3.0 Anthropogenic Sources of Nitrogen and Phosphorus

Highlights

- In 1996, 73% of Canadians were served by municipal sewer systems. An additional 25% relied on septic beds for sewage treatment. The remaining 2% were likely serviced by lagoons.
- Human waste is the largest source of nitrogen and phosphorus to municipal wastewater treatment plants.
- In 1996, at least 94% of the sewage collected by sewers received primary treatment or better. The majority of the sewage collected in the interior of the country, from Alberta to Ontario, receives secondary treatment or better. For Canadians living on the coasts, discharge of untreated sewage is common.
- Phosphorus loading from municipal wastewater treatment plants in Canada has decreased by 37% from 1983 to 1996. N loads, however, have increased by 17%.
- Agricultural crop production in Canada has doubled in the last 50 years. This increase is due to improved crop varieties, improved crop management, pesticide use, and increased use of manure and fertilizers.
- Fertilizer, manure, and legume nitrogen fixation are the major sources of nutrients to agricultural land. In 1996, fertilizer was typically applied to cropland in Canada at rates of 60 to 86 kg/ha nitrogen and 10 to 33 kg/ha phosphorus. Manure was typically applied at rates of 114 to 301 kg/ha N or 38 to 184 kg/ha P.
- Agricultural activities contribute about 91% of the ammonia from Canadian sources to the atmosphere. Agricultural runoff and leaching is also a source of nutrients to surface and ground waters.
- The majority of the 204 t P/yr and 956 t N/yr added to Canadian inland waters by aquaculture operations is the result of uneaten food fragments and metabolic waste.
- Atmospheric deposition supplies, on average, 3.4 kg/ha/yr dissolved inorganic N east of the Manitoba-Ontario border and 0.8 kg/ha/yr west of this border. Wet and dry deposition of P ranges from 0.01 to 0.7 kg P/ha/yr for all of Canada.

Nitrogen and phosphorus enter the environment as a result of both natural processes and human activity (see Chapter 2). The largest reservoir of N exploited by humans is nitrogen gas (N_2) in the atmosphere. Most manufactured N compounds are made from atmospheric nitrogen gas. The major manufactured N-containing product is fertilizer. Ammonia is also used as a nutrient in fermentation processes in food and beverage industries, and for production of some synthetic fibres (e.g., nylon) (Kettrup and Hüppe 1988). Derivatives of hydrazine (N_2H_4) are used as chemotherapeutic agents, particularly in the treatment of leprosy and tuberculosis. Nitrate and nitrite compounds are also used in the production of commercial explosives, azo dyes and pharmaceuticals.

Industrial P chemicals are made from phosphate rock transformed into phosphoric acid by either smelting or treatment with acid. Of the phosphate produced by the world's industry today, about 80 to 85% is used in fertilizers. The next largest user is the detergent industry. Until the 1950s, most detergents were soap-based products made from animal fat and lye (sodium hydroxide). In 1947, the

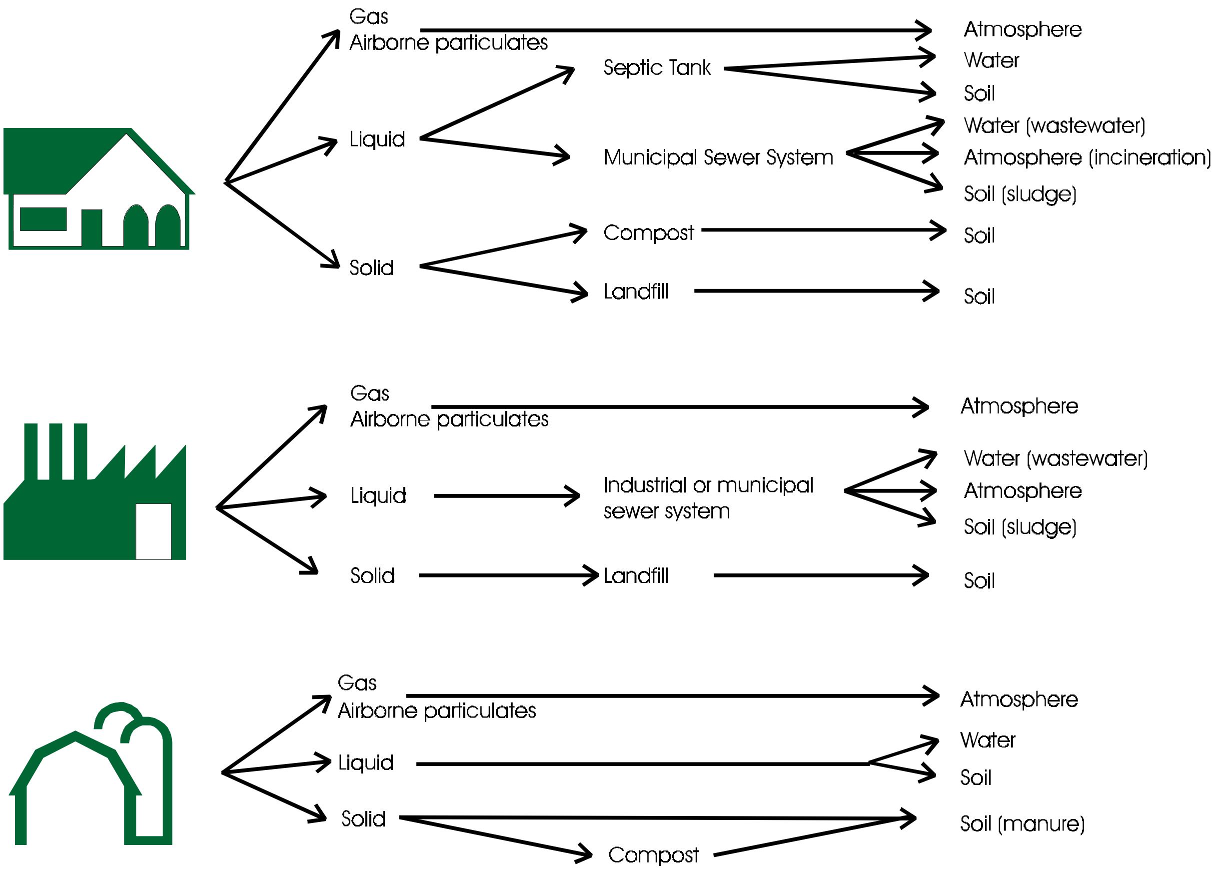


Figure 3.1. Household, industrial and agricultural sources and fate of N and P in the environment.

first synthetic detergents were introduced and gained wide acceptance because of their improved cleaning performance. The basis of these new formulations was sodium tripolyphosphate, used as a "builder" to soften water and optimize washing conditions for other active ingredients. Until the late 1980s, sodium tripolyphosphate was used almost exclusively as the builder in laundry detergents. Because of effects on water quality, other builders have been introduced in recent years although shortcomings in the performance of these builders, as compared to sodium tripolyphosphate, require additions of other chemicals (CEEP 1998).

Phosphate is also used in the manufacture of animal feed supplements because of its nutritive value. Food-grade phosphates are used in food products such as dairy, meat and bakery products, and in soft drinks. For example, phosphate compounds are used as leavening agents by bakers and as a polishing agent in toothpastes. Other industrial applications include the manufacture of flame retardants, in the treatment of metal surfaces to prevent rusting ("phosphatizing"), and as a bath for the electropolishing of stainless steel articles (Kettrup and Hüppe 1988).

In short, nitrogen and phosphorus are integral components of our daily lives. Nitrogen and phosphorus fertilizers make it possible to meet much of the world's food demands. Many of the products that we use contain N or P or have required N or P during their manufacture. In addition, N and P are vital components of growth and metabolism for all animals, including humans. In humans, P accounts for 1.1 to 1.2 g/kg body weight, most (85%) of which occurs in bone and teeth. Nitrogen forms the foundation of amino acids which act as the building blocks of proteins and DNA and thus plays an important role in the regulation of essential physiological reactions (West et al. 1966). A consequence of the transformation of N and P from natural reservoirs to products used in homes and industries and to food consumed by humans and other animals is the undesirable loss of nutrients to the environment. Transformation of N and P by biological and industrial processes are not completely efficient such that nutrients are lost at every stage in the process.

The purpose of this chapter is to identify and quantify the human derived, or anthropogenic, sources of P and N to the Canadian environment. The major anthropogenic sources are municipal, industrial and agricultural losses. For these sectors, nutrients may be released to the atmosphere as gases or airborne particulates; to surface or ground waters in the form of wastewater discharges and runoff, in the case of land-based operations such as agriculture or forestry operations; and to the soil as solid waste (Figure 3.1). In this chapter, the release of nutrients to surface and ground waters, to the atmosphere and to soils is considered for municipal, industrial, agricultural, aquacultural and forestry sectors.

3.1 Municipal Waste

Municipal waste consists of liquid waste, also known as wastewater or sewage, and solid waste or the garbage collected from households and businesses.

Municipal wastewater is a complex mixture of suspended solids, micro-organisms, debris and a variety of chemicals derived from both household and industrial sources (New Brunswick Environment 1982; Birtwell et al. 1983; OME 1988). Almost all households, office buildings and small to medium-size industries discharge their wastewater to a municipal sewer system. Large industries (pulp mills, mining operations, large manufacturing plants, etc.) often independently treat and discharge their wastewater; discharges from industries with provincial operating permits are presented in Section 3.2.

Municipal wastewater is conveyed from households, businesses and roadways by a complex series of sewers. There are two types of sewer systems:

- Separate systems, comprising sanitary sewers that carry raw sewage from homes and businesses to wastewater-treatment facilities, and storm sewers that carry storm runoff from streets, parking lots, and roofs through pipes and ditches and eventually into streams, lakes or coastal waters,
- Combined sewer systems that carry raw sewage, with or without storm water, to wastewater treatment facilities during periods of no or low precipitation, but discharge excess raw sewage and storm water into receiving waters during periods of high rainfall or snowmelt when their flow capacity is exceeded.

Cities have either a separate sewer system (consisting of independent storm sewers and sanitary sewers) or a combined sewer system. In rural settings, low population densities do not make sewer systems necessary or economically feasible. Instead, rural households typically discharge sewage to septic disposal systems or holding tanks.

Effluents from Municipal Wastewater Treatment Plants

In 1992, there were approximately 2 800 municipal wastewater treatment plants (MWTPs) in Canada. The percentage of Canadians served by wastewater treatment has increased in recent years. Surveys conducted by Environment Canada (1996a) showed that 73% of Canadians were served by municipal sewer systems as of 1996. The remaining 27% (8 million Canadians) were in villages (with populations less than 1000) or rural settings and were largely served either by septic disposal systems (25%) or lagoons (2%). Of those hooked up to municipal sewers, 94% (20.7 million Canadians) were served by wastewater treatment (primary or better) in 1996 compared with 85% (17.4 million Canadians) in 1991 (Figure 3.2). The remaining 6% (1.3 million Canadians) were serviced by sewage collection structures not connected to wastewater treatment facilities but that discharged untreated sewage directly into lakes, rivers or oceans (Environment Canada 1996a).

Defining Sewage Treatment Types

Treatment Type	Description
Primary	The mechanical screening and sedimentation of sewage, to decrease influent biochemical oxygen demand (BOD) by 20 to 30% and total suspended solids (TSS) by about 60%.
Secondary	The mechanical aeration of sewage, to encourage biological degradation of soluble organic matter, followed by sedimentation of solids to decrease influent BOD and TSS by 80 to 95%.
Tertiary	The additional treatment by sand filtration or a polishing lagoon after secondary treatment to achieve higher TSS and BOD removal.
Lagoons/ Waste Stabilization Ponds	The treatment of sewage by biological processes in one or a series of relatively shallow basin(s). This process is commonly used in small communities and produces effluent equivalent to secondary treatment.
Phosphorus removal	A process in which either iron or aluminum solution (i.e., alum) is added to the sewage to reduce effluent TP concentrations. TP removal can be added at any stage of sewage treatment.

Definitions after OMEE 1993.

The level of sewage treatment is improving in Canada as more municipalities upgrade their wastewater treatment facilities. In 1996, tertiary treatment (largely advanced P removal) was provided to 38% of the municipal population, up from 36% in 1991 (Figure 3.3). Secondary treatment (including both mechanical systems, such as activated sludge methods process or percolating filters, and non-mechanical systems such as lagoons) was provided to 34% of the population, up from 29%,

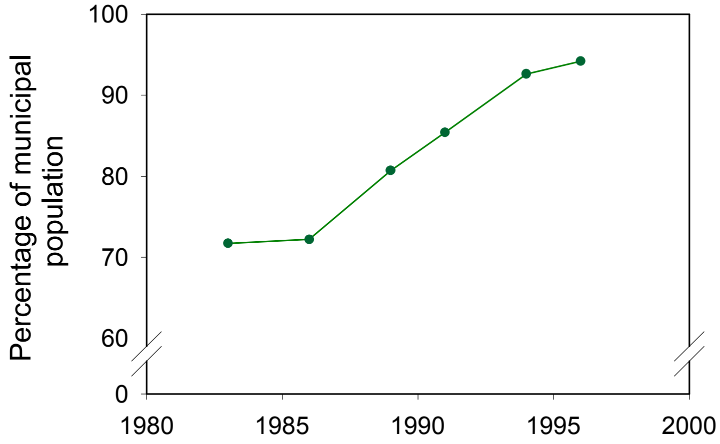


Figure 3.2. The proportion of Canada's population with municipal wastewater treatment, 1983-1996. Data are for communities with populations greater than 1 000 served by sewers (Environment Canada 1996a).

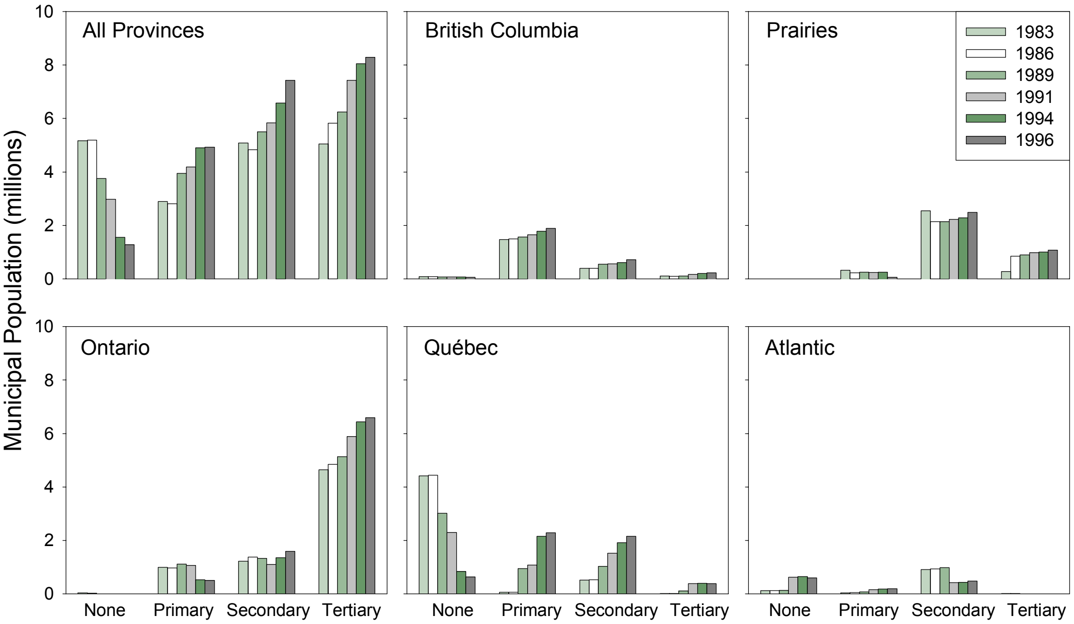
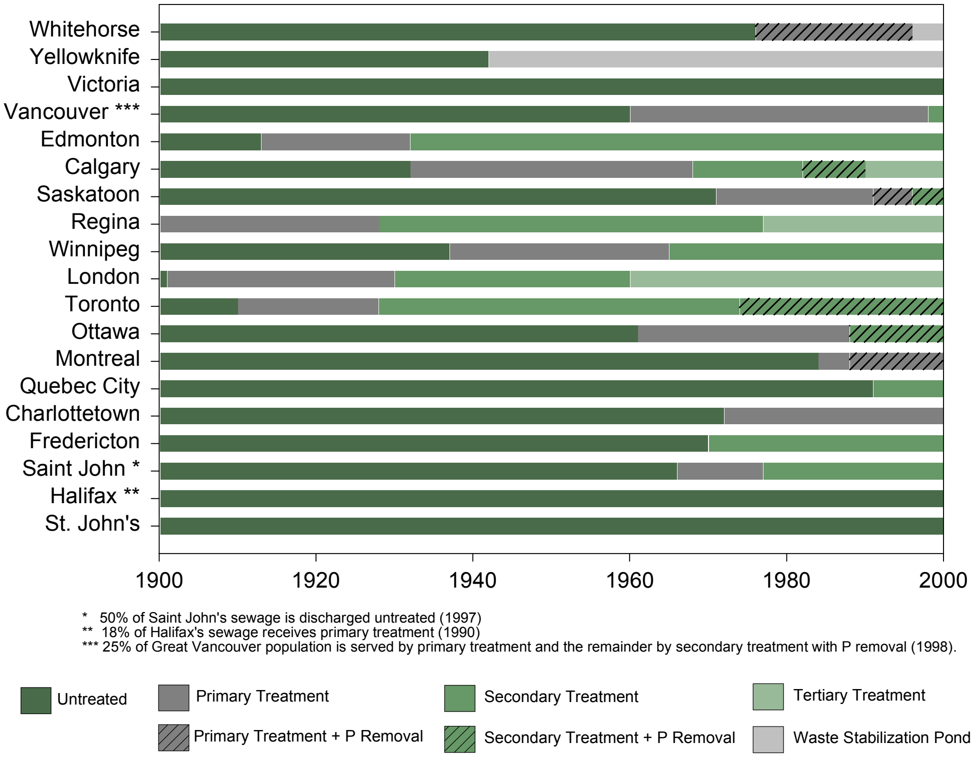


Figure 3.3. The number of Canadians in each region of Canada, excluding the Territories, served by sewage treatment, 1983-1996. Data are for communities with populations greater than 1 000 served by sewers (Environment Canada 1996a). Territorial data are not presented, as the small numbers are not distinguishable at this scale. Communities served by lagoons or by secondary treatment have been pooled as lagoons produce effluent equivalent to secondary treatment.

and primary treatment was provided to 22%, up from 20%. Much of this change occurred in Québec where the population served by wastewater treatment increased from 2 to 75% between 1980 and 1991 (MEFQ 1995).

