



Indicator of The Risk of Water Contamination by Phosphorus

Agri-Environmental Indicators Report

The Environmental Sustainability of Canadian Agriculture

Census Year 2021



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Indicator of The Risk of Water Contamination by Phosphorus

Agri-Environmental Indicators Report, Census Year 2021

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The issue and why it matters

Phosphorus (P) is an essential nutrient for all plants and animals. It is added to agricultural soils as mineral fertilizer where soil reserves are inadequate to sustain crop yields, or as livestock manure or biosolids. Since the early 1950s, intensified crop and livestock production has resulted in P applications in some regions greater than the removal of P in the harvested portion of crops. Over time, cumulative P surpluses have enriched the soil and increased the risk that soil P will be released and transported from agricultural fields in runoff. The risk of P loss is dependent on the co-occurrence of two factors: P source and P transport. These will vary with local and regional conditions and with weather. Therefore, periods of high runoff, such as spring snowmelt and heavy rain events, result in a greater risk of P being released and transported into freshwater bodies.

In natural freshwater systems, P occurs in very low concentrations but may vary significantly as a function of the stream size and ecosystem characteristics. Relatively small increases in P concentration in surface fresh water can contribute to eutrophication of rivers and lakes, and to the formation of harmful or nuisance algal blooms. These result in decreased water quality and limitations on bathing, drinking and recreational activities, subsequently leading to economic and social impacts on the local community (Watson et al. 2016). This has been most evident in relatively shallow lakes with a large proportion of the watershed under agricultural or urban land uses, like Lake Winnipeg, Lake Erie and Missisquoi Bay in Lake Champlain. While the source of the P is not only agricultural, municipal and industrial wastewater, as well as residential contributions from wastewater or leaky septic systems, significant effort has been expended on reducing or mitigating agricultural contributions. Agricultural sources of P present different management challenges compared to urban areas because the sources are diffuse across the landscape and transport is episodic during runoff events. Agricultural Beneficial Management Practices (BMPs) have focused on using P more efficiently for plant uptake, resulting in requiring less input, as well as mitigating P movement within the landscape to reduce contamination into freshwater bodies.

The indicator

The Indicator of the Risk of Water Contamination by Phosphorus (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. It is calculated for 3,487 Soil Landscapes of Canada (SLC) polygons with greater than 5% agricultural land. Previous reports had consolidated the data for these polygons into 280 watersheds, but this

report has maintained the greater detail. The structure of IROWC-P follows that of a component P Index (Reid, Schneider & McConkey, 2018), considering the following four components:

- Dissolved P from the soil, where the P source (estimated from the cumulative P balance and the resulting degree of P saturation) is multiplied by the modelled volume of surface plus tile runoff.
- Dissolved P incidental to application of mineral P fertilizers or livestock manure. The P available for runoff is estimated from application rates, solubility of P source, application timing and degree of incorporation. A P distribution factor is used to calculate how much P is retained in the field as water infiltrates into the soil and how much is carried in runoff.
- Dissolved P from overwintering vegetation, estimated from the quantity of P in the vegetation that is released as soluble P modified by the proportion of this P which infiltrates into the soil. Losses are greatest when there is no loss until spring thaw and the runoff occurs over frozen soils that cannot absorb the P.
- The bioavailable portion of particulate P from soil erosion. The amount of water erosion is calculated in the soil erosion indicator (WatERI) and multiplied by the soil test P concentration to estimate the portion of particulate P that could contribute to eutrophication.

For each of the components, transport off the field is estimated using both the surface runoff and the portion of tile drainage that has reached the tiles through quickflow (preferential flow) through earthworm burrows in the soil. Delivery from the field to surface water is estimated considering the stream density, dominant surface landforms and connectivity through tile drains.

Model updates from previous versions

Several changes related to data input and calculation were made to reflect better the risk of P movement from agricultural land in the following ways:

- Use of data from the Farm Management Survey (FMS) to estimate the timing and placement of fertilizer and manure application per commodity.
- Implement two scenarios of water budget estimates (historical and normals) to compare the impact of on-farm management practices and variation in weather on the risk of P runoff.
- Initial soil test P values were adjusted for Ontario to reflect the high applications of fertilizer and manure during the 1960s and 1970s. Previous versions of the indicator had adjusted the initial values on a provincial basis; however, for this

indicator, data on P balance were collected at the county scale, providing improved spatial discretization.

