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# Severn Sound Remedial Action Plan: Evaluation of a Vegetated Filter Strip (VFS) for Barnyard Runoff

**Julie P. Cayley**
Project Coordinator, Rural Non-Point Source
Severn Sound Remedial Action Plan

**Michael R Toombs**
Rural/Urban Interface Specialist
Ontario Ministry of Agriculture, Food and Rural Affairs

## ABSTRACT

As part of the Severn Sound Remedial Action Plan (RAP), a vegetated filter strip (VFS) was constructed to treat barnyard runoff from a 20 head cow-calf operation. The VFS was constructed and monitored over a two year period. Monitoring included measurement, sampling and analysis of soils, runoff and groundwater for eleven parameters, including nitrates, phosphorous and chlorides. Results revealed no increase in any parameters including nitrates in the groundwater. Over the course of the evaluation period the VFS proved to be an economical and environmentally sound treatment system for barnyard runoff.

**KEYWORDS:** Vegetated Filter Strip (VFS),barnyard runoff, monitoring, groundwater

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## INTRODUCTION

Severn Sound is a collection of bays in the southeast portion of Georgian Bay, Lake Huron (Figure 1). Eutrophication, due to anthropogenic phosphorus loading, has been a concern in Severn Sound since the 1960's. Problems associated with eutrophication include excessive algae blooms, decreased water clarity and changing fish communities. Due to deteriorated water quality and subsequent impaired use, the area has been listed by the US\Canada International Joint Commission (IJC) as one of 43 Great Lakes Areas Of Concern (AOC). A Remedial Action Plan (RAP) has been developed to restore environmental quality and uses of the area.

Between one third and one half of the 1000 km' watershed draining into the Severn Sound is used for crop and livestock production (Severn Sound RAP, 1993). Measures to control phosphorus and bacteria from various sources, including agricultural non-point sources, have been investigated. Barnyard runoff is one of the agricultural practices being targeted for remediation.

