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SOURCES AND CHARACTERISTICS OF WASTE — WITH SPECIFIC REFERENCE TO CANADA —

by

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1.0 INTRODUCTION

1.1 The Problem of Waste

The problem of WASTE MANAGEMENT means different things to different individuals. This is especially true in regards to different organizations, professions, governments, regions, and countries. The general perception of *what constitutes waste* or what a *"hazardous"* waste is also differs considerably between the various groups (or countries). The preceding notwithstanding, it is indeed clear that the problem of waste management -- i.e. generation and disposal needs to be properly handled if we are to avoid (1) burying ourselves with the total amounts of wastes generated *(that need to be disposed)*, (2) endangering our health through harmful contact with hazardous and toxic wastes that are improperly stored and disposed, (3) endangering the environment and other living species, (4) contaminating one of our most important resources -- GROUNDWATER.

The dangers posed by present-day methods of handling wastes threaten the very existence of both the environment and living species (humans, animals etc.). "Standard" definitions which serve to identify and separate hazardous and toxic wastes (from presumably non hazardous and toxic wastes), and legislation (guidelines, criteria, etc.) mounted in view of these definitions, have at times contributed to a magnification of the problem of protection of the environment and human health! The differentiation between hazardous solid waste (HSW) and municipal solid waste (MSW), and the implicit perception that HSW is the main source of hazardous and toxic wastes -- as opposed to MSW -- all contribute to the endangerment of the environment and human health.

Various types of industries have literally "sprung up” overnight to handle the problem of waste management -- from transporting the waste, to disposal via incineration, “treatment” prior to landfilling, landfilling, and “remediation”. Other industries have also addressed the 4 R’s -- source reduction of waste, reuse, recycle and recovery. To properly manage the entire spectrum -- to ensure that all safety standards are met -- “government” needs to mount the kinds of legislation needed to protect the environment and human health. To do so, one requires standards, criteria, technology available or best suited, etc. The responsibility of Professional groups is clearly one which must be fulfilled if the “overnight” industries and government groups are to function properly.

The question of *how to handle the total problem of waste management* is not easily answered -- simply because of the many different aspects of the total problem and the various complexities and interdependent activities associated with any one part of the problem. To illustrate the point, we can take the simple problem of WHAT IS A HAZARDOUS WASTE? If we assume that the responsibility for identifying what constitutes a hazardous waste lies with the governmental regulatory body, it then becomes clear that the “body” must answer the first set of questions relating to *irreversible damage to human health and the environment.* Do we separate the problem into acceptable acute and chronic levels of exposure? If so, how do we define them? To begin to answer the first simple sets of questions posed, the “decision making body” needs access to “experts” in the fields of medical and health sciences, natural sciences, statistical sciences, etc. We can continue *ad infinitum* with the further ramifications for consultation and study needed to fully answer the simple question posed. Suffice to say that interactions between the entire spectrum of experts is needed if the complex problem is to be properly addressed.

1.2 CSCE National Task Force

The Canadian Society for Civil Engineering (CSCE) created a National Task Force[1] in 1986. Designed to develop greater awareness of the totality of the problem in such a way as to inform the Profession of the many issues that confront the general Public, it must also alert the Profession as to their individual and collective responsibilities. It was felt that the various sets of expertise resident in the broad discipline of Civil Engineering were indeed the kinds of expertise needed to handle (manage) the complex problem of waste generation and disposal. However, perhaps because of lack of total awareness and understanding of the various issues, the Problem was not being adequately addressed by the Profession.

The difficulties in sensitizing the responsible parties, or subdisciplines, which comprise the overall discipline of Civil Engineering to the many facets of the overall problem, lie not in the complexity of the problem, but primarily in the fact that the "Problem" has not been presented in terms of its many interactive and interdependent parts. Basically, if we are to address the three points articulated in the first paragraph, we must consider the problem of waste disposal in all its aspects -- inasmuch as they all interact to provide the various issues which constitute the overall problem.

To elaborate on the preceding, the various parts consist of: (a) the nature and quantity of waste generated, (b) the manner in which it is handled prior to disposal *(recycle, reuse, recovery, treated, etc.)*, (c) the manner in which it is disposed, (d) assured long-term safe disposal and protection of the environment and human health, (e) monitoring, assessment and evaluation, and (f) criteria, legislation, and enforcement requirements to assure that the environment and human health are protected.

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[1] CSCE National Task Force on Management of Waste Contamination of Groundwater, with R. N. Yong as Task Force Chairman.

What parts of the above concern the subdisciplines of Civil Engineering? All of the above -- to a greater or lesser extent! To permit us to properly handle the problem of waste containment, treatment, and disposal, it is considered prudent that a proper knowledge of WHAT CONSTITUTES THE PROBLEM be obtained, i.e., we need to *"know the nature of the beast that confronts us"*. It follows that sensible solutions will be found if "the nature of the beast" is known!

1.3 The Report

The intent of this Report is to bring to the attention of the engineering profession the many sets of problems and concerns that need attention -- *the kind of attention that can be given by engineers, and in particular, the environmental engineers.* We need to remember that regardless of what one does to the waste material -- industrial or consumer waste -- the final resting place for the waste is in the ground. Thus, proper care must be exercised if we are to avoid problems created by land disposal of waste, especially if we are concerned with environmental and health threatening issues resulting from exposure to the waste or waste leachates. By focusing initially on the sources and characteristics, an attempt at understanding "the nature of the beast" is made.

The material presented herein represents the first part of what may turn out to be a long project on the study of WASTE GENERATION AND DISPOSAL IN CANADA. As a beginning point, this Report looks at Canada from a very broad perspective, without particular attention to any one single industry. At this time, because of the need to provide a starting point, not all industries are examined, and no detailed process control explanations are developed. To do so would be impossible -- given the very wide variety of industries and processes. Those well versed in the art will undoubtedly testify that obtaining *hard* information concerning the sets of numbers, figures, etc. is indeed difficult, and one is generally tested (as to how imaginative one needs to be) to obtain coherent and relevant information. In making this presentation, we make no pretense as to completeness or absolute accuracy. Extrapolation of various pieces of information have at times forced us to "go out on a limb". However, it is felt that some reporting at this time would perhaps permit one to continue to put the proper "flesh" on the problem. The Report attempts to give a general perspective of the nature of the wastes generated from various kinds of industries -- and also from material disposed as Municipal Solid Waste. It is hoped that with this beginning, the Profession can gather momentum to and continue the examination of WHAT NEEDS TO BE DONE.

Much of what is given in the Report, in terms of "numbers" and "Tables" has been gathered from various References and Publications. These have been obtained in the course of study by a TEAM made up by the post-graduate students in the two graduate courses given by Yong on *Waste Impact* and *Waste Sources and Characterization*. It should be noted that whilst the students will be acknowledged individually in the ACKNOWLEDGEMENTS, it is fitting that the collective acknowledgement be given here for their help and input. Furthermore, it is hoped that as more work is performed, the Report will be augmented with other reports covering other types of industries and also........further elaboration of the various pieces of information will be made.

At this time, however, we do believe it appropriate to give a special acknowledgement to Dr. Sudhakar M. Rao, a Research Scientist at the Indian Institute of Science in Bangalore, India. Dr. Rao's contribution to the original draft copy of this report cannot be overstated. His efforts went a long way in guaranteeing the completion of this document.

2.0 WASTE CLASSIFICATION

2.1 Source Categorization

Although, it is obvious that all societies produce large amounts of waste, what constitutes waste is not always clear. In many instances, through recycle and reuse requirements, waste generated by one industry (or source) could constitute a resource material for that same industry or another industry (user). The problem of defining what constitutes waste becomes particularly tricky when one attempts to distinguish among the different kinds of wastes. The different ways of categorizing waste are:

(l) by the medium to which they are released,namely, air, water or land;
(2) according to their physical characteristics - whether they are gaseous, liquid or solid;
(3) type of risk or problem they create - i.e., solid wastes (mainly non - hazardous), hazardous wastes and radioactive waste;
(4) according to their origin, i.e., mine tailings, municipal waste andindustrial waste;

Although the first and second methods of categorization provide ready estimates of wastes generated, they tend to overlook the primary processes that produce the waste. This is a very important factor for reduction of waste at source. Category 3 reflects the regulatory philosophy of governmental waste management programs. With such a mode of statutory control, only the regulated (hazardous and radioactive) wastes are tracked and managed; similar means or types of tracking information on unregulated wastes (primarily contributed by municipal solid waste MSW) are difficult or almost impossible to obtain. In the preliminary studies now being implemented, broad-brush inventories of MSW are being made in some Canadian cities. However, the categories of substances constituting the MSW are very diverse and consequently do not easily lend themselves to convenient classifications.

Monitoring and proper management of unregulated wastes, and in particular MSW, are critical since they contain a whole series of hazardous household products, such as, paints, solvents, drain sludge removers, household cleaners, insecticides, pesticides, batteries, aerosols, etc. These wastes are generally exempt from the stringent regulations enacted for hazardous solid wastes (HSW). In many instances, because of the perceived *small generated quantities*, awareness of the dangers that these substances or discards pose is lacking. However, cumulatively, when disposed of at a municipal landfill, these wastes may be a significant threat to groundwater quality -- they are a definite source of groundwater pollution. With respect to the problem of waste definition, it is considered reasonable to categorize wastes according to their sources of origin. This does not imply waste classification in terms of the hazardous levels represented by the respective wastes. The advantage of this system of division (i.e., categorization) is that it takes into account the processes that create the wastes, whilst permitting identification of areas where waste generation can be minimized or suitably recycled. More importantly, this method of categorization permits one to identify or recognize the requirements for proper and safe management/disposal of the wastes that are not recycled.

The sources and characterization of wastes from the following areas are considered in this Report.

Mining;
Metal Smelting and Refining;
Pulp and Paper;
Petroleum Refining;
Agriculture -- Pesticides and Inorganic Fertilizers;
Household and Municipal Wastes;
Food Processing;
Chemical (Organic); and
Metal Finishing.

2.2 Hazardous Solid Wastes and Toxic Substances

The terms HAZARDOUS and TOXIC most often create confusion insofar as a general and common understanding of what they mean. Unfortunately, there exist~~s~~ many definitions (and classification schemes) for HAZARDOUS WASTES. Indeed, the record shows, for example, that estimates of the amount of hazardous solid wastes (HSW) generated in the OECD (Organization for Economic Cooperation and Development) countries vary from 25 to 1000 kilograms per person per year. The difference factor of 40 times is attributed to the absence of clear definition(s) of what constitutes HSW.

We recognize that there are as many definitions of HSW and toxicity as there are groups of interested professionals (and even non-professionals). It is not the intent of this Report to settle the debate over various finer points of definition. The term HAZARDOUS WASTE used in this report is similar to that in common use[2] and means a solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may --

(A) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or

(B) pose a substantial hazard (present or potential) to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

In Canada, the TRANSPORTATION OF DANGEROUS GOODS ACT (TDGA) is also a very useful source for establishment of the various categories and classes of hazardous "goods". Jurisdictional control over HSW, between the Federal and Provincial governments, render the problem of classification of solid waste somewhat complex, since the added responsibility of ENFORCEMENT needs to accompany control over HSW.

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[2] U.S. Resource Conservation and Recovery Act (RCRA) of 1976, (Public Law 94-580).

It is useful to bear in mind that the term SOLID WASTE does not mean solid only. Section 1004(27) of RCRA 1976 considers a SOLID WASTE to mean "..... *any GARBAGE, REFUSE, SLUDGE from waste water treatment plants, water supply treatment plants or air pollution control facilities, and other discarded material INCLUDING SOLID, LIQUID, SEMI-SOLID, or contained gaseous materials resulting from industrial, commercial, mining and agricultural activities, and from community activities.......*" The general criterion (RCRA 1976) considers a hazardous solid waste as one which "*contains substances which are defined as hazardous, or exhibit characteristics of ignitability, corrosivity, reactivity, or toxicity*". Whilst *toxicity* is included as an assessment criterion in the determination of whether a *waste* is hazardous, the term TOXIC WASTE does not necessarily follow from the criterion. A toxic waste refers to waste material that contains substances that cause death or serious injury to humans and/or animals. Thus, one generally refers to "toxic substances" in classification schemes designed to asses whether a waste material is hazardous.

3.0 MINING WASTES

3.1 General

Mining wastes can be associated with production of metals - aluminum, iron, copper, gold, lead, molybdenum, silver, tungsten, uranium, zinc or non-metals such as coal, asbestos, gypsum, barite, syenite, potash mineral, salt mineral, quartz, lime, sand and gravel and stone. It is estimated that the Canadian Mining industry produces in excess of 500 million tonnes of solid waste - which include metal, uranium, coal and industrial. Waste water associated with the mining and milling operations constitutes an even greater quantity of waste.

The existing policy concerning waste disposal cost disclosure, in the Canadian Mining Industry, is one of non-disclosure. Though unclear, the reasons for this policy, as reported by various company representatives, include: a) inability to separate waste management and operational costs, b) inability to actually cost the waste disposal activities, and c) company politics - which even prevent the transfer of this information from operations to management. Based on an October 1989 MAC (Mining Association of Canada) bulletin it was stated that in the meeting of September 19, 1989, "the members agreed that the proposed survey of member companies' environmental expenditures should be deferred this year in favor of work on an Environmental Code of Practice." The reasons for a deferral are apparent when, according to a source at CANMET in Ottawa, the number of actual mining operations in Canada is not even documented. Therefore, any costs presented in this chapter will have been attained, primarily, from government sources or engineering firms performing environmental work in this industry.

3.2 Wastes of Sulfide Ores

Mining operations generally consist of both underground and surface methods. Underground mines involves relatively little surface disturbance. Surface methods - - i.e., open pit and strip mining, usually require the removal of large quantities of material in addition to the ore body and results in the disturbance of a considerable area of land. Therefore, surface mining generates large quantities of solid waste material. In fact, according to Ripley et al. (1978), open pit mining produces approximately 50 times the solid waste volume as is produced by underground mining.

3.2.1 SOLID WASTES

Solid wastes generated from mining activities include the overburden and waste rock. The overburden consists of the overlying unconsolidated material, i.e., organic layer, sands, silts, clays, gravels, weathered rock, etc. -- which needs no blasting for its removal. Waste rock contains no ore, or ore which is not economically feasible to remove. The geometry and depth of the ore body along with the characteristics of the geologic formation generally dictate the mine design and the quantity of waste produced. The rate of production of waste rock generally increases with increasing ore depth and/or decreasing ore grade. Greater overburden problems are associated with open pit and strip mining methods. Underground methods also contribute to the production of waste rock, but as was previously indicated, not to the same extent.

The milling process, also called benefaction, is the concentration and preparation of the ore for subsequent stages of processing. Ore milling generally removes unwanted ore constituents, alters the physical properties of the ore (i.e., particle size and moisture content) and increases the desired mineral concentration (i.e., ore upgrade). Solid wastes in the milling process consists of the host rock, since the minerals have been removed by various concentration processes. The wastes are known as tailings and there exists three options for tailing disposal; the discharge as a slurry into a specifically designed containment area (tailings ponds), underwater disposal in lakes or coastal waters, or mine backfill.

Although underwater disposal is employed in Canada, it is extremely site specific and "environmentally", extremely difficult to contain or control. Historically, the discharge of tailings into an impoundment area constitutes the most common method of tailings disposal in Canada -- inasmuch as it (i.e., the disposal method) was economically attractive and the "ponds" were easy to operate[3]. However, there are numerous disadvantages associated with tailings ponds. In addition to several operational difficulties, the large surface area (5 - 12 hectares per 1000 tonnes of tailings solids discharged per day) associated with most tailings ponds can pose reclamation problems. Seepage, through impoundment structures, normally requires collection and treatment. Dust problems can also be severe, unless surface stabilization is achieved through the use of vegetation, chemical binders, or rock covers.

Table 1 quantifies the ore mined and rock quarried in Canada during the period 1957-86. In general, there has been a steady production growth since World War II into the 1970's. Annual production has since fluctuated between 200 and 300 million tonnes. The Energy, Mines and Resources (EMR) Canada conducts an annual census of mines, quarries, and sand pits which, among other production information, includes the source of material hoisted or removed, the quantities of waste produced, and the waste disposal destinations. Summaries of the 1986 data are presented in Table 2. It is interesting to note that the waste materials (including tailings) produced are proportionally related to the ore concentration obtained. Therefore, as is observed, the further the ore is processed to complete extraction of the specified minerals, the greater will be the volume of associated waste materials.

Using the production data of ore mined and waste produced, a 10 year projection of accumulated waste is estimated (Table 3). The assumptions made in above calculations include: 1) the 1986 data as average values for the projected decade, 2) a waste density of 3.3 tonnes per cubic meter, and 3) an average waste heap (i.e., rock or tailings) of 20 meters. We note a projected accumulation over the next ten years of solid waste equal to about 3,500 million tonnes!

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[3] It is very important to note that present requirements and regulations concerning waste disposal and environmental protection have rendered this method of tailings disposal more "expensive". The "historic" ponds previously put into service have been found, by and large, to be deficient with respect to to environmental protection requirements.

Table 1: Canada Ore Mined and Rock Quarried in the Mining Industry, 1957–86 (in million tonnes)

Year	Metals	Industrial[1]	Coal	Total
1957	76.4	74.5		150.9
58	71.4	71.2		142.6
59	89.9	82.2		172.1
1960	92.1	88.7		180.8
61	90.1	96.7		186.8
62	103.6	103.8		207.4
63	112.7	120.4		233.1
64	128.0	134.1		262.1
65	151.0	146.5		297.5
66	147.6	171.8		319.4
67	169.1	177.5		346.6
68	186.9	172.7		359.6
69	172.0	178.8		350.8
1970	213.0	179.1		392.1
71	211.5	185.8		397.3
72	206.0	189.7		395.7
73	274.9	162.6		437.4
74	278.7	178.8		457.5
75	264.2	158.7		422.9
76	296.5	167.1		463.6
77	299.5	205.2	33.8	538.5
78	248.1	205.5	36.3	489.9
79[2]	274.8	200.1	39.8	514.6
1980[2]	290.1	193.5	43.9	527.5
81[2]	301.5	172.5	48.2	522.2
82[2]	238.4	121.2	53.0	412.5
83[2]	219.0	137.0	54.8	410.9
84[2]	246.4	167.8	71.2	485.4
1985[2]	245.0	171.9	76.7	493.6
86[2]	256.3	194.2	72.7	523.3

[1] Includes nonmetallic mineral mining and all stone quarried, including stone used to make cement and lime. From 1979 onwards, coverage includes miscellaneous nonmetal mines previously excluded.

[2] Revised.

Note: Components may not add due to rounding.

Source: *Energy Mines and Resources Canada, 1988.*

In comparison, an estimate for the previous 40 years, using the same source of data, EMR census statistics, and identical assumptions, indicates that approximately 6700 million tonnes of ore were mined producing 9000 million tonnes of solid waste. This would suggest an increase of between 35 to 50% in solid waste produced.

It must be noted that not all mine wastes are deposited in tailings or waste heaps. Some are used as mine backfill and in road or yard maintenance or are shipped elsewhere for additional processing or other uses. Table 4 presents the disposition of solid wastes from metal mines in Canada for the year 1981. The amount of waste that ends up as tailings or waste ranges from around 25% to 100%, but overall, about 80% is disposed off in this manner. The quantity of solid waste is very large, but the bulk is usually waste rock. Nevertheless, a number of toxic substances, such as arsenic, cadmium, lead, and mercury, may also be present in sufficient concentrations to be a threat to both human health and the environment.

3.2.2 LIQUID WASTES

The liquid waste of a mining operation is the hydrologic drainage from the mining site, which occurs at the intersection of mine openings with the water table, percolation from waste rock and mill tailings piles, and surface run-offs. The drainage water generally constitutes a contamination problem because of the reducing environments which normally characterize mine sites. The subsequent lowering of the drainage water pH and its continued contact with the rock materials induces the solubility and mobility of heavy metals. This acid mine drainage (AMD) has a significant environmental impact which can persist for hundreds of years following a mine closure. Because of its special relevance to the Canadian mining industry, the AMD problem is discussed separately in a later section.

The chief source of liquid waste in the milling process consists of the waste water decanted from the tailings ponds. The waste liquids are generally highly complex effluents and traditionally contain water and a wide range of inorganic and organic dissolved constituents. Residues of the reagents used for mineral recovery in the froth flotation of ores and found in the aqueous portion of the tailings are shown in Table 5, (Baker and Bhappu, 1974). Most of the organics, i.e., hydrocarbons, alcohols and ethers, that remain in the tailings water evaporate, decompose, or

Table 3: Solid Waste Production

	Average	10 year accumulation			
	(mil. tonne)	(mil. tonne)	(mil. m^3)	(mil. m^2)	(hectare)
Tailings	194	1 900	633	32	3 200
Waste Rock	153	1 500	500	25	2 500
Total solid Waste	347	3 500	1 200	58	5 800

Source: EMR Canada, 1986.

Table 4: Disposition of Solid Wastes from Metal Mines in Canada, 1981

Ecozone		Solid Waste[1]				
		Number of Establishments	Total Quantity Disposed[2] (000s tonnes)	% Mine Backfill	% Transferred to Waste Heap	% Other[3]
1	Tundra Cordillera	1	200-600[4]	15.80	84.20	0
2	Boreal Cordillera	6	33 528	0.02	99.98	0
3	Pacific Maritime	7	51 122	0.26	70.54	29.20
4	Montane Cordillera	21	263 845	0.01	75.24	24.75
5	Boreal Plain	3	2 600-5 300	6.60	93.40	0
6	Taiga Plain	1	12 500-25 000	73.82	26.18	0
7	Prairie	0				
8	Taiga Shield	10	45 149	0.45	99.53	0.02
9	Boreal Shield	67	127 964	9.46	86.34	4.20
10	Hudson Bay Plain	0				
11	Mixed-Wood Plain	0				
12	Atlantic Maritime	8	11 551	5.67	94.01	0.32
13	Southern Arctic	0				
14	Northern Arctic	1	300-700		100.00	0
15	Arctic Cordillera	0				
	Canada	125	548 759-564 759	2.45	81.43	16.12

[1] Solid waste includes rock and fine particles discarded following concentration and recovery of the desired mineral.

[2] Total quantity disposed includes rock waste hoisted or removed from mining and tailings and residues (from own and custom-treated purchased ores.

[3] Other includes tailing and residues and waste rock used for road and yard maintenance, shipped for sale or sold to others.

[4] Ranges are used to meet the confidentiality restrictions of the *Statistics Act*.

Source: EMR Canada, 1986.

biodegrade. However, as is indicated in the sixth (last) column of Table 5, those that do not biodegrade or evaporate, remain and constitute significant toxic substances.

Individually, most of the constituents of the mining process and waste liquids are well characterized as to their toxicity and relative effects on humans and plants (Table 6). Difficulties arise with these liquids because, when mixed, they become complex blends of components that can act synergistically. These "mixtures" are often toxic and can affect lining materials (used in containment ponds or basins) in a variety of ways different from the individual constituents.

Volume estimates of the mine drainage water and mill effluent are difficult to make, inasmuch as attempts to locate published figures have been unsuccessful. In addition, it is noted that any data obtained would be extremely site specific and would have limited use in terms of an industrywide application. However, with the use of material flow charts and information detailing quantities of ore mined, estimates are possible (Table 7). Generally speaking, the water expected from mining and milling operations, relative to the quantity of ore mined, is twice that for surface mines, equal for underground, and about 1.5 times that for the milling process.

In an attempt to estimate the volume of wastewater which will be produced over the next years certain assumptions were made. Firstly, it was assumed that the annual average amount of mined and milled ore for the next 10 years is equal to the 1986 production values and secondly, the wastewater volumes presented in Table 7, calculated from the material flowcharts, are acceptable. Therefore, the total wastewater produced during the next 10 years which will need treatment is about 7100 million tonnes or 7100 million cubic meters. This is approximately twice the quantity of total solid wastes (Table 3) estimated to be accumulated in 10 years.

Table 5: Common Flotation Reagents Used in the Recovery of Minerals from Ores

Reagent type and name	Chemical composition	Amount added	Reagents distribution		Toxic species
			solids	Solution	
<u>Collectors</u>					
Xanthate	ROCSSH	<0.1	Mostly complexed	Minor	CS_2
Thiophosphates	$(RO)_2PSSH$	<0.1	Mostly complexed	Minor	$H_2PO_4^-$, HS^-, H_2S
Fatty acids	RCOOH	0.5 to 2.0	Complexed with minerals and ions	Minor	Biodegradable
Sulfonates and sulfates	RSO_3H RSO_4	0.5 to 2.0	Complexed with minerals and ions	Minor	Biodegradable (except cyclic)
Amines	RNH_2Acetate	0.2 to 2.0	Absorbed on silicates	Minor	Free amine[a]
Fuel oils	Saturated	0.1	Selectively absorbed	minor	Volatile hydrocarbons
<u>Frothers</u>					
Pine oil	Aromatic alcohols	<0.1	Carried over in froth	Appreciable	Volatile, carcinogenic
Dow froth	Higher alcohols	<0.1	Carried over in froth	Appreciable	Volatile, biodegradable
MIBC	Methyl isobutylcarbinol	<0.1	Carried over in froth	Appreciable	Volatile, biodegradable
<u>Conditioners</u>					
Sodium Sulfides	Na_2S, NaHS	1 to 15	Selectively complexed	Major	HS^-, H_2S, SO_4^-
Phosphorous pentasufide	P_2S_5	1 to 4	Selectively complexed	Major	HS^-, H_2S
Sodium cyanide	NaCN	0.005 to 0.1	Mostly complexed	Minor	CN^-
Sodium silicate	Na_2SiO_3	0.2 to 1.0	Mostly complexed	Appreciable	H_4SiO_4
Milk of lime	$Ca(OH)_2$	1 to 4	Mostly complexed	Appreciable	OH^-
Separan	Polyacrylamide	<0.01	Mostly adsorbed	Minor	Biodegradable

[a] Unknown toxicity.

Source: Baker and Bhappu, 1974, p. 77.

Table 6 : Symptoms of Metal Toxicity in Plants

Element	Effect
Aluminum	Stubby roots, leaf scorch, mottling
Boron	Dark foliage; marginal scorch of older leaves at high concentrations; stunted, deformed, shortened internodes; creeping forms; heavy pubescence; increased gall production
Chromium	Yellow leaves with green veins
Cobalt	White dead patches on leaves
Copper	Dead patches on lower leaves from tips; purple stems, chlorotic leaves with green veins, stunted roots, creeping sterile forms in some species
Iron	Stunted tops, thickened roots; cell division disturbed in algae, resulting cells greatly enlarged
Manganese	Chlorotic leaves, stem and petiole lesions, curling and dead areas on leaf margins
Molybdenum	Stunting, yellow-orange colouration
Nickel	White dead patches on leaves, apetalous sterile forms
Uranium	Abnormal number of chromosomes in nuclei; unusually shaped fruit; sterile apetalous forms, stalked leaf rosette
Zinc	Chlorotic leaves with green veins, white dwarfed forms: dead areas on leaf tips: roots stunted

Source: Ripley, Redman and Maxwell, 1978.

Table 7: Wastewater Production (in million tonne)

	Ore Average	Wastewater Average	10 year accumulation
Surface Mining	61	122	1 200
Underground Mining	195	195	2 000
Milling	256	385	3 900

Source: EMR Canada, 1988.

3.2.3 ACID MINE DRAINAGE

Most Canadian base metal, precious metal, and uranium mines contain mineralization, either in the ore or the surrounding waste rock, which is a combination of metal and sulfur. These sulfide minerals (e.g. lead, copper, nickel, zinc, iron, and silver) are unstable and oxidize when exposed to oxygen and water at the surface. The reaction yields sulfuric acid which increases the solubility of heavy metals and promotes their mobility. Initially the reaction rates are relatively moderate. However, as the reaction proceeds the temperature and acidity increase, resulting in an increased reaction rate. At pH levels of 2 to 4, reactions and reaction rates can increase two to three orders of magnitude (Table 8) due to bacterial catalysts.

Acid mine drainage is not only encountered in metal mining,it is a serious problem in coal mining activities as well. Coal seams in the Maritime region (found mainly in Nova Scotia and New Brunswick) contain pyrite, as does the enclosing rock strata. The tailings generated by coal processing and purification contain up to 6% pyrite (FeS_2). Disposal is on land, in ditches, in tailings ponds, and sometimes backfilled where the original excavation was done. Upon exposure to atmosphere, the pyrite component of the coal tailings undergoes geochemical oxidation releasing sulfuric acid, ferrous, ferric and hydrogen ions (Paines, 1987). Water seeping through ponds and ditches containing pyritic coal tailing dumps can show pH values as low as 2.0 (Table 9).

In general, coal found in Western Canada (British Columbia, Alberta, and Saskatchewan) contains less pyrite Maritime coal. Furthermore, because of the presence of limestone, found in the rock strata surrounding the coal, the geochemical action of pyrite is neutralized. This effectively eliminates the problem of AMD.

Table 8: Mine Drainage Class

Parameter	class I Acid Discharge	Class II Partially Oxidized and/or Neutralized	Class III Oxidized and Neutralized and/or Alkaline	Class IV Neutralized and Not Oxidized
pH	2 – 4.5	3.5 6.6	6.5 – 8.5	6.5 – 8.5
Acidity mg/L ($CaCO_3$)	1 000 – 15 000	0 –1 000	0	0
Fe^{2+} mg/L	500 – 10 000	0 – 500	0	50 – 1 000
Fe^{3+} mg/L	0	0 – 1 000	0	0
Al mg/L	0 – 2 000	0 – 20	0	0
SO_4 mg/L	1 000 – 20 000	500 – 10 000	500 – 10 000	500 – 10 000

Source: Proceedings, Acid Mine Drainage Workshop, 1987.

Table 9: Ranges of Component Concentration in Appalachian Mine Drainage

Major Components:	Suggested Ranges (mg/L)
Hydrogen ions	
pH	1.4 – 7.0
acidity, as $CaCO_3$	0 – 45 000
alkalinity, as $CaCO_3$	1 – 400
Soluble iron — total	1 – 10 000
Fe^{2+}	1 – 10 000
Fe^{3+}	1 – 10 000
Sulfate	1 – 20 000
Aluminum	1 – 2 000
Calcium	1 – 500
Magnesium	1 – 200
Total dissolved solids	5 – 10 000
Suspended solids ferric oxyhydroxides, clays, silica and organics as: coal fines, sewage particles, plant components as algae.	to – 3 000
Minor Components;	
Sodium	to 100
Potassium	to 50
Silica	to 100
Chloride	to 200
Trace Components:	
Mn	to 50
Ni	to 5
V	to 2
Zn	to 10
Sr, Ba, Ti	to 5
Cd, Be, Cu, Ag, Co, Pb, Cr	1
Hg	0.05

Source: Proceedings, Acid Mine Drainage Workshop, 1987.

