EXHIBIT P

Canadian Environmental Protection Act, 1999

PRIORITY SUBSTANCES LIST ASSESSMENT REPORT

FOLLOW-UP TO THE STATE OF SCIENCE REPORT, 2000

Aluminum Chloride
Aluminum Nitrate
Aluminum Sulphate

Chemical Abstracts Service Registry Numbers
7446-70-0
13473-90-0
10043-01-3

Environment Canada
Health Canada

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LIST OF ACRONYMS AND ABBREVIATIONS

Aβ	amyloid beta
ACH	aluminum chlorohydrate
AD	Alzheimer's disease
AD_{AF}	chemical-specific animal to human toxicodynamic adjustment factor
ADP	adenosine diphosphate
ADRDA	Alzheimer's Disease and Related Disorders Association
AK_{AF}	chemical-specific animal to human toxicokinetic adjustment factor
AMS	accelerator mass spectrometry
ApoE	apolipoprotein E
ASFA	Aquatic Sciences and Fisheries Abstracts (World Health Organization Food and Agricultural Organization)
ATP	adenosine triphosphate
ATPase	class of enzymes that catalyze the decomposition of ATP into ADP
ATSDR	Agency for Toxic Substances and Disease Registry (U.S. Department of Health and Human Services)
BAF	bioaccumulation factor
BCF	bioconcentration factor
BIOSIS	Biosciences Information Services
CAplus	Chemical Abstracts Plus
CAB	Commonwealth Agricultural Bureaux
cAMP	cyclic adenosine monophosphate
CAS	Chemical Abstracts Service
CASReact	CAS Reaction
CBTB	Canadian Brain Tissue Bank
CEPA	Canadian Environmental Protection Act
CEPA 1999	Canadian Environmental Protection Act, 1999
CESARS	Chemical Evaluation Search and Retrieval System (Ontario Ministry of the Environment and Michigan Department of Natural Resources)
cGMP	cyclic guanosine monophosphate
ChemCats	Chemical Catalogs online
Chemlist	regulated Chemicals Listing
CHRIS	Chemical Hazard Release Information System
CI	confidence interval
CSHA	Canadian Study of Health and Aging
CT	computer tomography
CTV	Critical Toxicity Value
D_a	administered dose

D_b	base diet dose
D_c	cumulative dose
DIN	Drug Identification Number
DNA	deoxyribonucleic acid
DOC	dissolved organic carbon
DOM	dissolved organic material
DSM	Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association)
dw	dry weight
DWTP	drinking water treatment plant
EC_{50}	median effective concentration
ECETOC	European Centre for Ecotoxicology and Toxicology of Chemicals
EDI	estimated daily intake
EEM	Environmental Effects Monitoring
ELIAS	Environmental Library Integrated Automated System (Environment Canada library)
EPA	Environmental Protection Agency (U.S.)
ETAAS	electrothermal atomic absorption spectroscopy
FAO	Food and Agricultural Organization (United Nations)
GD	gestational day
GEOREF	Geo Reference Information System (American Geological Institute)
GLP	good laboratory practice
GVRD	Greater Vancouver Regional District
GVS&DD	Greater Vancouver Sewerage & Drainage District
HD_{AF}	chemical-specific human variability toxicodynamic adjustment factor
HK_{AF}	chemical-specific human variability toxicokinetic adjustment factor
HSDB	Hazardous Substances Data Bank (U.S. National Library of Medicine)
ICD	International Classification of Diseases (World Health Organization)
IM	intramuscular
IPCS	International Programme on Chemical Safety (World Health Organization)
IV	intravenous
JECFA	Joint FAO/WHO Expert Committee on Food Additives
KASAL	alkaline aluminum phosphate and dibasic sodium phosphate

