Depending upon the nature of the forest practice, forestry activities may significantly affect water quality of surface waters draining forests, and these are typically regulated as non-point sources of pollution.[223] The primary pollutants associated with forest practices are pesticides, sediments, nitrate-N, and phosphates. The first typically enters into aquatic surface waters or groundwater via direct over-spraying or spray drift during aerial applications for pest control, runoff, and leaching.[224] In most cases, pesticides used in forestry are non-persistent and degrade quickly under normal environmental conditions. However, the impact, when present, may be felt by organisms not targeted, primarily fish, which have been investigated extensively in relation to historical applications of DDT, aminocarb, and fenitrothion used to control forest pests.[225] Overall, there are few documented accounts of forest pesticides in drinking water. In a 1993 review of over a decade of research on the use of pesticides in forestry operations, Neary et al. concluded that the low concentrations and short persistence of forestry pesticides in surface water and groundwater do not pose a significant risk to water quality, aquatic biota, or human health.[226]

In addition to pesticides, forestry may contribute significant quantities of sediments, nitrate-N, and phosphorus; loadings of these compounds typically increase after the harvesting and fertilization of forests. The environmental significance of siltation was discussed earlier in relation to the general degradation of surface waters and fish habitat. Nitrate-N can be a significant problem for human health, but the overall contribution of nitrate from forestry operations is very small compared to agricultural and atmospheric sources, and it is rare that forestry practices contribute N at levels exceeding water quality criteria in the United States or Canada.[227] Phosphorus is not a significant concern in drinking water, but it may cause increased enrichment (eutrophication) of receiving-water environments, leading to an increase in productivity in lakes and streams and a corresponding reduction in water and habitat quality.

---

[223] D. Binkley and T.C. Brown, 1993, "Forest practices as non-point sources of pollution in North America," *Water Resources Bulletin,* vol. 29, pp. 729–40.

[224] D.G. Neary et al., 1993, "Fate, dissipation and environmental effects of pesticides in southern forests: A review of a decade of research progress," *Environmental Toxicology and Chemistry,* vol. 12, pp. 411–28.

[225] D.C. Eidt et al., 1989, "Pesticides in forestry and agriculture: Effects on aquatic habitats," *Aquatic Toxicology and Water Management* (New York: John Wiley & Sons), Advances in Environmental Science and Technology series, vol. 22, pp. 245–84.

[226] Neary et al., 1993.

[227] Binkley and Brown, 1993.

Urban/Suburban Pesticide Use The home and garden sector uses relatively small amounts of pesticides compared to agriculture (see figure 2-7). For example, in the United States, 8.9% (herbicides), 14.3% (insecticides), and 5.9% (fungicides) of all pesticide use was attributed to urban activities such as lawn and garden maintenance, golf course and cemetery applications, and insect pest control of household plants and gardens. Among insecticides, chlorpyrifos and diazinon are most common where they are used in numerous household applications, such as dormant sprays on fruit trees, in professional landscape and maintenance uses, and in structural pest control agents.[228] Both are regularly detected in urban runoff and occasionally in drinking water. For example, Bailey et al. measured these two insecticides in several urban streams in California.[229] Both were detected in the majority of samples collected. More importantly, diazinon levels exceeded the California Fish and Game criterion for this pesticide in 85% of samples collected (n = 231); chlorpyrifos exceeded its criterion in 80% of samples collected (n = 90). Recently, the USEPA initiated a ban on certain uses of chlorpyrifos because of potential increased risks to children, including exposure via drinking water.[230] Parker et al. found that organochlorines such as DDT, DDE, dieldrin, chlordane, and toxaphene were ubiquitous, although generally low in concentration, in urban runoff samples collected in Phoenix, Arizona, despite the fact that these compounds have been banned for up to 30 years.[231]

Many of the transport pathways along which pesticides move to surface water or groundwater are the same in urban areas as they are in agricultural areas; however, the greater frequency of impervious surfaces (concrete, asphalt) in urban areas increases the efficiency and rapidity with which pesticides (and other contaminants) are moved to surface waters by runoff during rainfall or lawn watering. Moreover, the impermeable surfaces of urban areas have few adsorptive sites that might otherwise bind and retain the pesticides. Interestingly, studies have shown that well maintained lawns, including those on golf courses,

---

[228] H.C. Bailey et al., 2000, "Diazinon and chlorpyrifos in urban waterways in northern California," *Environmental Toxicology and Chemistry,* vol. 19, pp. 82–87.

[229] Ibid.

[230] United States, Environmental0 Protection Agency, 2000a, "Chlorpyrifos revised risk assessment and agreement with registrants," *Prevention, Pesticides, and Toxic Substances* (7506C) [online], [cited October 23, 2001], <www.epa.gov/pesticides>.

[231] J.T.C. Parker et al., 2000, "Chemical characteristics of urban stormwater sediments and implications for environmental management, Miricopa County, Arizona," *Environmental Management*, vol. 26, pp. 99–115.

can prevent or greatly mitigate the loss of pesticides applied to them, thereby minimizing the amount reaching surface waters and groundwater.[232]

Roadway and Rights-of-Way Herbicides are often applied to roadways and rights-of way to control weeds and grasses for safety and aesthetic purposes, and occasionally to create firebreaks.[233] The most common herbicides used in this context include 2,4-D, triclopyr, and picloram. On rare occasions, such insecticides as fonofos may also be applied to control pests, e.g., grasshoppers, during periods of heavy infestation. Pesticides used along roadways and rights-of-way may enter adjacent aquatic or groundwater environments via spray drift, volatilization, runoff, or leaching; however, the relative contribution from each source is unclear.[234] A study conducted in Ontario showed that 2,4-D applied to a right-of way could be detected in soil samples taken up to 36 m from the original place of application and in water samples taken from a nearby lake.[235] However, residual concentrations of this herbicide were well below levels of toxicological concern. The Watson team found little evidence of movement of the herbicide picloram applied to roadsides in a mountain valley.[236] In contrast to these studies, Abke et al. wrote in 1993 about their findings that 87% of groundwater control wells (n = 150) were contaminated with various herbicides used for weed control along railway tracks in Germany.[237] The soils in that study were sandy, which likely aided the transport of the herbicides to the local groundwater aquifers.

In general, herbicide use to control weeds along roadways and rights-of-way is relatively insignificant. Hence, the contribution of pesticides from this application to surface waters and groundwater (and thus to drinking water) in Ontario is probably quite minor and poses little risk to human health.

---

[232] S.A. Harrison et al., 1993, "Nutrient and pesticide concentrations in water from chemically treated turf-grass," in K.D. Racke and A.R. Leslie (eds.), *Pesticides in Urban Environments: Fate and Significance,* American Chemical Society Symposium Series (Washington, D.C.: American Chemical Society); Gustafson, 1993.

[233] Larson et al., 1997.

[234] Ibid.

[235] R.S. Mckinley and G.P. Arron, 1987, *Distribution of 2,4-D and Picloram Residues in Environmental Components Adjacent to a Treated Right-of-Way* (Ottawa: Department of Energy and Mines), Research Report OH/R-87/49/K.

[236] V.J. Watson et al., 1989, "Environmental fate of picloram used for roadside weed control," *Journal of Environmental Quality,* vol. 18, pp. 198–205.

[237] W. Abke et al., 1993, "Pollution of downstream groundwater near railway tracks treated with herbicides," *Vom Wasser,* vol. 81, pp. 257–73.

Aquatic Plant Control Pesticides may be applied directly to surface waters for control of insect pests (e.g., blackflies, mosquitoes, and nuisance midges), algae, and aquatic macrophytes. Herbicides (e.g., 2,4-D, glyphosate, copper sulphate) are the most commonly applied pesticides in aquatic environments, where they are used to control invasive weeds (e.g., water hyacinth and Eurasian watermilfoil) in reservoirs and canals and algae in ponds.[238] Insecticides are commonly applied directly to surface waters in areas prone to heavy infestations of nuisance aquatic insect pests. Historically, insecticides used in this capacity included DDT and a number of organophosphorus compounds (e.g., fenthion, malathion, fenitrothion); some of the latter are still used in some regions of Canada. However, in recent years, bacterial agents such as *Bacillus thuringiensis* var. *isrealensis* (Bti) and growth regulators such as methoprene have been used increasingly to control aquatic pests such as mosquitoes.[239] Pesticides applied to control aquatic weeds could enter drinking water if this is drawn from the treated water bodies around or shortly after a spray program. However, most of the pesticides used in current pest control applications quickly degrade under normal environmental conditions.

Greenhouses Although pesticides are commonly used in greenhouses (or glasshouses), this industry probably represents only a minor source of pesticide loading to surface waters or groundwater.[240] Where contamination does occur, it is likely to be restricted in area (point source) and limited in magnitude. Contributions of pesticides to drinking water from greenhouse sources may occur when drainage water containing pesticides is released to surface waters that also serve as a source of drinking water.[241]

Nutrients The two predominant sources of nutrients in agriculture are animal wastes and fertilizers applied to crops. The origin of nutrients from animal wastes, and their management, is the subject of the Goss et al. Walkerton Inquiry Commissioned Paper 6 and will not be considered further here. However, fertilizers may also represent a significant source of nutrients to both surface waters and groundwater; these are considered in detail below.

When fertilizers are applied to soil, the nutrients contained within them will be taken up by the crop, remain in the soil, or be lost from the soil of the crop systems through one of several possible mechanisms. The relative amounts of nutrient exported from soil to surface waters and groundwater vary widely,

---

[238] Larson et al., 1997.
[239] Ibid.
[240] Gustafson, 1993.
[241] Ibid.

depending on the nutrients, the soil type, and the climatic and agricultural circumstances. The two most significant nutrients in terms of their potential impact on aquatic ecological integrity, and/or the threat they pose to human health, are nitrogen (N) and phosphorus (P). High levels of nitrate in drinking water are of great concern to human health due to the potential for nitrate toxicosis or methaemaglobinaemia (oxygen starvation). Nitrates are less significant to aquatic biota from a direct toxicological perspective. However, nitrate, along with phosphorus, contributes to eutrophication and degradation of water quality. It is also important in the formation of ammonia, which is toxic to aquatic organisms, especially fish. Fertilizers can also contain trace amounts of a variety of metals such as arsenic, cadmium, and lead that may contribute to the contamination of surface water and groundwater. In most cases, however, contributions of metals from fertilizers are small relative to other sources, typically much less than 1% of total metal loading to aquatic environments.

Leaching, runoff, and atmospheric transport are the primary mechanisms by which nutrients enter aquatic environments. Nitrogen and phosphorus may enter surface waters from agricultural, atmospheric, and urban (sewage) sources. Total nitrogen concentrations found in Canadian rivers, lakes, and underground water bodies have been estimated to range between 1 and 10 mg/L but may be considerably higher in localized areas, most notably in regions of high agricultural intensity. Nitrate is also produced naturally (e.g., by blue-green algae) and is assimilated from water through uptake by aquatic plants or denitrification in bottom sediments. However, nitrogen in excess of that which can be assimilated by an aquatic system may, in conjunction with phosphorus loading, contribute to eutrophication (nutrient enrichment) and a concomitant decline in water quality and ecological diversity.

Phosphorus in the chemical form of phosphate is one of the principal nutrients for plants. Assimilation of fertilizer phosphorus by crops is generally poor and that which is not taken up is effectively converted to water-insoluble forms or is strongly adsorbed by soil particles. Thus, loss of phosphorus to surface water or groundwater via leaching is relatively low, typically less than 1–2 kg of phosphorus per annum per hectare.[242] Phosphorus loading to aquatic environments occurs primarily as runoff of soil particles to which the phosphorus is adsorbed.[243] The

---

[242] International Potash Institute, 1983, *Handbook on Environmental Aspects of Fertilizer Use*, edited by M. Nijhoff (The Hague: W. Junk).

[243] O.C. Bøckman et al., 1990, *Agriculture and Fertilizers: Fertilizers in Perspective* [online], Oslo: Agricultural Group, Norsk Hydro [cited February 6, 2002], <www.tfi.org/publications/pubsearch/images/ki760_.pdf>.

phosphorus content of streams in Canada ranges between 0.01 and 0.1 mg/L in forest watersheds and up to 0.5 mg/L in agricultural runoff.[244] Phosphorus loading to streams may account for up to 80% of phosphorus present in these systems.[245]

From a human health perspective, phosphorus does not pose a significant risk when present in drinking water, and there are currently no water quality standards for phosphorus in this matrix. However, phosphorus can have a significant effect on the ecological integrity of surface waters, where it is the primary cause of eutrophication. Indeed, phosphorus from agricultural fertilizers is the main source of nutrient loading to, and eutrophication of, the lower Great Lakes, particularly Lake Erie and the St. Lawrence River.[246] Fortunately, because phosphorus is quickly adsorbed by soil particles, best management practices directed at reducing non-point sources of pollution, such as erosion control, can greatly reduce phosphorus loading to aquatic environments.

Leaching is the most significant source of nitrates in groundwater. Nitrate in soil generally follows the main flow-paths of water but will also migrate by diffusion. Nitrogen leaching in soil depends on soil structure and porosity, water supply from precipitation and irrigation, evaporation from the soil surface, and the degree of drainage (table 2-13). Groundwater in areas of high agricultural activity is most susceptible to contamination by nitrates. Consequently, it is frequently detected in drinking water derived from domestic wells in these areas, often at levels that exceed water quality criteria. Wells located in sandy soils are most susceptible to nitrate contamination. For example, Hill found high concentrations of nitrates in several wells located in sandy

Table 2-13 Factors Affecting Nitrogen Leaching to Groundwater

Factor	Less Leaching	More Leaching
Crop	Vigorous crop Established crop	Poor crop Seedbed application
Soil	Heavy soil Poor drainage	Light soil Good drainage
Time of application	At the beginning of the main growing period or during active crop growth	At the end of the growing season or out of season
Climate	Low rainfall	High or irregularly distributed rainfall

---

[244] International Potash Institute, 1983.

[245] Bøckman et al., 1990.

[246] Canada, Environment Canada, 1996.

soils near Alliston, Ontario.[247] Nitrate concentrations in well waters often exceed water quality criteria. For example, Briggins and Moerman found that 13% of wells sampled in an agricultural area of Nova Scotia exceeded provincial guidelines for nitrate.[248] In Ontario in 1990, Frank et al. found that 15.5% and 6.6% of wells (n = 180) exceeded the provincial maximum allowable concentration (MAC) of 10 mg/L.[249] A survey by Goss et al. and written up in 1998, found that 14% (n = 1,292) of wells surveyed in rural areas of northen and southern Ontario contained nitrate concentrations above the MAC.[250] Rudolph et al., as part of the same study, showed that 23% (n = 144) of multilevel monitoring wells contained concentrations of nitrate that exceeded the provincial drinking water standard (MAC).[251] Our survey of southern Ontario drinking water treatment stations also showed that nitrate was a common contaminant in treated waters. However, there were few instances in which nitrate, nitrite, or ammonia exceeded provincial standards.

2.3.2 Atmospheric Transport

The atmosphere is a principal recipient and global transporter of a wide range of pollutants. It also represents a significant source of contaminants to surface waters of streams and lakes. Most atmospheric pollutants occur in the troposphere, which extends from the earth's surface to an altitude of about 10 km. Uncontaminated air comprises a complex mixture of nitrogen (78.09%), oxygen (20.94 %), rare gases (0.93 %), carbon dioxide (0.03 %), and a number of trace constituents (0.01 %; table 2-14). Contaminated air may contain a large number of both polar and lipophilic compounds. For example, Majewski and Capel in 1995 identified 63 pesticides and pesticide transformation products in the atmosphere that were deposited in rain, snow, and fog.[252] Atmospheric transport is also a significant route for persistent organic pollutants (POPs) to enter into aquatic environments (table 2-15).

---

[247] A.R. Hill, 1982, "Nitrate distribution in the groundwater at the Alliston region of Ontario," *Groundwater,* vol. 20, pp. 696–702.

[248] Briggens and Moerman, 1995.

[249] Frank et al., 1990.

[250] Goss et al., 1998.

[251] Rudolph et al., 1998, pp. 295–311.

[252] M.S. Majewski and P.D. Capell, 1995, "Pesticides in the atmosphere: Distribution, trends, and governing factors. "*Pesticides in the Hydrologic System Series,* vol. 1 (Chelsea, Mich.: Ann Arbor Press).

Pollutant emissions to the atmosphere are typically categorized as anthropogenic (released by human activities), natural (e.g., releases of geologically bound pollutants by natural processes), or re-emitted (e.g., mass transfer of previously deposited pollutants to the atmosphere by biological/geological processes). Anthropogenic emissions include those from industrial stacks, municipal waste incinerators, agricultural activities (e.g., pesticide applications), and vehicle exhaust. Natural emissions include those associated with volcanic eruptions, windblown gases and particles from forest fires, windblown dust and soil particles, and sea spray. In many cases, it is difficult to differentiate between

Table 2-14 Trace Constituents of the Normal Troposphere

Constituent	Formula	Conc. (ppb)	Conc. (µg/m³)
Carbon compounds			
Methane	CH_4	1,400	900
Carbon monoxide	CO	60–200	70–230
Terpenes	$(C_5H_8)_n$	36,900	36,979
Formaldehyde	CH_2O	< 10	< 12
Halogenated compounds			
Methyl chloride	CH_3Cl	0.5	1
Carbon tetrachloride	CCl_4	0.1–0.25	0.6–1.6
Freon 12	CF_2Cl_2	0.2	1
Freon 11	$CFCl_3$	0.1	0.7
Oxygen compounds			
Ozone	O_3	37,193	20–60
Nitrogen compounds			
Nitrous oxide	N_2O	330	600
Ammonia	NH_3	37,061	36,994
Nitric acid	HNO_3	3	7.5
Nitrogen oxides	NO/NO_2	1	~1.6
Sulphur compounds			
Sulphur dioxide	SO_2	36,894	36,960
Hydrogen sulphide	H_2S	< 0.2	< 0.3

Source: D. G. Crosby, 1998, *Environmental Toxicology and Chemistry* (New York: Oxford University Press).

natural and anthropogenic atmospheric pollutants. Depending on weather conditions and the chemical and physical properties of the contaminant, air pollutants can be transported varying distances and may undergo significant physical, chemical, and/or biological transformation during this transport.[253] Indeed, many atmospheric pollutants are transported over long distances, leading to deposition and accumulation in areas, such as the Arctic, in which they have never been used or released (see below).

Pollutant loading to water bodies from the atmosphere primarily occurs through wet or dry deposition. The process of wet deposition refers to the removal of air pollutants from the air by a precipitation event, such as rain or snow. The deposition of atmospheric vapor and dust by absorption and physical entrainment into raindrops is an important transport route over much of the world. All but the largest drops of water (possibly containing many pollutants) may remain airborne for many minutes, hours, or even days, depending on the chemical, physical characteristics of the pollutant, and the climatic conditions.

The process of dry deposition refers to the removal of aerosol pollutants through eddy diffusion and impaction, of large particles through gravitational settling,

Table 2-15 Deposition of Selected Persistent Contaminants in Rain

Pollutant	Typical Concentration in Air (ng/m^3)	Concentration in Rain (ng/L)
PCBs, total	1	30
Chlorinated pesticides		
DDT, total	0.03	5
BHC, total	2.3	20
Dieldrin	0.05	2
HCB	0.2	2
Methoxychlor	1	8
Total PAH	20	100
Phthalate esters	4	12

Source: S.J. Eisenreich et al., 1981, "Airborne organic contaminants in the Great Lakes ecosystem," *Environmental Science and Technology*, vol. 15.

---

[253] U.S., Environmental Protection Agency, Office of Air Quality Planning and Standards, 1997a, *Deposition of Air Pollutants to the Great Waters: Second Report to Congress* (Washington, D.C.: US EPA), EPA-453/R-97-011.

and of gaseous pollutants through direct transfer from the air to the water (i.e., gas exchange). Air pollutants can also enter surface waters indirectly, when an air pollutant is deposited on land and is subsequently carried into a receiving water body by other routes, such as stormwater runoff or inflow from tributaries. The tendency of a specific pollutant to enter a water body through wet or dry deposition, or gas exchange, is strongly influenced by the physical and chemical properties of the pollutant and the meteorological conditions to which it is subjected.

Although a potentially significant source of contaminants to surface waters, atmospheric deposition is generally only a minor direct source of contaminants to groundwater. However, contaminants of atmospheric origin may nonetheless eventually find their way into groundwater via indirect pathways, through exchange of previously deposited contaminants between sediment–water interfaces, movement of surface waters into fluvial aquifers, or up-welling/ down-welling events in streams (see below).

2.3.2.1 *Persistent Organic Pollutants (POPs) and Other Contaminants Transported in the Atmosphere*

Persistent organic pollutants consist of a group of chemicals that are highly persistent in the environment, bioaccumulate in tissues, and exhibit significant toxicological properties.[254] These chemicals have no natural sources and are produced entirely through commercial and industrial activity.[255] Many have been banned, phased out, or severely restricted in use for many years; however, only recently has the United Nations Environment Programme (UNEP) agreed to completely abolish the worst offenders (table 2-16) and set forth a process to determine the next chemicals to be proscribed.[256] These chemicals are semi-

---

[254] Crosby, 1998.

[255] R.E. Hester and R.M. Harrison, 1994, *Waste Incineration and the Environment* (Cambridge: Royal Society of Chemistry); S.J. Harrad, 1996, “Sources and fates of polychlorinated sibenzo-p-dioxins, dibenzofurans, and biphenyls: The budget and source inventory approach,” in R.E. Hester and R.M. Harrison (eds.), *Chlorinated Organic Micropollutants* (Cambridge: Royal Society of Chemistry), *Issues in Environmental Science and Technology,* no. 006, pp. 1–15; G.V. Edjulee and P. Cains, 1996, “Control of PCDD and PCDF emissions from waste combusters,” in R.E. Hester and R.M. Harrison (eds.), *Chlorinated Organic Micropollutants* (Cambridge: Royal Society of Chemistry), Issues in Environmental Science and Technology series, no. 006.

[256] United Nations Environment Programme, 1999, *UNEP Chemicals: Status Report on POPs* [online], [cited October 23, 2001], <irptc.unep.ch/pops/statrep/jun99/pdf/report1.pdf>; J. Kaiser and M. Enserink, 2000, “Treaty takes a POP at the dirty dozen,” *Science,* vol. 290, p. 2053.

volatile, so they are capable of undergoing long-range atmospheric transport, a process that is characterized by the gradual movement of chemicals produced in mid-latitude regions toward polar regions in a series of volatilization-distillation events (figure 2-10). This process, also referred to as the global distillation hypothesis[257] or the grasshopper effect, has led to high concentrations of these contaminants in Arctic environments and bioaccumulation in associated biota and humans. Indeed, many persistent organic pollutants (POPs) can be detected in virtually every environmental matrix around the world. Some of

Table 2-16 POPs Currently Listed under the UNECE and UNEP Initiatives

Pesticides	By-Products	Industrial Chemicals
Aldrin/Dieldrin	PCDDs	Hexabromobiphenyl
Endrin	PCDFs	PCBs
DDT/DDE	PAHs	
HCH/Lindane	HCB	
Chlordane		
Heptachlor		
Chlordecone		
Mirex		
Toxaphene		

Source: UN Environment Programme, 1999.

Figure 2-10 Movement of Persistent Organic Pollutants

---

[257] F. Wania and D. Mackay, 1993, “Global fractionation and cold condensation of low volatility organochlorine compounds in polar regions,” *Ambio*, vol. 22, pp. 10–18.

these chemicals (e.g., organochlorine pesticides, DDT dioxins/furans) have been implicated as potential endocrine-disrupting compounds, raising concerns about possible developmental, immunological, and reproductive effects in wildlife and humans (see also above). Despite long-time bans on most of these chemicals, adults and children in polar regions continue to experience significant health problems due to exposure through dietary sources. Because exposure of humans and biota to these compounds is overwhelmingly via food (it is estimated that less than 1% of their uptake is accumulated via non-dietary sources), there is little risk of exposure via drinking water.[258] In fact, although many of the POPs listed in table 2-16 have at one time or another been detected in drinking water (see table A1), most are extremely rare in this matrix today. The primary reason for their absence from drinking water is that they are sparingly soluble, preferring instead to be associated with lipophilic matrices such as sediments and lipids.

PCBs are one of the most important POPs from a human health perspective. In general, the number and magnitude of PCB sources have decreased significantly (twenty-fold) in the past 20 years. The largest national-level stationary air emission source of PCBs is incineration of hazardous waste materials and consumer products containing PCBs. The primary route for human health exposure is diet, and because PCBs are rarely found in water, there is little risk associated with ingestion of drinking water.

Some persistent pesticides are also commonly encountered in the atmosphere[259] and are subject to long-range atmospheric transport.[260] Pesticides can enter the atmosphere as spray drift generated as droplets or as particles of the pesticide formulation. Such particles or droplets may travel considerable distances. In a global monitoring survey of air and surface seawater from 1989 to 1990, Iwata et al. found hexachlorocyclohexane (HCH) to have the highest concentration among organic pollutants.[261] Concentrations were greatest in tropical source regions and in cold water deposition areas near the Arctic. Other persistent organic pesticides, such as chlordane, showed a more uniform global distribution. Although long-range transport of persistent pesticides is of greatest interest, due to human health concerns, it is important to recognize that polar pesticides may also be transported

---

[258] Canada, Environment Canada, 1991.

[259] Majewski and Capell, 1995.

[260] D.A. Kurtz, 1990, *Long Range Transport of Pesticides* (Boca Raton, Fla.: Lewis Publishers).

[261] H. Iwata et al., 1994, “Geographical distribution of persistent organochlorines in air, water and sediments from Asia and Oceania, and their implications for global redistribution from lower latitudes,” *Environmental Pollution,* vol. 85, pp. 15–33.

long distances in the atmosphere. For example, Thurman and Cromwell found residues of atrazine, a highly polar and widespread herbicide, in pristine areas of Isle Royale National Park in Lake Superior.[262] This area is well removed from the primary agricultural areas of the mid-west United States, where atrazine is applied.

Atmospheric deposition also represents a significant route for the entry of mercury into aquatic ecosystems. Anthropogenic mercury emissions are only one component of the global mercury cycle; the amount of mercury in the land, water, and air at any one location comprises mercury from the natural global cycle, from the global cycle perturbed by human activities, and from regional anthropogenic sources. Other sources of mercury include direct discharges to water or the application of mercury in the form of fungicides to protect crops. In total, natural, industrial, and recycled anthropogenic mercury contributes about one-third of the current mercury burden in the global atmosphere.[263] Estimates of the global contribution of mercury emissions to the atmosphere from anthropogenic sources are 2,000 to 4,000 tons per year (tpy) and from natural sources are 2,200 to 4,000 tpy, resulting in total mercury air emissions of 4,200 to 8,000 tpy.[264] In comparison, U.S. mercury air emissions for 1994–1995 were 158 tpy.[265] Approximately 87% of anthropogenic mercury emissions in the U.S. are from combustion sources, including waste and fossil fuel combustion.

Interestingly, new measurement methods suggest that the rates of natural mercury emissions from mercury-rich soils and bedrocks may be larger than previously estimated. Also recently identified as a source of mercury to the atmosphere are emissions of elemental mercury gas (Hg^0) from soils that have been amended with municipal sewage sludge.[266] These researchers estimated

---

[262] E.M. Thurman and A.E. Cromwell, 2000, "Atmospheric transport, deposition, and fate of triazine herbicides and their metabolites in pristine areas at Isle Royale National Park," *Environmental Science and Technology,* vol. 34, pp. 3079–85.

[263] N. Pirrone et al., 1996, "Regional differences in worldwide emissions of mercury to the atmosphere," *Atmospheric Environment,* vol. 30, no. 7, pp. 2981–87.

[264] N. Pirrone et al., 1998, "Historical atmospheric mercury emissions and depositions in North America compared to mercury accumulations in sedimentary records," *Atmospheric Environment,* vol. 32, no. 5, pp. 929–40.

[265] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards and Office of Research and Development, 1997b, *Mercury Study Report to Congress,* vols. I–VIII (Washington, D.C.: US EPA), EPA-452/R-97-005.

[266] A. Carpi and S.E. Lindberg, 1997, "Sunlight-mediated emission of elemental mercury from soil amended with municipal sewage sludge," *Environmental Science and Technology,* vol. 31, no.7, pp. 2085–91.

that land application of sewage sludge in the U.S. and the European Union may account for approximately 5 × 10^6 g/year (5 metric tons/year) of Hg^0 released to the atmosphere based on the area of land amended each year and measured Hg^0 emission rates. It is important to understand the source of mercury and the amount of mercury contributed by each source type so that the most efficient control strategies can be devised.

The atmosphere also represents a significant source of nitrogen to surface waters.[267] The predominant natural source of nitrogen in the atmosphere is via microbial decomposition of organic matter in soil and water. Microorganisms release ammonia (NH_3) to the atmosphere during the breakdown of amino acids.[268] Predominant anthropogenic atmospheric nitrogen sources include (1) emissions of nitrogen oxides from the combustion of fossil fuel, (2) ammonia (NH_3) and ammonium (NH_4^+) emissions from fertilizer and explosive factories, and (3) volatilisation of ammonia-based fertilizer from agricultural fields.[269]

As with many atmospheric contaminants, once emitted into the atmosphere, nitrogen may be deposited locally or may travel great distances before deposition. More than 3.2 million tons of atmospheric nitrogen are deposited on watersheds of the United States annually. In Canada, atmospheric deposition of nitrogen to surface waters amounts to approximately 182,000 tonnes per year.[270] Wet deposition accounts for the majority of nitrogen removed from the atmosphere.[271] The degree to which a watershed retains nitrogen is a function of the soil characteristics, topography, underlying geology, the amount and type of surface vegetation, and the degree of impervious cover.[272] Inevitably, a significant amount of deposited nitrogen will be transported during a precipitation event, via overland or subsurface flow, into a freshwater system. Here, it may contribute to processes such as eutrophication of aquatic systems or it may enter into groundwater supplies through various exchange mechanisms with surface waters.

---

[267] United States, National Atmospheric Deposition Program/National Trends Network, 2000, "Nitrogen in the nation's rain" [online], [cited October 23, 2001], <http://nadp.sws.uiuc.edu>.

[268] T.R. Oke, 1978, *Boundary Layer Climates* (London: Methuen & Co. Ltd.).

[269] Oke, 1978; M. Lippman, 1989, *Health Benefits of Air Pollution Control: A Discussion* (Washington, D.C.: The Library of Congress), Congressional Research Service (CRS) Report for Congress; H.W. Paerl, 1993, "Emerging role of atmospheric deposition in coastal eutrophication: Biogeochemical and trophic perspectives," *Canadian Journal of Fisheries and Aquatic Sciences,* vol. 50, pp. 2254–69.

[270] Chambers et al., 2001.

[271] H.W. Paerl et al., 1990, "Stimulation of phytoplankton production in coastal waters by natural rainfall inputs: Nutritional and trophic implications," *Marine Biology*, vol. 107, pp. 247–54.

[272] Paerl, 1993.

Recently, a number of persistent *polar* organic pollutants (PPOPs) have come to the attention of environmental scientists. Like POPs, this class of chemicals contains several highly persistent compounds, some with half-lives in the order of thousands of years. Examples include trifluoroacetic acid (TFA, an atmospheric breakdown product of some chlorofluorocarbon replacement compounds), chlorodifluoroacetic acid (CDFA), and perfluorooctane sulfonate (PFOS), a fluorinated surfactant that is commonly used as a stain repellent in products such as ScotchGuard®. Unlike the POPs, however, these compounds are highly water soluble and, therefore, generally do not bioaccumulate in tissues. Furthermore, most PPOPs also appear to exhibit low levels of toxicity to most organisms. However, a notable exception is PFOS. This compound has been detected in tissues of wildlife, mammals, and humans[273] and may be globally ubiquitous. Unfortunately, data are scarce on the exposure of humans to PPOPs via diet or drinking water and the potential risks to human or ecosystem health. However, in view of their solubility and general recalcitrance to microbial and chemical breakdown, the occurrence of some of these compounds in drinking water would not be surprising.

