewater			Solids					
	(m)	pH	EC (uS)	PO_4-P (mg/L)	P (mg/kg) Plant	P (mg/kg) Acid	Fe (mg/kg) Plant	Fe (mg/kg) Acid	Al (mg/kg)	Ca (mg/kg)
TD1	0.3	5.8	94	<0.2	8	710	11	17,500	4,400	3,100
	0.5	5.2	635	0.5	73	1300	27	26,700	5,400	4,300
	0.6	5.6	220	2.5	117		35			
	0.7	5.4	140	2.5	85	1070	17	26,100	5,800	4,500
	0.8	5.6	123	4	52		12			
	0.9	5.3	155	4	51	870	14	30,600	6,600	4,700
	1.2				5					
	1.4				4	740		27,500	7,100	4,900
TD2	0.5	5.4	220	0.4	27		9			
	0.6	5.7	238	<0.2	49		9			
	0.7	5.6	150	3	55		10			
	0.8	5.6	140	2.5	48		11			
	0.9	5.4	141	1.5	44		11			
TD3	0.5	5.0	175	0.1	5		27			
	0.6	6.4	219	0.1	48		9			
	0.7	6.2	132	0.2	52		11			
	0.8	6.0	160	0.3	43		12			
	0.9	6.2	150	0.3	39		10			
	1.1				5		36			
	1.2				2					
	1.4				12					
TD4	0.5	4.9	114	<0.1	6		14			
	0.6	5.0	390	0.3	38		14			
	0.7	5.9	145	2	34		15			
	0.8	5.7	110	2	26		14			
	0.9	5.8	260	0.5	14		21			
	1.0	5.9	210	0.5	12		31			
	1.2				4					
TD5	0.5				3					
	0.6				1					
	0.7				26					
	0.8				24					
	1.0				2					
	1.2				3					

TD6	0.5				7					
	0.6				8					
	0.7				2					
	0.8				1					
	1.0				1					
	1.25				1					
TD7	0.5				2					
	0.6				2					
	0.7				3					
	0.8				3					
	1.0				3					
	1.25				1					

Table 3. Chemical composition of sand sediments from five septic system sites in Ontario. Acid-extractable constituents.

Core	Depth (m)		Mn (mg/kg)	Al (mg/kg)	Ca (mg/kg)	(wt %)	Fe (mg/kg)	Mg (mg/kg)	P (mg/kg)
Harp L.									
Dyk3	0.2		155	11,900	2100	0.21	24,700	1400	120
	0.5		167	11,100	2600	0.26	19,400	2000	130
	0.8		150	8,000	2700	0.27	12,300	2000	320
Dyk23	0.2		118	17,100	1700	0.17	23,700	1300	160
	0.5		140	14,900	2100	0.21	22,900	1600	160
	0.8		163	10,400	2500	0.25	21,300	2100	190
L. Joseph									
CB21	0.3		175	15,000	2000	0.20	17,100	800	440
	0.4		187	22,200	2600	0.26	23,200	1400	720
	0.6		139	7,800	2700	0.27	10,500	1400	480
	0.8		142	4,200	3000	0.30	15,000	600	540
Sturgeon B.									
TD1	0.3		168	4,400	3100	0.31	17,500	900	710
	0.5		284	5,400	4300	0.43	26,700	1200	1300
	0.7		311	5,800	4500	0.45	26,100	1300	1070
	1.0		243	6,600	4700	0.47	30,600	1400	870
	1.4		245	7,100	4900	0.49	27,500	1300	740
Cambridge									
UG100	0.3		2340	22,000	5,100	0.51	37,600	4400	510
	0.6		570	5,600	28,800	2.9	17,800	5600	630
	0.9		408	4,900	30,400	3.0	15,400	3700	600
	1.2		274	2,000	78,200	7.8	22,200	7900	750
	1.5		314	1,900	80,900	8.1	15,200	5200	700
	1.9		386	2,200	79,300	7.9	17,100	6100	690
Long Point									
LP128	1.0		168	1,000	71,800	7.2	16,800	5600	750
	1.2		216	1,300	52,600	5.3	29,200	4200	970
	1.4		242	1,300	54,000	5.4	47,200	4500	760
	1.6		207	1,600	69,000	6.9	12,900	6000	860
	1.8		209	1,500	65,700	6.6	17,000	4800	430

