

Paper 1 of 3 · Water pollution & agriculture

Who Actually Pays for Water Pollution in Canada?

The Unaccounted Costs of Agricultural Nonpoint Source Pollution and the Failure of the Polluter-Pays Principle

AUTHOR

John Crandlemire, P.Eng.

Independent research

DATE

July 2026

High River, Alberta

FORMAT

Independent analysis

KEYWORDS

water pollution

agricultural runoff

nonpoint source

polluter-pays principle

environmental economics

soil degradation

cost externalization

Executive summary

In Canada's major agricultural watersheds (Lake Erie, Lake Winnipeg, the St. Lawrence, the middle Bow and South Saskatchewan irrigated corridors, and comparable nutrient-stressed basins), Environment and Climate Change Canada (ECCC) indicators and basin plans attribute the bulk of phosphorus loading to agriculture and other nonpoint sources, yet public-program receipts attributed to agriculture are only about \$22M (0.9% of the management ledger), not including total private beneficial management practice (BMP) spend, under program-design accounting: a 158:1 fiscal-incidence intensity ratio versus municipal ratepayers at the central 75% attribution parameter. That ratio measures who pays for remediation under current institutions, not marginal abatement cost. Against \$2.57 billion in annual management cost, agriculture's attributed shortfall is about \$1.91B (5) while net externalization of the taxpayer pool alone is approximately \$1.11 billion per year (6). A bottom-up allocation model combines six cost pools, basin indicators, and payor weights across nutrient treatment, pesticide removal, monitoring, watershed restoration, and eutrophication damages (agricultural attribution varied 65–85%). Net externalization ranges \$956M–\$1.26B across that band. On-farm soil degradation (\$3.0B annually) is reported separately as private productivity loss and is not summed with public cleanup costs. Alongside remediation, taxpayer-funded agri-environmental assistance (Sustainable Canadian Agricultural Partnership [Sustainable CAP], On-Farm Climate Action Fund [OFCAF], Manitoba Growing Outcomes in Watersheds [GROW], Prime-Vert, and related streams) sits in a separate account on the order of \$0.9–1.0B/yr (working estimate; outside the remediation ledger), so the public funds both cleanup and on-farm practice payments while agriculture contributes \$22M to the remediation ledger. Structural drivers and a phased, jurisdiction-aware policy framework are compared with polluter-pays instruments applied to mining, oil and gas, landfills, and waste facilities, and with provincial nutrient regimes from Quebec, Ontario, Alberta, British Columbia, and Prince Edward Island.

1. Introduction

1.1 Research Question

Before a mine is permitted to break ground in Canada, the operator must post a reclamation bond covering the full estimated cost of environmental restoration (Bond Connect Canada, n.d.). When an oil or gas well is drilled in Alberta, the company responsible must provide financial security to cover abandonment and reclamation liabilities (Environmental Law Centre (Alberta), n.d.). When a tanker enters Canadian waters, it must carry mandatory pollution insurance of up to \$162 million per large vessel (Transport Canada, n.d.). When a factory discharges industrial effluent, it requires a permit, pays fees, and carries liability insurance (Government of Canada 2012). When a landfill or commercial waste facility opens under Alberta's **Environmental Protection and Enhancement Act**, the operator must post financial security for closure and reclamation before operations begin (Government of Alberta, n.d.-a; -b). These programs are enforced across Canadian jurisdictions to keep the public and governments from bearing the environmental liabilities of private operations.

However, when a farmer applies fertilizer to a field, applies pesticides, or allows manure to run off into adjacent waterways, there is no bond, no financial security requirement, no mandatory insurance, and no discharge permit tied to water quality outcomes. The resulting pollution, nutrients, sediment, pesticides, and pathogens, flows into Canada's rivers, lakes, and groundwater systems, and the costs of managing, treating, and remediating that pollution fall almost entirely on someone else.

The fiscal question is who bears water-pollution management cost when agricultural runoff is largely unpriced at source.

1.2 The Polluter-Pays Principle

The polluter-pays principle is a foundational concept in Canadian environmental law and policy since it was first articulated by the Organisation for Economic Co-operation and Development (OECD) in 1972 and adopted by Canada as a guiding principle for environmental protection. It holds that those who produce pollution should bear the costs of managing it to prevent damage to human health or the environment (OECD 1972). The principle is embedded in the **Canadian Environmental Protection Act, 1999**, provincial environmental statutes, and numerous international agreements to which Canada is a party (Government of Canada 1999).

In practice, the principle is applied consistently across Canadian industry with the exception of agriculture. Despite dominant nutrient and pesticide loading in major and minor agricultural watersheds, farm operations remain largely outside the polluter-pays framework. The exemption reflects decades of policy choice and a persistent claim that agricultural nonpoint runoff differs from industrial point discharge in ways that justify separate treatment.

1.3 Scope and Structure

This paper's contribution is a transparent fiscal-incidence account: six named cost pools, basin-anchored loading shares, payor weights, and the \$1.11B taxpayer-pool externalization under central attribution (6), with sensitivity on σ_A . Evidence spans Great Lakes, Lake Winnipeg, St. Lawrence, and South Saskatchewan irrigated corridors (including the middle Bow phosphorus-management reach), then turns to water pricing, soil degradation, land tenure, and regulatory asymmetry.

The body covers four topics in order: the magnitude and sources of water pollution, with emphasis on agricultural nonpoint runoff and Indigenous receiving communities; the allocation of pollution costs across sectors and provinces and the resulting taxpayer burden, estimated bottom-up; the compounding cost of associated soil degradation; and the structural, regulatory, and economic factors that perpetuate the inequity. It closes with a policy framework for moving Canadian agriculture toward the polluter-pays principle, drawing on instruments already used in other industries and on provincial nutrient regimes already in force.

2. Methods and Data Sources

2.1 Procedure

The fiscal-incidence calculation proceeds in the following order: (1) define the allocation equations and system boundary; (2) assign each symbol from published budgets, utility accounts, basin indicators, or damage studies; (3) evaluate the same equations on the Canadian ledger. A supplementary Excel workbook presents the arithmetic for audit. All dollar figures are nominal current dollars in CAD.

Watershed restoration (c_4) excludes routine municipal source-water planning already counted under drinking-water source protection (c_6). Eutrophication drinking-water premiums in c_5 are incremental to nutrient removal already counted in c_1 .

2.2 Notation and System Boundary

Let $k \in \{1, \dots, 6\}$ index annual cost categories: nutrient removal; pesticide and chemical treatment; monitoring and compliance; watershed restoration; eutrophication damages; drinking-water source protection. Let $j \in \{M, I, A, T\}$ index payors: municipal ratepayers, industrial operators, agricultural operators, and general taxpayers. Let c_k be category cost (M\$/yr) and $w_{k,j}$ the program-design share of category k paid by payor j :

$$\sum_{j \in \{M, I, A, T\}} w_{k,j} = 1 \quad \text{for every } k. \quad (1)$$

Let σ_j be attributed loading share of polluting sector j (percent), with $\sigma_A + \sigma_M + \sigma_I = 100$. Taxpayers are a payor only; σ_T is undefined.

C_{total} includes recurring public and ratepayer spending on treatment or removal of agricultural pollutants in water systems; water-quality monitoring and compliance; watershed restoration and source protection in agricultural watersheds; and documented eutrophication damages (treatment premiums, recreation, property, fishery, and health-monitoring lines). It excludes groundwater nitrate and private-well pesticide remediation; pesticide health effects beyond drinking-water treatment; biodiversity and fishery losses outside the eutrophication build; greenhouse-gas costs from soil carbon loss; Indigenous water impacts (qualitative discussion in Section 3.7); and agri-environmental cost-share or ecological-goods payments to producers (On-Farm Climate Action Fund [OFCAF], Sustainable Canadian Agricultural Partnership [Sustainable CAP / SCAP] streams, Manitoba Growing Outcomes in Watersheds [GROW], Québec Prime-Vert, and similar assistance; see Table 15), which are a separate public account and are never added to C_{total} . On-farm soil yield loss is a private productivity cost reported later and is never added to C_{total} .

2.3 Allocation Equations

Total management cost and payor burdens:

$$C_{\text{total}} = \sum_{k=1}^6 c_k, \quad C_j = \sum_{k=1}^6 w_{k,j} c_k. \quad (2)$$

σ_j does not enter (2). Fiscal incidence intensity and the disparity relative to agriculture are

$$B_j = \frac{C_j}{\sigma_j}, \quad j \in \{M, I, A\}. \quad (3)$$

$$D_{j,A} = \frac{B_j}{B_A}. \quad (4)$$

B_j and $D_{j,A}$ measure payment per attributed loading point under present program design. They are not marginal abatement costs or Pigouvian rates.

Agriculture's attributed shortfall on the full ledger, and net externalization of the taxpayer pool alone, are

$$S_A = (\sigma_A/100) C_{\text{total}} - C_A, \quad (5)$$

$$E_A = (\sigma_A/100) C_T - C_A. \quad (6)$$

S_A uses C_{total} ; E_A uses only C_T . Linearity in σ_A gives

$$\partial E_A / \partial \sigma_A = C_T / 100. \quad (7)$$

Municipal and industrial cross-subsidies to agriculture lie outside E_A , so (6) is a lower bound on sectoral externalization.

The municipal rate benchmark used in Section 4 is the population-weighted mean over surveyed cities i :

$$\bar{r} = \frac{\sum_i p_i r_i}{\sum_i p_i}, \quad (8)$$

with Census population p_i and published combined water and wastewater rate r_i . The numerical value is evaluated when Table 7 is introduced.

2.4 Numerical Check (Illustrative)

The following values are for hand-checking (2) through (7). They are simplified numbers used for example only.

Take $c_k^{\text{ex}} = 100$ for each k , so $C_{\text{total}}^{\text{ex}} = 600$ M\$/yr, and payor totals $C_M^{\text{ex}} = 200$, $C_I^{\text{ex}} = 100$, $C_A^{\text{ex}} = 20$, $C_T^{\text{ex}} = 280$. With $\sigma_A^{\text{ex}} = 75$, $\sigma_M^{\text{ex}} = 15$, $\sigma_I^{\text{ex}} = 10$:

$$B_M^{\text{ex}} = 200/15 \approx 13.3, \quad B_I^{\text{ex}} = 10.0, \quad B_A^{\text{ex}} = 20/75 \approx 0.27, \quad (9)$$

$$D_{M,A}^{\text{ex}} \approx 49, \quad D_{I,A}^{\text{ex}} \approx 37, \quad (10)$$

$$S_A^{\text{ex}} = 0.75 \times 600 - 20 = 430, \quad E_A^{\text{ex}} = 0.75 \times 280 - 20 = 190, \quad (11)$$

$$\partial E_A^{\text{ex}} / \partial \sigma_A = 2.8 \text{ M}\backslash\$ \text{ per point}. \quad (12)$$

Canadian c_k , $w_{k,j}$, and σ_j enter only in the evaluation below.

2.5 Loading Shares σ_j

Canada publishes no national nutrient mass balance comparable to a greenhouse-gas (GHG) inventory. Central σ_j are rounded from Environment and Climate Change Canada (ECCC) basin indicators and related basin plans where restoration and treatment expenditure concentrate (Table 1) (Environment and Climate Change Canada 2023a; 2024a; Environment and Climate Change Canada 2023b; 2023c; 2012; Government of Alberta 2014a):

Table 1: Agricultural contribution to nutrient loading in major problem basins. Used to set central σ_A ; not a national pollutant inventory.

Receiving water / indicator	Nutrient	Agricultural share (reported)	Primary source
Lake Erie basin	Total phosphorus	>50% from agricultural lands; 79% nonpoint overall (Environment and Climate Change Canada 2023a)	ECCC Canadian Environmental Sustainability Indicators (CESI)
St. Lawrence (southern QC)	Total phosphorus (TP) and total nitrogen (TN)	70% TP; 75% TN (Environment and Climate Change Canada 2024a)	ECCC CESI
Lake Winnipeg basin	Phosphorus loading	Dominant source; Red River $\approx$ 68% of lake P (Environment and Climate Change Canada 2023c)	ECCC; Lake Winnipeg basin programs
Middle Bow (Bears paw–Bassano)	Phosphorus (multi-source)	Municipal wastewater, urban stormwater, and rural nonpoint from irrigated cropland and livestock share the middle-reach load (Government of Alberta 2014a)	Bow River Phosphorus Management Plan (PMP)
National freshwater pesticides	Detections	Elevated in ag-dominated land-use regions (Environment and Climate Change Canada 2023b)	ECCC CESI

Central case: $\sigma_A = 75$, $\sigma_M = 15$, $\sigma_I = 10$, for allocation arithmetic on these problem basins. Sensitivity: E_A is reported for $\sigma_A \in [65, 85]$ (Figure 8), covering basins where forestry, mining, or municipal combined sewer overflows raise the non-agricultural share.

2.6 Category Costs c_k

Each c_k is estimated independently (Table 2). $C_{\text{total}} = \sum_k c_k$.

Table 2: Category costs c_k (M\$/yr, nominal). Methods and sources; values enter (2).

Category c_k	Central	Estimation method	Primary sources
c_1 Nutrient removal	345	$c_1 = \pi C_{WW}$ with $C_{WW} = \$2.3\text{B}$ municipal wastewater O&M (Statistics Canada, n.d.); central $\pi = 0.15$ (13).	(Statistics Canada, n.d.; U.S. Environmental Protection Agency 2015; Oleszkiewicz and others 2015)
c_2 Pesticide/chemical treatment	360	Advanced-treatment costs scaled across plants with agricultural source water (working estimate).	Municipal capital reports; Ontario Clean Water Agency
c_3 Monitoring and compliance	375	Sum of federal, provincial, and municipal water-quality monitoring budgets.	ECCC departmental plans; provincial Main Estimates
c_4 Watershed restoration	730	Named lake/river programs, conservation authorities, municipal source-water planning, Alternative Land Use Services (ALUS) cost-shares (upper bound on ag-targeted public restoration).	Federal departmental plans; Conservation Ontario; ALUS Canada
c_5 Eutrophication damage	362	Sum of component damages below; Dodds et al. (Dodds et al. 2009) as external bracket only.	(Dodds et al. 2009; Bingham et al. 2015; Ulrich et al. 2009)
c_6 Source-water protection	400	Provincial source-protection regimes and municipal wellhead/intake programs (working estimate).	(Government of Ontario 2006); provincial plans

Nutrient removal. With Statistics Canada wastewater O&M $C_{WW} = 2300$ M\$/yr (Statistics Canada, n.d.),

$$c_1 = \pi C_{WW}. \quad (13)$$

Central $\pi = 0.15$ lies below US Environmental Protection Agency (EPA) tertiary uplift bands (30–50%) (U.S. Environmental Protection Agency 2015) and below Canadian Water Network (CWN) doubling-to-tripling ranges for very low effluent TP/TN (Oleszkiewicz and others 2015); it is a lower-bound national average across plants with and without dedicated nutrient polishing.

$$c_1 = 0.15 \times 2300 = 345 \text{ M}\backslash\$/\text{yr}. \quad (14)$$

Table 3: Sensitivity of c_1 to premium π . Base $C_{WW} = \$2.3\text{B}$ (Statistics Canada, n.d.).