It is important to point out that new POPs continue to be identified and detected in the tissues of Arctic biota. For example, polychlorinated paraffins and polybrominated diphenyl ethers (PBDEs, used as fire retardants and structurally similar to PCBs) and the pesticide endosulfan, which is still used in Canada, have recently been added to the UNEP list of potentially important POPs that are subject to long-range atmospheric transport. In some cases (e.g., PBDEs), these compounds appear to be undergoing significant increases in many aquatic environments, but there is little information on their potential effects on human health and ecosystem integrity. As with many of the classic POPs, the most significant route of exposure to these compounds for humans and aquatic biota will be dietary; exposure via treated drinking water is likely to be negligible.

---

[273] J.P. Giesy and K. Kannan, 2001, "Global distribution of perfluorooctane sulfonate and related compounds in wildlife," *Environmental Science and Technol*ogy, vol. 35, pp. 1339–42; Kannan et al., 2001, "Perfluorooctane sulfonate and related fluorinated organic chemicals in marine mammals," *Environmental Science and Technology,* vol. 35, 1593–98; F.D. Gilliland and J.S. Mandel, 1996, "Serum perfluorooctanoic acid and hepatic enzymes, lipoproteins, and cholesterol: A study of occupationally exposed men," *American Journal of Industrial Medicine,* vol. 29, pp. 560–68.

2.3.3 Urban/Suburban Runoff

Urban runoff is a significant source of contamination in surface waters. Its impact on the quality of surface waters has become a key issue in Canada. Approximately 80% of Canadians now live in urban areas, but this proportion is expected to increase within the next 15 years as the population rises to a projected 35 million.[274] Approximately 80–90% of this expansion will occur in urban areas. Intensified urbanization and the resultant increase in impervious surfaces (concrete, pavements, roofs, etc.) will alter the volume and quality of urban runoff.[275] There is already concern about stormwater pollution in the Great Lakes Basin, particularly in Hamilton Harbour and the Toronto Waterfront,[276] where stormwater is often contaminated with suspended solids, phosphorus, heavy metals, hydrocarbons, and fecal bacteria.[277]

Runoff from urban centres primarily occurs during or shortly after precipitation or snowmelt events. As the water contacts and then moves over the many urban surfaces, many kinds of contaminants may be dissolved or suspended in the resulting runoff, which is ultimately discharged into receiving waters, either before or after being passed through stormwater treatment facilities, if such technologies exist in the municipality.[278] Thus, coastal areas, large rivers, and the Great Lakes are the main recipients of urban runoff. However, small streams and metropolitan lakes often accept primary inflows.[279]

Precipitation intensity and volume are both important removal mechanisms of surface contaminants in runoff.[280] In most cases, precipitation intensity is the most significant removal mechanism,[281] but water volume can be very important in transporting solids, particularly those of large diameter.[282] Runoff volume is

---

[274] Canada, Statistics Canada, 2000, *Human Activity and the Environment* (Ottawa: Industry Canada), Catalogue No. 11-509-XPE.

[275] J.B. Ellis, 1986, "Pollutant aspects of urban runoff," in H.C. Torno et al. (eds.), *Urban Runoff Pollution* (New York: Springer-Verlag), pp. 1–38.

[276] J. Marsalek and S. Kok, 1997, "Stormwater management and abatement of combined sewer overflow pollution," *Water Quality Research Journal of Canada,* vol. 32, no.1, pp. 1–5.

[277] Chambers et al., 1997.

[278] Ibid.

[279] D.H. Waller and W.C. Hart, 1986, "Solids, nutrients, and chlorides in urban runoff," in H.C. Torno et al. (eds.), *Urban Runoff Pollution* (Heidelberg: Springer-Verlag).

[280] Ellis, 1986.

[281] R.K. Price and G. Mance, 1978, "A suspended solids model for stormwater runoff," in P. Helliwell (ed.), *Urban Storm Drainage* (London: Pentech Press), pp. 546–55.

[282] Ellis, 1986.

dependent on the type (industrial, commercial, residential) and density of development, as well as the conditions and gradient of the developed area.[283] Precipitation of low pH can also affect the dislodgibility of pollutants, since acidic rain solubilizes some pollutants (e.g., metals) that are weakly bound to urban surfaces.[284] Typically, the first flush that accompanies each storm or snowmelt event is the most concentrated and contaminated outflow, especially if the period between precipitation events has been long.[285]

Contaminants in runoff originate from a variety of non-point sources in the urban environment. Solids such as glass, asphalt, stone, rubber, rust, building materials, pavements, dust, and human litter accumulate on paved surfaces (highways and large parking lots) between storm events.[286] Urban snowpacks also accumulate large quantities of solids and contaminants over the winter months. Schroeter assessed the wastewater contaminant discharges in 17 Ontario areas where wastewater pollution is a concern.[287] He reported that during wet weather events, stormwater accounted for 77–100% of the solid loadings into receiving waters. Although solids are frequently found in surface waters, they rarely migrate into groundwater, due to the filtering and adsorptive properties of soil.[288] Hence, environmental problems associated with solids in runoff (e.g., sediment loading) are generally restricted to impacts on aquatic biota.

Canadian highways and parking lots also accumulate high levels of salt, which is widely used as a deicing agent and, in smaller quantities, as a dust suppressant. Salt is very water soluble, and its ions may be persistent in both surface and ground waters.[289] All road salts are chloride-based, and thus chloride is the principal contributing anion to salinity from road salt application. Salt use in urban Ontario has increased substantially over the past few decades, leading to an increase in chloride concentrations in receiving waters. For example, Bowen and Hinton (1998) reported that chloride concentrations in Highland Creek, a stream in the Greater Toronto Area (GTA), increased from 150 mg L^{-1} in 1972

---

[283] Ibid.

[284] Ibid.

[285] Ferguson, 1994, pp. 154–64.

[286] Ibid.

[287] Schroeter, 1997.

[288] W.C. Bianchi and D.C. Muckel, 1970, *Ground-Water Recharge Hydrology* (Washington, D.C.: Department of Agriculture, Agricultural Research Service), ARS 41-161.

[289] R. Mayer et al., 1999, "Spatial characterization of the occurrence of road salts and their environmental concentrations as chlorides in Canadian surface waters and benthic sediments," *Water Quality Research,* vol. 34, pp. 545–74.

to over 250 mg L^{-1} in 1995.[290] Similarly, median chloride concentrations in Duffin Creek, also in the GTA, were 10 to 20 mg L^{-1} in the 1960s but increased to between 30 and 40 mg L^{-1} in the early 1990s.[291] Road salt contamination of surface waters also exhibits significant seasonal variations, which are characterized by "salt pulses." For example, in the Don River, Toronto, the autumn baseline chloride concentration ranged from 100 to 150 mg L^{-1},[292] whereas in the winter months concentrations were as high as 1000 mg L^{-1} after thaw periods.[293] Indeed, deicing compounds are a major contributor to snowpack contamination.[294] These trends precipitated a joint assessment by Environment Canada and Health Canada of the environmental impacts from road salts.[295] They concluded that road salts were entering aquatic habitats at concentrations that had, or were predicted to have, immediate or long-term harmful effects on the environment and its biological diversity.[296] As a result, road salts are now considered to be toxic under Section 64 of the *Canadian Environmental Protection Act.*

Urban oil spills also represent a significant source of organic pollution in runoff in Ontario. Between 1988 and 1997, an estimated 6.84 million litres of oil were spilled in the highly populated Golden Horseshoe area of Southwestern Ontario.[297] Approximately 1.34 million litres of this oil passed through the urban drainage systems within the region and entered Lake Ontario,[298] contributing to the contamination of surface water from which many municipalities draw drinking water.

Automobile emissions and the wear of automobile parts and road construction materials are the primary sources of lead, zinc, copper, and iron on roadways

---

[290] G.S. Bowen and M.J. Hinton, 1998, "The temporal and spatial impacts of road salt on streams draining the Greater Toronto Area," *Groundwater in a Watershed Context Proceedings*, December 2–4, Canada Centre for Inland Waters, Burlington, Ontario (Cambridge, Ont.: Canada Centre for Inland Waters). Available on CD-ROM, see [online], [cited February 2, 2002] <www.cwra.org/branches/arts/gw/gwcdpromo.html>.

[291] Ibid.

[292] W.S. Scott, 1980, "Road salt movement into two Toronto streams," *Journal of Environmental Engineering Division,* vol. 106, no. EE3, pp. 547–560.

[293] Ibid.

[294] G.L. Oberts et al., 2000, "Review of water quality impacts of winter operation on urban drainage," *Water Quality Research Journal of Canada,* vol. 35, no. 4, pp. 781–808.

[295] Canada, Environment Canada, 2000, *Priority Substances List Assessment Report: Road Salts*, Canadian Environmental Protection Act (CEPA), 1999 (Ottawa: Environment Canada), Draft for Public Comment.

[296] Ibid.

[297] J. Li and P. MacAteer, 2000, "Urban oil spills as a non-point pollution source in the Golden Horseshoe of Southern Ontario," *Water Quality Research Journal of Canada,* vol. 35, pp. 331–40.

and parking lots.[299] However, the banning of leaded gasoline in the 1970s greatly reduced lead residues found on and surrounding roadways.[300]

Pesticides and fertilizers from intensively managed golf courses, parks, and lawns are common constituents in urban runoff. The most prevalent contaminants that originate from fertilizers are nitrogen and phosphorus; however, metals can also be leached out of some fertilizers.[301] Nutrient enrichment problems exist in a number of harbours on the Canadian side of the Great Lakes,[302] where eutrophication, as well as elevated biological and chemical oxygen demands, have been evident.[303] Additionally, fecal bacteria from dog, cat, rodent, and bird wastes frequently contaminate urban runoff.[304]

Roofs are sources of numerous contaminants such as solids, metals, and bacteria. Solids are often deposited on rooftops via atmospheric sources in quantities large enough for roofs to be deemed one of the key origins of solids in urban runoff.[305] Roofs are also a source of metal contamination. Malmquist suggested that as much as 70–90% and 50–70% of the total mass discharges of copper and zinc, respectively, in urban runoff are derived from the corrosion of roofing materials.[306] Copper, zinc, and lead are also components of exterior paints, which flake or are leached off walls and roofs.[307] Roof runoff can also be high in bacterial pathogens, a problem that been associated with bird droppings.[308]

Other urban sources of runoff contaminants include construction sites, where soil and metal particulates can originate, and urban garbage disposal sites, which are sources of bacterial pathogens, nitrogen, and phosphorus.[309]

---

[298] Ibid.

[299] J. Marsalek, 1986, "Toxic contaminants in urban runoff: A case study," in H.C. Torno et al. (eds.), *Urban Runoff Pollution* (Heidelberg: Springer-Verlag); Ferguson, 1994.

[300] Marsalek, 1986.

[301] Ferguson, 1994.

[302] D.H. Waller and Z. Novak, 1980, "Pollution loadings to the Great Lakes from municipal sources in Ontario," *Journal of the Water Pollution Control Federation*, vol. 52, pp. 387–95.

[303] Ellis, 1986.

[304] B.M. Feldman, 1974, "The problem of urban dogs," *Science,* vol. 185, p. 903.

[305] Ellis, 1986.

[306] P.A. Malmquist, 1983, *Urban Stormwater Pollutant Sources* (Gothenburg: Chalmers University of Technology).

[307] Marsalek, 1986; Ferguson, 1994.

[308] Ellis, 1986.

[309] Ferguson, 1994.

2.3.4 Sediments

Sediment consists of a heterogeneous matrix of all detrital, inorganic, and organic particles that occur on the bottom of a body of water.[310] From a pollution standpoint, sediments have the unique characteristic of acting as both a source and a sink for many natural and anthropogenic contaminants. A sink, because contaminants from many of the point and non-point sources outlined above become entrained in sediments, either by partitioning out of the water or via deposition of suspended solids to which they are adsorbed. Many contaminants and organic wastes discharged to aquatic systems eventually accumulate in sediments, where they may adversely affect the benthic biota and enter into pelagic and human food chains.[311] Particularly problematic in this regard are lipophilic chemicals (having a strong affinity for lipids), which preferentially partition into sediments and other environmental matrices (e.g., tissues). Significant sediment contamination exists in well defined areas throughout North America, as indicated by the numerous Areas of Concern in the Great Lakes and many of the Superfund sites in the United States. In these areas, sediment contamination could be considered as a point source for pollution of aquatic habitats. However, most sediment contamination is relatively diffuse, characterized by low-level contamination spread over broad geographical ranges.

As a source, contaminated sediments may release chemicals to water via desorption from organic ligands into surrounding interstitial water. One of the theories used to describe this process is equilibrium partitioning (EqP), which is based on the assumption that organic chemicals and certain metals reach a thermodynamic equilibrium between benthic fauna, solid phases in the sediment (e.g., organic ligands), and interstitial water (figure 2-11).[312] If the dissociated free chemical is lipophilic, it may be taken up and accumulated from the interstitial water by benthic aquatic organisms that come into contact with it. An equally important route for accumulation of contaminants by benthos is ingestion of sediment particles and organic matter to which the contaminants are adsorbed; the contaminants desorb in the gut and pass across

---

[310] E.A. Power and P.M. Chapman, 1992, "Assessing sediment quality," in G.A. Burton Jr. (ed.), *Sediment Quality Assessmen*t (Boca Raton, Fla.: Lewis Press), pp. 1–18.

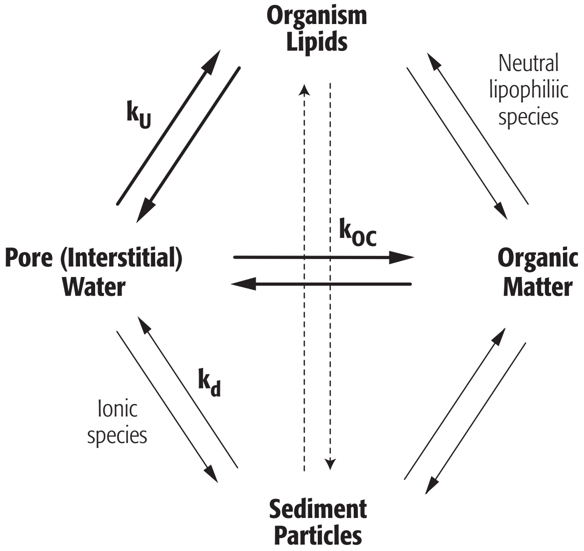
[311] N.A. Thomas, 1994, "EPA/ORD role and perspective in sediment research," in J.V. DePinto et al. (eds.), *Transport and Transformation of Contaminants Near the Sediment-water Interface* (Boca Raton, Fla.: CRC Press), pp. 7–16.

[312] R.F. Lee, 1992, "Models, muddles, and mud: Predicting bioaccumulation of sediment-associated contaminants," in G.A. Burton Jr. (ed.), *Sediment Quality Assessment* (Boca Raton, Fla.: Lewis Press).

the intestinal wall into the tissues.[313] In either case, the compounds may subsequently be passed through the food chain as organisms at each trophic level are consumed by those at higher levels; the contaminants may become increasingly concentrated with each level, a process referred to as biomagnification. This route of exposure is typical for lipophilic compounds such as DDT, PCBs, and mercury, and it can lead to significant impacts on aquatic and terrestrial biota, as illustrated by the decline of bald eagles in the Great Lakes region due to egg shell thinning and by widespread fish-consumption advisories due to mercury contamination. Metals may be accumulated in a similar fashion, but these are also subjected to natural biogeochemical cycling processes (see metals sections following 2.2.1 above).[314]

The EqP approach has formed the cornerstone of the USEPA's program to establish sediment quality criteria for the protection of aquatic life; however,

Figure 2-11 Partitioning Relationships Between Sediment Phases and Biotic Tissues as a Basis for Equilibrium Partitioning



---

[313] S.W. Fisher, 1995, "Mechanisms of bioaccumulation in aquatic systems," *Reviews of Environmental Contamination and Toxicolology*, vol. 142, pp. 87–117.

[314] See also H.E. Allen, 1995, *Metal Contaminated Aquatic Sediments* (Chelsea, Mich.: Ann Arbor Press; D.M. Di Toro et al., 1991, "Technical basis for establishing sediment quality criteria for non-ionic organic chemicals using equilibrium partitioning," *Environmental Toxicology and Chemistry*, vol. 10; G.T. Ankley et al., 1996, "Technical basis and proposal for deriving sediment quality criteria for metals," *Environmental Toxicology and Chemistry*, vol. 15.

this approach has been subjected to considerable scrutiny in recent years[315] the more it is recognized that a true thermodynamic equilibrium between the sediment and interstitial water or between the interstitial water and the organism is probably rarely achieved. For this and other reasons, a number of alternative approaches have been proposed,[316] although these are not without limitations. Regardless of the approach used, it is critical that sediment criteria be reassessed periodically, to ensure that they are protective of both human health and ecosystem integrity; this will mean that they must be sufficiently flexible,[317] particularly in terms of acceptance and application by key regulatory agencies, to accommodate new scientific understanding of sediment-associated processes and factors that affect the bioavailability of contaminants.

One of the most significant routes for contaminants in sediments to enter overlying water is dredging. Dredging is routinely conducted in harbours, ports, and other areas of high boat and water transportation activity.[318] Because resuspension of contaminants and associated impacts due to dredging activities are usually restricted to a local scale (e.g., a harbour), dredging is essentially a point source form of pollution. Due to the lipophilic nature of most sediment-associated contaminants, they tend to remain tightly bound to sediment particles during dredging activities.[319] Nonetheless, dredging can lead to the dissolution of certain contaminants, particularly metals, into the water column, and these may exert toxicological effects on surrounding biota. Recognition of the potential impacts of dredging activities on aquatic communities led to the development of some of the first sediment bioassays[320] and arguably marked

---

[315] P.M. Chapman et al., 2001, "Sediment quality values (SQVs) – challenges and recommendations," *SETAC Globe,* vol. 2, no. 2.

[316] T.B. Reynoldson et al., 1997, "The reference condition approach: A comparison of multiple and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates," *Journal of the North American Benthological Society,* vol. 16, pp. 833–52; E.R. Long et al., 1998, "Predicting toxicity in marine sediments with numerical sediment quality guidelines," *Environmental Toxicology and Chemistry,* vol. 17, pp. 714–27; G.A. Burton Jr., 2001, "Moving beyond sediment quality values and simple laboratory toxicity tests," *SETAC Globe* 2, vol. 2, pp. 26–7.

[317] L.J. Standley and T.L. Bott, 2001, "Appropriate role for biology in establishing sediment quality criteria," *SETAC Globe* 2, vol. 2, no. 2, pp. 29–30.

[318] U.S. National Research Council, 1997.

[319] F.A. Digiano et al., 1993, "Predicting the release of PCBs at the point of dredging," *Journal of Environmental Engineering,* vol. 119, pp. 72–89.

[318] Lee, 1992.

[319] M.S. Greenberg et al., 2000, "Considering groundwater–surface water interactions in sediment toxicity assessment," *SETAC Globe*, vol. 1, pp. 42–44.

[320] H.A.J. van Lanen and R. Djiksma, 1999, "Water flow and nitrate transport to a groundwater-fed stream in the Belgian-Dutch chalk region," *Hydrological Processes,* vol. 13, pp. 295–307.

the beginning of sediment toxicology and the development of sediment quality criteria. Risks to humans from dredging are unknown but probably minor, due to the localized nature of this activity. Plausibly, sediment-associated contaminants that are liberated during dredging could enter into drinking water if such water was extracted from the same area in which the dredging activity occurred.

Although considerable effort has been directed toward understanding relationships between sediment and overlying (surface) water regarding the movement and bioavailability of contaminants in aquatic environments, much less effort has been directed toward understanding such relationships between surface water and groundwater. Potentially, contaminants that desorb from sediments, or which are adsorbed to suspended particles, could enter groundwater if the overlying surface water into which the contaminants partition enters into a fluvial aquifer (a stream that drains into a groundwater aquifer). Recent evidence has shown that sediment-associated contaminants may also move to groundwater via down-welling of water, particularly in streams.[321] These authors hypothesize that localized sediment contamination and the exchange of contaminants between surface water and groundwater are strongly influenced by up-welling or down-welling events in streams. Areas of up-welling may facilitate entry of contaminants associated with groundwater into surface waters, where they may enter into drinking water supplies extracted from the water body. Such exchanges have been demonstrated in groundwater-dominated streams in agricultural areas where nitrate loading to surface waters via groundwater has caused significant deterioration of drinking water supplies.[322] In addition to potential human health risks, the contribution of contaminants via up-welling may impact benthic communities that live in the sediments and serve as the basis of production in these systems.[323]

Down-welling, in contrast, can move contaminants associated with surface waters and sediments into sub-surface systems, where they may be incorporated into the groundwater. These contaminants may become incorporated into shallow aquifers that supply domestic wells, or they may resurface at another location in a stream via up-welling.

---

[323] Duncan, 1999.

2.3.5 Other Sources of Contaminants to Surface Waters and Groundwater

A number of sources of environmental stressors cannot be definitively categorized as either point or non-point sources of pollution, or may not constitute chemical contaminants *per se*, yet may significantly affect the quality of surface waters or groundwater and hence produce effects on in-stream ecological integrity and risks to human health. These sources include construction (e.g., land development, roads), habitat modification (e.g., removal, addition of riparian buffer zones), hydrologic modification (e.g., dams, channelization), discharge of cooling water effluents, and the occurrence of natural toxins. The most significant of these sources are described briefly below. In the United States, sediment/siltation has long been recognized as the most significant "non-toxic" pollutant contributing to degradation of surface waters.[324] Increased sedimentation in streams due to habitat or hydrologic modification can result in significantly increased sediment loading, with a corresponding loss of benthic productivity and fish habitat.[325]

From the perspective of human exposure to contaminants in drinking water, these sources generally do not directly contribute toxic chemicals per se to aquatic environments. However, they can have a significant effect on the physico-chemical characteristics of receiving water or sedimentary environments, which may, in turn, affect the environmental chemodynamics of naturally occurring contaminants (e.g., metals) or contaminants contributed from other anthropogenic sources. This could ultimately change the pathways along which many contaminants may eventually come to be present in drinking water. For example, increased runoff and transport of soil particles to which contaminants are adsorbed can lead to reductions in water quality and loss of habitat in developed watersheds, particularly in agricultural areas. Such events have been closely linked with the removal of riparian or wetland vegetative zones, which is a common practice in watersheds being developed from human use.[326]

---

[324] W.R. Oschwald, 1972, "Sediment-water interactions," *Journal of Environmental Quality*, vol. 1, pp. 360–66; U.S. Environmental Protection Agency, 1990, *The Quality of Our Nation's Water: A Summary of the 1988 National Water Quality Inventory* (Washington, D.C.: US EPA), US EPA report 440/4-90-005.

[325] Waters, 1995.

2.3.5.1 *Hydrologic and Habitat Modification*

Historically, hydrologic and habitat modification of streams and lakes has arguably been the most significant disturbance of aquatic systems since the arrival of humans in North America. Hydrologic modification includes activities such as channelization, dredging (see sediment section 2.3.4 above), dam construction, and flow regulation.[327] Habitat modification includes removal of riparian vegetation, stream bank modification, and drainage and filling of wetlands. In general, hydrologic and habitat modification of aquatic environments poses far greater risks to aquatic biota and ecosystem health than it does to human health. However, such modifications can significantly affect the transport and chemodynamics of pollutants in the environment and hence the exposure of humans to them. For example, the removal of forest, grass, or wetland riparian buffer zones along streams can lead to an increase in the quantity of sediments, nutrients, or other pollutants (e.g., pesticides) transported from terrestrial landscapes into aquatic environments. Humans could experience increased exposure to these pollutants if drinking water were extracted from the contaminated surface waters.

The most common forms of hydrologic modification are channelization/diversions and dam construction, which are often found together in aquatic systems. In the United States, channelization is extensive: 26,550 km of channelization were completed by 1977.[328] In Canada, Quinn documented 54 inter-basin diversions, representing a mean annual flow rate of approximately 1 m/s.[329] These are mostly used in hydroelectric development. Smaller-scale channelization is particularly common in urban areas, to ensure expeditious movement of water to wastewater treatment facilities or receiving waters, and in agriculture where it is often used to divert stream water for use in crop

---

[326] R.J. Naiman, et al., 1988, "The potential importance of boundaries to fluvial ecosystems," *Journal of the North American Benthological Society,* vol. 7, pp. 289–306; R.C. Petersen Jr., 1992, "The RCE: a riparian, channel, and environmental inventory for small streams in the agricultural landscape," *Freshwater Biology,* vol. 27, pp. 295–306; Rabeni, 1995, pp. 211–19.

[327] U.S. Environmental Protection Agency, 1998a.

[328] L.B. Leopold, 1977, "A reference for rivers," *Geology,* vol. 5, pp. 429–30.

[329] F. Quinn, 1987, "Interbasin water diversions: A Canadian perspective," *Journal of Soil and Water Conservation,* vol. 42, pp. 389–93.

irrigation. From an ecosystem perspective, stream channelization disrupts the riffle-pool habitat complexes required by many organisms for the completion of life cycles and destroys spawning habitat for fish.[330] Although channelization may yield benefits in terms of flood control, this is often offset by losses in habitat diversity and ecological condition. The effects of dams on the physical and biotic integrity of stream ecosystems has been well documented, perhaps most dramatically in relation to declines in migrating fish populations (e.g., salmon) that cannot reach critical spawning grounds located above the dams.[331] Damming and pooling of streams may also lead to significant increases in water temperature downstream due to the increased residence time and surface area of dammed water, which allows for greater solar heating. This may lead to substantial declines in, or loss of, sensitive species such as trout or to shifts in fish community structure, e.g., the replacement of cold-water species with warm-water species.

Other forms of habitat modification can also significantly alter water and habitat quality in water courses. Loss of riparian buffer zones along streams and lakes and loss of wetlands through draining and filling can have dramatic effects in this regard. The riparian zone is the area of land adjacent to streams and rivers or surrounding lakes, an important transition zone that regulates the flow of energy and materials between the terrestrial landscape and the aquatic environment;[332] this interface is often referred to as an ecotone. Loss of riparian vegetation, because of its important function in regulating the flow of materials, can lead to a significant increase in non-point source pollution and the export of toxic contaminants to aquatic environments. Conversely, the presence of riparian buffer areas has been shown to significantly reduce inputs of nutrients and suspended solids from agricultural activities and forestry to aquatic systems.[333] Wetlands have been shown to function similarly in this capacity.[334] Riparian zones and wetlands may also serve to impede the movement of, or permanently retain, water- and particle-borne toxic contaminants such as

---

[330] H.E. Allen et al., 1995.

[331] W. Nehlsen et al., 1991, "Pacific salmon at the crossroads: Stocks of salmon at risk from California, Oregon, Idaho, and Washington," *Fisheries,* vol. 16, pp. 40–51.

[332] Naiman et al., 1997; Naiman et al., 2000, "Riparian ecology and management in the Pacific coastal rain forest," *BioScience,* vol. 50, pp. 996–1011.

[333] W.T. Peterjohn and D.L. Correll, 1984, "Nutrient dynamics in an agricultural watershed: Observation on the role of riparian forest," *Ecology,* vol. 65, pp. 1466–75; S.V. Gregory et al., 1991, "An ecosystem perspective on riparian zones," *BioScience,* vol. 41, pp. 540–51.

[334] C. Richardson, 1999, "Ecological functions of wetlands in the landscape," in M.A. Lewis et al. (eds.), *Ecotoxicology and Risk Assessment for Wetlands* (Pensacola, Fla.: SETAC Press). [Special Publication] Society of Environmental Toxicology and Chemistry.

pesticides. Regardless of the class of pollutant, the increased contact time afforded by retention within the soil or sediment matrix of the riparian zone or wetland provides a significantly increased opportunity for attenuation and degradation of the contaminants via chemical and microbial processes. Constructed wetlands have been shown to be very effective as treatment systems for reducing contaminant and pathogen concentrations and the toxicity of point source effluents and non-point source pollution.[335] Increasing the proportion of riparian and wetland structures also significantly improves habitat quality, thereby improving the overall health of the ecosystem.[336]

Recognition of the important role of riparian zones and wetlands in this regard has led to the initiation of a number of restoration initiatives throughout North America. For example, in 1997, the United States Department of Agriculture introduced the National Conservation Buffer Initiative program, in which financial assistance and technical guidance are provided to landowners to develop buffer strips in both rural and urban settings to reduce non-point source pollutant loadings to aquatic environments. The goal of this ambitious program is to have a total of 3.2 million km of buffer strips in place along the nation's waterways by the year 2002. A similar program was launched in Prince Edward Island in 1999, wherein the province has legislated the requirement of vegetative buffers for all watercourses. Similar "buffer strip" initiatives are being proposed in Ontario through various conservation authorities.

2.3.5.2 *Cooling Water Effluent*

Effluent discharged as a result of cooling operations in industry is a form of point source pollution to aquatic environments. This form of pollution does not contribute toxic chemicals to surface waters per se, so there is little risk to human health. However, cooling water effluents can have a significant effect on receiving waters' ecosystems. In streams, large fluctuations in temperature can significantly affect species richness, due to the elimination of thermal cues needed to break egg diapause, reduction in degree days needed to complete

---

[335] Richardson, 1999; J.H. Rodgers et al., 1999, "Constructed wetlands as a risk mitigation alternative," in M.A. Lewis et al. (eds.), *Ecotoxicology and Risk Assessment for Wetlands* (Pensacola, Fla.: SETAC Press), [Special Publication] Society of Environmental Toxicology and Chemistry, pp. 9–25; G.M. Huddleston et al., 2000, "Using constructed wetlands to treat biochemical oxygen demand and ammonia associated with a refinery effluent," *Ecotoxicology and Environmental Safety,* vol. 45, pp. 188–93.

[336] Naiman et al., 2000.

development, and loss of synchrony in life cycles.[337] In both streams and lakes, a change in temperature profile can also alter the type of fish community present.

2.3.5.3 *Radionuclides*

Exposure to radionuclides may occur from both natural and artificial sources. The former account for approximately 82% and include sources of cosmic, internal, and terrestrial origin as well as exposure to radon.[338] Artificial sources account for 18% of exposure and include medical applications, occupational exposure, nuclear fuel cycle, and fallout. On average, Canadians are exposed to 2.6 mS/year (milliSieverts per year), which is slightly higher than the average global exposure of 2.4 mS.[339]

Radionuclides are frequently detected in both surface and groundwater sources that supply drinking water; however, the contribution of drinking water to total exposure is very small and is primarily the result of the presence of naturally occurring radionuclides in the uranium and thorium decay series.[340] Sources of radionuclides to surface waters include atmospheric deposition to both surface waters and soil, loss from soils due to surface runoff and leaching to soil water, and direct addition from effluent radionuclides associated with industrial activities.[341]

Radon is the major source of naturally occurring radiation exposure for humans.[342] Exposure occurs as the result of ingestion of water in which radon is dissolved or via inhalation of atmospheric radon. Because radon is volatile, surface water concentrations tend to be low, typically in the order of 0.01 Bq/L (becquerels per litre). However, groundwater may contain higher levels, often in the range of

---

[337] J.D. Allan, 1995, *Stream Ecology: Structure and Function of Running Waters* (New York: Chapman & Hall).

[338] U.S. National Research Council, Committee on the Biological Effects of Ionizing Radiation, 1990, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation* (Washington, D.C.: National Academy Press).

[339] Canada, Health Canada, 1996, *A One-year Survey of Halogenated Disinfection By-products in the Distribution Systems of Treatment Plants Using Three Different Disinfection Processes* (Ottawa: Health Canada), Report 960-EHD-206.