- Allocation of fertilizer P to SLC polygons was based on the relative value of fertilizer purchases by different farm types within each polygon, rather than assuming manure P displaced fertilizer P.
- Components were added to account for P losses incidental to the application of fertilizer or manure, and for losses from over-wintering vegetation.
- Calculation of potential P losses through tile drains was updated to reflect better estimates of the proportion of quickflow to tiles.
- Improved alignment with other indicators, including the use of a common hydrology model to predict runoff (the hydrology module of the DNDC model); using the allocation of manure to agricultural land calculated for the IROWC-N indicator; and using the water erosion outputs from the soil erosion indicator to calculate particulate P losses.
- Results have been reported by SLC polygon, rather than consolidated into watersheds, so there is more detail in the spatial patterns of risk of P loss.

Limitations

IROWC-P assesses the risk originating from P management in agricultural fields; point source P (agricultural or non-agricultural) is not considered. Calculations of P inputs and cumulative P balance follow Census of Agriculture data from 1981 to 2016. Except for Ontario, there is insufficient data to allow accounting for P enrichment prior to 1976.

Data for nutrient application timing and application method follow the Farm Environmental Management Survey. This does not differentiate among different fertilizer types, so there is some uncertainty regarding the incorporation and timing of P fertilizer specifically.

The spatial extent of tile drainage is poorly enumerated, particularly in provinces where it is a relatively new practice.

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

Data is aggregated at the SLC polygon level, so considerable variation is expected within these polygons in soil P accumulation, application rate, method, timing and water

erosion. Depending on the location of “hot spots” for P loss, the actual risk of P loss to surface water can vary from the aggregated values.

Patterns of risk of P accumulation in 2021

High accumulations of P in the soil, from long-term additions of P in fertilizer and manure that exceed crop removal, increase the risk of desorption from the soil surface during runoff events, as well as higher levels of bioavailable P in eroded sediment. The greatest accumulations tend to be in areas with high concentrations of livestock or of horticultural crops. Areas of high P accumulation from livestock include pockets in the lower Fraser Valley in BC, the feedlot area near Lethbridge in AB, the inter-lake region in MB, mid-western Ontario, southern Quebec, the St. John’s River valley in NB and the province of NL. Areas of high P accumulation from horticultural crops include PEI, parts of NB, southwestern Ontario, and the lower Fraser Valley in BC.

