Investigation and Evaluation of Vegetated Buffer Strips within Manitoba Landscapes

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Executive Summary

Vegetated buffer strips (VBS) have somewhat varied definitions, but the principle is simple. A VBS is a strip of permanent vegetation between a field and a waterway that is envisioned to entrain sediment, nutrients and/or contaminants that are flowing with runoff off the field. The VBS may have grasses, shrubs or trees, and may be actively managed or natural. The waterway may be a municipal ditch or a natural creek, stream, river or lake. At its most refined, the VBS is land taken out of annual crop production and managed specifically to mitigate runoff, at cost to the landowner. In practice, many VBS are field margins left untilled because the soil in most years is too wet.

There are many mechanisms by which the VBS could mitigate runoff, including physical entrainment of sediment, slowing the runoff flow to allow infiltration, and otherwise enhancing infiltration because of improved soil structure. Although proven effective in some regions and commonly considered beneficial, their effectiveness in Manitoba remains in question. There is little doubt that VBS can retain sediment and nutrient from runoff flow, the questions are whether the amount retained is of any real value and whether the retention is permanent or fleeting. The peculiarities of the Manitoba situation are that, in contrast to many other regions using VBS, runoff flow in Manitoba is slow with little sediment load, there are high proportions of dissolved phosphorus (which is not easily entrained), the runoff is often in discrete channels from the field, and Manitoba VBS are often snow filled and flooded during the runoff season.

This study set out to evaluate VBS in three very different watersheds over at least 2 years. Four mini-catchments were sampled in each of the three watersheds. In each sampling position, runoff samples were collected at the field-edge and at 5 m into the VBS along the expected runoff flowpath. As an additional treatment, the vegetation at half of the mini-catchments was cut and removed, as a potential management strategy (the idea is that removing the vegetation removes nutrient from the system). The runoff sampling was done with small weirs installed with self-closing sampling bottles, although grab samples of runoff were used if the weirs were flooded. The theoretical result, if the VBS were effective, would be that the concentrations of nitrogen (N) and phosphorus (P) would be lower from the weir inside the VBS versus the weir at the field edge. To further evaluate the VBS, one catchment from each watershed was subjected to soil sampling. These samples were taken from upstream and downstream in the runoff flowpath and outward laterally from the flowpath. Both P and ^{137}Cs (used as an indicator of soil erosion) were measured in these soils samples.

The runoff concentrations of N and P sampled in the weirs were seldom decreased as the runoff flow passed from the field-edge weir to the weir 5 m into the VBS. In effect, the VBS was nearly as often a source of nutrient than it was a sink for nutrient. There were some statistically significant occurrences of lowered concentrations because of the VBS. In one watershed, there were very high total N concentrations in the runoff, and some of this was attenuated in the VBS. At another watershed, the VBS seemed to retain dissolved P in summer and fall runoff events, but this was not consistent and it is spring

runoff events that are most important in Manitoba. The net result was ambiguous and not strongly supportive of the effectiveness of VBS. More importantly, it appeared that the VBS could be source of N and P to the runoff flow, probably because nutrient leached from the vegetation, a process known to be accentuated by freeze/thaw conditions. There was no effect of the removal of vegetation on the effectiveness of the VBS – this may require a longer-term study.

Based on the soil analyses, there was evidence of P retention in soils at several of the weir pairs, but not all. Five of the 12 weir pair locations appeared to have retained P in the VBS. The fields at all three watersheds had soil P concentrations that were little different from background, so these sites do not represent cases of extreme buildup of soil P because of fertilization.

The overall conclusion is that VBS can retain N and P, but the amount retained may not be sufficient to be relevant, and the VBS have the potential to become a source of N and P to the runoff flow. In other words, at least some of the entrained N and P will be released at a later date, and the net effect is unknown. There is a lot of variability in VBS effectiveness, and these VBS were situated in known runoff flow channels. Obviously, VBS in landscape positions between flow channels would have no effect. This implies that if VBS were mandated along all field/waterway interfaces, that most of this land would not be performing as expected of a VBS – it may serve other functions such as wildlife corridors or to minimize overspreading of agricultural chemicals.

The specific points:

- The 12 VBS sites were ineffective to change P concentrations in runoff flow, about half the cases the VBS added P to the runoff, half the cases the VBS removed P from runoff
- In 5 of 12 sites, the soils of the VBS appear to have accumulated P assumed to be from runoff

Acknowledgments

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Investigation and Evaluation of Vegetated Buffer Strips within Manitoba Landscapes

Background

Vegetated buffer strips (VBS) are a potential beneficial management practice (BMP) to mitigate loss of sediments, nutrients and contaminants from farm land, and have added benefits to the ecosystem including habitat diversity and migration corridors. A VBS can be defined as a linear band of permanent vegetation adjacent to a waterway (Fischer and Fischenich, 2000). For the context of this paper, as per Hickey and Doran (2004) and Sheppard et al. (2006), downslope vegetated field margins will also be considered as VBS. There is an implication that a VBS is land taken out of production and vegetation established specifically to serve as a BMP (Hickey and Doran 2004), although in practice land along waterways and in downslope positions may not be suitable for crop production and become intrinsic VBS.

A significant amount of research has been conducted regarding the effectiveness of VBS, but this has only proven that there is “no one size fits all” solution. Many variables alter the effectiveness of VBS, including the nature of the runoff and materials intended to be retained in the VBS, management of the VBS (Dabney et al., 2006), vegetation composition and width (Fischer and Fischenich, 2000; Syverson, 2005). As a general guideline, Fischer and Fischenich (2000) recommended a buffer width in the order of 5 – 30 m for VBS designed to improve water quality, and this seems at least practical because less than 5 m is probably not consistently effective and more than 30 m becomes as major investment. Much greater widths have been shown as necessary in some cases (Dabney et al., 2006).

It has been suggested that advocating buffer strips as an effective mitigation tool for non-point source pollutants is not based on sufficient evidence (Hickey and Doran, 2004; Daniels and Gilliam, 1996; Lee et al., 2000). Dillaha et al. (1989) particularly comment that the apparent effectiveness of VBS in controlled experimental settings may not transfer to real farm settings because of the differences in flow conditions. Despite these contrary reports, VBS remain popular and the Province of Manitoba has recently enacted legislation that would see 30-m VBS adjacent to “vulnerable” lakes, 15-m VBS along rivers used as sources for drinking water and 3-m along between manured land and waterways in the Province[1]. This is in spite of the fact that runoff does not occur continuously along the edges of waterways, but tends to be in discrete channels governed by the gently undulating physiography. In a recent Manitoba-based study designed to represent flat landscapes, the efficacy of VBS to reduce phosphorus (P) concentration was examined (Sheppard et al., 2006). Results proved VBS to be effective in reducing P concentrations in 50% of the samples. However, in 32% of the samples there was no change in P concentrations and in the remaining 18% of samples P concentration actually increased. Additionally, runoff was observed only in very short sections of VBS and although these short sections clearly retained P, it was evident that they were saturated in their ability to do this.

Leaching of P from vegetation is a further impediment to the effectiveness of VBS: much of the P absorbed by plants when they are growing is released from leaves and stalks as soluble P once the plant senesces, and this P can enter the runoff flow (Bechman et al. 2005, Hoffman et al. 2009, Kull et al. 2008, Stutter et al. 2009). Thus the VBS becomes a source of P, not a sink. For this reason, harvesting the vegetation to remove the plant P is a potentially essential management practice.

Another particular problem with VBS in Manitoba is that about 80% of the runoff from farm land occurs in early spring with snowmelt. The vegetation in the VBS is not growing at this stage, and the VBS where the runoff occurs is often snow covered and flooded because, by definition, the runoff occurs in the lowest positions on the landscape. In the nearly flat Manitoba landscape, ponding and flooding in swales and slight depressions is common: this channelizes flow and very likely overwhelms any function the VBS may have that is flooded.

Despite, or because of, the expected limitations, there is value in Manitoba-specific optimization of VBS. In this study, the ability of VBS to decrease P concentrations was examined in three landscapes representative of the majority of agro-Manitoba. In addition, the management of these buffer strips was studied by having paired samples of harvested and unharvested VBS. The study will be a complement to work done by Sheppard et al. (2006) and will be largely based on their design. Based on findings of Sheppard et al.

[1] https://www.gov.mb.ca/agriculture/soilwater/soilmgmt/fsm01s04.html?print

(2006), it is expected that runoff events large enough to allow sampling will most likely be experienced between April and June. This time period includes snowmelt

Methods

Site Selection

The sites were representative of different landscapes, but with some attributes in common. Each site was located adjacent to a waterway (i.e. stream, river, drainage channel) and had a pre-existing strip of relatively uniform perennial grass or sedge with a minimum width of 10 m. For the purposes of this study, there was no minimum length required for the VBS, but there was a requirement that there be an apparent runoff flow path. Each study site was divided into two treatments, one in which the vegetation was harvested and the second where the vegetation was left standing. The ideal was to have one continuous VBS within which two distinct flow paths existed to allow for the two management treatments.

The East Interlake Conservation District (EICD) site was located in the Rural Municipality of Gimli (NW-36-18-03 E). Willows Creek passes through the site and flows into Lake Winnipeg. The site is part of the Lake Winnipeg terrace. Surface drainage is generally poor and movement of precipitation is controlled by the ridge/swale landforms that are characteristic of these lacustrine deposits. Soils are stratified layers of thin clayey deposits over calcareous glacial till and are dominantly Chernozemic dark grays (Michalyna and Podolsky 1980). The site has an established riparian zone which was sampled as the VBS, and this included some deciduous trees such as aspen and Saskatoon, as well as grasses and sedges. The field upstream of the VBS did not have a crop in 2009 due to excessive soil moisture, and this was common in the area in 2009 and on some sampling dates the weirs were also flooded.

The Little Saskatchewan River Conservation District (LSRCD) site was in the R.M. of Blanshard, near the town of Cardale (E1/2 24-14-22WPM) and located on Broughton's Creek. The project site is within the slightly degrading blackearth sub-zone, specifically, the Newdale Undulating Phase (Ehrlich et al. 1956). The Newdale association consists of medium textured soils developed on boulder till of mixed materials derived from shale, limestone, and granitic rock sediments. Topography in this area is generally undulating, with prairie potholes, sloughs and meadows. Drainage is variable depending on landscape position and is largely facilitated by Little Saskatchewan River and its tributaries. It is part of the Assiniboine watershed in a section of the Saskatchewan plain where soils developed on glacial till with shale, limestone and granite bedrock deposits. This site has the most variable topography of the three, with slopes ranging from 5 – 9 % (Podolsky 1988). The VBS vegetation consisted of native meadow species for one weir pair (7,8) and was a recently seeded hay mixture at the other weir pairs. The upland field was planted to flax in 2009 and wheat in 2010. The flax straw was burned in fall 2009, and this resulted in a high sediment load in the runoff samplers. One weir pair (1,2) had an especially large catchment area compared to the others.

The Pembina Valley Conservation District (PVCD) site was located just outside Manitou, in the R.M. of Pembina in the south central part of the province (NW-36-03-09- W). It is located adjacent to an un-named tributary of Mary Jane Creek that then flows into the Pembina River. The area is part of the Pembina River plain, specifically the Manitou plain, which is characterized by level to gentle undulating slopes of morainal deposits. At this site the riparian soils were poorly to imperfectly drained Gleyed rego black soils of lacustrine deposits, while upland positions were moderately-well drained orthic black soils over shale bedrock (Podolsky 1993). The VBS vegetation was mostly grasses and sedges, with some weedy species such as Stinging Nettle. Upland fields were sown with wheat, although around weir pairs 5,6 and 7,8 roughly 100 m of alfalfa was planted between the intended VBS and the wheat.

Mean monthly precipitation at the three sites has similar trends.

Harvest treatments

The harvest of VBS material was done for half or the weir pairs on each site 3 times in 2009. The harvest was completed by using a weed trimmer, leaving approximately 1 cm of vegetation. The harvested material was removed from the site. The vegetation grew back after harvest, so that the treatment had an effective time of about 2 months, and during this time at 2 to 3 runoff events were collected at each site.