The long term economic and environmental effects of the Canadian acid generating waste sites are unknown. This is due to the fact that there has never been a comprehensive site survey completed in Canada. British Columbia, Saskatchewan, Manitoba, Ontario, Quebec, the Yukon and Northwest Territories all bave existing and abandoned acid generating mine sites. A recent Ontario survey identified 100 abandoned mine sites, of which 20 pose an acid mine problem. In Quebec, about 67 abandoned mine sites exist, 21 of which have been classified as hazardous due to an acid mine drainage problem.

Recently, CANMET and the industry co-sponsored two projects to define the extent of acid generating mine sites in Canada. A minimum of 15,000 hectares (i.e., 37,000 acres) of acid generating mine waste and tailings were identified, most at operating mines (Tables 10, 11). These wastes are largely the accumulation of forty years of non-ferrous base metal mining since World War II. It appears that the mining of low grade ores, coupled with an increasing mineral production, could lead to the accumulation of an equal quantity of acidic tailings over the next twenty years.

Utilizing the census data (unpublished), waste disposal information has been assembled detailing the quantities and destinations of tailings and rock waste produced (Table 12). The data indicate that 94% of the total solid waste produced is transferred to on site waste heaps - that is, 346 million tonnes of tailings and waste rock piles.

Table 10: Some Major Sulphide Tailings Deposits

Mine Name/Location	Mine Status	Sulphide Tailings Disposal
New Brunswick		
Brunswick Mining	In operation since 1964, expected to operate at least to 2005	607 ha tailings disposal area, dams are constructed of tailings, some revegetation trails, massive sulphide tailings, highly acid generating
Heath Steele Mines	In operation 1955–1958 and 1962 to 1983, closed, future uncertain	202 ha tailings disposal area, borrow material dam, some revegetation trails, massive sulphide tailings
Quebec		
Campbell Resources Ltd. Cedar Bay & Henderson Mines	In operation 1955	138 ha tailings disposal area, revegetation is being attempted
East Malarctic Mines	In operation 1938 to 1979	170 ha tailings disposal area has been revegetated
Falconbridge Cooper	In operation 1964	77 ha tailings disposal area containing massive sulphides, revegetation test plots have been established
Falconbridge Cooper	In operation 1954	153 ha tailings disposal area formed by draining of lake
Noranda Murdochville	In operation since 1952	316 ha tailings disposal area
Lamaque Mines	In operation from 1935 to 1985	280 ha tailings disposal area, revegetation test plots
Matagami	In operation since 1963	200 ha tailings disposal area in drained lake, large scale revegetation tests, massive sulphide tailings
Sigma Mines	In operation since 1957	126 ha tailings disposal area, some areas have been revegetated
Ontario		
Mattabi Mines, Sturgeon Lake	In operation since 1972	160 ha tailings disposal area
Geco Division, Noranda	In operation since 1957	130 ha tailings disposal area
Kidd Creek Mines	In operation since 1966	1200 ha tailings disposal area, use cone discharge disposal method
Sudbury District Mines of Inco	In operation since 1930s	2400 ha tailings disposal area, extensive areas of revegetation
Sudbury Area operation of Falconbridge Ltd.	In operation since 1930s	70 ha tailings disposal area, extensive areas of revegetation

Table 10: (cont'd)

Manitoba		
Fox Mine - Sherritt Gordon	In operation 1970 to 1983	Tailings will be flooded to stabilize
Lynn Lake - Sherritt Gordon	In operation 1953 to 1976	125 ha tailings disposal area containing massive sulphides
Ruttan Mine - Sherritt Gordon	In operation since 1973	Tailings discharged into Ruttan Lake
Thompson Mine - Inco	In operation since 1960	1800 ha tailings disposal area containing massive sulphides
Stall Lake - HBMS	In operation since 1964	Tailings discharged into Anderson Lake (365 ha)
Anderson Lake Mine - HBMS	In operation since 1970	Tailings discharged into Anderson Lake (365 ha)
Flin Flon Mine - HBMS	In operation since 1970	230 ha tailings disposal area
British Columbia		
Sam Goosly	In operation since 1979	230 ha tailings disposal area, revegetation test plots have been established
Westmin Resources	In operation since 1975	Tailings discharged into Buttle Lake, tailings contain massive pyrite
Gibraltar Mines	In operation since 1972	533 ha tailings disposal area, small area has been reclaimed
Sullivan Mine - Cominco	In operation since 1910	370 ha tailings disposal area, very extensive revegetation research
Yukon, NWT		
Anvil Mine	In operation since 1969	23 ha tailings disposal area containing massive sulphides

Source: Intergovernmental Working Group on the Mineral Industry, 1988.

Table 11: Known Reactive Waste Rock at Base Metal Mines in Canada

Province/Property	Material Mined	UG or OP	Currently Active ?	Tonnage of Reactive Waste Rock	Comments
British Columbia					
Gibraltar	Cu	OP	Yes	91 $\times 10^6$	Concern over bioleaching of waste piles.
Equity Silver	Cu, Ag Au	OP	Yes	70 $\times 10^6$	Waste pile temperatures of 55 ^{0}C recorded
Westmin	Cu, Zn	OP & UG	Yes	8 $\times 10^6$	Several different AWR management strategies considered.
Noranda Bell	Cu	OP	Yes	60 $\times 10^6$	Operation well close in 2 - 3 years.
Sullivan	Zn, Pb	UG	Yes	Minor	Tailings primary issue.
Brittania	Cu	UG & GH	No	Minor	AMD primary concern.
Anyoz	Cu	UG	No	See next column	No waste piles but AWR in rail bed.
Mount Washington	Cu	OP	No	0.4 $\times 10^6$	Cover & other measures being considered.
Tuisequah	Cu, Pb, Zn, Au	UG	No	Minor	AMD primary concern.
Alberta					
No base metal mines					
Saskatchewan					
No base metal mines					
Manitoba					
Flin Flon	Cu, Zn	OP & UG	Yes	See next column	No current evidence of acid generation.
Ruttan	Cu, Zn	OP & UG	Yes	Not known	Acid but drains into tailing pond.
Dickson	Cu, Zn	UG	No	Minor	
Pipe	Ni	OP & UG	Yes	See next column	WR appears to be acid consuming.
Thompson	Ni	OP	Yes	See nest column	WR appears to be acid consuming.
Maskawa	Ni, Cu	OP	No	See next column	Thought to be little sulphide in WR.
Dun Barton	Ni, Cu	UG	No	Minor	Thought to be little sulphide in WR.
Manibridge	Ni, Cu	UG	No	Minor	Thought to be little sulphide in WR.
Don-jon	Cu, Zn	UG	No	Minor	Acid but only small volume.
Ontario					
Kidd Creek	Ni, Cu	OP & UG	Yes	Not known	WR is low grade ore, being milled.

Murrey-Clarabeile	Ni, Cu	UG	Yes	12×10^6	Many AWR piles, leachate collected and treated.
Creighton	Ni, Cu	OP & UG	Yes	Not Known	Many AWR piles, leachate collected and treated.
Garson	Ni, Cu	UG	Yes	1×10^6	Tailings primary issue.
Levack	Ni, Cu	UG	Yes	1×10^6	Development rock used for constn.
Strathcona Creek	Ni, Cu	UG	Yes	10×10^6	Widely dispersed. Used for constn.
Fraser	Ni, Cu	UG	Yes	3×10^6	12 ha wastepile & mine yard.
Fecunis	Ni, Cu	UG	Yes	See next column	Tonnage included in Strathcona area.
Onaping-Craig	Ni, Cu	UG	Yes	0.7×10^6	AWR used in roads, etc.
Sherman	Fe	OP	Yes	1.9×10^6	AWR very reactive.
Mattabi	Cu, Zn, Pb, Ag	OP & UG	Yes	$+1.7 \times 10^6$	Overburden, gossan, & waste coffer piles(3).
Lyon Lake	Cu, Zn, Pb, Ag	UG	Yes	Minor	AMD primary concern.
F Group	Cu, Zn, Ag	OP	No	Minor	Leachate treated in open pit.
Geco	Cu, Zn, Ag	OP & UG	Yes	Not known	AWR used extensively for constn.
Kam Kotia	Cu, Zn	OP & UG	No	0.2×10^6	Tailings primary concern. Controlled by Crown.
Other	Varies	Varies	No	Not known	Estimated approximately 200 abandoned sites in province, many with associated AWR problems.
Quebec					
Gaspe	Cu	OP & UG	Yes	Minor	AWR is actually leach opn. residue.
Weedon	Cu, Zn	OP	No	Not known	AWR used extensively for constn.
Soidec Cupra	Cu, Zn	UG	No	30 000	Sulphide waste pile covered in 1979.
Doyon	Au	OP	Yes	Ref. note a	Took several years to go acid.
East Sullivan	Zn, Pb, Cu, Au	OP & UG	No	Not known	120 acres mined tailings & AWR.
Manitou-Barvue	Zn, Pb, Cu, Au	OP & UG	Yes (mill only)	Not known	AWR used extensively for constn.
Poirier	Cu, Zn	UG	No	Not known	AWR used extensively for constn.
Lac Watson	Cu, Zn, Ag	UG	Yes	Not known	Tailings primary concern.
Normetal	Cu, Zn, Ag, Au	UG	Yes	Not known	Tailings primary concern.
New Brunswick					
Brunswick No. 6	Pb, Zn, Cu	OP	No*	$+3 \times 10^6$	Four AWR piles, reclamation in progress.
Heath Steele	Pb, Zn, Cu	OP & UG	No*	-1×10^6	20+ AWR piles.
Caribou, NB	Pb, Zn, Cu	OP & UG	No*	Not known	Majority of AWR moved to pit.
Key Anacon	Pb, Zn	UG	No	Not known	Small AWR pile.

Wedge	Cu	UG	No	N/A	Site reclaimed.
Northumberland	Pb, Zn, Au, Ag	OP	Proposed	N/A	Removal of gossan and leaching proposed.
Nova Scotia					
No base metal mines with AWR					
Prince Edward Island					
No base metal mines					
Newfoundland and Labrador					
Rambler	Cu	UG	No	Minor	AWR not considered as issue.
Buchans	Cu, Pb, Zn	UG & GH	No	Minor	AWR not considered as issue.
Whales Back	Cu	UG	No	Minor	AWR not considered as issue.
Gullbridge	Cu	UG	No	Minor	AWR not considered as issue.
Yukon					
Curragh Resources	Pb, Zn	OP	Yes	10×10^6	[b]Focus primarily on tailings to date.
United Keno Hill	Ag, Pb, Zn	UG	Yes	Minor	AMD primary concern.
Northwest Territories					
Narusivik	Pb, Zn	UG	Yes	Not known	Acid development rock on site.

AWR: Acid Waste Rock; WR: Waste Rock; OP: Open Pit Mine; UG: Underground Mine; GH: Glory Hole.

[*] Acid drainage treatment maintained.

[a] Total volume approx. 30×10^6 tonnes but not included in inventory total due to not being a base metal property.

[b] Total volume of WR is 200×10^6 tonnes but only 5% is acid producing.

Source: Intergovernmental Working Group on the Mineral Industry, 1988.

Table 12: Disposal of Solid Waste from Sulphide Ore Mine, 1981

Disposal of Tailings and Residues	Nickel Copper Zinc	Iron	Gold	Silver Lead Zinc	Misl. Metals	Uranium	Total
Used for mine backfill (underground)	5 103	–	1 227	11	48	165	6 554
Used for roads and yard maintenance	240	–	–	–	10	–	250
Transferred to waste heap	108 022	53 107	10 275	10 493	5 171	6 893	193 961
Shipped for sale (residue)	4 407	–	426	–	–	–	4 833
Other	1 425	–	988	–	37	–	2 450
Total	119 197	53 107	12 917	10 504	5 266	7 058	208 049
Rock waste disposal							
Used for underground mine backfill							
– from underground development, not hoisted	1 004	–	485	513	23	129	2 154
– from other waste rock, hoisted or open pit	2 246	–	504	277	41	–	3 068
Used for maintenance of roads and yard	1 653	403	905	97	941	78	4 077
Transferred to waste heap	101 333	23 219	7 678	12 708	2 450	6 115	153 003
Shipped for sale (residue)	–	–	41	–	–	–	41
Total	106 236	23 622	7 613	13 095	3 455	6 322	162 343
Total solid waste produced							
Rock waste and tailings piles	209 355	76 326	17 703	22 701	7 621	13 008	346 914
Reused	16 078	403	4 627	898	1 100	372	23 478
Total	225 433	76 729	22 530	23 599	8 721	13 380	370 392

Source: Annual census of mines, quarries, and sand pits. Energy, Mines, and Resources, 1986.
Note: Quantities are expressed as kilotonnes.

3.3 Tailings Disposal Costs

As was mentioned previously, actual tailings disposal costs, as reported by individual mining operations, were not made available. However, support industry personnel, i.e., design engineers, were somewhat more cooperative. The following figures, which represent actual capital costs, are presented to help the reader appreciate the investments which are required to deal with the tailings problem. It must be understood that they are site specific and should not be applied liberally across the industry. However, it is reasonable to assume, for operations of similar size, that the costs will be in the same order of magnitude.

The following costs represent the capital expenditures made by a Canadian gold mining operation for the design and construction of a tailings disposal system. The figures were originally in 1983 dollars, but have been compounded (5% inflation rate assumed) to represent 1990 costs. Daily ore extraction is approximately 2,000 tonnes per day or 730,000 tonnes per year.

Cut	$ 26,578
Topography	$ 24,111
Water Analysis	$ 9,870
Pits, Excavation	$ 3,807
Rental of Equipment	$ 1,692
Surveying	$ 53,157
Preliminary Study	$ 18,894
Culverts	$ 12,549
Design of Pond	$ 490,680
Foundation	$ 8,460
Pipelines	$ 282,000
Access Roads	$ 662,700
Clearing	$ 231,240
Material	$ 201,489
Additional Roads	$ 469,530
Total	$ 2,496,757

As is evident, proper tailings disposal has become a serious investment. Unfortunately, this initial cash outlay, which is most likely amortized over a twenty year period, does not cover the system operational costs. A sample of what should be expected is as follows: 1) Wastewater Treatment - chemical costs normally range between $0.5 and $2.0 million yearly, but in some instances they have been as high as $10 million., 2) Supervision - this usually requires two people at a cost of $50,000 to $75,000 each annually (includes benefits, pensions, insurance, etc.)., 3) Maintenance - one person at an annual cost of about $75,000., 4) Energy/Power - considered a major cost although actual figures are not available., and 5) Environmental Monitoring - testing costs at least $10,000 per year. These costs represent a cross-section of the more obvious operational expenditures and they do not take into consideration those which are site specific or problem related.

3.4 Non-Metal and Structural Mining Wastes -- Particulate Emissions

Particulate emissions are primarily associated with the non-metal mining industry segment and they include; asbestos, clay, sand and gravel, stone, potash and other salts, lime, and gypsum. These mining activities are primarily dominated by open pit operations. The physical action of excavation promotes large quantities of rock 'flour' or dust. Particulates have the ability to accumulate in the lung tissue and can eventually contribute to the destruction of this tissue. Furthermore, long term inhalation of asbestos fibers has been shown to be carcinogenic. It is estimated that two-thirds of the particulate emissions from non-metal mining come from the stone and sand and gravel industries. The following examples demonstrate some of the specific cases.

3.4.1 SAND AND GRAVEL

Sand and gravel, in terms of total production (tonnes), are the most important of the industrial minerals. Most sand and gravel pits are located near large urban areas. This is due primarily to the industry dependence upon the demands of the construction industry. About 90% of particulate emissions occur during stockpiling and handling. According to Ripley et al., (1978), particulate emissions from sand and gravel quarries are about 0.016 tonne/tonne.

3.4.2 STONE

Stone is a structural material that is subjected to physical alteration, but not chemical. Therefore, particulate emissions are the primary environmental concerns when quarrying. Table 13 presents the expected particulate emissions from stone processing and handling. Limestone, granite, sandstone, and marble are the most common "stone" materials used in the construction, iron and steel, and chemical industries.

3.4.3 LIME

Lime, normally referred to as *quicklime*, is produced by calcining or burning limestone. in general, the emissions resulting from the quarrying, handling, or crushing of raw limestones are similar to those associated with stone and sand and gravel production. Ontario and Quebec produce most of Canada's total output. In estimating the amount of particular emission an average of 0.085 tonne/tonne is assumed (Ripley et al., 1978).

3.4.4 GYPSUM

About two-thirds of Canada's gypsum production comes from Nova Scotia. Gypsum is used in the cement, paint, paper, and wallboard industries. Like all other industrial mining operatis, particulate emissions are a problem. These emissions originate in the quarrying, handling, crushing, screening, and calcining operations. Particulate emissions are estimated to be, on average, 0.065 tonne/tonne (Ripley et al., 1978).

3.4.5 ASBESTOS

The term asbestos refers to a number of different types of fibrous mineral silicates that are incombustible and mechanically separable into filaments. Chrysotile is the most widely mined type. Quebec produces 85% of Canada's asbestos, the remainder

Table 13: Particulate Emissions (Without Controls) from Processing and Handling of Stone (Kg per Tonne of Material Handled)

Operation	Local Emissions if Uncontrolled	Remaining after Local Settling Out
Primary crushing	0.25	0.05
Secondary crushing and screening	0.75	0.30
Tertiary crushing and screening	3.0	1.8
Recrushing and screening	2.5	1.25
Fine mill	3.0	2.25
Conveying and handling	1.0	–
Storage pile loses	5.0	–

Source: Ripley et al. 1978.

comes from British Columbia, the Yukon, and Newfoundland. Particulate emissions are assumed to be 0.02 tonne/tonne (Ripley et al., 1978).

3.4.6 POTASH AND OTHER SALTS

During the processing of potash and other salts, chlorides of potassium and sodium are released into the atmosphere. The composition of potash dust usually consists of 2/3 HCL and 1/3 NaCl. Particulate emissions for potash and salt are assumed to be 0.0044 tonne/tonne (Ripley et al., 1978). Most of the potash operations in Canada are located in Saskatchewan.

4.0 METAL SMELTING AND REFINING WASTES

4.1 Wastes From the Iron and Steel Industry

In Canada, iron ore removal represents the major metal mining activity in the country. The primary use of the ore is in steel fabrication. Basically, the pig iron is extracted from the ore and then sent to a smelter in order to produce steel. Steel production methods include; open hearth, basic oxygen furnace, blast furnace, and electric furnace. Steel finishing involves a number of processes that impart desirable surface and mechanical characteristics to the steel.

In the standard process, at least 6 steps are required for production of the finished product. Each process step is responsible for the generation of a waste material. The composition and nature (physical state) of the waste govern disposal methodology. The principal steps in the standard process include:

STEP 1 -- Iron production in the blast furnace from a combination of iron ore, coke, and limestone. Output is pig iron.

Flue dust and slag are generated as waste material during this operation.

STEP 2 -- Production of steel from pig iron and specified amounts of carbon in the open hearth furnace (or equivalent furnace as noted above). Output is steel ingots.

As in Step 1, flue dust and slag are generated in this operation.

STEP 3 -- Rolling mill operations wherein the steel ingots are subject to chipping, grinding and scarifying.

Scale bearing wastes are generated during this process.

STEP 4 -- Pickling process in which surface oxides are removed from the steel ingots. Acid pickling solutions consist of H_2SO_4, HCl, or combinations of the two.

Pickle acid wastes generated

STEP 5 -- Finishing operations using "finishing" oils.

Contaminated "finishing" oils are generated as waste products.

STEP 6 -- Cleaning and rinsing operations using alkaline detergents.

Contaminated alkaline solutions are generated as waste products .

4.2 Waste Characteristics

4.2.1 GAS-WASHER WATER

The flue dust generated from the furnaces in Steps 1 and 2 is trapped in "wet" dust collectors or cleaners. The water leaving the wet dust cleaners usually contains between 1000-10,000 mg/l of suspended solids. This depends upon the furnace burden, furnace size, operating methods employed, and type of gas washing equipment. When fine ore and high blast rates are used, the highest concentration of suspended solids is obtained.

Plain gravity sedimentation in either circular or rectangular basins is the preferred method of gas-washer water treatment. Older installations typically have two 4m by 35m rectangular sedimentation basins handling a flow of 3.5 mgd from a 880 ton/day blast furnace. The effluent concentration typically averages about 250 mg/l suspended solids.

The dredged sludge is generally sent to a sintering plant. Today's modern installations may consist of a 75 foot diameter clarifier, with a 6.9 mgd capacity from a 1200 ton/day ballast furnace. The effluent suspended solids concentration is about 80 mg/l.

Tables 14 and 15 provide the chemical analysis and physical properties of the blast furnace fine dust. The dust and sludges contain trace elements such as Zn, Pb, S, P, Na, and K that are both undesirable and difficult to remove. The finer materials (i.e., wet collected dusts) are often difficult to contain in normal operations. Airborne particulates from the handling of these products can be a serious environmental problem. Furthermore, the oil present in some of these wastes can vaporize and lead to pollution control equipment operating difficulties.

Table 14: Blast Furnace Flue Dust and Steelmaking Dust

Chemical analysis of blast furnace flue dusts (%)

	Dry collected		Wet-collected	
	Older Furnace	No. 7 BOF	Older Furnace	No. 7 BOF
Fe	30.6	13.9	25.6	21.6
Fe^{++}	12.8	1.6	5.5	ND
C	31.3	55.8	42.3	49.3
Si	3.0	2.3	3.0	2.8
Al	0.9	0.7	1.1	1.3
Ca	5.1	4.2	3.6	1.7
Mg	1.2	1.0	1.1	0.5
Mn	0.6	ND	0.3	ND
Cr	<0.1	ND	ND	ND
S	0.5	0.6	0.4	ND
Zn	0.1	0.1	0.4	1.2
Pb	0.1	ND	0.1	ND
Na	0.1	0.2	0.1	MD
K	0.3	0.1	0.2	ND
P	0.1	<0.1	0.1	ND

ND = Not Determined.

Source: Gurman, 1965.

Table 15: Blast Furnace Flue Dust and Steelmaking Dust

Physical Properties of Dry Collected Blast Furnace Flue Dust from the Older Blast Furnace

Bulk Density (Kg/m^3) = 980
Theoretical Density (Kg/m^3) = 2 700

Size (mm)	2.38	1.68	1.19	0.84	0.59	0.42	0.297	0.21
% Retained	3.4	1.6	2.1	3.6	7.7	19.4	12.4	19.6

Size (mm)	0.149	0.074	0.047	0.036	0.026	0.018	0.014	-0.014
% Retained	16.5	0.2	7.3	1.9	1.2	0.9	0.9	1.3

Comment: Size distribution for No. 7 Blast Furnace is comparable.
Source: Gumham, 1965.

4.2.2 SCALE BEARING WASTES

Scale bearing wastes originate from the various rolling mill operations (Step 3). Usually, the total iron loss from scales averages about 2.5%. Approximately one third of the waste oxide material consists of mill scale. These scales are collected in pits and the coarser fragments are fed into the blast furnace. The finer materials are sent to a sinter plant. Tables 16 and 17 show the chemical and physical characteristics of mill scale.

4.2.3 PICKLING SOLUTIONS

Pickling solutions constitute one of the most environmentally hazardous by-products of steel production. Sulfuric acid represents about 90% of the acid used in pickling steel. Pickling solutions contain free acids, ferrous sulfate, undissolved scale and dust, various inhibitors and wetting agents, as well as dissolved trace elements. Spent sulfate pickling solutions are discharged at temperatures of from 70 deg. C to 68 deg. C (possible source of temperature pollution) and can amount from 400 - 4000 liters/day in a large mill. The acid used and its concentration are largely dependent upon the type of iron being produced.

4.2.4 OIL BEARING WATER

The effluents from the finishing operation (Step 5) contain rolling oils, lubricants, and hydraulic oils. The oils are both in the free and emulsified states and are generally identified as oil bearing water(s). Soluble oils, which may also be present in the effluents, are associated with the cold reduction mills, electrolytic tin lines, and a variety of machine shop operations. The effluent from a typical mill will contain about 200 mg of oil/liter, of which 25% is a stable emulsion.

The oil bearing waters represent an environmental problem when discharged to receiving waters. For example, emulsified oil can contribute to BOD and free oil is objectionable due to its contribution to the formation of widespread surface films.

Table 16: Chemical analysis of mill scale (%)

	Mill Scale (%)	Soaking Pit Rubble (%)	Swarf (%)
Fe	73.7	57.0	93.2
Fe (Met)	1.2	0.4	64.9
Fe^{++}	48.5	10.5	23.2
Fe^{+++}	22.1	ND	5.8
Al	0.7	1.0	ND
Si	0.4	0.9	0.1
Ca	1.4	2.4	ND
Mg	0.1	3.4	ND
Mn	0.5	0.6	1.0
P	<0.1	<0.1	ND
S	<0.1	ND	0.2
Na	<0.1	<0.1	ND
K	<0.1	<0.1	ND
Oil	0.5	ND	<0.1
C	ND	ND	2.9

ND = Not Determined.

Source: Gurman, 1965.

Table 17: Physical Characteristics of Fine Mill Scale

Bulk Density (Kg/m^3) = 2 130
Theoretical Density (Kg/m^3) = 4 300
% Magnetic Material = 48.0

Size (mm)	2.38	1.41	1.00	0.59	0.297	0.210	0.149	0.074	0.044	-0.044
% Retained	7.8	8.4	11.8	4.6	36.2	14.2	9.2	1.5	5.8	0.5

Source: Gumham, 1965.

Production of iron and steel generates significant amounts of wastes that can be broadly categorized under:

(a) iron oxide containing wastes from fine dust, slag, etc.,
(b) acid wastes, and
(c) oil containing wastes.

The iron and steel industry is attempting to reduce the amount of wastes by adopting more efficient processes and mill recycling programs. Unfortunately, there is a great volume of waste that cannot be recycled and must be disposed of properly (i.e., spent pickling solution). The possibility of other industries using such wastes in their processes should be explored (waste exchange).

4.3 Wastes Of Non-Ferrous Metals: Smelting And Refining

Non ferrous metals commonly include copper, zinc, lead, and nickel. Copper and zinc production in Canada is five fold that of nickel and lead. Consequently, wastes associated with the smelting and refining of non-ferrous metals are largely produced at copper and zinc facilities.

4.3.1 COPPER

The details of the copper mines and industries in Canada are shown in Tables 18 and 19. Copper smelting and refining processes generate smelter wastes. Metal contents of wastes from copper smelters in the United States are listed in Table 20. The higher copper concentrations at the plants sampled were found in solids from the acid plant blowdown thickener (up to 380,000 mg/kg) and in the electrostatic precipitator (ESP) dust (240,000 to 280,000 mg/kg). The data also shows that the lead and zinc concentrations in the acid plant sludge and the ESP dust can also be high (>10,000 mg/kg).

Table 18: Canadian Copper and Copper-Nickel Smelters.
Source: Statistics Canada, Canada's Mineral Production Catalogue 26-202.

Company and Location	Product	Rated Annual capacity, tonnes of ores & concentrates	Blister or Anode Copper Produced in 1985[1], tonnes	Remarks
Falconbridge Ltd. Falconbridge, Ont.	Cooper nickel matte	570 000	26 800	A smelter modernization program begun in 1975 was completed in 1978 at a cost of $79 million. Fluid bed roasters and electric furnaces replaced older smelting equipment. A 1 800 tpd sulphuric acid plant treats roaster gasses. Matte from the smelter is refined in Norway.
Inco Ltd. Sudbury, Ont.	Molten "blister" copper, nickel sulphide and nickel sinter for the company's refineries; nickel oxide sinter for market, soluble nickel oxide for market	3 630 000[2]	119 800*[3]	Oxygen flash-smelting of copper concentrate: converters for production of blister copper. Roasters, reverperatory furnaces for smelting of nickel-copper concentrate, converters for production of nickel-copper Bessemer matte. Production of matte followed by matte treatment, floatation, separation of copper and nickel sulphides, then by sintering to make sintered-nickel products for refining and marketing. Electric furnace melting of copper sulphide and conversion to blister copper.
Falconbridge Ltd. Timmins, Ont.	Molten "blister" copper	under expansion	70 000*	Mitsubishi-type smelting, separation and converting furnaces, acid plant and oxygen plant to treat continuous copper concentrate feed stream to yield molten 99 per cent pure copper which is transported by ladles and overhead cranes to two 350 t anode furnaces in 1984 was essentially completed by end of 1986.
Noranda Inc. Horne smelter, Noranda, Que.	Copper anodes	838 000	186 000	One oxy-fuel fixed reverperatory furnace; five converters; 1 continuous Noranda Process reactor; oxygen for the reverperatory furnace and Noranda are supplied by two plants with a combined total of 540 tpd. Continuous reactor modified to produce matte instead of metal.
Noranda Inc. Gaspé, Que.	Copper anodes	325 000	43 500	Equipped with one fluid bed roaster, one reverperatory furnace and two converters plus an acid plant. Treats Gaspé and custom concentrates.
Hudson Bay Mining & Smelting Co., Ltd. Flin Flon, Man.	Copper anodes	400 000	66 000	Five roasting furnaces, one reverperatory furnace and three converters. Company treats its own copper concentrate from mines at Flin Flon and Snow Lake, as well as custom copper concentrates, zinc plant residues and stockpiled zinc-plant residues fed to reverperatory furnace.

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[1] Smelter output as reported in corporate annual reported: if no smelter data available, then refinery output shown and indicated by * following number.
[2] Includes copper and nickel-copper concentrates. This capacity cannot be fully utilized owing to Ontario government sulphur dioxide mission regulations.
[3] Includes a small tonnage of copper from Inco's Manitoba operations.

Table 19: Copper Refineries in Canada.
Source: Statistics Canada, Canada's Mineral Production Catalogue 26-202.

Company and Location	Rated Annual capacity, tonnes	Output in 1985[1], tonnes	Remarks
Noranda Inc. Division CCR East Montreal, Quebec	435 000	304 800	Refines anodes from Noranda's Horne and Gaspé smelters, from the Flin Flon smelter and also from purchased scrap. Copper sulphate and nickel sulphate recovered by vacuum evaporation. Previous metals, selenium and tellurium recovered from slimes. Produces CCR brand electrolytic 6opper cathodes and cakes and billets. $19 million program to construct new slimes treatment plant announced in 1986 to be completed by mid-1988.
Inco Ltd. Copper Cliff. Ont.	180 000	119 800	Casts and refines anodes from molten converter copper from the Copper Cliff smelter; also refines purchased scrap. Gold, silver, selenium and tellurium recovered from anode slimes, along with platinum metals concentrates. Recovers and electro-wins copper from Copper Cliff nickel refinery residue. Produces ORC brand electrolytic copper cathodes, and wirebars. Modernization program began in 1986.
Falconbridge Ltd. Timmins, Ont.	(See note)	70 000	Molten copper from two 350 t anode furnaces is cast in a Hazelett continuous casting machine into continuous copper strip, then formed to 145 kg anodes in a blanking press. Spent and scrap anodes are remelted in a 40 t ASARCO shaft furnace. Cathodes formed in jumbo sized electrolytic tanks in a highly automated tankhouse. A decopperized precious metal slime is also marketed. Switch-over to stainless steel blanks for cathodes growth almost completed by end of 1986. Note: Expansion to 90 000 tpy by 1988 under way since 1984.