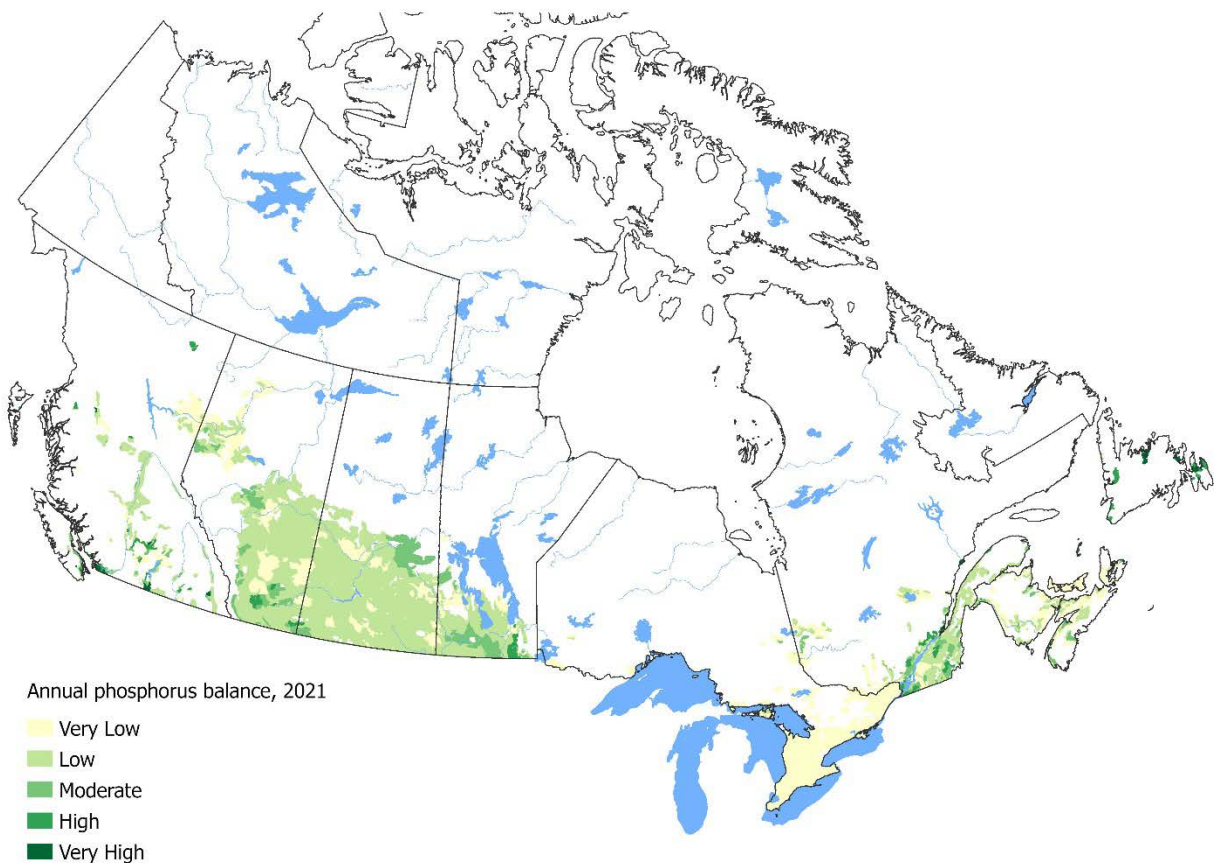


Figure 1: Soil phosphorus accumulation (legacy P source risk) in Canada in 2021.

Most parts of the country have seen a significant increase in P accumulation during the four decades since 1981. Exceptions include some small areas in southwestern ON, where soybean farming has supplanted livestock agriculture, and in the grain growing areas of Saskatchewan. This accumulation is the source of P that can be desorbed from the soil and lost to surface and tile runoff.

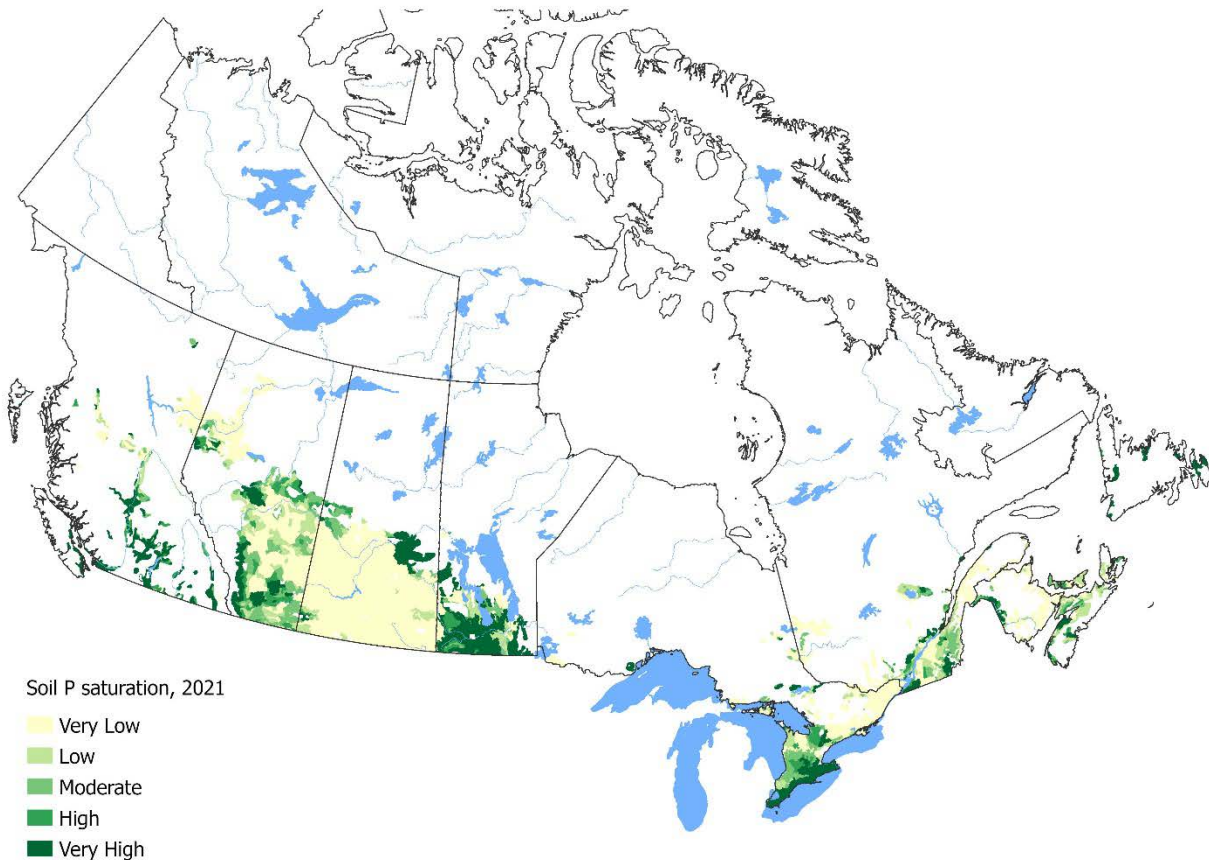


Figure 2: Soil P saturation (water extractable P) in Canada in 2021.