1) Cores Dyk3 and Dyk23, below tile bed, Harp L. site (Wood, 1993).
2) Core CB21, 10 m downgradient of tile bed, L. Joseph site (Robertson, 2003).
3) Core TD1, below tile bed, Sturgeon Bay site (this study).
4) Core UG100, 20m upgradient of tile bed, Cambridge site (Robertson et al., 1998).
5) Core LP128, 9m downgradient of tilebed, Long Point 2 site (Robertson et al., 1998).

Table 4. Mean acid-extractable Fe, Al, and Ca concentrations of sand sediments from the five septic system sites.

	N[1]	Fe[2] (wt %)	Al (wt %)	Ca (wt%)
P-attenuated sites				
Harp L.	6	2.1 ± 0.4	1.2 ± 0.3	0.23 ± 0.04
L. Joseph	4	1.7 ± 0.4	1.2 ± 0.7	0.26 ± 0.03
Sturgeon Bay	5	2.6 ± 0.4	0.59 ± 0.09	0.43 ± 0.06
P-mobile sites				
Cambridge	6	2.1 ± 0.8	0.64 ± 0.70	5.0 ± 3.0
Long Point	5	2.5 ± 1.2	0.13 ± 0.02	6.3 ± 0.8

1) N, number of samples (from Table 3).
2) Values are site means and standard deviations calculated from data given in Table 3.