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[1] As reported in corporate reports or as advised by company.

Table 20: Trace Element Analysis, mg/L of Copper Smelting and Refining Wastes.
Source: EPA-SW-145

Plant	Type of sample	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Sb	Se	Zn	Sn
Primary copper												
A	Fine dust from ESP on converters	520	50	280 000	0.8	90	110	8 000	500	30	28 000	–
	Reverberatory furnace slag	<5	45	10 000	0.9	230	10	250	250	40	3 700	–
	Fine dust from ESP on reverberatory furnace	310	45	240 000	2.5	100	35	12 000	750	80	44 000	–
	Sludge from lagoon receiving acid plant Blowdown	180	25	22 000	5.0	8	10	>12 000	800	550	1 900	–
B	Electric furnace slag	<5	50	3 700	0.5	165	5	250	<100	10	8 000	–
C	Reverberatory furnace slag	10	100	6 200	0.7	450	25	100	400	20	7 800	–
D	Converter slag	<5	40	40 000	0.5	140	100	200	200	20	1 000	–
	Reverberatory slag	<5	160	6 100	0.8	170	20	80	100	20	650	–
	Solids from acid plant Blowdown thickener Overflow	<5	30	150 000	–	10	<10	10 000	1 200	150	120	–
	Solids from acid plant blowdown thickener underflow	60	90	380 000	6.0	72	95	5 800	200	40	1 000	–
Secondary copper												
A	Blast furnace slag	<5	20	12 000	–	7 000	260	2 800	<100	–	75 000	–
	Brass casting dross	160	–	340 000	–	–	4 100	–	–	–	330 000	17 000
	Nickel brass dross	160	–	420 000	–	–	1 200	–	–	–	210 000	1 000
B	Chrome brass dross	25	15 5000	100 000	–	–	–	–	–	–	460	100 000
	Baghouse dust	5 000	–	47 000	–	–	–	12 000	–	–	520 000	7 5000
	Water treatment sludge	10	94 000	170 000	–	–	16 600	900	–	–	1 850	20 000

Notes: –, No data available. Data are from six U. S. plants.

Limited leaching tests show that low concentrations of metals can be leached out of the slag, while higher concentrations can be leached out of the fine dust. As an example, the metal concentrations from 2-hour column tests on reverberatory furnace slag using acetic acid show:

11.0 mg/l copper
0.04 mg/l manganese
0.02 mg/l lead
0.7 mg/l zinc

When the material is leached, (as might occur in landfilling operations), the pH of the leachate will show values increasing to 7.6 and then dropping rapidly to a final pH of about 6.3. Sulfate concentrations in the leachate will reach approximately 32 mg/l in the first pore volume leachate. This will subsequently decline to less than 4 mg/l in the second and later pore volumes. Leachate from 7-day column tests (in the laboratory,) of the fine dust, show average concentrations of:

227.0 mg/l arsenic
553.0 mg/l cadmium
37,233 mg/l copper
4.2 mg/l lead
23,700 mg/l zinc

Results of the column leaching tests on wastes from 6 plants are listed in Table 21. The experiments were performed using 50 percent solids and water as the leaching solution. These tests show a similar pattern of high metal concentrations in the dust samples, low concentrations in the slag, and moderate concentrations in the acid plant sludge.

Table 21: Results of Column Leaching Tests.
Source: EPA-SW-145.

	Priimary Copper (SIC 3331)												
	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Sb	Zn	Se	pH	Cond
Reverberatory slag	0.04	0.01	0.01	0.37	0.02	0.01	0.05	0.3	0.2	0.24	0.09	10.8	600
Electric furnace slag	0.05	0.15	0.02	0.58	0.02	0.2	0.05	6.0	0.2	3.0	0.13	7.8	100
Converter dust	3.44	170	0.9	31 000	0.03	33	15	8.3	2.0	9 000	0.05	3.9	20
Acid plant sludge	0.80	8.4	0.5	850	–	1.0	0.64	7.8	0.2	300	–	3.0	2 700
Reverberatory dust	0.30	130	0.1	29 000	0.01	15	2.5	7.3	0.2	13 000	0.05	4.2	10 000
	Secondary Copper (SIC 33412)												
Blast furnace slag	–	1.0	0.03	170	–	0.3	–	6	0.2	55	–	9.4	90
Water treatment sludge	–	0.05	7.1	0.63	–	0.06	–	0.5	0.2	0.01	–	8.6	2 000

Note: –, No data available.

4.4 Quantity of Waste Produced

Table 22 presents the amounts of copper smelting slag produced in Canada in 1985. The slag is generally stored on-site and used as construction materials for roads and embankments.

Acid plants produce both scrubber dust and blowdown slurry. Typical production figures were estimated by the U.S. EPA for type cases in the United States. These proportions were applied to Canadian figures and an estimate of Canadian Production (Table 23) was derived. Scrubber dust is typically recycled and acid blowdown slurry is treated. The sludge is impounded on site. Dredged materials are commonly sent to mine tailing heaps.

Refinery waste amounts are estimated with the help of published figures for typical cases in the United States. These EPA projections were applied to Canadian production figures obtained from Canadian statistics on mineral production (Table 24). The slime filter rake is processed for mineral recovery and the slag is recycled to the smelter furnace. Miscellaneous slurries and arsenical sludges are treated and subsequently sent to ponds and storage sites.

4.4.1 ZINC

Canada produces one fifth of the total world production of zinc. Zinc is mined in all provinces except Alberta and Saskatchewan. Table 25 lists the metallurgical plants in Canada and their production capacities. The zinc metal ore is converted to metallic zinc by a combination of pyrometallurgical and electrolytic processes.

Unlike copper smelting, slag is not produced in the roasting of zinc concentrate. Waste is produced as a goethite sludge in subsequent steps of refining operations. Geothite waste is sent to ponds on-site and the wastewaters are treated and discharged. Canadian zinc refineries produce approximately 50,000 tonnes of goethite waste per year (expressed as a dry weight). The sludge, when pumped to ponds, contains approximately 60 percent water. The pond discharge and other acidic wastewaters produced (eg. cooling water), are treated before discharge to receiving waters. Zinc refineries treat approximately 2000 - 7000 gallons per day.

Table 22: Estimation of Copper Smelter Slag Produced in Canada, 1985

	(kilotonnes)
Ni-Cu-Zn Ore Removed from Mines	126 660.
Mineral Removed (3% of ore)	3 800.
Concentrate Produced (30% copper)	12 700.
Slag Produced (75% of non-copper concentrate)	6 630.

Source: estimated proportions by Environment Canada.

Table 23: Estimation of Acid Plant Wastes Produced at Copper Smelters in Canada, 1985.

	(tonnes)
Mineral Copper Produced	730 000.
Gas Scrubbing from ESP (1t. /28t. Cu)	26 300.
Sludge from Acid Blowdown Slurry (1/27)	27 000.

Source: EPA-AW-145.

Table 24: Estimation of Refinery Produced in Canada, 1985.

	(tonnes)
Mineral Copper Produced	730 000.
Slime Filter Cake (1.2 kg/sht. t. Cu)	966.
Slag (9.8 kg/sht. t. Cu)	7 890.
Arsenical Sludge (2.1 kg/sht. t. Cu)	1 690.
Misc. Slurries (2.6 kg/sht. t. Cu)	2 090.

Source: EPA-AW-145.

Scrubber dust and blowdown slurry volumes produced at the acid plants are estimated from EPA published proportions for typical cases in United States (Table 26). Scrubber dust is usually recycled, acid blowdown slurry is treated, and the sludge is ponded on site.

Lead is mined, principally as a co-product of zinc, in New Brunswick, British Columbia, the North West Territories, and the Yukon. Smaller amounts are mined as by-products of polymetallic ores in Ontario and Manitoba. Primary lead metallurgical works are located in Belledune, New Brunswick and Trail, British Columbia. Normal capacities of these lead plants are 72,000 tonnes per year (tpy) and 36,000 tpy respectively, but effective capacities depend upon feed material and other factors. Eight secondary plants -- those recycling lead-bearing scrap, have a combined capacity of 118,000 tpy. These are located in Quebec, Ontario, Manitoba, and British Columbia. Both types of facilities are equipped with acid plants.

The processes involved in lead metal production include; sintering, charring in a blast furnace, drossing, and further refining to remove impurities. The primary wastes generated by lead smelting are characterized by blast furnace slag, solids in the slag-granulation slurry, and wastes associated with the scrubbing of SO_2 gases.

Metal concentrations in slags, dusts, and sludges from smelters in the United States are shown in Table 27. All but one of the slag samples are high in lead, the range being 50 - 164,000 ppm. Zinc, copper, and cadmium concentrations are also high. Leaching tests on lead wastes (Table 28) generally show low metal concentration, the exceptions being copper and zinc in blast furnace dust (130 mg/l and 45 mg/l respectively).

An estimate of the lead smelting slag produced in Canada during the year 1985, is provided in Table 29A. As with copper and zinc processing, the slag is stored on site and used as construction material for roads and embankments. Slag is also milled into the concentrate.

Scrubber dust and blowdown slurry volumes, produced at acid plants, are estimated from EPA figures for typical cases in the United States by applying them to Canadian production figures (Table 29B). Scrubber dust is typically recycled,

Table 25: Canada Zinc Metal Production Capacity, 1986

Company and Location	Annual Rated Capacity (tonnes of slab zinc)
Canadian Electrolytic Zinc Ltd. (CEZ) Valleyfield, Quebec	227 000.
Falconbridge Ltd. Timmins, Ontario	133 000.
Hudson Bay Mining and Smelting Co., Ltd. Flin Flon, Manitoba	73 000.
Cominco Ltd. Trail, British Columbia	272 000.
Canada Total	705 000.

Source: Statistics Canada.

Table 26: Estimation of Waste from Acid Plants at Zinc Smelters in Canada, 1985

	(tonnes)
Zinc Mineral Produced	1 039 000.
Gas Scrubbing Waste from ESP (1 t. /55.6 t. Zn)	18 700.
Sludge from Acid Blowdown Slurry (1/52.6)	19 740.

Source: EPA-AW-145.

Table 27: Chemical Analysis of Selected Metals in Lead Smelting Wastes.

Source: EPA-SW-145

Plant	Waste Type	Concentration of constituents (ppm)									
		Cd	Cr	Cu	Hg	Pb	Zn	Sb	Ti	Mn	Ni
						Primary Smelters					
A	Fresh blast furnace slag	10	34	1 850	–	33 500	131 000	–	–	–	–
	Old blast furnace slag	88	37	2 330	–	68 500	51 000	–	–	–	–
	Sinter scrubber sludge	900	11	10 400	0.1	164 000	25 600	–	–	–	–
	Lagoon Dredgings (Slag granulation)	700	28	1 490	–	115 000	132 000	–	–	–	–
	Baghouse dust (From blast furnace)	14 000	10	5 350	–	148 000	82 000	–	20	–	–
B	Fresh blast furnace	1 150	37	2 750	–	61 900	110 000	–	–	–	–
	Old blast furnace slag	73	79	2 250	–	46 700	160 000	–	–	–	–
C	Fresh lead fuming slag	10	150	1 500	–	25 000	42 000	33	–	14 560	–
	Old lead fuming slag	5	90	1 600	–	20 000	31 000	20	–	13 500	–
	Blast furnace slag	350	30	1 500	–	94 000	120 000	440	–	11 500	–
	Lagoon dredgings from lead smelter	640	60	6 200	–	140 000	80 000	3 000	–	2 900	–
D	Blast furnace slag	–	–	2 600	–	38 000	108 000	–	–	–	–
E	Blast furnace slag	–	–	2 500	–	35 000	150 000	–	–	–	–
F	Blast furnace slag	–	–	–	–	25 000	120 000	–	–	–	–
						Secondary Smelters					
A	Scrubber sludge	340	30	20	–	53 000	25	1 100	–	120	5
	Wastewater treatment sludge	10	35	80	–	2 700	140	250	–	74	5
B	Smelter furnace slag	5	500	120	–	50	500	100	–	800	5
	Smelter furnace dust*	900	150	400	–	120 000	120 000	1 800	–	5	5
C	White Metal Dross*	–	–	–	–	160 000	4 700	–	–	–	–
	White Metal Dross*	–	–	–	–	145 000	2 600	–	–	–	–

Notes: Data are from six U. S. plants denoted A to F. –, not analyzed.
*This material is recycled.

Table 28: Leachate Concentrations of Selected Metals in Lead Smelting Wastes.

Source: EPA-SW-145.

Waste Type	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Sb	Zn	Se
Blast furnace slag	<0.003	0.03	<0.01	0.1	<0.02	<0.01	<0.05	<0.2	<0.2	0.22	0.12
Lead fuming slag	0.089	<0.01	<0.01	1.0	<0.02	0.03	<0.05	<0.2	1.0	0.64	<0.05
Blast furnace dust	0.117	8.0	<0.01	130	<0.02	0.25	0.09	7.3	<0.2	45	<0.05
Sinter scrubber sludge	–	9.1	<0.01	2.6	<0.02	1.3	<0.05	5.5	<0.2	7.5	0.17
Lagoon dredgings (smelter)	0.231	11	<0.01	0.53	<0.02	27	0.08	4.5	<0.2	9.5	<0.05

Note: Values given in mg/L.

Table 29a: Estimation of Lead Smelting Slag Produced in Canada, 1985.

	(tonnes)
Lead Mineral Produced	264 000.
Coarse Slag (0.28 tonne/tonne of lead)	73 900.
Fine Slag Sludge (0.14 tonne/tonne of lead)	37 009

Source: EPA–SW–145.

Table 29b: Estimation of Waste from Acid Plants at Lead Smelters in Canada, 1985

	(tonnes)
Lead Mineral Produced	264 000.
Gas Scrubbing waste from ESP (1 t. /55.6 t. Pb)	4 750.
Sludge from Acid Blowdown Slurry (1/52.6)	5 020.

Source: EPA–AW–145.

acid blowdown slurry is treated, and the sludge is ponded on site. Dredged material is commonly treated as mine tailings.

Table 30 summarizes the waste produced from the smelting and refining of copper, zinc, and lead in Canada during 1985. Copper production generates the maximum amount of waste. Among the various steps in metal production, the smelting process results in maximum waste production. However, the slag produced is relatively inert and does not pose a serious environmental threat.

Conversely, the sludges produced from the refining process are of great concern. Although they are not produced in great quantities, they contain elevated levels of hazardous metals. The sludges are typically neutralized and stored in ponds on site, and subsequently, the dredged material is landfilled at the mine site as tailings.

The production of SO_2 gas is also considered a serious waste problem. Although acid plants remediate approximately 50 percent of the problem,the uncaptured gas vents directly to the atmosphere.

The primary waste associated with the acid plants is the blowdown sludge. Normally, these sludges are neutralized and sent to ponds on site. Characteristically, the sludges contain elevated levels of metals, generally higher than those found in refinery sludges, and hence pose serious contamination problems.

Table 30: Estimated Quantity of Waste Produced from Smelting and Refining of Copper, Zinc, and Lead, in Canada, 1985 (tonnes).

Waste	Copper	Zinc	Lead	Total
Smelting slag[1]	6 650 000	na	74 000	6 700 000
Acid blowdown sludge	27 000	20 000	5 000	52 000
Arsenical sludge	1 700	na	na	1 700
Goethite sludge[2]	na	150 000	na	150 000
Fine slag sludge	na	na	37 000	37 000
Misc. slurries	2 100	1 500	small	3 600

[1] Some reused as road material and some remilled into concentrate.

[2] Expressed as dry weight, the sludge contains 60% water.

na — not applicable.

Source: EPA - SW - 145.

5.0 PULP AND PAPER INDUSTRY WASTES

5.1 Preliminary Remarks on Paper Production

Pulp and paper industries and their by-products are of great economic importance to Canada. This industry, with an annual production of $20 billion is the third largest employer in the country (figures correspond to the year 1988). The annual production and export of the various pulp and paper products for the year 1981 is presented in Table 31. Tables 32, 33, 34, and 35 highlight the Canadian wood pulp production by kind and by province, the lumber production by province, and the distribution and total employee numbers by province of the Pulp and Paper industry, for the years 1985 and 86, respectively.

Wood is by far the most important raw material for the production of pulp and paper. Its main components are cellulose (45%), hemicellulose (25%), lignin (25%), and extractives (5%).

The various steps in the production of paper include:

* wood preparation
* pulping
* bleaching
* paper making

Each of the processes generate effluents, sludges, and atmospheric emissions which are discussed in the following sections.

Table 31: Canadian Pulp and Paper Shipments by Product (in millions of dollars)

Product Category	Number of Establishments		Value of Shipments	
	1985	1986	1985	1986
Pulp Mills	37	38	3 545	4 267
Newsprint Mills	42	42	6 631	7 183
Paperboard	27	28	1 325	1 470
Building Board	5	6	84	101
Other Paper	26	28	1 822	2 051
Asphalt Roofing	18	19	367	450
Cartons and Set-up Boxes	104	106	704	784
Corrugated Box	115	118	1 394	1 462
Paper Bag	32	29	271	250
Coated and Treated Pap.	45	52	406	496
Stationary Paper Prod.	77	71	403	384
Paper Consumer Prod.	15	17	441	452
Other Converted Paper Pr.	145	144	681	715
TOTAL	688	698	18 075	20 067

Source: Statscan 36-250, 1986.

Table 32: Wood Pulp Production By Kind (in 1 000 tonnes)

TYPE OF PULP	1985		1986	
	Volume	Percentage	Volume	Percentage
Unbleached Sulphite	1 317	6.5	1 298	6.4
Bleached Hardwood	1 136	5.6	1 277	6.3
Bleached Softwood	5 955	29.5	6 386	31.4
Semi - Bleached	1 048	5.2	847	4.2
Unbleached	1 479	7.3	1 390	6.8
Mechanical	5 320	26.4	4 930	24.3
Thermo-mechanical	2 914	14.4	2 749	13.5
Other	1 004	5.0	1 440	7.1
TOTAL	20 173	100.0	20 317	100.0

Source: Statscan, 1986 (Catalogue 36-250)

Table 33: Wood Pulp Production By Province (in 1 000 tonnes)

PROVINCE	1985		1986	
	Volume	Percentage	Volume	Percentage
Quebec	6 030	29.9	6 120	30.1
Ontario	4 272	21.2	4 182	20.6
British Columbia	6 175	30.6	6 118	30.1
Others	3 697	18.3	3 897	19.2
TOTAL	20 173	100.0	20 317	100.0

Source: Statscan, 1986 (Catalogue 36-250)

Table 34: Lumber Production By Province (in 1 000 cubic meters)

PROVINCE	1985		1986	
	Volume	Percentage	Volume	Percentage
Newfoundland	47	0.1	52	0.1
Prine Edward Island	11	-	14	-
Nova Scotia	426	0.8	466	0.9
New Brunswick	1 304	2.5	1 477	2.8
Quebec	9 920	19.0	11 309	21.3
Ontario	4 946	9.5	5 121	9.7
Manitoba	167	0.3	223	0.4
Saskatchewan	482	0.9	457	0.9
Alberta	2 687	5.2	2 944	5.5
British Columbia (Interior)	8 594	16.5	8 836	16.7
British Columbia (Coastal)	23 525	45.1	22 161	41.8
TOTAL	52 109	100.0	53 059	100.0

Source: Statscan, 1986 (Catalogue 35-250)

Table 35: Pulp and Paper Industries - Canadian Distribution

INDUSTRY (with totals)	# of Emp	B.C.	Pra.	Ont.	Que.	Atl.	Totals
Pulp Mills	< 100	1	-	-	2	-	3
	100 - 500	10	1	2	4	3	20
38 establishments	> 500	5	2	3	1	4	15
18 506 employees	Total	16	3	5	7	7	38
Newsprint Mills	< 100	-	-	-	-	-	-
	100 - 500	-	1	3	4	1	9
42 establishments	> 500	4	-	6	17	6	33
38 892 employees	Total	4	1	9	21	7	42
Paperboard	< 100	-	2	2	2	-	6
	100 - 500	1	-	8	7	3	19
28 establishments	> 500	1	-	1	1	-	3
7 998 employees	Total	2	2	11	10	3	28
Other Paper	< 100	-	-	1	4	1	6
	100 - 500	1	1	4	6	1	13
28 establishments	> 500	1	-	4	4	-	9
13 242 employees	Total	2	1	9	14	2	28
Carton/Set-Up Box	< 100	-	3	-	3	1	7*
	100 - 500	1	-	14	12	2	29
106 establishments	> 500	1	1	16	6	-	24
6 759 employees	Total	2	4	30	21	3	60*
Corrugated Box	< 100	-	1	3	-	-	4*
	100 - 500	3	4	16	6	3	32
118 establishments	> 500	3	3	23	11	2	42
10 370 employees	Total	6	8	42	17	5	78*

* Not true totals due to omissions by Statscan.

Source: Statscan, 1986 (Catalogue 36-250)

5.1.1 WOOD PREPARATION

Bark is an essentially non-fibrous material and as such, has limited value in paper making. Therefore, it, along with any surface dirt, is removed from the log as an unwanted layer. Several pieces of equipment are designed to achieve bark removal and include:

- wet drums
- dry drums
- hydraulic jets
- mechanical barkers

The two most common processes being used in the industry are wet and dry barking drums. Both function on the principle that friction between the logs will remove the bark. In the wet barking process, water is introduced to help loosen the bark and flush any particulates out of the drum. After soaking and contact, the logs continue through the drum and the loosened bark falls through slots at the base. The bark is then collected in a dewatering system where it passes through a bark dewatering press and then enters the bark burning furnace.

The dry barking process involves the use of drums which are longer and rotate faster than those used in the wet system. The bark exits the drum through slots and because it is dry, can enter the bark burning furnace directly. Dry process wood loss is in the 5% range.

Hydraulic jet barkers utilize high pressure streams of water (7000 KPa) to remove the bark. This technology, used primarily on the large logs in West Coast Canada, is not suited to the frozen or small sized logs commonly encountered in Eastern Canada. Although bark removal is efficient, with less than a 2% wood loss, capital costs and energy requirements are high. Furthermore, the removed bark and wood debris is fully saturated and must undergo additional processing to be usable as a fuel.

Dry mechanical barkers are normally restricted to smaller operations (i.e., sawmills), although some large operations do employ this method. Basically, the system utilizes rotating knives which physically strip the bark from the logs.

Previously, (until the 1970's) bark was a major source of solid waste from the pulp operations and was commonly buried, or dumped into the nearest river. However, with rising energy costs the bark has become an attractive alternate energy source. Through incineration, the bark is used in an energy recovery system designed for boiler vapor production. The major hazard faced in bark combustion is the release of PCDD (polychlorinated dibenzo-p-dioxins) and/or PCDF (polychlorinated dibenzofurans) into the atmosphere resulting from the burning of bark contaminated with chlorophenols or other pesticides. Both are considered to be health threatening airborne contaminants.

Based on comparisons of the effluent properties of the two most common barking methods, it has been shown that for 500t of newspaper/day production, the dry barking process generates significantly less effluent along with a reducing the suspended solids and BOD by 75% and 87% respectively. It was reported (McCubbin, 1984), that wood handling and debarking systems with internal recycle have an effluent flow of about 10,000 litres per oven dry ton (ODt) of wood processed. Typical wet woodrooms discharge about 40 kg of suspended solids per ODt processed. This can be reduced to about 3 kg/ODt with the installation of an effluent clarifier. BOD levels can vary widely and show marked increases when recycled process wastewater is used in place of fresh water.

5.1.2 PULPING

Pulping is the process of loosening and separating the individual fibers of the wood. The two technologies which predominate pulping involve either chemical or mechanical processes. Pulping yield is defined as the weight of pulp produced from a specified amount of dry wood. Pulping yields are directly related to the pulping process used and can vary from 40% to greater than 95%.

Stone groundwood, a process which involves forcing whole logs into contact with a revolving groundstone, is probably the oldest and simplest mechanical pulping process. Refiner mechanical pulp is produced when the chips are passed through additional single or double revolving disc systems. Thermomechanical pulp (TMP) is obtained by softening the chips with pressurized steam (3 minutes at 110 - 130 deg. C at 150 - 210 KPa) before passing them through the disc system. If sodium sulfite is used along with the steam treatment, chemi-thermomechanical pulp is produced.

All mechanical pulping occurs with the logs submerged in water. Referred to as "white water", this water normally contains minor amounts of solids and any chemical additives which may have been used.The pulping yield of the mechanical processes is usually at least 80%, with the quality of the pulp being directly related to the energy input (i.e., operating pressures). TMP, on average, requires 30 to 50% more energy than does stone groundwood. However, this energy inbalance can be offset by the recovery of the steam produced (2.3 tonnes per tonne of fiber produced) in the TMP process. Recovered steam can be utilized in two different ways; 1) heating incoming air, water, and white water, or 2) powering the paper machine driers. Through recovery, the net energy costs of TMP and groundwood can become almost even. The only negative of the steam recovery systems is that they will increase the BOD of the mill effluent by about 2 kg/t. In general, the BOD and relative toxicity of the TMP effluent is 50 - 100% greater than the stone groundwood, but, the suspended solids discharges are lower.

Chemical pulping processes are generally divided into two types, sulfite and kraft. Sulfite operates in an acid environment while kraft (or sulphate) utilizes an alkaline environment. These processes are subject to many variations across the industry and the resulting pulping yields normally range from 35 to 60%. Chemical pulping removes almost all the lignin and most of the hemicellulose from the pulp. The basic chemical pulping operation involves incorporating the chips with a chemical solution (liquor) in an enclosed digester unit and then heating and pressurizing for a set period of time. The processed pulp is then blown hot into a blow tank and is subsequently diluted and pumped to be washed.

Sulfite pulping was the main method of chemical pulping up until the mid-1940's. At that time, methods were developed to bleach the darker kraft pulp, without a major strength loss, and kraft became the more popular method of pulping.

The chemical pulping operations generate hazardous waste streams through their use of chemicals to separate the fibers from the lignin in the wood. The kraft or sulfate pulping process generates sludges high in chromium, lead, and sodium

(Table 36) and is the predominant type of chemical pulping in Canada. Fortunately, a large proportion of the plants using this process recycle many of their wastes. Table 37 shows the untreated effluents from the older mills in the first three columns, while the last three columns depict the characteristics of effluents from mills built after the 1970's. The data indicate a net improvement in the control of flow, suspended solids, and BOD, along with a substantial reduction in accidental losses. This is due to the implementation of better system designs and controls over the past two decades.

5.1.3 PULP SCREENING AND CLEANING

The objective of pulp screening and cleaning is the removal of dirt and foreign matter such as slivers, knots, grit, bark, sand, uncooked chips, etc., from the pulp. The technology normally employed involves coarse screening, fine screening, and centrifugal cleaning operations.

Fiber rejects from kraft mills are reported to range from 1 to 5 kg/t production, while in mechanical pulp mills, screening and cleaning rejects vary from 2 to 10 kg/t production. These rejects are sewered or dewatered for landfilling or incineration.

5.1.4 BLEACHING

Pulp, depending on the lignin content and pulping method used, can range in colour from dark brown to nearly white. Because lignin derivatives are the major color constituents in paper, they must be removed to produce the desired whiteness. This is accomplished by chlorine or oxygen bleaching of the pulp. Much unbleached pulp is used for boxes, bags, and newsprint, but over half must be bleached to produce white paper products. The degree of whiteness, or a surface's ability to reflect all the colours of the spectrum equally is, in this industry, termed brightness.

The brightness required for mechanical pulps is not normally as high as that for chemical pulps. Subsequently, decolourization can be accomplished through the simple addition of reducing or oxidizing agents. The agents used are determined by

Table 36: Chemical Analysis of Primary and Secondary Treatment Sludges from the Pulp and Paper Industry.

Constituent[1]	Primary and secondary sludge from semi-chemical pulping	De-inking sludge # 1 (recycled paper)	De-inking sludge # 2	Pretreatment sludge from paper coating	Board mill sludge	Combined primary and secondary sludge
Water (%)	90–96	77.06	–	86	–	40
Solids (%)	4–10	22.4	–	14	–	60
Ash (%)	1–2.5	–	–	–	–	40
COD	60 000–120 000	–	–	400 000	–	–
Phenol	5	–	–	–	–	–
PCB	<13	–	–	–	–	–
Oil and Grease	1	–	–	–	–	–
Total nitrogen	1 400	–	–	–	–	4
Aluminum	–	21 300	–	100 000	–	–
Cadmium	1.5	32	–	–	–	4.6
Calcium	4 000–15 000	4 390	–	–	–	–
Chloride	–	332	–	–	–	–
Chromium	–	20	180	–	79	16
Copper	ND[2]	–	330	–	62	–
Iron	–	538	1 500	200 000	2 400	–
Lead	120	32	1 300	–	380	47
Magnesium	–	1 170	–	–	–	–
Manganese	250	16	–	–	–	1 146
Nickel	25	2.3	8	3 000	11	52
Phosphorous	–	310	–	–	–	2
Potassium	1 600	114	–	–	–	–
Sodium	1 400	146	–	–	–	–
Sulfate	120	0.03	–	–	–	–
Zinc	260	151	300	4 000	350	397

Source: Energy Resources Co. 1979 and EPA (1979).

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[1] In ppm unless otherwise noted.

[2] ND = Not Detected.

Table 37: Kraft Mill Effluent Breakdown

	Older Mill			Maximum In-plant Control		
	Flow (m^3/t)	SS (kg/t)	BOD (kg/t)	Flow (m^3/t)	SS (kg/t)	BOD (kg/t)
Wood Preparation (wet)	15	90	16	–	–	–
Wood Preparation (dry)	–	–	–	5	2	1
Pulping (non-process)	10	3	3	5	0.2	0.1
Washing and Screening	15	5	15	3	0.3	0
Contaminated Condensates	20	0	5	3	0	1
Evaporator (non-process)	20	0	5	3	0	1
Recovery Furnace/Power Boiler	15	0	0	5	0	0
Bleaching CEDED	75	1	25	–	–	–
Bleaching OC_dEDED	–	–	–	10	0.2	10
Recausticising (process)	2	10	5	0	0.1	0
Recausticising (non-process)	5	1	0	2	–	0
Pulp Dryer	15	10	1	3	0.2	0.1
Accidental Losses	20	30	30	10	5	5
Totals	202	150	115	44	8	17.2

Source: Energy Resources Co. 1979 and EPA (1979).

the desired brightness and hydrosulphites appear to be the most common. The average yield loss contribution to BOD from the mechanical processes is normally about 1%. Extremes may run this value to 4%, with the related BOD load surpassing 25 kg BOD/t pulp.

Chemical pulp bleaching is often considered an extension of the delignification stage which began in the digestion stage of the pulping. On the brightness scale, the initial brightness of kraft pulps is about 20, while sulfite pulps are around 60. Consequently, it is more difficult to attain a desired brightness level when the base pulp is kraft, thus making the bleaching process that much more critical.