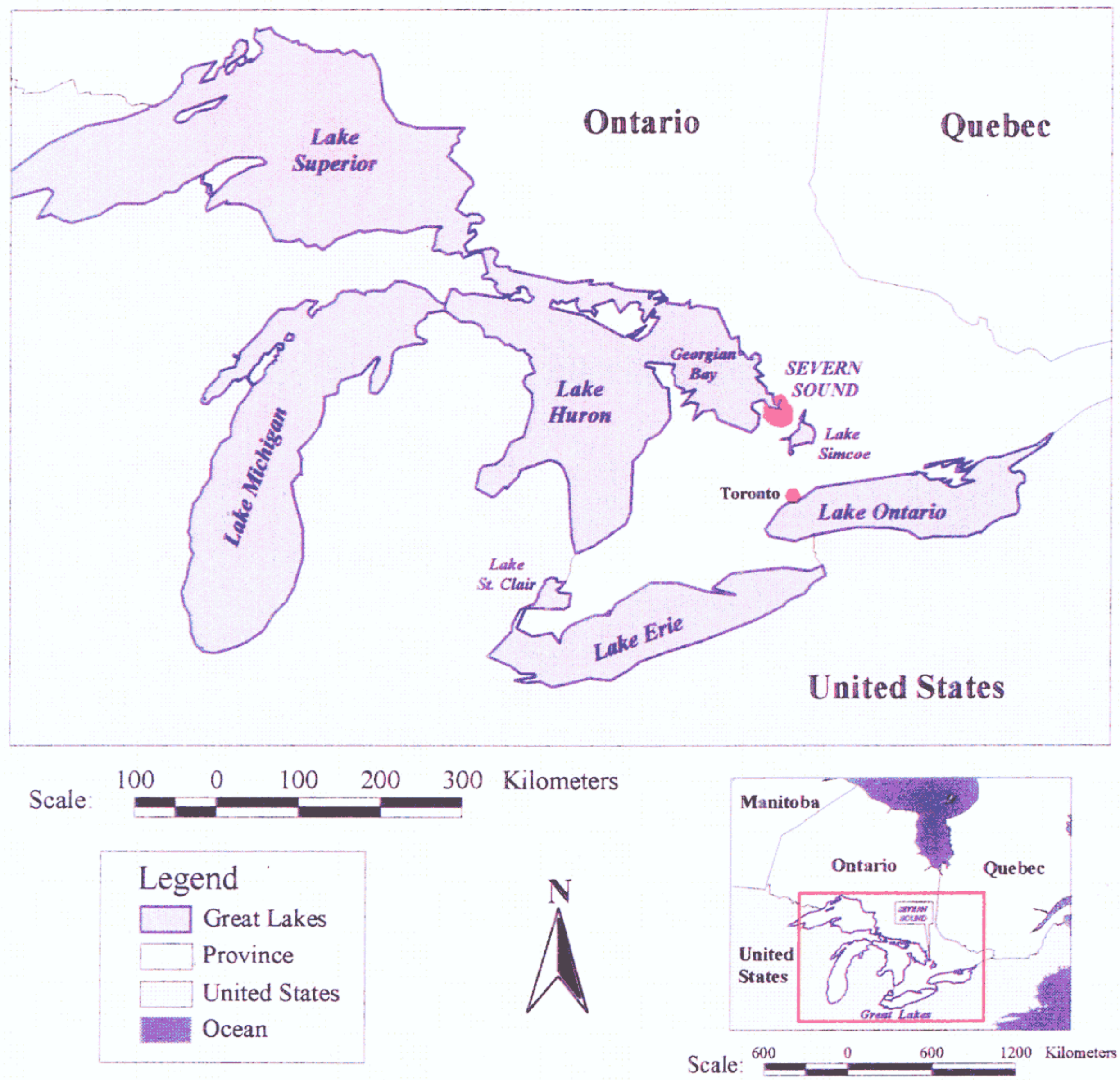



**Figure 1: Location Map of the Severn Sound, South East Georgian Bay, Lake Huron (ESRI, 1997).**

Current recommendations for handling barnyard runoff generally suggest that these wastes be eliminated or stored and land-applied. Due to the large volumes and relatively low fertility values, the recommendations are generally not economically feasible nor practical. Vegetated filter strips (VFS) in the United States (Dillaha et. al. 1989) have demonstrated to be cost-effective, practical and environmentally safe solutions to handling agricultural wastewater and runoff
The objectives of this study were to evaluate and demonstrate the VFS as an economical and environmentally sound treatment system for barnyard runoff in Severn Sound. This paper will summarize the results and the evaluation of the effectiveness of the Severn Sound VFS.

## MATERIALS AND METHODS

### Vegetative Filter Strip Description

The VFS is a system in which a vegetated area is used for treating runoff by infiltration, settling, dilution, filtration and absorption of pollutants. A VFS system consists of a settling area, usually the yard, a filter box, a gravel spreader and a vegetated area. The Severn Sound VFS was designed to handle strictly barnyard runoff The site included a roofed solid manure storage with capacity to hold barnyard runoff for approximately 240 days as a backup to the VFS.

The barnyard (520 $m^2$) was constructed with recycled concrete slabs (1.5 m by 9 m), originally ice rink floor from the local arena, grouted together and graded to slope towards the filter box (Figure 2). The filter box controls the flow rate of yard runoff and consists of a removable mesh screen with approximately 12.5 mm square openings and a pump chamber. The filter box itself is a concrete precast crypt (without the lid). The pump chamber is located in the filter box at the end farthest from the barnyard and is equipped with a half horsepower sewage pump. PVC pipe (51 mm) fitted with ball valves, directs pump chamber liquid to the gravel spreader and/or to or from the roofed manure storage. The lid to the pump chamber was fitted with 42 mm holes to control the rate at which the chamber filled. This ensures that the VFS is not overloaded during large storm events. The pump operates on a float switch, pumping only when the chamber is full.

The size of the VFS is dependent on the size of the contributing feedlot or yard, the slope of the land, and the soil type. The vegetative area can have a slope of 0.5 to 4 percent, and can be anywhere from 90 to 260 m long with typical widths starting at 9 m. The width of the VFS should be designed to accommodate the width of the hay harvesting equipment to be used. A small ridge is constructed around the VFS to divert clean water away. The Severn Sound VFS is 91.5 m long by 3.7 m wide with 0.5 percent slope, designed so that the flow will never exceed 1.3 cm (0.5 in).

