8.0 Conclusions

8.1. Issue

Nitrogen (N) and phosphorus (P) are natural resources for which there is intense competition in terrestrial and aquatic ecosystems not greatly affected by human activity. Until recently, the supply of N and P for most plants, and ultimately to animals, was limited. The most abundant N source, N gas, could only be used by plants once it was fixed by certain bacteria or algae into ammonium or nitrate compounds. Similarly, the most abundant P source, P-bearing minerals, only became available by weathering. Consequently, N or P was a limiting nutrient in most ecosystems prior to human settlement and agricultural development. Moreover, because N and P were in high demand, these nutrients were stored and recycled in close proximity to the locale from which they were scavenged. This pattern was true for plants and animals, including humans because, prior to urbanization, faeces from livestock and humans along with other composted waste was returned to the soil, thereby closing nutrient recycling loops and maintaining the fertility of the soil.

The amount of N and P available for plant uptake has increased dramatically in the past several decades. The causes are a massive increase in the use of fertilizer, burning of fossil fuels, development of large urban populations, and an upsurge in land clearing and deforestation. The amount of available N has more than doubled since the 1940s, with human activities contributing 210 million tonnes per year to the global supply of N, compared to only 140 million tonnes generated per year by natural processes (Vitousek et al. 1997). Similarly, natural weathering of phosphate-bearing rocks is now overshadowed by mining activities as a source of P, with approximately 140 million tonnes of phosphate-bearing rock now mined each year.

This influx of nutrients has disrupted the natural cycles of both N and P. Where animal manure and human wastes were historically spread on farmland to recycle nutrients, a “once-through” system now predominates. Thus, phosphates extracted from mined phosphate rock and inorganic N fixed from N gas by industrial processes are applied to agricultural land or fed to livestock. Nutrients in the form of foodstuffs flow from the farm to the cities, where most ultimately end up in landfill (sewage sludge, incinerator ash), or in surface or ground waters. Reactive N and P released to the atmosphere as a result of agricultural practices, as industrial emissions and, in the case of N, as by-products of home heating and automobile engine combustion are transported and deposited hundreds or thousands of kilometres from their origin.

This once-through system of nutrient use is not economically sustainable. In the case of P, the known reserves of currently exploitable phosphate rock are about 3.6 to 8 billion tonnes P_2O_5 with another 11 to 22 billion tonnes P_2O_5 considered potentially available if the necessary investments were made (Steen 1998). At the current rate of consumption (31 million tonnes P_2O_5 in 1995-1996 and allowing for intensification of agriculture in developing countries), current economically exploitable reserves could be exhausted in 100 years (Steen 1998). Moreover, high-grade phosphate reserves are already depleted from some sources and the quality of phosphate rock used worldwide is declining (i.e., phosphate rock reserves are now lower in their P content and higher in their contaminant content, specifically heavy metals, iron and aluminum) (Steen 1998).

In addition to the economic consequences of the breakdown in nutrient recycling, the environmental consequences resulting from addition of bioavailable N and P to the Earth's ecosystems could be profound. Globally, one of the best-documented problems caused by N overload is the eutrophication of estuaries and coastal seas (Nixon 1996). Eutrophication in coastal waters has led to increased anoxia and hypoxia, loss of seagrasses, alteration of foodwebs, loss of biological diversity, and increased incidences of nuisance algal blooms (Howarth 1993). A recent report from the US National Academy of Sciences concluded that "perhaps the most pressing problem in many estuarine and marine systems today is that of nutrient enrichment" (Boland et al. 1993). Similarly, additions of anthropogenically-derived P have increased eutrophication of aquatic ecosystems throughout much of the world (Caraco 1993).

