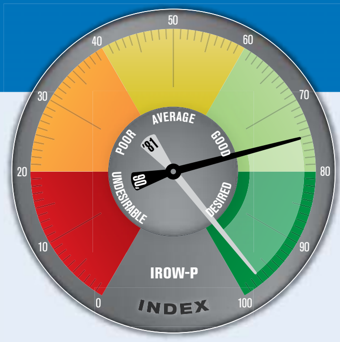
13 Phosphorus



AUTHORS

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INDICATOR NAME

Risk of Water Contamination by Phosphorus (IROWC-P)

STATUS

National Coverage 1981 to 2006

Summary

Phosphorus (P) is an important nutrient for plant and animal growth. However, additions of P to the land as livestock manure and inorganic fertilizer may lead to an increased risk of soil P saturation and resulting movement of P to water bodies. Excessive amounts of P in surface water contributes to eutrophication of rivers and lakes and to *Cyanobacteria* blooms. These result in decreased water quality and limitations on water use. The Risk of Water Contamination by Phosphorus (IROWC-P) Indicator was developed to assess the trends over time for the risk of surface water contamination by P from Canadian agricultural land at the watershed scale.

Overall risk of water contamination by P is increasing in Canada. Increases in livestock production and the use of mineral fertilizers repeatedly created regional P surpluses between 1981 and 2006. The wide range of soil types across Canada have different characteristics for retaining nutrients such as P and therefore some soils are better able than others to sustain intensive agriculture. Surface runoff, deep drainage and soil erosion by water on agricultural land contribute significantly to the risk of P contamination of surface water in eastern Canada. In western Canada, surface runoff seems to be the major factor contributing to P transport. Local implementation of nutrient management plans, regulations, conservation practices and beneficial management practices (BMPs) have considerably decreased the P surplus in some areas. However, cumulative P surpluses over time continue to enrich soil P levels. Increased efforts at controlling both P sources and transport are required to reduce the risk of P loss to water and prevent surface water eutrophication and algal blooms.

The Issue

Phosphorus is an essential nutrient for all plants and animals. It is applied to soils through inorganic P fertilizers, manures and biosolids to sustain crop yields. Since the early 1950s, intensified cropping and animal production have increased soil nutrients in some regions to levels in excess of what crops need. Over time, cumulative P surpluses have enriched the soil and increased the risk that soil P will be released and transported from agricultural fields to surface water bodies.

In natural freshwater systems, P occurs in very low concentrations but may vary significantly as a function of stream size and ecosystem characteristics. Excessive amounts of P in surface fresh water contribute to eutrophication of rivers and lakes and to Cyanobacteria blooms. These result in decreased water quality and limitations on bathing, drinking and recreational activities (Carpenter et al., 1998). Government programs and regulations have extensively promoted a reduction in agricultural P contamination from manure storage structures as well as during manure application. Nutrient management plans including P have been developed specifically for farming operations to reduce the risk of contamination by nutrients of adjacent surface water bodies in Quebec (1997), Ontario (2002) and Manitoba (2006).

The Indicator

The IROWC-P Indicator was developed to assess the status and trends over time for the risk of surface water contamination by P from Canadian agricultural land and is reported for agricultural watersheds. IROWC-P first estimates the annual amount of dissolved P that may potentially be released from agricultural soils (P source). P source is estimated as a function of cumulative P additions and removals (P-balance) over a 30-year period up to 2006 and the resulting degree of soil P saturation. IROWC-P then integrates the P source through a *transport-hydrology* function, which considers such processes as surface runoff, drainage and water erosion. IROWC-P also considers *hydrological connectivity*, which includes a topographic index, tile drainage, surface drainage and *preferential flow*. The indicator uses information from the transport and hydrological functions to estimate the likelihood for P to enter streams or water bodies.

