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Characterization and Treatability of Drainage Samples from Coal Piles at Steam Electric Power Stations

Economic and Technical Review
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Water Pollution Control Directorate
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CHARACTERIZATION AND TREATABILITY OF DRAINAGE SAMPLES FROM COAL PILES AT STEAM ELECTRIC POWER STATIONS

by

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for the

Water Pollution Control Directorate
Environmental Protection Service
Environment Canada

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ABSTRACT

This study was conducted to illustrate characteristics and treatability of drainage from coal piles at Canadian steam electric generating stations and coke piles at Canadian steel mills. A review of the technical literature was conducted, followed by selective field sampling, analyses and bench-scale treatability studies.

Based on the review of the literature, the factors governing coal pile drainage characteristics were determined to be the type and properties of the stored coal, meteorological conditions, and coal pile management practices. Drainage samples from coal piles in Eastern Canada have been found to be highly acidic and to contain excessive concentrations of dissolved iron and other metals. Western coals, which contain less sulphur than eastern coals, produced discharge samples that contained lower levels of dissolved metals and trace elements, with a more neutral pH, but higher suspended solids concentrations than eastern coal piles. Drainage samples from the coke piles at the Canadian steel mills selected for this study were characteristically slightly alkaline and generally contained significantly lower concentrations of inorganic and organic contaminants than coal piles.

For this study, discharges from coal piles at five steam electric generating stations and two coke piles at steel-making facilities were sampled, analyzed, and evaluated for treatment. It was concluded that the coal pile drainage samples could be successfully treated to meet the criteria applied in this study using relatively simple physical-chemical treatment technology. The most cost-effective treatment for the eastern coal pile drainage sample was determined to be pH adjustment using lime and the addition of an anionic polyelectrolyte as a coagulant aid. Successful treatment of the western coal pile drainage samples involved the addition of either calcium chloride or lime as a primary coagulant. In some instances, an anionic polyelectrolyte was required to improve settling. The most cost-effective treatment method would depend on the characteristics of the specific coal pile drainage.

Samples collected during the study were not intended to precisely characterize the coal or coke pile discharges from each site or each region. For this reason, samples were not taken flow-proportionally over a long period. Rather, they were taken to distinguish the range of wastewater characteristics that can be produced from a variety of coal and coke piles. It should not be assumed that the untreated coal or coke pile discharges from which samples were taken were released from any of the sites.

RÉSUMÉ

L'objet de l'étude était de détérminer les caractéristiques et la traitabilité des eaux de ruissellement provenant des tas de charbon des centrales électriques ainsi que de tas de coke des aciéries canadiennes, à partir d'une étude bibliographique puis d'un échantillonnage sélectif sur le terrain, d'analyses ainsi que d'essais de traitabilité en laboratoire.

D'après l'étude bibliographique, les facteurs qui régissent les caractéristiques des eaux provenant des tas de charbon sont le type et les propriétés du charbon, les conditions météorologiques ainsi que les méthodes d'aménagement des tas de charbon. Les échantillons prélevés dans les tas de charbon de l'est du Canada sont très acides et contiennent des concentrations excessives de fer dissous et d'autres métaux. Par contre, les échantillons des charbons de l'Ouest, qui contiennent moins de soufre que ceux de l'Est, ont des concentrations moindres de métaux dissous et d'éléments à l'état de traces, et leur pH s'approche de la neutralité, mais les concentrations de matières en suspension y sont plus fortes que dans ceux de l'Est. Les échantillons provenant des tas de coke étaient en général légèrement alcalins et contenaient des concentrations beaucoup plus faibles de contaminants inorganiques et organiques que les tas de charbon.

Nous avons échantillonné et analysé les eaux provenant de tas de charbon de cinq centrales électriques et de tas de coke d'aciéries et évalué leur traitabilité. Nous avons conclu qu'il est possible de traiter les échantillons provenant des tas de charbon pour répondre aux critères employés, au moyen de techniques physico-chimiques relativement simples: le traitement le plus rentable pour les échantillons provenant de tas de charbon de l'Est est le réglage du pH par ajout de chaux ainsi que d'un polyélectrolyte anionique comme adjuvant; pour ceux des tas de charbon de l'Ouest, il suffit d'ajouter soit du chlorure de calcium, soit de la chaux comme coagulant principal; dans certains cas, il faut ajouter un polyélectrolyte anionique afin d'améliorer la décantation. Pour le choix de la méthode de traitement la plus rentable, les eaux de chaque tas de charbon constituent des cas d'espèce.