Runoff Sample Collection and Analysis

Sampling design and collection was largely based on methods described by Sheppard et al. (2006). Runoff water samples were captured using a constructed sampling bottle – a plastic pipe with its bottom capped and a passive shut-off valve at the top. The sampling bottle had a volume of 200 mL and was designed to collect samples of the initial runoff and then be closed to further runoff. Galvanized steel weirs, 50-cm wide at the mouth and 2-cm wide at the outlet were used to funnel runoff to the sampling bottle, which was positioned in a hole below grade. The weirs were positioned with the mouth edge just below grade, typically inserted under the VBS sod. The weirs were designed with a partial cover that prevented precipitation from directly entering the sample bottles. Interior surfaces of the weirs were coated with a clear polyurethane finish. To capture spring snowmelt runoff, the weirs were put into position in late fall of the initial set-up year. The sample bottles were then inserted in the following spring prior to the first melt event. To put the sample bottles in place, holes were dug through the snow directly over the weirs, with care taken to not disturb the snow in front of the weir.

Each sampling site had 8 weirs, and the intent was to have 4 with harvested VBS and 4 with unharvested VBS. This was done only in 2009. The 8 weirs were in pairs, one weir was positioned at the field edge, one at 4.5 m into the VBS away from the field edge. These paired weirs were in the same general runoff flow path but were positioned as well as possible to minimize direct in-line interference. The 4 pairs were set up in separate flow paths within the VBS.

The sample bottles were checked for runoff generally within 24 hours of every substantial rain or snowmelt event. To allow for paired comparisons, only runoff events large enough to produce water in both paired sampling weirs were included. In some cases the weirs were flooded. If weirs were flooded by water coming off of the field, the samples were retained. If the weirs were flooded from water coming up from the waterway, the samples were rejected. Often, during the spring melt the first samples were taken from the collection tubes, after that the weirs were too flooded to put the tubes back in place so grab samples were taken once or twice a day at the weir locations. Flooding was not a problem at the LSRCD site because the slopes were sufficient to prevent flooding. Collected runoff water samples were sent to a qualified lab within 1 day of collection. Regardless of whether a sample was retained, the sample bottles were emptied and re-positioned in preparation for the next runoff event (except as noted above in cases of flooding). In a few cases where runoff samples were thought to have been in the tubes longer than 2-3 days, the samples were rejected.

Once in the laboratory, the samples were thawed and split, with one sample filtered to pass a 0.45µm filter. An aliquot of the filtered sample was analyzed for P using inductively coupled plasma (ICP) spectroscopy, and this was designate 'total dissolved P'. The unfiltered sample was digested and then was analyzed for P using ICP, and this was designate 'total P'. The difference between total P and total dissolved P was taken to be the 'total particulate P'.

The samples were also analyzed for nitrate plus nitrite N and total N, with total Kjeldahl N calculated as total N minus (nitrate plus nitrite N).

Soil Sample Collection and Analysis

Field and VBS soil samples were collected at each weir location during the fall of 2009. At each weir location, 2 depths from 5 cores at each of 18 positions were sampled, and these were combined resulting in 18 composite samples for analysis. At each of the 18 positions, 5 cores 1.7-cm in diameter were taken from a 1-m^2 quadrant. Each core was split to separate soils from 0 to 7.5 cm and 7.5 to 15 cm, and these were composited to give 2 samples (i.e., 2 depths) per quadrant (position). The 18 positions were from a 6 x 3 matrix with 6 positions on a line parallel to the field/VBS interface and 3 positions perpendicular. Of the 6 parallel positions, 2 were immediately on either side of the runoff flowpath, which was the lowest contour along the field/VBS interface. Two others were on the crest or highest contour either side of the flowpath or at 20 m either side of the flowpath. The remaining 2 were on either side at the midslope between the flowpath and the crest. The 3 positions in the other dimension were 5 m upstream (into the field) from the field/VBS interface, 0.5 m into the VBS and 5 m into the VBS. Samples from these 18 positions were then further composited, combined to give flowpath, midslope and crest samples from -5 m, +0.5 m and +5 m away from the field/VBS interface: 9 samples of each of 2 depths for analysis. Because there were 4 weir locations on each of the 3 study sites, there were in total 9 x 2 x 4 x 3 = 216 soil samples.

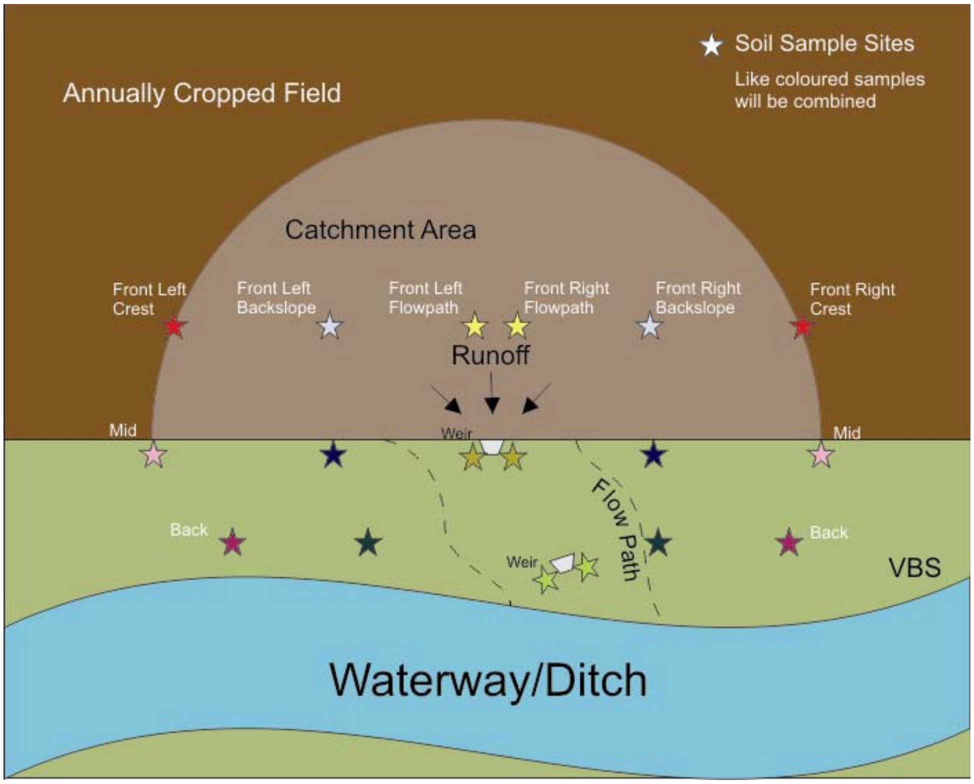

Figure 1. Schematic of soil sampling positions. Stars indicate the sampling positions and like colored stars indicate where samples were pooled into composite samples (from S. Carlyle)

All composite soil samples were analyzed for available soil P by the Olsen extraction method ($NaHCO_3$), a common agronomic soil test in Manitoba. The determination was of ortho P in the extract, following Murphy and Riley (1962). Soils from one weir pair at each site were selected for analysis of ^{137}Cs. These weir pairs were selected based on soil P analysis, selecting pairs where there was the most difference between the field and the VBS P concentrations. The ^{137}Cs was determined by gamma spectroscopy.

Statistical Interpretation of Runoff Data

The resulting experimental design involved 4 weir pairs (a pair is field-edge weir and a weir inside the VBS) at three sites, with samples on a number of dates at each site in spring and summer of 2 years (not the same dates from site to site). Additionally, in a few cases some of the weir pairs were in harvested VBS and others from the same site and sampling date were in non-harvested VBS. The data summaries of value are the concentrations of N and P in the field-edge weir, to characterize the runoff conditions, and the differences or proportions between the pairs, to characterize the effectiveness of the VBS.

Differences were computed as concentration from the downstream in-VBS weir minus concentration from the upstream field-edge weir. Negative differences suggest the VBS has retained the nutrient. Proportions were computed as the difference in concentrations divided by the concentration in the upstream field-edge weir, and again negative proportions suggest the VBS has retained the nutrient.

For statistical interpretation, it is important to examine the structure of the data, specifically whether the data are normally distributed or in some way skewed or kurtose. If data distributions are different from normal, then simple statistical inferences based on t and F tests are not meaningful and some kind of data transformation is required. None of the present data conformed to normal: the concentration data were strongly skewed, the difference data had extreme upper and lower outliers, and the proportion data had extreme upper outliers (Figure 1). Environmental concentration data are often lognormally distributed, and so log transformation was used and the log data were normal. Thus t and F tests of logtransformed concentration data are valid. Because the difference and proportion data had negative values, transformations such as log and square root could not be computed. Instead, rank scores were used, which results in all the statistical tests being equivalent to the classical non-parametric[2] tests such as the Wolcoxon t test and Spearman correlation.

The statistical design was somewhat unbalanced, because collection of runoff was opportunistic (it could not be planned). Three statistical methods were used. The overall effectiveness of VBS, regardless of site, date or harvest, was done by a t test of measured differences between downstream and upstream weirs versus a zero difference. Analysis of variance (ANOVA) was used to test effects of site and season, where season was defined as spring (March to May) versus summer and fall (June to October). The spring samples included snowmelt runoff. Another ANOVA was used to contrast harvested versus unharvested VBS. Statistical significance was considered to apply when the probability level that the null hypothesis of no effect was true was $P < 0.05$ (i.e., within the level of precision afforded by the experiment, in 5% of the cases the conclusion of statistical significance will be wrong, but it will be correct in 95% of the cases).

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[2] Non-parametric implies a transformation that removes the units of measure, and replacing the data with the rank score, i.e. numbering the data from lowest to highest data value, is perhaps the most common.

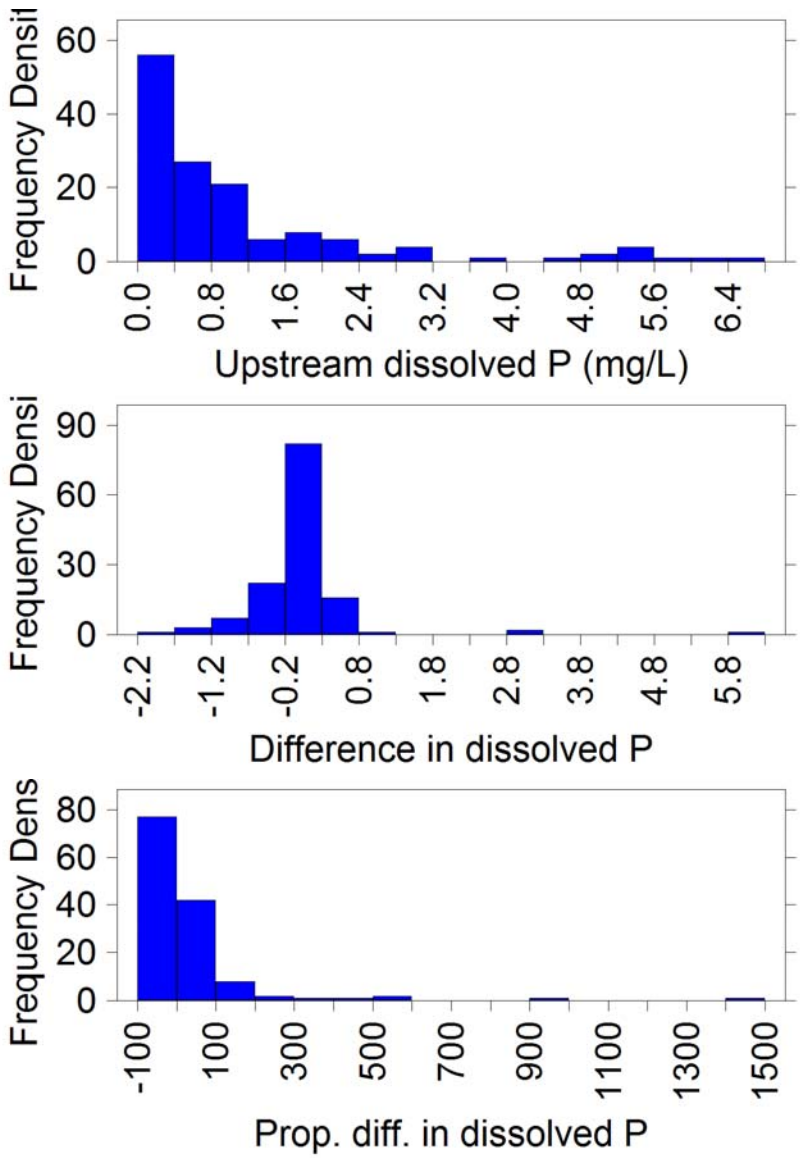


Figure 1. Frequency density of untransformed data, using dissolved P as the example.