LC_{50}	median lethal concentration
LD_{50}	median lethal dose
LOAEC	lowest observed adverse effect concentration
LOEC	lowest observed effect concentration
LOEL	lowest observed effect level
LSA	Ontario Longitudinal study of Aging
MEDLINE	Medical Literature Analysis and Retrieval System Online (U.S. National Library of Medicine)
MINEQL+	chemical equilibrium modeling software
MMAD	mass median aerodynamic diameter
MMSE	Mini-Mental State Examination
MOE	margin of exposure
mRNA	messenger ribonucleic acid
MS	multiple sclerosis
MWWTP	municipal wastewater treatment plant
NADPH	nicotinamide adenine dinucleotide phosphate
NATES	National Analysis of Trends in Emergencies System
NEMISIS	National Enforcement Management Information System and Intelligence System
NFT	neurofibrillary tangles
NICNAS	National Industrial Chemicals Notification and Assessment Scheme (Australian Government Department of Health and Aging)
NIH	National Institutes of Health (U.S. Department of Health and Human Services)
NINCDS	National Institute of Neurological and Communicative Disorders and Stroke
NOEC	no observed effect concentration
NOEL	no observed effect level
NTIS	National Technical Information Service (U.S. Department of Commerce)
OECD	Organisation for Economic Co-Operation and Development
OR	odds ratio
p value	the probability of obtaining a value of the test statistic at least as extreme as the one that was actually observed, given that the null hypothesis is true
PAC	polyaluminum chloride
PAQUID	Principle lifetime occupation and cognitive impairment in a French elderly
PAS	polyaluminum sulphate
PASS	polyaluminum silicate sulphate
PEC	Predicted Environmental Concentration

PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 micrometers in aerodynamic diameter
PM_{10}	particulate matter less than 10 micrometers in aerodynamic diameter
PND	postnatal day
PNEC	Predicted No-Effect Concentration
POLTOX	Cambridge Scientific Abstracts (U.S. National Library of Medicine)
PPP2	Protein Phosphatase 2
PSL	Priority Substances List
PSL2	Second Priority Substances List
PTEAM	Particle Total Exposure Assessment Methodology
PubMed	free Internet access to MEDLINE
RMOC	Regional Municipality of Ottawa-Carleton
RR	relative risk
RTECS	Registry of Toxic Effects of Chemical Substances (U.S. National Institute for Occupational Safety and Health)
SALP	sodium aluminum phosphate
SOS	State of the Science
$t_{½}$	half-life
TDI	total dietary intake
Tf	transferrin
$TNF^{-\alpha}$	alpha tumour necrosis factor
TOXLINE	toxicology database (U.S. National Library of Medicine)
TRI93	Toxic Chemical Release Inventory (U.S. Environmental Protection Agency, Office of Toxic Substances)
TSS	total suspended solids
USEPA-ASTER	Assessment Tools for the Evaluation of Risk (U.S. Environmental Protection Agency)
V_d	volumes of distribution
WASTEINFO	Waste Management Information (Bureau of the American Energy Agency)
WHAM	Windermere Humic-Aqueous Model software designed to calculate equilibrium chemical speciation in surface and ground waters, sediments and soils
WHO	World Health Organization

SYNOPSIS

The three aluminum salts, aluminum chloride, aluminum nitrate and aluminum sulphate, were included on the Second Priority Substances List (PSL2) under the *Canadian Environmental Protection Act, 1999* (CEPA 1999) in order to assess the potential environmental and human health risks posed by exposure to aluminum derived from these three salts in Canada.

In December 2000, the PSL2 assessment of the three aluminum salts was formally suspended due to limitations in the available data for assessing health effects. At the same time, a State of the Science report (Environment Canada and Health Canada 2000) on the three aluminum salts was released, providing an in-depth review of toxicity and exposure information relating to human health and the environment. During the suspension period, additional health effects information was published in the scientific literature, and they are considered here.

In Canada, municipal water treatment facilities are the major users of aluminum chloride and aluminum sulphate, accounting for 78% of the estimated 16.1 kilotonnes of the 2006 domestic consumption. Industrial water and wastewater treatment, and use in the pulp and paper industry, account for an additional 20 %. Aluminum sulphate and aluminum chloride are also used as ingredients in drugs and cosmetics, such as antiperspirants and topical creams. Aluminum sulphate is permitted as a food additive in a limited number of products. Aluminum nitrate, used in far less quantities than the sulphate and chloride salts, may be used in fertilizers, and as a chemical reagent in various industries.

Aluminum salts occur naturally in small quantities in restricted geological environments and aluminum can be released into the Canadian environment from these natural sources. However, since aluminum is present in relatively large amounts in most rocks, dominantly in aluminosilicate minerals, which weather and slowly release aluminum to the surface environment, the small amounts of aluminum in surface waters resulting from weathering of aluminum salts such as aluminum sulphate cannot be distinguished from other natural aluminum releases.