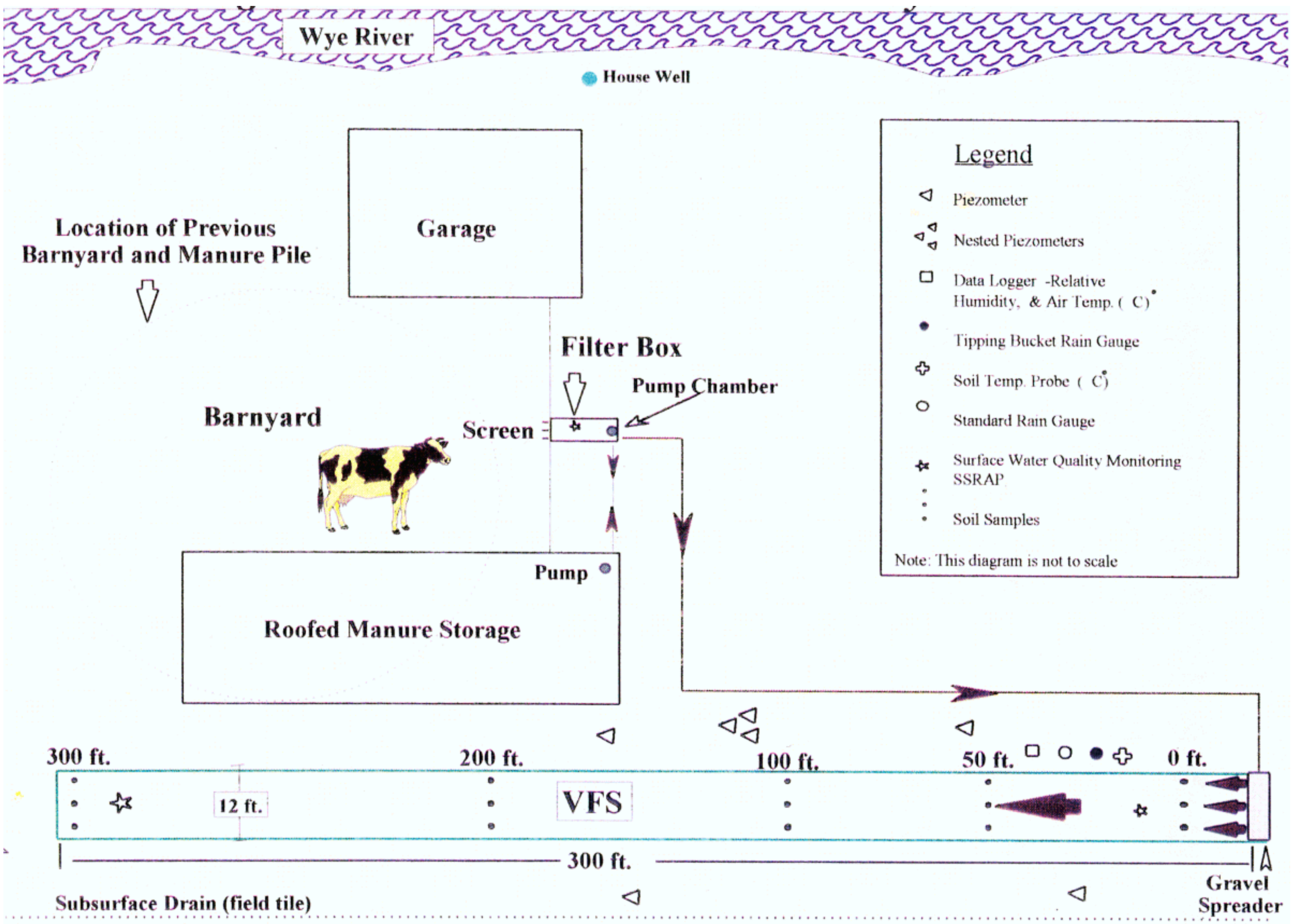



Figure 2: Severn Sound VFS Site Layout

The buildings surrounding the barnyard were equipped with eavestroughing to reduce the volume of clean water being contaminated by the barnyard and consequently needing treatment.

In the case of a small rainfall event, yard runoff will flow to a filter box at the low end of a yard. Debris (manure solids, saw dust bedding, hay, etc.) will be strained by the filter screen. The runoff will then flow into the pump chamber. Once full, the float switch will trigger the pump and the runoff will be pumped approximately 61 m into the gravel spreader 15 cm deep, 1.8 m wide, running across the width of the VFS. The gravel spreader will slow the runoff velocity down, filter out fine solids, and evenly distribute the flow across the vegetative strip. The runoff will move slowly in a sheet flow, down the strip, infiltrating as it flows.