π	c_1 (\$M)	Share of C_{total}	Bracket
0.10	230	8.9%	Limited dedicated nutrient polishing
0.15 (central)	345	13.4%	Below EPA tertiary range
0.25	575	22.4%	Toward CWN/EPA advanced polishing (Oleszkiewicz and others 2015; U.S. Environmental Protection Agency 2015)

Pesticide treatment ($c_2 = 360$). Scaled from documented advanced-treatment costs at agricultural-source facilities. Moderate-low confidence; no single national line item.

Monitoring ($c_3 = 375$). Direct budget roll-up. Moderate-high confidence on totals; source-class attribution uncertain.

Watershed restoration ($c_4 = 730$). Includes Great Lakes Protection Initiative $\approx \$45\text{M}$, Lake Winnipeg Basin Program $\approx \$25\text{M}$, St. Lawrence Action Plan $\approx \$15\text{M}$, plus conservation-authority and ALUS lines. Full published program totals enter c_4 ; benefit attribution to agriculture alone is an assumption, so 730 is an upper bound on ag-targeted public restoration. Budget 2023 Freshwater Action Plan and Great Lakes ecosystem envelopes enlarge the federal restoration floor relative to those named-program anchors (Environment and Climate Change Canada 2024b); the $\$730\text{M}$ central value is retained as a conservative ledger input and is not recalibrated here.

Eutrophication (c_5). Component sum (Dodds et al. (Dodds et al. 2009) US $\$2.2\text{B/yr}$ used only as bracket; population scaling $\approx \$240\text{M}$ for Canada):

- Lake Erie drinking-water premium: $\$50\text{M/yr}$ (Bingham et al. 2015)
- Lake Winnipeg basin treatment: $\$30\text{M/yr}$
- Other affected systems: $\$40\text{M/yr}$
- Lake Erie recreation (Canadian share): $\$80\text{M/yr}$
- Lake Winnipeg recreation: $\$40\text{M/yr}$
- Property-value impacts (annualized): $\$100\text{M/yr}$
- Commercial fishery losses: $\$7\text{M/yr}$
- Health monitoring: $\$15\text{M/yr}$

$$c_5 = 50 + 30 + 40 + 80 + 40 + 100 + 7 + 15 = 362 \text{ M}\$/\text{yr}. \quad (15)$$

Source-water protection ($c_6 = 400$). Ontario Clean Water Act $\approx \$100\text{M/yr}$ (Government of Ontario 2006) plus other provincial and municipal wellhead/intake programs, held separate from c_4 to limit double-counting.

Pools c_2 , c_4 , and c_6 are working estimates (scaled roll-ups). The supplementary workbook records source notes for each.

2.7 Payor Weights $w_{k,j}$

Weights follow program design, not loading share:

1. Federal and provincial watershed grants $\rightarrow$ primarily T .
2. Municipal wastewater O&M and ratepayer treatment premiums $\rightarrow M$.
3. Industrial pretreatment and trade-waste charges $\rightarrow I$.
4. ALUS and farm stewardship cost-shares $\rightarrow A$ (about 2% of restoration spending in the central ledger).

Every $w_{k,j}$ is listed in the supplementary workbook. Section 4 reports $C_j = \sum_k w_{k,j} c_k$ in Table 9. Read C_j (who pays), σ_j (attributed load), and $D_{j,A}$ (incidence ratio) as distinct quantities.

2.8 Evaluation on the Canadian Ledger

From Table 2 and (2):

$$C_{\text{total}} = 345 + 360 + 375 + 730 + 362 + 400 = 2,572 \text{ M}\$/\text{yr} (\$2.57\text{B/yr}). \quad (16)$$

Program weights give

$$C_M = 695, \quad C_I = 349, \quad C_A = 22, \quad C_T = 1,506 \quad (\text{M}\backslash\$/\text{yr}). \quad (17)$$

$C_A = 22$ is public-program receipts attributed to agriculture (cost-share and monitoring lines), not private on-farm BMP or manure-handling spend. With $(\sigma_A, \sigma_M, \sigma_I) = (75, 15, 10)$:

$$B_M = 695/15 \approx 46.33, \quad B_I = 34.9, \quad B_A = 22/75 \approx 0.293, \quad (18)$$

$$D_{M,A} \approx 157.95 \approx 158, \quad D_{I,A} \approx 119, \quad (19)$$

$$S_A = 0.75 \times 2,572 - 22 = 1,907 \quad \text{M}\backslash\$/\text{yr} (\$1.91\text{B}/\text{yr}), \quad (20)$$

$$E_A = 0.75 \times 1,506 - 22 = 1,107.5 \quad \text{M}\backslash\$/\text{yr} (\$1.11\text{B}/\text{yr}), \quad (21)$$

$$\partial E_A / \partial \sigma_A \approx 15.1 \quad \text{M}\backslash\$ \text{ per point}. \quad (22)$$

For $\sigma_A \in [65, 85]$, E_A spans about \$956M to \$1.26B (Figure 8).

Table 4: Evaluated ledger. Quantities from (2) through (7) using Table 2, workbook $w_{k,j}$, and central σ_j .

Quantity	Central value	Source
C_{total}	\$2,572M/yr	(16)
C_M, C_I, C_A, C_T	695 / 349 / 22 / 1,506	$w_{k,j}$ on c_k
$\sigma_A, \sigma_M, \sigma_I$	75 / 15 / 10	Table 1
B_M, B_I, B_A	46.4 / 34.9 / 0.29	(3)
$D_{M,A}, D_{I,A}$	≈ 158 / ≈ 119	(4)
S_A	\$1.91B/yr	(5)
E_A	\$1.11B/yr	(6)
$\partial E_A / \partial \sigma_A$	$\approx \$15.1\text{M}/\text{point}$	(7)

2.9 Provincial Allocation

Provinces do not publish a harmonized pollution-management ledger. Table 5 is an illustrative split of the national c_k by (i) urban population and tertiary-treatment intensity for treatment costs; (ii) named program geography for restoration and eutrophication (Great Lakes/Erie $\rightarrow$ Ontario; Lake Winnipeg $\rightarrow$ Manitoba with SK/AB upstream shares; St. Lawrence $\rightarrow$ Quebec; Bow/Oldman corridor programs within Alberta's South Saskatchewan share); (iii) provincial program presence for monitoring and source protection. Shares sum to 100% of C_{total} and do not change national E_A .

Table 5: Illustrative provincial allocation of \$2.57B (\$ millions). Keys: program geography and urban population; not audited provincial accounts.

Cost pool	ON	QC	MB	SK/AB	BC	Atl./Terr.
Nutrient + pesticide treatment	280	145	55	95	70	60
Monitoring and compliance	140	75	35	55	40	30
Watershed restoration	260	95	180	95	50	50
Eutrophication damage	140	40	120	35	15	12
Source-water protection	180	70	35	50	40	25
Pool subtotal	1,000	425	425	330	215	177
Share of \$2.57B	39%	17%	17%	13%	8%	7%

Ontario’s share reflects Great Lakes treatment and source-protection intensity (Government of Ontario 2006; Environment and Climate Change Canada 2023a). Manitoba’s restoration and eutrophication shares reflect Lake Winnipeg programs (Environment and Climate Change Canada 2023c; Government of Manitoba 2020a). Saskatchewan and Alberta enter partly as upstream Assiniboine–Qu’Appelle–Saskatchewan contributors to Lake Winnipeg (Crandlemire 2026a), and Alberta also carries in-basin nutrient management along the Bow and Oldman corridors of the South Saskatchewan River Basin, where irrigation return flows, confined feeding operations, and municipal wastewater share the same middle-reach phosphorus problem (Government of Alberta 2014a).

2.10 Limitations

Evaluated figures are nominal current dollars. Central $\sigma_A = 75$ is a basin-indicator synthesis (Table 1); E_A moves from about \$956M to \$1.26B over $\sigma_A \in [65, 85]$ (Figure 8).

Category totals may overlap at margins (nutrient premiums vs eutrophication drinking-water lines; restoration vs source-protection planning). Weights $w_{k,j}$ follow program design rather than audited cash flows.

Excluded from C_{total} are groundwater and private-well remediation; pesticide health effects beyond drinking-water treatment; biodiversity and fishery losses outside c_5 ; soil-carbon greenhouse-gas costs; and Indigenous water impacts (Section 3.7). Soil productivity loss (\$3.0B) is private and must not be summed with \$2.57B as a single welfare total (Table 16). E_A covers only C_T . Table 5 is illustrative. Companion paper (Crandlemire 2026a) develops landlord-scale enforcement exposure; this paper reports the fiscal incidence those holders inherit.

3. The Scope and Scale of Water Pollution in Canada

3.1 Agricultural Runoff as the Dominant Source

Water pollution in Canada is conventionally divided into point sources (directly identifiable discharge points such as industrial pipes or municipal wastewater outfalls) and nonpoint sources (diffuse watershed runoff). Over the past four decades, Canada has made substantial progress in controlling point source pollution through regulation, permitting, and treatment infrastructure. Industrial and municipal wastewater discharges are subject to the **Wastewater Systems Effluent Regulations** under the **Fisheries Act**, with mandatory monitoring, reporting, and compliance enforcement (Environment and Climate Change Canada, n.d.-a).

Nonpoint source pollution has proven far more resistant to regulatory control. Within nonpoint sources, agricultural runoff is the dominant contributor in ECCC basin indicators.

Environment and Climate Change Canada's Canadian Environmental Sustainability Indicators program identifies agriculture as the primary contributor of phosphorus and nitrogen to Canadian waterways. In the Lake Erie basin, nonpoint sources contribute approximately 79% of total phosphorus loading, with agricultural lands alone accounting for more than 50% of the total phosphorus entering the lake (Environment and Climate Change Canada 2023a). In the St. Lawrence River watershed, agricultural activities account for approximately 70% of total phosphorus inputs and 75% of total nitrogen inputs in the southern Quebec region (Environment and Climate Change Canada 2024a).

On the basis of these ECCC basin indicators (Table 1), corroborated by Lake Winnipeg eutrophication research (Schindler et al. 2012), pesticide patterns in the ECCC Pesticides in Freshwater indicator (Environment and Climate Change Canada 2023b), and the middle Bow multi-source phosphorus plan (Government of Alberta 2014a), we use a central attribution of 75% of **attributed nutrient and pesticide loading in the problem basins that drive public expenditure** to agriculture for cost-allocation arithmetic (range 65–85% in sensitivity analysis). Municipal sources contribute approximately 15%, and industrial sources approximately 10%. These proportions allocate costs and compute E_A ; they are not a national pollutant mass inventory and should not be read as “75% of all Canadian water pollution.”

3.2 Nutrient Loading: Nitrogen and Phosphorus

The nutrient loading problem is most visible in Canada's freshwater systems. While point source nutrient discharges have declined substantially since the 1970s due to wastewater treatment upgrades and phosphate detergent bans, nonpoint agricultural sources have not followed the same trajectory.

Lake Erie. The western basin of Lake Erie has experienced a resurgence of harmful algal blooms (HABs) since the mid-1990s, driven primarily by dissolved reactive phosphorus from agricultural runoff. The 2014 bloom forced the City of Toledo, Ohio, to issue a “do not drink” advisory to 400,000 residents after microcystin toxins were detected in the municipal water supply (Michalak et al. 2013). While the most dramatic events have occurred on the U.S. side, Canadian agriculture in the Lake Erie basin, particularly intensive corn, soybean, and livestock operations in southwestern Ontario, is a significant contributor. The Canada-Ontario Lake Erie Action Plan targets a 40% reduction in phosphorus loading from Canadian sources, but progress has been slow and the 11,000-tonne annual total phosphorus target under the Great Lakes Water Quality Agreement continues to be exceeded (Environment and Climate Change Canada 2023a).

Satellite imagery confirms the scale of bloom events: Figure 1 shows an August 2024 bloom along the northern shore, illustrating the persistence of western-basin HABs decades after point-source controls.



Figure 1: Toxic algae bloom in Lake Erie, 13 August 2024. Green filaments extend from the northern shore across the western basin. Captured by Landsat-9 OLI-2. Source: NASA Earth Observatory (public domain).

Lake Winnipeg. Lake Winnipeg, the world's tenth-largest freshwater lake by surface area, has become one of the most eutrophic large lakes on Earth. The lake receives nutrient loads from a watershed spanning four Canadian provinces and four U.S. states, with agricultural runoff as the dominant source. Algal blooms in Lake Winnipeg now commonly cover several thousand square kilometres, and nearshore microcystin concentrations frequently exceed Health Canada's recreational water quality guideline of 20 µg/L (Schindler et al. 2012).

Figure 2 documents a September 2023 Landsat-9 scene with approximately 8,400 km² of bloom extent; annual maxima vary with weather and loading. That scale of bloom helps explain why Manitoba and federal restoration spending targets this basin specifically.



Figure 2: Emerald swirls of algae in Lake Winnipeg, September 25, 2023. Captured by Landsat-9 satellite. Source: NASA Earth Observatory (public domain).

Bow River and South Saskatchewan tributaries. Downstream of Calgary, the middle Bow between Bearspaw and Bassano is a documented phosphorus-stress reach where municipal wastewater, urban

stormwater, and rural nonpoint loads from irrigated cropland and livestock operations accumulate in the same corridor (Government of Alberta 2014a). The Bow River Phosphorus Management Plan treats that middle reach as a multi-source management problem: residual loading after point-source upgrades remains dominated by agricultural manure spreading, fertilizer timing, wetland loss, and irrigation return flows through tributaries such as Crowfoot Creek, where basin-scale nutrient-export scenario modeling tested wetland protection, manure management, and riparian conversion options (Government of Alberta 2014b). The pattern mirrors Lake Erie and Lake Winnipeg at corridor scale: after point sources tighten, field and feedlot pathways continue to set the remaining load under current farm-outlet rules.

