Can riparian buffer zones reduce phosphorus loss from agricultural land in Manitoba?

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Abstract

Riparian buffer zones are a beneficial management practice used to minimize the transport of phosphorus from agricultural land to surface waters. Surface waters are highly sensitive to increases in phosphorus, which can lead to eutrophication. The objective of this research project is to assess long term effectiveness of vegetated buffers as phosphorus sinks through analysis of soil test phosphorus concentrations (STP). Composite soil samples were taken at the crest, back slope and flow path from the left and right side of field runoff channels. At each site, a total of 18 samples were collected. Samples were collected along the flow path 5 m upstream of the buffer, 0.5 m into the buffer and 5 m downstream into the buffer at three landscape positions adjacent to the flow path (middle of flow path, midslope away from the flow path and crest above the flow path). Two soil depths were sampled: 0-7.5 cm and 7.5-15 cm. Four sites were sampled in each of three conservation districts (CD) in Manitoba, resulting in a total of 216 samples. If the vegetated buffers are acting as phosphorus sinks and phosphorus is being accumulated, STP will be greater in the buffer than in the field and greater along the flow path than in the upslope positions. Using Cs-137, it was possible to determine that there has been an enrichment of eroded soil in the VBS, but this accumulation only occurred at only two of the three CDs. The degree to which VBS accumulated both P and eroded soil was positively correlated to the slope of the adjacent field. This project was part of a larger study being led by the East Interlake Conservation District and Manitoba Conservation District Association.

Introduction and Background

Over the past 30 years water quality in Lake Winnipeg has been deteriorating. As the size of communities has increased and development has expanded in Lake Winnipeg's watershed, nutrient loading has also increased, with damaging effects. In 2003, Manitoba's provincial government launched the Lake Winnipeg Action Plan and announced its intentions to reduce nitrogen and phosphorus to pre-1970's levels (LWSB 2006). Although both nitrogen and phosphorus are addressed in the plan, research is indicating that controlling phosphorus (P) is of greatest concern because very small increases of P concentration in freshwater bodies create large responses in the cyanobacteria, or blue-green algae, responsible for eutrophication. Severe eutrophication causes massive algal blooms, which starve the lake of oxygen causing fish kills, in some cases making the water toxic to livestock and pets, and unsuitable for recreation (Schindler 1974, Sharpley et al. 1994, Sharpley et al. 1999). This has serious implications for Lake Winnipeg, which has a 20 million dollar per year fishing industry, a large cottage community and is a popular recreation spot for many Manitobans.

Water quality problems are compounded by Lake Winnipeg's characteristics. With an area of 24, 500 km^2 it's the 10th largest freshwater lake in the world. A large surface area combined with shallow depths means that air mixes easily with lake water, promoting algae growth. It also has the largest watershed to surface area ratio of any large lake in the world. Lake Winnipeg's watershed includes four Canadian provinces and four American states. The majority of western Canadian agriculture is located in the watershed. Manitoba's agricultural sources of P account for 15% of total P entering the lake (LWSB 2006). New regulations in Manitoba aimed at improving surface water quality are promoting vegetative buffer strips as a beneficial management practice for reducing the transport of nutrients in agricultural runoff.

A vegetative buffer strip (VBS) is defined as "any strip of vegetation between a river stream or creek and an adjacent upland land use activity." (Hickey and Doran 2004) Vegetative buffers function via three main processes: physical, chemical and biological.

A key part of a VBS is the rougher surface that slows and increases turbulence of the incoming surface water. Similar to the implementation of a cover crop to reduce erosion, VBS may be an effective means of reducing particulate P in runoff water (Puustinen et al. 2006). In many regions that use VBS, phosphorus loss is usually associated with soil erosion because it is attached to the fine and easily erodible soil particles (Dorioz et al. 2006, Schmitt et al. 1999, Syverson 2002). Infiltration and adsorption are the primary mechanisms for reducing concentrations of dissolved phosphorus. Buffer vegetation, just like a perennial crop, increases soil macroporosity and infiltration. Soil matrix properties dictate adsorption to soil particles. Generally, high clay soils have higher retention capacity for dissolved nutrients (Sharpley et al. 1999, Syverson and Borsch 2005). When effective, VBS are intended to slow the velocity of surface water, allowing eroded particulate phosphorus to settle and dissolved phosphorus to infiltrate the soil. Buffer vegetation can then absorb the biologically available dissolved P from the soil solution. (Dorioz et al.2006). The temporal variation of runoff, and the state of the soil during that time, is essential when determining the dominant form of P in runoff (Syverson 2002). In Manitoba, approximately 80% of our runoff is during spring snowmelt, with dissolved P as the dominant form (J. Elliott, in CEC Report 2007).

Dissolved phosphorus (DP) is often less affected by VBS than particulate phosphorus. Studies show retention of DP has very high variability, and is generally less effectively reduced (Dorioz et al. 2006, Schmitt et al. 1999, Syverson 2005). Dissolved phosphorus makes up the majority of total-P concentrations in Manitoba's spring runoff (Glozier et al. 2006). Since DP is primarily influenced by infiltration, factors that affect soil structure and texture may be irrelevant since little or no infiltration is possible when the surface layers are frozen and runoff is at its peak (Syverson 2002). As thawing and infiltration begins, soil can become quickly saturated by the high volume of snowmelt. Tests of the effect of water volume on phosphorus retention indicated that for high volumes, retention efficiency for DP was significantly reduced compared to low volumes (Syverson 2005). Therefore, flooding renders a VBS useless, especially if water is above the height of vegetation (Dorioz et al. 2006). Conversely, thawed soils with growing vegetation enable VBS to do what it was designed to do, slow down runoff, increase sedimentation and infiltration.

In the fall of 2008, the East Interlake Conservation District, with support from the Manitoba Conservation Districts Association, started a two year study on VBS management and effectiveness in Manitoba. The project takes place over three conservation districts: East Interlake Conservation District, Little Saskatchewan River Conservation District and Pembina Valley Conservation District. For the purposes of this paper, the focus will be on the analysis of soil samples taken in the fall of 2009. The objective was to assess the long term effectiveness of the VBS as a sink for phosphorus by comparing sampling points in the field to points within the buffer. If phosphorus has been accumulating over time then it is expected that concentrations will be greater in the VBS than in the field. Using Ceasium-137 it can be assessed whether greater P concentrations are due to the soil interception mechanics and functions of the VBS or caused by natural soil forming processes in the landscape, and are actually attributed to spatial differences in the landscape.

Methods

Site Characterization

The Little Saskatchewan River Conservation District (LSRCD) site is found in the R.M. of Blanshard, a few kilometers outside the town of Oak River (NW-24-14-22W). 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 Oak River and its contributories. 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 with slope ranging from 5 – 9 % (Podolosky 1988). Located on Broughton's creek, vegetation consisted of meadow species.