Patterns of risk of P losses in 2021

The risk of P losses follows a similar pattern to that of P accumulation, with the difference due to the amount of runoff across the country and the soil mineralogy in different regions. The risk of losses was lower than the P accumulation in Atlantic Canada due to the high capacity of the acidic soils to bind P, and in the Prairie

provinces because of the low rainfall and therefore low runoff risk. Across the country, the losses of bioavailable P through soil erosion and desorption from accumulated P in the soil were roughly equal, each representing about 40% of the total losses. Most of the remaining 20% is from incidental losses to P application, with only a small fraction representing losses from overwintering vegetation.

These losses are calculated first as the amount that is assumed to leave the edge of fields within the SLC, which is then multiplied by a delivery ratio to represent the amount that could reach the nearest surface water. The delivery ratio is based on the average distance to a water body in an SLC and the dominant topography. Phosphorus that has entered a tile drain is assumed to be delivered directly to surface water.

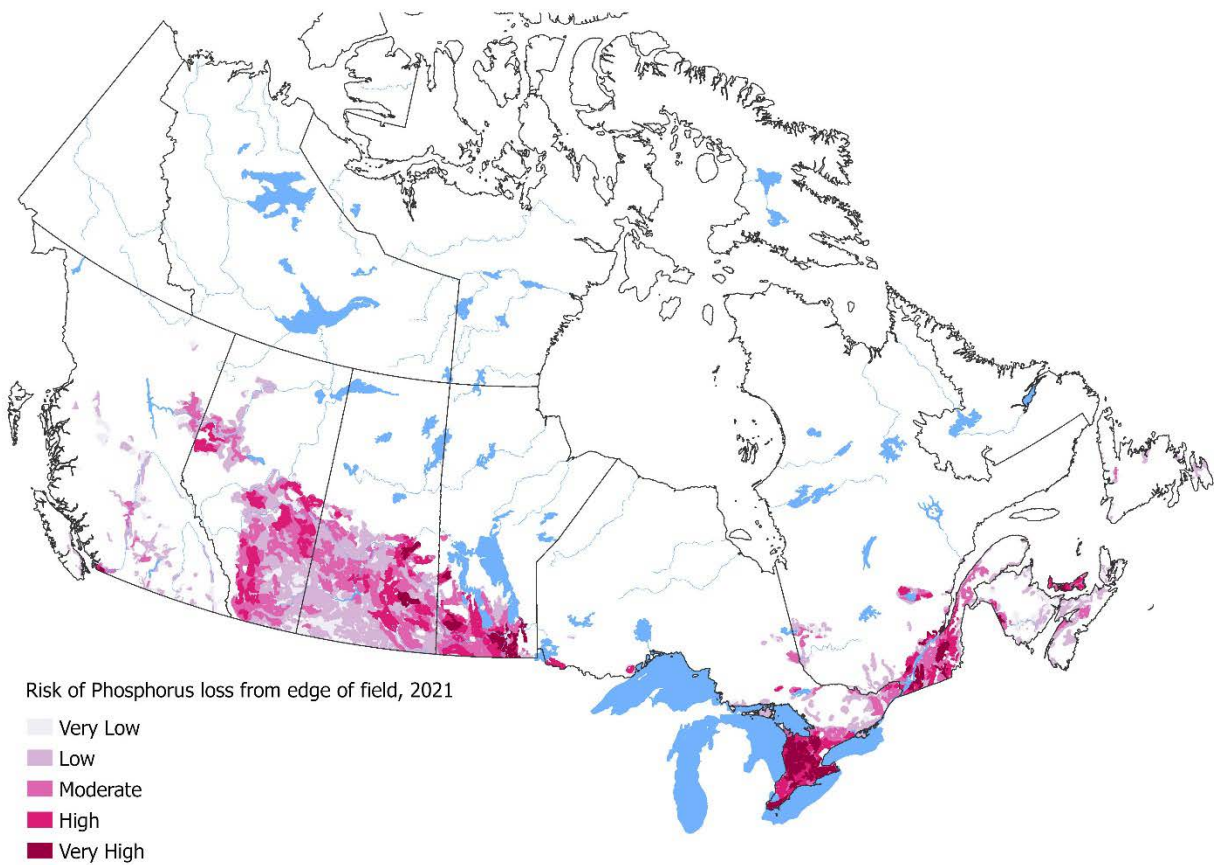


Figure 3: Risk of phosphorus loss from edge-of-field in Canada in 2021.

