PHOSPHORUS RISK INDICATORS:

CORRELATION WITH WATER QUALITY IN MANITOBA

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January 16, 2006

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EXECUTIVE SUMMARY

Many phosphorus (P) risk indicators have been developed to assess site vulnerability to water contamination. These indicators employ a semi-quantitative approach to assess the impact of agricultural management activities on water quality and can be used by landowners and public agencies to target mitigation efforts. Most of the indicators are designed to predict P loss from land where rainfall-induced erosion of particulate P over sloping landscapes is the main process of P loss from agricultural land. However, there is relatively little information regarding snowmelt-driven losses of soluble P over nearly level landscapes, the main process for P loss on the Canadian Prairies. Furthermore, very few indicators have been validated with water quality measurements and none have been validated in the Canadian Prairies. Therefore, the main objective of this project was to validate several P risk indicators, including the Minnesota P Index, a preliminary P risk indicator for Manitoba and Canada's National Indicator of Risk of Water Contamination by Phosphorus (IROWC-P), using water quality data from fourteen regional watersheds in Manitoba, Canada.

The Minnesota P Index rated most Manitoba watersheds as being at low to very low risk of P loss, in spite of water samples frequently testing high in P. The preliminary P risk indicator for Manitoba rated most watersheds as medium risk and the IROWC-P was the only indicator to correctly rate most watersheds as high risk for P loss.

Overall, none of the risk indicators was significantly correlated with mean concentrations of total P in water or P export per hectare. Part of the reason for these poor correlations appears to be the large influence of erosion risk on these indicators, relative to the small influence of erosion on P loss in the watersheds. For example, erosion played a highly significant and dominant role in determining the variability of the risk index values for the watersheds (r values ranging from 0.65 - 0.72**) but no significant role in determining mean concentrations of total P in water ($r = 0.02^{n.s}$, for all indicators) or P export intensity ($r = -0.16^{n.s}$, for all indicators).

However, several site characteristics correlated well with water quality parameters. For example, soil test P values were very highly correlated with mean concentrations of total P in water (r = 0.80*** for Minnesota P index and IROWC-P), but not with P export intensity (r = -0.03 for the same indicators). The high correlation of water quality with soil test P is at least part of the reason for the poor performance of the preliminary P risk indicator for Manitoba. Also, the land

capability for agricultural production and Manitoba's proposed water quality management zones were highly correlated with mean concentrations of total P in water (r = -0.70** and -0.78***, respectively), but not with P export per hectare (r = -0.05 and -0.10, respectively). Part of this is probably due to the intrinsic tendencies of high quality agricultural land to be prone to P loss and part is probably due to the intensive agricultural practices, including nutrient application and annual cropping, on these soils.

In conclusion, existing P risk indicators appear to be focused towards the process of P loss by rainfall induced erosion of particulate P, where the role of transport factors, such as erosion, may be relatively more important than source factors, such as soil test P. More research is needed to provide a reasonable estimate of a site's potential for P loss to surface water, under the soil, landscape and climatic conditions of the Eastern Prairies, where snowmelt-induced runoff of dissolved P is the predominant form of P loss. Such knowledge will be essential for identifying the appropriate management practices for reducing the transfer of P to surface water in Manitoba.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the operational funding of this research provided by the Sustainable Development Innovations Fund (SDIF) for this project. We also want to thank the Natural Sciences and Engineering Research Council of Canada (NSERC) for two years of post-doctoral fellowship support. Also, many thanks to the following people and organization for their helpful contributions:

- Special thanks to Alain N. Rousseau and Renaud Quilbé from INRS-ETE (University of Quebec, Québec city) for their inspiration, guidance and valuable support.
- Thanks to Patsy Michiels and Conrad J. Wyrzykowski from PFRA who provided valuable support by sharing their expertise and precious data.
- Many thanks to Norma Sweetland from AAFC (Land resource group) for her support on data gathering and GIS support, Walter Fraser and Glenn Lelyk for their help and computer support.
- Particular thanks to Norwest Labs for all the soil test P data and especially to Elise Dubourg and Danial Heaney.
- Thanks to Alexandra Bourne and Nicole Armstrong from Manitoba Water Stewardship for their technical support and water quality data for all watersheds.
- Many thanks to the IROWC-P team from Québec city: Eric van Bochove for his extensive knowledge of the indicator, Georges Theriault for his technical expertise, Farida Dechmi for support in calculation of the indicator. Their help and technical support allowed me to have a better understanding of this indicator. Also thanks to Alexandre Lefebvre, NAHARP Manager from Agriculture and Agri-Food Canada.
- Thanks to Adam Birr from University of Minnesota for his technical support on the Minnesota P index.
- Many thanks to the members of my post-doctoral advisory Committee: Petra Loro (MAFRI), Dwight Williamson (Manitoba Water Stewardship), Bob Eilers (AAFC, Land Resource Group), John Fitzmaurice (PFRA), Ken Snelgrove (University of Manitoba, Engineering Department) and Wole Akinremi (University of Manitoba, Soil Science Department).

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LIST OF ABBREVIATIONS

AAFC	Agriculture and Agri-Food Canada
ACC	Agriculture Capability class
A.U.	Animal Unit
CEC	Cation Exchange Capacity
DSPS	Degree of soil phosphorus saturation
GIS	Geographic Information System
ha	Hectares
IROWC-P	Indicator of Risk and Water Contamination
kg	Kilogram
P	Phosphorus
PFRA	Prairies Farm Rehabilitation Administration
ppm	Parts per million
PSI	Phosphorus Sorption Index
SLC	Soil Landscape
STP	Soil test phosphorus
TP	Total phosphorus
USLE	Universal Soil Loss Equation
WQMZ	Water quality management zones

1. INTRODUCTION

Phosphorus (P) contamination of surface waters from nonpoint sources is a very complex set of transfers that involves many processes before P reaches surface waters. To overcome the limitations of using a critical limit for soil test P as the only measure of site P export potential in all situations, many indicators and models have been developed to help resource managers and stakeholders assessing an individual site's vulnerability to P loss. Most indexes integrate both P transport factors (e.g., soil erosion, irrigation erosion, runoff class and, distance to water) and P source factors (e.g., soil test P, application of manure and commercial fertilizer P). These indicators and models are used as a semi-quantitative approach to evaluate the impacts of site characteristics and management practices on water quality. Most of the P risk indicators have been developed to predict P loss from land where rainfall-induced erosion of particulate P over sloping landscapes is the main process of P loss from agricultural land. However, there is relatively little information regarding snowmelt-driven losses of soluble P over nearly level landscapes, the main process for P loss on the Canadian Prairies. Furthermore, very few indicators have been validated with water quality measurements and none have been validated in the Canadian Prairies.

This study represents an adaptation of the work of Birr and Mulla (2001) for Minnesota. Three indicators were used for this validation of P risk indicators in Manitoba watersheds: the Minnesota P Index (Birr and Mulla, 2001), the Preliminary P Risk Indicator for Manitoba (AXYS Agronomics, 2002), and Canada's National Indicator of Risk of Water Contamination by Phosphorus (IROWC-P, Bolinder et al., 2000).

One of the challenges of this research project was data gathering for the risk indicators and the water quality parameters. Numerous data sources were identified and utilized: Soil Landscapes of Canada (SLC)[1], 2001 Census of Agriculture[2], Manitoba Crop Insurance Corporation[3], National Surface Water Data[4], and Manitoba Water Stewardship. GIS was used for the validation of the risk indicators with water quality. Watershed data were provided by PFRA (Prairie Farm Rehabilitation Administration (AAFC), and water quality data were provided by Manitoba Water Stewardship and hydrologic water data were from the Archived Hydrometric Data of Environment Canada[5].

[1] http://sis.agr.gc.ca/cansis/nsdb/slc/intro.html (consulted May 05, 2004)
[2] http://www.statcan.ca/english/agcensus2001/ (consulted May 05, 2004)
[3] http://www.mcic-online.com (consulted May 05, 2004)
[4] http://www.climat.meteo.ec.gc.ca/rel_arch/index_e.html (consulted May 05, 2004)
[5] http://www.wsc.ec.gc.ca/hydat/H2O/ (revised May 9, 2005)

2. METHODS

This chapter describes the methods and data used for this study. First, the studied watersheds are presented. Next, a detailed description of the water quality data is provided. Finally, the three P risk indicators and the other indicators chosen for evaluation are described.

2.1. Watersheds

Validation of these terrestrial risk indicators was conducted using long-term water quality monitoring data consisting of total phosphorus (TP) concentrations collected from several watersheds in Manitoba. A total of 14 watersheds were selected to represent two different regions of Manitoba: Eastern Manitoba (La Salle, Seine, Rat-Marsh, Cypress, Boyne, Cooks Creek, Brokenhead and, Roseau River watersheds) and Western Manitoba (Valley, Little Saskatchewan, Wilson, Ochre, Vermillion and, Turtle River watersheds) (Figure 2.1). The topography is considered as rolling topography for the Western region and nearly level for the Eastern region. Watershed sizes range from 37,100 hectares for Ochre River watershed to 414,500 hectares for Little Saskatchewan River watershed (Table 2.1). Table A.1 in Appendix A presents a detailed description of the selected watersheds. For all watersheds, agriculture is one of the principal activities (livestock watering and irrigation). Recreation activities such as fishing and canoeing represent also parts of the water uses in all watersheds. In some watersheds, the rivers are a source of drinking water for communities.

2.2. Water Quality

A summarized description of water data is presented in Table 2.2. For most monitoring years, the average of water sampling frequency was three or four times per year (once every three or four months). However, water quality sampling had been more frequent for some watersheds and for some years (starting mid-90s) including: La Salle, Seine, Cooks Creek, Ochre and Turtle River watersheds. Table 2.2 shows that water quality data was collected from 1973 to 2000 with a gap of approximately 10 years for most watersheds except for Cooks Creek, Ochre River and Turtle River watersheds. As for water flow data, they were for the most part available on a daily basis.

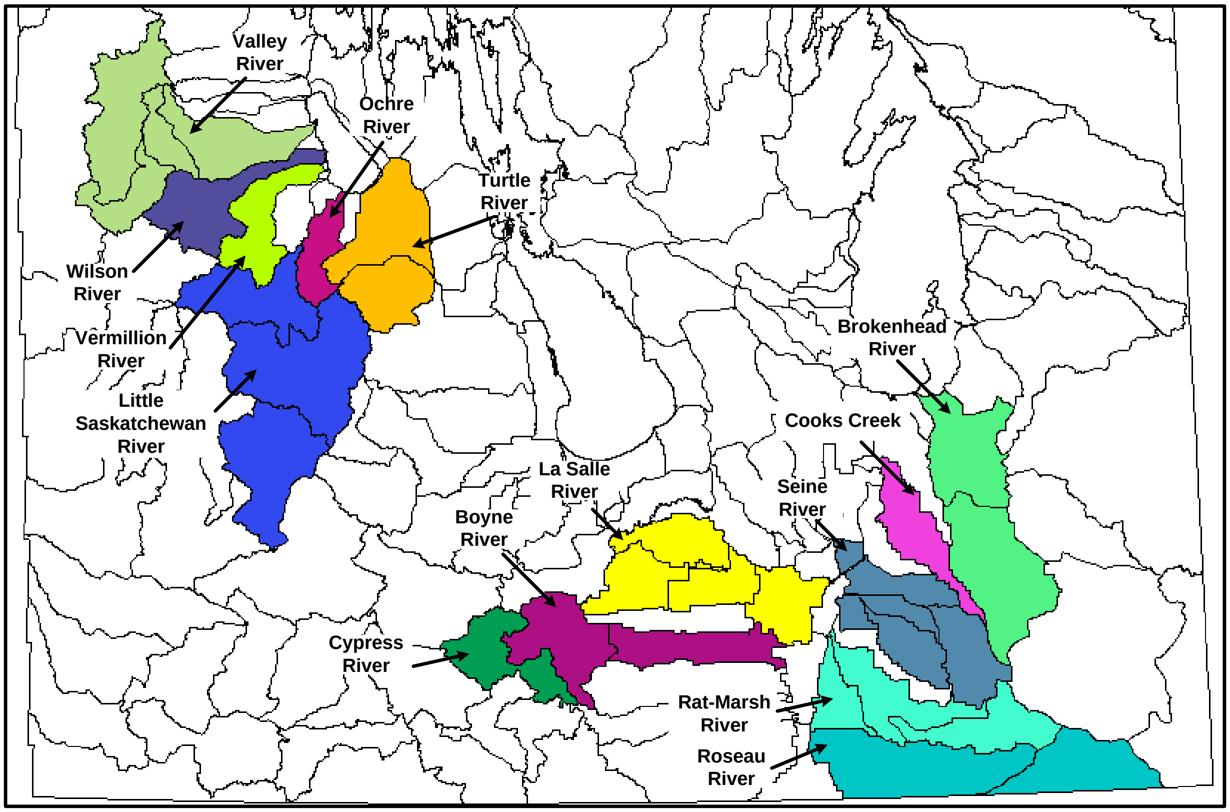

Figure 2.1 Location of the selected watersheds in Manitoba[6].

2.3. P Risk Indicators

Three indicators were used for this validation: Minnesota P Index (Birr and Mulla, 2001), the Preliminary P Risk Indicator for Manitoba (AXYS Agronomics, 2002), and Canada's National Indicator of Risk of Water Contamination by Phosphorus (IROWC-P, Bolinder et al., 2000). P indexes are designed as a simple, semi-quantitative tool to estimate the risk of P transfer to surface water from various fields (Lemunyon and Gilbert, 1993). Table 2.3 summarizes the principal components of each indicator. The first two groups of site characteristics (source and transport factors) are common for all three P risk indicators. For Manitoba's Preliminary P Risk Indicator and IROWC-P, there is also third distinctive factor: annual P balance. The following sections briefly summarize the methods used for the calculation of each P risk indicator and its components. Detailed methodologies for calculating these P risk indicators are described in Appendix B.

[6] From Manitoba Riparian Health Council website (PFRA): http://www.riparianhealth.ca/tools_mapviewer.html# (verified 09/08/2005).

Table 2.1 General characteristics of the selected watersheds (from Jones and Armstrong, 2001).

Watersheds	Tributary of	Area (ha)	Principal land uses	Principal water uses
La Salle River	Red River	240,624	Intensively cultivated agricultural land with livestock operations.	Fishing, canoeing, raw water for communities, livestock and irrigation.
Seine River	Red River	210,748	Cereal crop and livestock production (beef and dairy cattle, chickens, and hogs).	Agriculture and recreational activities.
Rat-Marsh River	Red River	201,132	Forest uplands, marshes, and drained peat lands. Pasture, rangeland and hay crops.	Impoundment (St-Malo), fish and wildlife habitat, recreational activities and livestock watering.
Cypress River	Assiniboine River and Red River	81,317	Agriculture, livestock production and cereal crop cultivation.	Fish habitat, livestock watering and agricultural irrigation.
Boyne River	Red River	174,529	Crop production.	Agriculture, recreation activities (fishing, boating, canoeing and swimming). Drinking water (Carman).
Cooks Creek	Red River	74,680	Intense cultivation. Dredged and channeled for flood control and agricultural use.	Intense cultivation in western and northern extremes.
Brokenhead River	Lake Winnipeg	263,688	Cereal and forage crop production (western portion) and forested uplands and wetlands (eastern portion).	Agriculture (western portion).
Roseau River	Red River	259,082	Agricultural activities (livestock husbandry, cereal crop cultivation, and hay crop.	Habitat for fish and associated riparian wildlife sp. Sport fishing, canoeing and agricultural watering.
Valley River	Dauphin Lake	296,128	Forest (provincial parks), agriculture (cereal and hay crop) and livestock.	Raw water for communities and spawning river for number of fish species.
Little Saskatchewan River	Assiniboine River	414,551	Crops and pastureland.	Recreation purposes and raw water source for town of Rivers.
Wilson River	Dauphin Lake	99,619	National Park and agriculture.	Agriculture (crop cultivation).
Ochre River	Dauphin Lake	37,115	Forested uplands and cultivated fields.	Agriculture.
Vermillion River	Dauphin Lake	75,673	Recreation and wildlife habitat and agricultural crops and livestock production.	Raw water, recreation purposes and important spawning waterway.
Turtle River	Dauphin Lake	176,684	Forested uplands and narrow valleys and agriculture.	Recreational purposes, aquatic habitat, some irrigation and drinking water.

Table 2.2 Location and time-period of water quality data for all watersheds.

Watersheds	Water quality station (#)	Hydrometric station (#)	Water quality data Period	Observations
La Salle River	WQ0068	MB05OG001	1973-77 & 1988-2000	97
Seine River	WQ0166	MB05OH006 & MB05OH009	1973-77 & 1988-2000	166
Rat-Marsh River	WQ0131	MB05OE001	1973-77 & 1988-2000	57
Cypress River	WQ0398	MB05MH008	1978-83 & 1988-2000	76
Boyne River	WQ0029	MB05OF003	1973-77 & 1988-2000	67
Cooks Creek	WQ0644 & WQ0643	MB05OJ019 & MB05OJ006	1990-2000	116
Brokenhead	WQ0038	MB05SA002	1973-77 & 1988-2000	83
Roseau River	WQ0153	MB05OD001	1973-77 & 1988-2000	68
Valley River	WQ0250	MB05LJ010	1974-83 & 1988-2000	87
Little Saskatchewan River	WQ0105	MB05MF018	1973-84 & 1988-2000	148
Wilson River	WQ0255	MB05LJ045	1978-83 & 1988-2000	97
Ochre River	WQ0227	MB05LJ005	1988-2000	90
Vermillion River	WQ0252	MB05LJ012	1978-83 & 1988-2000	85
Turtle River	WQ0245	MB05LJ007	1988-2000	121

Table 2.3 Summarized description of the P risk indicators.

Model	Components of site characteristics	
	Transport factors	*Source factors*
Minnesota P Index (Birr and Mulla, 2001)	Soil erosion, runoff and percentage of cropland within 91.4 m of a watercourse	Soil test P, fertilizer P application method and rate, organic P source application method and rate
Preliminary P risk indicator for Manitoba (AXYS Agronomics, 2002)	Soil erosion and overland flow potential	Overall P balance, crop residue P and estimated P sorption index
IROWC-P (Bolinder et al., 2000)	Soil erosion and surface runoff	Degree of soil P saturation, soil test P, crop residue P, manure P and mineral fertilizer P

2.3.1. Minnesota P Index

Table 2.4 presents all site characteristics and ratings associated with P export potential for Minnesota P Index. Detailed information is presented in section B.1 in Appendix B. This index has two main categories of site characteristics: transport factors (soil erosion, runoff, and percentage of cropland and pastureland within 91.4 m of a watercourse) and source factors (soil test P, fertilizer P application rate and application method, organic P source application rate and application method). These site characteristics are expressed in five risk classes: very low, low, medium, high and very high. This index is the summation of the product of the rating value and the corresponding weighting value for each site characteristic.

Soil erosion

Soil erosion potential was estimated with the results from the Universal Soil Loss Equation (USLE[7]) from the data sets prepared by AAFC: SLC[8] version 3.0. Each polygon is ranked within seven classes: negligible (<6 t/ha/y), low (6-11 t/ha/y), moderate (11-22 t/ha/y), high (22-33 t/ha/y), severe (>33 t/ha/y), water and unclassified. These classes are estimated by summarizing the estimated soil loss on bare unprotected soil using all soil components in the map polygon. After sorting all the polygons of the watershed into those water erosion risk classes, the percentage of the land represented by each of the different classes was estimated. The percentage area and value for each erosion class (t/ha) were used to develop a weighted average of estimate of erosion in the watershed. For several watersheds, the percentage of polygon ranked as unclassified was relatively large. For the most part, the land unclassified was comprised of forested land in either provincial or national park. According to Brady and Weil (1999), erosion is markedly affected by different types of vegetative cover and cropping system: undisturbed forests and dense grass provide the best soil protection. To acknowledge the low susceptibility of this type of land use to erosion, we assumed that its erosion rating was negligible (< 6 t/ha/y) (David Lobb, personal communication).

Runoff

For the assessment of the average runoff value, average annual discharge was calculated and divided by the drainage basin area defined for the region (Birr and Mulla, 2001). For this study, the drainage area considered was the entire watershed area. Mean annual flow rate[9] measured by the gauging station of each watershed was used. This method, therefore, includes groundwater-fed base flow in the runoff estimate, an important source of water flow in coarse-textured land and “pothole” topography.

[7] Developed by Wischmeier and Smith (1965).
[8] SLCs were originally conceived as a standardized database consisting of major attributes important to plant growth, land management, and soil degradation. SLCs were compiled at a scale of 1:1 million, and information is organized according to a uniform national set of soil and landscape criteria based on permanent natural attributes.
[9] Archived Hydrometric Data. Available on line at http://www.wsc.ec.gc.ca/hydat/H2O/ (verified 15/06/2005)

Table 2.4 Minnesota P index (Birr and Mulla, 2001).

Site characteristic (weighting value)	P loss potential (rating value)				
	Very low (0)	Low (1)	Medium (2)	High (4)	Very high (8)
Transport factors					
Soil erosion (t/ha) (1.5)	0	1-5	6-14	15-21	> 21
Runoff (cm) (0.5)	0-8	9-13	14-16	17-21	> 21
Percentage of cropland[1] (1.5)	0-1.2	1.3-3	3.1-4.2	4.3-6.2	> 6.2
Source factors					
Soil test P[2] (0.75)	0-19	20-26	27-31	32-39	> 39
Fertilizer P application rate (kg P/ha) (1.0)	0-7	8-13	14-19	20-24	> 24
Fertilizer P application method (0.5)	None applied	With planter[3]	Incorporated[4]	Incorporated[5] or surface applied[6]	Surface-applied[5]
Organic P source application rate (kg P/ha) (0.5)	0-2	3-6	7-8	9-11	> 11
Organic P source application method (0.5)	None applied	With planter[3]	Incorporated[4]	Incorporated[5] or surface applied[6]	Surface-applied[5]
Risk classes	0 - 21	21 - 26	26 - 30	30 - 34	> 34

[1] And pastureland within 91.4 m of a watercourse.
[2] Bray P1 or Olsen-P (mg P/kg).
[3] Deeper than 5 cm.
[4] Immediately before crop.
[5] More than 3 months before crop.
[6] Less than 3 months before crop.

Percentage of cropland and pastureland

Birr and Mulla (2001) estimated the area of cropland and pastureland within 91.4 m of drainage ditches and perennial streams by using hydrography coverages. This distance reflects a setback standard for manure application established by the Minnesota Pollution Control Agency for controlling nonpoint source pollution loads from agricultural lands. However, for this project, only the percentages of land cover (e.g. cropland, pastureland and forage) in a 50-m buffer area around all water courses and waterbodies in the watershed were available (AAFC-PFRA, 2004).

Soil test P

Soil test P data were provided by Norwest Labs for specific legal locations and covered the period 2000 to 2003. All P analyses were performed with the modified-Kelowna method. First, data were sorted and linked to their respective watershed. Among the total soil analysis available (almost 5,900), a total of 2,032 soil test P data were used for this study (Table C.1 in Appendix C). The number of samples varied substantially between the watersheds: only 12 analyses for Ochre River versus 539 for Boyne River watershed. For calculation of Minnesota P index, soil test P data needed to be based on values for Bray P1 analysis method. Therefore, the following conversion equations were used to estimate Bray P1 values from the modified-Kelowna extraction data:

Olsen-P = 2.26 + 0.77 modified Kelowna-P (Akinremi et al., 2004)

Bray P1 = Olsen-P / 0.71 (Moncrief et al., 2002)

As mentioned previously, for several watersheds, the percentage of forested land was high. A brief review of the literature demonstrated that soil test P concentration in forested soils should not be considered negligible. For example, Huang and Schoenau (1996) and Schoenau et al. (1989) obtained a wide range of soil test P concentration in boreal forest soil from Saskatchewan: results varied from 0.90 to 47 ppm (bicarbonate inorganic P) for three slope positions (upper, mid and lower). Some soil test P data from soil survey transects West of Thompson (Manitoba), were also considered (Hugo Veldhuis, unpublished data). The average soil test P value from these literature values is 11.1 ppm Bray P1 (Table C.2 in Appendix C). The mean soil test P concentration for the watershed was calculated as a weighted average, taking into account percentage of agricultural land and forested land, using the measured values for the former and the literature-based estimate for the latter.

Fertilizer P application rate and method

To estimate fertilizer P application rate at the regional level, data were extracted from the 2001 Census of Agriculture database and a report on Canadian Fertilizer Consumption, Shipment and Trade (Korol, 2002). Fertilizer P values were based on summation of area-weighted municipality-based values within the watersheds. The only values available at this scale were fertilizer expenses. These values were converted to application rates by assuming the fertilizer P was distributed equally over the total fertilized area and that the proportion of fertilizer dollars spent on P in each watershed was similar to that recorded for Manitoba as a whole.

Five methods of fertilizer P application were available to choose from. For all watersheds, we chose the application method “placed with planter deeper than 5 cm” as the most representative of what happens in those regions (Don Flaten, personal communication).

Organic P source application rate and method

Production of livestock manure P was calculated based on the total number of cattle[10], pigs[11], poultry[12] and other type of livestock[13] reported for the watershed. Data from the 2001 Census of

[10] Including beef cows, bulls, calves, total heifers, dairy cows and steers.

Agriculture were used. These values for manure P were then distributed over the total area of the watershed.

Similar to fertilizer P application, five different methods were available to choose for the organic P application method. For watersheds in Manitoba, none of these methods applied. Therefore, we had to choose an application method representative of the potential for nutrient export prevailing in the watershed: a medium P export potential (corresponding to incorporated) was selected for the watershed with cattle as the predominant livestock and for the watershed with pigs as predominant livestock, a high P export potential (corresponding to incorporated or surface applied) was chosen (Petra Loro, personal communication).

2.3.2. Preliminary P Risk Indicator for Manitoba

This preliminary P risk indicator for Manitoba was presented in AXYS Agronomics (2002). Table 2.5 summarized site characteristics and ratings associated with this indicator for assessing the vulnerability of a site. Detailed information is presented in section B.2 in Appendix B. This indicator has two main site characteristic categories: P source factors (overall P balance, crop residue P and estimated P sorption index) and P pathway factors (soil erosion and overland flow potential). Soil test P concentrations are not included in the source factors; this indicator was developed for situations where private soil test data may not be available to the public. As for the Minnesota P Index, the preliminary P risk indicator for Manitoba is the summation of the product of the rating value and the corresponding weighting value for each site characteristics.

Table 2.5 Preliminary P risk indicator for Manitoba of short-term risk of surface water contamination.