The level of wastewater treatment varies greatly across Canada (Figure 3.3). Most of the population of British Columbia is served by primary treatment; however, this figure is an overestimate because Victoria's sewage treatment consists of screening through a 6-mm wire mesh but not sedimentation. Only slight increases in secondary and tertiary treatment in British Columbia have occurred in the past five years. In the Prairie Provinces, secondary treatment and tertiary treatment serve most of the population. Ontario's population is largely served by tertiary treatment, with substantial increases in this level of service since 1983 in response to programs to clean up the Great Lakes. In Québec, a mix of primary or secondary treatment serves most of the population, many of these upgrades having occurred in the past 10 years. In the Atlantic Provinces, more than half of the population is served by sewer systems releasing untreated wastewater directly into estuarine or coastal waters.

The variation in wastewater treatment across Canada is also evident in the current and historical status of service provided by major cities (Figure 3.4). Waste stabilization ponds (lagoons) currently serve the comparatively small populations of Whitehorse and Yellowknife. The two major West Coast cities, Vancouver and Victoria, have a long history of no sewage treatment. Victoria implemented screening in 1989 to remove large floatables such as logs and plastics from the sewage. Vancouver added primary treatment in 1961 followed, in 1998, by upgrades to secondary treatment for two of the city's three MWTPs. All the major Prairie cities (Edmonton, Calgary, Saskatoon, Regina, and Winnipeg)



* 50% of Saint John's sewage is discharged untreated (1997)
** 18% of Halifax's sewage receives primary treatment (1990)
*** 25% of Great Vancouver population is served by primary treatment and the remainder by secondary treatment with P removal (1998).

Figure 3.4. The history of sewage treatment in major Canadian cities, 1900-2000. The dates represent the beginning of upgrades to the treatment plants and not the dates of 100% implementation of the treatment. Data were obtained through consultation with each city's engineering or utilities department.

provide at least secondary treatment, with Regina, Saskatoon and Calgary also undertaking advanced P removal. In Ontario, Toronto and Ottawa have secondary treatment with advanced P removal; London has tertiary treatment. In Québec, Montreal's sewage receives primary treatment with advanced P removal whereas Québec City's sewage receives secondary treatment. In the Atlantic Provinces, many cities discharging sewage to the ocean (e.g., St. John's, Halifax, Charlottetown) provide no treatment or only primary treatment. Fredericton provides secondary treatment, whereas only half of the sewage from Saint John receives secondary treatment and the other half is discharged untreated.

Wastewater

In 1991, approximately 4 300 million cubic metres of municipal wastewater was discharged to Canadian lakes, rivers and coastal waters (Statistics Canada 1994). Although not all MWTPs measure the composition of their effluents, nutrient loads can be estimated from information on the average per capita nutrient load for the various levels of treatment. Data from a comprehensive study of municipal wastewater discharges by treatment type in Ontario in 1991 were used to calculate an average influent total P load of 3.38 g per capita per day as well as the average effluent total P load and removal efficiency for each level of sewage treatment (Table 3.1). To estimate the MWTP load for total P, the influent P load (3.38 g/capita/day) was then multiplied by the population served by each level of sewage treatment (Figure 3.3) and the removal efficiency for each sewage type (Table 3.1). Information on N loads was not collected as part of the Ontario survey. We therefore used an influent load of 10 g total N per capita per day based upon Tchobanoglous and Burton's (1991) estimate of 12 g N per capita per

Table 3.1. Total phosphorus load in the final effluent and removal efficiency for various levels of wastewater treatment. (Values were calculated from data presented in a 1991 survey of Ontario MWTPs (OMEE 1993). Removal efficiency was calculated as the difference between the influent and effluent load, expressed as percent of the influent load.)

Treatment Type	P Removal ?	Number of Facilities Sampled	Effluent Total Phosphorus Load (g/capita/d)	Total Phosphorus Removal Efficiency (%)
Primary	no	9	1.71	36.3
	yes	19	0.75	75.5
	Average	**28**	**1.06**	**62.9**
Secondary	no	46	1.03	59.0
	yes	137	0.42	88.4
	Average	**183**	**0.58**	**81.0**
Lagoons	no	45	0.78	65.5
	yes	76	0.20	92.5
	Average	**121**	**0.42**	**82.4**
Tertiary	no	2	1.02	58.7
	yes	33	0.15	94.7
	Average	**35**	**0.20**	**92.7**

day (which equates to delivery to the MWTP of 350 L/day at 35 mg/L TN) minus a 10% loss during sewage treatment (assuming no advanced treatment for N removal). The MWTP load for total N was estimated by multiplying the influent N load (10 g/capita/day) by population (Figure 3.3.).

In 1996, 5.6 thousand tonnes of P (as total P) was released to lakes, rivers and coastal waters in Canada from MWTPs (Figure 3.5). This discharge represents a 37% decrease since 1983 and a 20% decrease from 1991 loads. The total P load from Ontario MWTPs (1 thousand tonnes in 1996) is similar to that from the Atlantic Provinces (0.9 thousand tonnes) and British Columbia (1 thousand tonnes), despite the population of Ontario being five times larger than that of the Atlantic region and three times larger than British Columbia. These similar loads are due to the fact that most of the population in Ontario is served by tertiary treatment compared to no treatment or primary treatment for coastal populations. Overall, total P release in 1996 from municipal wastewater was 4.3 thousand tonnes to inland waters, 0.44 thousand tonnes to Pacific coastal waters, 0.84 thousand tonnes to Atlantic coastal waters, and 0.002 thousand tonnes to Arctic coastal waters.

Total N released to lakes, rivers and coastal waters in Canada was approximately 80 thousand tonnes in 1996. This value represents a 17% increase over 1983 and a 7% increase over 1991 loads. Loads from Ontario and Québec were the largest of all provinces, because of their large populations. Overall, total N release in 1996 from municipal wastewater was 71 thousand tonnes to inland waters, 4 thousand tonnes to Pacific coastal waters and 5 thousand tonnes to Atlantic coastal waters.

The nutrient loads given above are for total N and total P. Only a portion of the total load is present in forms that have the potential to cause eutrophication or, in the case of N, have the potential to be toxic. For P, about 65 to 100% of the total load from sewage is bioavailable (Sonzogni et al. 1982, Tchobanoglous and Burton 1991, Berge and Källqvist 1998). For N, about 60% of the total load is in the form of free ammonia with the remainder being organic N (Tchobanoglous and Burton 1991).

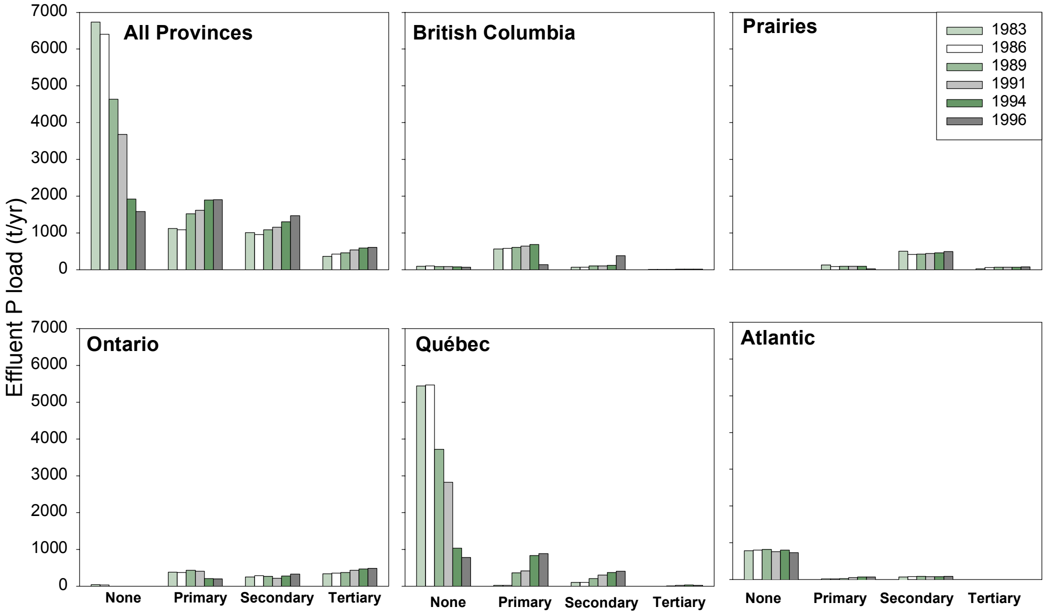


Figure 3.5. P loading as a result of municipal effluent releases for each provincial region of Canada, 1983-1996. Population served by primary, secondary or tertiary treatment (Environment Canada 1996a) multiplied by P removal values in Table 3.1. The population not served by sewage treatment was estimated as the difference between census population estimates for the region (Statistics Canada 1998a) and the Environment Canada (1996a) database of populations served by sewage treatment. Territorial data not presented, as the small numbers are not distinguishable at this scale.

Sources of nutrients in municipal wastewater include human waste, household cleaning products (laundry detergent, automatic dishwashing detergent and general-purpose cleaners), and by-products from industries that dispose wastewater to municipal sewer systems. Nitrogen enters domestic wastewater primarily from human waste; this source constitutes >90% of the household N load, with the dominant form of N being ammonia followed by organic N forms. Industrial discharges to the municipal sewer system also add N, however human waste generally represents most of the input.

Phosphorus sources to municipal wastewater are more varied than N sources. Prior to regulation of the P content of laundry detergent under Part III of the *Canada Water Act* (which restricted P content to8.7% by weight in 1970 and then to 2.2% in 1973), P loads from human waste and laundry detergent were roughly equal. Analysis of 1996 data shows human waste was the largest contributor to municipal P loading in Canada followed by commercial and industrial sources (Table 3.2). Automatic dishwashing detergents, general-purpose cleaners and laundry detergent each contributed ≤ 7% of the municipal P load.

In addition to routine operational wastewater discharge, MWTPs on occasion experience a discharge of raw sewage known as a bypass. A bypass differs from a combined sewer overflow in that raw sewage is released from a MWTP rather than from a sewer. Bypasses in both sanitary and combined sewers may occur for a number of reasons including significant increase in wastewater volume due to a storm event or spring thaw, operation problems such as equipment breakdown, or population and industrial growth exceeding the design capacity of the MWTP. In most provinces, bypasses are not allowed except in emergency situations, such as protecting basements from flooding, preventing damage to

Table 3.2. Sources of phosphorus in Canadian municipal wastewaters, 1996.

Source	**P Content**	**Quantity**	**P Load (t/yr)**	**% of Total**
Human waste	1.8 g/capita/day[1]	28,846,761[2] (population)	18,952	53
Laundry detergents	0% for 95% of detergent sold; 2.2% for 5% of detergent sold[3]	150x10^3 t[4]	165	<1
Automatic dishwashing detergents	6.0%[5]	42x10^3 t[6]	2,520	7
General purpose cleaners	2.2%[7]	54x10^3 t[8]	1,188	3
Commercial & industrial sources			12,763[9]	36
Household total	3.38g/capita/d[10]	28,846,761[2] (population)	**35,588**	100
Municipal load after treatment and discharge from MWTP[11]			**5,563**	

[1] Values typically range from 1.5 to 2.0 g/capita/day (Alexander and Stevens 1976; Balmer and Hultman 1988; Holtan et al. 1988; Barr Engineering 1993)

[2] Statistics Canada (1988a)

[3] The major manufacturers of laundry detergent (Proctor & Gamble, Lever Brothers) have eliminated P from laundry detergents sold in North America. Other manufacturers have not changed their formulations but they represent only 5% of the market (K.J. Ott, Albright & Wilson Americas Ltd., Mississauga, Ontario, personal communication).

[4] 1993 data (Environment Canada 1993)

[5] K.J. Ott, Albright & Wilson Americas Ltd., Mississauga, Ontario, personal communication

[6] In 1993 about 35x10^3 t of dishwasher detergent used in Canada. The number of Canadian households with an automatic dishwasher increased by 29% from 4.4 million in 1992 to 5.7 million in 1997 (Statistics Canada 1992, 1997c). Given that dishwasher numbers increased on average by 5% per year between 1992 and 1997, dishwater detergent use likely also increased by 5% per year. Therefore in 1996, dishwater detergent consumption in Canada was likely 42x10^3 t.

[7] Grenon (1994)

[8] 1993 data (Environment Canada 1993c)

[9] Commercial and industrial P load calculated as the difference between the household total and the loads from human waste, detergents and cleaners.

[10] Calculated from a 1991 Ontario study of municipal wastewater discharges (OMEE 1993)

[11] Total municipal load for 1996 from Figure 3.5. The municipal P load discharged to surface waters (i.e., 5.6 thousand t/yr) is less than the household total because 63 to 93% of the P is removed at the MWTP, depending on the level of sewage treatment provided.

MWTP equipment, or averting the wash-out of solids. Data from Ontario for 1991 showed that 75 of the 204 reporting MWTPs (or 37%) had bypasses (OMEE 1993), most of which occurred during the spring thaw months of March and April. The total annual volume was 2.2 million cubic metres for primary bypass and 9.6 million cubic metres for secondary bypass, representing 0.11 and 0.46%, respectively, of the total effluent volume treated in 1991 (OMEE 1993).

Sewage Sludge

Sewage sludge refers to the organic and inorganic solids resulting from decomposition and settling of wastewater as it undergoes treatment (Warman 1997). Sludge is produced during every stage of wastewater treatment (primary, secondary and tertiary, as well as in lagoons). Biosolids are the portion of the sewage sludge that has been stabilized through digestion to meet public health regulations for application to land (OMEE & OMAFRA 1996; WEF 1998). Biosolids are a semi-liquid material containing at least 10% suspended solids (WEF 1998). Solids produced during preliminary screening of sewage are generally not used as biosolids as they contain the large lumps, sticks, rags, pieces of metal and rocks that enter the wastewater treatment plant. They do not meet guidelines for application to agricultural land and, hence, are landfilled or incinerated (WEF 1998; M. Webber, wastewater consultant, personal communication).

The quantity of sludge generated increases as the level of sewage treatment increases. A primary treatment plant produces approximately 80 g sludge solids/person•day and contains a high percentage of grit and other inert material (Black et al. 1984). A secondary treatment plant yields about 115 g sludge solids/person•day whereas a tertiary treatment plant typically produces about 145 g sludge solids/person•day (Black et al. 1984). Sludge is digested either aerobically or anaerobically to kill pathogens and reduce water content.

As biosolids are a by-product of sewage treatment, they are rich in inorganic and organic materials and plant nutrients. Nutrient values for biosolids are typically 4% N and 2.5% P (Webber and Bates 1997). Biosolids are therefore a desirable additive to agricultural land because they recycle plant nutrients and organic matter to soil (Webber and Bates 1997). However, depending upon industrial contribution to the MWTP and its treatment process, biosolids may have high concentrations of heavy metals and pathogens (Webber and Bates 1997). Most provinces have guidelines for the management of land application of biosolids (Table 3.3; NSE 1992; CBCL Ltd. 1996; NBE 1996; OMEE & OMAFRA 1996; AEP 1997; BCELP 1998a; SERM 1998;) designed to match biosolid nutrient content with the nutrient demands of the crop, while limiting accumulation of micro-nutrients such as molybdenum, copper and zinc which can be toxic when present in high concentrations. In Canada, the application rates for digested sludge range from 8 to 25 tonnes dry solids/ha over two to five years depending on soil texture, field slope and soil pH (Table 3.3). In general, application rates are based on laboratory measurements of soil N content and can be further constrained by soil P concentrations.

With increasing landfill fees, agricultural application is becoming the most economical sludge management option. Sewage sludge production for Canada was estimated to be 500 000 t/yr (dry weight) in the early 1980s (OECD 1995). More recent data for the entire country do not exist, although the City of Toronto sewage sludge production for 1999 was about 70 000 t/yr (dry weight). Data from the early 1980s indicated that 42% of Canadian sludge was applied to agricultural land, 18% was landfilled, and the remaining 40% was incinerated (OECD 1995). Based on sludge production of 500 000 t/yr (dry weight) and typical N and P contents of 4% and 2.5%, respectively, on a dry weight basis (Webber and Bates 1997) sewage sludge in Canada accounts for 20 thousand tonnes N and 12.5 thousand tonnes P per year. Of this total, 3.6 thousand tonnes N and 2.3 thousand tonnes P are landfilled; 8.4 thousand tonnes N and 5.3 thousand tonnes P are applied to agricultural land; and 8 thousand tonnes N and 5 thousand tonnes P are incinerated.

Discharges from Municipal Sewers

In urban areas, snowmelt or stormwater runoff from house roofs, parking lots, and streets empty into the municipal sewer system. Sewer systems built before the early 1940s disposed of household wastewater simply by discharging it directly into rivers, lakes or coastal waters. These sewer lines also carried stormwater and, hence, are referred to as combined sewer systems. As the deleterious consequences of raw sewage discharge became apparent, trunk sewers were built to divert the household sewage in combined sewers to sewage treatment plants. However, the cost of constructing treatment facilities with sufficient capacity to handle most of the stormwater flow was considered

Table 3.3. Nutrient derived guidelines for land application of biosolids for Canadian provinces (na indicates information not available).

