Assessment of Phosphorus Inputs to St. Mary Lake from Septic Systems

Prepared for
Salt Spring Island Watershed Protection Authority
Technical Advisory Committee

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Synopsis

In 1983 the BC Ministry of Environment (MoE) released a report[1] identifying the important sources of phosphorus to St. Mary Lake. The two major sources were stated to be internal loading from sediments, accounting for about 67% of the total, and infiltration from septic fields, amounting to another 28%. Other sources were much smaller. These same estimates were brought forward as the basis of the St. Mary Lake management plan released in 2009. For over 30 years, discussions of reducing the septic contribution by means of a sewer system of some kind have taken place based on these numbers.

The septic estimate of about 300 kg each year provided in the MoE report was derived from engineering calculations typical of the time. Assumptions were made about the number of occupants of residences and resorts, the per capita phosphorus contribution and transmission rates based on soil and setback parameters. Importantly, however, no site-specific data on phosphorus transmission were collected for St. Mary Lake.

The objective of the present study was to update the estimate of phosphorus seeping into the lake from septic systems, taking changes in phosphate content of household products into account (a major factor) and verifying phosphorous uptake by local soils and modern septic drain fields. This second step was based on direct field measurements.

These measurements were made over the period 2014-2016 by installing 15 groundwater monitoring wells at three different residential properties fronting onto the lake. Additional sampling sites were installed in the lake itself, and in the shallow surface zone close to the drain fields. The sampling locations were confirmed to lie in the pathway of the septic effluent using chemical tracers, including phosphorus. Samples were collected monthly from November through to the end of May. It was noted, that at all sites, no groundwater was present in the sand layer above the glacial till when the monitoring wells were drilled in August. This agrees with the description in the Van Vliet et al.[2] that groundwater is seasonal, and means that during late summer there is, by definition, no means for phosphorus to reach the lake.

For Langs Road east, and at Tripp Road, groundwater became re-established in November and rose rapidly to occupy about two-thirds of the sand layer. By late January, the water table had receded to roughly one-half of the sand layer thickness where it remained until July. Phosphorus measurements consistently showed that groundwater concentrations ranged from about 1% to 2% of concentrations in

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[1] Nordin, R.N., C.J.P. McKean and J.H. Wiens, 1983. St. Mary Lake Water Quality: 1979-1981. Working Report, BC Min. of Environ., File 64.080302.

[2] Van Vliet, L.J.P., A.J. Green and E.A. Kenney, 1987. Soils of the Gulf Islands of British Columbia, Vol. 1, Soils of Saltspring Island. Report No. 43, British Columbia Soil Survey, Research Branch, Agriculture Canada

the effluent entering the drain fields. Concentrations decreased with distance out from the drain fields, and no evidence of septic phosphorus was detected in lake-side samplers. These results are in good agreement with the recent, comprehensive body of research carried out in Ontario[3]

At the third site, along Langs Road west, no groundwater was present for the entire sampling period. This means that rainfall, and flow from higher land, is completely removed by run-off, by direct evaporation and taken up by trees and released through evapotranspiration. There is no flow from septic drain fields toward the lake and no pathway for phosphorus to reach the lake. This condition is likely the case for all properties along the western portion of Langs Road in view of the forest cover and setback distances from the lake.

In conclusion, on-site sewage treatment systems are working efficiently, with phosphorus retention factors immediately under the drain fields exceeding 95% for the slightly acidic soils around St. Mary Lake. The evidence also shows that no phosphorus attributable to septic systems is reaching the shoreline waters of the lake, indicating that even if phosphorus plumes form in the groundwater below drain fields, all of it is adsorbed to soil particles before reaching the lake.

A revised estimate for the total load of phosphorus to the lake is less than 5 kg each year, considering the efficient retention and low or nil transmission factor for local soil conditions. This estimate, based on 151 possible contributing properties, also takes the reduction in phosphates in household products into account, as well as the actual seasonal water use for lake-side residents.

Because a load of about 5 kg, or less, is negligible in terms of the phosphorus content of the lake and other external sources, wastewater collection and treatment facilities are not necessary, and would provide no benefit for water quality in St. Mary Lake.

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[3] Robertson, W.D., S.L. Schiff, C.J. Ptacek (1998). Review of phosphate mobility and persistence in ten septic system plumes. *Groundwater*, 36: 1000-1010.

1.0 INTRODUCTION

As noted in the synopsis, the purpose of this investigation was to update the estimates of phosphorus entering the lake from on-site sewage treatment systems, specifically the septic drain fields associated with such systems. The following report provides a description of current conditions around the lake, the methods used in the monitoring program, and a discussion of the results. This is followed by new estimates of the loading to St. Mary Lake, and the conclusions. Before that, however, I have included a brief review of current understanding of how septic drain fields work, and how phosphorus is removed from effluent as it percolates through soil. This discussion is based on a large body of research carried out in the 1990s and early 2000s, principally by researchers at the University of Waterloo in Ontario, which has been summarized in detail in a review paper by Lombardo (2006), and earlier by Robertson et al. (1998). More recently, Sinclair (2014) also provides an excellent review of the subject in his thesis (see especially chapter 2). This information provides a good basis for understanding the results of the present study.

2.0 ON-SITE SEWAGE TREATMENT SYSTEMS

2.1 Review of Current Understanding

A schematic diagram for conventional septic systems is shown in Fig. 2.1. This type of system is representative of those surrounding St. Mary Lake, including the resorts. The size of the septic tank and the placement and coverage of the dispersal system (drain field) are scaled to accommodate the amount of effluent discharged from the residence or resort. Our interest here is the amount of phosphorus exiting the septic tank and entering the drain field, passing through the vadose zone and entering the groundwater where it potentially flows toward the lake.

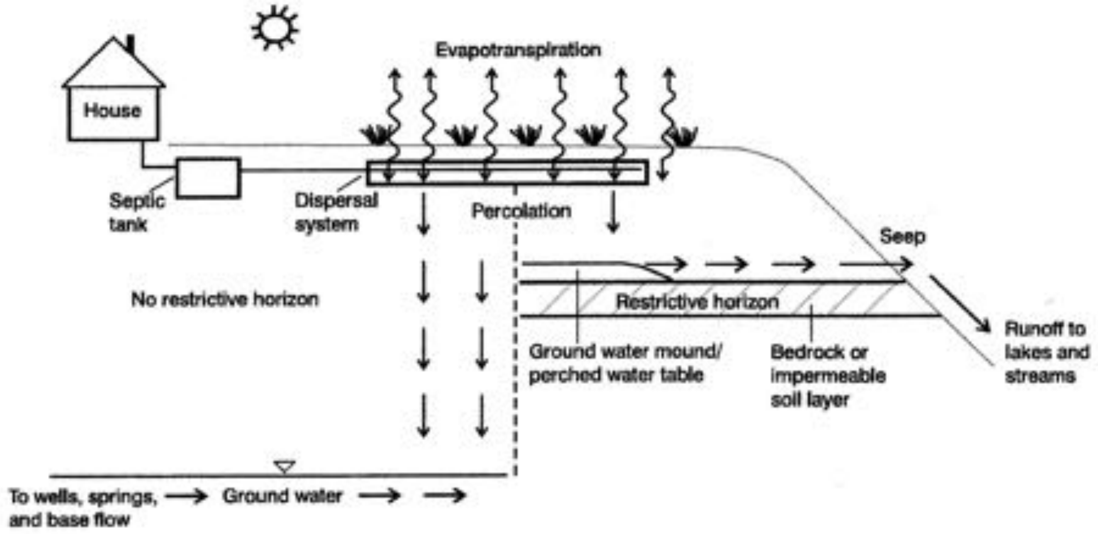

Figure 2.1 Schematic diagram of an on-site sewage treatment system. The terminology is defined in the greyed block below.

In a soil absorption system, septic tank effluent is discharged through a dispersal system to the infiltration zone, the vadose zone, and, ultimately, to groundwater. The infiltration zone may be only a few centimetres thick (~20 to 100 cm), but is the most biologically active zone in the subsurface and is often referred to as the "biomat". The vadose zone, also called the unsaturated zone, is generally required to be at least 1 m or more in depth. This zone allows oxygen transport to the infiltration zone, facilitating geochemical reactions resulting from soil-water interaction.