	P risk weighting (rating value)				
Site characteristics (weighting value)	**Very low (1)**	**Low (2)**	**Medium (4)**	**High (8)**	**Very high (16)**
P Source Factors					
Overall P balance (kg P/ha/yr) (2.0)	<0	0-20	20-40	40-60	>60
Crop residue P (kg P/ha/yr) (1.0)	<0.5	0.5-1.0	1-4	4-10	>10
Estimated P sorption index (PSI) (4.5)[1]	>600	400-600	250-400	100-250	<100
P Pathway Factors					
Soil erosion (kg/ha) (1.0)	<500	500-2,000	2,000-6,000	6,000-15,000	>15,000
Overland flow potential (2.5)	Very low	Low	Moderate	High	Very high
Composite index	11-17	18-34	35-68	69-136	136-176

[11] Including boars, sows and gilts, nursing and weaner pigs, grower and finishing pigs.
[12] Including broilers, roasters and Cornish, laying hens, pullets and turkeys
[13] Horses and ponies, various large livestock (boars, bison, llamas and deer), various small livestock (mink, rabbits and/or fox), sheep and lambs and goat.

Soil erosion

Assessment of soil erosion was made by the same method used for Minnesota P Index (see section 2.3.1). The only difference is that soil erosion results are expressed as kg/ha in the preliminary P risk indicator for Manitoba.

Overland flow potential

Overland flow was estimated differently than for the Minnesota P Index. To evaluate the overland flow potential (true runoff) for the Manitoba Preliminary P Risk Indicator, slope percentage and soil permeability classes were assessed at the watershed level. To do so, the SLC database was used to estimate average slope and predominant soil texture classes for the watershed. Table B.3, in Appendix B, presents the parameters used to determine runoff from soil permeability class and slope percentage. Five ranking classes are used to characterize the overland flow potential for each watershed: very low, low, moderate, high and very high. The runoff class for the agricultural portion of the watershed was assumed to be representative of the forested portion, if the forested land was not rated.

Overall P balance

This site characteristic was calculated with the following equation:

$$\text{Overall P Balance} = \text{Manure P} + \text{Fertilizer P} - \text{Crop Export}$$

Manure P was calculated from the total number of cattle, pigs, poultry, and others livestock reported for the watershed with data from the 2001 Census of Agriculture (see section 2.3.1). With the total number of animal units for each type of livestock, the total weight was determined to assess the P production per 1,000 kg of animal weight per day. Distribution of manure P application is assumed to be uniform throughout the total watershed area. Fertilizer P was assessed with the same method used for Minnesota P Index (section 2.3.1). To assess crop export, three variables for each crop were calculated: area (watershed-based data from 2001 Census of Agriculture), yields (data from Manitoba agriculture year book, 2001) and nutrient removal (data from AXYS Agronomics, 2002). Chosen crops were grain corn, all wheat, barley, oats, rye, canola, flax, potatoes, alfalfa and other tame hay; these represented in excess of 95% of total crop production in Manitoba (Flaten et al., 2003). Crop export results were also distributed uniformly over the watershed.

Crop residue P

Crop residue P was assessed with P content of straw and chaff remaining on fields after harvest (AXYS Agronomics, 2002). Crops chosen were: grain corn, all wheat, barley, oats, rye, canola, flax, potatoes, alfalfa and other tame hay. Data were from the 2001 Census of Agriculture. As for erosion, runoff and soil test P, the contribution from the forested portion of certain watersheds needed to be considered. Indeed, Schoenau et al. (1989) showed that the inorganic P concentration in the litter horizons (L-F-H), could be three to five times the concentration in the mineral soil horizon (Ae). Therefore, the contribution for the leaf litter layer could not be ignored and was accounted for the same way agricultural crop residues were, using agricultural crop residue P results for the major crops, uniformly distributed across the watershed.

Estimated P sorption index

In the absence of soil test P data, we used PSI to estimate P retention capacity. However, at the time that this index was developed, this measure of P retention capacity had not been determined in Manitoba soils. Therefore, PSI values were estimated from CEC values in the SLC database according to the following equation derived for neutral to calcareous soils in Quebec (Regis Simard, unpublished data as reported in AXYS Agronomics, 2002):

$$PSI = 25 + 8.73 \ CEC$$

2.3.3. IROWC-P

The national IROWC-P evaluated in this study was based on the first IROWC-P version developed by Bolinder et al. (2000) and shares a common heritage with the Manitoba Preliminary P Risk Indicator. This IROWC-P version includes three components: soil P status (soil test P and DSPS), annual P balance (mineral fertilizer P, manure P and crop residues P) and P transport (soil erosion and surface runoff). Table 2.6 summarizes the components, their site characteristics and weighting factors. IROWC-P values were associated with five vulnerability classes to obtain a corresponding magnitude of risk for each polygon: from very low to very high. As with the other risk indicators, IROWC-P is the summation of the product of the rating value and corresponding weighting factor for each site characteristic. Detailed information is presented in section B.3 in Appendix B.

Table 2.6 IROWC-P developed in Quebec at the SLC polygon level.

Site characteristics (weighting factor)	P loss rating (rating value) Very low (1)	Low (2)	Medium (4)	High (8)	Very high (16)
P status					
Soil test P (STP)[1] (2.5)	< 60	60 - 150	150 - 250	250 - 500	> 500
Degree of soil P saturation (DSPS)[2] (2.0)	0 - 2.5%	2.5 - 5.0%	5.0 - 10%	10 - 20%	> 20%
P balance					
Mineral fertilizer P[3] (1.0)	< 50%	50 - 100%	100 - 150%	150 - 200%	> 200%
Manure P[4] (2.0)	< 50%	50 - 100%	100 - 150%	150 - 200%	> 200%
Crop residue P[5] (1.0)	< 2%	2 - 5%	5 - 20%	20 - 50%	> 50%
P transport[6]					
Soil erosion[7] (1.0)	< 500	500 – 2,000	2,000 – 6,000	6,000 -15,000	> 15,000
Surface runoff (2.5)	Very low	Low	Moderate	High	Very high
Weighted rating values	12 - 18	19 - 36	37 - 72	73 - 144	145 - 192
Site vulnerability classes	Very low	Low	Medium	High	Very high

[1] Mehlich-III extractable P (kg P ha^{-1}).
[2] (Mehlich-III P/Mehlich-III Al) x 100.
[3] Estimated with the dollars spent on fertilizer and lime at the polygon level (source: 2001 Census of Agriculture database).
[4] Estimated from livestock, manure production coefficients and manure P coefficient for each category (source: 2001 Census of Agriculture database).
[5] Estimated for P uptake and P harvest coefficients (source: 2001 Census of Agriculture database).
[6] Many subcomponents are under development (algorithms, weighted factors and P loss rating value are to be precise.
[7] Soil water erosion loss (kg ha^{-1}).

Soil test P

The standard soil P test analysis for the IROWC-P is Mehlich-III extractable P. As mentioned for the other risk indicators, the only agricultural soil P test data available for the selected watersheds were obtained with modified-Kelowna analysis method. Therefore, the following mathematical transformation was used to obtain the necessary P soil test values:

Mehlich-III = 4.85+1.37 * modified Kelowna (Akinremi et al., 2004)

As for the Minnesota P index, a soil test P concentration was assessed for the entire watershed using a weighted average for agricultural and forested land, with literature values used for the latter (see section 2.3.1).

Degree of soil phosphorus saturation (DSPS)

In Bolinder et al. (2000), soil P saturation percentage was the ratio between the soil P content and aluminium content in a field, both extracted by Mehlich-III solution. This value is calculated with the following equation:

DSPS = [Mehlich-III P content (kg P/ha) / Mehlich-III Al content (mg Al/kg soil) x 2.2] x 100

Unfortunately, the only soil test P data available for the selected watersheds were modified Kelowna-P extraction values and Mehlich-III Al content is not correlated with P sorption capacity in Manitoba soils (Ige et al., 2005). Therefore, the following mathematical transformation from Ige et al. (2005) was used to assess DSPS:

$$DSPS = \text{Mehlich-III P content} / PSI \times 100$$

Mehlich-III P content was assessed with the same mathematical transformation used for soil test P and PSI with the equation presented in 2.3.2. Since the determination of DSPS is directly related with STP, the contribution of forested land is then comprised in that value.

Mineral fertilizer P balance

Mineral fertilizer P application rates were determined by the same method used for the fertilizer P application rate for Minnesota P Index (section 2.3.1). Thereafter, the results were converted to a percentage of plant biomass P exports [(P input/exported P) x 100]. As for the previous site characteristics, mineral fertilizer P balance values were distributed equally over the total area of each watershed.

Manure P balance

Manure P application rates were determined with data from 2001 Census of Agriculture and the number of animals of the following species: poultry, dairy cattle, beef cattle, slaughter cattle, calves, and pigs. Sheep, horses, mink and fish were not considered for the manure P estimations because of the great variability in manure quantity. No distinction was made between solid and liquid manure. P coefficients (kg P produced year^{-1} animal unit^{-1}) were estimated using provincial census data on the number of animals within each species as well as constants for calculating animal waste variables used in Canada (Barnett, 1996). The following equation was used to calculate manure P balance: Manure P balance = (input/output) x 100. The input is the amount of manure P produced, as estimated from numbers and categories of livestock, and the output is the amount of P exported from crop areas. To calculate the input component, the manure was assumed to be distributed over cropland based on crop N requirements using the directives of IROWC-N (MacDonald and Spaling, 1995). Manure P balance values were distributed evenly over the total area of each watershed.

Crop residue P balance

This subcomponent estimates the quantities of exported P and quantities of crop residue P remaining on the agricultural soil after harvest. The crop residue was also considered in the P balance calculations. Crop residue P was also estimated with the 2001 Census of Agriculture database and Provincial Census information, plus standard P uptake and P harvest coefficients (MAFRI, 2001). Only major annual crops and hay categories were considered. The amount of P exported from these crops was determined using the average crop yields and P harvest figures. Average yield data were obtained from provincial census figures for different agricultural regions and adapted to fit the crop categories at the SLC polygon level. The following equation was used: Crop residue P balance = (P in residues/exported P) x 100. As for the other site characteristics, crop residue results were also assessed on a watershed basis.

Soil Erosion

As for the other risk indicators, soil erosion potential was calculated using USLE (see section 2.3.1). In this case, soil loss was expressed in kg/ha. Contribution from forested portion of the watershed was also regarded as negligible, as it was for the previous P risk indicators.

Overland flow potential

Overland flow potential categories were estimated with a matrix relating percentage of slope to runoff curve numbers (McFarland et al., 1998). Runoff curve number was determined from a matrix using information on land use, treatment or practice (e.g. straight row, contoured, and terraced, hydrologic condition (i.e. poor, fair, and good) and soil hydrologic groups. Several assumptions were made to estimate these characteristics (Bolinder et al., 2000). An arithmetic mean estimate of overland flow potential was used for the entire watershed (both agricultural and forested land).

2.4. Other Risk Indicators: Soil Capability for Agriculture and Water Quality Management Zones

To complete this exercise of correlation of risk indicators with water quality, two other agricultural indicators were tested. The first indicator selected is comprised of seven classes from the Canada Land Inventory Soil Capability Classification for Agriculture with modifications made for Manitoba's conditions. The area of each agricultural capability class (ACC) in each watershed was determined using data sets prepared by AAFC: SLC version 3.0. In these data sets, each polygon is ranked within ten classes: agricultural capability class 1 to 7, organic soils, water and urban, modified or unclassified. As in section 2.3.1 for the determination of soil erosion, the percentage area and value for each agricultural capability class were used to develop a weighted average ACC value for each watershed. The unclassified portion of the land, was mostly forested land; therefore, we assumed that it had no agricultural capability for either arable culture or permanent pasture, equivalent to class 6 (Petra Loro, personal communication).

The second group of other indicators evaluated was Water Quality Management Zones (WQMZ) for nutrients proposed by the Government of Manitoba (Manitoba Water Stewardship, 2005). Manitoba's landscape has been separated into four zones based on the principal factors that influence runoff and leaching potential to regulate nitrogen and P application (Manitoba Water Stewardship, 2005). Those factors included land slope, topography, soil texture, permeability, distance to groundwater, erosion potential, soil characteristics and crop yield potential (see Table B.5 in Appendix B). Therefore, these factors are for the most part, similar to those used for determining ACC. The zones are classified according to agricultural productivity and leaching risk and range from highly productive lands (Zone 1, ACC classes 1, 2, 3 except 3M and 3W), moderately productive lands (Zone 2, ACC classes 3M, 3W, 4), marginally productive lands (Zone 3, ACC class 5) and generally non-productive agricultural lands (Zone 4, ACC classes 6, 7). For the watershed portion identified as "unclassified", we assumed, once again, that this was generally non-productive agricultural land and we regarded this land as equivalent to WQMZ #4. Estimation of the percentage area and WQMZ value for each watershed was calculated by an equivalent method and the same dataset used for the ACCs.

3. RESULTS AND DISCUSSION

This chapter begins with the water quality data analysis. Three water quality parameters were chosen for this analysis: arithmetic average TP concentration, percent of samples exceeding 0.25 mg TP/L, and P export intensity to water on a kg/ha/yr basis. The results for each P risk indicator and correlations between water quality results and the three selected P risk indicators, plus several other agriculture related factors are also presented.

3.1. TP Concentrations in Water and P Export Intensity

In order to determine which time-period of the water quality parameters data set to use, how to express the water quality data and if any adjustments were required to reflect the watershed contribution of P, we examined the dispersion of TP values over time, the relations between water flow and TP concentration and finally the contributions from point source.

3.1.1. Sampling time-period

As mentioned previously, water quality data were collected consistently in the mid-1970s and in the 1990s but, inconsistently in the 1980s (Tables D.1 to D.14 in Appendix D). Therefore, the appropriateness of using all or part of data was investigated. Two time-periods were evaluated: the entire sample collection period (1973-2000) and the most recent decade (1989-1999). For most watersheds, the frequency of water samples was highest for the 1989-1999 period: 67.2% of the water quality data were from this period (Table 3.1). Only four watersheds showed a lower frequency of sampling in this recent period: Cypress River, Valley River, Little Saskatchewan River and, Vermillion River.

Coefficient of variation in TP concentrations provides a relative measure of data dispersion compared to the mean: a low coefficient represents TP concentrations remaining fairly constant over time. Coefficients of variation were calculated for both time periods. Coefficients of variation were slightly lower for 1989-1999 period: 67.8% for this period versus 69.1% for the entire data period (Table 3.1). However, this could be in part explained by a higher frequency of water quality sampling in the more recent period. Nevertheless, the frequency of water sampling, its time-proximity to current agricultural practices, and a good coefficient of variation of TP justified the choice of the 1989-1999 period for the purposes of this project.

Table 3.1 Number of data and coefficient of variation for TP concentration.

Watersheds	Number of samples 1973-2000	Number of samples 1989-99	Coefficient of variation (%) 1973-2000	Coefficient of variation (%) 1989-99
La Salle	97	79	49	35
Seine	163	140	50	56
Rat-Marsh	57	38	43	36
Cypress	76	34	83	81
Boyne	65	43	47	46
Cooks Creek	95	94	107	106
Brokenhead	147	45	59	60
Roseau	87	35	53	55
Little Saskatchewan	82	57	42	32
Valley	97	49	77	83
Wilson	90	86	92	98
Ochre	85	35	103	111
Vermillion	121	116	86	61
Turtle	68	43	84	84

3.1.2. Temporal distribution

Figure 3.1 shows the distribution of arithmetic mean annual TP concentration over time (1989-1999). For some watersheds, a temporal trend in TP concentration was observed: increases in TP concentration for the La Salle River ($r = 0.76^{**}$) and Little Saskatchewan River ($r = 0.71^{**}$); and decreases for the Seine River ($r = -0.54^{ns}$), Rat-Marsh river ($r = -0.69^{*}$) and Brokenhead River ($r = -0.60^{*}$). However, the increases were not consistent or substantial enough to justify an adjustment to the mean values for TP concentrations.

3.1.3. Relationship between TP concentration and water flow

Correlations between water quality parameters and water flow were examined in an attempt to establish which process was prevailing in the studied areas: watershed-based processes where TP concentration correlated well with water flow versus direct effluent discharge where there is no correlation between TP concentration and water flow. These correlations were also studied to examine the possibility of using a flow-weighted mean TP concentration versus an arithmetic mean. Figure 3.2 shows coefficient of correlation between TP concentration and water flow. Only three watersheds showed a coefficient of correlation greater than 0.30 and significant: La Salle River ($r^2 = 0.35^{*}$), Valley River ($r^2 = 0.41^{*}$), and Vermillion River ($r^2 = 0.44^{*}$). These results could mean that for those watersheds, the TP originated mostly from diffuse pollution (watershed-based process).

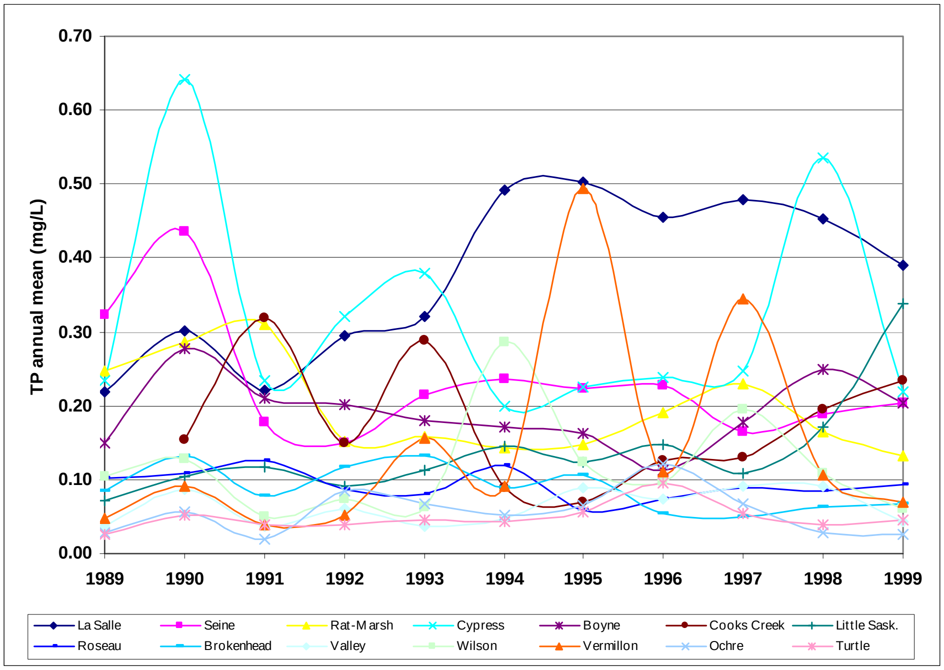

Figure 3.1 Temporal variation of annual mean of TP concentration (mg/L) for all watersheds (1989-1999).

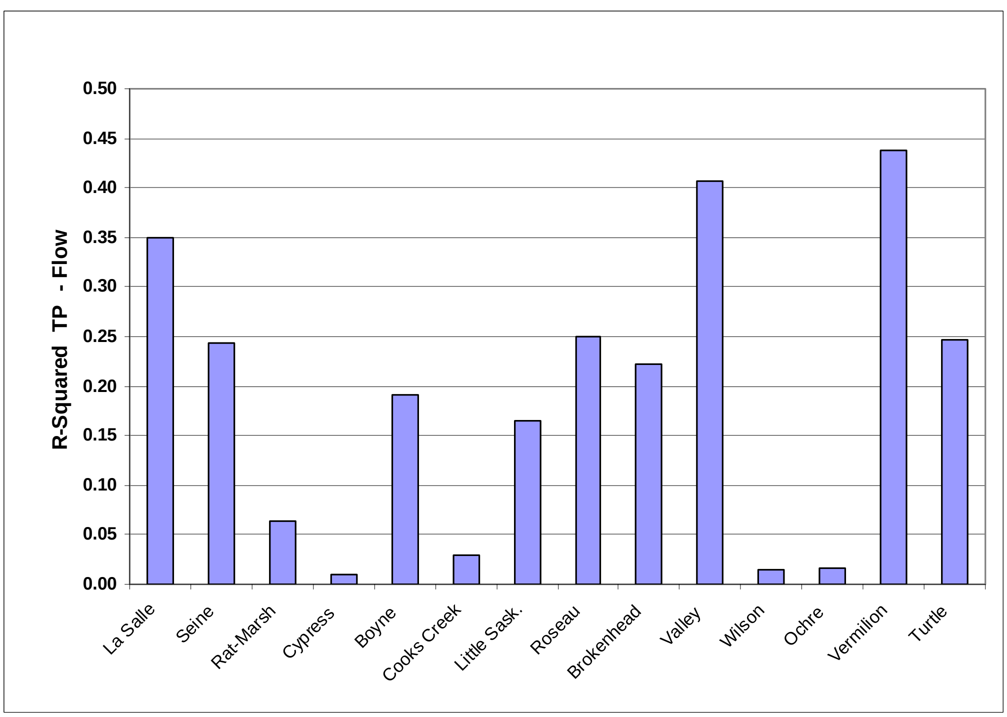

Figure 3.2 Correlation between TP concentration (mg/L) and water flow (m^3/s) for all watersheds.

For the other watersheds, the poor correlations could be the result of different processes occurring in the watershed: direct effluent discharge, groundwater discharge. Also, in this study, “in-stream processes" such as stream bank erosion, sedimentation, etc. have not been accounted for. The lack of information on the effect of these processes on water quality in these watersheds is another factor that detracts from our capacity to clearly account for the influence of the terrestrial portion of the watershed. Conversely, these poor correlations may also be the result of the discontinuous non-dendritic drainage pathways of many of Manitoba’s natural landscapes. Further research on the point and nonpoint sources located in the watersheds is necessary to explain what happened in each watershed. However, the lack of any consistent relationship between TP concentration and flow meant that the TP concentrations did not require adjustment to a flow weighted mean basis.

3.1.4. Point source contribution

Point source inputs of P should also be accounted for. It is noteworthy that major cities as well as smaller communities discharge secondary effluent directly into the Red River or into one of its many tributaries (Jones and Armstrong, 2001). In this study, no watersheds with major point sources were included; therefore, point source P inputs were not considered. Periodic (e.g., semi-annual) discharges from municipal lagoons could have a significant impact on water quality measurements, especially if samples were collected shortly after the discharge. However, according to Armstrong (personal communication, 2005), the location of the water quality stations and the timing of the water quality sampling should not have had a significant impact on the water quality.

3.1.5. Mean TP concentrations in watersheds

As mentioned, the main objective of this research was to study the correlation between regional water quality and P risk indicators. Examination of the water quality data first showed that no temporal trend could be significantly determined. The last decade of data did seem to be the most representative and appropriate for the purposes of this study. The fact that no correlation between flow data and TP concentration in water was an important part of the decision of not using a weighted mean to represent the water quality parameters chosen. Finally, since the P risk indicators are represented by a single value (risk rating), for each watershed, we decided that the most appropriate way to express water quality was also by a single value, using the arithmetic, unweighted mean concentration of TP in the water samples.

The overall mean concentrations of TP in the watersheds varied from 0.05 to 0.38 mg P/L over 1989-1999 (Figure 3.3). As a whole, watersheds located in the Eastern region of Manitoba (La Salle, Seine, Rat-Marsh, Cypress, Boyne, Roseau, Cooks Creek and Brokenhead Rivers) showed higher annual average TP concentrations than those in the Western region (Little Saskatchewan, Valley, Vermillion, Wilson, Ochre, and Turtle Rivers): 0.23 mg TP/L versus 0.09 mg TP/L.

Overall, the high concentrations of TP in these watersheds reveal a high risk of eutrophication, according to the water quality standards proposed by the Canadian Council of Ministers of the Environment (Table 3.2). These concentrations also exceed those that have been considered by the Government of Manitoba. For example, in some of Manitoba's initial proposals for water quality objectives, the upper target was set at 0.05 mg P/L for streams and rivers and 0.025 mg P/L for lakes (Manitoba Conservation, 2002). So, even though these concentrations represent extremely small amounts of TP lost from the watershed from an agronomic perspective, they are generally regarded as very significant from an environmental perspective.

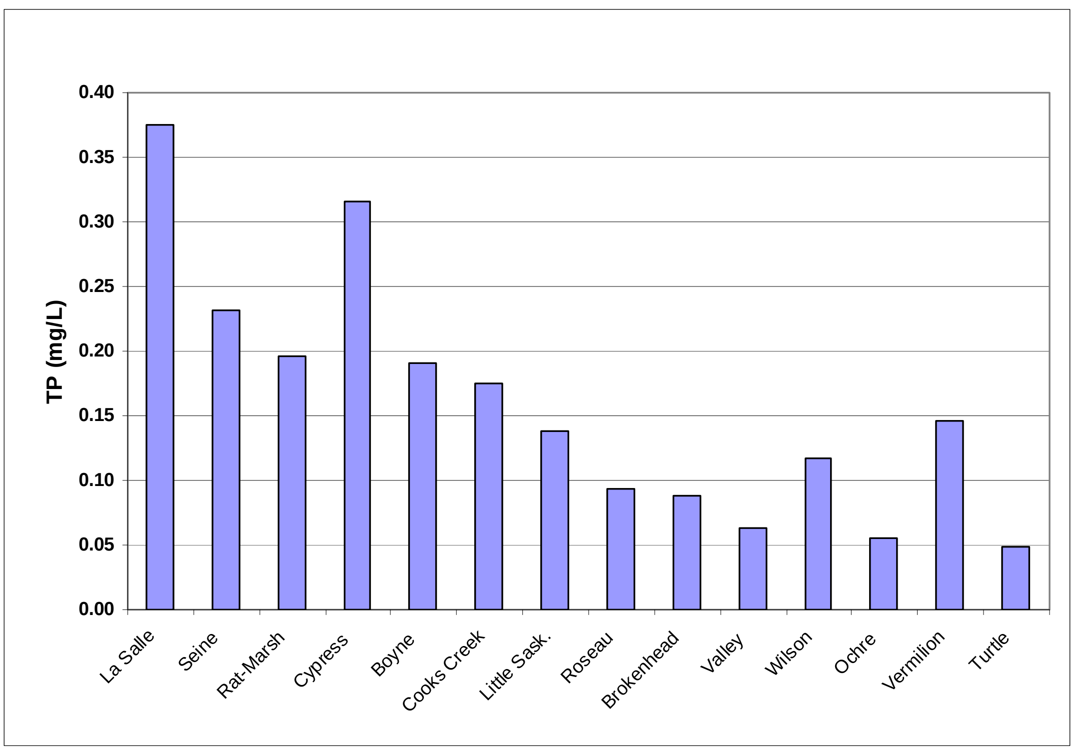

Figure 3.3 Overall mean of arithmetic unweighted annual average of TP concentration for all watersheds (1989-1999).