Province	Sewage Biosolids	Application Guideline	Notes	Reference
Nova Scotia New Brunswick Prince Edward Island	Stabilized sludge only	5.6 t dry solids /ha (=160 kg N/ha/ 2 yr)	Only applied every 2 years due to upper limits of acceptable P concentration in soil Soil pH ≥ 6.0; optimal is 6.0-6.8 Field slope ≤ 8% Approval required before application allowed in NS	NSE 1992; CBCL 1996; NBE 1996
Québec		na	Heavy metal content of biosolids; soil P concentration	MEFQ 1997
Ontario	Aerobically digested sludge	8 t solid/ha/ 5 yr	Soil concentration of P <60 mg/g in top 15 cm	OMEE & OMAFRA 1996
	Anaerobically digested sludge	135 kg N/ha/ 5 yr	Soil pH ≥ 6.0 which may be achieved through liming	
Manitoba		15 t dry solid/ha/yr	Plant-available N cannot exceed 100 kg/ha/yr pH ≥ 6.0 Field slope ≤ 5% Sodium bicarbonate extractable P cannot exceed 60 µg P/g soil in the upper 15 cm	M. Van Den Bosch, Manitoba Conservation, personal communication
Saskatchewan	Undigested sewage	na	Not allowed on sandy soils Field slope <9%	SERM 1998
Alberta	Digested sludge	25 t dry solids/ha/ 3 yr	Soil pH ≥ 6.5 which may be achieved through liming	AEP 1997
	Undigested sludge	5 t solids/ha/ 3 yr	Medium to fine textured soils preferred Field slope < 9% with closed drainage	
British Columbia		na	organic matter must be <15% dry weight TKN must be <6% by weight C:N >15:1	BCELP 1998a

prohibitive. Consequently, the outfalls in the combined sewer system were left to act as "relief valves", and diversion or regulator structures were installed to divert flows in excess of sewer or MWTP capacity to these outfalls. As a result, whenever rain or snowmelt exceeds the design capacity of the sewer system or the MWTP, raw sewage and stormwater are released from the combined sewer outfalls into the receiving water. These discharges are referred to as combined sewer overflows (CSOs) and are typical for older parts of many Canadian cities.

Table 3.4. Nitrogen (TN, NO_3^-, NH_4^+) and total phosphorus (TP) loads from stormwater runoff and combined sewer overflows (CSOs) for selected Canadian urban areas expressed based on the size of the urban land (kg/ha) as well as the total load (t/yr).

City	Nitrogen		TP		Reference
	kg/ha	t/yr	kg/ha	t/yr	
Stormwater					
North York, ON	13 TN		2.6		Singer 1977
Burlington, ON					
Malvern (residential)	11.2 TN		1.3		Marsalek 1984
Aldershot (commercial)	14.3 TN		1.6		Marsalek 1984
Windsor, ON	4.6 TN		0.7		Singer 1977
Calgary, AB	10.3 NO_3; 0.16 NH_4^+	18 NO_3; 0.28 NH_4^+	0.22	0.4	Dixon 1994
Fraser River Basin					
Upper Fraser	1.3 TN; 0.5 NO_3; 0.1 NH_4^+	78 TN; 31NO_3; 7 NH_4^+	0.26	16	Stanley Associates Engineering Ltd. 1992
Middle Fraser	3.9 TN; 1.6 NO_3; 0.3 NH_4^+	13 TN; 5 NO_3; 1NH_4^+	0.78	3	
Thompson	2.0 TN; 2.0 NO_3; 0.2 NH_4^+	24 TN; 9 NO_3; 2 NH_4^+	0.39	5	
Lower Fraser	13 TN; 5.0 NO_3; 1.1 NH_4^+	764 TN; 306 NO_3; 66 NH_4^+	2.5	153	
Greater Vancouver				21	Environment Canada and BCELP 1992
CSO					
Greater Vancouver		213 TN; 88 NH_4^+		42	Environment Canada and BCELP 1992

In most urban areas developed since the 1950s, wastewater is collected in a separate sewer system consisting of sanitary sewers that transport household, commercial, institutional and industrial wastewaters, and storm sewers that convey stormwater. Surface runoff enters the storm sewer system through curb-side drains or other connections and is either discharged directly to the receiving water or passed through stormwater management facilities that may reduce flows and improve water quality (Marsalek and Kok 1997).

Detailed data are not available on the proportion of the Canadian population served by storm sewers versus combined sewer systems. However, most urban areas developed prior to the early 1940s are served by combined sewer systems. In large cities, many combined sewer outfalls exist and contribute to a great spatial extent of CSO impacts on a single receiving waterbody. For example, in Greater Vancouver, 252 stormwater and 53 combined-sewer outfalls discharge to the Lower Fraser River and estuary (UMA 1994, 1995). Winnipeg and Metropolitan Toronto have 75 and 79 combined-sewer outfalls, respectively, of which 74 of the Toronto outfalls are designated as priorities for pollution abatement action (Thorp et al. 1997; Winnipeg Web 1999). Given that combined sewers were used mostly in the older sections of cities where populations are now declining and that sewer separation programs have been undertaken by some communities during the past 25 years, the current Canadian population served by combined sewers is likely smaller than in 1969. All provinces now require that new sewer construction should be of the 'separate' type and municipalities are encouraged to replace combined sewer systems as soon as possible. CSO remediation is currently underway or planned in many cities, notably Vancouver, Edmonton, Winnipeg, Hamilton, Toronto, Ottawa, Montreal and Québec City.

Table 3.5. Concentrations of total phosphorus and total nitrogen in municipal wastewater.

Wastewater Type	Total Phosphorus (mg P/L)	Total Nitrogen (mg N/L)
Stormwater	0.33	2.18
Combined Sewer Overflows (CSO)	4	11

Data Sources: CSO data USEPA 1974
Stormwater data USEPA 1983

Quantities of both stormwater and CSOs vary temporally and with location, and depend on local climate, sewer design and drainage practices. Large-scale estimates gave an average annual stormwater discharge of about 760 L/capita/d for the Great Lakes basin (Marsalek and Schroeter 1988). However, the stormwater discharges would be 2000 to 3000 L/capita/d if the averaging was done just for the wet-weather days. The average annual discharge was about 473 L/capita/d for urban runoff and CSOs in the Greater Vancouver Regional District (Environment Canada and BCELP 1992). These flows greatly exceed the average municipal sewage flow of 300 L/capita/d. Expressed as an annual nutrient load, these discharges range from 1.4 to 14 kg/ha urban land for N and 0.2 to 2.6 kg/ha urban land for P (Table 3.4). A useful rule-of-thumb from a USEPA initiative, which assessed stormwater loadings from 22 locations (the Nationwide Urban Run-off Program, USEPA 1983), is that for a given urban population, stormwater will contribute about one-tenth the P load of a properly maintained secondary sewage treatment plant.

CSO or stormwater discharges are not routinely monitored in Canada; therefore, estimates of their volume and impact on receiving waters are rare. In general, stormwater volume is comparable in volume to the 4 300 million cubic metres discharged annually by MWTPs, however, its release is confined to wet weather periods (J. Marsalek, DOE, personal communication). Stormwater is also more dilute with respect to nutrients than raw or treated sewage or CSO. To estimate stormwater nutrient loads, stormwater volume (estimated to be 4 300 million m^3) was multiplied by 0.33 mg/L total P or 2.18 mg/L total N (Table 3.5) to give 1.4 thousand tonnes P and 9.4 thousand tonnes N per year. In contrast to stormwater, CSOs represent approximately 5% of MWTP annual discharge and are generally more dilute than raw sewage but higher in nutrient concentration than stormwater or treated sewage (Table 3.5). CSO nutrient loading was estimated by multiplying 5% of the annual MWTP discharge (4 300 million m^3) by 4 mg/L total P or 11 mg/L total N to give 0.9 thousand tonnes total P and 2.4 thousand tonnes total N (Table 3.5). Compared to sewage where 65 to 100% of the total P load is bioavailable and about 60% of the total N load is in the form of free ammonia (Sonzogni et al. 1982; Tchobanoglous and Burton 1991; Berge and Källqvist 1998), stormwater P is largely particulate (about 95%) and N is primarily in the form of organic material and nitrate+nitrite (Waller and Hart 1986; J. Marsalek, DOE, personal communication).

Septic Disposal Systems

A septic system is a small wastewater treatment system designed to treat wastewater from one or several homes. The system consists of a tank usually connected to a series of pipes set into trenches. Wastewater from the home flows into the tank. Heavier solids, or sludge, collect on the bottom of the tank; lighter solids, like hair and grease, float to the top and form a scum layer on the water. Both the top and bottom layers of solids are trapped in the tank where they are broken down by micro-organisms. The clarified wastewater is transported to a drain field by a pipeline. The drain field (sometimes called a tile field or leach field) consists of a series of distribution pipes set in trenches filled with gravel. These distribution pipes have holes so that the wastewater from the septic tank flows out into the gravel trenches then trickles through the gravel and into the soil under the drain field.

Approximately 25% of Canadians are served by septic disposal systems. These systems were originally designed for houses widely separated from their nearest neighbour, such as farmhouses and the occasional rural residence. Today, in many parts of the country, septic disposal systems present in too great numbers for the land base, not properly maintained, or built in unsuitable sites (i.e., too close to shorelines, in unsuitable rock or soil conditions) are sources of contamination to ground water and, ultimately, surface water. Wastewater from poorly maintained systems can also reach streams and lakes through overland flow. An average of 61% of septic field systems in various surveys of cottage systems in Ontario were not properly designed, constructed or maintained (Dillon et al. 1986).

The degree to which nutrients are retained in a septic field depends on the age of the field and soil characteristics, including adsorption capacity, natural drainage and permeability. Nitrate is not significantly retained by most soils (Bohn et al. 1985) and is readily transported by soil water and ground water. Phosphate migration in the saturated zone appears to be controlled primarily by sorption processes that significantly retard migration (Robertson 1995; Harman et al. 1996). However, as the adsorption capacity becomes saturated, migration of phosphate in the ground water zone may occur: low but perceptible rates of phosphate movement have been observed at several sites (Robertson 1995).

In general, septic tanks retain about 20 to 55% of the N and 25 to 40% of the P entering the system (Ryding and Rast 1989). Additional P is also retained in the unsaturated soil zone under the drain field so that, for properly designed septic tile filter beds, much of the P entering the system is retained either in the tank or in the unsaturated zone (see studies reviewed by Dillon et al. 1986; Robertson et al. 1998). Based on a population of 7 975 664 living in communities with a population less than 1 000 in 1996, an effluent volume of 160 L/capita/day (Siegrist et al. 1976), a P influent concentration of 15 mg/L (Laak 1974, Whelan and Titmanis 1982, Bicki et al. 1984), and a P retention coefficient of 72% for both the septic tank and drain field (an average of 10 sites studied by Robertson et al. 1998), 1.9 thousand tonnes of P is released from septic systems annually. Similarly, N release is 15.4 thousand tonnes/yr based on an influent concentration of 55 mg N/L (Epp 1984) and retention coefficient of 40% (Ryding and Rast 1989) for the same population.

Residential Solid Waste

Solid waste refers to the garbage collected from households and industries that requires incineration or disposal in a landfill. An estimated 10.5 million tonnes of residential solid waste were collected by municipalities across Canada in 1992 (Environment Canada 1996c). This averaged 0.38 tonnes per person per year. A 1989 Ontario survey showed that approximately one-third of residential solid waste was paper (of which half was newspaper), another third was organic material (food waste and yard waste), and the remaining third was a mixture of glass, metal (food containers and appliances), plastic, textiles and other materials (OME 1991). The majority of residential solid waste is landfilled, with the remainder being incinerated, recycled or composted. For example, in 1994, 75% of residential solid waste in British Columbia was landfilled or incinerated; the remainder was recycled (BCELP 1998b). Residential recycling is increasing. For example, only 0.5 million households in Ontario recycled in 1987 but by 1997, this number had increased to 3.1 million households (3Rs Information Partnership 1999).

The contribution from incineration of solid waste (residential and industrial) to atmospheric P release was estimated to be 123 tonnes in 1978 for Canada (Environment Canada 1983). Based upon 1995 data, incineration of municipal waste (solid and sewage sludge) also released about 293 tonnes of N as NO_x (Environment Canada 1999a). There are no national estimates of nutrient losses from landfills. Recent information from British Columbia indicates municipal landfills in the Fraser River basin leaked 145 tonnes of ammonia-N per year to surface waters in 1995 (Gartner Lee Ltd. 1997).

The Composting Council of Canada estimates that approximately 20% of the 7 million tonnes of organic waste produced annually is composted (CCC 1998). Compost is defined as the solid mature product resulting from composting, a managed process of bio-oxidation of solid heterogeneous organic substrate including a thermophilic phase (CCC 1998). In 1997, materials composted included leaf and yard waste, wood, animal manure, industrial/commercial/institutional waste (including supermarket and restaurant waste), paper materials (sludge, boxboard and unrecyclable paper), residential food waste, and fish waste and other marine materials (Antler 1997). Composting is conducted at centralized composting sites as well as in backyard composters. Currently, approximately 1.2 million backyard composters have been distributed to Canadian households (CCC 1998). Compost is a beneficial additive to soils as it supplies organic matter and nutrients, improves water retention and reduces soil compaction. High quality compost from centralized composting sites is sold for use in agriculture, horticulture, landscaping and home gardening. Medium quality compost is used for erosion control and roadside landscaping. Low quality compost is used as a landfill cover or in land reclamation projects (CCC 1998). Since 1991, composting has gained a strong foothold in the Canadian waste management infrastructure. Approximately 600 thousand tonnes of finished compost was produced in 1996 (Antler 1997). Typically, vegetable compost contains 2-7.9 kg/t N (mean = 5.0 kg/t N), and 6.2-11.9 kg/t P (mean = 9.1 kg/t P; Gagnon et al. 1999). Assuming that all of the finished compost is applied to land, 3 thousand tonnes N/yr and 5.5 thousand tonnes P/yr are applied to soil as compost.

3.2 Industrial Discharges

Industries produce waste that may be released directly to the atmosphere, land, surface waters or ground water or, in the case of solid or liquid waste, transferred off-site for land-based application, disposal in landfills or treatment in municipal wastewater plants. Most light industries discharge their wastewater into the municipal sewage system, their solid waste to municipal landfills, and their gaseous waste to the atmosphere. Industrial waste discharged to a licensed facility (e.g., a municipal wastewater treatment plant) is not typically regulated by the provincial or federal government with respect to the quantity or quality of their discharge. Some municipalities have sewer-use bylaws regulating the strength of industrial discharges to sewer systems. MWTPs are designed to reduce bacterial contamination and biochemical oxygen demand, remove most P (in the case of facilities with advanced P removal) and, in some cases, convert ammonia to nitrate. There is little ability to do more than volatilize or dilute many industrial wastes.

Large industries (e.g., pulp mills, mining operations, large manufacturing plants, etc.) that independently discharge their waste to air, water or land must obtain operating permits from the provincial government in which they are situated or, in the case of industries operating in the Territories, by the Federal Government (unless this responsibility has been devolved to the Territory). This permit may stipulate the quantity and/or quality of waste that can be disposed to land, air or water.

Table 3.6. Number of manufacturing industries in Canada, number of industries with discharge permits, number of permitted industries reporting wastewater discharge, and number of permitted industries with wastewater discharge that report total P, nitrate-N (NO_3-N) or ammonium-N (NH_4^+-N).

Region	Number of Manufacturing Industries[1]	Number of Industries with Discharge Permits[2]	Number of Permitted Industries reporting Nutrients in Wastewater Discharge[3]	Number of Permitted Industries with Wastewater Discharge[3] Reporting:		
				TP	NO_3^-	NH_4^+
Atlantic	1,919	283[a]	6	1	0	3
Québec	10,603	370	101	42	38	34
Ontario	14,471	274	160	100	28	59
Prairies	4,827	175[b]	49	36	19	31
BC	4,378	805	16	9	3	14
Territories	41	223	4	3	3	2
Canada	36,236	2,130	336	191	91	142

[1] Statistics Canada 1997d

[2] A permit to discharge does not necessarily mean that the industry is discharging directly to the environment.

[3] Data not supplied by New Brunswick, Prince Edward Island and Nova Scotia. Québec data are only for industries discharging to the St. Lawrence River basin.

[a] New Brunswick supplied the number of water approvals. A plant can have more than one water approval.

[b] Alberta supplied the number of major industries required to report the quality of their discharge on a monthly basis. Alberta has many more industries with approvals with different frequency of discharge or discharge to municipal systems.

Wastewater Discharges

Estimates of wastewater N and P loading were obtained from the provincial and territorial governments for industries with operating permits. The data spanned the period 1988 to 1999. New Brunswick, Prince Edward Island and Nova Scotia did not supply data; Québec data are only for industries that discharge to the St. Lawrence River basin. Of the data obtained from the provincial and territorial governments, 336 industries (16% of all industries with permits to operate) reported discharge of nutrients in wastewater (Table 3.6). Not all industries are required to measure N and P loads even though they had a wastewater discharge. Therefore, industrial N and P loads are an underestimate of the quantity actually being discharged. Of the 336 industries in Canada that reported nutrients in wastewater discharges, total P concentration was measured by 191 industries, NO_3^- by 91 industries and NH_4^+ by 142 industries. Not all industries reported total N or the forms of N that would allow calculation of total N.

Industrial N and P loads to surface waters are presented in Figure 3.6. These values represent only the measured and reported amounts and likely underestimate actual loads. Comparison of N and P loads among regions and among sectors cannot be made because not all provinces provided data and because provincial/ territorial governments differ in the parameters they require a particular industrial sector to monitor. Given these caveats, the available data indicate that at least 2 048 tonnes per year of total P, 7 588 tonnes per year of nitrate-N (NO_3-N), and 4 231 tonnes per year of ammonium-N (NH_4^+-N) are discharged from permitted industries in Canada to surface waters (Figure 3.6).