The Pembina Valley Conservation District (PVCD) site is located just outside Manitou, in the R.M. of Pembina in the south central part of the province (NW-36-03-09- W). 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 are poorly to imperfectly drained Gleyed rego black soils of lacustrine deposits, while upland positions are moderately well drained orthic black soils over shale bedrock (Podolosky 1993). The riparian vegetation was mostly grasses and sedges, with some weedy species like Stinging Nettle. At the time of sampling (2 September 2009), the riparian channel itself was dry although it is probably inundated in spring and after heavy rainfall during summer months. Upland fields were sowed with wheat, although around weirs 5,6 and 7,8 roughly 100 m of alfalfa was planted on either side of the buffer followed by wheat upslope.

The East Interlake Conservation District (EICD) site is located in the Rural Municipality of Gimli in the NW-36-18-03 E quarter section. This land has been in the same family for many generations. Running through their property is Willows creek, which feeds into Lake Winnipeg. It has an established riparian zone, including some deciduous trees such as aspen, Saskatoon, grasses and sedges. The field adjacent to the buffer did not get a crop in that growing season due to excessive field moisture that plagued the Interlake in general. This also meant that at weir 3,4 soil was sampled through ponded water. The physiography in the area is a "ridge and swale" landform, and 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 the lacustrine deposits found here. Soils are stratified layers of thin clayey deposits over calcareous glacial till and are dominantly Chernozemic dark grays (Michalyna and Podolosky 1980).

Mean monthly precipitation at the three conservation districts is illustrated by Figure 1. Overall, Gimli and Manitou are fairly similar, although the Gimli area has higher spring and fall precipitation and Manitou has higher precipitation in the summer months. Generally, the Rapid City station, used to indicate precipitation at the LSRCD site, has lower precipitation compared to the Gimli and Manitou stations.

Soil Sampling

At each of the three conservation district (CD) sites, four pairs of water sampling weirs were set up in four separate flow path channels moving off the cropped field. One weir was placed at the fields edge and one downstream the channel, 4.5 m into the buffer. Soil sampling consisted of 18 samples per weir pair location, which means 72 samples per CD for a total of 216 samples taken in fall 2009.

Composite soil samples were taken at the crest, back slope and flow path from the left and right side of field runoff channels. Samples were collected along three longitudinal transects: 5 m upstream of the buffer, 0.5 m into the buffer and 5 m into the buffer (Fig. 2). Two soil depths were sampled: 0-7.5 cm and 7.5-15 cm. If crests were not easily identified, sampling points were measured out to a maximum of 20 m from the flow path. At each sampling position, five cores were taken from a 1 m^2 area using a 1 $^1/_4$ diameter Backsaver auger.

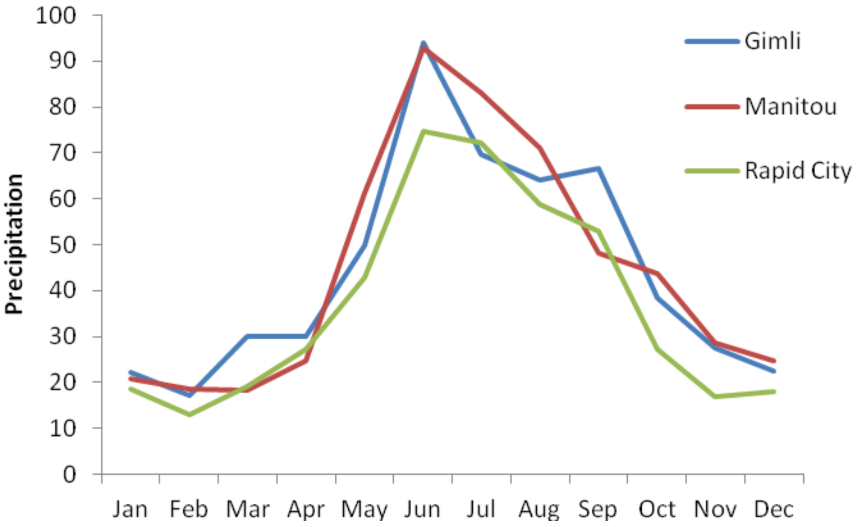

Figure 1. Mean monthly precipitation (mm) at Environment Canada weather stations in Gimli, Manitou and Rapid City.

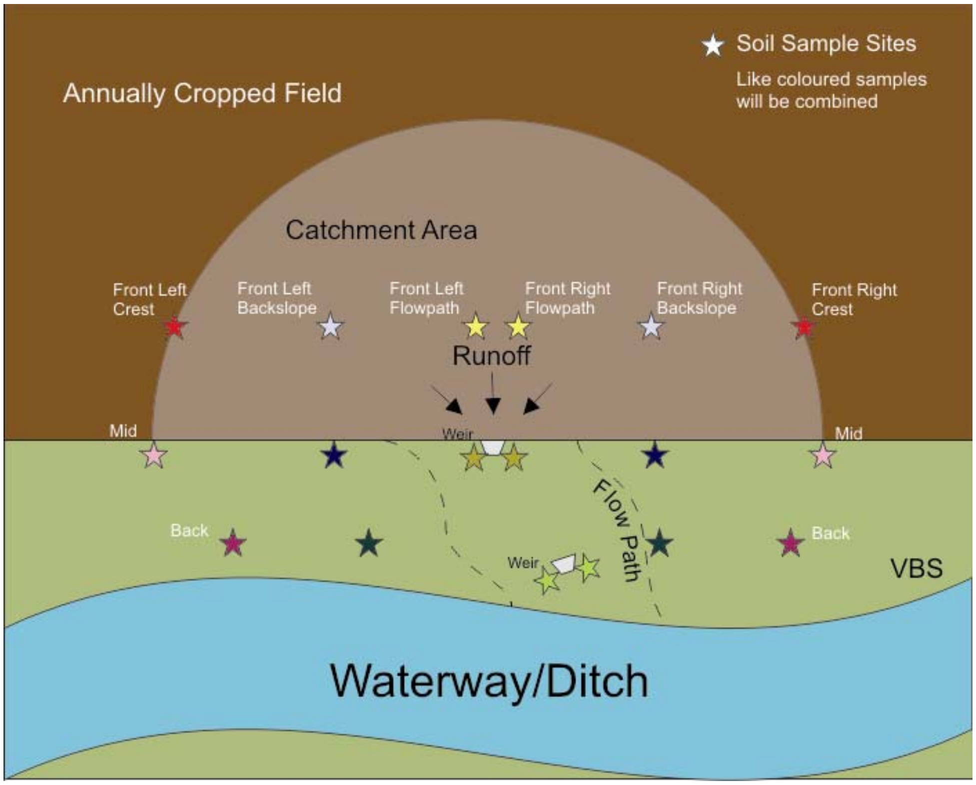

Figure 2. Sampling protocol of one catchment resulting in 18 soil samples at two depths: 0-7.5 cm and 7.5-15 cm (S. Carlyle).