The bleaching of chemical pulps involves several stages which can be applied in various sequences. Usually, the initial stage is chlorination, in which the solubilization of the residual lignin is attempted. The chlorinated lignin products are then washed out and the pulp is thickened. Secondly, an alkaline environment is created, normally through sodium hydroxide addition, and the residual reaction products are dissolved. This is called the alkaline extraction stage. Other stages involve the addition of oxidative agents such as sodium hypochlorite and chlorine dioxide. It is possible to achieve brightness levels exceeding 90 through a combination of the stages.

The bleach plant effluent normally exhibits a BOD level ranging from 15 to 25 kg/t. This is considered the principal source of toxicity in most bleached kraft mills. The principal source of toxicity in chlorine based bleaching processes is the chlorine itself. This problem can be solved by replacing chlorine with a suitable substitute, i.e.,chlorine dioxide.

Since the early 70's, oxygen has partially replaced chlorine in a few Canadian mills. The use of oxygen has resulted in a 40% reduction in the BOD and COD contents of the related effluents. In some instances, where the chlorine bleaching still remains, an oxygen bleaching sequence was included and a decrease in the chlorine content of the wastewaters has been observed.

5.1.5 PAPER MAKING

The pulp suspension is converted into paper mechanically through the use of a paper machine. Paper making consists of three steps; wet-end or forming, pressing, and drying. Water usage in these processes can reach levels as high as 45 tonnes per tonne of paper produced. Wastewaters are relatively high in suspended solids but exhibit relatively low BOD. The primary contributors to BOD are the dissolved wood organics and coating materials. For example, in a news print mill effluent, the suspended solids vary from about 1-55%, while BOD ranges only from 1-5%.

5.2 Environmental Protection

The Federal government, the Provincial governments, and the municipalities all have different jurisdictional powers involving environmental protection and pulp and paper industry. Broadly speaking, the Provincial regulations are compatible with the Federal Regulation Guide Lines. However, in certain cases, the Provincial restrictions are more severe than the Federal guidelines

5.2.1 EFFLUENT

All wastewaters entering watercourses, are legislated by Federal guidelines whose overall intention is to control pollution at the source by use of better technology. In November 1971, the Federal Government issued a regulation for limited pollution in the Canadian pulp and paper industry effluents under the 'Fisheries Act' (Water Pollution Control Directorate, Schedule A and B, 1971). Under the Federal Fisheries Law, the following points are considered:

** suspended solids
** substances with high BOD
** toxic materials
** total suspended solids

The rejection of suspended solids in Canada for the year 1982 was 20 kg per pulp ton. Comparing this to the 1969 value of 49 kg./ton, a 59% reduction is indicated.

Further reductions were recorded in 1984, with values dropping to about 13.5 kg/ton. If all the mills conformed to the Federal regulations, the average annual amount of suspended solids in the associated effluents would be about 12 kg/ton. Table 38 is based on a 1990 Environment Canada study of a large Kraft plant located in Quebec and gives a comprehensive overview of what might be expected in the effluent along with relative loadings and concentrations.

5.2.2 BIOLOGICAL OXYGEN DEMAND

The Federal requirement in this case applies to the manufacture of chemical pulp only. The average BOD levels for 1982 were 38 kg/ton of production, about a 42% reduction compared to 1969. If all the mills conformed to the Federal regulations, the annual effluent BOD would be about 29kg/ton.

Industry research shows different BOD values for newspaper, kraft pulp, commercial pulp industries, and others. The highest BOD rejects are shown to be associated with newspaper integrated with bisulfite pulp fabrication, kraft pulp, or bought chemical pulp. The BOD rejects from factories using kraft pulp are lower for the industries in the Pacific, North-West, and Atlantic regions because they treat their wastewaters biologically before discharge. Finally, it should be noted that the Quebec based industries are responsible for the largest amount of BOD rejects in the country and the majors are detailed in Table 39.

Table 39: Summary Of Major Quebec Pulp and Paper Mills

COMPANY/ LOCATION	PRODUCTION	FLOW		SUSPENDED SOLIDS		BOD (5 day)	
	(tonnes/day)	(m^3/d)	(m^3/t)	(kg/d) (kg/t)	(mg/l)	(kg/d) (kg/t)	(mg/l)
Domtar	65	7 450	114.6	140	18.8	600	80.5
- Beauharnois				2.2		9.2	
Perkins	76	4 500	59.2	360	80.0	1 800	400.0
- Candiac				4.7		23.7	
Canadian Pacific	1 125	89 600	79.6	4 389	49.0	83 000	926.0
- Trois-Rivieres				3.9		73.8	
Stone Consolid.	574	73 000	127.2	7 017	96.1	11 000	150.7
- Trois-Rivieres				12.2		19.2	
Kruger	1 100	83 000	75.5	6 500	78.3	22 800	274.7
- Trois-Rivieres				5.9		20.7	
Domtar	620	39 000	62.9	11 500	294.9	15 000	384.6
- Donnacona				18.5		24.2	
Diashowa	1 465	140 000	95.6	4 700	33.6	71 900	513.6
- Quebec				3.2		49.1	
Price	450	35 000	77.8	3 400	97.1	23 500	671.4
- Beaupre				7.6		52.2	
Donohue	925	45 500	49.2	5 200	114.3	11 000	241.8
- Clermont				5.6		11.9	
F.F. Soucy	525	22 500	42.9	3 100	137.8	10 000	444.4
R.-du-Loup				5.9		19.0	
Que. & Ontario	1 300	130 000	100.0	14 000	107.7	74 000	569.2
- Baie Comeau				10.8		56.9	
Cascades	510	42 160	82.7	4 700	111.5	6 100	144.7
- Jonquiere				9.2		11.9	
Stone Consolid.	1 050	70 000	66.7	12 000	171.4	33 000	471.4
- La Baie				11.4		31.4	
Price	635	80 000	126.0	5 350	66.9	19 450	243.1
- Alma				8.4		30.6	
Price	540	82 000	151.9	9 300	113.4	8 500	103.7
- Kenogami				17.2		15.7	
TOTAL	10 960	943 710	86.1	91 656	97.1	391 650	450.0
				8.4		35.7	

Source: Environment Canada, 1990.

Table 38: Pulp and Paper Mill Effluent Analysis (Quebec Plant)

PARAMETER	LOADING (avg.) (kg/day)	CONCENTRATION (avg.) (mg/l)*
Effluent Flow	93 960 m^3/d	
pH		5.6 - 8.2
Temperature		29 - 34 deg. C
Suspended Solids	12 124	129.0
Dissolved Solids	19 537	207.9
Total Solids	31 460	334.8
Settleable Solids	9 289	98.9
Total Lipids	1 311	14.0
Potassium	750	8.0
Manganese	71.9	765 ug/l
Iron	51.9	552 ug/l
Aluminum	215.1	2.3
Magnesium	724.5	7.7
Calcium	3 564	37.9
Sodium	2 272	24.2
Hydrocarbons	500.6	5.3
Total Phosphorus	121.4	1.3
Total Suspended Phosphorus	63.4	675 ug/l
Total Dissolved Phosphorus	16	170 ug/l
Total Kjeldahl Nitrogen	157.3	1.7
Chemical Oxygen Demand	40 629	432.4
Biochemical Oxygen Demand	16 546	176.1
Filtrate Biochemical Oxygen Demand	13 643	145.2
Trout Mortality (96 hrs), 100% Sample		100%
Trout Mortality (96 hrs), 65% Sample		50%
Lethal Time (50% Mortality), 100% Sample		6 - 24 hr
Lethal Time (50% Mortality), 65% Sample		24 - 48 hr

* Unless otherwise indicated.

Source: Environment Canada, 1990.

5.2.3 TOXICITY

Table 40 illustrates the degree of conformity for each region in Canada. Environment Canada estimated that in the year 1984, about 43 mills conformed to the relative requirements for toxicity. When biological wastewater treatment is utilized for toxicity control, the results become apparent almost immediately. Furthermore, within a few months, the toxicity levels normally conform to the Federally prescribed levels. However, if internal treatments are utilized, it usually requires a few years to conform to the prescribed toxicity levels. Both procedures have their pros and cons. Biological treatment allows for quicker processing, but involves substantial capital costs, high energy consumption, and is primarily applicable to biodegradable substances only. Conversely, internal measures are time consuming, but more cost effective. It has been noted that, in numerous cases, internal toxicity reduction results in energy savings and is amenable to more efficient resource allocation.

According to Environment Canada (1987), most of the acute toxicity of pulp and paper mill effluent is attributable to resin and fatty acids, chlorinated phenols (where chlorine bleaching is practised), and a wide range of neutral compounds. Mechanical pulping effluent is generally more toxic than chemical pulping whole mill effluent. Table 41 lists ranges of the resin and fatty acids present in groundwood pulping effluent, untreated and biologically treated, and ranges of concentrations which are toxic to 50% of a rainbow trout population exposed for 96 hours. Table 42 details the other various toxic and hazardous wastes found in pulp and paper effluent, the associated effects, the process most likely to produce this waste, and the most reasonable treatment.

Table 40: Water Pollution Compliance Levels of Pulp and Paper Mills, by Major Drainage Area, 1982[1]

Major drainage area	number of mills[2]	Biochemical oxygen demand (BOD_5)				Total suspended solids (TSS)			
		loadings	compliance levels[2]	compliance index[3]	number of mills not in compliance	loadings	compliance levels[2]	compliance index[3]	number of mills not in compliance
		tonnes per day	tonnes per day			tonnes per day	tonnes per day		
Atlantic Ocean Basin	84	1 834	1 526	1.2	37	733	555	1.3	40
Atlantic Ocean Coastal	3	71	55	1.3	1	38	16	2.4	1
Gulf of St. Lawrence Coastal	13	432	356	1.2	7	140	104	1.3	7
Bay of Fundy Coastal and Saint John River	9	72	58	1.2	3	38	37	1.0	4
St. Lawrence River	29	703	551	1.3	16	336	203	1.7	19
Ottawa River	10	246	189	1.3	4	111	54	2.1	6
Lake Huron Shore	9	22	39	0.6	1	14	17	0.8	1
Lake Superior Shore	7	190	224	0.8	3	36	97	0.4	1
Hudson Bay and Ungava Bay Basin	11	253	292	0.9	4	75	99	0.8	4
Hudson Bay and Ungave Bay Coastal	5	159	156	1.0	2	37	49	0.8	1
Lake Winnipeg Shore	4	85	86	1.0	2	27	42	0.6	1
Saskatchewan River	2	9	50	0.2	0	11	8	1.4	2
Arctic Ocean Basin	4	12	70	0.2	0	20	22	0.9	1
Mackenzie River	4	12	70	0.2	0	20	22	0.9	1
Pacific Ocean Basin	21	351	684	0.5	2	236	150	1.6	15
Columbia River	2	29	44	0.7	1	11	8	1.4	2
Fraser River	8	26	143	0.2	0	38	30	1.3	4
Pacific Ocean, North Coastal	2	50	67	0.7	1	26	14	1.9	2
Pacific Ocean, South Coastal	9	246	430	0.6	0	161	98	1.6	7
Canada	120	2 450	2 572	1.0	43	1 064	826	1.3	60

[1] Loadings are presented in terms of Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD_5). Note: figures do not include small mills and those that discharge into municipal treatment systems; for this reason underestimation occurs in some areas.

[2] Compliance refers to permitted deposits of either BOD_5 and TSS in pounds per air-dry ton of product rather than the assimilative capacity of receiving waters. Further, note that the compliance is variable according to the technology in place at the plant.

[3] Index value of one or less indicates that the compliance has been met, a value greater than one indicates that the mills are discharging effluents which exceed compliance.

Source: Environment Canada, Environmental Protection Service (EPS), unpublished data.

Note: The EPS acting under the authority of pulp and paper effluent regulations of the Federal Fisheries Act sets individual compliance levels for each plant.

Table 41: Resins And Fatty Acids In Groundwood Pulp Mill Effluent

RESIN ACIDS	96-hr LC_{50} (ug/l)	GROUNDWOOD PULP EFFLUENT (ug/l)	
		Untreated	Treated
Abietic	700 - 1 500	210 - 16 000	14 - 4 200
Dehydroabietic	800 - 1 740	490 - 15 100	8 - 5 800
Isopimaric	400 - 1 000	150 - 9 300	12 - 7 900
Levopimaric	700 - 1 000	80 - 22 000	11 - 1 800
neoabietic	610 - 730	30 - 6 800	<1 - 3 800
palustric	500 - 600	300 - 7 700	-
pimaric	700 - 1 200	20 - 6 800	<1 - 5 700
FATTY ACIDS			
Linoleic	2 000 - 4 500	490 - 9 000	23 - 1 500
Linolenic	2 000 - 6 000	<100 - 800	-
oleic	3 500 - 8 200	230 - 4 300	24 - 1 400

Source: Environment Canada, 1987.

Table 42: Toxic And Hazardous Waste Products

POLLUTANT	EFFECT	PROCESS	TREATMENT
Resin Acids Fatty Acids	Responsible for acute toxicity	All pulping processes	Biodegradable Secondary treatment
Phenolic Compounds	Taste in drinking water and fish tainting	All pulping processes	Biodegradable Secondary treatment
Chlorinated Organics Dioxins	Persistent Bioaccumulable Possibly toxic	Chlorine bleaching	Substitution Process modification Reduction at source
Additives and Other Agents	To be determined	All processes and paper machines	Substitution Reduction at source
Examples: Hydrocarbons	Possibly toxic	All processes	Reduction at source
Heavy Metals	Toxic	Machinery Chemical additives	- Substitution

Source: MENVIQ, 1989; Environment Canada, 1987.

5.3 Industry Related Costs

Realistically, as is the case in most major industries, the overall capital and operating costs related to environmental concerns must be estimated. In the Pulp and Paper industry, this is due primarily to the fact that much of the equipment required for environmental protection, is also an integral part of the production systems. This is particularly highlighted by the more "modern" in-plant technology developments. For example, the installation of a particular $15 million precipitator recovery scrubber was directly related to the fact that the associated energy recovery system was adaptable to existing mill processes. The more intelligent environmental purchases appear to be less sensitive with respect to price and more so to systems which can also offer some method to help offset or recoup the capital investment (i.e., cost savings due to energy recovery).

Unfortunately, not all environmental problems can be addressed by systems which offer a tangible payback. Therefore, both capital and operational spending are affected by existing mill processes and the environmental regulations which must be satisfied (Table 43). Subsequently, it can be said that environmental spending in the Pulp and Paper industry is extremely site specific. McCubbin (1984) has contributed the following factors which can further impact the cost effects of local variations:

1) quality and ingenuity of engineering and project management;
2) constraints due to previous technical decisions;
3) topography;
4) local energy costs; and
5) land availability.

Table 43: Projected Environmentally Related Capital Costs For Select Companies (Millions of Dollars)

COMPANIES	COST	PROJECT	TYPE OF FACILITY
CP Forest Products Ltd.	$17m	Gold River, B.C. and other mills	Air and water treatment
Canfor Corp.	$170m	Prince George, B.C.	Air and water treatment
Cascades Inc.	$150m	Kingsey Falls, Que.	De-inking plant
Fletcher Challenge Canada Ltd.	$211m	Campbell River, Crofton, and Mackenzie, B.C.	Air, water, and sludge treatment
Kruger Inc.	$53m	Bromptonville, Que.	De-inking plant
MacMillan Bloedel Ltd.	$68m	Nanaimo, B.C. and other B.C. mills	air and effluent treatment
Repap Enterprises Inc.	$40m	Prince Rupert, B.C.	Air and effluent treatment

Source: Marotte (1990)

5.3.1 COST ESTIMATES

As was indicated previously, due to their site specific nature, any attempt to quantify environmentally related costs will be an estimate. Acknowledging this, the following expenditure estimates are based on actual production values and cost estimates as reported by Beak Consultants (1977), McCubbin (1984), Statistics Canada (1986), and 1989 industry surveys. Where applicable, in order to bring dollar values to 1989 levels, a 5% inflation rate was assumed. Furthermore, in some instances, annual capital cost contribution was attained by assuming a twenty year expected life for newly purchased machinery. Presented in Tables 44 to 47, the overall industry cost, before considering opportunity costs, is approximately $432 million. Taking into consideration the expected 20 million tonnes of production, this breaks down to roughly $21.60/tonne or 2.5% of the expected selling cost.

Table 44: Breakdown Of Capital Cost By Production Category ($/tpd)*
(1989 Dollars)

Capital Cost Category	Kraft	Low Yield Sulphite	Integrated Newsprint/ Sulphite	Newsprint (without sulphite)	Other Non-integrated Paper
In-plant Improvement	2 365	3 565	2 705	930	1 585
Collection	415	5 765	3 940	1 100	1 015
Primary	1 180	15 090	9 795	2 195	3 285
Secondary	3 920	53 505	26 230	7 065	3 955
Recovery	20 770	148 990	-	12 020	-
Piping	675	13 995	6 475	2 000	1 195
Engineering	4 425	32 940	7 305	3 690	1 665
TOTALS	33 750	273 850	56 450	29 000	12 195

* Dollars/tonne of pulp per day.

Source: Beak Consultants (1977), McCubbin (1984), Statistics Canada (1986), and 1989 industry surveys.

Table 45: Annual Capital Costs For Water Pollution Control (1989 Dollars)

PRODUCTION CATEGORY	Average Daily Production (tpd)	Capital Cost ($/tpd)	Total Capital Cost ($1 000)	Annual Capital Cost ($1 000/yr)*
Kraft	28 700	33 750	968 625	48 430
Low Yield Sulphite	6 600	273 850	1 807 410	90 370
Integrated Newsprint/ Sulphite	19 950	56 450	1 126 175	56 310
Newsprint (without sulphite)	7 700	29 000	223 300	11 170
Other Non-integrated Paper	3 500	12 700	44 450	2 200
TOTALS	66 450	-	4 169 960	208 500

* Assuming a 20 year life expectancy for the pollution control equipment.

Source: Beak Consultants (1977), McCubbin (1984), Statistics Canada (1986), and 1989 industry surveys.

Table 46: Annual Operating Costs For Water Pollution Control Equipment (1989 Dollars)

PRODUCTION CATEGORY	Annual Production (1 000 tonnes/yr)	Operating Costs ($/tonne)	Annual Operating Costs ($1 000/yr)
Kraft	8 800	10.00	88 000
Low Yield Sulphite	2 000	(7.00)	(14 000)
Integrated Newsprint /Sulphite	6 100	4.50	27 450
Newsprint (without sulphite)	2 400	7.00	16 800
Other Nonintegrated Papers	1 100	4.50	4 950
TOTALS	20 400	-	123 200

Source: Beak Consultants (1977), McCubbin (1984), Statistics Canada (1986), and 1989 industry surveys.

Table 47: Summary Of Annual Pollution Costs Incurred By The Pulp And Paper Industry. (1989 Dollars)

EQUIPMENT	COST ($1 000)
Water Pollution Control	
- Capital Costs	208 500
- Operating Costs	123 200
Atmospheric Emission Control	
- Capital Costs	
Kraft Mills	36 370
Other Mills	36 000
- Operating Costs	
Kraft Mills	14 080
Other Mills	14 000
TOTAL	432 150

Source: Beak Consultants (1977), McCubbin (1984), Statistics Canada (1986), and 1989 industry surveys.

5.4 Social and Environmental Pressures

By far the most important and far-reaching environmental and sociological change which will most likely impact the Pulp and Paper industry is that of recycling. No longer a radical idea, recycling poses a serious threat to the existing Canadian Pulp and Paper industry. This issue was presented in the October 1, 1989 CBC broadcast of "Venture". The topic was presented from the viewpoint of the recycling pressures (newsprint) being exerted upon the newspaper publishers in various U.S. cities. This pressure comes in the form of a new government legislation dictating that large publishers will be expected to use at least 90% recycled newsprint within the next decade. Putting this into a Canadian perspective, it should be noted that Canada exports 80% ($5.7 billion in 1986) of its newsprint production to the United States. It is imperative that the Canadian industry respond to these changing conditions, or risk losing major market share. Whether this will occur remains to be seen, because on the same broadcast, Canadian industry leaders were unveiling plans for new, large-scale, expansion, none of which addressed the recycling issue. If present plans are not adjusted, future responses will involve major capital outlays with, most probably, marginal returns.

6.0 PETROLEUM REFINING WASTES

6.1 Processes

Transforming crude oil into petroleum products involves 4 major process categories:
(a) separation, (b) conversion, (c) treatment, and (d) blending.

6.1.1 SEPARATION

Separation involves the physical separation of different classes of molecules. For example, removing inorganic salts from crude oil, fractionating the products of each process, and removing impurities from the products. Separation is generally achieved by atmospheric vacuum distillation.

6.1.2 CONVERSION

Conversion processes such as cruding, reforming, and alkylation use the natural fractions of the crude as raw materials to produce new hydrocarbons. Conversion changes the less desirable hydrocarbons into more marketable types. Conversion is achieved by cracking processes. There are four major cracking methods, these include; catalytic cracking, hydrocracking, visbreaking, and coking.

6.1.3 TREATMENT

After primary separation, most crude fractions contain impurities. Treatment processes are implemented to increase the number of products that can be made from the heavy distribution fraction, the reduced crudes, and to improve the overall quality of many products. The methods of treatment can be divided into hydrotreatment, chemical treatment, gas treatment, and physical treatment.

6.1.4 BLENDING

Blending and additives -- Blending is the final step in producing finished petroleum products to meet quality specifications and market demand. The blending operation involves accurate proportioning of the base stocks along with proper mixing to produce a homogenous product.

Improvement of the properties of the products is achieved by the use of additives. For example, tetraethyl-lead is added to gasoline to increase the octane number. Anti-oxidants, anti-icing agents and metal de-activators are used to inhibit gum formation.

6.2 Sources and Characteristic of Waste

6.2.1 AIR EMISSIONS

The potential sources of the various gaseous contaminants are summarized in Table 48. This table details contaminant concentrations, based on 200,000 British barrels/day of crude feed. The major contributor to the air pollutants are the hydrocarbons. Emissions from the petroleum refining industry account for nearly 8% of the total annual hydrocarbon emissions (2 million tons for the year, 1980).

6.2.2 WASTE WATER

The major use of water in petroleum refining is for steam generation and heat transfer. The summary of refinery wastewater sources is shown in Table 49. Raw refinery wastewater contains large quantities of both free (floatable) and emulsified oils. Water soluble hydrocarbons (i.e., phenolic compounds) present in petroleum also appear in the wastewater. Trace heavy metals can be found in wastewater depending on the type and quantity of corrosion inhibitor used in the non-contact cooling water circuits.

Table 48: Module Atmospheric Emissions, Fuel Oil Refinery Module (lb/day)

Basis: 200 000 bbl/day Crude Feed

	Particulate	SO_4	CO	Hydrocarbons	NO_3
Crude distillation	3 080	6 400	533	533	5 330
Gas oil hydrotreater	280	539	90	128	1 084
Naphtha hydrotreater	19	27	16.2	27.7	219
Heavy Naphtha reformer	1 960	4 073	340	340	3 390
Propane deasphalting unit	474	673	49.6	84.8	680
Deasphalted oil hydrotreater	30	42	25.2	42.9	340
Tail gas treating	3.4	3 410[*]	3.0	4.9	39
Light ends recovery	2.6	3.7	2.2	3.8	30.4
C_s/C_o isomerization	120	250	21	20.8	208
Storage					
1). Crude	–	–	–	7 550	–
2). Motor gasoline	–	–	–	3 730	–
3). Light fuel oil	–	–	–	564	–
4). Heavy fuel oil	–	–	–	neg	–
Sludge incineration	354	597	125	41	510
Miscellaneous emissions	–	–	–	60 900	–
Total	6 320	16 000	1 200	73 970	11 830

[*] Mainly due to the tail gas itself.

Source: Sittig, 1978.

Table 49: Summary of Refinery Wastewater Effluents and Applicable Treatments

	Major pollutant present								Applicable treatments			
Waste sources	H_2S	NH_3	Phenol	Oil	Dissolved Solids	Suspended Solids	BOD	COD	In-Plant*	Primary Treatment	Secondary Treatment	Tertiary Treatment
Process wastes												
Crude desalting	–	–	x	x	x	–	x	x	–	x	x	x
Atmospheric distillation	x	x	x	x	–	–	x	x	x	x	x	–
Pentane deasphalting	–	–	–	x	–	–	x	x	–	x	x	–
Deasphalted oil HDS	x	x	–	x	–	–	x	x	x	x	x	–
Partial oxidation	x	x	–	x	x	–	x	x	x	x	x	x
Hydrocracking	x	x	–	x	–	–	x	x	x	x	x	–
Fluid catalytic cracking	x	x	x	x	–	–	x	x	x	x	x	–
HF alkylation	x	–	x	x	–	–	x	x	x	x	x	–
Sulfur recovery (tail gas treating unit)	x	–	–	–	–	–	–	–	x	–	–	–
Refinery cooling system**												
(cooling tower)	–	–	–	–	x	–	–	–	–	–	–	x
Auxiliary refinery systems and wastes												
Stream generation	–	–	–	–	x	–	–	–	–	–	–	x
Electric power generation	–	–	–	–	x	–	–	–	–	–	–	–
Sanitary wastes***	–	–	–	–	–	x	x	–	–	–	x	x
Precipitation runoff†	–	–	–	x	–	x	x	x	–	x	–	–
Water treatment wastes	–	–	–	–	x	x	–	–	–	x	–	x
Miscellaneous operations	–	–	–	x	x	x	x	x	–	x	x	–

*Refers to sour water stripper.

**Cooling tower operating at 20 cycles of concentration.

***Represents refinery sanitary waste, only.

†Includes runoff from process and tank areas, only.

Source: Sittig, 1978.

The Canada Petroleum Refinery Effluent Regulations, issued in November 1973, established the regulation guidelines for new refineries. The regulations and guidelines limit the deposits of oil and grease, phenols, sulfide, ammonia, nitrogen, total suspended solids, and the pH level (Table 50). Table 51 shows the compliance status of water pollution abatement for the petroleum refining industry. Of the 36 operating refineries in Canada, one had no discharge during the year, 5 were in compliance 100 percent of the time, and 13 exceeded the discharge limits more than 5 percent of the time. On a regional basis, with the exception of refineries in the Quebec region, the actual discharges of oil and grease and suspended solids did not exceed the authorized level substantially (20 and 10 percent respectively). Refineries in all regions reported discharges well below the authorized levels of phenols, sulfides, and ammonia.

6.2.3 SOLID WASTES

The sources of solid wastes are highly variable and are summarized in Table 52. Using estimates of aggregated solid waste generation in the United States, the solid wastes generated for three baselike refineries are presented in Table 53.

Table 50: Amounts to Be Used for Calculating Maximum Allowable Deposits of Substances.

	Monthly amount lb/10^3 bbl/d (kg/10^3 m^3/d) of crude oil		One-day amount lb/10^3 bbl/d (kg/10^3 m^3/d) of crude oil		Maximum daily amount lb/10^3 bbl/d (kg/10^3 m^3/d) of crude oil	
Substance	Guidelines	Regulations	Guidelines	Regulations	Guidelines	Regulations
Oil and Grease	6.0 (17.1)	3.0 (8.6)	11.0 (31.4)	5.5 (15.7)	15.0 (42.8)	7.5 (21.4)
Total Suspended Matter	14.4 (41.1)	7.2 (20.5)	24.0 (68.5)	12.0 (34.2)	30.0 (85.6)	15.0 (42.8)
Phenols	0.6 (1.7)	0.3 (0.9)	1.1 (3.1)	0.55 (1.6)	1.5 (4.3)	0.75 (2.1)
Sulphide	0.2 (0.6)	0.1 (0.3)	0.6 (1.7)	0.3 (0.9)	1.0 (2.9)	0.5 (1.4)
Ammonia Nitrogen	5.0 (14.3)	3.6 (10.3)	8.0 (22.8)	5.7 (16.3)	10.0 (28.5)	7.2 (20.5)
pH					6.0 to 9.5	
Toxicity					No more than 50% fish mortality	

Note: The regulation and guideline limits are in imperial units only; metric units in brackets have been rounded.

Source: Environment Canada, 1987.

Table 51: Water Pollution Abatement, Canadian Petroleum Refining Industry, 1980

		Atlatic Region	Quebec Region	Ontario Region	Western & Northern Region	Pacific Region
Number of refineries		4	7	8	9	7
Reference crude rate (1 000 m^3/day)		45.28	87.2	103.3	63.52	27.68
Oil and grease (kg/1 000 m^3)	Actual	4.3	20.19	5.58	2.6	9.6
	Authorized	15.6	17.2	13.73	16	16.6
Phenols (kg/1 000 m^3)	Actual	0.26	1.29	0.14	0.3	1.4
	Authorized	1.5	1.7	1.37	1.7	1.7
Sulphides (kg/1 000 m^3)	Actual	0.05	0.37	0.05	0.01	0.4
	Authorized	0.51	0.57	0.46	0.6	0.5
Ammonia (kg/1 000 m^3)	Actual	3.3	9.1	4	1.3	4.8
	Authorized	13.6	14.3	12.73	13.7	14
Suspended solids (kg/1 000 m^3)	Actual	15.59	46.19	15.3	7.9	13.1
	Authorized	37.5	41.2	33.18	38.6	40

Source: Environment Canada, *Status Report on Abatement Pollution from the Canadian Petroleum Refining Industry 1980,* EPS 3-WP-83-3, March 1983.

Table 52: Petroleum Refinery Solid Wastes-sources and Characteristics

Type of wastes	Sources	Description	General characteristics
Process solids	Crude oil storage, desalter	Basic sediment water	Iron rust, iron sulfides, clay, sand, water, oil
	Catalytic cracking	catalyst fines	Inert solids, catalyst particles, carbon
	Coker	Coker fines	Carbon particles, hydrocarbons
	Alkylation	Spent sludges	Calcium fluoride, bauxite, aluminum chloride
Lube oil treatment	spent clay sludge,	clay acid sludge, oil press dumps	
	Drying and sweetening	Copper sweetening residues	Copper compounds, sulfides hydrocarbons
	Storage tanks	Tank bottoms	Oil, water, solids
	Slop oils treatment	Precoat vacuum filter sludges	Oil diatomaceous earth, solids
Effluent treatment solids	API separator	Separator sludge	Oil, sand, and any of the above process solids
	Chemical treatment	Flocculant aided precipitates	Aluminum or ferric hydroxides calcium carbonate
	Air flotation	Scums or froth	Oil, solids flocculants (if used)
	Biological treatment	Waste sludge	water, biological solids inerts
General waste	Water treatment plant	Water treatment sludges	Calcium carbonate, alumina ferric oxide, silica
	Maintenance	Heat exchanger bundle cleaning	Iron rust, sediment, oil

Source: Sittig, 1978.