[340] Ibid.

[341] L.G. Cockerham and M.B. Cockerham, 1994, “Environmental ionizing radiation,” in L.G. Cockerham and B.S. Shane (eds.), *Basic Environmental Toxicology* (Boca Raton, Fla.: CRC Press), pp. 231–61.

[342] Canada. Health Canada, 1996.

10–75 Bq/L.[343] In some jurisdictions in the United States, radon is a significant contaminant of drinking water, particularly in locations in which radon occurs at high natural concentrations in groundwater or when it is found at high indoor atmospheric concentrations.[344] However, in Canada, it has been concluded that radon poses little risk to humans via drinking water exposure.[345] For this reason, a MAC has not been established for this radionuclide; however, it is recommended that in situations in which indoor air concentrations of radon exceed the acceptable level of 800 Bq/m3 (as an annual average concentration in a normal living space), groundwater supplies should be examined to determine levels in that matrix.

Table 2-17 Concentration Ranges for Radionuclides Measured in Various Stages of Water Treatment

Compound	**Concentrations Ranges**		
	Influent (Surface)	**Treated**	**Distribution**
Southern Region			
Gross Alpha radiation (Bq/L)	0.08-0.31 (24/4/2)[1]	0.05-0.72 (23/23/23)	0.05-0.84 (47/15/10)
Gross Beta radiation (Bq/L)	0.04-0.19 (24/22/22)	0.04-0.32 (23/23/23)	0.04-0.34 (47/7/6)
Tritium	6.0-11.0 (24/6/5)	----- (23/1/0)	6.0-8.0 (47/7/6)
Radium	----- (24/6/0)	----- 23/1/0)	----- (47/8/0)
Northern Region			
Gross Alpha radiation (Bq/L)	----- (9/1/0)	0.04-0.12 (6/3/3)	0.05-0.06 (15/4/2)
Gross Beta radiation (Bq/L)	0.04-0.07 (9/7/7)	0.05-0.21 (6/6/6)	0.04-0.13 (15/12/12)
Tritium	---- (9/2/0)	----- (6/1/0)	----- (15/3/0)
Radium	----- (9/0/0)	----- (6/0/0)	----- (15/0/0)

[1] First number in parentheses represents # of municipal water treatment plants searched, second number represents # of municipal water treatment plants that tested for presence of compound, and third number represents the # of municipal water treatment plants that detected it on at least one occasion.

Source: Ontario Drinking Water Surveillance Program, 2000, *Reports for 1998 and 1999* [online], [cited October 23, 2001], <www.ene.gov.on.ca/envision/dwsp9899/dwsp.htm.

---

[343] Ibid.

[344] A.V. Nero Jr., 1988, “Radon and its decay products in indoor air: An overview,” in W. Nazaroff and A.V. Nero Jr. (eds.), *Radon and its Decay Products in Indoor Air* (New York: John Wiley and Sons), pp. 1–53; Canada, Health Canada, 1996.

[345] Canada, Health Canada, 1996.

In Ontario, the radionuclide of primary concern in drinking water is tritium, which is routinely monitored as part of the Ontario Drinking Water Surveillance Program.[346] Average tritium concentrations have been shown to range from 5 to 10 Bq/L in surface waters across Canada, between 7 and 10 Bq/L in Great Lakes surface waters, and to average 6 Bq/L in Ontario surface waters based on samples taken from various locations.[347] These values are all well below the Canadian drinking water quality maximum allowable concentration (MAC) for tritium of 7,000 Bq/L. Moreover, data from the ODWSP indicate that tritium has never been found above the Ontario drinking water objective, although the provincial drinking water objective for tritium is currently under review.[348] In some jurisdictions in the United States, radon is a significant contaminant of drinking water, particularly in locations in which radon occurs at high natural concentrations in groundwater or when it is found at high indoor atmospheric concentrations.[349] However, in Canada, it has been concluded that radon poses little risk to humans via drinking water exposure.[350] For this reason, a MAC has not been established for this radionuclide; however, it is recommended that in situations in which indoor air concentrations of radon exceed the acceptable level of 800 Bq/m3 (as an annual average concentration in a normal living space), groundwater supplies should be examined to determine levels in that matrix.

2.3.5.4 *Natural Toxins*

There are numerous examples of naturally occurring toxins in aquatic environments. Of primary concern to human health are toxins in drinking water that originate from cyanobacteria. Cyanobacteria grow in surface waters of freshwater lakes and rivers throughout the year but are typically most prevalent during the warm mid- to late-summer months, when they may bloom to high concentrations.[351] These algae proliferate during this time of the year because (1) they have superior light-capturing capacity relative to some other

---

[346] Ontario Drinking Water Surveillance Program, 2000, *Reports for 1998 and 1999* [online], [cited October 23, 2001], <www.ene.gov.on.ca/envision/dwsp9899/dwsp.htm>.

[347] Canada, Health Canada, 1996.

[348] Ontario Drinking Water Surveillance Program, 2000.

[349] Nero, 1988, pp. 1–53; Canada, Health Canada, 1996.

[350] Canada, Health Canada, 1996.

[351] E.P.Y. Tang et al., 1997, "Cyanobacterial dominance of polar freshwater ecosystems: Are high-altitude mat-formers adapted to low temperature?" *Journal of Phycology,* vol. 33, pp. 171–81; R.E. Lee, 1999, *Phycology* (Cambridge: Cambridge University Press), p. 614.

algae; (2) they have a high affinity for nitrogen and phosphorus when supplies are limited; (3) they can regulate their position in the water column via gas vacuoles to better exploit areas of higher nutrient enrichment; and (4) they have relatively high temperature optima for growth.[352] Not surprisingly, it is during this time of the year that they pose the greatest threat to humans and wildlife of poisoning following ingestion. These algae occur across Canada, but they are particularly prevalent in the prairies, where cyanobacterial poisoning has been the cause of livestock deaths.[353] However, cyanobacterial blooms have increased in the Great Lakes, so there may be increased risks to humans in these (and other) areas using this water for drinking purposes. Interestingly, it has been hypothesized that one reason for the apparent increase in these blooms in the Great Lakes region is a corresponding general increase in lake-wide measurements of nitrogen.[354] Although studies to investigate this apparent relationship are lacking, it underscores the potential interactive nature of many contaminants in aquatic environments. More importantly, it has serious implications for the management of environmental contaminants in aquatic environments insofar as regulation of single compounds may not be appropriate, nor sufficiently protective, for both humans and aquatic biota, if interactions with other compounds or abiotic factors exert a strong influence on the behaviour and concentration of the contaminant to which the regulation(s) is (are) directed.

Some cyanobacteria produce toxins (cyanotoxins) of which there are two basic types: neurotoxins and hepatotoxins.[355] Neurotoxins are alkaloids (low molecular-weight nitrogen-containing compounds) that block the transmission of nerve impulses between neurons and between neurons and muscles. Hepatotoxins are inhibitors of protein phosphatases 1 and 2A and cause bleeding of the liver.[356] There are two types of hepatotoxins: microcystins (produced by several species) and nodularins (produced by a single species). The former is most commonly encountered in freshwater and poses the greatest risk to humans and wildlife that drink contaminated water. The occurrence of these toxins in

---

[352] Ibid.

[353] Canadian Water Resources Association, [n.d.] “What are toxic blue-green algae?” *Manitoba Rural Water Quality: Toxic Blue-Green Algae* [online], publication #2 in a series of water quality factsheets, [cited February 4, 2002] <www.cwra.org/branches/arts/manitoba/pub2page1.html>.

[354] Chambers, 1997.

[355] S.G. Bell and G. A. Cobb, 1994, “Cyanobacterial toxins and human health, *Reviews in Medical Microbiology*, vol. 5.

[356] A.R. Arment and W.W. Carmichael, 1996, “Evidence that microcystin is a thio template product,” *Journal of Phycol*ogy, vol. 32, pp. 591–97.

drinking water is most likely to occur in areas that do not have water treatment. However, these toxins may also occur in treated water even when the water is chlorinated. Indeed, although suitable analytical methods are poorly developed, it appears that a reduction in toxicity due to these neurotoxins in treated water can only be achieved using activated carbon or ozonation treatment processes.[357]

The proposed guideline for consumption of algal toxins from drinking water in Canada is 1.5 μg/L which is slightly higher than the World Health Organization guideline of 1.0 μg/L. However, these guidelines do not address risks associated with the potential for cancer from these toxins, which have been shown to promote tumour development. Interestingly, in a recent survey of drinking water in the United States and Canada, algal toxins were found to exceed World Health Organization guidelines in a number of jurisdictions (e.g., Winnipeg, Regina, central Alberta). In the lower Great Lakes, particularly Lake Erie, the frequency of recent blue-green dominated algal blooms appears to be increasing. Possible causes for these increases are unknown but they may reflect lake-wide increases in nitrogen or possibly an indirect effect of the invasive zebra mussel, whose filtering activity may be removing species that would otherwise compete with these algae. Similar competitive interactions have been shown between the zebra mussel and the deepwater amphipod, *Diporiea* spp. It has been hypothesized that population densities of the latter are declining in southern Lake Michigan due to removal of diatoms, its primary food base, via feeding (filtering) activity of the zebra mussels.[358]

Pfiesteria, which has been connected to intense agricultural practices, is another natural toxic agent that has recently emerged as a significant threat to human and aquatic ecosystem health. Outbreaks of *Pfiesteria piscicida*, a dinoflagellate marine alga, are uncommon in Canada, but it has been a significant problem in the United States estuaries, particularly in South Carolina, where it has been connected with large-hog farming practices.[359] These outbreaks are mostly the result of poor watershed-management practices, such as inadequate protection from agricultural runoff. They provide a dramatic indication of the intimate

---

[357] World Health Organization, 1993.

[358] P.F. Landrum et al., 2001, "Evaluation of Lake Michigan sediment for causes of the disappearance of Diporiea spp. in southern Lake Michigan," *Journal of Great Lakes Research,* vol. 26.

[359] U.S. Environmental Protection Agency, Office of Water, 1998b, *National Water Quality Inventory: 1998 Report to Congress. Appendix IV. Environmental Impacts of Animal Feedlot Operations* [online], [cited October 23, 2001], <www.epa.gov/305b/98report/toc.html>.

relationship between humans and ecosystems and the effect that each can have on the other.[360]

Pfiesteria poses risks to both humans and ecosystems, although we have a much better understanding of the latter than the former.[361] In fish, *Pfiesteria* causes characteristic lesions, the origin of which is assumed to be a toxin secreted by the alga that damages the mucus/skin of the fish, allowing penetration of harmful bacterial or fungal species present in the water.[362] In humans, the potential routes of exposure and the mechanisms of toxicity are poorly understood. In one of the few comprehensive studies conducted to date, Glasgow and team reported that individuals having contact with the contaminated water exhibited symptoms of headaches, skin lesions, and skin burning.[363] Unfortunately, because there is currently little information on the occurrence of *Pfiesteria* in drinking water supplies in areas where this organism occurs, the potential exposure via this route is virtually unknown.

2.3.6 Summary of Sources and Pathways

Although our discussion has been necessarily brief in scope and general in conception, we have attempted to identify the most significant point and non-point sources of contaminants, the transport pathways (e.g., erosion, leaching, deposition) through which the contaminants move, and some of the factors (e.g., hardness, pH) that affect their composition and toxicity in the environment as they become incorporated into the groundwater and surface water resources that supply our drinking water. Although we have attempted to be as thorough as possible in our consideration of the various sources and pathways of water contamination, we realize that some important aspects (e.g., specific compounds) have not been addressed at a level of detail that might otherwise be warranted based on their perceived or actual importance. However, it must be realized that our goal was not to provide a comprehensive assessment in this regard but, rather, to provide the reader with an introduction to, and appreciation of, the myriad sources, pathways, and types of contaminants that

---

[360] E.K. Silbergeld et al., 2000, *"Pfiesteria*: Harmful algal blooms as indicators of human:ecosystem interactions," *Environmental Research,* vol. 82, pp. 97–105.
[361] Ibid.
[362] E.J. Noga et al., 1996, "A new ichthyotoxic dinoflagellate: Cause of acute mortality in aquarium fishes," *Veterinary Record*, vol. 133, pp. 96–97.
[363] H.B. Glasgow et al., 1995, "Insidious effects of a toxic estuarine dinoflagellate on fish survival and human health," *Journal of Toxicology and Environmental Health*, vol. 46, pp. 501–522.

occur in surface waters, groundwater, and drinking water, to serve as a basis for assessing the relative risks to human health posed by selected contaminants in drinking water. We have provided the reader with numerous references that may be used as a starting point for additional investigation. With these thoughts in mind, we now turn our attention to issues of risk assessment, with the goal of describing risk assessment methodologies and the risks that selected compounds in drinking water pose to human health.

3 Assessing Relative Risk and Risk Characterization

Risk assessment has traditionally been done by comparing the exposure concentration of the stressor(s) to the responses reported for that (those) stressor(s) in laboratory tests. These comparisons usually make use of response data from surrogate species such as laboratory rats and mice for assessing risks in humans and fish and from other wildlife for assessing risks in the environment. Risk assessments for humans usually employ a number of conservative steps to ensure that the population is protected from almost all eventualities; however, for environmental risk assessment, some effects may be tolerated, especially if the activities that produce the risks also bring benefits, such as the use of pesticides in the production of food.

3.1 Deterministic versus Stochastic Effects in Risk Assessment

Before we discuss the process of risk assessment, it may be valuable to explain the difference between deterministic and stochastic effects in the context of risk assessment. Deterministic effects are those for which the severity of the damage caused is proportional to the dose and for which a threshold dose exists below which they do not occur.[364] Effect endpoints that measure toxicity, such as mortality or growth inhibition, are examples of deterministic endpoints. On the other hand, stochastic effects are those for which the probability of occurrence, rather than the severity, is proportional to the dose. It is assumed that there is no threshold below which stochastic effects do not occur. Cancer is the primary example of a stochastic effect. Deterministic effects may be categorized as either somatic or developmental, whereas stochastic effects may be categorized as somatic, hereditary, or teratogenic.

---

[364] Canada, Health Canada, 1996.

In terms of applying risk assessment methodologies, a key difference between these two categories of health effect is that approaches such as hazard quotient assessments (see below), which are referenced to deterministic endpoints (e.g., no observed effect concentrations), may not be appropriate for assessing risks associated with stochastic effects. In this sense, the approach to risk assessment, and the resulting development of regulatory criteria, differs for each category of effect. Specifically, whereas deterministic approaches, such as the use of hazard quotients, may be suitable for endpoints for which thresholds can be defined, probabilistic approaches may be more appropriate for stochastic endpoints (see below). For example, stochastic effects are the most important consequence of exposure to environmental levels of radiation and hence form the basis of the current radiological guidelines.[365]

3.2 Tiers in Risk Assessment

For logistical reasons, it is frequently necessary to divide complex tasks into smaller components that can be more easily managed or divided among workers. Nowhere is this more true than in risk assessment, where relationships between exposure and responses can be very complex. The use of tiers, or steps, in the process of risk assessment is one method used to reduce complexity and narrow the focus of risk assessments to the key issues and has been recommended frequently for use in risk assessments.[366] The use of tiered approaches in risk assessment has several advantages. The initial use of conservative criteria allows substances that truly do not present a risk to be eliminated from the risk assessment process, thus shifting the focus of expertise to more problematic substances or situations. From one tier to the next, the estimates of exposure and effects become more realistic as uncertainty is reduced by the acquisition of more or better quality data. Tiers are normally designed such that the lower tiers in the risk assessment are more conservative (less likely to pass a hazardous substance or activity) while the higher tiers are more realistic, with assumptions more closely approaching reality. Because lower tiers are designed to be protective, failing to meet the criteria for these tiers does not necessarily mean

---

[365] Ibid.

[366] U.S. National Research Council, 1993, *Issues in Risk Assessment* (Washington, D.C.: National Academy Press); U. S. Environmental Protection Agency, Risk Assessment Forum, 1998, *Guidelines for Ecological Risk Assessment* (Washington, D.C.: US EPA); U.S. Environmental Protection Agency, Office of Pesticide Programs, 1999, "ECOFRAM aquatic draft report" and "ECOFRAM terrestrial draft report," *Ecological Risk Assessment Page* [online], [cited February 4, 2002], <www.epa.gov/oppefed1/ecorisk/index.htm>.

that a disaster is imminent. Rather, it is an indication that an assessment based on more realistic data is needed before a regulatory decision can be reached.

3.3 The First Tier of Risk Assessment – Classification Systems

Classification systems only make use of the physical or biological properties of the stressor. They have been used over the years by a large number of organizations for the purposes of ranking and selecting substances for further regulatory action.[367]

The basic principle of a scoring system is to assign a rank or priority to a list of potential stressors. This is usually accomplished by assigning a score to several of the properties of the substances being assessed, manipulating these scores in some way, and then using the scores to rank (and select) some of these substances for further action. Some scoring systems use single criteria (above or below a threshold) for a property while others may use multiple criteria, which are assigned numerical scores. Very few scoring systems use decision criteria for multiple values, i.e., where different authors report different values. Some systems use the smallest value, regardless of source or provenance (validity of the methods used to determine the value). Some scoring systems use mathematical formulae, where scores are added, multiplied, or subtracted to give a combined score. The combined score is then ranked to identify compounds of higher or lower priority. Yet other scoring systems use the scores in a taxonomic key, where, after the scores have been evaluated in a series of questions, the compound is classified into a particular category. This has the advantage that scores may be combined in specific ways for different combinations of properties and that the system may be integrated into a computerized expert system.

Correctly used, scoring systems have been used to rank substances in order of priority for further assessment. This is usually in the first tier of risk assessment. Further assessment is normally required, because the scoring systems commonly make use of worst-case data and they do not handle missing values, weighting, or scaling in clear or appropriate ways. The rank numbers produced from combinations of scores have no meaning in the real world – their only use is to allow prioritization of substances for more detailed assessment.

---

[367] International Joint Commission, 1993, *A Strategy for the Virtual Elimination of Persistent Toxic Substances,* vol. 1, Report of the Virtual Elimination Task Force to the IJC (Windsor, Ont.: IJC); Ontario, Ministry of the Environment and Energy, Hazardous Contaminants Branch, 1990, *The Ontario Ministry of the Environment Scoring System: A Scoring System for Assessing Environmental Contaminants* (Toronto: Ministry of the Environment and Energy).

3.4 The Use of Quotients for Assessing Hazard

The most widely used method of assessing risk is the hazard quotient (HQ) method, by which the exposure concentration of a stressor, either measured or estimated, is compared to an effect concentration such as an EC50 or no observed effect concentration (NOEC).[368] These are simple ratios of single exposure and effects values and may be used to express hazard or relative safety. For example:

$$\text{Hazard} \approx \frac{\text{Exposure concentration}}{\text{Effect concentration}} \quad \text{or Margin of Safety} \approx \frac{\text{Effect concentration}}{\text{Exposure concentration}}$$

Hazard quotients have normally been calculated by comparing the effect concentration of the most sensitive organism or group of organisms to the greatest exposure concentration measured or estimated in the environmental matrix. In this case, if the hazard ratio is greater than 1, a hazard exists. Many HQ assessments incorporate some form of uncertainty factor, either explicitly as part of the calculation itself or in the criteria for acceptance of the HQ (see Canadian Water Quality Guidelines[369] and table 3-1).

Because they frequently make use of worst-case data, HQs are designed to be protective of almost all possible situations. However, reduction of the probability of a type II error (false negative) through the use of very conservative application factors and assumptions can lead to the implementation of expensive measures of risk mitigation for stressors that pose little or no threat to humans or the environment.[370] A common error in the interpretation of HQs is the assumption that the HQ itself is exactly proportional to the "risk." As the concept of risk should always incorporate an element of probability, the HQ is biased because it assumes that the conditions of the HQ exist on every occasion and in every location. In addition, the HQ is based on a point estimate of effect (EC50 or

---

[368] D.J. Urban and N.J. Cook, 1986, *Standard Evaluation Procedure for Ecological Risk Assessment* (Washington D.C.: U.S. Environmental Protection Agency, Office of Pesticide Programs), EPA/540/09-86/167; E.J. Calabrese and L.A. Baldwin, 1993, *Performing Ecological Risk Assessments* (Boca Raton, Fla.: Lewis Publishers).

[369] Canadian Council of Resource and Environment Ministers, Task Force on Water Quality Guidelines, 1999, *Canadian Water Quality Guidelines* (and updates), (Ottawa: CCREM).

[370] D.R.J. Moore and B.J. Elliot, 1996, "Should uncertainty be quantified in human and ecological risk assessments used for decision-making?" *Human Ecological Risk Assessment*, vol. 2, pp. 11–24; G.F. Lee and A. Jones-Lee, 1995, "Appropriate use of numeric chemical concentration-based water quality criteria," *Human Ecological Risk Assessment,* vol. 1, pp. 5–11.

NOEC) and does not consider the relationship between the concentration and the effect (the dose-response). Although very great HQs are obviously more important than small HQs, small differences between these ratios should not be considered significant. At the other end of the scale, HQs that are less than 1, no matter how small, are all indicative of low risks, provided that appropriate uncertainty factors have been considered. Because of this, the HQ approach is only really useful for early tiers or preliminary risk assessments and for the elimination of substances from the need for further assessment.

3.5 The Probabilistic Approach

The probability of occurrence of a particular event is, and has been, widely used in the characterization of risk from many physical and medical events in humans (the insurance industry) and for protection against failure in mechanical and civil engineering projects (time between failures, 1-in-100-year floods, etc.). Probabilistic risk assessment procedures make use of distributions of values for exposures and effects to estimate the likelihood that a particular combination of exposure and response will occur. Probabilistic approaches offer an additional refinement to HQ approaches.

Distributional approaches have been used in the regulation of food additives[371] for the protection of human health for several years. The idea of using these distributions for setting environmental quality guidelines originated

Table 3-1 Uncertainty Factors in Assessing Risks from Substances in Humans

From	To	Uncertainty factor
Average	sensitive human	≥10
Animal	human	≥10
LOAEL	NOAEL	≥10
Subchronic	Chronic	≥10
Database inadequacies		≥10
Modifying factors		0

---

[371] I.C. Munro, 1990, “Safety assessment procedures for indirect food additives: An overview,” *Regulatory Toxicology and Pharmacology*, vol. 12, pp. 2–12.

from early work in the Netherlands[372] and the United States.[373] Comparing distributions of species sensitivity directly to distributions of exposure concentrations[374] was recommended for pesticide risk assessment by the Aquatic Risk Assessment Dialogue Group,[375] demonstrated for metals and other substances,[376] and incorporated in a computer program.[377]

Probabilistic risk assessment has been recommended for regulatory risk assessment of pesticides.[378] The general concepts, as they apply to ecological and human health risk assessment, have been reviewed and extensively discussed.[379]

---

[372] N.M. Van Straalen, 1982, personal communication; S.A.L.M. Kooijman, 1987, "A safety factor for LC50 values allowing for differences in sensitivity among species," *Water Research*, vol. 21, pp. 269–76.

[373] C.E. Stephan et al., 1985, *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (Washington, D.C.: U.S. Environmental Protection Agency), EPA 22/R-85-100, pp. 1–97. (Other authors have expanded upon the probabilistic risk estimation process: N.M. Van Straalen and C.A.J. Denneman, 1989, "Ecotoxicological evaluation of soil quality criteria," *Ecotoxicology and Environmental Safety*, vol. 18 ; C. Wagner and H. Løkke, 1991, "Estimation of ecotoxicological protection levels from NOEC toxicity data," *Water Research,* vol. 25; T. Aldenberg and W. Slob, 1991, "Confidence limits for hazardous concentrations based on logistically distributed NOEC toxicity data," *Ecotoxicology and Environmental Safety*, vol. 18; T. Aldenberg and W. Slob, 1993, "Confidence limits for hazardous concentrations based on logistically distributed NOEC toxicity data," *Ecotoxicology and Environmental Safety,* vol. 25; P.C. Okkerman et al., 1991, "Ecotoxicological effects assessment: A comparison of several extrapolation procedures," *Ecotoxicology and Environmental Safety,* vol. 21; and P.C. Okkerman et al., 1993,"Validation of some extrapolation methods with toxicity data derived from multiple species experiments," *Ecotoxicology and Environmental Safety*, vol. 25.)

[374] R.D. Cardwell et al., 1993, "Aquatic ecological risk," *Water Environment Technology*, vol. 5, pp. 47–51.

[375] Society for Environmental Toxicology and Chemistry (SETAC), Aquatic Risk Assessment and Mitigation Dialog Group, 1994, *Pesticide Risk and Mitigation*, Final Report (Pensacola, Fla.: SETAC Foundation for Environmental Education).

[376] B.R. Parkhurst et al., 1996, *Aquatic Ecological Risk Assessment: A Multi-tiered Approach to Risk Assessment* (Alexandria, Va.: Water Environment Research Foundation).

[377] Cadmus Group Incorporated, 1996, *Aquatic Ecological Risk Assessment* (Alexandria, Va.: Water Environment Research Foundation).

[378] U.S. Environmental Protection Agency, Office of Pesticide Programs, 1999.

[379] R.W. Suter et al., 1993b, *Ecological Risk Assessment* (Boca Raton, Fla.: Lewis Publishers; T.L. Forbes and V. E. Forbes, 1993, "A critique of the use of distribution-based extrapolation models in ecotoxicology," *Functional Ecology,* vol. 7; V.E. Forbes and T.L. Forbes, 1994, *Ecotoxicology in Theory and Practice* (London: Chapman & Hall); F. Balk et al., 1995, *Guidance Document for Aquatic Effects Assessment* (Paris: Organization for Economic Co-operation and Development); Solomon, 1996; G.M. Richardson, 1996, "Deterministic versus probabilistic risk assessment: Strengths and weaknesses in a regulatory context," *Human and Ecological Risk Assessment,* vol. 2, pp. 44–54; P.S. Anderson and A.L. Yuhas, 1996, "Improving risk management by characterizing reality: A benefit of probabilistic risk assessment," *Human and Ecological Risk Assessment,* vol. 2, pp. 55–58; D.E. Burmaster, 1996, "Benefits and costs of using probabilistic techniques in human health risk assessments – with emphasis on site-specific risk assessments," *Human and Ecological Risk Assessment,* vol. 2, pp. 35–43; M. Power and L.S. McCarty, 1996, "Probabilistic risk assessment: Betting on its future," *Human and Ecological*

The major advantage of probabilistic risk assessment is that it uses all relevant data and allows quantitative estimation of risks. In addition, the data may be revisited and the decision criteria become more robust with additional data. And the method is transparent and consistent – producing the same results with similar data sets. The method does have some disadvantages. More data are usually needed. For new substances not yet found in the environment, models must be used to estimate exposures and have not been widely validated for these uses. Probabilistic approaches are also less easily applied where exposure is from multiple sources.

It is important to recognize that, as with risk assessment generally, all probabilistic risk assessment methods are essentially similar but may be used for different purposes. Risk assessments are sometimes used to set environmental guidelines and criteria while probabilistic risk assessment may be used to assess risks in situations where exposures are known and their significance is being assessed.

For the setting of criteria, an *a priori* decision must be made as to what level of protection is acceptable.[380] For example, the U.S. EPA method of setting environmental water quality criteria[381] uses a 95% protection level (with an extrapolation factor of 2) but applies this to acute, chronic, and tissue residues. Similar techniques have been recommended for water quality determination in the North American Great Lakes Initiative.[382]

Probabilistic risk assessment is also used in assessing risks from situations that already exist, such as, for example, where a substance has been released or is about to be released into the environment and a risk assessment needs to be applied to a risk-benefit regulatory decision. In this case, no predefined percentage of species to protect is necessary, as this will vary from one situation to another, depending on other lines of evidence, such as the types of organism most likely to be affected or the toxicological properties of the substance. Unlike the process of criteria setting, it may be very appropriate to exclude certain types of organisms from the assessment or, based on biological knowledge, to tolerate more frequent exceedences of species response values for some groups of organisms than others. Because the potential adverse effects of measured or

---

Risk Assessment, vol. 2, pp. 30–34; V.M. Bier, 1999, "Challenges to the acceptance of probabilistic risk analysis," *Risk Analysis,* vol. 19, pp. 703–09; S.M. Roberts, 1999, "Practical issues in the use of probabilistic risk assessment," *Human and Ecological Risk Assessment*, vol. 5, pp. 729–36; L. Postuma et al. (eds.), 2001, *Species Sensitivity Distributions in Risk Assessment* (Pensacola, Fla.: SETAC Press).

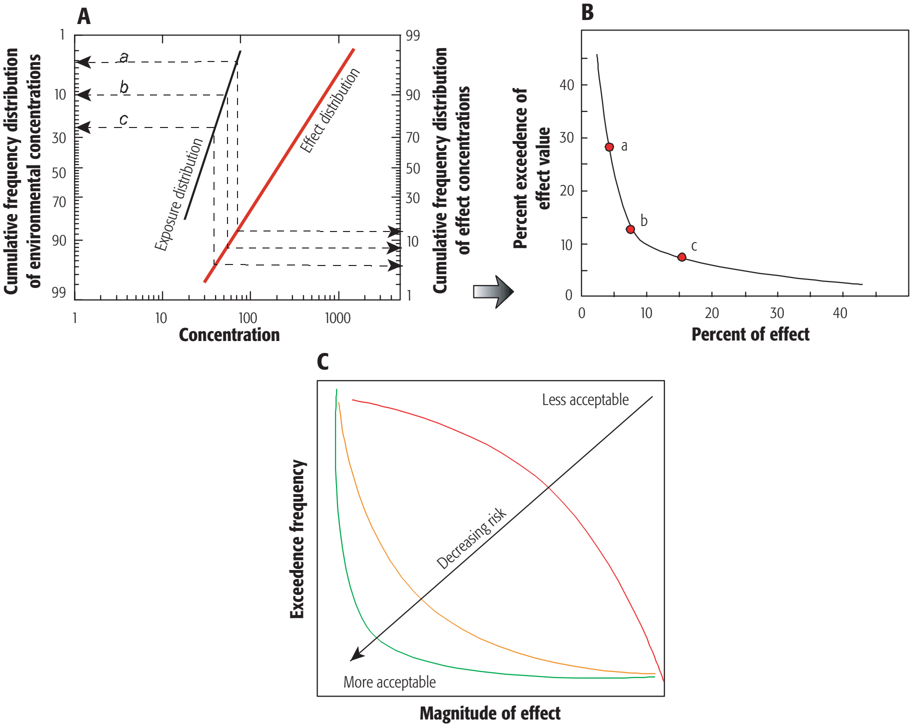
[380] Balk et al., 1995.

[381] Stephan, 1985.

[382] U. S. Environmental Protection Agency, 1995, "Final water quality guidance for Great Lakes System," *Federal Register* (Washington, D.C.: Thursday, March 23), pp. 15366–15425.

estimated exposures are being assessed in this method, combination or segregation of exposure data sets adds significant utility to the risk assessment process. It allows more realistic toxicity and exposure information to be applied to the ranking of exposure scenarios for the purposes of mitigation or regulatory decision making. Because risk assessment considers both likelihood of exposure concentrations and likelihood of effects, risk can be expressed as a joint probability, for example, that n% of organisms will be affected x% of the time or in y% of the locations, depending on the type of exposure data collected. These risks can be expressed as the probability of exceeding a fixed criterion of response[383] or as an exceedence profile (EP), (see figure 3-1), a relatively simple and useful tool for communication of risks.[384]

Figure 3-1 Exceedence Probabilities (A) as a Continuum of Likelihoods in an Exceedence Profile (EP) (B) and the Use of These Curves in Decision Making (C)



Source: U.S. Environmental Protection Agency, 1999.