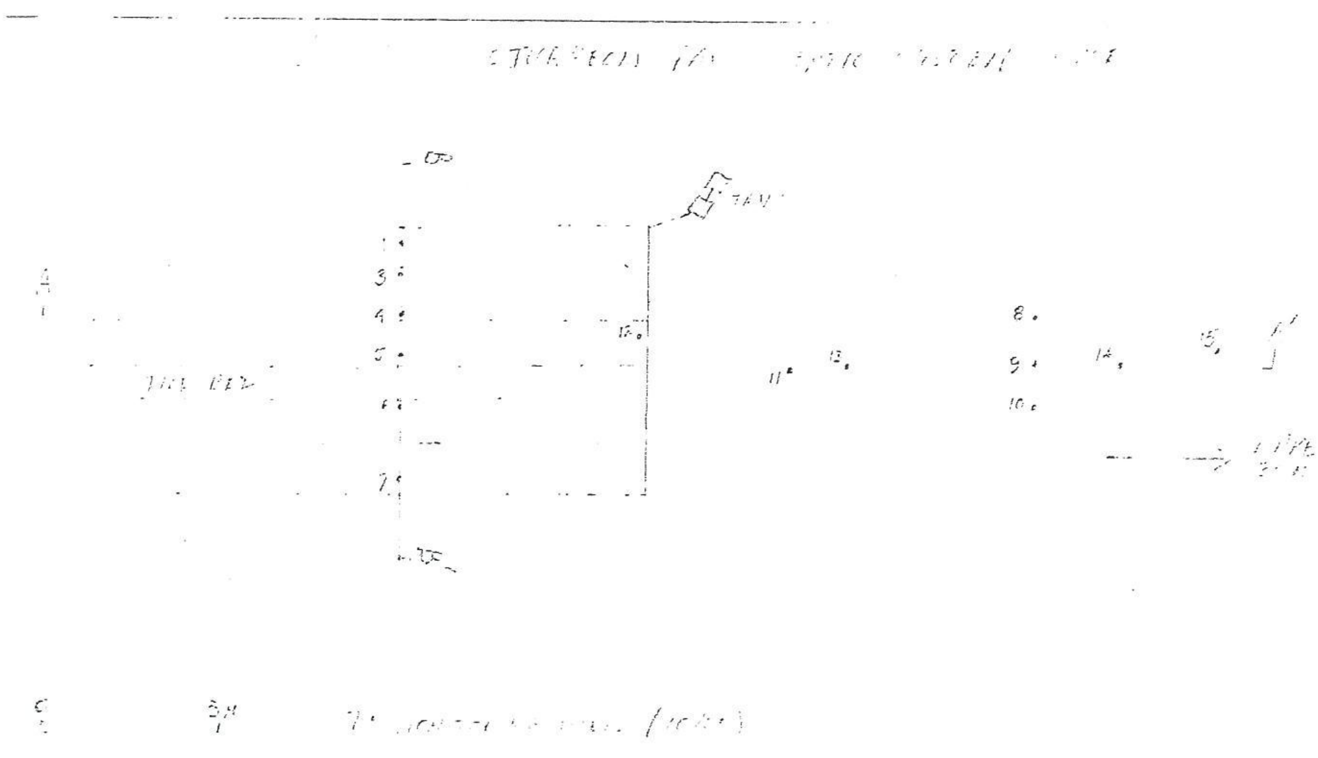

Fig. 1. Sturgeon Bay septic system site showing tile bed layout and location of monitoring wells.