Les échantillons prélevés au cours de l'étude n'étaient pas destinés à caractériser précisément les eaux de ruissellement provenant des tas de charbon ou de coke de chaque endroit ou région. C'est pourquoi nous n'avons pas prélevé d'échantillons en proportion du débit pendant une période prolongée. Nous les avons plutôt prélevés en vue de distinguer la gamme de caractéristiques des eaux usées pouvant provenir de divers tas de charbon et de coke. On ne doit pas présumer que les eaux brutes d'où étaient prélevés les échantillons provenaient d'un endroit donné.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Coal-fired steam electric stations generate about 40 percent of the fossil-fuel-derived electricity in Canada (1). Current trends indicate that coal will be increasingly utilized for the generation of electricity. Over the next decade, more than 5000 MW of new coal-fired generating capacity is planned (2). This represents an increase of about 40 percent.

At coal-fired steam electric generating stations, coal is stored in large uncovered piles adjacent to the powerhouse. This coal is exposed to climatic conditions ranging from freezing temperatures in winter to heat and humidity in summer.

When moisture comes into contact with the coal pile, a contaminated leachate and runoff can result. The amounts of the contaminants in this water are dependent on the chemical characteristics of the coal, extent of exposure to local climatic conditions, characteristics of the rainfall, and duration of contact between the water and the coal. Large volumes of coal and coke are also stored in open piles at steel-making facilities. Runoff from coke piles may also be contaminated, if significant amounts of substances are leached from the coke.

The problems of coal and coke pile drainages and the appropriate control technologies have not been addressed in detail in a Canadian context. For example, there are practically no data on the characteristics of drainage from western coal piles, and only two stations in Eastern Canada now chemically treat these wastewaters directly. However, preliminary work by a number of U.S. researchers has shown that environmental degradation can occur if drainage from stockpiled coals is released without treatment. For these reasons, and due to the anticipated increase in the use of coal for the generation of electricity and of coal and coke for steel-making, a study of Canadian coal and coke pile drainages in terms of their possible contents and treatments was conducted.

1.1 Objectives of the Study

A major objective of this study was to examine the aqueous discharges from coal stored at selected steam electric generating stations and coke stored at steel-making facilities across Canada. More specific objectives included:

- A review of the technical literature on the nature of coal and coke pile drainages and their treatment.
- An examination of discharges from selected coal and coke storage piles with specific emphasis on heavy metals and organic contaminants.

- An examination of the operation of any existing facilities that treat coal pile drainage in Canada.
- Physical-chemical treatability studies to demonstrate optimum treatment techniques for different types of coal pile drainage.
- An investigation of the possible treatment of coal pile drainage by blending with other waste streams from steam electric generating stations.

1.2 Rationale for Study Program

Coal-fuelled electric power generation stations in Canada are diverse. Existing plants encompass a wide range of generating capacities, are located in several different geographic regions, and are subject to a variety of climatic conditions. More important, a variety of coal types are stored and burned at these stations. These include high and low sulphur bituminous, sub-bituminous, lignite and metallurgical grade reject coals. The coals may be run-of-mine or blended, or washed before use. Discharges from piled coal can be leachates, which have had a long contact time with the coal, or direct runoffs from a rainfall event, which have had shorter contact times. Distinct differences may exist in the chemical contents of these wastewaters. A similar situation may exist with stockpiled coke.

Samples of runoff and leachate were collected at selected stations across the country to permit comparisons between discharges from a variety of coals, coal and coke, and runoffs and leachates. This also permitted some examination of the influence of regional climates, sulphur content of coals and coal ranks. Discharge throughout a discrete rainfall event was sampled to demonstrate changes in the discharge in relation to rainfall duration, and samples were also taken to illustrate spatial and further temporal variations.

The sampling program was organized to produce as great a contrast as possible in order to highlight differences that might exist between coal pile discharges at sites across Canada and to demonstrate treatment of different types of discharge.