TERMINOLOGY

Drain field: Also called leach field, tile bed, infiltration bed, dispersal field, or disposal field, the drain field is a series of covered trenches or beds used for subsurface septic tank effluent dispersal. Trenches are usually shallow, level excavations, containing a perforated distribution pipe usually under- and overlain by media, typically rock. Bed systems consist of an excavated area with perforated distribution pipes 1 to 2 m apart, or a series of chambers. Wastewater effluent is discharged through the trench or bed surfaces, from which it infiltrates into the underlying soil.

Groundwater: Also called the saturated zone, groundwater is defined by the presence of soil pores that are saturated with water. The water table does not mark the upper limit of the saturated zone, however, as it is always overlain by a tension-saturated capillary fringe of variable thickness. The water table is the point of total water saturation at atmospheric pressure.

Infiltration zone: This is the zone directly below, or adjacent to, the dispersal system. For example, in leach field trenches, the infiltrative surfaces are the bottom and the sidewalls of the trench. The infiltration zone is usually associated with a biomat that is a very biologically active zone in which BOD oxidization and nitrification occur.

Phosphorus rapid attenuation zone: Zone, immediately underlying the infiltration zone, in which phosphorus accumulates as secondary minerals.

Vadose zone: Also called the unsaturated zone, the vadose zone is the zone immediately below the land surface (and wastewater dispersal system) and above the water table where the pores contain both water and air, but are not totally saturated with water. In the context of soil absorption systems, the vadose zone is also known as the percolation zone. The vadose zone includes the capillary fringe and allows oxygen transport to the infiltration zone

Wastewater soil absorption system: Includes the drain field, the infiltrative surfaces of the drain field, and the soil around and beneath (percolation zone) the drain field.

Most of the phosphorus and pathogen removal occurs in the vadose zone and the greatest accumulation of P is typically found within ~1 m of the drain field pipes or chambers. P-removal rates range from about 23%, up to 99%, with the highest rates corresponding to noncalcareous and/or fine-grained soils with low buffering capacity. Mineral precipitation reactions, in which PO_4-P binds with Al and Fe cations, provide the dominant mechanism for permanently sequestering P in this zone, with adsorption playing a secondary role. Robertson and Harmon (1999) refer to this layer as the “rapid transformation zone”, or “rapid attenuation zone in Lombardo (2006); it is located immediately under the infiltration zone. Calculations of the amount of mineral grains formed by these reactions indicate that these grains would not fill up the interstitial spaces for centuries, well beyond the lifetime of a soil adsorption system. Thus, there is no loss of removal capacity with aging septic systems.

As the effluent reaches the bottom of the vadose zone, the remaining dissolved phosphorus enters the groundwater and, in principle, migrates down-slope towards the lake. It is clear that PO_4-P is removed from the effluent plume in the saturated zone, principally by adsorption onto mineral grains. As the surfaces available for sorption are used up, the P-plume advances down-slope, but at a much slower rate than the groundwater itself because of this removal mechanism. Robertson and his colleagues have measured P-migration rates between 1/20 and 1/100 of the groundwater flow rates, depending on soil composition. Some typical numbers from the Ontario studies are as follows:

Soil type	groundwater velocity	P-migration rate
silt, fine sand	<1 – 3 m/a	0.01 – 0.06 m/a
medium sand	~ 20 – 40 m/a	0.4 – 2 m/a
coarse sand/till	100 – 400 m/a	> 2.5 m/a

The P-migration rates in fine-grained soils imply a travel time in excess of several centuries for a distance of 30 m (minimum 100 foot setback). In medium sand to sandy loams like soils around St. Mary Lake, the time to travel 30 m is, roughly, two to three decades. Thus, there is a considerable lag period between the installation of a drain field and phosphorus potentially reaching the shoreline. Obviously, the greater the setback, the greater this time lag will be.

As shown in Fig. 2.1, evapotranspiration results in a loss of water from the effluent as it is dispersed in the drain field pipes or chambers. This loss is considered significant in dry summer climates like those occurring in the Gulf Islands (and confirmed by our measurements). Since the dispersion rate of phosphorus through the vadose zone depends on the flow of water supplied by the effluent, a loss of some or all of the liquid effluent will also be a factor governing the movement of P.

This very brief summary touches only the high points. A great deal more detailed information and related data, particularly on the chemistry controlling the mineralization and adsorption of PO_4-P, are presented in the referenced review papers, and articles cited therein. The interested reader is encouraged to look at these papers.

2.2 The Situation Around St. Mary Lake

We are fortunate to have a detailed mapping of surficial soils for Salt Spring Island prepared by Van Vliet et al., (1987). Although the classification of soil types results in a large number of categories, around St. Mary Lake soils consist, for the most part, of gravely sandy loams to gravely sand, and are well drained. Exceptions are some localized pockets of silty clay loam of marine origin around the south end of the lake and along Bradbury Road, which tend to be poorly drained. The soils are noncalcareous.

A second characteristic noted by Van Vliet et al., and confirmed in our drilling program, is the existence of a widespread glacial till layer occurring at depths of 3 to 5 m, which is impermeable, or nearly so. During summer months the soil column above the till layer dries out, usually between about July to November. Thus, for several months there is no groundwater, and hence no pathway for P to move laterally from the vadose zone beneath the drain field. Since the till layer is impermeable, there is no means for P to be transported toward the lake at deeper depths. The situation around St. Mary Lake corresponds to the right-hand panel in Fig. 2.1: the glacial till forms a restrictive layer above which lies a perched water table for a few months each year.

These are important characteristics: because the soils are noncalcareous we anticipate that the sequestration rate of PO_4-P under the drain field will be high, with little dissolved phosphorus reaching the saturated zone. And, since the groundwater is intermittent, lateral flow and transport of the remaining P will be interrupted annually, and one may anticipate a slow process. (I have not found any discussion in the literature about the effects of repeated drying and wetting on the chemistry of the phosphorus that is "stranded" above the till layer when the saturated zone disappears, but one assumes there must be some consequence to this process.)

Given these soil characteristics, and the well-established processes that take place in soil absorption systems, the monitoring program was designed to establish the sequestration rate of PO_4-P in the vadose zone, adjacent to but not immediately under the drain field, and to measure the phosphorus gradient with distance away from the drain field, if any.

3.0 MONITORING PROGRAM

Monitoring of phosphorus in groundwater was carried out at three sites around the lake (Fig. 3.1). At each location, the owners granted permission to drill several shallow wells and extract samples for two years. The site maps and descriptions are contained in Fig. 3.2, and the main characteristics of the septic drain fields are listed in Table 3.1. It is noted that none of the monitoring wells were located within the drain fields to avoid the risk of damage to the pipes or chambers.

Figure 3.1 Monitoring site locations.

The wells were drilled with an M5T track-mounted hydraulic auger drill (Fig. 3.3) and lined with standard 2” diameter PVC pipe consisting of a screen section and a solid section. The liner pipe was capped at the bottom, below the screen. Clean filter sand was placed around and a few inches above the top of the screen, and bentonite was added above the filter sand to form a seal to prevent groundwater from seeping down the well bore. All wells were capped with iron collars and lids flush to the ground. The wells were drilled down to the glacial till layer at all locations. There was no doubt about hitting the till; the fractional resistance was sufficient to bring the auger to a standstill until more torque was applied, and at no point did we succeed in penetrating through this cementous layer. Total depth and screen length are listed in Table 3.2.

Site notation is as follows: e.g., 137L refers to 137 Langs Road. The well number is appended to the site name, 137L-1 denotes well number 1, and so on.

Table 3.1: On-site sewage treatment system characteristics.

Site	*Setback from lake (m)*	*Year of installation*	*Age of drain field (years)*	*Type of drain field*	*Infiltration zone material*	*Maintenance*
343L	64	1976	40	PVC pipe, 212 feet	in-situ soil	yes
137L	46	2002	14	Chambers, 240 feet, pressure distribution, sand mound	clean sand bed over in-situ material	yes
191T	61	c. 1975	c. 41	PVC pipe, 200 feet	in-situ soil	yes

Site 343L – this is an old drain field (40 years) situated on level ground (behind the drilling crew), surrounded by mature fir and cedar trees. The ground slopes gently from the reference well, down toward the lake past well 3.

Site 137L – the drain field, located on the north side of the property, is constructed on a raised, level mound. The mound is visible to the left of the drilling crew and lies well above all measured groundwater elevations. The property slopes gradually down to the lake from the edge of the mound. The reference well filled with water to about 2 feet above the bottom of the liner during drilling, which with local knowledge suggested that the groundwater flow direction is as shown by the block arrow. Well 5 was located on that basis. Shallow piezometer 7 was located approximately 20 m to the east of the position shown on the map.