Table 3.2 TP trigger ranges for Canadian lakes and rivers (Environment Canada, 2004).

Trophic Status	Canadian Trigger Ranges for TP (mg P/L)
Ultra-oligotrophic	< 0.004
Oligotrophic	0.004 - 0.010
Mesotrophic	0.010 - 0.020
Meso-eutrophic	0.020 - 0.035
Eutrophic	0.035 - 0.100
Hyper-eutrophic	> 0.100

3.1.6. P export

Annual P export was determined to assess the total quantity of P that flows out of each watershed. Mass of P exported from each watershed is a useful measure of which watersheds account for the greatest contribution of P in the overall drainage basin. Annual P export rate was assessed with the product of the TP annual mean multiplied by the mean annual flow[14] (Figure 3.4). Watersheds in the Eastern region showed the highest annual export values (16,204 versus 8,462 kg/year). For example, Roseau River watershed had the highest overall mean P export rate (41,297 kg/year) and Ochre River watershed the lowest (2,518 kg/year).

However in our study, we also wanted to compare the factors responsible for P export on an equivalent basis, independent of the size of the watershed. Therefore, all the parameters associated with watershed characteristics and water quality were expressed as intensive measures, e.g. on a per hectare or percentage basis. For example, P export intensity was calculated as the product of the TP annual mean concentration multiplied by the annual flow and expressed as a mean for the entire watershed (Figure 3.5). Similar to TP concentrations, some watersheds showed a noticeable increase in P export intensity over the 1989-1999 period: Seine River ($r = 0.70^{***}$), Boyne River ($r = 0.64^{*}$), Little Saskatchewan River ($r = 0.77^{***}$) and Roseau River ($r = 0.79^{***}$). It is noteworthy that in 1995, the Vermillion River watershed's annual mean P export intensity was much higher than for the other years and for the other watersheds. This high P export is the result of a combination of an abnormally high TP concentration for that year (Figure 3.1) and much higher annual flow (Figure D.1 in Appendix D). For the remaining watersheds, a slight increase was observed over the time period, except for Ochre River watershed where no change was observed. Similar to the trend for TP concentration, the highest overall mean annual P export was in the Eastern region: 0.08 versus 0.06 kg/ha/year. The Roseau River watershed had the highest overall mean P export intensity (0.16 kg/ha/year) and Turtle River watershed had the lowest (0.02 kg/ha/year) (Figure 3.6).

[14] Calculation is made according to Bourne et al. (2002).

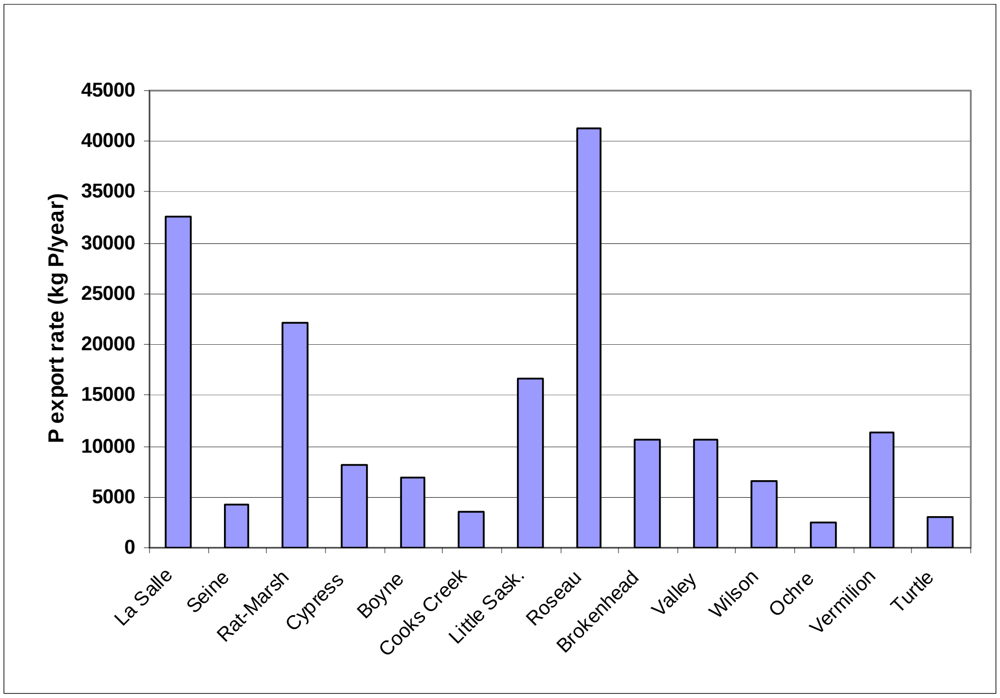

Figure 3.4 Annual average P export rate (kg P/year) for Manitoba watersheds (1989-1999)

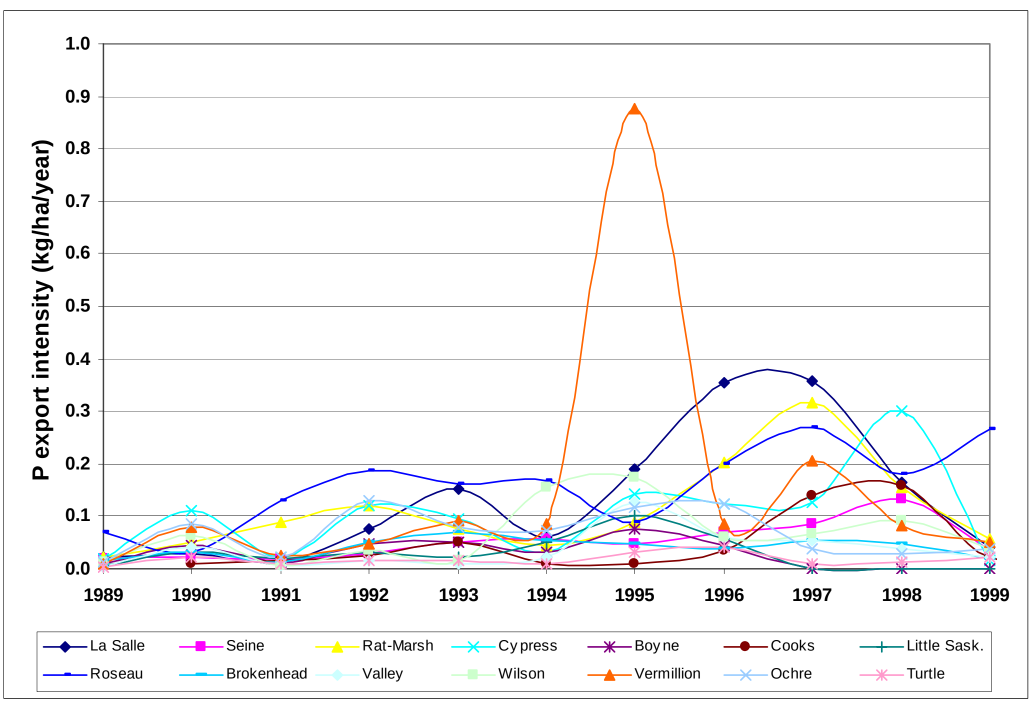

Figure 3.5 Annual average P export intensity (kg P/ha/year) for Manitoba watersheds (1989-1999).

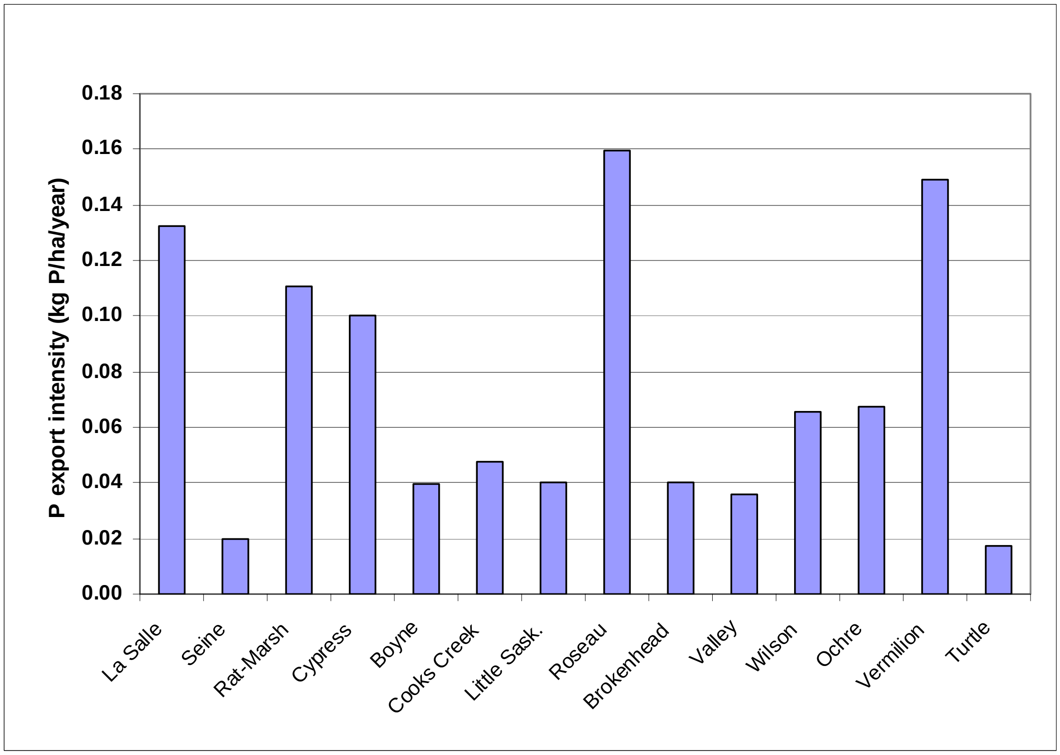

Figure 3.6 Overall mean of annual average P export intensity (kg P/ha/year) for Manitoba watersheds (1989-1999).

3.2. Minnesota P Index

3.2.1. Transport factors

For Minnesota P Index transport factors, the highest estimated soil erosion value was for Cypress and Valley River watersheds (14.0 t/ha) and the lowest for Rat-Marsh River watershed (2.2 t/ha) (Figure 3.7). The risk of soil erosion for the watersheds located in the Eastern region of Manitoba (4.8 t/ha) was rated lower than for the Western region (8.9 t/ha). Similarly, the highest runoff values were estimated in the Western region, with an average of 6.1 cm versus 5.4 cm for the Eastern region. The highest runoff value was for the Roseau River watershed with 18.1 cm and the lowest for the Boyne River watershed with 2.3 cm. Detailed results for erosion risk and runoff are presented in Table E.1 of Appendix E.

For individual watersheds, percentages of cropland located within 50 m of water courses varied from 2.8 for Brokenhead River watershed to 15.8 for Little Saskatchewan River watershed. On a regional basis, 4.8% of cropland was estimated to be located within 50 m of water courses for the Eastern region compared to 8.8% for the Western part of the province (Figure 3.7).

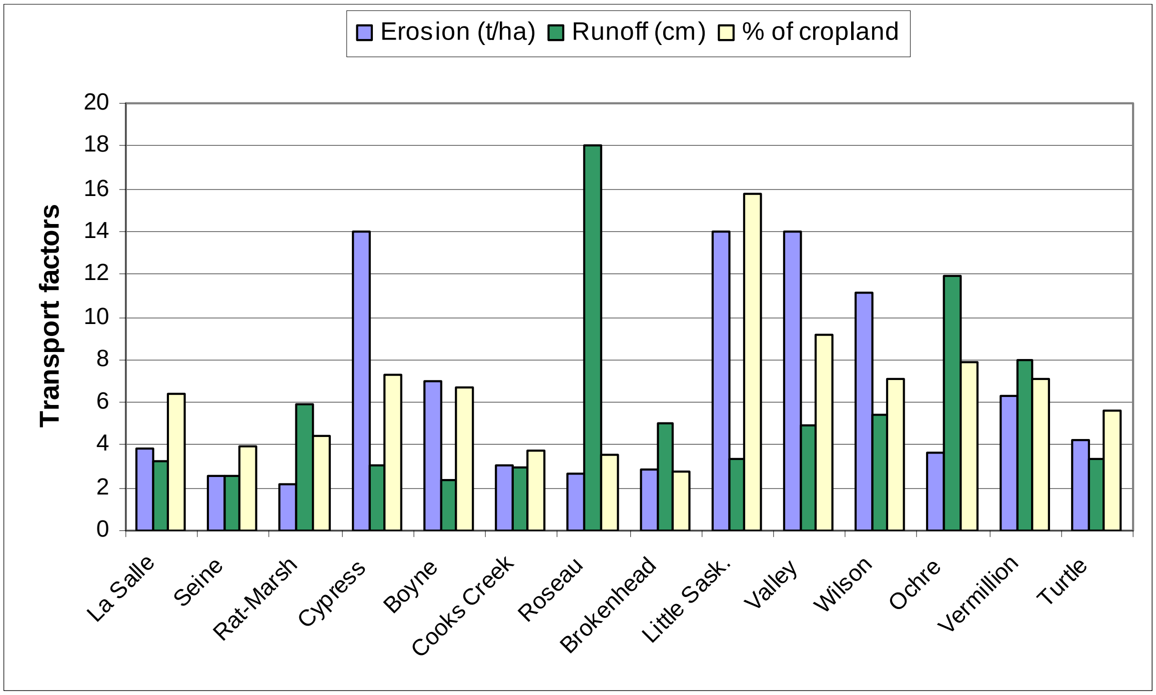

Figure 3.7 Minnesota P Index transport factors (erosion, runoff and percentage of cropland located within 50 m of a water course) for Manitoba watersheds.

3.2.2. Source factors

The lowest soil test P concentration was in Ochre River (13.1 ppm) and the maximum in Cypress River watershed (29.9 ppm) (Figure 3.8). Soil test P concentrations for the Eastern region averaged 23.0 ppm compared to 16.8 ppm for the Western region. Soil test P concentration is often associated with the presence of agricultural land and livestock production intensity partly due to the high natural fertility of land suited to agricultural production and partly due to application of nutrients onto agricultural land. Therefore, agricultural intensity followed the same trend as for soil test P: livestock density and crop production area were significantly higher for the Eastern region: 0.24 versus 0.14 A.U./ha and 121,433 ha[15] versus 106,547 ha, respectively.

The highest fertilizer P application rate was estimated for the La Salle River (20.4 kg P/ha) and the lowest in the Ochre River watershed (7.4 kg P/ha) (Figure 3.9). Comparison between the Eastern and Western part of the Province showed a higher application rate for the Eastern region (17.7 versus 13.8 kg P/ha).

[15] Number of hectares considered as the agricultural land use area: land in crops (excluding Christmas trees), summerfallow, tame or seeded pasture, natural land for pasture and all other land (including Christmas tree) (2001 Census of Agriculture).

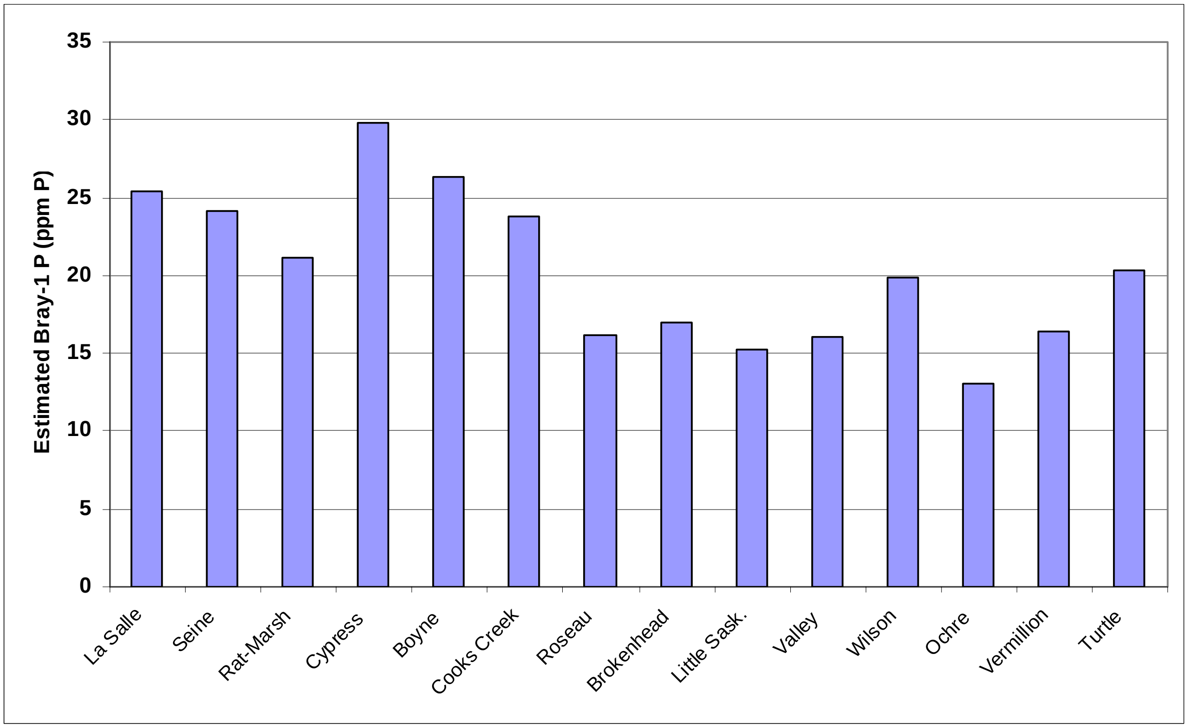

Figure 3.8 Estimated soil test P (Bray P1) concentrations for Manitoba watersheds.

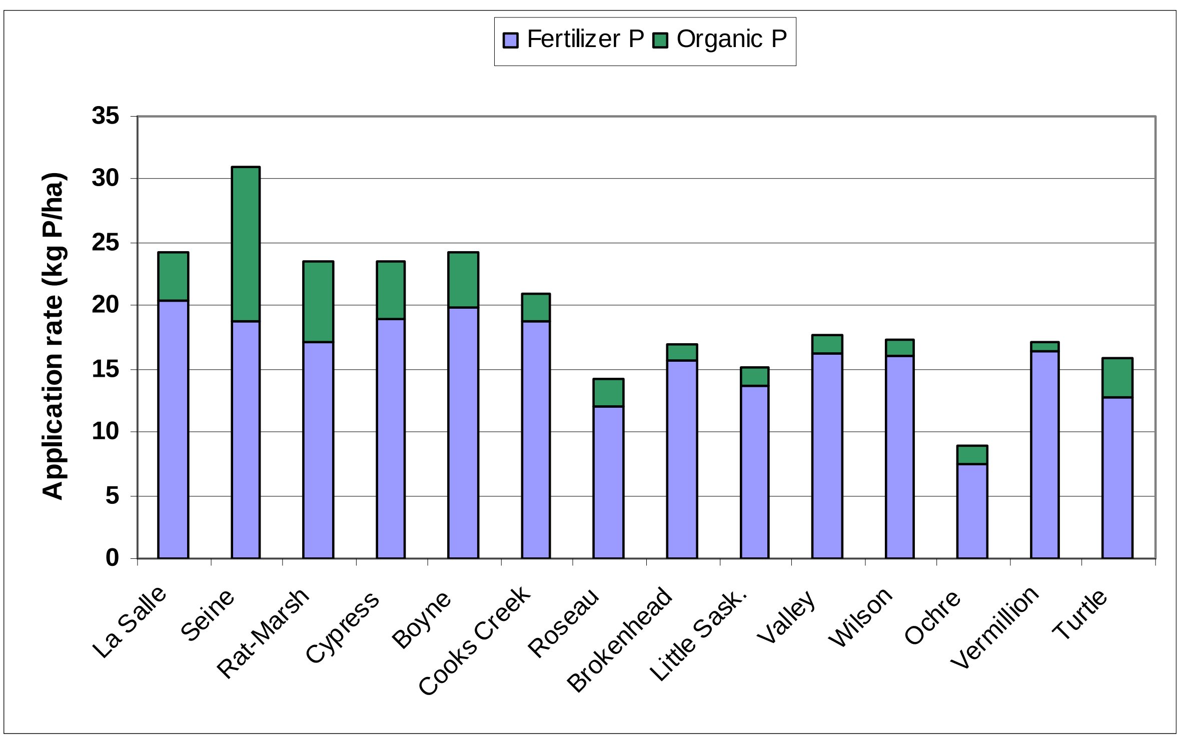

Figure 3.9 Fertilizer and organic P application rates for Manitoba watersheds.

The highest application rate of organic fertilizer P (manure) was estimated for Seine River watershed (12.3 kg P/ha) and the lowest for Vermillion River watershed (0.71 kg P/ha). Comparison between the two regions showed that the Eastern region, manure P application rate was three times greater than that in the Western region (4.6 versus 1.5 kg P/ha). Once again, those results are directly correlated with the livestock population in those regions: more than 280,115 A.U. were assessed for the Eastern region versus 87,765 A.U. for the Western one. As for the total application of P (fertilizer and organic sources), Seine River is the watershed with the highest application rate (31.0 kg P/ha) and Ochre River has the lowest (8.9 kg P/ha). Once again, the Eastern region showed a higher average rate of application for all sources of P: 22.3 versus 15.3 kg P/ha.

3.2.3. Overall rating of risk according the Minnesota P Index

As mentioned previously, the modified version of the P Index for Minnesota is the summation of the product of the rating value and corresponding weighting value for each site characteristic (Birr and Mulla, 2001). According to the Minnesota P index rating, values between 0-21 characterized watersheds as very low risk and between 21-26 as low risk; all the watersheds risk ratings fell within these two types of low risk categories (Figure 3.10). Given the high TP concentrations frequently observed in Manitoba's watersheds, these estimates of very low and low risk appear not to be an accurate representation of the water quality in those watersheds. The watershed with the lowest P Index rating was Brokenhead River (8.5) and the one with the highest rating, Valley River (23.8). The Western region had a higher P Index average than the Eastern region (19.7 versus 16.0).

3.2.4. Correlation between site characteristics and P Index rating

For transport factors, soil erosion and percentage of cropland showed the highest correlations with P Index (Table 3.3). The correlation between risk index value and all other transport and source factors, including soil test P, were not significant. Some correlations among site characteristics were interesting: e.g. a positive correlation between soil erosion and percentage of cropland within 50 m of a watercourse, a negative correlation between runoff and soil test P and between runoff and fertilizer P and a positive correlation between fertilizer P application rate and soil test P. Detailed results are presented in Appendix F.

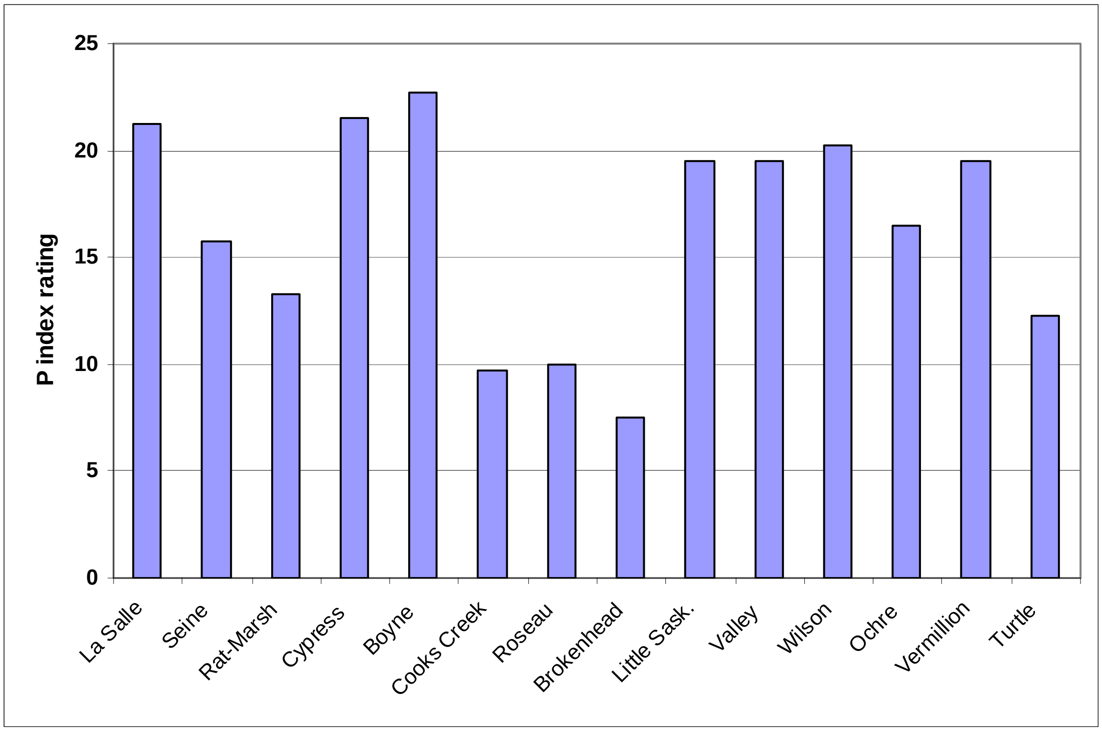

Figure 3.10 Minnesota P index rating for rates for Manitoba watersheds.

Table 3.3 Pearson's correlation coefficients for Minnesota P index and its site characteristics (n = 14).

Site characteristics	**TRANSPORT FACTORS**			**SOURCE FACTORS**		
	Soil erosion	**Runoff**	**Cropland[1]**	**Soil test P**	**Fertilizer P rate**	**Organic P rate**
Soil erosion						
Runoff	-0.29^{ns}					
% of cropland	0.76***	-0.18^{ns}				
Soil test P	0.03^{ns}	-0.59*	-0.28^{ns}			
Fertilizer P application rate	0.09^{ns}	-0.67**	-0.21^{ns}	0.80***		
Organic P application rate	-0.29^{ns}	-0.32^{ns}	-0.31^{ns}	0.55*	0.43^{ns}	
Minnesota P Index	0.65**	-0.34^{ns}	0.60*	0.31^{ns}	0.32^{ns}	0.04^{ns}

[1] Percentage of cropland located within 50 of a watercourse.
*,**, *** Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ probability levels, respectively.
ns: not significant.

3.2.5. Correlations with water quality parameters

The only significant correlations with TP concentration in water were those with fertilizer P application rate, soil test P, and organic P source application rate (Table 3.4). Regarding the percentage of samples exceeding 0.25 mg TP/L, the highest correlation coefficients was with fertilizer P application rate. For P export intensity, all correlations were low and significant, except runoff. Erosion risk was unrelated to any measure of P export to water; it implies that this mechanism does not appear to play a major role in P export intensity in Manitoba watersheds. The highest and only significant correlation between water quality parameters and Minnesota P Index was with percentage of samples exceeding 0.25 mg TP/L. Finally, the P index itself was not significantly correlated with TP concentration or P export intensity.