2 LITERATURE REVIEW

The technical literature on coal pile management and known chemical characteristics of North American coal pile drainage was reviewed to provide a background for assessing coal pile drainage at Canadian steam electric generating stations. Subject areas reviewed included management of coal piles, changes in stored coal, acid generation problems in stored coal, and results of any previous characterization studies of coal pile discharges in the United States and Canada. Similar information on the storage of coke at Canadian steel-making facilities and the nature of discharges from coke storage piles was also reviewed.

2.1 Coal Storage and Pile Management

Coal is the carboniferous remains of prehistoric vegetable matter. The decay of vegetable matter during coal formation is both biological, resulting from transformations by microorganisms, and chemical, due to oxidation. Both of these may occur in nature simultaneously (3). These decay processes continue after coal is mined and placed in storage.

Decay during storage may cause relatively rapid changes in the size of coal and in its coking properties. The calorific value of stored coal may diminish by up to 15 percent over time due to oxidation. If the temperature of the coal in the pile exceeds 70°C, the loss of heating value may double. The largest relative changes in heating value occur during the first months of storage when the coal is freshly mined or crushed. Fine coals and uncompacted piles lose much more of their calorific value than coarser coal particles with smaller surface areas and storage piles that have been compacted (4).

Faster rates of oxidation can also be expected with coals containing higher concentrations of natural moisture, oxygen and sulphur. Increased flow of air or water through the coal, or alternate wetting and drying of the coal surface, also increase the rate of oxidation of coal (5).

Spontaneous heating and combustion occur when more heat is produced in the pile than is allowed to escape. While oxygen can enter the pile, the oxidation process can continue. When the pile temperature exceeds 70°C, an irreversible rapid rise of temperature may occur which will lead to combustion.

The process of spontaneous combustion has been widely studied (6,7,8,9); however, there are basically two opposing views on the correct method to prevent it. One is to encourage air circulation to remove the heat of oxidation and prevent a dangerous rise in the temperature. When this approach is used, the surface area to volume ratio of the coal pile is increased. This tends to increase coal pile runoff and, because of enhanced oxidation, increases concentrations of pollutants in the runoff. The second method is to prevent contact between oxygen in the air and the coal by compacting. When this method is used, oxidation rates decrease due to the reduction in the surface area to volume ratio of the pile. As a result, fewer pollutants are released by the oxidation process (7). The U.S. National Coal Association suggests that plants having a reserve pile of greater than about 450 tonnes should compact the coal during storage (10). They also state that the top of the coal pile should have a minimum area for the best pile management.

Pollutants in coal pile drainage are increased by (6):

- increased pile area to volume ratio;
- any condition that increases the oxidation rate of coal;
- increased pyrite content in coals of equal rank;
- decreasing coal rank, for coals with similar mineral contents.

Strategies being developed to deal with coal pile drainage have focused on collection and treatment. A complementary approach in which the coal pile design is used to reduce the pollutant concentration or amount of runoff has been presented by Lowthian (5).

Management of coal piles to reduce the pollution associated with coal pile drainage should take into account the effect of water on the oxidation of coal. High humidity or wetting the coal in an oxidizing environment can produce spontaneous heat. At low temperatures the heat produced by wetting is more than that produced by oxidation. Damp conditions favour self-ignition of coal in storage, while alternate wetting and drying accelerates oxidation of coal (3).

Lowthian (5) investigated four approaches to reducing or eliminating pollution due to coal pile runoff for a 0.1-hectare coal pile at an industrial facility. The general approaches included:

- prevention of coal-water contact,
- reduction of coal oxidation,
- containment of coal and contaminated water,
- an improved collection and treatment strategy.

A pit-and-berm storage method, shown in Figure 1, was the lowest cost alternative for coal storage at the site studied which met the existing U.S. non-point discharge standards. The berm provides a positive containment, a solid periphery against which the pile can be compacted, and an air-tight side for the pile. Access is sloped so that a portion of it drains back into the pile, preventing pile runoff from escaping. Spontaneous combustion and polluted discharges were eliminated at this pile as a result.