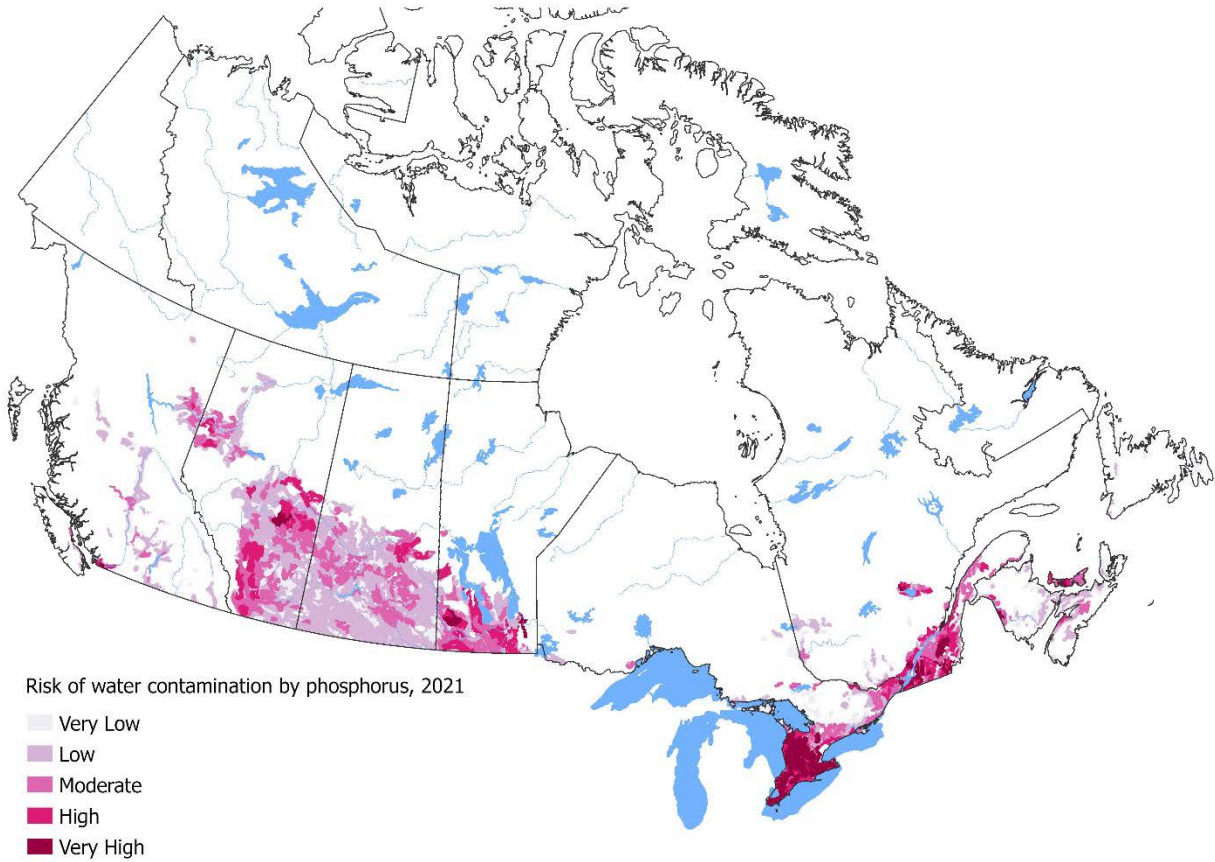


Figure 4: Risk of contamination by phosphorus in Canada in 2021.

Changes in risk of P losses from 1981 to 2021

Most areas in the country have reduced their P balance since 1981, both due to increased crop removal from higher yields and to reduced fertilizer use. The exceptions are areas where intensive livestock production has moved to those areas during the 1990s and 2000s, like southern Manitoba and southern Alberta.