Soil Analysis

Phosphorus was extracted using the sodium bicarbonate extractable phosphorus (Olsen-P) extraction method. This method provides an index of plant-available P which makes it sensitive to management practices that increase bioavailable P. This quality has made the Olsen-P method popular for making recommendations about fertilizer use (Schoenau and O'Halloran 2008). For this methodology, 1.0 g of the air dried soil sample, ground to 2 mm, was combined with 0.25 g charcoal plus 20 mL of 0.5 M $NaHCO_{3.}$ The sample was placed on a reciprocal shaker for 30 minutes at 120 strokes per minute. The sample was filtered to remove soil and charcoal, leaving just the reagent and the dissolved phosphorus in 20 mL plastic vial.

Using the ascorbic acid-molybdate method (Murphy and Riley 1962), P concentration was derived through colormetric determination. Two reagents were used; Reagent A combined 12 g of ammonium molybdate dissolved in 250 mL of deionized water, 0.2908 g of potassium antimonyl tartate in 100 mL of deionized water and 148 mL of sulfuric acid in 1000 mL of deionized water. Reagent B was formulated using 1.056 g of ascorbic acid in 200 mL of regent A. Two to 5 mL of soil extract was combined with approximately 10mL of deionized water and 4 mL of reagent B. Colour was allowed to develop for 15 minutes and P concentration was determined on a spectrophotometer set at 882 nm. A set of standard P solutions containing 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 ppm P by transferring 0, 0.5, 1, 2, 3, 4 and 5 mL of 5 ppm stock into a 25 mL volumetric flask. The blank and P standards should contain the same volume of the extracting solutions used for the soil P test.

Lastly, using the Department of Soil Science gammaspectrometers, Cesium-137 analysis was done on one basin, or weir pair, from each the CD's. Sites were chosen based on the distribution of P concentration across the landscape, specifically looking at those with good variability between field and buffer sampling points. Air dried and ground samples were weighed and processed by the gamaspectrometers for a minimum of 24 hours.

Results

The mean Olsen-P concentrations show the spatial variability between landscape positions. The expected result of having greater concentrations immediately inside the VBS, specifically in the flow path is represented at two of the three CD's, LSRCD and PVCD (Fig. 3, 6). The Cs-137 concentrations at these two sites also follow the same trend (Fig. 4, 7), with greater concentrations in the flow path at the VBS edge than in the field flow path position. As expected, there is a strong correlation between the phosphorus and Cs-137 concentrations at LSRCD, less so at PVCD and EICD (Fig. 5). For correlation and regression analysis, only the individual catchment values for P were used, not the mean values.

At Little Saskatchewan River Conservation District (LSRCD), moving downstream the flow path from the field to the VBS edge, there is an increase in P concentration (Fig. 3). Towards the crest of the flow path channel there are lower concentrations of P. These trends are more evident in the Cs-137 concentrations (Fig.4). At crest positions Cs-137 concentrations are typical background levels, but there is an accumulation in the flow path resulting in concentrations as high as 35.97 Bq/Kg in the VBS edge. This indicates that the fine erodible top soil is accumulating at the rougher surface of the VBS edge.

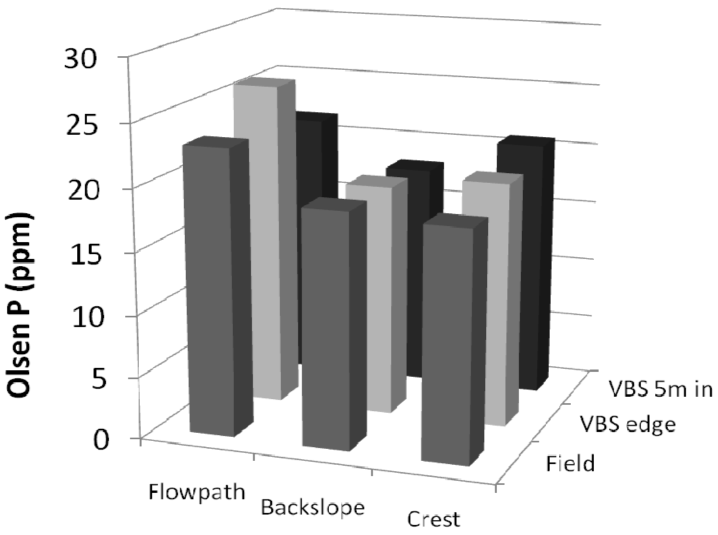

Figure 3. Mean Olsen-P concentrations in soil (0 -15 cm) at Little Saskatchewan River Conservation District.

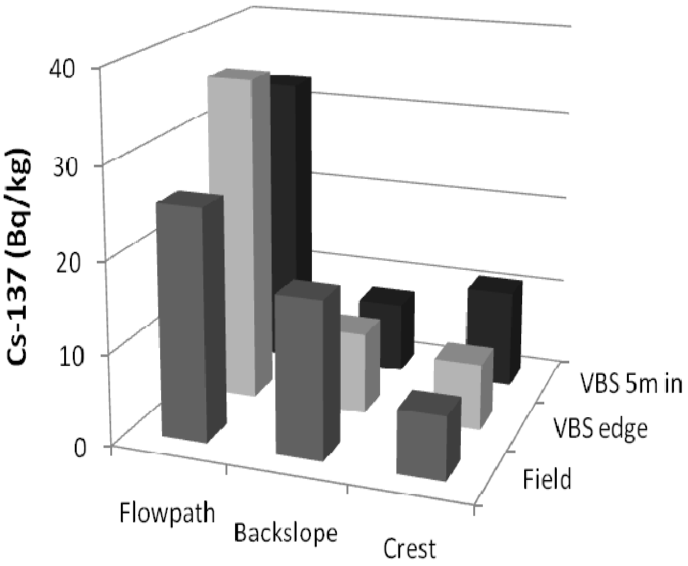

Figure 4. Cesium-137 concentrations for the weir 1,2 catchment at LSRCD

There is a strong positive correlation between the Olsen-P and Cs-137 at this site (Fig. 5). The R-squared value indicates that 95% of the variability is explained.