Figure 3.2 Site maps showing the location of various monitoring wells and piezometers.

Site 191 – the drain field is located on level ground immediately below the house and all wells were placed on the down-slope line. The photograph shows the location of the reference well, above the septic tank. The reference well, drain field and wells 1 and 2 are prone to periodic winter saturation at ground level.

Figure 3.2 continued.

Figure 3.3 Drill rig used for installing the deep monitoring wells.

Table 3.2: Total depth below ground and screen lengths for wells and piezometers.

	343L									
	deep wells									
	R	***1***	***4***	***2***	***5***	***3***				
Total depth (cm)	168	174	155	184	174	211				
Length of screen (cm)	91	91	91	91	91	122				
Length of screen (ft)	3	3	3	3	3	4				
	137L									
	deep wells					in-lake piezometers			piezometers	
	R	***1***	***3***	***2***	***5***	***4***	***6***	***7***	***8***	***9***
Total depth (cm)	236	282	389	254	234	156				
Length of screen (cm)	152	152	152	152	122	61	30	30	30	30
Length of screen (ft)	5	5	5	5	4	2	1	1	1	1
	191T									
	deep wells				piezometers					
	R	***1***	***2***	***3***	***5***	***6***				
Total depth (cm)	266	387	357	173	36	38				
Length of screen (cm)	152	152	152	61	28	28				
Length of screen (ft)	5	5	5	2	1	1				

There were two parts to the monitoring program – documenting soil properties at the selected sites, and measuring the concentration of phosphorus and E. coli bacteria in groundwater.

Soil properties were documented by photography at the time of drilling, grain size analysis and chemical analysis for total extractable phosphorus and soil pH.

Groundwater monitoring consisted of four components:

1) Measurements of phosphorus concentration (denoted by [P] from here on) and E. coli counts in septic tank effluent (i.e., after the septic tank) discharged to the drain field – samples were obtained from pump chambers;

2) Measurements of [P] and E. coli counts in groundwater near and down-slope from the drain field – samples obtained from the deep monitoring wells;

3) Measurements of [P] and E. coli counts in the littoral zone of the lake– samples obtained from piezometers in lake sediment – and in lake water near the shoreline;

4) Measurements of tracer compounds (chloride, bromide, boron and caffeine) at one site (137L) to establish the effluent pathway – samples obtained from the deep monitoring wells.

5) Supplemental measurements of groundwater [P] in the near-surface zone (with 30-cm screens) during periods when the ground was saturated – samples obtained from shallow piezometers.

Measurements were also made of effluent and groundwater pH at the beginning of the program.

During periods when groundwater was present in the monitoring wells, 250 mL samples for P and bacteria were obtained with a dip sampler. The sampler was disinfected with a chlorine bleach solution and rinsed between wells, and all wells were purged completely (pumped dry) between sampling events. The analytical protocols for phosphorus were:

Total phosphorus (TP) – Standard Methods 4500P-Stannous Chloride auto/Standard Methods 3120B,

Soluble reactive phosphorus (SRP) – Standard Methods 4500-PD (method detection limit 10 μg/L); US Environmental Protection Agency EPA 365.1 (method detection limit 0.1 μg/L).

At each location, a reference well was drilled, located far enough from the drain field to provide a measurement of background [P]. With the exception of site 137L the reference wells were up-slope from the drain field. At 137L there was no suitable, accessible drilling location above the drain field and the reference station was placed as far from the septic system as possible (the chemistry obtained there suggests no influence from the drain field). The reference concentrations were subtracted from the concentrations measured at the exposed wells to provide an estimate of the contribution from the septic system.

Water level in each well was measured with a metal tape and a flashlight. This proved to be by far the easiest and best method (e.g., compared with acoustic sounding) – detecting surface disturbance with the tip of the measuring tape was unambiguous. Depth to the water table was measured from the top of the well liner, and the tops of the well liners were levelled to the lake surface. The relationship of lake level to GSC datum is known, allowing the water table measurements to be converted to that reference datum.

4.0 DISCUSSION OF RESULTS

4.1 Soils and Percolation Rates

The *in situ* soil photographs from each location are shown in Fig. 4.1, for the reference site and for a site closest to the drain field. Generally, grain size and composition varied little with depth down to the till layer, and between sites at each location. As a result, these photographs are representative of conditions that potentially conduct the effluent plume and phosphorus, in the vadose zone and the saturated zone. As noted, during drilling, between August 19th and 21st, 2014, all wells were dry with the exception of 137L-R, the reference site at the northeast corner of the lake, which contained a saturated zone just above the till.

Figure 4.1 Soil photographs during auger drilling.

Figure 4.1 continued.

Soil samples were extracted from the auger drill at one depth within the vadose zone (Fig. 4.2) and analyzed for grain size (Table 4.1, Fig. 4.3). The soils from all sites are predominantly compacted sand with about 15% to 20% gravel. The fine fraction is comprised of >80% sand, with the remainder silt. Clay is virtually absent from all sites. The standard classification would be sand or loamy sand (Fig. 4.4).

When sampled in August 2014 in the vadose zone (unsaturated zone), the soil moisture content ranged from 9% to 12% at 191T and 343L. The moisture content at 137L-3 and 137L-R was 15% and 17%, respectively, at a depth of ~1 m. The other wells at 137L ranged from 12% to 13%.

Based on the permits issued for on-site sewage treatment systems, percolation rates were measured in the range of 5 to 15 minutes per inch, consistent with the sandy soils at the three sites. According to the Provincial standard, percolation rates in this range impose only slight site restrictions on the design of septic systems (recognizing that percolation is only one of several criteria for defining site constraints), and that the soils are suitable for on-site sewage treatment systems. Consequently, given the soil composition, structure and drainage, good sewage treatment performance is expected, not the converse.

4.2 Groundwater

Water table measurements were made at every sampling visit to sites 191T and 137L, and the top of each well liner was levelled using the lake as a datum[4](Fig. 4.5). Less frequent checks were made at 343L to confirm that all wells remained dry[5], which was the case.

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[4] Lake levels are measured daily and are adjusted to the GSC datum. These data allowed the well surveys to be adjusted to the GSC datum.

[5] I will use the term “dry” to mean that no saturated zone was present. It does not mean that the vadose zone contains no moisture – measurements showed moisture contents of about 9% to 17% in the sandy soils, as noted above.

Figure 4.2 Soil samples removed from the auger flights during monitoring well drilling.

Table 4.1: Grain size analysis for soil samples from each site.

site	sample depth	v coarse sand	coarse sand	medium sand	fine sand	v fine sand	silt	Clay
	feet	2 - 1 mm	0.5-1 mm	0.5-0.25 mm	0.25-0.1 mm	0.1-.05 mm	0.05-0.002 mm	< 0.002 mm
		Percent						
343L-4	3	21	20	18	22	8	10	1
137L-3	3	14	19	41	12	9	4	1
191T-R	7	19	11	31	17	3	18	2
						sand	silt	clay
343L-4						88	10	1
137L-3						95	4	1
191T-R						80	18	2

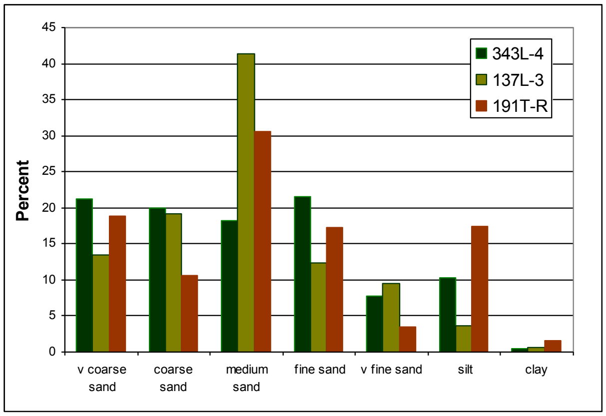


Figure 4.3 Grain size distributions in the vadose zones.

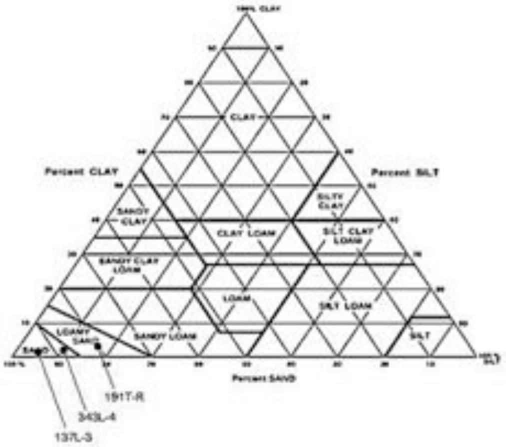


Figure 4.4 Texture diagram for monitoring location soils.