Table 53: Estimation of Base Case Solid Waste Generation

	Total estimated U. S. refinery Solid waste generation rate* (West basin)		Base case refinery solid-waste Generation	
			200 000 BPD East and Gulf Coast refineries	175 000 BPD West coast Refinery
Solid waste stream	(tons/year)	(tons/10^6 BPD)	(tons/year)	(tons/year)
Neutralized HF alkylation sludge	18 430	4.25	264	231
Coke fines	3 820	0.88	54.6	47.8
FCC catalyst fines	34 100	7.85	487	426
API separator sludge	76 500	17.6	1 091	955
Nonleaded product tank storage	91 500	21.1	1 308	1 145
Slop oil emulsion solids	37 200	8.57	531	465
Cooling water sludge	41 300	9.5	589	515
Waste bio sludge**	89 500	20.6	1 277	1 117
Storm water runoff silt	33 200	7.65	474	415
Boiler feedwater lime sludge	858 700	197.9	12 270	10 736
Kerosene filter clays	4 800	1.1	68	60
Exchanger bundle clearing sludge	1 450	0.33	20.4	17.9
Air flotation float	66 200	15.25	946	828
Crude tank sludge	830	0.19	11.8	10.3
Cooling tower sludge	500	0.12	7.5	6.6
Leaded tank sludge	1 840	0.42	26	22.8
Total	1 359 870	313.3	19 425	16 700

Note: Unit loads are based on a total U. S. refining capacity of 14×10^6 BPD or 4 340×10^6 barrels per year.

*Source: "Assessment of Industrial Hazardous Waste Practice, Petroleum Refining — Draft Report," U. S. Environmental Protection Agency, January 1975.

**Waste bio sludge estimate is on a wet basis, and therfore differs from the estimates of incinerated sludge presented in the water pollution section.

Source: Gurnham, 1985.

7.0 AGRICULTURE -- PESTICIDES AND INORGANIC FERTILIZERS

7.1 General

Agriculture, the largest user of pesticides, consumes about 72% of the volume sold annually. Pesticides contribute to high agricultural productivity and to the control of insect borne diseases. Approximately one third of the world's food crops are destroyed by pests during growth, harvesting, and storage. It is believed that without chemical control, losses would be 30 to 40% higher. The cost of pesticide research and development is extremely high and presently is undertaken by only large multinational companies. The Canadian Agricultural Chemicals Association states that 96% of all the pesticide active ingredients sold in Canada originate from the USA, West Germany, Belgium, and Japan. The actual pesticide formulation is performed in.Canada, with the majority of the plants located in Western Canada or Ontario.

In Canada, before any new chemical compound can be sold, it must be approved and licensed by the Canadian Department of Agriculture. Statistics for 1985 (Table 54), indicate that over 500 pesticide active ingredients were registered in Canada for use in about 5,000 pest control products. The listed active ingredients (Table 54) represent over 80% of the total sales for their respective pesticide category.

7.2 Pesticide Applications

In 1985 (most recent year for which complete data is available), 36,175 metric tonnes of pesticide active ingredients were sold in Canada (Table 55). The majority, 83.4% was in the herbicide category, while insecticides and fungicides accounted for 8.8% and 7.8%, respectively (other classes include rodenticides, fumigants, and growth regulators). From a provincial usage perspective, as is expected, the prairie provinces (Saskatchewan, Manitoba, and Alberta) dominate by utilizing 69.1% of the total herbicides and 51.3 of the total insecticides sold in Canada. The highest individual user is Saskatchewan which applied 10,577 tonnes, or 29.2% of the Canadian total (pesticide active ingredients) (Pierce and Wong, 1988).

Table 54: The Major Pesticides Sold In Canada And Their Uses (1985)

PESTICIDE	MAJOR FIELD OF USE
Herbicides	
Alachlor	control of weeds in beans, corn, potatoes, and soybeans
Atrazine	control of grassy weeds in corn; soil sterilant on non-cropland
Bromoxynil	weed control in barley, canary seed, corn, flax, oats, and wheat
2,4-D	weed control, soil sterilant, and aquatic weed control
Difenzoquat	post-emergent control of wild oats in barley, canary grass and wheat
Diclofop-methyl	control of annual grasses in alfalfa, barley, soybeans, vegetables, wheat, flax and canola
Glyphosate	non-selective weed control in field crops, non-cropland and turf
MCPA	control of weeds in alfalfa, barley, corn, flax, oats, rye, and wheat
Metolachlor	control of weeds in corn, soybeans, and potatoes
Triallate	pre-emergent control of wild oats in barley, flax, mustard, peas, canola, sugar beets, and wheat
Trifluralin	pre-emergent weed control in field crops and vegetables
Insecticides	
Carbaryl	control of specified insects in livestock buildings, field crops, and fruits and vegetables
Carbofuran	control of specified root worms, maggots, beetles, and leafhoppers
Chlorpyrifos	control of specified insects in field crops, vegetables, and fruits; seed treatment for corn, beans, and peas; mosquito control
Diazinon	control of certain insects on fruits, vegetables, turf, and non-cropland ;insect control in livestock buildings; seed treatment
Fenitrothion	control of certain insects on fruits, vegetables, turf, and non-cropland ;insect control in livestock buildings; seed treatment
Fonofos	control of specified insects in corn, onions, potatoes, and tobacco
Lindane	control of insects on livestock, lawns, certain grains; seed treatment
Malathion	control of specified insects on livestock and in certain field crops
Phorate	control of specified insects on beans, corn, lettuce, and potatoes
Terbufos	control of specified worms in corn and sugar beets; control of flea beetles in mustard and canola
Fungicides	
Captan	control of specified fungal diseases on potato seed pieces, flowers, fruits, vegetables, turf, and tobacco
Chlorothalonil	control of fungal diseases on vegetables, potatoes, tomatoes, turf, and conifers
Mancozeb	control of specified fungal diseases on various fruits, vegetables and corn and potato seeds
Maneb	control of specified fungal diseases on certain fruits and vegetables; seed treatment for barley, flax, oats, rye, sugar beets, and wheat
Metiram	control of specified fungal diseases on potato seed pieces; seed treatment for barley, flax, oats, and wheat
Thiram	control of specified fungal diseases in turf; seed treatment for wheat, vegetables, mustard, canola, barley, rye, oats, flax, corn, soybeans, alfalfa, and fruits

Source: Environment Canada/Agriculture Canada, 1987

Table 55: Quantities Of Pesticides Sold In Canada (1985 in tonnes)

PROVINCE	HERBICIDES	INSECTICIDES	FUNGICIDES	TOTALS
Newfoundland	3	-	< 1	3
PEI	58	41	328	427
Nova Scotia	67	25	138	230
New Brunswick	153	89	359	601
Quebec	1 912	278	490	2 680
Ontario	6 819	998	1 035	8 852
Manitoba	4 306	281	174	4 761
Saskatchewan	9 607	897	73	10 577
Alberta	6 932	449	87	7 468
British Columbia	323	114	139	576
CANADA	30 180	3 172	2 823	36 175

Source: Environment Canada/Agriculture Canada, 1987

In Canada, the sale of pesticides has increased every year until 1985 and then showed a substantial decrease in 1986 (Tables 56 and 57). This drop corresponds to a set of restrictions put forth by Agriculture Canada which directly impacted many of the active ingredients used to formulate Canadian herbicides and insecticides. For example, on December 31, 1985, the use of all products containing chlordane was suspended, affecting the registration of 43 different products. Chlordane is a broad-spectrum insecticide used to control certain soil insects as well as spiders. Registration was also cancelled for the 39 products containing the following; 2,4,5-T, alachlor - a herbicide used to control weeds in corn, soybean, and potato crops, dinoseb - a herbicide used in pea and bean production, and barban - a wild oat herbicide (Cedar,1986). These reductions, new methods of pest control which are being introduced and slowly adapted, and farm attrition, are most likely responsible for the reported drop in sales.

The physical application of pesticides is most often accomplished through spraying and dusting. Based on the area to be covered, there are four categories of application:

1. band - when a continuous strip must be treated.
2. broadcast - when an entire area must be covered.
3. spot treatment - when small distinct areas must be covered.
4. directed spraying - to treat selected weeds or to avoid crop contact.

Application efficiency is directly related to the method chosen, the inclination of the treated field, pesticide formulation, precipitation after application, reaching the target site, and the scale of the operation. For example, precipitation within 2 weeks after spraying can increase runoff losses from 0.5% to 20%. Furthermore, it has been noted that the concentration of pesticide residues in surface runoff is normally higher in those areas where the pesticide has been applied to the foliage versus direct soil application.

In Canada, in 1985, over 44 million hectares (ha) of farm land were "treated". Of this total, almost 27.5 million ha were sprayed or dusted which is a 63.2% increase over 1980 (Table 58). In terms of treated area, the Prairie provinces dominate with 80% (Saskatchewan - 21 million ha, Alberta - 13 million ha, and Manitoba - 5.5

Table 56: Retail Sales Of Pest Control Products In Canada (1983-87)
(Millions of Dollars)

PRODUCTS	1983	1984	1985	1986	1987
CANADA					
Herbicides	528.7	577.4	632.6	540.6	511.0
Insecticides	53.7	58.3	101.2	97.9	53.0
Fungicides	38.3	41.3	42.8	42.9	30.0
Rodenticides	2.6	3.9	3.1	2.1	4.5
Soil Fumigant /nematocides	8.8	8.2	6.3	6.5	7.3
Growth Reg.	4.8	4.9	6.9	6.5	6.0
Livestock Pesticides	6.6	8.7	7.9	7.0	11.4
Home & Gar.	64.6	73.8	66.0	55.2	50.8
Other	1.2	2.3	2.5	3.5	33.2
Total	709.3	778.8	869.3	762.3	707.3
EASTERN	PROVINCES				
Herbicides	119.2	124.2	154.4	143.8	140.5
Insecticides	34.4	33.5	46.8	39.4	35.6
Fungicides	25.7	23.9	24.2	21.1	25.0
Rodenticides	1.8	3.0	2.5	1.8	3.4
Soil Fumigant /nematocides	8.6	8.1	6.0	6.3	7.0
Growth Reg.	4.4	4.5	6.2	6.0	4.7
Livestock Pesticides	4.1	4.5	3.7	3.0	5.9
Home & Gar.	53.3	48.7	45.7	38.4	35.9
Other	1.2	1.9	2.0	2.7	6.1
Total	252.7	252.4	291.7	259.5	264.3
WESTERN	PROVINCES				
Herbicides	409.5	453.1	478.3	396.8	370.5
Insecticides	19.3	24.8	54.4	58.5	17.4
Fungicides	12.6	17.4	18.6	21.8	5.0
Rodenticides	0.8	0.9	0.6	0.4	1.1
Soil Fumigant /nematocides	0.3	0.2	0.2	0.2	0.3
Growth Reg.	0.3	0.5	0.7	0.5	1.3
Livestock Pesticides	2.5	4.2	4.1	4.1	5.5
Home & Gar.	11.3	25.1	20.3	16.8	14.9
Other	0	0.4	0.5	0.8	27.0
Total	456.6	526.6	577.6	499.9	443.1

Source: Handbook of Selected Agricultural Statistics, 1988

Table 57: Provincial Farm Pesticide Expenditures (1983-87)
(Millions of Dollars)

PROVINCE	1983	1984	1985	1986	1987
Newfoundland	0.21	0.21	0.23	0.26	0.29
PEI	5.7	5.8	6.1	6.3	6.6
Nova Scotia	3.2	3.4	3.4	3.4	3.6
New Brunswick	5.7	5.8	5.8	6.0	6.0
Quebec	30.3	30.9	32.8	37.6	39.5
Ontario	126.3	127.4	129.1	135.0	128.5
Manitoba	97.8	110.0	115.3	106.1	107.3
Saskatchewan	179.4	208.0	237.3	227.1	205.6
Alberta	124.8	141.0	146.0	148.9	132.0
British Columbia	10.6	11.8	12.7	13.7	14.4
TOTAL	584.0	644.4	688.7	684.4	643.8

Source: Handbook of Selected Agricultural Statistics, 1988

Table 58: Spraying And Dusting By Province (1980 and 1985)

PROVINCE	1980		1985	
	Number of Farms	Hectares Dusted or Sprayed	Number of Farms	Hectares Dusted or Sprayed
Newfoundland	217	1 171	182	1 553
PEI	2 243	113 771	1 953	120 586
Nova Scotia	1 541	31 972	1 439	36 902
New Brunswick	1 524	67 030	1 351	71 372
Quebec	17 082	489 171	17 484	617 022
Ontario	50 891	2 307 639	46 206	2 408 446
Manitoba	17 462	2 787 654	19 755	4 000 316
Saskatchewan	39 179	5 951 839	53 671	13 232 748
Alberta	31 778	4 969 889	33 600	6 872 762
British Columbia	5 795	152 177	6 000	171 924
TOTAL	167 712	16 868 980	181 641	27 533 632

Source: Canada Yearbook, 1988.

million ha), while Ontario is next with 4.1 million ha.

7.3 Pesticide Side Effects and Hazards

The use of pesticides has now become an integral part of modern farm management. However, high application rates are often required and this may be responsible for undesirable side effects and hazards to the environmental system. These include:

** the destruction of non-target species
** the development of immunity
** secondary pest outbreak
** accumulation in the food chain
** persistence in various ecosystems
** contamination of irrigation water
** transport to water resource systems

The persistence of a pesticide is a measure of the time required for the complete degradation of the material into harmless products. Since the primary mode of degradation is biochemical, factors which reduce biological activity decrease the rate of degradation. These include; low soil moisture content, low oxygen content, low temperature, low organic matter content, and extreme pH. The relative influence of each factor depends on the specific pesticide and site conditions. As noted, the risk of environmental pollution is highest with those chemicals that exhibit the greatest persistence. In that regard, arsenic, chlorinated hydrocarbon insecticides, and triazine herbicides represent the most "dangerous" of these pesticides.

7.4 Pesticide Production Wastes

Many pesticide wastes are aqueous solutions or suspensions of organic and halogenated organic compounds. Some biocide wastes are generated in the production of dieldrin, methyl parathion, dioxin, aldrin, chlordane DDD, DDT, 2,4-

D, endrin, guthion, heptachlor, and lindane. Inorganic based wastes result from the production of arsenic, arsenate, and mercurial compounds. Thallium and thallium sulfate are found in rodenticide wastes.

Pesticide wastes result largely from the periodic cleaning of formulation lines, filling equipment, spills, area washdown, drum washing, air pollution control devices, and area run-off. Wash waters are steam condensates from cleaning operations and are the sources of liquid wastes from the formulation lines and filling equipment. Steam cleaning condensates and rinse water from other processing units such as mix tanks, drum washers, and air pollution control equipment are also sources of pesticide wastes. The scrubber waters themselves constitute a waste stream with area washdowns, leaks, and spills making up the remaining principal sources.

The principal constituents of wastewaters from the pesticide industry are dissolved organics, suspended solids, dissolved inorganic solids, and variable pH. Unfortunately, the large variety of manufactured end products effectively precludes the presentation of a "general" waste composition chart or table.

Because of the great range of sizes of pesticide manufacturing plants, it is plausible to accept the occurrence of the following developments with respect to the disposal of generated wastes. For the small generator, the produced wastes, due to small volumes, might be accepted into a municipal wastewater management system. In such an instance, the pollution impact, if discernable, would be minor. For the large generator, an in-plant waste-water pretreatment or treatment system would likely be in place, with the waste being treated, wholly or partially, and then concentrated. The concentrated waste would then be disposed of in a landfill, stabilized, or containerized and then landfilled.

7.5 Case Study: Ontario Section of the Great Lakes Drainage Basin

Table 59 provides a comparison of quantities of the active ingredients in pesticides used in the Ontario part of the Great Lakes drainage basin. During the period surveyed, the data show substantial increase in the use of both herbicides and insecticides for field crops in all drainage basins, except for insecticide use in the Lake Erie basin. Southwestern Ontario is one of the most intensive areas of agricultural chemical application in Canada. However, the area of concentration becomes more striking when one considers that 90% of the insecticides and 60% of the herbicides applied to field crops in 1973 and 1978 were in the Lake Erie - Lake St.Clair basin. This basin is smaller than the Lake Ontario basin, and is about one third the size of Lake Huron and the Georgian Bay basin.

The data from the NAQUADAT (National Water Quality Data Bank) water quality datafile in the western region regarding the presence of 2,4-D in surface water samples from the western region water basins for the period 1971 to 1982 are summarized in Table 60. The maximum acceptable level for 2,4-D as per Canadian Drinking Water Objectives is 100 mg/l and the desirable level is 1.0 mg/l. The data show that there is no evidence that 2,4-D is causing widespread contamination of river basins. Also the NAQWEST (National Water Quality Data Bank for Western Regions) datafile entries recorded for dieldrin, endrin, and chlordane indicate levels below the detection limits in 99.5% of the cases. Some data reported detectable levels of aldrin, DDT, lindane, methoxychlor, and 2,4,5-T, but` these values were substantially lower than published guidelines.

Some pesticides are known to be highly persistent, mobile, and bio-accumulative and have been associated with adverse ecological or human health effects. Compounds such as DDT (or its metabolite DDE), dieldrin, and the dioxin 2,3,7,8-TCDD are examples of this category. Consequently, levels of DDT and dieldrin in tobacco soils in Ontario have been sampled sporadically since 1970. The results of tests where samples have been obtained from more than 30 farms, (although the fields tested were not always the same), indicate that the two compounds (DDT and dieldrin) persist in the soils with their concentrations decreasing at a very small rate.

Table 59: Quantities of Active Ingredients of Pesticides Used in the Ontario Part of the Great Lakes Drainage Basin, 1973 and 1978 (kilograms)

	Quantities of Active Ingredients of Pesticides Used in Field Crops							
	1973				1978			
Drainage Basin[1]	Herbicides	insecticides	Fungicides	Total	Herbicides	insecticides[2]	Fungicides	Total
Lake Hudson & Georgian Bay	406 000	19 350	425	425 775	715 250	26 470	1 090	742 810
Lake St. Clair	515 160	226 520	240	741 920	1 114 270	310 340	2 070	1 426 680
Lake Erie	466 840	1 160 030	3 570	1 630 440	687 680	980 050	860	1 668 590
Lake Ontario	225 030	18 380	70	243 480	405 120	25 320	460	430 900
Total	1 613 030	1 424 280	4 305	3 041 615	2 922 320	1 342 180	4 480	4 268 980

	Quantities Used on Field Crops, Fruits, Vegetables & Roadsides			
	1978			
Drainage Basin[1]	Herbicides	insecticides[2]	Fungicides	Total
Lake Hudson & Georgian Bay	1 014 590	94 400	91 580	1 200 570
Lake St. Clair	1 217 130	327 390	26 320	1 570 840
Lake Erie	1 094 540	1 347 270	91 740	2 533 550
Lake Ontario	683 410	203 920	157 640	1 044 970
Total	4 009 670	1 972 980	367 280	6 349 930

[1] For the field crop comparisons, the drainage basin defined in the 1978 report were used except for the elimination of lakeside land from each basin. For the field crops, fruit, vegetables and roadsides summary,all areas were included as shown in the 1978 report.

[2] For 1978, insecticides is an aggregate of insecticides, nematocides and growth regulators.

For all Ontario in 1978, 5 herbicides accounted for 75% of the herbicides used, 7 insecticides accounted for 50% of the insecticides used, and 1 nematocide accounted for 60% of the nematocides, fungicides and growth regulators.

Source: Ontario Ministry of Agriculture and Food, *Survey of Pesticide Use in Ontario 1973* and *Survey of Pesticide Use in Ontario 1978*.

Table 60: NAQUADAT Water Quality — 2,4-D[1]

Drainage Basin	1971-73			1974-76			1977-79			1980-82		
	Number of samples	% of samples >0.5μg/L	% of samples >1.0μg/L	Number of samples	% of samples >0.5μg/L	% of samples >1.0μg/L	Number of samples	% of samples >0.5μg/L	% of samples >1.0μg/L	Number of samples	% of samples >0.5μg/L	% of samples >1.0μg/L
1 Atlantic Coast												
2 Gulf of St. Lawrence												
3 Bay of Fundy												
4 St. Lawrence River												
5 Ottawa River												
6 Lake Ontario												
7 Lake Erie/St. Clair												
8 Lake Hudson												
9 Lake Superior												
10 Hudson Bay	14	0	0	39	0	0	67	0	0	78	0	0
11 Nelson Bay	–			–			–			–		
12 Lake Winnipeg	32	3.1	0	77	0	0	160	4.4	3.8	183	0	0
13 Assiniboine River	295	8.5	3.4	304	1.3	0.7	155	3.9	1.3	140	0	0
14 Saskatchewan River	288	0	0	442	0	0	381	1.8	0.5	378	0.3	0
15 Mackenzie River	106	0	0	149	0	0	66	0	0	90	0	0
16 Arctic Ocean												
17 Columbia River												
18 Fraser River												
19 Yukon River												
20 Pacific North Coast												
21 Pacific South Coast												
22 Milk River	6	0	0	31	0	0	77	0	0	85	0	0
Total	743	3.5	1.3	1 042	0.4	0.2	906	2.2	1.1	954	0.1	0

[1] Data from NAQWEST only.

[2] NAQUADAT parameter code for 18500 was used to prepare this table.

[3] Herbicide formulation industries are located near Regina and Winnipeg (Water Basins 12 and 13).

Source: Environment Canada, NAQWEST portion of NAQUADAT database.

Before the use of organochlorine pesticides in the late 1960's, a number of other pest control and agricultural practices resulted in the contamination of certain agricultural soils with arsenic, lead ,and mercury. Lead arsenate was widely used as an insecticide in apple and cherry orchards and various mercuric salts were used as fungicides. Measurements for arsenic, cadmium, and mercury in a variety of Ontario agricultural soils, collected between 1972 and 1975, are summarized in Table 61. Higher concentrations of arsenic, lead, and mercury were observed in those soils whose crops had been treated with compounds containing these elements.

7.6 Inorganic Fertilizer Application

Fertilizers are classified into 3 major groups on the basis of nutrients supplied, these include nitrogen, phosphorous, and potassium fertilizers. The consumption of fertilizers in the world for the year 1986-87 was about 134 million tons. The amount of commercial fertilizers used by the different provinces in Canada, during the year 1985, is presented in Tables 62 and 63. Assuming an average value of 140 kg/ha per year, the recommended annual consumption for Quebec cropland is 166,500 tonnes/year and corresponds to 40% of the actual annual consumption in Quebec (Table 63). This discrepancy indicates an overuse of fertilizers, and in terms of cost, represents an annual over-expenditure of $44 million for the province of Quebec alone.

7.7 Impact of Inorganic Fertilizers on the Environment

The major source of pollution in fertilizer application arises from the use of nitrogen fertilizers. The nitrogen compounds in these fertilizers degrades the quality of the aquatic environment in surface and subsurface water courses. Presence of nitrogen in surface water causes an increase in biologic activity, the depletion of dissolved oxygen, the production algal blooms, and an overall acceleration in the rate of eutrophication. The amount of total nitrogen (organic and inorganic) should not exceed 0.5 mg/l in the aquatic environment.

Table 61: Contamination of Agricultural Soils in Ontario, 1972–75.

Contaminant	Number of Measurements	Concentration (ppm dried soil)	
		Mean	Range
Arsenic			
Apples, cherries, potatoes	89	26.5	1.66–91.6
Other crops	207	6.27	1.10–16.7
All soils	296	12.4	1.10–91.6
Cadmium			
All soils	296	0.56	0.10–8.10
Lead			
Tree & vine fruit soils	86	123.0	4.40–888.0
Other crops	210	14.1	1.50–50.1
All soils	296	45.8	1.50–888.0
Mercury			
Vegetable organic soils, apples	44	0.33	0.03–1.14
Other crops	252	0.08	0.01–0.78
All soils	296	0.11	0.01–1.14

Soils collected to represent all types of crop production. Each sample a composite of samples from 10–20 randomly selected sites and to a depth of 15cm at each location
86 samples from orchards & vineyards, 82 from vegetable producing farms, 126 from hay & cash crops and 15 from unimproved pastures.
Crops has been treated with various fertilizers and pesticides for various periods of time. Contamination levels vary with crop, with soil types and with treatment conditions.
Source: R. Frank et al., "Metals in Agricultural Soils of Ontario", *Canadian Journal of Soil Science*, 56 (1976): 181–196

Table 62: Commercial Fertilizer Use, by Province

No.	Item	Unit	Canada	Newfoundland	Prince Edward Island	Nova Scotia	New Brunswick
1	Total area fertilized, 1985	ac.	57 199 888	11 755	279 964	210 145	207 688
2		ha.	23 147 970	4 757	113 297	85 042	84 048
3	Farms reporting	No.	193 797	356	2 200	2 722	2 291
	Types of fertilizer applied on this land:						
4	Tonnes, total	No.	4 052 491	2 262	57 605	29 199	47 944
	Dry granular						
5	Tonnes used	No.	3 179 274	2 230	57 425	29 113	47 805
6	Farms reporting	"	188 757	347	2 198	2 708	2 280
	Pressurized liquid or gas						
7	Tonnes used	No.	523 397	x	174	x	114
8	Farms reporting	"	33 146	7	12	14	11
	Non pressurized liquid						
9	Tonnes used	No.	320 490	x	x	23	19
10	Farms reporting	"	8 843	4	2	7	8
	Suspensions						
11	Tonnes used	No.	29 329	–	x	x	3
12	Farms reporting	"	665	–	1	13	6

Source: Frank, 1976.

Table 63: **Commercial Fertilizer Use for Canada, Province of Quebec**

1985 — F. A. O. — Report 1986

	Canada	%	Quebec	%
Total area fertilized - ha	23 147 970		1 189 232	
Type of fertilizers applied				
Total - Tones	4 052 491		455 907	
Dry granular (1) Tonnes	3 179 274	.76	435 962	.96
(2) Costs	$845 Millions		$105 Millions	
pressurized liq/gas	188 757	.13	15 475	.03
non pressurized liquid	320 490	.08	4 331	.009
suspensions	29 329	<.01	139	<.001

Nitrogen, in the nitrate form, is transported from agricultural land by soil erosion, runoff, and leaching. Nitrate contamination is a worldwide problem and in many areas, the groundwater nitrate concentration exceeds the recommended limit for drinking water (10 mg/l). Table 64 shows the various chemical and physical processes that can be used in the removal of various nitrogen compounds. However, it should be noted that the methods tend to be costly, even if they are not totally effective.

Gaseous loss of nitrogen can also occur from soils; the most important process being denitrification wherein nitrates are reduced to nitrogen oxide compounds and to elemental nitrogen by microbial action. The loss of nitrous oxide (N_2O) from the soil to the atmosphere is considered to have a detrimental effect on the environment. For example, released N_2O may participate in reactions that result in the destruction of the ozone layer, the earth's natural protective shield against the sun's harmful ultraviolet radiations.

Table 64: Chemical and Physical Processes for the Removal of Various Nitrogen Compounds

Process	Type[a]	Nitrogen Removal, %		
		NH_3	Org N	NO_3^-
Adsorption	P		50–90	
Chemical Treatment				
Guggenheim	C,P	80–95	60–80	
With Chlorine	C	80–95		
With Ozone	C	80–95		
Reduction	C			50–90[b]
Electro-chemical	C	70–85		
Filtration[c]	P		20–40	
Flotation	P		20–40	
Gas Phase Separation	P	50–70[d]		
Ion Exchange				
Standard Resins	P	85-98	80-95	80-90
Organic Scavengers	P		60-90	
Zeolites	P	85-98		
Land Application	P	60–80	80–95	5–15
Precipitation				
Alum	C		30-50	
Lime	C	5-15	30-50	
Air Stripping	C,P	85–98		
Demineralization				
Distillation	P	—[e]	—[e]	90-98
Electrodialysis	C	—[f]	—[f]	—[f]
Reverse Osmosis	P	60–85	60-85	50–70

[a] P = physical, C = chemical

[b] Conversion to ammonia

[c] Settled sewage effluent

[d] Process is not developed fully

[e] Carry-over varies with operation

[f] Reliable data unavailable

Adapted from G. Tchobanoglous, 1970.

8.0 MUNICIPAL SOLID WASTE

8.1 Classification and Sources

As noted in Table 65, the material commonly found in municipal solid waste (MSW) may be classified under – food wastes, rubbish, ashes and residues, demolition and construction wastes, special wastes, and treatment plant wastes. The detailed description of the various kinds of individual substances given in the Table shows great potential for generation of leachates which would, under normal circumstances, be classified as either toxic or hazardous. A simple example is the transistor radio batteries which generally end up in the household garbage bin, they will produce toxic metal leachates when exposed to weathering conditions typical in a landfill dump. The list in Table 65 shows many more substances which will produce the same type of leachates.

Municipal solid waste (MSW) encompasses the heterogeneous mass of THROWAWAYS from residential and commercial sources, open areas, and treatment plant sites (Table 66). Providing regulations concerning disposal or management of these wastes is almost impossible if proper cooperation from the "public" is not obtained. The consumer needs the necessary sets of controls if sensible disposal of various potential hazardous leachates (from MSW) is to be implemented.

Table 65: Classification of Materials Comprising Municipal Solid Waste

Compound	Description
Food wastes	The animal, fruit, or vegetable residues (also called garbage) resulting from the handling, preparation, cooking, and eating of foods. Because food wastes are putrescrible, they will decompose rapidly, especially in warm weather.
Rubbish	Combustible and noncombustible solid wastes, excluding food wastes or other putrescrible materials. Typically, combustible rubbish consists of materials such as paper, cardboard, plastics, textiles, rubber, leather, wood, furniture, and garden trimmings. Noncombustible rubbish consists of items such as glass, crockery, tin cans, aluminum cans, ferrous and nonferrous metals, dirt, and construction wastes.
Ashes and residues	Materials remaining from the burning of wood, coal, and other combustible wastes. Residues from power plants normally are nor included in this category. Ashes and residues are normally composed of fine, powdery materials, cinders, clinkers, and small amounts of burned and partially burned materials.
Demolition and construction wastes	Wastes from razed buildings and other structures are classified as demolition wastes. Wastes from the construction, remodeling,a nd repairing of residential, commercial, and industrial building, and similar structures are classified as construction wastes. These wastes may include dirt, stones, concrete, bricks, plaster, lumber, shingles, and plumbing, heating, and electric parts.
Special wastes	Wastes such as street sweepings, roadside litter, catch-basin debris, dead animals, and abandoned vehicles are classified as special wastes.
Treatment-plant wastes	The solid and semisolid wastes from water, wastewater, and industrial-waste treatment facilities are included in this classification.

Source: Peavy et al. (1985).

Table 66: General Sources of Municipal Solid Wastes

Source	*Typical facilities, activities, or locations where wastes are generated*	*Types of solid wastes*
Residential	Single-family and multifamily dwellings, low-, medium-, and high-rise apartment, etc.	Food wastes, rubbish, ashes, special wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, print shops, auto repair shops, medical facilities and institutions, etc.	Food wastes, rubbish, ashes, demolition and construction wastes, special wastes, occasionally hazardous wastes
Open areas	Street, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.	Special wastes, rubbish
Treatment plant sites	Water, wastewater, and industrial treatment process, etc.	Treatment-plant wastes, principally composed of residual sludges

Source: Peavy et al. (1985).