Regional phosphorus surpluses. Material-flow accounting of Canada's phosphorus cycle for 1961–2018 shows persistent agricultural soil P surpluses in most provinces outside Saskatchewan, with the highest surplus intensities in Quebec and Atlantic Canada and lower but positive surpluses in Ontario, Manitoba, Alberta, and British Columbia (Wang et al. 2022). Edge-of-field synthesis across Saskatchewan, Manitoba, and Ontario confirms that agricultural runoff delivers dissolved and particulate P to receiving waters, with snowmelt often dominating loads and Manitoba dissolved-P concentrations tightly linked to surface-soil Olsen P (Liu et al. 2021). Ontario and Great Lakes watersheds also face water-quality impacts from legacy phosphorus accumulated in agricultural soils over decades of intensive farming (Liu et al. 2021; Environment and Climate Change Canada 2023a).

St. Lawrence River. Nutrient loading to the St. Lawrence River from agricultural sources in southern Quebec remains high. ECCC indicators updated in 2024 show that total phosphorus concentrations exceed the Quebec water quality guideline for the protection of aquatic life at 74% of monitoring stations in agricultural watersheds. Nitrogen loading follows a similar pattern, with nitrate concentrations in agricultural tributaries exceeding the 3 mg/L guideline at the majority of monitoring sites (Environment and Climate Change Canada 2024a).

The St. Lawrence drains the Great Lakes system and receives nutrient loads from southern Quebec and Ontario tributaries (Figure 3); its receiving-water status makes downstream municipal treatment and provincial restoration programs part of the \$2.57B cost pool attributed in Section 4.



Figure 3: Thin ice forming on the St. Lawrence River at its mouth, Québec, January 17, 2010. Semi-transparent ice reveals green river water beneath; thicker ice lines the south shore. The St. Lawrence drains the Great Lakes and receives agricultural nutrient loads from southern Quebec and Ontario tributaries. Captured by MODIS on NASA's Aqua satellite. Source: NASA Earth Observatory via Wikimedia Commons (public domain).

3.3 Loading Pathways: Tile Drainage, Snowmelt, Irrigation Return Flow, Legacy Phosphorus, and Timing

Agricultural nutrient delivery to Canadian surface waters is pathway-dependent. The same fertilizer or manure application can produce very different edge-of-field loads depending on drainage infrastructure, freeze-thaw hydrology, soil phosphorus status, and application timing. This subsection summarizes the dominant pathways that drive the basin indicators in Table 1. Throughout, C_{total} measures surface-water management spend (treatment, restoration, monitoring, and documented eutrophication damages). It is not a national contaminant-mass inventory and not a full account of groundwater risk.

Tile drainage and dissolved reactive phosphorus (southwestern Ontario / Lake Erie). In the intensively drained watersheds of southwestern Ontario, subsurface tile systems short-circuit surface detention and deliver dissolved reactive phosphorus (DRP) rapidly to ditches and tributaries that feed western Lake Erie. Edge-of-field synthesis shows that tile and surface pathways both matter for Canadian phosphorus export, with dissolved fractions especially important where soils are fine-textured and drainage intensity is high (Liu et al. 2021). ECCC Lake Erie indicators attribute more than half of total phosphorus entering the lake to agricultural lands, with nonpoint sources overall near 79% (Environment and Climate Change Canada 2023a). Tile-driven DRP delivery helps explain why western-basin blooms persist after point-source phosphorus controls.

Prairie snowmelt-dominated runoff. On the Prairies, a large share of annual runoff and nutrient export occurs during spring snowmelt rather than summer rainfall events. Edge-of-field results across Saskatchewan, Manitoba, and Ontario confirm that snowmelt often dominates annual phosphorus loads, and that Manitoba dissolved-P concentrations track surface-soil Olsen P closely (Liu et al. 2021). Snowmelt over frozen or partially thawed soils limits infiltration, so nutrients at or near the soil surface move with meltwater into Prairie streams that feed Lake Winnipeg and the Assiniboine–Red system (Environment and Climate Change Canada 2023c; Schindler et al. 2012). In the irrigated South Saskatchewan corridors, snowmelt interacts with canal and return-flow hydrology: nutrients mobilized from manured or fertilized fields can enter drainage works and tributaries that feed the Bow and Oldman, extending the spring pulse beyond the classic Prairie pothole pathway (Government of Alberta 2014a; Liu et al. 2021).

Irrigated return flow and confined feeding (Bow–Oldman). Southern irrigated districts combine dense confined feeding operations with canal systems that move water, and dissolved nutrients, off the field and into receiving rivers. The **Agricultural Operation Practices Act** (AOPA) sets manure storage design, setbacks from water bodies, incorporation timing, soil nitrate and salinity limits, and land-base requirements for confined feeding operations, administered by the Natural Resources Conservation Board (NRCB) (Government of Alberta 2000; -c). Those standards govern how manure is stored and applied; receiving-water phosphorus objectives at the farm outlet remain outside that permit frame. Crowfoot Creek modeling under the Bow phosphorus plan shows that manure management and riparian measures can reduce rural nonpoint loads in simulation, and that watershed-scale water-quality gains still require sustained, multi-practice uptake (Government of Alberta 2014b). That combination, intensive livestock nutrients plus conveyance infrastructure, is the Prairie counterpart to southwestern Ontario’s tile-DRP pathway.

Legacy soil phosphorus. Material-flow accounting of Canada’s phosphorus cycle for 1961–2018 documents persistent agricultural soil P surpluses in most provinces outside Saskatchewan (Wang et al. 2022). Decades of surplus application leave a legacy soil P store that continues to supply dissolved and particulate phosphorus to runoff even when current-year fertilizer rates fall. Ontario and Great Lakes watersheds illustrate the water-quality consequence: legacy P in agricultural soils sustains loads that restoration programs must manage for years after source rates change (Liu et al. 2021; Environment and Climate Change Canada 2023a). Legacy stores therefore complicate any short-run reading of fiscal incidence as a proxy for current-year stewardship effort.

Manure winter spreading and application timing. Where livestock density is high, manure storage limits and winter spreading windows concentrate nutrients at the soil surface during freeze-thaw and snowmelt periods, raising the probability that applied nutrients leave the field before crop uptake. Provincial nutrient-management rules increasingly restrict frozen-ground spreading: AOPA incorporation and setback standards for confined feeding manure are one Prairie instance (Government of Alberta 2000; -c), while coverage and enforcement remain uneven across provinces and crop types (see Agriculture: The Exception). Timing controls are therefore a loading-pathway instrument: they change when nutrients sit in the hydrologically active zone that feeds spring runoff (Liu et al. 2021).

These pathways justify treating basin-scale agricultural shares as the allocation basis for C_{total} without treating that dollar ledger as a national mass balance or as groundwater remediation liability.

3.4 Pesticides in Canadian Freshwater

Pesticide contamination is pervasive in agricultural watersheds: 38% of ECCC freshwater samples exceeded aquatic-life guidelines for at least one compound (Environment and Climate Change Canada 2023b). Atrazine,

metolachlor, neonicotinoids, and glyphosate dominate detections in Ontario, Quebec, and Prairie row-crop regions; neonicotinoid restrictions have not yet reduced surface-water frequencies (Environment and Climate Change Canada 2023b). This paper's management ledger prices pesticide removal through existing drinking-water and treatment lines; a full social-cost account of pesticide contamination in receiving waters sits outside that ledger. Source-control measures that cut nutrient and pesticide runoff together would reduce both accounts.

3.5 Geographic Distribution of Agricultural Water Pollution

The contribution of agriculture to water pollution varies considerably by region, reflecting differences in land use intensity, crop types, livestock density, soil characteristics, and climate (Environment and Climate Change Canada, n.d.-b). Table 6 maps the dominant pollution pathways and receiving waters by region.

Table 6: Agricultural water pollution by Canadian region.

Region	Primary Agricultural Pollution Concerns	Key Water Bodies Affected
Southwestern Ontario	Phosphorus, nitrogen, pesticides from intensive corn-soybean rotations and livestock	Lake Erie (western basin), Thames River, Grand River
Southern Quebec	Phosphorus, nitrogen from intensive livestock (swine, dairy) and row crops	St. Lawrence River, Lac Saint-Pierre, Chaudière River
Southern Manitoba	Phosphorus, nitrogen from grain and oilseed production, livestock	Lake Winnipeg, Red River, Assiniboine River
Southern Alberta	Nutrients, sediment, pesticides from irrigated agriculture and confined feeding; irrigation return flows	South Saskatchewan River Basin, Oldman River, Bow River (middle reach)
Saskatchewan	Nutrients, pesticides from grain and oilseed production	South Saskatchewan River, Qu'Appelle River
Atlantic Canada (PEI, NB)	Nitrates, sediment, pesticides from potato production	Gulf of St. Lawrence, Wilmot River, numerous estuaries
British Columbia (Fraser Valley)	Nutrients, pathogens from intensive livestock and horticulture	Fraser River, Sumas River
British Columbia (Okanagan)	Nutrients, pesticides from orchards and vineyards	Okanagan Lake system

In Prince Edward Island, nitrate contamination of groundwater from intensive potato production has reached critical levels, with some municipal wells approaching or exceeding the 10 mg/L nitrate-N drinking water guideline. The province imposed a moratorium on new high-capacity irrigation wells in 2002 due to groundwater depletion and contamination concerns (Government of Prince Edward Island, Department of Environment, Energy and Climate Action, n.d.).

Along the Bow and Oldman, the policy problem is less a single municipal-well crisis than a shared middle-reach phosphorus budget: Calgary and regional wastewater plants, urban stormwater, irrigated cropland, and confined feeding operations all load the same South Saskatchewan tributaries (Government of Alberta 2014a). Basin plans already catalogue rural BMP packages; the fiscal question in this paper is who pays when those loads still arrive at the river and force treatment or restoration spending downstream.

PEI's municipal-well cases are the visible tip of a larger groundwater account. Private-well nitrate and pesticide exceedances, common in intensive potato, corn-soybean, and livestock regions, are excluded from the \$2.57B surface-water management ledger. Household treatment, well replacement, bottled-water substitution, and health-risk management for those wells do not appear in municipal utility or federal restoration budgets. Even a qualitative working bound of tens to hundreds of millions of dollars per year in social cost would raise national externalization; we do not monetize that band here because Canada lacks a consolidated private-well damage inventory comparable to the surface-water program accounts in Table 9.

3.6 The Monitoring Gap

One of the defining features of agricultural water pollution in Canada is the acute shortage of systematic monitoring. Unlike industrial and municipal point sources, which are subject to mandatory discharge monitoring and reporting, agricultural runoff is almost entirely unmonitored at the farm level. The Canadian Environmental Sustainability Indicators program provides regional-scale assessments, but no jurisdiction in Canada requires individual farms to monitor or report their nutrient or pesticide discharges to water (Standing Senate Committee on Agriculture, Fisheries and Forestry 1984).

The monitoring gap means that the contribution of specific agricultural operations to water quality impairment cannot be quantified; regulatory enforcement based on water quality outcomes is essentially impossible; the effectiveness of voluntary conservation programs cannot be validated with farm-level data; and the true scale and distribution of agricultural water pollution remains a matter of modeling and inference rather than direct measurement. The absence of monitoring also creates a circular policy challenge: agriculture is exempt from pollution regulation partly because nonpoint source pollution is considered inherently difficult to measure and attribute, yet no systematic effort is made to measure or attribute it.

3.7 Indigenous Communities and Downstream Water Impacts

The \$2.57B management ledger and \$1.11B externalization estimate are incomplete as measures of who bears agricultural water pollution. First Nations and Métis communities live along, fish from, and draw drinking water from the same receiving waters that concentrate agricultural nutrient and pesticide loads: Lake Winnipeg, the Great Lakes–St. Lawrence system, Prairie rivers, and Atlantic estuaries, yet CESI indicators and municipal utility accounts are not disaggregated by Indigenous land tenure (Environment and Climate Change Canada 2023c; 2023a).

Documented intersections include:

1. **Lake Winnipeg fisheries and shoreline communities.** Lake Winnipeg supports commercial and subsistence fisheries central to First Nations and Métis livelihoods; sustained algal blooms and eutrophication degrade water quality, beach use, and fishery conditions that those communities rely on (Government of Manitoba 2020b; Schindler et al. 2012).
2. **Prairie rivers and irrigation corridors.** First Nations and Métis communities along the South Saskatchewan system, including Bow and Oldman reaches that receive irrigation return flows and confined-feeding runoff, share receiving waters with municipal utilities already investing in nutrient control (Government of Alberta 2014a; Environment and Climate Change Canada 2023c).
3. **Great Lakes / Thames River watershed.** The Canada–Ontario Lake Erie Action Plan evaluation records Chippewas of the Thames First Nation agricultural management and water-quality monitoring on Deshkan Ziibi (Thames River), and the Thames River Clear Water Revival Shared Waters Approach as

examples of Indigenous-led and co-governed responses to nutrient loading in an agriculture-dominated basin (Environment and Climate Change Canada and Ontario Ministry of the Environment, Conservation and Parks 2024).

4. **Drinking-water governance asymmetry.** Human Rights Watch and related assessments document that many First Nations reserves face contaminated or unreliable drinking water under a regulatory regime that does not bind on-reserve systems the way provincial rules bind off-reserve municipalities (Human Rights Watch 2016). Upstream agricultural loading can worsen source-water quality for communities that already operate with thinner treatment margins and less fiscal capacity than municipal utilities counted in Table 9.

These impacts are not monetized in C_{total} or E_A . Doing so would require community-specific health, fishery, cultural, and treaty-rights valuation methods beyond the scope of this fiscal-incidence model. The omission means the \$1.11B figure understates the full social cost of agricultural externalization for Indigenous Nations. Policy frameworks that extend polluter-pays instruments to agriculture without Indigenous co-design risk repeating the pattern of offloading cleanup onto communities with the least fiscal and jurisdictional power to refuse it (Standing Senate Committee on Agriculture and Forestry 2024; Environment and Climate Change Canada and Ontario Ministry of the Environment, Conservation and Parks 2024).

UNDRIP, section 35, and instrument design. The **United Nations Declaration on the Rights of Indigenous Peoples Act** affirms Canada's commitment to implement UNDRIP in consultation and cooperation with Indigenous peoples (Parliament of Canada 2021). Section 35 of the **Constitution Act, 1982** and the Crown's duty to consult and accommodate apply when nutrient-management, financial-assurance, or watershed instruments may affect Aboriginal or treaty rights in receiving waters. This paper does not assign a dollar value to Indigenous harms. Co-design of nutrient instruments with First Nations and Métis governments is a governance requirement for credible polluter-pays reform, not an optional outreach step. Omitting Indigenous fishery, drinking-water, and cultural-water harms from C_{total} and E_A understates the social cost of agricultural externalization.