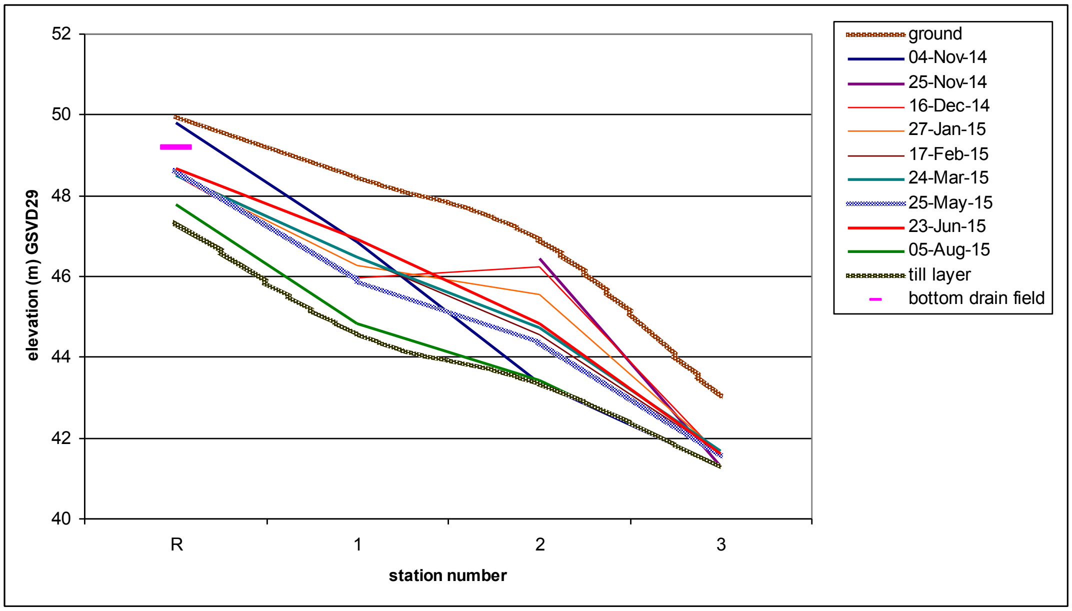
Figure 4.5 Levelling the monitoring wells.

Figure 4.6 shows the variation in water table elevation over the course of the fall and winter months. Only 137L-R had a saturated zone when it was drilled, and our assessment on site was that there is likely a permanent saturated zone above the till layer to the east of the drain field at this site, with flow oriented in a south-easterly direction (see block arrow in Fig. 3.2).

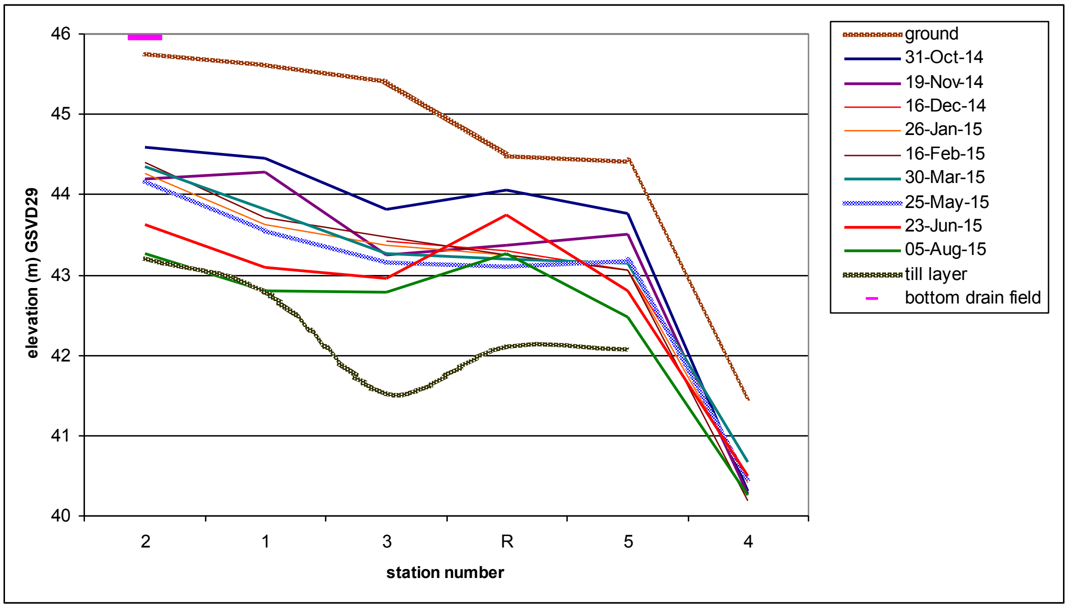
As shown in these graphs, the saturated zone was re-established by late October or early November when it reached its maximum elevation (minimum depth). By January, and through the remainder of the spring, the water table stabilized at about one-half of the depth to the till layer. This meant that the saturated zone was about 1.2 to 1.8 m thick. With either 1-m or 1.2-m screens, the deep monitoring wells provided an integrated sample over most, or all, of the saturated zone.

In August 2015 the saturated zone had essentially dried up at 191T, and at sites 1, 2 and 5 at 137L. Sites 3 and R at 137L retained a saturated zone about 1 to 1.5 m thick, above the till layer.

It is commonly noted on Salt Spring Island that heavy winter rains saturate the ground surface in some areas, and this was certainly the case at 191T and 137L through November to January 2014-15. This is shown, for example, by the water table depth of zero on Nov. 4th at 191T-R. However, at all sites the standing water table in the monitoring wells fell to, roughly, 2 m below the ground surface by January, even though the ground saturated periodically. It is not clear if this surface saturated zone was perched above the water table, with an unsaturated zone in between, or if the two were connected for periods of time after heavy rains. In any case, shallow piezometers with 30-cm screens were installed to measure PO_4-P just below ground level to see if transport were taking place close to the surface, and at what concentrations. Water table measurements were made again on Jan 11, 2016 (Fig. 4.7) and show that the saturated zone was re-established at similar depths to one year previously.