During their use in water treatment, aluminum salts react rapidly, producing dissolved and solid forms of aluminum with some release of these to Canadian surface waters. The amount of anthropogenic aluminum released nationally in Canada is small compared with estimated natural aluminum releases; however anthropogenic releases can dominate locally near strong point sources. Most direct release into surface waters of aluminum derived from the use of aluminum salts in water treatment processes originates from drinking water treatment plants (DWTPs). However, direct releases of process waters from DWTPs are regulated by many provincial and territorial authorities, and these releases typically occur in circumneutral water, where the solubility of aluminum is minimal. Disposal of sludge produced by municipal and industrial water treatment facilities on land through landfarming practices is a source of aluminum to the terrestrial environment. However, the presence of dissolved organic matter and inorganic chelating agents will lower the amount of bioavailable aluminum in both the terrestrial and aquatic environments.

While extensive recent data on total aluminum concentrations in Canadian surface waters are available, few data exist on levels in areas close to sites where releases occur. The situation for sediment and soil is similar, in that data exist for the Canadian environment in general, but not for areas where releases occur. A large number of environmental toxicity data are available for acidified environments, but relatively few exist for circumneutral environments similar to those where most releases occur.

Based on a comparison of highest measured and estimated aluminum levels present in both aquatic and terrestrial environments in Canada that receive direct inputs of aluminum from the use of the three aluminum salts, and Predicted No-Effect Concentrations (PNECs) derived from experimental data for aquatic and terrestrial biota, it is considered that, in general, it is unlikely that organisms are exposed to harmful levels of aluminum resulting from the use of aluminum salts in Canada. However, it is acknowledged that under some release conditions there is potential for local impacts to benthic organisms related to the settling of aluminum sludge from DWTPs onto the sediment surface. As such, it is proposed that the three aluminum salts (i.e., aluminum chloride, aluminum nitrate, aluminum sulphate) are not entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity.

With respect to human health, both epidemiological and experimental animal data were reviewed. Considering experimental animal studies, the dose at which neurotoxic, reproductive, and developmental effects have been repeatedly observed was used to establish an exposure level of concern.

General population exposure to total aluminum was quantified. With respect to the three salts—aluminum chloride, aluminum nitrate, and aluminum sulphate—their contribution to total aluminum exposure can only be qualitatively estimated, however, the only media in which the mean concentration may be significantly affected by the use of these salts is drinking water, in which aluminum sulphate or aluminum chloride may be added during the treatment process. As a surrogate for quantitative exposure estimation it was assumed that all aluminum in drinking water is derived from aluminum chloride and aluminum sulphate. Comparison of the exposure level of concern to the age-group with the highest average daily intake of total aluminum from drinking water results in a margin of exposure that is considered adequate.

Based on the information available for human health and the environment, it is proposed that the three aluminum salts, aluminum chloride, aluminum nitrate, aluminum sulphate, are not entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity or that constitute or may constitute a danger to the environment on which life depends. It is also proposed that aluminum from aluminum chloride, aluminum nitrate and aluminum sulphate, are not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health. It is therefore proposed that aluminum chloride, aluminum nitrate and aluminum sulphate do not meet the definition of "toxic" under section 64 of the *Canadian Environmental Protection Act, 1999.*

1 INTRODUCTION

The *Canadian Environmental Protection Act, 1999* (CEPA 1999) requires the Ministers of the Environment and of Health to prepare and publish a Priority Substances List (PSL) that identifies substances (including chemicals, groups of chemicals, effluents and wastes) that may be harmful to the environment or constitute a danger to human health. The Act also requires both Ministers to assess these substances to determine whether they meet or are capable of meeting the criteria as defined in section 64 of the Act. A substance meets the criteria under CEPA 1999 if it is entering or may enter the environment in a quantity or concentration or under conditions that:

(a) have or may have an immediate or long term harmful effect on the environment or its biological diversity;

(b) constitute or may constitute a danger to the environment on which life depends; or

(c) constitute or may constitute a danger in Canada to human life or health.