The IROWC-P was calculated for 280 watersheds (Natural Resources Canada. 2003) across Canada that contain more than 5% agricultural land. Results were tested against P water quality monitoring data collected in 88 agricultural watersheds in Canada from 1981 to 2001. IROWC-P values were grouped separately for western and eastern Canada into five risk classes (very low, low, moderate, high and very high). The risk classes are relative rankings wherein 50% of watersheds are classified in the very low risk class and that the highest 5% of IROWC-P values fall into the high and very high risk classes in each of the two regions.

Limitations

IROWC-P assesses the risk originating from agricultural P; non-agricultural P is not considered. Calculations of cumulative P balance follow Census of Agriculture data from 1976 to 2006. There were insufficient data to allow accounting for soil P enrichment before 1976 in Canada, except for in Ontario where trends reported by the Potash and Phosphate Institute were available.

Risk classes were defined separately for eastern Canada and western Canada to more accurately reflect the different conditions in different parts of the country, and are therefore not comparable.

Hydrological *connectivity factors* represent the pathways of P transfer to water bodies and were assumed to have equal weight in all agricultural areas across Canada.

The calculation of IROWC-P accounts for most BMPs that lower P levels at the source but accounts for few BMPs that mitigate the movement of P in the landscape. This is due to a lack of comprehensive national BMP adoption data such as buffer strips.

This indicator was calibrated using the annual median P concentrations of 88 watersheds located across the country. In these cases, the P may have come from a variety of sources, including urban wastewater and forest. Since agricultural activity may be concentrated on relatively small proportions of watershed area, the IROWC-P value may be influenced by the remaining non-agricultural area.

Results and Interpretation

In 2006, four watersheds classed as very high risk and twelve at high risk of water contamination by P were located in both eastern Canada (Nova Scotia, Quebec, Ontario) and western Canada (Saskatchewan, Alberta and British Columbia) where the combination of agriculture intensity and P transport factors pose a significant risk to water quality and mitigation measures are likely required (Figure 13-1). Forty-eight watersheds were estimated to be at moderate risk.