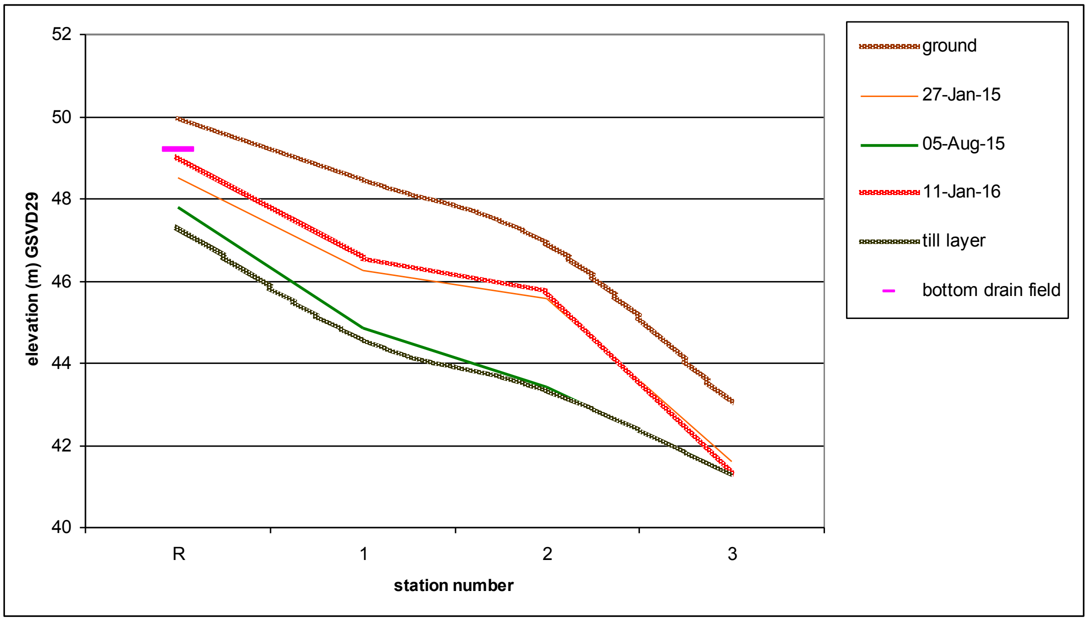


site 191T

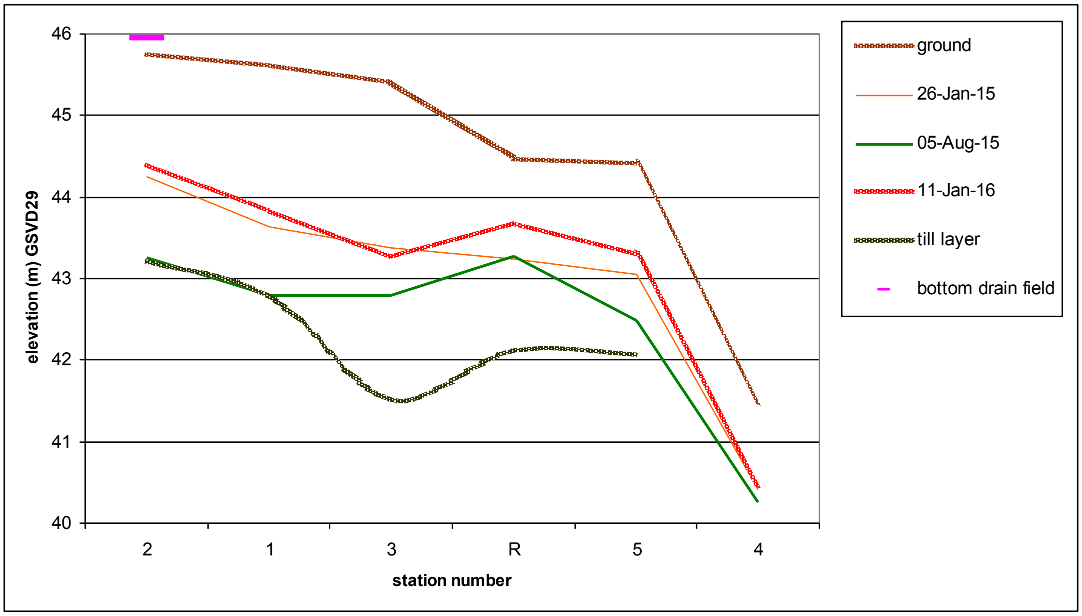


Site 137L

Figure 4.6   Variations in water table elevation with time.



Site 191T



Site 137L

Figure 4.7 Comparison of water table elevation in January 2016 with January and August 2015.

4.3 Phosphorus Uptake

The results for [P] (as SRP) are shown in Table 4.2 for the two sites with groundwater – 137L and 191T. Considering 137L first, background concentrations averaged 11 ± 3.3 µg/L (n=7) compared with averages of 22 to 28 µg/L at wells 1, 3 and 5. The difference between these wells and background ranges from 12 to 17µg/L, and is considered real at the 1% level of significance (t-test for equal variance). There is also a

Table 4.2: Results for dissolved P (SRP) at site 137L and 191T.

Site 137L:

	deep wells					piezometers						
Date	***R***	***1***	***3***	***2***	***5***	***4***	***6***	***7***	***8***	***9***	***lake***	***effluent***
											water	
	SRP											
	µg/L											
20-Nov-14	11.7	21.8	21.7	13.5	16.8	2.14	-	-	-	-	18.8	1690
16-Dec-14	17.1	29.7	31.8	15.9	32.8	7.72	5.39	10.0	-	-	18.2	854
26-Jan-15	7.89	22.0	20.6	13.6	18.9	1.84	1.17	1.84	67.7	48.5	11.6	1470
16-Feb-15	8.70	20.2	32.4	16.1	20.3	2.89	-	-	110.0	34.4	2.49	1880
30-Mar-15	13.1	24.6	31.1	16.8	25.0	7.15	-	-	41.2	30.1	10.7	1915
25-May-15	9.08	18.0	21.6	18.9	21.7	-	-	-	-	-	1.41	1915
11-Jan-16	8.73	25.4	35.1	15.5	23.0	10.7					26.1	
mean	10.9	23.1	27.8	15.8	22.6	5.41	3.28	5.92	73.0	37.7	12.8	1621
std dev	3.31	3.84	6.18	1.87	5.22	3.64	2.98	5.77	34.70	9.63	8.98	414
mean difference		12.2	16.9	4.9	11.7							
percent of effluent		0.8%	1.0%	0.3%	0.7%							
retained in drain field		99.2%	99.0%	99.7%	99.3%							

Table 4.3 continued – site 191T:

	deep wells				piezometers		
Date	***R***	***1***	***2***	***3***	***5***	***6***	***lake water***
	SRP microg/L						
04-Nov-14	10.6	21.4	-	-	-	-	-
25-Nov-14	15.4	20.4	14.4	-	-	-	-
16-Dec-14	31.6	30.9	35.7	13.5	-	-	12.8
27-Jan-15	27.5	11.9	36.0	15.3	70.7	13.7	10.3
17-Feb-15	17.5	12.3	21.4	20.3	-	-	4.8
24-Mar-15	18.0	13.0	19.2	15.8	22.3	3.6	2.7
25-May-15	9.5	19.9	23.9	12.0	-	-	1.6
11-Jan-16	11.2	10.7	25.5	-	-	-	-
mean	17.7	17.6	25.2	15.4	46.5	8.67	6.44
std dev	8.06	6.91	8.12	3.14			4.89
mean difference			7.5		28.8		
percent of effluent			0.5%		1.8%		
retained in drain field			99.5%		98.2%		

(note: both the septic tank and distribution box at 191T were inaccessible and no effluent samples could be obtained)

small gradient between well 3 and well 5, which we believe is in the direction of water movement; however, the difference is too small to be considered statistically significant. The average at well 2 is slightly above background (4.5 µg/L) and is probably not exposed to the septic effluent.

As shown in the last row of the table, the amount of dissolved P retained in the drain field exceeds 99%.

The piezometers installed in the littoral zone of the lake show P-values that are generally *lower* than the reference station 137L-R, and thus much lower than at wells 3 and 5, as well as the lake water itself (~12 to 18 µg/L at the time of sampling). We also found that the water level in the piezometers was always *lower* than the lake level, by a few centimetres. Hydraulically this implies that flow in the saturated zone below the lakebed, is toward the land, not from the land to the lake. These results were a little surprising, but *suggest* that P from septic drain fields is not reaching the margin of the lake in any significant quantity.

Two shallow in-ground piezometers with 30-cm screens (wells 8 and 9), were also monitored during a period when the lawn below the drain field was saturated from rain. Clearly, the P-values measured here are above background and wells 3 and 5 (Table 4.3). However, we also observed that the lawn was heavily covered in goose feces throughout this period and that values in the lake at this time were at their lowest and well below the readings in the lawn. It was not possible to reach a definite conclusion regarding the source(s) of P in the piezometers, but we suspect that the bird fecal matter was the primary one.

At 191T the reference station concentrations vary with time and seem to show a rapid increase as the water table rose quickly after the fall rains began, and then tapered off over the winter. The overall average is 17.7 ± 8.1 μg/L ($n=8$) with a range spanning 9.5 to 31.6 μg/L – a little greater than at 137L.

There is virtually no difference between well 1 and the reference station; however, the difference at well 2 (7.5 μg/L) is statistically significant and indicates that the groundwater does provide a pathway for septic effluent at this location. Similar to 137L the phosphorus uptake exceeds 98% at this site. The results for well 3 show that no phosphorus originating from the septic drain field is reaching this location – the mean concentration was less than the reference station.

Samples from the lake also show concentrations that are consistently below the groundwater reference station, and below those from well 3 located within ~15 m of the shoreline. Site conditions (overgrowth) prevented installation of piezometers in the near-shore zone, and so the lake measurements provide the only indicator of possible phosphorus loading in line with the drain field. Given that the concentrations in the lake are so much lower than both the reference site and well 3, we conclude that there is little or no significant input of dissolved P from a septic source.