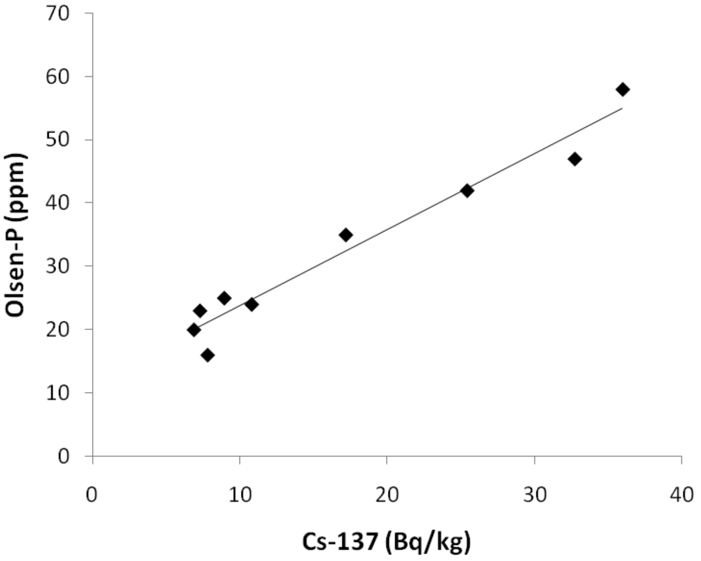

Figure 5. Regression analysis showing positive relationship between Olsen-P and Cs-137 concentrations for the catchment at weir 1,2 in LSRCD. (R-squared = 0.955 and P-value < 0.001)

At Pembina Valley Conservation District (PVCD), there is also an increase in P concentration moving downstream along the flow path. This site had very high Olsen-P values, approaching 80 ppm. Crest values were also high, and follow the expected result of having lower values at those points. The Cs-137 values show that there is an accumulation of Cs-137 in the VBS. At this site Cs-137 accumulating in the flow path is occurring 5 m into the VBS, taking greater distance to deposit. In the back slope position there is a steady increase in Cs-137 concentration, but at the crest position, Cs-137 concentrations decrease moving downstream into the VBS.

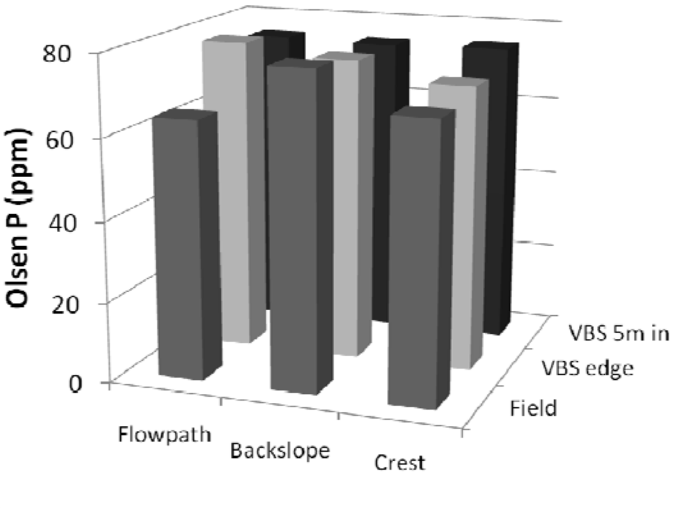

Figure 6. Mean Olsen-P concentrations in soil (0 -15 cm) at Pembina Valley Conservation District.

Correlation between the Olsen-P and Cs-137 concentrations at PVCD is less strong than at LSRCD. The r-squared value is 56% so only about half the variation between the two variables is explained here.

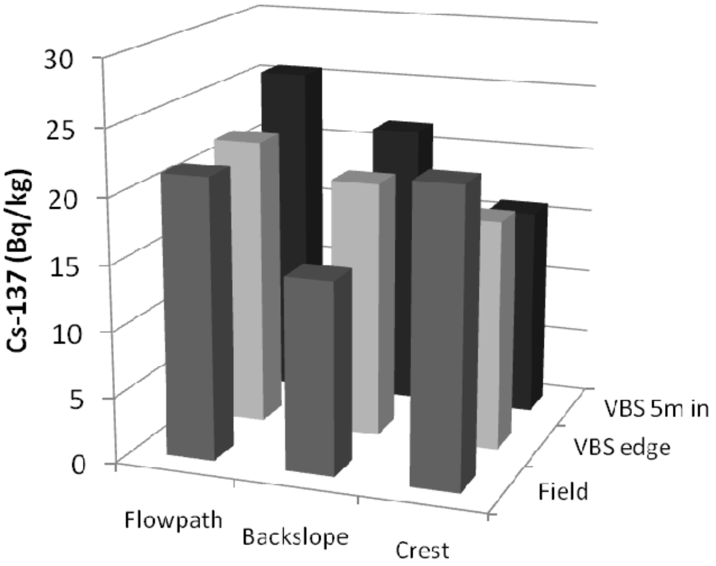

Figure 7. Cesium-137 concentrations in soil (0 – 15 cm) for the catchment at weir 7,8 at PVCD.

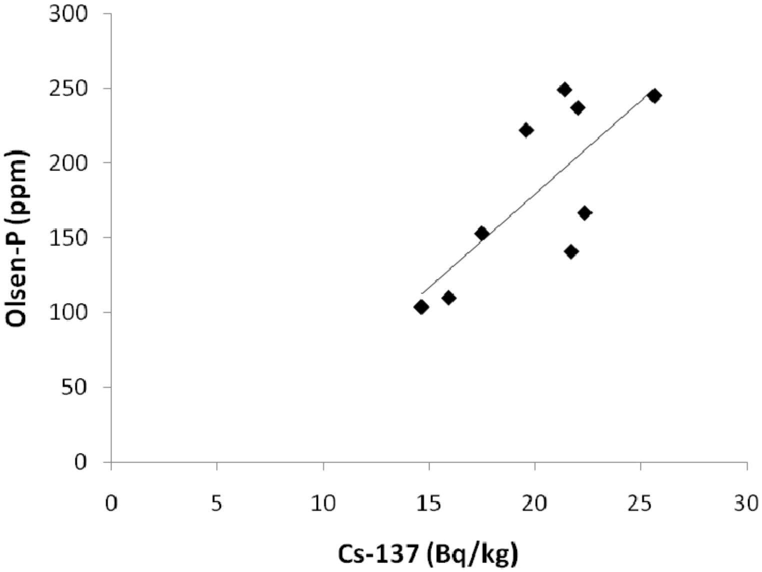

Figure 8. Regression analysis showing positive relationship between Olsen-P and Cs-137 concentrations for the catchment at weir 7,8 in PVCD. (R-squared = 0.564 and P value = 0.434)

East Interlake Conservation District's site had the most variable Olsen-P concentrations. Phosphorus concentrations were higher in the field in some catchments than in the VBS. The mean values show this in the flow path, where P concentration drops in the VBS at the field's edge and also at the back slope position (Fig.9).