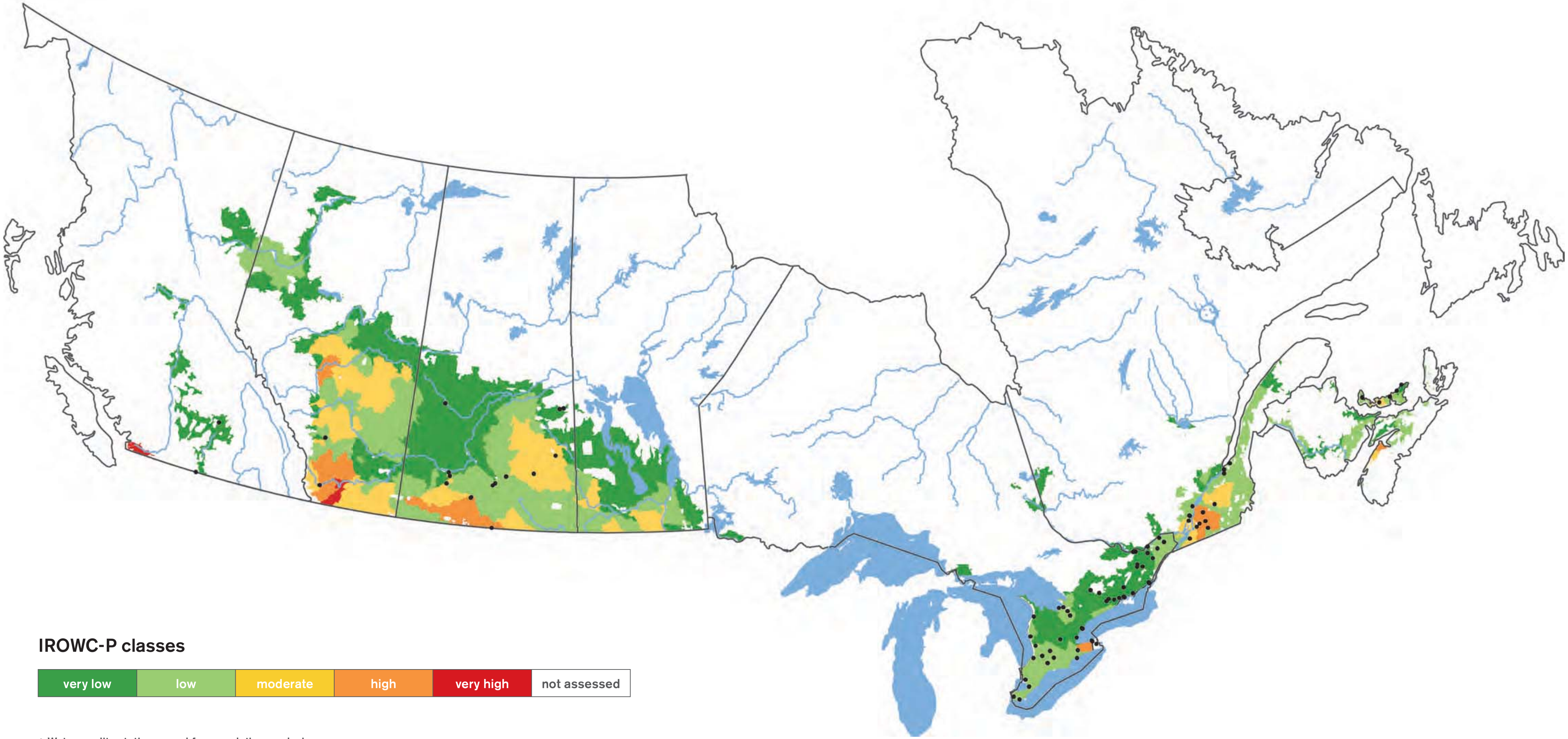
Between 1981 and 2006, 43% of the 280 watersheds moved to higher risk classes (Figures 13-2 and 13-3), indicating that more adoption and implementation of P control measures are needed to protect surface water at risk of being significantly degraded. The general analysis of trends over time across Canada (Table 13-1) shows that approximately 7% of the farmland located in British Colombia shifted from low risk in 1981 to very high risk of P water contamination in 2006. A shift to higher risk classes has occurred since 1991 in Alberta, Saskatchewan and Manitoba, mainly because the P balance has increased steadily (Figure 13-4). However, risk values are highly dependant on climate, as shown in Table 13-1 where the proportion of farmland in the IROWC-P very low risk class for the drier year (2001) (Figure 13-5) was higher than in 1996 and 2006. In eastern Canada, the risk in Ontario has remained stable. The risk in Quebec, New Brunswick, Nova Scotia and Prince Edward Island has shown the same gradual shift to higher classes since 1991 that was observed in the Prairie Provinces (Table 13-1).

Any BMPs that have the potential to decrease P so that it is not in excess of crop needs or reduce the transport of P to surface water will decrease the risk of water contamination by P.

IROWC-P values and trends are a function of agricultural intensity and its influence on P source, and of transport processes that are highly dependent on regional climatic variations (Figure 13-5). There has generally been an increasing trend in the P-source levels in the surface of agricultural soils in Canada since 1976 as intensified agricultural practices have resulted in the application of P in excess of crop uptake (also called positive annual P balance) and have therefore increased soil P saturation (Figure 13-6). In 2006, very high concentrations of P (more than 4 mg of P per kg per year, or >4 mg P kg^{-1}) at risk for release by storm events were located in regions where the agricultural production has been historically intensive and where soils have reached high P saturation values. These regions are located around Abbotsford, British Columbia; Lethbridge, Alberta, some areas in the Great Lakes basin in Ontario; the St. Lawrence Lowlands in Quebec; Grand Falls, New Brunswick; and Annapolis Valley, Nova Scotia (Figure 13-7, Table 13-2). High risk (3 to 4 mg P kg^{-1}) areas were also identified surrounding these regions as well as in Manitoba and Prince Edward Island.