The data in Table 3.7 provide an illustration of the discrepancies found in industrial records. Although total values for ammonia loading are similar for both the National Pollutant Release Inventory (NPRI) and provincial/territorial records, the loads differ considerably between certain industrial sectors. NPRI

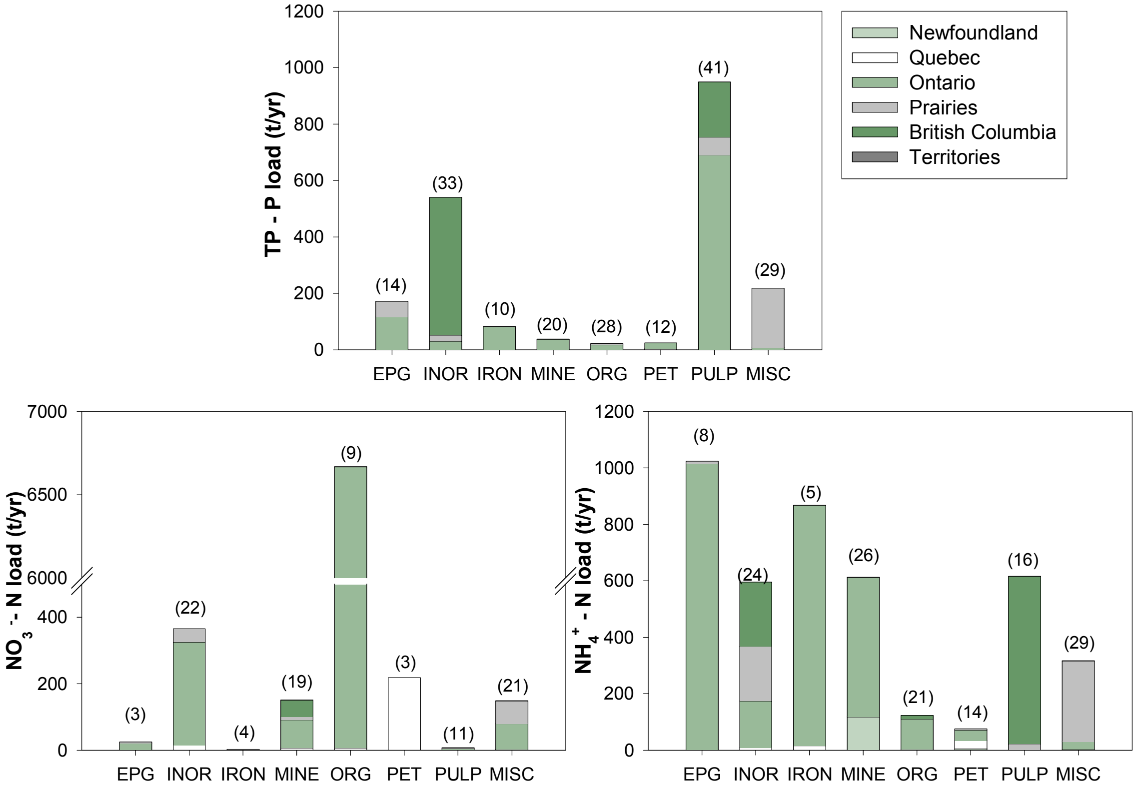


Figure 3.6. Industrial wastewater nutrient loads (total P, nitrate and ammonium) by region and sector, as provided by the agencies listed below. Numbers above each bar indicate the number of reporting industries by sector. Industrial sectors are abbreviated as follows: EPG: Electric Power Generation; INOR: Inorganic Chemicals; IRON: Iron and Steel; MINE: Metal Mining and Refining; ORG: Organic Chemical Manufacturing; PET: Petroleum Refining; PULP: Pulp and Paper; MISC: Miscellaneous, includes metal casting, food processing, industrial minerals, and metal, plastic fabricating and finishing. Data sources: Newfoundland loads were calculated from 1997 self-reported data provided by the Newfoundland Office of Environmental Protection of Environment Canada; Québec loads were calculated for 1990 to 1997 from data obtained from St. Lawrence Vision 2000 (1998) and represent 106 industries discharging into the St. Lawrence River; Ontario loads were calculated from 1995 MISA data provided by Ontario Ministry of Environment; 1999 Manitoba loads were provided by Manitoba Environment; Saskatchewan loads were calculated from 1988 to 1991 data provided by Saskatchewan Environment and Resource Management; Alberta loads were calculated from 1997 data provided by Alberta Environmental Protection; British Columbia loads were calculated for 1994 to 1998 using data provided by the British Columbia Ministry of Environment, Lands and Parks; Northwest Territories and Nunavut loads were calculated from 1997 data for the Northwest Territories provided by Environment Canada; Yukon loads were calculated from 1998 data provided by INAC and Environment Canada; data were not available for NB, NS and PEI.

Table 3.7. Comparison of total ammonia in industrial wastewater reported to the National Pollutant Release Inventory (NRPI) for 1996 (Environment Canada 1996b) and ammonium (NH_4^+) load reported to provincial/territorial departments. (Provincial/territorial data sources as for Figure 3.6.)

Industrial Sector	NPRI data (t ($NH_4^+ + NH_3$) /yr)	Provincial/Territorial data[1] (t NH_4^+ /yr)
Metal casting		1
Electric power generation	71	1024
Food processing	528	75
Inorganic chemical manufacture	315	595
Iron and steel	868	867
Metal and plastic fabricating and finishing	22	3
Metal mining and refining	737	613
Miscellaneous	2	238
Organic chemical manufacturing	143	123
Petroleum refining	72	75
Pulp and paper	1220	616
Total	3978	4231

[1] Data sources as for Figure 3.6.

requires all Canadian industries employing a workforce equivalent to 10 or more full-time employees and manufacturing or using ammonia (or any one of another 175 substances in 1996 or 276 substances in 2000) in quantities greater than 10 tonnes to report these releases. Exempted facilities include those engaged in research, testing or education, and growing, harvesting, or extraction of natural resources. Ammonia loads provided to NPRI may be reported as ammonium (NH_4^+), ammonia (NH_3), or ammonium or ammonia expressed as N. The NPRI total ammonia loads are not necessarily based on measured concentrations but may be based on engineering estimates, mass balances or emission factors. In contrast, provincial/territorial data are based on measured concentrations and report ammonium or ammonia expressed as N. However, not all industries are required to report their ammonia or ammonium loads to the provincial or territorial government.

In addition, NPRI indicates that 6 421 tonnes of N as ammonia were injected underground in 1996 (Environment Canada 1996b). This process involves injecting wastes into known geological formations, generally at great depths, and occurred largely in Alberta and, to lesser extent, in Saskatchewan. It was associated mainly with fertilizer manufacturing, petroleum refining and organic chemical manufacturing sector in Alberta and the mining industry in Saskatchewan.

Air Emissions

Industries release N to the atmosphere as nitrous oxide (N_2O), other nitrogen oxides (NO_x) and ammonia (NH_3).

Nitrous oxide (N_2O) is largely produced from the combustion of coal, petroleum products and natural gas. Of the total Canadian emissions for 1995 (98 thousand tonnes N_2O-N), industrial combustion-related emissions accounted for only 3 thousand tonnes of N (Table 3.8). Another 2 tonnes of N were emitted to the atmosphere as a result of manufacturing nitric acid, an intermediate product formed during the manufacture of N fertilizers. Twenty-two tonnes of N were also emitted during production of adipic acid, a chemical used to manufacture nylon and polyurethane foam. However, the sole

Table 3.8. Emissions of nitrogen compounds to the atmosphere from industrial sources. N_2O data from Environment Canada 1997a; NO_x data from Environment Canada 1999a; 1995 ammonia data from Vézina 1997.

Industrial Sector	1995 N_2O (10^3 t N)	1995 NO_x (10^3 t N)	1995 NH_3 (10^3 t N)
Combustion-related emissions			
Power and steam generation	2	77	0.4
Industrial	1	9	
Industrial Processes			
Chemical manufacture	24	7	8.8
Metal mining and refining		8	
Metal & plastic fabricating & finishing		0.1	
Pulp and paper manufacture		17	
Iron and steel manufacture		8	
Petroleum/petrochemical industry		113	8.5
Miscellaneous		36	9.6
Canadian Industrial Total	27	275	26.9
Canadian Anthropogenic Total	98[1]	750[2]	623[3]

[1] includes 38x10^3 t N from agriculture in 1996 (Desjardins and Keng 1999), 31x10^3 t N from transportation combustion, and 2x10^3 t N from other sources

[2] includes 393x10^3 t N from transportation combustion, 64x10^3 t N from forest fires, and 18x10^3 t N from other sources

[3] anthropogenic total for 1995 includes 570x10^3 t N from agriculture, 2.4x10^3 t N from non-industrial fuel combustion, 4.2x10^3 t N from transportation combustion, and 18.9 x10^3 t N from other sources

Canadian producer introduced new technology in to reduce N_2O emissions (Environment Canada 1997a).

Nitric oxide and nitrogen dioxide (i.e., NO_x) are also produced during the combustion process. Canadian NO_x emissions from anthropogenic sources for 1995 were 750 thousand tonnes N, of which 52% was attributable to transportation (i.e., cars, trucks, airlines and boats) (Environment Canada 1999a). The petroleum/petrochemical industry accounted for 113 thousand tonnes of N, representing the second highest source of anthropogenic NO_x emissions (Table 3.8).

Ammonia is released to the atmosphere by chemical and chemical products industries. According to Environment Canada (1999b) after Vézina (1997a), 27 thousand tonnes of N as ammonia were released to the atmosphere by Canadian industries in 1995. Of this, 33% was produced by industries engaged in the manufacture of chemicals (Table 3.8).

A 1978 study of atmospheric P emissions in Canada estimated that 1.98 thousand tonnes of P were released by industrial processes, most of which was associated with the production of fertilizer (Environment Canada 1983, Table 3.9). Fertilizer production entails grinding of phosphate rock and production of phosphoric acid, and accounted for 0.5 thousand tonnes of atmospheric P emission in 1978.

Solid Waste Disposal

About 10 million tonnes of solid waste were generated by Canadian industries in 1995 (Statistics Canada 1998b). A 1989 study showed that solid waste generated by Ontario industries was composed of paper products (23%), wood (21%), other organic material (11%), metal material (11%), glass (5%),

Table 3.9. Total phosphorus emissions to the atmosphere from industrial sources - 1978. Data source: Environment Canada 1983.

Industrial Sector	Phosphorus (t)
Phosphate rock processing	58
Phosphoric acid production	688
Phosphate fertilizer production	488
Elemental phosphorus production	682
Other chemical industries	19
Primary aluminum production	30
Miscellaneous sources	15
Canadian Industrial Total	1980
Canadian Total[1]	3402

[1] includes 783 t from fertilizer application, 255 t from forest fires, 199 t from fuel combustion for stationary sources, 123 t from solid waste incineration, 47 t from slash burning and 15 t from transportation sources.

plastic (3%), tires (2%) and other miscellaneous material (24%) (OME 1991). Major contributors to industrial solid wastes in Ontario for 1989 were the construction industry (30% of total tonnage) and the communications and services sector (22% of total tonnage). Large quantities of the solid waste generated by industry are potentially recyclable (e.g., paper products, wood, plastic, metal, tires). Since the 1989 Ontario study considerable effort has been directed at incorporating “reduce, reuse, recycle” activities in industrial solid waste management efforts.

Of the approximately 10 million tonnes of industrial solid waste generated in Canada in 1995, 78% was landfilled, 20% was recycled, and the remainder incinerated (Statistics Canada 1998b). The contribution from incineration of solid waste (residential and industrial) to atmospheric P release was estimated to be 123 tonnes in 1978 for Canada (Environment Canada 1983). Incineration of industrial and commercial waste also released about 226 tonnes of NO_x-N in 1995 (Environment Canada 1999a). There are no national estimates of nutrient losses from landfills. A recent British Columbia study reported that ammonia-N loading from pulp and paper mill landfills in the Fraser River basin was 6 tonnes per year (Gartner Lee Ltd. 1997).

3.3 Agricultural Loading

Plant nutrients (in the form of fertilizer and manure) are essential additions to agricultural lands as they contribute to maintenance of soil health and optimal crop yield. However, application of fertilizer or manure in excess of plant requirements can lead to a build-up of nutrients in the soil and, once the soil’s retention capacity is surpassed, their eventual loss to the environment. This loss can be to surface or ground waters or to the atmosphere. Conversely, underuse of fertilizers can lead to a loss of soil fertility (known as mining of the soil) and will eventually result in crop reductions. Effective use of nutrients contributes to agricultural sustainability by enhancing farm profitability through efficient use of costly soil additives and minimization of environmental impacts due to excessive nutrients.

Agriculture is practised widely in seven of Canada’s 15 ecozones (see Figure 1.1 for ecozone locations). The Pacific Maritime ecozone has some of the mildest and wettest climatic conditions in Canada. Farmland is confined to the Fraser River valley and eastern coastal area of southern Vancouver Island and consists of dairy, hog, and poultry operations as well as speciality products such

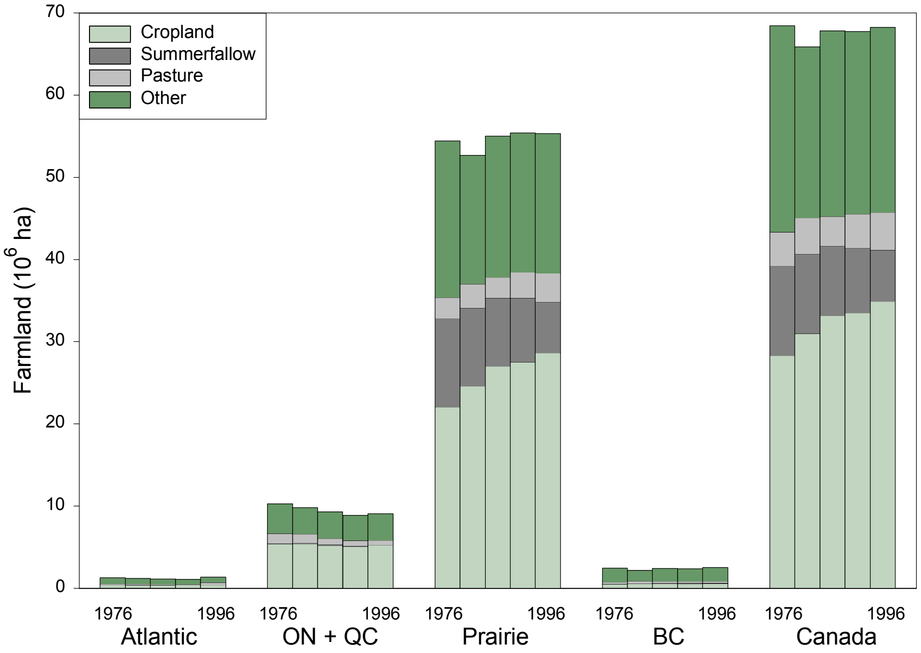


Figure 3.7. Use of Canada's agricultural land for the census years 1976-1996. The category 'Other' includes farmland area occupied by farm buildings, lanes, woodlots, wetlands and tree windbreaks. Data are from Statistics Canada (1997b).

as nursery, floriculture, greenhouse vegetables, and berry crops. In the Montane Cordillera ecozone, tree fruit production and viticulture dominate under the mild climate of the semi-arid valleys in the south whereas beef cattle production is common in the northern valleys and high-elevation plateaux. The Boreal Plains supports productive agriculture across a band located just north of the Prairies ecozone and is dominated by the production of cereals, oilseeds and forages. About two-thirds of all farmland in Canada is located in the Prairies ecozone. Here, grain and oilseed production are the major farming activities, followed by beef cattle production. The Mixedwood Plains ecozone is characterized by a warm, humid climate conducive to the production of a wide range of products including most of Canada's dairy products, vegetables and speciality crops. Pockets of mixed agriculture also extend north of the Mixedwood Plains into the Boreal Shield. In the Atlantic Maritime ecozone, cool-season vegetables, forage, and dairy production are the major outputs. Agriculture is the dominant land use throughout Prince Edward Island and is concentrated in river valleys elsewhere in the Atlantic Maritime ecozone.

Approximately 7% of Canada's total land area, 68 million hectares, is agricultural land of which 46 million hectares is cropland, pasture, or summerfallow (Figure 3.7; Statistics Canada 1997b). The total area of farmland in Canada has remained relatively constant for the last 50 years. However, regional changes have occurred in recent decades: for example, there have been large increases in cropland area in the Prairies, lesser increases in British Columbia, and decreases in Ontario, Québec and the Atlantic Provinces (Figure 3.7). In addition, the number of farms has declined, from 280 043 in 1991 to 276 548 in 1996, while the size of individual farms has increased (Statistics Canada 1997a).

Fertilizer Production and Use

Commercial fertilizers are a major source of nutrients to crops. Improved crop varieties developed over the last 40 years have increased productivity substantially, with yields doubled for many crops. These new hybrid crops take up more nutrients from the soil than their lower-yielding predecessors. For example, an average of 200 thousand tonnes of N and 36 thousand tonnes of P was applied annually to the western Canadian grain crop between 1883 and 1953 (Flaten and Hedlin 1988). By comparison, more than 1.1 million tonnes of N and 170 thousand tonnes of P were applied to the western Canadian grain crop in 1986, a four-fold increase over the 1883 to 1953 average. During the same period (1953 to 1986), the Prairies cropland base increased by 1.6 times from 18 to 28 million ha. Natural nutrient supplies are insufficient to reach high yield potentials, making it necessary to use supplementary fertilizer nutrients.

Both N and P fertilizers are manufactured in Canada. Nitrogen fertilizers are based on ammonia, which can be used directly as a fertilizer or converted to solid forms (urea, ammonium phosphate, ammonium nitrate, and/or ammonium sulfate) or to N solutions (e.g., anhydrous ammonia, urea-amonium nitrate solution). Canada produced 4 025 thousand tonnes of N fertilizer in 1996 (FAO 1999). Of this, approximately 60% was exported (mostly to the United States); an additional 210 thousand tonnes of N as fertilizer were imported into Canada (FAO 1999). There were 1 576 thousand tonnes of N as fertilizer applied to crops in Canada in 1996 (Agriculture and Agri-Food Canada 1998).

Phosphate fertilizers are produced from phosphate rock and sulfuric acid. Canada imports all its phosphate rock from Togo or the United States: 1 140 thousand tonnes in 1996 (Paul Lansbergen, Canadian Fertilizer Institute, personal communication). Phosphate rock is 12 to 18% P (Potash and Phosphate Institute 1988). About 175 thousand tonnes of P as fertilizer were produced in 1996 in Canada (FAO 1999) and of this, 7.9 thousand tonnes of P were exported; an additional 129 thousand tonnes of P as fertilizer were imported. In 1996, 297 thousand tonnes of P as fertilizer were applied to croplands in Canada (Agriculture and Agri-Food Canada 1998).