4. The Economics of Water Pollution: Who Pays?

4.1 Water Pricing Across Sectors

The price that different sectors pay for water in Canada reveals a sharp asymmetry. Municipal and industrial users pay rates that reflect, at least partially, the full cost of water supply, treatment, and wastewater management. Agricultural users pay a fraction of those rates, and in many cases pay nothing at all for the water they use in operations, while returning flow to the hydrological cycle with contamination.

Municipal/Residential. Published 2024 water and wastewater rates for six major Canadian cities appear in Table 7. Substituting 2021 Census city populations p_i and combined rates r_i into (8) yields $\bar{r} = \$3.28/\text{m}^3$ (unweighted mean $\$3.19/\text{m}^3$). That benchmark feeds the cross-sector comparison in Table 8.

Table 7: Municipal water and wastewater rates, selected Canadian cities (2024). Sources: City of Toronto Water 2024 Rates; Metro Vancouver 2024 Utility Rates; City of Calgary Water Utility 2024; Ville de Montréal 2024 Tarification; Halifax Water 2024 Rate Schedule; City of Winnipeg Water and Waste 2024.

City	Water Supply (\$/m ³)	Wastewater (\$/m ³)	Combined (\$/m ³)
Toronto	1.56	2.48	4.04
Halifax	1.25	2.15	3.40
Calgary	1.35	2.10	3.45
Vancouver	1.50	1.80	3.30
Winnipeg	1.35	1.50	2.85
Montreal	1.00	1.10	2.10
Population-weighted avg	1.38	1.90	3.28
Unweighted mean	1.34	1.86	3.19

Industrial/Commercial. Industrial water users typically pay rates of \$4.00–\$5.00 per cubic metre. Applying a conservative large-user rate differential of 1.35× to the population-weighted municipal average yields an estimated industrial rate of \$4.43/m³.

Agricultural. Agricultural water users pay dramatically less. Irrigation water is priced at approximately \$0.004–0.012 per cubic metre in Alberta’s irrigation districts (administrative fees only under the Irrigation Districts Act), even in South Saskatchewan districts that convey return flows into phosphorus-stressed Bow and Oldman reaches (Government of Alberta 2014a). Saskatchewan charges no volumetric fee for agricultural water. British Columbia charges nominal fees of approximately \$0.001/m³ under the Water Sustainability Act. Ontario charges no volumetric fee for agricultural water-taking under the Permit to Take Water program. For this analysis, we use \$0.05/m³ as a generous upper bound.

Once documented irrigation and drainage subsidies are included, agricultural water remains roughly an order of magnitude below municipal and industrial true cost (Table 8).

Table 8: True cost of water by sector, including infrastructure subsidies. Municipal and industrial user-pay rates exclude capital transfers (see note).

Sector	Direct Cost/m ³	Infrastructure Subsidy	True Cost/m ³
Municipal/Residential	\$3.28	not estimated ¹	\$3.28+
Industrial/Commercial	\$4.43	not estimated (0–10% where applicable)	\$4.43+
Agricultural	\$0.05	\$0.38 (50–75%)	\$0.43

Agricultural water is roughly 8× cheaper than municipal water and 10× cheaper than industrial water on a volumetric true-cost basis even before municipal capital grants are counted. The agricultural infrastructure subsidy of \$0.38/m³ is a pro-rated estimate based on documented 50–75% cost-share programs for agricultural water infrastructure administered by Agriculture and Agri-Food Canada (AAFC) and provincial governments. Municipal and industrial true costs marked “+” are lower bounds that exclude capital transfers.

¹Published municipal volumetric rates are designed as user-pay for operations and debt service already on the rate base. They do not include the present-value share of federal–provincial capital transfers (for example Investing in Canada Infrastructure Program and related wastewater grants) that fund treatment plant upgrades. A national \$/m³ capital-transfer subsidy is not estimated here; the \$0.00 cell in earlier drafts was therefore misleading.

4.2 The Pollution Cost Gap: Bottom-Up Cost Accounting

Section 2 defines the allocation equations (2) through (6), assigns each c_k and $w_{k,j}$ from published sources, and evaluates the Canadian ledger (Table 4). This section presents the same results as fiscal narrative: Figure 4 shows the source-to-payor structure; Table 9 lists C_j ; incidence and externalization figures restate the evaluated arithmetic for readers entering from the pollution evidence in Section 3.

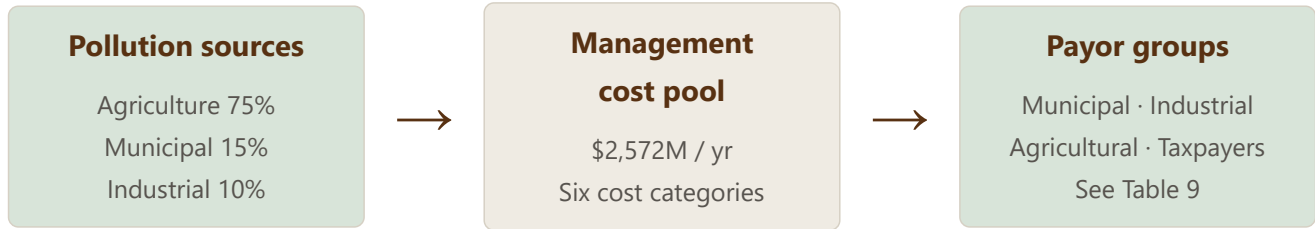


Figure 4: Cost-allocation structure. Attributed pollution shares σ_j (left) map to total management cost $C_{\text{total}} = \$2.57\text{B}$ (centre) and payor burdens C_j from (2) (right; detail in Table 9). Net externalization follows (6).

Table 9: Annual water pollution costs and payor allocation (\$ millions).

Cost Category	Municipal	Industrial	Agricultural	Taxpayers	Total
Nutrient removal treatment	190	69	0	86	345
Pesticide/chemical treatment	162	90	0	108	360
Monitoring and compliance	112	94	8	161	375
Watershed restoration programs	73	36	14	607	730
Eutrophication economic damage	18	0	0	344	362
Drinking water source protection	140	60	0	200	400
TOTAL	695	349	22	1,506	2,572

Under central attribution, agriculture's column in Table 9 is \$22 million (0.9% of direct management cost). That \$22M is public-program receipts attributed to agriculture (cost-share and monitoring lines in the ledger), not total private on-farm BMP, nutrient-management, or manure-handling expenditure. Private compliance spend is outside C_{total} ; an illustrative national bound of roughly \$100–300M/yr is consistent with Manitoba pig-sector phosphorus-regulation compliance costs alone of about \$18–28M/yr (Mann and Grant 2015) as a lower-bound evidence point for one province and commodity. As a peer-instrument benchmark, that single-province, single-commodity compliance band already approaches or exceeds agriculture's entire national public-program share (\$22M), underscoring how thin the attributed agricultural payor column is relative to binding nutrient instruments already operating in one Canadian jurisdiction (Mann and Grant 2015). Against the 75% loading-share parameter in (3), the public-program \$22M remains a small share of the management ledger. Figure 5 shows payor splits by category; Figure 6 compares attributed loading share with cost paid.

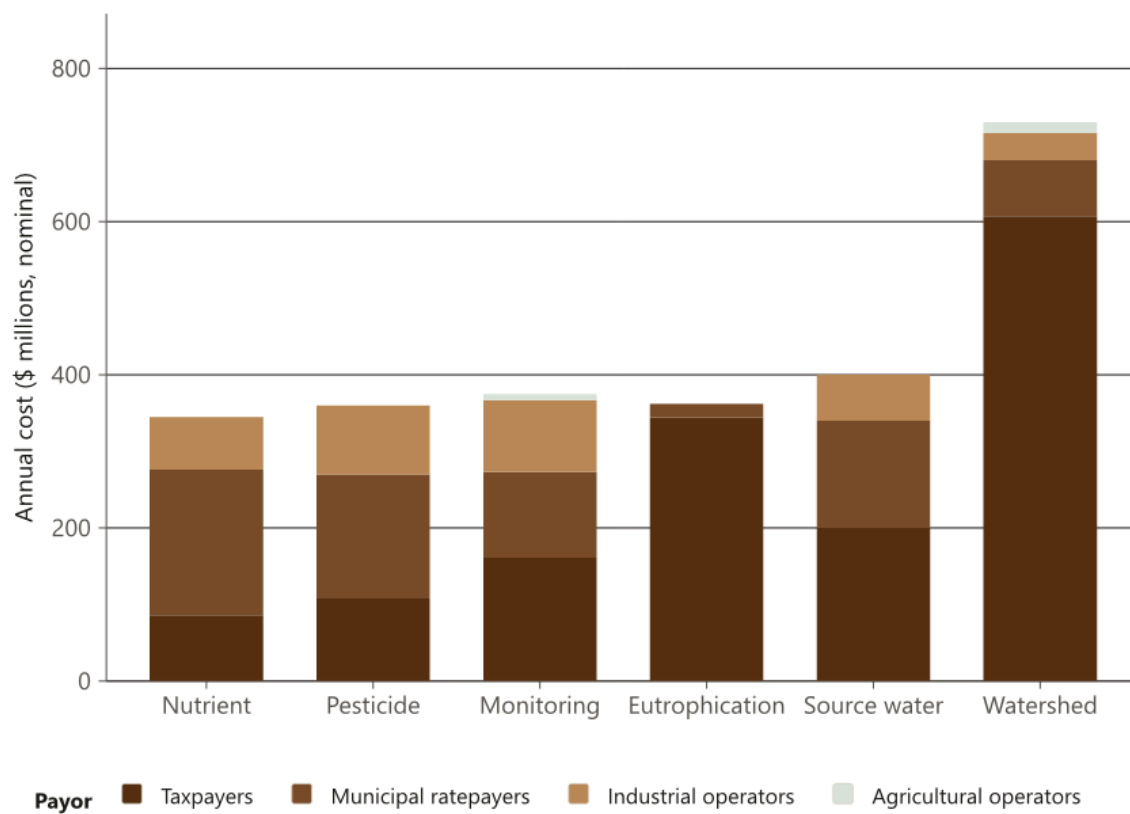


Figure 5: Payor allocation by cost category (Table 9 data). Stacked segments follow the Payor legend. Watershed restoration and eutrophication damage are dominated by taxpayer funding; treatment categories fall mainly on municipal ratepayers. Agricultural operator shares appear only in monitoring and watershed restoration.

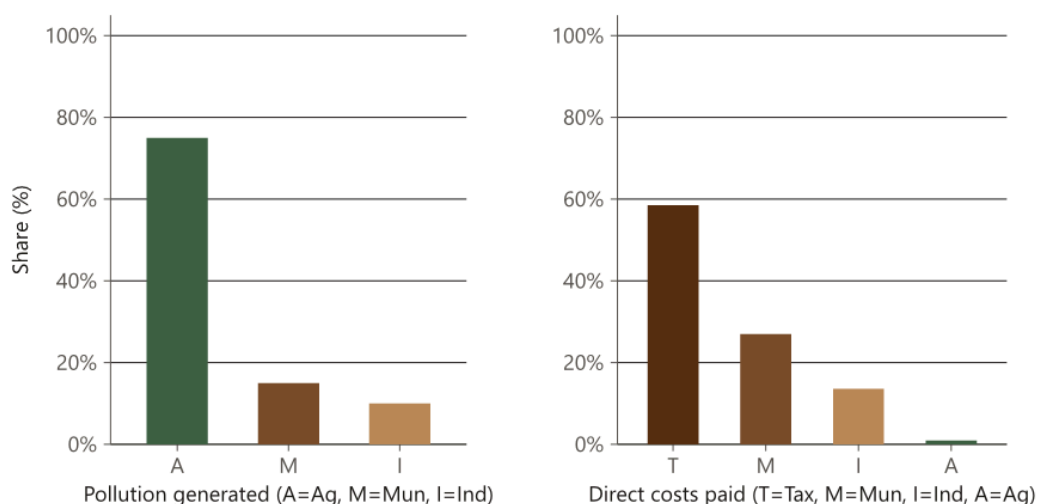


Figure 6: The central asymmetry. Left column: attributed share of nutrient and pesticide loading in major problem basins (model parameter σ_j). Right column: share of the \$2.57B direct management cost actually paid under program design. Side-by-side panels compare each sector across columns. At central attribution, agriculture's 75% loading share maps to a 0.9% cost share; the gap is absorbed largely by taxpayers and municipal ratepayers.

Cost per unit of pollution. Under the central 75% agricultural attribution, municipal ratepayers pay far more per percentage point of attributed pollution than agricultural operators (Table 10). This ratio measures fiscal incidence under current institutions, not marginal abatement cost.

Table 10: Fiscal incidence per percentage point of attributed pollution, by sector.

Sector	Pollution Share	Cost Paid (\$M)	Cost per % of Pollution (\$M)
Municipal	15%	695	46.4
Industrial	10%	349	34.9
Agricultural	75%	22	0.3

Municipal ratepayers contribute \$46.4 million for each percentage point of pollution they generate, per (3). Industrial operators contribute \$34.9 million per percentage point. The agricultural sector contributes \$0.3 million per percentage point, a disparity ratio (4) of 158:1 and 119:1 respectively under central assumptions (Figure 7). Table 11 and Figure 8 bound net externalization across the 65–85% attribution range.

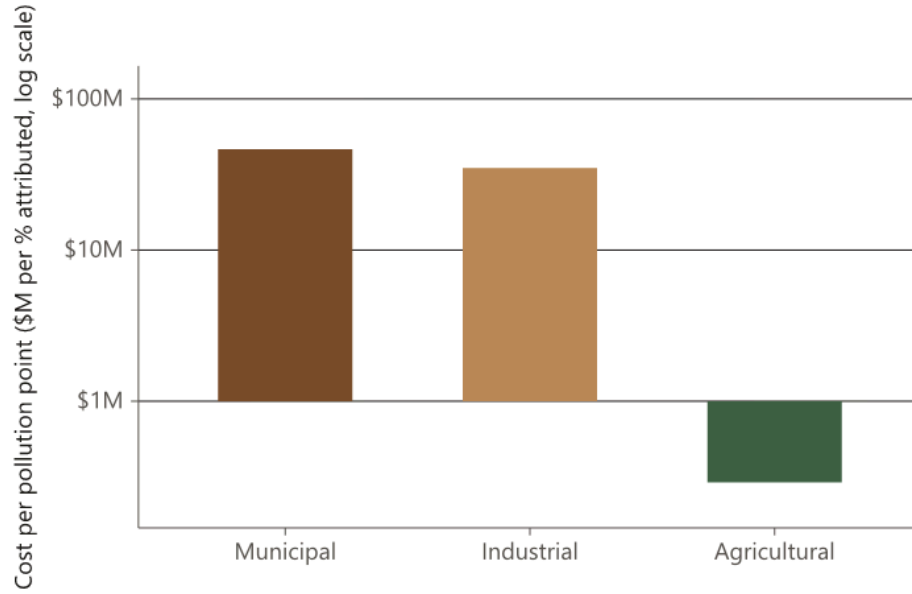


Figure 7: Fiscal incidence intensity B_j from (3): annual cost paid per percentage point of attributed pollution, log scale. The two-order-of-magnitude gap between agriculture and the other polluting sectors holds across the full 65–85% attribution range.