Response Options

Any BMPs that have the potential to decrease P so that it is not in excess of crop needs or reduce the transport of P to surface water will decrease the risk of water contamination by P. For example, appropriate use of the enzyme *phytase* in monogastric animal feed enables producers to reduce the quantities of P supplement they introduce in the animal ration and, consequently, reduce the P concentration of manures. As the proportion of animals fed with phytase increases nationally, the quantities of P in manure will decrease. Another example of a BMP that can potentially reduce P source is the introduction of crops with high P uptake into crop rotations on P-enriched soils. These crops take up large amounts of P, which is removed at harvest. Conducting regular soil nutrient testing and manure



IROWC-P classes

very low	low	moderate	high	very high	not assessed

● Water quality stations used for correlation analysis

FIGURE 13-1 Risk of water contamination by phosphorus in agricultural watersheds under 2006 management practices

TABLE 13-1 Proportion of farmland in various IROWC-P classes, 1981–2006*

	Proportion (%) of Farmland in Different Risk Classes																													
	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	93	93	93	93	93	93	7	7	0	0	0	0	0	0	4	0	0	0	0	0	3	4	4	0	0	0	0	3	3	7
AB	98	76	59	32	95	21	1	19	37	28	5	48	1	4	3	37	0	24	0	1	1	3	0	6	0	0	0	0	0	1
SK	88	59	43	50	80	43	12	31	24	48	16	32	0	6	30	2	3	17	0	4	2	0	0	7	0	0	0	0	0	0
MB	100	81	83	53	54	36	0	19	11	34	35	45	0	0	6	14	5	19	0	0	0	0	6	0	0	0	0	0	0	0
ON	53	49	49	33	37	47	36	37	48	22	47	50	11	11	3	42	16	0	0	3	0	3	0	3	0	0	0	0	0	0
QC	37	34	31	8	32	13	55	39	38	38	40	46	8	27	23	17	20	22	0	0	8	29	8	18	0	0	0	8	0	0
NB	100	100	100	30	100	40	0	0	0	70	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NS	63	63	28	18	28	18	37	37	54	48	54	48	0	0	18	16	18	16	0	0	0	18	0	18	0	0	0	0	0	0
PE	34	100	34	21	34	6	66	0	66	79	66	56	0	0	0	0	0	38	0	0	0	0	0	0	0	0	0	0	0	0
NL	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CANADA	**89**	**68**	**56**	**41**	**77**	**33**	**9**	**25**	**29**	**35**	**18**	**42**	**1**	**6**	**13**	**21**	**4**	**19**	**0**	**2**	**1**	**3**	**1**	**6**	**0**	**0**	**0**	**0**	**0**	**1**

* Proportion calculated as percentage of farm land classified for the whole watershed over the total amount of farm land in the province