In the case of larger storms, the filter box and pump chamber will control the flow of runoff onto the strip by temporarily storing the runoff on the yard (usually no more than 12 hours) until it can be safely treated by the filter strip. The yard must be able to provide a temporary ponding or settling area to ensure the 1.3 cm depth of flow on the strip is not exceeded. The temporary ponding area also provides for settling of the larger particles in the runoff. The settling area should be as large as possible, and be easily accessible for maintenance. In some cases, instead of using the yard as a temporary settling area, it is economical to construct a temporary ponding area of earth or concrete off the existing yard.

**Vegetative Filter Strip: General Design**

The VFS design was developed after examining the literature and visiting several systems in other jurisdictions. The filter box and gravel spreader were adopted from Wisconsin (Bellam-Mather et. al., 1992) based on their research data and actual trial and error field observations of systems installed over a 20 year period. The authors of the Wisconsin paper found it essential to keep solids off the vegetative area of the strip and a multiple mesh screen system evolved. The use of a gravel spreader to distribute the runoff evenly across the width of the strip also evolved over time. Concrete or wood structures are expensive and tended to shift creating uneven flows over the vegetative strip. Gravel is inexpensive, flexible and if it shifts, it can be easily adjusted. The VFS area and calculations are similar to the Illinois vegetative filter design criteria (Steams et. al., 1982) and to Vanderholm et. al. (1979), whereby the infiltration area is based on the design storms. This approach (Dillaha, 1989) can lead to large land requirements as it ignores other removal mechanisms. However, as infiltration is the most easily quantifiable VFS treatment mechanism, it was felt that a conservative approach should be followed.

Barker et. al., (1985), Steams et. al., (1982) and Vanderholm, (1979) used a 1 year, 2 hour storm event. Schellinger et. al., (1992), used a 2 year, 24 hour storm event. The states of Minnesota, Iowa, Pennsylvania and North Carolina use a 25 year, 24 hour storm event in accordance with US legislation for non-point source contaminants.

After reviewing the literature, examining historical precipitation data in Ontario and evaluating the consequences of under sizing the VFS system, a minimum of a 2 year 2 hour design storm was selected. The potential of the yard to provide increased ponding, in effect, increases the actual design storm used. The additional capacity of the roofed manure storage at this site provided a system capacity exceeding a 25 year design storm.

## Materials and Construction

In order to keep costs low and to develop a readily adaptable system, an effort was made to select materials available from any hardware store. The mesh screens, pipes, and fasteners are common hardware material. This site was constructed by a contractor using a bulldozer and laser leveling equipment. Other sites have been constructed more cost effectively by the farmers using farm equipment and levels (Toombs, 1997).

## Plant Selection

The vegetation was selected based on nutrient uptake, wet/dry tolerance and palatability. Vanderholm et. al., (1979), compared the use of orchard-grass *(Dactylis glomerata L.),* smooth bromegrass *(Bromus inermus leyes)* and reed canarygrass *(Phalaris arundinacea L.)* for overload flow systems, concluding that reed canarygrass is the best grass for most situations. Reed canary grass was used at this site. However, many Ontario farmers are hesitant to use reed canarygrass because of its vigorous growth and poor palatability of earlier varieties. For other VFS projects in Ontario, a mixture of a new, more palatable variety of reed canarygrass, along with a smooth bromegrass has been used (Toombs, 1997).

## Vegetative Filter Strip Management and Maintenance

The VFS system requires ongoing management and maintenance to sustain its effectiveness. The feedlot or yard should be regularly scraped every ten days or before major storms. This reduces solid and nutrient loadings on the system. The solids captured by the screens and filter box should be cleaned after storm events. The distribution pipe should be checked for clogging to ensure even runoff distribution across the gravel spreader.

The VFS should be checked for solids build-up, rill formation and checked to ensure the side berms are intact. The vegetation should be harvested and treated as any hay field. Cattle should be kept off the VFS to prevent damage.

## Experimental Site

This site was selected due in part to its representation of a typical small cow-calf beef operation in the Severn Sound watershed as well as the willingness and enthusiasm of the landowner. The VFS complimented an existing Clean Up Rural Beaches (CURB) program demonstration roofed solid manure storage at the site. The site had a low potential to impact the environment and minimal construction requirements.