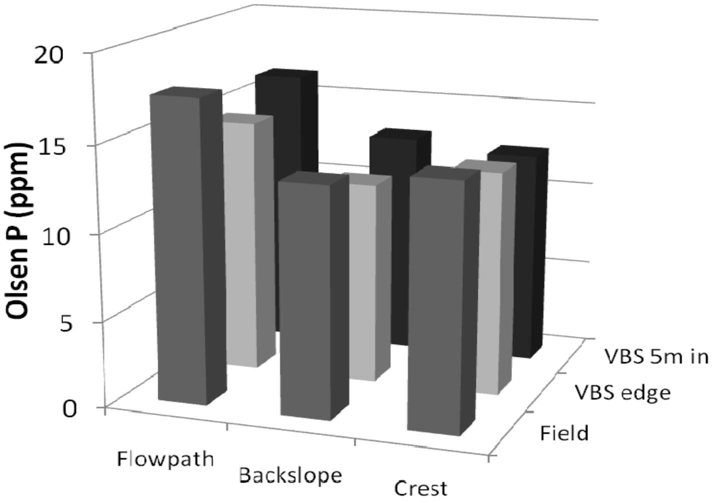

Figure 9. Mean Olsen-P concentrations in soil (0 -15 cm) at East Interlake Conservation District.

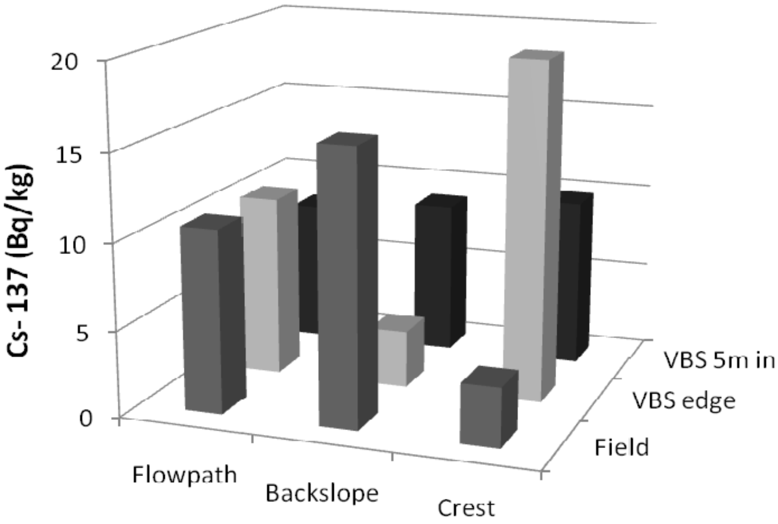

Figure 10. Cesium-137 concentrations for the catchment at weir 1,2 at EICD

The Cs-137 values are also highly variable and do not depict any of the expected trends. This fact is clearly indicated by a very low r-squared value, where only .04% of the variation between variables is explained.

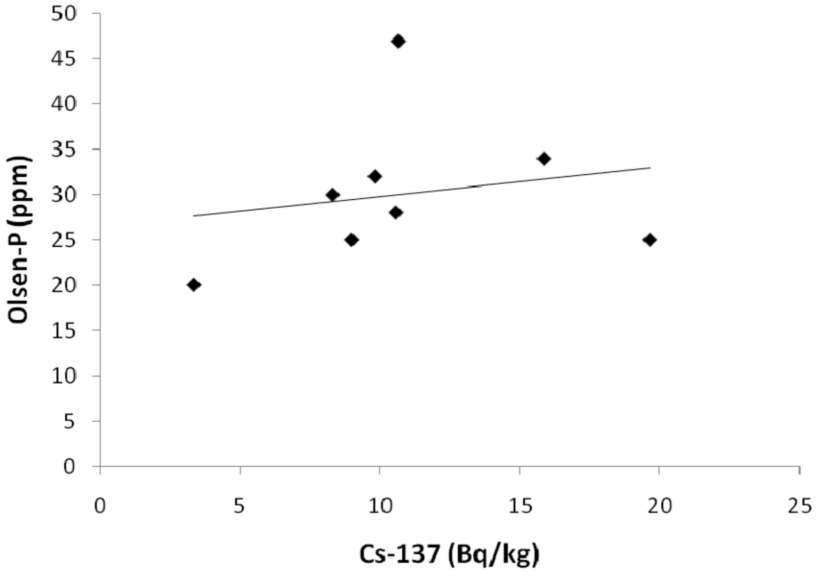

Figure 11. Regression analysis showing positive relationship between Olsen-P and Cs-137 concentrations for the catchment at weir 1,2 in EICD. (R-squared = 0.039 and P value = 0.014)

The following figures (12,13,14) compare the mean P concentrations between the surface (0 – 7.5 cm) and subsurface (7.5 – 15 cm) soil in the flow path at each conservation district site. Standard error bars indicate the distribution of the individual points around the mean.

At LSRCD it is evident that there is greater accumulation in the surface soil than in the subsurface soil but there is still an increase in P concentration in the subsurface soil at the VBS edge. Soil P eventually decreases along the flow path at this both depths.

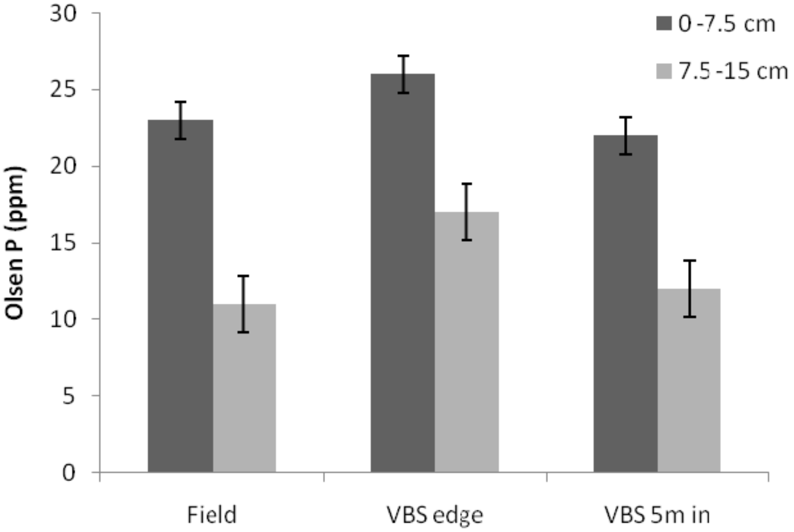

Figure 12. Comparison of mean Olsen P of surface (0- 7.5 cm) and subsurface (7.5 – 15 cm) soil in the flow path at LSRCD. Standard error bars shown.

At PVCD there is roughly equivalent concentration of P in surface and subsurface soil within the field position of the flow path. At this site P concentration decreases just inside the VBS and increases 5 m downstream the flow path. East Interlake Conservation District shows relatively similar P concentrations across along all points in the flow path.