The results from the shallow piezometers do, however, show a substantial increase in dissolved P over reference groundwater, reaching levels of 70 μg/L or more close to the drain field at well 1. There is also a marked gradient between well 1 and 2, about a five-fold reduction in concentration. These (very limited) data do *suggest* that when the ground becomes completely saturated, there is some lateral transport of P away from the drain field. This transport is intermittent, depending upon rainfall and the level of the water table, and P appears to be removed rapidly from solution with distance from the field. Given that concentrations from the septic tank to the drain field are likely to exceed 1,500 μg/L, the average uptake by soil appears to be at least 98% within about 5 m of the edge of the field. Although a pathway for septic effluent, these data imply that no significant amount of P would reach the lake (or even mid-way down the slope of this property at well 2).

4.4 Bacteriological Results

E. coli results from site 137L were typically <10 cfo[6]/100 mL at all of the deep wells, with the greatest value of 50 cfo/100 mL (one observation). There was no difference between the reference site and the wells closest to the drain field. Effluent concentrations ranged from 120,000 – 360,000 cfo/100 mL; thus, for all practical purposes, bacterial removal is complete (100%). Piezometers 4 and 6, in the lake, did show concentrations of 250 and 180 cfo/100 mL on one occasion (16-Dec-2014), but not later. It is noted that this area of the lake is heavily populated by waterfowl at that time of year, and it is unlikely that the elevated counts were the result of sewage effluent based on the other evidence.

The observations at 191T were much the same, with one exception on 16-Dec-2014 when counts were elevated at all wells including the reference well (~50 – 60 cfo/100 mL). There is no obvious explanation other than to note that sampling followed a period of heavy rain that saturated the ground and possibly flooded wells R and 1.

4.5 Chemical Tracers at Site 137L

Samples collected at wells 191T-R, -3, -5 and the lake were analyzed for Cl^-, Br^-, Boron (B) and caffeine, as possible tracers for septic effluent. The results are shown in Table 4.3. Wastewater effluent tends to have higher concentrations of Cl^- relative to naturally occurring Br^-, which is generally not found in household products. Thus the ratio Cl^-/Br^- can be a potentially useful tracer of effluent in groundwater. A

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[6] cfo = coliform organisms

brief literature review indicated that groundwater ratios typically range from 100 – 200 while septic effluents range from about 300 – 600. A review study undertaken by the CRD (Anderson et al., 2015) suggested that the difference between an exposed site, compared with a reference (unexposed site) should differ by at least 20%. The results in Table 4.3 are ambiguous: the ratio is high at the reference site, suggesting that it may have some (low) exposure, and the difference between it and well 3 is, perhaps, a bit low. On the other hand, the difference at well 5 fits the definition for exposure.

Boron concentrations vary widely in surface waters and groundwater. Literature values show averages in surface waters of about 10 μg/L, while concentrations in groundwater range from about 5 to over 4000 μg/L, with a median value of 20 μg/L. The concentration at the reference site is certainly greater than the quoted median value, but well within the observed range. However, the difference between reference and well 3 indicates that it is exposed to septic effluent. On the other hand, the result at well 5 contradicts the Cl- and Cl$^-$/Br$^-$ ratio and the dissolved P data.

Table 4.3: Results for septic effluent tracers.

Well		***R***	***1***	***3***	***2***	***5***	***lake***
SRP	(microg/L)	9.08	18	21.6	18.9	21.7	
pH		6.73	5.88	6.31	6.26	6.30	
E. coli	(cfo/100 mL)		50	1	<2		
Cl-	(mg/L)	16		19		43	
Br-	(mg/L)	0.064		0.067		0.114	
Boron	(microg/L)	63		271		25	
Caffeine	(microg/L)	<0.020		0.023		0.034	<0.020
Cl-/Br-		250		284		377	
Cl-/Br- change				13%		51%	

The caffeine results show that the reference site and the lake water were both less than 20 ng/L, which is the quoted method reporting limit (MRL) by the laboratory. Since MRLs generally contain a safety factor, the actual detection limit is presumably smaller. At 23 and 34 ng/L, sites 3 and 5 are thus likely exposed to septic effluent. The lake is probably not, although one cannot draw a general conclusion from one sample. The residence uses caffeine-containing products and so it should be a valid tracer of septic effluent at this site.

On balance, the evidence confirms that wells 3 and 5 were located in the septic effluent plume.

4.6 Summary

Surficial soils around St. Mary Lake are, for the most part, noncalcareous sands and sandy loams containing a small fraction of gravel, and are well drained. Exceptions occur in a small zone around the south end of the lake and the northeast corner, where soils contain a higher fraction of silt and clay and are poorly drained (lower permeability) compared with the sandy soils. There is a widespread layer of impermeable glacial till beneath the sand-gravel zone that forms a barrier to percolation, and the water table above the till is ephemeral. It generally disappears by mid-summer, and is re-established during the fall rains each November and December. In some locations, (e.g., the west end of Langs Road) there is no saturated zone throughout the year, presumably because of absorption by duff, evaporation and evapotranspiration from the heavy forest cover. A saturated zone is necessary for transport of phosphorus from septic drain fields toward the lake.

The soil conditions are considered suitable for septic systems by Provincial standards and when properly installed, good performance from drain fields is expected. Differences in soil classification, as shown for example, on van Vliet's maps, are small in terms of permeability and composition, and are not critical to the performance of septic distribution systems. Consequently, the sampling sites[7] are generally representative of the expected behaviour of phosphorus uptake for the majority of properties bordering the lake. The exception might be along Bradbury Road where soils are less permeable; however, that does not imply that more phosphorus would reach the lake. Rather the opposite since the rate of groundwater flow would be slower, and adsorption of soluble phosphate in the effluent plume would be effective.

The evidence is convincing that some monitoring wells at each site were exposed to septic effluent in groundwater at the locations with a saturated zone above the till, and provide us with estimates of P uptake by the drain fields. The retention of dissolved P exceeds 98%, which is the same result reported by Robertson et al. (1998) for similar soil properties in Ontario. There is no indication that groundwater is contributing soluble phosphorus to the lake, regardless of the setback of the drain field. Removal of E. coli bacteria is virtually 100%.

Given the high summer-time evaporation and the ephemeral saturated zone around St. Mary Lake it is logical to infer slow down-slope migration of the small amount of phosphorus leaving the area of the drain field. Robertson et al. found that migration of P was a great deal slower than the groundwater itself due to adsorption of phosphorus onto soil particles. Given similar conditions here, this suggests that the time-scale of phosphorus reaching the lake is at least several decades. This seems to be borne out at 191T, for example, where well 3 at the foot of the slope shows no evidence of elevated P above background even after more than 40 years of operation.

The next section describes a calculation of the total load of soluble P that could potentially reach the lake. This requires extrapolating the results described here to all of the bordering properties. Based on these new results, I have used an uptake by drain fields of 95%, and no transmission of remaining P by ground water.

One could object and say these values are much too high in terms of P retention. However, one must also consider the evidence from the lake itself. If septic systems were contributing hundreds of kilograms of P each year, as suggested by Nordin et al. in 1983, one would expect to see a steady increase in the phosphorus content of the lake (unless you could postulate a large sink for it). The evidence shows that this is not taking place, over the last 40 years, and likely the past 150 years (see Hodgins, 2016, for an analysis of trends in phosphorus in St. Mary Lake).

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[7] It would, of course, been desirable to have more sites; however, both funding and willingness of property owners to let us drill holes in their lawns were limited.

5.0 ESTIMATES OF THE TOTAL SEPTIC PHOSPHORUS LOAD TO ST. MARY LAKE

5.1 Benchmarking Residential Loads

The residences, resort and trailer court along Tripp Road are serviced with metered drinking water by the North Salt Spring Waterworks District. So too are the residences along Bradbury Road, with the exception of the Cottage Resort at the foot of Suffolk Road. The metered consumption data provide a means of estimating the amount of water entering septic drain fields, particularly over the winter months when water is not used for irrigation. The assumption is that water used within the household ultimately enters the septic system. A conservative (high) estimate of P loading is obtained by assuming 100% of the consumed water follows this route.

Figure 5.1 illustrates the water consumed for the residences along the lake-side of Tripp Road, and along Bradbury Road, based on about 60 to 80 months of data. Clearly there is a great deal of variation between residences, which likely reflects the differing rates of occupancy during the winter. However, the averages are close, 373 L/d on Tripp Road and 379 L/d on Bradbury Road.

If we assume the concentration of P in the septic effluent is 2,000 μg/L (see Appendix A) and multiply each consumption value by this concentration, the resulting total load is 9.2 ± 0.40 (n=23) kg/yr for Tripp Road and 3.0 ± 0.27 (n=11) kg/yr for Bradbury Road, including the trailer court and the resort[8]. The individual property values are shown in Fig. 5.2.