Results of Runoff Samples

Concentrations

The overall concentrations of the 3 forms of N and P in the upstream field-edge weirs are shown in Table 1. For N, about half the total N in runoff was nitrate plus nitrite N and the other half was detected after Kjeldahl digestion which implies N in chemically reduced forms such as ammoniacal N and other organic species. Nitrate plus nitrite N is highly mobile in the environment, it may be present in these runoff samples as leachate from either soils or plants. The reduced N forms are less mobile and are more likely present as the leachate from plants (no manure was present in the immediate watersheds). The skewness of the untransformed data is manifest in the very large range between maxima and minima, and the success of the logtransformation is indicated because in general the geometric means are close to the medians. The geometric standard deviations (GSD) of 3 to 7 are relatively large, but these include site-to-site, date-to-date and treatment (harvested versus unharvested) variation.

For P, the dissolved P was on average 65% of the total P, the remainder (by definition) was particulate P. This is consistent with expectation for non-erosive landscapes and runoff P measurements in previous studies in Manitoba (Sheppard et al. 2006, Glozier et al. 2006). A substantial portion of the P in these runoff samples is probably from leachate of plants, as much of plant leachate P is soluble, especially after freezing and thawing (Bechmann et al. 2005). The particulate P may include P adhering to dust[3] and plant particles as well as to soil particles. Again, the success of the logtransformation is indicated because in general the geometric means are close to the medians.

Table 1. Concentrations (mg L^{-1}) of N and P in runoff water captured by the upstream field-edge weir.

Statistic	Total N	Nitrate plus nitrite N	Kjeldahl N	Total P	Dissolved P	Particulate P
n	147	139	141	147	141	139
Minimum	0.06	0.01	0.03	0.06	0.01	0.01
Maximum	151	90	148	10.9	6.65	9.60
Median	10.6	3.23	4.50	0.89	0.68	0.26
Geometric mean	9.7	2.7	4.7	0.87	0.45	0.27
GSD[a]	3.5	7.3	3.1	3.3	4.7	3.4

[a] GSD is geometric standard deviation. A GSD of 3.5 implies that ~68% of the data (1 sigma) are within 3.5-fold above and 3.5-fold below the geometric mean, 2 x GSD or 12-fold is the 95[th] percentile confidence interval.

Downstream minus upstream differences

An overall statistical test of the effectiveness of VBS is whether the differences are significantly different from zero. To do this as a t test in rank score transformation requires that the rank score for difference = 0 be determined for each variable. This was done by interpolation, so for example the rank score for differences in total N equal to zero was 80. The t test had a null hypothesis of rank(difference) = 80. For total N, the test was significant ($P < 0.04$), the mean rank was 72.5, so overall total N concentrations were significantly lower in the VBS than at the field/VBS interface. This was the only N or P species where there was an overall effect of the VBS. For dissolved P, perhaps the most important variable, the results were exactly divided with half having negative differences and half having positive differences. Clearly the VBS are neither consistently beneficial nor detrimental; they were as often a source of nutrient as they were a sink.

[3] Dust intended here to mean particles of atmospheric deposition, which may include soil from either on-site and off-site sources.

There remains the possibility that within some subset of the sites and/or weir pairs, there are consistent non-zero differences.

To examine the effects of site and season, an analysis of variance (ANOVA) was done with site, season (spring versus summer and fall) and the site x season interaction as the factors (Table 2). Again, differences in total N were significant, and by means comparison (Scheffe's test), the PVCD (mean rank score 53) was significantly lower than the LSRCD site (mean rank score 86). Essentially, this means the VBS at the PVCD site was effective at retaining total N. For dissolved P, the effects of site and season were nearly significant and the interaction was significant. This means the effect of season varied from site to site (or this could be restated as the effect of site varied season to season). By means comparison, only summer and fall samples from the LSRCD site were different from any of the others, and for it the mean rank score was 28, indicating an effective VBS for dissolved P at this site and time. Particulate P differed by season, where in spring the mean rank score was 72 (the same rank score as a zero difference) and in the summer and fall the mean rank score was 52, indicating the VBS effectively retained particular P in summer and fall events. Here season also differentiates snowmelt from rainfall runoff, and so the VBS retained particulate P in rainfall events. Overall, the results for nutrient interception by the VBS are somewhat ambiguous: some VBS were effective for some nutrient species some of the time.

Table 2. Overall effect of VBS by t test of downstream minus upstream differences, analyzed in rank transformation.

Statistic	Total N	Nitrate plus nitrite N	Kjeldahl N	Total P	Dissolved P	Particulate P
Mean rank	72.5	65.5	68.5	73	68	68
Rank at difference = 0	80	72	72	77	68	72
Overall t test of difference = 0	0.033 *	0.051 ns	0.30 ns	0.25 ns	1.0 ns	0.24 ns
F test of site	0.008 **	0.14 ns	0.27 ns	0.79 ns	0.057 ns	0.73 ns
F test of season	0.85 ns	0.48 ns	0.46 ns	0.14 ns	0.051 ns	0.014 *
F test site x season	0.51 ns	0.56 ns	0.65 ns	0.24 ns	0.023 *	0.62 ns

It is instructive to consider these trends in more detail. In Figure 2, the differences in total N (both as a simple difference and as the rank score) are plotted versus the upstream total N concentrations. A negative slope in this plot is expected because the values are related. What is notable is that the upstream samples from the PVCD site had exceptionally high total N concentrations, and the differences indicate these were obviously much higher than from the in-VBS samples (i.e., the VBS was effective in retaining runoff N at high N concentrations). This is the site where alfalfa was growing between the tilled field and the VBS. Several of these high total N observations were from the weirs at this site where there was alfalfa growing between the tilled field and the

VBS. Of the 6 highest total N concentrations and most negative ratios, 3 were early spring and 3 were summer events, and so season did not seem to be important. Alfalfa as a legume is high in N. Very likely some of this high total N is leachate from the alfalfa, and perhaps it rapidly infiltrated in the VBS between the field-edge and in-VBS weirs. In some of these cases, the high total N was 50% to 100% nitrate plus nitrite N, which would infiltrate rapidly especially in rainfall events. The very highest total N was from the weir pair below the alfalfa, the N was nearly all Kjeldahl N and it was high in a March event. This may still be plant leachate, but of organic N.

The results in rank transformation, especially in Figure 3, are nearly balanced above and below the zero line. This illustrates the overall result, that the VBS had little net effect on total N, and the only exception to this was the PVCD site where very high total N addition was observed some of the time.

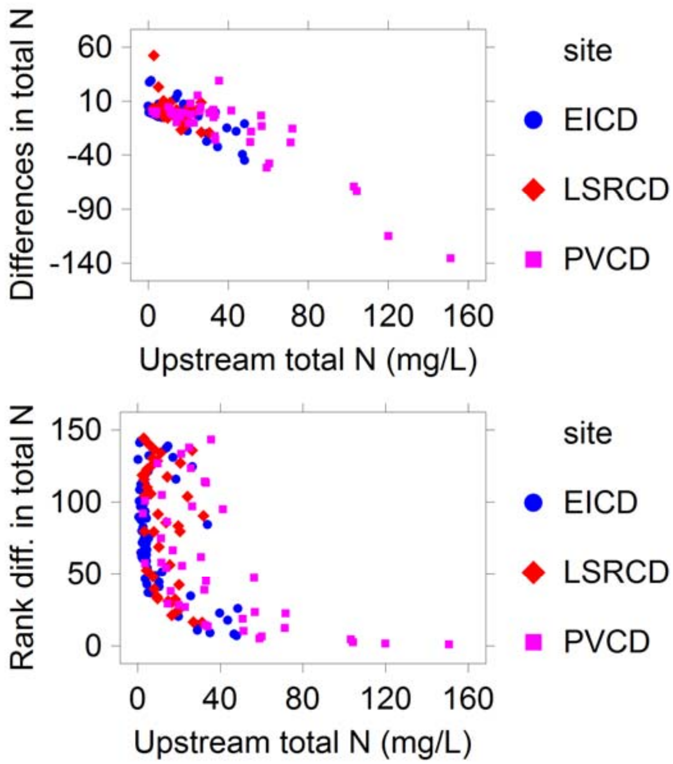
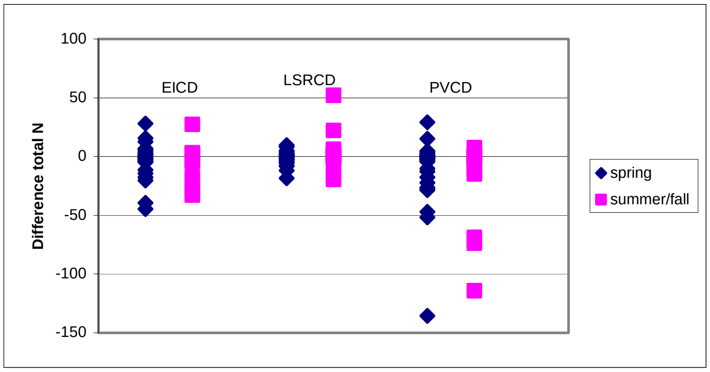


Figure 2. The difference in total N (downstream minus upstream, where negative values indicate nutrient retention by the VBS) plotted versus the concentration of total N in the upstream weir, differentiated by site. The upper plot is the difference, the lower is the difference in rank score transformation as used in ANOVA, where scores <80 indicate nutrient retention by the VBS.



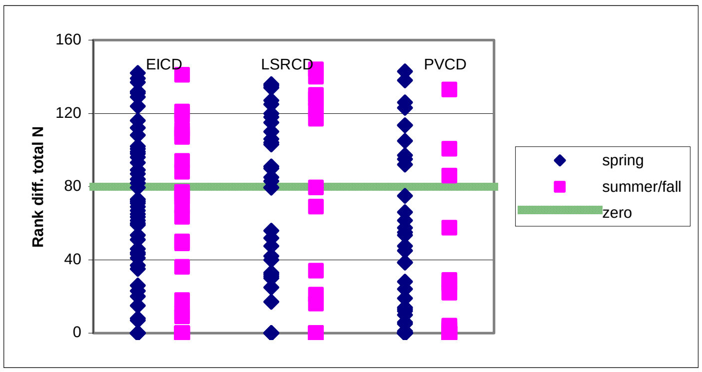


Figure 3. Scatter plot of the downstream minus upstream differences in total N, differentiated by site and season. The upper plot is the difference (negative values indicate nutrient retention by the VBS); the lower is the difference in rank score transformation where scores <80 indicate nutrient retention by the VBS.

The detailed interpretation of the dissolved P data is more complicated because there was a significant interaction. As with total N, the concentrations of dissolved P were higher at the PVCD site that the others. However, unlike the results for total N, the differences between upstream and downstream concentrations of dissolved P were equally positive and negative at the PVCD site (Figures 4 and 5). The high concentrations of dissolved P at the PVCD site, like N, are probably the result of the alfalfa upstream from the VBS. According to recent studies in Wisconsin, alfalfa has the potential to contribute large amounts of P to runoff, especially after cycles of freezing and thawing or drying and wetting (Roberson et al. 2007). At the LSRCD site there is a cluster of data with low differences (more evident in the plot of rank differences, below about rank score 40). Most, but not all, of these were summer or fall rainfall events. In this case, these observations of negative differences were not related to exceptional upstream dissolved P concentrations. Overall, this is not strong evidence of an effective VBS, because other weirs on the same site and date were not effective, and it is the spring when Manitoba requires mitigation of runoff dissolved P.