8.2. Impacts of Nutrients on Canadian Environments

There is clear evidence that nutrients are causing problems in certain Canadian ecosystems. The severity and geographic extent of nutrient-induced environmental problems are not yet as great as in countries with a longer history of settlement or agricultural production (e.g., many European countries). Our assessment of the effects of anthropogenic nutrients on Canadian ecosystems showed that aquatic ecosystems (lakes, rivers, freshwater and coastal wetlands, and coastal waters) are subjected to some of the highest nutrient loading and show the greatest nutrient impairment. The addition of nutrients to inland waters typically exhibits a two-phase response whereby moderate nutrient addition to relatively low-nutrients waters stimulates aquatic plant and animal productivity and increases biodiversity (Table 4.6). However, prolonged nutrient addition results in excessive aquatic plant growth, loss of plant species (particularly rare species), depletion of oxygen, and deleterious changes in abundance and diversity of aquatic invertebrates, fish and possibly birds and mammals dependent upon these habitats. Ground waters across Canada also exhibit elevated nitrate concentrations that have human health implications for consumers of this water and may contribute to the eutrophication of surface waters (Table 4.6). Although concentrations of N are also elevated in the atmosphere, the ecological consequences from atmospheric deposition of N are not as pervasive as those observed from loading to surface waters. Atmospheric deposition of inorganic N is greater in eastern Canada (east of the Manitoba-Ontario border) and there is evidence that some N limited forests have responded with increased productivity and that some forested watersheds in central Ontario and southern Québec are in the early stages of N saturation (Table 4.6).

Based upon our review of available scientific evidence, we are certain that N and P loading from human activity has:

- accelerated eutrophication of certain rivers, lakes and wetlands in Canada, resulting in loss of habitat, changes in biodiversity and, in some cases, loss of recreational potential (Figure 4.10; Table 4.6).
- increased the frequency and spatial extent to which the drinking-water guideline for nitrate has been exceeded in ground waters across Canada and caused economic burden for those Canadians who must transport household water from off-site sources (Table 5.10).

- caused and continues to cause fish kills in Southwestern Ontario due to ammonia toxicity (Table 5.7; Table 5.8; ‘Agricultural Water Pollution: Fish Kills in Southwestern Ontario’ text box, Chapter 5.2).
- contributed to the decline in amphibians in southern Ontario due to long-term exposure to elevated nitrate concentrations (Amphibians in Danger’ text box, Chapter 5.2).
- led to elevated risks to human health through increased frequency and spatial extent of toxic algal blooms in Canadian lakes and coastal waters (‘Contaminated Mussels’ text box, Chapter 5.2).
- contributed to acidification of soils and lakes in southern Ontario and Québec and resulted in incipient N saturation in some forested watersheds (Chapter 4.1).
- increased carbon production in Canada’s forests due to N deposition (Chapter 4.2). Uncertainty remains, however, as to whether the productivity gains resulting from increased N deposition along with a warming climate and elevated CO_2 levels in the atmosphere have offset the carbon loss caused by timber harvest, fire and insect-induced mortality.
- increased concentrations of the potent greenhouse gas N_2O and increased concentrations of N oxides that contribute to the formation of photochemical smog in certain Canadian cities (Chapter 2.1).
- contributed to quality of life concerns for Canadians through water use impairments (e.g., excessive algal and aquatic weed growth; Table 4.6); aesthetic (taste and odour) concerns related to water supplies (e.g., due to geosmin and 2-methylisoborneol) (Chapter 4.2); and contamination of water supplies (e.g., by nitrate and by trihalomethanes (THMs) produced as by-product of disinfection of water containing organic material) (Chapter 5.3).
- increased the economic burden to Canadians as a result of the need for treatment, monitoring and remediation of contaminated water (Chapter 6.1).

8.3. Sources of Nutrients to Canadian Surface and Ground Waters

Municipal Wastewater

Municipal wastewater is the largest point source of N and P to the Canadian environment (Table 3.20). In 1996, an estimated 6 thousand tonnes of total P and 80 thousand tonnes of total N were released to lakes, rivers and coastal waters from Canadian households. This loading occurred despite the fact that 73% of Canadians were served by municipal sewer systems and at least 94% of the wastewater collected by sewers received primary or higher treatment.

Phosphorus discharges from municipal wastewater treatment plants (MWTPs) have decreased while N discharges have increased in recent years. Phosphorus discharge has decreased by 37% since 1983 and by 20% since 1991 as compared to 1996. This trend is due to the implementation of advanced P removal at many MWTPs discharging to inland waters. In contrast, most municipal wastewater discharged to coastal waters is either untreated or receives only primary treatment. Consequently, P loading to Atlantic or Pacific coastal waters has remained constant or increased in areas with increasing population. Nitrogen removal is rarely employed at Canadian MWTPs because of the high infrastructure costs associated with N removal technology and because most fresh waters are limited by P. Nitrogen loading to Canadian surface waters has therefore increased in response to population increases, and in 1996 was 17% higher than in 1983 and 7% higher than in 1991.