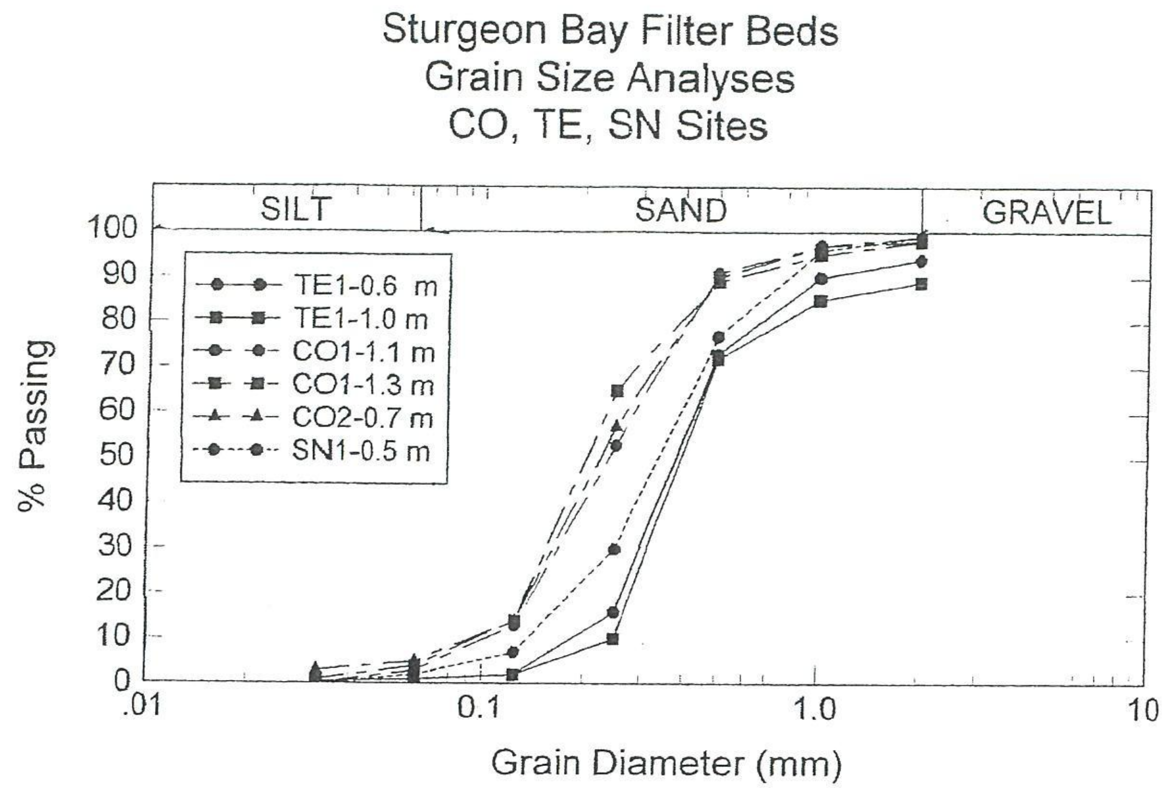

Fig. 2. Grain size distribution of subtile sediments, at three septic system sites on Sturgeon Bay (from Robertson, 2005). TE site is focus of detailed 2005 study.

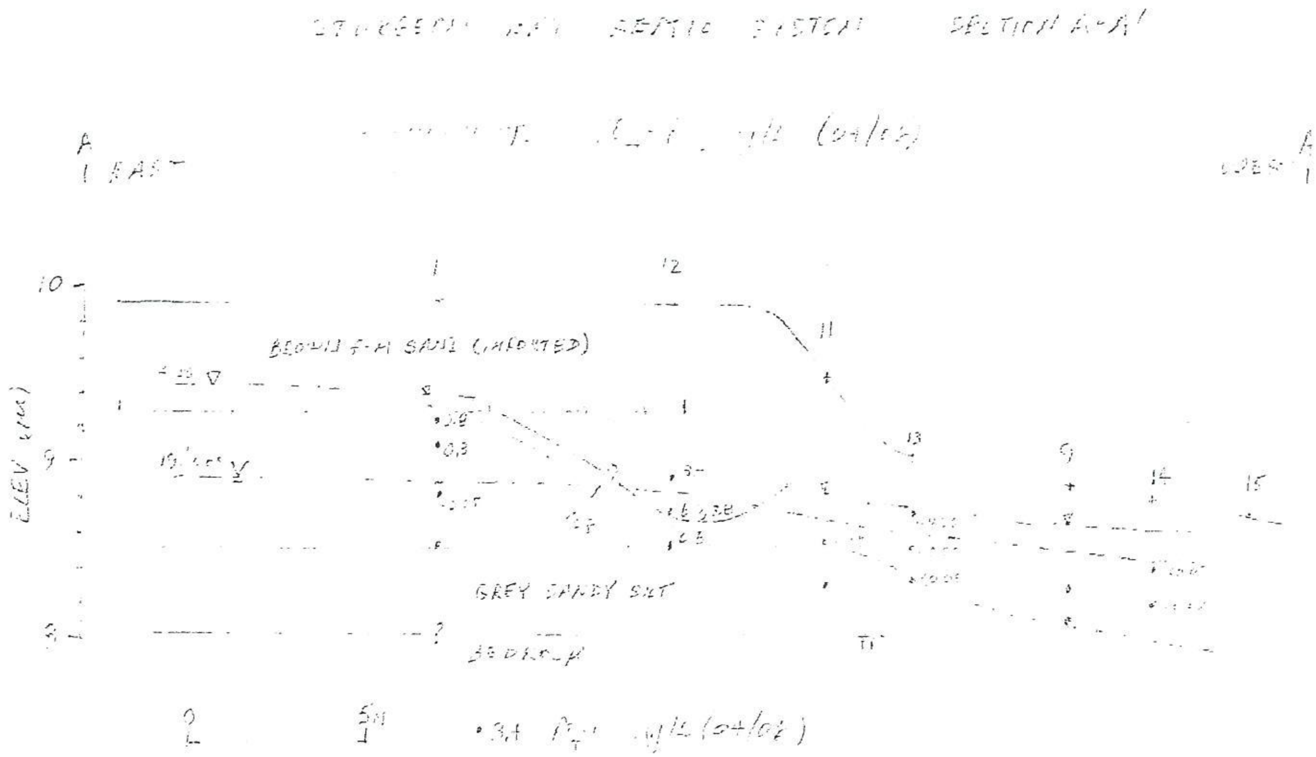

Fig. 3. Section A-A', Sturgeon Bay septic system site; PO_4-P distribution in groundwater, 04/06.