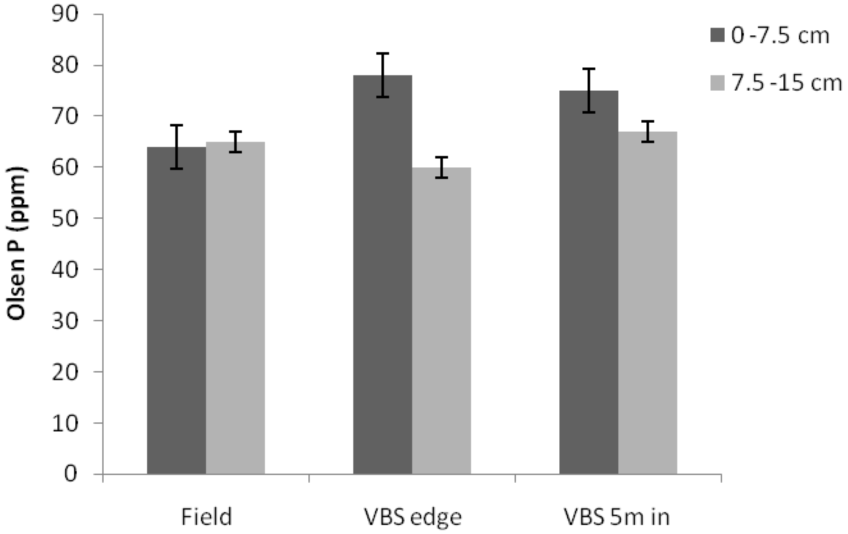

Figure 13. Comparison of mean Olsen P of surface (0- 7.5 cm) and subsurface (7.5 – 15 cm) soil in the flow path at PVCD. Standard error bars shown.

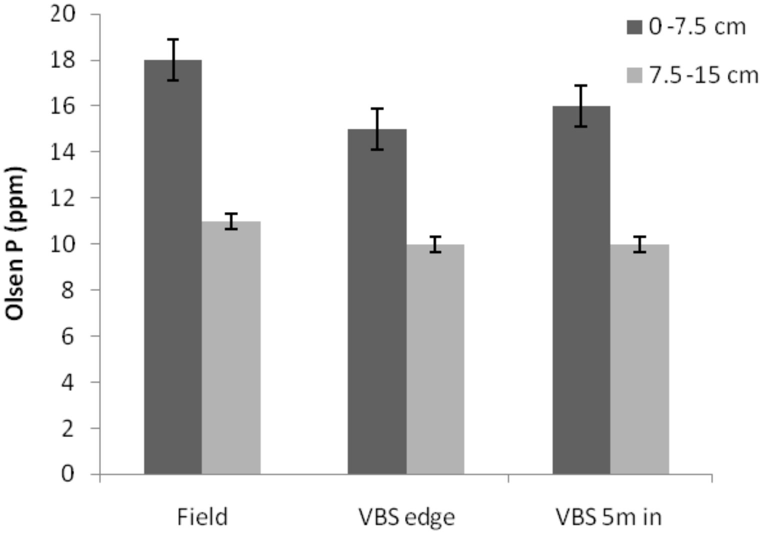

Figure 14. Comparison of mean Olsen P of surface (0- 7.5 cm) and subsurface (7.5 – 15 cm) soil in the flow path at EICD. Standard error bars shown.

Discussion

It is important to recognize the key assumptions this study relies upon and what the limitations are before attempting to interpret the results. This study offers a snap shot of the P distribution at three locations in Manitoba. Soil samples were taken over a three day period in the last week of August 2009 and show only the accumulation of P in the VBS up to date, if there was any. There is no way to infer from these results the year to year variation of soil P, and therefore one cannot distinguish between a steady accumulation over the years or from a few specific runoff events. There is also no way to tell the role dissolved P may have had in the accumulation of P in the VBS, which has been determined to be the dominant form in flat landscapes in Manitoba. Using Cs-137 it was possible to evaluate whether there was an enrichment of P in the VBS due to soil erosion. However, due to the design of the study, which was prior to the addition of the Cs-137 analysis, the sampling depth is not deep enough to provide an accurate representation of the entire Cs-137 inventory. This means that in some points, particularly in the flow path, the Cs-137 (Bq/m^2) measurement would not include the entire profile. In addition, Cs-137 was done for only one catchment at each site, also contributing to an incomplete inventory of Cs-137 since there is spatial variation to account for.

The concentrations of soil P show that there is an accumulation of P in the VBS, and as expected, it is accumulating in the flow path channel. This is most evident at LSRCD and at PVCD (Fig. 3 and Fig. 6), but less so at EICD (Fig. 9), where soil P was sometimes higher in the field. It was expected than P concentrations would be greater in the flow path than at upland positions because P moves down the slope with water, either in particulate or dissolved form, and runoff from agricultural land in Manitoba tends to move into either natural or engineered channels before flowing off field. This fact was identified as one of two important factors that are limiting the potential of VBS to retain P in Manitoba. On flat landscapes runoff occurs only through small sections of a VBS, meaning there is only a small portion of the VBS that is in contact with the P rich runoff (Sheppard et al. 2006).

The accumulations of P at the LSRCD and PVCD sites also have significant enrichment of Cs-137 moving downstream the flow path into the VBS (Fig.4 and Fig.7). The strength of the correlation between P and Cs-137 likely corresponds with the topography at each site. The steepest slopes were found at LSRCD, likely between 5 - 9 % while at PVCD slope was roughly 2-5%. Slope is associated with erosion. P, similar to Cs-137, bound to the fine, highly erodible particles in soil. This means that sediment accumulation due to erosion is likely to correspond to enrichments of P. To reinforce this, a study in Belgium compared P and Cs-137 as soil erosion indicators, because they both strongly adsorb to fine soil particles and found they were strongly correlated (r^2= 0.699) (Steegan et al. 2000). Therefore, P and Cs-137 are moving together and we can say with some confidence that over the years, at LSRCD and PVCD, there has been movement of P from the field with sediment, due to erosion. Patterns at EICD were less clear. This site had the most level landscape of all three sites. Here there was very little correlation between P and Cs-137 (r2=), because there is not likely to be much erosion occurring on nearly level land. Sheppard et al. (2006) points out that there was minimal rill or sheet erosion on the flat land for their study in south-eastern Manitoba. Syverson (2005) states that larger particles travelling in runoff are more easily trapped by the VBS than smaller particles. In general, many studies on the effectiveness of VBS point out that particulate P is more effectively filtered than the dissolved P.