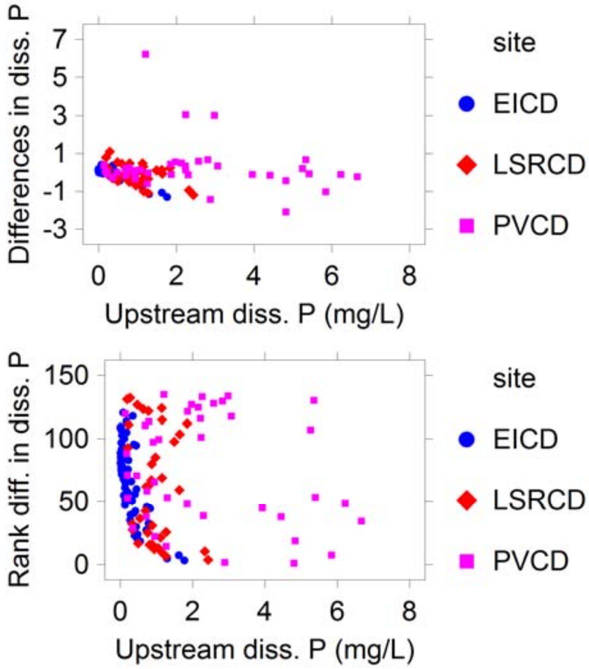


Figure 4. The difference in dissolved P (downstream minus upstream, where negative values indicate nutrient retention by the VBS) plotted versus the concentration of dissolved P in the upstream weir, differentiated by site. The upper plot is the difference, the lower is the difference in rank score transformation where scores <68 indicate nutrient retention by the VBS.

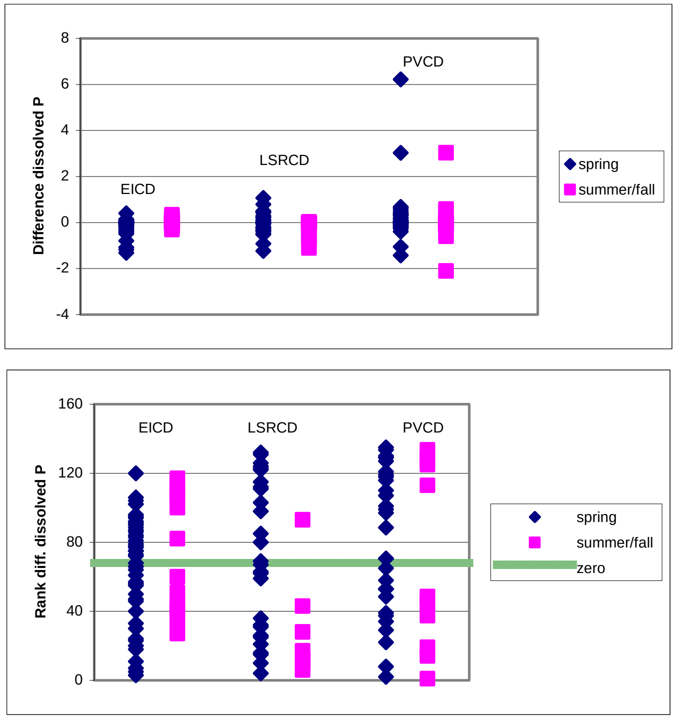


Figure 5. Scatter plot of the downstream minus upstream differences in dissolved P, differentiated by site and season. The upper plot is the difference (negative values indicate retention of nutrient by the VBS), the lower is the difference in rank score transformation where scores <68 indicate nutrient retention by the VBS.

The other nutrient species with significant effects was particulate P, where season effects were significant. This effect may be significant overall, but in Figures 6 and 7 it is obvious that for all sites there were both positive and negative differences in the summer and fall events. This apparent effectiveness was ambiguous.

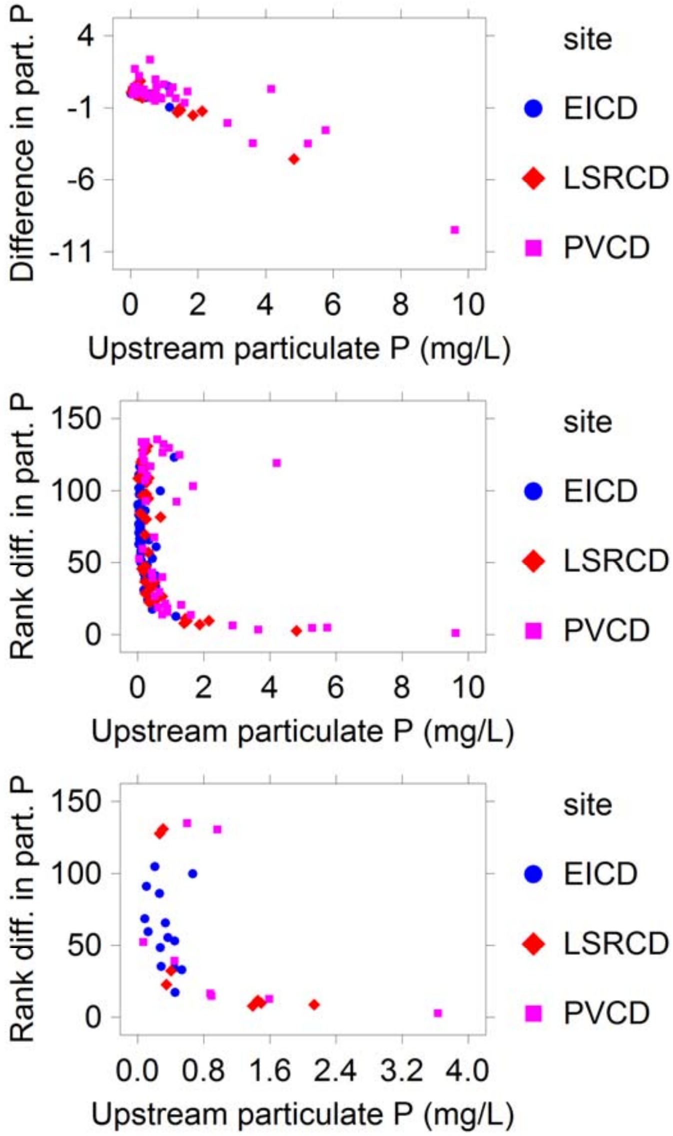


Figure 6. The difference in particulate P (downstream minus upstream, where negative values indicate nutrient retention by the VBS) plotted versus the concentration of particulate P in the upstream weir, differentiated by site. The upper plot is the difference, the middle is the difference in rank score transformation, and the lower plot is the difference in rank score transformation for summer and fall events only, where scores <72 indicate nutrient retention by the VBS.

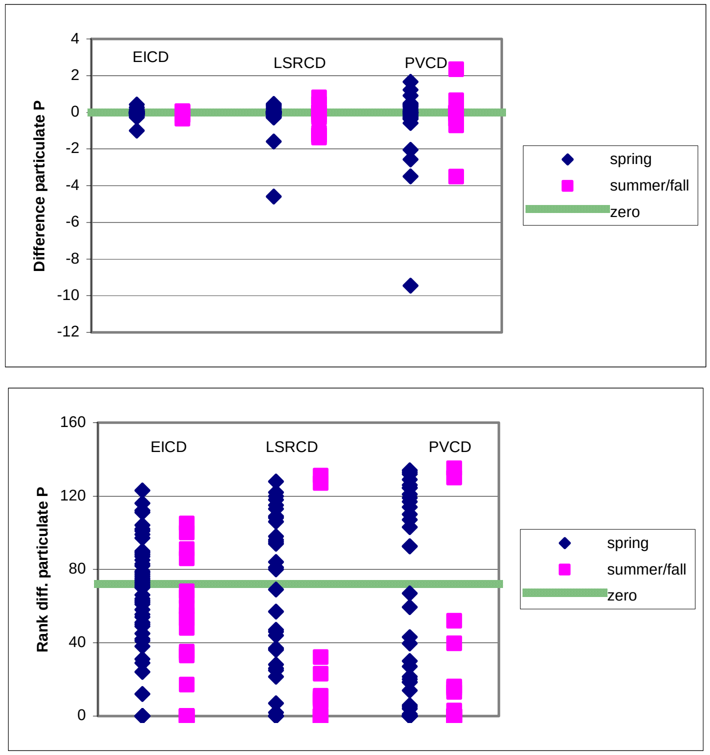


Figure 7. Scatter plot of the downstream minus upstream differences in particulate P, differentiated by site and season. The upper plot is the difference (where negative values indicate nutrient retention by the VBS), the lower is the difference in rank score transformation where scores <72 indicate nutrient retention by the VBS.

At each site, the VBS in half of the weir pairs was harvested in about June in 2009, and there were 2 or 3 runoff events at each site in the 2 months after harvest. This resulted in only about 14 observations, so the statistical test (Table 3) is not strong. There was a significant effect of harvest only for total N, and this seemed to be also reflected in a similar trend with nitrate plus nitrite N. The unharvested VBS was more effective in retaining total N than the harvested VBS. Because this was mid summer, the unharvested VBS may have been more effective because the larger standing biomass would have a larger N requirement, or more water may have been extracted from the soil under the unharvested VBS so that infiltration of runoff was better. This result is supportive of VBS as a BMP because more standing vegetation was better, but it does not contribute to the discussion of the need to harvest VBS to remove nutrients from the runoff flowpath.

Table 3. The effect of harvesting the VBS, contrasting the harvested versus the unharvested weir pairs in events that occurred in the 2 months following the early summer harvest. The F test was by ANOVA of rank scores of differences, with harvest as the single factor.

Statistic	Total N	Nitrate plus nitrite N	Kjeldahl N	Total P	Dissolved P	Particulate P
Mean difference for harvested VBS	-5	-6	1	0	0	0
Mean difference for unharvested VBS	-34	-25	-9	-1	-1	0
F test harvested versus unharvested	0.04 *	0.10 ns	0.55 ns	0.46 ns	0.05 ns	0.52 ns

Downstream minus upstream difference as a proportion

Examining the differences in concentration between weir pairs as a proportion of the concentration in the upstream weir is really just another way to interpret the data already described. The discussion of simple differences as in the above section tends to emphasize samples where concentrations were high and differences were large. However, it is plausible that VBS are effective when concentrations are lower and the effects are in the relative or proportional differences. It could be quite beneficial for a VBS to be consistently effective at lower concentrations even if it is not as effective at high concentrations. We present the analysis of proportional differences in the same order and format as above.

The t test of overall rank score versus the rank score corresponding to zero proportional differences was not significant for all N and P species (Table 4). As before, this implies that the VBS were just as often a source of nutrient as a sink. The more detailed analysis, by ANOVA, showed that VBS effectiveness varied among sites and seasons (Table 4).

For nitrate plus nitrite N, there were significant effects of site and season and their interaction. The VBS at the PVCD and LSRCD sites were effective in retaining nitrate plus nitrite N in summer and fall events (negative proportional differences). In contrast, the VBS at the EICD sites was source of nitrate plus nitrite N in summer and fall events (positive proportional differences). None of the VBS influenced nitrate plus nitrite N concentrations in spring runoff events. This is a somewhat different conclusion than found in the analysis of simple differences (the previous section). There, none of the sites effectively retained (or released) nitrate plus nitrite N and at the PVCD site the VBS retained total N. Perhaps this inconsistency is the most important observation.

Table 4. Overall effect of VBS by t test of differences between downstream minus upstream concentrations as a proportion of the upstream concentration, analyzed in rank transformation.