In addition to routine discharge of wastewater, MWTPs may occasionally experience a discharge of raw sewage (known as a bypass). In most provinces, these are not allowed except in emergency situations, such as protecting basements from flooding, preventing damage to MWTP equipment and averting the wash-out of solids. Data from Ontario in 1991 showed that 37% of MWTPs reported a bypass and the volume released during all bypasses equalled 0.6% of the total effluent volume treated. Bypasses of even small volumes are important because the P concentration in raw sewage is about ten times that in treated sewage.

Although most Canadians are served by MWTPs, approximately 25% are served by septic disposal systems. These systems were originally designed for houses widely separated from their nearest neighbour; however, today, septic disposal systems are present in many parts of the country in numbers too great for their land base, for example in the Lower Fraser Valley. In addition, older septic systems are not always properly maintained and some were built in unsuitable sites. In general, septic systems retain about 20 to 55% of the N and 25 to 40% of the P entering the system, with additional P retained in the drain field (Ryding and Rast 1989). Based on a 1996 population, an estimated 1.9 thousand tonnes of P and 15 thousand tonnes of N were released from septic systems in Canada. The released N and P can move into ground water and, from there, to surface waters.

Most of the N and P in household sewage is from human waste. In the case of N, more than 90% of the household load is derived from urine and faeces. P sources are more varied than for N. Analysis of 1996 data showed that human waste was the largest contributor to municipal P loading in Canada followed by commercial and industrial sources.

Discharges from Municipal Sewers

In urban areas, snowmelt or stormwater runoff empties into the municipal sewer system. Sewer systems built before the early 1940s convey both raw sewage and stormwater (so-called “combined sewers”). When rain or snowmelt exceed the capacity of the sewer system or MWTP, raw sewage and stormwater are released from outfalls into rivers, lakes or coastal waters, an event known as a combined sewer overflow (CSO). Urban areas developed since the 1950s typically have two sewer systems: one that collects raw sewage (i.e., sanitary sewers) and a second system that conveys stormwater (i.e., storm sewers). The quantity and quality of both combined sewer overflow and stormwater vary temporally and regionally, and are not routinely measured. In general, combined sewer overflows represent about 5% of the national MWTP annual discharge; they are typically more dilute than raw sewage but stronger in concentration than stormwater or treated sewage. Stormwater volume is comparable in volume, however, to the 4 300 million cubic metres discharged annually by MWTPs, although it is discharged only during wet weather. The majority of the N and P in combined sewer overflows and stormwater is in a particulate form and, thus, does not contribute immediately to eutrophication. The most immediate consequences of stormwater release or combined sewer overflows are bank erosion and elevated water turbidity and bacterial counts.

Industrial Wastewater

Most light industries discharge their wastewater into the municipal sewage system for treatment at the MWTP; therefore they are not necessarily required to report on the quality of their wastewater. However, some municipalities have sewer use bylaws that regulate the strength of industrial discharges to sewer systems. MWTPs are designed to reduce bacterial contamination and biological oxygen demand, remove most P and, in some cases, convert ammonia to nitrate. There is little ability to do more than volatilize or dilute many industrial wastes.

Industries not connected to a municipal sewage system must obtain operating permits from the government of the province 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.

Because not all provinces provided industrial release data and because not all industries that release wastewater are required to measure nutrients, comparisons of N and P loads among regions and among sectors cannot be made. 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 to surface waters in Canada (Figure 3.6).

Agricultural Runoff and Leaching

Nutrient balances for Canada in 1996 indicated that crop removal of N and P was 89% and 87%, respectively, of nutrients added as manure, fertilizer and, in the case of N, atmospheric deposition and legume fixation. The portion remaining in the field (i.e., the difference between input and output) represents a nutrient surplus. Expressed on an areal basis, the 1996 N surplus for Canada was 4.3 kg/ha for the total area of agricultural land (68 million ha) or 8.4 kg/ha for cropland (35 million ha). Similarly, P surplus for Canada was 0.8 kg/ha for total area of agricultural land or 1.6 kg/ha for cropland in Canada. It should be noted, however, that these are average values and N surplus or deficits may occur at a local or regional scale. 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 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 St. John River Valley in New Brunswick (MacDonald 2000a).