3.3. Preliminary P Risk Indicator for Manitoba

3.3.1. P pathway transport

As mentioned, the risk of soil erosion was estimated for this indicator by the same method as for Minnesota P Index and follows the same pattern as previously presented (Figure 3.7).

However, for this indicator, overland flow potential (runoff) was determined differently and the values differ from those for the Minnesota P index (Table 3.5). For the Manitoba indicator, the risk of runoff focused on true overland flow. The initial step in this determination was to identify the predominant soil texture class, using the SLC database. Those texture classes were associated with different soil permeability classes and slopes (Bob Eilers, personal communication). Overall, the runoff assessed ranged from very low for Rat-Marsh and Roseau river watersheds to high for La Salle, Seine, Brokenhead and Little Saskatchewan watersheds. Detailed results for the quantitative rating of runoff risk and other watershed characteristics for this indicator are presented in Table E.2 in Appendix E.

3.3.2. P source factors

For this indicator, the overall P balance is determined by the summation of manure P application and fertilizer P minus crop export. The estimated rate of P application from both these sources was the same as for the Minnesota P index (section 3.2.2). Assessment of crop export of P showed the lowest P removal for La Salle River watershed at 14.2 P kg/ha, and highest for Ochre River at 17.7 kg P/ha (Figure 3.11). As for the overall P balance results, Ochre River watershed had the lowest balance (-8.8 kg P/ha) and Seine River watershed had the highest balance (15.3 kg P/ha). The Eastern region had an overall P surplus but the Western region had an overall P deficit (7.0 versus -1.2 kg P/ha). A negative balance means that P removal is higher than P application. Over time, this represents a depletion of P in soil

For crop residue P left after the harvest, the Seine River watershed had the lowest value, with 3.8 kg residue P/ha, and Vermillion River the highest, with 6.2 kg P/ha (Figure 3.12). For both regions, the crop residue P values were similar: 5.1 for the Eastern versus 5.4 kg P/ha for the Western region.

Table 3.4 Pearson's coefficients for correlations between Minnesota P Index, its site characteristics and water quality parameters (n = 14).

Variables	Water quality parameters		
	TP (mg/L)	% exceeding 0.25 mg/L TP	P export intensity (kg/ha/year)
Soil erosion	0.02^{ns}	0.28^{ns}	-0.16^{ns}
Runoff	-0.42^{ns}	-0.39^{ns}	0.58*
% of cropland	-0.06^{ns}	0.08^{ns}	-0.16^{ns}
Soil test P[1] (Bray P1)	0.80***	0.43^{ns}	-0.03^{ns}
Fertilizer P application rate	0.75**	0.59*	0.02^{ns}
Organic P source application rate	0.48*	0.27^{ns}	-0.19^{ns}
P Index	0.43^{ns}	0.49*	0.08^{ns}

[1] Estimated from modified-Kelowna test P.
*, **, *** Significant at p < 0.05, p < 0.01 and p < 0.001 probability levels, respectively.
ns: not significant.

Table 3.5 Runoff class determination from soil permeability and percentage of slope.

Watersheds	Slope (%)	Soil texture classification	Soil permeability class	Runoff class
La Salle	1 – 4.99	Clay	Very slow	High
Seine	1 – 4.99	Clay	Moderately slow, slow	High
Rat-Marsh	1 – 4.99	Sand	Moderately rapid, rapid	Very low
Cypress	5 - 9.99	Fine loamy	Slow	Moderate
Boyne	1 – 4.99	Clay	Very slow	Moderate
Cooks Creek	1 – 4.99	Clay	Very slow	Moderate
Brokenhead	1 – 4.99	Fine Loamy	Slow	Moderate
Roseau	1 – 4.99	Sand	Moderately rapid, rapid	Very low
Valley	1 – 4.99	Fine Loamy	Slow	Moderate
Little Saskatchewan	5 - 9.99	Fine Loamy	Slow	High
Wilson	1 – 4.99	Fine Loamy	Slow	Moderate
Ochre	1 – 4.99	Fine Loamy	Slow	Moderate
Vermillion	1 – 4.99	Fine Loamy	Slow	Moderate
Turtle	1 – 4.99	Fine Loamy	Slow	Moderate

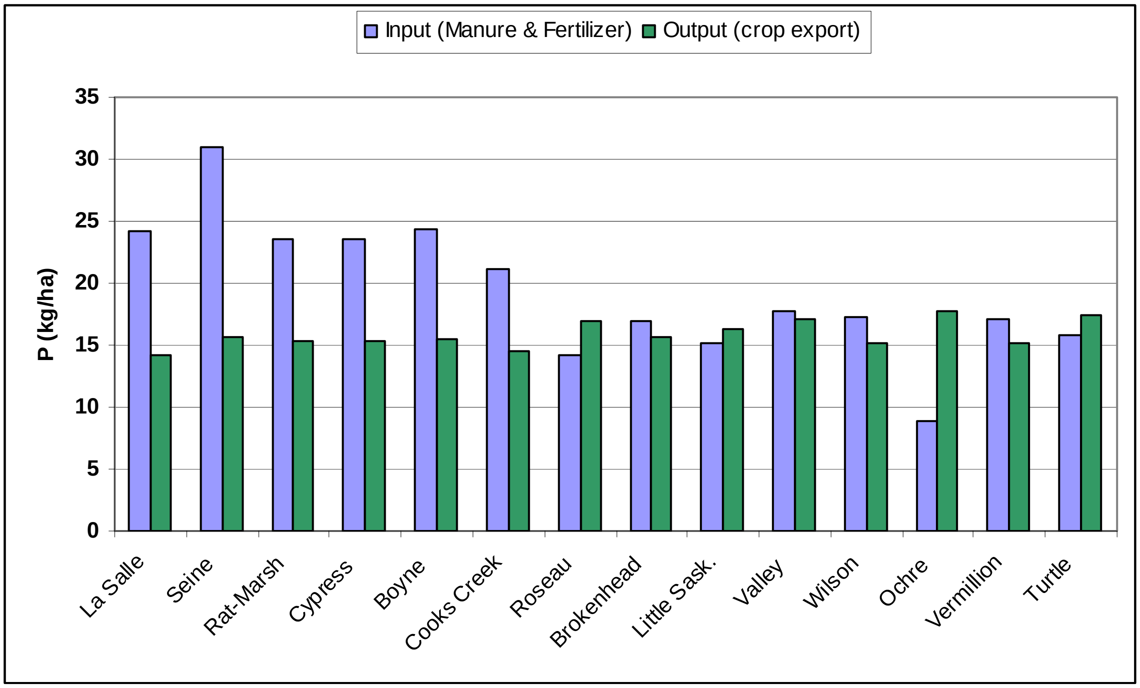

Figure 3.11 Overall P balance (manure and fertilizer input and crop export) for Manitoba watersheds.

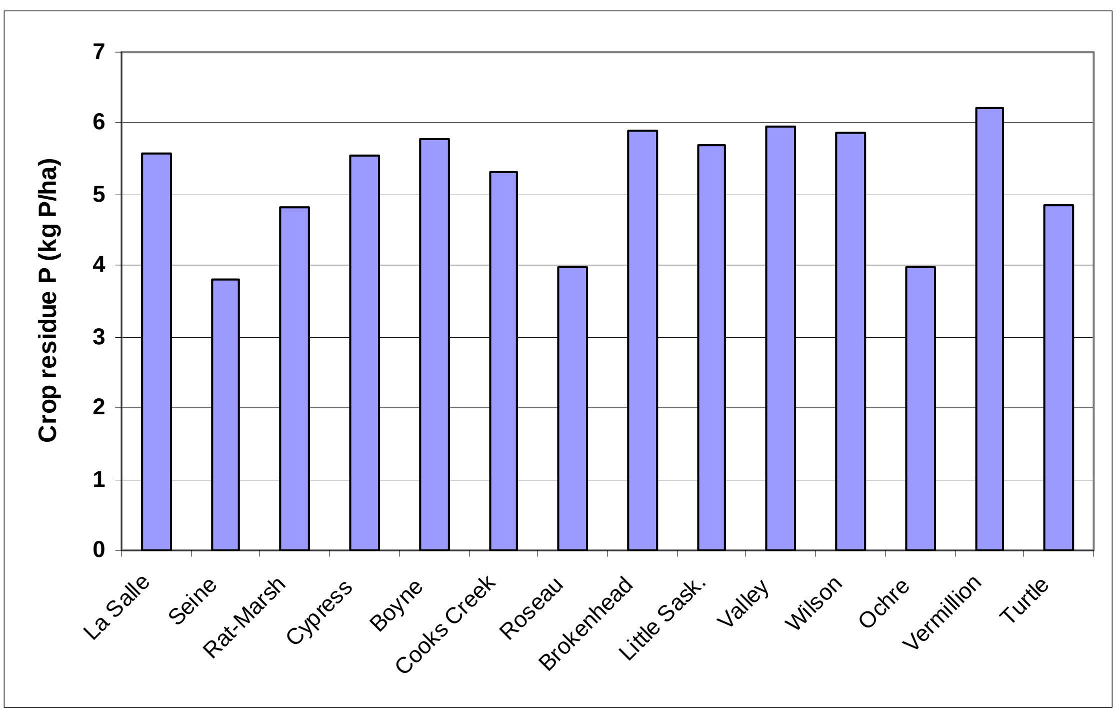

Figure 3.12 Crop residue P for Manitoba watersheds.

The watersheds varied greatly in their soils' capacity to retain P (Figure 3.13). Estimated PSI values were highest in the Brokenhead River watershed (552) and Ochre River watershed the lowest (114). Overall, the PSI values for the Western region (210) were lower than for the Eastern region (372). No soil test P values were used for this indicator, because, as mentioned previously, this indicator was designed to predict P loss where soil test P information may not be available.

3.3.3. Overall ratings of risk according to the preliminary P risk indicator for Manitoba

As for the other risk indicator, the preliminary P risk indicator for Manitoba is the summation of the product of the rating value and corresponding weighting value for each site characteristic. Watersheds with a rating value between 11 and 17 are characterized as very low risk, between 18 and 34 as low risk and between 35 and 68 as medium risk. All watersheds were ranked with medium risk vulnerability except Little Saskatchewan River watershed with high risk and Roseau River watershed with low (Figure 3.14). As mentioned, high TP concentrations were frequently observed in Manitoba's watersheds, thus those estimates of P risk appear to be more accurate that those obtained with the Minnesota P index. The watershed with the lowest P Index rating was Roseau River (30.5) and the one with the highest rating, Little Saskatchewan River (75.0). P index ratings of the Eastern watersheds (44.8) were higher than those for the Western watersheds (64.7).

3.3.4. Correlation between site characteristics and P indicator rating

Correlation between the Manitoba preliminary risk indicator values and site characteristics with P Index rating were generally poor (Table 3.6). Overall, with the exception of the correlations between soil erosion and crop residue and between overall P balance and PSI, site characteristics were not significantly correlated among themselves. For the P risk indicator, the only significant correlations were with soil erosion and PSI.

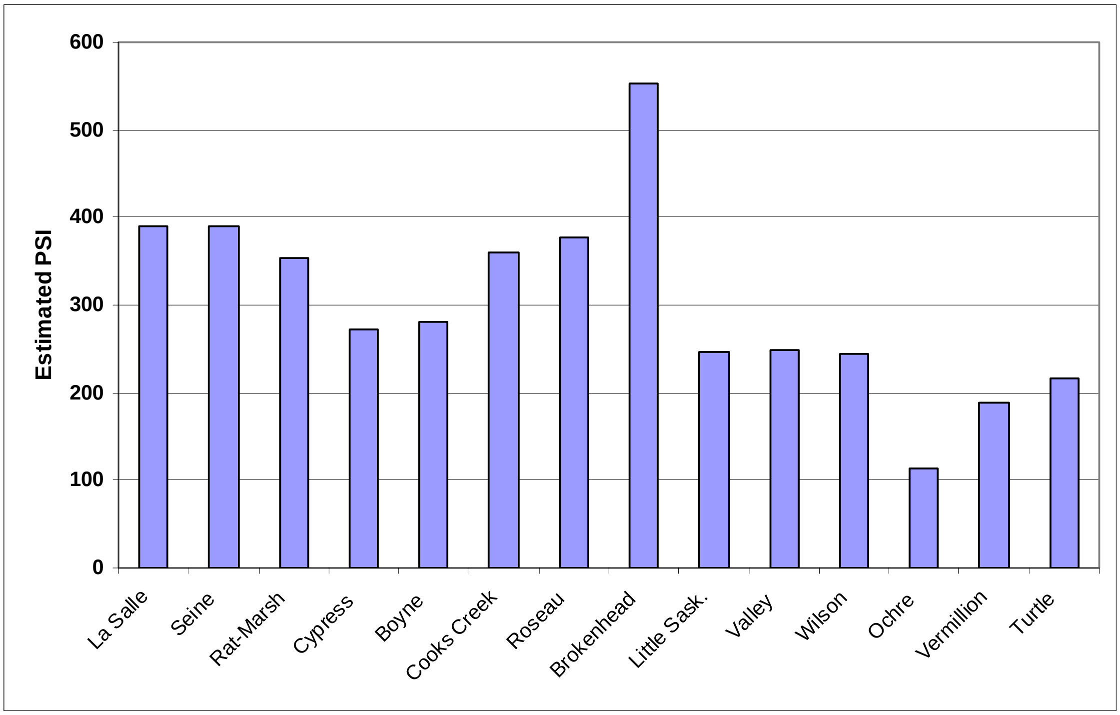

Figure 3.13 Estimated PSI for Manitoba watersheds.

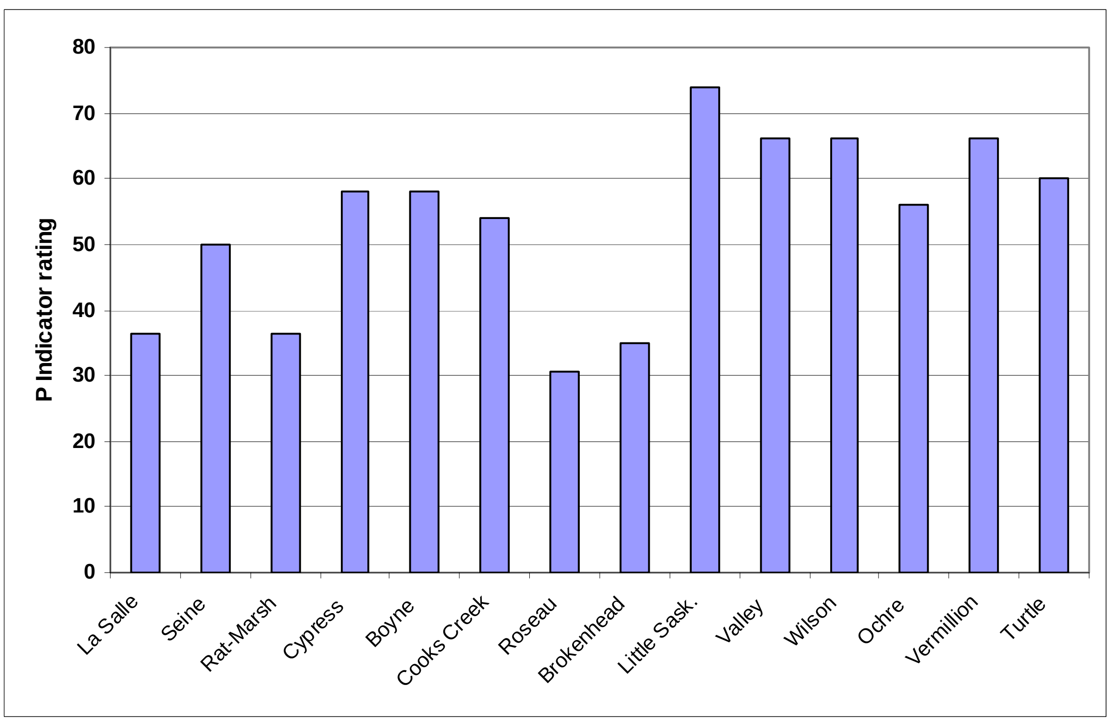

Figure 3.14 Preliminary P risk indicator rating for Manitoba.

3.3.5. Correlations with water quality parameters

The only site characteristics for Manitoba preliminary P risk indicator that were significantly correlated with TP concentration were runoff and P balance (Table 3.7). For the percentages of samples exceeding 0.25 mg TP/L, the only site characteristic significantly correlated with it was P balance. For the correlations with P export intensity, all were low and insignificant. The preliminary P risk indicator for Manitoba was not significantly correlated with any of the water quality parameters. The poor performance of this indicator is probably related to the lack of soil test P information in its determination. In the other two indicators, soil test P values correlated very highly with TP concentration, indicating the importance of including this characteristic in any assessment of P loss.

Table 3.6 Pearson's correlation coefficients for the Manitoba preliminary P risk indicator and its site characteristics (n = 14).

Variables	P pathway factors		P source factors		
	Soil erosion	Flow potential	P balance	Crop residue	PSI
Soil erosion					
Overland flow potential	0.28^{ns}				
Overall P balance	-0.11^{ns}	0.52*			
Crop residue P	0.55*	0.22^{ns}	0.08^{ns}		
Estimated P sorption index	-0.42^{ns}	0.03^{ns}	0.47*	-0.01^{ns}	
P Indicator	0.72**	0.31^{ns}	-0.23^{ns}	0.36^{ns}	-0.77**

*, **, *** Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ probability levels, respectively.
ns: not significant.

Table 3.7 Correlations between preliminary P risk indicator for Manitoba, its site characteristics and water quality parameters (n = 14).

Variables	Water parameters		
	TP (mg/L)	% exceeding 0.25 mg/L TP	P export intensity (kg/ha/year)
Soil erosion	0.02^{ns}	0.28^{ns}	-0.16^{ns}
Flow potential	0.59*	0.34^{ns}	-0.15^{ns}
P balance	0.79***	0.51*	0.08^{ns}
Crop residue	0.12^{ns}	0.21^{ns}	0.44^{ns}
PSI	0.29^{ns}	0.11^{ns}	0.31^{ns}
P risk indicator	-0.24^{ns}	0.06^{ns}	-0.41^{ns}

* Significant at $p < 0.05$ probability level, respectively.
ns: not significant.

3.4. IROWC-P

3.4.1. P transport

Assessment of soil erosion risk for this indicator was similar to what was reported for the other indicators. Runoff potential, however, was determined using a method different from those used for the other indicators. This method resulted in runoff estimates that were more similar to those for the Manitoba preliminary risk indicator than those to the Minnesota P index, probably because the runoff values for the latter also include subsurface flow. The highest runoff rating for the IROWC-P indicator was for the Cypress River and Little Saskatchewan River watersheds (high risk) and the lowest for the Valley River and Wilson River watersheds (low risk). Overall, watersheds for the Eastern part of Manitoba showed a higher risk for runoff than the Western region. Detailed results are presented in Table E.3 in Appendix E.

3.4.2. P status

Mehlich-III soil test P values were estimated from modified-Kelowna test values, using a conversion factor for Manitoba soils (section 2.3.3). Estimated Mehlich-III soil test P concentrations varied from 17.4 ppm for Ochre River to 38.5 ppm for Cypress River watershed (Figure 3.15). Watersheds in the Eastern region of Manitoba presented a higher average soil test P concentration than for the Western region: 29.9 versus 22.1 ppm. As for the estimated degree of soil P saturation, Brokenhead River watershed had the lowest degree (4.0%) and Ochre River watershed the highest (15.3%). The highest average of soil P saturation was assessed for the Western region (11.0% versus 8.6%).

3.4.3. Annual P balance

For this indicator, the annual P balance is calculated as percentage of crop removal not in kg P/ha as in the Manitoba preliminary P risk indicator. Three site characteristics were used to determine annual P balance of this indicator. For the mineral P fertilizer, the highest value was in La Salle River watershed (144%) and the lowest value in Ochre River watershed (42%) (Figure 3.16). Application of fertilizer P averaged 116% of crop removal in the Easter region and 85% in the Western region. As for manure P, the highest value was in the Seine River watershed (78% of removal) and the lowest in the Vermillion River watershed (5%). Manure P application in the Eastern region was 30% of crop removal and only 9% for the Western region. The highest values for crop residue P, as a percentage of crop removal were in the Vermillion River watershed (41%) and the lowest in the Ochre River watershed (23%). The Eastern and Western regions had similar values for crop residues relative to crop removal (33%).

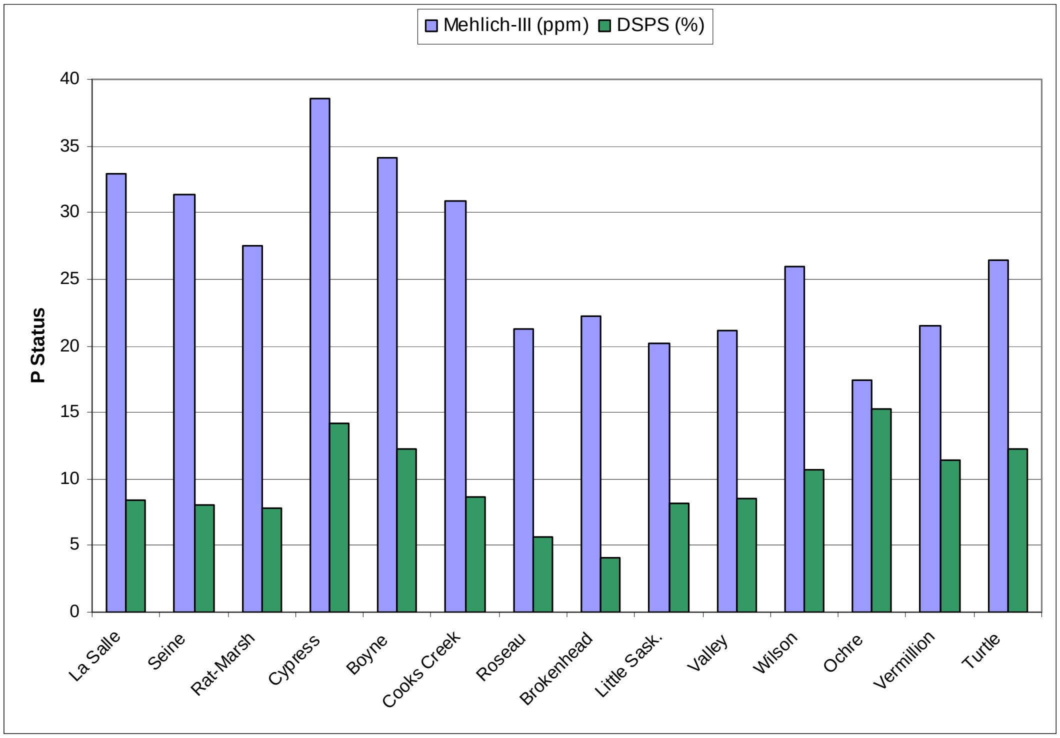

Figure 3.15 P Status results from IROWC-P for Manitoba watersheds.

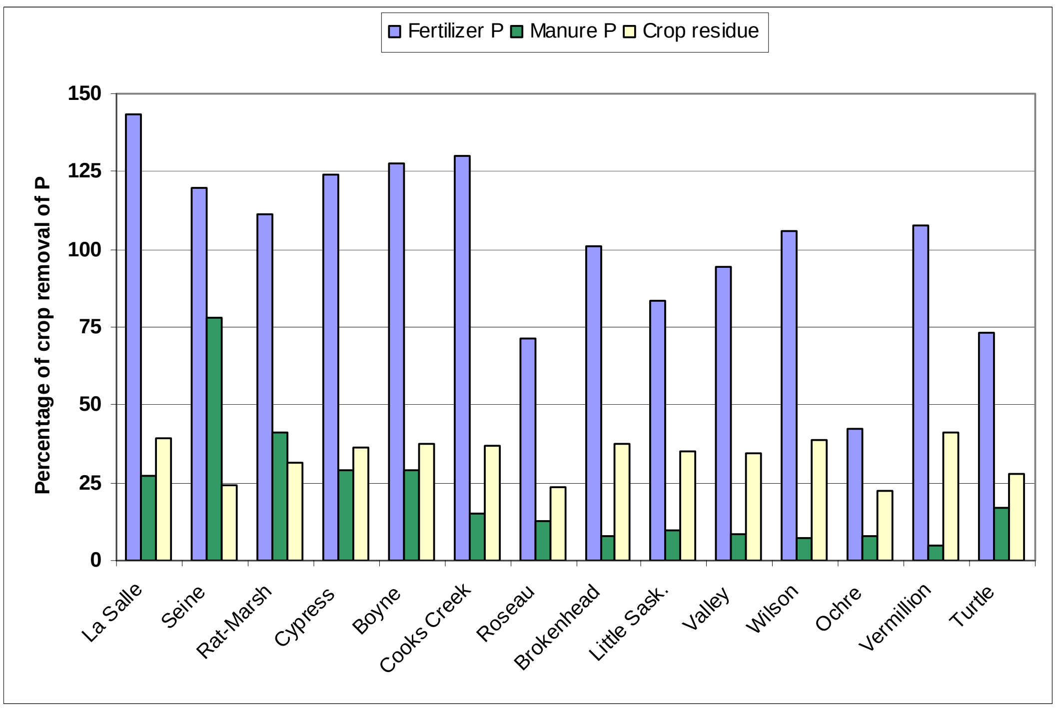

Figure 3.16 Variables comprised in the determination of annual P balance for IROWC-P for Manitoba watersheds.

3.4.4. Overall rating of risk according to IROWC-P

Watersheds with IROWC-P ratings value between 12 and 18 are characterized as very low risk, between 19 and 36 as low risk and between 37 and 72 as medium risk. All watersheds were ranked with high risk vulnerability except Roseau River and Brokenhead River with medium risk (Figure 3.17). Brokenhead River was the watershed with the lowest rating (69) and Cypress River the one with the highest (102). The difference between the risk rating average of the Eastern and Western regions was low (79 versus 82). Given the high TP concentrations frequently observed in Manitoba's surface waters, these estimates of high P risk appear to be more accurate overall, than the low to medium risk values for the other indicators.

3.4.5. Correlation between IROWC-P and its site characteristics

Table 3.8 presents the Pearson's coefficients for the correlation among site characteristics and between IROWC-P and its site characteristics. Soil test P was well correlated with mineral fertilizer P application and manure P. Mineral fertilizer P application rates were also well correlated with crop residue P. The only significant correlations with IROWC-P rating values were with erosion, runoff and, DSPS; similar to the Minnesota P index, soil test P concentrations were not significantly correlated with the risk indicator values.