Table 11: Attribution sensitivity: net externalization and payor ratios at 65%, 75%, and 85% agricultural pollution share.

Ag. share	Net ext. (\$M)	Mun:Ag ratio	Ind:Ag ratio
65%	956	137:1	103:1
75% (central)	1,107	158:1	119:1
85%	1,257	178:1	134:1

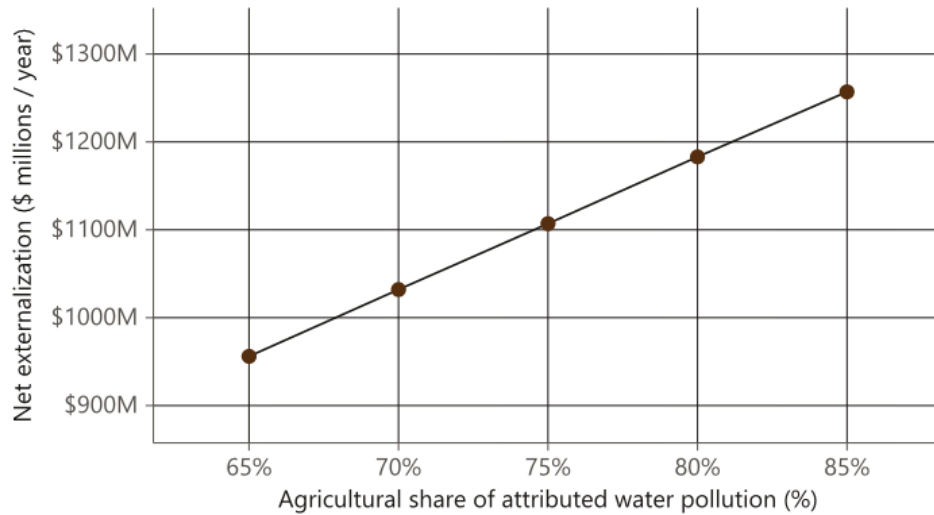


Figure 8: Net externalization E_A from (6) across the attribution sensitivity range. Because (6) is linear in σ_A , each percentage point of attribution shifts the estimate by approximately \$15M; the conclusion that externalization is on the order of \$1B/yr holds across the entire range.

4.3 The Taxpayer Burden in Detail

The \$1.51 billion annual taxpayer burden flows mainly through watershed restoration grants (\$607M), eutrophication damages coded to the public sector (\$344M of \$362M total), infrastructure grants for advanced treatment (\$86–108M), and source-water protection (\$200M taxpayer share per Table 9). Program names and budget anchors match Table 2; the supplementary workbook lists each line item. The eutrophication component remains conservative relative to population-scaled US comparators ((Dodds et al. 2009)), as noted in Methods.

4.4 Net Externalization from Agriculture

Attributing taxpayer-funded pollution costs to pollution sources proportionally via (6), agriculture's 75% pollution share corresponds to \$1,129 million of the \$1,506 million taxpayer burden. Subtracting the agricultural sector's direct contribution of \$22 million yields a net externalization of approximately \$1.11 billion per year, costs caused by agricultural pollution but paid by the general public.

The externalization estimate is conservative in several directions. It attributes only the taxpayer pool C_T , not municipal or industrial payor shares, so the full cross-subsidy from agriculture to other payors is larger than \$1.11B. It treats all pollution as equally costly to manage per unit; if diffuse agricultural loading requires costlier treatment than point-source loading, as tertiary nutrient removal engineering suggests, (6) is biased downward. The eutrophication component (\$362M) counts only documented economic impacts and excludes ecosystem service losses. Groundwater nitrate remediation and private-well pesticide contamination are omitted because they cannot be isolated in public accounts. Conversely, the 75% attribution may overstate agriculture's share in basins where municipal combined sewer overflows dominate; the 65–85% sensitivity band in Figure 8 bounds that uncertainty without changing the order of magnitude.

4.5 Crop Insurance and Agricultural Subsidy Programs

Agriculture externalizes pollution management costs while receiving substantial business risk management support (Agriculture and Agri-Food Canada, n.d.-a): AgriInsurance (60/40 federal–provincial premium sharing), AgriStability (\$500M–\$2B/yr depending on commodity prices), AgriInvest (\$100–200M/yr), and water infrastructure subsidies (50–75% capital cost-share, $\approx \$0.38/\text{m}^3$ in our water-pricing build). These programs address production risk, not pollution liability, but they reinforce a fiscal environment where environmental costs are socialized and input costs subsidized.

5. Soil Degradation and Productivity Loss

5.1 The Cost of Soil Erosion

Agricultural water pollution is directly linked to soil degradation that increases nutrient and sediment export. Soil erosion on Canadian cropland transports phosphorus-laden sediment into waterways, reduces the soil's capacity to retain applied nutrients (increasing leaching and runoff), and imposes direct economic costs on farmers through lost productivity (Soil Conservation Council of Canada 2016).

AAFC's Soil Erosion Risk Indicator supports yield-reduction cost estimates of approximately \$3.0 billion annually (Agriculture and Agri-Food Canada 2023), tripling since 1971 even as the area at moderate-to-

severe risk fell 74% (Table 12). Higher-value crops and persistent organic-matter decline on remaining eroded positions explain the rise in dollar damage (Agriculture and Agri-Food Canada 2023; Soil Conservation Council of Canada 2016; Ontario Ministry of Agriculture, Food and Rural Affairs, n.d.).

Table 12: Soil erosion costs and extent on Canadian cropland (1971–2011). Sources: Lobb et al. (2019); AAFC Soil Erosion Risk Indicator (2023); Soil Conservation Council of Canada (2016).

Metric	1971	2011	Change
Annual crop yield loss from erosion	\$1.0 billion	\$3.0 billion	+200%
Crop production value lost	7%	10%	+3 pp
Cropland moderately to severely eroded	11.1 M ha (37%)	2.9 M ha (9.5%)	–74%
Cumulative loss (1940–2011)	\$20–30 billion		
Average annual farm-level loss	\$35,000		

5.2 Agricultural Sectors by Soil Degradation Impact

Tillage intensity and crop type drive erosion risk; Table 13 ranks sectors from potato and sugar-beet production (12–20 t/ha/yr) to diversified and organic systems (<1 t/ha/yr) (Government of New Brunswick, Department of Agriculture, Aquaculture and Fisheries, n.d.; Li et al. 2007; Top Crop Manager, n.d.; Farming Smarter, n.d.).

Table 13: Soil degradation risk by Canadian agricultural sector.

Agricultural Sector	Risk Level	Tillage Intensity	Erosion Rate (tonnes/ha/yr)	Yield Loss on Eroded Areas	Soil Organic Carbon Trend
Potato production	Very High	Extreme (10–15+ passes)	12–20	40–60%	Severe decline (–30 to –50%)
Sugar beet production	Very High	Extreme (12+ passes)	10–18	40–60%	Severe decline (–25 to –45%)
Corn/soybean (row crop)	High	High (6–8 passes)	8–15	26–40%	High decline (–20 to –35%)
Dry beans	High	High (8–10 passes)	8–12	30–50%	High decline (–20 to –30%)
Intensive cattle grazing	Moderate-High	Low (pasture)	3–8	10–25%	Moderate decline (–10 to –20%)
Monoculture grain	Moderate	Moderate (4–6 passes)	4–8	10–20%	Moderate decline (–15 to –25%)
Conventional wheat/canola	Low-Moderate	Low-Moderate (2–4 passes)	2–6	5–15%	Low decline (–5 to –15%)
Diversified mixed farming	Low	Low (3–4 passes)	1–3	<5%	Minimal (–2 to –8%)
Organic/conservation agriculture	Very Low	Minimal (0–2 passes)	<1	<5%	Positive (0 to +15%)

The soil degradation and water pollution feedback loop. Eroded soil carries phosphorus-laden sediment into waterways; degraded soils leak more applied fertilizer; compaction increases runoff (Lobb 2008). The \$3.0B soil cost and \$2.57B water management cost share the same failure to internalize environmental damage.

5.3 The Senate Report: Critical Ground

In June 2024, the Standing Senate Committee on Agriculture and Forestry released **Critical Ground**, updating its 1984 **Soil at Risk** report after testimony from 153 witnesses (Standing Senate Committee on Agriculture and Forestry 2024). Its central finding: Canada's agricultural soils are degrading faster than monitoring and policy can respond. The committee issued 25 recommendations across soil-as-national-asset designation, a national soil strategy, improved monitoring, outcome-based incentives, and Indigenous community engagement; the federal response (November 2024) offered general support with limited implementation detail (Agriculture and Agri-Food Canada 2024; Standing Senate Committee on Agriculture and Forestry 2024).

6. Land Tenure and Cost Externalization

6.1 Why Tenure Matters for Polluter-Pays

When ownership and operations split, neither party has a default incentive to invest in multi-year conservation. Statistics Canada and Farm Credit Canada data show 39% of Canadian agricultural land is rented, 57% of rental agreements are one-year leases, and 89% of farmers under 35 rely on rented land (Farm Credit Canada 2024; Canadian Centre for Policy Alternatives 2022; Statistics Canada 2021). Short horizons shift stewardship costs onto landowners (soil depreciation) and the public (downstream treatment in Section 4). Illustrative ranges link annual leases to \$45–75/acre/yr degradation cost versus \$5–10 for owner-operators; the full lease-duration matrix and entity profiles are in the supplementary workbook.

Farmland consolidation into institutional and absentee landlords amplifies the oversight gap: portfolio holders inherit soil and water liability without operational control unless they verify tenant practices (Crandlemire 2026a). Paper 2 in this series (**The Consolidation of Risk** (Crandlemire 2026a)) develops landlord-tenant liability, Saskatchewan large-holder growth (84 entities at 10,000+ acres by 2023), watershed routing, and probability-weighted exposure scenarios. Here we note only that tenure structure is a structural driver of the externalization quantified above, not a separate fiscal line item.

7. The Regulatory Asymmetry: How Other Industries Are Treated

7.1 The Polluter-Pays Principle in Practice

Every major resource-extracting or polluting industry in Canada operates under polluter-pays financial assurance; agriculture is the exception (Table 14).

Mining requires reclamation bonds covering 100% of estimated closure costs ((Bond Connect Canada, n.d.)). **Oil and gas** operators post abandonment security, strengthened in Alberta after orphan-well liabilities accumulated ((Environmental Law Centre (Alberta), n.d.; Environmental Defence Canada 2020)). **Landfills and waste management facilities** under the **Environmental Protection and Enhancement Act** (EPEA) must post financial security for closure and reclamation before operations begin (with limited Crown and local-

authority exceptions) (Government of Alberta, n.d.-a; -b). **Anaerobic digesters** follow the same assurance logic along an on-farm / off-farm line: manure-dominant digesters (at least 50% manure by wet weight, with listed co-feedstocks) can store and land-apply digestate under AOPA/NRCB rules, while plants that take substantial off-farm organics are typically approved as EPEA waste-management facilities and carry Director-set reclamation security like other waste plants (Natural Resources Conservation Board 2023; Government of Alberta, Agriculture and Forestry, n.d.; Government of Alberta 2000). **Forestry** licensees must reforest and post security ((Government of British Columbia, Ministry of Forests, n.d.)). **Marine shipping** carries mandatory pollution insurance up to \$162M per large tanker ((Transport Canada, n.d.)). **Industrial manufacturing** requires effluent permits, fees, and often liability insurance ((Environment and Climate Change Canada, n.d.-a)). **US municipal stormwater utilities** charge property owners \$3–5/month for diffuse runoff management ((Smart Prosperity Institute 2016; U.S. Environmental Protection Agency 2015)), the closest analogue to agricultural nonpoint pollution.

7.2 Agriculture: The Exception

Table 14 compares financial assurance requirements across major polluting industries; agriculture remains the outlier at the farm-level, outcome-based scale, even though some provinces already regulate nutrient management for defined operation classes.

Existing provincial instruments (partial coverage). Quebec's **Regulation respecting agricultural operations** (AOR; Q-2, r. 26) requires agro-environmental fertilization plans and annual phosphorus reports for specified livestock and spreading operations (Gouvernement du Québec, Ministère de l'Environnement 2025). Ontario's **Nutrient Management Act, 2002** (NMA) and **Clean Water Act, 2006** (CWA) source-protection plans impose certified nutrient management strategies and plans on larger livestock operations and drinking-water-threat activities (Government of Ontario 2002; 2006). Alberta's AOPA sets manure storage, setback, incorporation, soil nitrate/salinity, and land-base standards for confined feeding operations, administered by the NRCB, and supports the Bow River Phosphorus Management Plan's rural nonpoint work in the middle Bow (Government of Alberta 2000; -c; 2014a). British Columbia's **Code of Practice for Agricultural Environmental Management** (AEM Code) applies to all agricultural operations regardless of size, with setbacks, manure-storage standards, agronomic nitrogen matching, and phased nutrient-management plans in high-risk areas (Government of British Columbia 2019). Prince Edward Island's **Agricultural Crop Rotation Act** (ACRA) requires three-year rotations for potatoes and row crops, with buffer and slope limits under companion regulations, alongside nitrate-driven irrigation-well restrictions (Government of Prince Edward Island, n.d.; Government of Prince Edward Island, Department of Environment, Energy and Climate Action, n.d.). Saskatchewan regulates intensive-livestock waste plans under the **Agricultural Operations Act** but has no province-wide nutrient-management act for cropland; its Environmental Farm Plan (EFP) program ended in 2024 and was replaced by a self-directed agri-environmental risk assessment (Government of Saskatchewan, n.d.-a; -b). Across provinces, BC and PEI apply the broadest binding practice standards; Ontario, Quebec, and Alberta remain livestock-threshold centred; Saskatchewan is the weakest cropland nutrient-control anchor. These regimes demonstrate that field-level nutrient accountability is administratively feasible but remain patchwork: thresholds differ by province, many row-crop operations fall outside livestock-based triggers, and enforcement is not tied to receiving-water quality outcomes at the farm outlet nationally.