Removing the trailer court and resort from the totals yields a value of approximately 8 kg/yr for Tripp and Bradbury Roads combined, with a total of 30 residential units. The equivalent unit load is thus, roughly, 0.3 kg/residence-yr, which agrees with the estimate derived in Appendix A for LP_1. A second useful statistic is the unit load for a resort cottage. The total water consumption for Maple Ridge Cottages is about 1450 L/d based on a weighted average for winter and summer. The unit consumption is thus, approximately 300 L/d for each of the five cottages and the residence, and the corresponding load is 0.2 kg/cottage-yr. This load is slightly less than the residence average because cottage occupancy is less than full-time, and visitors may use less water than permanent residents (this last point is speculative but seems plausible).

5.2 Extrapolating Unit Loads to the Other Residences

By including the properties on the lower portion of Fairway Drive and along South Bank Drive, there are 151 potentially P-contributing septic systems bordering the lake. Other residences are considered to be too far back from the lake to transmit phosphorus via groundwater. Applying unit residential P-load of 0.3 kg/yr, a unit resort load of 0.2 kg/yr, and actual production from the trailer court, yields a total load to all septic systems of approximately 74 kg/yr (Table A1 – Appendix A).

For a P-removal efficiency of 95%, the potential load to groundwater is less than 4 kg/yr. Even assuming no further uptake by adsorption from ground water, this load is insignificant to the phosphorus balance of the lake. Further, even if the load per residence is too low by, say, a factor of two, the result is still insignificant.

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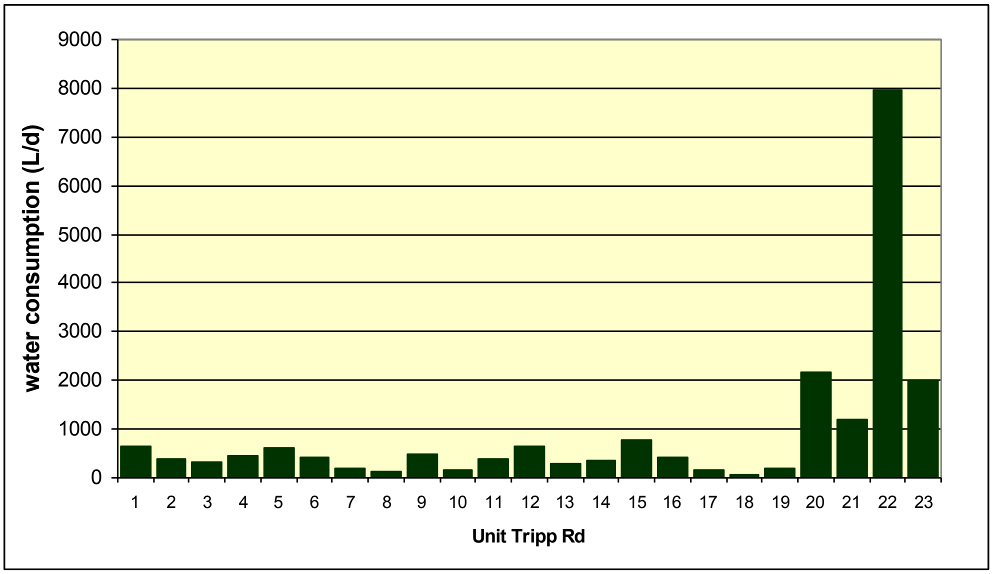
[8] The trailer court and resort were calculated for winter and summer months separately, assuming all water consumed during summer ended up in the septic system. This may be reasonable for Maple Ridge Resort which does not have a large area requiring irrigation, but likely over-estimates the load for the trailer court which does have a fair amount of landscape plantings. It is noted that for the four summer months water consumption at the trailer court exceeded the other eight months by a factor of 1.8, most likely due to an increase in occupancy.



Note: units 20 and 22 are the trailer court for winter and summer respectively. Units 21 and 23 are Maple Ridge Cottages for winter and summer.

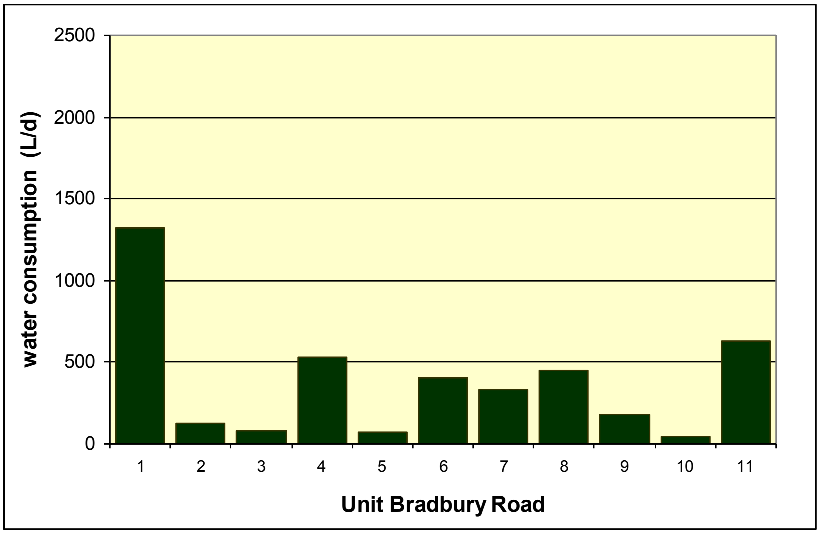
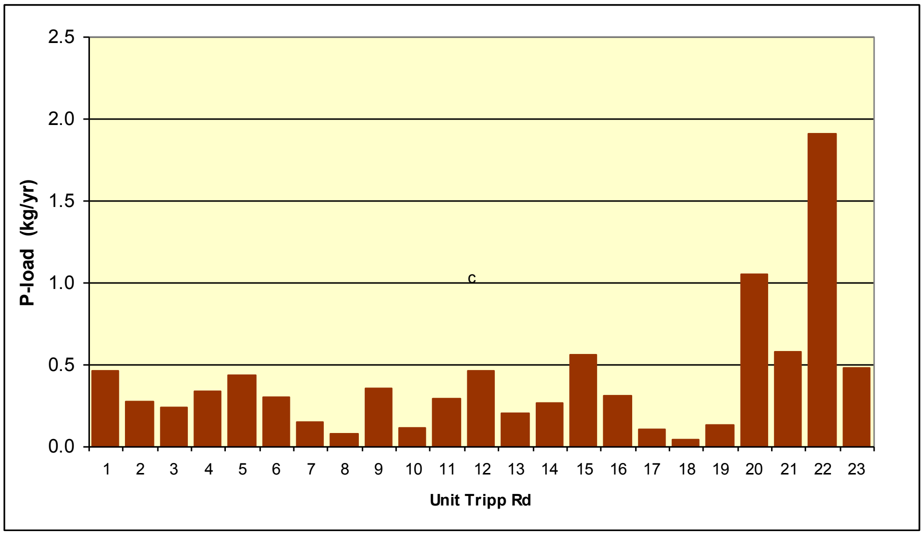


Figure 5.1 Average water consumption in L/d based on metered data spanning 2004-2013.

Such low P-septic loading values lie well below the amount of phosphorus contained in the lake (roughly averaging 400 kg and more, Hodgins, 2016), and significantly less than loads from runoff and rainfall (around 100 kg/yr). They are also the reason that minor variations in soil composition and structure surrounding St. Mary Lake do not play a role in determining septic effects on lake water quality.



Note: units 20 and 22 are the trailer court for winter and summer respectively. Units 21 and 23 are Maple Ridge Cottages for winter and summer.

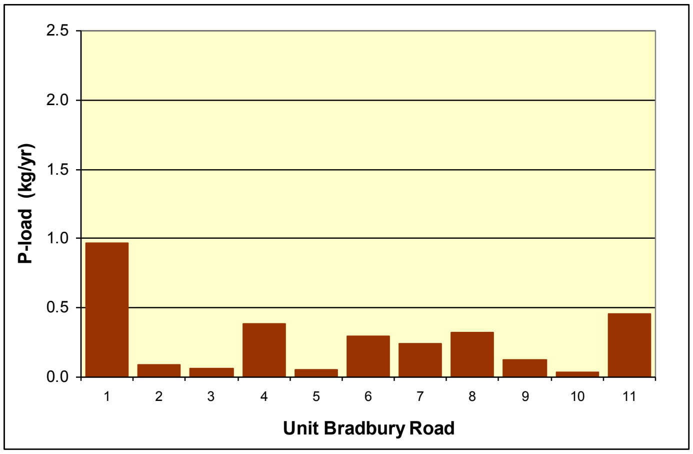


Figure 5.2 Average P-load in kg/yr based on water consumed and measured phosphorus concentrations at St. Mary Lake.