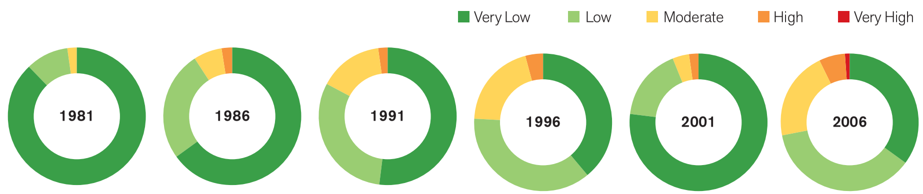


FIGURE 13-3 Percentage area of farmland in risk classes, by census year

TABLE 13-2 Proportion of farm land in various P-Source classes, 1981–2006

	Proportion (%) of Farmland in Different Risk Classes																													
	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	6	0	0	0	0	0	88	91	81	70	48	32	4	2	11	21	40	54	1	3	1	1	3	4	0	2	4	5	6	6
AB	59	54	47	35	17	7	41	45	53	63	81	83	0	0	0	1	1	9	0	0	0	0	1	1	0	0	0	0	0	1
SK	68	63	64	62	53	39	31	37	36	37	46	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MB	100	100	92	87	77	61	0	0	8	12	23	36	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
ON	37	25	19	17	15	14	56	60	58	49	45	42	7	15	23	29	31	35	0	0	1	5	9	10	0	0	0	0	0	0
QC	48	2	0	0	0	0	50	69	56	31	18	15	0	27	25	38	44	42	0	0	16	17	17	19	0	0	0	12	18	21
NB	72	2	0	0	2	2	26	88	64	47	13	4	2	8	26	41	62	60	0	2	8	10	14	24	0	0	2	2	9	11
NS	64	1	0	0	0	0	36	96	60	12	6	6	0	3	38	81	74	48	0	0	2	7	17	39	0	0	0	0	3	7
PE	66	0	0	0	0	0	34	100	74	32	0	0	0	0	26	67	69	54	0	0	0	0	30	46	0	0	0	0	0	0
NL	32	3	0	0	0	0	54	56	21	21	3	3	5	18	37	37	18	18	0	14	18	0	33	0	9	9	23	41	41	74
CANADA	**68**	**60**	**55**	**49**	**37**	**26**	**31**	**38**	**42**	**45**	**54**	**61**	**0**	**1**	**2**	**4**	**5**	**9**	**0**	**0**	**1**	**1**	**1**	**2**	**0**	**0**	**0**	**1**	**1**	**1**

* Proportion calculated as percentage of farm land classified for the whole watershed over the total amount of farm land in the province