---

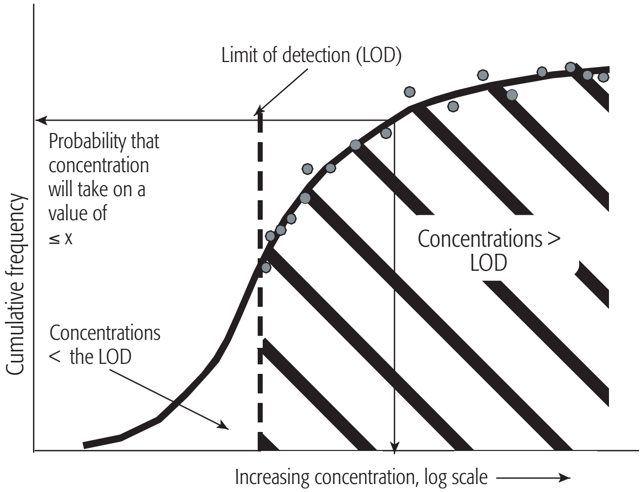
[383] K.R. Solomon et al., 1996, “Ecological risk assessment of atrazine in North American surface waters,” *Environmental Toxicology and Chemistry,* vol. 15, pp. 31–76.

[384] U.S. Environmental Protection Agency, Office of Pesticide Programs, 1999; L. Postuma, 2001.

Distributional analysis must be applied to concentrations of substances in the environment with due consideration for the fact that these data are usually censored by the limits of analytical detection (figure 3-2). In practice, all exposure concentration data below the limit of detection (LOD) or limit of quantization (LOQ) are assigned a dummy value of zero. These data are used in the calculation of the total number of samples (n) but are not used to estimate centiles directly. The assumption used here is that the values below the LOD lie on the same distribution as the values above the LOD. With recent advances in analytical chemistry, values below the LOD are usually of little toxicological significance; however, the regression equation for the distribution may be used to estimate the concentration of data points below the LOD for the purposes of developing an exceedence profile. The substitution of a value of half the LOD for all the data points below the LOD – a practice used for estimating mean concentration of a data set – results in a biased data set that will be difficult to fit to any model.

Probabilistic risk assessment has been applied to a number of substances as part of a higher tiered and more realistic assessment of their ecological risks. While probabilistic risk assessment provided tools to more thoroughly address these assessments and to handle large data sets, other lines of evidence were also important in reaching the final conclusions. These risk assessments incorporated a broad range of expertise and resources and were most easily carried out where good data sets for toxicity and exposure values were available. Probabilistic risk assessment is a significant improvement on the traditional HQ approach but it

Figure 3-2 Censoring of a Distribution of Measured Concentration Data by the Level of Detection of the Analytical Method



will likely continue to evolve as the entire science moves forward and as exceptions test the interpretation of the methods. As has been pointed out, one of the major hurdles that probabilistic risk assessment will face is its acceptance by the public and regulators.[385] Risk managers will likely continue to demand or, at least, interpret probabilistic risk estimates as point estimates of high certainty.[386] Decision makers want to know whether it is safe and prefer being told what will happen, not what might happen.[387] Similarly, the public demands absolute safety but has less understanding of probability and greatly misperceives risks to themselves, fellow humans, and the environment.[388]

3.6 Risk Perception

Once risk has been characterized, it will almost always be necessary to develop a risk communication strategy. Effective risk communication is not easy to achieve, especially if the result of the assessment is contrary to conventional wisdom or to the interests of certain stakeholder groups. Information about risks often involves using terms that are not part of the public vocabulary and hence may be difficult for the public to understand (NOELs, MATCs, uncertainty, etc.). Understanding risk means dealing with a large amount of information. An audience can only assimilate a certain amount of the data that they are given, and this is often greatly oversimplified in the process of assimilation.

Perceptions of human health risk are based on our social structures and morals, and it is necessary to take these into account when communicating risks to the public. A person's perception of risk will also be determined by his or her implicit "world view" and knowledge or assumptions of who (or what) receives the benefits and who (or what) pays the costs for the risk management decisions.[389] While the scientific definition of risk is usually taken as the probability that a particular event will occur (i.e., an automobile accident), the

---

[385] K.R. Solomon, 1999, "Integrating environmental fate and effects information: The keys to ecotoxicological risk assessment for pesticides," in G.T. Brooks and T.R. Roberts (eds.), *Pesticide Chemistry and Bioscience: The Food-Environment Challenge* (London: Royal Society of Chemistry), pp. 313–26; Roberts, 1999.

[386] Moore and Elliott, 1996; Richardson, 1996.

[387] M.G. Morgan, 1998, "Uncertainty analysis in risk assessment," *Human and Ecological Risk Assessment,* vol. 4, pp. 25–39.

[388] P. Slovic, 1987, "Perception of risk," *Science,* vol. 236, pp. 280–285.

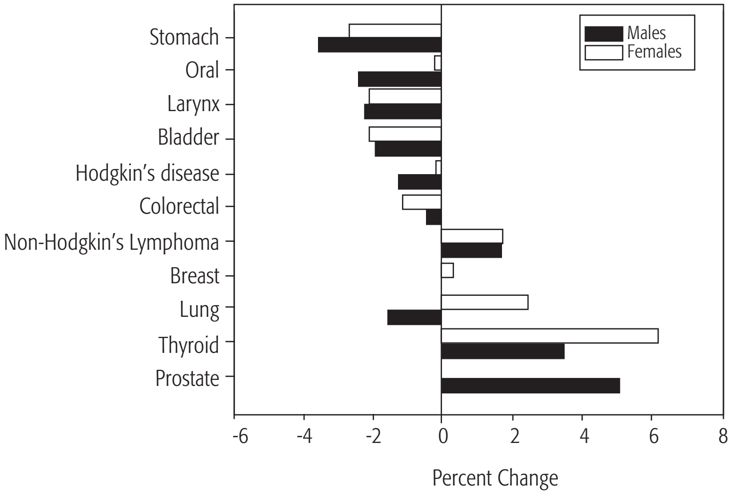
[389] R.T. Lackey, 1995, "The future of ecological risk assessment," *Human and Ecological Risk Assessment*, vol. 1, pp. 339–43.

public perception of risk is a summation of observability (knowledge) and controllability.[390] Thus, the public will perceive a different risk for a voluntary versus a coerced activity or one controlled by the individual versus one controlled by society, government, or another group. The perception of individual and societal risks also varies with expertise and knowledge.[391]

As an example of risk perception, there is a determinant philosophy among the public that cancer rates are rising and that these "increases" are directly linked to exposure to chemicals in drinking water or food. In some cases, this perception is correct and statistics will bear this out. In many cases, however, medical statistics on cancer are incongruent with this perception of increasing cancer rates. For example, of the leading causes of cancer in men and women in Canada, many have either declined or remained comparable relative to their rates of 20 years or so ago (figure 3-3).

In essence, the perception of the public represents uncertainty that can be ascribed to some of the reasons discussed above. Uncertainty is discussed in the next section.

Figure 3-3 Annual Percent Change in Age-Standardized Incidence Rates for Selected Cancer Sites (1988–1995)



Source: Health Canada, 2000, *Canadian Cancer Statistics* [online], [cited October 23, 2001], <www.cancer.ca>.

---

[390] Morgan, 1993, "Risk analysis and management," *Scientific American*, vol. 269, pp. 32–41.

[391] P. Slovic et al., 1980, "Facts and fears: Understanding perceived risk," in R.C. Schwing and W. Albers (eds.), *Societal Risk Assessment: How Safe Is Safe Enough?* (New York: Plenum Press).

3.7 Uncertainty

One of the most elusive concepts in risk assessment to convey to the public is the relative nature of risk. Uncertainty analysis is an important step in the risk assessment process, as it both identifies and, to the extent possible, quantifies the uncertainty in the entire process of problem formulation, analysis, and risk characterization.[392] In addition, an assessment of uncertainty may allow identification of ways in which uncertainty can be reduced. Uncertainties in risk assessment have three sources: ignorance or imperfect knowledge, systematic errors, and non-systematic errors.

The first is ignorance or imperfect knowledge of things that should be known, e.g., not knowing that a pathogen or potentially toxic substance is present in a water source.

Uncertainty from lack of knowledge can never be addressed to everyone's complete satisfaction; however, the more data that are available, the less likely that errors from lack of knowledge will occur. Uncertainty resulting from co-occurring stressors and possible interactions in mixtures is currently a matter of concern. Uncertainty from insufficient data is considered in the probabilistic process, as the estimated exceedences are responsive to the number of data points.

Systematic errors in the risk assessment process are those which may occur through computational mistakes (incorrect position of the decimal, data entry errors) or through incorrect instrumental calibration. Provided that these errors can be identified, they can be addressed through better quality control and quality assurance or through a correction factor. Systematic errors include: errors in sampling where non-representative samples are taken; errors in analysis such as a lack of correction for recovery of the analytical method; errors in analytical techniques where systematic but different errors occur at different concentrations; and incomplete data collections that do not fully represent the entire year, resulting in samples biased towards seasonal drivers that are present during that particular time of the year.

Non-systematic errors are random or stochastic errors that result from the random nature of the system being assessed and, unlike systematic errors, are just as likely to give a value that is too low as a value that is too high. These

---

[392] W.J. Warren-Hicks and D.R.J. Moore, 1998, *Uncertainty Analysis in Ecological Risk Assessment* (Pensacola, Fla.: SETAC Press).

types of errors can be described and quantified but cannot be avoided or corrected for. For example, in the analysis of small concentrations of substances, recoveries are more variable and quantification techniques are subjected to relatively greater interference from matrix effects. Similarly, variability in the results of toxicity tests for a given species performed in different experiments or by different laboratories is a potential source of random (or non-systematic) errors. This type of error can be addressed by taking the smallest value in the set (worst-case, conservative approach) or by using the geometric mean of all the data points for the species.

3.8 Exposure Values and Water Quality Guidelines Used in HQ Assessment

To provide insight into the relative risks to human health of toxic contaminants found in drinking water, we conducted an assessment of selected compounds using the HQ approach. The criteria for the selection of compounds were: (1) whether they pose a known or potential concern to human health (see table A1), and/or (2) availability of measurements in drinking water. The compounds selected for the HQ assessment are identified in table A2, along with their respective Ontario, Canadian, and World Health Organization water quality guideline values.

Assessments were conducted on both treated water and domestic wells. Hazard assessments on treated water were based on information derived from the Ontario Drinking Water Surveillance Program (DWSP). These are available on-line at <www.ene.gov.on.ca/envision/dwsp9899/dwsp.htm>. The DWSP was initiated in 1986 to provide reliable and current information about the quality of municipal drinking water. Participation by municipal water treatment plants (MWTPs) in this program is voluntary, although inclusion in the program is also based on the population served, geographic location, and risk of contamination. In theory, each MWTP monitors a wide range of water quality parameters and toxic compounds, although this is not consistent between plants. Metals, chloroaromatic compounds, chlorophenols, n-nitrosodimethylamine (NMDA), disinfection by-products, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, volatile organics, pesticides, radionuclides, and taste- and odour-impairing compounds are monitored with varying frequency. In practice, however, only metals, nitrates, disinfection by-products, atrazine, and a few individual organic compounds are routinely monitored; it is from these groups of substances that we selected individual contaminants for the current assessment (table 3-2). Measurements at

Table 3-2 Concentration Ranges for Contaminants in Various Stages of Water Treatment

Class	Compound	Concentration Ranges		
		Influent	Treated	Distribution
Pesticides (µg/l)	Atrazine (ATR)	0.05-0.95 (81/36/30)[1]	0.05-0.56 (119/58/54)	-----[2]
	2,4-D	0.24 (81/2/1)	0.02-0.16 (119/3/2)	-----
	Dicamba (DIC)	0.06-0.51 (81/3/2)	0.06-0.20 (119/4/3)	-----
	Dinoseb (DIN)	----- (81/0/0)	0.023 (119/1/1)	-----
	Diquat (DIQ)	----- (81/0/0)	0.80 (119/1/1)	-----
	Paraquat (PAR)	0.20-0.80 (81/3/2)	0.20 119/3/1)	-----
	Prometryne (PRO)	0.08 (81/2/1)	0.05 (119/2/1)	-----
	Simazine (SIM)	0.06-0.07 (81/3/2)	----- (119/2/0)	-----
Inorganic (µg/l)	Nitrates	0.01-9.4 (24/23/23)	0.006-5.7 (23/23/23)	0.01-5.7 (47/29/29)
Metals (µg/l)	Arsenic (AS)	0-2.37 (24/23/23)	0-7.78 (23/23/23)	0-7.2 (47/45/45)
	Cadmium (CD)	0-0.13 (24/23/23)	0-43 (23/23/23)	0-0.21 (47/45/45)
	Chromium (CR)	0-17.8 (24/23/23)	0-31.5 (23/23/23)	0-33.3 (47/45/45)
	Lead (PB)	0-5.99 (24/23/23)	0-8.45 (23/23/23)	0-22.3 (47/44/44)
DBPs (µg/l)	Trihalomethanes (TTHM)	0.5-50.5 (24/23/11)	1.0-52 (23/21/4)	0.5-238 (47/43/43)
	Dichloroacetic acid (DCA)	0.1-13.7 (24/23/14)	0.1-14.8 (23/23/11)	0.2-36.9 (47/45/45)
	Trichloroacetic acid (TCA)	0.5-9.3 (24/22/19)	0.05-36.7 (23/22/13)	0.1-138 (47/43/42)
	Bromodichloromethane (BDM)	0.1-12.6 (24/23/8)	0-6.2 (23/22/4)	0.4-24.4 (47/44/44)
	Bromoform (BRO)	0.5 (24/18/1)	0-7.0 (23/15/2)	0.2-8.5 (47/32/24)
	Chloroform (CHL)	0.1-38.6 (24/23/17)	0-44.6 (23/23/8)	0.2-122 (47/45/44)
Organics (µg/l)	Carbon Tetrachloride (CT)	----- (81/14/0)	-----	0.2-1.6 (119/18/6)
	1,4-Dichlorobenzene (DCB)	0.02-0.15 (81/21/9)	-----	0.05-0.5 (119/24/14)
	Nitrosodimethylamine (NMDA)	0.001-0.005 (81/53/34)	-----	0.001-0.005 (119/4/4)
	Pentachlorphenol (PCP)	0.01-0.016 (81/2/2)	-----	----- (119/0/0)
	Tetrachlorethylene (TCE)	0.05-0.15 (81/16/7)	-----	0.05-4.75 (119/23/9)

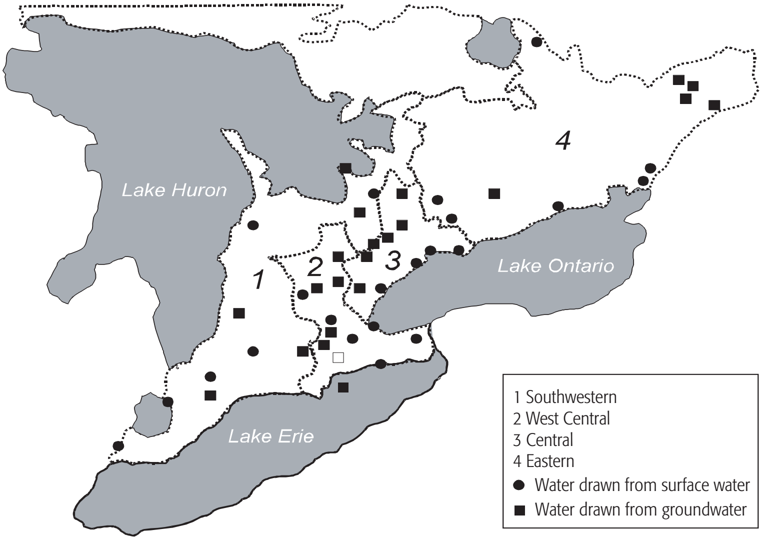
[1] First number in parentheses represents # of municipal water treatment plants searched, second number represents # of municipal water treatment plants that tested for presence of compound, and third number represents the # of municipal water treatment plants that detected it on at least one occasion.

[2] Not measured

the MWTPs are typically made at three stages of water treatment prior to human consumption: (1) raw (influent) water, drawn from surface or groundwater sources, (2) treated laboratory water, and (3) distribution water, which is measured at various locations within the municipality.

For assessments on municipal water treatment, concentrations of the compounds listed in table 3-2 were taken from 47 randomly selected MWTPs in four regions of Ontario, 12 from each of the three southern-most regions and 11 from the eastern region (figure 3-4). Of the 47 plants selected, 24 (six per region) extracted water from surface water sources (streams, lakes) and 23 extracted it from groundwater sources. At each plant, we recorded the minimum and maximum value measured for each compound in the influent (surface or ground) and distribution stages of water treatment from the 24 surface water stations and the 23 groundwater stations. However, because few MWTPs regularly monitor levels of pesticides and contaminants, we searched all water treatment plants in Southern Ontario (119 plants in total) for pesticide concentration data. Hazard quotients were determined for each of the metals, disinfection by-products, nitrates, pesticides, and organics selected

Figure 3-4 Location of Municipal Water Treatment Stations Used in the Hazard Quotient (HQ) Assessment for Metals, Pesticides, Disinfection By-products, and Nitrates



Sources: Briggens and Moerman, 1995; Frank et al., 1990; Goss et al., 1998; Ontario, Ministry of the Environment, 1985.

from the drinking water database. In all cases, except pesticides, the HQ estimates were based on maximum concentrations in the distribution water (48 stations), as we felt that these concentrations would be most representative of those to which humans would be exposed via ingestion of water. In the case of pesticides, which were not routinely measured in distribution waters in the DWSP, we used values from the treatment stage.

For untreated well water, we assessed only pesticides and nitrate concentrations. For these compounds, we used the information from Ontario Ministry of the Environment, Frank et al., Rudolph and Goss, and Briggins and Moerman.[393] As with treated water assessments, we used the maximum value in the HQ assessment; however, we were careful to differentiate between normal contamination levels (e.g., those which might occur as a result of groundwater contamination or normal runoff events) and those due to spills, back-siphoning, or other unusual events that could bias the estimates. Thus, HQ values based on mean and median exposures were also included where this information was provided.

For both treated and untreated water, the HQ assessment was determined as the ratio of the maximum measured concentration in either the treated or well water and the Provincial Water Quality Criterion for that compound (Canadian guidelines were used when provincial guidelines were not available):

$$\text{Hazard} \approx \frac{\text{Maximum exposure concentration}}{\text{Water quality guideline concentration}}$$

This approach is highly conservative for two reasons. First, some water quality criteria typically incorporate uncertainty factors to enhance protection. Second, by using the maximum concentration detected, we are essentially evaluating a worst-case scenario. That is, the HQ that we calculate in most cases is likely to be much greater than would be predicted had we used mean or median values for the data. Overall, this approach allows us to better detect "meaningful violations" and hence to gain a better sense of potential risk to human health.

Where we found HQ values >1 (an indication of potential risk), these were further analyzed using a probabilistic risk assessment. For this analysis, we

---

[393] Ontario, Ministry of the Environment, 1987a; Frank et al., 1990; Rudolph and Goss, 1993; Briggens and Moerman, 1995.

constructed cumulative frequency distributions of data points corresponding to all measured concentrations of each substance in distribution water from the DWSP database for the 47 water treatment plants. The number of measurements, and hence data points, for each compound for each water treatment plant varied widely in this database, ranging from one to several; all available data points were used in the assessment. The data was plotted separately according to whether it originated from surface water (24 stations) or groundwater (23 stations).

Where possible, we have provided an indication of the frequency with which these compounds are detected in drinking water or in surface waters, if the former was not available. For some compounds, frequency of detection data has been presented in the preceding sections.

3.9 Results of HQ Assessment

The ranges of concentrations for each compound at each stage of the water treatment process from the DWSP are provided in table 3-2. Our assessment of these data in drinking water showed that the HQ values for most contaminants were well below 1 (figures 3-5–3-9). These data suggest that there is little risk to humans from exposure to these substances through ingestion of water. In fact, the HQs that we report here are based on highest exposure levels (maximum concentrations), so it is likely that the HQs based on the average or median concentrations, and the implied level of risk, would be even lower, as illustrated by the pesticide HQ estimates from well water (table 3-3).

Pesticides All of the pesticides evaluated from treated municipal water had HQ values <1 (figure 3-5). HQ values ranged from 0.002–0.190 for surface water samples (figure 3–5a) and 0.002–0.112 for groundwater samples (figure 3-5b). For both sources, atrazine generally yielded the highest HQ values, with surface waters (0.190) being slightly higher than groundwater (0.112). It must be kept in mind that the data used to estimate the HQs for pesticides, other than atrazine, were based on very few data points because pesticides are not routinely measured as part of the DWSP.

The HQ value for the mean concentration of atrazine measured in well water (from the study of Goss et al., 1998), was 0.138 (figure 3-5c). The HQ value for the maximum concentration recorded in that study (18 µg/L) was 3.6. A number of other pesticides detected in that survey had HQ values >1 (table 3-3); however, these occurred very infrequently and, based on median values, the majority yielded HQ values well below 1. Only six out of the 1,292 wells (0.46%) sampled in that survey contained pesticides above the provincial MAC.[394]

Nitrates HQ estimates for nitrates in water sampled from each stage of the treatment process in municipal water treatment plants were <1 (figure 3-6); however, the HQ value for the highest concentration in surface water was just below 1 (0.94). In contrast, based on several studies, HQ values >1 were frequently determined for the highest nitrate concentrations in rural water wells (table 3-4). This result is consistent with the relatively high number of exceedences of the nitrate water quality guideline reported for well water in rural areas in Ontario and elsewhere in Canada.[395]

Metals Except for lead in distribution water, for which we estimated an HQ value of 2.23, the HQ values for chromium, cadmium, and arsenic were <1 (figure 3-7) in all water treatment stages. Elevated lead levels in distribution water is not surprising due to the occurrence of lead piping in some older architecture. The lead data are analyzed in greater detail below using a probabilistic approach.

Table 3-3 Summary of Pesticide Findings from a 1991/92 Survey of Ontario Rural Wells

Pesticide	Frequency of Detection (no of wells)	Frequency of Detection (%)	Concentrations (μg/l)		
			Max	Mean	Median
Alachlor	1	0.1	15.0 (0.75)[1]	15.0 (0.75)	NA
Atrazine	126	10.5	18.9 (3.6)	0.69 (0.14)	0.30 (0.06)
Di-ethyl atrazine	76	6.3	8.2 (2.3)	0.98 (0.20)	0.72(0.14)
Cyanazine	3	0.3	3.6 (0.36)	1.7 (0.17)	1.2 (0.12)
Metribuzin	9	0.3	0.69 (0.009)	0.61 (0.008)	0.63 (0.008)
Metolachlor	3	0.8	93 (1.9)	17.3 (0.35)	1.7 (0.60)

[1] Based on WHO (1993) drinking water guidelines.

Source: D.L. Rudolph and M.J. Goss, 1993, *The Ontario Farm Groundwater Survey – Summer 1992*, report to Agriculture Canada under the Federal-Provincial Environmental Sustainability Initiative (Guelph, Ont.: University of Guelph), June.

---

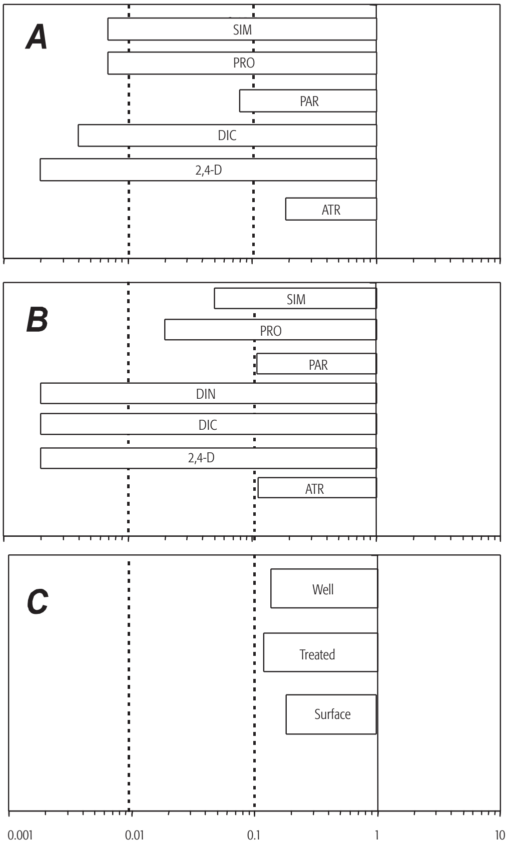
[394] Goss et al., 1998.

[395] Frank et al., 1990; Briggens and Moerman, 1995; Goss et al., 1998.

Organics The HQ estimates for all of the organic compounds for which data were collected from the DWSP database were all <1, ranging from 0.005–0.57 in influent (surface) water to 0.1–0.56 in distribution water (table 3-5).

Disinfection By-products The HQ values for the maximum concentration of total trihalomethanes were 0.505, 0.520, and 2.38 for surface water, groundwater, and distribution water, respectively (figure 3-8). Except for trichloracetic acid in distribution water (HQ = 1.38), the HQ estimates for each of the individual components of THMs (di- and trichloroacetic acid, bromodichloromethane, bromoform, and chloroform) did not exceed 1. The HQ values for these

Figure 3-5 Hazard Quotient Values for Selected Pesticides in Influent (A) and Treated (B) Water and Comparison of Municipal Water to Well Water for Atrazine (C)



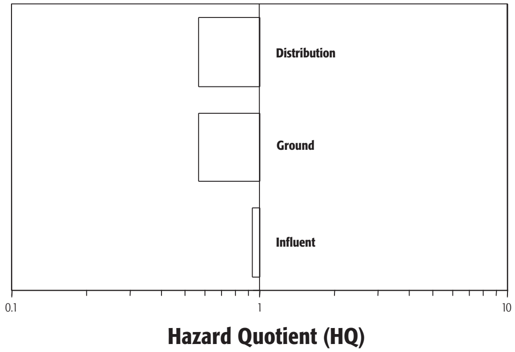
Note: See Appendix B for abbreviations.
Source: Ontario Drinking Water Surveillance Program, 2000.

compounds were generally higher in distribution water; this is not surprising because DBPs are formed, in part, as a result of interactions with naturally occurring organic precursors in surface and groundwater during and after the treatment process.

3.10 Probabilistic Assessment

Those compounds for which the estimated HQ was >1 in the assessment of treated municipal water (trichloroacetic acid, total trihalomethanes, and lead)

Figure 3-6 Hazard Quotient Values for Nitrates in Influent (Surface and Ground) and Distribution Water in Municipal Water Treatment Plants



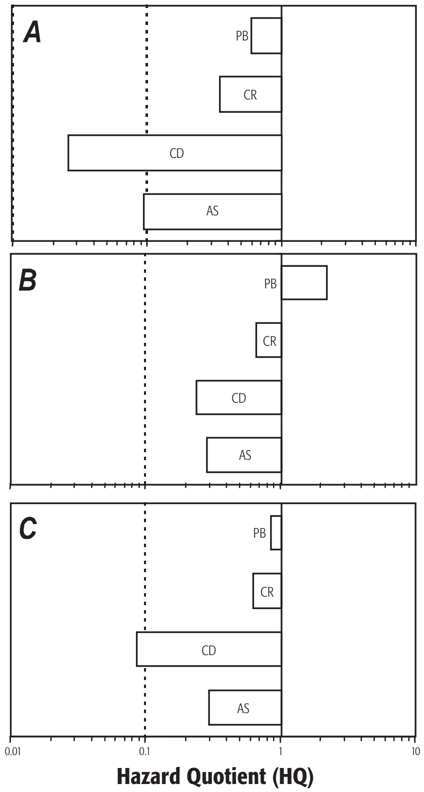
Source: Ontario Drinking Water Surveillance Program, 2000.

Table 3-4 Summary of Nitrate Concentrations in Well Water and Estimated Hazard Quotients (in Parentheses)

Study	Concentrations (µg/l)		
	Max	Mean	Median
Briggens and Moerman (1995)	46.1 (4.61)	4.61 (0.46)	2.68 (0.27)
Frank et al. (1990) -1986	55 (5.5)	NA	NA
Frank et al. (1990) -1987	43 (4.3)	NA	NA
Goss et al. (1998) - summer	87 (8.7)	NA	NA
Goss et al. (1998) - winter	77 (7.7)	NA	NA
Ministry of Environment (1985)	60 (6.0)	NA	NA

Sources: Briggens and Moerman, 1995; Frank et al., 1990; Goss et al., 1998; Ontario, Ministry of the Environment, 1985.

Figure 3-7 Hazard Quotients for Selected Metals in Influent (A), Ground (B), and Distribution (C) Water



Note: See Appendix B for abbreviations.
Source: Ontario Drinking Water Surveillance Program, 2000.

Table 3-5 Hazard Quotient Estimates for Selected Organic Substances in Drinking Water

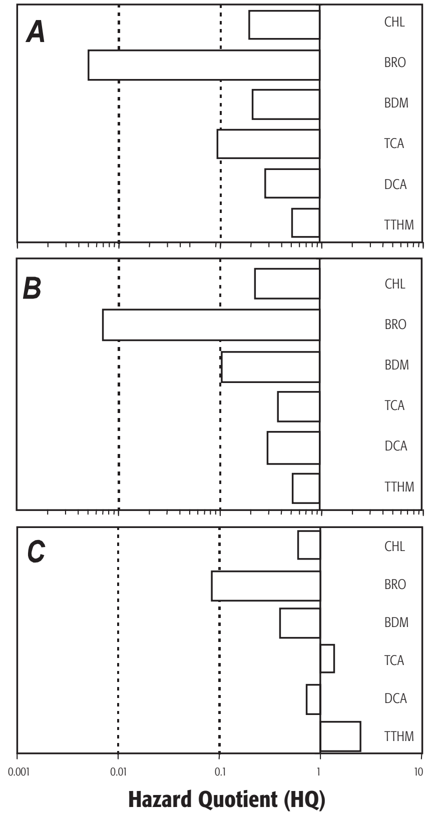
Compound	Influent (Surface) Water	Distribution Water
Benzene	0.4	0.17
Carbontetrachloride	-----	0.32
1,4-dichlorobenzene	0.11	0.1
Nitrosodimethylamine (NDMA)	0.57	0.56
Pentachlorophenol	0	-----
Tetrachloroethylene	0.005	0.32

Source: Ontario Drinking Water Surveillance Program, 2000.

were subsequently analyzed using a probabilistic assessment based on cumulative frequency distributions to estimate the likelihood of the measured values exceeding the respective MACs.

The regression coefficients for the cumulative frequency distributions (table 3-6) were used to estimate the likelihood of the measured values exceeding the MAC (table A2). For all three compounds, >95% of the measured values fell below the MAC in surface water, and 100% of values fell below the MAC in groundwater (figures 3-9–3-11). While these exceedences are relatively low, they must be considered in the context of the sampling base from which they were drawn. Analyses for these substances are conducted relatively infrequently (every 3–6 months in most locations), so these samples may not represent the entire period between samples. In the absence of analyses for the intermediate times, the distribution analyses suggest that exceedences could be of relatively long duration.

Figure 3-8 Hazard Quotients for Selected Disinfection By-products for Influent (A), Ground (B), and Distribution Water (C)



Note: See Appendix B for abbreviations.
Source: Ontario Drinking Water Surveillance Program, 2000.

Table 3-6 Regression Coefficients and Intercepts for Various Contaminants in Drinking Water

Data source	y = ax + b[1]				Regression intercepts (µg/L)	Probability of exceeding the MAC
	a	b	r^2	MAC	90%	
TCA surface water	1.72	3.74	0.95	100	30	1.44
TCA groundwater	1.25	5.04	0.99	100	10	0.54
THM surface water	2.97	0.77	0.98	100	72	4.36
THM groundwater	1.77	3.77	0.99	100	26	1.05
Lead surface water	1.14	5.83	0.92	10	2	2.39
Lead groundwater	1.62	5.96	0.96	10	2	0.48

[1] Note that the values for the regression are based on a linear regression analysis on the log- and probability-transformed values from the plotted data.