Statistic	Total N	Nitrate plus nitrite N	Kjeldahl N	Total P	Dissolved P	Particulate P
Mean rank	72.5	65.5	68.5	73	68	68
Rank at the proportional difference = 0	71	64	67	72	64	64
Overall t test of proportional difference = 0	0.67 ns	0.65 ns	0.66 ns	0.77 ns	0.24 ns	0.24 ns
F test of site	0.07 ns	0.03 *	0.48 ns	0.65 ns	0.019 *	0.81 ns
F test of season	0.78 ns	0.04 *	0.55 ns	0.25 ns	0.078 ns	0.043 *
F test site x season	0.61 ns	0.03 *	0.76 ns	0.055 ns	0.010 *	0.18 ns

Both dissolved P and particulate P varied with site and/or season (Table 4). Dissolved P was more effectively retained at the LSRCD site in summer and fall than at the other sites and weir pairs. Particulate P was more effectively retained in summer and fall than in spring, especially at the PVCD and LSRCD sites. These conclusions generally agree with those found for simple differences (the previous section).

For the 3 nutrient species that showed significant effects among proportional differences, the plots of proportional differences versus upstream concentrations are shown Figures 8 - 13.

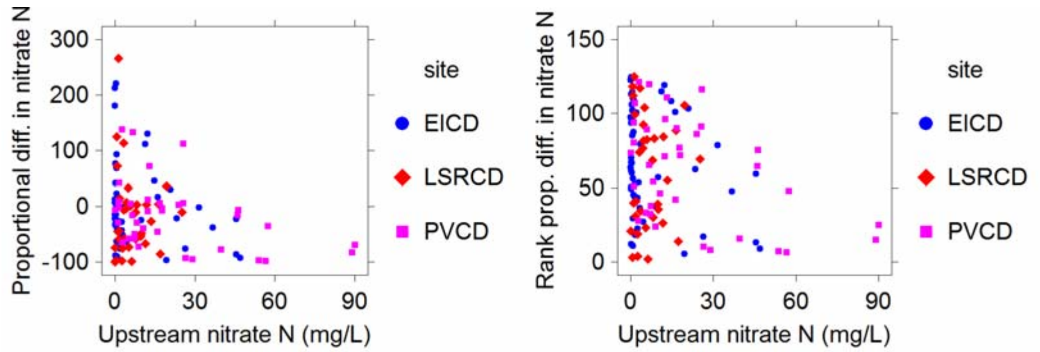


Figure 8. The proportional difference in nitrate plus nitrite N (downstream minus upstream then divided by upstream, where negative values indicate nutrient retention by the VBS) plotted versus the concentration of nitrate plus nitrite N in the upstream weir, differentiated by site. The upper plot is the proportional difference (the highest 5 values were outside the range shown), the lower is the proportional difference in rank score transformation, where scores < 66 indicate nutrient retention by the VBS.

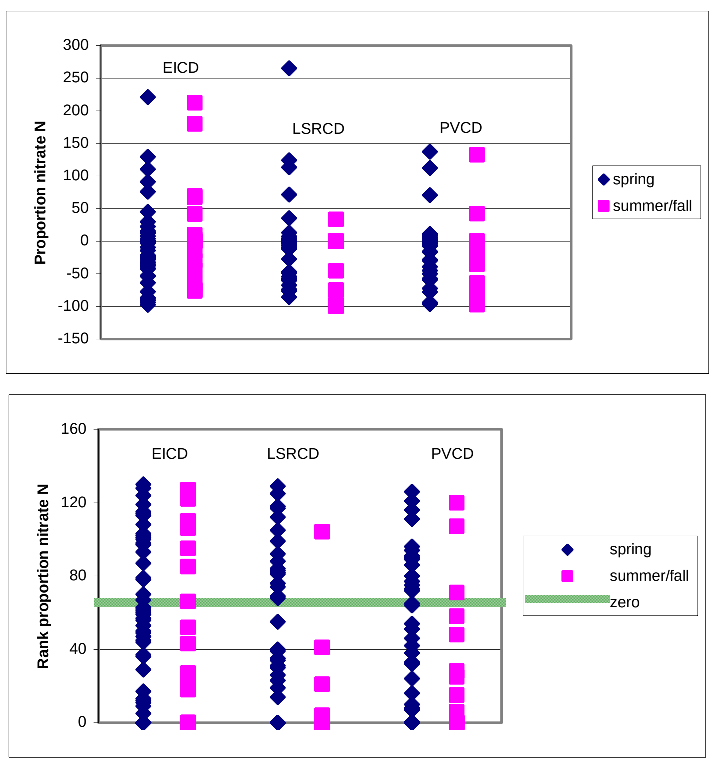


Figure 9. Scatter plot of the downstream minus upstream proportional differences in nitrate plus nitrite N, differentiated by site and season. The upper plot is the proportional difference (negative values indicate nutrient retention by the VBS), the lower is the proportional difference in rank score transformation where scores <66 indicate nutrient retention by the VBS.

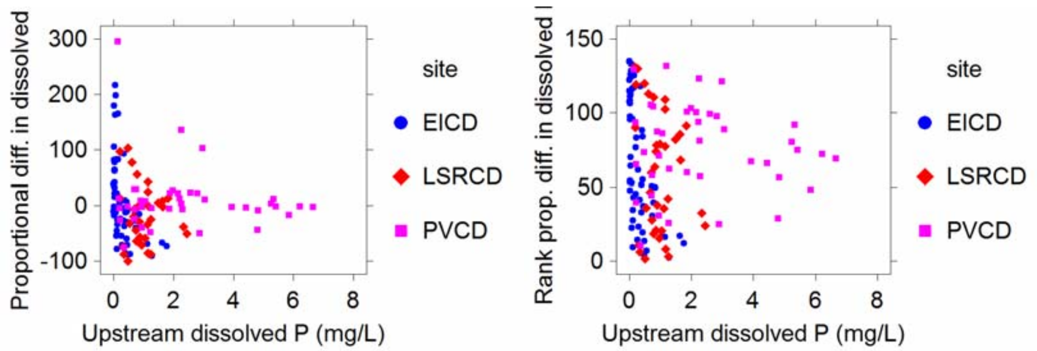


Figure 10. The proportional difference in dissolved P (downstream minus upstream upstream then divided by upstream, where negative values indicate nutrient retention byt the VBS) plotted versus the concentration of dissolved P in the upstream weir, differentiated by site. The upper plot is the proportional difference (the highest 6 values were outside the range shown), the lower is the proportional difference in rank score transformation, where scores <66 indicate nutrient retention by the VBS.

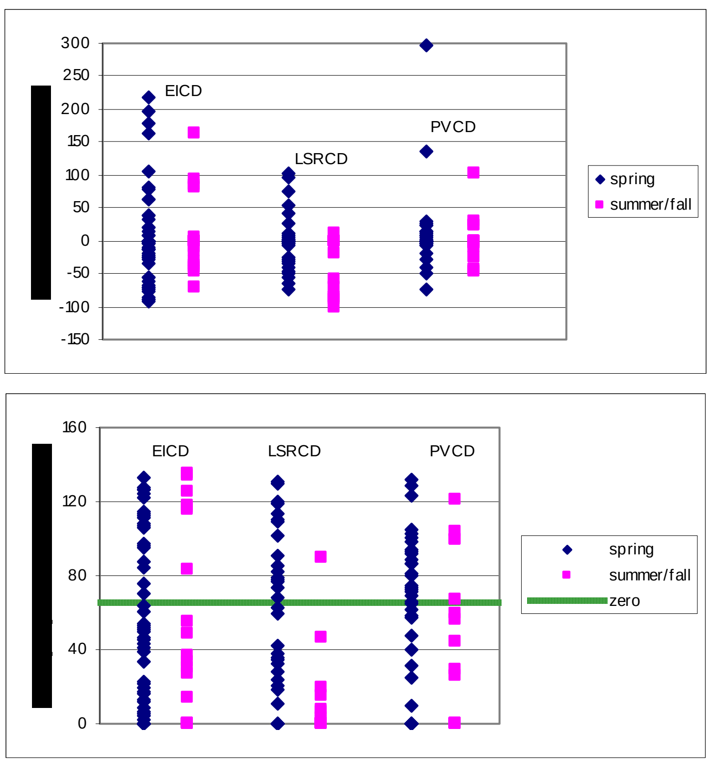


Figure 11. Scatter plot of the downstream minus upstream proportional differences in dissolved P, differentiated by site and season. The upper plot is the proportional difference (negative values indicate nutrient retention by the VBS), the lower is the proportional difference in rank score transformation where scores <66 indicate nutrient retention by the VBS.

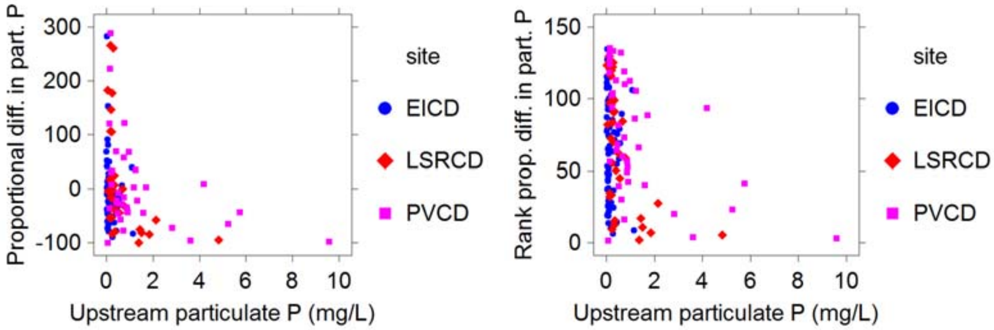


Figure 12. The proportional difference in particulate P (downstream minus upstream upstream then divided by upstream, where negative values indicate nutrient retention by the VBS) plotted versus the concentration of particulate P in the upstream weir, differentiated by site. The upper plot is the proportional difference (the highest 7 values were outside the range shown), the lower is the proportional difference in rank score transformation, where scores <68 indicate nutrient retention by the VBS.

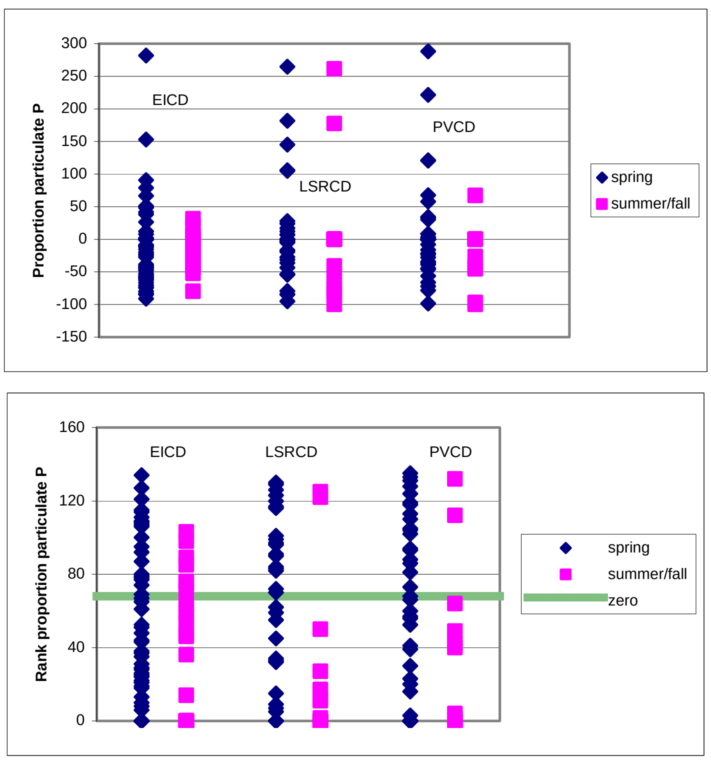


Figure 13. Scatter plot of the downstream minus upstream proportional differences in particulate P, differentiated by site and season. The upper plot is the proportional difference (negative values indicate nutrient retention by the VBS), the lower is the proportional difference in rank score transformation where scores <68 indicate nutrient retention by the VBS.