This farm site is a 22.7 hectares (50 acres) cow-calf beef operation with a herd size of approximately 20 cows. A main tributary to the Severn Sound, the Wye River, flows through the farm and was receiving contaminated runoff from the manure pile and barnyard prior to construction of the manure storage and VFS. Approximately 18 tillable hectares at this site were systematically drained with subsurface drainage tiles at 18 m spacings running roughly south to north. The VFS was constructed between two of the drains, 7.3 m from the edge of the VFS to either drain. The drain to the east side of the VFS was disconnected during construction of the manure storage. The 17 m house well drilled in 1989 was located approximately 70 m from the VFS. The soil type at this site is generally a Berrian sandy loam.

VFS construction, including planting, was completed in August of 1994 and replanted in the spring of 1995.

## MONITORING

Monitoring included measurement, sampling and analysis of barnyard runoff (raw waste), VFS surface runoff, field tile outlet, farm house well and groundwater. The barnyard runoff, VFS surface runoff, field tile outlet and groundwater sample parameters were analyzed by the Ontario Ministry of Environment and Energy laboratory. All sampling locations are identified on the site map (Figure 2).

Samples of the barnyard runoff were taken to establish raw waste characteristics. VFS surface runoff samples were collected to compare with raw waste characteristics in order to attempt to establish removal rates and VFS treatment effectiveness.

Groundwater samples were collected from piezometers in order to monitor the potential impact of the VFS on local groundwater. Four piezometers were constructed to a depth of 4.3 m to 5.2 m. One nested piezometer was constructed with three depths: 3.0 m, 4.3 m, and 6.1 m. If any groundwater contamination from the VFS was observed, this nested piezometer was expected to identify any vertical contaminant movement. For the purpose of this report, only nitrate and chloride results for groundwater will be discussed. The Ontario Ministry of Environment and Energy (1984) established drinking water guidelines for nitrates at 10 mg/L (maximum allowable limit) and for chlorides at 250 mg/L (maximum desirable limit). Nitrate concentrations above the maximum allowable limit pose an immediate and serious human health threat. Nitrate has been implicated in infantile methemoglobinemia (Ontario Ministry of Environment, 1983). Methemoglobinemia occurs when nitrate ions convert to nitrite in the intestine which in turn reacts with the iron of hemoglobin impairing the ability of the blood to carry oxygen (Ontario Ministry of Environment, 1983). Although chlorides have no significant human health implications, elevated concentrations can impart an undesirable taste (Ontario Ministry of Environment, 1983). Chloride concentrations above 500 mg/L may be an indication of animal (faecal) waste pollution (Nathanson, 1986). Elevated chloride concentrations have been observed in distinct groundwater contamination plumes where the source of contamination is known to be from manure (Miller et. al., 1989).

Soil was sampled in order to determine the effects of the runoff application on the concentration of soil nutrients at various locations in the soil profile. Sampling parameters included total nitrogen, phosphorus, potassium and pH. Soil samples were analyzed by an accredited, professional laboratory. The percentage of sand, silt and clay in the soil profile was also determined.

A Campbell Scientific CR10 data logger recorded soil and air temperature, relative humidity, and rainfall in order to establish field conditions in which the VFS was operating. For the purpose of this report, only significant rainfall events exceeding 25.4 mm (1 in) will be reported.

The following observations were also noted by the field samplers:

<u>Observations:</u>

- Type and changes in vegetation
- Harvest dates, amount baled
- Maintenance requirements — yard, screens, gravel strip, filter strip
- Damage to VFS, cattle access — rills, erosion

<u>Storm Event Monitoring and Sampling</u>

| | | |
|---|---|---|
| Precipitation | - amount, duration, date | |
| Feedlot/Yard | - maximum height of pooled liquid in the yard | |
| | - time to peak | - height of pooled liquid |
| | - time to dissipate | - time required for liquid to flow off the yard |
| VFS | - maximum depth of liquid on strip (peaks) and average depth | |
| | - distribution of flow | - pooling/channeling on strip |
| | - maximum distance flow reached on strip | |
| Barnyard Runoff | - leaving yard, before screens | |
| VFS Surface Runoff | - at gravel spreader | |
| | - at maximum distance flow reached | |

<u>Monitoring and Sampling Frequency</u>

Groundwater sampling, and piezometers were sampled seasonally (Oct/Jan/Apr/July). Surface water and barnyard runoff samples were collected on a storm event basis.