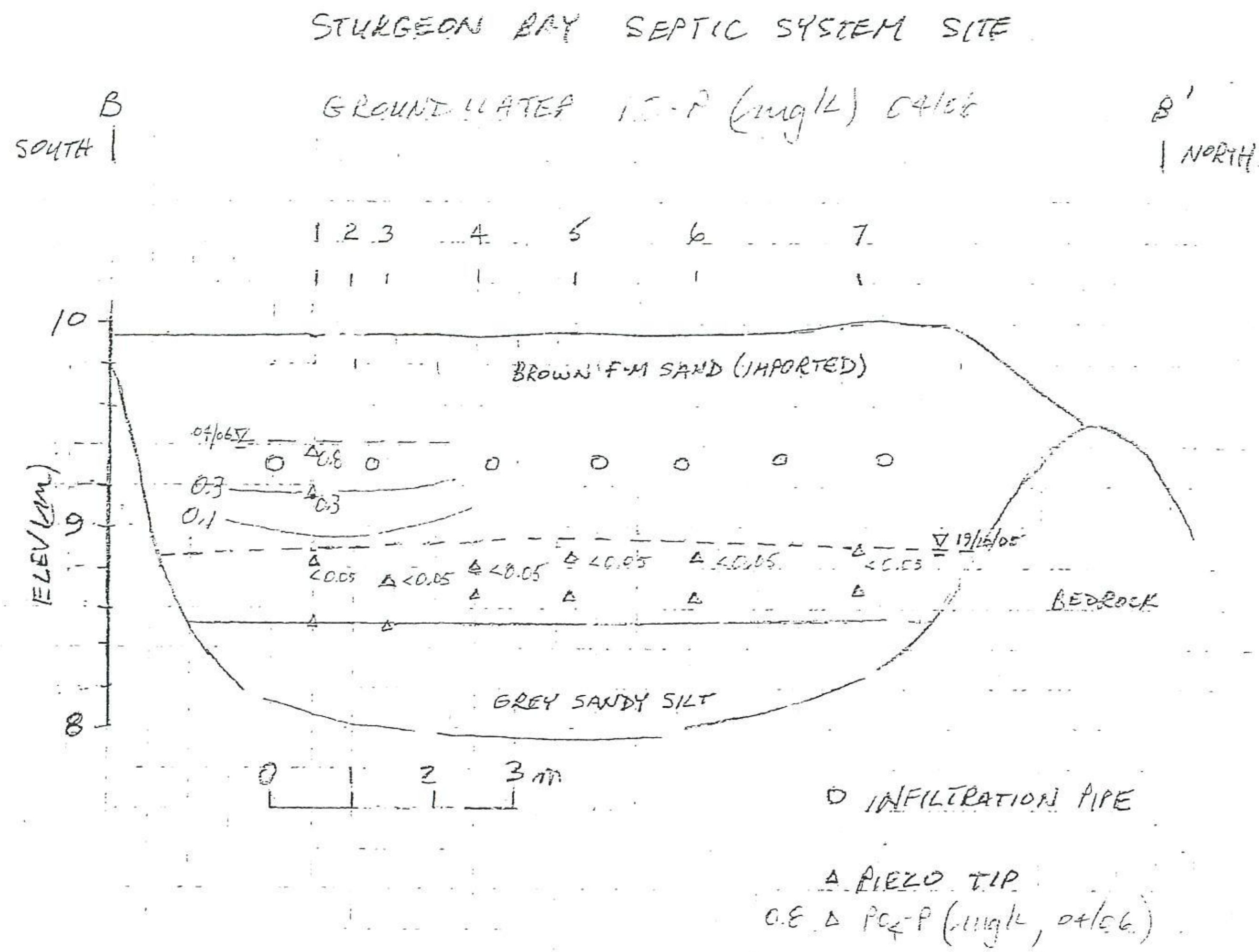

Fig. 4. Section B-B' Sturgeon Bay septic system site; groundwater PO_4-P distribution, April 13, 2006.