Comparing the effect of harvest versus not harvested as proportional differences, there was again a significant effect of harvest for total N, and also significant effect for nitrate plus nitrite N (Table 5).

Table 5. The effect of harvesting the VBS, contrasting the harvested versus the unharvested weir pairs in events that occurred in the 2 months following the early summer harvest. The F test was by ANOVA of rank scores of proportional differences, with harvest as the single factor.

Statistic	Total N	Nitrate plus nitrite N	Kjeldahl N	Total P	Dissolved P	Particulate P
Mean proportional difference for harvested VBS	98	85	89	83	82	70
Mean proportional difference for unharvested VBS	47	33	67	52	45	67
F test harvested versus unharvested	0.047 *	0.028 *	0.24 ns	0.35 ns	0.22 ns	0.98 ns

Multivariate analysis

The results of analysis of each nutrient species separately did not indicate a consistent effect of VBS. However, the differences and proportional differences for almost all the nutrient species were significantly inter-correlated: if a VBS was effective for one nutrient, it tended to also be effective for the other. To investigate if a multivariate expression of the results would indicate a more consistent overall trend, Eigen values (principal components analysis) based on correlation matrices were computed. The Eigen value is an artificial variable that is computed in a way so that it is most correlated to the underlying variables. One Eigen value was computed using rank differences for all 6 nutrient species, and another was computed using rank proportional differences. Each Eigen value explained over 50% of the variability in the underlying variables. However, ANOVA of the Eigen values showed no significant differences supportive of VBS effectiveness. Thus, this multivariate analysis was not more effective than the analysis of each nutrient species separately for describing the effectiveness of the VBS.

Summary of the runoff N and P results

The runoff concentrations of N and P were seldom decreased as the runoff flow passed from the field-edge weir to the weir 5 m into the VBS. In effect, the VBS was nearly as often a source of nutrient than it was a sink for nutrient. There were some statistically significant occurrences of lowered concentrations because of the VBS. At the PVCD site, there were very high total N concentrations in the runoff, and some of this was attenuated in the VBS. The LSRCD site seemed to retain dissolved P in summer and fall runoff events, but this was not consistent and it is spring runoff events that are most important.

Results of analysis of Olsen extractable P in soil

The soil test results were quite variable from weir pair to weir pair even within a site. At the EICD site, Olsen extractable P in the field soils at 0-7.5 cm depth had 13 ± 6 mg kg^{-1} and the VBS was little different at 12 ± 4 mg kg^{-1}. At the LSRCD site, the soils at 0-7.5 cm depth in the field had 16 ± 7 mg kg^{-1} and the VBS was the same at 16 ± 9 mg kg^{-1}. At the PVCD site, all the soils were much high than the other sites: the soils at 0-7.5 cm depth in the field had 63 ± 40 mg kg^{-1} and in the VBS it was 71 ± 47 mg kg^{-1}. Note that these standard deviations include the effects of position (flowpath, midslope and crest). The concentrations were slightly skewed and were significantly different site to site and among the weir pairs. To control for differences among weir pairs and to improve the distribution of the data, all the data were expressed as a ratio relative to the concentration at the edge of the VBS in the flow path. The results for 0-7.5 cm depth are illustrated in Figures 14-16 and selected statistical tests are shown in Table 6. The results for 7.5-15 cm depth are illustrated in Figures 17-19 and selected statistical tests are shown in Table 7.

The statistical tests require a measure of random or error variance. Because each weir pair was unique in some respect, it was deemed inappropriate to use a pooled measure of variance across all the weir pairs (as one would do in an overall analysis of variance). Instead, the variance for each set of weir pair soil samples was approximated separately. The variance among the 4 samples from within the VBS and away from the flow path (0.5 and 5 m from the field/VBS interface at the midslope and crest positions) was considered representative of natural or background variation at each weir-pair location. This variance was used to compute the following t test comparisons:

Comparison	**Interpretation**
The 4 midslope and crest positions versus the edge position in the flow path (which has the value of unity in the transformation used).	The midslope and crest positions are expected to have lower concentrations, if they are not lower then the VBS would appear to be ineffective at least at the edge.
The position 5 m into the VBS in the flowpath versus the edge position in the flow path.	The position further into the VBS along the flowpath is expected to have a lower concentration because if the VBS is effective then there should be lower concentrations along the flowpath.
The position in the field in the flowpath versus the edge position in the flow path.	Two outcomes are plausible. The field position might be at lower concentrations because the VBS soil is enriched in P. Conversely, the field soil may be higher because it has received fertilizer and the VBS has not.
The midslope and crest positions in the field versus the flowpath position in the field.	The midslope and crest positions are expected to have lower concentrations than in the flowpath because of P movement and redeposition downslope in the field.

Weir pair 1,2 at the EICD site, 0-7.5 cm depth, (Figure 14 and Table 6) is a nearly perfect example of the expected trends. The soil at the field edge in the flowpath had significantly higher soil P than background – suggesting the VBS has retained runoff P. The soil 5 m into the VBS along the flow path was not different in concentration from the edge position - suggesting that P entering the VBS flowed past the 5-m position as well. Because the concentrations at 0.5 m and 5 m are the same, it suggests the 4.5 m of VBS in between did little to limit the flow of P, the concentrations flowing past the 5-m position must have been similar to those at the 0.5-m position. This implies the retention capacity of the VBS between these positions is saturated (this does not mean the soil sorption capacity is saturated, it is the net retention mechanism that is saturated). In other words, the VBS retained P but had little effect on the net flow rate of P. It is possible to compute a mass balance:

- Assume the flowpath is 4-m wide through the VBS
- There is 4.5 m between the two soil sampling positions in the VBS
- So the relevant VBS patch is 18 m^2
- The surface soil to 7.5 cm depth weighs 90 kg m^{-2}, so the VBS patch has 1620 kg of soil
- The soil in the flowpath in the VBS has 18 mg Olsen-P kg^{-1}, the background soils have 13 mg Olsen-P kg^{-1}, so the VBS patch may be holding 5 mg Olsen-P kg^{-1} as extra P (note that downslope positions may have higher P levels due to pedogenic processes and not related to recent runoff, eg., Roberts et al. 1985)
- Olsen P may be as little as 0.4% of total P (e.g., Kashem et al. 2004) and perhaps upward to 3% (Sheppard, unpublished data), so assuming Olsen P is 1% of total P the VBS patch may be holding 500 mg total-P kg^{-1} (this is probably the least assured assumption, many factors affect the fraction of total P extracted by the Olsen process.
- That is 810,000 mg P retained in the VBS patch
- The average P concentration in runoff at this site was 0.43 mg L^{-1}
- Thus the VBS has retained the P from 1900000 L or 1900 m^3 of water
- The catchment area for this VBS could be as small as ~0.25 ha based on digital elevation mapping, so 1900 m^3 of water corresponds to ~800 mm of precipitation, about the annual precipitation, and assuming the VBS has been present for 20 years this is 0.5% of the annual precipitation.
- Runoff water flow was not recorded at these sites, but could be as little as 1% to 10% of the gross annual precipitation (e.g., Li et al. 2011)
- In addition to P held in the 0-7.5 cm depth, more P is held in lower soils of the VBS
- Thus, this crude mass balance supports the VBS concept in that, at this weir-pair at least, the VBS soils have retained an amount of P that could have left the site as runoff in the past 20 years.
- The above results were for a weir pair with a nearly ideal pattern of P levels, these results must be considered in the context of the other weir pairs with less ideal patterns.

The next statistical tests of interest have to do with the concentrations in the field. At EICD weir-pair 1,2 at 0-7.5 cm depth, the field soil in the flowpath had significantly higher concentrations than the soils at the midslope and crest positions in the field. This does not necessarily imply a direct flow linkage, the runoff water from these midslope and crest positions may not pass over the position in the flowpath that was sampled. However, if these midslope and crest positions are taken as representative of the rest of the field, it suggests the soil in the flowpath was enriched in P because of runoff from the catchment area. This would be expected, in effect the flowpath in the field is serving as a buffer. On the whole, the soil data for EICD weir pair 1,2 support the concept that the VBS retains P in the flowpath, although the total amounts appear to be negligible.

The other weir pairs at the EICD at the 0-7.5 cm depth site show some of the same trends. Weir pair 3,4 showed accumulation of P in the flowpath in the field, not at the edge of the VBS, but P was retained 5 m into the VBS. Weir pair 5,6 was as effective as weir pair 1,2. Weir pair 7,8 had very little differences between positions, but as a result of this low variation the trends were statistically significant. Overall, all weir pairs at the EICD site support the concept that the VBS retains P in the flowpath, even if the total amounts may be negligible

At the LSRCD site for the 0-7.5 cm depth, weir pair 1,2 seems to have an inconsistent pattern (Figure 15), but the specific statistical tests are more positive. The edge position in the flowpath had a higher concentration of P than the average of the 4 background positions, despite the variability among these background positions. The 5-m position in the flowpath had a lower concentration than the edge position, suggesting the P retention capacity of this VBS is not saturated. The soil P concentrations in the field are not easily interpreted. Weir pair 3,4 is more ambiguous, here the edge position in the flowpath was not different from background, suggesting the VBS has not retained much if any P. Weir pair 5,6 is similar, although in this weir pair there is clear accumulation of P in the field position in the flow path. This suggests that P is moving in the runoff, but is not appreciably retained by the VBS. Weir pair 7,8 is also ambiguous. Although the edge position in the flowpath had higher P concentrations than in the field, it was not different from background in the VBS and so this result may be spurious.

At the PVCD site for the 0-7.5 cm depth, weir pair 1,2 is consistent with an effective VBS: the edge position in the flowpath is enriched in P relative to background, the 5-m position is lower than the edge position, suggesting the retention capacity is not saturated. In contrast, none of the other weir pairs at PVCD can be said to be supportive of P retention by the VBS. The trends at weir pair 7,8 appear supportive, but because of large variation among the 4 background positions, these trends were not statistically meaningful. The trends at weir pair 3,4, where all VBS samples had higher P concentrations than the field soil, would suggest that runoff occurred at the midslope and crest positions as well as in the flowpath.

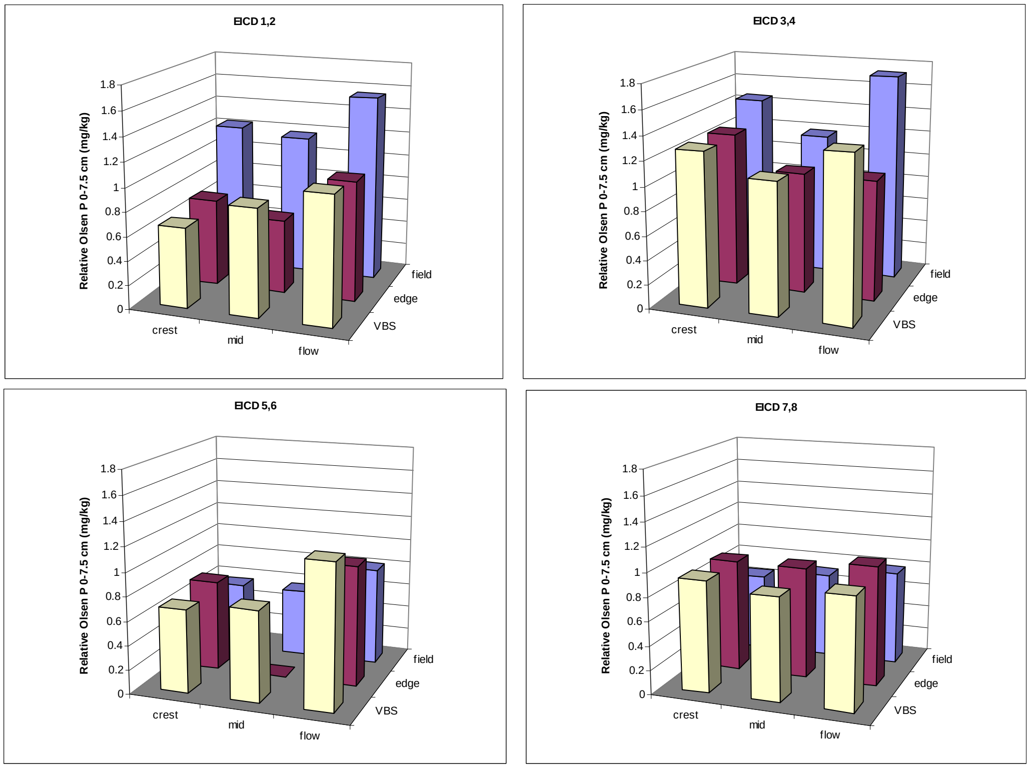


Figure 14. Soil concentrations of available P (Olsen test) 0- to 7.5-cm depth at the EICD site, by weir pair and expressed relative to the concentration in the soil at the field edge in the runoff flow path. Statistical inferences for these data are shown in Table 6.