2.2 Stored Coal at Canadian Steam Electric Stations

According to a recent survey (1978), about 16 000 MW of the nominal generating capacity in Canada are coal fired (1). Table 1 summarizes the locations, generating capacities and annual fuel consumption for existing Canadian generating stations. About 30 percent of the generating capacity is located in Alberta and Saskatchewan, 61 percent in Ontario, and the remainder in the Maritimes and Manitoba. Table 2 shows the annual fuel consumption based on coal rank at these generating stations. Bituminous-ranked coal represents about 53 percent of the annual amount of coal burned at generating stations in Canada and is used predominantly in Ontario and the Maritimes. Sub-bituminous coal represents 31 percent of the coal burned in Canada, the majority of which is used in Alberta. About 14 percent of the coal burned at utilities is lignite. This is the primary fuel in Saskatchewan and Manitoba. At one station in Alberta, Milner G.S., rejects and mine tailings from metallurgical coal production are used as the primary fuel.

Table 3 summarizes the proposed locations, anticipated capacities and fuel use at planned new generating stations in Canada. About 5500 MW of new generating capacity are planned by the end of the 1980's. About 75 percent of the additional capacity will be located in Alberta and British Columbia and will burn sub-bituminous coal. One plant in Saskatchewan, Poplar River G.S., and two new 150-MW units in Ontario, at Thunder Bay G.S., will be fuelled with lignite. One plant in British Columbia, East Kootenay G.S., will burn rejects from a metallurgical coal operation.

Table 4 presents data from a recent inventory of Canadian steam electric plants on the configuration of coal piles at stations across Canada and the volumes of coal maintained in inventory (1). The pile areas range from 0.37 to 28 ha, heights range from 4.3 to 30 m, and pile volume can be between 3.0×10^4 to 5.6×10^6 m^3. The coal stored per megawatt generating capacity varies from 77 to 18 877 m^3 per megawatt generating capacity.