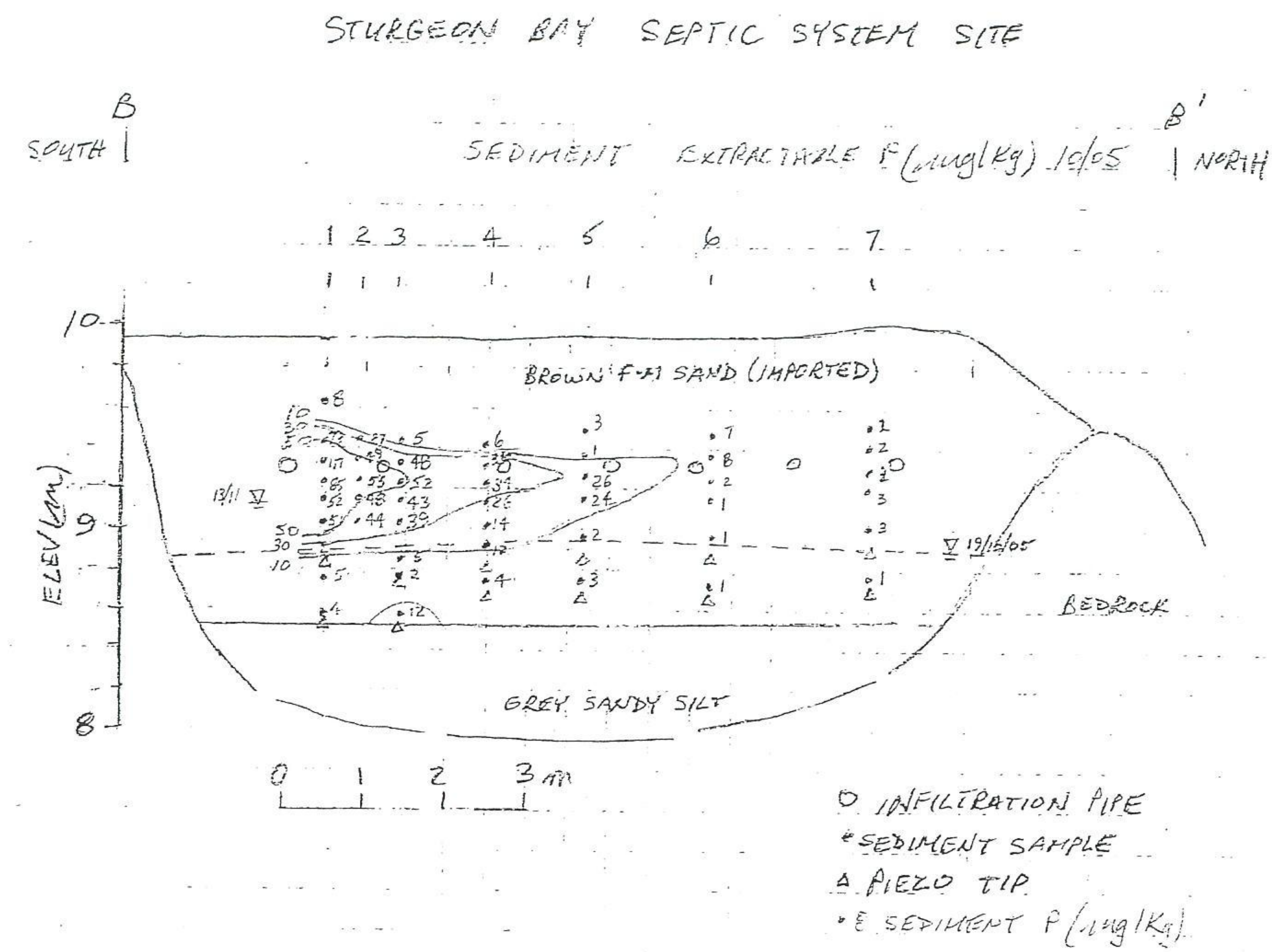

Fig. 5. Section B-B'; distribution of plant available P in sediment.