8.1.1 PROPERTIES OF MSW

The important properties of MSW with regard to composition include:

* PHYSICAL COMPOSITION: *--individual components or constituents, particle (constituent) size, moisture content, and density.*

- *Individual Components* -- The "typical" waste stream reported by EPA (1986) shows the components identified in Table 67. It should be noted that the composition of MSW can vary significantly due to: (a) differences in climate, (b) seasonal differences, (c) social attitudes, and (d) economic considerations.

- *Particle Size* -- The size of the component material is of importance in the recovery process, especially with mechanical means such as trommel screens and magnetic separators. However, data regarding the size distribution of the various waste constituents is unavailable.

- *Moisture Content* -- Moisture content, which has a great influence on the energy content of MSW, depends on the nature of the constituents or components of the MSW (Table 68).

- *Density* -- The estimation of density is important in the calculation of the required landfill space. Typical density values are shown in Table 69. It should be noted that the density will vary with geographic location, season of the year, and length of time in storage.

* CHEMICAL COMPOSITION: -- energy content and chemical content.

- *Energy content* -- Typical data on the energy content and residues for MSW are reported in Table 70. It is of interest to note that the energy content diminishes with an increase in water content and inert residue percent.

Table 67: Components of Municipal Solid Waste

Component	Percent of all refuse by wt	Component	Percent of all refuse by wt
Rubbish (64%)		Rubbish (Cont'd)	
Paper	42.0	Street sweepings	3.0
Wood	2.4	Dirt	1.0
Grass	4.0	Unclassified	0.5
Brush	1.5	Food wastes (12%)	
Greens	1.5	Garbage	10.0
Leaves	5.0	Fats	2.0
Leather	0.3	Non-combustibles (24%)	
Rubber	0.6	Metals	8.0
Plastic	0.7	Glass and ceramic	6.0
Oils, paint	0.8	Ashes	10.0
Linoleum	0.1		
Rags	0.6	Total	100%

Source: Ham et al., 1979.

Table 68: Moisture Contents of Components of a Typical U. S. Municipal Solid Waste

Component	Moisture content (%)	Component	Moisture Content (%)
Rubbish		Rubbish (Cont'd)	
Paper	10.2	Street sweepings	20.0
Wood	20.0	Dirt	3.2
Grass	65.0	Unclassified	4.0
Brush	40.0	Food wastes	
Greens	62.0	Garbage	72.0
Leaves	50.0	Fats	0.0
Leather	10.0	Non-combustibles	
Rubber	1.2	Metals	3.0
Plastic	2.0	Glass and ceramic	2.0
Oils, paint	0.0	Ashes	10.0
Linoleum	2.0	All refuse	20.7
Rags	10.0		

Source: Ham et al., 1979.

Table 69: Typical densities for solid wastes components and mixtures

Item	Density, kg/m³	
	Range	Typical
Component*		
Food wastes	120–480	290
Paper	30–130	85
Cardboard	30–80	50
Plastics	30–130	65
Textiles	30–100	65
Rubber	90–200	130
Leather	90–260	160
Garden trimmings	60–225	105
Wood	120–320	240
Misc. organics	90–360	140
Glass	160–480	195
Tin cans	45–160	90
Nonferrous metals	60–240	160
Ferrous metals	120–1 200	320
Dirt, ashes, bricks, etc.	320–960	480
Municipal solid wastes		
Uncompacted	90–180	130
Compacted (in compactor truck)	180–450	300
In landfill (compacted normally)	350–550	475
In landfill (well compacted)	600–750	600

*Data for components is on an as-discarded basis.

Source: Peavy et al., 1985.

Table 70: Typical data on inert residue and energy content of municipal solid wastes

	Inert residue* present			Energy **, kJ/kg	
Component	w (%)	Range	Typical	Range	Typical
Food wastes	72.0	2–8	5	3 500–7 000	4 650
Paper	10.2	4–8	6	11 600–18 600	16 750
Cardboard	–	3–6	5	13 950–17 450	16 300
Plastics	2.0	6–20	10	27 900–37 200	32 600
Textiles	10.0	2-4	2.5	15 100–18 600	17 450
Rubber	1.2	8–20	10	20 900–27 900	23 250
Leather	10.0	8–20	10	15 100–19 800	17 450
Garden trimmings	45.0	2–6	4.5	2 300–18 600	6 500
Wood	20.0	0.6-2	1.5	17 450–19 800	18 600
Misc. organics	–	2–8	6	11 000–26 000	18 000
Glass	2.0	96-99**	98	100–250	150
Tin cans	5.0	96–99**	98	250–1 200	700
Nonferrous metals	–	90–99**	96		
Ferrous metals	–	94–99**	98	250–1 200	700
Dirt, ashes, bricks, etc.	3.2	60–80	70	2 300–11 650	7 000
Municipal solid wastes				9 300–12 800	10 500

*After combustion.

**As-discarded basis.

Source: Peavy et al., 1985.

- *Chemical content* -- The chemical content of the MSW is an important parameter for assessing the hazardous potential of a waste with regards to leaching and future processing. The chemical composition of the various components of typical municipal refuse are reported in Table 71. It needs to be noted that the non-combustible fraction is principally contributed to by metallic contaminants in the leachates generated from the MSW.

8.2 Municipal Solid Waste Generation in Canada

The generated amount of MSW in Canada is about 20 million tonnes per year. It is projected that by the year 2000, the amount of MSW generated will be about 1 tonne per person per year[4]. Presently, about 90% of the MSW generated goes into the ground. The annual required space to landfill the obtained waste-volume is 39 million m^3 or 2.6 km^2 (by 15m depth). Analyses of domestic wastes from select Canadian cities indicate that the principal components are generally paper and food waste. Table 72 highlights the situation for the province of Quebec.

8.3 Collection and Transport of MSW

Collection of municipal solid waste is normally handled in one of two ways: 1) by a particular department of the municipal government (i.e., public works), or 2) by waste collection companies which are given short-term contracts by the municipality. However, in certain situations, a combination of the two may be used.

Voluminous wastes (i.e., kitchen appliances) are usually collected by special collecting companies hired by the municipality. In some instances, municipalities may own their own collector vehicles and perform this task themselves.

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[4] Unpublished reports show that Canada generates the most MSW per person per year!

Table 71: Composition and Analysis of Average Municipal Refuse from Studies by Purdue University

Component	percent of all refuse by weight	Moisture percent by weight[b]	Analysis (percent fry weight)[a]						
			Volatile matter	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Non-comus-tibles
Rubbish, 64%:									
Paper	42.0	10.2	84.6	43.4	5.8	44.3	0.3	0.20	6.0
Wood	2.4	20.0	84.9	50.5	6.0	42.4	0.2	0.05	1.0
Grass	4.0	65.0	–	43.3	6.0	41.7	2.2	0.05	6.8
Brush	1.5	40.0	–	42.5	5.9	41.2	2.0	0.05	8.3
Greens	1.5	62.0	70.3	40.3	5.6	39.0	2.0	0.05	13.0
Leaves	5.0	50.0	–	40.5	6.0	45.1	0.2	0.05	8.2
Leather	0.3	10.0	76.2	60.0	8.0	11.5	10.0	0.40	10.1
Rubber	0.6	1.2	85.0	77.7	10.4	–	–	2.0	10.0
Plastic	0.7	2.0	–	60.0	7.2	22.6	–	–	10.2
Oils, paint	0.8	0.0	–	66.9	9.7	5.2	2.0	–	16.3
Linoleum	0.1	2.1	65.8	48.1	5.3	18.7	0.1	0.40	27.4
Rags	0.6	10.0	93.6	55.0	6.6	31.2	4.6	0.13	2.5
Street sweepings	3.0	20.0	67.4	34.7	4.8	35.2	0.1	0.20	25.0
Dirt	1.0	3.2	21.2	20.6	2.6	4.0	0.5	0.01	72.3
Unclassified	0.5	4.0	–	16.6	2.5	18.4	0.05	0.05	62.5
Food wastes, 12%:									
Garbage	10.0	72	53.3	45.0	6.4	28.2	3.3	0.52	16.0
Fats	2.0	0.0	–	76.7	12.1	11.2	0.0	0.00	0.0
Non-combustibles, 24%:									
Metals	8.0	3.0	0.5	0.8	0.04	0.2	–	–	99.0
Glass and ceramics	6.0	2.0	0.4	0.6	0.03	0.1	–	–	99.3
Ashes	10.0	10.0	3.0	28.0	0.5	0.8	–	0.5	70.2
Composite refuse, as rec'd:									
All refuse	100	20.7	–	28.0	3.5	22.4	0.33	0.16	24.9

Source: Ilam et al., 1979.

[a] Analysis of the respective components.

[b] Moisture content of the respective component in the waste.

Table 72: Composition Of MSW In Quebec

CATEGORY	PERCENTAGE
Paper/Cardboard	36
Glass	8
Metal (ferrous)	6
Metal (non-ferrous)	1
Plastic	8
Decomposable Materials (i.e., foodwaste)	28
Other	13
TOTAL	100

Source: L' urgence d' offrir une "vie d' Ange" a nos sacs verts, 1987.

8.4 Disposal of MSW

The two main methods of MSW disposal in developed countries are landfilling and incineration. As is indicated by Tables 73 and 74, available land can be the deciding factor as to which process predominates.

Sanitary landfills, hopefully lined with either an adequate clay layer or some type of geomembrane, are landfills in which the waste is spread into thin layers, compacted, and then covered by a layer of soil (20 cm in Quebec, but variable on a provincial basis). This method of landfilling is prescribed by just about all government regulatory bodies in North America, even if they do allow the passage of leachate. In the US, impermeable double membrane liners are becoming mandatory as are bi-level leachate collection systems. It is hoped that the use of geomembranes will eliminate the groundwater contamination problem, but at this point, there is not sufficient data to draw any realistic conclusions.

Incineration is a MSW disposal method which involves the controlled burning of solid waste in a furnace, boiler, or special container designed for this purpose. The main end products of incineration are ashes and gases. Waste volumes can be reduced by up to 95% and the waste weight can be reduced by as much as 75%. Residual ashes (normally highly concentrated contaminants) are landfilled and gases (often toxic even after scrubbing) are released directly into the atmosphere.

8.4.1 LANDFILLING

In Canada, landfilling is the preferred method of MSW disposal. However, landfills receive more than just the MSW itself, they also receive the ashes from the incineration of MSW. These ashes are concentrated in terms of heavy metals and any other substances or compounds which were not fully destroyed by the incineration process. Furthermore, it must be understood that landfills have a finite life, a problem which is receiving much attention presently and will ultimately dictate the way in which we deal with our garbage.

In the province of Quebec, upwards of 75% of the MSW is disposed of in sanitary landfills. On the island of Montreal, there are three legal landfill sites, RDP,

Table 73: MSW Elimination Methods (Quebec, 1988)

METHOD	TONNAGE	PERCENTAGE
Sanitary Landfill	4 070 000	72
Incineration	566 000	10
Others	995 000	18
TOTAL	5 631 000	100

Source: MENVIQ, 1988

Table 74: MSW Elimination Methods By Country

COUNTRY	SANITARY LANDFILL	INCINERATION	OTHER (composting, trenchdeposits, etc.)
U.S.A. (1985)	90%	5%	5%
Japan (1982)	32%	65%	3%
France (1982)	44%	38%	18%

Source: MENVIQ, 1987

Miron, and Meloche which handled an estimated 1,851,000 tonnes in 1987. The following breakdown is designed to highlight the annual volumes and characterize the refuse received at landfills servicing major urban centers (MENVIQ, 1984).

RDP Landfill:

85,000 tonnes of incineration residue;
107,000 tonnes of special collection, construction material, earth, etc.;
34,000 tonnes of residential waste.

TOTAL 226,000 tonnes/year

Miron Landfill (directly serves 1,200,000 residents):

375,000 tonnes of waste (commercial and industrial);
50,000 tonnes of incinerator residue;
15,000 tonnes of surplus incinerator residue;
800,000 tonnes of MSW

TOTAL 1,225,000 tonnes/year

The Meloche landfill receives 400,000 tonnes of MSW annually. With a total capacity of 2,500,000 tonnes, it is scheduled to be closed in 1990 - 91. The two other Montreal landfills, RDP and Miron are scheduled for 1991 and 1994 closures, respectively. As is extremely evident, Montreal will soon be facing a landfill space availability crisis very similar to the one Toronto is presently battling.

8.4.2 INCINERATION

The percentage of Canadian MSW which is presently incinerated is relatively small when compared to landfilling. This is due to various reasons, but the two primary are the relative small number of incinerators operating in Canada and the fact that incineration costs range between five and ten times higher than landfilling costs.

Using the province of Quebec to again highlight the scenario, it is noted that as of November 1988, there were only three incinerators in operation. The city of Montreal has only one incinerator which handles MSW. This incinerator has a capacity of 1,000 tonnes per day and receives approximately 300,000 tonnes (1987) of MSW annually (based on 47 weeks of operation). In its present condition, the incinerator is scheduled for closure in the year 2002. However, with renovations, the incinerator may remain operational until 2007. The volume of MSW incinerated in Montreal is 14%, which is marginally higher than the provincial average of 10%.

8.5 Environmental Concerns Regarding Landfills

8.5.1 LEACHATE PRODUCTION

The leachate produced by MSW is of principal concern with respect to pollution and liner (synthetic or other type of engineered barrier) durability. This is because the leachate produced from the MSW is a highly complex liquid mixture of soluble organic, inorganic, ionic, nonionic, and bacteriological constituents, and suspended colloidal solids in a principally aqueous medium. It (the leachate) contains degradation products from the organic materials and soluble ions which will create contamination threats and problems in surface and ground waters. The quantity of leachate depends on the composition of the waste and the combined physical, chemical, and biological activities.

The precise composition of leachate is both waste and site specific, depending on such variables as type of waste, amount of infiltrating water, landfill age, and pH. Table 75 lists the leachate parameters which are used as analytical indicators for groundwater monitoring near an existing landfill (EPA, 1977). The characteristic substances and materials exhibit both a toxic and hazardous nature. Needless to say, if one were not aware of the origin of the leachate, it would not be illogical to assume the source material was as a hazardous solid waste (HSW).

Table 75: Parameters for Characterizing MSW Leachate

	Chemical		
Physical	Organic	Inorganic	Biological
Appearance pH Oxidation-reduction potential Conductivity Color Turbidity Temperature Odor	Phenols Chemical oxygen demand (COD) Total organic carbon (TOC) Volatile acids Organic nitrogen Tannins, lignins Ether soluble (oil and grease) MBAS Organic functional groups as required Chlorinated hydrocarbons	Total bicarbonate Solids (TSS, TDS) Volatile solids Chloride Phosphate Alkalinity and acidity Nitrate-N Nitrite-N Ammonia-N Sodium Potassium Calcium Magnesium Hardness Heavy metals (Pb, Cu, Ni Cr, Zn, Cd, Fe, Mn, Hg, As, Se, Ba, Ag) Cyanide Fluoride	Biochemical oxygen demand (BOD) Coliform bacteria (total, fecal; fecal streptococcus) Standard plate count

Source: EPA, 1977.

Tables 76 and 77 present data to show the complex composition of actual leachate from MSW. The data confirms the above stated concerns for the need to realistically assess MSW as a generator of hazardous and toxic leachates. As noted in the early part of this Report, it is unfortunate that regulations concerning management and disposal of MSW are not as stringent as those imposed for HSW, -- i.e., MSW is still considered a non-regulated waste.

Table 78 presents the composition of raw and digested sludges from a wastewater treatment plant near Washington D.C. Tables 79 and 80 present the ranges of metal and pesticide concentrations in sludge extracts from municipal landfills in the Greater Chicago district. The data show that the leachates and sludges generated from the disposal of municipal wastes may include high concentrations of such heavy metals as zinc, copper, nickel, cadmium, and lead, toxic substances such as barium and arsenic, and organic compounds including chlorinated solvents and aromatic hydrocarbons.

Co-disposal of these types of sludges, with MSW, in sanitary landfills is practised by many municipalities. Land farming of these sludges is also performed in certain areas. The obvious fact that these sludges are generators of toxic and hazardous leachates should not be overlooked, but current disposal techniques seem to indicate that this is happening.

8.6 Hazardous Components in MSW

The discovery of a large number of hazardous substances in MSW generated leachate and sludges has prompted many workers to inquire as to their probable sources.

It is obvious that some toxic compounds find their way into these landfills because of the great difficulty in controlling incoming wastes. Studies have found that self haulers (direct disposal by individuals) are the greatest contributors of hazardous waste to landfills.

Perhaps a more obvious source of hazardous waste contributions to the municipal waste stream are household products such as paints, solvents, drain openers,

Table 76: **Composition of Three MSW Landfill Leachates**

Concentration of Constituents (mg/L), Except pH and Electrical Conductivity

	Source of data		
Constituent	Wigh, 1979	Breland, 1972	Griffin & Shimp, 1978
BOD_5	–	13 400	–
COD	42 000	18 100	1 340
TOC	–	5 000	–
Total solids	36 250	12 500	–
Volatile suspended solids	–	76	–
Total suspended solids	–	85	–
Total volatile acid as acetic acid	–	9 300	333
Acetic acid	–	5 160	–
Propionic acid	–	2 840	–
Butyric acid	–	1 830	–
Valeric acid	–	1 000	–
Organic nitrogen as N	–	107	–
Ammonia nitrogen as N	950	117	862
Kjeldahl nitrogen as N	1 240	–	–
pH	6.2	5.1	6.9
Electrical conductivity (μmho/cm)	16 000	–	–
Total alkalinity as $CaCO_3$	8 965	2 480	–
Total acidity as $CaCO_3$	5 060	3 460	–
Total hardness as $CaCO_3$	6 700	5 555	–
Chemicals and metals:			
Arsenic	–	–	0.11
Boron	–	–	29.9
Cadmium	–	–	1.95
Calcium	2 300	1 250	354.1
Chloride	2 260	180	1.95
Chromium	–	–	<0.1
Copper	–	–	<0.1
Iron	1 185	185	4.2
Lead	–	–	4.46
Magnesium	410	260	233
Manganese	58	18	0.04
Mercury	–	–	0.008
Nickel	–	–	0.3
Phosphate	82	1.3	–
Potassium	1 890	500	–
Silica	–	–	14.9
Sodium	1 375	160	748
Sulfate	1 280	–	<0.01
Zinc	67	–	18.8

Table 77: **Characteristics of MSW Leachates**[a]

Constituent	Reference[b] (mg/L)	Reference[c] (mg/L)	Reference[d] (mg/L)	Reference[e] (mg/L)	Reference[f]	
					Fresh	old
BOD_5	9–54 610	–	7 500–10 000	–	14 950	–
COD	0–89 520	100–51 000	16 000–22 000	500–1 000	22 650	81
Total dissolved solids	0–42 276	–	10 000–14 000	–	12 620	1 144
Total suspended solids	6–2 685	–	100–700	–	327	266
Total nitrogen	0–1 416	20–500	–	–	989	7.51
pH	3.7–8.5	4.0–8.5	5.2–6.4	6.3–7.0	5.2	7.3
Electrical conductivity (μmho/cm)	–	–	6 000–9 000	1 200–3 700	9 200	1 400
Total alkalinity as $CaCO_3$	0–20 850	–	800–4 000	630–1 730	–	–
Total hardness as $CaCO_3$	0–20 800	200–5 250	3 500–5 000	390–800	–	–
Chemicals and metals:						
Cadmium (Cd)	–	–	0.4	–	–	–
Calcium (Ca)	5–4 080	–	900–1 700	111–245	2 136	254
Chloride (Cl)	34–2 800	100–2 400	600–800	100–400	742	197
Copper (Cu)	0–9.9	–	0.5	<0.04–0.11	0.5	0.1
Iron (Fe)	0.2–5 500	200–1 700	210–325	20–60	500	1.5
Lead (Pb)	0–5.0	–	1.6	–	–	–
Magnesium (Mg)	16.5–15 600	–	160–250	22–62	277	81
Manganese (Mn)	0.6–1 400	–	75–125	1.02–1.25	49	–
Phosphate (P)	0–154	5–130	–	21–46	7.35	4.96
Potassium (K)	2.8–3 770	–	295–310	107–242	–	–
Sodium (Na)	0–7 700	100–3 800	450–500	106–357	–	–
Sulfate (SO_4)	1–1 826	25–500	400–650	13–84	–	–
Zinc (Zn)	0–1 000	1–135	10–30	<0.04–0.47	45	0.16

[a] EPA, 1975a. [b] EPA, 1973. [c] Steiner et al., 1971. [d] Genetelli and Cirello, 1976. [e] Ham, 1975. [f] Brunner and Carnes, 1974.

Table 78: **Composition of Raw and Digested Sludges from the Washington D. C., Blue Plains Wastewater Treatment Plant, and their Respective Composts Processed at the USDA Composting Facility, Beltsville, MD.**

Component	Raw Sludge	Raw Sludge Compost	Digested Sludge	Digested Sludge Compost
pH	5.7	6.8	6.5	6.8
Water, %	78	35	76	35
Organic carbon, %	31	23	24	13
Total N, %	3.8	1.6	2.3	0.9
$NH_4^+ - -N, ppm$	1 540	235	1 210	190
Phosphorus, %	1.5	1.0	2.2	1.1
Potassium, %	0.2	0.2	0.2	0.1
Calcium, %	1.4	1.4	2.0	2.0
Zinc, ppm	980	770	1 760	1 000
Copper, ppm	420	300	725	250
Cadmium, ppm	10	8	19	9
Nickel, ppm	85	55	–	–
Lead, ppm	425	290	575	320
PCB[a], ppm	0.24	0.17	0.24	0.25
BHC[b], ppm	1.22	0.10	0.13	0.05
DDE[c], ppm	0.01	0.01	–	0.008
DDT, ppm	0.06	0.02	–	0.06

[a] Polychlorinated biphenyls as Arochlor 1254.

[b] The gamma isomer of benzene hexachloride is also called lindane.

[c] DDE results from the dehydrochlorination of DDT.

Source: Epstein, E. and Parr, J. P., *Water Management Technology and Resource and Energy Recovery*, 1977, 321.

Table 79: **Ranges of Metal Concentrations in Extracts from Metropolitan District of Greater Chicago Sludges**[a]

Sludge Source (No. of Samples)	Ranges of Metal Concentration (mg/L)							
	As	Ba	Cd	Cr	Pb	Hg[b]	Se	Ag
Heat Dried Sludge (21)	<0.2	<0.2	0.14–0.59	0.09–0.65	<0.02–0.23	<0.2–2.4	<0.2	<0.02
Nu Earth (6)	<0.2	<0.2	<0.02–0.22	0.19–0.42	0.06–0.23	<0.2–1.2	<0.2	<0.02
WSW Digester Drawoff (30)	<0.2	<0.2	<0.02–0.08	0.06–0.23	<0.02—0.12	<0.2–5.8	<0.2	<0.02
Calumet Digester Drawoff (30)	<0.2	<0.2	<0.02	<0.02–0.39	<0.02—0.14	<0.2–3.7	<0.2	<0.02
Hanover Park Digester Drawoff (20)	<0.2	<0.2	<0.02–0.05	0.03–0.60	<0.02–0.17	<0.2–2.7	<0.2	<0.02
John Egan Digester Drawoff (30)	<0.2	<0.2	<0.02–0.10	0.02–0.11	<0.02–0.13	<0.2–2.5	<0.2	<0.02
WSW[c] Lagoon Sludge (13)	<0.2	<0.2	<0.02–0.03	0.11–0.27	<0.02–0.12	<0.2–7.8	<0.2	<0.02
Hanover Side Lagoon Sludge (2)	<0.2	<0.2	<0.02	0.06	<0.02	1.0–26	<0.2	<0.02
North Side Sludge (30)	<0.2	<0.2	<0.02–0.05	<0.04–0.25	<0.04–0.16	<0.2–3.8	<0.2	<0.02
Lemont Sludge (7)	<0.2	<0.2	<0.02	<0.04	<0.04–0.07	0.2–3.7	<0.2	<0.02

[a] Extractions performed according to the procedure on pp. 33127–33128 of the *Fed. Regist.*, May 19, 1980.

[b] Results in milligrams per liter, except for Hg, which is given in micrograms per liter.

[c] WSW = West-Southwest Sewage Treatment Plant.

Source: Francis and Ancrbach, 1983.

Table 80: **Ranges of Pesticide Concentrations in Extracts from Metropolitan Sanitary District of Greater Chicago Sludges**[a]

Sludge Source	No. of Samples	Ranges of Pesticide Concentration (mg/L)					
		Toxaphene	Endrin[b]	Lindane	Methoxychlor	2,4-D	Silvex
Heat Dried Sludge	2	<0.2	<1.0	<0.1	<0.1	<0.01	<0.01
Nu Earth	2	<0.2	<1.0	<0.1	<0.1	<0.01	<0.01
WSW[c] Digester Drawoff	2	<0.2	<1.0	<0.1	<0.1	<0.01	<0.01
Calumet Digester Drawoff	2	<0.2	<1.0	<0.1	<0.1	<0.01	<0.01
Hanover Park Digester Drawoff	1	<0.2	<1.0	<0.1	<0.1	<0.01	<0.01
John Egan Digester Drawoff	1	<0.2	<1.0	<0.1	<0.1	<0.01	<0.01
North Side Sludge	1	<0.2	<1.0	<0.1	<0.1	<0.01	<0.01
Lemont Sludge	1	<0.2	<1.0	<0.1	<0.1	<0.01	<0.01

[a] Extractions performed according to the procedure on pp. 33127–33128 of the *Fed. Regist.*, May 19, 1980.

[b] Results in milligrams per liter, except for Endrin, which is given in micrograms per liter.

[c] WSW = West-Southwest Sewage Treatment Plant.

Source: Francis and Anerbach, 1983.

household cleansers, insecticides, pesticides, aerosols, batteries, metal cans, and others. These wastes are exempt from any hazardous waste regulations by Federal or Provincial authorities because of their apparent small generated quantities and the fact that MSW is generally classified as a "NON HAZARDOUS WASTE". However, the total amount of these hazardous household products, when disposed of at a municipal landfill, may be a significant source of hazardous leachates and eventual groundwater contamination.

For example, a study conducted to establish the concentrations of hazardous chemicals in a MSW stream in Washington State yielded 1500 potentially hazardous items. It was further observed that samples from self-haul wastes contained:

adhesives
floor and car wax
aerosols
paint
pesticides
solvents

In addition, samples from commercial solid wastes (collected from offices, institutes, and apartment buildings) were found to contain:

inks and dyes
bases

The typical residential waste contains:

medicines
cleaning products
cosmetics
alcohols, oil and grease

Table 81 details the sources of hazardous (as indicated by US EPA) organic compounds in MSW leachates. Table 82 lists the sources of hazardous metals in some common household products.

Canadian figures indicate that about 20 million tons of municipal waste and 3.3 million tons of hazardous (regulated) waste are produced yearly in the country. Considering a 5 percent content of hazardous components in the municipal waste, it is readily seen that there is an EXTRA 1 million tons of hazardous material (unregulated -- coming from MSW). The amounts of unregulated hazardous wastes

Table 81: Hazardous Organic Compound Found in Municipal Solid Waste Leachate.

Compound	Uses, Sources and Toxicity
O-xylene	Raw material used in manufacture of motor fuels, dyes; moderately toxic
P-xylene	Manufacturing of insecticide; moderately toxic
Ethyl carbamate	Solvent for various organics, solubilizer and co-solvent for pesticides, fumigants and cosmetics; moderately toxic
Acetic acid	Production of plastics, insecticides, photographic chemicals and food additives
Trichloroethylene	An unreactive solvent for fats, waxes, resins, oils, rubber, paint, varnishes, adhesives. Used for degreasing and in dry-cleaning; considerable nacrotic potency, can be fatal
Methyl ethyl ketone	Solvent for adhesives, rubber, printing ink, paint removers, cleaning solutions, coating systems; weakly toxic, irritant
Tetrachloroethylene	Used by dry-cleaning and textile industry, metal cleaning; mostly vapor inhaled, can be fatal
Acetone	Used as a solvent and chemical intermediate; moderately toxic, an irritant
Benzene	Excellent solvent, natural constituent of auto fuels; very toxic
Toluene	Present in gasoline, used as a solvent in paints, gums, resins, rubber coatings, in the production of dyes, explosives and saccharin; moderately toxic; irritant

Sources: Long (1982), Gilman and Goodman (1985), U. S. EPA (1977).

Table 82: Hazardous Metal Composition of Some Common Household Products.

Product	Compound	Product Division
	— — Element = Arsenic — —	
Insect pesticide	Arsenic, arsenic trioxide	House and garden pesticides
Lawn pesticide	Lead arsenate	House and garden pesticides
Termite killer	Arsenic trioxide	House and garden pesticides
Anti-corrosion paint	Arsenic	Paints
	— — Element = Barium — —	
Face and shaving powder	Barium sulfide	Cosmetic
Motor and gear oils	Barium petroleum sulfonate	Oils
Floor paint	Barium sulfate	Paints
Paste wax	Barium soaps	Polish
	— — Element = Cadmium — —	
Dyes and tints for hair	Cadmium chloride	Cosmetics
Shampoo	Cadmium lauryl sulphate, cadmium stearate	Cosmetics
Lawn pesticide	Cadmium succinate	House and garden pesticides
	— — Element = Chromium — —	
Corrosion inhibitors	Sodium chromate, potassium bichromate	Auto products
Garden flower pesticides	Copper zinc chromate	House and garden pesticides
Traffic paint	Lead chromate	Paints
Metal primer	Zinc chromate	Paints
	— — Element = Cooper — —	
Sewer, cesspool, septic tank cleaners	Copper sulfate	Cleaners
Dyes, tints for hair preparation	Copper chloride	Cosmetics
Garden flower pesticides	Copper, copper oxychloride, copper zinc chromates	House and garden pesticides, medicine
Skin ointment	Copper sulfate	Pesticides
Water treating chemicals	Copper sulfate	Pesticides

	— — Element = Lead — —	
Dyes, tints for hair preparation	Lead acetate	Cosmetics
Motor fuel additive	Tetraethyl lead	Fuels
Garden pesticides	Lead arsenate	House and garden pesticides
Traffic paints	Lead chromate, lead molybdate, lead sulfate	Paints
House paint, exterior primers	Lead	Paints
Lacquers	Lead acetate	Paints
	— — Element = Mercury — —	
Facial bleach and ointments	Ammoniated mercury, mercuric chloride	Cosmetics
Face wax	mercurized wax	Cosmetics
Facial bleach and ointments	Ammoniated mercury, mercuric chloride	Cosmetics
Lawn pesticides	Mercurous chloride	House and garden pesticides
Skin and ophthalmic ointment	Ammoniated mercury, mercury bichloride. mercuric oxide	Medicine
	— — Element = Zinc — —	
Liquid make-ups	Zinc oxide, zinc stearate	Cosmetics
Mouthwash	Zinc chloride, zinc oxide	Cosmetics
Astringent	Zinc sulfate, zinc oxide	Cosmetics
Soldering paste	Zinc halide	Fillers
Garden pesticides	Zinc	House and garden pesticides
Anti-corrosion paint	Zinc oxide, zinc chromate	Paints
House paint, exterior oil	Zinc oxide	Paints
Water treating chemicals	Zinc sulfate	Pesticides

Source: Atkins and Hawley, 1978.

which find their way into the municipal landfills are comparable to the regulated hazardous waste produced. It should be understood that the above figures evaluating hazardous materials in municipal waste do not consider the potential contribution of toxic compounds from the decomposition/transformation reactions of paper, plastics, and related wastes.