Federal prohibition, reactive enforcement. Section 36(3) of the **Fisheries Act** prohibits depositing deleterious substances into waters frequented by fish, including via surface runoff and groundwater (Environment and Climate Change Canada, n.d.-c). That prohibition reaches agricultural runoff in principle. In practice,

enforcement concentrates on acute, single-event fish kills: **R. v. Brookfield Gardens Inc.** (PEI) produced a \$15,000 fine after pesticide-bearing carrot-field runoff caused a 2014 North River fish kill (Environment and Climate Change Canada, n.d.-d). Chronic diffuse nutrient loading is not the routine target of those actions.

Table 14 summarizes sector-wide financial assurance; agriculture alone lacks reclamation-style bonding for diffuse runoff at scale.

Table 14: Environmental financial assurance across Canadian industries. Provincial nutrient-management regimes ((Gouvernement du Québec, Ministère de l'Environnement 2025; Government of Ontario 2002; Government of Alberta 2000)) cover defined operation classes but not the farm-level bonding model in the first column.

Industry	Pollution Type	Financial Security Required?	Who Pays?	Typical Amount
Mining	Point and nonpoint	Yes, reclamation bonds (100% liability)	Company	\$30K–\$500M+ per site
Oil and Gas	Point and nonpoint	Yes, bonds/deposits	Company	\$10K–\$100M per company
Landfills / waste facilities	Point (leachate, residuals)	Yes, EPEA financial security (AB)	Operator	Site-specific; Director-set
Anaerobic digesters	Organics / residuals	Yes on EPEA waste pathway; AOPA digestate pathway when manure-dominant	Operator	Site-specific when secured
Marine Shipping	Point (oil spills)	Yes, mandatory insurance	Polluter	\$162M per vessel
Forestry	Nonpoint (sediment)	Yes, reforestation bonds	Licensee	Variable by area
Industrial Manufacturing	Point	Yes, liability insurance	Company	\$100K–\$10M per facility
Municipal Stormwater (U.S.)	Nonpoint	Yes, user fees	Property owners	\$3–5/month per property
Agriculture (Canada)	Nonpoint	Partial provincial NMP; no national bond	Taxpayers + operators	\$0 bond; receives subsidies

Agriculture remains the only major sector without national mandatory financial assurance calibrated to diffuse water-quality outcomes. Provincial nutrient plans and source-water protection ((Gouvernement du Québec, Ministère de l'Environnement 2025; Government of Ontario 2002; 2006; Government of Alberta 2000; Government of British Columbia 2019; Government of Prince Edward Island, n.d.)) cover subsets of operations but not the reclamation-bond, outcome-linked model applied to mining, oil and gas, landfills, and EPEA-pathway digesters. There are no national reclamation bonds for eroded soil, no mandatory liability pool for nutrient runoff, and no farm-outlet discharge permits tied to receiving-water quality. The sector pays a minimal share of public remediation cost (Table 9) while receiving substantial business risk management and infrastructure subsidies ((Agriculture and Agri-Food Canada, n.d.-a)).

7.3 Public Assistance for On-Farm Pollution Control

Binding provincial nutrient rules are only half of Canada's agri-water instrument stack. The larger dollar volume sits in taxpayer-funded voluntary assistance: cost-share and ecological-goods payments that pay producers to adopt beneficial management practices (BMPs). Table 15 separates control (binding practice standards) from assistance (public payments). Assistance is a distinct fiscal account. It is not added to C_{total} , not netted against E_A , and not a substitute for the \$22M remediation receipts attributed to agriculture in Table 9.

Table 15: Selected Canadian instruments for agricultural nutrient, sediment, and related water-quality control or assistance. Multi-year program envelopes are primary announced or audited totals; annualizations in the text are working bounds. Assistance rows are public payments *to* agriculture; they are outside C_{total} .

Instrument	Type	Jurisdiction	Published envelope	Who pays
Sustainable CAP (2023–2028)	Assistance	Federal–provincial	\$3.5B / 5 yr (Agriculture and Agri-Food Canada, n.d.-b)	Fed 60% / prov 40%; producer match
OFCAP (nitrogen, cover, grazing)	Assistance	Federal	\$704.1M total; +\$300M 2025–28 (Agriculture and Agri-Food Canada 2025; -c)	Federal taxpayer
Resilient Agricultural Landscapes Program (RALP, within SCAP)	Assistance	Federal–provincial	\$250M / 5 yr (Agriculture and Agri-Food Canada, n.d.-b)	Fed/prov; producer adoption
Manitoba GROW	Assistance	Manitoba	\$204M endowment; \$10M/yr (Government of Manitoba, n.d.)	Provincial endowment
Québec Prime-Vert	Assistance	Québec	\$66M / 3 yr (Gouvernement du Québec 2023)	Province (+ SCAP where stacked)
Ontario Agricultural Stewardship Initiative (ASI) / EFP cost-share	Assistance	Ontario (SCAP)	Intake-specific (Ontario Soil and Crop Improvement Association, n.d.)	Fed/prov + producer match
AOPA / NRCB manure standards	Control	Alberta	Compliance (no runoff bond)	Operator
BC AEM Code	Control	British Columbia	Compliance (all operations)	Operator
PEI ACRA + buffers	Control	Prince Edward Island	Compliance (row crops)	Operator
ON NMA / CWA; QC AOR	Control	Ontario; Québec	Compliance (threshold livestock)	Operator

Working annualization of the assistance envelopes in Table 15 (SCAP environment-relevant share treated as a substantial fraction of the \$700M/yr partnership run-rate, plus OFCAP \$100M/yr, RALP \$50M/yr, GROW \$10M/yr, Prime-Vert \$22M/yr) places public agri-environmental assistance on the order of \$0.9–1.0 billion per year. That band is a working bound from multi-year announcements, not an audited national line item, and it includes practices whose primary stated objective is greenhouse-gas reduction with water-quality co-benefits

(OFCAF nitrogen and cover crops). Even so, the order of magnitude exceeds agriculture's \$22M contribution to the public remediation ledger by more than an order of magnitude (Figure 9).

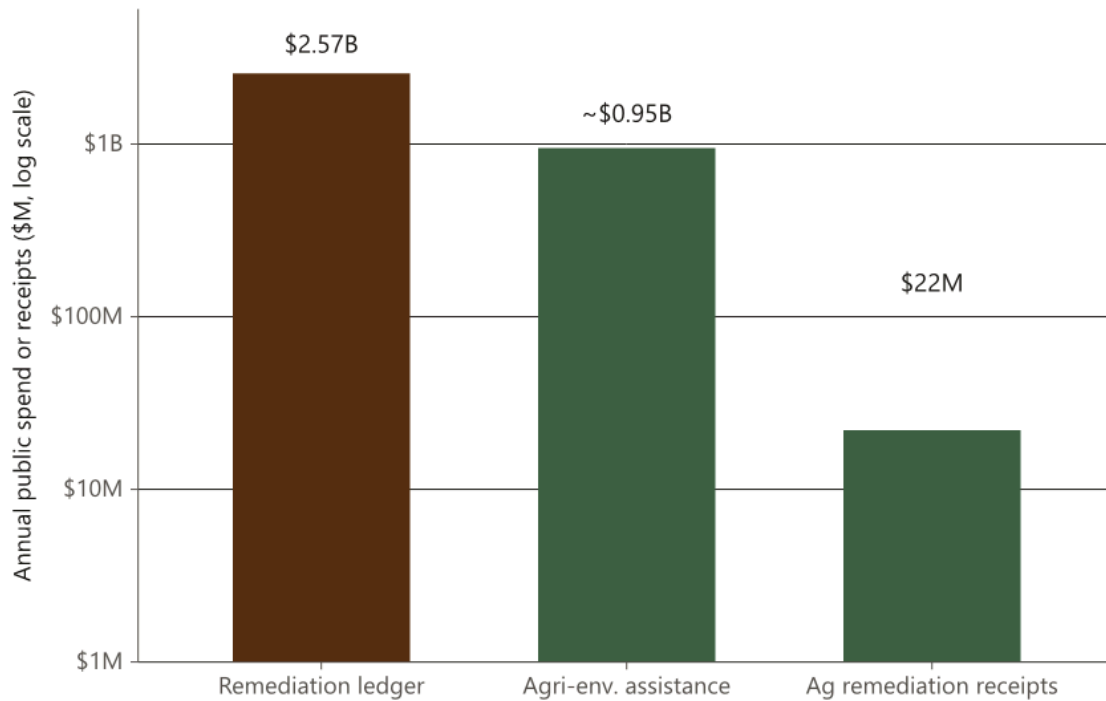


Figure 9: Three distinct fiscal accounts (log scale): public water-pollution remediation ledger (\$2.57B), public agri-environmental assistance to producers (working \$0.95B/yr from Table 15 envelopes), and agriculture's remediation receipts in the ledger (\$22M). Accounts are not summed; assistance is not netted against E_A .

Taxpayers therefore fund both end-of-pipe and watershed remediation (\$2.57B in C_{total}) and on-farm practice payments (\$0.9–1.0B/yr working), while agriculture's direct remediation receipts remain \$22M. Mining, land-fill, and EPEA waste-facility operators, by comparison, post financial assurance before residual risks transfer to the public (Table 14).

7.4 The Historical Roots of Agricultural Exceptionalism

The agricultural exemption reflects the family-farm narrative, the genuine difficulty of attributing nonpoint pollution, disproportionate political weight relative to GDP share, and competitiveness arguments that ignore stricter environmental conditions in peer exporters (Potato News Today 2024).

8. The Combined Environmental Cost

8.1 Total Annual Externalization

When water pollution and soil degradation costs are reported side by side for context, their arithmetic sum is approximately \$5.57 billion annually (Table 16). That sum aggregates two distinct accounts. \$2.57B is largely public remediation and management expenditure; \$3.0B soil yield loss is primarily private on-farm productivity loss measured by AAFC erosion indicators (Agriculture and Agri-Food Canada 2023). Adding them double-

counts neither line item nor produces a single social-cost estimate: they share structural drivers (failure to price environmental damage at the field) but answer different accounting questions.

Table 16: Side-by-side annual environmental cost accounts (\$ billions). The \$5.57B line is an arithmetic sum of distinct public and private accounts.

Cost Category	Annual Cost	Primary Payor
Water pollution management (all sectors)	\$2.57	Taxpayers (58.5%), Municipal (27.0%), Industrial (13.6%), Agricultural (0.9%)
Soil degradation (yield loss)	\$3.00	Farmers (lost productivity)
Arithmetic sum (distinct accounts)	\$5.57	Public remediation + private yield loss
Agricultural sector's direct pollution contribution	\$0.022	Agriculture (public-program receipts)
Taxpayer burden (water pollution)	\$1.51	Taxpayers
Taxpayer burden attributable to ag pollution share	\$1.13	Taxpayers (75% of \$1.51B)
Net agricultural externalization (E_A)	\$1.11	Shifted from agriculture to taxpayers

While farmers bear the productivity cost of soil degradation directly through reduced yields (\$3.0 billion), this cost is partially offset by crop insurance payouts and income stabilization programs. The net effect is that the broader public bears approximately \$1.1 billion annually in direct water pollution costs caused by agriculture but paid by taxpayers, plus a share of the water infrastructure subsidy costs that enable agricultural water use at below-cost rates.

8.2 Distribution of Costs

In percentage terms, the immediate cost distribution for water pollution is:

- **Taxpayers: 58.5%** (\$1.51 billion annually)
- **Municipal ratepayers: 27.0%** (\$695 million)
- **Industrial operators: 13.6%** (\$349 million)
- **Agricultural operators: 0.9%** (\$22 million)

Including soil-degradation costs and attributing the taxpayer water-pollution share to agriculture's loading parameter yields the following incidence: the agricultural sector directly pays \$22 million of the \$2.57 billion public management ledger attributed to it under the central share, while bearing \$3.0 billion in on-farm productivity losses from soil degradation. The \$1.11 billion net water-pollution externalization is the taxpayer-pool cost attributable to agriculture under (6), a fiscal transfer from the Canadian public into agricultural production under current institutions.

In mining, oil and gas, waste facilities, and other sectors covered by financial assurance or discharge permits, polluters fund pollution management through direct payments, posted security, or regulatory compliance expenditures. Historical closure failures and pollution events, including Giant Mine and the Redwater contaminated-site complex, have prompted tighter scrutiny and stronger upfront cost allocation to operators; the public still bears residual orphan liabilities from past failures.

8.3 Food Price Implications

The Soil Conservation Council of Canada has estimated that continued soil degradation could increase food price inflation by an additional 1–3 percentage points over baseline, doubling to 2–6 percentage points over a 20-year horizon. The projected impact on Canadian households is approximately \$250 per year in additional food costs, with low-income households affected most (Soil Conservation Council of Canada 2016). These projections indicate that the long-term costs of delayed soil protection fall on consumers, including households with the least capacity to absorb price increases.

8.4 Comprehensive Cost and the Question of Scale

Our \$2.57B management-cost estimate is conservative relative to full ecosystem valuation. Dodds et al. (2009) estimated US freshwater eutrophication damages at approximately \$2.2 billion annually (Dodds et al. 2009); scaled comparisons suggest Canadian eutrophication damages could exceed our \$362 million bottom-up build. Broader ecosystem service valuations would increase totals further. Our method prioritizes directly measurable management and damage costs. Under central basin attribution, agriculture's direct payment toward public water-pollution management (\$22M) remains small relative to its attributed loading share and the \$1.11B net externalization of the taxpayer pool. Both the public remediation ledger and the private \$3.0B soil-productivity loss reflect under-priced field-level environmental damage.

9. Policy Recommendations: A Framework for Aligning Agriculture with the Polluter-Pays Principle

9.1 Principles for Reform

Any policy framework for transitioning Canadian agriculture toward the polluter-pays principle must balance several objectives:

1. **Environmental effectiveness:** Policies must achieve measurable reductions in nutrient, pesticide, and sediment loading to water bodies.
2. **Economic viability:** Policies must be designed to maintain a competitive and viable Canadian agricultural sector.
3. **Equity:** Costs should be borne by those who cause pollution.
4. **Phased implementation:** Requirements should be introduced gradually, starting with the largest and highest-risk operations.
5. **Monitoring and accountability:** Policies must include field-level monitoring to measure outcomes and ensure compliance.