Of the surplus N or P measured in a field, only a portion actually moves from the field to ground or adjacent surface waters. Although national estimates are not available for nutrient losses from agricultural fields to surface and ground waters, a recent assessment of N losses from agricultural land where the soils have a water surplus predicted 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. Information on P losses from agricultural fields in Canada is not yet available.

Other sources of agricultural nutrients to surface waters are discharges such as milk house wastes that drain through connected tile drains to streams, cattle allowed unlimited access to streams, erosion of stream banks due to livestock trampling or tillage, and greenhouse waste. Feedlots, in particular, are an unprecedented concentration of nutrients in the form of imported food and resultant waste into a small area. There are few regional or no national data on these types of losses.

Releases associated with Aquaculture Operations and Fisheries Enhancement

Nutrient release from fish production systems ("aquaculture") results from excretion of dissolved or solid waste and from unconsumed feed. In addition to the number of fish cultivated, the quantity and quality of the feed are the most important factors that determine the generation of nutrient release in the form of feed wastage and excretion (Persson 1991; Cho and Bureau 1997). Emissions and treatment of effluents from tank or pond aquaculture are controlled by provincial legislation; cage finfish aquaculture occurring directly in water bodies is of more concern. Unlike terrestrial feedlots and agricultural operations that have been under pressure for decades to reduce nutrient pollution of water, cage aquaculture waste is entirely released to the surrounding aquatic ecosystem.

In 1996, 53 thousand tonnes of finfish were harvested from aquaculture operations in ten Canadian provinces. Of this production, 58% was in marine environments and 42% in freshwater operations, the majority occurring in British Columbia and New Brunswick. Phosphorus and nitrogen losses for the total Canadian finfish production in 1996 were 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. By comparison, a population of 100 000 served by secondary sewage treatment releases 25 t/yr P and 365 t/yr N as wastewater.

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 for salmon fry. For example, 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, which increased both spawner size and fecundity of Kokanee salmon (Ashley et al. 1997).

Runoff from Landfill Sites

There are no national estimates of nutrient losses from landfills, although localized inputs may be significant. For example, municipal landfills in the Fraser River Basin, British Columbia released an estimated 145 tonnes of ammonia-N per year to surface waters in 1995; an additional 6 tonnes per year of ammonia-N was leached from pulp and paper mill landfills (Gartner Lee Ltd. 1997).

Forest Management Practices

Undisturbed forested lakes and streams on uplands of the Canadian Shield generally contain low concentrations of NO_3^-, NH_4, and PO_4 (Nicolson 1988; D'Arcy and Carigan 1997; Carginan et al. 2000). The relative areal extent of peat and beaver pond is important to the amount of TP, NH_4, and TON exported from forested catchments (Dillon et al. 1991). Disturbance of forested ecosystems has had variable effects on dissolved nutrient movement in soil, and on subsequent nutrient loss to streams and lakes (Krause 1982; Feller and Kimmins 1984; Nicolson 1988; Titus et al. 1997). Forest management practices that disrupt the normally efficient cycling of nutrients between the soil and trees may produce increases in streamwater concentrations of dissolved N and, to a lesser extent, P. For example, paired watershed studies have been used to demonstrate that clearcutting of coastal coniferous forests (Feller and Kimmins 1984) or temperate hardwood forest (Krause 1982) can produce short-term increases in NO_3^- concentration in streams. Comparisons of Boreal Shield lakes in reference and harvested watersheds have shown high total P and total organic N concentrations and higher phytoplankton abundance in the disturbed lakes immediately after timber harvest (Carignan et al. 2000; Planas et al. 2000).

In general, N or P fertilizers are not routinely applied to forests in most of Canada. In British Columbia, N is occasionally applied to coastal forests. Experimental studies suggest that most of the N applied to a coastal fir forest (Preston et al. 1990) and boreal pine forests (e.g., Morrison and Foster 1977) was retained by the trees and soil, although low recoveries of added N have been reported (Preston et al. 1990). Short-lived NO_3^- increases in soil leachate (Pang and McCullough 1982) and stream water (Heatherington 1985) have been reported. The impact of N fertilizers on streams and lakes, nevertheless, should be short–term and minimal if fertilization with nitrate based fertilizers and direct application to surface waters are avoided.

Nutrient losses to stream water from forest management practices have been defined for relatively few sites in Canada. It is difficult to generalize about the effect of forest management practices on water quantity and quality, regionally or nationally, because of the large climatic, topographic, soil and vegetation diversity across the country that must be considered when assessing management impacts.