8.7 MSW Disposal Costs

The majority of Canadian MSW, as was previously detailed, is disposed of in sanitary landfills. Sanitary landfills earn their revenues by charging what is known as a "tipping fee". This fee is normally charged on a per tonne basis and can range from \$20 - \$30 in Montreal to \$70 to \$80 in Toronto (both centres are expecting substantial increases in 1991). Tipping fees are set by the landfill, but are subject to review by the appropriate government agencies. The simplest method of tipping fee determination is total annual costs divided by the total amount of refuse accepted by the landfill (tonnes). Tables 83 and 84 detail the annual operating costs for two of the Montreal based landfills.

Tipping fees, while an important cost, are only a portion of the total cost of MSW disposal. The same can be said for the per tonne fee which is charged for incineration. When an urban centre is dealing with the MSW problem, various areas must be addressed including; collection, supervision, and administration. Tables 85 and 86 detail the operating budgets for metropolitan Montreal and Toronto, respectively. Furthermore, Tables 87, 88, and 89 give the provincial perspective (Quebec and Ontario) along with a per capita breakdown.

Table 83: Costs Incurred By Miron Site

COST FACTORS	COSTS ($)
Land	370 421
Buildings	2 589 248
Final Soil Cover	822 726
Operating Costs	10 036 246
Credit - lease	727 166
Post Closure	690 677
TOTAL	15 236 484

Source: CMQ, 1988

Table 84: Costs Incurred By Meloche Landfill

COST FACTORS	COSTS ($)
Operating Costs	3 772 555
Administration	267 851
Buildings	596 436
Post Closure	227 300
Profit	486 414
TOTAL	5 350 556

Source: CMQ, 1989

Table 85: City Of Montreal MSW Disposal Budget (1988 and 1989)

CATEGORY	COSTS ($)	
	1988	1989
ADMINISTRATION		
Permanent White Collar (PWC)	396 900	357 900
Auxiliary White Collar (AWC)	13 100	5 000
Permanent Blue Collar (PBC)	-	-
Auxiliary Blue Collar (ABC)	-	-
Sup. Time White Collar (STWC)	5 500	5 600
Sup. Time Blue Collar (STBC)	-	-
Sick Days (SD)	12 200	11 500
Social Charges (marginal benefits) (SC)	128 400	11 500
Transportation (TRANS)	1 300	2 300
Professional Services (PR.S)	-	907 000
Leasing, Maintenance (L.M.)	2 900	3 600
Non-duarbles (ND)	9 500	9 700
Others	142 100	-
Sub-Total	570 800	1 414 100
SUPERVISION		
PWC	-	355 500
STWC	-	16 500
SD	-	11 400
SC	-	110 700
Sub-Total	-	494 700
COLLECTION BY CONTRACT		
TRANS	106 000	110 900
PR.S.	13 311 400	2 587 400
L.M.	-	54 600
Sub-Total	13 417 400	12 752 900
COLLECTION BY THE CITY		
PBC	-	1 033 100
STBC	-	31 300
SD	-	33 100
SC	-	287 900
L.M.	-	17 600
ND	-	5 000
Sub-Total	-	1 404 000
LANDFILLING		
PWC	38 400	98 100
AWC	-	4 400
PBC	153 800	227 400
ABC	44 300	13 100
STWC	3 000	3 100
STBC	12 300	12 300
SD	5 900	10 400
SC	56 200	95 900
L.M.	121 800	84 800
ND	36 600	77 600
Sub-Total	472 300	627 100

Table 85: City Of Montreal MSW Disposal Budget (1988 and 1989) (con't)

INCINERATION		
PWC	301 700	320 800
PBC	1 806 200	2 263 300
ABC	20 200	20 700
STBC	29 800	31 100
STWC	264 600	270 900
SD	64 900	82 700
SC	564 800	747 100
TRANS	1 200	1 200
PR.S.	3 000	3 100
L.M.	528 300	541 500
ND	917 700	940 700
Others	85 000	85 000
Sub-Total	4 587 400	5 308 100
SUMMARY		
Administration	570 800	1 414 100
Supervision	-	494 100
Collection by Contract	13 417 400	12 752 900
Collection by City	-	1 404 000
Landfilling	472 300	267 100
Incineration	4 587 400	5 308 100
TOTAL	19 047 900	22 000 300
TOTAL MUNICIPAL BUDGET	1 515 318 300	1 578 808 100

Source: City of Montreal, 1989

Table 86: Metropolitan Toronto MSW Disposal Budgets

ACTIVITY	1982 ($)	1983 ($)	1986 ($)*	1987 ($)*
Administration	218 000	274 400	N/A	N/A
Incineration	3 866 600	3 913 400	N/A	N/A
Landfilling	5 038 100	5 363 200	N/A	N/A
Transfer Stations	11 805 000	12 882 900	N/A	N/A
Equipment	1 827 500	2 212 300	N/A	N/A
TOTAL	18 154 100	34 272 400	103 179 000	111 260 000

* N/A (not available)

Source: Ontario Ministry of Municipal Affairs, 1988

Table 87: Provincial MSW Disposal Budgets (Quebec 1982-88)

YEAR	MSW BUDGET ($)	% of BUDGET	PER CAPITA ($)
1982	105 300 000	2.7	16.45
1983	111 500 000	2.7	17.20
1984	119 500 000	2.8	18.44
1985	129 300 000	2.8	19.94
1986	139 200 000	2.8	21.38
1987	146 022 778	2.8	21.38
1988	163 061 067	2.8	24.54

Source: MENVIQ, 1987; Ministere des Affaires Municipales du Quebec, 1989

Table 88: Ontario MSW Disposal Budgets (1986 and 1987)

AREAS	1986 ($)	1987 ($)
Metropolitan Toronto	103 179 000	111 260 000
Regions	100 840 000	121 911 000
Counties	57 080 000	33 923 000
Districts	13 067 000	14 878 000
TOTAL	274 166 000	315 895 000

Source: Ontario Ministry of Municipal Affairs, 1988

Table 89: Ontario MSW Disposal Per Capita Estimates (1986-88)

YEAR	POPULATION *	BUDGET ($)	PER CAPITA ($)
1986	9 125 800	274 166 000	30.04
1987	9 281 750	315 895 000	34.03
1988	9 437 700	363 279 250	38.49

* Based on Statscan 1986 census and estimates.

Source: Ontario Ministry of Municipal Affairs, 1988.

8.7.1 MSW DISPOSAL: A NATIONAL PERSPECTIVE

From a population point of view, Quebec and Ontario account for 16,081,000 inhabitants, or 62% of the total Canadian population (25,938,600 according to Statscan, 1988). The combined total 1988 expenditures for MSW disposal by both these provinces was $506,766,067 (based on an applied 15% increase[5] of the Ontario 1987 budget). Utilizing this figure, the average per capita cost ($31.51) for both Quebec and Ontario was determined. Assuming this rate as the national average, it was determined that the remaining Canadian population (9,857,500) would account for an additional $310,609,825. Therefore, the total Canadian expenditure on MSW disposal in 1988 is estimated to be $817,375,892. Utilizing the 15% increase factor, long term projections, considered to be conservative, show the annual figure rising to $1,644,034,875 in 1994 and $3,306,741,363 by 1999.

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[5] An increase of 15% was assumed because historically, for both the Montreal 1988 - 89 and Toronto 1986 - 87 city budgets, the actual increases have been approximately 15% over the previous year.

9.0 THE CANADIAN FOOD PROCESSING INDUSTRY

9.1 General

According to Statistics Canada (1986), there are over 3,000 establishments in the Canadian Food Processing Industry. An industry which employs almost 200,000 workers. In general, the wastes produced are not normally considered "hazardous", however, their characteristics (volumes and concentrations) are such that proper treatment can still represent a considerable expense.

Industries examined in this section include: 1) Meat and meat products, 2) Bakery products, 3) Fluid milk and other dairy products, 4) Fish and seafood processing, 5) Canned and preserved fruits and vegetables, 6) Poultry products, and 7) Vegetable oils.

9.2 Industry Characteristics

Table 90 lists the twenty categories of food processing related industries as reported in Statistics Canada (1986). Although diverse, the basic processes remain relatively unchanged across the industry. These include: 1) Raw material cleansing, 2) Removal of inedible parts, and 3) Food preparation and packaging. Wastes can result from spoiled raw material or product, rinse and wash water, transport water, and process water and overflow. Other sources may include water and/or cleansers used to clean floors and equipment, any liquid discharges from the product, unusable product (pieces and rejects), as well as any discarded packaging materials.

Table 90: The Canadian Food Processing Industry (Millions of Dollars)

CATEGORY	NUMBER OF ESTABLISHMENTS	NUMBER OF EMPLOYEES	VALUE OF GOODS SHIPPED
Meat and Meat Prod.	548	31,169	8.5
Poultry	101	11,515	1.7
Fish and Seafood	404	28,934	2.3
Fruits and Vegetables	185	12,021	1.9
Frozen Fruits and Veg.	37	5,049	0.7
Fluid Milk	160	13,647	2.9
Other Dairy Products	233	12,554	3.7
Cereal and Grain Flour	40	2,932	0.9
Prep. Flour & Cereal	19	3,082	0.5
Feed	532	8,952	2.5
Vegetable Oil Mills	11	1,052	0.7
Biscuits	34	6,268	0.5
Bread & Bakery Prod.	479	22,000	1.6
Cane and Beet Sugar	8	1,915	0.2
Chewing Gum	6	2,313	0.2
Sugar and Chocolate	107	6,795	0.8
Tea and Coffee	33	3,403	0.9
Dry Pasta	33	1,761	0.2
Potato Chips, Pretzels	24	5,226	0.5
Other	275	14,462	2.6

Source: Statistics Canada, 1986

Waste characterization in this industry, due to the variations within and across different categories, proves to be very difficult. However, Nemerow (1978) puts forth the following:

> All food processing effluents contain both suspended and soluble organic matter. However, volumes can vary from negligible to 4,546,000 liters per day, BOD can range from 100 to 100,000 ppm, and total suspended solids (TSS) can be found in concentrations of 0 to 120,000 ppm. Nitrogen and phosphorus may be absent, or present in quantities exceeding acceptable levels. In addition, the wastewater can be acidic or alkaline, ranging in pH from 3.5 to 11.0.

Suspended solids, fat, oil and grease (FOG), and BOD are in many cases prevalent enough to require treatment. Due to their overriding organic nature, these wastes are most often treated biologically using either aerobic or anaerobic techniques. In situations were protein and fat recovery is desirable (i.e., for use as animal fodder), physico-chemical treatment is also used.

Basically, there are three treatment and disposal options for wastewater. The two most widely used are pretreatment and discharge to a sewer system and direct discharge to land. The third option is full treatment of the wastewater followed by discharge to a receiving body of water. With this method, there appears to be some discrepancy as to what "full treatment" entails.

It appears that most members of the food processing industry employ some type of primary treatment designed for liquid-solid separation. Settleable solids are normally removed to reduce the possibility of system blockages or overloads. Furthermore, recovered solids can be sold to rendering plants or used in the makeup of feedstock for methane or other fermentation processes.

In this industry, primary treatment technology consists of screens, clarifiers, and air flotation devices. Occasionally, chemical flocculation is utilized and although often superior for solids removal and COD reduction, as compared to dissolved air flocculation devices, its associated costs (chemicals, storage, equipment, and operator time), normally prove prohibitive.

Secondary treatment (for BOD reduction) in the food industry is normally achieved through biological treatment. The most popular methods being activated sludge, aerated ponds, and trickling filters. Anaerobic treatment is not used extensively in this industry. Although a net energy gain, due to methane production, is possible, prohibitive capital costs make this option unattractive. Perhaps rising energy costs will change the industry outlook and make methane recovery technology more acceptable.

Factors affecting wastewater treatment costs vary with local conditions, plant construction and operation, wastewater volume and makeup, and levels of treatment performed. As in many industries, process water usage must be addressed before the situation can be improved. Through reduction, reuse, recycling, and some process modifications, the treatable volumes and overall costs can be reduced while the overall efficiency of operations is increased.

9.3 Industries Surveyed

9.3.1 MEAT AND MEAT PRODUCTS

This area of food production includes the slaughter, processing, and packaging of red meats. Characteristic wastes include liquid effluent, blood, offal, residual meat, bones, and any discarded packaging materials. Wastewaters are characterized by high levels of BOD (up to 5,000 ppm (McComis and Litchfield (1979))), solids, fat, oil and grease, and sometimes large concentrations of ammonia.

9.3.2 BAKERY PRODUCTS

Compared to the other sectors of the food processing industry, bakeries appear to have the least amount of waste to deal with. Recycling of process water is prevalent and water used for equipment cleaning is acceptable for direct disposal to the sewer. Waste dough is usually cooked and compacted along with the rejected final product (between 1 and 2%) for use as animal feed. Because the process is relatively "clean", the major sources of waste in this industry are generated through the day to day plant operations and consist primarily of papers, plastic sacks, and some metals. Therefore the costs are based on materials handling (in-plant), transportation, and landfill tipping fees.

9.3.3 MILK AND DAIRY PRODUCTS

Dairy wastes have a high pollution potential. According to Hemming (1980), whole milk has a BOD of 100,000 to 110,000 ppm and an average size plant can have an effluent load equivalent to that of a town with a population of 14,000. MENVIQ (1988) has determined that less than two litres of milk can contribute roughly the same pollution load as one person in a day and the lactoserum used in cheese fabrication contributes 45,000 ppm BOD.

Waste sources in this industry are primarily operational, consisting of spills, drippings, and waste products. The volumes produced are variable as are relative concentrations. However, BOD, fat content, and pH are normally of concern. PH is a secondary problem because even though most dairy wastes are originally neutral, they can become acidic due to the fermentation of milk sugars to lactic acid. Water usage can also be considered a problem in the industry due to the fact that 1.9 litres are consumed for every litre of milk produced. Highlighted by the 36,000 tonnes of milk produced yearly in Quebec alone, the national water usage and effluent production becomes apparent.

9.3.4 FISH AND SEAFOOD PROCESSING

With respect to waste management, the Canadian fish and seafood industry appears to be well behind the other industries. Ocean dumping, at best a controversial method which involves the actual dumping of all the fish and seafood processing related wastes back into the sea, is still prevalent. Unfortunately, there are no concrete regulations governing these wastes as they are neither considered hazardous or solid wastes (Article 131, Reglements sur les dechets solides).

The industry is characterized by its small size and seasonal nature (approximately 130 days per year (MENVIQ 1986)). However, the waste volumes generated are substantial with 30 to 85% of the landed fish ending up as waste material (Green and Mattick 1979). MENVIQ (1986) estimates that 100 litres of water is used per kilogram of product and associated waste waters contain organic substances, oil and grease, solids (suspended and dissolved) and BOD ranging from 300 ppm to 100,000 ppm depending on the plant surveyed.

9.3.5 CANNED AND PRESERVED FRUITS AND VEGETABLES

Fruit and vegetable processing, like the fisheries industry, is primarily seasonal. Most establishments are small and profits margins are normally quite low.

Industry wastewaters vary significantly in terms of contaminant load (solids, BOD, and pH being the areas of concern) and relative volumes. With waste being produced at every stage of the process; washing, peeling, cutting, mixing and sorting, product transformation, cooling, and equipment cleaning, the controlling factor is usually the type of product being processed. For example, pea and yellow bean processing produces large volumes of relatively unpolluted wastewater, carrots, tomatoes, apples, and beets generate an intermediate volume and strength wastewater, while corn processing produces a small volume, extremely high BOD wastewater (MENVIQ 1988). Most plants process a variety of fruits and vegetables based on their growing/harvest seasons.

9.3.6 POULTRY PROCESSING

There are 231 abattoirs in Quebec, of which 38 (16%) are poultry processors. Although by weight pork accounts for 46% of all production, the poultry sector accounts for 53% of the organic load generated by the Quebec abattoirs (MENVIQ 1988). This organic loading is greater than that experienced in the red meat processing industry.

Poultry processing wastes are characterized by fecal matter, dilution and wastewater, blood, and any discarded pieces. This waste load is characterized by high levels of BOD, suspended solids, and fat, oil and grease.

9.3.7 VEGETABLE OILS

Wastes produced in the edible oil industry are extremely varied with some being classified as hazardous. All wastewater, including process cooling water is contaminated with fat which is the dominant source of BOD. More diverse wastes are created through the production processes. For example, clay is used to remove pigment from the oil during the bleaching process, with the spent clay becoming a waste material. Furthermore, a nickel catalyst is used during the hydrogenation process with the spent catalyst considered a hazardous waste as are the laboratory wastes and the spent mineral oils from maintenance.

9.4 Costs

Representative companies were selected and interviewed for the seven largest categories in the food industry in Canada in an attempt to evaluate the overall industry expenditures on waste management and any associated items. Capital costs, equipment specifically, were calculated with a ten year amortization period unless otherwise specified (i.e., screens have an expected life of only 3 to 5 years). Opportunity costs for land or space used for waste treatment were considered, but only land or space specifically bought or constructed for waste management was accounted for in the final calculations. In this case, the costs were amortized over a fifty year period. Fixed and variable costs were calculated for each industry based on the information obtained. The overall industry (category) costs were then estimated based on the relative number of employees in each category (Table 91). Employee number was chosen because it was the only applicable statistic which was representative and available. The industries studied represented 70% of the Canadian food processing industry. The total cost was then estimated based on the total number of employees in the industry. Projections were derived through the use of a 5% interest rate which was compounded annually. Please note that the employee numbers used were obtained from a 1986 Statistics Canada publication meaning that the 1989 values presented may or may not be conservative based on the individual industry performances over the past three years.

Table 91: Annual Waste Management Costs in the Food Processing Industry.

CATEGORY	1989 (Millions of Dollars)	1994 (Millions of Dollars)
Meat and Meat Products	(1.5)	3.6
Bakeries	18.5	22.5
Milk and Other Dairy	44.7	75.1
Fish and Seafood	15.9	23.7
Fruits and Vegetables	11.5	13.0
Poultry Products	6.9	15.3
Vegetable Oils	1.0	1.4
Category Totals	97.0	154.6
INDUSTRY TOTAL	142.2	226.7

Source: Industry Surveys and Interviews

9.5 Waste Management Benefits

The meat processing industry has achieved a very lucrative position, at least for the moment, through the sale of any waste meat and edible fats to local rendering plants. These plants subsequently process them into animal feed and fertilizer. As is noted in the projections, this situation is expected to change. The changes will most likely be due to the tightening environmental regulations which will affect the rendering plants themselves. Basically, it is expected that as the rendering plants start allocating increased funds for their own waste treatment, the amount of money they will be able to pay for their "raw material" will decrease. It has been estimated (Lanoue, Courtchesne, and Macuzzi, 1989) that, over the next five years, the cost of doing business for the rendering plants will increase from 15 to 100%. Therefore, industries which benefit from these services (mainly meat and poultry), as their own fiscal responsibilities simultaneously increase, will no longer experience the same benefits and will themselves be forced into a reactive position.

10.0 THE CANADIAN CHEMICAL INDUSTRY

10.1 General

The chemical and chemical products industry in Canada was responsible for shipments of $22.5 billion in 1988. This represents approximately 8% of all the manufactured goods shipped in Canada (Anonymous, 1989). The geographic and employee distribution of the Canadian chemical industry is presented in Table 92. The sectors which were considered for this study include: 1) The inorganic chemical industry, 2) The organic chemical industry, 3) The plastic and resin industry, and 4) The pharmaceutical and medicine industry.

10.2 Environmental Policies

According to industry sources, it appears that those companies which do adhere to environmental regulations base their actions on government regulations and/or directives. However, there are some companies which are implementing their own standards, more stringent than those put forth by the government or municipality. This is most likely a good strategy because present government regulations are quite often minimal and it is believed that they will be tightened in the near future as associated problems develop a higher profile. Therefore adapting tougher standards now will lessen or negate the impact (financial, production disruption, retooling, etc.) of future changes. Eventually, it is hoped that an adequate national waste exchange program will be implemented and production waste can become a revenue generating vehicle. This will almost guarantee competent industry-wide waste management.

Table 92: Chemical Industry Breakdown (1986)

Industry	Maritimes	Quebec	Ontario	Western Can.	Total
INORGANIC CHEMICAL					
Establishments	9	22	35	38	104
Percentage	8.6	21.2	33.7	36.5	100
Employees	83	1 451	2 242	784	4 560
Percentage	1.8	31.8	49.2	17.2	100
ORGANIC CHEMICAL					
Establishments	2	10	27	16	55
Percentage	3.6	18.2	49.1	29.1	100
Employees	*	523	3 958	1 749	-
Percentage	-	-	-	-	-
PLASTIC and RESIN					
Establishments	0	24	54	16	94
Percentage	0	25.5	57.5	17.0	100
Employees	0	1 090	2 186	600	3 876
Percentage	0	28.1	56.4	15.5	100
PHARM. & MEDICAL					
Establishments	4	45	67	21	137
Percentage	2.9	32.9	48.9	15.3	100
Employees	*	3 118	4 245	262	-
Percentage	-	-	-	-	-

* Employee figures were not made available.

Source: Statistics Canada, 1987 (Catalogue 46-250B 3711, 3712, 3731, 3741)

10.3 Waste

10.3.1 WASTE GENERATION

Wastes generated in the chemical industry include solid and liquid process wastes, wastewater, and air emissions. The solid and liquid process wastes require disposal at secondary facilities. The amounts and types of wastes generated vary from facility to facility as well as industry to industry. Factors governing this situation include; the products manufactured, the processes utilized, facility size, production volumes, operational efficiencies, reuse and recycling programs in effect, efficiency of primary treatment (if any), skill of personnel, etc.

10.3.2 WASTE CHARACTERIZATION

Wastes produced in the chemical industry are as diverse as the products produced. The major categories include; solid and liquid wastes resulting from solvent or water purification, solid and liquid process by-products (i.e., urea-formaldehyde during formaldehyde production), products that do not meet company standards, used filters or containers, returned products (i.e., pharmaceutical tablets returned after the expiration date), solvents, and for companies involved in medical research, dead animals.

Taking as an example, an average organic chemical plant which produces the products listed in Table 93, the following water usage analysis and effluent characterizations are applicable.

10.3.3 WATER USAGE

The plant uses approximately 6,630 m^3/day of water. The water is derived from two sources, the municipal system (822 m^3) and a river intake (5,805 m^3). The municipal water is used for sanitary purposes, while the river water is used for vapor production (658 m^3/day), replenishment of the cooling towers (2,575 m^3/day), and various processes (2,575 m^3/day).

Table 93: Typical Products and Volumes for an Organic Chemical Plant

PRODUCT	VOLUME (tonnes/year)
Ethtlene Glycol	54 431
Ethylene Oxide	68 038
Antifreeze	18 239
Amines	4 500
Glycol Ethers	4 500
Conditioned Polyethelene	44 115
Hydrogen and Methane	42 369
Hydrocarbon Concentrates	108 949
Specialized Chemical Products	9 070
Low Density Polyethelene	110 288
TOTAL VOLUME	464 499

Source: Unpublished Environment Canada Report, 1989.

The vapor production system recycles 50% of the daily production, with the remaining 50% being incorporated into the finished products, evaporated, or purged from the system. Prior to use, this water undergoes both ion exchange and anti-corrosion treatment.

The cooling water includes all waters used for cooling purposes that do not come into direct contact with any of the products or associated processes. The cooling system is a continuous recycling system with an overall volume of 281,500 m^3/day. Replenishment occurs in order to maintain the required operational volume which suffers losses due to purges (avoid salt build-up), evaporation, leaks, etc. The cooling waters are treated for algae growth and with anti-corrosion chemicals (chromium-zinc, sulfuric acid).

Process waters are those used in all wet processes involving product contact and include direct cooling, washing, and distillation.

10.3.4 EFFLUENT CHARACTERIZATION

The average daily effluent release is approximately 4,920 m^3. 4,760 m^3 are discharged directly (after pretreatment) into a watercourse, with the remaining 160 m^3 entering a sanitary sewer system. Water entering the river system is composed primarily of process, cooling, and storm water, while the sewer effluent is made up of sanitary, overflow, and surface drainage waters. The two following tables characterize the associated effluent with Table 94 detailing the daily volumes of the principal contaminants and Table 95 giving the overall make-up and relative concentrations. Unfortunately, the individual analyses for the high priority organics (i.e., polycyclic aromatic hydrocarbons, benzene, chlorinated hydrocarbons, etc.) are not presently available. However, their presence is reflected by the relatively high COD levels.

Table 94: Treated Effluent Quality Before River Discharge (Organic Plant)

CONTAMINANT PARAMETER	LOADING (kg/day)*
Chemical Oxygen Demand (COD)	2 347.00
Total Suspended Solids (TSS)	171.00
Oil and Grease	33.00
Phenols	0.24
Chromium (Cr)	2.09
Zinc (Zn)	1.62

* Based on a daily flow volume of 4 760 m^3.

Source: Confidential Company Reports, 1988.

Table 95: Treated Effluent Quality Before Sewer Discharge (Organic Plant)

PARAMETER	CONCENTRATION (mg/l)
pH	6.0 - 9.4
Total Suspended Solids (TSS)	6.0 - 209
Oil and Grease	0.1 - 53
Lead	<0.05 - 0.6
Cadmium	<0.002 - 0.03
Zinc	0.1 - 2.6
Total Mercury	<0.02 - 1.6 ug/l
Nickel	<0.02 - 0.3
Copper	<0.01 - 1.3
Total Chromium	0.1 - 2.5
Arsenic	<0.002 - 0.006
Tin	<0.08
Sulfides	<0.02 - 3.8
Total Cyanides	<0.02
Phenols	<0.01 - 0.56
Chemical Oxygen Demand (COD)	215 - 3 600
Biochemical Oxygen Demand (BOD)	4.0 - 2 100
Total Organic Carbon (TOC)	86 - 512

Source: Available Company Analyses for 1988 and 1989.

10.4 Waste Disposal Options

Many wastes created by the chemical industry can be considered hazardous wastes under the Hazardous Waste Classification (1986) which falls under the Transportation of Dangerous Goods Regulations. Because of this, the wastes must be stored, transported, and destroyed according to specific government guidelines. This includes secure storage facilities, personnel spill prevention and reaction training, transportation manifests, and disposal or destruction at government approved facilities.

The options available for secondary disposal are limited primarily to stabilization technology, incineration, or government approved landfills. The actual mode of destruction is often dictated by the waste to be destroyed. For example, stabilization, which involves the treatment of wastes by mixing them with calcium based cement and aluminum silicate powder to form synthetic rock, can only be used on inorganic wastes (i.e., acids, bases, cyanides, and metal hydroxides (Glen and Orchard, 1986)). Incineration technology is popular in the industry, but special conditions do exist. Halogenated wastes (chlorine containing) must be incinerated at a constant temperature of at least 1250 degrees Celsius, while non-halogenated wastes require temperatures in the 1000 degree Celsius range (Glen and Orchard, 1986). Some wastes produced are considered so hazardous, that they are shipped to the United States for destruction by high temperature (> 2500 deg. C) incineration in a cement kiln (Cistech Inc.). Wastes deemed nonhazardous, due to relative volume or chemical makeup, can be disposed of in a government approved landfill. As is evident, there is no one "acceptable" destruction technology. Due to this, most companies are forced to use more than one facility to dispose of their wastes.

Not all the waste generated is sent away for treatment. Wastewater generated through in plant processes, cooling, and surface run-off from plant operating areas must also be treated. These waters are not treated as hazardous wastes because they are not addressed by the Hazardous Waste Regulations even though they are covered by some provincial regulations (i.e., Environmental Quality Act of Quebec). In-plant treatment, when used, can consist of a combination of the following; neutralization, precipitation, coagulation, chemical flocculation, biological treatment, and filtration. Any sludges produced must be dewatered and disposed of in the same manner described above for hazardous wastes. Wastewater volumes can be substantial with companies reporting totals exceeding 1,380,000 m^3 annually in the organic chemical-plastic industry.

Air emissions are controlled by the Quality of Atmosphere Regulations as stipulated under the Environmental Quality Act. Airborne contaminants are emitted through manufacturing processes vented to the atmosphere, chemical storage, and incineration of liquid and solid wastes. Reduction of these emissions can be accomplished through flare stacks, floating lids in chemical storage tanks, and smokestack scrubbers (Liptack, 1974). The number of companies actually utilizing any of the existing air pollution reduction technology is at present difficult to assess.

10.5 Costs

10.5.1 SPECIFIC COST INFORMATION

A survey of select companies, chosen to represent the various sectors of the industry, was performed to evaluate spending in specific waste related areas. The data obtained, while being industry specific, is believed to accurately reflect trends which are industry wide. The areas of interest include: 1) Capital Investments in On-Site Facilities, 2) Manpower Costs, 3) Chemical Costs, 4) Storage Facilities, 5) Transportation Costs, 6) Disposal Costs at Secondary Facilities, 7) Insurance, and 8) Projected Capital Improvement Costs.

10.5.2 CAPITAL INVESTMENTS IN ON-SITE FACILITIES

The majority of companies surveyed (80%), at this point in time, have already invested in some type of on-site treatment technology. It must be noted that required technology is directly dependent upon waste volumes, concentrations, overall make-up, and whether the waste is receiving full treatment (wastewater or air emissions) or is being prepared (storage and handling) for disposal at a secondary facility. The reported investments ranged from $100,000 to $15 million with the majority of money being spent on the treatment of emissions which will be released directly into the environment. Due to the high profile of this industry as far as environmental impact is concerned, it is expected that all companies will have to deal with their effluents, whether it is voluntarily or a result of government or public pressure.

10.5.3 MANPOWER COSTS

As was expected, there are significant costs associated with the manpower required for the on-site treatment or handling and storage of generated wastes. Again, these costs can be directly attributed to the types and volumes of wastes produced as well as the associated tasks performed. Costs reported varied from $16,000 to $500,000 with the larger firms spending the most. In fact, in the smaller firms these jobs are performed on a part-time basis (i.e., 3 days a week) while the larger companies have full-time staffs.

10.5.4 CHEMICAL COSTS

Chemicals being used for waste treatment include; drying agents, caustic soda (absorption of chlorine), hydrochloric acid (neutralization), ferric chloride (coagulation), and various polymers (flocculation). As is evident, the majority of these chemicals are used for on-site wastewater treatment. Unfortunately, the cost information obtained on this topic can at best be considered as vague. Only one industry actually reported a cost ($600,000) while the others only identified chemicals used. However, it can be rationalized that because many of the required chemicals may actually be produced within the company, these costs can be extremely difficult to assess.