Figure 3-9 Probability Distributions for Total Trihalomethane (THMs) Concentrations in Surface Water and Groundwater

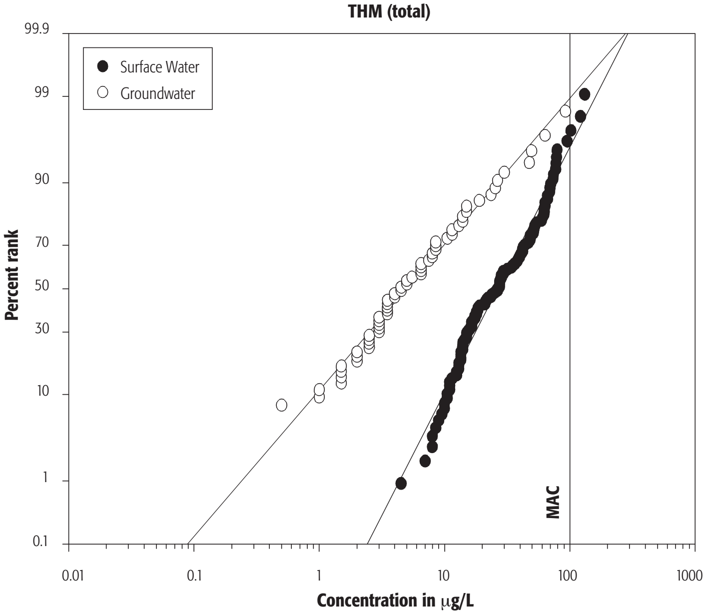


Figure 3-10 Probability Distributions for Lead (Pb) Concentrations in Surface Water and Groundwater

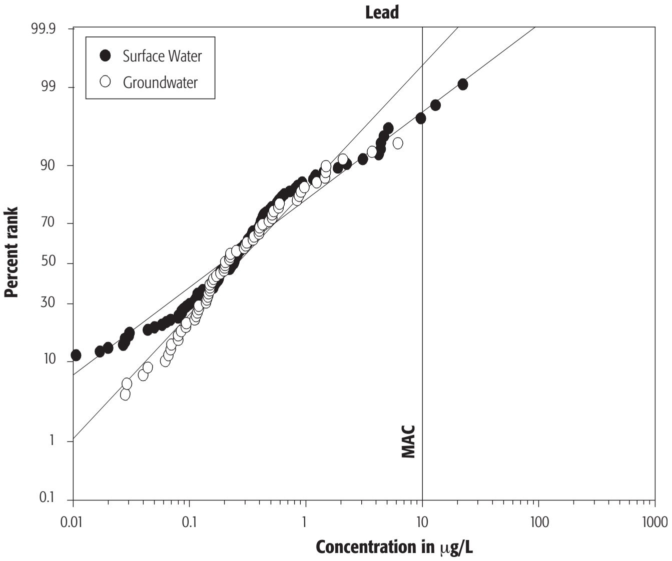
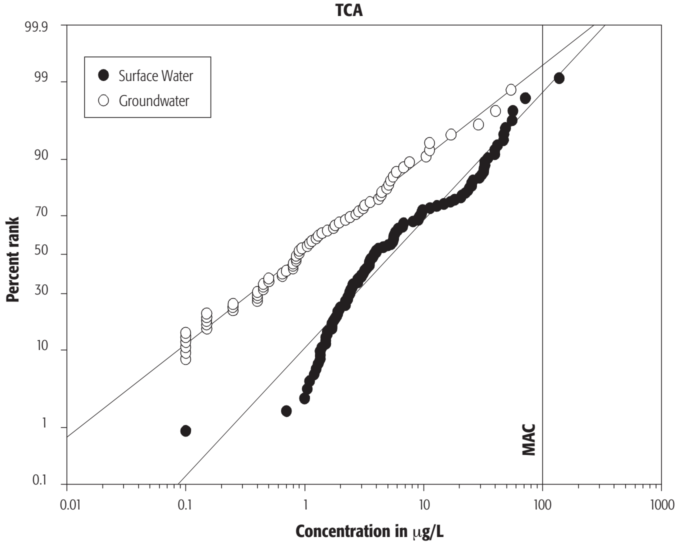


Figure 3-11 Probability Distributions for Trichloracetic Acid (TCA) Concentrations in Surface Water and Groundwater



As might be expected for TCA and total THMs, exceedences of the MAC in the distribution water drawn from surface water were greater than those from groundwater (no exceedences). Exceedences of the MAC for lead were also greater in surface water than in groundwater. While this may be the result of contamination from lead pipes, it is more likely from contaminants from other sources such as in runoff from contaminated soil or from atmospheric deposition.

4 Summary and Conclusions

Addressing issues of drinking water quality and management requires a thorough understanding and evaluation of the types and environmental behaviour of contaminants that lead to impairment of this critical resource. A key aspect of this evaluation is the need for an enhanced understanding of the sources and nature of contaminant loadings to, and the transport pathways within, the primary water systems that serve as sources of drinking water for humans and a place of residence for aquatic organisms. While the tragic events at Walkerton were precipitated by pathogenic contamination of the drinking water supply, it is important to realize that water quality issues in Ontario and other jurisdictions extend well beyond issues of pathogenic contamination and its associated risks to human health. Indeed, significant risks to human health may result from exposure to non-pathogenic, toxic contaminants, many of which are globally ubiquitous in waters from which drinking water is derived. In this context, we undertook the current review to address two important objectives: (1) to identify the major sources of contaminants from anthropogenic activities to aquatic surface waters and groundwater and the pathways through which toxic contaminants travel, and (2) to assess the health significance of selected contaminants in drinking water and identify some of the inherent uncertainties in terms of exposures and potential effects.

The loading of contaminants to surface waters, groundwater, sediments, and ultimately drinking water occurs as either point source or non-point source pollution. Point source pollution originates from discrete sources whose inputs into aquatic systems can often be defined in a spatially explicit manner. Examples of point source pollution include industrial effluents from pulp and paper mills and steel refineries (hazardous waste materials), municipal sewage treatment plants and combined sewage-storm water overflows (pathogens, nutrients, heavy metals), resource extraction (mining), and land disposal sites (landfill sites, industrial impoundments). Non-point source pollution, in contrast, originates from poorly defined, diffuse sources that typically occur over broad geographical scales. Examples of non-point source pollution include agricultural runoff (pesticides, pathogens, and fertilizers), stormwater and urban runoff, and atmospheric deposition (wet and dry through-put of persistent organic pollutants).

In most cases, pollutant loading to surface waters, either as direct deposition of effluents or via atmospheric deposition, represents the primary route for contaminants to become incorporated into drinking water. Since the drinking water supply of most Canadians is derived from surface water sources, this is likely to be the most significant route for exposure to anthropogenic contaminants and the associated potential risks to human health. Contamination of surface waters and associated sediments is certainly the most significant route by which aquatic communities are exposed to anthropogenic contaminants and associated risks that threaten the ecological integrity of aquatic systems. Despite this fact, apart from some focused regional studies,[396] there has been surprisingly little effort to undertake comprehensive, national monitoring programs of contaminants in Canadian surface waters. Such programs can be very expensive to undertake; however, as demonstrated by recent national monitoring programs in the United States (e.g., by the U.S. Geological Survey and U.S. Environmental Protection Agency), they can also provide important spatial and temporal information about surface water contamination that can feed into the risk assessment process and aid managers in regulatory initiatives on both the regional and the national level.

Pollutant loading to groundwater occurs through direct exchange with contaminated surface water or leaching of contaminants through soil. Although fewer Canadians draw their drinking water from groundwater sources, this route is the most significant source for exposure of humans to contaminants in drinking water in rural communities. Risks to human health may be much higher in rural areas because drinking water, particularly that associated with privately owned wells, is often not treated. In this context, although several comprehensive studies have been conducted to evaluate levels and distributions of relevant contaminants in rural well water, no structured monitoring program exists.

For both surface water and groundwater, historical approaches regarding the governance and management of groundwater/surface water research have been

---

[396] An example of one such study is by J. Struger et al., 2000, “Pesticide concentrations in urban aquatic environments of Ontario, Canada,” abstract from the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, Tenn., abstract PHA129.

to treat these as distinctly separate water systems.[397] However, that the intimate chemical and biological connections between groundwater and surface waters form an integral component of the hydrological cycle has gained wide acceptance by scientists and greater appreciation by environmental managers. Understanding the nature of groundwater/surface water relationships is a crucial step to understanding the pathways through which contaminants may be exchanged between these two systems and how this may affect exposure of humans and aquatic biota to contaminants. Thus, it is imperative that future assessment and management of water quality be conducted in a manner that recognizes the intimate connection between these two systems.

For selected compounds in both surface water and groundwater subjected to the hazard assessment, most of the estimated HQs were <1. This indicates that there is little risk associated with exposure from drinking water to the compounds tested. There were some exceptions. For example, nitrates were found to commonly yield HQs >1 in drinking water taken from many rural areas. Some pesticides from well water also yielded HQs >1. In treated distribution waters (water distributed to households), lead, total trihalomethanes, and trichloroacetic acid each yielded HQs >1. These latter compounds were further assessed using a probabilistic approach; these assessments indicated that the maximum allowable concentrations (MACs) or Interim MACs for the respective compounds were exceeded <5% of the time. In other words, there is a very low probability of finding these compounds in drinking water at levels that pose a risk to humans through ingestion.

Our review was carried out in accordance with the conventional principles of risk assessment. Application of the risk assessment paradigm requires rigorous data on both exposure and toxicity in order to adequately characterize potential risks of contaminants to human health and ecological integrity. Uncertainty rendered by poor data, or lack of data, in either the exposure or the effects stages of the risk assessment process significantly reduces the confidence that can be placed in the overall risk assessment.

Although our review suggested selected instances of potential risks to human health from exposure to contaminants in drinking water, we also noted a distinct paucity of information on exposure levels for many contaminants in this matrix. We suggest that this is a significant limitation to conducting sound risk assessments and introduces considerable uncertainty with respect to the

---

[397] Naiman et al.,1995; Duncan, 1999.

management of water quality. In this context, future research must place greater emphasis on targeted monitoring and assessment of specific contaminants in drinking water for which there is currently little information. Such an undertaking need not be resource-intensive nor cost-prohibitive as long as research priorities are directed to problem compounds identified using the appropriate tools of sound risk assessment. This could be accomplished by using a tiered risk approach, beginning with, for example, assessments based on the use of hazard quotients. Ideally, these would not be used as a basis for rendering final management decisions, although this is often the practice. Potentially problematic compounds identified in these preliminary assessments would then be subjected to more comprehensive risk assessments using probabilistic methods, if sufficient data exists to do so. On this latter point, there is often a lack of adequate exposure and/or toxicity information for many compounds (e.g., pharmaceuticals) from which to construct distributions to estimate the probability of risk, thus providing little opportunity to undertake adequate ecological or human risk assessments. In such cases, basic research must be conducted into exposure and toxicity.

Appendix A Chemicals in Drinking Water

Table A1 Chemicals Detected in Ontario Drinking Water, Their Priority Substance List (PSL) Designation, and Status Regarding Human Health Concerns

Chemical	Class	Description of Use/Origin	CEPA Priority Pollutant? (PSL1/2[1])	Human Health Concern (Yes/No)
Alachlor	Pesticide (OC)[2]	Herbicide used mainly on corn and soybeans to control the growth of weeds.		Yes
Aldrin	Pesticide (OC)	A pesticide used to control soil insects.		Yes
Aluminum	Metal (I)	Found naturally in the form of very fine particles of alumino-silicate clay.	PSL 2	No
Arsenic	Metal (I)	Arsenic is sometimes found at higher levels in groundwater in hard rock areas in Ontario through the dissolution of arsenic-containing minerals, in some mine drainage waters, and in some mine waste leachates.		Yes
Atrazine	Pesticide	A triazine pesticide used mainly as a pre-emergent herbicide on corn for annual grass control.		Yes
Azinphos-methyl	Pesticide	A broad-spectrum insecticide used against foliage-feeding insects.		Yes
Barium	Metal (I)	Barium is a common constituent in sedimentary rocks such as limestone and dolomite.		Yes
Bendiocarb	Pesticide	Bendiocarb is a carbamate insecticide used to control specific insects in buildings and greenhouses.		Yes
Benzene	Organic	Benzene is present in small amounts in gasoline and other refined petroleum products. Benzene is reported to occur in vehicle emissions and cigarette smoke. Drinking water is not considered a significant source of benzene because of its objectionable taste and odour in water.	PSL 1	Yes
Benzo(a)pyrene	Organic	Formed during the incomplete burning of organic matter and is found in poorly adjusted diesel exhaust and in coal/coking tar.		Yes
Boron (Borate)	Inorganic	Acute boron poisonings have resulted from the use of borates as antiseptic agents and from accidental ingestion; however, the consumed amounts were much higher than would be encountered through drinking water.		Yes
Bromoxynil	Pesticide	Herbicide used in Ontario for the control of specific weed seedlings in grain crops.		Yes
Cadmium	Metal (I)	Cadmium is a relatively rare element that is extremely unlikely to be present as a significant natural contaminant in drinking water. Cadmium compounds used in electroplated materials and electroplating wastes may be a significant source of drinking water contamination.	PSL1	Yes
Carbaryl	Pesticide	Carbaryl is a commonly used broad-spectrum carbamate insecticide used in agriculture and forestry for control of foliar pests and as a home and garden product for specific garden and lawn pests. It is also used for the control of parasites on livestock and pets.		Yes
Carbofuran	Pesticide	Carbofuran is a broad-spectrum carbamate insecticide used in agriculture for control of foliar pests.		Yes
Carbon tetrachloride	Organic	Carbon tetrachloride is likely to be found only in groundwater from old industrial sites where chlorinated solvents were made or used.		Yes

[1] PSL = Priority substance list 1 or 2. Contaminants on this list are designated as described in CEPA (*Canadian Environmental Protection Act*).

[2] Abbreviations used in this table: OC = Organochlorine; I = Inorganic; O = Organic

Table A1 Chemicals Detected in Ontario Drinking Water, Their Priority Substance List Designation, and Status, cont'd

Chemical	Class	Description of Use/Origin	CEPA Priority Pollutant? (PSL1/2[1])	Human Health Concern (Yes/No)
Chloramines	Organic	Chloramines are produced when ammonia is added to chlorinated water during the disinfection process. Chloramine is a weak disinfectant that usually results in lower levels of trihalomethanes and other chlorination by-products in the drinking water.	PSL2	Yes
Chlordane	Pesticide (OC)	Chlordane is an organochlorine insecticide that was once used extensively in agriculture as a soil insecticide and for domestic control of cockroaches, ants, and termites. Chlordane is very persistent is soil. The use of chlordane in Ontario was banned in 1994.		Yes
Chloride	Inorganic	Chloride is a common non-toxic material present in small amounts in drinking water and produces a detectable salty taste. Chloride is widely distributed in nature, generally as the sodium (NaCl), potassium (KCl), and calcium (CaCl2) salts.		No
Chloroform	Organic	A common by-product of water chlorination.	PSL2	Yes
Chlorpyrifos	Pesticide	Common organophosphate insecticide used for the control of insects on agricultural crops, for domestic use, and for flea and tick control.		Yes
Chromium	Metal (I)	Trivalent chromium, the most common and naturally occurring state of chromium, is not considered to be toxic. However, chromium present in untreated water may be oxidized to a harmful hexavalent form during chlorination. Chromium in the more highly oxidized form may be present in older yellow paints and in residues from plating operations and around old recirculating water-cooling systems.		Yes
Copper	Metal (I)	Copper occurs naturally in the environment, but is rarely found in untreated water. Copper is used extensively in domestic plumbing in tubing and fittings and is an essential component of food. Drinking water has the potential to be corrosive and to cause copper to dissolve in water.		No
Cyanazine	Pesticide	A triazine herbicide registered for control of weeds in crop and non-crop areas.		Yes
Cyanide	Inorganic	Widely used in metal plating and refining industries. Industrial effluents are the major potential sources of cyanide contamination.		Yes
Diazinon	Pesticide	An organophosphate insecticide used to control foliar and soil pests. Also used to control flies in barns, ants, and cockroaches.		Yes
Dicamba	Pesticide	A benzoic acid herbicide that is used for control of broadleaf weeds in grains, corn, flax, sorghum, and pastures, and weed control in lawns.		Yes
1,2-Dichloro-benzene	Organic	Used in a variety of specialty chemical blends (e.g., degreasing agents, imported dye carriers).	PSL1	Yes
1,4-Dichloro-benzene	Organic	A persistent synthetic material with a strong "medicinal" smell. It has been used widely in toilet pucks and mothballs.	PSL1	Yes

[1] PSL = Priority substance list 1 or 2. Contaminants on this list are designated as described in CEPA (*Canadian Environmental Protection Act*).

[2] Abbreviations used in this table: OC = Organochlorine; I = Inorganic; O = Organic

Table A1 Chemicals Detected in Ontario Drinking Water, Their Priority Substance List Designation, and Status, cont'd

Chemical	**Class**	**Description of Use/Origin**	**CEPA Priority Pollutant? (PSL1/2[1])**	**Human Health Concern (Yes/No)**
1,2-Dichloro-ethane	Organic	Used principally as a starting material for vinyl chloride production, as a solvent and a fumigant. It is released into the environment via atmospheric emissions and the discharge of industrial wastewaters.	PSL1	Yes
1,2-Dichloro-ethylene	Organic	This chemical is not produced in Canada; however, it is imported for use in the food industry and the textile industry for furniture and automotive upholstery, drapery fabric, and outdoor furniture.		Yes
Dichloromethane	Organic	Used extensively as an industrial solvent for paint stripping and as a degreasing agent.	PSL1	Yes
2,4-Dichloro-phenol	Organic	Chlorophenols are highly odorous synthetic materials that are most often present in drinking water due to the action of chlorine on phenolic precursors. Lighter phenols are found in water only as a result of industrial contamination.		Yes
2,4-D (2,4-Dichlorophenoxy acetic acid)	Pesticide	Commonly used herbicide for control of broadleaf weeds in cereal crops and lawns.		Yes
Diclofop-methyl	Organic – pesticide	Diclofop-methyl is a chlorophenoxy derivative that is used for control of annual grasses in grain and vegetable crops.		Yes
Dieldrin	Pesticide (OC)	A pesticide used to control soil insects.		Yes
Dimethoate	Pesticide	Organophosphate miticide and insecticide used on a wide range of plants for control of mites and both sucking and leaf-feeding insects. It is also used for fly control in livestock pens.		Yes
Dioxins	Organic (OC)	Dioxins are formed in very small amounts in combustion processes, particularly combustion of chlorine-containing materials such as scrap tires and, potentially, in some poorly controlled industrial processes such as bleached paper manufacturing.	PSL1	Yes
Diquat	Pesticide	Herbicide used primarily as a crop desiccant in seed crops and as an aquatic herbicide.		Yes
Diuron	Pesticide	A substituted urea-based herbicide used for the control of vegetation in crop and non-crop areas, including sites and rights-of-way.		Yes
Ethylbenzene	Organic	A component of gasoline additives used for octane rating boosting. It is also used in solvent-based paint formulations.		No
Fluoride	Inorganic	Where fluoride is added to drinking water, it is recommended that the concentration be adjusted to the optimum level for control of tooth decay to prevent excessive human exposure.	PSL2	Yes
Glyphosate	Pesticide	Broad-spectrum, non-selective herbicide used for weed control on rights-of-way, forestry plantations, and in-site preparations for planting of crops, as well as for domestic control of plants.		Yes

[1] PSL = Priority substance list 1 or 2. Contaminants on this list are designated as described in CEPA (*Canadian Environmental Protection Act*).

[2] Abbreviations used in this table: OC = Organochlorine; I = Inorganic; O = Organic

Table A1 Chemicals Detected in Ontario Drinking Water, Their Priority Substance List Designation, and Status, cont'd

Chemical	Class	Description of Use/Origin	CEPA Priority Pollutant? (PSL1/2[1])	Human Health Concern (Yes/No)
Hardness (caused by dissolved calcium and magnesium)	Inorganic	Hardness is caused by dissolved calcium and magnesium, and is expressed as the equivalent quantity of calcium carbonate. On heating, hard water has a tendency to form scale deposits and can form excessive scum with regular soaps. However, certain detergents are largely unaffected by hardness.		No
Iron	Metal (I)	Iron may be present in groundwater as a result of mineral deposits and chemically reducing underground conditions. It may also be present in surface waters as a result of anaerobic decay in sediments and complex formation.		No
Lead	Metal (I)	Lead is only present in drinking water as a result of corrosion of lead solder, lead-containing brass fittings, or lead pipes that are found close to or in domestic plumbing and the service connection to buildings.		Yes
Lindane	Pesticide (OC)	Organochlorine insecticide used in seed treatment; may also be used in pharmaceutical preparations of human lice and mite shampoos.		Yes
Malathion	Pesticide	Broad-spectrum organophosphate insecticide used on fruits and vegetables, as well as for mosquito, fly, and tick control.		Yes
Manganese	Metal (I)	Present in some groundwaters because of reducing conditions underground, coupled with the presence of manganese mineral deposits. Manganese is also occasionally present, seasonally, in surface waters when anaerobic decay processes in sediments are occurring.		No
Mercury	Metal (O)	Sources of mercury in drinking water include air pollution from coal combustion, waste incineration, and metal refining operations and natural mineral deposits in some hard rock areas. Food is the major source of human exposure to mercury, with freshwater fish being the most significant local source.		Yes
Methane	Organic	Occurs naturally in some groundwater and acts as a stimulant for microbiological fouling in the water distribution system. If methane is allowed to accumulate in confined areas, the potential for explosive combustion exists.		No
Methoxychlor	Pesticide (OC)	An organochlorine insecticide. It is non-accumulative in biological tissues, making it an attractive insecticide for use on products nearing harvest, in dairy barns for housefly control, and as either a larvicide or an adulticide against black flies and mosquitoes.		Yes
Metolachlor	Pesticide	A selective herbicide used for pre-emergence and pre-plant broadleaf weed control in corn, soybeans, peanuts, grain sorghum, pod crops, woody ornamentals, and sunflowers.		Yes
Metribuzin	Pesticide	Triazine herbicide used for the control of broadleaf weeds and grasses infesting agricultural crops. It is used selectively on soybeans and potatoes, all crops that are highly sensitive to most other triazine herbicides.		Yes

[1] PSL = Priority substance list 1 or 2. Contaminants on this list are designated as described in CEPA (*Canadian Environmental Protection Act*).

[2] Abbreviations used in this table: OC = Organochlorine; I = Inorganic; O = Organic

Table A1 Chemicals Detected in Ontario Drinking Water, Their Priority Substance List Designation, and Status, cont'd

Chemical	Class	Description of Use/Origin	CEPA Priority Pollutant? (PSL1/2[1])	Human Health Concern (Yes/No)
Monochlorobenzene (Chlorobenzene)	Organic	Used in the production of chloronitrobenzene and diphenyl ether, as a rubber intermediate, and as a solvent in adhesives, paints, waxes, polishes, and inert solvents. It is also used in metal cleaning operations and may be present in industrial discharges.	PSL1	Yes
Nitrate	Inorganic	Present in water (particularly ground water) as a result of decay of plant or animal material, the use of agricultural fertilizers, domestic sewage or treated wastewater contamination, or geological formations containing soluble nitrogen compounds.		Yes
Nitrite	Inorganic	Rapidly oxidized to nitrate and therefore seldom present in surface waters in significant concentrations. Nitrite may occur in groundwater sources; however, if chlorination is practiced the nitrite will usually be oxidised to nitrate.		Yes
NTA (Nitrilo-triacetic acid)	Organic	NTA is mainly used in laundry detergents, most of which is eventually disposed of in domestic wastewater.		Yes
NDMA (N-Nitrosodimethyl-amine)	Organic	NDMA is used industrially but has been used as an antioxidant, as an additive for lubricants, and as a softener of copolymers. It has been detected in some foods, particularly smoked foods and very occasionally in treated river/lake water in heavily farmed locations.	PSL2	Yes
Paraquat	Pesticide	Highly toxic herbicide used as a contact herbicide and for desiccation of seed crops. It is also used for non-crop and industrial weed control.		Yes
Parathion	Pesticide	Highly toxic organophosphate, broad-spectrum insecticide used in agriculture against foliar pests and the adult stage of root maggots.		Yes
Pentachlorophenol	Organic (OC)	Is rarely found in commercial use today but was used extensively as a pesticide and wood preservative. It is the most environmentally persistent of the chlorophenols.		Yes
Phorate	Pesticide	An organophosphate insecticide used for control of sucking insects, larvae of the corn rootworm, and leaf-eating beetles.		Yes
Picloram	Pesticide	A phenoxy alkanoic acid herbicide used for broadleaf weed and brush control on rights-of-way and roadsides.		Yes
PCBs (Polychlori-nated Biphenyls)	Organic (OC)	Among the most ubiquitous and persistent pollutants in the global ecosystem. PCBs were marketed extensively for a wide variety of purposes but are no longer manufactured or used.	PSL1	Yes
Prometryne	Pesticide	Herbicide used to selectively control annual grasses and broadleaf weeds in crops and non-crops.		Yes
Selenium	Metal (I)	Occurs naturally in waters at trace levels as a result of geochemical processes such as weathering of rocks. Food is the main source of selenium intake other than occupational exposure. Selenium is an essential trace element in the human diet.		Yes

[1] PSL = Priority substance list 1 or 2. Contaminants on this list are designated as described in CEPA (*Canadian Environmental Protection Act*).

[2] Abbreviations used in this table: OC = Organochlorine; I = Inorganic; O = Organic

Table A1 Chemicals Detected in Ontario Drinking Water, Their Priority Substance List Designation, and Status, cont'd

Chemical	Class	Description of Use/Origin	CEPA Priority Pollutant? (PSL1/2[1])	Human Health Concern (Yes/No)
Simazine	Pesticide	Triazine herbicide that is used for pre-emergence weed control in annual row crops. Simazine is the least soluble of all the triazine herbicides and is easily leached to groundwater where it may persist for years.		Yes
Sodium	Inorganic	Sodium is not toxic. The average intake of sodium from water is only a small fraction of that consumed in a normal diet. Softening using a domestic water softener increases the sodium level in drinking water and may contribute a significant percentage to the daily sodium intake for a person on a sodium-restricted diet.		No
Sulfate	Inorganic	High levels of sulfate may be associated with calcium, which is a major component of scale boilers and heat exchangers. In addition, sulfate can be converted into sulfide by some anaerobic bacteria, creating odour problems and potentially greatly accelerating corrosion.		No
Sulfide	Inorganic	Sulfide is undesirable in water supplies mainly because, in association with iron, it produces black stains on laundered items and black deposits on pipes and fixtures.		No
Temephos	Pesticide	Organophosphate insecticide used to control mosquito and black fly larvae.		Yes
Terbufos	Pesticide	Terbufos is an organophosphate insecticide used for insect control in corn.		Yes
Tetrachloro-ethylene (per-chloro-ethylene)	Pesticide	Is no longer produced in Canada but continues to be imported primarily as a solvent for the dry cleaning and metal cleaning industries. It has been found in groundwater, primarily after improper disposal or dumping of cleaning solvents.	PSL1	Yes
2,3,4,6-Tetrachlorophenol	Organic	2,3,4,6-Tetrachlorophenol was used extensively, along with pentachlorophenol, to preserve wood.		Yes
Toluene	Organic	Used in gasoline and other petroleum products and in the manufacture of benzene-derived medicines, dyes, paints, coating gums, resins, and rubber. It may be found in industrial effluents.	PSL1	No
Triallate	Pesticide	A thiocarbamate herbicide used for control of wild oats in grain crops, mustard, and sugar beets.		Yes
Trichloro-ethylene	Organic	Mostly used in dry cleaning. Some is used in metal degreasing operations and in tetrachloroethylene production. Trichloroethylene may be introduced into surface and groundwater through industrial spills and illegal disposal of effluents.	PSL1	Yes
2,4,6-Tri-chlorophenol	Organic	Used in the manufacture of pesticides.		Yes
2,4,5-T (2,4,5-Trichlorophenoxy acetic acid)	Pesticide	A phenoxy alkanoic acid herbicide that was once an important stem/foliage treatment for deciduous brush control on roadsides and power lines. 2,4,5-T is no longer used in Ontario.		Yes
Trifluralin	Pesticide	A dinitroaniline herbicide used for weed control in summer fallow and for controlling annual grasses in wheat, barley, and canola.		Yes

[1] PSL = Priority substance list 1 or 2. Contaminants on this list are designated as described in CEPA (*Canadian Environmental Protection Act*).

[2] Abbreviations used in this table: OC = Organochlorine; I = Inorganic; O = Organic

Table A1 Chemicals Detected in Ontario Drinking Water, Their Priority Substance List Designation, and Status, cont'd

Chemical	Class	Description of Use/Origin	CEPA Priority Pollutant? (PSL1/2[1])	Human Health Concern (Yes/No)
Trihalomethanes (e.g., chloroform, bromodichloro-methane, chlorodi-bromomethane and bromoform)	Organic	Trihalomethanes are the most widely occurring synthetic organics found in chlorinated drinking water. The principal source of trihalomethanes in drinking water is the action of chlorine with naturally occurring organic (precursors) left in the water after filtration.	PSL1	Yes
Uranium	Metal (I)	Uranium is normally present in biological systems and aqueous media as the uranyl ion ($UO2^{2+}$).		Yes
Vinyl Chloride (chloroethene)	Organic	Vinyl chloride is a synthetic chemical with no known natural sources. It is used in making PVC (polyvinyl chloride) plastic items such as water main pipe, siding, and many other common plastic items, all of which are now made in such a way that there is no trace of vinyl chloride present in them.		Yes
Xylenes	Organic	There are three isomers of dimethyl benzene, which are almost identical chemically and are collectively called xylenes. Xylenes are used as industrial solvents and as an intermediate for dyes and organic synthesis. They are a component of household paints and paint cleaners and gasoline and other petroleum products.	PSL1	No
Zinc	Metal (I)	The concentration of zinc may be considerably higher at the drinking water tap in standing water because of corrosion taking place in galvanized pipes.		No

[1] PSL = Priority substance list 1 or 2. Contaminants on this list are designated as described in CEPA (*Canadian Environmental Protection Act*).

[2] Abbreviations used in this table: OC = Organochlorine; I = Inorganic; O = Organic

Sources: Ontario Drinking Water Surveillance Program, 2000; Canada, Environment Canada, 2000.