9.2 Federal, Provincial, and Municipal Jurisdiction

Water-quality management in Canada is constitutionally shared. Provinces hold primary authority over agriculture, natural resources, and most environmental permits; nutrient management, drainage, and lease law sit here. Municipalities own and rate-base drinking-water and wastewater systems (the \$695M municipal column in Table 9). Federal roles include fisheries protection (**Fisheries Act**, Wastewater Systems Effluent Regulations

[WSER]), pesticide registration, Great Lakes and transboundary agreements, and transfer payments that fund watershed programs in C_T . Recommendations below note the responsible order of government where it matters:

1. Items 1, 6, 8, 9, 12: primarily federal leadership with provincial implementation (soil asset designation, subsidy conditionality, national targets).
2. Items 2, 5, 7, 10, 11: primarily provincial (water pricing in irrigation districts, lease terms, runoff fees, tiered regulation, cover crops).
3. Source-water protection and utility treatment upgrades: municipal/regional conservation authorities and utilities, often cost-shared from provincial and federal grants.

No single order of government can close the fiscal-incidence gap alone; coordinated provincial rollout following Quebec, Ontario, Alberta, British Columbia, and Prince Edward Island livestock- and crop-nutrient precedents (Gouvernement du Québec, Ministère de l'Environnement 2025; Government of Ontario 2002; Government of Alberta 2000; Government of British Columbia 2019; Government of Prince Edward Island, n.d.), and building on basin plans already in place such as the Bow River Phosphorus Management Plan (Government of Alberta 2014a), is the most administratively proven path.

9.3 Tier 1: Immediate Actions (Year 1–2)

1. Designate soil as a strategic national asset. Implement Senate recommendation 1 from **Critical Ground** (Standing Senate Committee on Agriculture and Forestry 2024).

2. Implement agricultural water pricing reform. Phased increase to \$0.20–\$0.50/m³ would begin to reflect the true cost of water supply while remaining well below municipal and industrial rates. In irrigation-district jurisdictions, volumetric reform should be paired with return-flow and nutrient accounting so that cheap conveyance does not continue to underwrite free nutrient delivery to receiving rivers (Government of Alberta 2014a). This alone would generate significant revenue for water quality management while creating conservation incentives.

3. Extend nutrient management plans to larger operations nationally. Quebec requires agro-environmental fertilization plans and phosphorus reporting for defined livestock and spreading thresholds (Gouvernement du Québec, Ministère de l'Environnement 2025); Ontario requires certified nutrient management for larger livestock operations under the **Nutrient Management Act** (Government of Ontario 2002); Alberta already regulates confined feeding manure storage, setbacks, and land-base limits under AOPA (Government of Alberta 2000); British Columbia's AEM Code already covers all agricultural operations (Government of British Columbia 2019); Prince Edward Island's crop-rotation and buffer rules cover potato and row-crop systems (Government of Prince Edward Island, n.d.). Other provinces should adopt comparable thresholds, starting with operations above 40 ha or 30 animal units, harmonized where possible with existing source-water protection policies and basin phosphorus plans (Government of Ontario 2006; Government of Alberta 2014a).

4. Establish soil conservation bonds for high-risk crops. Potatoes and sugar beets should be subject to soil conservation bond requirements modeled on mining reclamation bonds, calibrated to estimated restoration cost per hectare (Bond Connect Canada, n.d.; Government of New Brunswick, Department of Agriculture, Aquaculture and Fisheries, n.d.; Top Crop Manager, n.d.).

9.4 Tier 2: Short-Term (Year 2–4)

5. Mandate minimum lease terms for rented farmland. Provincial legislation should mandate minimum three-year lease terms, addressing the 57% of leases that are currently annual (Canadian Centre for Policy Alternatives 2022; Farm Credit Canada 2024); portfolio landlords and enforcement exposure are analyzed in Paper 2 (Crandlemire 2026a).

6. Redirect agricultural subsidies toward environmental outcomes. Replace unconditional infrastructure subsidies with outcome-based payments conditional on verifiable environmental performance, the EU's cross-compliance model.

7. Implement agricultural runoff fees. Following the US municipal stormwater utility model, fees would be calibrated to tillage intensity, crop type, and proximity to sensitive water bodies, with revenues dedicated to watershed restoration (Smart Prosperity Institute 2016).

8. Enhanced monitoring and public reporting. Farms exceeding 100 hectares should be required to participate in water quality monitoring at drainage outlets, with annual public reporting.

9.5 Tier 3: Medium-Term (Year 4–7)

9. Full polluter-pays implementation for water quality. Nutrient discharge limits for agricultural drainage, pesticide application restrictions tied to water quality data, and mandatory financial assurance for nutrient management.

10. Tiered regulatory framework. EU Water Framework Directive-style: small operations receive education and technical assistance; medium operations face mandatory management planning; large operations face bonding, monitoring, and enforcement.

11. Mandatory cover crops for high-erosion areas. Areas with erosion risk exceeding 6 tonnes/ha/year should be subject to mandatory winter cover crop requirements.

12. Long-term targets. National targets for soil organic carbon increase (10% by 2035), watershed-specific nutrient load reduction targets, and agricultural greenhouse gas emission reductions.

9.6 Expected Outcomes

Implementation of this framework is intended to reduce nutrient and sediment loading, align subsidy programs with environmental performance, and shift remediation costs toward polluters. Illustrative targets from international precedents (EU cross-compliance, New Zealand freshwater caps) suggest material reductions in externalization over a decade, though quantitative savings require policy simulation beyond this paper's scope.

10. Conclusion

10.1 The Central Finding

In the major agricultural watersheds that drive Canadian public water-quality expenditure, agriculture is attributed roughly 75% of nutrient and pesticide loading (basin indicators in Table 1) but pays approximately 0.9% of direct management cost under current program design. The resulting \$1.11 billion net externalization of the taxpayer pool, after agriculture's \$22M direct contribution, is borne by general taxpayers and, through

cross-subsidies, municipal ratepayers. Separately, on-farm soil productivity loss is estimated at \$3.0B annually (Agriculture and Agri-Food Canada 2023); that private cost remains its own on-farm productivity account alongside the \$2.57B public management ledger (Table 16). A third public account, agri-environmental assistance to producers (\$0.9–1.0B/yr working; Table 15; Figure 9), pays for voluntary on-farm practice change and is not counted in C_{total} or E_A .

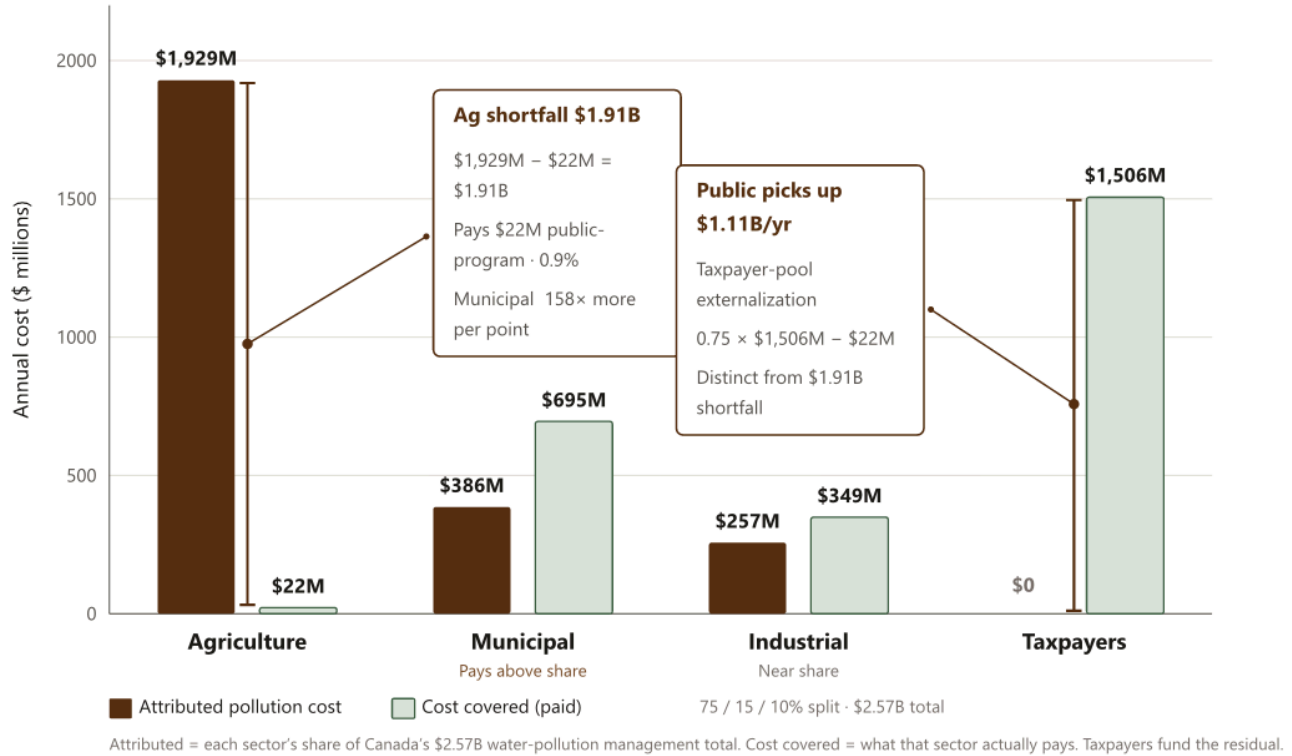


Figure 10: Attributed pollution cost versus cost covered, by sector (75 / 15 / 10% of the \$2.57B total). Two callouts are distinct: agriculture's attributed shortfall $S_A = \$1.91B$ is attributed share of C_{total} minus \$22M paid (5); public taxpayer-pool pickup $E_A = \$1.11B/\text{yr}$ is $0.75 \times C_T - C_A$ (6). Municipal and industrial payors cover more than their attributed shares; taxpayers fund \$1,506M with \$0 attributed. Municipal payors cover 158× more per pollution point than agriculture (4) (exact $D_{M,A} = 157.95$).

Cost maldistribution reflects deliberate policy choices that exempt agriculture from polluter-pays instruments applied to other major polluting sectors in Canada.

10.2 The Structural Drivers

Persistent cost externalization is associated with water-pricing inequity (agricultural water roughly 7–10 times cheaper than municipal water on a true-cost basis, including irrigation-district fees in South Saskatchewan corridors that convey return flows into phosphorus-stressed Bow and Oldman reaches (Government of Alberta 2014a)), short land-tenure terms (57% annual leases; see Paper 2 (Crandlemire 2026a)), regulatory asymmetry in financial assurance, and sustained political accommodation of agricultural interests.

10.3 Next Steps

The Senate report **Critical Ground** (2024) recommends designating soil as a strategic national asset and treating soil degradation as a priority for federal action (Standing Senate Committee on Agriculture and Forestry 2024). Extending to agriculture the financial assurance and discharge accountability already required of mining, oil and gas, landfills and waste facilities, forestry, and marine shipping can proceed in phases by building on provincial nutrient regimes already in force (Quebec AOR, Ontario NMA/CWA, AOPA, BC AEM Code, PEI ACRA) and on basin phosphorus plans such as the middle Bow program (Gouvernement du Québec, Ministère de l'Environnement 2025; Government of Ontario 2002; Government of Alberta 2000; Government of Alberta 2014a; -a; Government of British Columbia 2019; Government of Prince Edward Island, n.d.). Assistance programs (Sustainable CAP, OFCAF, GROW, Prime-Vert) remain useful for adoption, but they do not close the remediation incidence gap documented in (6).

Food-price pass-through, export competitiveness, and whether today's \$2.57B management ledger covers social damage are taken up in a companion cost–benefit analysis (Crandlemire 2026b).

Under current institutions, municipal ratepayers and general taxpayers fund most water-pollution management tied to agricultural nonpoint loading. Aligning fiscal incidence with the polluter-pays principle remains the central policy task for the next decade.

11. Acknowledgment

The author is principal of Newcopia Intelligence, an independent soil-health prediction and management platform. This analysis is independent; the author has no financial interest in agricultural operations or municipal utilities.

The author thanks Environment and Climate Change Canada; Alberta Environment and Protected Areas for the Bow River Phosphorus Management Plan open materials; past members of the Alberta Water Council, whose work under the Water for Life strategy informed multi-sector phosphorus management on the Bow and Oldman reaches; the Standing Senate Committee on Agriculture and Forestry; and researchers at the Johnson Shoyama Graduate School of Public Policy, whose public data and reports underpin this analysis.

12. Data Availability

The complete economic model (cost components, payor weights, externalization arithmetic, three fiscal accounts including agri-environmental assistance outside C_{total} , water pricing comparison, soil degradation costs, and incidence analysis) accompanies this paper as a supplementary Excel workbook, with soft pools (\$360M / \$730M / \$400M) marked as working estimates and source-note columns. A copy is also available on request from john@newcopia.ca. Open-access PDF: <https://doi.org/10.5281/zenodo.21500230>.

13. Abbreviations

Introduced abbreviations used more than once. Full titles appear at first use in the body.

Table 17: Abbreviations used in this paper.

Abbreviation	Expansion
AAFC	Agriculture and Agri-Food Canada
ACRA	Agricultural Crop Rotation Act (Prince Edward Island)
AEM	Agricultural Environmental Management (British Columbia Code of Practice)
ALUS	Alternative Land Use Services
AOPA	Agricultural Operation Practices Act (Alberta)
AOR	Regulation respecting agricultural operations (Québec)
ASI	Agricultural Stewardship Initiative (Ontario)
BMP	Beneficial management practice
CESI	Canadian Environmental Sustainability Indicators
CWA	Clean Water Act, 2006 (Ontario)
CWN	Canadian Water Network
DRP	Dissolved reactive phosphorus
ECCC	Environment and Climate Change Canada
EFP	Environmental Farm Plan
EPEA	Environmental Protection and Enhancement Act (Alberta)
GHG	Greenhouse gas
GROW	Growing Outcomes in Watersheds (Manitoba)
EPA	United States Environmental Protection Agency
NMA	Nutrient Management Act, 2002 (Ontario)
NMP	Nutrient management plan
NRCB	Natural Resources Conservation Board (Alberta)
OECD	Organisation for Economic Co-operation and Development
OFCAF	On-Farm Climate Action Fund
PMP	Phosphorus Management Plan (Bow River)
RALP	Resilient Agricultural Landscapes Program
SCAP / Sustainable CAP	Sustainable Canadian Agricultural Partnership (2023–2028)
TN	Total nitrogen
TP	Total phosphorus
WSER	Wastewater Systems Effluent Regulations

13. References

- Agriculture and Agri-Food Canada. 2023. *Soil Erosion Risk Indicator*. Technical report.
- Agriculture and Agri-Food Canada. 2024. “Government Response to the 2024 Senate Report: Critical Ground.”.
- Agriculture and Agri-Food Canada. 2025. “Minister Macaulay Announces Funding to Help Farmers Lower Emissions and Build Resilience.”. <https://www.canada.ca/en/agriculture-agri-food/news/2025/01/minister-macaulay-announces-funding-to-help-farmers-lower-emissions-and-build-resilience.html>.