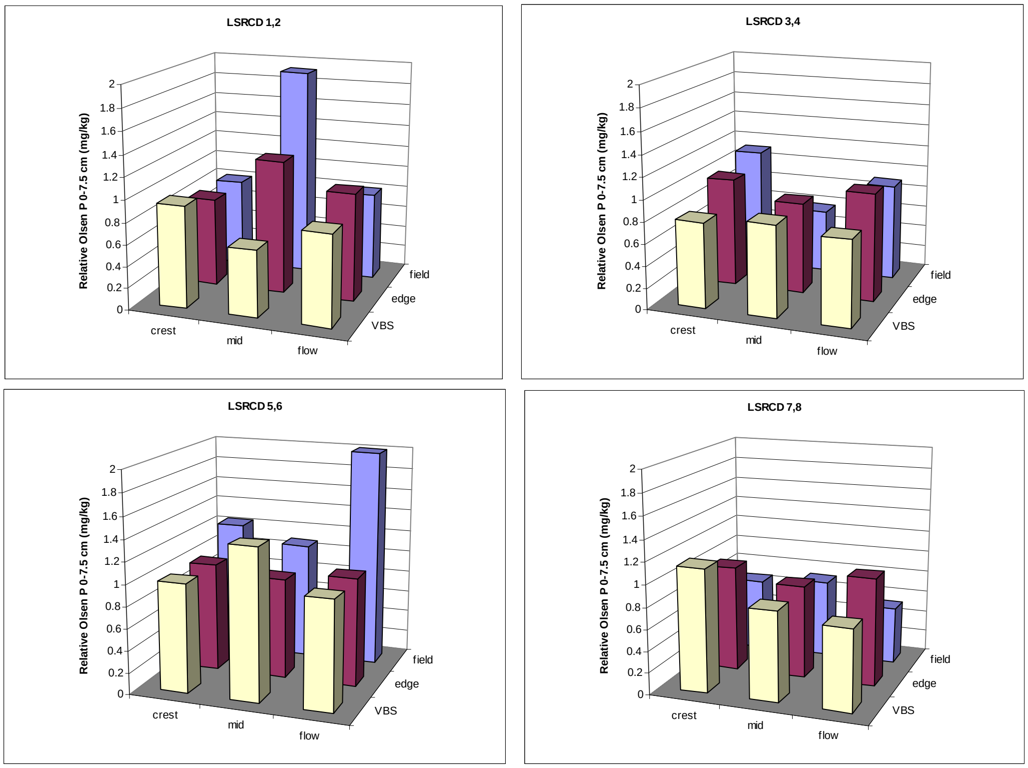


Figure 15. Soil concentrations of available P (Olsen test) 0- to 7.5-cm depth at the LSRCD site, by weir pair and expressed relative to the concentration in the soil at the field edge in the runoff flow path. Statistical inferences for these data are shown in Table 6.

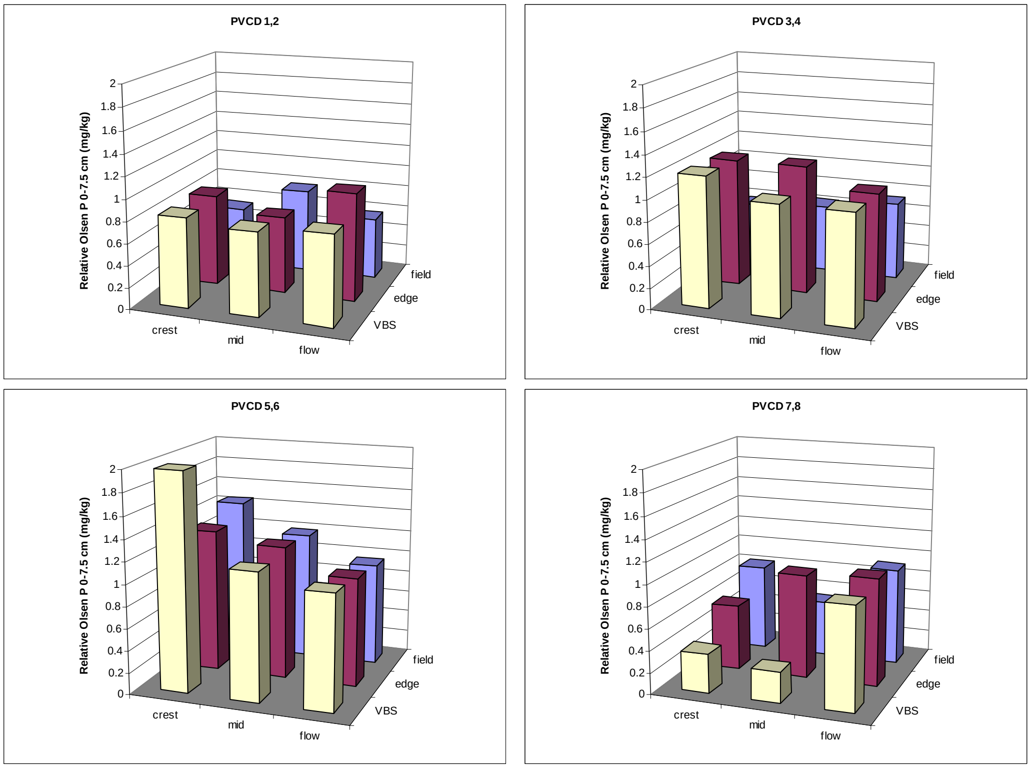


Figure 16. Soil concentrations of available P (Olsen test) 0- to 7.5-cm depth at the PVCD site, by weir pair and expressed relative to the concentration in the soil at the field edge in the runoff flow path. Statistical inferences for these data are shown in Table 6.

Table 6. Results of 2-tailed t tests of among the soil concentrations of available P (Olsen test) at the 0- to 7.5-cm depth. The standard error (SE) was approximated separately for each weir pair as the SE among the 4 soils in the non-flow-path positions in the VBS, giving 3 degrees of freedom for each test. The 5 specific tests and the a priori expectations are indicated.

		Field edge in flow path versus:			In field in flow path versus:	
Site	Weir pair	4 non-flow path positions in the VBS - expect L	5 m into the VBS in the flow path – expect L	in the field in the flow path – no expectation	in field crest – expect L	in field midslope – expect L
EICD	1,2	L[a]	ns[b]	H[c]	L	L
	3,4	ns	H	H	L	L
	5,6	L	H	L	L	L
	7,8	L	L	L	L	L
LSRCD	1,2	L	L	L	ns	H
	3,4	ns	L	ns	H	L
	5,6	ns	ns	H	L	L
	7,8	ns	L	L	H	H
PVCD	1,2	L	L	L	ns	H
	3,4	H	ns	L	L	ns
	5,6	ns	ns	ns	ns	ns
	7,8	ns	ns	ns	ns	ns

[a] L indicates significantly lower concentrations in the soil at the described position compared to the soil at the field edge in the flow path or the soil in the field in the flow path.
[b] ns indicates no significant difference.
[c] H indicates significantly higher concentrations in the soil at the described position compared to the soil at the field edge in the flow path or the soil in the field in the flow path.

The results for the 7.5-15 cm depths are comparable (Figures 17-19 and Table 7), although the trends are not necessarily the same at each weir pair as shown above for the 0-7.5 cm depth. At the EICD site, at none of the weir pairs was the soil at the edge in the flowpath different from background. At weir pair 1,2 there was significant accumulation of P in the flowpath in the field at 7.5-15 cm just as there was at the shallower depth.

Weir pairs 1,2 and 3,4 at the LSRCD site, 7.5-15 cm depth (Figure 18) are exactly as expected for an effective VBS. In contrast, there was no differences in P concentration at weir pair 5,6. At weir pair 7,8 the only tests that were statistically significant was that in the flow path, the soil at the edge was higher than either in the field or in the VBS, which would be supportive of this being an effective except the trend for the other edge positions soils is unusal.

At the PVCD site for the 7.5 to 15 cm depth, there were few significant differences. The only significant difference that follows the expectations for an effective VBS is at weir pair 1,2 where at 5 m into the VBS the soil concentrations were elevated, and there was a trend (not significant) for the edge position in the flowpath to be elevated relative to background.

Summary of the Olsen extractable soil P results

There was evidence of P retention in soils at several of the weir pairs, but not all. At the 0-7.5 cm depth, 5 of the 12 weir pair locations appeared to have retained P in the VBS, and 5 of the 12 showed increased P concentrations in the flowpath in the field relative to other positions in the field. The fields at all three sites had soil P concentrations at 0-7.5 cm that were little different from background, so these sites do not represent cases of extreme buildup of soil P because of fertilization. At the 7.5-15 cm depth, the same general trends were evident, but even fewer weir pair locations had results that indicated the VBS were effective.

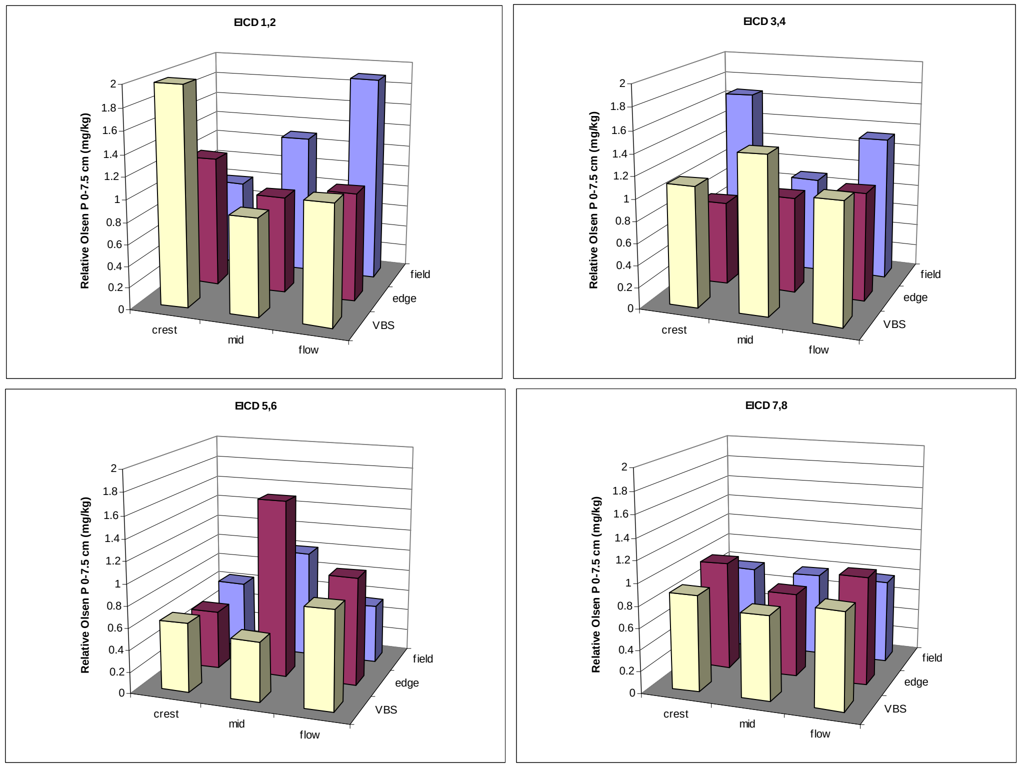


Figure 17. Soil concentrations of available P (Olsen test) 7.5- to 15-cm depth at the EICD site, by weir pair and expressed relative to the concentration in the soil at the field edge in the runoff flow path. Statistical inferences for these data are shown in Table 7.