For substances deemed to meet the criteria defined in section 64, risk management measures are identified and implemented in consultation with stakeholders, in order to reduce or eliminate the risks posed to human health or the environment. These measures may include regulations, guidelines, pollution prevention plans or codes of practice to control any aspect of the life cycle of the substance, from the research and development stage through to manufacture, use, storage, transport and ultimate disposal.

Based on initial screening of readily accessible information, the rationale provided by the Ministers' Expert Advisory Panel in 1995 for including aluminum chloride, aluminum nitrate and aluminum sulphate on the Second Priority Substances List was as follows (Environment Canada and Health Canada 2000):

> *"Aluminum, from both natural and man-made sources, is widespread in the Canadian environment. Intakes of aluminum among the human population and ambient airborne concentrations in some parts of the country are close to those that have induced developmental and pulmonary effects in animal studies. Epidemiological studies have indicated that there may be a link between exposure to aluminum in the environment and effects in humans. Aluminum compounds are bioaccumulative, and can cause adverse ecological effects, especially in acidic environments. The Panel identifies three aluminum compounds as being of particular concern. An assessment is needed to establish the weight of evidence for the various effects, the extent of exposure and the aluminum compounds involved. If necessary, the assessment could be expanded to include other aluminum compounds."*

A preliminary report was completed for the three aluminum salts and released as a State of the Science (SOS) report in December 2000. With respect to immediate or long term harmful effects of the three aluminum salts on the environment or its biological diversity, the report proposed that, based on measured and estimated aluminum levels in Canadian aquatic and terrestrial environments receiving direct inputs of aluminum from the use of aluminum salts and on the Predicted No-Effect Concentrations (PNECs) derived from experimental data for aquatic and terrestrial biota, it is in general unlikely that organisms are exposed to harmful levels of aluminum resulting from the use of aluminum salts in Canada.

With respect to human health, a conclusion regarding section 64(c) could not be reached in 2000, owing to the limitations in the available data for assessing health effects. Therefore, the assessment of aluminum salts was suspended in December 2000 for a period of six years to allow for the development of additional human health effects data in order that Health Canada could reach a conclusion on whether aluminum salts (chloride, nitrate and sulphate) should be considered as "toxic" under CEPA 1999.

In terms of this draft PSL2 assessment, the conclusions made under section 64 of CEPA 1999 relate directly to the three aluminum salts nominated by the Ministers' Expert Advisory Panel (chloride, nitrate, and sulphate). However, different approaches are taken by Environment Canada and Health Canada in evaluating the potential for risk.

In characterizing the potential for risk to the environment, data relevant to the entry of the three listed salts into the Canadian environment from local point sources (e.g., drinking water treatment plants) were examined in conjunction with data on environmental fate and exposure. The focus was on assessing potential for effects on the environment near point sources. This evaluation formed the basis for determining whether the three aluminum salts identified by the Ministers' Expert Advisory Panel (chloride, nitrate and sulphate) are "toxic" under section 64 of CEPA 1999.

The human health risk characterization consists of a two-stage evaluation. In the first stage, exposure of the general Canadian population to total aluminum in air, drinking water, diet, and soil is quantified. In the second stage, the relative contribution of each of the three listed aluminum salts (chloride, nitrate, and sulphate) to this total aluminum exposure is qualitatively evaluated, and a recommendation with respect to section 64(c) of CEPA is made for the three salts.

Health Canada chose this two-stage approach on the basis of both scientific and practical considerations. First, overall exposure to the aluminum moiety (Al^{3+}), and not exposure to a particular aluminum compound, is the critical parameter for evaluating potential toxicological risk[1]. Second, concentrations of aluminum in foods, soil, drinking water, and air are generally reported as total aluminum, and not in terms of specific salts, consequently it is difficult to determine with great precision the relative contribution of the three salt forms being considered. Although information on sources and uses of aluminum-containing

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[1] Note, however, that different aluminum salts are absorbed into the bloodstream to different degrees (Yokel et al. 2006) and this aspect is considered in this assessment within section 2.3.3.1.

compounds are used to characterize total aluminum exposure, the risk characterization is limited to the three specific aluminum salts.

The search strategies employed in the identification of relevant data are presented in Appendix A. All original studies that form the basis for decision making have been critically evaluated and are described in the assessment. For issues relevant to the environmental and human health effects of aluminum, but outside the scope of the present assessment, the information is summarized briefly and the reader is referred to recent critical reviews published in the scientific literature for a more detailed discussion.