Soil Samples were collected twice, once prior to application of barnyard runoff to the VFS and then following a season of VFS use. The first set of soil samples did not include vertical profiles.

These samples were collected at four locations (1 m, 10 m, 30 m and 100 m) along the length of the strip (1 m being closest to the gravel spreader) and were composite samples at each location to a maximum depth of 15 cm (6"). The second set were sampled at the same locations at depths of 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-46 cm, and 46-61 cm (vertical profiles).

**RESULTS & DISCUSSION**

The Severn Sound VFS was constructed in August 1994 and monitored until October 1996 when the cattle were sold from the farm. Pre-construction ground water monitoring, including the field drain, commenced in June 1994. Total cost of the VFS, including construction, gravel, plumbing and electrical was $2400.00 (Canadian).

The VFS required a landowner commitment to maintenance. The filter box screens proved to be an essential component, and required ongoing cleaning. The vegetation was slow to establish, possibly due to soil compaction during construction.

The data logger operated only during the growing season or ice free months from October 3, 1994 to November 30, 1996. During this time period 9 rain events exceeding 25.4 mm (1 in) occurred with a maximum event recorded of 46.7 mm (1.8 in) on June 29, 1996. During this time period, no surface flow was observed leaving the VFS.

Average values of the untreated barnyard runoff characteristics are reported in Table 1. These parameters were below those of Toombs (1997) indicating that the runoff from this site was less concentrated and well within the range of VFS treatment capabilities. The barnyard containment and VFS prevented an estimated annual load of 145 kg of phosphorus from reaching the Wye River.

A pump test was conducted in June 1995. Approximately 4634 L (1225 gal) of stored runoff was pumped onto the VFS over a 30 minute period at a rate of 2.6 L/s. The maximum surface flow distance along the VFS was 6.7 m. To generate a rainfall storm event situation, 25 mm of rain must fall on the barnyard (Toombs, 1997). With this in mind, the pump test created a simulated rainfall event equivalent to 9 mm over 30 minutes. No significant increases in contaminant (N, P or Cl) were observed in the field drain in the 24 hours immediately following the pump test.

| **Table 1:** **Untreated (Raw) Barnyard Runoff - Average Characteristics (runoff from SSRAP VFS barnyard site)** | | | | | |
|---|---|---|---|---|---|
| **Parameter** | **Mean Concentration** | **Standard Deviation** | **Max** | **Min** | **Sample Size (N)** |
| Phosphate | 9.19 | 6.99 | 18 | 0.9 | 5 |
| Total phosphorus. | 17.03 | 12.73 | 30 | 0.09 | 6 |
| N total Kjeldahl | 225.17 | 126.75 | 424 | 28 | 6 |
| Total Ammonia | 84.37 | 54.8 | 180 | 8.65 | 5 |
| Nitrite | 0.49 | 0.32 | 0.76 | 0.04 | 5 |
| Nitrate+ nitrite | 0.35 | 0.39 | 1 | 0.05 | 5 |
| Chloride | 213.1 | 93.9 | 315 | 70.2 | 4 |
| sodium | 23 | 12.57 | 37.3 | 6.71 | 3 |
| Potassium | 523.37 | 408.14 | 1040 | 1.47 | 4 |
| Conductivity (uS/cm) | 3324 | 1742 | 5670 | 805 | 6 |
| pH | 7.68 | 0.36 | 8.37 | 7.19 | 6 |
| Turbidity | 406 | 80.2 | 507 | 284 | 4 |
| Total Ammonia | 84.37 | 54.8 | 180 | 8.65 | 5 |
| Nitrite | 0.49 | 0.32 | 0.76 | 0.04 | 5 |
| E. coli counts/100mL | 98367 | 404100 | 820000 | 11800 | 2 |
| Feacal strep. (counts/100mL) | 32863 | 28500 | 72000 | 15000 | 2 |
| Pseudomonas aeruginosa (counts/100mL) | 100 | 0 | 100 | 100 | 2 |
| Suspended Solids | 415.33 | 291.76 | 1030 | 153 | 6 |
| DOC | 706.25 | 503.51 | 1380 | 67.5 | 6 |
| DIC | 225.47 | 132.46 | 478 | 54.8 | 6 |
| Silicon (reactive) | 21.77 | 11.6 | 40 | 6.64 | 6 |