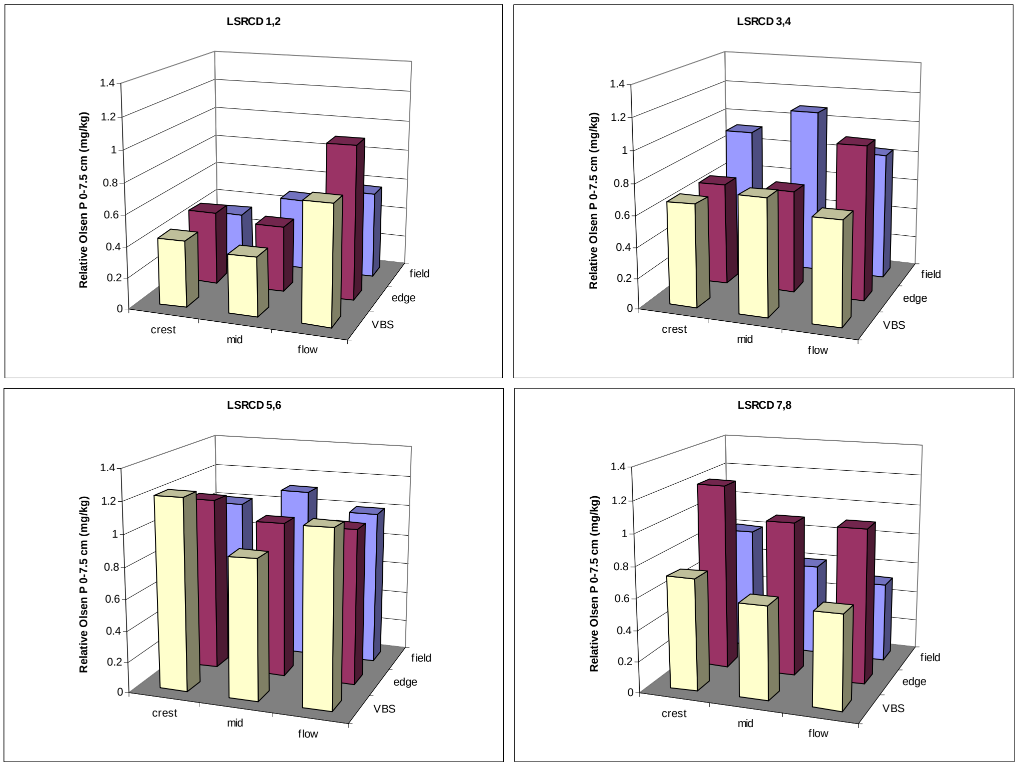


Figure 18. Soil concentrations of available P (Olsen test) 7.5- to 15-cm depth at the LSRCD site, by weir pair and expressed relative to the concentration in the soil at the field edge in the runoff flow path. Statistical inferences for these data are shown in Table 7.

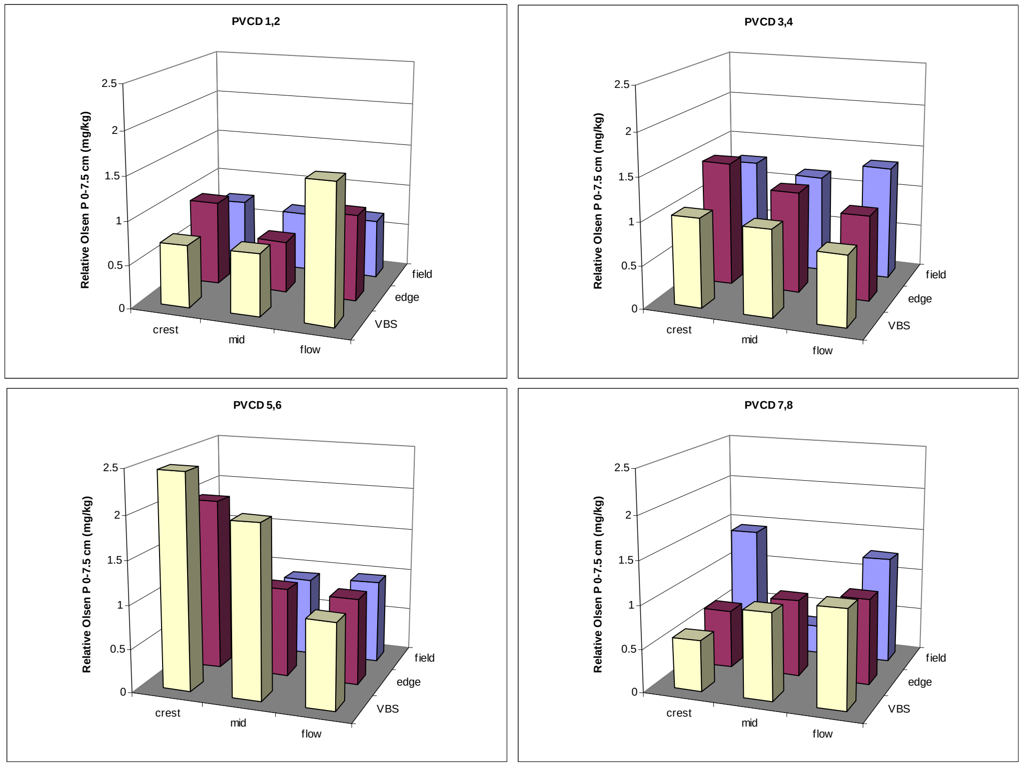


Figure 19. Soil concentrations of available P (Olsen test) 7.5- to 15-cm depth at the PVCD site, by weir pair and expressed relative to the concentration in the soil at the field edge in the runoff flow path. Statistical inferences for these data are shown in Table 7.

Table 7. Results of 2-tailed t tests of among the soil concentrations of available P (Olsen test) at the 7.5- to 15-cm depth. The standard error (SE) was approximated separately for each weir pair as the SE among the 4 soils in the non-flow-path positions in the VBS, giving 3 degrees of freedom for each test. The 5 specific tests and the a priori expectations are indicated.

		Field edge in flow path versus:			In field in flow path versus:	
Site	Weir pair	4 non-flow path positions in the VBS - expect L	5 m into the VBS in the flow path – expect L	in the field in the flow path – no expectation	in field crest – expect L	in field midslope – expect L
EICD	1,2	ns[a]	ns	H[b]	L[c]	ns
	3,4	ns	ns	ns	ns	ns
	5,6	ns	ns	ns	ns	ns
	7,8	ns	ns	L	ns	ns
LSRCD	1,2	L	L	L	L	L
	3,4	L	L	L	H	H
	5,6	ns	ns	ns	ns	ns
	7,8	L	ns	L	ns	ns
PVCD	1,2	ns	H	L	ns	ns
	3,4	ns	ns	H	ns	ns
	5,6	ns	ns	ns	ns	ns
	7,8	ns	ns	ns	ns	L

[c] L indicates significantly lower concentrations in the soil at the described position compared to the soil at the field edge in the flow path or the soil in the field in the flow path.
[a] ns indicates no significant difference.
[b] H indicates significantly higher concentrations in the soil at the described position compared to the soil at the field edge in the flow path or the soil in the field in the flow path.

Results of analysis of soil ^{137}Cs

There were fewer data for ^{137}Cs, and so the results can only be discussed qualitatively. The theory is that ^{137}Cs was deposited onto all soils in Canada during the atmospheric nuclear weapons testing that ended in the 1960's. The deposition was not necessarily even for all soils, and since the 1960's the ^{137}Cs has been decaying (less than half now remains) and the ^{137}Cs has been moving. The ^{137}Cs tends to sorb strongly to clay particles, so there is little downward movement but there can be substantial lateral movement with erosion. Plants also absorb ^{137}Cs. To interpret ^{137}Cs concentrations in soil, the concentration must be considered relative to other soil concentration in the same vicinity. In general, higher concentrations are expected where eroded clay particles might deposit, such as the lower positions in the landscape in tilled fields and less so in areas with permanent vegetation. The results for EICD and PVCD (Figure 20) do not show trends that are consistent with expectation. However, the LSRCD site, which has the steepest slopes, does conform to expectation. The flowpath soils are all elevated in ^{137}Cs relative to other soils at that site (and relative to soils at the other sites). Thus, there appears to have been notable movement of clay on the LSRCD site from the upslope positions and into the flowpath (which is by definition in the downslope position).

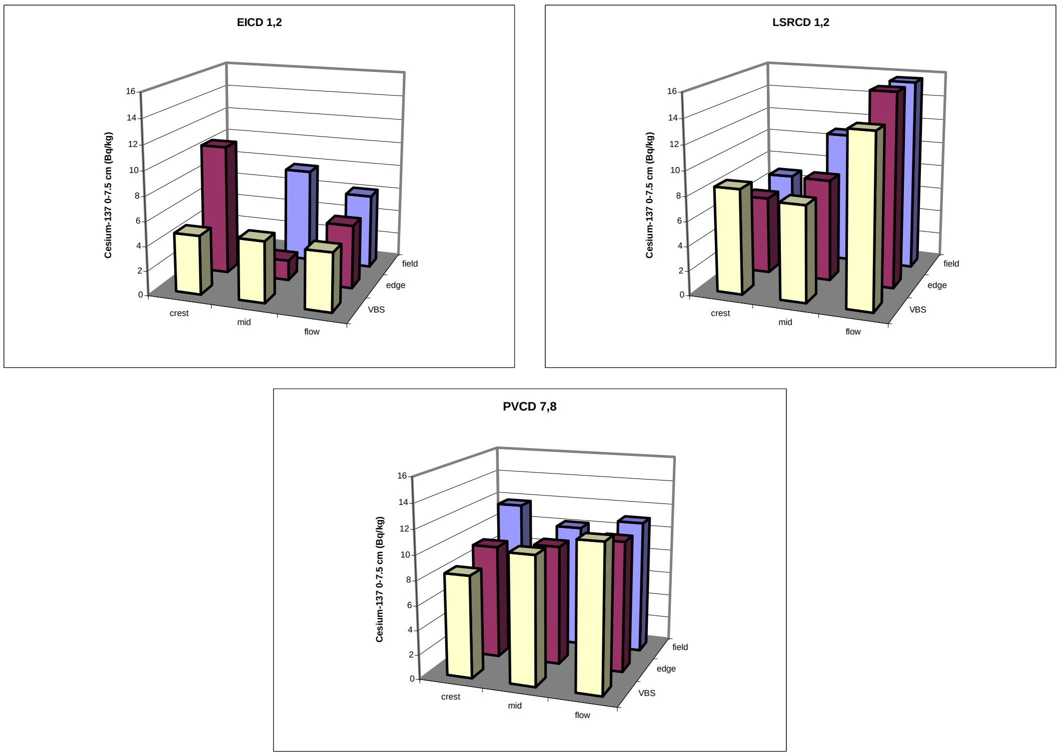


Figure 20. Soil concentrations of ^{137}Cs (Bq kg^{-1}) at the 0- to 7.5-cm depth at one weir pair at each site.

Conclusions

The results from both runoff water samples and soil samples suggest that the VBS have some ability to retain N and P. The effect was not consistent in space or time, and it was marginally significant in a statistical sense. If the VBS locations sampled here are representative of flowpaths leaving tilled fields, only a few of the VBS in these flowpaths retained nutrient and the capacity of these few effective VBS to retain nutrient seems to be dwarfed by the mass of runoff P leaving the fields over many years.

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