The human health components of the present document were prepared by the Safe Environments Programme- Quebec Region, in collaboration with the Existing Substances Division of the Safe Environments Programme (National Capital Region) and other Health Canada programs. The environmental components were prepared by the Existing Substances Division of the Science and Technology Branch. While external peer review comments were taken into consideration, the final content and outcome of the risk assessment remain the responsibility of Health Canada and Environment Canada.

The human health components of this assessment have been peer reviewed by the following external experts:

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Information relevant to environmental components of this assessment has been reviewed by the following external experts:

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2 SUMMARY OF INFORMATION CRITICAL TO ASSESSMENT OF "TOXIC" UNDER CEPA 1999

2.1 Identity and physical/chemical properties

Aluminum chloride is also known as aluminum trichloride, aluminum chloride (1:3) and trichloroaluminum (ATSDR 2006). It has the Chemical Abstracts Service (CAS) registry number 7446-70-0 and a chemical formula of $AlCl_3$. In its hydrated form, $AlCl_3 \cdot 6H_2O$, it is called hexahydrated aluminum chloride (CAS No. 7784-13-6). Trade names include Aluwets, Anhydrol and Drichlor.

Synonyms for aluminum nitrate include aluminum trinitrate and aluminum (III) nitrate (1:3). The CAS registry number is 13473-90-0 and the chemical formula is $Al(NO_3)_3$. The nonahydrate aluminum nitrate, $Al(NO_3)_3 \cdot 9H_2O$ (CAS No. 7784-27-2), is the stable form of this compound.

Aluminum sulphate can also be identified as alum, alumsulphate (2:3), aluminum trisulphate, dialuminum sulphate and dialuminum trisulphate. The CAS registry number for aluminum sulphate is 10043-01-3 and the chemical formula is $Al_2(SO_4)_3$. Alum is often represented as $Al_2(SO_4)_3 \cdot 14H_2O$. It may be found in different hydrated forms. The commercial product, called cake alum or patent alum, is an octadecahydrate aluminum sulphate, $Al_2(SO_4)_3 \cdot 18H_2O$.

In addition to these three compounds, aluminum polymers such as polyaluminum sulphate (PAS) and polyaluminum chloride (PAC) are used in water treatment. The general formula for PAS is $Al_a(OH)_b(SO_4)_c$, where $b + 2c = 3a$; for PAC, the general formula is $Al_a(OH)_bCl_c$, where b/a is usually about 2.5 (e.g., $Al_2(OH)_5Cl$). Mixed aluminum polymers may also be used; their general formula is $Al_a(OH)_bCl_c(SO_4)_d$, and b/a varies between 0.4 and 0.6.

Physicochemical properties of the three aluminum salts are presented in Table 2.1.

Table 2.1 Physicochemical properties of aluminum chloride, aluminum nitrate and aluminum sulphate [1]

Property	**Aluminum chloride**	**Aluminum nitrate**	**Aluminum sulphate**
CAS No.	7446-70-0	13473-90-0	10043-01-3
Molecular formula	$AlCl_3$	$Al(NO_3)_3$	$Al_2(SO_4)_3$
Molecular weight	133.34	213.00	342.14
Colour	White when pure, ordinarily gray or yellow to greenish	Colourless[2]	White, lustrous
Physical state	White hexagonal deliquescent or moisture sensitive plates	Rhombic crystals[2]	Crystals, pieces, granules or powder
Density (g/mL)	2.48	No data	1.61
Melting point (°C)	194 at 527 kPa	73[2]	Decomposes at 770
Boiling point (°C)	182.7 (1.00×10^5 Pa or 752 mm Hg; sublimation temperature)	Decomposes at 135°C[2]	No data, substance has no boiling point
Solubility in water (g/100 mL)	69.86 (15°C) (Reacts violently with water)	63.7 (25°C)	36.4 (20°C)
Solubility in other solvents	Soluble in benzene, carbon tetrachloride, chloroform	Very soluble in alcohol; slightly soluble in acetone almost insoluble in ethyl acetate, pyridine[2]	Insoluble in ethanol
pH	No data	Aqueous solution is acidic	No data
Vapour pressure (Pa)	100 (20°C)	No data	0 (20°C) substance has no vapour pressure