Data on the land base to which fertilizer is applied and the quantity of fertilizer used by each province are available from Statistics Canada (1997a) and Agriculture and Agri-Food Canada (1998a), respectively (Appendix 1). Based on these data, average P and N application in 1996 ranged from 10 kg P/ha and 60 kg N/ha in the Prairies to 33 kg P/ha and 86 kg N/ha in the Atlantic Provinces (Figure 3.8). Comparisons from 1981 to 1996 showed that fertilized land increase by about 9% in the Atlantic Region, declined by about 10% in Québec, 5% in Ontario, and 0.2% in British Columbia, and increased by 32% in the Prairie Provinces. Over the same time period, fertilizer N inputs (per ha) increased for the Atlantic and Prairie regions and Québec, declined in Ontario, and remained relatively constant in British Columbia. Fertilizer P inputs (per ha) have remained relatively constant in Québec and the Atlantic region, but declined in British Columbia, Ontario and the Prairie Provinces over the same time. Overall, 297 thousand tonnes of P as fertilizer and 1 576 thousand tonnes of N as fertilizer were applied to 24 943 thousand ha of Canadian cropland in 1996.

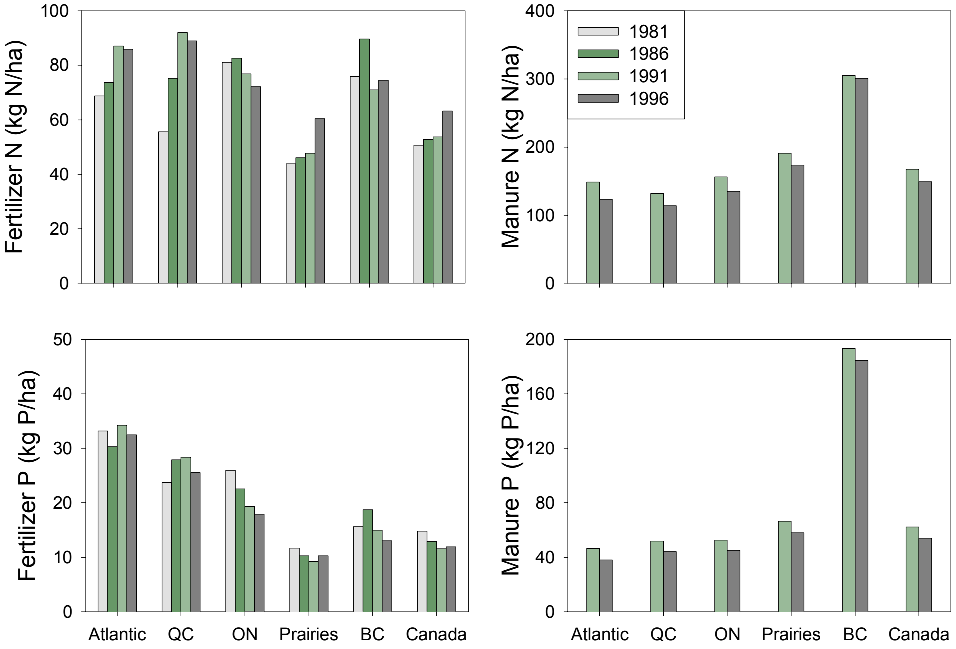


Figure 3.8. N and P added as fertilizer (1983-1996) and manure (1991-1996) to Canada's cultivated land. Fertilizer data are from Statistics Canada (1997a) and Agriculture and Agri-Food Canada (1998a) for census years. Manure data are from Statistics Canada (1997a) and Table 3.10.

Manure Production and Use

Manure consists of undigested feed (liquid and solid), metabolic waste, bedding material, and wasted feed and water. In 1996, 4 680 585 beef cattle, 1 227 732 dairy cattle, 102 255 149 poultry and 14 224 664 other livestock were reared in Canada (Statistics Canada 1997a). A total of 97 920 farms or 44% of all farms in Canada in 1995 were considered to be "livestock farms" with an additional 20% of all farms reporting that some livestock were kept, but were not their main agricultural activity (Agriculture and Agri-Food Canada 1997). These statistics indicate that manure storage and disposal is presently a management consideration on many Canadian farms. Historically, manure was not a problem because most farms had a mix of livestock and crops and the small livestock numbers on an individual farm compared to many farms today meant it was feasible to recycle nutrients between crops and livestock.

Almost all manure produced on Canadian farms is applied to agricultural land (Patni 1991). Some of the manure is excreted directly to pasture and is not practically accessible. However, manure produced when livestock are housed or confined in collecting yards is readily available for use as fertilizer on fields. Manure is an important additive to agricultural soils because it supplies both nutrients and organic matter. Depending upon the type of livestock and the rations being fed, fresh manure can contain 50 to 80% of the N and P originally present in the feed. Not all nutrients in manure are immediately available to crops, however. Some are tied up in organic forms and become available over time as the material decomposes, thereby acting as a nutrient source over several years. In addition, the organic matter in manure contributes to improved soil structure, nutrient and water-holding capacity, and drainage.

Table 3.10. Total nitrogen and phosphorus manure production (t/yr) calculated by multiplying the number of animals in each province (Statistics Canada 1997b) by the N and P content of manure for each province (from Appendix 1).

Year	Atlantic	QC	ON	Prairies	BC
Nitrogen (10^3 t/yr)					
1976	23.0	106.8	178.7	209.8	33.2
1981	24.5	119.4	189.2	201.8	41.4
1986	24.7	104.0	165.9	198.0	35.3
1991	23.0	102.2	154.0	217.1	36.8
1996	22.4	109.4	151.0	259.7	39.5
Phosphorus (10^3 t/yr)					
1976	4.3	28.2	38.2	52.5	12.2
1981	4.7	33.2	41.1	48.2	15.9
1986	4.9	28.6	36.3	46.2	14.7
1991	4.6	27.9	33.9	50.9	15.1
1996	4.5	29.7	33.1	56.3	15.7

Estimates of manure N and P production (tonnes/year) for each province were derived from data on livestock numbers (Statistics Canada 1997b) and manure N and P production per animal type (Appendix 2; Table 3.10). Nutrients are lost from manure between the time it is produced and its application to fields. Much is in the liquid portion of manure, and significant losses occur if this liquid is allowed to run off feedlots and from manure storage facilities. In addition, a large proportion of manure N is in the form of ammonium (NH_4^+) and, upon exposure to air, can be converted to ammonia gas (NH_3) and lost to the atmosphere. To estimate manure application to farmland, we assumed a 40% loss of N from cattle manure and a 25% loss of N from swine and poultry manure from the time of excretion to field application (Environment Canada 2000b; MacDonald 2000a). Phosphorus does not exchange with the atmosphere and we therefore assumed zero loss between production and field application. Beef cows are commonly left out to pasture for most of the year; consequently, we did not include beef cows in our calculations of manure nutrient loads to cropland.

Based on manure production estimates, stated assumptions as to nutrient loss, and area of application reported in the agricultural census (Statistics Canada 1997a), average manure P and N application was estimated for each province (Appendix 3). Average manure application in 1996 ranged from 114 kg N/ha (Québec) to 301 kg N/ha (British Columbia) and 38 kg P /ha (Atlantic) to 184 kg P/ha (British Columbia) (Figure 3.8). The land base to which manure was applied increased in the Prairie Provinces (by 27%), Ontario/Québec (by 19%), the Atlantic Provinces (by 19%), and in British Columbia (by 9%) from 1991 to 1996, coinciding with decreased manure application rates (kg N or P per ha) across all regions. Over the same time period, cattle numbers across the whole country increased by 14%, and pigs and poultry numbers each increased by 8%. Compared to commercial fertilizer, manure was applied at much higher rates: a total of 139 thousand tonnes P and 384 thousand tonnes N was applied to 2 579 thousand hectares of Canadian cropland in 1996.

Other N Inputs

Nitrogen fixed from the air by legume crops can add to the soil's N supply. The ability of legumes to improve soil N concentrations is the basis for crop rotation schedules on many farms. Atmospheric N_2 fixation rates for legume species range from 53 kg N/ha/yr for chickpeas to 100 kg N/ha/yr for clover (Appendix 4; F. Selles and R. Lemke, Agriculture and Agri-Food Canada, personal communication).

These estimates were multiplied by the area planted in legumes in 1996 (Statistics Canada 1997a) to give legume inputs of N to soil. N input from atmospheric N_2 fixation by legumes ranged from 20 thousand tonnes N in the Atlantic region to 477 thousand tonnes N in the Prairies, for a total of 773 thousand tonnes N fixed by legumes in Canada in 1996 (Table 3.11).

Harvest of the legume crop removed 896 thousand tonnes of N in 1996 (calculated by multiplying legume production [Statistics Canada 1997a] by the concentration of N in the harvested portion [Appendix 4; F. Selles and R. Lemke, Agriculture and Agri-Food Canada, personal communication]). Legumes acquire their N by absorbing it from the soil through their root system and by symbiotic fixation of atmospheric N_2. However, for the legume, it is more energy efficient to assimilate soil N than to fix N_2 from the atmosphere; thus, only 5 to 65% of N in the legume is fixed from the atmosphere; the remainder is absorbed from the soil (Biederbeck et al. 1996). The result of this is that harvest of legumes often removes more N than was fixed from the atmosphere. Incorporation of legume residues (the dead non-harvested portion of the plant) into the soil increases soil N reserves. A small fraction of this N, 10 to 30%, may become available to the next crop (Gleig and MacDonald 1998). The remaining N in the legume residue is incorporated into the soil organic matter and will contribute to the N supplying capacity of the soil.

In addition to N fixed by legumes, deposition from the atmosphere is a significant N source. In Canada, atmospheric deposition in the form of nitrate and ammonium (dissolved inorganic N, DIN) has steadily increased since the 1900s and, in the 1990s was estimated to supply, on average, 3.44 kg N/ha/yr east of the Manitoba-Ontario border compared to 0.80 kg N/ha/yr west of this border (see Section 3.6). Given 34 918 733 ha were in cropland in 1996, atmospheric loading of DIN was a source of approximately 43 thousand tonnes of N. National data are not available to estimate loadings expressed as total N.

Table 3.11. Nitrogen inputs due to legume atmospheric nitrogen fixation in 1996.

Region	**Legume N fixation (10^3 t)**
Atlantic	19.5
Québec	90.1
Ontario	150.8
Prairie	476.5
British Columbia	36.1
Total	773.0

Nutrient Uptake by Agricultural Crops

The amount of N and P removed from the field as harvested crop can be calculated from data on crop yields and the nutrient content of the harvested crop (Beauchamp and Voroney 1994; Bolinder et al. 1997). The harvested crop is the grain for crops such as wheat, barley and oats, hay for alfalfa and clover, and the fruit for fruit crops. Straw is assumed to be returned to the soil, either directly or in manure. In 1996, a total of 2 491 thousand tonnes of N and 386 thousand tonnes of P were removed in the harvested crop for Canada (Figure 3.9).

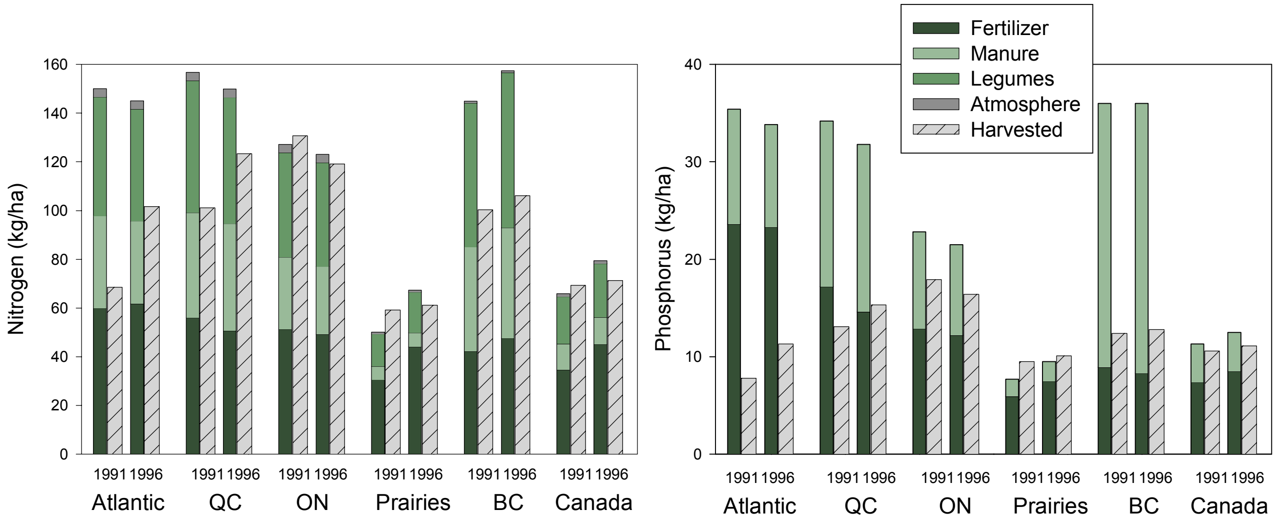


Figure 3.9. The amount of total N and total P added per hectare to agricultural fields as chemical fertilizer, manure, legume N-fixation and atmospheric deposition (dissolved inorganic N, only, for atmospheric deposition), and the amount removed in harvest in each region of Canada, 1991 and 1996.

Nutrient balances for Canada in 1996 indicate that crop removal of N and P was 89% and 87%, respectively, of nutrient additions as manure, fertilizer and, in the case of N, atmospheric deposition and legume fixation (Figure 3.9). In 1996, an estimated 2 784 thousand tonnes of N were added to agricultural soils (1 576 thousand tonnes from fertilizer, 384 thousand tonnes from manure, 773 fixed by legumes, 8 thousand tonnes as biosolids, and 43 thousand tonnes as atmospheric deposition). Likewise, an estimated 442 thousand tonnes of P were added to agricultural soils (297 thousand tonnes from fertilizer, 139 thousand tonnes from manure, and 5 thousand tonnes as biosolids). Although all provinces have surpluses of N, British Columbia and the Atlantic region tended to have the largest. In the case of P, cropland in the Prairie Provinces was under fertilized relative to the harvest (Figure 3.9).

Nutrient Losses from Agricultural Activity

Based on our assessment of N inputs to Canadian cropland (from fertilizer, manure, biological N fixation, atmospheric deposition, and sewage biosolids) and outputs as a result of crop harvest, the N surplus for Canada in 1996 was 4.3 kg/ha for the total area of agricultural land (68 million hectares) or 8.4 kg/ha for cropland (35 million hectares). Similarly, the P surplus in 1996 was 0.8 kg/ha for all agricultural land or 1.6 kg/ha for cropland. Our N estimate is comparable to values produced by the Organization for Economic Co-operation and Development (OECD) which estimated the N surplus in Canada to have been 13 kg/ha in 1995-1997 and 6 kg/ha in 1985-1987 based upon the total area of agricultural land (OECD 2000). These surpluses are among the lowest of the 28 OECD countries studied. OECD data are not available for P.

Although national data on nutrient surpluses or deficits are useful for examining patterns among countries, it should be recognized that these are average values and that, within a country, regional N surpluses or deficits may occur. For example, a recent analysis of residual N in Canadian farmland reported values of ≥ 41 kg/ha in the lower Fraser Valley of British Columbia; the corridor of agricultural land from Lethbridge through Red Deer to Edmonton in Alberta; the Melfort area in northeastern

Table 3.12. Proportion of farmland at risk of causing nitrogen contamination of water leaving farmland through overland flow (runoff) or leaching for regions in Canada where the soils have a water surplus, 1996 (MacDonald 2000b).

Province	Total Farmland[1] Area (1000 ha)	Farmland[1] area where soils have a water surplus (1000 ha)	Farmlands[1], where soils have a water surplus, classed according to their risk for nitrogen contamination of runoff or seepage water (%)		
			Low (0-6 mg/L N)	Medium (6.1 - 14 mg/L N)	High (> 14 mg/L N)
British Columbia	2018	70	6	25	69
Ontario	4577	4200	39	44	17
Québec	2267	1900	58	35	6
Atlantic	575	400	82	15	3

[1] Farmland refers to the sum of all *Agricultural Profile of Canada* land classes except 'All Other Land'. (Statistics Canada 1997a).

Saskatchewan; the Red River Valley in Manitoba; southwestern Ontario, the area around Lake Simcoe and the lower Ottawa Valley in Ontario; the St. Lawrence Lowlands in Québec and the region south of Québec City; the Annapolis Valley in Nova Scotia; and the Saint John River Valley in New Brunswick (MacDonald 2000a). However, most farmland in the four western provinces (69-92%) and the Atlantic Provinces (85%) had residual N levels of < 41 kg/ha in 1996. MacDonald (2000a) also reported residual N increased between 1981 and 1996 for all provinces except British Columbia. The percentage of farmland showing an increase of ≥ 5 kg/ha residual N ranged from 27% in British Columbia to 80% in Manitoba.

In establishing a reference level against which to monitor and assess changes in N surpluses, some studies suggest that values greater than 100 kg/ha annual should be taken as a baseline for increasing risk to possible nitrate leaching in ground and surface waters (Schleef and Kleinhanss 1994). A study by the USDA (1997) categorizes nutrient balances as high if the nutrient input (from fertilizer, manure and N fixed by legumes) exceeds output by more than 25%, moderate if nutrient input exceeds output by less than 25%, and negative if input was less than output. Canada's recent N surplus qualifies as low compared to the 100 kg/ha baseline suggested by Schleef and Kleinhanss (1994). Inputs (2784 thousand tonnes N and 442 thousand tonnes P) exceeded outputs (2491 thousand tonnes N and 386 thousand tonnes P) by 11% for N and 13% for P, indicative of moderate inputs for both N and P on the USDA scale.

Losses to Surface or Ground Waters from Agricultural Fields

National estimates of the quantity of N and P lost to surface and ground waters from agricultural lands are not available for Canada. In the USA, losses from cropland and from pasture and rangeland represented 39 and 13 %, respectively, of the 8 158 thousand tonnes of N and 31 and 17 %, respectively, of the 2 015 thousand tonnes of P discharged annually to surface waters (Carpenter et al. 1998). A recent assessment of N losses from Canadian agricultural fields related the average N surplus to the estimated volume of water leaving the fields through overland flow (runoff) or leaching for regions of Canada where the agricultural soils have a water surplus (i.e., Pacific Maritime, BC; Boreal Shield of northern Ontario, Québec and Manitoba; Mixedwood Plains of southern Ontario; and Atlantic Provinces; Macdonald 2000b). In British Columbia, 5% of the total agricultural land has a water surplus and 69% of this area was predicted to generate runoff or seepage water with N concentrations

> 14 mg N/L. In Eastern Canada, 17% of Ontario, 6% of Québec and 3% of Atlantic farmland that has soils with a water surplus was predicted to produce runoff or seepage water with > 14 mg N/L (Table 3.12). Risk of P loss from Canadian agricultural fields (based on the approach used for N) has only been completed for Québec and only identifies relative risk based on farm practices and soil, topographic, weather and other environmental conditions (Bolinder et al. 2000).