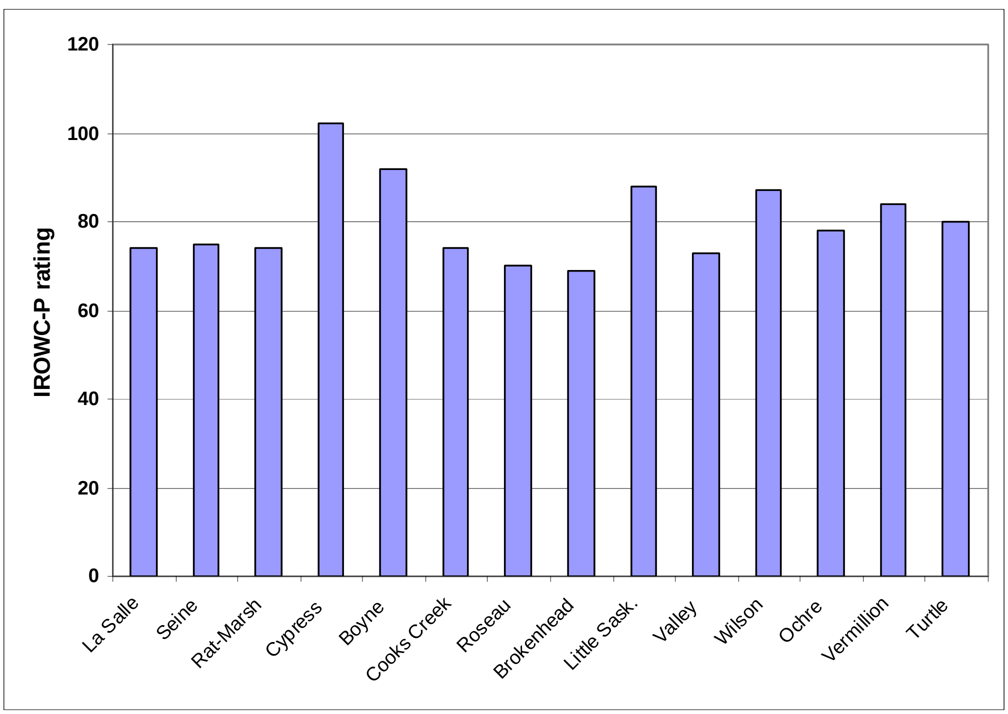

Figure 3.17 IROWC-P rating for Manitoba watersheds.

3.4.6. Correlations with water quality parameters

For IROWC-P, correlations between TP concentration and P fertilizer, manure P and soil test P were significant (Table 3.9). For the percentage of samples exceeding 0.25 mg/L, P fertilizer showed the highest correlation. All other correlations of water quality with site characteristics and the index itself were not statistically significant.

Table 3.8 Pearson's correlation coefficients for IROWC-P and its site characteristics (n = 14).

	P transport		P status		P balance		
Site characteristics	**Erosion**	**Runoff**	**STP**	**DSPS**	**Fertilizer**	**Manure**	**Crop residue**
Erosion							
Surface runoff	0.34^{ns}						
Soil test P	0.03^{ns}	0.24^{ns}					
DSPS	0.29^{ns}	0.17^{ns}	0.20^{ns}				
Mineral fertilizer P	0.03^{ns}	0.03^{ns}	0.80***	-0.17^{ns}			
Manure P	-0.30^{ns}	0.09^{ns}	0.57*	-0.07^{ns}	0.42^{ns}		
Crop residue P	0.40^{ns}	0.04^{ns}	0.28^{ns}	-0.06^{ns}	0.65**	-0.34^{ns}	
IROWC-P	0.66**	0.56*	0.44^{ns}	0.68**	0.19^{ns}	-0.02^{ns}	0.33^{ns}

*, **, *** Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ probability levels, respectively.
ns: not significant.

Table 3.9 Correlations between IROWC-P, its site characteristics and water quality parameters (n = 14).

Variables	Water quality parameters		
	TP (mg/L)	**% exceeding 0.25 mg/L TP**	**P export intensity (kg/ha/year)**
Erosion	0.02^{ns}	0.29^{ns}	-0.16^{ns}
Runoff	0.38^{ns}	-0.10^{ns}	-0.06^{ns}
Soil test P	0.80***	0.43^{ns}	-0.03^{ns}
Degree of phosphorus saturation	0.05^{ns}	-0.04^{ns}	-0.06^{ns}
P Fertilizer	0.79**	0.56*	0.09^{ns}
Manure P	0.52*	0.30^{ns}	-0.17^{ns}
Crop residues	0.35^{ns}	0.29^{ns}	0.11^{ns}
IROWC-P	0.31^{ns}	-0.02^{ns}	-0.04^{ns}

* Significant at $p < 0.05$ probability level, respectively.
ns: not significant.

3.5. Agriculture Production Intensity Parameters

Many agricultural activities can have an impact on water quality. Thus, several regressions with different agricultural production intensity parameters were examined: agricultural land use, crop production, livestock production intensity, and application rates of manure P and fertilizer P. As for crop production intensity, the proportion of land with the following crops was assessed: cereals (wheat, barley, oats, rye, buckwheat, corn for grain, mixed grain), oilseeds (canola, flaxseed, and sunflowers), perennial forages (alfalfa, alfalfa mixtures, tame hay, corn for silage, and forage for seed) and total annual crop (cereals, oilseeds, pulse crops and potatoes). The concentration of livestock, application of manure P and fertilizer P were also assessed on a density or rate per hectare basis. Detailed results are presented in Tables F.1 to F.3 in Appendix F.

First, correlations between agriculture production intensity parameters and P risk indicators were determined (Table 3.10). Minnesota P index and IROWC-P were significantly correlated with agricultural land use, cereal production, oilseed and annual crop. The preliminary P indicator for Manitoba was not significantly correlated with any of the intensity parameters.

Several measures of agricultural intensity were positively correlated with concentrations of P in water (Table 3.11). TP concentrations were highly correlated with agricultural land use, cereal production, oilseed production, total annual crop production, livestock, manure P rates and fertilizer P rates. Similarly, percentages of water samples exceeding 0.25 mg TP/L were also correlated with cereal production, oilseed production and total annual crop production and fertilizer P rates. However, none of the measures of agricultural intensity were correlated significantly with P export.

It is important to emphasize that the correlations between agricultural intensity and water quality are not, on their own, an indication of cause and effect. Intensive agricultural production is usually associated with production of annual crops and substantial application of nutrients. However, the high rates of nutrient application are usually required to match high rates of removal. Furthermore, intensive agriculture is not likely to occur unless the land is naturally fertile and the soils have a fine texture; precipitation is reasonably reliable and abundant; and where natural vegetation would otherwise grow abundantly. Therefore, the land on which intensive agricultural develops is probably intrinsically predisposed to higher rates of P loss than land that is not suited to intensive agriculture.

Table 3.10 Pearson's correlation coefficients between agriculture production intensity variables with P risk indicators (n = 14).

Variables	P risk indicators		
	Minnesota	Manitoba	IROWC-P
Agricultural land use (%)	0.57*	0.12^{ns}	0.62**
Cereal production (%)	0.67*	0.12^{ns}	0.59*
Oilseed production (%)	0.75**	0.21^{ns}	0.67**
Total Annual Crop (%)	0.70***	0.14^{ns}	0.63**
Perennial Forage (%)	-0.20^{ns}	-0.13^{ns}	0.15^{ns}
Livestock (A.U./ha)	0.22^{ns}	-0.11^{ns}	0.44^{ns}
Manure P (kg/ha)	0.04^{ns}	-0.26^{ns}	-0.02^{ns}
Fertilizer P (kg/ha)	0.31^{ns}	-0.09^{ns}	0.20^{ns}

*, **, *** Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ probability levels, respectively.
ns: not significant.

Table 3.11 Pearson's correlation coefficients between agriculture production intensity variables with water quality parameters (n = 14).

Variables	Water quality parameters		
	TP (mg/L)	% exceeding 0.25 mg/L TP	P export intensity (kg/ha/year)
Agricultural land use (%)	0.69**	0.41^{ns}	-0.03^{ns}
Cereal production (%)	0.77***	0.53*	0.08^{ns}
Oilseed production (%)	0.74***	0.53*	0.17^{ns}
Total Annual Crop (%)	0.76***	0.52*	0.11^{ns}
Perennial Forages (%)	0.04^{ns}	-0.12^{ns}	-0.08^{ns}
Livestock (A.U./ha)	0.63**	0.33^{ns}	-0.04^{ns}
Manure P (kg/ha)	0.48*	0.27^{ns}	-0.19^{ns}
Fertilizer P (kg/ha)	0.75***	0.59*	0.02^{ns}

*, **, *** Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ probability levels, respectively.
ns: not significant.

3.6. ACC and WQMZ for Nutrients

As mentioned in the preceding section, the intrinsic characteristics of land suited to intensive agriculture maybe at least partly responsible for high correlations between agricultural intensity and TP concentrations in water. To explore this issue further, the correlation between ACC, WQMZ for nutrients and water quality parameters were analyzed (Table 3.12). The numerical values for ACC and WQMZ were highly and negatively correlated with TP concentration, moderately and negatively correlated with percentage of samples exceeding 0.25 mg P/L. These correlations indicate that land suited to intensive agricultural production is also prone to P loss. Correlations for ACC and WQMZ with P export intensity were very low and insignificant.

As expected, the intrinsic characteristics of the watershed's land base were frequently correlated with agricultural intensity. For example, ACC was highly correlated with agricultural land use, cereal production, oilseed production, total annual crop acreage and fertilizer P rates (Table 3.13). Similar correlations were observed between these measures of agricultural intensity and WQMZ. Interestingly, livestock density was moderately and negatively correlated with ACC, but not significantly correlated with WQMZ.

Table 3.12 Correlations between ACC, WQMZ indicators and water quality parameters (n = 14).

Indicators	Water parameters		
	TP (mg/L)	% exceeding 0.25 mg/L TP	P export intensity (kg/ha/year)
Agricultural capability classes	-0.70**	-0.55*	-0.05ns
Water quality management zones	-0.78***	-0.61*	-0.10ns

*, **, *** Significant at p < 0.05, p < 0.01 and p < 0.001 probability levels, respectively.
ns: not significant.

Table 3.13 Pearson's correlation coefficients between ACC, WQMZ indicators and agriculture production intensity variables (n = 14).

Parameters	ACC	WQMZ
Agricultural land use (%)	-0.79***	-0.70**
Cereal production (%)	-0.81***	-0.83***
Oilseed production (%)	-0.69**	-0.72**
Total annual Crop (%)	-0.76***	-0.79***
Perennial forages (%)	-0.29ns	-0.01ns
Livestock (A.U./ha)	-0.46*	-0.38ns
Manure P (kg/ha)	-0.39ns	-0.38ns
Fertilizer P (kg/ha)	-0.81***	-0.92***

*, **, *** Significant at p < 0.05, p < 0.01 and p < 0.001 probability levels, respectively.
ns: not significant

It is important to mention that all correlations were negative: the lower the AC class and the WQM zone are, the more important the contamination by P is (higher TP concentration and higher percentage of exceeding). Lower numerical values for ACC and WQMZ represent highly productive agriculture lands where there is a relatively high risk of P loss to surface water (Manitoba Water Stewardship, 2005).

4. SUMMARY AND CONCLUSIONS

Overall accuracy of risk indicators

The overall risk ratings for the watersheds were substantially different, depending on which risk indicator was used (Table 4.1). IROWC-P generally gave the highest ratings of risk (vulnerability classes of medium and high) and Minnesota P Index the lowest (very low and low). As mentioned previously, the high overall risk ratings determined by IROWC-P may be more accurate than the ratings provided by other indicators, given that most of the TP concentrations would be regarded as highly conducive to eutrophication. From a regional perspective, the Minnesota P Index rated Western Manitoba watersheds as more vulnerable to P loss than Eastern Manitoba watersheds, but that trend was opposite for Manitoba's preliminary P risk indicator and no regional trend was observed for the IROWC-P.

Correlations between risk indicators and water quality

Correlations between P risk indicators and water quality parameters were poor and generally insignificant. The only significant correlation was between Minnesota P Index and percentage of samples exceeding 0.25 mg/L, where this P risk indicator accounted for 24% of the variation in this water quality parameter.

Table 4.1 Risk rating for Minnesota P Index, preliminary P risk indicator for Manitoba and IROWC-P for Manitoba watersheds.

Watershed	Minnesota		Manitoba		IROWC-P	
	P Rating	Risk Class	P Rating	Risk Class	P Rating	Risk Class
La Salle	21.3	Low	36.5	Medium	74.0	High
Seine	15.8	Very low	50.0	Medium	75.0	High
Rat-Marsh	13.2	Very low	36.5	Medium	74.0	High
Cypress	21.5	Low	58.0	Medium	102.0	High
Boyne	22.8	Low	58.0	Medium	92.0	High
Cooks Creek	9.8	Very low	54.0	Medium	74.0	High
Roseau	7.5	Very low	30.5	Low	69.0	Medium
Brokenhead	10.0	Very low	35.0	Medium	70.0	Medium
Little Saskatchewan	19.5	Very low	74.0	High	73.0	High
Valley	19.5	Very low	66.0	Medium	88.0	High
Wilson	20.3	Very low	66.0	Medium	87.0	High
Ochre	16.5	Very low	56.0	Medium	78.0	High
Vermillion	19.5	Very low	66.0	Medium	84.0	High
Turtle	12.3	Very low	60.0	Medium	80.0	High

Among the site characteristics that were utilized to generate the risk ratings, erosion risk was not significantly correlated with any of the water quality measurements, but accounted for nearly half of the variation in risk ratings for the three indicators. Conversely, soil test P accounted for 63% of the variation in TP concentrations, but was not significantly correlated with the variation in values for the Minnesota P index or the IROWC-P. In other words, although erosion seems to be the site characteristic with the most influence on the value of the P risk indicators, soil test P seems to be the characteristic with the most influence on TP concentrations in water. Therefore, existing P indexes appear to be too heavily weighted towards erosion processes (a transport factor) and too lightly weighted towards soil test P (a source factor) to be appropriate for use under Manitoba conditions. Also, any risk index that does not include soil test P values (e.g., the preliminary P risk indicator for Manitoba) is of little value.

The only indicator or site characteristic that was significantly correlated with P export intensity was runoff, as measured simply by total water flow (fed by surface and subsurface flow to the stream) in the Minnesota P Index. None of the risk indicators or terrestrial characteristics for the watersheds, including potential for overland flow, was significantly correlated with P export. Therefore, the value of using these risk indicators or site characteristics for predicting or managing this water quality issue appears to be extremely limited. In other words, P export intensity may be more a function of water management and climatic variables, than nutrient management and land characteristics.

Correlations between agricultural intensity or land capability and water quality

Measures of agricultural intensity (e.g., proportion of land used for agriculture, cereal production, oilseed production, total crop production) were well correlated with the Minnesota and IROWC-P risk indicator values and highly correlated with TP concentrations in water. However, none of the source factors (livestock density, manure P and fertilizer P) correlated significantly with the risk indicators, even though all of these factors were also positively correlated with TP concentrations water. Given that all of these source factors are significantly correlated with soil test P, this observation appears to corroborate the earlier conclusion, that soil test P values are a very important factor to consider when predicting P loss in Manitoba watersheds and may be under-emphasized in existing P risk indicators.

However, the positive correlation between agricultural intensity and TP concentrations in water does not imply a simple cause and effect relationship. As mentioned previously, the intrinsic properties of land that is suited to intensive agriculture may also play an important role. This type of land is often naturally prone to P loss because it is fine-textured, fertile, with moderate to low infiltration rates and large amounts of plant growth, rich in vegetative P. In addition, the large export of P in high yielding crops requires high rates of P application to maintain the fertility of the soil. Therefore, part of the correlation between agricultural intensity and water quality may be the nature of the land on which intensive agriculture is practiced.

With respect to land quality, ACC and WQMZ were strongly correlated with TP concentration, accounting for 49% and 60%, respectively, of the variation in TP concentrations in water samples. This observation substantiates the general perception that high quality agricultural land in Manitoba is generally more prone to P loss than low quality land (Manitoba Water Stewardship, 2005).

Recommendations

Given the poor correlations between the risk indicators and most water quality measurements, more work is needed to provide a reasonable estimate of a site's potential for P loss to surface water, under Manitoba's soil, landscape and climatic conditions, and under different agricultural management practices.

Some of the work that is required should be directed towards improved water quality measurements. Water quality data for this study were, for the most part, sparse, making it difficult to establish any trend in the temporal distribution of TP concentration. This also could be explained in part by the fact that in some regions of the Province, contribution from groundwater to surface water flow is important. These water inputs certainly have for effect to dilute any nutrient concentrations and then render any relation between surface runoff and water quality difficult to assess. This phenomenon should be investigated and if it is possible, be qualified and quantified. An event-based sampling frequency would also improve the quality of the data; most of the surface water flow occurs during the snowmelt and a few major rainfall events. These are the times when frequent samples for water quality should also be collected. Point source inputs of P should also be accounted for. Major cities as well as smaller communities discharge secondary effluent directly into Manitoba's waterways (Jones and Armstrong, 2001). In this study, no watersheds with major point sources were included; therefore, point source P inputs were not considered. However, periodic (e.g., semi-annual) discharges from municipal lagoons would have a significant impact on water quality measurements, especially if samples were collected shortly after the discharge. The contribution of P from those point sources should be accounted for, so that the data can be used more effectively for future research into watershed processes.

As mentioned, no P risk indicators correlated well with regional water quality data; none, for example, correlated significantly with TP concentrations in surface water. Therefore, more research is required to understand the processes that are responsible for P export in Manitoba watersheds and the management practices that will be required to reduce that loading. Source factors, such as soil test P, appear to be important factors determining P loss to Manitoba waterways, but are under-emphasized in existing indicators. Conversely, transport factors, such as erosion and runoff, are relatively unimportant factors and appear to be over-emphasized in existing indicators.

Without a clear understanding of the causes of excess P concentrations in our waterways, there is little chance of developing and implementing effective and efficient beneficial management practices (BMPs) to correct the problem. For example, given the extremely poor relationship between erosion and TP concentrations, traditional BMPs, such as conservation tillage and vegetative buffer strips, are unlikely to yield significant reductions in P loading to water under Manitoba conditions, where snowmelt-induced runoff of dissolved P is the predominant form of P loss.

Lastly, this study shows that the balance between the influence of source factors (e.g., soil test P) and transport factors (e.g., erosion and runoff) on P loss appears to vary with regional land and climatic factors. The challenge of developing a single indicator to predict the risk of P loss across Canada will be extremely difficult. Factors and weighting values might have to be adjusted from one ecoregion to another. For example, in areas where erosion is a relatively unimportant mechanism for P loading, erosion risk could be granted a very low weighting factor (perhaps as low as zero for preliminary evaluation). However, in the long term, calculation methods for P indicators should be reconsidered to obtain a more effective and universal rating system, that accounts for all processes of P loss to surface water, using a combination of adding factors (summation) and multiplying factors (product). Thus, there is still a substantial challenge to develop calculation methods that quantify the risk of P loss in a manner that will be representative of the dominant processes for P export in all areas of the country.

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APPENDIX A

WATERSHEDS DESCRIPTION

Table A.1 Watersheds description (from Jones and Armstrong, 2001).

Characteristics	La Salle River	Seine River	Rat-Marsh River	Cypress River	Boyne River	Cooks Creek	Brokenhead
Location	10 km southeast of Portage la Prairie	120 km from its headwaters in the Sandilands Forest to its confluence with the Red River in Winnipeg	In the Sandilands Provincial Forest region of southeastern Manitoba	Along the eastern edge of the Manitoba escarpment near the village of Somerset	On the northeastern edge of the Pembina Hills region in southern Manitoba	It flows in a northerly direction (60 km) before emptying into the Red River near Selkirk	Northwest of Sandilands Provincial Forest, east of Richer
Watershed size (km^2)	2,406	2,107	2,011	813	1,745	747	2,637
Tributary of	Red River	Red River	Red River	Assiniboine then Red River	Red River	Red River	Lake Winnipeg
Land uses	Intensively cultivated agricultural land with livestock operations	Cereal crop cultivation and livestock production (beef and dairy cattle, chickens, and hogs)	Forest uplands, marshes, and poorly drained peatlands Pasture, rangeland and hay crops	Agriculture, livestock production and cereal crop cultivation	Crop production	Intense cultivation Dredged and channeled for flood control and agricultural use	Cereal and forage crop prodduction (western portion) and forested uplands and wetlans (eastern portion)
Water uses	Multi-use: fishing and canoeing, raw water for several communities Livestock watering and agricultural irrigation	Agriculture and recreational activities	Impoundment (St-Malo Reservoir), fish and wildlife habitat and recreational activities and livestock watering	Fish habitat, livestock watering and agricultural irrigation	Agricultural, recreation activities such as fishing, boating, canoeing and swimming Drinking water source for Carman	Intense cultivation in western and nothern extremes	Agriculture (western portion)
Point source pollution	Several wastewater lagoons (secondary effluent)	Wastewater lagoons (2nd treated effluent, in the past) (La Broquerie, Ste-Anne, and Lorette)	Wasterwater treatment facilities at St-Pierre, St-Malo, St-Malo prov park, Winnipeg Bible College and Grunthal	Wastewater lagoons at Somerset, Cypress River and Holland	Hutterite colony lagoons as well as number of municipal lagoons (Treherne and Carman)	Municipal wastewater treatment facility at Oakbank	Effluent discharges (Beausejour)
Water quality stations	WQ0068	WQ0166	WQ0131	WQ0398	WQ0029	WQ0644 and WQ0643	WQ0038
Hydrometric stations	MB05OG001	MB05OH006 and MB05OH009	MB05OE001	MB05MH008	MB05OF003	MB05OJ019 and MB05OJ006	MB05SA002
Years of monitoring	1974 - 1999 (no data from 1978-1988)	1973 -	1973 - 1999 (no data from 1978-1987)	1978 - 1999	1973 - 1996 (no data from 1979-1989)	1990 - 1999	1973 -1999

Table A.1 Watersheds description (continued).

Characteristics	Valley River	Little Saskatchewan River	Wilson River	Ochre River	Vermillion River	Turtle River	Roseau River
Location	Southeastern corner of Duck Mountain Provincial Park	Source from Whitewater Lake in Riding Mountain National Park	Confluence of East Wilson River and West Wilson River north of Riding Mountain National Park	Confluence of 2 smaller streams in Riding Mountain National Park	Northern boundary of Riding Mountain National Park	Southeast of the community of McCreary (east of Riding Mountain National Park)	Enters Manitoba to meander in a westerly direction until its confluence with the Red River of Dominion City
Watershed size (km^2)	2,961	4,146	996	372	757	1,767	2,591
Tributary of	Dauphin Lake	Rivers Reservoir then in Assiniboine River	Dauphin Lake	Dauphin Lake	Dauphin Lake	Dauphin Lake	Red River
Land uses	Forest (provincial parks), agriculture (cereal and hay crop) and livestock	Crops and pastureland	National Park and agricultural (crop cultivation)	Forested uplands and cultivated fields	Recreation and wildlife habitat and agricultural crops and livestock production	Forested uplands and narrows valleys and agriculture outside the park	Agricultural activities: livestock husbandry and cereal crop cultivation, with hay crop production to the east
Water uses	Raw water for communities and spawning river for number of fish species	Recreation purposes and raw water source for town of Rivers	Agriculture (crop)	Agriculture	Raw water for Dauphin, recreation purposes and important spawning waterway	Recreational purposes, aquatic habitat, some irrigation and drinking water	Fish habitat and riparian wildlife. Recreational activities: sport fishing and canoeing and agricultural watering
Point source pollution	Wasterwater treatment lagoon and municipal facilities	Municipal wasterwater lagoon		Periodic discharges of treated effluent from municipal wasterwater treatment lagoon	Periodical discharges of treated effluent of Dauphin	Municipal wastewater discharges (treatment lagoons at Laurier and Ste-Rose Du Lac)	Discharges of treated wastewater effluent from Roseau (MN) and Dominion City (MB)
Water quality stations	WQ0250	WQ0105	WQ0255	WQ0227	WQ0252	WQ0245	WQ0153
Hydrometric stations	MB05LJ010	MB05MF018	MB05LJ045	MB05LJ005	MB05LJ012	MB05LJ007	MB05OD001
Years of monitoring	1978 - 1999	1965 - 1996	1979 - 1999	1988 - 1999	1974 - 1999	1988 - 1999	1973 - 1999

APPENDIX B

P RISK INDICATORS AND OTHER RISK INDICATORS DESCRIPTION

B.1 MINNESOTA'S P INDEX

This modified version of the original P Index developed by Lemunyon and Gilbert (1993) was used to prioritize P loss vulnerability at the regional level (Birr and Mulla, 2001). Table B.1 presents the site characteristics of this P index. The following sections briefly describe each site characteristic and how they will be assessed in this project.

Table B.1 Minnesota's P index (Birr and Mulla, 2001).

	P loss potential (rating value)				
Site characteristic (weighting value)	**Very low (0)**	**Low (1)**	**Medium (2)**	**High (4)**	**Very high (8)**
Transport factors					
Soil erosion (t/ha) (1.5)	0	1-5	6-14	15-21	> 21
Runoff (cm) (0.5)	0-8	9-13	14-16	17-21	> 21
% of cropland and pastureland[1] (1.5)	0-1.2	1.3-3	3.1-4.2	4.3-6.2	> 6.2
Source factors					
Soil test P[2] (0.75)	0-19	20-26	27-31	32-39	> 39
Fertilizer P application rate (kg P/ha) (1.0)	0-7	8-13	14-19	20-24	> 24
Fertilizer P application method (0.5)	None applied	With planter[3]	Incorporated[4]	Incorporated[5] or surface applied[6]	Surface-applied[5]
Organic P source application rate (kg P/ha) (0.5)	0-2	3-6	7-8	9-11	> 11
Organic P source application method (0.5)	None applied	With planter[3]	Incorporated[4]	Incorporated[5] or surface applied[6]	Surface-applied[5]

[1] Within 91.4 m of a watercourse
[2] Bray P1 or Olsen-P (mg P/kg)
[3] Deeper than 5 cm
[4] Immediately before crop
[5] More than 3 months before crop
[6] Less than 3 months before crop

B.1.1 TRANSPORT FACTORS

B.1.1.1 Soil Erosion

Soil erosion potential was calculated using USLE. We used the data sets prepared by Agriculture and Agri-Food Canada: SLC[1] version 3.0. The variable for the water erosion risk class is C_ERPOLY[2]. Each map polygon is ranked within seven classes: negligible (< 6 t/ha/y), now (6-11 t/ha/y), moderate (11-22 t/ha/y), high (22-33 t/ha/y), severe (>33 t/ha/y), water and unclassified. After sorting all the polygons of the studied watershed, according to the erosion risk classes, the percentage of the land represented by each of the different classes was calculated. The highest percentage determined the soil erosion potential of the watershed.