[1] Taken from Perry and Green (1984), Budaveri et al. (1989), Lewis (1992), European Commission (2000a,b) and ATSDR (2006)

[2] Refers to aluminum nitrate nonahydrate (CAS No. 7784-27-2)

2.2 Entry characterization

2.2.1 Production, import, export and use

Aluminum sulphate and aluminum chloride are produced in Canada, while aluminum nitrate is imported. Information on sources and emissions of aluminum salts or aluminum resulting from the use of aluminum salts was initially obtained through an industry survey carried out under the authority of section 16 of CEPA (CEPA 1988; Environment Canada 1997). Information regarding the use of aluminum chloride and aluminum sulphate in water treatment plants was obtained on a voluntary basis from Canadian municipalities with the help of provincial and territorial authorities. In 2007, additional research was conducted in order to review use patterns and quantities of aluminum derived from sources identified in the original assessment, as well as to identify and quantify potential new sources of aluminum to the environment resulting from the application of aluminum salts in Canada (Cheminfo Services Inc. 2008).

Table 2.2 provides estimated production, import, export and consumption values for the year 2006, based largely on input from Canadian aluminum salt producers. Unless otherwise stated, quantities reported in Table 2.2 and the accompanying text represent the amount of elemental aluminum present in the respective salts rather than the total amount of the salt. Polymeric forms of the chloride and sulphate are detailed separately, as these salts were found to be commonly used individually or in combination with other salts in water treatment processes. No producers or users of aluminum nitrate were identified for 2006 and, therefore, while it is likely that very small quantities were being imported into Canada in that year for a variety of low volume applications, no numerical data were available. Total Canadian consumption of aluminum as aluminum salts in 2006 was estimated at 16.1 kilotonnes, with aluminum sulphate accounting for approximately 80% of this demand, and PAC for the majority of the remainder (Cheminfo Services Inc. 2008). Approximately 80% of the total aluminum demand was for the treatment of drinking water and wastewater at municipalities. Industrial fresh water and wastewater treatment facilities accounted for the majority of the remaining demand in Canada.

Table 2.2 Estimated production, import, export and consumption of aluminum in the form of aluminum salts in Canada for 2006
(kilotonnes aluminum; Cheminfo Services Inc. 2008)[1]

	Aluminum Sulphate	**Aluminum Chloride**	**Other[2]**	**Total**
Production	11.9	0.1	4.6	16.6
Imports	0.6	0.2	1.0	1.8
Total supply	**12.5**	**0.3**	**5.6**	**18.4**
Demand				
Municipal Drinking Water Treatment Plants	4.3	0.1	2.4	6.8
Municipal Wastewater Treatment Plants	5.7	0.03	0.07	5.8
Industrial Fresh Water Treatment	0.3	0.03	0.67	1.0
Industrial Wastewater Treatment	0.5	0.03	0.44	0.9
Pulp and Paper Additive	1.1	0.01	0.16	1.3
Miscellaneous	0.1	0.1	0.1	0.3
Total Domestic Consumption	12.0	0.3	3.8	16.1
Exports	0.5	0.0	1.8	2.3
Total Disposition	**12.5**	**0.3**	**5.6**	**18.4**

[1] Quantities reported represent elemental aluminum present in the respective aluminum salts.

[2] This quantity represents the combined total of polyaluminum sulphate, polyaluminum chloride, aluminum chlorohydrate and sodium aluminate.

Five companies produced most of the aluminum salts used in Canada in 2006 (Cheminfo Services Inc. 2008). Imports and exports were roughly in balance, with imports representing approximately 10% of 2006 domestic consumption and exports representing approximately 14% of 2006 production. Alum, PAC and aluminum chlorohydrate (ACH) were the major imported aluminum salts, while PAC and alum were exported.

Total Canadian demand for aluminum salts remained relatively constant between 2000 and 2006 (Cheminfo Services Inc. 2008). Canada's salt producers indicate that the demand for alum and sodium aluminate declined during this period, while PAC, ACH and polyaluminum silicate sulphate (PASS) increased in use. While overall aluminum salts demand for municipal water treatment has increased slightly, use in the pulp and paper industry has dropped. The overall total amount of aluminum contained in the salts used in Canada has remained constant at close to 16 kilotonnes per year (Cheminfo Services Inc. 2008).