10.5.5 STORAGE FACILITIES

Eighty-five percent of the companies surveyed reported that they had on-site waste storage facilities. Typically, they consisted of areas for drum storage, large storage tanks, backup tanks, spill basins, and containment dikes. Again, tank sizing and system sophistication is related to the nature and volume of waste which is being stored. Backup tanks are important because if there is a problem or slowdown at the facility which disposes the waste, production does not have to be stopped or altered in order to deal with the excess waste volume. Associated costs range between $20,000 and $6 to 8 million, with the largest expenditures reported by the organic chemical and plastics manufacturers. The opportunity costs regarding the real estate used for these facilities versus other possible company operations was questioned but the companies declined to respond on this issue. With the popularity and necessity of environmental audits to determine relative real estate "quality", it is believed that the value of this land for any non-chemical related activity will be severely affected.

10.5.6 TRANSPORTATION COSTS

Transportation of wastes from the producing company to the secondary storage facility is typically done by truck or tanker truck. The trucks are either company owned, or more likely, owned by an independent transportation firm. Transportation of these wastes falls under the Transport Of Dangerous Goods Regulations with manifests being required to help guarantee transportation and proper disposal. Expenditures quoted range from $2,000 to $500,000 with costs directly dependent upon volumes produced and disposal destinations. The highest per volume cost ($240.00/m^3) was reported by a solvent recycling company, which had to send its wastes to the United States to be incinerated.

10.5.7 DISPOSAL COSTS AT SECONDARY FACILITIES

As was previously discussed, due to the diversity of the wastes produced, many companies are forced to use more than one secondary disposal facility. With different disposal methods requiring different fees, the types and volumes of waste produced will again dictate relative costs. Values reported range from nothing to $1.5 million. This may seem strange, but it appears that some companies have worked out interrelationships whereas the wastes are disposed together or the wastes can be used as a raw material (i.e., waste exchange) for one of the company's processes. This is the ideal scenario and it is believed that as disposal costs increase, more companies will seek out partners to make the whole process more efficient and subsequently, more cost effective.

10.5.8 INSURANCE

Environmental insurance, (i.e., spill liability), is still very rare in the chemical products industry. The reasons are three-fold: 1) The Canadian insurance industry has traditionally shown very little interest in environmental related business with only two or three companies offering coverage., 2) The major underwriter, Ian Elliot Limited, has set maximum payable limits at $2 million in Canada, while in the United States, the American companies offer up to $15 million in coverage., and 3) The premiums, as related to the available coverage, can be considered prohibitive. For example, premiums dealing with liability policies covering chemical storage facilities range between $10,000 and $20,000, while actual production facilities cost between $20,000 and $30,000. These can be considered minimums with some policies approaching or exceeding $100,000 (Smith, 1989). This whole scenario encourages the major companies in the industry to underwrite their own business or self-insure. The downside of this situation is that a single source, the company itself, is responsible for total payment regarding any environmental related disasters. If the costs get to high, there is basically nothing to keep the company from closing its doors (declaring bankruptcy) and leaving the government the responsibility of dealing with the problem. While this may be recognized as an extreme scenario, it is a possibility. Additional liability insurance is also required for any company vehicle involved in the transportation of hazardous wastes. Required liability limits, in Canada, appear to approach the $5 million mark. In order to circumvent this cost and any others associated with self-transport, most companies hire trucking companies with government approved certificates to transport the waste.

10.5.9 PROJECTED CAPITAL IMPROVEMENT COSTS

Seventy percent of the companies surveyed have indicated that they plan to invest in waste management/treatment facilities in the near future. The improvements vary across the different related industries and include: 1) Building a new filtration system (inorganic company), 2) Constructing new flare stacks to pick up all safety relief valve discharges from vessels containing toxic substances, the hydrocarbon safety valves, and the continuous discharges associated with air related processes, additional tank diking, and wastewater treatment (organic chemical - plastic plant), 3) Equipment to liquify solids and to separate water from liquid wastes (organic recycling company), and 4) Construction of a new incinerator and storage area (pharmaceutical company). The expected expenditures are in the millions of dollars, with some large hydrocarbon processing companies planning to spend $40 million or more over the next three to five years.

10.6 Estimated Total Industry Costs

With any total industry cost allocation estimation, there is an expected degree of error. Unfortunately, this remains true with the following presentation of industry cost figures. The possible discrepancies in this industry are a result of the overall lack of consistent spending by the industry members. This is not only applies to the different industry groups, but within groups which produce similar products. Furthermore, cost reporting by the different survey participants must also be treated carefully as it is not uncommon to have an industry put forth numbers which make it look more conscientious than it actually is.

10.6.1 TOTAL AND FUTURE COSTS

The following cost estimate was derived in the following way. Firstly, cost figures for select industries were chosen as representative for their respective industry sectors. Secondly, the employee totals for each respective industry were determined and dollar amounts were calculated for each individual sector. Finally, these results were extrapolated over the entire industry using the relative industry group contribution to the total 1988 dollar figures for chemicals and chemical products shipped.

The results suggest that approximately $700 million annually is spent on waste management and disposal in the Canadian chemical industry. Furthermore, it appears that on-site costs are roughly twice as high as secondary disposal (transportation and disposal) costs. Considering these costs, the projected capital improvements, and a five percent inflation rate, it is most probable that annual waste management costs in the Canadian chemical industry will surpass the $1 billion mark within the next five years.

11.0 THE CANADIAN METAL FINISHING INDUSTRY

11.1 Introduction

The term "metal finishing" refers to any process or combination of processes which ultimately result in the surface application of a substance other than the metal composing the article itself in order to lend properties to the surface of the article which are not possessed by the unaltered article (Dennis and Such, 1972; Environment Canada, March 1975; Lowenheim, 1978).

Metal finishing is necessary because even if a metal article is of the desired shape and characteristics, its surface may not be suitable for its intended use. Subsequently, the surface must be altered. The four most prevalent reasons for altering an articles surface, according to Environment Canada (1975) and Muller and Raub (1967), are as follows: 1) Corrosion prevention, i.e., treatment of metals such as steel, iron, zinc, and copper with a protective coating to retard corrosion., 2) Protection from the base metal, i.e., iron utensils may be coated with nickel or platinum to prevent sensitive chemicals or pharmaceuticals from reacting with the iron through simple contact., 3) Improvement of appearance, i.e., a steel car bumper exposed to the elements would rust, even though it would retain its functional strength characteristics. Coating with chrome improves its appearance without influencing its function., and 4) Modification of surface properties, i.e., if an article requires a hard surface, it can be coated with chromium or nickel, or if it requires a highly reflective surface, it can be coated with silver or rhodium.

11.2 Industry Breakdown

An overview of the Canadian metal finishing industry was compiled from a 1987 Environment Canada report. According to this report, as was determined in a 1983 nationwide survey, there are 644 metal finishing companies in Canada. The geographic breakdown of these companies is presented in Table 96. The total number of employees, as estimated from the average values reported, is approximately 15,000. These numbers are predicted to stay relatively stable until 1994 (Environment Canada, 1987). It is important to note that metal finishing companies can be divided into two distinct groups; job shops and captive shops. Job shops operate on individual contracts and serve various different clients. Captive shops, as is inferred by the name, serve only one client and are usually integrated with a large manufacturing industry (i.e., automobile). On average, job shops employ about 1.5 times more employees than do captive shops. The market served by metal finishers is both vast and diverse. Table 97 illustrates the industry categories served, based on revenues generated.

11.3 Industry Trends

Over the last decade, only limited growth has been experienced in the use of metals in the metal finishing industry. They have been replaced by plastic and lacquer finishes in wire goods, electrical appliances, and automobile parts. In fact, in small appliances it seems that the plated parts are being totally replaced by plastic parts.

Nickel consumption remained relatively stable between 1973 and 1981 at (3,630 tons/year), but decreased by 37.5% over the next two years. This decrease was attributed to lower economic activity and a subdued demand for decorative finishes. It is predicted that the annual nickel consumption rate will remain at about 2,200 tons/year until 1994.

Zinc demand increased by 8% between 1973 and 1983 and is expected to grow (Environment Canada, 1987) by 2 - 3% annually until 1994. This augmentation appears to be due to an increased consumer demand for functional finishes.

The two major trends of the late 1980's are the attempted enforcement of stricter environmental regulations and a shift to more functional, corrosion resistant finishes. The environmental concerns have led to research into substituting toxic plating metals with less toxic equivalents. For example, cyanide is being eliminated from zinc plating solutions and hexavalent chromium is being replaced by the less toxic trivalent variety. While the quest for more resistant finishes has led to the development of new plating solutions and plating formulas.

Table 96: Breakdown Of Metal Finishing Industry By Province (1983)

PROVINCE	NUMBER OF COMPANIES
Nova Scotia	10
New Brunswick	7
Quebec	128
Ontario	361
Manitoba	27
Saskatchewan	6
Alberta	33
British Columbia	72
TOTAL	644

Source: Environment Canada, 1987.

Table 97: Surface Finishing Market Breakdown

PRODUCT CATEGORY	MARKET PERCENTAGE (1983)
Automobile Parts	26.0
Steel Strip Mills	14.0
Hardware	12.0
Electrical Appliances	10.0
Wire Goods	10.0
Plumbing Fixtures	6.0
Electrical Equipment	5.0
Furniture	5.0
Pole Hardware and Heavy Metal	5.0
Electronics	4.0
Engine and Worn Parts	2.0
Hollow Ware and Flatware	0.5
Jewellery	0.5
TOTAL PERCENTAGE	100.0

Source: Environment Canada, 1987.

11.4 Metal Finishing Processes

There are four distinct classes of metal finishing processes: 1) Mechanical, 2) Physical, 3) Chemical, and 4) Electrolytic. Mechanical processes include; sandblasting, grinding, barrel finishing, and polishing and buffing. Physical processes include; plastic, paint, and hot dip coating. Chemical processes include; solvent cleaning, alkaline cleaning, acid pickling/etching/bright dipping, salt bath pot cleaning, quenching/cyaniding, chemical conversion coating, and Electroless and immersion plating. Electrolytic processes include; electrocleaning, electropolishing, anodizing, and electroplating. Figure 1 is a graphical illustration of the metal finishing processes.

11.5 Mechanical Processes and Associated Wastes

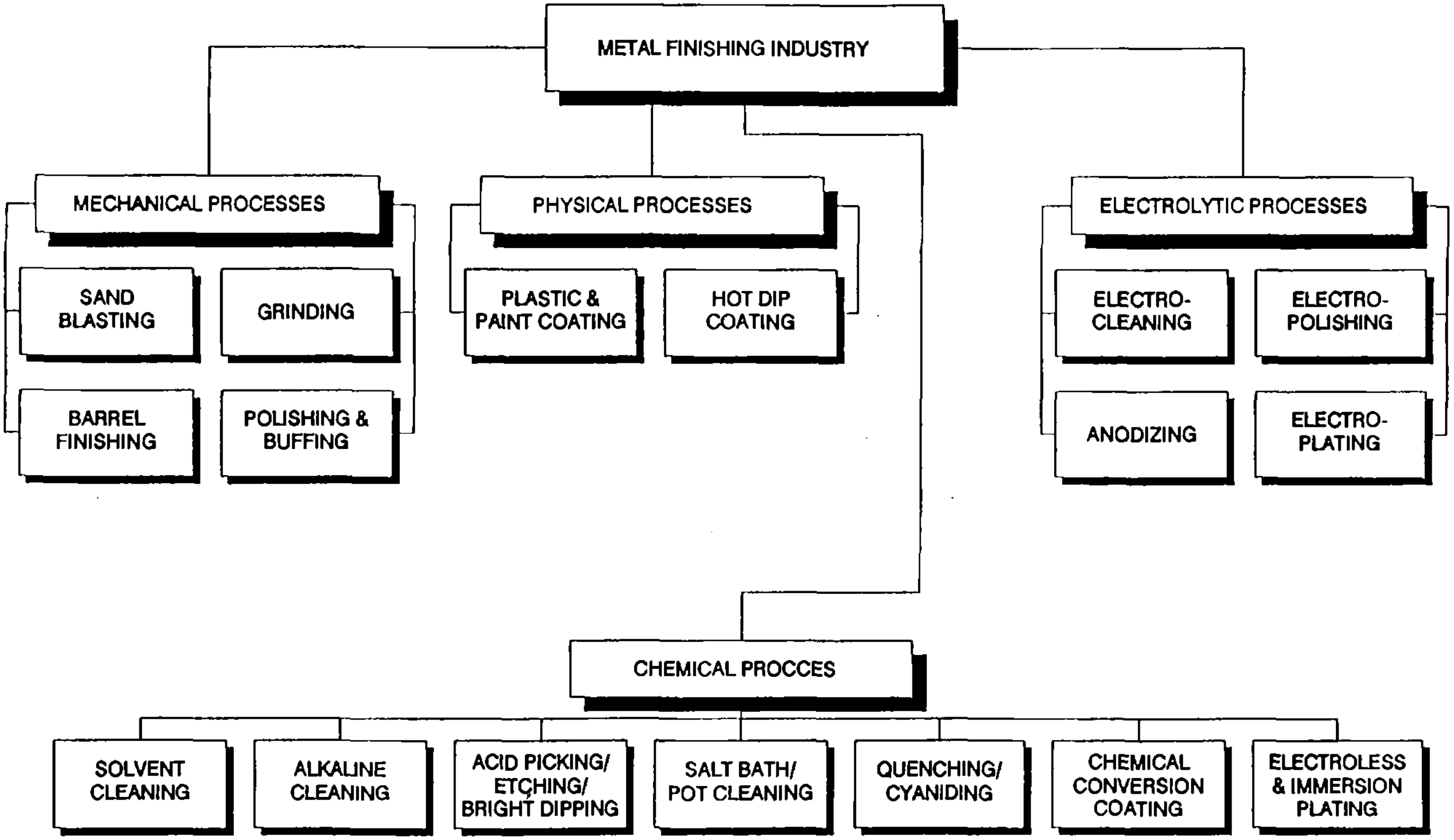
11.5.1 SANDBLASTING

Sandblasting is the process of propelling an abrasive aluminum oxide or silicon carbide with a pressurized air stream at a surface with the purpose of obtaining a clean, smooth surface. Wetting agents, rust inhibitors, and settling agents are usually added to the abrasive. Sandblasting produces solid wastes and wastewater.

11.5.2 GRINDING

Lubricating oils, wetting agents, and rust inhibitors are applied to an abrasive wheel or belt which is used to clean and smooth a surface. The waste produced in grinding is an oily sludge containing ground metal.

Figure 1
METAL FINISHING PROCESSES



Source: Env. Canada 1987

11.5.3 BARREL FINISHING

Barrel finishing involves cleaning articles by placing them in a rotating barrel containing abrasives, cleaners, rust inhibitors, acids and oils. Wastewater and solid wastes are the primary residues.

11.5.4 POLISHING AND BUFFING

Abrasives, grease, and cleaners are applied to a rotating dish or wheel which is placed in contact with a workpiece in order to polish or buff the surface. Residuals include wastewater and dust.

11.6 Physical Processes and Associated Wastes

Wastes produced by the physical processes normally originate from the precleaning and quenching of the workpiece and are primarily metal containing rinse or quenching waters.

11.6.1 PLASTIC AND PAINT COATINGS

Plastic coating consists of spraying an electro-statically charged plastic on an oppositely charged workpiece and then thermally fusing the coating to the workpiece. Paint coating is the simple application of industrial paint in spray booths or by dipping the workpiece in the paint (dip coating).

11.6.2 HOT DIP COATING

This process involves the dipping of a workpiece in a molten metal which results in the formation of an alloy of the two metals on the contact surfaces and binds the two metals (i.e., galvanizing (hot zinc coating)).

11.7 Chemical Processes and Associated Wastes

11.7.1 SOLVENT CLEANING

Liquid or vapor phase solvents, i.e., chlorinated hydrocarbons, are used to remove oil and grease from workpieces. Grease contaminated solvent is distilled, with the solvent being reused and the oil and grease being the waste material.

11.7.2 ALKALINE CLEANING

This involves the cleaning of a workpiece, before or after the unit operations, with an alkaline cleaner. Resulting wastewaters contain soap, grease, base metals, and solids.

11.7.3 ACID PICKLING/ETCHING/BRIGHT DIPPING

Acid pickling consists of a brief acid immersion of the workpiece in order to remove alkaline cleaners, scale, and rust. Pickling solutions include phosphoric, sulfuric, nitric, and chromic acid. Etching involves the use of acid combinations to dissolve the surface of the workpiece in a controlled manner in order to produce a desired design. Bright dipping removes surface oxides in order to prepare the piece for further finishing. These processes produce metal containing wastewaters, acids, and wetting agents.

11.7.4 SALT BATH POT CLEANING

Molten salt baths are used to remove rust and scale from the workpiece. The resulting wastes include sludge, metal containing wastewaters, cyanides, and burned oil residues.

11.7.5 QUENCHING/CYANIDING

Cyanide baths are used in heat treating, while quenching baths are used to cool the workpieces. The make-up of the quenching baths can vary, with the most common being oil, oil-chemical additives, water-oil emulsions, brine solutions, or water based solutions. Metal containing sludge and wastewater are the primary wastes along with oxides and oils.

11.7.6 CHEMICAL CONVERSION COATING

Metal plating which is achieved through a chemical reaction is called chemical conversion coating. Byproducts of the reaction and unused reactants are the primary waste materials and are included in the rinse waters and any batch discharges.

11.7.7 ELECTROLESS AND IMMERSION PLATING

The process of applying a metal coating without the use of an outside source of current (solution metal displaces base metal), is termed immersion plating. In electroless plating, the plating metal acts as its own catalyst and through reduction to its ionic state forms a deposit. Associated wastewaters include base metals, salts, chromates, etc.

11.8 Electrolytic Processes and Associated Wastes

Electrolytic processes are highlighted by the passing through of an electric current through a liquid resulting in a chemical reaction. These reactions involve electrodes (negative - cathode and positive - anode), a solution composed of electrolytes, and a source of electric current. The current moves through the system due to the movement of dissociated electrolyte ions.

11.8.1 ELECTROCLEANING

Electrocleaning involves the immersion of the cathodic workpiece into an alkaline bath and applying a current which results in the repulsion of all negatively charged colloid soil particles. Rinsewaters normally contain colloidal sized soil particles, metal residues, and alkaline cleaners.

11.8.2 ELECTROPOLISHING

This involves the immersion of the anodic workpiece in an acid bath with the desired results being a smooth surface. Resulting rinsewaters contain acids, bases, metals, soil particles, and oils.

11.8.3 ANODIZING

In this process, a thin oxide coating for protection against corrosion and abrasion is deposited on the workpiece (anode). Metals, chromates, etc. characterize the rinsewater and bath discharges.

11.8.4 ELECTROPLATING

Electroplating involves the deposition of a thin metallic coating on the surface of an object through electrolysis. With the bath solution containing metal salts, the cathode is the workpiece and the anode is composed of the plating metal. The dissolution of the metal anode and the metal containing bath solution are the main sources for the metal plating ions. Oxidation - reduction processes are responsible for the final metal deposition on the cathodic surface.

The make-up of the bath solution is determined by; 1) the metals used (nickel, chromium, copper, zinc, brass, tin, cadmium, gold, silver, lead, and iron are the most common), 2) desired results, and 3) relative costs. Table 98 details the bath make-up for various metals.

Table 98: Electroplating Bath Solutions

METAL	FINISH	SOLUTION
Nickel	Bright	Nickel Sulphate Nickel Chloride Boric Acid Sulphonic Acids Sulphonamides
	Semi-Bright	Nickel Sulphate Nickel Chloride Boric Acid
	Acid	Nickel Sulphate Nickel Chloride Boric Acid
	Black	Nickel Chloride Ammonium Chloride Sodium Thiocyanate Sodium Chloride
Chromium	Acidic	Chromium (III) Chloride Chromic Acid Sulphuric Acid Fluosilicic Acid
Copper	Cyanide	Copper Cyanide Complex Sodium Cyanide Potassium Cyanide Sodium Hydroxide Potassium Hydroxide
	Sulphate	Copper Sulphate Sulphuric Acid
	Pyrophosphate	Copper Pyrophosphate Potassium Hydroxide Ammonia

Table 98: Electroplating Bath Solutions (cont'd)

Zinc	Cyanide	Zinc Cyanide Sodium Cyanide Sodium Hydroxide
	Chloride	Zinc Chloride Hydrochloric Acid Ammonium Chloride Potassium Chloride
	Sulphate	Zinc Sulphate Aluminum Sulphate Sodium Acetate Glucose or Licorice
Brass		Copper Cyanide Zinc Cyanide Sodium Cyanide Sodium Carbonate Ammonia
Tin	Alkaline	Sodium Stannate Potassium Stannate Potassium Hydroxide Sodium Hydroxide
	Acid	Stannous Sulphate Stannous Fluoborate Sulphuric Acid Phenosulphonic Acid Fluoboric Acid
	Chloride	Stannous Chloride Nickel Chloride Ammonium Fluoride Ammonium Bifluoride Sodium Fluoride Hydrochloric Acid

Table 98: Electroplating Bath Solutions (cont'd)

Cadmium	Cyanide	Cadmium Cyanide Cadmium Oxide Sodium Cyanide Sodium Hydroxide
	Acid	Cadmium Fluoborate Ammonium Fluoborate Boric Acid Fluoboric Acid
Gold		Potassium Cyanide Potassium Gold Cyanide
Silver		Silver Cyanide Potassium/Sodium Cyanide Potassium/Sodium Carbonate Potassium Hydroxide Potassium Nitrate Carbon Disulphide
Lead		Lead Fluoborate Fluoboric Acid Boric Acid Hydroquinone
Iron		Ferrous Sulphate Ferrous Chloride Ferrous Fluoborate Calcium Chloride Ammonium Chloride Sodium Chloride Boric Acid

Source: Environment Canada, 1987

The application of a metal finish is not a one step operation. In fact, it is a combination of the mechanical, physical, chemical, and electrolytic processes previously highlighted. Electroplating, for example, involves a series of operations culminating with the "electroplating" step. A typical sequence for precision electroplating is as follows:

Step 1 - Solvent Cleaning (emulsion)
Step 2 - Spray clean detergent
Step 3 - Electrocleaning (alkaline cleaner)
Step 4 - Sulfuric acid dip (activate surface)
Step 5 - Electroplate
Step 6 - Electroclean
Step 7 - Sulfuric acid dip (activate surface)
Step 8 - Electroplate

Surface activation involves the removal of any films on the metal surface which may subsequently interfere with the process. Following Step 2, there is a rinse step and this is repeated after every step, including the last, until the process is complete.

11.9 The Metal Finishing Waste Stream

The three primary waste streams generated by the Metal Finishing industry are as follows: 1) Wastewaters, 2) Hazardous Wastes and Sludges, and 3) Air Emissions.

11.9.1 WASTEWATERS

Rinsewater, that is, water used to rinse and clean articles before or after the various finishing steps is the major source of wastewater in the metal finishing processes. Originally demineralized, the rinsewater is soon contaminated with base metals, plating metals, cyanide, oils, the solvents used to clean the workpieces, and any residual dirt or grease. Therefore, the contaminant make-up is directly related to the process previous to the rinsing.

Another source of wastewater is the plating solution or "drag out" which drips on the floor as the workpieces are transferred from bath to bath. This untreated wastewater is often released directly to the sewer system through floor drains in the process areas.

11.9.2 HAZARDOUS WASTES AND SLUDGES

Several spent process solutions are considered hazardous wastes, as defined by the Quebec Environment Ministry's "Hazardous Waste Regulations", and detailed in Chapter 2, Section 2.2. Included are:

- Acid waste (from pickling, etching, bright dipping, and electropolishing)
- Alkaline cleaning and electrocleaning baths
- Solvent degreasing waste
- Salt bath descaling solutions
- Spent plating baths

Acid wastes are extremely corrosive and have high concentrations of dissolved metals, oils, and suspended solids. Spent alkaline cleaning baths contain soap, emulsified greases, base metals, complexed metals, and solids. Electrocleaning bath discharges contain soil and metal residues. Solvent degreasing waste contains oil and grease, the additives and organic compounds dissolved by the solvent but trapped in the oily layer, soil, and any other associated solids. Composed of sodium hydroxide, sodium cyanide, and other chemical additives, the salt bath descaling solution is hazardous. Through processes, it is further contaminated with base metal in its solid form, associated residues, and oils. Spent plating solutions can be contaminated with any of the compounds detailed in Table 98 as well as those highlighted for electroless plating, hot dip coating, anodizing, and chemical conversion processes.

Nearly every process associated with metal finishing, including rinsing, produces some type of solid residue or "sludge". The composition of the sludge is directly dependent upon the process from which it originates. For example, sludge originating from a quenching/cyaniding bath will contain metals, cyanide, oil and grease, oxides, and metal scale. Various effluent treatment processes, i.e.

precipitation - coagulation - flocculation - sedimentation, will greatly increase the relative sludge volume, usually through the creation of metal hydroxides.

11.9.3 AIR EMISSIONS

Metal finishing produces the following air emissions; volatile organic compounds, acid and alkaline mists, and metal and abrasive dust generated during polishing and buffing. In general, these emissions are considered hazardous to both plant workers and the environment. For example, solvent based volatile organic compounds are irritating to nasal and lung tissue, while the acidic emissions, i.e., the acidic mist from chromium solutions, can contribute to the overall acid precipitation problem. Table 99 lists the most common airborne process contaminants and Table 100 gives an overview of expected contaminants from all the previously mentioned metal finishing processes.

11.10 Canadian Waste Volumes

11.10.1 WASTEWATER

Based on the Environment Canada (1987) report, over 50% of the companies surveyed reported treating their wastewater. Of the respondents, there appears to be an even distribution based on dollars spent. The quoted expenditure ranges are $0 - $10,000, $10,000 - $50,000, and over $50,000. From realistic terms, if only considering manpower, chemicals, and equipment, any company falling into the lower end of the overall dollar range reported, is not adequately treating their wastewater before disposal.

The volumes of wastewater produced seem distinctly divided, with 67% of the responding companies reporting annual discharges of 5,000 m^3 or less and the remaining 33% reporting volumes of 10,000 m^3 or greater. However, the numbers are production oriented and distinctly highlight the relative size distribution of operations across the metal finishing industry.

Table 99: Airborne Contaminants Released By Some Finishing Processes

PROCESS	COATING	CONTAMINANT
Pickling	Copper	Sulfuric Acid
	Silver	Sodium Cyanide
Electropolishing	Copper	Phosphoric Acid
	Nickel	Sulfuric Acid
Electroplating Fluoborate	Inidium	Fluoborate Salts
	Copper	Copper Fluoborate
Electroplating Acid	Chromium	Chromic Acid
	Iron	Chloride Salts
		Hydrochloric Acid
	Zinc	Zinc Chloride

Source: Metal Finishing, 1988.

Table 100: Overview Of Wastes Generated By Metal Finishing Processes

Process	Waste Waters Containing					Solid * Waste	Air Emissions
	Metal	Cr	Cyanide	Oils	Solvents		
Deburring	X	X	X	X		X	X
Polishing	X			X		X	X
Solvent Cleaning	X			X	X	X	X
Alkaline Cleaning	X		X	X	X	X	X
Pickling	X	X					X
Etching	X	X					X
Bright Dipping	X	X					X
Salt Bath Descaling	X		X	X		X	
Quenching	X		X	X		X	
Chromating	X	X					
Phosphating	X	X					
Passivating	X	X					X
Plastic Coating					X	X	X
Paint Coating	X				X	X	X
Hot Dip Coating	X						X
Electroless Plating	X	X	X				X
Anodizing	X	X					X
Electropolishing	X						X
Electrocleaning	X		X	X	X	X	X
Electroplating	X	X			X	X	X

* Solid waste refers to sludge

Source: Environment Canada, 1987.

11.10.2 HAZARDOUS WASTE AND SLUDGE

Seventy five percent of the respondents (Environment Canada, 1987) reported that they discharged their spent solutions. It is unclear what the remaining 25% did with theirs. Of the 75%, roughly 50% discharged to some type of a treatment site, while the remaining 50% reported dumping directly to the sewer system. Volumes of spent process solutions were divided into two distinct categories, greater than 5.0 m^3/year or less than 5.0 m^3/year. The industry split was almost even.

About 32% of the companies reported discharging solvents and oily waste. Reported volumes ranged from 1.0 - 2.5 m^3/year (55%) and greater than 5.0 m^3/year (31%). The remaining companies are either less than 1.0 m^3 or between 2.5 and 5.0 m^3.

Paint sludge discharges were reported by only 8% of the companies. Fifty percent of these had discharge volumes between 1.0 and 2.5 m^3/year, 25% were greater than 5.0 m^3/year, and the remaining companies fill the gaps.

Only half of the surveyed companies reported producing process sludge. The majority, 60%, generate between 1.0 and 5.0 m^3 annually, 24% reported production volumes between 5.0 and 50.0 m^3/year, and 16% produce over 50.0 m^3. Based on these figures, the estimated annual Canadian industrywide process sludge production volume is 17,210 m^3.

11.10.3 AIR EMISSIONS

Roughly 33% of the companies surveyed (Environment Canada, 1987) reported air emission generation. Fifty-four percent indicted that their emissions are either chromic or acidic while the remaining companies are evenly distributed between alkaline, dust, paint, and solvent emissions.

12.0 CONCLUDING REMARKS

In this first attempt at providing some attention to the sources and characteristics of waste materials, the intent has been to focus initially at some of the major industries and producers of waste products. The detailed description of the many processes contributing to the generation of the waste materials has not been developed, since this is not designed to be a process engineering report. Where necessary, an indication of the process source has been listed -- to provide some knowledge of the various kinds of waste streams that contribute to the overall stream. Those knowledgeable in the technology of each of the various industries will obviously be able to provide a very critical appraisal of the selectivity of information provided. It is expected that the Report will be updated as time passes, and that more waste generators will reported and discussed.

More reports are needed, not only to complete the work started above, but also to provide further information on the $$ impact of waste materials management. Present rough estimates indicate that recurring costs for the handling of waste materials in Canada vary from $5 to $10 billion, depending on how accurately the in-house handling costs are calculated. At this time, it is doubtful that one could provide a more concrete sets of $ numbers to cover the entire cost of management and safe disposal of both hazardous and non-hazardous waste material. This is due primarily to the fact that costs can vary significantly from company to company as well as from industry to industry and unless the internal reporting systems reflect these costs separately, quantification is nearly impossible.

Also, it should be reiterated at this time that the present regulations governing the management and disposal of hazardous and ‘‘perceived’’ non-hazardous wastes do not adequately address the problem. The Professions which have the necessary sets of expertise to provide guidance and develop the technology for safe disposal of waste have not yet responded to the challenge. Hopefully, through this and future Reports, the magnitude and urgency of the "problem" will be conveyed and the required interactions across the Professions will begin to occur. This, in time, should lead to the formulation of a comprehensive set of regulations which can accurately define the problem areas and the required technological solutions to "handle" them.

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