Although national estimates of the quantity of N and P lost to surface and ground waters from agricultural lands are not available for Canada, watershed or regional assessments have been attempted by assigning nutrient loss coefficients to different types of land (e.g., pasture, cropland, coniferous forest, etc.) or by estimating nutrient losses from agricultural land as percent of the nutrients applied in fertilizer and manure (Bolinder et al. 2000). Attempts to assess the portion of surplus nutrients moving to surface and ground waters have also employed field-scale measurements of losses from runoff, infiltration and leaching, and tile drains (MacDonald 2000b). For example, agricultural sources are estimated to contribute 70% of the N and 75% of the P load discharged from the Yamaska River, Québec to the St. Lawrence River (Chambers et al. 2000; see also Yamaska River case study in Section 4.3).

The information on nutrient surpluses/deficits and nutrient losses to surface and ground waters are for total N and total P. Only a portion of the total load is present in forms with the potential to cause eutrophication or, in the case of N, to be toxic. N and P are typically lost from agricultural lands in particulate forms that are not readily available to plants. However, recent research undertaken in Alberta indicated that 65-100% of the total P exported from agricultural watersheds was in dissolved forms (Anderson et al. 1998, Cooke and Prepas 1998). The predominance of dissolved P forms in runoff may be unique to the Boreal Plains and caused by watershed characteristics such as low-sloping topography (resulting in longer leaching times) and a high proportion of organic soils. Because dissolved forms are more-readily available for plant growth, they are likely to cause more rapid biological responses than particulate nutrients.

Losses to Surface or Ground Waters from Livestock Housing & Handling

A 1995 survey of Canadian farms found that 60% or 133 655 farms reported they stored manure. Of these, about 11% (14 885 farms) stored liquid manure, including all dairy farms most hog farms and about 25% of all poultry and egg farms. Of farms reporting liquid manure storage, the two most common methods were unlined lagoons (33%) and open tanks (31%). More than 95% of the farms storing liquid manure in 1995 reported that storage sites were at least 15 m from the nearest watercourse and at least 30 m from any well used for domestic purposes (Agriculture and Agri-Food Canada 1997). The exceptions were 595 farms in southern Ontario, southern Québec and the Atlantic Provinces that stored liquid manure within 15 m of a watercourse, and 565 farms in the Prairies Provinces, southern Ontario, southern Québec and Atlantic Provinces that stored liquid manure within 30 m of a well.

In addition to liquid manure storage, 126 470 farms stored solid manure in 1995 (Agriculture and Agri-Food Canada 1997). Farms with liquid manure storage also stored solid manure. All beef farms and mixed livestock farms and most poultry and egg operations and dairy farms reported storage of solid manure. Of the farms storing solid manure, 60% stored it in an open pile without a roof. Approximately 99% of farm operators reported storing solid manure storage more than 15 m from the nearest watercourse, and 97% stored it more than 30 m from any well used for domestic purposes (Agriculture and Agri-Food Canada 1997).

Other sources of agricultural nutrients to surface waters are discharges such as milk house wastes draining through connected tile drains to streams, cattle allowed access to streams, erosion of stream banks due to livestock trampling or tillage, and greenhouse waste. There are few regional and no national data on nutrient losses from livestock housing and handling facilities or from manure storage facilities to surface or ground waters. Localized studies have typically shown a 40% loss of N from cattle manure and a 25% loss of N from swine and poultry manure to soils, water and air (OMAFRA 1997; Environment Canada 2000b). For example, a study of agricultural nutrient management in the Lower Fraser Valley, British Columbia estimated that for housed beef and dairy cattle, approximately 15 to 20% of the manure N content was lost to the air; manure storage resulted in another 10 to 20% loss to air and 0 to 10% loss in runoff or infiltration (Brisbin 1995). In the same study, N losses for hog manure were estimated at 15 to 20% to the air when the animals were housed and 10 to 20% (most to the air) during manure storage.

National estimates were not calculated for N and P losses to surface or ground water from livestock housing and handling facilities or from manure storage facilities.

Losses to the Atmosphere

Within the agricultural sector, the majority of N losses to the atmosphere occur as a result of the volatilization of ammonia from livestock manure and fertilizers, and through the production of nitrous oxide by bacterially-mediated denitrification of soil nitrate. There is also some ammonia loss from the decomposition of crops, as well as losses of nitric and nitrous oxide from the soil following mineralization of organic matter. These losses of N from manure and fertilizer can represent a potentially serious economic loss to the farmer and impact to the environment. Losses also occur as a result of fuel combustion and biomass burning but these will not be addressed in this section. Wind and water erosion of soil are also transport pathways for nutrients. Agricultural management processes can accelerate natural rates of erosion (Podbury and Stushnoff 2000; Shelton et al. 2000); however, nutrient losses associated with erosion will not be addressed here.

Ammonia release to the atmosphere largely occurs as a result of storage and handling of livestock manure and fertilizer application. The majority of ammonia losses from manure and chemical fertilizers occurs during application to the soil surface and tends to be higher during warm, dry weather. Between 3 and 60% of applied NH_3 can be lost depending on the type of material applied, soil conditions (moisture and pH), and the length of time elapsing before the fertilizer is incorporated into the soil (McGinn and Janzen 1998). In 1995, Canadian agricultural emissions of N as ammonia were estimated to be 570 thousand tonnes (Vézina 1997). Of this number, manure accounted for 87% of the total ammonia N emissions with fertilizer making up the balance. Of the manure emissions, cattle manure accounted for 59%; poultry manure for 21%, and pig manure for 19% of the ammonia N.

Nitrous oxide (N_2O) release is also associated with fertilizer use. When either manure or inorganic N fertilizers are applied to soil, most of the N is oxidized to nitrates before being taken up by plants, resulting in a loss of nitrous oxide to the atmosphere. In Canada, nitrous oxide emissions from agricultural activity increased from 31 thousand tonnes N per year from 1981 to 1991 to 38 thousand tonnes of N in 1996 (Desjardins and Keng 1999). The largest agricultural source of nitrous oxide is

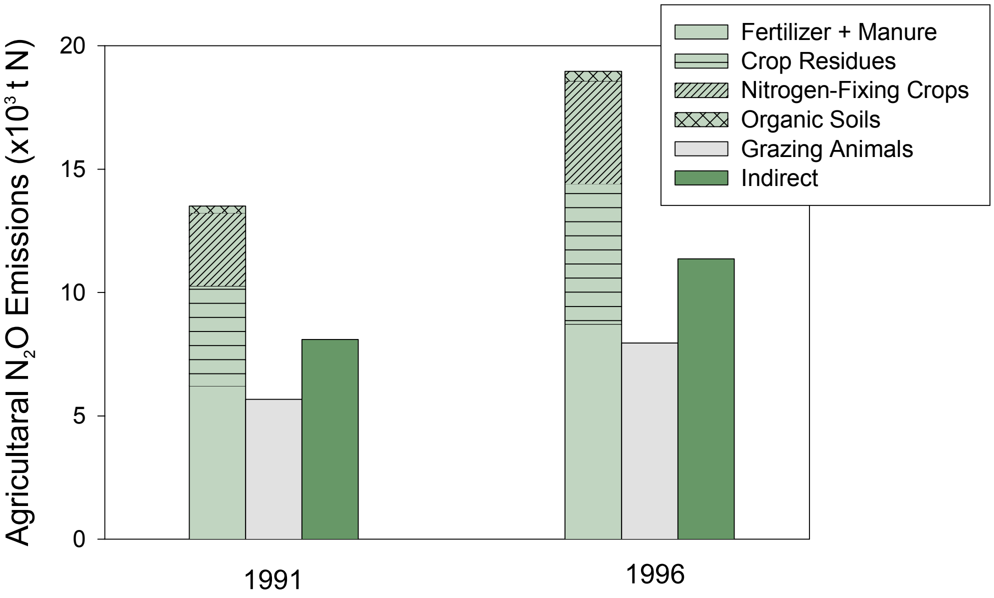


Figure 3.10. Canadian agricultural sources of nitrous oxide emissions for 1991 and 1996. Direct emissions occur from soils and grazing animals. Indirect emissions occur from N volatilization, leaching and runoff. Data adapted from Environment Canada 1997a, Monteverde et al. 1997, Desjardins and Keng 1999 and Desjardins and Reznek 2000.

direct soil emissions resulting largely from the application of manure and commercial fertilizer and which accounted for 6 thousand tonnes of N in 1991 and 9 thousand tonnes of N in 1996 (Figure 3.10; Desjardins and Keng 1999). Soil emissions can be subdivided into losses associated with manure and fertilizer use (23% of total emissions), crop residues (15% of total emissions), N-fixing crops (11% of total emissions), and cultivation of organic soils (<1% of total emissions) (Desjardins and Keng 1999). Grazing animals and manure management were responsible for 8 thousand tonnes of N in 1996 (21% of total N_2O emissions), while indirect emissions from the precipitation of NH_3 and NO_x and N leaching from soil were responsible for another 11 thousand tonnes of N (30% of total N_2O emissions) (Monteverde et al. 1997; Desjardins and Keng 1999).

Nitric oxide and nitrogen dioxide (i.e., NO_x) are also released to the atmosphere as a result of agricultural activities. Although national values for NO_x release from agriculture are not available, the quantity of N oxides released from soil (as a of product of nitrification and denitrification) may be similar to that from industrial sources (Janzen et al. 1998).

A small portion of P is lost to the atmosphere during fertilizer application. In 1978, an estimated 783 tonnes of P were released to the atmosphere as a result of fertilizer application, based on an emission factor of 9.81 x 10^{-4} tonnes P emitted per tonne fertilizer material used (Environment Canada 1983). Most of the lost P is in the form of phosphate.

3.4 Aquaculture and Fisheries Enhancement

In its broadest definition, aquaculture is “the cultivation of aquatic organisms (fish, molluscs, crustaceans, other invertebrates, unicellular algae, macroalgae, and higher plants) using extensive or intensive methods in order to increase the production or yield per unit area or unit volume to a level

Table 3.13. Fish and invertebrate species licensed for production in Canada. (Data from Moccia and Bevan 1996 and BC Fisheries 1998).

Fish

Lake sturgeon (*Acipenser fulvescens)*
Atlantic salmon (*Salmo salar)*
Brown trout (*Salmo trutta)*
Brook trout (*Salvelinus fontinalis)*
Lake trout (*Salvelinus namaycush)*
Arctic charr (*Salvelinus alpinus)*
Chinook salmon (*Oncorhynchus tshawytscha)*
Coho salmon (*Oncorhynchus kisutch)*
Pink salmon (*Oncorhynchus gorbuscha)*
Rainbow trout (*Oncorhynchus mykiss)*
Lake whitefish (*Coregonus clupeaformis)*
Lake herring (cisco) (*Coregonus artedii)*
Muskellunge (*Esox masquinongy)*
Northern Pike (*Esox lucius)*
Creek chub (*Semotilus atromaculatus)*
White sucker (*Catostomus commersoni)*
Bluntnose minnow (*Pimephales notatus)*
Fathead minnow (*Pimephales promelas)*
Redbelly dace (*Phoxinus eos)*
Atlantic halibut (*Hippoglossus hippoglossus*)
Atlantic cod (*Gadus morhua*)
Lumpfish (*Cyclopterus lumpus)*
Wolffish (*Anarhichas lupus*)
Finescale dace (*Phoxinus neogaeus)*
Common shiner (*Luxilus cornutus)*
Golden shiner (*Notemigonus crysoleucas)*
Emerald shiner (*Notropis atherinoides)*
Common carp (*Cyprinus carpio)*
Goldfish (*Carassius auratus)*
Brown bullhead (*Ameiurus nebulosus)*
Channel catfish (*Ictalurus punctatus)*
American eel (*Anguilla rostrata)*
Largemouth bass (*Micropterus salmoides)*
Smallmouth bass (*Micropterus dolomieu)*
Bluegill (*Lepomis macrochirus)*
Pumpkinseed (*Lepomis gibbosus)*
Black crappie (*Pomoxis nigromaculatus)*
Walleye (*Stizostedion vitreum)*
Sauger (*Stizostedion canadense)*
Yellow perch (*Perca flavescens)*
Tilapia (*Oreochromis, Sarotheradon, Tilapia)*
Haddock (*Melanogrammus aeglefins*)
Winter flounder (*Pleuronectes ferrugineus*)
Yellowtail flounder (*Pleuronectes americanus*)
Striped bass (*Morone saxatilis*)

Invertebrates

Pacific oyster (*Crassostrea gigas*)
Geoduck clam (*Panopea generosa*)
Manila clam (*Tapes philippinarum*)
Gallo mussel (*Mytilus galloprovincialis*)
Green sea urchin (*Strongylocentrotus droebachiensis*)
European oyster (*Ostrea edulis*)
Little neck clam (*Protothaca staminea*)
Japanese scallop (*Pecten yessoensis*)
Blue mussel (*Mytilus edulis*)
Crayfish (*Orconectes immunus, O. virilis, O. propinquus, Cambarus robustus, C. bartonii)*

above that obtained naturally in a particular aquatic environment" (Mariculture Committee of the International Council for the Exploitation of the Sea cited in Boghen 1989). The aquatic organisms resulting from these husbandry techniques are intended for use as food, ornamental or baitfish production, or for resource enhancement (Boghen 1989).

Aquaculture in Canada is currently a small industry. Its roots lie in hatcheries established to produce fingerlings for provincial stocking programs. Aquaculture is rapidly expanding, however, and now includes production of approximately 45 fish and eight invertebrate species (Table 3.13). Of these 40 fish species, rainbow trout (including steelhead), Atlantic salmon and arctic char represent the bulk of fish produced for human consumption (DFO 1998). Clams, oysters, mussels, and scallops compose the majority of invertebrate production in Canada (DFO 1998). In 1996, 53 thousand tonnes of finfish and 19 thousand tonnes of shellfish were harvested as a result of aquaculture in ten provinces representing a value of $350 million (Table 3.14). Of this production, 58% was in marine environments and 42% in freshwater operations (Table 3.15), the majority in British Columbia and New Brunswick.

Aquaculture operations range from small private ponds stocking dozens of fish for private capture to large ocean cage cultures producing thousands of tonnes of fish per year. These operations can be categorized using three broad categories: open, semi-closed and closed (Landau 1992). The

Table 3.14. 1996 Canadian aquaculture production statistics and value by province (Data Source: DFO 1998).

Province/Territory	Finfish Production (t)	Shellfish Production (t)	Value ($000)
Newfoundland	1,319	386	6,139
New Brunswick	16,380	733	123,818
Nova Scotia	1,511	773	10,421
Prince Edward Island	64	10,493	14,444
Québec	1,000	100	4,100
Ontario	4,000	0	16,060
Manitoba	(1)	0	(1)
Saskatchewan	775	0	3,420
Alberta	110	0	660
British Columbia	27,731	6,475	170,744
Canada	52,907	18,960	349,910

(1) Majority of aquaculture is private so no data are available

distinction among these depends on the water source. In open systems, a natural water source, such as the ocean or a lake, is used and enclosures such as clam beds or fish cages are installed within the water body (Landau 1992). Enclosures range from a retaining structure held in place with poles or stakes to floating rafts or cages. Semi-closed systems use natural water sources in specially designed facilities (Landau 1992). This system allows for greater control over growing conditions and results in more uniform growth and increased production per unit area. Hatcheries are typically semi-closed systems. Finally, closed systems involve no water exchange with the natural environment. Organisms are raised at very high densities in tanks or ponds in water extensively treated and recycled (Landau 1992). Nutrient release from fish production systems results from excretion of dissolved or solid waste and from unconsumed feed. Finfish operations require the introduction of feed, which increases the potential for fertilization of surrounding waters. In contrast, shellfish operations in Canada rely on natural food sources from the surrounding water (Bob Hooper, Memorial University, personal communication); there are no food-related nutrient additions to the environment.

Of the three categories of aquaculture operations, only open and semi-closed systems have water exchange with a natural water body (lake or coastal water) and, therefore, the potential to affect the

Table 3.15. Percentage of Canadian aquaculture sites situated in marine or freshwater environments for each province in 1996. Data Source: Provincial lease authorities compiled for Canadian Aquaculture Industry Alliance (CAIA 1998).

Province/Territory	Marine	Freshwater
Newfoundland	100	0
New Brunswick	63	37
Nova Scotia	100	0
Prince Edward Island	100	0
Québec	7	93
Ontario	0	100
Manitoba	0	100
Saskatchewan	0	100
Alberta	0	100
British Columbia	78	22
Canada	58	42

natural environment. Moreover, emissions and treatment of effluents from closed aquaculture operations are controlled by provincial legislation. In addition to the number of fish cultivated, the quantity and quality of the feed are the most important factors determining nutrient loss to the environment because they determine both feed wastage and excretion losses (Persson 1991; Cho and Bureau 1997). Food quantity depends on the fish species under cultivation as well as the production goals for the operation. The objective of the aquaculturist is to match food supply with consumption rates to maximize economic gain while minimizing possible negative impacts of poor water quality (resulting from overfeeding) on target organisms, some of which are sensitive to water quality (e.g., trout). Inherent in this goal is a critical balance between the proportion of the nutrients utilized for fish growth and that lost to the water as excess feed and/or excretion (Cho et al. 1994).

Considerable study has been undertaken in recent years to improve feed quality so as to increase biological conversion of food into animal production and reduce wastage (Cho et al. 1994; Cho and Bureau 1997). A detailed study by Cho et al. (1994) showed that P and N for common feeds ranged from 1.4 to 13.6% N and 0.3 to 5.9% P, depending upon the ingredients used in the formulation. As a result of improvements in feed formulation, N and P content has decreased from about 1.62% P and 8.45% N in the early 1980s to about 0.9% P and 7.2% N (Ackefors and Enell 1990). In an assessment of waste discharge from salmon aquaculture (DFO 1997) assumed the nutrient content of feed to be 1.2% P and 6.4% N.