2.2.1.1 Aluminum chloride

Aluminum chloride is used in either anhydrous or hydrated form. In the anhydrous form, it is used as a catalyst, in Friedel-Crafts reactions, in the manufacture of rubber, the cracking of petroleum, and the manufacture of lubricants. In its hydrated form, it is used by the pharmaceutical industry as an active ingredient in deodorants and antiperspirants, as well as in wood preservation, and in the manufacture of adhesives, paint pigments, resins, fertilizers and astringents (Germain et al. 2000; Pichard 2005; Merck 2006). Polymeric forms, primarily polyaluminum chloride (PAC) and the more concentrated and highly charged aluminum chlorohydrate (ACH), are used as coagulants and flocculants in water treatment.

PAC has the highest Canadian production and use volumes of the three aluminum chloride salts. PAC demand increased over the period 2000 to 2006, with greatest quantities being used in the treatment of drinking water (Cheminfo Services Inc. 2008). Similar increased demand was evident in other applications, including industrial freshwater treatment, municipal and industrial wastewater treatment, and as a pulp and paper additive (Cheminfo Services Inc. 2008). Production and demand were substantially lower for both aluminum chloride and ACH. Canadian consumption of aluminum chloride remained stable from 2000 to 2006, while ACH demand increased substantially (Cheminfo Services Inc. 2008). Most of the increased demand was associated with increased applications in industrial wastewater treatment, with slower rates of growth in other applications.

2.2.1.2 Aluminum nitrate

Aluminum nitrate is used as a chemical reagent (catalyst), in the leather tanning industry, as an antiperspirant, as a corrosion inhibitor, and in the manufacture of abrasives, refractories, ceramics, electric insulation, catalysts, paper, candles, pots, artificial precious stones and heat-resistant fibres (Budaveri et al. 1989; Pichard 2005). It is also used as an adsorbent in chromatography for the production of filter membranes, in radiation protection dosimetry in the uranium extraction sector, and as a nitrating agent in the food industry (Merck 2006).

There are no known producers of aluminum nitrate in Canada, and only one user was identified in a survey done in 1997 by Environment Canada (1997). This user reported that less than 400 kg of aluminum nitrate was included in fertilizers for export to the United States.

It is likely that very small quantities of aluminum nitrate are being imported into Canada for a variety of low volume applications, including laboratory uses, leather manufacturing, manufacturing of fire works, and other minor applications (Cheminfo Services Inc. 2008).

2.2.1.3 Aluminum sulphate

In Canada, aluminum sulphate is used primarily as a coagulant and flocculant in water and wastewater treatment. There are other applications, however, in the leather industry, the paper industry, as a mordant in dyeing, in the fireproofing and waterproofing of textiles, in resin manufacture, and in the preparation of fertilizers and paint pigments (Germain et al. 2000; Pichard 2005; Merck 2006). The Canadian Fertilizers Product Forum advises that aluminum sulphate (alum) is used as a soil pH adjuster in the Lawn and Garden industry (2008 email from The Canadian Fertilizers Product Forum to J. Pasternak, Environment Canada; unreferenced). Aluminum sulphate can also be used to waterproof concrete, decolorize petroleum products, and as a formulant in antiperspirants and pesticides (Budaveri et al. 1989). Aluminum sulphate or alum is used in the treatment of eutrophic or mesotrophic lakes, to reduce the amount of nutrients present in the water. Both alum ($Al_2(SO_4)_3$) and sodium aluminate ($Na_2Al_2O_4$) are highly effective coagulants and flocculants that adsorb and precipitate soluble phosphorus and other compounds such as organic matter, forming clumps that settle to the bottom of the lake. In saturated solutions, aluminum sulphate is considered a mild corrosive and can be applied to ulcers in concentrations of 5% to 10% to prevent mucous secretion (Pichard 2005). The substance is also used as a food additive and some foods, such as baking powder.

It is estimated that approximately 276 kilotonnes of aluminum sulphate (11.9 kilotonnes on an aluminum basis) were produced in Canada in 2006, 15 kilotonnes (0.6 kilotonnes of aluminum) were imported and 12 kilotonnes (0.5 kilotonnes of aluminum) exported (Table 2.2). Municipal drinking water and wastewater treatment plants were the main users, comprising almost 84% of the total demand for that year. Industrial water treatment facilities and the pulp and paper sector accounted for most of the remaining consumption (15.8%).