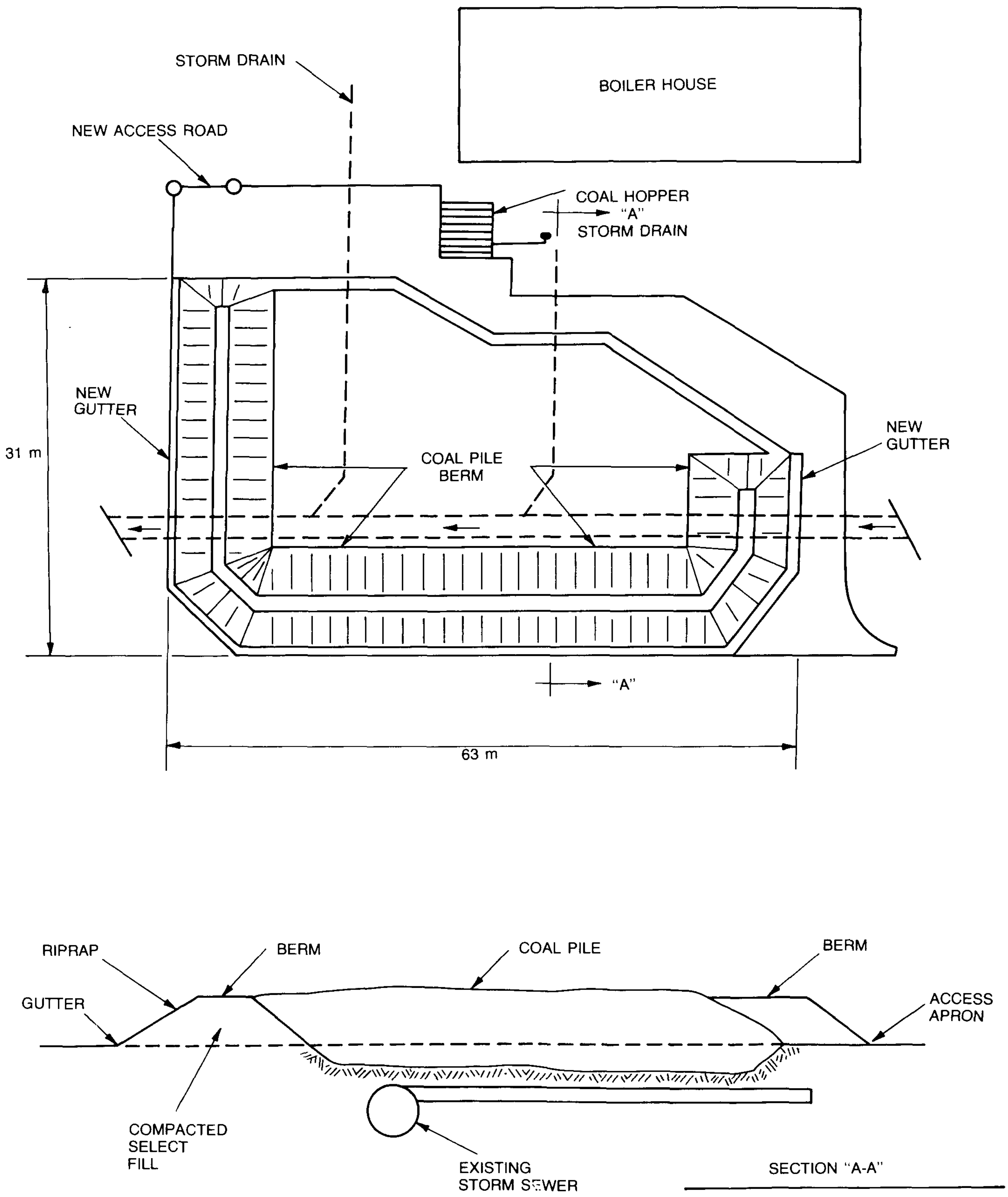

FIGURE 1 PIT AND BERM STORAGE METHOD (5)

TABLE 1 LOCATION, CAPACITY AND FUEL USAGE FOR EXISTING CANADIAN THERMAL GENERATING STATIONS (1)

Station/Location	Utility	Total Capacity (MW)	Coal Type; Origin	Annual Fuel Consumption (tonnes)
Alberta				
Battle River G.S. (Forestburg)	Alberta Power Ltd.	737 (1979)	Sub-bituminous coal; Alberta.	2.5×10^{6} (1979)
H.R. Milner G.S. (Grande Cache)	Alberta Power Ltd.	150	Rejects and dewatered tailings from metallurgical coal; Alberta.	3.4×10^{5} (1978)
Sundance G.S. (80 km west of Edmonton)	Calgary Power Ltd.	2 100	Sub-bituminous coal; Alberta	6.7×10^{6} (1980)
Wabamum G.S. (Wabamum)	Calgary Power Ltd.	582	Sub-bituminous coal; Alberta.	1.5×10^{6} (1980)
Saskatchewan				
Queen Elizabeth G.S. (Saskatoon)	Saskatchewan Power Corporation	232	Sub-bituminous coal; Alberta.	3.63×10^{5} (1980)
Estevan G.S. (Estevan)	Saskatchewan Power Corporation	67	Lignite coal; Saskatchewan	4.4×10^{5} (1979)
Boundary Dam G.S. (Estevan)	Saskatchewan Power Corporation	882	Lignite coal; Saskatchewan	4.2×10^{6} (1980)
Manitoba				
Selkirk G.S. (Selkirk)	Manitoba Hydro	156	Lignite coal, Saskatchewan	2.3×10^{4}
Brandon G.S. (Brandon)	Manitoba Hydro	237	Lignite coal, Saskatchewan	2.3×10^{4}
Ontario				
Lakeview G.S. (Mississauga)	Ontario Hydro	2 400	Bituminous coal; Pennsylvania, West Virginia	3.0×10^{6} (1980)
Nanticoke G.S. (Nanticoke)	Ontario Hydro	4 000	Low-sulphur bituminous coal; Alberta, blended with bituminous coal; West Virginia.	1.08×10^{7} (1980)
Lambton G.S. (Courtright)	Ontario Hydro	2 000	Bituminous coal; Pennsylvania, West Virginia	3.1×10^{6} (1980)
R.L. Hearn G.S. (Toronto)	Ontario Hydro	1 200	Bituminous coal; Pennsylvania, West Virginia	7.7×10^{4} (1978)
Thunder Bay G.S. (Thunder Bay)	Ontario Hydro	100	Bituminous coal; Pennsylvania, West Virginia	--
J.C. Keith G.S.	Ontario Hydro	264	Bituminous coal; Pennsylvania, West Virginia	--
Nova Scotia				
Trenton G.S. (Trenton)	Nova Scotia Power Corporation	210	75% bituminous coal; Cape Breton, 25% other sources	3.39×10^{5} (1980/81)
Glace Bay G.S. (Glace Bay)	Nova Scotia Power Corporation	112	Bituminous coal; Cape Breton	3.9×10^{5} (1980-81)
Lingan G.S. (Lingan)	Nova Scotia Power Corporation	300	Bituminous coal; Cape Breton	5.18×10^{5} (1980-81)
New Brunswick				
Grand Lake G.S. (Newcastle Creek)	New Brunswick Power Commission	104	Bituminous coal; New Brunswick	1.76×10^{5} (1977)
Dalhousie G.S. (Dalhousie)	New Brunswick Power Commission	212	Bituminous coal; New Brunswick.	2.72×10^{5} (1980)