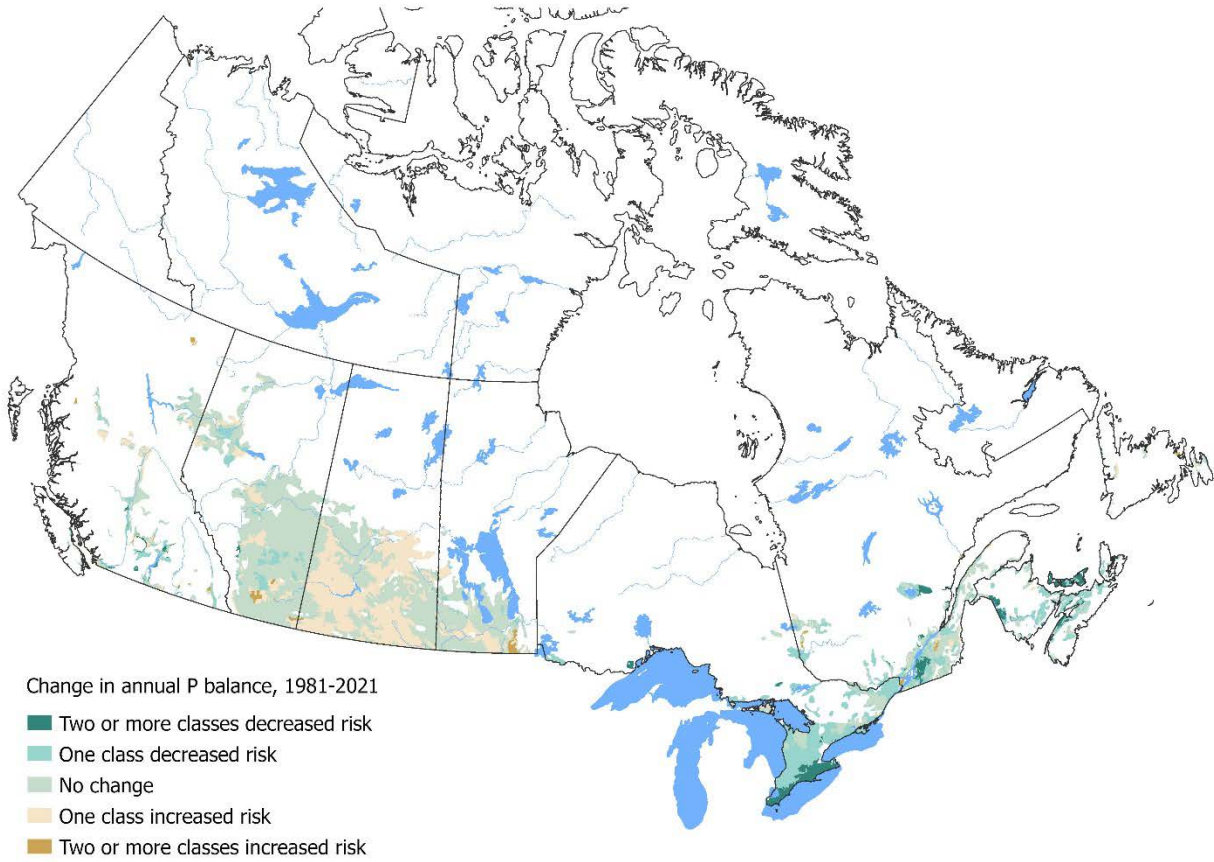


Figure 5: Change in annual P balance in Canada from 1981 to 2021.

The largest increases in risk of P losses generally followed the intensification of livestock production or field horticulture, but were ameliorated somewhat by the soil or weather conditions that reduced P transport. The greatest increases were in pockets in southwestern Ontario, southern Quebec, the inter-lake region in Manitoba and the lower mainland of British Columbia. There were smaller increases despite high P accumulations in southern Alberta, where dry conditions minimized transport, and in Atlantic Canada, where the binding capacity of the soils minimized P desorption.