Table A2 Chemicals of Health Significance in Drinking-water and Associated Water Quality Guidelines/Criteria

	WHO Drinking Water Quality Value	Canadian Drinking Water Quality Guideline		Provincial Water Quality Guideline/Objective	Ontario Drinking Water Quality Guideline		Used in HQ Assessment?
Inorganic Constituents							
antimony	0.005a			7,000c			
arsenic	0.01ba	0.025	IMAC	100,000			Yes
barium	0.7	1	MAC		1	MAC	
beryllium	NAD			100,000 c			
boron	0.3	5	IMAC		5	IMAC	
cadmium	0.003	0.005	MAC	200			Yes
chromium	0.05a	0.05	MAC	100,000	0.05	MAC	Yes
copper	2a	1.0	AO	5000			
cyanide	0.07	0.2	MAC		0.2	MAC	
fluoride	1.5	1.5	MAC		1.5 (3)	MAC	
lead	0.01	0.01	MAC	d	0.01	MAC	Yes
manganese	0.5a	0.05	AO				
mercury (total)	0.001	0.001	MAC	200	0.001		
molybedenum	0.07			10,000c			
nickel	0.02			25,000			
nitrate (as NO3-)	50(1)	45			10	MAC	Yes
nitrite (as NO2-)	3(1) a	3.2	(2)		1		
selenium	0.01	0.01	MAC	100,000	0.01	MAC	
uranium	NAD	0.1	MAC		0.1	MAC	
Organic Constituents							
chlorinated alkanes							
cabon tetrachloride	2	0.005	MAC		0.005	MAC	Yes
dichloromethane	20	0.05	MAC		0.05	MAC	
1,1-dichloroethane	NAD			200,000			
1,2-dichloroethane	30b	0.005	IMAC	100,000	0.005		
1,1,1-trichloroethane	2,000a			800,000			
chlorinated ethenes							
vinyl chloride	5b	0.002	MAC		0.002	MAC	
1,1-dichloroethene	30						
trichloroethene	70a						Yes

Table A2 Chemicals of Health Significance in Drinking-water and Associated Water Quality Guidelines/Criteria, cont'd

	WHO Drinking Water Quality Value	Canadian Drinking Water Quality Guideline		Provincial Water Quality Guideline/Objective	Ontario Drinking Water Quality Guideline		Used in HQ Assessment?
Organic Constituents *(cont.)*							
tetrachloroethene	40						
aromatic hydrocarbons							
benzene	10b	0.005	MAC	100 000c	0.005	MAC	Yes
toluene	700	0.024	AO	800c			
xylenes	500	0.3	AO				
ethylbenzene	300	0.0024	AO	8000c			
styrene	20			4000c			
benzo[a]pyrene	0.7b	0.00001	MAC		0.00001	MAC	
chlorinated benzenes							
monochlorobenzene	300	0.08	MAC	15 000	0.008	MAC	
1,2-dichlorobenzene	1000	0.2	MAC	2500			
1,3-dichlorobenzene	NAD			2500			
1,4-dichlorobenzene	300	0.005	MAC	4000			Yes
trichlorobenzenes (total)	20						
miscellaneous							
di(2-ethylhexyl)adipate	80						
di(2-ethylhexyl)pthalate	8			600			
acrylamide	0.5b						
epichlorohydrin	0.4a						
hexachlorobutadiene	0.6			70c			
edetic acid (EDTA)	200a						
nitrilotriacetic acid	200	0.4	MAC		0.4		
Pesticides							
dialkyltins	NAD						
tributyltin oxide	2			0.04c			
alachlor	20b				0.005	IMAC	
aldicarb	10				0.009	MAC	
aldrin/dieldrin	0.03	0.0007	MAC	1	0.0007	MAC	
atrazine	2	0.005	IMAC		0.06	IMAC	Yes
bentazone	30						
carbofuran	5	0.09	MAC		0.09		

Table A2 Chemicals of Health Significance in Drinking-water and Associated Water Quality Guidelines/Criteria, cont'd

	WHO Drinking Water Quality Value	Canadian Drinking Water Quality Guideline		Provincial Water Quality Guideline/Objective	Ontario Drinking Water Quality Guideline		Used in HQ Assessment?
Pesticides *(cont.)*							
chlordane	0.2	60			0.007		
chlorotoluron	30						
DDT	2	NG		3	0.03	MAC	
1,2-dibromo-3-chloropropane	1b						
2,4-D	30	0.1	IMAC		0.1	MAC	Yes
1,2-dichloropropane	20a						
1,3-dichlropropane	NAD						
1,3-dichloropropene	20b						
ethylene dibromide	NAD						
heptachlor and heptachlor epoxide	0.03	NG		1	0.003	MAC	
hexachlorobenzene	1b			6.5			
isoproturon	9						
lindane	2			1.0	0.004	MAC	
MCPA	2						
methoxychlor	20	0.9	MAC	40	0.9	MAC	
metolachlor	10	0.05	IMAC		0.05	IMAC	
molinate	6						
pendimethalin	20			500			
pentachlorophenol	9				0.06	MAC	Yes
permethrin	20						
propanil	20						
pyridate	100						
simazine	2	0.01	IMAC	10 000	0.01	IMAC	Yes
trifluralin	20	0.045	IMAC		0.045	IMAC	
Other chlorophenoxy herbicides							
2,4-DB	90						
dichloroprop	100						
fenoprop	9						
MCPB	NAD						
mecoprop	10						

Table A2 Chemicals of Health Significance in Drinking-water and Associated Water Quality Guidelines/Criteria, cont'd

	WHO Drinking Water Quality Value	Canadian Drinking Water Quality Guideline		Provincial Water Quality Guideline/Objective	Ontario Drinking Water Quality Guideline		Used in HQ Assessment?
Pesticides (cont.)							
2,4,5-T	9				0.2	MAC	
Disinfectants							
monochloroamine	3				3	MAC	
di- and trichloramine	NAD						
chlorine	5			2000			
chlorine dioxide	NAD						
iodine	NAD						
Disinfectant By-products							
bromate	25ba						
chlorate	NAD						
chlorite	200a						
chlorophenols							
2, chlorophenol	NAD	NAD					
2,4-dichlorophenol	NAD	0.9	MAC		0.9		
2,4,6-trichlorophenol	200b	0.005	MAC		0.005	MAC	
formaldehyde	900						
MX	NAD						
trihalomethanes					0.1	MAC (total)	Yes
bromoform	100				0.35	MAC	
dibromochloromethne	100				0.35	MAC	
dibromodichloromethane	60b				0.35	MAC	
chloroform	200b				0.35	MAC	
chloroacetone	NAD						
halogenated acetonitriles dichloroacetonitrile	100a						
bromochloroacetonitrile	NAD						
trichloroacetonitrile	1a						
cyanogen chloride	70						
chloropicrin (as CN)	NAD						

Table A2 Chemicals of Health Significance in Drinking-water and Associated Water Quality Guidelines/Criteria, cont'd

All values in mg/L

MAC= Maximum Acceptable Concentration
IMAC = Interim Maximum Acceptable Concentration
AO = Aesthetic Objective
NG = No Guideline Available
NAD = No Available Data

1. The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1.
2. In cases where nitrate and nitrite are determined separately.
3. The MAC for naturally occurring fluoride in drinking water is 2.4mg/L. A MAC of 1.5mg/L was established to ensure that when fluoride is added to drinking water the concentration (1.2 ± 0.2mg/L) is maintained such that the population obtains optimal benefit.

(a) Provisional guideline value, used for constituents for which there is some evidence of a potential hazard but where the available information on health effects is limited; or where an uncertainty factor greater than 1000 has been used in the derivation of the tolerable daily intake (TDI).
(b) For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking water associated with an excess lifetime cancer risk of 10e-5 (one additional cancer per 100 000 of the population ingesting drinking water containing the substance at the guideline value for 70 years). Concentrations associated with estimated excess lifetime cancer risks of 10e-4 and 10e-6 can be calculated by multiplying and dividing, respectively, the guideline value by 10.
(c) These values represent proposed Provincial Water Quality Guidelines/Objectives.
(d) PWQO/G either is a narrative or is dependent on pH, alkalinity, or hardness.

Sources: Canada, Health Canada, 1996; Phyper and Ibbotson, 1994; WHO, 1993.

Abbreviations

ARD	Acid Rock Drainage
Ag	silver
Al	aluminum
AO	Aesthetic Objective
As	arsenic
BOD	Biological Oxygen Demand
$CaCO_3$	calcium carbonate
CCME	Canadian Council of Ministers of Environment
Cd	cadmium
CEPA	Canadian Environmental Protection Act
CO_2	carbon dioxide
Cr	chromium
Cu	copper
DBP	Disinfection By-product
DWSP	Drinking Water Surveillance Program
ECOFRAM	Ecological Framework for Risk Assessment
EPA	Environmental Protection Agency
EqP	Equilibrium Partitioning
Fe	iron
HAA	Hormonally Active Agents or Haloacetic Acids
HCH	Hexachlorocyclohexane
Hg	mercury
HQ	Hazard Quotient
IARC	International Agency for Research on Cancer
IJC	International Joint Commission
IMAC	Interim Maximum Acceptable Concentration
ISQG	Interim Sediment Quality Guidelines
LC	Lethal Concentration

LOD	Limit of Detection
LOQ	Limit of Quantization
LUST	Leaking Underground Storage Tank
MAC	Maximum Acceptable Concentration
MATC	Maximum Allowable Toxicant Concentration
mg/L	milligrams per litre = ppm
mg/kg	milligrams per kilogram = ppm
Mn	manganese
MWTP	Municipal Water Treatment Plant
NOEC	No Observed Effect Concentration
NOEL	No Observed Effect Level
NRC	National Research Council
Ni	nickel
OC	Organochlorine
OMAFRA	Ontario Ministry of Agriculture and Rural Affairs
PAH	Polycyclic Aromatic Hydrocarbons
Pb	lead
PBDE	Polybrominated Diphenyl Ethers
PEL	Probable Effects Level
pH	hydrogen ion concentration
PCB	Polychlorinated Biphenyls
PFOS	Perfluorooctane Sulfonate
ppb	parts per billion = μg/L
ppm	parts per million = mg/L
POP	Persistent Organic Pollutant
PPOP	Persistent Polar Organic Pollutant
PRA	Probabilistic Risk Assessment
PSL	Priority Substance List
PWQG	Provincial Water Quality Guideline
PWQO	Provincial Water Quality Objective
Se	selenium
SETAC	Society of Environmental Toxicology and Chemistry
Sn	tin
TBT	Tributyl Tin
TCA	Trichloroacetic Acid
TEL	Threshold Effects Level
THM	Trihalomethanes
U	uranium
UNEP	United Nations Environmental Program

USEPA	United States Environmental Protection Agency
UST	Underground Storage Tank
µg/kg	microgram per kilogram = 10^{-6} g/kg = ppb
µg/L	microgram per litre = 10^{-6} g/L = ppb
WHO	World Health Organization
WWTP	Waste Water Treatment Plants
Zn	zinc

Glossary of Terms

Abiotic. Not associated with living organisms.

Acute Toxicity. The adverse effect occurring within a short time of exposure (relative to generation time).

Adsorption. The adhesion of molecules to surfaces of solids (e.g., particles).

Alkalinity. The acid-neutralizing (i.e., proton accepting) capacity of water; the quality and quantity of constituents in water that shift the pH toward the alkaline side on neutrality (pH of 7).

Application factor (AF). A dimensionless value: the chronically toxic threshold concentration of a chemical divided by its acutely toxic concentration. The AF is usually reported as a range and is multiplied by the median lethal concentration of a chemical as determined in a short-term (acute) toxicity test to estimate the expected no effect concentration under chronic exposure.

Benthic. Living on the bottom of aquatic systems; occurring on or in sediments.

Bioaccumulation. The net result of the uptake, distribution, and elimination of a substance due to all routes of exposure (e.g., air, water, soil/sediment, food).

Bioavailability. The ability of a substance to interact with the biosystem of an organism. Systemic bioavailability will depend upon the chemical or physical reactivity of the substance and its ability to be absorbed through the gastrointestinal tract, respiratory tract, or skin.

Bioconcentration. The net result of the uptake, distribution and elimination of a substance due to water-borne exposure of an organism.

Biomagnification. The accumulation and transfer of chemicals via the food web (e.g., algae – invertebrate – fish – mammal) due to ingestion, resulting in an increase in the internal concentration of organisms at succeeding trophic levels.

BOD. Biochemical Oxygen Demand.

Cancer. Disease that results from the development of a malignant tumour and its spread into surrounding tissues.

Carcinogenicity. The capacity of chemical, physical, or biological agents to induce malignant neoplasms.

Chronic. Extended or long-term exposure to a stressor (conventionally taken to include at least one-tenth of the lifespan of a species) or the effects resulting from such exposure. Exposure concentrations are usually low.

Criterion. The level of exposure (concentration and duration) of a contaminant in a particular medium that is thought to result in an acceptably low level of effect on populations, communities, or use of the medium (e.g., water and sediment quality criteria).

Deterministic Analysis. An analysis in which all population and environmental parameters are assumed to be constant and accurately specified.

Dose. A measure of integral exposure. Examples include the amount of chemical ingested or ejected, the amount of a chemical actually taken up, and the product of the ambient exposure concentration and the duration of exposure.

Ecotone. A zone or interface between two ecological systems (e.g., water-sediment, terrestrial-aquatic) through which energy and materials are exchanged.

Effects assessment. The component of an environmental risk analysis concerned with quantifying the manner in which the frequency and intensity of effects increase with increasing exposure to a contaminant or other source of stress (also known as a dose-response assessment).

Endocrine. Pertaining to hormones or glands that secrete hormones directly into the blood stream.

Endpoint. A response measure in a toxicity test, i.e., the measurements(s) or values(s) derived from a toxicity test that constitute the results of the tests (e.g., NOEC or LC50).

Environmental Risk Assessment (Analysis). Determination of the probability of adverse effects on humans and other biota resulting from an environmental hazard (a chemical, physical, or biological agent occurring in or mediated by the environment).

Equilibrium. The state of a system in which no further change occurs and in which the free energy is at a minimum (also referred to as steady-state).

Estimated (or Expected) Environmental Concentration (EEC). The concentration of a material estimated to be likely to occur in environmental waters to which aquatic organisms are exposed as a result of planned manufacture, use, and disposal.

Estrogens. Endogenous compounds that act as agonists at the estrogen receptor.

Exposure assessment. The component of an environmental or human risk assessment that estimates the emissions, pathways, and rates of movement of a chemical in the environment, and its transformation or degradation, in order to estimate the concentrations/doses to which ecological systems and populations are or may be exposed.

Extrapolation. An estimation of a numerical value of an empirical (measured) function at a point outside the range of data used to calibrate the function or the use of data derived from observations to estimate values for unobserved entities or conditions.

Fate. Disposition of a material in various environmental compartments (e.g., soil, sediment, water, air, biota) as a result of transport, partitioning, transformation, and degradation.

Hardness. The concentration of all cations in water that will react with a sodium soap to precipitate an insoluble residue. In general, hardness is a measure of the concentration of calcium and magnesium ions in water and is frequently expressed as mg/L calcium carbonate or equivalent.

Hazard Quotient. The definition of environmental and/or health risks by combining the results of exposure assessment (Estimated Environmental Concentration – EEC) and the results of an effects assessment (e.g., NOEC).

Hydrophilic. Describes the character of a molecule or atomic group which has an affinity for water. Opposite of Lipophilic.

Hydrophobic. Describes the character of a molecule or atomic group which has a tendency to repel water.

LC/D (50). The median lethal concentration/dose (i.e., the concentration/dose of a substance that is estimated to be lethal to 50% of the test organisms). The LC50 and its confidence intervals are usually derived by statistical analysis of mortalities in several test concentrations, following a fixed period of exposure. The duration of exposure must be specified (e.g., 96 hr LC50).

Leachate. Water or wastewater that has percolated through a column of soil or solid waste in the environment.

Lipophilic. Having an affinity for fat and high lipid solubility.

Lowest Observed Effect Concentration (LOEC). The lowest concentration of a material used in a toxicity test that has a statistically significant adverse effect on the exposed population of test organisms compared with the controls. When derived from a partial life cycle test, it is the same as the upper limit of the maximum allowable toxicant concentration (MATC).

Maximum Allowable Toxicant Concentration (MATC). The geometric mean of the lowest exposure concentration that causes a statistically significant adverse effect and the highest exposure concentration where no effect is observed.

Maximum Allowable Concentration (MAC). Regulatory value defining the maximum concentration of a compound that does not appear capable of causing appreciable harm in the light of present knowledge.

Median lethal concentration. The concentration of material in air, water, soil, or sediment to which an organism is exposed that is estimated to be lethal to 50% of the test organisms.

No Observed Effect Concentration (NOEC). The highest concentration of a test substance to which organisms are exposed that does not cause any observed and statistically significant adverse effects on the organisms compared with the controls.

Octanol-water partition coefficient (k_{ow}). The ratio of a chemical's solubility on n-octanol and water at equilibrium.

Partition coefficient. A constant ratio that occurs when a heterogeneous system of two phases is in equilibrium; the ratio of concentrations (or, strictly, activities) of the same molecular species in the two phases is constant at constant temperature.

Parts per billion (ppb). One unit of chemical (usually expressed as mass) per 1,000,000,000 (109) units of the medium (e.g., water). Also expressed as micrograms per litre (g/L). Other measures of concentration include: parts per million (ppm; mg/L), parts per thousand (ppt; g/L).

Percentiles. Divides frequency distribution into 100 equal portions. Hence the 95 percentile is the value that 95% of the population does not exceed.

Persistence. Attribute of a substance that describes the length of time that the substance remains in a particular environment before it is physically removed or chemically or biologically transformed.

pH. The negative logarithm of the hydrogen ion activity in gram equivalents per litre. The pH value expresses the degree or intensity of both acidic and alkaline reactions on a scale of 0-14, with 7 representing neutral, numbers less than 7 signifying increasingly acidic conditions, and numbers greater than 7 signifying increasingly basic or alkaline conditions.

Point source. Emission sources(s), either single or multiple, that can be quantified by means of location and the amount of substance emitted per source and emission unit (e.g., amount per unit time).

Pollutant. A potentially harmful agent occurring in the environment or products or at a workplace as a result of human activities.

Population. A group of interacting and, typically, interbreeding organisms (sharing genes) of the same species.

Pore water. The water in sediment or soil that surrounds the soil particles. The amount of interstitial water is calculated and expressed as the percentage ratio of the weight of water in the sediment to the weight of the wet sediment. (Also referred to as interstitial water.)

Probability. A quantitative statement about the likelihood of a specified outcome. Probability values can range from 0 to 1.

Quality criteria. Quality guidelines based on the evalution of scientific data.

Quality guidelines. Numerical limits or text statements established to support and maintain designated uses of the environment or to protect human health.

Quality objectives. Numerical limits or narrative statements established to protect and maintain human health or designated uses of the environment at a particular site.

Quality standards. Fixed upper limits for exposure to certain chemicals recognized under law by one or more levels of government. Examples include air, water, and soil quality standards, as well as threshold limit values for air pollutants in the workplace.

Receiving water. Surface water (e.g., a stream, river, or lake) that has received a discharged waste, or is about to receive such a waste.

Remediation. Concerned with correction and clean-up of chemically contaminated sites.

Riparian zone. The area of land, and its vegetation, adjacent to streams and rivers or surrounding lakes. Represents an important transition zone that regulates the flow of energy and materials between the terrestrial landscape and the aquatic environment.

Risk. The probability of an adverse effect on man or the environment resulting from a given exposure to a chemical or mixture. It is the likelihood of a harmful effect or effects occurring due to exposure to a risk factor (usually some chemical, physical, or biological factor). Risk is usually expressed as the probability of an adverse effect occurring, i.e., the expected ratio between the number of individuals that would experience an adverse effect in a given time and the total number of individuals exposed to the risk factor. The term absolute risk is sometimes expressed per unit dose (or exposure) or for a given dose (exposure).

Risk assessment. A process that entails some or all of the following elements: hazard identification, effects assessment, exposure assessment, and risk characterization. It is the identification and quantification of the risk resulting from a specific use or occurrence of a chemical compound including the determination of dose-response relationships and the identification of target populations.

Risk characterization. The estimation of the incidence and severity of the adverse effects likely to occur in a human population or environmental compartments due to actual or predicted exposure to a substance. It also serves as a summary and description of the results of a risk analysis for a risk manager or the public and other interested parties.

Risk management. A decision-making process that entails the consideration of political, social, economic, and engineering information together with the risk-related information in order to develop, analyze, and compare the regulatory options and select the appropriate regulatory response to a potential health or environmental hazard.

Risk perception. The subjective perception of the gravity or importance of the risk based on the individual's knowledge of different risks and the moral and political judgement attached to them and their importance.

Risk quotient. See hazard quotient.

Safety factor. A factor applied to an observed or estimated toxic concentration or dose to arrive at a criterion or standard that is considered to be safe. Safety factors and uncertainty factors are often used synonymously.

Speciation. Determination of the exact chemical form of a compound in which an element occurs in a sample (e.g., whether arsenic is in the form of trivalent or pentavalent ions or as part of an organic molecule) and the quantitative distribution of the different chemical forms that may exist.

Stochastic. Due to, pertaining to, or arising from chance and, hence, involving probability and obeying the laws of probability. The term stochastic indicates that the occurrence of the effects would be random. This means that, even for an individual, there is no threshold of dose below which the effect will not occur and the chance (probability) of experiencing the effect increases with increasing dose. Hereditary effects and cancer induced by radiation are considered to be stochastic effects.

Surfactant. A surface-active substance (e.g., a detergent) that reduces surface tension and facilitates dispersion of substances in water.

Teratogenesis. The potential or capacity of a substance to cause defects in embryonic and foetal development.

Threshold. Dose or exposure concentration below which an effect is not expected to occur.

Toxin. Natural poison; a toxic substance produced by a living organism.

Uncertainty. Imperfect knowledge concerning the present or future state of the system under consideration. A component of risk resulting from an imperfect understanding of the degree of hazard or of its spatial and temporal pattern of expression.

Vitellogenin. Phospholipoprotein produced by the liver in response to estrogens and used as a yolk-precursor in females.

Waste water. A general term that includes effluents, leachates, and elutriates.

References

Abke, W., H. Korpien, and B. Post. 1993. "Pollution of downstream groundwater near railway tracks treated with herbicides." *Vom Wasser.* Vol. 81.

Adams, S.M., W.D. Crumby, M.S. Greeley Jr., L.R. Shugart, and C.F. Taylor. 1992. "Responses of fish populations and communities to pulp mill effluents: A holistic assessment." *Ecotoxicology and Environmental Safety.* Vol. 24.

Aldenberg, T., and W. Slob. 1991. "Confidence limits for hazardous concentrations based on logistically distributed NOEC toxicity data." *Ecotoxicology and Environmental Safety.* Vol. 18.

———. 1993. "Confidence limits for hazardous concentrations based on logistically distributed NOEC toxicity data." *Ecotoxicology and Environmental Safety.* Vol. 25.

Allan, J.D. 1995. *Stream Ecology: Structure and Function of Running Waters.* New York: Chapman & Hall.

Allan, J.D., D.L. Erickson, and J. Fay.1997. "The influence of catchment land use on stream integrity across multiple scales." *Freshwater Biol*ogy. Vol. 37.

Allard, B., K. Hakansson, and S. Karlsson. 1987. "The importance of sorption phenomena in relation to trace metal speciation and mobility." In L. Landner (ed.), *Speciation of Metals in Water, Sediment and Soil Systems.* New York: Springer-Verlag.

Allen, H.E. 1995. *Metal Contaminated Aquatic Sediments.* Chelsea, Mich.: Ann Arbor Press.

Allen, H.E., E.M. Perdue, and D.S. Brown. 1993. *Metals in Groundwater.* Boca Raton, Fla.: Lewis Publishers.

Alloway, B.J. 1995. *Heavy Metals in Soils.* 2nd ed. New York: Chapman & Hall.

Anderson, P.S., and A.L Yuhas. 1996. "Improving risk management by characterizing reality: A benefit of probabilistic risk assessment." *Human and Ecological Risk Assessment.* Vol. 2.

Ankley, G.T., D.M. Di Toro, D.J. Hansen, and W.J. Berry. 1996. "Technical basis and proposal for deriving sediment quality criteria for metals." *Environmental Toxicology and Chemistry.* Vol. 15.

Apselin, A.L. 1994. *Pesticide Industry Sales and Usage: 1992 and 1993 Market Estimates.* Washington, D.C.: U.S. Environmental Protection Agency, Office of Pesticide Programs, Biological and Economic Analysis Division, Economic Analysis Branch. Report 733K-92–001.

Arment, A.R., and W.W. Carmichael. 1996. "Evidence that microcystin is a thio template product." *Journal of Phycol*ogy. Vol. 32.

Atkins, E., and J. Hawley. 1978. *Sources of Metals and Metal Levels in Municipal Wastewaters*. Research Program for the Abatement of Municipal Pollution under Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. Ottawa and Toronto: Environment Canada and Ontario Ministry of Environment. Research Report No. 80.

Baccay, T., and Z. Ahmed. 1996. "Municipal Wastewater Treatment Plant C." In *Classroom Case Studies and Database Application: Part I, Environmental Engineering Across the Engineering Curriculum* [online]. [Cited February 14, 2002.] <www.cooper.edu/~ahmed/mtpc.html>.

Bailey, H.C., L. Deanovic, E. Reyes, T. Kimball, K. Larson, K. Cortright, V. Connor, and D.E. Hinton. 2000. "Diazinon and chlorpyrifos in urban waterways in northern California." *Environmental Toxicology and Chemistry*. Vol. 19.

Baker, J.L., R.S. Kanwar, and T.A. Austin. 1985. "Impact of agricultural drainage wells on groundwater quality." *Journal of Soil and Water Conserv*ation. Vol. 40.

Balk, F., P.C. Okkerman, J.W. Dogger. 1995. *Guidance Document for Aquatic Effects Assessment*. Paris: Organization for Economic Co-operation and Development.

Bannerman, R.T., D.W. Owens, R.B. Dodds, and N.J. Hornewer. 1993. "Sources of pollutants in Wisconsin stormwater." *Water Science and Technology*. Vol. 28.

Barbash, J.E., G.P. Thelin, D.W. Kolpin, and R.J. Gilliom. 1999. *Distribution of Major Herbicides in Groundwater of the United States*. Sacramento: U.S. Geological Survey. United States Geological Survey, Water Resources Investigation Report 98-4245.

Barber, S. A. 1984. *Soil Nutrient Bioavailability: A Mechanistic Approach*. New York: J. Wiley & Sons.

Barcelona, M., A. Wehrmann, J.F. Keely, and W.A. Pettyjohn. 1990. "Contamination of groundwater: Prevention, assessment, and restoration." *Pollution Technology Review*. Vol. 184.

Bell, S.G., and G.A. Cobb. 1994. "Cyanobacterial toxins and human health." *Reviews in Medical Microbiol*ogy. Vol. 5.

Bendell-Young, L.I., M. Dutton, and F.R. Pick. 1992a. "Contrasting two methods for determining trace metal partitioning in oxidized lake sediments." *Biogeochemistry*. Vol. 1.

Bendell-Young, L.I., and H.H. Harvey. 1992b. "Geochemistry on Mn and Fe in lake sediments in relation to lake acidity." *Limnology and Oceanogr*aphy. Vol. 37.

Bennie, D. T. 1999. "Review of the environmental occurrence of alkylphenols and alkylphenol ethoxylates." *Water Quality Research Journal of Canada.* Vol. 34.

Bennie, D.T., C.A. Sullivan, H.-B. Lee, T.E. Peart, and R.J. Maguire. 1997. "Occurrence of alkylphenols and alkylkphenol mono- and diethoxylates in natural waters of the Laurentian Great Lakes basin and upper St. Lawrence River." *The Science of the Total Environment.* Vol. 193.

Beychok, M.R. 1980. "State-of-the-art wastewater treatment." In James D. Wall (ed.), *Environmental Management Handbook for the Hydrocarbon Processing Industries.* Houston: Gulf Publishing Company.

Bianchi, W.C., and D.C. Muckel. 1970. *Ground-Water Recharge Hydrology.* Washington, D.C.: Department of Agriculture, Agricultural Research Service. ARS 41-161.

Bier, V.M. 1999. "Challenges to the acceptance of probabilistic risk analysis." *Risk Analysis.* Vol. 19.

Binkley, D., and T.C. Brown. 1993. "Forest practices as non-point sources of pollution in North America." *Water Resources Bulletin.* Vol. 29.

Black, T.A., R.F. Roberts, D.M Johnson, D.D. Minicucci, K.H. Mancy, and H.E. Allen. 1973. "The significance of physiochemical variables in aquatic bioassays of heavy metals." In G.E. Glass (ed.), *Bioassay Techniques and Environmental Chemistry.* Ann Arbor, Mich.: Ann Arbor Science Publishers, Inc.

Bøckman, O.C., O. Karstaad, O.H. Lie, and I. Richards. 1990. *Agriculture and Fertilizers: Fertilizers in Perspective* [online]. Oslo: Agricultural Group, Norsk Hydro. [Cited February 6, 2002.] <www.tfi.org/publications/pubsearch/images/ki760_.pdf>.

Bonsor, N., N. McCubbin, and J.B. Sprague. 1988. *Kraft Mill Effluents in Ontario.* Report prepared for Ministry of the Environment. [Toronto]

Bowen, G.S., and M.J. Hinton. 1998. "The temporal and spatial impacts of road salt on streams draining the Greater Toronto Area." *Groundwater in a Watershed Context Proceedings*, December 2–4, Canada Centre for Inland Waters, Burlington, Ontario. Cambridge, Ont.: Canada Centre for Inland Waters. Available on CD-ROM. See [online]. [Cited February 2, 2002.] <www.cwra.org/branches/arts/gw/gwcdpromo.html>.

Bowen, H. J. M. 1979. *Environmental Chemistry of the Elements.* New York: Academic Press.

Brezonik, P. 1976. "Analysis and speciation of trace metals in water supplies." In A.J. Rubin (ed.), *Aqueous-Environmental Chemistry of Metals*. Ann Arbor, Mich.: Ann Arbor Science Publishers, Inc.

Briggens, D.R., and D.E. Moerman. 1995. "Pesticides and farm well water quality in Kings County, Nova Scotia." *Water Quality Research Journal of Canada*. Vol. 30.

Burmaster, D.E. 1996. "Benefits and costs of using probabilistic techniques in human health risk assessments – with emphasis on site-specific risk assessments." *Human and Ecological Risk Assessment*. Vol. 2.

Burton, G.A., Jr. 2001. "Moving beyond sediment quality values and simple laboratory toxicity tests." *SETAC Globe*. Vol. 2, no. 2.

Buser, H.-R., T. Poiger, and M.D. Muller. 1999. "Occurrence and environmental behavior of the chiral pharmaceutical drug Ibuprofen in surface waters and in waste water." *Environmental Science and Technology*. Vol. 33.

Cadmus Group Incorporated. 1996. *Aquatic Ecological Risk Assessment*. Alexandria, Va.: Water Environment Research Foundation.

Calabrese, E.J., and L.A. Baldwin. 1993. *Performing Ecological Risk Assessments*. Boca Raton, Fla.: Lewis Publishers.

Campbell, P.G.C., A.G. Lewis, P.M. Chapman, A.A. Crowder, W.K. Fletcher, B. Imber, S.N. Luoma, P.M. Stokes, and M. Winfrey. 1988. *Biologically Available Metals in Sediments*. Associate Committee on Scientific Criteria for Environmental Quality. Ottawa: National Research Council. NRCC No. 27694.

Canada. Environment Canada. 1987. *Aquatic Toxicity of Pulp and Paper Mill Effluent: A Review*. Ottawa: Environment Canada. Report EPS 4.PF/1.

———. 1991. *The State of Canada's Environment*. Ottawa: Environment Canada. En21-54/1991E.

———. 1994. *Towards a Toxic Substances Management Policy for Canada: A Discussion Document for Consultation Purposes*. Ottawa: Environment Canada.

———. 1996. *The State of Canada's Environment*. Ottawa: Environment Canada. En21-54/1996E.

———. 1997. *Ontario Region Compliance Inspection Summary Report 1996/97* [online]. August 14. [Cited October 23, 2001.] <www.on.ec.gc.ca/glimr/data/summary-report/intro.html>.

———. 2000. *Priority Substances List Assessment Report: Road Salts*. Canadian Environmental Protection Act (CEPA), 1999. Ottawa: Environment Canada. Draft for Public Comment.

———. 2001. “Groundwater – Nature’s hidden treasure.” Freshwater Series A-5 [online]. [Cited October 23, 2001.] <www.ec.gc.ca/water/en/info/pubs/FS/e_FSA5.htm>.

Canada. Fisheries and Oceans Canada. 2000a. *Metal Mining Liquid Effluent Regulations* [online]. April 30. [Cited October 23, 2001.] <canada.justice.gc.ca/en/laws/f-14/CRC-c819/index.html>.