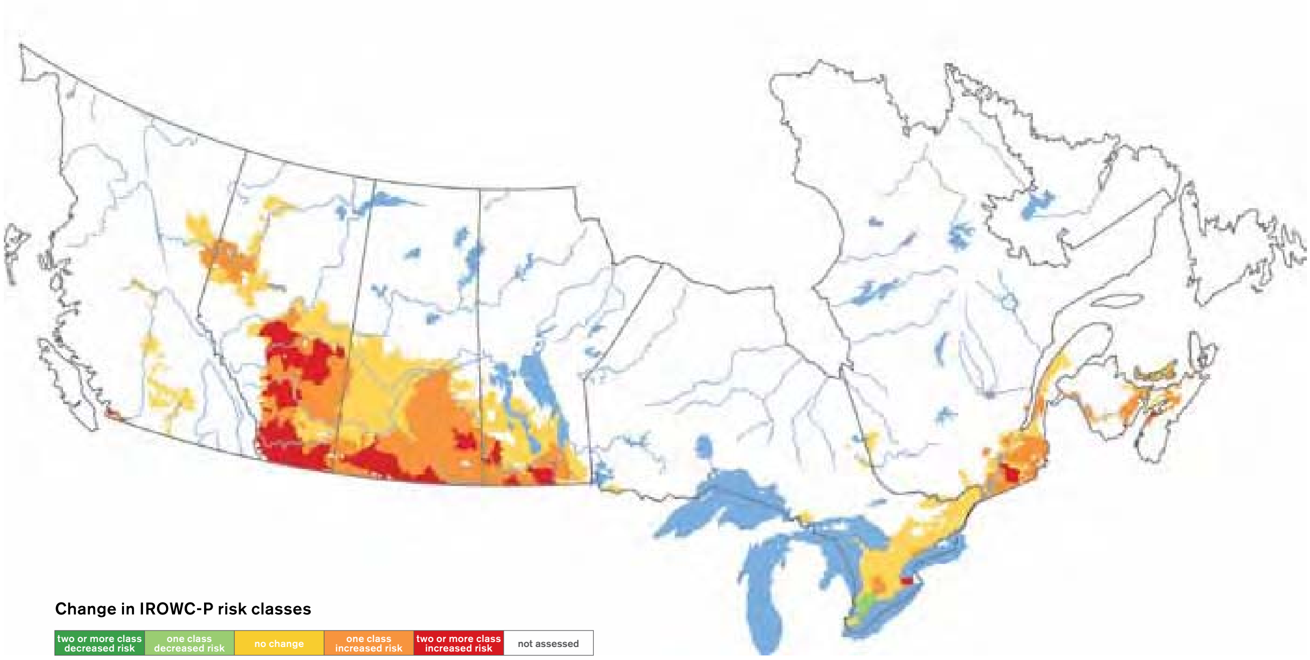


FIGURE 13-2 IROWC-P risk class change, 1981–2006

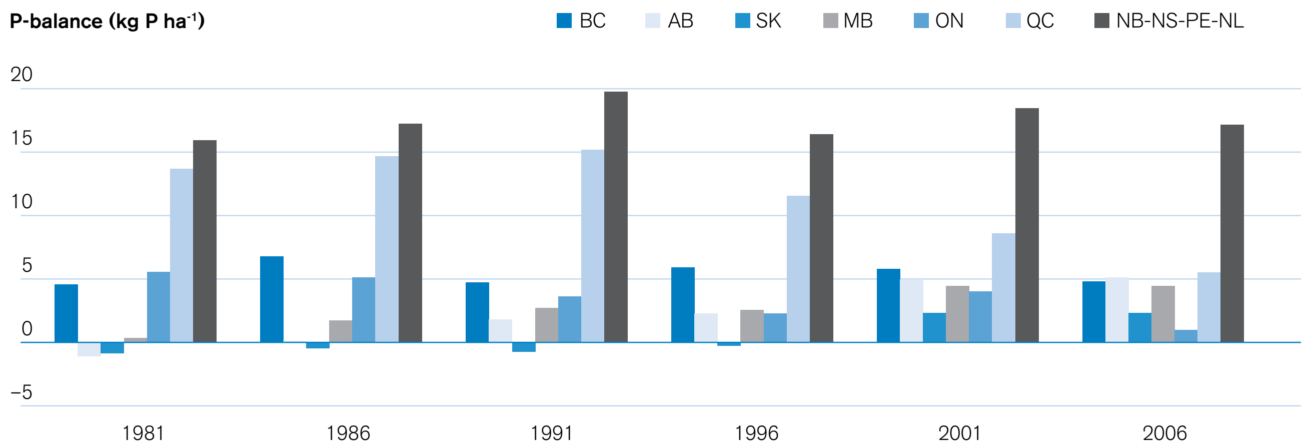


FIGURE 13-4 P balance (kg P ha^{-1}) by province, 1981–2006