*concentrations are in mg/L unless otherwise indicated

The subsurface drainage tile outlet was monitored for a variety of parameters including nitrate and phosphorus, both limiting nutrients for the nuisance growth of algae in freshwater systems. This outlet is a surface discharge to the Wye River. Sampling occurred on a wet event basis, part of the routine Severn Sound RAP surface water sampling protocol. In figure 3a, data indicates that nitrate concentrations did increase significantly after the VFS treatment (F test, $P<0.05$) but remained well within the Provincial drinking water guidelines (10mgAL). In figure 3b, data indicates that phosphorus concentrations did not increase significantly after the VFS treatment (F test, $P>0.05$). It is not possible to conclusively link this significant increase in nitrate concentrations to the VFS as this subsurface tile network drains a large area of fields surrounding the VFS.

There was an increase in surface phosphorous soil test results taken October 1994 and June 1996. In the first 1 m from the gravel spreader, phosphorus concentrations increased from 60 to

**Figure 3a: VFS Subsurface Drainage Outlet Nitrate Concentrations - pre vs post treatment**

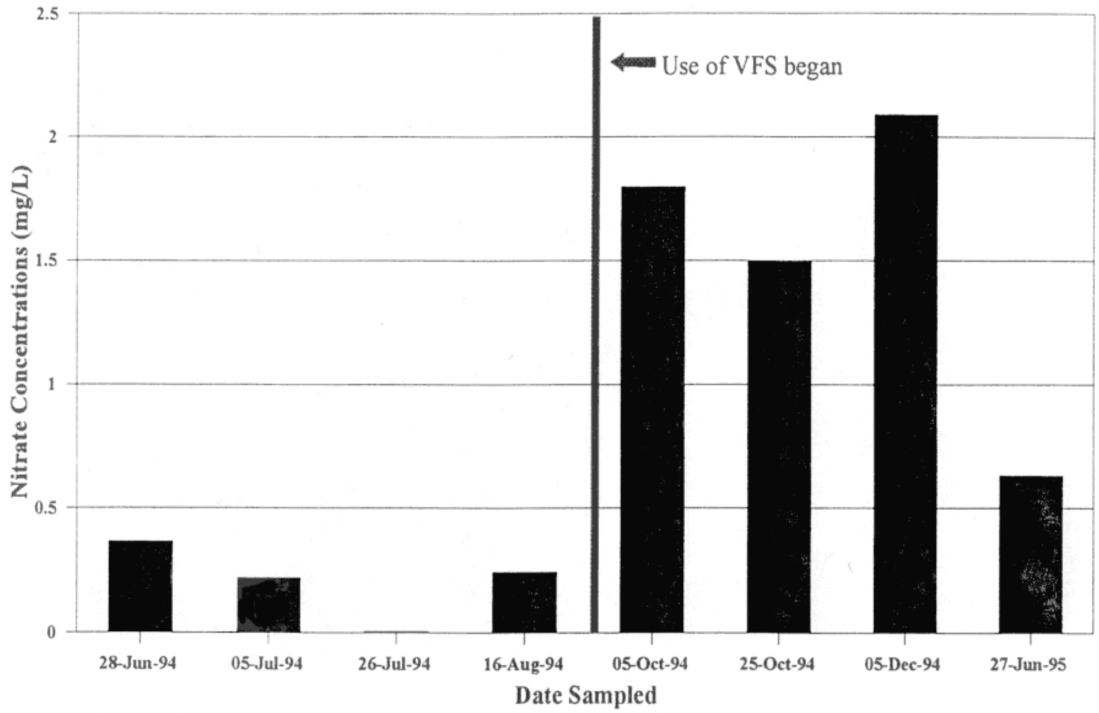
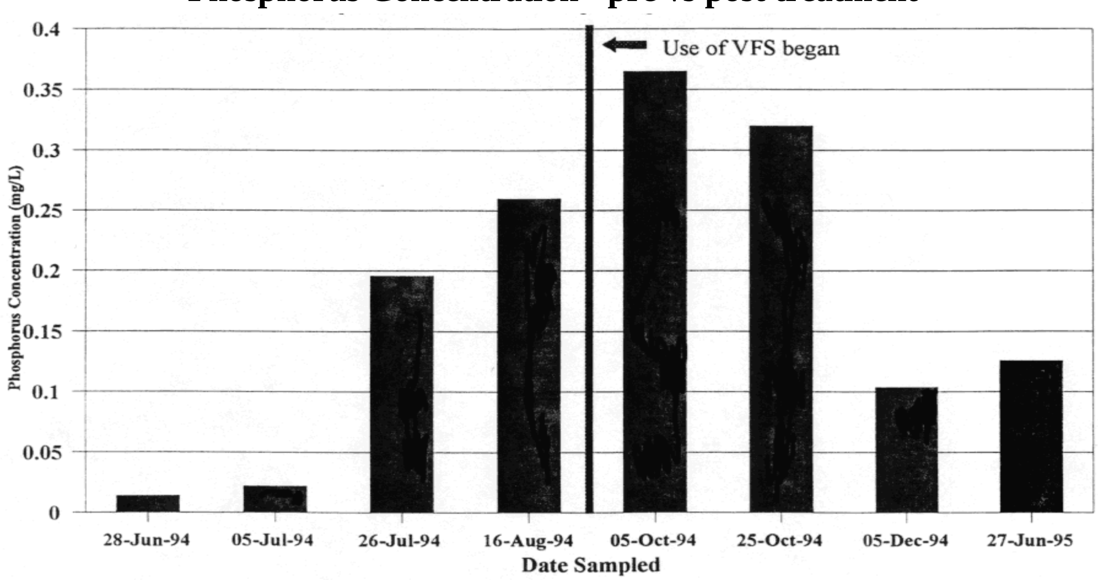