There are no biogeochemical processes that reduce P quantity over time, as for denitrification of nitrogen. Therefore, the accumulation of P in the VBS continues until the retention capacity of the vegetation and soil is saturated (Dorioz et al. 2006). The fixation capacity of soil necessary to trap P depends on many factors such as: number of fixation sites available, pH, amount of clay and organic matter (OM) present in soil, temperature and duration water spends flowing through the buffer. Although no specific test was done on the soil to determine its fixation capacity in this study, it is possible to make some general comments about the type of soil present in each conservation district. Similar to most soils in Manitoba, all three sites have moderate to strongly calcareous soil. Soils for the VBS at LSRCD and PVCD are predominately loams and fine loams, while that at EICD is typically a thin clay layer over silty sediment. Loams are typically less than 35% clay and fine loams are between 18% and 35% clay

(Podolosky). This means that P has relatively abundant adsorption sites in clays because of high amounts of calcium. Clays also tend to have the slowest release of P because of greater fixation capacity (Brady and Weil 2002).

Referencing the work by Sheppard et al. (2006) once again, and considering that dissolved P is the dominant form of P in Manitoba's runoff, I thought it was important to consider the movement of dissolved P as well. Through a comparison between mean Olsen P values in the flow path for surface and subsurface soil some generalizations can be made about dissolved P at these sites. In the VBS, assuming that the field edge has remained unchanged over the years and there has been no mixing through tillage, it is probable that the concentrations in subsurface soil are due to the infiltration of dissolved P. Sheppard documented the accumulation of P in the subsurface layer where runoff entered the VBS and a decrease downstream along the flow path. This is visible at LSRCD, but not at PVCD or EICD. This reinforces that there is accumulation of P, perhaps in both forms, in the more topographically variable LSRCD VBS site and less so at the more level sites.

Conclusions and Recommendations

Vegetative buffer strips (VBS) are being promoted as a beneficial management practice to reduce the transport of P from agricultural land in Manitoba, but the use of VBS here has not been proven to be completely successful. The results from the analysis of soil test phosphorus concentrations in this study show that there are cases where the VBS are accumulating P. However, like previous work in Manitoba, that trend is inconsistent. Unlike previous research, this study showed that Cs-137 can be used to correlate the movement and enrichment of P into a VBS. The results from this analysis show that where sedimentation is occurring, there is also a deposition of P.

For future work, in the continuation of this 2 year study or on another, it would be valuable to directly link site specific factors to the enrichment of P in a VBS in Manitoba. If Cs-137 were to be used in the future, a more extensive sampling method would be important in order to understand the spatial differences and to acquire a complete inventory of Cs-137 in Manitoba's landscape. Since samples were from only one season it is not possible to make comments about the annual rate of decrease. A long term comparison of the accumulation of P in VBS soil would provide insight into the potential for VBS to be an effective BMP for filtering P from agricultural runoff water. It is important that we understand where and when VBS are effective so they can be properly implemented to achieve the desired results. This may be a BMP that will have to be applied where site conditions are favorable to the mechanics of the VBS (i.e. not on nearly level slope).

However, even if a VBS does not reduce the amount of P reaching surface water, there are benefits of establishing permanent vegetation in riparian zones, such as easing flooding, acting as wildlife corridors, increasing biodiversity, promoting beneficial insects and maintaining stream bank stability. These are all very valuable environmental practices that should not be overlooked. There are already provincial programs in place for managing riparian areas for cattle and crop producers, such as in the Environmental Farm Plan. Municipalities are also responsible for establishing zoning by-laws on setbacks from water ways through the Planning Act. Perhaps the next step should be to establish guidelines on how to manage these areas, for example harvesting the vegetation so thawed vegetation cannot release nutrients, now that we are gaining an understanding of how riparian buffer vegetation functions in Manitoba.

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Appendices

Table 1. Olsen (sodium-bicarbonate extractable) phosphorus concentrations (mg/kg) from Little Saskatchewan River Conservation District (LSRCD), Pembina Valley Conservation District (PVCD) and East Interlake Conservation District (EICD) at each catchment (identified by weir pairs) measured at two depths (0 - 7.5 and 7.5 - 15 cm) and three landscape positions.

		0 - 7.5 cm			**7.5 - 15 cm**		
Site/ Weir		**Crest**	**Backslope**	**Flowpath**	**Crest**	**Backslope**	**Flowpath**
LSRCD							
1,2	Field	13	25	30	7	10	12
	VBS edge	13	16	37	10	9	21
	VBS 5m in	15	8	31	9	8	16
3,4	Field	21	11	17	11	13	10
	VBS edge	19	16	19	8	8	12
	VBS 5m in	15	16	15	8	9	8
5,6	Field	16	14	26	9	10	9
	VBS edge	13	12	13	10	9	9
	VBS 5m in	13	18	13	11	8	10
7,8	Field	24	26	19	20	15	13
	VBS edge	35	31	36	30	25	25
	VBS 5m in	41	30	27	18	15	15
PVCD							
1,2	Field	31	45	33	24	22	22
	VBS edge	49	41	58	31	19	32
	VBS 5m in	48	45	48	23	23	51
3,4	Field	25	27	31	34	31	36
	VBS edge	51	51	43	39	32	27
	VBS 5m in	52	44	44	28	27	22
5,6	Field	110	90	72	113	72	76
	VBS edge	100	93	76	156	81	79
	VBS 5m in	151	89	80	194	156	78
7,8	Field	109	70	122	148	34	128
	VBS edge	82	130	135	70	92	103
	VBS 5m in	49	38	128	61	103	117
EICD							
1,2	Field	22	21	28	8	13	19
	VBS edge	13	11	18	12	9	10
	VBS 5m in	12	16	19	20	9	11
3,4	Field	16	13	19	15	8	12
	VBS edge	14	11	11	7	8	9
	VBS 5m in	14	12	15	10	13	10
5,6	Field	9	9	13	7	11	6
	VBS edge	12	108	16	6	18	11
	VBS 5m in	11	12	19	7	6	10
7,8	Field	9	10	11	7	7	7
	VBS edge	13	13	14	9	7	9
	VBS 5m in	13	12	13	8	7	8

Table 2. Cs-137 data for the Little Saskatchewan River Conservation District catchment at weir pair 1, 2