Improvements in feed quality have reduced the feed coefficient (wet weight of feed used to wet weight of fish produced). Thus, the feed coefficient has declined at least 3.5-fold since the inception of salmon farming in Norway approximately 45 years ago and between 1.5 and 2-fold since 1985 in British Columbia (DFO 1997). The DFO study used feeding coefficients for farmed Atlantic and Pacific salmon in British Columbia of 1.15 and 1.3, respectively, giving an average feeding coefficient (weighted for the proportion of each species in cultivation in British Columbia) of 1.2.

The method of feeding can also influence the rate at which food is lost to the environment. In a study of salmon cages in Sooke Basin on southern Vancouver Island, Levings (1994) noted automatic fish feeders resulted in deposition of waste food and particulate matter at a rate of 54.3 g dry weight/m^2/d, which was significantly higher than deposition rates of 19.1 g dry weight/m^2/d observed when fish were hand fed.

Studies on the loading of nutrients from aquaculture operations into aquatic ecosystems have tended to focus on large salmonid cage-culture operations in coastal waters and, to a lesser extent, fresh waters. Studies of rainbow trout and Atlantic salmon aquaculture have shown nutrient losses (both dissolved and particulate) from cage cultures ranged from 3 to 35 kg P and 20 to 260 kg N per tonne fish (Penczak et al. 1982; Ackefors and Enell 1990; Holby and Hall 1991; Jensen 1991; Johnsen and Wandsvik 1991; Hall et al. 1992; Levings 1994; Einen et al. 1995; MacIsaac and Stockner 1995). These studies have typically shown only about 20 to 30% of nutrients added to the aquaculture operation are incorporated into fish biomass and removed at harvest; the other 70 to 80% of added nutrients is lost to the environment in the form of metabolic waste, faeces and uneaten food fragments.

In an assessment of nutrient loading from Swedish fish farms to coastal waters, Ackefors and Enell (1990) assumed P loss to be 9.5 kg/t fish produced (based on a feed coefficient of 1.5 and a feed P content of 0.9%) and N loss to be 78 kg/t fish produced (based on a feed coefficient of 1.5 and a feed N content of 7.2%). In a similar assessment for Atlantic and Pacific salmon operations in British Columbia, DFO (1997) data gave losses of 9.2 kg P and 43 kg N per tonne of fish produced (based on a feed coefficient of 1.2 and feed contents of 1.2% P and 6.4% N). Assuming the DFO (1997) N and P loss coefficients are applicable to the entire finfish industry in Canada, nutrient introduction from Canadian aquaculture operations is 204 t/yr P and 956 t/yr N to inland waters, and 282 t/yr P and 1 320 t/yr N to coastal waters (calculated by multiplying the total finfish production for Canada in Table 3.14 by the percent of that production that is marine or inland in Table 3.15 and then multiplying by 9.2 kg P/yr or 43 kg N/yr). By comparison, a population of 100 000 served by secondary sewage treatment releases 25 t/yr P and 365 t/yr N as wastewater (based on 3.38 g P/capita/d and 80% P removal, and 10 g N/capita/d).

In addition to commercial aquaculture operations, direct fertilization has been used to enhance the production of sport fish, especially anadromous sockeye salmon, in oligotrophic lakes and rivers in British Columbia. Nutrients are added in an attempt to enhance food supply (algal and, in turn, benthic invertebrate or zooplankton abundances) for salmon fry. For example, nutrient additions to the Keogh River, British Columbia to increase summer average nutrient concentrations from 25 µg N/L and <1µg P/L to 30 to100 µg N/L and 10 to 15 µg P/L caused a 5 to 10-fold increase in periphyton biomass resulting in a 1.4 to 2.0-fold increase in salmonid fry weights (Johnston et al. 1990). In Kootenay Lake, British Columbia, five years of N and P additions of 47 t P/yr and 206 t N/yr resulted in increased zooplankton densities that increased both spawner size and fecundity of Kokanee salmon stocks (Ashley et al. 1997). Overall, nutrient additions to a variety of British Columbia lakes and rivers have enhanced bacteria, phytoplankton and zooplankton abundances with an associated 60% increase in smolt weight of juvenile salmon, helping revitalize the British Columbia salmon fishery (Stockner and MacIsaac 1996).

3.5 Forest Management Practices

Forests, particularly those occupying steep terrain and supplied with abundant precipitation, contribute a large proportion of the water that enters streams and lakes. Forests efficiently cycle large quantities of N and other nutrients with very small losses to surface waters. Evidence from small catchment studies and broader-scale monitoring programs indicates that streams draining undisturbed forest generally have high water quality with low concentrations of dissolved nutrients and suspended sediments. Forest management practices that disrupt the cycle of nutrients between the soil and trees may increase stream water concentrations of dissolved N, base cations and to a lesser extent P. However, nutrient losses to stream water from forest management practices have been defined for relatively few sites in Canada. The effect of forest management practices on water quantity and quality is difficult to assess, therefore, and confounded by climatic, topographic and vegetation diversity across the country.

Harvesting

Manipulation of forest watersheds can drastically affect water quality of streams and lakes. The most significant effects are on the physical characteristics of the water. Sediment from logging roads, skid trails, and landings and soil erosion in steep terrain increase the concentration of suspended sediments (including particulate forms of N and P) in streams. Under high flows, the concentration of suspended solids in streams in recently clear-felled forest catchments can rise dramatically compared to baseflow conditions. For example, sediment transport in streams in a coastal British Columbia forest increased

Table 3.16. Effect of harvesting on stream nitrogen and phosphorus concentrations [+].

	NO_3-N (mg/L)		PO_4-P (µg/L)			
Province	Control Stream	Treated Stream	Control Stream	Treated Stream	Treatment	Reference
NB	0.12	0.60	--	--	100% clearcut	Krause (1982)
ON	0.03	0.02	10.0	20.0	100% clearcut	Nicolson et al. (1982)
ON	0.11	0.08	10.8	9.0	75% clearcut	Nicolson (1988)
BC	0.04	0.50	--	--	100% clearcut	Feller and Kimmins (1984)
BC	0.003	0.006	0.08	0.07	100% clearcut	Scrivener (1987)

[+] Maximum average annual concentration in post-treatment period.

up to 10-fold owing to stream bank erosion following clearcutting. Impacts vary with the soil type, slope, climate, and severity of management treatment. Degradation of water quality is most likely to occur where forest management practices are poorly implemented.

Clearcutting of forests has also been shown to increase the concentration of dissolved nutrients (including nitrate). Forest removal affects nutrient leaching from forests by eliminating nutrient uptake by trees for a period of time. The impact of clearcutting on nitrate concentrations in first-order streams draining small, undisturbed, forested catchments at the Hubbard Brook Watershed in New Hampshire, USA is well documented (control 0.2 mg/L NO_3-N, clearcut 3.9 mg/L NO_3-N; Hornbeck et al. 1987; control < 1mg/L NO_3, stripcut 9 mg/L NO_3, clearcut 30 mg/L NO_3 one year after harvest, Martin et al. 2000). Increases in stream nitrate concentrations after clearcutting have also been observed for some but not all catchment studies in Canada (Table 3.16). When increases in nitrate were observed they were quite low, relative to the Hubbard Brook results. Few studies have examined changes in dissolved phosphate concentrations and those that have, typically show concentrations either remained unchanged after logging or exhibited short-lived increases. For example, three lakes on the boreal shield of northern Ontario showed little change in water quality in the first three years after experimental logging of 45 to 75% of the watershed (Steedman 2000). An exception to this observation is a recent study on boreal shield streams in Québec that reported no increase in nitrate export from streams draining harvested as compared to reference watersheds but a two-fold increase in total P and total N export in the year following harvest (Lamontagne et al. 2000). Although export from these boreal streams decreased in the years following harvest, nutrient export was still greater for harvested than reference watersheds two (total P) or three (total N) years after harvest. Impacts of timber harvest on nutrient concentrations are magnified by increases in water production after clearcutting. For example, P (dissolved and suspended) leaching from a jack pine-black spruce watershed in northwestern Ontario increased from 0.07 to 0.22 kg/ha/yr immediately after clearcutting (Nicolson et al. 1982).

The impact of harvesting on stand or catchment nutrient retention can also be assessed by mass budget calculations. Nutrient balances have been computed for only a few forests (e.g., Table 3.17). Studies of nutrients removed in the harvest products and by post-harvest leaching of the soil at an infertile coniferous site and a moderately fertile deciduous site suggest that, over the long term, clearcut harvesting will produce only small net gains to or losses from soil nutrient pools, with the exception of N in the tolerant hardwood forest. As a consequence the overall impact, viewed from the perspective of a forest crop rotation of 60 to 100 years, will typically represent only small increases or decreases in nutrient inputs to aquatic systems. For example, a paleolimnological study of phytoplankton

Table 3.17. Nutrient balance for a coniferous and a deciduous forest in Ontario. Data source: Mahendrappa et al. 1986; N. Foster, Natural Resources Canada, unpublished data.

Forest Type	**Nutrient (kg/ha/yr)**	
	N	**P**
Boreal conifer forest (mature jack pine on podzolic soil)		
Input		
Precipitation	3.0	0.5
Dry deposition	0.7	0.1
Atmospheric nitrogen fixation	0.02	--
Outputs		
Harvest bole	1.3	0.1
Harvest crown	1.5	0.15
Stream flow	0.1	0.01
Gain/Loss to soil nutrient pool	+0.8	+0.3
Temperate tolerant hardwoods (mature sugar maple on podzolic soil)		
Input		
Precipitation	8.7	0.3
Dry deposition	2.2	0.1
Atmospheric nitrogen fixation	0.3	--
Outputs		
Harvest bole	1.8	0.1
Harvest crown	1.9	0.1
Stream flow	3.7	0.02
Gain/Loss to soil nutrient pool	+3.8	+0.2

composition did not reveal evidence of eutrophication following the onset of logging ca. 1870-1890 in the watershed of a northern Michigan lake (Scully et al. 2000). However, over the short-term (i.e, the first several years following harvest), comparatively small nutrient inputs may affect lakes, particularly those with naturally-low nutrient concentrations. For example, total P and total organic N concentrations were significantly higher in boreal shield lakes in Québec in the three years following timber harvest as compared with lakes in undisturbed watersheds (Carignan et al. 2000). In the lakes exposed to timber harvest, a significant increase in phytoplankton abundance was observed in the first year following harvest, an increase that likely would have been even greater if not for lower light penetration caused by inputs of dissolved organic carbon that coloured the water (Planas et al. 2000).

The impact of timber harvest on concentrations of dissolved solids (including N and P) depends on the intensity of harvest, forest cover, soil type, and slope steepness. Impacts will also vary with the level of protection afforded during disturbance, through the use of lake shore reserves and buffer strips. Increases in nitrate are dependent on atmospheric N deposition, nitrification rates in soil, and N demands of regenerating vegetation and stream biota. Recovery of water quality is particularly dependent on the rate of re-establishment of vegetative cover.

Site Preparation and Slashburning

Site preparation is commonly applied after logging to help provide a more favourable environment for the establishment and early growth of planted seedlings. Exposure of mineral soil by site preparation can result in increased surface runoff and off-site movement of nutrients in dissolved form or in sediment transport. The greatest negative impacts may be associated with complete removal and

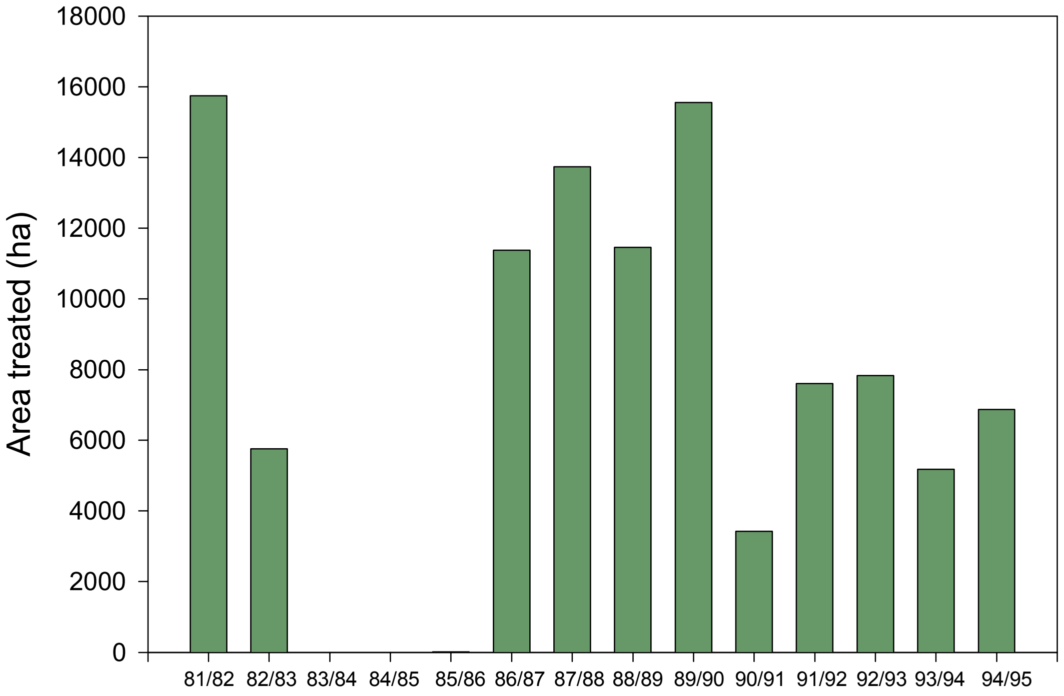


Figure 3.11. The area of Crown land in British Columbia treated with N fertilizer, 1981-1995. (Data source: BCF 1997).

windrowing of logging slash and forest floor organic layers. Actual nutrient losses, through leaching to surface waters after site preparation, have not been quantified.

In British Columbia, the increase in first-order stream nitrate concentrations following slashburning was substantial, relative to the small response to clearcutting (Feller and Kimmins 1984). The ash raised the pH of strongly acid forest soils, thereby favouring increased rates of nitrification in the soil. Leaching or washing of ash into streams, after wildfire, has also been observed. However, in all cases the highest nitrate concentrations observed were well below drinking water standards.

Fertilization

Nitrogen and phosphorus fertilizers are not applied to natural or plantation forests throughout most of Canada, for economic reasons. In British Columbia, however, they have been applied to a limited extent to both coastal and interior conifer forests on Crown (Figure 3.11) and private land, to increase wood production on medium and good sites. Nitrogen is applied at rates of 150 to 250 kg/ha, but rarely more than once during a crop rotation. Based on 1994-95 data of approximately 6800 ha treated with N fertilizer and assuming an application rate of 200 kg/ha N, then a total of 1.4 thousand tonnes N were used to fertilize forests in British Columbia. In a summary of fertilization research from the Pacific northwest USA, Binkley and Brown (1993) concluded that N fertilizers do not lead to excessive nitrate levels in streams. Two exceptions are studies in British Columbia and New Brunswick where N application resulted in short-lived substantial increases in stream nitrate that approached values of concern for human health. In these studies no efforts were made to minimize application over streams, so initial nitrate increases resulted from stream interception of aerial applied N. Even when inorganic N concentrations in streams (Table 3.17) and soils were significantly elevated in the year of application, they were rapidly dissipated thereafter (Jewett et al. 1995). Up to 90% of the N applied was retained by vegetation and soil or volatilized from the soil surface when urea was applied to a boreal pine forest (Morrison and Foster 1977).

In summary, the limited data indicate that nutrient losses from forest management practices have generally been small relative to those in harvested biomass or in the smoke of slash burns. There is, however, insufficient information on nutrient leaching from Canadian forests to generalize about nutrient losses associated with forest management practices. Additional research is required to quantify nutrient losses from terrestrial systems to ground and surface waters following timber harvest for the diversity of forested ecozones in Canada.

3.6 Atmospheric Transport and Deposition

Pollutants in the atmosphere may be transported by winds and global air circulation anywhere from a few tens of metres to thousands of kilometres beyond their point of release before they are deposited. Atmospheric deposition refers to wet or dry deposition of a chemical from the atmosphere to the Earth's surface by physical processes. Wet deposition is the removal of chemicals from the atmosphere by precipitation (rain, snow or fog). Forms of nutrients commonly found in wet deposition are ammonium, nitrate and phosphate as well as organic N and P. Dry deposition refers to any process that does not involve precipitation, such as the settling of particles of dust or soil or the incorporation of gaseous compounds into plants or water. Turbulent processes in the boundary layer, the chemical and physical nature of the deposition species, and the capacity of the surface to capture or absorb gases and particles govern dry deposition. N and P can be bound to or incorporated into particles (such as eroded soil particles or particles released as a result of industrial process) that enter the atmosphere and are then dispersed, transported and later deposited. Wet deposition has typically received more attention than dry fallout as a source of atmospheric N and P, possibly because of the difficulty in obtaining accurate estimates of dry deposition due to the effects of turbulence on small particles.

Since 1977, Environment Canada and most Canadian provinces have monitored precipitation to determine wet deposition of acid-related substances, commonly known as acid rain (AES-EC 1997). Nitrate and sulfate are the main components of acid precipitation (AES-EC 1997). Nitrate in the atmosphere is derived from the oxidation of nitrogen oxides to nitric acid. Nitrogen oxides are produced naturally through bacterial activity, wildfires and lightening. Their abundance is greatly enhanced by industrial combustion processes that oxidize atmospheric N gas (N_2). Ammonia is released on occasion following transport accidents, from refrigerator systems, near sources of anhydrous ammonia production, and from areas of intensive livestock management (Van der Eerden 1982; Teshow and Anderson 1989).