[1] SLCs were originally conceived as a standardized database consisting of major attributes important to plant growth, land management, and soil degradation.
[2] Classification field for Water Erosion Risk Class categorized by summarizing the estimated soil loss on bare unprotected soil using all soil components in the map polygon. Summary calculation of estimated soil loss on bare unprotected soil implementing the USLE in the map polygon measured in t/ha/year.

B.1.1.2 Runoff

We assessed the runoff with the method used by Birr and Mulla (2001). The average runoff value is calculated as the average annual discharge divided by the drainage basin area defined for the region. Therefore, not all the “runoff” in this estimate is true surface runoff; some of this flow especially in coarse-texture areas and “pothole” topography is groundwater-fed base flow. We use the mean annual flow rate or the river, measured by the gauging station of each watershed.

B.1.1.3 Percentage of cropland and pastureland within 91.4 m of a watercourse

Birr and Mulla (2001) estimated the area of cropland and pastureland within 91.4 m of drainage ditches and perennial streams by using hydrography coverages. For Manitoba, those data were not available. We chose to use the percentage of land cover (e.g. cropland, pastureland and forage) in a 50 m buffer area around all water courses and waterbodies in the watershed based on the 1:50,000 National Topographic Series (NTS) data sheets (AAFC_PFRA, 2005).

B.1.2 SOURCE FACTORS

B.1.2.1 Soil test P

For this P index, the P soil test recommended is either Bray P1 or Olsen-P. However, the only P soil test data available in Manitoba were obtained using the Kelowna-modified method of analysis. These data were from a private analytical testing laboratory. For the most part, data were associated to legal location. Once the data were sorted by location, it was possible to calculate a mean value of P soil test for each watershed.

The following conversion equation was used to assess the Olsen P soil value: Olsen-P = 2.26 + 0.77 Kelowna-P (Akinremi et al., 2004). This result was then divided by a conversion factor of 0.71 to obtain a Bray P1 value (Moncrief et al., 2002).

B.1.2.2 Fertilizer P application rate

To assess the fertilizer P application rate, we needed to determine the quantity of fertilizer P applied on the cropland area of the watershed (number of hectares used for crop and hay production and summerfallow). The only values available at the regional scale were the fertilizer expenses. The fertilizer P values were based on summation of area-weighted census-district--based values intersecting the watershed. The aggregated fertilizer P value was divided by the aggregated reported fertilized land for each region to determine fertilizer P application rates. This procedure assumes that the fertilizer P is distributed equally over the total fertilized area.

These data are from the 2001 CENSUS of Agriculture: the variable is FERTPD (fertilizer and lime purchased in dollars). Fertilizer dollars spent for Manitoba ($_Fertilizer_Manitoba) come from the document Canadian Fertilizer Consumption, Shipment and Trade (Korol, 2002). The proportion of the fertilizer expenses watershed versus province, was then used to assess the quantity of P_2O_5 (tonnes) for the watershed.

$$\frac{\text{\$\_Fertilizer\_Watershed}}{\text{\$\_Fertilizer\_Manitoba}} = \text{Proportion\_Fertilizer}$$

$$\text{Proportion\_Fertilizer} * \text{Total\_Manitoba} = \text{Quantity\_Watershed}$$

B.1.2.3 Fertilizer P application method

Regarding the fertilizer P application method, we had to choose among five different methods the most representative one for the region. For all watersheds, we choose the application method "placed with planter deeper than 5 cm" as the most representative of what happens in those regions (Don Flaten, personal communication).

B.1.2.4 Organic P source application rate

For the Minnesota P index, the P content of livestock manure was calculated based on the total number of cattle[3], pigs[4], poultry[5] and others[6] reported for the watershed. The data from the 2001 CENSUS of Agriculture were used. The total number of animal units for each type of livestock was assessed, then the total weight was calculated to enable us to assess the P production per 1,000 kg per day. This value was then distributed on the total crop land area of the watershed (number of hectares used for crop and hay production and summerfallow). The distribution of organic P application was assumed to be uniform throughout the total reported cropland area.

B.1.2.5 Organic P source application method

Similar to fertilizer P application, five different methods were available to choose for the organic P application method. For watersheds in Manitoba, none of these methods applied. Therefore, we had to choose an application method representative of the potential for nutrient export prevailing in the watershed: a medium P export potential was selected for the watershed with cattle as the predominant livestock and for the watershed with pigs as predominant livestock, a high P export potential was chosen (Petra Loro, personal communication)..

B.1.3 CALCULATION OF THE P INDEX

The P Index rating is the summation of the product of the rating value and corresponding weighting value for each site characteristic.

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[3] Beef cows, bulls (1 year and over), calves (under 1 year), total heifers (1 year and over), dairy cows and steers (1 year and over)
[4] Boars, sows and gilts for breeding, nursing and weaner, grower and finishing
[5] Broilers, roasters and Cornish, laying hens (19 weeks and over), pullets (under 19 weeks) and turkeys
[6] Horses and ponies, various large livestock (boars, bison, llamas and deer), various small livestock (mink, rabbits and/or fox)

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B.2 MANITOBA PRELIMINARY P INDICATOR

This P indicator is part of a model designed to provide an overview of the ability of Manitoba's land to support intensive livestock operations (AXYS Agronomics, 2002). The model was organized in terms of source, pathway and receptor for both nitrogen- and P-related variables. Table B.2 summarized the site characteristics and the P risk weighting composing this P index.

Table B.2 Preliminary P Indicator for Manitoba of short-term risk of surface water contamination.

	P risk weighting (rating value)				
Site characteristics (weighting value)	**Very low (1)**	**Low (2)**	**Medium (4)**	**High (8)**	**Very high (16)**
P Source Factors					
Overall P balance (kg P/ha/yr) (2.0)	<0	0-20	20-40	40-60	>60
Crop residue P (kg P/ha/yr) (1.0)	<0.5	0.5-1.0	1-4	4-10	>10
Estimated P sorption index (PSI) (4.5)[1]	>600	400-600	250-400	100-250	<100
P Pathway Factors					
Soil erosion (kg/ha) (1.0)	< 500	500-2,000	2,000-6,000	6,000-15,000	>15,000
Overland flow potential (2.5)	Very low	low	Moderate	High	Very high
Composite index	11-17	18-34	35-68	69-136	136-176

Notes: 1 PSI = X/log C
X = amount of sorbed P (mg/kg)
C = P concentration in solution (mg/L)
SOURCE: adapted from Bolinder et al. (2000)

B.2.1 P SOURCE FACTORS

The source of P includes both source and sinks of P. The overall concentration of P on a given field available as a "source" depends upon three factors:

- P additions from manure, fertilizer and crop residue;
- P retention capacity (measured using PSI);
- P removal via crop export.

B.2.1.1 Overall P balance

The overall P balance is used to account for additions form manure and fertilizer and removals from crop. The unit for this variable is kg P/ha/yr. The P balance is determined using the following equation:

Overall P balance = Manure P + Fertilizer P – Crop export

B.2.1.2 Manure P

For the preliminary P index for Manitoba, the P content of livestock manure was calculated with the total number of cattle[7], pigs[8], poultry[9] and, others[10] reported for the watershed. The data

[7] beef cows, bulls (1 year and over), calves (under 1 year), total heifers (1 year and over), dairy cows and steers (1 year and over)
[8] boars, sows and gilts for breeding, nursing and weaner, grower and finishing
[9] broilers, roasters and Cornish, laying hens (19 weeks and over), pullets (under 19 weeks) and turkeys

from the 2001 CENSUS of Agriculture were used. The total number of animal units for each type of livestock was assessed, then the total weight was calculated to enable us to assess the P production per 1,000 kg per day. The distribution of organic P application was assumed to be uniform throughout the total reported cropland area.

B.2.1.3 Fertilizer P

To assess the fertilizer P application rate, we needed to determine the quantity of fertilizer P applied on the cropland area of the watershed (number of hectares used for crop and hay production and summerfallow). The only values available at the regional scale were the fertilizer expenses. The fertilizer P values were based on summation of area-weighted census-district--based values intersecting the watershed. The aggregated fertilizer P value was divided by the aggregated reported fertilized land for each region to determine fertilizer P application rates. This procedure assumes that the fertilizer P is distributed equally over the total fertilized area.

Those data are from the 2001 CENSUS of Agriculture: the variable is FERTPD (fertilizer and lime purchased in dollars). Fertilizer dollars spent for Manitoba ($_Fertilizer_Manitoba) come from the document Canadian Fertilizer Consumption, Shipment and Trade (Korol, 2002). The proportion of the fertilizer expenses watershed versus province, was then used to assess the quantity of P_2O_5 (tonnes) for the watershed.

$$\frac{\text{\$\_Fertilizer\_Watershed}}{\text{\$\_Fertilizer\_Manitoba}} = \text{Proportion\_Fertilizer}$$

$$\text{Proportion\_Fertilizer} * \text{Total\_Manitoba} = \text{Quantity\_Watershed}$$

B.2.1.4 Crop export

As mentioned, the main sinks for soil P are crop uptake and removal. To assess the crop export, we used three variables for each crop: area (watershed-based data from CENSUS 2001), yields (data from Manitoba agriculture year book, 2001) and nutrient removal (data from AXYS Agronomics, 2002). The crops chosen were grain corn, all wheat, barley, oats, rye, canola, flax, potatoes, alfalfa and other tame hay were used; they represented in excess of 95% of total crop production in Manitoba (Flaten et al., 2003).

B.2.1.5 Crop residue P

Crop residue is determined by assessing the P content of straw and chaff remaining on fields after harvest. It was determined by assessing the P content of straw and chaff remaining on fields after harvest (AXYS Agronomics, 2002). As for crop export, the crops chosen were grain corn, all wheat, barley, oats, rye, canola, flax, potatoes, alfalfa and other tame hay. The data for those crops were from the CENSUS 2001.

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[10] horses and ponies, various large livestock (boars, bison, llamas and deer), various small livestock (mink, rabbits and/or fox)

B.2.1.6 P retention capacity

PSI is used to estimate P retention capacity. P retention capacity has not been determined in Manitoba soils; the estimate of retention capacity is based on an empirical equation derived for P retention studies on neutral to calcareous in Quebec. Correlation and multivariate analysis using the Quebec (Regis Simard, personal communication) data showed that the soil's cation exchange capacity (CEC) provided a reasonable estimate of the PSI. The following equation is used to determine PSI (r^2=0.52):

$$PSI = 25 + 8.73\ CEC$$

CEC is available for the documented soil series in Manitoba in the Manitoba Soil Layer File. Further research is needed to assess this parameter adequately.

B.2.2 P PATHWAYS FACTORS

B.2.2.1 Soil erosion

Soil erosion potential was calculated using USLE. We used the data sets prepared by Agriculture and Agri-Food Canada: SLC[11] version 3.0. The variable for the water erosion risk class is C_ERPOLY[12]. Each map polygon is ranked within seven classes: negligible (< 6 t/ha/y), now (6-11 t/ha/y), moderate (11-22 t/ha/y), high (22-33 t/ha/y), severe (>33 t/ha/y), water and unclassified. After sorting all the polygons of the studied watershed, according to the erosion risk classes, the percentage of the land represented by each of the different classes was calculated. The highest percentage determined the soil erosion potential of the watershed.

B.2.2.2 Overland flow potential

The parameters used were the topography (% of slope, variable C_SLOPE[13]) and texture (profile, variable C_SURFTEXT[14]). The values for the variables came from SLC V. 3.0. The percentage of each of the different classes was calculated to assess the most important one. We then compute the percentage of the watershed characterized by those classes. We did that for each variable. Then we use the classification of the table to determine the most important type of runoff for the watershed. Table B.3 (from AXYS Agronomics, 2002) was then used to assess the runoff class from soil permeability and slope.

[11] SLCs were originally conceived as a standardized database consisting of major attributes important to plant growth, land management, and soil degradation.

[12] Classification field for Water Erosion Risk Class categorized by summarizing the estimated soil loss on bare unprotected soil using all soil components in the map polygon. Summary calculation of estimated soil loss on bare unprotected soil implementing the USLE in the map polygon measured in tonnes/hectare/year.

[13] Classification field summarizing slope steepness based on the dominant slope gradient of map polygon.

[14] Classification field for summarizing surface texture representing the dominant soil series of the map polygon.

Table B.3 Runoff class determination from soil permeability and slope (from AXYS Agronomics, 2002).

Slope (%)	Soil Permeability Class				
	Very rapid	Moderately rapid, Rapid	Moderately Slow, Moderate	Slow	Very slow
< 1	VL	VL	VL	L	M
1-4.99	VL	VL	L	M	H
5-9.99	VL	L	M	H	VH
10-20	VL	L	M	H	VH
>20	L	ML	H	VH	VH

The runoff classes are as follow: VL-very low; M-moderate; H-high, VH-very high.

B.2.3 CALCULATION OF THE P INDICATOR

The preliminary Manitoba P Indicator is the summation of the product of the rating value and corresponding weighting value for each site characteristic.

REFERENCES

AXYS Agronomics. 2002. Manitoba Conservation Soil Sustainability Study Model Parameters. Report AG123, October 2002. 127 pages.

Korol, M. 2002. Canadian Fertilizer Consumption, Shipments and Trade 2000/2001. Report prepared for Agriculture Agri-Food Canada. April 2002. 31 pages.

B.3 INDICATOR OF WATER CONTAMINATION BY PHOSPHORUS (IROWC-P)

The IROWC-P is derived from the P-Index developed by Lemunyon and Gilbert (1993) and combined with aspects of IROWC-N (Indicator of Water Contamination by Nitrogen). This index allowed the evaluation of various topographic and pedological configurations such as various practices of management on the risk of transport of P towards the rivers. The procedure was based on characteristics like the erosion, runoff, relative proximity of a water body, type of vegetation, presence of pasture, nutrients concentration in soil as well as the amounts, the mode and the period of P application. The actual version of the national IROWC-P was built on the IROWC-P version developed for Quebec soils by Bolinder et al. (2000). The national version will be calculated at both SLC polygon and watershed levels using existing 2001 CENSUS of Agriculture of Agriculture, farm environmental management surveys, hydrology and climate databases (van Bochove et al., 2004).

The modified IROWC-P includes three components: the *soil P-status component* (PS), the *annual P-balance component* (PB) and the *P transport-hydrology component* (PT-H). The different subcomponents will be weighted to estimate their relative importance for P transfer and rated by their corresponding P class values. Table B.4 summarizes the components, their site characteristics and weighting factors. The three component values will be combined according to the following equation to estimate the risk of water contamination by P (van Bochove et al., 2004):

IROWC-P = (PS + PB) PT-H

As mentioned, IROWC-P values will be associated to five vulnerability classes to obtain a corresponding magnitude of risk for each polygon. The following sections present a brief description for each IROWC-P components. For a more detailed description, see van Bochove et al. (2004).

B.3.1 P STATUS

The P status component is characterized by the degree of soil P saturation and its long-term capacity to retain P. It is defined as the ratio of the soil-test P to the inherent soil characteristic, the P sorption capacity.

B.3.1.1 P Soil test

The P soil analysis is estimated with by Mehlich-III extractable P. However, the only P soil test data available for the selected watersheds were done with modified-Kelowna analysis. These data were obtained from a private analytical testing laboratory. Some calculations will be needed to transform the latter in Mehlich-III to be able to assess the indicator..

B.3.1.2 Degree of soil phosphorus saturation (DSPS)

DSPS was computed from two databases, both at the SLC polygon and watershed levels: a soil-test P and P sorption capacity. The degree of soil P saturation has five rating values from very low to very high.

Table B.4 IROWC-P develop in Quebec at the SLC polygon level

	P loss rating (value)				
Site characteristics (weighting factor)	**Very low (1)**	**Low (2)**	**Medium (4)**	**High (8)**	**Very high (16)**
P status					
P soil test (STP)[1] (2.5)	< 60	60-150	150-250	250-500	> 500
DSPS[2] (2.0)	0-2.5%	2.5-5.0%	5.0-10%	10-20%	> 20%
P balance					
Mineral fertilizer P[3] (1.0)	< 50%	50-100%	100-150%	150-200%	> 200%
Manure P[4] (2.0)	< 50%	50-100%	100-150%	150-200%	> 200%
Crop residues P[5] (1.0)	< 2%	2-5%	5-20%	20-50%	> 50%
P transport[6]					
Soil water erosion loss (kg/ha) (1.0)	< 500	500-2000	2000-6000	6000-15000	> 15000
Surface runoff (2.5)	Very low	low	Moderate	High	Very high
Infiltration[7]					
Topographic index[7]					
Tile drainage[7]					
Preferential flow[7]					
Surface drainage density[7]					
Weighted rating values	12-18	19-36	37-72	73-144	145-192
Site vulnerability classes	Very low	Low	Medium	High	Very high

[1] Mehlich-III extractable P (kg P ha^{-1})
[2] (Mehlich-III P/Mehlich-III Al) x 100
[3] Estimated with the dollars spent on fertilizer and lime at the polygon level (source: 2001 Census of Agriculture database)
[4] Estimated from livestock, manure production coefficients and manure P coefficient for each category (source: 2001 Census of Agriculture database)
[5] Estimated for P uptake and P harvest coefficients (source: 2001 Census of Agriculture database)
[6] Many subcomponents are under development (algorithms, weighted factors and P loss rating value are to be precise.
[7] In development

The soil P saturation percentage is the ratio between the soil P content and aluminium content in a field, both extracted by Mehlich-III solution. This value is calculated in the following manner:

[M-III P content (kg P/ha) / M-III Al content (mg Al/kg soil) x 2.2] x 100

As for the P soil test, some calculations will be needed to transform the P soil test data available. mathematical transformation was used to obtain the necessary P soil test values:

Mehlich-III = 4.85+1.37 * modified Kelowna (Akinremi et al., 2004)

B.3.2 P BALANCE

B.3.2.1 Mineral fertilizer P

To assess the fertilizer P application rate, we needed to determine the quantity of fertilizer P applied on the cropland area of the watershed (number of hectares used for crop and hay production and summerfallow). The only values available at the regional scale were the fertilizer expenses. The fertilizer P values were based on summation of area-weighted census-district-based values intersecting the watershed. The aggregated fertilizer P value was divided by the aggregated reported fertilized land for each region to determine fertilizer P application rates. This procedure assumes that the fertilizer P is distributed equally over the total fertilized area.

Those data are from the 2001 CENSUS of Agriculture: the variable is FERTPD (fertilizer and lime purchased in dollars). Fertilizer dollars spent for Manitoba ($_Fertilizer_Manitoba) come from the document Canadian Fertilizer Consumption, Shipment and Trade (Korol, 2002). The proportion of the fertilizer expenses watershed versus province, was then used to assess the quantity of P_2O_5 (tonnes) for the watershed.

$$\frac{\text{\$\_Fertilizer\_Watershed}}{\text{\$\_Fertilizer\_Manitoba}} = \text{Proportion\_Fertilizer}$$

$$\text{Proportion\_Fertilizer} * \text{Total\_Manitoba} = \text{Quantity\_Watershed}$$

B.3.2.2 Manure P

The P content of livestock manure was calculated based on the total number of cattle[15], pigs[16], poultry[17] and, others[18] reported for the watershed. The data from the 2001 CENSUS of Agriculture were used. The total number of animal unit for each type of livestock was assessed, then the total weight was calculated to enable us to assess the P production per 1,000 kg per day. This value was then distributed on the total area of the watershed.

The amount of manure P was determined from the provincial census and the number of animals within the following species: poultry, dairy cattle, beef cattle, slaughter cattle, calves and pigs. Sheep, horses, mink and fish were not considered for the manure P estimations because of the great variability in manure quantity. No distinction was made between solid and liquid manure in the former IROWC-P. The P coefficients (kg P produced year^{-1} animal unit^{-1}) were estimated using provincial census data on the number of animals within each species as well as constants for calculating animal waste variables used in Canada (Barnett, 1996):

$$\text{Manure P} = (\text{input/output}) \times 100$$

where the input is the amount of manure P estimated from numbers and categories of livestock, and the output is the amount of P exported from crop areas. To calculate the input component, the manure was distributed over cropland based on crop N requirements using the directives of IROWC-N (MacDonald and Spaling, 1995).

B.3.2.3 Crop residues P

Crop residue P is also estimated for the 2001 CENSUS of Agriculture database and Provincial Census information: P uptake and P harvest coefficients. It is noteworthy that only major annual crops and hay categories are considered. This subcomponent estimates the quantities of exported P and quantities of crop residue P remaining on the agricultural soil after harvest. The crop residues were considered in the P balance calculations. The amount of P exported from these crops was determined using the average crop yields and P harvest figures. Average yield data were obtained from provincial census figures for different agricultural regions) and adapted to fit the crop categories at the SLC polygon level.

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[15] beef cows, bulls (1 year and over), calves (under 1 year), total heifers (1 year and over), dairy cows and steers (1 year and over)
[16] boars, sows and gilts for breeding, nursing and weaner, grower and finishing
[17] broilers, roasters and Cornish, laying hens (19 weeks and over), pullets (under 19 weeks) and turkeys
[18] horses and ponies, various large livestock (boars, bison, llamas and deer), various small livestock (mink, rabbits and/or fox)

Crop residue P component = (P in residues/exported P) x 100

B.3.3 TRANSPORT FACTORS

B.3.3.1 Soil Erosion

Soil erosion potential was calculated using USLE. We used the data sets prepared by AAFC: SLC[19] version 3.0. The variable for the water erosion risk class is C_ERPOLY[20]. Each map polygon is ranked within seven classes: negligible (< 6 t/ha/y), now (6-11 t/ha/y), moderate (11-22 t/ha/y), high (22-33 t/ha/y), severe (>33 t/ha/y), water and unclassified. After sorting all the polygons of the studied watershed, according to the erosion risk classes, the percentage of the land represented by each of the different classes was calculated. The highest percentage determined the soil erosion potential of the watershed.

B.3.3.2 Overland flow potential

The overland flow potential categories were estimated using a matrix relating percentage of slope to runoff curve numbers (McFarland et al., 1998). The runoff curve number was determined from a matrix using information on land use, treatment or practice (e.g. straight row, contoured, and terraced, hydrologic condition (i.e. poor, fair, and good) and soil hydrologic groups. Several assumptions were made to estimate these characteristics (Bolinder et al., 2002).

B.3.4 CALCULATION OF THE IROWC-P

IROWC-P is the summation of the product of the rating value and corresponding weighting factor for each site characteristic.

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[19] SLCs were originally conceived as a standardized database consisting of major attributes important to plant growth, land management, and soil degradation.

[20] Classification field for Water Erosion Risk Class categorized by summarizing the estimated soil loss on bare unprotected soil using all soil components in the map polygon. Summary calculation of estimated soil loss on bare unprotected soil implementing the USLE in the map polygon measured in tonnes/hectare/year.

MacDonald, K.B and Spaling, H. 1995. Indicator of risk of water contamination: Concepts and principles. Report No. 5. Ontario Land Resource Unit, Centre for Land and Biological Resources research, Research Branch, Agriculture and Agri-Food Canada. Guelph, ON. 21 pp.

McFarland, A., Hauck, J., White, W., Donham, J., Lemunyon, J.L. and Jones, S. 1998. Nutrient Management Using a Phosphorus Risk Index for Manure Application Fields. In Proceeding of manure management: In harmony with the environment and society. Soil and Water Conservation Society, Ankeny, IA.

van Bochove, E., Theriault, G., Dechmi, F., Rousseau, A.N. Quilbe, R. Leclerc, M.L. and Goussard, N. 2004. Indicator of risk of water contamination by phosphorus from Canadian agricultural land. 8th International Conference on Diffuse/Nonpoint Pollution, Kyoto, Japan 24th – 29th October 2004.

Table B.5 Factors defining water quality management zones for nutrients (from Manitoba Water Stewardship, 2005)

	ZONE 1 (Except 3M, 3MW, and Special Irrigated Crops)			ZONE 2 (Including 3M and 3MW and Special Irrigated Crops)	ZONE 3	ZONE 4 (Including Unimproved Organic Soils)	
Subclass Limitations	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
	No significant limitations in use for crops.	Moderate limitations that restrict the range of crops or require moderate conservation practices.	Moderate severe limitation that restrict the range of crops or require special conservation practices.	Severe limitations that restrict the range of crops or require special conservation practices or both.	Very severe limitations that restrict soil capability to produce perennial forage crops, and improvement practices are feasible.	Soils are capable only of producing perennial forage crops, and improvement practices are not feasible.	No capability for arable culture or permanent pasture.
Climate (C)	All Ecodistricts[1] within ARDA boundary not explicitly listed under 2C and 3C.	Ecodistricts: 664, 666, 668, 670, 671, 672, 674, 675, 676, 677, 714, 715, 716	Ecodistricts: 356, 357, 358, 359, 363, 366, 663, 665	None within ARDA boundary			
Consolidated Bedrock (R)				50-100 cm	20-50 cm	< 20 cm	Surface bedrock Fragmental over bedrock
Moisture limitation[2] (M)		Stratified loams Moderate moisture holding capacity	Loamy Sands Low moisture holding capacity	Sands Very low moisture holding capacity	Skeletal Sands Very severe moisture deficiency	Stabilized sand dunes	Active sand dunes
Topography[3] (T)	a, b (0-2%)	c (>2-5%)	d (>5-10%)	e (>10-15%)	f (>15-30%)	g (>30-45%) Eroded slope complex	h (>45 - 70%) i (>70 - 100%) j (> 100%)
Structure and/or Permeability (D)	Granular Clay	Massive clay or till soils[4] Slow permeability	Solonetzic intergrades Very slow Permeability	Black Solonetz Extremely slow permeability			
Salinity[5] (N) a.00-60cm depth b.60-120cm depth	None < 2dS/m < 4dS/m	Weak 2-4 dS/m 4-8 dS/m	Moderate (s) 4-8 dS/m 8-16 dS/m	Strong (t) 8-16 dS/m 16-24 dS/m	Very Strong (u)[6] 16-24 dS/m >24 dS/m		Salt Flats
Inundation[7] (I)	No overflow during growing season	Occasional overflow (1 in 10 years)	Frequent overflow (1 in 5 years) Some crop damage	Frequent overflow Severe crop damage	Very frequent (1 in 5 years) Grazing > 10 weeks	Very frequent Grazing 5-10 weeks	Land is inundated for most of the season
Excess Water (W)	Well and imperfectly drained		Loamy to fine textured Gleysols with improved drainage	Course textured Gleysols with improved drainage	Poorly drained, no improvements	Very Poorly drained	Open water, marsh
Stoniness (P)	Non stony (0) and Slightly Stony (1)	Moderately Stony (2)	Very Stony[8] (3)	Exceedingly Stony (4)[9]		Excessively Stony (5)	Cobbly Beach Fragmental
Erosion[10] (E)		Moderate erosion (2)	Severe wind or water erosion (3) lowers the basic rating by one class to a minimum rating of Class 6[11].				
Cumulative minor Adverse Characteristics[12] (X)							

[illegible]

1 [illegible]

2 [illegible]

3 [illegible]

4 [illegible]

5 [illegible]

6 [illegible]

7 [illegible]

8 [illegible]

9 [illegible]

10 [illegible]

11 [illegible]

12 [illegible]

APPENDIX C

SOIL TEST P DATA

Table C.1 Soil test data.