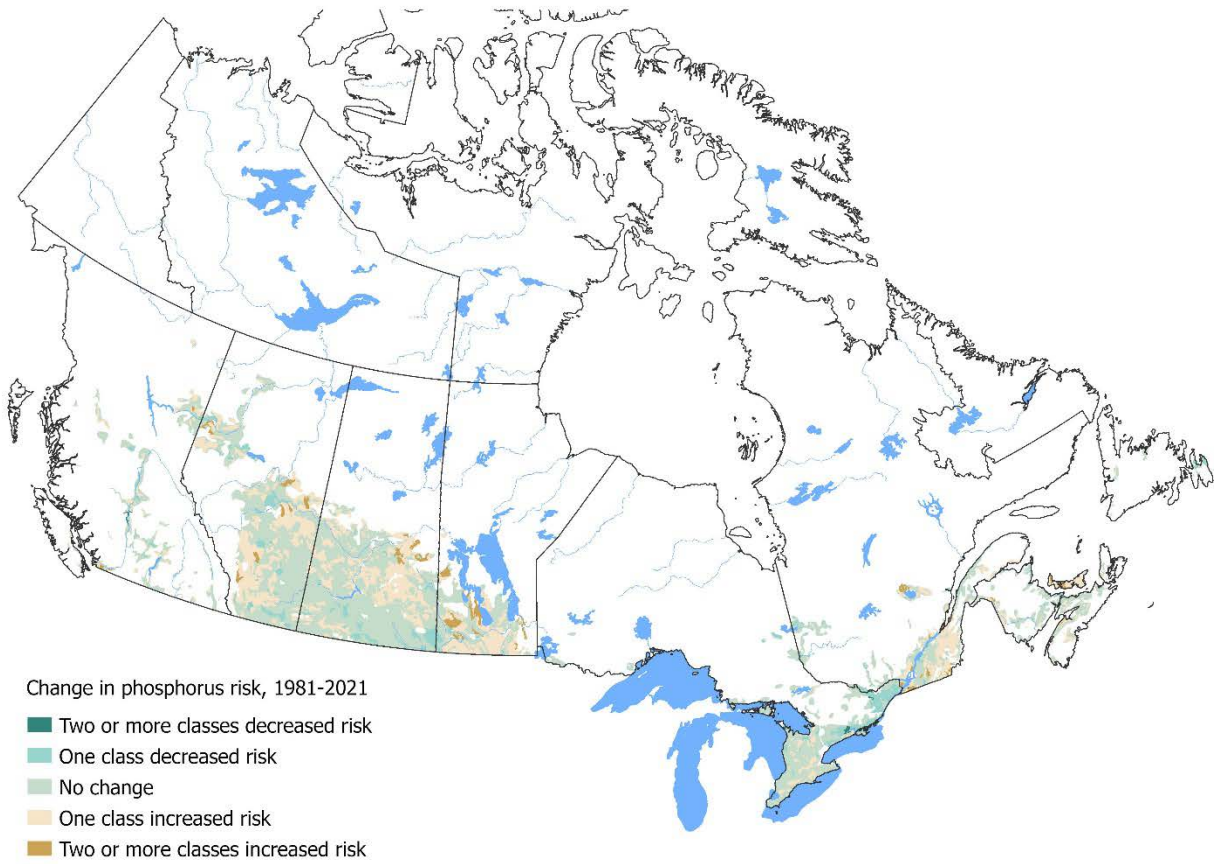


Figure 6: Change in risk of water contamination from agricultural land in Canada from 1981 to 2021.

Trends in risk of water contamination by P from 1981 to 2021

Nationally, there has been a gradual but consistent increase in the risk of water contamination by P during the past four decades, indicated by a decline in the indices of P risk (Figure 7). The primary driver for this trend appears to be the intensification of livestock production, even though the number of animals is stable or declining. Because manure is applied close to where it is generated, the consolidation of livestock operations is creating zones of P excess in those areas, while the regions where livestock numbers have declined have switched to crop production, where the risk of P losses is stable or declining only very slowly.

Provincially, Ontario shows the greatest risk of P loss due to the intensity of agricultural production (both cropping and livestock), which has been present since the 1960s. The risk appears to be stable over time, despite some year-to-year variations. Quebec

showed a rapid increase in risk from 1981 to 2006, during the time when the swine industry was rapidly expanding, but there appears to be some improvement since then.

The risk of P loss from soils in Atlantic Canada is limited by the affinity of those soils for P absorption. Despite this, there is a trend of an increasing risk of P loss in these provinces, particularly in Prince Edward Island. This is related to the intensity of P fertilizer application to potatoes in PEI and NB, and to horticultural crops in the Annapolis Valley of NS.