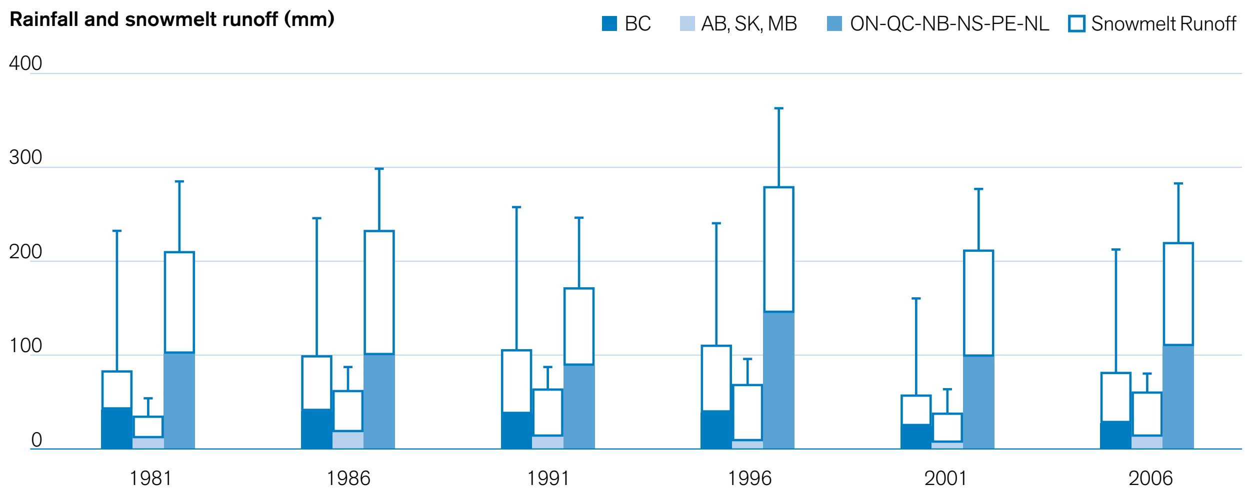


FIGURE 13-5 Rainfall (blue) and snowmelt runoff (white); error bars indicate standard deviation of total runoff.