2.2.2 Sources and releases

Aluminum sulphate minerals such as aluminite and alunite occur naturally in Canada in certain restricted geological environments. Aluminum chloride and aluminum nitrate do not occur naturally in the environment. Aluminum can be released from natural aluminum sulphate minerals; however, since aluminum is a common constituent of rocks, where it occurs dominantly in aluminosilicate minerals (e.g., kaolinite, boehmite, clay, gibbsite, feldspar, etc.), which weather and slowly release aluminum to the surface environment. Aluminum present in surface waters due to man-made applications cannot be distinguished from natural aluminum released during weathering of aluminum-bearing minerals.

While aluminum chloride, aluminum nitrate and aluminum sulphate have many commercial applications in Canada, releases of aluminum to the environment from most commercial applications are expected to be small. However there is potential for release of relatively large amounts of aluminum resulting from the use of aluminum chloride and aluminum sulphate in water treatment plants (industrial water, drinking water or wastewater).

In this application, aluminum will react rapidly, producing sludge, usually in the form of aluminum hydroxide ($Al(OH)_3$). Most sludge produced by municipal wastewater treatment plants (MWWTPs) or industries is sent to landfills or spread on land, with the remainder being composted, held in permanent lagoons, or incinerated prior to landfilling (Germain et al. 2000). Most provinces control DWTP waste flows through their respective systems of permits and/or approvals. Sludge purged from clarifiers or accumulated in sedimentation basins of drinking water treatment plants (DWTPs) cannot be released directly to the aquatic environment in many provinces. It may be sent to sewers, incinerated with wastewater sludge and landfilled, held in permanent lagoons, spread on land or landfilled. Likewise, backwash waters (used to clean filters) cannot be discharged directly into open water bodies in many provinces where these discharges are often subjected to requirements for pretreatment (e.g., diversion to sedimentation ponds) or diversion to MWWTPs. While many provinces do not generally allow direct discharge to surface water of any DWTP effluents containing sludges or backwash waters (e.g., Alberta, Manitoba, Ontario and New Brunswick), some of their existing plants may continue to discharge effluents directly to surface waters. Communication with provincial agencies indicates that these provinces are generally requiring some type of environmental impact assessments of the subject discharges with consideration of alternatives to direct discharge. Some existing large plants in these provinces have recently removed their DWTP direct discharges from surface water (e.g., Britannia DWTP and Lemieux Island DWTP in Ottawa, ON), or are developing plans for alternatives to direct discharge to surface waters (e.g., certain plants in Alberta). In other provinces, direct discharge may be allowed through provincial approvals systems if it is shown that the discharge results in no adverse effects (defined based on varying criteria) on the receiving body of water (e.g., Saskatchewan, Nova Scotia and Newfoundland). It should be noted that some provinces and territories either do not have any coagulant usage for drinking water treatment, or they only use very small amounts and have requirements for DWTP effluent treatment destined for surface water (e.g., Prince Edward Island, Yukon Territory, Northwest Territories and Nunavut Territory) (Environment Canada unpublished 2008a)

While most aluminum is released in particulate form, a certain proportion occurs as the dissolved metal and it is this form that is considered easily absorbed and therefore bioavailable to aquatic organisms. The following section therefore discusses aluminum releases in general, with additional emphasis given to dissolved forms. This approach was necessary because very few studies examine monomeric aluminum levels in the environment or in anthropogenic releases.

2.2.2.1 Natural Sources

Atmospheric deposition of aluminum on land or water is small compared with internal releases by weathering and erosion of rock, soil and sediment (Driscoll et al. 1994). Weathering and erosion of "alum"-containing rocks will release aluminum into soils and streams, in part as Al^{3+} and other dissolved cationic and anionic species, depending on pH and the availability of complexing ions (Garrett 1998). These releases will be small, however, in relation to releases from weathering and erosion of aluminosilicate minerals.

There are no reliable estimates of the quantities of aluminum released to the environment by natural processes on a global scale, most of which comes from natural aluminosilicate minerals. Quantification of total or dissolved aluminum releases in Canada and