**Figure 3b: VFS Subsurface Drainage Outlet Phosphorus Concentration - pre vs post treatment**



128 mg/L and at 10m from 31 to 45 mg/L. At 30 m, the results indicated a decrease from 30 to 15 mg/L. This data supports the results in Toombs (1997). Due to the lack of pre-treatment vertical soil sample profile data, the results cannot be tested statistically.

Comparing pre-treatment to post-treatment piezometer samples, no significant increase was observed in groundwater nitrate concentrations (F test, $P>0.05$). Of all pre and posttreatment samples for all seven piezometers, only one sample (I 1 mg/L) exceeded the Provincial drinking water nitrate standard of 10 mg/L.

Chloride is a potential indicator of fecal waste material (Nathanson, 1986). Comparing pre-treatment to post-treatment piezometer samples, no significant increase was observed in groundwater chloride concentrations (F test, $P>0.05$). The maximum chloride level recorded during the study period was 17 mg/L, far below the Provincial drinking water guideline of 250 mg/L.

In summary, during the two years of the project, there was no surface runoff at the end of the VFS. This represents a 145 kg reduction in the annual phosphorus load to the Wye River, one of the main tributaries to the Severn Sound. Groundwater monitoring indicated that there was no significant increase of contamination and, in fact, groundwater quality remained well within Ontario Ministry of Environment and Energy drinking water standards. The total cost of construction of the project was $2400.00. The Severn Sound VFS proved to be an effective, economical and environmentally sound treatment system for barnyard runoff.

**ACKNOWLEDGMENTS**
The technical and financial support provided by Keith Sherman, Severn Sound RAP Coordinator, and his staff were vital in the completion and ultimate success of this project. This project would not have been possible without the various funding partners involved: The landowner (skilled labour for plumbing and electrical installation, barnyard materials and construction); Severn Sound Remedial Action Plan (including the Ontario Ministry of Environment and Energy) (staff, technical support, field equipment, surface and groundwater quality analysis costs); North Simcoe Soil and Crop Improvement Association (filter strip construction costs); Ontario Ministry of Agriculture Food and Rural Affairs (project engineering, soil sample analysis costs); Agriculture and Agri-Food Canada (data logger); Pickseed (Reed canary grass seed); Environmental Youth Corps (seasonal staff).

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**Authors' Addresses:**

J. Cayley, Severn Sound RAP, C/o Wye Marsh Wildlife Centre, Box 100, Hwy 12 E, Midland, Ontario, Canada, L4R 4K6 Email: julie.cayley@omafra.gov.on.ca

M.R. Toombs, OMAFRA, 60 Van Edward Dr., Port Perry, Ontario, Canada, L9L 1G3