			Annual Mean[1]			Overall Mean[1]			
Watersheds	Year	# samples	Modified-Kelowna ppm	Olsen-P ppm	Bray-1 P ppm	Modified-Kelowna ppm	Olsen-P ppm	Bray-1 P ppm	Samples total
La Salle River	2000	172	22.4	19.5	27.4	21.9	19.2	27.0	175
	2001	3	18.4	16.4	23.2				
	2003	-	-	-	-				
Seine River	2000	70	27.0	23.2	32.5	25.2	21.7	30.5	88
	2001	12	20.7	18.2	25.7				
	2003	6	19.2	17.1	24.1				
Rat-Marsh River	2000	8	18.3	16.4	23.0	23.4	20.3	28.6	30
	2001	18	24.9	21.4	30.2				
	2003	4	31.5	26.5	37.3				
Cypress River	2000	383	24.8	21.4	30.1	25.1	21.6	30.4	420
	2001	3	35.3	29.4	41.5				
	2003	34	22.4	19.5	27.5				
Boyne River	2000	519	21.5	18.8	26.5	22.0	19.2	27.0	539
	2001	5	28.2	24.0	33.8				
	2003	15	21.0	18.4	26.0				
Cooks Creek	2000	19	19.3	17.1	24.1	27.4	23.4	32.6	28
	2001	9	37.6	31.2	44.0				
	2003	-	-	-	-				
Brokenhead River	2000	68	22.1	19.3	27.1	23.8	20.6	29.0	78
	2001	5	38.2	31.6	44.6				
	2003	5	9.7	9.7	13.7				
Valley River	2000	97	14.5	13.4	18.9	16.6	15.0	20.8	113
	2001	6	21.5	18.8	26.5				
	2003	10	34.3	28.7	40.4				
Little Saskatchewan River	2000	358	14.0	13.0	18.4	13.9	13.0	17.8	358
	2001	-	-	-	-				
	2003	-	-	-	-				
Wilson River	2000	52	17.2	15.5	21.8	20.5	18.0	25.4	57
	2001	4	14.0	13.0	18.3				
	2003	1	60	48.5	68.3				
Vermillion River	2000	21	17.2	15.5	21.8	17.2	15.5	21.8	21
	2001	-	-	-	-				
	2003	-	-	-	-				
Turtle River	2000	41	15.7	14.3	20.2	18.0	16.1	22.7	49
	2001	8	26.3	22.5	31.7				
	2003	-	-	-	-				
Ochre River	2000	11	10.2	10.1	14.3	11.9	11.5	16.1	12
	2001	1	20.6	18.1	25.5				
	2003	-	-	-	-				
Roseau River	2000	53	11.6	11.2	15.8	17.3	15.6	10.9	64
	2001	11	32.6	27.4	38.6				
	2003	-	-	-	-				

[1] Values are measured by modified Kelowna method on agricultural land, estimated from literature values for forested land, and converted to Bray P1 values using equations develop by Akinremi et al. (2004) and Moncrief et al. (2002).

Table C.2 Soil test data in forest soils.

Data source	# samples	Olsen-P (ppm)	Bray-1 P (ppm)
Thompson field study (Veldhuis, unpublished data)	1	7.65	10.77
	2	6.11	8.61
	3	6.11	8.61
	4	9.96	14.03
	5	8.42	11.86
	6	6.11	8.61
	7	6.11	8.61
	8	6.11	8.61
	9	8.42	11.86
	10	11.50	16.20
	11	9.19	12.94
	12	9.96	14.03
	13	8.42	11.86
	14	7.65	10.77
	15	9.19	12.94
	16	6.11	8.61
	17	6.11	8.61
	18	6.88	9.69
	19	6.11	8.61
	20	6.11	8.61
	21	6.11	8.61
	22	13.04	18.37
	23	6.88	9.69
	24	6.11	8.61
	25	6.11	8.61
	26	6.11	8.61
	27	6.11	8.61
	28	2.26	3.18
	29	2.26	3.18
Huang and Schoenau (1996)	1	9.10	12.82
	2	2.90	4.08
	3	1.80	2.54
	4	0.90	1.27
	5	47.00	66.20

APPENDIX D

WATER QUALITY DATA

Table D.1 Annual average of TP concentration, flow, P load and water yield for La Salle River watershed.

	La Salle River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)**	(kg/ha/y)	(g P/ha/y)	(mm)	
1973	0.190	0.141	74.43	0.473	2834.14	0.012	11.52	6.06	2
1974	0.323	0.190	58.87						3
1975	0.347	0.289	83.47						3
1976	0.350	0.339	96.95	2.470	27262.87	0.111	110.82	31.66	4
1977	0.173	0.097	56.08	0.565	3073.58	0.012	12.49	7.24	4
1978									
1979									
1980									
1981									
1982									
1983									
1984									
1985									
1986									
1987									
1988	0.235	0.177	75.22	0.461	3416.45	0.014	13.89	5.91	2
1989	0.219	0.114	52.00	0.782	5394.63	0.022	21.93	10.02	4
1990	0.301	0.144	47.77	0.712	6764.16	0.027	27.50	9.13	4
1991	0.220	0.093	42.32	0.462	3205.32	0.013	13.03	5.92	4
1992	0.296	0.066	22.24	2.010	18746.81	0.076	76.21	25.77	4
1993	0.321	0.125	39.01	3.680	37194.82	0.151	151.20	47.18	4
1994	0.493	0.214	43.45	0.950	14763.89	0.060	60.02	12.18	5
1995	0.503	0.070	**13.92**	2.928	46470.76	0.189	188.91	37.53	14
1996	0.454	0.109	**24.02**	6.100	87392.38	0.355	355.25	78.20	17
1997	0.479	0.241	50.39	5.814	87804.42	0.357	356.93	74.53	9
1998	0.453	0.172	37.99	2.810	40102.84	0.163	163.02	36.02	11
1999	0.390	0.065	16.56	0.825	10158.19	0.041	41.29	10.58	3
2000									

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.2 Annual average of TP concentration, flow, P load and water yield for Seine River watershed.

	Seine River Watershed								
	TP (mg/l)			Flow (m3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1973	0.090	0.056	61.86	1.070	3036.92	0.01441	14.41	16.01	3
1974	0.133	0.059	43.95	2.470	10385.86	0.04929	49.29	36.97	3
1975	0.125	0.039	30.98	0.700	2759.40	0.01310	13.10	10.48	4
1976	0.120	0.033	27.22	0.499	1888.38	0.00896	8.96	7.47	4
1977	0.173	0.068	39.27	0.591	3230.55	0.01533	15.33	8.85	3
1978									
1979									
1980									
1981									
1982									
1983									
1984									
1985									
1986									
1987									
1988	0.260	0.099	38.07	0.218	1788.83	0.00849	8.49	3.27	2
1989	0.323	0.152	47.24	0.419	4258.84	0.02021	20.21	6.27	4
1990	0.435	0.394	90.58	0.358	4911.10	0.02331	23.31	5.36	4
1991	0.179	0.098	55.07	0.727	4096.26	0.01944	19.44	10.88	4
1992	0.149	0.073	49.05	1.228	5778.71	0.02743	27.43	18.38	4
1993	0.214	0.114	53.32	1.584	10699.40	0.05078	50.78	23.71	12
1994	0.236	0.100	42.47	1.605	11949.71	0.05671	56.71	24.02	45
1995	0.224	0.153	68.23	1.411	9975.25	0.04734	47.34	21.12	34
1996	0.227	0.110	48.45	2.051	14666.38	0.06961	69.61	30.70	15
1997	0.164	0.075	45.72	3.488	18037.53	0.08561	85.61	52.20	4
1998	0.189	0.102	53.96	4.677	27820.72	0.13204	132.04	70.00	11
1999	0.203	0.118	58.26	1.153	7371.29	0.03498	34.98	17.26	3
2000	0.135	0.056	41.52	0.994	4222.56	0.02004	20.04	14.87	4

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.3 Annual average of TP concentration, flow, P load and water yield for Rat-Marsh River watershed.

	Rat-Marsh River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1973	0.090	0.026	29.397	1.41	4001.92	0.01990	19.90	22.11	3
1974	0.160	0.036	22.535	8.50	42888.96	0.21324	213.24	133.27	3
1975	0.140	0.058	41.239	1.46	6445.96	0.03205	32.05	22.89	4
1976	0.125	0.120	96.167	0.94	3717.31	0.01848	18.48	14.79	2
1977	0.080	0.035	43.301	0.58	1458.22	0.00725	7.25	9.06	3
1978	0.020	-	-	1.96	1236.21	0.00615	6.15	30.73	
1979									
1980									
1981									
1982									
1983									
1984									
1985									
1986									
1987	0.090	-	-	3.19	9053.99	0.04502	45.02	50.02	
1988	0.450	-	-	0.26	3745.29	0.01862	18.62	4.14	1
1989	0.248	0.025	9.999	0.54	4186.40	0.02081	20.81	8.41	2
1990	0.285	0.205	71.951	1.14	10272.64	0.05107	51.07	17.92	2
1991	0.310	0.098	31.483	1.82	17792.61	0.08846	88.46	28.54	3
1992	0.151	0.067	44.770	5.12	24340.75	0.12102	121.02	80.28	4
1993	0.159	0.035	22.082	3.01	15069.08	0.07492	74.92	47.19	4
1994	0.142	0.084	58.940	1.97	8837.41	0.04394	43.94	30.89	4
1995	0.148	0.034	23.036	3.79	17709.09	0.08805	88.05	59.42	6
1996	0.191	0.034	18.056	6.72	40424.11	0.20098	200.98	105.36	4
1997	0.231	0.113	49.050	8.71	63387.56	0.31515	315.15	136.63	3
1998	0.165	0.080	48.675	6.02	31385.38	0.15604	156.04	94.38	3
1999	0.132	0.024	18.484	2.69	11157.07	0.05547	55.47	42.13	3
2000	0.162	0.174	107.853	5.01	25524.31	0.12690	126.90	78.50	3
2001				7.85				123.01	
2002				9.38				147.07	

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.4 Annual average of TP concentration, flow, P load and water yield for Cypress River watershed.

	Cypress River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1965				0.593				23.00	
1966				0.904				35.07	
1967				0.714				27.70	
1968				0.56				21.72	
1969				1.7				65.94	
1970				1.91				74.09	
1971				0.752				29.17	
1972				0.65				25.21	
1973				0.208				8.07	
1974				1.94				75.25	
1975				0.288				11.17	
1976				0.747				28.98	
1977				0.126				4.89	
1978	0.340	0.314	92.408	0.665	7120.97	0.08759	87.59	25.80	7
1979	0.278	0.294	105.898	1.76				68.27	5
1980	0.104	0.082	78.386	0.183	602.67	0.00741	7.41	7.10	7
1981	0.203	0.227	111.857	0.094	600.29	0.00738	7.38	3.65	8
1982	0.134	0.121	90.273	0.145	614.05	0.00755	7.55	5.62	7
1983	0.141	0.101	71.756	0.449	2000.05	0.02460	24.60	17.42	4
1984									
1985									
1986									
1987									
1988	0.075	-	-	0.104	245.98	0.00303	3.03	4.03	1
1989	0.235	0.342	145.570	0.191	1415.49	0.01741	17.41	7.41	3
1990	0.643	0.484	75.388	0.448	9077.32	0.11165	111.65	17.38	2
1991	0.235	0.173	73.735	0.244	1808.27	0.02224	22.24	9.46	3
1992	0.321	0.449	139.786	0.954	9667.42	0.11891	118.91	37.01	3
1993	0.379	0.157	41.334	0.651	7774.00	0.09562	95.62	25.25	3
1994	0.199	0.153	76.805	0.413	2587.51	0.03183	31.83	16.02	3
1995	0.226	0.130	57.294	1.61	11484.84	0.14126	141.26	62.45	5
1996	0.238	0.084	**35.368**	1.35	10146.71	0.12481	124.81	52.37	3
1997	0.246	0.233	94.906	1.32	10240.37	0.12596	125.96	51.20	3
1998	0.536	0.491	91.499	1.44	24355.88	0.29958	299.58	55.86	3
1999	0.219	0.131	59.937	0.177	1220.57	0.01501	15.01	6.87	3
2000	0.139	0.046	32.751	1.41	6195.56	0.07621	76.21	54.69	3
2001	0.108	0.114	105.450	0.227	773.14	0.00951	9.51	8.81	
2002	0.154	0.134	87.192	0.68	3304.27	0.04064	40.64	26.39	

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.5 Annual average of TP concentration, flow, P load and water yield for Boyne River watershed.

	Boyne River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1973	0.09	0.03	33.31	0.31	850.00	0.00487	4.87	5.62	3
1974	0.21	0.23	107.75	3.71	24569.70	0.14080	140.80	67.05	2
1975	0.08	0.03	34.82	0.78	2018.93	0.01157	11.57	14.02	4
1976	0.07	0.03	37.98	1.34	3063.72	0.01756	17.56	24.22	4
1977	0.07	0.02	24.74	0.26	573.96	0.00329	3.29	4.70	4
1978									
1979									
1980									
1981									
1982									
1983									
1984									
1985									
1986									
1987									
1988	0.23	-	-	0.30	2211.71	0.01267	12.67	5.44	1
1989	0.15	0.04	24.94	0.33	1537.38	0.00881	8.81	5.87	4
1990	0.28	0.18	66.23	0.90	7876.12	0.04514	45.14	16.26	4
1991	0.21	0.10	45.67	0.35	2356.12	0.01350	13.50	6.39	4
1992	0.20	0.10	50.25	1.28	8175.73	0.04685	46.85	23.14	4
1993	0.18	0.09	47.93	1.53	8625.47	0.04943	49.43	27.61	4
1994	0.17	0.03	15.80	1.04	5669.28	0.03249	32.49	18.86	4
1995	0.16	0.13	82.29	2.60	13374.73	0.07665	76.65	46.95	4
1996	0.11	0.03	29.25	2.23	7876.43	0.04514	45.14	40.30	4
1997	0.18	0.12	65.21	-	-	-	-	-	4
1998	0.25	0.17	70.19	-	-	-	-	-	4
1999	0.20	0.02	10.55	-	-	-	-	-	3
2000	0.22	0.13	60.78	-	-	-	-	-	4
2001	0.13	-	-	8.67	35812.13	0.20523	205.23	156.66	
2002	-	-		0.78	-	-	-	14.08	

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.6 Annual average of TP concentration, flow, P load and water yield for Cook Creeks River watershed.

	Cooks River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1990	0.153	0.128	83.369	0.155	748.84	0.01002	10.02	6.55	5
1991	0.318	0.359	113.070	0.128	1276.62	0.01709	17.09	5.38	8
1992	0.150	0.113	75.105	0.386	1825.93	0.02444	24.44	16.30	12
1993	0.289	0.485	168.172	0.403	3670.16	0.04913	49.13	17.03	11
1994	0.089	0.051	56.914	0.258	724.43	0.00970	9.70	10.88	6
1995	0.069	0.059	86.647	0.378	818.37	0.01096	10.96	15.95	9
1996	0.126	0.108	85.745	0.628	2497.69	0.03344	33.44	26.51	8
1997	0.130	0.139	106.938	2.557	10505.70	0.14064	140.64	107.93	10
1998	0.195	0.360	184.451	1.940	11930.07	0.15971	159.71	81.90	12
1999	0.234	0.224	95.585	0.233	1720.33	0.02303	23.03	9.82	13
2000	0.219	0.268	122.628	0.440	3034.73	0.04063	40.63	18.58	1
2001	0.170	0.180	105.668	1.861	9977.04	0.13356	133.56	78.57	
2002	-			0.666	-	-	-	28.13	

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.7 Annual average of TP concentration, flow, P load and water yield for Little Saskatchewan River watershed.

	Little Saskatchewan River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1973	0.133	0.065	49.057	1.82	7604.91	0.01834	18.34	13.84	4
1974	0.135	0.070	52.203	7.39	31461.89	0.07588	75.88	56.21	4
1975	0.070	0.022	30.861	9.31	20552.01	0.04957	49.57	70.82	4
1976	0.075	0.031	41.096	8.79	20790.11	0.05014	50.14	66.86	6
1977	0.113	0.051	45.542	2.05	7272.99	0.01754	17.54	15.59	4
1978	0.124	0.069	55.409	2.69	10506.10	0.02534	25.34	20.46	13
1979	0.196	0.222	112.975	7.76	48002.64	0.11578	115.78	59.03	13
1980	0.125	0.073	58.819	1.71	6736.33	0.01625	16.25	13.01	12
1981	0.113	0.048	42.228	2.01	7131.08	0.01720	17.20	15.29	12
1982	0.151	0.123	81.436	2.85	13571.52	0.03273	32.73	21.68	10
1983	0.109	0.050	46.127	4.59	15801.90	0.03811	38.11	34.91	12
1984	0.100	0.028	28.284	1.30	4099.68	0.00989	9.89	9.89	2
1985									
1986									
1987									
1988	0.088	0.018	20.203	1.69	4663.39	0.01125	11.25	12.85	2
1989	0.072	0.019	26.261	1.19	2702.00	0.00652	6.52	9.05	4
1990	0.105	0.031	29.459	4.01	13215.00	0.03187	31.87	30.50	4
1991	0.116	0.044	37.721	2.09	7662.07	0.01848	18.48	15.90	4
1992	0.090	0.006	6.968	4.74	13453.26	0.03245	32.45	36.05	4
1993	0.113	0.030	26.473	2.65	9401.67	0.02268	22.68	20.16	4
1994	0.146	0.036	24.956	4.54	20879.46	0.05036	50.36	34.53	6
1995	0.123	0.037	30.027	10.90	42366.25	0.10219	102.19	82.91	4
1996	0.147	0.026	17.712	5.14	23787.45	0.05737	57.37	39.10	4
1997	0.108	0.013	12.259	-	-	-	-	-	4
1998	0.171	0.109	63.638	-	-	-	-	-	4
1999	0.337	0.277	82.141	-	-	-	-	-	3
2000	0.104	0.039	37.333	-	-	-	-	-	4

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.8 Annual average of TP concentration, flow, P load and water yield for Roseau River watershed.

	Roseau River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1973	0.117	0.021	17.843	4.21	15489.43	0.05978	59.78	51.24	3
1974	0.100	0.078	78.102	20.7	65279.52	0.25195	251.95	251.95	3
1975	0.070	0.074	106.266	13.7	30243.02	0.11672	116.72	166.75	4
1976	0.063	0.028	44.061	3.54	6977.34	0.02693	26.93	43.09	4
1977	0.070	0.020	28.571	1.97	4348.81	0.01678	16.78	23.98	4
1978	0.060	-	-	9.53	18032.28	0.06960	69.60	115.99	1
1979									
1980									
1981									
1982									
1983									
1984									
1985									
1986									
1987									
1988	0.068	0.025	36.665	1.28	2724.71	0.01052	10.52	15.58	2
1989	0.101	0.100	99.013	5.69	18123.42	0.06995	69.95	69.26	4
1990	0.108	0.055	50.629	2.3	7857.72	0.03033	30.33	27.99	3
1991	0.126	0.092	72.694	8.51	33881.88	0.13077	130.77	103.58	4
1992	0.086	0.063	73.768	17.7	48004.10	0.18527	185.27	215.43	4
1993	0.080	0.041	51.174	16.7	42000.43	0.16210	162.10	203.26	4
1994	0.120	0.040	33.056	11.5	43519.68	0.16796	167.96	139.97	5
1995	0.059	0.016	27.504	12.5	23257.80	0.08976	89.76	152.14	4
1996	0.073	0.037	51.485	22.6	51849.91	0.20012	200.12	275.07	4
1997	0.089	0.045	50.725	24.7	69459.34	0.26808	268.08	300.37	4
1998	0.085	0.060	70.979	17.6	47096.77	0.18177	181.77	213.85	4
1999	0.094	0.023	24.048	23.4	69218.86	0.26715	267.15	284.20	3
2000	0.097	0.042	43.027	14.8	45246.64	0.17463	174.63	179.57	4
2001				36.8				447.48	
2002				32.1				390.67	

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.9 Annual average of TP concentration, flow, P load and water yield for Brokenhead River watershed.

	Brokenhead River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1973	0.053	0.049	92.492	4.59	7720.01	0.02928	29.28	54.89	3
1974	0.088	0.078	89.199	10.3	28421.82	0.10778	107.78	123.18	4
1975	0.080	0.020	25.000	2.47	6231.51	0.02363	23.63	29.54	3
1976	0.058	0.017	29.701	2.16	3916.77	0.01485	14.85	25.83	4
1977	0.078	0.033	42.256	1.99	4871.48	0.01847	18.47	23.80	4
1978				4.46					
1979				4.58					
1980				0.854					
1981				0.811					
1982				2.28					
1983				1.9					
1984				1.46					
1985				1.07					
1986				3.89					
1987	0.070	0.070		1.72				20.57	1
1988	0.115	0.078	67.636	0.297	1077.11	0.00408	4.08	3.55	2
1989	0.084	0.054	64.110	1.68	4423.87	0.01678	16.78	20.09	4
1990	0.131	0.109	83.426	1.96	8112.64	0.03076	30.76	23.44	4
1991	0.078	0.035	45.467	1.4	3421.66	0.01298	12.98	16.74	4
1992	0.116	0.082	70.352	3.73	13645.00	0.05174	51.74	44.61	4
1993	0.132	0.109	83.259	4.45	18454.08	0.06998	69.98	53.22	4
1994	0.088	0.054	60.960	5.25	14536.52	0.05513	55.13	62.78	5
1995	0.107	0.099	92.104	3.75	12681.65	0.04809	48.09	44.85	17
1996	0.054	0.019	36.003	6.15	10376.13	0.03935	39.35	73.55	4
1997	0.050	0.024	48.963	8.902	14036.15	0.05323	53.23	106.46	4
1998	0.063	0.013	20.589	6.492	12847.57	0.04872	48.72	77.64	4
1999	0.067	0.034	50.786	2.269	4770.87	0.01809	18.09	27.14	3
2000	0.060	0.037	62.245	8.697	16318.04	0.06188	61.88	104.00	4
2001				16.204				193.78	
2002				9.354				111.86	

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.10 Annual average of TP concentration, flow, P load and water yield for Valley River watershed.

	Valley River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	**Ave**	**Std**	**Coeff.var.**	**Ave**	**(kg/y)**	**(kg/ha/y)**	**(g P/ha/y)**	**(mm)**	
1974	0.060			8.835	16717.86	0.05646	56.46	94.10	1
1975	0.520			6.474	106162.58	0.35854	358.54	68.95	1
1976	-			7.297					-
1977	0.030			1.197	1132.69	0.00383	3.83	12.75	1
1978	0.040	0.033	82.102	1.887	2402.76	0.00811	8.11	20.10	8
1979	0.080	0.112	139.614	6.978	17604.03	0.05945	59.45	74.32	9
1980	0.044	0.041	92.580	1.404	1954.73	0.00660	6.60	14.96	7
1981	0.040	0.023	56.695	0.932	1175.45	0.00397	3.97	9.92	8
1982	0.047	0.065	139.971	0.808	1189.61	0.00402	4.02	8.61	6
1983	0.035	0.010	28.113	6.116	6814.70	0.02301	23.01	65.14	6
1984									
1985									
1986									
1987									
1988	0.025	0.000	0.00	3.956	3119.24	0.01053	10.53	42.14	2
1989	0.037	0.033	90.80	0.613	709.21	0.00240	2.40	6.53	3
1990	0.087	0.107	123.24	4.624	12638.86	0.04268	42.68	49.25	3
1991	0.037	0.025	67.27	1.267	1465.15	0.00495	4.95	13.50	3
1992	0.060	0.028	47.53	2.735	5145.99	0.01738	17.38	29.13	3
1993	0.038	0.021	55.27	2.460	2922.32	0.00987	9.87	26.20	3
1994	0.049	0.019	38.18	4.061	6232.12	0.02105	21.05	43.25	3
1995	0.090	0.094	**104.41**	13.122	37159.68	0.12550	125.50	139.75	5
1996	0.074	0.076	**102.70**	7.543	17524.31	0.05918	59.18	80.34	3
1997	0.092	0.099	107.52	5.650	16331.82	0.05516	55.16	60.17	3
1998	0.092	0.099	108.06	3.797	11015.80	0.03720	37.20	40.44	3
1999	0.043	0.027	63.77	4.780	6431.44	0.02172	21.72	50.91	3
2000	0.025	0.003	11.40	2.301	1838.43	0.00621	6.21	24.51	3

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.11 Annual average of TP concentration, flow, P load and water yield for Wilson River watershed.

	Wilson River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1974	0.330								1
1975	0.150								1
1976	0.060								1
1977	0.050								1
1978	0.068	0.070	102.584						8
1979	0.131	0.187	142.560	4.598	19012.99	0.19089	190.89	145.60	9
1980	0.049	0.030	62.407	0.582	892.31	0.00896	8.96	18.42	8
1981	0.068	0.031	45.318	0.386	822.56	0.00826	8.26	12.23	8
1982	0.098	0.158	160.461	0.780	2418.81	0.02429	24.29	24.70	6
1983	0.061	0.026	42.641	2.805	5371.08	0.05393	53.93	88.82	7
1984									
1985									
1986									
1987									
1988	0.043	0.011	24.96	1.021	1368.09	0.01374	13.74	32.32	2
1989	0.103	0.058	56.50	0.418	1360.52	0.01366	13.66	13.22	3
1990	0.128	0.153	119.47	1.585	6414.35	0.06440	64.40	50.18	3
1991	0.049	0.010	20.71	0.438	676.57	0.00679	6.79	13.86	3
1992	0.073	0.094	127.80	1.554	3599.72	0.03614	36.14	49.21	16
1993	0.063	0.051	81.09	0.860	1712.64	0.01720	17.20	27.22	6
1994	0.285	0.351	123.06	1.726	15508.38	0.15571	155.71	54.63	3
1995	0.123	0.205	**167.08**	4.502	17406.14	0.17476	174.76	142.55	5
1996	0.098	0.073	**74.13**	1.910	5903.17	0.05927	59.27	60.48	3
1997	0.195	0.269	137.80	1.080	6654.37	0.06681	66.81	34.20	3
1998	0.107	0.078	72.23	2.665	9021.51	0.09058	90.58	84.39	3
1999	0.061			1.969	3788.24	0.03803	38.03	62.35	1
2000				0.792					

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.12 Annual average of TP concentration, flow, P load and water yield for Vermillion River watershed.