———. 2000b. *Petroleum Refinery Liquid Effluent Regulations* [online]. April 30. [Cited October 23, 2001.] <canada.justice.gc.ca/en/laws/f-14/CRC-c828/index.html>.

Canada. Health Canada. 1995. *A National Survey of Chlorinated Disinfection By-products in Canadian Drinking Water.* Ottawa: Health Canada. Report 95-EHD-197.

———. 1996. *A One-year Survey of Halogenated Disinfection By-products in the Distribution Systems of Treatment Plants Using Three Different Disinfection Processes.* Ottawa: Health Canada. Report 960-EHD-206.

———. 1997. “Water.” In *Health and Environment: Partners for Life* [online]. Ottawa: Health Canada. [Cited February 5, 2002.] <www.hc-sc.gc.ca/ehp/ehd/catalogue/general/97ehd215.htm>.

———. 2000. *Canadian Cancer Statistics* [online] [Cited October 23, 2001.] <www.cancer.ca>.

———. 2001. *Guidelines for Canadian Drinking Water Quality – Supporting Documents* [online]. [Cited October 23, 2001.] <www.hc-sc.gc.ca/ehp/ehd/catalogue/bch_pubs/dwgsup_doc/dwgsup_doc.htm>.

Canada. Health Canada. Federal-Provincial Subcommittee on Drinking Water. 1996. *Guidelines for Canadian Drinking Water Quality.* 6th ed. Ottawa: Health Canada. Cat. # H48-10/1996E.

Canada. National Research Council. 1976. *Effects of Chromium in the Canadian Environment.* Ottawa: National Research Council. NRCC No. 15017.

———.1978. *Effects of Lead in the Canadian Environment – 1978.* Ottawa: National Research Council. NRCC No. 16736.

———. 1979. *Effects of Cadmium in the Canadian Environment.* Ottawa: National Research Council. NRCC No. 16743.

Canada. Statistics Canada. 1994. *Human Activity and the Environment 1994.* Ottawa: Industry Canada.

——. 2000. *Human Activity and the Environment.* Ottawa: Industry Canada. Catalogue No. 11-509-XPE.

Canadian Council of Ministers of the Environment. 1995. *Protocol for the Derivation of Canadian Sediment Quality Guidelines for the Protection of Aquatic Life.* Winnipeg, Man.: CCME. PN1176.

Canadian Council of Resource and Environment Ministers. Task Force on Water Quality Guidelines. 1999. *Canadian Water Quality Guidelines* (and updates). Ottawa: CCREM.

Canadian Water Resources Association. [n.d.] "What are toxic blue-green algae?" *Manitoba Rural Water Quality: Toxic Blue-Green Algae* [online]. Publication #2 in a series of water quality factsheets. [Cited February 4, 2002.] <www.cwra.org/branches/arts/manitoba/pub2page1.html>.

Cardwell, R.D., B.R. Parkhurst, W. Warren-Hicks, and J.S. Volosin. 1993. "Aquatic ecological risk." *Water Environment Technology.* Vol. 5.

Carigan, R., F. Rapin, and A. Tessier. 1985. "Sediment porewater sampling for metal analysis: A comparison of techniques." *Geochemica et Cosmochimica Acta.* Vol. 49.

Carpi, A., and S.E. Lindberg. 1997. "Sunlight-mediated emission of elemental mercury from soil amended with municipal sewage sludge." *Environmental Science and Technology.* Vol. 31, no. 7.

Carson, R. 1962. *Silent Spring.* New York: Houghton Mifflin.

Chambers, P.A., M. Allard, S.L. Walker, J. Marsalek, J. Lawrence, M. Servos, J. Busnarda, K.S. Munger, K. Adare, C. Jefferson, R.A. Kent, and M.P. Wong. 1997. "Impacts of municipal wastewater effluents on Canadian waters: A review." *Water Quality Research Journal of Canada.* Vol. 32.

Chambers, P.A., M.. Guy, E. Roberts, M.N. Charlton, R.A. Kent, C. Gagnon, G. Grove, and N. Foster. 2001. *Nutrients and Their Impact on the Canadian Environment.* Agriculture and Agri-Food Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada, and Natural Resources Canada. [online]. [Cited February 2, 2002.] <www.durable.gc.ca/group/group7/report/index_e.phtml>.

Chapman, P.M. 1995. "How should numerical criteria be used?" *Human Ecological Risk Assessment.* Vol.1.

Chapman, P.M., et al. 2001. "Sediment quality values (SQVs) – challenges and recommendations." *SETAC Globe.* Vol. 2, no. 2.

Cherry, J.A., and J. Harmon. 1994. "Organic chemicals in Canadian groundwater." *Hazardous Materials Management.* Vol. 6.

Cockerham, L.G., and M.B. Cockerham. 1994. "Environmental ionizing radiation." In L.G. Cockerham and B.S. Shane (eds.), *Basic Environmental Toxicology.* Boca Raton, Fla.: CRC Press.

Cocklin, C., S. Parker, and J. Hay. 1992. "Notes on cumulative environmental change I: Concepts and issues." *Journal of Environmental Management.* Vol. 35.

Colborn, T., F.S. vom Saal, and A.M. Soto. 1993. "Developmental effects of endocrine disrupting chemicals in wildlife and humans." *Environmental Health Perspectives.* Vol. 101.

Colborn, T., D. Dumanoski, and J.P. Myers. 1996. *Our Stolen Future.* New York: Dutton Press.

Conboy, M.J., and M.J. Goss. 1997. "Is *Escherichia coli* an effective predictor of health risks and source of water contamination for rural populations?" *Toxicology and Exotoxicology News.* Vol. 4.

———.1999. "Contamination of rural drinking water wells by fecal origin bacteria – survey findings." *Water Quality Research Journal of Canada.* Vol. 34.

Costner, P., and J. Thornton. 1989. *We All Live Downstream – The Mississippi River and the National Toxics Crisis.* Washington, D.C.: Greenpeace USA.

Crosby, D. G. 1998. *Environmental Toxicology and Chemistry.* New York: Oxford University Press.

Cullen, W., and K. Reimer. 1989. "Environmental arsenic chemistry." *Chemical Reviews.* Vol. 89.

Daughton, C.G., and T.A. Ternes. 1999. "Pharmaceuticals and personal care products in the environment: Agents of subtle change?" *Environmental Health Perspectives.* Vol.107 (Suppl. 6).

Davis, D.L., H.L. Bradlow, M. Wolff, D.G. Woodruff, D.G. Hoel, and H. Anton-Culver. 1993. "Medical hypothesis: Xenoestrogens as preventable causes of breast cancer." *Environmetal Health Perspect*ives. Vol. 101.

Demayo, A., A.R. Davis, and M.A. Forbes. 1978. *Forms of Metals in Water.* Ottawa: Environment Canada, Inland Water Directorate, Water Quality Branch. Scientific Series No. 87.

Digiano, F.A., C.T. Miller, and J. Yoon. 1993. "Predicting the release of PCBs at the point of dredging." *Journal of Environmental Engineer*ing. Vol. 119.

Di Toro, D.M., C. Zarba, D.J. Hansen, R.C. Swartz, C.E. Cowan, H.E. Allen, N.A. Thomas, P.R. Paquin, and W.J. Berry. 1991. "Technical basis for establishing sediment quality criteria for non-ionic organic chemicals using equilibrium partitioning." *Environmental Toxicology and Chemistry.* Vol.10.

Devinny, J.S. 1990. "The composition of hazardous waste." In J.S. Devinny, L.G. Everett, J.C.S. Lu, and R.L. Stoller (eds.), *Subsurface Migration of Hazardous Wastes.* New York: Van Nostrand Reinhold.

Devinny, J.S., and J.C.S. Lu. 1990. "Introduction." In J.S. Devinny, L.G. Everett, J.C.S. Lu, and R.L. Stoller (eds.), *Subsurface Migration of Hazardous Wastes.* New York: Van Nostrand Reinhold.

Dobson, S.I., C.M. Merritt, J.-P. Shannahan, and C.M. Schults. 1999. "Low exposure concentrations of atrazine increase male production in *Daphnia pulicaria.*" *Environmental Toxicology and Chemistry.* Vol. 15.

Doyle, E., et al. 2002a. *Production and Distribution of Drinking Water.* Toronto: Ontario Ministry of the Attorney General. Walkerton Inquiry Commissioned Paper 8. Walkerton Inquiry CD-ROM. <www.walkertoninquiry.com>.

———. 2002b. *Wastewater Collection and Treatment.* Toronto: Ontario Ministry of the Attorney General. Walkerton Inquiry Commissioned Paper 9. Walkerton Inquiry CD-ROM. <www.walkertoninquiry.com>.

Duncan, P.B. 1999. "Groundwater-surface water interactions: No longer ignoring the obvious at superfund sites." *SETAC News.* Vol.19, no. 5.

Eckel, W.P., B. Ross, and R. Isensee. 1993. "Pentobarbital found in ground water." *Ground Water.* Vol. 31.

Edjulee, G.H., and P. Cains. 1996. "Control of PCDD and PCDF emissions from waste combusters." In R.E. Hester and R.M. Harrison (eds.), *Chlorinated Organic Micropollutants.* The Royal Society of Chemistry. Issues in Environmental Science and Technology series. No. 006.

Eidt, D.C., J.E. Hollebone, W.L. Lockhart, P.D. Kinsbury, M.C. Gadsby, and W.R. Ernst. 1989. "Pesticides in forestry and agriculture: Effects on aquatic habitats." In J.O. Nriagu and J.S.S. Lakshminarayana (eds.), *Aquatic Toxicology and Water Management.*. New York: J. Wiley & Sons. Advances in Environmental Science and Technology series, vol. 22.

Elder, J.F. 1988. *Metal Biogeochemistry in Surface-Water Systems: A Review of Principles and Concepts.* Denver, Colo.: U.S. Geological Survey. U.S. Geological Survey Circular 1013.

Eisenreich, S.J., B.B. Looney, and J. D. Thornton. 1981. "Airborne organic contaminants in the Great Lakes ecosystem." *Environmental Science and Technology.* Vol. 15.

Ellis, J.B. 1986. "Pollutant aspects of urban runoff." In H.C. Torno, J. Marsalek, and M. Desbordes (eds.), *Urban Runoff Pollution.* New York: Springer-Verlag.

Exner, M.E. and R.F. Spaulding. 1985. "Groundwater contamination and well construction in southeast Nebraska." *Ground Water.* Vol. 23.

Feldman, B.M. 1974. "The problem of urban dogs." *Science*. Vol. 185.

Fenn, M.E., M.A. Poth, J.D. Aber, J.S. Baron, B.T. Bormann, D.W. Johnson, D. Lemly, S.G. McNulty, D.F. Ryan, and R. Stottlemeyer. 1998. "Nitrogen excess in North American ecosystems: Predisposing factors, ecosystem responses, and management strategies." *Ecological Applications*. Vol. 8.

Ferguson, B.K. 1994. *Stormwater Infiltration*. Boca Raton, Fla.: CRC Press.

Fergusson, J.E. 1990. "Methyl compounds of the heavy elements." *The Heavy Elements: Chemistry, Environmental Impact and Health Effects*. Toronto: Pergamon Press.

Finelt, S., and J.R. Crump. 1980. "Pick the right water reuse system." In James D. Wall (ed.), *Environmental Management Handbook for the Hydrocarbon Processing Industries*. Houston: Gulf Publishing Company.

Fisher, S.W. 1995. "Mechanisms of bioaccumulation in aquatic systems." *Reviews of Environmental Contamination and Toxicolology*. Vol. 142.

Forbes, T.L., and V.E. Forbes. 1993. "A critique of the use of distribution-based extrapolation models in ecotoxicology." *Functional Ecology*. Vol. 7.

Forbes, V.E. and T.L. Forbes. 1994. *Ecotoxicology in Theory and Practice*. London: Chapman & Hall.

Forlin L., T. Anderson, L. Balk, and A. Larsson. 1995. "Biochemical and physiological effects in fish exposed to bleached kraft mill effluents." *Ecotoxicology and Environmental Safety*. Vol. 30.

Fox, G.A. 1992. "Epidemiological and pathobiological evidence of contaminant-induced alterations in sexual development in free-living wildlife." In T. Colborn and C. Clement (eds.), *Chemically-Induced Alterations in Sexual and Functional Development: The Wildlife-Human Connection*. Princeton, N.J.: Princeton Scientific Publishing.

Frank, R. 1985. "Farm water quality and pesticides." *Highlights of Agricultural Research in Ontario*. No. 8.

Frank, R., H.E. Braun, B.D. Ripley, B.S. Clegg, R. Johnson. 1990. "Survey of farm wells for pesticides, Ontario, Canada, 1986 and 1987." *Bulletin of Environmental Contamination and Toxicology*. Vol. 44.

Frank, R., B.S. Clegg, B.D. Ripley, and H.E. Braun. 1987a. "Investigations of pesticide contaminations in rural wells, 1979-1984, Ontario, Canada." *Archives of Environmental Contamination and Toxicology*. Vol. 16.

Frank, R., B.D. Ripley, H.E. Braun, B.S. Clegg, R. Johnson, and T.J. O'Neill. 1987b. "Survey of farm wells for pesticide residues, Southern Ontario, Canada, 1981–1982, 1984." *Archives of Environmental Contamination and Toxicology*. Vol. 16.

Frank, R., G.J. Sirons, and B.D. Ripley. 1979. "Herbicide contamination and decontamination of well waters in Ontario, Canada, 1969–1978." *Pesticide Monitoring Journal.* Vol. 13.

Frank, R., G.J. Sirons, R.L. Thomas, and K. McMillan. 1982. "Triazine residues in suspended solids (1974–1976) and water (1977) from mouths of the Canadian streams flowing into the Great Lakes." *Journal of Great Lakes Research.* Vol. 5.

Gadh, R., O.V. Singh, S.N. Tandon, and R.P. Mathur. 1991. "Determination of different soluble species in Yamuna River Waters." *Environmental Technology.* Vol. 12.

Geldreich, E.E. 1990. "Microbiological quality of source waters for water supply." In G.A. McFeters (ed.), *Drinking Water Microbiology.* New York: Springer-Verlag.

———. 1996. *Microbial Quality of Water Supply in Distribution Systems.* Boca Raton, Fla.: CRC Press.

Gibbons, D.C. 1986. *The Economic Value of Water.* Washington, D.C.: Resources for the Future.

Giesy, J.P., and K. Kannan. 2001. "Global distribution of perfluorooctane sulfonate and related compounds in wildlife." *Environmental Science and Technol*ogy. Vol. 35.

Giesy, J.P., J.P. Ludwig, and D.E. Tillet. 1994. "Deformities in birds of the Great Lakes region: Assigning causality." *Environmental Science and Technology.* Vol. 28.

Gilliland, F.D., and J.S. Mandel. 1996. Serum perfluorooctanoic acid and hepatic enzymes, lipoproteins, and cholesterol: A study of occupationally exposed men. *American Journal of Industrial Medicine.* Vol. 29.

Gilliom, R.J., J.E. Barbash, D.W. Koplin, and S.J. Larsen. 1999. "Testing water quality for pesticide pollution." *Environmental Science and Technology.* Vol. 33.

Glasgow, H.B., J.M. Burkholder, J.D. Schmechel, P.A. Tester, and P.A. Rublee. 1995. "Insidious effects of a toxic estuarine dinoflagellate on fish survival and human health." *Journal of Toxicology and Environmental Health.* Vol. 46.

Goss, M.J., and D.A.J. Barry. 1995. "Groundwater quality: Responsible agriculture and public perceptions." *Journal of Agricultural and Environmental Ethics.* Vol. 8.

Goss, M.J., D.A.J. Barry, and D.L. Rudolph. 1998. "Contamination in Ontario farmstead domestic wells and its association with agriculture. 1. Results from drinking water wells." *Journal of Contaminant Hydrology.* Vol. 32.

Goss, M.J., K.S. Rollins, K McEwan, J.R. Shaw, and H. Lammers-Helps. 2002. *The Management of Manure in Ontario with Respect to Water Quality.* Toronto: Ontario Ministry of the Attorney General. Walkerton Inquiry Commissioned Paper 6. Walkerton Inquiry CD-ROM. <www.walkertoninquiry.com>.

Gray, N.F. 1998. "Acid mine drainage composition and the implications for its impact on lotic systems." *Water Resources.* Vol. 32.

Greenberg, M.S., G.A. Burton, and P.B. Duncan. 2000. "Considering groundwater–surface water interactions in sediment toxicity assessment." *SETAC Globe.* Vol.1.

Gregory, S.V., F.J. Swanson, A. McKee, and K.W. Cummins. 1991."An ecosystem perspective on riparian zones." *BioScience.* Vol. 41.

Grout, H., M.R. Wiesner, and J-Y. Bottero. 1999. "Analysis of colloidal phases in urban stormwater runoff." *Environmental Science and Technology.* Vol. 33.

Gustafson, D.I. 1993. *Pesticides in Drinking Water.* New York: Van Nostrand Reinhold.

Halberg, G. R. 1989. "Pesticide pollution of groundwater in the humid United States." *Agriculture, Ecosystems and Environment.* Vol. 26.

Halling-Sorensen, B., N. Nielson, P.F. Lanzky, F. Ingerslev, H.C.H. Lutzhoft, and S.E. Jorgensen 1998. "Occurrence, fate, and effects of pharmaceutical substances in the environment – a review." *Chemosphere.* Vol. 36.

Harding, J.S., R.G. Young, J.W. Hayes, K.A. Shearer, and J.D. Stark. 1999. "Changes in agricultural intensity and river health along a river continuum." *Freshwater Biology.* Vol. 42.

Harrad, S.J. 1996. "Sources and fates of polychlorinated sibenzo-p-dioxins, dibenzofurans, and biphenyls: The budget and source inventory approach." In R.E. Hester and R.M. Harrison (eds.), *Chlorinated Organic Micropollutants.* Cambridge: The Royal Society of Chemistry. Issues in Environmental Science and Technology series. No. 006.

Harrison, R.M. 1990. "Cycles, fluxes and speciation of trace metals in the environment." In J.W. Patterson and R. Passino (eds.), *Metal Speciation, Separation and Recovery.* Vol. 2. Boca Raton, Fla.: Lewis Publishers Inc.

Harrison, S.A., T.L. Wastchke, R.O. Mumma, A.R. Jarrett, and G.W. Hamilton, Jr., 1993. "Nutrient and pesticide concentrations in water from chemically treated turf-grass." In K.D. Racke and A.R. Leslie (eds.), *Pesticides in Urban Environments: Fate and Significance.* American Chemical Society Symposium Series. Washington, D.C.: American Chemical Society.

Hester, R.E., and R.M. Harrison. 1994. *Waste Incineration and the Environment.* Cambridge: Royal Society of Chemistry.

Hill, A.R. 1982. “Nitrate distribution in the groundwater at the Alliston region of Ontario.” *Groundwater*. Vol. 20.

Hirsch, R., T. Ternes, K. Haberer, and K.-L. Kratz. 1999. “Occurrence of antibiotics in the aquatic environment.” *The Science of the Total Environment.* Vol. 225.

Holm, J.V., K. Rugge, P.L. Bjerg, and T.H. Christiansen. 1995. “Occurrence and distribution of pharmaceutical organic compounds in the groundwater down-gradient of a landfill (Grinsted, Denmark).” *Environmental Science and Technology*. Vol. 29.

Honeyman, B.D., and P.H. Santaschi. 1988. “Metals in aquatic systems.” *Environmental Science and Technology*. Vol. 22.

Hosmer, A., J. Warren, J. Brady. 2000. “Effects of atrazine on the sex ratio of *Daphnia pulicaria*.” Abstract from the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry. Nashville, Tenn. Abstract PTP139.

Huddleston, G.M., W.B. Gillespie, and J.H. Rodgers, Jr. 2000. “Using constructed wetlands to treat biochemical oxygen demand and ammonia associated with a refinery effluent.” *Ecotoxicology and Environmental Safety*. Vol. 45.

Huggett, R.J., P.A. Van Veld, C.L. Smith, W.J. Hargis, Jr., W.K. Vogelbein, and B.A. Weeks. 1992. “The effects of contaminated sediments in the Elizabeth River.” In G.A. Burton Jr. (ed.), *Sediment Toxicity Assessment.* Boca Raton, Fla.: Lewis Publishers.

Hunter, C., and B. McGee. 1994. *Survey of Pesticide Use in Ontario, 1993.* Toronto: Ontario Ministry of Agriculture, Food and Rural Affairs. Economics Information Report No. 94-01.

International Joint Commission. 1993. *A Strategy for the Virtual Elimination of Persistent Toxic Substances.* Vol. 1. Report of the Virtual Elimination Task Force to the IJC. Windsor, Ont.: International Joint Commission.

International Potash Institute. 1983. *Handbook on Environmental Aspects of Fertilizer Use*. Edited by M. Nijhoff. The Hague: W. Junk.

Iwata, H., S. Tanabe, N. Sakai, A. Nishimura, and R. Tatsukawa. 1994. “Geographical distribution of persistent organochlorines in air, water and sediments from Asia and Oceania, and their implications for global redistribution from lower latitudes.” *Environmental Pollution*. Vol. 85, no. 1.

Jacobsen, P., and L. Berglind. 1988. “Persistence of oxytetracycline in sediments from fish farms.” *Aquaculture*. Vol. 70.

James, M.O., and K.M. Kleinow 1994. "Trophic transfers of chemicals in the aquatic environment." In D.C. Mallins and G.K. Ostrander (eds.), *Aquatic Toxicology: Molecular, Biochemical, and Cellular Perspectives.* Boca Raton, Fla.: Lewis Publishers.

Jernelöv, A. 1974. "Factors in the transformation of mercury to methylmercury." In R. Harting and B.D. Dinman, *Environmental Mercury Contamination.* Ann Arbor, Mich.: Ann Arbor Sciences Publishers, Inc.

Johnson, L.B. and S.H. Gage. 1997. "Landscape approaches to the analysis of aquatic ecosystems." *Freshwater Biology.* Vol. 37.

Jorgensen, E.P. 1989. *The Poisoned Well: New Strategies for Groundwater Protection.* Sierra Club Legal Defense Fund. Washington, D.C.: Island Press.

Kaiser, J. and M. Enserink. 2000. "Treaty takes a POP at the dirty dozen." *Science.* Vol. 290

Kannan, K., J. Koistenen, K. Beckman, T. Evans, J. Gorzelany, P.D. Jones, and J.P. Giesy. 2001. "Perfluorooctane sulfonate and related fluorinated organic chemicals in marine mammals." *Environmental Science and Technology.* Vol. 35.

Kapustka, L.A., ed. 2000, "Ecosystem vulnerability." *Environmental Toxicology and Chemistry.* Vol. 19, Special Issue, no. 4, part 2 (April).

Karr, J.R., L.A. Toth, and D. R. Dudley. 1985. "Fish communities of midwestern rivers: A history of degradation." *BioScience.* Vol. 35.

Keith, L.H. 1997. *Environmental Endocrine Disruptors: A Handbook of Property Data.* New York: Wiley Interscience.

Keith, L.J. 1979. "Priority pollutants. I. A perspective view." *Environmental Science and Technology.* Vol. 13.

Kerry, J., M. Hiney, R. Coyne, S. NicGabhhaim, D. Gilroy, D. Cazabon, and P. Smith. 1995. "Fish feed as a source of oxytetracycline-resistant bacteria in the sediment under fish farms." *Aquaculture.* Vol. 131.

Klassen, R., 1998. "Geological factors affecting the distribution of trace metals in glacial sediments in central Newfoundland." *Environmental Geology.* Vol. 33.

Kleinow, K.M., and M.S. Goodrich. 1994. "Environmental aquatic toxicology." In L.G. Cockerham and B.S. Shane (eds.), *Basic Environmental Toxicology.* Boca Raton, Fla.: CRC Press.

Koenig, B.G., C.D. Metcalfe, T. Ternes, and R. Hirsch. 2000. "Drugs in sewage treatment plant effluents in Canada." Abstract from the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, Tenn., Abstract 342.

Kooijman, S.A.L.M., 1987. "A safety factor for LC50 values allowing for differences in sensitivity among species." *Water Research.* Vol. 21.

Krewski, D., J. Balbus, D. Butler-Jones, C. Haas, J. Isaac-Renton, K. Roberts, and M. Sinclair. 2002. *Managing Health Risks from Drinking Water.* Toronto: Ontario Ministry of the Attorney General. Walkerton Inquiry Commissioned Paper 7. Walkerton Inquiry CD-ROM. <www.walkertoninquiry.com>.

Kummerer, K. 2000. "Health risk potential from drinking water polluted with domestic sewage and excreta: Drugs, diagnostic agents, and disinfectants in waste water." *Schrift des Ver Wasser Boden und Lufthyg.* Vol. 15.

Kurtz, D.A. 1990. *Long Range Transport of Pesticides.* Boca Raton, Fla.: Lewis Publishers.

Lackey, R.T. 1995. "The future of ecological risk assessment." *Human and Ecological Risk Assessment.* Vol. 1.

Lammert, M., and J.D. Allan 1999. "Assessing biotic integrity of streams: Effects of scale in measuring the influence of land use/cover and habitat structure on fish and macroinvertebrates." *Environmental Management.* Vol. 23.

Lancaster, J. 2000. "The ridiculous notion of assessing ecological health and identifying the useful concepts underneath." *Human and Ecological Risk Assessment.* Vol. 6.

Landrum, P.F., D.C. Gossiaux, T.C. Nalepa, and D.L. Fanslow. 2001. "Evaluation of Lake Michigan sediment for causes of the disappearance of Diporiea spp. in southern Lake Michigan." *Journal of Great Lakes Research.* Vol. 26.

Larson, S.J., P.D. Capel, and M.S. Majewski.1997. "Pesticides in surface waters: Distribution, trends, and governing factors." In *Pesticides in the Hydrologic System.* Vol. 3. Chelsea, Mich.: Ann Arbor Press, Inc.

Leckie, J.O., and R.O. James. 1976. "Control mechanisms for trace metals in natural waters." In A.J. Rubin (ed.), *Aqueous-Environmental Chemistry of Metals.* Ann Arbor, Mich.: Ann Arbor Publishers Inc.

Lee, G.F., and A. Jones-Lee. 1995. "Appropriate use of numeric chemical concentration-based water quality criteria." *Human Ecological Risk Assessment.* Vol.1.

Lee, R.E. 1999. *Phycology.* Cambridge: Cambridge University Press.

Lee, R.F. 1992. "Models, muddles, and mud: Predicting bioaccumulation of sediment-associated contaminants." In G.A. Burton, Jr., (ed.), *Sediment Quality Assessment.* Boca Raton, Fla.: Lewis Press.

Leopold, L.B. 1977. "A reference for rivers." *Geology.* Vol. 5.

Li, J., and P. MacAteer. 2000. "Urban oil spills as a non-point pollution source in the Golden Horseshoe of Southern Ontario." *Water Quality Research Journal of Canada*. Vol. 35.

Lippman, M., 1989. *Health Benefits of Air Pollution Control: A Discussion.* Washington, D.C.: The Library of Congress. Congressional Research Service (CRS) Report for Congress.

Long, E.R., L.J. Field, and D.D. MacDonald. 1998. "Predicting toxicity in marine sediments with numerical sediment quality guidelines." *Environmental Toxicology and Chemistry*. Vol. 17.

Majewski, M.S., and P.D. Capell. 1995. "Pesticides in the atmosphere: Distribution, trends, and governing factors." *Pesticides in the Hydrologic System Series,* Vol. 1. Chelsea, Mich.: Ann Arbor Press.

Malmquist, P.A. 1983. *Urban Stormwater Pollutant Sources.* Gothenburg: Chalmers University of Technology.

Marsalek, J. 1986. "Toxic contaminants in urban runoff: A case study." In H.C. Torno, J. Marsalek, and M. Desbordes (eds.), *Urban Runoff Pollution.* Heidelberg: Springer-Verlag.

Marsalek, J., and S. Kok. 1997. "Stormwater management and abatement of combined sewer overflow pollution." *Water Quality Research Journal of Canada*. Vol. 32, no. 1.

Marsalek, J., and H. Schroeter. 1988. "Annual loadings of toxic contaminants in urban runoff from the Canadian Great Lakes basin." *Water Pollution Research Journal of Canada*. Vol. 23.

Marschner, H. 1986. *Mineral Nutrition of Higher Plants*. London: Academic Press.

Mayer, R., W.J. Snodgrass, and D. Morin. 1999. "Spatial characterization of the occurrence of road salts and their environmental concentrations as chlorides in Canadian surface waters and benthic sediments." *Water Quality Research*. Vol. 34, no. 4.

McCrae, B. 1991. *The Characterization and Identification of Potentially Leachable Pesticides and Area Vulnerable to Groundwater Contamination by Pesticides in Canada.* Ottawa: Agriculture Canada, Food Production and Inspection Branch. Backgrounder 91-01.

Mckinley, R.S., and G.P. Arron. 1987. *Distribution of 2,4-D and Picloram Residues in Environmental Components Adjacent to a Treated Right-of-Way*. Ottawa: Department of Energy and Mines. Research Report OH/R-87/49/K.

McMaster, M.E., G.J. Van der Kraak, C.B. Portt, K.R. Munkittrick, P.K. Sibley, I.R Smith, and D.G. Dixon. 1991. "Changes in hepatic mixed-function oxygenase (MFO) activity, plasma steroid levels and age at maturity of a white sucker (*Catostomus commersoni*) population exposed to a bleached kraft pulp mill effluent." *Aquatic Toxicology*. Vol. 21.

Mierle, G., and R. Ingram. 1991. "The role of humic substances in the mobilization of mercury from watersheds." *Water, Air, Soil Pollution.* Vol. 56.

Miller, D.W. 1980. *Waste Disposal Effects on Groundwater: A Comprehensive Survey of the Occurrence and Control of Groundwater Contamination.* Berkeley, Calif.: Premier Press.

Miller, T.G., and W.C. Mackay. 1980. "The effects of hardness, alkalinity, and pH of test water on the toxicity of copper to rainbow trout (*Salmo gairdneri*)." *Water Research.* Vol. 14.

Millette, L., and D.S. Mavinic. 1988. "The effect of pH adjustment on the internal corrosion rate of cast-iron and copper water distribution pipes." *Canadian Journal of Civil Engineering*. Vol. 15.

Mills, C.J., R.J. Bull, K.P. Cantor, J. Reif, S.E. Hrudey, P. Huston. 1999. "Health risks of drinking water chlorination by-products: Report of an expert working group." *Chronic Diseases in Canada.* Vol. 19.

Miner, J.R., F.J. Humenik, and M.R. Overcash. 2000. *Managing Livestock Wastes to Preserve Environmental Quality.* Ames, Iowa: Iowa State University Press.

Moore, D.R.J., and B.J. Elliott. 1996. "Should uncertainty be quantified in human and ecological risk assessments used for decision-making?" *Human Ecological Risk Assessment.* Vol. 2.

Moore, J., and S. Ramamoorthy, 1984. *Heavy Metals in Natural Waters.* New York: Springer-Verlag.

Morgan, M.G. 1993. "Risk analysis and management." *Scientific American.* Vol. 269.

———. 1998. "Uncertainty analysis in risk assessment." *Human and Ecological Risk Assessment.* Vol. 4.

Mueller, J.G., P.J. Chapman, and P.H. Pritchard. 1989. "Creosote-contaminated sites: Their potential for remediation." *Environmental Science and Technology*. Vol. 23.

Munkittrick, K.R., M.E. McMaster, C.B. Portt, G.J. Van der Kraak, I.R. Smith, D.G. Dixon. 1992. "Changes in maturity, plasma sex steroids, hepatic MFO activity and the presence of external lesions in lake whitefish exposed to bleached kraft mill effluent." *Canadian Journal of Fisheries and Aquatic Sciences.* Vol. 49.