TABLE 2 ANNUAL FUEL CONSUMPTION BY COAL RANK (2)

Coal Rank	Annual Fuel Consumption (tonnes)	Percentage of Total (Weight Basis)
Bituminous	1.867×10^7	53
Sub-bituminous	1.106×10^7	31
Lignite	5.049×10^6	14
Others - including rejects and dewatered tailings	3.4×10^5	1
TOTAL	3.512×10^7	

Nichols (11) described typical piles at U.S. utilities as being 8 to 12 m high, covering 6 to 30 ha and storing 600 to 1800 m^3 of coal per megawatt generating capacity. Coal piles at utilities in the U.S. are generally about the same height as those at Canadian stations but tend to cover a larger area with less coal per MW generating capacity being maintained in on-site storage piles.

The relatively large variation in coal pile configuration among Canadian utilities can be explained by three factors. In many cases, particularly in Alberta, Saskatchewan and Nova Scotia, the generating station is located adjacent to the mine. This permits a lower inventory of coal to be maintained on-site and generally the coal is stored for a shorter period of time. In Ontario, coal is delivered by ship by way of the Great Lakes-St. Lawrence Seaway System. A larger inventory must be accumulated during the shipping season to ensure sufficient supplies during periods when coal cannot be delivered. The coal is more likely to remain in storage piles for longer durations at these facilities. The highest volume of stored coal per megawatt capacity in Canada is at Milner G.S. in Alberta where metallurgical coal is stocked for sale and reject coals are used for fuel. The largest coal pile in terms of area is located at Nanticoke G.S. in Ontario.

2.3 Coal Pile Dust Suppression, Drainage, and Collection

Only limited information has been published on the control of dust from coal piles at Canadian thermal generating stations. The problem of dust control is related to the drainage from the coal piles since large volumes of water may be applied to the pile

TABLE 3 LOCATION, CAPACITY AND FUEL USAGE FOR PLANNED NEW CANADIAN THERMAL GENERATING STATIONS (2)

Station/Location	Utility	Planned Capacity (MW)	Coal Type; Origin	Annual Fuel Consumption (tonnes)
<u>British Columbia</u>				
Hat Creek G.S. (Ashcroft)	British Columbia Hydro	2 240 (1989)	Sub-bituminous coal; British Columbia	1.1×10^7 (1989)
East Kootenay G.S. (Sparwood)	British Columbia Hydro	600 (1989)	Refuse from metallurgical coal; British Columbia	2.5×10^6 (1989)
<u>Alberta</u>				
Sheerness G.S. (Hanna)	Alberta Power Limited	750 (1986)	Sub-bituminous coal; Alberta	3.3×10^6 (1986)
Keephills G.S. (80 km west of Edmonton)	Calgary Power Limited	750 (1985)	Sub-bituminous coal; Alberta	2.1×10^6 (1985)
Genesee G.S. (Genesee)	Edmonton Power	375 (1986)	Sub-bituminous B coal; Alberta	2.7×10^6 (1986)
<u>Saskatchewan</u>				
Poplar River G.S. (Coronach)	Saskatchewan Power Corporation	300 (1981)	Lignite coal; Saskatchewan	1.9×10^6 (1981)
<u>Ontario</u>				
Thunder Bay G.S. (Thunder Bay)	Ontario Hydro	400 (1981)	Bituminous coal; Pennsylvania, West Virginia. Lignite coal; Saskatchewan	2.69×10^5 (1981)