	Vermilion River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1974	1.000			4.74	149543.71	1.97548	1975.48	1033.15	1
1975	0.310			3.80	37185.25	0.49122	491.22	1783.01	1
1976	0.700			3.31	73146.18	0.96626	966.26	100.40	1
1977	0.050			0.57	905.21	0.01196	11.96	29.74	1
1978	0.476	0.663	139.347	1.49	22368.22	0.29549	295.49	95.72	8
1979	0.204	0.292	143.026	3.53	22784.43	0.30098	300.98	281.60	9
1980	0.052	0.017	32.969	0.65	1056.47	0.01396	13.96	17.71	8
1981	0.101	0.087	85.523	1.12	3575.38	0.04723	47.23	55.70	8
1982	0.330	0.412	124.781	1.28	13298.26	0.17567	175.67	103.79	6
1983	0.602	1.186	197.067	2.15		0.00000	0.00	79.02	6
1984									
1985									
1986									
1987									
1988	0.453	0.598	132.05	1.23	17577.12	0.23219	232.19	8.39	2
1989	0.047	0.008	16.37	0.49	715.85	0.00946	9.46	8.64	3
1990	0.092	0.050	54.91	2.11	6088.75	0.08043	80.43	60.41	3
1991	0.040	0.014	34.32	1.47	1837.51	0.02427	24.27	8.67	3
1992	0.052	0.031	59.03	2.20	3625.62	0.04789	47.89	31.56	3
1993	0.156	0.089	56.89	1.43	7024.52	0.09279	92.79	102.48	3
1994	0.092	0.018	19.98	2.21	6397.63	0.08451	84.51	89.43	3
1995	**0.493**	**0.425**	**86.13**	**4.27**	**66409.49**	**0.87727**	**877.27**	**805.81**	**5**
1996	0.111	0.086	**77.53**	1.87	6573.19	0.08683	86.83	84.92	3
1997	0.344	0.451	131.18	1.43	15455.71	0.20417	204.17	241.32	3
1998	0.107	0.079	73.40	1.83	6165.22	0.08144	81.44	207.84	3
1999	0.070	0.037		1.74	3852.17	0.05089	50.89	51.95	3
2000	0.066	0.047		1.36	2811.03	0.03713	37.13	58.96	3

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.13 Annual average of TP concentration, flow, P load and water yield for Ochre River watershed.

	Ochre River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1974	0.360		0.00	2.666	30263.21	0.81353	813.53	1466.594	1
1975	0.090		0.00	3.788	10751.02	0.28901	289.01	715.494	1
1976	0.050		0.00	2.514	3963.94	0.10656	106.56	230.586	1
1977	0.060		0.00	1.367	2586.43	0.06953	69.53	74.856	1
1978									
1979									
1980									
1981									
1982									
1983									
1984									
1985									
1986									
1987									
1988	0.020	0.000	0.00	0.864	545.05	0.01465	14.65	14.073	2
1989	0.028	0.019	66.81	0.551	492.26	0.01323	13.23	61.320	3
1990	0.056	0.081	144.33	1.801	3194.50	0.08587	85.87	239.667	8
1991	0.021	0.009	43.40	1.312	848.35	0.02281	22.81	53.906	8
1992	0.084	0.117	140.21	1.818	4789.79	0.12876	128.76	197.279	10
1993	0.068	0.126	184.67	1.358	2920.55	0.07851	78.51	152.376	10
1994	0.053	0.044	84.06	1.601	2653.21	0.07132	71.32	226.807	9
1995	0.065	0.152	**234.86**	2.106	4303.06	0.11567	115.67	35.446	9
1996	0.120	0.134	**111.37**	1.208	4580.45	0.12313	123.13	199.280	7
1997	0.066	0.081	122.40	0.700	1459.20	0.03923	39.23	31.557	8
1998	0.027	0.021	77.95	1.249	1066.71	0.02868	28.68	97.702	11
1999	0.026	0.004	15.75	1.715	1387.96	0.03731	37.31	-	3
2000	0.123	0.144	117.18	1.679	6487.53	0.17440	174.40	-	2

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

Table D.14 Annual average of TP concentration, flow, P load and water yield for Turtle River watershed.

	Turtle River Watershed								
	TP (mg/l)			Flow (m^3/s)*	P load			Water yield	# data
Year	Ave	Std	Coeff.var.	Ave	(kg/y)	(kg/ha/y)	(g P/ha/y)	(mm)	
1974	0.120			4.184	15832.02	0.08960	89.60	444.395	1
1975	0.170			6.786	36377.88	0.20587	205.87	365.868	1
1976	0.060			4.843	9164.20	0.05186	51.86	90.485	1
1977	0.060			1.297	2453.19	0.01388	13.88	18.918	1
1978									
1979									
1980									
1981									
1982									
1983									
1984									
1985									
1986									
1987									
1988	0.045			0.727	1032.17	0.00584	5.84	1.892	2
1989	0.025	0.015	60.00	0.569	448.86	0.00254	2.54	17.550	3
1990	0.052	0.037	72.18	2.350	3838.10	0.02172	21.72	58.318	19
1991	0.040	0.027	69.06	1.355	1697.38	0.00961	9.61	4.732	18
1992	0.038	0.039	102.63	2.131	2574.29	0.01457	14.57	20.762	20
1993	0.045	0.039	87.05	1.839	2615.85	0.01480	14.80	56.318	9
1994	0.042	0.047	110.23	1.083	1445.27	0.00818	8.18	62.238	9
1995	0.056	0.087	154.79	3.222	5713.13	0.03233	32.33	17.113	9
1996	0.094	0.066	70.35	2.433	7235.51	0.04095	40.95	39.121	7
1997	0.054	0.037	68.07	1.080	1851.81	0.01048	10.48	71.062	8
1998	0.038	0.036	93.60	1.705	2067.86	0.01170	11.70	78.983	11
1999	0.046	0.015	32.40	2.775	4055.35	0.02295	22.95	6.342	3
2000	0.061	0.056	92.29	1.646	3165.92	0.01792	17.92	5.390	3

* Flow data (monthly mean discharge) from the Archived Hydrometric Database (Environment Canada, http://www.wsc.ec.gc.ca/hydat/H2O/).
** Calculation made according Bourne et al. (2002).

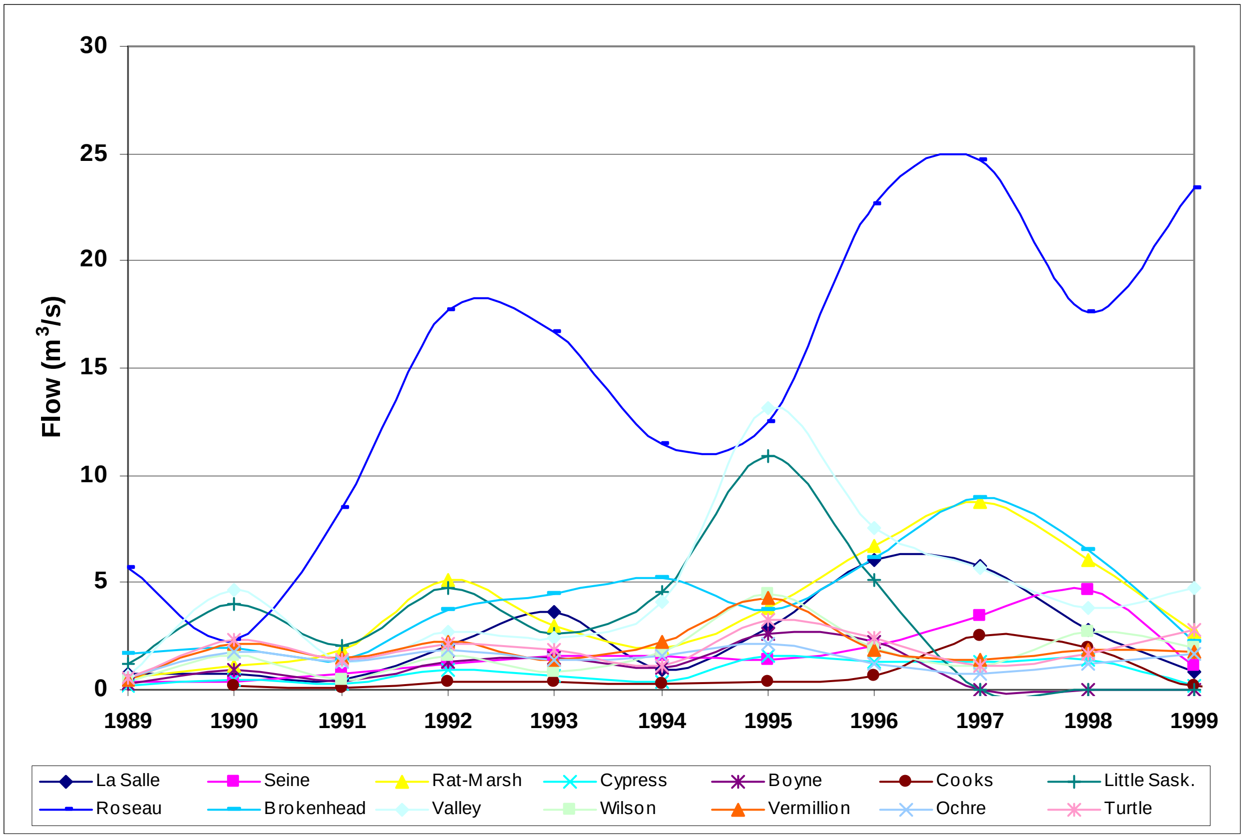

Figure D.1 **Annual mean of monthly average flow data for all watersheds.**

APPENDIX E

P RISK INDICATOR RESULTS

Table E.1 Summarized results for Minnesota's P Index.

Site characteristics	Units	La Salle	Seine	Rat-Marsh	Cypress	Boyne	Cooks	Roseau
1. TRANSPORT FACTORS								
a. Soil erosion (tonnes/ha)	**Mg/ha**	3.84	2.58	2.21	13.98	6.99	3.06	2.63
b. Runoff (cm)	**cm**	3.23	2.54	5.92	3.10	2.32	2.98	18.05
c. % of cropland	**%**	6.40	3.90	4.40	7.30	6.70	3.70	3.50
2. SOURCE FACTORS								
a. Soil test P (Bray-P, mg P/kg)	**mg P/kg**	25.44	24.18	21.16	29.85	26.35	23.81	16.21
b. Fertilizer P application rate (kg P/ha)	**kg P/ha**	20.39	18.77	17.13	19.01	19.82	18.85	12.09
c. Fertilizer P application method		1	1	1	1	1	1	1
d. Organic P source application rate (kg P/ha)	**kg P/ha**	3.82	12.27	6.36	4.49	4.49	2.20	2.13
e. Organic P source application method		2	4	2	2	2	2	2
	P Index	**21.25**	**15.75**	**13.25**	**21.5**	**22.75**	**9.75**	**10**

Table E.1 Summarized results for Minnesota's P Index (continued).

Site characteristics	Units	Brokenhead	Little Sask.	Valley	Wilson	Ochre	Vermililon	Turtle
1. TRANSPORT FACTORS								
a. Soil erosion (tonnes/ha)	**Mg/ha**	2.83	13.95	13.98	11.11	3.62	6.33	4.24
b. Runoff (cm)	**cm**	5.00	3.35	4.90	5.38	11.91	7.97	3.33
c. % of cropland	**%**	2.80	15.75	9.18	7.10	7.90	7.10	5.60
2. SOURCE FACTORS								
a. Soil test P (Bray-P, mg P/kg)	**mg P/kg**	16.98	15.28	16.06	19.90	13.09	16.36	20.30
b. Fertilizer P application rate (kg P/ha)	**kg P/ha**	15.71	13.60	16.23	16.10	7.44	16.40	12.79
c. Fertilizer P application method		1	1	1	1	1	1	1
d. Organic P source application rate (kg P/ha)	**kg P/ha**	1.24	1.55	1.44	1.15	1.43	0.71	2.98
e. Organic P source application method		2	2	2	2	2	2	2
	P Index	**7.5**	**19.5**	**19.5**	**20.25**	**16.5**	**19.5**	**12.25**

Table E.2 Summarized results for Manitoba's P risk indicator.

Site characteristics	Units	La Salle	Seine	Rat-Marsh	Cypress	Boyne	Cooks	Roseau
1. P SOURCE FACTORS								
Overall P balance	**kg/ha**	10.01	15.33	8.13	8.17	8.80	6.55	1.37
Crop residue P	**cm**	5.58	3.79	4.83	5.54	5.78	5.33	5.89
Estimated P sorption index	**-**	391	391	353	273	280	359	552
2. P PATHWAY FACTORS								
Soil erosion	**kg/ha/yr**	3837	2585	2206	13976	6993	3056	2827
Overland flow potential	**kg/ha/yr**	8	8	1	8	8	8	4
	P Index	**36.50**	**50.00**	**36.50**	**58.00**	**58.00**	**54.00**	**30.50**

Table E.2 Summarized results for Manitoba's P risk indicator (continued).

Site characteristics	Units	Brokenhead	Little Sask.	Valley	Wilson	Ochre	Vermillion	Turtle
1. P SOURCE FACTORS								
Overall P balance	**kg/ha**	-2.69	-1.10	0.49	2.06	-8.81	1.88	-1.65
Crop residue P	**cm**	3.97	5.70	5.96	5.87	3.99	6.23	4.84
Estimated P sorption index	**-**	378	247	248	244	114	189	217
2. P PATHWAY FACTORS								
Soil erosion	**kg/ha/yr**	2631	13950	13977	11107	3623	6334	4236
Overland flow potential	**kg/ha/yr**	1	8	4	4	4	4	4
	P Index	**35.00**	**74.00**	**66.00**	**66.00**	**56.00**	**66.00**	**60.00**

Table E.3 Summarized results for IROWC-P.

Site characteristics	Units	La Salle	Seine	Rat-Marsh	Cypress	Boyne	Cooks	Roseau
1. PHOSPHORUS STATUS								
Phosphorus Soil test (STP)	**kg/ha**	32.97	31.37	27.56	38.54	34.12	30.91	21.30
Degree of soil P saturation	**cm**	8.44	8.03	7.81	14.14	12.20	8.60	5.63
2. PHOSPHORUS BALANCE								
Mineral fertilizer P	**%**	143.54	119.49	111.49	124.01	127.77	129.95	71.48
Manure P	**%**	26.92	78.10	41.43	29.31	28.93	15.19	12.62
Crop residues P	**%**	39.30	24.16	31.46	36.16	37.25	36.72	23.46
3. PHOSPHORUS TRANSPORT								
Soil erosion	**kg/ha/yr**	3837.20	2584.90	2206.10	13976.40	6993.00	3056.10	2631.30
Surfarce runoff		4	4	4	8	4	4	4
	P Index	**74**	**75**	**74**	**102**	**92**	**74**	**70**

Table E.3 Summarized results for IROWC-P (continued).

Site characteristics	Units	Brokenhead	Little Sask.	Valley	Wilson	Ochre	Vermillion	Turtle
1. PHOSPHORUS STATUS								
Phosphorus Soil test (STP)	**kg/ha**	22.28	20.13	21.11	25.96	17.37	21.49	26.48
Degree of soil P saturation	**cm**	4.04	8.16	8.50	10.65	15.28	11.37	12.22
2. PHOSPHORUS BALANCE								
Mineral fertilizer P	**%**	100.85	83.68	94.48	106.04	42.07	107.67	73.41
Manure P	**%**	7.94	9.53	8.39	7.54	8.10	4.68	17.12
Crop residues P	**%**	37.80	35.08	34.70	38.65	22.54	40.88	27.76
3. PHOSPHORUS TRANSPORT								
Soil erosion	**kg/ha/yr**	2826.90	13949.60	13977.20	11107.30	3622.60	6334.30	4235.70
Surfarce runoff		4	8	2	2	4	4	4
	P Index	**69**	**88**	**73**	**87**	**78**	**84**	**80**

APPENDIX F

CORRELATION RESULTS

Table F.1 Pearson's coefficient between Minnesota's P Index, its site characteristics and water quality parameters.

Variables	TRANSPORT FACTORS			SOURCE FACTORS			P Index
	Soil erosion	Runoff	% cropland	Soil test P	Fert. P Rate.	Org. P rate	
Soil erosion							
Runoff	-0.29^{ns}						
% of cropland	0.76***	-0.18^{ns}					
Soil test P (Bray-P)	0.03^{ns}	-0.59*	-0.28^{ns}				
Fertilizer P appl. rate	0.09^{ns}	-0.67**	-0.21^{ns}	0.80***			
Organic P source appl. rate	-0.29^{ns}	-0.32^{ns}	-0.31^{ns}	0.55*	0.43^{ns}		
P index	0.65**	-0.33^{ns}	0.61*	0.30^{ns}	0.31^{ns}	0.04^{ns}	
TP (mg/l)	0.02^{ns}	-0.42^{ns}	-0.06^{ns}	0.80***	0.75**	0.48^{ns}	0.43^{ns}
Flow (m^3/s)	-0.15^{ns}	0.76***	-0.13^{ns}	-0.42^{ns}	-0.35^{ns}	-0.17^{ns}	-0.39^{ns}
P export intensity (kg/ha/yr)	-0.16^{ns}	0.59*	-0.16^{ns}	-0.03^{ns}	0.02^{ns}	-0.19^{ns}	0.08^{ns}
% exceeding 0.25 mg/l	0.28^{ns}	-0.38^{ns}	0.08^{ns}	0.43^{ns}	0.59*	0.27^{ns}	0.49^{ns}
Livestock number (A.U.)	-0.27^{ns}	-0.29^{ns}	-0.17^{ns}	0.35^{ns}	0.36^{ns}	0.93***	0.01^{ns}
Livestock intensity (A.U./ha)	0.11^{ns}	-0.34^{ns}	-0.17^{ns}	0.74**	0.44^{ns}	0.75**	0.22^{ns}
Agricultural land use (%)	0.23^{ns}	-0.55*	0.08^{ns}	0.86***	0.60**	0.39^{ns}	0.57*
Cereals production (%)	0.30^{ns}	-0.59*	0.09^{ns}	0.83***	0.77***	0.18^{ns}	0.66**
Oilseeds production (%)	0.42^{ns}	-0.53*	0.24^{ns}	0.72**	0.66**	0.07^{ns}	0.75**
Total Annual Crop (%)	0.33^{ns}	-0.56*	0.14^{ns}	0.79***	0.73**	0.14^{ns}	0.70**
Perennial Forages (%)	-0.12^{ns}	0.06^{ns}	-0.16^{ns}	0.34^{ns}	-0.15^{ns}	0.25^{ns}	-0.20^{ns}
Manure P (kg/yr)	-0.30^{ns}	-0.27^{ns}	-0.21^{ns}	0.35^{ns}	0.36^{ns}	-	0.00^{ns}
Manure P (kg/year/ha)	-0.29^{ns}	-0.32	-0.31^{ns}	0.55*	0.43^{ns}	-	0.04^{ns}
Manure tot (kg/yr)	-0.26^{ns}	-0.27^{ns}	-0.17^{ns}	0.33^{ns}	0.33^{ns}	-	-0.01^{ns}
Manure tot (kg/yr/ha)	-0.26^{ns}	-0.32^{ns}	-0.31^{ns}	0.57*	0.40^{ns}	-	0.04^{ns}
Fertilizer P (kg/ha)	0.09^{ns}	-0.67**	-0.21^{ns}	0.80***	-	0.43^{ns}	0.31^{ns}
Fertilizer P (t/yr)	0.12^{ns}	-0.50^{ns}	0.23^{ns}	0.45^{ns}	-	0.36^{ns}	0.47^{ns}

*, **, *** Significant at p < 0.05, p < 0.01 and p < 0.01 probability levels, respectively.
ns: not significant

Table F.2 Pearson's coefficient for between preliminary P risk indicator for Manitoba, its site characteristics and water quality parameters.

Variables	P SOURCE FACTORS			P PATHWAY FACTORS		P Indicator
	P balance	Crop residue	P sorption Index	Soil erosion	Flow potential	
Overall P balance						
Crop residue P	0.07ns					
Estimated PSI	0.47ns	-0.01ns				
Soil erosion	-0.11ns	0.55*	-0.42ns			
Overland flow potential	0.52*	0.22ns	0.03ns	0.28ns		
P Indicator	-0.23ns	0.35ns	-0.77***	0.72**	0.31ns	
TP (mg/l)	0.78***	0.12ns	0.29ns	0.02ns	0.59*	-0.24ns
Flow (m^3/s)	-0.19ns	0.21ns	0.65**	-0.14ns	-0.30ns	-0.48ns
P export intensity (kg/ha/yr)	0.08ns	0.44ns	0.31ns	-0.15ns	-0.15ns	-0.41ns
% exceeding 0.25 mg/l	0.50*	0.21ns	0.11ns	0.28ns	0.34ns	-0.06ns
Livestock number (A.U.)	0.69**	-0.40ns	0.42ns	-0.26ns	0.26ns	-0.28ns
Livestock intensity (A.U./ha)	0.66**	-0.24ns	0.16ns	0.11ns	0.41ns	-0.11ns
Agricultural land use (%)	0.62*	0.26ns	0.00ns	0.23ns	0.66**	0.12ns
Cereals production (%)	0.62*	0.42ns	0.00ns	0.30ns	0.63*	0.12ns
Oilseeds production (%)	0.50*	0.49ns	-0.12ns	0.42ns	0.60*	0.21ns
Total Annual Crop (%)	0.57*	0.43ns	-0.05ns	0.33ns	0.62*	0.14ns
Perennial Forages (%)	0.09ns	-0.09ns	0.14ns	-0.11ns	0.20ns	-0.13ns
Manure P (kg/yr)	0.70**	-0.42ns	0.41ns	-0.30ns	0.25ns	-0.29ns
Manure P (kg/year/ha)	0.77***	-0.46ns	0.33ns	-0.29ns	0.31ns	-0.26ns
Manure tot (kg/yr)	0.67**	-0.40ns	0.43ns	-0.26ns	0.25ns	-0.28ns
Manure tot (kg/yr/ha)	0.74***	-0.46ns	0.30ns	-0.26ns	0.33ns	-0.24ns
Fertilizer P (kg/ha)	0.86***	0.25ns	0.32ns	0.09ns	0.45ns	-0.09ns
Fertilizer P (t/yr)	0.56*	0.16ns	0.27ns	0.12ns	0.53*	-0.11ns

*, **, *** Significant at $p < 0.05$, $p < 0.01$ and $p < 0.01$ probability levels, respectively.
ns: not significant

Table F.3 Pearson's coefficient for between IROWC-P, its site characteristics and water quality parameters.

Variables	P STATUS		P BALANCE			P TRANSPORT		P Index
	Soil P test	P sat.	P Fertilizer	Manure P	Crop residues	Erosion	Runoff	
Phosphorus Soil test (STP)								
Degree of soil P saturation	0.20ns							
Mineral fertilizer P	0.80***	-0.17ns						
Manure P	0.57*	-0.07ns	0.42ns					
Crop residues P	0.28ns	-0.06ns	0.65**	-0.34ns				
Soil erosion	0.03ns	0.29ns	0.03ns	-0.30ns	0.40ns			
Surface runoff	0.24ns	0.17ns	0.03ns	0.09ns	0.04ns	0.34ns		
P Index	0.44ns	0.68**	0.19ns	-0.02ns	0.33ns	0.65**	0.56*	
TP (mg/l)	0.80***	0.05ns	0.79***	0.53*	0.35ns	0.02ns	0.37ns	0.31ns
Flow (m^3/s)	-0.42ns	-0.57*	-0.37ns	-0.19ns	-0.38ns	-0.15ns	-0.06ns	-0.43ns
P export intensity (kg/ha/yr)	-0.03ns	-0.06ns	0.09ns	-0.17ns	0.11ns	-0.16ns	0.06ns	-0.03ns
% exceeding 0.25 mg/l	0.43ns	-0.04ns	0.56*	0.30ns	0.29ns	0.28ns	-0.10ns	-0.02ns
Livestock number (A.U.)	0.33ns	-0.31ns	0.29ns	0.91***	-0.38ns	-0.28ns	0.03ns	-0.21ns
Livestock intensity (A.U./ha)	0.74**	0.24ns	0.40ns	0.75***	-0.17ns	0.11ns	0.47ns	0.44ns
Agricultural land use (%)	0.86***	0.42ns	0.58*	0.40ns	0.24ns	0.23ns	0.32ns	0.62*
Cereals production (%)	0.83***	0.30ns	0.78***	0.22ns	0.60*	0.30ns	0.22ns	0.02ns
Oilseeds production (%)	0.72**	0.38ns	0.67**	0.10ns	0.62**	0.42ns	0.31ns	0.67**
Total Annual Crop (%)	0.79***	0.34ns	0.74**	0.18ns	0.60*	0.33ns	0.26ns	0.63**
Perennial Forages (%)	0.34ns	0.30ns	-0.19ns	0.23ns	-0.53*	-0.12ns	0.29ns	0.15ns
Manure P (kg/yr)	0.35ns	-0.29ns	0.31ns	-	-0.37ns	-0.30ns	0.03ns	-0.19ns
Manure P (kg/year/ha)	0.55*	-0.07ns	0.38ns	-	-0.37ns	-0.29ns	0.08ns	-0.02ns
Manure tot (kg/yr)	0.33ns	-0.31ns	0.27ns	-	-0.40ns	-0.26ns	0.06ns	-0.20ns
Manure tot (kg/yr/ha)	0.57*	0.00ns	0.34ns	-	-0.41ns	-0.26ns	0.13ns	0.03ns
Fertilizer P (kg/ha)	0.80***	-0.18ns	-	0.46ns	0.62**	0.09ns	0.02ns	0.20ns
Fertilizer P (t/yr)	0.45ns	-0.22ns	-	0.39ns	0.29ns	0.12ns	0.14ns	0.07ns

*, **, *** Significant at $p < 0.05$, $p < 0.01$ and $p < 0.01$ probability levels, respectively.
ns: not significant