Position	**Depth**	**Cs-137 Activity**	**Cs-137 Activity**	**Olsen P**	**Error**	**Soil Bulk Density**	**Soil Mass**	**Cs-137 Activity**		
	(cm)	**(Bq/kg)**	**(0 - 15 cm)**	**(mg/kg)**	**1SD**	**(kg/m3)**	**(kg/m2)**	**Bq**	**(Bq/kg)**	**(Bq/m2)**
Back Flow Path	7.5 - 15	**18.89**			**0.49**	1200	90.0	3256	16.08	**3256**
Back Flow Path	0 - 7.5	**13.83**	**32.72**	**47.00**	**0.62**	1500	112.5			
Back Backslope	7.5 - 15	**0.00**				1200	90.0	878	4.33	878
Back Backslope	0 - 7.5	**7.80**	**7.80**	**16.00**	**0.47**	1500	112.5			
Back Crest	7.5 - 15	**2.27**			**0.27**	1200	90.0	1163	5.74	1163
Back Crest	0 - 7.5	**8.52**	**10.79**	**24.00**	**0.40**	1500	112.5			
Mid Flow Path	7.5 - 15	**20.24**			**0.51**	1200	90.0	3591	17.73	**3591**
Mid Flow Path	0 - 7.5	**15.73**	**35.97**	**58.00**	**0.59**	1500	112.5			
Mid Backslope	7.5 - 15	**0.61**			**0.21**	1200	90.0	991	4.89	991
Mid Backslope	0 - 7.5	**8.32**	**8.93**	**25.00**	**0.45**	1500	112.5			
Mid Crest	7.5 - 15	**0.94**			**0.24**	1200	90.0	798	3.94	798
Mid Crest	0 - 7.5	**6.34**	**7.28**	**23.00**	**0.43**	1500	112.5			
Front Flow Path	7.5 - 15	**9.77**			**0.40**	1200	90.0	2638	13.03	**2638**
Front Flow Path	0 - 7.5	**15.63**	**25.41**	**42.00**	**0.47**	1500	112.5			
Front Backslope	7.5 - 15	**6.32**			**0.30**	1200	90.0	1791	8.84	1791
Front Backslope	0 - 7.5	**10.86**	**17.18**	**35.00**	**0.38**	1500	112.5			
Front Crest	7.5 - 15	**0.00**				1200	90.0	773	3.82	773
Front Crest	0 - 7.5	**6.87**	**6.87**	**20.00**	**0.39**	1500	112.5			

Table 3. Cs-137 data for the Pembina Valley Conservation District catchment at weir pair 7, 8

Position	**Depth**	**Cs-137 Activity**	**Cs-137 Activity**	**Olsen P**	**Error**	**Soil Bulk Density**	**Soil Mass**	**Cs-137 Activity**		
	(cm)	**(Bq/kg)**	**(0 - 15 cm)**	**(mg/kg)**	**1SD**	**(kg/m3)**	**(kg/m2)**	**Bq**	**(Bq/kg)**	**(Bq/m2)**
Back Flow Path	7.5 - 15	**13.74**			**0.49**	1200	90.0	2575	12.72	2575
Back Flow Path	0 - 7.5	**11.90**	**25.64**	**245.00**	**0.43**	1500	112.5			
Back Backslope	7.5 - 15	**11.26**			**0.42**	1200	90.0	2189	10.81	2189
Back Backslope	0 - 7.5	**10.45**	**21.71**	**141.00**	**0.37**	1500	112.5			
Back Crest	7.5 - 15	**7.59**			**0.38**	1200	90.0	1623	8.01	1623
Back Crest	0 - 7.5	**8.35**	**15.94**	**110.00**	**0.39**	1500	112.5			
Mid Flow Path	7.5 - 15	**11.36**			**0.36**	1200	90.0	2223	10.98	**2223**
Mid Flow Path	0 - 7.5	**10.67**	**22.03**	**237.00**	**0.46**	1500	112.5			
Mid Backslope	7.5 - 15	**9.78**			**0.38**	1200	90.0	1984	9.80	1984
Mid Backslope	0 - 7.5	**9.81**	**19.59**	**222.00**	**0.36**	1500	112.5			
Mid Crest	7.5 - 15	**8.17**			**0.34**	1200	90.0	1785	8.82	1785
Mid Crest	0 - 7.5	**9.33**	**17.50**	**153.00**	**0.41**	1500	112.5			
Front Flow Path	7.5 - 15	**10.41**			**0.38**	1200	90.0	2175	10.74	**2175**
Front Flow Path	0 - 7.5	**11.00**	**21.41**	**249.00**	**0.42**	1500	112.5			
Front Backslope	7.5 - 15	**4.46**			**0.28**	1200	90.0	1547	7.64	1547
Front Backslope	0 - 7.5	**10.18**	**14.65**	**104.00**	**0.34**	1500	112.5			
Front Crest	7.5 - 15	**10.61**			**0.39**	1200	90.0	2275	11.24	2275
Front Crest	0 - 7.5	**11.74**	**22.35**	**257.00**	**0.41**	1500	112.5			

Table 4. Cs-137 data for the East Interlake Conservation District catchment at weir pair 1, 2

Position	**Depth (cm)**	**Cs-137 Activity (Bq/kg)**	**Cs-137 Activity (0 - 15 cm)**	**Olsen P (mg/kg)**	**Error 1SD**	**Soil Bulk Density (kg/m3)**	**Soil Mass (kg/m2)**	**Cs-137 Activity**		
								Bq	**(Bq/kg)**	**(Bq/m2)**
Back Flow Path	7.5 - 15	**3.57**			**0.23**	1200	90.0	853	4.21	**853**
Back Flow Path	0 - 7.5	**4.73**	**8.30**	**30.00**	**0.29**	1500	112.5			
Back Backslope	7.5 - 15	**3.99**			**0.23**	1200	90.0	920	4.54	920
Back Backslope	0 - 7.5	**4.98**	**8.98**	**25.00**	**0.29**	1500	112.5			
Back Crest	7.5 - 15	**5.02**			**0.24**	1200	90.0	992	4.90	992
Back Crest	0 - 7.5	**4.80**	**9.82**	**32.00**	**0.25**	1500	112.5			
Mid Flow Path	7.5 - 15	**5.39**			**0.26**	1200	90.0	1067	5.27	**1067**
Mid Flow Path	0 - 7.5	**5.17**	**10.56**	**28.00**	**0.28**	1500	112.5			
Mid Backslope	7.5 - 15	**1.70**			**0.20**	1200	90.0	337	1.67	337
Mid Backslope	0 - 7.5	**1.64**	**3.34**	**20.00**	**0.22**	1500	112.5			
Mid Crest	7.5 - 15	**9.04**			**0.30**	1200	90.0	2006	9.91	2006
Mid Crest	0 - 7.5	**10.60**	**19.64**	**25.00**	**0.35**	1500	112.5			
Front Flow Path	7.5 - 15	**4.52**			**0.26**	1200	90.0	1096	5.41	**1096**
Front Flow Path	0 - 7.5	**6.13**	**10.65**	**47.00**	**0.19**	1500	112.5			
Front Backslope	7.5 - 15	**8.11**			**0.32**	1200	90.0	1602	7.91	1602
Front Backslope	0 - 7.5	**7.75**	**15.86**	**34.00**	**0.39**	1500	112.5			
Front Crest	7.5 - 15	**3.43**			**0.13**	1200	90.0	NA	NA	
Front Crest	0 - 7.5	NA	**3.43**	30		1500	112.5			

NA - Not applicable pertains to an error in methodology
- Results available if re-analyzed