- Agriculture and Agri-Food Canada. n.d.-c. "Agricultural Climate Solutions – on-Farm Climate Action Fund." Accessed July 13, 2026. <https://agriculture.canada.ca/en/programs/agricultural-climate-solutions-farm-climate-action-fund>.
- Agriculture and Agri-Food Canada. n.d.-a. "Business Risk Management Programs." Accessed May 26, 2025. <https://agriculture.canada.ca/en/programs>.
- Agriculture and Agri-Food Canada. n.d.-b. "Sustainable Canadian Agricultural Partnership." Accessed July 13, 2026. <https://agriculture.canada.ca/en/departement/initiatives/sustainable-canadian-agricultural-partnership>.
- Bingham, Michael, Sanjiv K. Sinha, and Frank Lupi. 2015. *Economic Benefits of Reducing Harmful Algal Blooms in Lake Erie*. Technical report. <https://ijc.org/files/tinymce/uploaded/Publications/Economic-Benefits-Due-to-Reduction-in-HABs-October-2015.pdf>.
- Bond Connect Canada. n.d. "Reclamation Bonds for Mining Operations." Accessed May 26, 2025. <https://www.bondconnect.ca/reclamation-bond/>.
- Canadian Centre for Policy Alternatives. 2022. *The Wild West: Farmland Ownership and Rental in the Prairie Provinces*. Technical report.
- Crandlemire, John. 2026b. "If Agriculture Paid: Food Prices, Export Competitiveness, And the Adequacy of Canada's Water-Pollution Cost Bucket".
- Crandlemire, John. 2026a. "The Consolidation of Risk: Institutional Farmland Ownership and the Erosion of Agricultural Exceptionalism in Canadian Water Pollution Policy".
- Dodds, Walter K., Wes W. Bouska, Jeffrey L. Eitzmann, et al. 2009. "Eutrophication of U.S. Freshwaters: Analysis of Potential Economic Damages." *Environmental Science & Technology* 43 (1): 12–19.
- Environment and Climate Change Canada. 2023a. *Canadian Environmental Sustainability Indicators: Phosphorus Loading to Lake Erie*. Technical report.
- Environment and Climate Change Canada. 2023c. *Nutrients in Lake Winnipeg Indicator*. Technical report.
- Environment and Climate Change Canada. 2023b. *Pesticides in Freshwater Indicator*. Technical report.
- Environment and Climate Change Canada. 2024a. *Nutrients in the St. Lawrence River Indicator*. Technical report.
- Environment and Climate Change Canada. 2024b. "Canada Water Act Annual Report for 2022 to 2023". <https://www.canada.ca/en/environment-climate-change/services/water-overview/publications/canada-water-act-2022-2023.html>.
- Environment and Climate Change Canada. n.d.-b. *Overview of Agricultural Non-Point Source Water Pollution in Canada*. Technical report.
- Environment and Climate Change Canada. n.d.-c. "Fisheries Act Registry: Frequently Asked Questions." Accessed July 13, 2026. <https://www.canada.ca/en/environment-climate-change/corporate/transparency/acts-regulations/fisheries-act-registry/frequently-asked-questions.html>.
- Environment and Climate Change Canada. n.d.-d. "Prince Edward Island Company Sentenced for Violation Causing a Fish Kill." Accessed July 13, 2026. <https://www.canada.ca/en/environment-climate-change/services/environmental-enforcement/notifications/prince-edward-island-company-sentenced-violation-fish-kill.html>.
- Environment and Climate Change Canada. n.d.-a. "Wastewater Systems Effluent Regulations: Overview." Accessed May 26, 2025. <https://www.canada.ca/en/environment-climate-change/services/wastewater-regulations.html>.
- Environment and Climate Change Canada and Ontario Ministry of the Environment, Conservation and Parks. 2024. *Canada-Ontario Lake Erie Action Plan: 2024 Evaluation and Update Report*. Technical report. <https://www.canada.ca/content/dam/cwa-ace/documents/great-lakes-documents/Canada-Ontario%20Lake%20Erie%20Action%20Plan%202024%20Evaluation%20and%20Update%20Report.pdf>.
- Environmental Defence Canada. 2020. *Past Due: Tallying the Costs of Oil and Gas Cleanup in Canada*. Technical report.
- Environmental Law Centre (Alberta). n.d. "The Next Government Needs to Address Alberta's Fossil Fuel Liabilities." Accessed May 26, 2025. <https://elc.ab.ca/post-library/the-next-government-needs-to-address-albertas-fossil-fuel-liabilities-part-1/>.
- Farm Credit Canada. 2024. *2024 Farmland Rental Rates*. Technical report.
- Farming Smarter. n.d. "Saving Soils: Soil Conservation for High-Disturbance Irrigated Crops." Accessed May 26, 2025. <https://farmingsmarter.ca/>.

- Gouvernement du Québec. 2023. "Prime-Vert Program Relaunch." <https://www.quebec.ca/nouvelles/actualites/details/lancement-dune-version-amelioree-du-programme-prime-vert-des-investissements-importants-pour-accroitre-les-pratiques-agroenvironnementales-52938>.
- Gouvernement du Québec, Ministère de l'Environnement. 2025. "Regulation Respecting Agricultural Operations, Q-2, R. 26."
- Government of Alberta. 2000. "Agricultural Operation Practices Act, R.S.A. 2000, C. A-7."
- Government of Alberta. 2014a. *Bow River Phosphorus Management Plan*. Technical report. <https://open.alberta.ca/publications/9781460116265>.
- Government of Alberta. 2014b. *Bow River Phosphorus Management Plan: Scenario Modeling Results for Crowfoot Creek*. Technical report. <https://open.alberta.ca/publications/9781460116272>.
- Government of Alberta. n.d.-b. "Financial Security for Land Reclamation." Accessed July 13, 2026. <https://www.alberta.ca/financial-security-for-land-reclamation>.
- Government of Alberta. n.d.-c. "Manure Management Guidelines and Legislation." Accessed July 13, 2026. <https://www.alberta.ca/manure-management-guidelines-and-legislation>.
- Government of Alberta. n.d.-a. "Waste Facilities – Financial Security." Accessed July 13, 2026. <https://www.alberta.ca/waste-facilities-financial-security>.
- Government of Alberta, Agriculture and Forestry. n.d. "Anaerobic Digesters: Frequently Asked Questions." Accessed July 13, 2026. <https://www1.agric.gov.ab.ca/departement/deptdocs.nsf/all/agdex11290>.
- Government of British Columbia. 2019. "Code of Practice for Agricultural Environmental Management, B.C. Reg. 8/2019." https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/8_2019.
- Government of British Columbia, Ministry of Forests. n.d. "Reforestation and Regeneration Requirements." Accessed May 26, 2025. <https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/silviculture>.
- Government of Canada. 1999. "Canadian Environmental Protection Act, 1999, S.C. 1999, C. 33."
- Government of Canada. 2012. "Wastewater Systems Effluent Regulations, SOR/2012-139."
- Government of Manitoba. 2020a. *A Proposed Regulation under the Water Protection Act: Nutrient Targets for Lake Winnipeg (Plain Language Summary)*. Technical report. https://manitoba.ca/sd/pubs/water/lakes-beaches-rivers/nutrient_targets_regulation_plain_language_summary_fall_2020.pdf.
- Government of Manitoba. 2020b. *State of Lake Winnipeg: 2nd Edition*. Technical report.
- Government of Manitoba. n.d. "Growing Outcomes in Watersheds (Grow)." Accessed July 13, 2026. <https://www.gov.mb.ca/sd/water/watershed/grow/>.
- Government of New Brunswick, Department of Agriculture, Aquaculture and Fisheries. n.d. "Agricultural Soil Erosion." Accessed May 26, 2025. <https://www2.gnb.ca/content/gnb/en/departments/10/agriculture.html>.
- Government of Ontario. 2002. "Nutrient Management Act, 2002, S.O. 2002, C. 4."
- Government of Ontario. 2006. "Clean Water Act, 2006, S.O. 2006, C. 22."
- Government of Prince Edward Island. n.d. "Agricultural Crop Rotation Act." Accessed July 13, 2026. https://www.princeedwardisland.ca/sites/default/files/legislation/a-08-01-agricultural_crop_rotation_act.pdf.
- Government of Prince Edward Island, Department of Environment, Energy and Climate Action. n.d. "Nitrate in Groundwater." Accessed May 26, 2025. <https://www.princeedwardisland.ca/en/information/environment-energy-and-climate-action/nitrate-in-groundwater>.
- Government of Saskatchewan. n.d.-b. "Agri-Environmental Risk Assessment." Accessed July 13, 2026. <https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/programs-and-services/environment-programs/agri-environmental-risk-assessment>.
- Government of Saskatchewan. n.d.-a. "Agricultural Operations Act, R.S.S. 1978 (Supp.), C. A-12.1." Accessed July 13, 2026. <https://pubsaskdev.blob.core.windows.net/pubsask-prod/365/A12-1.pdf>.
- Human Rights Watch. 2016. *Make It Safe: Canada's Obligation to End the First Nations Water Crisis*. Technical report. <https://www.hrw.org/report/2016/06/07/make-it-safe/canadas-obligation-end-first-nations-water-crisis>.

- Li, Sheng, David A. Lobb, and Kevin H. D. Tiessen. 2007. "Soil Erosion and Potato Production in Atlantic Canada." *Soil and Tillage Research* 97 (2): 123–34.
- Liu, Jian, Jane A. Elliott, Henry F. Wilson, Merrin L. Macrae, Helen M. Baulch, and David A. Lobb. 2021. "Phosphorus Runoff from Canadian Agricultural Land: A Cross-Region Synthesis of Edge-of-Field Results." *Agricultural Water Management* 255 : 107030. <https://doi.org/10.1016/j.agwat.2021.107030>.
- Lobb, David A. 2008. "Soil Movement by Tillage and Other Agricultural Activities." In *Encyclopedia of Ecology, Encyclopedia of Ecology*. Elsevier.
- Mann, Janelle, and Charles Grant. 2015. "Economics of Nutrient Management Systems for Compliance with Phosphorus Regulations: Method and Case Study." *Agricultural Systems* 138 : 10–17. <https://doi.org/10.1016/j.agsy.2015.04.002>.
- Michalak, Anna M., Eric J. Anderson, Dmitry Beletsky, et al. 2013. "Record-Setting Algal Bloom in Lake Erie Caused by Agricultural and Meteorological Trends Consistent with Expected Future Conditions." *Proceedings of the National Academy of Sciences* 110 (16): 6448–52.
- Natural Resources Conservation Board. 2023. "Storage and Application of Digestate on Agricultural Land Directive." <https://www.nrcb.ca/public/download/files/238208>.
- OECD. 1972. "Recommendation of the Council on Guiding Principles Concerning International Economic Aspects of Environmental Policies."
- Oleszkiewicz, Jan, and others. 2015. *Options for Improved Nutrient Removal and Recovery from Municipal Wastewater in the Canadian Context*. Technical report. <http://cwn-rce.ca/wp-content/uploads/2015/11/CWN-EN-Oleszkiewicz-5-pager-for-web.pdf>.
- Ontario Ministry of Agriculture, Food and Rural Affairs. n.d. "Soil Erosion: Causes and Effects." Accessed May 26, 2025. <http://www.omafra.gov.on.ca/english/engineer/facts/12-053.htm>.
- Ontario Soil and Crop Improvement Association. n.d. "Agricultural Stewardship Initiative." Accessed July 13, 2026. <https://www.ontariosoilcrop.org/agricultural-stewardship-initiative/>.
- Parliament of Canada. 2021. "United Nations Declaration on the Rights of Indigenous Peoples Act." <https://laws-lois.justice.gc.ca/eng/acts/U-2.2/FullText.html>.
- Potato News Today. 2024. *Canada's Senate Publishes Landmark Report on Soil Health*.
- Schindler, David W., Robert E. Hecky, and Greg K. McCullough. 2012. "The Rapid Eutrophication of Lake Winnipeg: Greening under Global Change." *Journal of Great Lakes Research* 38 (3): 6–13.
- Smart Prosperity Institute. 2016. *Incentives for Managing Stormwater in Canada*. Technical report.
- Soil Conservation Council of Canada. 2016. *Cost of Soil Erosion and Sedimentation to Canadians*. Technical report.
- Standing Senate Committee on Agriculture and Forestry. 2024. *Critical Ground: Why Soil Is Essential to Canada's Economic, Environmental, And Social Well-Being*. Technical report.
- Standing Senate Committee on Agriculture, Fisheries and Forestry. 1984. *Soil at Risk: Canada's Eroding Future*. Technical report.
- Statistics Canada. 2021. "Census of Agriculture, 2021."
- Statistics Canada. n.d. "Survey of Drinking Water Plants and Wastewater Treatment Plants."
- Top Crop Manager. n.d. "Sugar Beets and Soil Conservation." Accessed May 26, 2025. <https://www.topcropmanager.com/>.
- Transport Canada. n.d. "Marine Liability and Compensation for Oil Spills." Accessed May 26, 2025. <https://tc.canada.ca/en/marine-transportation/marine-safety/marine-liability-compensation-oil-spills>.
- U.S. Environmental Protection Agency. 2015. *Stormwater Utility Fee Guidance Manual*. Technical report.
- Ulrich, Andrea, Diane Malley, and Vivek Voora. 2009. *Peak Phosphorus: Opportunity in the Making*. Technical report. https://www.iisd.org/system/files/publications/peak_phosphorus.pdf.
- Wang, Jiaxin, Zhiming Qi, and Elena M. Bennett. 2022. "Changes in Canada's Phosphorus Cycle 1961–2018: Surpluses and Deficits." *Global Biogeochemical Cycles* 36 (8). <https://doi.org/10.1029/2022gb007407>.