Munkittrick, K.R., G.J. Van der Kraak, M.E. McMaster, C.B. Portt, M.R. Van den Heuval, M.R. Servos. 1994. "Survey of receiving-water environmental impacts associated with discharges from pulp mills: 2. gonad size, liver size, hepatic EROD activity and plasma sex steroid levels in white sucker." *Environmental Toxicology and Chemistry*. Vol. 13.

Munro, I.C. 1990. "Safety assessment procedures for indirect food additives: An overview." *Regulatory Toxicology and Pharmacology*. Vol. 12.

Naiman, R.J., R.E. Bilby, and P.A. Bisson. 2000. "Riparian ecology and management in the Pacific coastal rain forest." *BioScience*. Vol. 50.

Naiman, R.J., and H. Descamps. 1997. "The ecology of interfaces." *Annual Review of Ecology and Systematics*. Vol. 28.

Naiman, R.J., H. Descamps, J. Pastor, and C.A. Johnston. 1988. "The potential importance of boundaries to fluvial ecosystems." *Journal of the North American Benthological Society*. Vol. 7.

Naiman, R.J., J.J. Magnuson, D.M. McKnight, and J.A. Stanfield. 1995. *The Freshwater Imperative: A Research Agenda*. Washington, D.C.: Island Press.

Neary, D.G., P.B. Bush, and J.L. Michael. 1993. "Fate, dissipation and environmental effects of pesticides in southern forests: A review of a decade of research progress." *Environmental Toxicology and Chemistry*. Vol. 12.

Nehlsen, W., J.E. Williams, and J.A. Lichatowich. 1991. "Pacific salmon at the crossroads: Stocks of salmon at risk from California, Oregon, Idaho, and Washington." *Fisheries*. Vol. 16.

Nero, A.V., Jr. 1988. "Radon and its decay products in indoor air: An overview." In W. Nazaroff and A.V. Nero, Jr. (eds.), *Radon and Its Decay Products in Indoor Air*. New York: J. Wiley & Sons.

Noga, E.J., L. Khoo, J.B. Stevens, Z. Fan, and J.M. Burkholder. 1996. "A new ichthyotoxic dinoflagellate: Cause of acute mortality in aquarium fishes." *Veterinary Record*. Vol. 133.

Nowell, L.H., P.D. Capel, and P.D. Dileanis. 1999. "Pesticides in stream sediment and aquatic biota: Distribution, trends, and governing factors." *Pesticides in the Hydrologic System*, Vol. 4. New York: Lewis Publishers.

Nriagu, J.O. (ed.). 1994. *Arsenic in the Environment: Part 1: Cycling and Characterization*. Toronto: J. Wiley & Sons.

Nriagu, J.O. 1997. *Origin, Long-range Transport, Atmospheric Deposition, and Associated Effects of Heavy Metals in the Canadian Environment.* Prepared for the Atmospheric Environment Service, Environment Canada. Downsview, Ont.: Environment Canada..

Nriagu, J.O., G. Lawson, H.K.T. Wong, and V. Cheam. 1996. "Dissolved trace metals in lakes Superior, Erie, and Ontario." *Environmental Science and Technology.* Vol. 30, pp. 178–187.

Nriagu, J.O., H.K.T. Wong, G. Lawson, and P. Daniel. 1998. "Saturation of ecosystems with toxic metals in Sudbury basin, Ontario." *The Science of the Total Environment.* Vol. 223.

Oberts, G.L., J. Marsalek, and M. Viklander. 2000. "Review of water quality impacts of winter operation on urban drainage." *Water Quality Research Journal of Canada.* Vol. 35, no. 4.

Oke, T. R. 1978. *Boundary Layer Climates.* London: Methuen & Co. Ltd.

Okkerman, P.C., E.J. van de Plassche, H.J.B. Emans, J.H. Canton. 1993. "Validation of some extrapolation methods with toxicity data derived from multiple species experiments." *Ecotoxicology and Environmental Safety.* Vol. 25.

Okkerman, P.C., E.J. van de Plassche, W. Sloof, C.J. Van Leeuwen, J.H. Canton. 1991. "Ecotoxicological effects assessment: A comparison of several extrapolation procedures." *Ecotoxicology and Environmental Safety.* Vol. 21.

Olivieri, V.P. 1986. "Human pathogens, disinfection, and chlorine." In R.L. Jolley, R.J. Bull, W.P. Davis, S. Katz, M.H. Roberts, and V.A. Jacobs (eds.), *Water Chlorination: Chemistry, Environmental Impact, and Health Effects.* Vol. 5. Chelsea, Mich.: Lewis Publishers.

Ontario Drinking Water Surveillance Program. 2000. *Reports for 1998 and 1999* [online]. [Cited October 23, 2001.] <www.ene.gov.on.ca/envision/dwsp9899/dwsp.htm>.

Ontario. Ministry of Agriculture, Food, and Rural Affairs. 1998. *Water wells.* Infosheet # 2 [online]. [Cited October 23, 2001.] <www.gov.on.ca/OMAFRA/english/environment/EFP/efp2-water_wells.htm>.

———. 2000. *Factsheet: The Land Application of Sewage Biosolids for Crop Production* [online]. [Cited October 23, 2001.] <www.gov.on.ca/OMAFRA/english/environment/facts/00-023.htm>.

Ontario. Ministry of the Environment. 1985. *Alachlor Monitoring of Ontario Drinking Water, May–November 1985.* Report of the Water Resources Branch, Ministry of the Environment. Toronto: Ministry of the Environment.

———. 1987a. *Pesticides in Ontario Drinking Water, 1985.* Report of the Water Resources Branch. Toronto: Ministry of the Environment.

———. 1987b. *Pesticides in Ontario Drinking Water, 1986.* Report of the Water Resources Branch. Toronto: Ministry of the Environment.

———. 1998. “Water wells and groundwater: Recommended methods for plugging abandoned water wells. *Green Tips.* [Toronto: Ministry of the Environment.] 1M-09-98.

Ontario. Ministry of the Environment. Water Resources Branch. 1988. *Thirty-seven Municipal Water Pollution Control Plants: Pilot Monitoring Study.* Vol 1. Interim Report, and Vol. 2, Appendix A. [Toronto: Ministry of the Environment.]

Ontario. Ministry of the Environment and Energy. 1994. *Policies, Guidelines and Provincial Water Quality Objectives.* Toronto: Ministry of the Environment and Energy. PIBS 3303E.

Ontario. Ministry of the Environment and Energy. Hazardous Contaminants Branch. 1990. *The Ontario Ministry of the Environment Scoring System: A Scoring System for Assessing Environmental Contaminants.* Toronto: Ministry of the Environment and Energy.

Oschwald, W.R. 1972. “Sediment-water interactions.” *Journal of Environmental Quality.* Vol. 1.

Owens, J.W. 1991. “The hazard assessment of pulp and paper effluents in the aquatic environment: A review.” *Environmental Toxicology and Chemistry.* Vol. 10.

Paerl, H.W., J. Rudek, and M.A. Mallin. 1990. “Stimulation of phytoplankton production in coastal waters by natural rainfall inputs: Nutritional and trophic implications.” *Marine Biology.* Vol. 107.

Paerl, H.W. 1993. “Emerging role of atmospheric deposition in coastal eutrophication: Biogeochemical and trophic perspectives.” *Canadian Journal of Fisheries and Aquatic Sciences.* Vol. 50.

Pankow, J.F. 1991a. “Solubility behaviors of simple mineral salts, and metal oxides, hydroxides and oxyhydroxides.” In his *Aquatic Chemistry Concepts.* Chelsea, Mich.: Lewis Publishers.

———. 1991b. “Solubility behavior of metal carbonates in closed systems. ” In his *Aquatic Chemistry Concepts.* Chelsea, Mich.: Lewis Publishers.

Parametrix, Inc. 1995. *Persistence, Bioaccumulation and Toxicity of Metals and Metal Compounds.* Prepared for the International Council on Metals and the Environment. Ottawa: International Council on Metals and the Environment.

Parker, J.T.C., K.D. Fossum, and T.L. Ingersoll. 2000. "Chemical characteristics of urban stormwater sediments and implications for environmental management, Miricopa County, Arizona." *Environmental Management.* Vol. 26.

Parkhurst, B.R., W. Warren-Hicks, R.D. Cardwell, J. Volison, T. Etchison, J.B. Butcher, S.M. Covington. 1996. *Aquatic Ecological Risk Assessment: A Multi-tiered Approach to Risk Assessment.* Alexandria, Va.: Water Environment Research Foundation.

Pearson, R., K. Hornbuckle, S. Eisenreich, and D. Swackhammer. 1996. "PCBs in Lake Michigan water revisited." *Environmental Science and Technol*ogy. Vol. 30.

Personen, M., and T. A. Personen, M., and T. Anderson. 1992. "Toxic effects of bleached and unbleached paper mill effluents in primary cultures of rainbow trout hepatocytes. *Ecotoxicology and Environmental Safety.* Vol. 24.

Peterjohn, W.T., and D.L. Correll. 1984. "Nutrient dynamics in an agricultural watershed: Observation on the role of riparian forest." *Ecology.* Vol. 65.

Petersen, R.C. Jr. 1992. "The RCE: A riparian, channel, and environmental inventory for small streams in the agricultural landscape." *Freshwater Biology.* Vol. 27.

Phyper, J.-D., and B. Ibbotson. 1994. *The Handbook of Environmental Compliance in Ontario.* 2nd ed. Toronto: McGraw-Hill Ryerson.

Pirrone, N., I. Allegrini, G.J. Keeler, J.O. Nriagu, R. Rossmann, and J.A. Robbins. 1998. "Historical atmospheric mercury emissions and depositions in North America compared to mercury accumulations in sedimentary records." *Atmospheric Environment.* Vol. 32, no. 5.

Pirrone, N., G. Keeler, and J. Nriagu. 1996. "Regional differences in worldwide emissions of mercury to the atmosphere." *Atmospheric Environment.* Vol. 30, no. 7.

Postuma, L., T. Traas, and G.W. Suter (eds.). 2001. *Species Sensitivity Distributions in Risk Assessment.* Pensacola, Fla.: SETAC Press.

Power, E.A, and P.M. Chapman. 1992. "Assessing sediment quality." In G.A. Burton, Jr. (ed.), *Sediment Quality Assessment.* Boca Raton, Fla.: Lewis Press.

Power, M., and L.S. McCarty. 1996. "Probabilistic risk assessment: Betting on its future." *Human Ecological Risk Assessment.* Vol. 2.

Price, R.K., and Mance, G. 1978. "A suspended solids model for stormwater runoff." In P. Helliwell (ed.), *Urban Storm Drainage.* London: Pentech Press.

Qasim, S.R., and W. Chiang. 1994. *Sanitary Landfill Leachate: Generation, Control, and Treatment.* Lancaster, Pa.: Technomic Publishing.

Quinn, F. 1987. "Interbasin water diversions: A Canadian perspective." *Journal of Soil and Water Conservation.* Vol. 42.

Rabeni, C.F., and M.A. Smale. 1995. "Effects of siltation on stream fishes and the potential mitigating role of the buffering riparian zone." *Hydrobiologia.* Vol. 303.

Randall, L., J.S. Han, and J.H. Weber. 1986. "Determination of inorganic tin, methyltin and butyltin compounds in sediments." *Environmental Technology Letters.* Vol. 7.

Rapport, D.J. 1989. "What constitutes ecosystem health?" *Perspectives in Biology and Medicine.* Vol. 33.

Rasmussen, P.E. 1998. "Long-range atmospheric transport of trace metals: The need for geoscience perspectives." *Environmental Geology.* Vol. 33.

Reynoldson, T.B., R.H. Norris, V.H. Resh, K.E. Day, and D.M. Rosenberg. 1997. "The reference condition approach: A comparison of multiple and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates." *Journal of the North American Benthological Society.* Vol. 16.

Richards, C., G.E. Host, and J.W. Arthur. 1993. "Identification of predominant environmental factors structuring stream macroinvertebrate communities within a large agricultural catchment." *Freshwater Biology.* Vol. 29.

Richardson, C. 1999. "Ecological functions of wetlands in the landscape." In M.A. Lewis, F.L. Mayer, R.L. Powell, M.K. Nelson, S.J. Klaine, M.G. Henry, and G.W. Dickson (eds.), *Ecotoxicology and Risk Assessment for Wetlands.* Pensacola, Fla.: SETAC Press. [Special Publication] Society of Environmental Toxicology and Chemistry.

Richardson, G.M., 1996. "Deterministic versus probabilistic risk assessment: Strengths and weaknesses in a regulatory context." *Human and Ecological Risk Assessment.* Vol. 2.

Ripley, B., T. Arbuckle, L. Ritter, and B. Archibald. 1998. "The contribution of well water to overall farm family pesticide exposure." *Toxicological Sciences.* Vol. 42.

Ritter, W.F. 1988. "Reducing impacts of nonpoint source pollution from agriculture: A review." *Journal of Environmental Science and Health.* Vol. A23.

Roberts, S.M. 1999. "Practical issues in the use of probabilistic risk assessment." *Human and Ecological Risk Assessment.* Vol. 5.

Rodgers, J.H., Jr., G.W. Dickson, T. Dillon, P.B. Dorn, J.W. Farmer, R.A. Gearheart, J.F. Hall, B. McFarland, M.K. Nelson, P. Nix, C.J. Richardson, D.P. Tierney. 1999. "Constructed wetlands as a risk mitigation alternative." In M.A. Lewis, F.L. Mayer, R.L. Powell, M.K. Nelson, S.J. Klaine, M.G. Henry, and G.W. Dickson (eds.), *Ecotoxicology and Risk Assessment for Wetlands*. Pensacola, Fla.: SETAC Press. [Special Publication] Society of Environmental Toxicology and Chemistry.

Rudolph, D.L., D.A.J. Barry, and M.J. Goss. 1998. "Contamination in Ontario farmstead domestic wells and its association with agriculture. 2. Results from multilevel monitoring well installations." *Journal of Contaminant Hydrology*. Vol. 32.

Rudolph, D.L., and M.J. Goss. 1993. *The Ontario Farm Groundwater Survey – Summer 1992.* Report to Agriculture Canada under the Federal-Provincial Environmental Sustainability Initiative. Guelph, Ont.: University of Guelph. June.

Salomons, W., and U. Forstner. 1991. *Metals in the Hydrocycle*. Heidelberg: Springer-Verlag.

Sang, S., and B. Lourie. 1995. "Mercury in Ontario: An inventory of sources, use and releases." In *Proceedings of the 1995 Canadian Mercury Network Workshop*. Report of a workshop held September 29–30, 1995, York University, Toronto.

Schaeffer, D.J., E.E. Herricks, and H.W. Kerster. 1988. "Ecosystem health 1. Measuring ecosystem health." *Environmental Management*. Vol. 12.

Schroeder, J.E., and K.R. Solomon. 1998. *Impact of road salt on an urban watershed*. Abstract from the 19th Annual Meeting of the Society of Environmental Toxicology and Chemistry, Charlotte, N.C.

Schroeter, H.O. 1997. "Toxic contaminant loadings from municipal sources in Ontario areas of concern." *Water Quality Research Journal of Canada.* Vol. 32.

Schultz, R., and M. Liess. 1999. "A field study of the effects of agriculturally-derived insecticide input on stream macroinvertebrate dynamics." *Aquatic Toxicology*. Vol. 46.

Scott, W.S. 1980. "Road salt movement into two Toronto streams." *Journal of Environmental Engineering Division.* Vol. 106, no. EE3.

Scrimgeour, G.J. 1989. "Effects of bleached kraft mill effluent on macroinvertebrate and fish populations in weedbeds in a New Zealand hydro-electric lake." *New Zealand Journal of Marine and Freshwater Research.* Vol. 23.

Servos, M. R. 1999. "Review of the aquatic toxicity, estrogenic responses and bioaccumulation of alkylphenols and alkylphenol polyethoxylates." *Water Quality Research Journal of Canada.* Vol. 34.

Seyfried, P., and D. Joy. 1995. "Pathogenic viruses in septic systems and their removal." In *Alternative Systems: Nutrient Removal and Pathogenic Microbes*. Conference proceedings, Septic System Conference. Waterloo, Ont.: Waterloo Centre for Groundwater Research, University of Waterloo.

Shah, K.L. 2000. *Basics of Solid and Hazardous Waste Management Technology.* Columbus, Ohio: Prentice Hall.

Sheppard, S.C. 1998. "Geophagy: Who eats soil and where do possible contaminants go?" *Environmental Geology.* Vol. 33.

Sibley, P.K., D.A. Benoit, G.T. Ankley, M.K. Balcer, C. West, G.L. Phipps, and R.A. Hoke. 1999. "An exposure apparatus for the *in situ* assessment of sediment toxicity and bioaccumulation." *Environmental Toxicology and Chemistry.* Vol.18.

Sibley P.K., D.G. Dixon, D.R. Barton. 2000. "Impact of bleached kraft mill effluent on benthic community structure in relation to environmental factors." *Journal of Aquatic Ecosystem Stress and Recovery.* Vol. 7.

Silbergeld, E.K., L. Grattan, D. Oldach, and J.G. Morris. 2000. "*Pfiesteria*: Harmful algal blooms as indicators of human:ecosystem interactions." *Environmental Research.* Vol. 82.

Singer, P.C. 1974. *Trace Metals and Metal-Organic Interactions in Natural Waters.* Ann Arbor, Mich.: Ann Arbor Science Publishers, Inc.

Slovic, P. 1987. "Perception of risk." *Science.* Vol. 236.

Slovic, P., B. Fischoff, and S. Lichtenstein. 1980. "Facts and fears: Understanding perceived risk." In R.C. Schwing and W. Albers (eds.), *Societal Risk Assessment: How Safe Is Safe Enough?* New York: Plenum Press.

Smeet, J.M.W., I. van Holstein, J.P. Giesy, W. Seinen, and M. van den Berg. 1999. "Estrogenic potencies of several environmental pollutants, as determined by vitellogenin induction in carp hepatocyte assay." *Toxicological Science.* Vol. 50.

Smith, J.D., and T.E. Hamilton. 1992. "Trace metal fluxes to lake sediments in south-eastern Australia." *The Science of the Total Environment.* Vol. 125.

Smith, R.L. 1990. *Ecology and Field Biology.* New York: Harper Collins Publishers.

Snoeyink, V.L., and D. Jenkins. 1980. "Oxidation-reduction reactions." In *Water Chemistry.* Toronto: J. Wiley & Sons.

Society for Environmental Toxicology and Chemistry (SETAC). Aquatic Risk Assessment and Mitigation Dialog Group. 1994. *Pesticide Risk and Mitigation*. Final Report. Pensacola, Fla.: SETAC Foundation for Environmental Education.

Solomon, K.R., 1996. "Overview of recent developments in ecotoxicological risk assessment." *Risk Analysis.* Vol.16.

———. 1999. "Integrating environmental fate and effects information: The keys to ecotoxicological risk assessment for pesticides." In G. T. Brooks and T. R. Roberts (eds.), *Pesticide Chemistry and Bioscience: The Food-Environment Challenge*. London: Royal Society of Chemistry.

Solomon, K.R., D.B. Baker, P. Richards, K.R. Dixon, S.J. Klaine, T.W. La Point, R.J. Kendall, J.M. Giddings, J.P. Giesy, L.W.J. Hall, C. Weisskopf, and M. Williams. 1996. "Ecological risk assessment of atrazine in North American surface waters." *Environmental Toxicology and Chemistry*. Vol. 15.

Southern California Coastal Water Research Project. 1992. "Characteristics of effluents from large municipal wastewater treatment plants in 1992." In *Southern California Coastal Water Research Project* [online]. Annual Report 1992/93. [Cited February 14, 2002.] <www.sccwrp.org/pubs/annrpt/92-93/ar-01.htm>.

Stan, H.J., T. Heberer, and M. Linkerhagner. 1994. "Occurrence of clofibric acid in the aquatic system – Is the use in human medical care the source of the contamination of surface, ground, and drinking water?" *Vom Wasser*. Vol. 83.

Standley, L.J., and T.L. Bott 2001. "Appropriate role for biology in establishing sediment quality criteria." *SETAC Globe.* Vol. 2, no. 2.

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman, and W.A. Brungs. 1985. *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses.* Washington, D.C.: U.S. Environmental Protection Agency. EPA 22/R-85-100.

Stevens, A.A., L.A. Moore, and R.J. Miltner. 1989. "Formation and control of non-trihalomethane disinfection by-products." *Journal of the American Water Works Association.* Vol. 81.

Strachan W.M.J. 1987. "Development needs for Canada's national water quality guidelines." *Water Pollution Research Journal of Canada.* Vol. 22.

Struger, J., P. Martos, B. Ripley, and G. Gris. 2000. "Pesticide concentrations in urban aquatic environments of Ontario, Canada." Abstract from the 21st Annual Meeting of the Society for Environmental Toxicology and Chemistry, Nashville, Tenn. Abstract PHA129.

Stumpf, M., T.A. Ternes, R.-D. Wilken, S.V. Rodrigues, and W. Baumann. 1999. “Polar drug residues in sewage and natural waters in the state of Rio de Janeiro, Brazil.” *The Science of the Total Environment.* Vol. 225.

Sullivan, R.H., W.D. Hurst, T.M. Kipp, J.P. Heaney, W.C. Huber, and S. Nix. 1978. *Evaluation of the Magnitude and Significance of Pollution from Urban Storm Water Runoff in Ontario.* Ottawa: Supply and Services Canada.

Suntio, L.R., W.Y. Shiu, and D. MacKay. 1988. “A review of the nature and properties of chemicals present in pulp mill effluents.” *Chemosphere.* Vol. 17.

Suter, G.W. 1993a. “A critique of ecosystem health concepts and indices.” *Environmental Toxicology and Chemistry.* Vol. 12.

Suter, G.W., L.W. Barnthouse, S.M. Bartell, T. Mill, D. Mackay, S. Patterson. 1993b. *Ecological Risk Assessment.* Boca Raton, Fla.: Lewis Publishers.

Svanberg, O., and B.-E. Bengtsson. 1996. “Impact of bleached pulp mill effluents on the aquatic environment (The Swedish Environment/ Cellulose Project) – a case study.” *Resource Conservation and Recycling.* Vol. 16.

Swaigen, J. 1995. *Time Bombs: The Regulation of Canada’s Leaking Underground Storage Tanks.* Canadian Institute of Environmental Law and Policy. Toronto: Edmond Montgomery Publications Ltd.

Tana, J. A., K.-J. Rosemarin, J. Lehtinen, O. Hardig, Grahn, and L. Landner. 1994. “Assessing impacts on Baltic coastal ecosystems with mesocosm and fish biomarker tests: A comparison of new and old wood pulp bleaching technologies.” *The Science of the Total Environment.* Vol. 145.

Tang, E.P.Y., R. Tremblay, and W.F. Vincent. 1997. “Cyanobacterial dominance of polar freshwater ecosystems: Are high-altitude mat-formers adapted to low temperature?” *Journal of Phycology.* Vol. 33.

Tas, J.W., and C.J. Van Leeuwen. 1995. “Glossary.” In “Ecotoxicological effects.” In *Risk Assessment of Chemicals: An Introduction.* Dordrecht: Kluwer Publishers.

Tessier, A., P.G. Campbell, and M. Bisson. 1979. “Sequential extraction procedure for the speciation of particulate trace metals.” *Analytical Chemistry.* Vol. 51.

Tessier, A., R.C. Carignan, and N. Belzile. 1994. “Processes occurring at the sediment-water interface: Emphasis on trace elements.” In J. Buffle and R.R. Devitre (eds.). *Chemical and Biological Regulation of Aquatic Systems.* Boca Raton, Fla.: CRC Press.

Thomas, N.A., 1994. "EPA/ORD role and perspective in sediment research." In J.V. DePinto, W. Lick, and J.F. Paul (eds.), *Transport and Transformation of Contaminants Near the Sediment-water Interface*. Boca Raton, Fla.: CRC Press.

Thurman, E.M., and A.E. Cromwell. 2000. "Atmospheric transport, deposition, and fate of triazine herbicides and their metabolites in pristine areas at Isle Royale National Park." *Environmental Science and Technology*. Vol. 34.

Thurman, E.M., D.A. Gooslby, M.T. Meyer, and D.W. Kolpin. 1991. "Herbicides in surface waters of the Midwestern United States: The effect of the spring flush." *Environmental Science and Technology*. Vol. 25.

Tobin, G.A., and R. Rajagopal. 1990. "Expert opinion and groundwater quality: The case of agricultural drainage wells." *Journal of Soil and Water Conservation*. Vol. 45.

Travis, C.C., and A.G. Nixon. 1996. "Human exposure to dioxin." In R.E. Hester and R.M. Harrison (eds.), *Chlorinated Organic Micropollutants*. The Royal Society of Chemistry. Issues in Environmental Science and Technology series. Vol. 6.

United Nations Environment Programme. 1999. *UNEP Chemicals: Status Report on POPs* [online]. [Cited October 23, 2001.] <irptc.unep.ch/pops/statrep/jun99/pdf/report1.pdf>.

United States. Environmental Protection Agency. 1990. *The Quality of Our Nation's Water: A Summary of the 1988 National Water Quality Inventory*. Washington, D.C.: US EPA. US EPA report 440/4-90-005.

———.1992. *Framework for Ecological Risk Assessment*. Washington, D.C.: US EPA.

———. 1995. "Final water quality guidance for Great Lakes system." *Federal Register*. Washington, D.C., Thursday, March 23, pp. 15366–15425.

———. 2000a. "Chlorpyrifos revised risk assessment and agreement with registrants." *Prevention, Pesticides, and Toxic Substances (7506C)* [online] [Cited October 23, 2001.] <www.epa.gov/pesticides>.

———. 2000b. *Site Remediation Technology InfoBase: A Guide to Federal Programs, Information, Resources, and Publications on Contaminated Site Cleanup Technologies*. Washington, D.C.: US EPA. EPA 542-B-00-005.

United States. Environmental Protection Agency. Office of Air Quality Planning and Standards 1997a. *Deposition of Air Pollutants to the Great Waters: Second Report to Congress*. Washington, D.C.: US EPA. EPA-453/R-97-011.

United States. Environmental Protection Agency. Office of Air Quality Planning and Standards and Office of Research and Development. 1997b. *Mercury Study Report to Congress*. Vols. 1 to 8. Washington, D.C.: US EPA. EPA-452/R-97-005.

United States. Environmental Protection Agency. Office of Pesticide Programs. 1999. "ECOFRAM aquatic draft report" and "ECOFRAM terrestrial draft report." *Ecological Risk Assessment Page* [online]. [Cited February 4, 2002.] <www.epa.gov/oppefed1/ecorisk/index.htm>.

United States. Environmental Protection Agency. Office of Water. 1998a. *National Water Quality Inventory: 1998 Report to Congress* [online]. [Cited October 23, 2001.] <www.epa.gov/305b/98report/toc.html>.

———. 1998b. *National Water Quality Inventory: 1998 Report to Congress. Appendix IV. Environmental Impacts of Animal Feedlot Operations* [online]. [Cited October 23, 2001.] <www.epa.gov/305b/98report/toc.html>.

United States. Environmental Protection Agency. Office of Water, Regulations, and Standards 1988. *U.S. EPA/Paper Industry Cooperative Dioxin Screening Study.* Washington, D.C.: US EPA. EPA-440/1-88-025.

United States. Environmental Protection Agency. Risk Assessment Forum. 1998. *Guidelines for Ecological Risk Assessment.* Washington, D.C.: US EPA.

United States. Federal Interagency Stream Restoration Working Group. 1998. *Stream Corridor Restoration: Principles, Process, and Practices.* Springfield, Va.: National Technical Information Service.

United States. National Atmospheric Deposition Program/National Trends Network. 2000. "Nitrogen in the nation's rain" [online]. [Cited October 23, 2001.] <nadp.sws.uiuc.edu>.

United States. National Research Council. 1983. *Risk Assessment in the Federal Government.* Washington, D.C.: National Academy Press.

———. 1993. *Issues in Risk Assessment.* Washington, D.C.: National Academy Press.

———. 1997. *Contaminated Sediments in Ports and Waterways: Cleanup Strategies and Technologies.* Washington, D.C.: National Academy Press.

———. 1999. *Hormonally Active Agents in the Environment.* Washington, D.C.: National Academy Press.

United States. National Research Council. Committee on the Biological Effects of Ionizing Radiation. 1990. *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation.* Washington, D.C.: National Academy Press.

United States. Office of Technology Assessment. 1984. *Protecting the Nation's Groundwater from Contamination.* Vols. 1 and 2. Washington, D.C.: US OTA. Reports OTA-0-233 and OTA-0-276.

Urban, D.J., and N.J. Cook. 1986. *Standard Evaluation Procedure for Ecological Risk Assessment.* Washington, D.C.: Hazard Evaluation Division, Office of Pesticide Programs, U.S. Environmental Protection Agency. EPA/ 540/09-86/167.

Van Lanen, H.A.J., and R. Dijksma. 1999. "Water flow and nitrate transport to a groundwater-fed stream in the Belgian-Dutch chalk region." *Hydrological Processes.* Vol. 13.

Van Leeuwen, C.J. 1995. "Ecotoxicological effects." In *Risk Assessment of Chemicals: An Introduction.* Dordrecht: Kluwer Publishers.

Van Straalen, N.M. 1982. Personal communication.

Van Straalen, N.M., and Denneman, C.A.J. 1989. "Ecotoxicological evaluation of soil quality criteria." *Ecotoxicology and Environmental Safety.* Vol. 18.

Wagner, C., and H. Løkke. 1991. "Estimation of ecotoxicological protection levels from NOEC toxicity data." *Water Research.* Vol. 25.

Waller, D.H., and W.C. Hart. 1986. "Solids, nutrients, and chlorides in urban runoff." In H.C., Torno, J. Marsalek, and M. Desbordes (eds.), *Urban Runoff Pollution.* Heidelberg: Springer-Verlag.

Waller, D.H., and Z. Novak. 1980. "Pollution loadings to the Great Lakes from municipal sources in Ontario." *Journal of the Water Pollution Control Federation.* Vol. 52.

Wania, F., and D. Mackay. 1993. "Global fractionation and cold condensation of low volatility organochlorine compounds in polar regions." *Ambio.* Vol. 22.

Warren-Hicks, W.J., and D.R.J. Moore. 1998. *Uncertainty Analysis in Ecological Risk Assessment.* Pensacola, Fla.: SETAC Press.

Waters, T.F. 1995. *Sediment in Streams: Sources, Biological Effects, and Control.* Bethesda, Md.: American Fisheries Society. Monograph 7.

Watson, V.J., P.M. Rice, and E.C. Monning. 1989. "Environmental fate of picloram used for roadside weed control." *Journal of Environmental Quality.* Vol. 18.

Wickstrom, L.H., and M.T. Baranoski. 2000. 'Industrial-waste-disposal wells in Ohio." Ohio Department of Natural Resources, Division of Geological Survey [online]. [Cited February 5, 2002.] <www.dnr.state.oh.us/ geosurvey/gen/environment/Class1a.htm>.

Wilber, W.G., and J.V. Hunter. 1979. "The impact of urbanization on the distribution of heavy metals in bottom sediments of the Saddle River." *Water Resources Bulletin.* Vol. 15.

Williams, S.L., D.B. Aulenbach, and N.L. Clesceri. 1976. “Sources and distribution of trace metals in aquatic environments.” In A.J. Rubin (ed.), *Aqueous-Environmental Chemistry of Metals.* Ann Arbor, Mich.: Ann Arbor Science Publishers, Inc.

World Health Organization. 1984. *Fluorine and Fluorides*. Geneva: World Health Organization. Environmental Health Criteria 36.

———. 1993. *Guidelines for Drinking-water Quality.* Vol. 1. *Recommendations.* 2nd ed. Geneva: World Health Organization.