APPENDIX G – MNR'S LIST OF SPECIES AT RISK KNOWN OR PRESUMED TO OCCUR IN THE GEOGRAPHIC TOWNSHIP OF SPENCE

SPENCE

SAR Designations

Endangered
Threatened
Special Concern

Jump To: List of Municipalities

		Key Habitats Used By Species (See below for wetland definitions)	Timing of Life History Events
Barn Swallow	Known To Occur	Ledges and walls of man-made structures such as buildings, barns, boathouses Cliffs or caves ESA Protection: Species and general habitat protection	Nests: May - July
Blanding's Turtle	Known To Occur	Fen (poor fens), marsh, swamp Open areas of sand or fine gravel Rock-barren ESA Protection: Species protection only	Active: April – October Nests: June Hatchling Emergence: September Hibernates: October – April Spring survey best time to determine where potential hibernation sites would be
Bobolink	Presumed to Occur	Large old fields and meadows, tall grasslands, hayfields ESA Protection: Species and general habitat protection	Nests: May - July
Chimney Swift	Presumed to Occur	Man-made structures such as chimneys Hollow trees or cavities in old growth or mature forests ESA Protection: Species and general habitat protection	Nests: May-July
Eastern Hog-nosed Snake	Known To Occur	Open areas of sand or fine gravel Rock-barren ESA Protection: Species protection only	Active: May - October Mates: August and early September Nests: late June - mid July Hibernates: October - April
Eastern Meadowlark	Presumed to Occur	Grasslands, pastures, agricultural fields, old fields, meadows; often overgrown with shrubs Can also use golf courses and sand dunes ESA Protection: Species and general habitat protection	Nests: May - July
Eastern Ribbonsnake	Presumed to Occur	Marsh, swamp, fen (bog) ESA Protection: N/A	Active: early May - October Live Young: September Hibernates: October - April
Snapping Turtle	Known To Occur	Marsh, swamp, fen (poor fens) Shallow waters in lakes or along streams Open areas of sand or gravel ESA Protection: N/A	Active: April - October Nests: June
Whip-Poor-Will	Presumed to Occur	Areas with a mix of open and forested areas ESA Protection: Species and general habitat protection	Active: May - July Nests: Last weeks of May at dusk, on cloudless nights during full moons Requires special surveying effort

Jump To: List of Municipalities

Wetland Definitions	Marsh: wet areas periodically inundated with standing or slowly moving water and/or permanently inundated areas. Characterized by robust emergents such as cattails and anchored floating plants and submergents. Substrate is mineral or organic soils with high mineral content. Open water marshes are marshes with permanent open water, usually less than 2 m deep and with floating, submergent or partially emergent vegetation.
	Swamp: wooded wetlands dominated by trees or tall shrubs. The soils are continuously waterlogged and standing or gently moving water may be present seasonally. There are usually pools and channels, and the understory is usually densely vegetated with trees, tall shrubs, low shrubs, herbs and mosses.
	Bogs: peat-covered wetlands characterized by a high water table and surface carpet of mosses, mainly Sphagnum sp. Trees are not usually present, or if present, are restricted to stunted black spruce, and ericaceous shrubs are usually present. These wetland types are nutrient poor and acidic and are characterized by low species diversity.
	Fens (poor fens): peatlands with a dominant component of sedges and mosses (Sphagnum sp may be present but not necessarily) typical of this wetland type. Shrubs (including non-ericaceous shrubs) and stunted trees (including white cedar and tamarack) may be present, and this wetland type has higher species diversity than bogs.