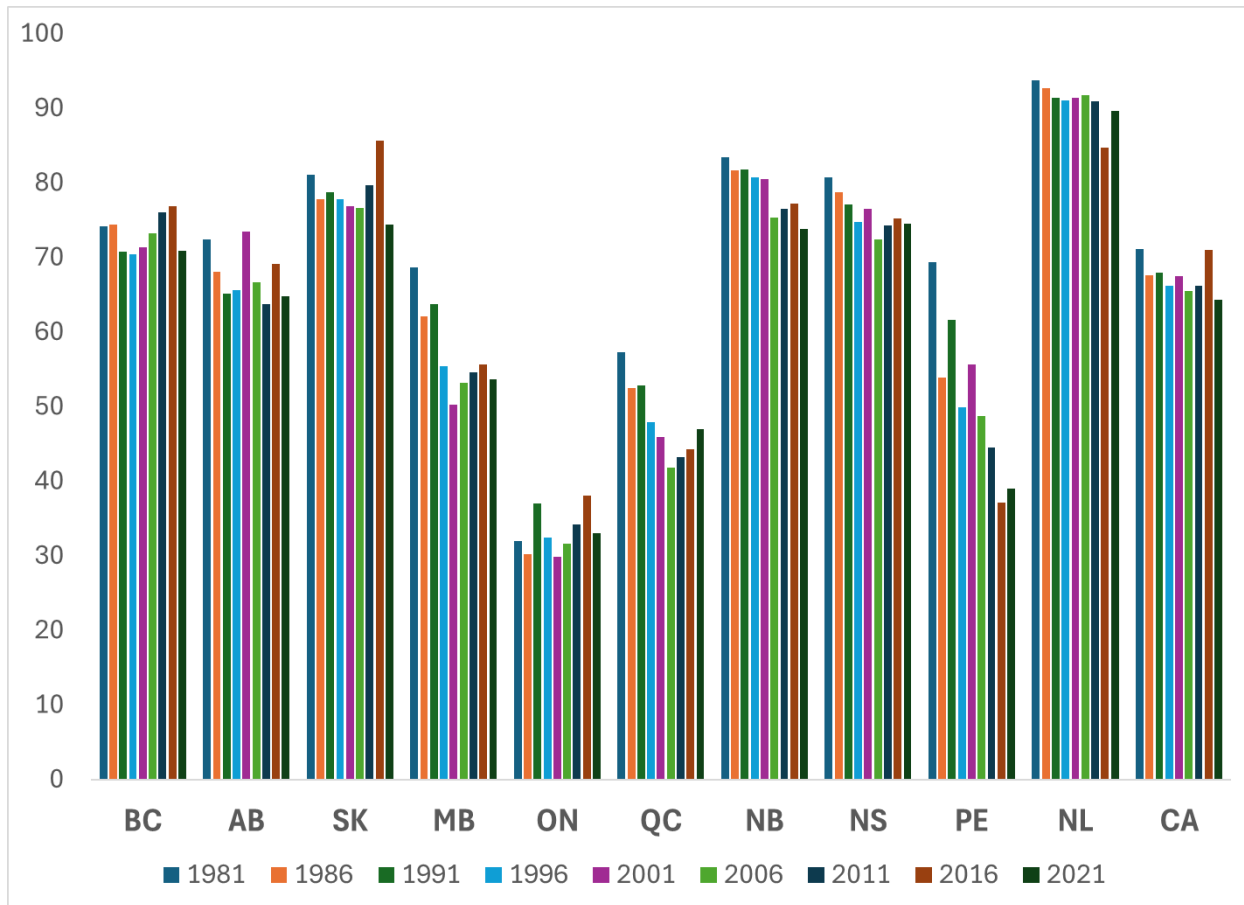


Figure 7: Trends in IROWC-P risk of water contamination in Canada from 1981 to 2021.

The soils in the Prairie provinces have much lower ability to hold on to P than their eastern counterparts, but the intensity of P application is also much lower, and the amount of runoff from the low precipitation is less. Saskatchewan has low P application rates, which are leading to P deficiencies in some areas. The increase in risk of P loss in Manitoba can be attributed to the intensification of the hog industry in the inter-lake

region. Alberta has some pockets of elevated risk where there is concentrated beef feedlot production.

Management options to mitigate risk of P losses

Reducing the risk of P losses will involve managing both the source and the transport of P from agricultural fields. Maintaining P application rates to meet but not exceed crop requirements will have effects in both the short and long term, as this will gradually draw down soil reserves of P where they are excessive. This can be challenging on livestock farms that have been using manure primarily as a nitrogen source, since the amount of P applied is greater than the crop removal; reducing the manure application rate and supplementing with N fertilizer will avoid this, but also means a larger land area is required to utilize the manure produced.

Applying P below the soil surface, either through sub-surface banding or rapid incorporation, will protect the applied P from runoff losses. The impact of this will be immediate, but while this can have significant local impacts, it has only been shown to affect about 20% of the total losses, with most of the remainder coming from the build-up in the soil from past applications.

Reducing the volume of runoff will reduce the risk of P losses, which can be achieved through greatly improved soil structure and the inclusion of perennial forage crops in the rotation. Adding filter strips or riparian buffers can also trap P from surface runoff before it reaches surface water. These practices are not accounted for in the IROWC-P model.

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