In Canada, atmospheric deposition arriving from long distance transport supplies approximately 2.5 kg/ha/yr N in the form of nitrate and ammonium, based on 1990s data (Figure 3.12). This value is five-fold greater than pre-industrial values of 0.5 kg/ha/yr N. The increase in wet deposition of nitrate and ammonium in recent decades, both in absolute terms as well as in relation to sulfate, is a major concern particularly in eastern Canada (Grennfelt and Hultberg 1986; Berden and Nilsson 1996; AES-EC 1997). Wet deposition of N is considerably higher in eastern than in western Canada. Ten-year averages (calculated using a kriging method to estimate spatial means) are 3.44 kg N/ha/yr east of the Manitoba-Ontario border (C-U. Ro, Environment Canada, personal communication) compared to 0.80 kg N/ha/yr west of the border. The most recent data (1996) show wet deposition for fourteen

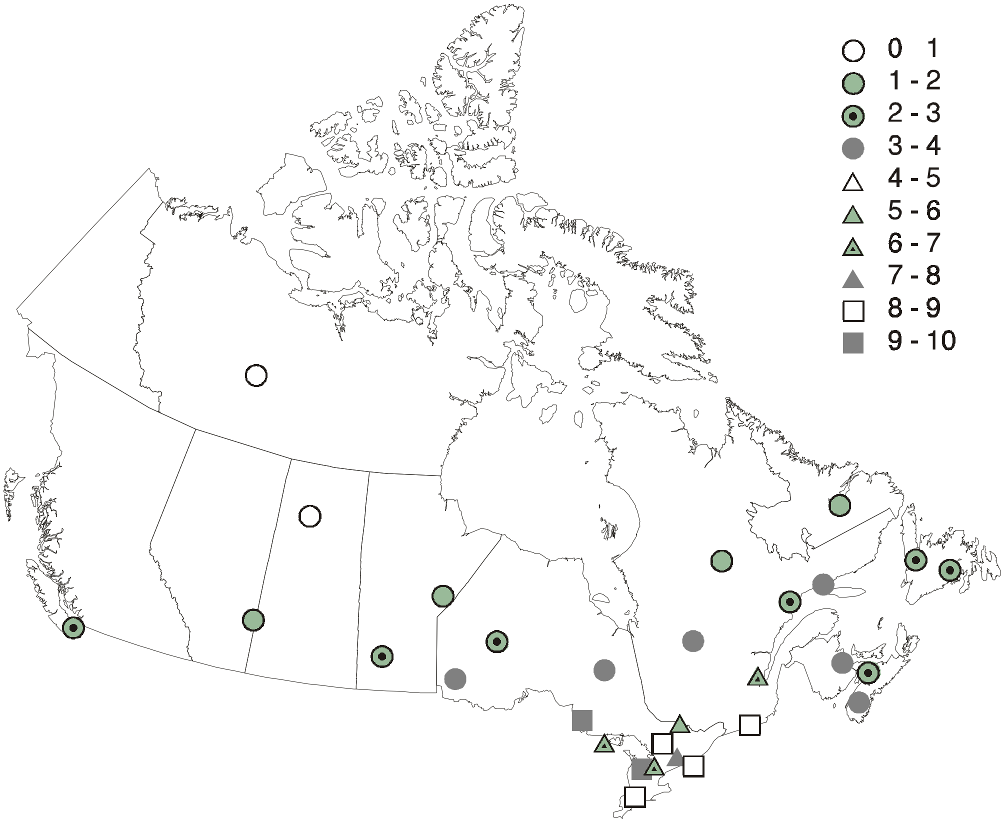


Figure 3.12. Map showing the wet deposition (kg N/ha/yr) of nitrate and ammonium measured at 30 sites across Canada during 1984-1994, based on measurements made by Canadian Air and Precipitation Monitoring Network (Ro et al. 1998).

locations in Canada ranging from 0.25 to 5.09 kg/ha/year for nitrate as N and 0.31 to 3.39 kg/ha/year for ammonium as N (Table 3.18). National data are not available for dry deposition of N; dry deposition, however, may be a considerable source of N. In southern Ontario, total atmospheric N deposition arriving from long distance transport was estimated to be 18.4 kg/ha and included wet deposition of 10.4 kg/ha and dry deposition of 8.0 kg/ha (Barry et al. 1993). Our estimates of atmospheric N deposition include only wet deposition of ammonium and nitrate. Using the 10-year wet deposition rates of 3.44 kg N/ha/yr east of the Manitoba-Ontario border and 0.80 kg N/ha/yr for west of this border, atmospheric deposition of ammonium and nitrate is estimated to add 182 thousand tonnes N to freshwaters (106 223 600 ha), 43 thousand tonnes to cropland (34 918 733 ha), 117 thousand tonnes to agricultural land not used for crops (31 064 291 ha) and 1 378 thousand tonnes to non-agricultural land (835 983 249 ha) in Canada each year.

In contrast to N, phosphorus does not exist in a gaseous form. Phosphorus in the atmosphere is present as particulates (dust and organic debris) and as water-soluble phosphate (PO_4^{3-}). Natural sources of atmospheric P include terrestrial airborne matter, volcanic dust and meteoric particles; anthropogenic sources include releases from fertilizer application as well as industrial sources that produce P products (e.g., fertilizer production, phosphate rock processing, and elemental P production). Atmospheric P loading is not routinely measured. The few Canadian studies to do so have been part of larger projects aimed at developing detailed P budgets for lakes. These studies found that, in Canada, atmospheric P loading due to both wet and dry deposition ranged from 0.01 to 0.74 kg/ha/yr (Table 3.18). Of this deposition, dry fallout of total P accounted for 34-65% in both Alberta and South-Central

Table 3.18. 1996 Annual precipitation, weighted-mean concentration (mg/L), and load (kg/ha/year) of nitrate-N and ammonium-N in wet deposition for various Canadian sites. (Data source: Ro et al. 1998).

CITY	Total Precipitation (cm)	Nitrate-N mg/L	Nitrate-N kg/ha/year	Ammonium-N mg/L	Ammonium-N kg/ha/year
Snare Rapids, NWT	38.92	0.063	0.25	0.078	0.31
Saturna, BC	105.48	0.185	1.95	0.099	1.05
Esther, AB	33.29	0.215	0.71	0.266	0.88
Point du Bois, MB	46.36	0.021	1.20	0.119	2.13
Island Lake, MB	48.44	0.014	0.73	0.046	0.93
Experimental Lakes Area, ON	101.41	0.201	2.04	0.245	2.49
Warsaw Caves, ON	108.74	0.468	5.09	0.312	3.39
Chalk River, ON	93.90	0.404	3.80	0.290	2.72
Mingan, QC	127.22	0.122	1.55	0.059	0.75
Montmorency, QC	163.35	0.221	3.62	0.131	2.14
Harcourt, NB	129.71	0.158	2.05	0.087	1.13
Kejimkujik, NS	162.14	0.151	2.45	0.071	1.15
Bay d'Espoir, NF	154.47	0.077	1.19	0.043	0.66
Goose Bay, NF	112.15	0.066	0.73	0.039	0.44

Ontario (Shaw et al. 1989; Scheider et al. 1979). Typically, atmospheric deposition represents only 1 to 6% of the total P budget in Canadian lakes (Peters 1973; Ahl 1988); however, in the very dilute lakes of northwestern Ontario, precipitation may supply as much as 80% of the P input (Barica and Armstrong 1971).

3.7 Conclusions

This chapter presents information on N and P loading to Canadian water, land and air from household, industrial, agricultural, aquacultural and atmospheric sources. These estimates were obtained using several approaches. In the case of municipal sewage, septic disposal and aquacultural losses to surface waters, manure production by livestock and crop uptake of nutrients, our approach was to multiply census data (population numbers for humans and livestock; production for crops and finfish) by average coefficients for nutrient emission (in the case of humans, livestock and finfish) or nutrient content (in the case of crops). Estimates of industrial and agricultural N releases to the atmosphere (Environment Canada 1997a, Monteverde et al. 1997, Vézina 1997, Desjardins and Keng 1999, Environment Canada 1999a, Desjardins and Reznek 2000) and household compost production (CCC 1998) were calculated using a similar approach by the reporting agency. In the case of industrial loads to water and fertilizer use, measured values are reported. Atmospheric deposition of nitrate and ammonium is based upon measured values from which weight-averaged regional values were calculated by the reporting agency (Ro et al. 1998). All data are based on mid-1990s values, except for estimates of biosolid application to farmland. The most recent national estimates for this are from the early 1980s (OECD 1995). The use of average emission factors and census data to estimate nutrient loading to water, land and air does not allow consideration of the variability around an average value (e.g., due to temporal or regional variation in pollutant loading) and these may be significant. However, at present, pollutant-loading estimates based upon average emission factors and census data represent the best (and most widely used) approach to obtain regional and national estimates of pollutant loading. These estimates allow comparison of the magnitude of N and P loading from various sectors to Canadian water, air and land.

Table 3.19. Annual bulk (wet and dry) deposition (kg/ha/yr) of total phosphorus (TP) for various location in Canada.

Location	TP (kg/ha/yr)	Reference
Arctic (Cornwallis Island)	0.05	Schindler et al. 1974
Saqvaqjuac, NWT	0.01	Welch and Legault 1986
Central Alberta	0.20	Shaw et al. 1989
Northwestern Ontario	0.33	Schindler et al. 1976
	0.25 (wet only)	Linsey et al. 1987
Central Ontario	0.42 (bulk)	Scheider et al. 1979
	0.17 (wet only)	Scheider et al. 1979
	0.39	Jeffries et al. 1978
	0.37	Gomolka 1975
	0.74	Nicholls and Cox 1978
Eastern Ontario	0.30	Schindler and Nighswander 1970

Discharges to Surface and Ground Waters

Household sewage is the largest point source of N and P to the Canadian environment. In 1996, an estimated 5.6 thousand tonnes of total P and 80 thousand tonnes of total N were released to lakes, rivers and coastal waters from MWTPs in Canada (Table 3.20). This load occurred despite the fact that in 1996 73% of Canadians were served by municipal sewer systems and at least 94% of the wastewater collected by sewers received primary or higher treatment. Most of the N and P in household sewage is from human waste (urine and faeces) and is present in forms immediately available for plant uptake. In addition to household sewage collected in sewers, 1.9 thousand tonnes of P and 15 thousand tonnes of N are released from septic sewage systems and make their way to ground water. Stormwater sewers and combined sewer overflows likely also add approximately 2.3 thousand tonnes of P and 11.8 thousand tonnes of N to surface waters; most of these nutrients are present in particulate forms and are therefore not immediately available to plants. There are no national figures for losses due to leaching from municipal landfills.

Discharge of industrial wastewater adds at least 2.0 thousand tonnes of total P and 11.8 thousand tonnes of N (as nitrate and ammonia) to Canadian surface waters (Table 3.20). This number is an under-estimate as data are not available for NB, NS, PEI, and Québec industries that do not discharge to the St. Lawrence River Basin. In addition, not all industries are monitored in all provinces or territories and N is reported not as total N but as ammonia and nitrate. There are also no national figures for losses due to leaching from industrial landfills.

In 1996, approximately 56 thousand tonnes of P and 294 thousand tonnes of N remained in the field after crop harvest (see details in Table 3.20). There is no national information on how much of this residual P and N moves to surface or ground waters. A recent assessment of N losses from agricultural land where the soils have a water surplus predicted that 17% of Ontario, 6% of Québec and 3% of Atlantic farmland would produce runoff or seepage water with > 14 mg N/L. (Macdonald 2000b). In British Columbia, 5% of the agricultural land has a water surplus and 69% of this area was predicted to generate runoff or seepage water with N concentrations > 14 mg/L.

Table 3.20: Comparison of P and N loading to Canadian surface and ground waters from various sources, 1996. Industrial N loads are based on NO_3 + NH_3 and not total N; industrial data are not available for NB, NS and PEI and Québec industries that do not discharge to the St Lawrence River. Agricultural residual is the difference between the amount of N or P added to cropland and the amount removed in the harvested crop (see Table 3.22 for detailed calculations); data are not available as to the portion of this residual that moves to surface or ground waters.

Nutrient Source	**Total Phosphorus (10^3 t/yr)**						
	Atlantic	**Québec**	**Ontario**	**Prairies**	**British Columbia**	**Territories**	**Canada**
Municipality							
MWTPs[1]	0.9	2.1	1.0	0.6	1.0	0.01	5.6
Sewers							2.3
Septic Systems	0.3	0.5	0.6	0.3	0.2	0.01	1.9
Industry	0[2]	0.01	1.0	0.4	0.7	0	2.0
Agriculture (residual in the field after crop harvest)	10	29	18	-19	13	n/a	56
Aquaculture	0.2	0.01	0.04	0.01	0.2	n/a	0.5
Atmospheric Deposition to Water							n/a

Nutrient Source	**Total Nitrogen (10^3 t/yr)**						
	Atlantic	**Québec**	**Ontario**	**Prairies**	**British Columbia**	**Territories**	**Canada**
Municipality							
MWTPs[1]	4.6	19.9	31.7	13.2	10.6	0.3	80.3
Sewers							11.8
Septic Systems	2.2	3.7	5.0	2.6	1.9	0.05	15.4
Industry	0.1[2]	0.3[3]	9.9	0.6	0.9	0	11.8
Agriculture (residual in the field after crop harvest)	18	46	14	188	29	n/a	294
Aquaculture	0.8	0.04	0.2	0.04	1.2	n/a	2.3
Atmospheric Deposition to Water (NO_3^- N and NH_4^+ N only)	11.9	60.7	54.4	13.9	1.6	39.9	182

[1] MWTPs, municipal wastewater treatment plants

[2] data from Newfoundland only

[3] data for industries discharging to the St. Lawrence River

Aquaculture is a small but growing source of nutrients to Canadian waters. Nutrient release from fish production systems results from the excretion of dissolved or solid waste and from unconsumed feed. Approximately 0.5 thousand tonnes of P and 2.3 thousand tonnes of N are released to coastal and fresh waters from aquaculture operations in Canada (Table 3.20).

Forest management practices that disrupt the cycle of nutrients between the soil and trees (e.g., timber harvest, site preparation and slashburning, and fertilization) may increase stream water concentrations of N and, to a lesser extent, P. However, because the effects have been studied at relatively few sites in Canada, changes in nutrient loading caused by forest management practices cannot be described for most of the country.

Atmospheric Release and Deposition

At least 1 400 thousand tonnes of N is released to the atmosphere each year from anthropogenic sources in Canada (Table 3.21). Of this total, the largest single source of N emissions is agricultural activity, in particular the release of ammonia associated with handling and application of manure and fertilizer. Release of nitrous oxide (N_2O) was split approximately evenly amongst industrial, transportation-related, and agricultural sources. In the case of nitric oxide and nitrogen dioxide (i.e., NO_x), the largest emissions were from industrial and transportation-related sources; NO_x emissions are not available for agricultural emissions but are likely similar to industrial emissions (Janzen et al. 1998). Reliable data are not available for P emissions to air.

Once pollutants are released to the air, they may be transported by winds and global air circulation for great distances before they are deposited on land and water. Nitrate is the nutrient in highest abundance in atmospheric deposition. Nitrogen loads due to wet deposition of nitrate and ammonium average 3.4 kg N/ha/yr east of the Manitoba-Ontario border compared to 0.8 kg N/ha/yr west of the border (Figure 3.12). Nitrate and ammonia deposition is considerably higher in eastern than in western Canada as a result of industrial activities in Central Canada and the northeastern USA. In contrast to N, P deposition is not routinely measured. The few studies conducted found that P inputs from wet and dry deposition together ranged from 0.01 to 0.7 kg/ha/yr.

Table 3.21. Sectoral comparison of N loading from anthropogenic sources to the Canadian atmosphere. Data are 1995 estimates unless indicated otherwise. N_2O data from Environment Canada 1997a except agriculture N_2O data which are from Desjardins and Keng 1999; NO_x data from Environment Canada 1999a; industrial ammonia data from Environment Canada 1999b; other ammonia data from Vézina 1997.

Nutrient Source	**N_2O (10^3 t/yr N)**	**NO_x (10^3 t/yr N)**	**NH_3 (10^3 t/yr N)**
Industrial emissions	27	275	27
Transportation combustion	31	393	4
Agricultural emissions[1]	38[2]	n/a[3]	570
Other	2	82	19
Canadian anthropogenic total	98	750	623

[1] does not include fuel combustion or biomass burning.

[2] 1996 data

[3] possibly similar in magnitude to industrial emissions (Janzen et al. 1998); agricultural emissions not included in total.

Additions to Soils

Fertilizer and manure nutrients applied to agricultural lands are essential to maintain crop yield and soil health. In 1996, 297 thousand tonnes of P and 1576 thousand tonnes of N as fertilizer were applied to cropland in Canada (Table 3.22). In addition, 139 thousand tonnes of P and 384 thousand tonnes of N were applied as manure. Biosolids (the portion of sewage sludge that has been stabilized to meet regulations for land application) may also be applied to agricultural land. Of the estimated 500 thousand tonnes of sewage sludge produced annually in Canada (early 1980s data; OECD 1995), approximately 42% is applied to agricultural land and supplies 8 thousand tonnes of N and 5 thousand tonnes of P. An additional 43 thousand tonnes of N are added to cropland as a result of wet deposition of nitrate and ammonium.

In addition to desirable nutrient inputs to soils (e.g., commercial fertilizer, manure and biosolids), nutrients are also added as a result of waste disposal. An estimated 10.5 million tonnes of residential solid waste were collected by municipalities across Canada in 1992 (Environment Canada 1996c). The majority of residential solid waste is landfilled, with the remainder incinerated, recycled, or composted, in the case of some organic waste. In the case of industrial solid waste, approximately 12 million tonnes were generated in Canada in 1995. Of this, 78% was landfilled, 20% recycled, and the remainder incinerated (Statistics Canada 1998b). Nitrogen and P release from the breakdown of solid waste is not known.

Table 3.22. Sectoral comparison of N and P loading from anthropogenic sources to Canadian soil. Fertilizer, manure and legume data are from 1996; forestry data are from 1994-95; biosolids are data from the early 1980s; compost data are from 1996, and atmospheric data are from 1995. See text for data sources and calculations. Atmospheric deposition includes only NO_3^--N and NH_4^+-N.

Nutrient Source	**TN (10^3 t/yr N)**	**TP (10^3 t/yr P)**
Added to Crop Land		
Fertilizer	1576	297
Manure	384	139
Legumes (total atmospheric N fixed)	773	
Biosolids	8.4	5.3
Atmospheric Deposition (arriving from long distance transport)	43	
Total added	2784	442
Removed with the harvest	2491	386
Difference	293	56
Added to Forested Land	1.4	
Compost	3	5.5
Atmospheric Deposition to Non-Cropland	1495	
Added to Landfill		
Biosolids	3.6	2.3
Solid waste	n/a	n/a