8.4. Sources of Nutrients to Canadian Soils

Fertilizer and manure nutrients applied to agricultural lands are essential to maintain crop yield and soil health. Only a small portion of these nutrients is returned in the form of agricultural (livestock and crop) production. In 1996, 1 576 thousand tonnes of N and 297 thousand tonnes of P as fertilizer were applied to cropland in Canada (Table 3.22). In addition, 384 thousand tonnes of N and 139 thousand tonnes of P 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 biosolids 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.

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. 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). The majority of residential solid waste is landfilled, with the remainder incinerated, recycled or composted, in the case of some organic waste. As regards industrial solid waste, approximately 10 million tonnes were generated in Canada in 1995. Of this, 78% was landfilled and 20% was recycled, with the remainder incinerated (Statistics Canada 1998b). N and P release from the breakdown of solid waste is not known.

Nitrogen and phosphorus also enter terrestrial (as well as aquatic) ecosystems from atmospheric deposition. 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. N deposition (as nitrate and ammonium) averages 3.4 kg N/ha/yr east of the Manitoba-Ontario border compared to 0.8 kg N/ha/yr west of the border (Table 3.18). Fewer data are available on dry deposition of N; typically dry deposition accounts for a much smaller fraction of atmospheric N loads than wet deposition. 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 0.74 kg/ha/yr. An estimated 43 thousand tonnes of N fall on cropland, 117 thousand tonnes of N fall on farmland not used for growing crops, 182 thousand tonnes of N fall on inland waters and 1 378 thousand tonnes of N fall on non-agricultural land in Canada as a result of atmospheric deposition of nitrate and ammonium.

8.5. Sources of Nutrients to the Canadian Atmosphere

N is released to the atmosphere largely as nitrous oxide (N_2O), other N oxides (NO_x) and ammonia (NH_3).

Nitrous oxide (N_2O) is largely produced from the combustion of coal, petroleum products and natural gas, and from the use of manure or commercial N fertilizers. In 1995, 60 thousand tonnes of N_2O-N were released to the atmosphere from Canadian non-agricultural sources. Most (31 thousand tonnes) of this N was released as a result of the combustion of fuel for transportation (i.e., in car, truck, airline and boat engines) (Table 3.21). Only 3 thousand tonnes of N_2O-N were due to industrial combustion-related emissions. Another 24 tonnes of N_2O-N were emitted to the atmosphere as a result of manufacturing nitric and adipic acid. Nitrous oxide can also be released from agricultural soils following the application of manure or inorganic N fertilizers. In 1996, 38 thousand tonnes of N_2O-N were released as a result of agricultural activities in Canada (i.e., direct emission from agricultural soils, direct emission from grazing animals and animal waste management, and indirect emission from volatilization, leaching and runoff) (Desjardins and Keng 1999).

Nitric oxide and nitrogen dioxide (i.e., NO_x) are also produced during the combustion of fossil fuels. Canadian nitrogen oxide emissions for 1995 were 750 thousand tonnes N, excluding agricultural emissions for which no data were available (Environment Canada 1999a; Table 3.21). Fossil fuel combustion attributable to transportation (i.e., cars, trucks, airlines and boats) contributed 393 thousand tonnes. Another 189 thousand tonnes of NO_x-N were emitted as a result of industrial processes. Agriculture emissions are estimated to be of similar magnitude to industrial emissions (Janzen et al. 1998).

Anthropogenic release of ammonia largely arises from the storage and handling of manure and fertilizer, adding 570 thousand tonnes of ammonia-N to the atmosphere in 1995 (Vézina 1997; Table 3.21). An additional 27 thousand tonnes of ammonia-N were released to the atmosphere by industrial emissions, most from industries engaged in the manufacture of N fertilizers

Recent data are not available for P release to the atmosphere. A 1978 assessment reported that 3 402 tonnes of P were released to the atmosphere by Canadian sources (Environment Canada 1983). Of this, an estimated 1.98 thousand tonnes were from industrial processes, most of which were associated with the production of fertilizer. Another 783 tonnes of P were lost to the atmosphere during fertilizer application. The contribution from incineration of solid waste (residential and industrial) to the atmosphere was estimated to be 123 tonnes of P.