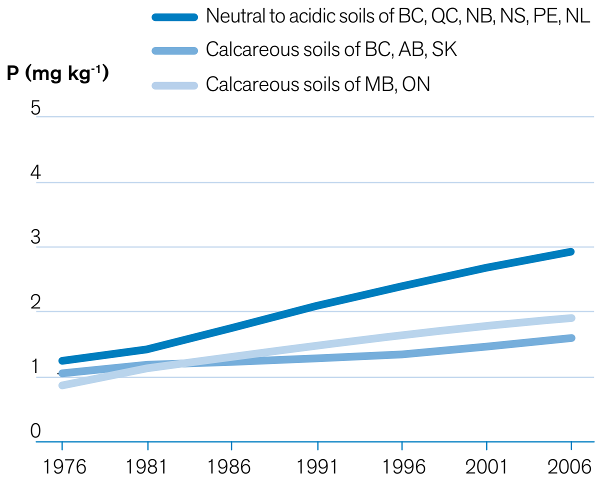


FIGURE 13-6 P source (mg P kg^{-1}), 1976–2006

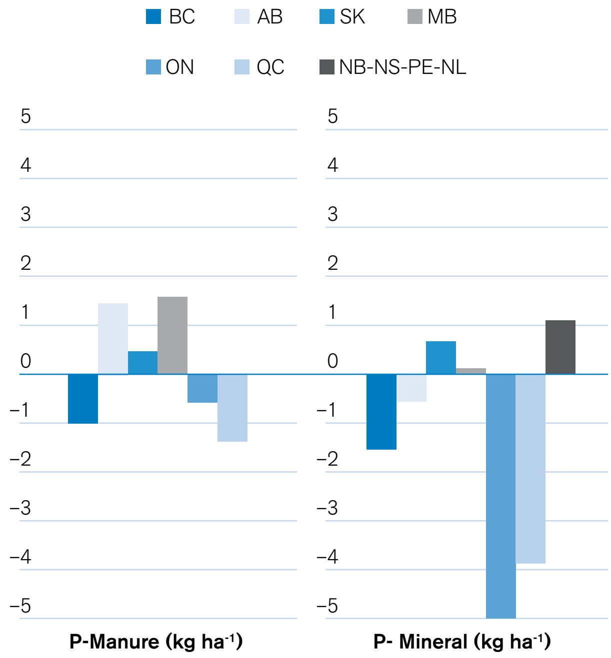


FIGURE 13-8 Change of P inputs, 1981–2006

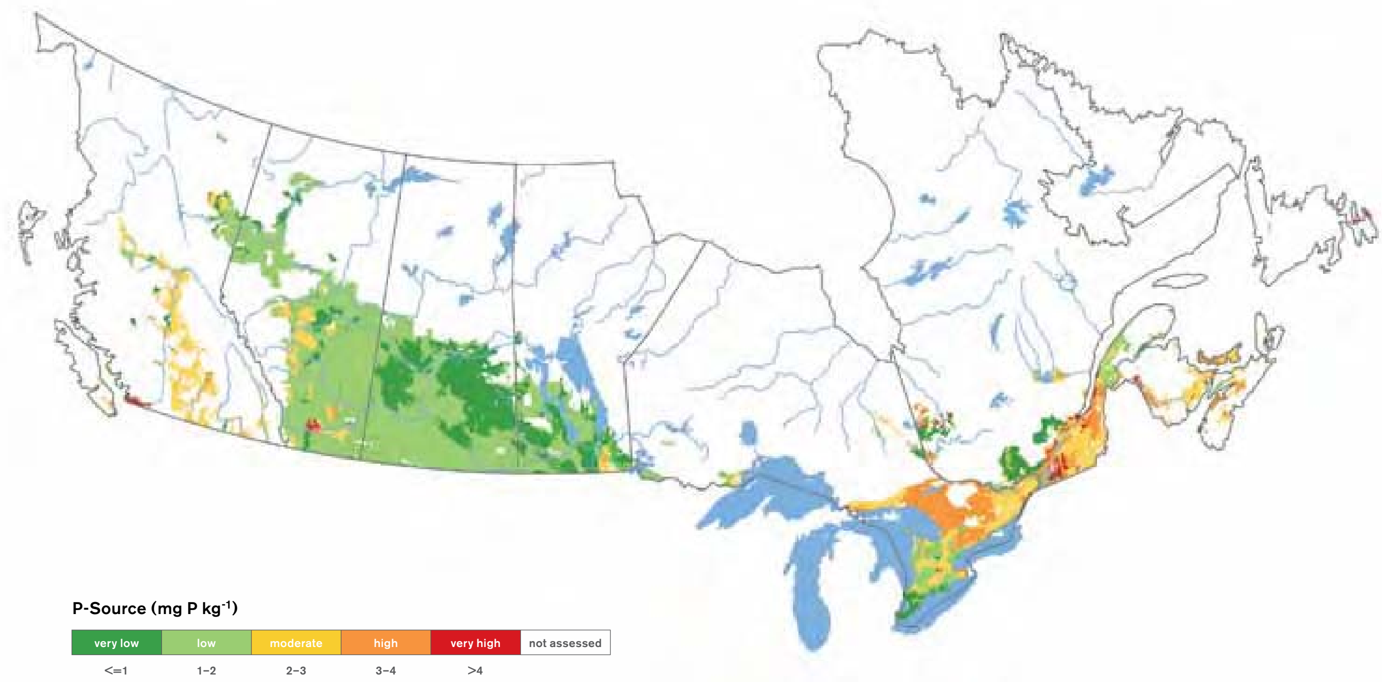


FIGURE 13-7 Risk of P release in agricultural land under 2006 management practices

nutrient testing can help producers have a better idea of the level of nutrients already present in the soil, and how much is potentially being added, which can have both economic benefits and help manage P levels in the soil. In the long run, such crop management can progressively reduce the quantity of soil P available for transport to surface waters and return agro-ecosystems to lower risk classes.

Implementation of BMPs to impede the movement of P into the drainage network, such as the establishment of buffer strips around surface water bodies will reduce the risk of P contamination of surface waters. However, buffer strips can impede agricultural activities. In order to render this BMP more economically acceptable for producers, plant species that offer potential economic return to producers should be prioritized for buffer strips.

IROWC-P enables the identification of areas with a high risk of water contamination by P from agricultural sources. A more detailed examination of agricultural practices in these regions could reveal which regional characteristics contribute to the risk of water contamination by P. This could facilitate targeted mitigation practices or research efforts.

IROWC-P could be further developed by incorporating information about new or existing BMPs that have been adopted and have significantly impacted P source and P transport. Currently, there is a lack of national data on the extent and location of such BMPs. This means that few BMPs associated with the transport component of the IROWC-P are adequately taken into account by the indicator algorithm. Infrastructures that address surface runoff could easily be included in the IROWC-P assessment. For example, as national data on buffer strips around surface water bodies become more extensively available, their integration into the IROWC-P calculation will reflect their impact on P transport to surface waters.

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