6.0 CONCLUSIONS

The new data collected between 2014 and 2016 have led to a number of conclusions that radically alter the assessment dating from the 1980s. They are:

1. The well-drained, sandy-loamy noncalcareous soils around St. Mary Lake provide good substrate for septic drain fields. Phosphorus uptake rates immediately under these drain fields exceed 95%, even for older systems dating back 40 years. Such rates are entirely consistent with 20 years of research in Ontario.
2. Residential P-loads to septic drain fields average approximately 0.3 kg/yr, based on measured concentrations and water consumption, are lower than standard literature values. This is attributed to seasonal use of many properties, low occupancy rates corresponding to an older demographic for this area and continued reduction of phosphates in household products.
3. Phosphorus loads to shallow groundwater originating from septic drain fields are negligible (< 5 kg each year), have no significant effect on the overall balance of P-sources and P-sinks for the lake, and are far below loads from rainfall and runoff.
4. Intervention that attempts to reduce septic P-loads would not achieve a measurable benefit to lake water quality.

7.0 WHO MADE ALL THIS POSSIBLE

The project described here came about because the Salt Spring Island Watershed Protection Authority (SSIWPA) provided the organizational support to mobilize the various agencies and individuals into the collaborative effort required. To begin with the most important: those property owners who volunteered to let us drill holes in their lawns,

Virginia and Jack Giles
Anne and Mike Marshall
Randy and Sally Dolliver
Rose Murakami
Karen and Hugh Preddy

Financial and technical support was provided by the Vancouver Island Health Authority and the Capital Regional District (CRD). Data essential to the project were provided by both the CRD and the North Salt Spring Waterworks District. I would also like to acknowledge the review of this manuscript in draft form, and the valuable comments provided by John Sprague. And a final note of thanks to Mud Bay Drilling Co., who installed the wells and gave us a break on the cost. Your support is much appreciated; we've learned a great deal.

8.0 REFERENCES

Anderson, L. & four other authors, 2015. Environmental and human health impacts from onsite sewage treatment systems. Prepared for Capital Regional District by Royal Roads University (Arbutus Environmental).

Hodgins, D.O., 2016. Analysis of phosphorus and algal abundance data for St. Mary Lake, British Columbia, Submitted to the Technical Working Group of the Salt Spring Island Watershed Protection Authority, February 2016.

Hutchinson, N. J., 2002. Limnology, plumbing and planning: evaluation of nutrient-based limits to shoreline development in Precambrian Shield watersheds. In France, R. L. (Ed.), *Handbook of water sensitive planning and design.* pp. 647-680. Lewis Publishers.

Lombardo P. 2006. Phosphorus Geochemistry in Septic Tanks, Soil Absorption Systems, and Groundwater. Prepared by Lombardo Associates, Inc., Newton, MA. (Available in pdf format: http://lombardoassociates.com/pdfs/060410-P-Geochemistry-FINAL-LAI-Version.pdf)

Robertson, W.D., S.L. Schiff, C.J. Ptacek, 1998. Review of phosphate mobility and persistence in ten septic system plumes. *Groundwater*, 36: 1000-1010.

Robertson, W. D. and J. Harman, 1999. "Phosphate plume persistence at two decommissioned septic system sites." *Groundwater* 37: 228-236.

Schusslera, J., Bakera, L. & Chester-Jones, H., 2007. Whole-system phosphorus balances as a practical tool for lake management. *Ecological Engineering* , *29*, 294-304. doi:10.1016/j.ecoleng.2006.09.009

Sinclair, A.C., 2014. An Integrated Modeling Approach for Evaluation of Phosphorus Loading In Rural Nova Scotia Watersheds. Ph.D. Thesis, Dalhousie University, Halifax, Nova Scotia.

Sewerage System Standard Practice Manual, British Columbia Ministry of Health, Sept. 2006.

Van Vliet, L.J.P., A.J. Green and E.A. Kenney, 1987. Soils of the Gulf Islands of British Columbia, Vol. 1, Soils of Saltspring Island. Report No. 43, British Columbia Soil Survey, Research Branch, Agriculture Canada.

6.0 APPENDIX A

The calculation of the total P-septic load was carried out as follows.

Let LP_1 = phosphorus load per residence for one year,
nr = number of residential properties,
L_1 = total residential property P load,
LP_2 = phosphorus load per resort cottage for one year,
nc = number of guest cottages or units in each resort,
o = maximum occupancy of each guest cottage,
o_{MR} = maximum occupancy of each cottage at Maple Ridge Cottages (= 2),
L_2 = total resort P load,
L_3 = total P-load from the trailer court.

then

$$L_1 = nr \times LP_1 \tag{A1}$$

$$L_2 = \Sigma\,[nc \times LP_2 \times (o/\,o_{MR})] \tag{A2}$$

where Σ is the sum of the six resorts. The factor o/o_{MR} scales up the unit load derived from the Maple Ridge Cottages data, where the cottages accommodate two adults, to cottages with greater accommodation limits.

L_3 was calculated using the average water consumption for winter (245 days) and summer (120 days) multiplied by the rounded-up septic tank effluent concentration measured at site 137L of 2 mg/L.

These calculations are shown in Table A1. The total septic tank effluent load is $L_1 + L_2 + L_3 = 74$ kg/yr. This is the estimated amount delivered to the drain fields.

LP_1 (0.3 kg/yr) was estimated using the average effluent [P] value of 1641 μg/L from 137L, times a household consumption of 520 L/d for the two full-time occupants. It is noted that this loading value is well below conventional values in the literature (1.2 to 1.4 kg/yr for a two-person household, Hutchison, 2002; Schusslera et al., 2007). The lower value for 137L may be explained by several factors: (i) household water use has been declining, certainly since the Hutchison data were published, and (ii) continued reductions in phosphates in household products combined with a greater appreciation for using products without added phosphates. There is compelling evidence for lower water consumption and hence less load to the septic systems. The average water consumption for residential households along Tripp Road and Bradbury Road was 375 L/d, which is about one-half of the Canadian residential standard (2.2 persons × 353 L/c.d). As noted before, this is likely due to seasonal use of many properties, in additional to water conservation practices in recent years.

The second factor may help explain the apparently low [P] of about 1.6 mg/L in the septic tank effluent. For example, Robertson et al. (1998) found concentrations of 7.7 ± 3.2 mg/L based on 67 observations. However, Robertson's data are more than 20 years old, and were obtained in Ontario where phosphates were used to offset the effects of hard water. Again, changes in household products with time and location will have resulted in lower amounts of dissolved P entering the septic systems around St. Mary Lake, compared with the older data.

LP_2 was calculated using the water consumption for Maple Ridge Cottages (1452 L/d) times a concentration of 2 mg/L, divided by the five cottages and one residence (6 units). This concentration value was found by rounding the measured [P] plus one standard deviation, for effluent samples collected at 137L (Table 4.2). The values are [P] = 1641 ± 414 µg/L (n=6), providing a conservative estimate of 2.055 mg/L, rounded to 2 mg/L.

Table A1 Calculation of septic tank effluent phosphorus loads.

	Residential			Unit	
	Properties			Load	
	Nr			LP_1	
				(kg/yr)	
Total residences L_1	144			0.3	**43**
			Average		
	Guest Cottages	Occupancy	Occupancy	Unit	P-load
			per cottage	Load	
	Nc	o	o/nc	LP_2	
				(kg/yr)	(kg/yr)
St. Mary Lake Resort	10	38	3.8	0.2	3.8
Cottage Resort	9	31	3.4	0.2	3.1
Cedar Beach Resort	42	102	2.4	0.2	10.2
Green Acres Resort	20	74	3.7	0.2	7.4
Lakeside Gardens Resort	11	24	2.2	0.2	2.4
Maple Ridge Cottages	6	12	2.0	0.2	1.2
Total resorts L_2					**28**
	Winter	Summer			
	Consumption	Consumption		[P]	
	(L/d)	(L/d)		(mg/L)	
Total trailer court L_3	2153	7965		2	**3**
Total $L_1 + L_2 + L_3$ (kg/yr)					**74**