8.6. Summary

This review has demonstrated the national scope of nutrient-related impacts on aquatic and terrestrial ecosystems in Canada. In response to the objectives identified for this assessment, namely “to determine whether or not nutrients in general are causing negative environmental effects; whether only certain nutrients, rather than nutrients as a class, are problematic, and; whether those effects are limited … to water or to entire ecosystems, including wildlife” (Government of Canada 1995), we conclude that:

- ***nutrients released to the environment from human activity are impairing the health of certain ecosystems, contributing to quality of life concerns for Canadians and, on occasion, endangering human health.*** There is clear evidence that N and P loading from human activity has contributed to eutrophication of certain rivers, lakes and wetlands in Canada; caused fish and amphibian lethality; increased the frequency and spatial extent to which the drinking-water guideline for nitrate has been exceeded in ground waters across Canada; led to elevated risks to human health through increased frequency and spatial extent of toxic algal blooms in Canadian lakes and coastal waters; contributed to the acidification of soils and lakes in southern Ontario and Québec and resulted in incipient N saturation in some forested watersheds; increased concentrations of the potent greenhouse gas N_2O and increased concentrations of N oxides that contribute to the formation of photochemical smog in certain Canadian cities; contributed to quality of life concerns for Canadians through water use impairments and aesthetic concerns related to water supplies; and increased the economic burden to Canadians as a result of the need for treatment, monitoring and remediation of contaminated water.
- ***these nutrient impacts tend to be associated with certain nutrient forms.*** Most lakes and many rivers in Canada are intrinsically P limited. Consequently, addition of bioavailable P (i.e., P in the form of phosphate, PO_4^{3-}) has accelerated eutrophication of certain lakes, rivers, and wetlands. In contrast to inland waters, the complex nature of coastal environments, high flushing rates, and inputs of N-rich deep oceanic waters have generally minimized widespread effects of anthropogenic nutrients on these ecosystems although localized problems exist. Nitrate contamination is of concern with respect to ground water reserves used as sources of drinking water. Concerns about nutrients in the atmosphere also relate primarily to N because of its role in urban smog production and greenhouse warming. Atmospheric deposition of nitrate and ammonium has increased carbon production in Canada's forests. Atmospheric deposition of nitrate has also contributed to the acidification of soils and lakes in southern Ontario and Québec.
- ***although the predominant and most demonstrable impacts to date have occurred in aquatic ecosystems and caused water use impairments, the first symptoms of negative effects on forest ecosystems have also been observed.*** For example, atmospheric deposition of nitrate has contributed to acidification of soils and lakes in southern Ontario and Québec and resulted in incipient N saturation in some forested watersheds. Deposition of ammonia and nitrate has also increased carbon production in certain forests in Canada; however, associated changes in plant and wildlife biodiversity as seen in countries with high levels of atmospheric N loading have not been reported in Canada to date.

8.7. Information Gaps

This assessment identified the effects of anthropogenic nutrients on Canadian ecosystems and the sources of these nutrients. We have documented deleterious changes in Canadian ecosystems as a result of nutrient loading and the impacts of these changes on the quality of life of Canadians (see Chapter 8.2). However, our ability to assess changes in ecosystems in response to added nutrients was constrained by data limitations. These limitations could largely be divided into two categories: insufficient monitoring data of emissions and discharges and ambient conditions, and insufficient knowledge as to the effects of nutrient additions to ecosystem and human health.

Insufficient monitoring data: Although every attempt was made to define the status of Canadian ecosystems with respect to nutrients, data on sources and impacts became progressively less available as one moved from lakes to rivers/streams to wetlands to ground water to coastal waters to forests. Topics requiring particular attention are:

- industrial loading to surface waters. At present, the availability of N and P data for industries not connected to MWTPs is erratic: monitoring and reporting requirements vary among provinces and territories, and among industrial sectors. Of the 2 130 industries in Canada with discharge permits, we obtained data on nutrient loading for only 91 for nitrate, 142 for ammonium, and 191 for total P (Table 3.6). Moreover, the data are not stored in any single database.
- MWTP loading to surface waters. At present, data on N and P loading are available for certain MWTPs in Canada but the data are not consistent in parameters measured or frequency of sampling. In addition, the data are not stored in any single database. Our analysis of nutrient loading from MWTPs was achieved by applying per capita nutrient loading coefficients to the population served by the various levels of sewage treatment.
- agricultural loading to surface and ground waters. Although studies have been conducted at the scale of plots, fields or small watersheds, regional or national estimates of nutrient loading to surface and ground water could not be calculated.
- atmospheric deposition of P and total N. Although estimates of atmospheric deposition of inorganic N are available through a network of provincial and federal monitoring sites, similar data are not available for P or total N, nor are estimates available for release from various sectors.
- ground water quality. Water well survey programs are patchy across the country. Some wells are already above or close to guidelines for nitrate and bacteria. Little information is available on ammonia and P in ground water.
- fish kills from accidental spills/discharges of nutrient-related compounds. Currently, reporting is on a voluntary basis.

Effects of nutrient addition on ecosystem and human health: Nutrient management is a persisting environmental issue unlike others, such as toxic chemicals that can be eliminated by reformulation or discontinuance. Additional research is required to understand the effects of added nutrients on Canadian ecosystems. Areas requiring particular attention are:

- fate and transport of nutrients within different ecosystems (wetlands, coastal waters, forests, rivers, and lakes) and effects on biota.
- the role of nutrients in inducing blue-green algal blooms and toxin production.
- the role of nutrients in causing taste and odour problems in drinking-water supplies.
- interactions of nutrients with organic contaminants and their effects on aquatic food webs.
- effects of sewage and industrial wastewater plumes on aquatic life during periods of ice cover (i.e., limited mixing of the plume and cold water temperatures).
- effects of long term (decades) of nutrient loading on aquatic and terrestrial ecosystems, including water and sediment/soil quality and food webs.
- effects of forest management practices on nutrient loss from forests to aquatic ecosystems.
- cumulative effects on the aquatic environment from the combination of several nutrient sources all operating within a region.
- the relationship between nutrient concentrations and aquatic plant biomass, particularly for streams and coastal waters, and the level of nutrients that begins to impair beneficial uses of streams for the preservation of aethetics/recreation and protection of aquatic life.

8.8. Prognosis for Future

Over the past 100 years, the demand for water has increased steadily in Canada. This is partly a result of population growth and increasing municipal demands for water. It is also related to energy-intensive industrial development, expansion of irrigated agriculture, and rising living standards.

The Brundtland Commission called for sustainable development that meets the needs of this generation without compromising the ability of future generations to meet their needs. Maintaining the quality of the air, water and soil environments with respect to nutrients is an important component of sustainable development. Yet studies have already shown that in parts of the world, a surfeit of fixed N (compounds such as ammonia and nitrogen oxides) is overwhelming ecosystems ranging from forests to coastal waters. This N, largely from synthetic N fertilizers and nitrogen oxides discharged from cars and industries, can no longer be absorbed by terrestrial ecosystems and so is ending up in rivers, lakes, estuaries and oceans. This additional N is causing coastal algal blooms that can be toxic and can deplete the water's oxygen supply when they sink and decay. In addition, excess N is also adversely affecting terrestrial ecosystems by displacing ions from forest soils, thereby leading to mineral deficiencies and ultimately death of forest trees. In 1997, both the Ecological Society of America and the International Scientific Committee on Problems of the Environment named N pollution as a "pre-eminent problem" that is not being given enough public recognition.

This report has clearly demonstrated the symptoms of environmental degradation from anthropogenic nutrient loading in Canada. At present, environmental problems caused by excessive nutrients are less severe in Canada than in countries with a longer history of settlement and agricultural production. This trend is due to our relatively small population compared to our land base and the protective measures implemented by both the federal and provincial/territorial governments in the last 30 years. However, while successes have been realized, environmental and human health problems related to nutrients are evident across Canada. Unlike countries with long histories of settlement and agriculture and, consequently, more severe pollution, we are currently in the position of being able to deal with nutrient pollution before it is overwhelming. Science-based solutions are available that can assist in further reducing nutrient losses and, in turn, improving environmental quality. New technologies are emerging that can minimize nutrient loading to the environment. Options for reducing nutrient loading are available, particularly from countries with a long history of nutrient problems. Nutrient-related research and monitoring are essential to ensure decision-making is based upon sound science. It is critical that the gains achieved by improved wastewater treatment and other control measures not be reversed by relaxation of standards or by failure to keep pace with population growth, and that the best and most advanced science be integrated into practical solutions.