TABLE 4 COAL STORED AT EXISTING CANADIAN THERMAL GENERATING STATIONS (1)

Station	Coal Pile Area (ha)	Coal Pile Height (m)	Coal Pile Volume (m^3)	Volume of Stored Coal per MW Generating Capacity (m^3/MW)
Battle River	0.37	7.6	2.8×10^{4}	77
H.R. Milner	19	15	2.8×10^{6}	18 877
Sundance	2.0	15	3.0×10^{5}	222
Wabamum	1.3	6.0	7.8×10^{4}	134
Queen Elizabeth	2.7	11	3.0×10^{5}	1 293
Estevan	0.65	4.6	3.0×10^{4}	448
Selkirk	6.6	10	6.6×10^{5}	5 000
Brandon	6.2	10	6.2×10^{5}	2 616
Lakeview	13	30	3.9×10^{6}	1 698
Nanticoke	28	20	5.6×10^{6}	1 400
Lambton	19	9	1.7×10^{6}	855
R.L. Hearn	6.4	4.3	3.3×10^{5}	275
Trenton	0.84	9.1	7.6×10^{4}	362
Lingan	0.90	15	1.4×10^{5}	467
Grand Lake	2.5	10	2.5×10^{5}	2 404
Dalhousie	1.5	4.6	6.9×10^{4}	325
Minimum	0.37	4.3	3.0×10^{4}	77
Maximum	19	30	5.6×10^{6}	18 877
Average	6.9	11.3	1.1×10^{6}	2 278

for this purpose. Based on recent inventory data, the water used on coal piles, and coal pile drainage and treatment at Canadian generating stations are summarized in Table 5 (1).

Five generating stations, Estevan, Lakeview, Nanticoke, Lambton and R.L. Hearn, regularly use water sprays for dust suppression on coal piles (1). The Estevan station is very small by industry standards and the annual water use for this purpose is unknown. The remaining four stations, operated by Ontario Hydro, maintain large on-site coal piles since they are not located adjacent to the coal source and must rely on seasonal coal delivery. These plants include two of the largest coal-fired stations in Canada. The volumes of coal that must be handled preclude the use of stacker-reclaimers and require that the pile be contoured and compacted to prevent spontaneous combustion. The continuous movement of coal using tractor-scrapers causes a dust problem which is remedied by the application of water sprays and, in some cases, by spraying of waste oils.

The average annual water use for each of the four Ontario Hydro stations is 1.0×10^5 m^3 (1). However, this water volume is small when viewed in terms of the total rainfall on the coal piles throughout the year. Further, the water for dust suppression is presumably applied during the driest pile conditions when evaporation from the pile surface would be highest.

An overview of the control of air and water contaminants from coal piles at Ontario Hydro thermal stations was prepared by Featherby and Dodd (12). Water spray nozzles are installed on all hopper discharges and conveyor transfer points at coal handling facilities for dust suppression purposes. Due to the size of the coal piles at Ontario Hydro plants, fixed conveyors and underground reclaim hoppers cannot be used. The stored coal must be compacted to avoid spontaneous combustion and fires. Mobile equipment used for this purpose creates a significant dust problem. Water trucks are used to spray water on the pile access roads and working areas in the pile. During the warm summer season, these trucks are in almost continuous use.

A more detailed report on coal dust management at Nanticoke Thermal Generating Station has been prepared (13). This report details the equipment and procedures for dust suppression at Nanticoke. At this station, the operation of tractor-scrapers on haul roads is the largest source of coal dust. Converted scrapers fitted with 45000-L water tanks are used to wet the coal haul roads and access roads within the pile. The water wagons operate continually during coal movement on the stacker-reclaimer and the main coal pile. During winter a dusting problem at Nanticoke was caused by freeze

TABLE 5 WATER USE AND MANAGEMENT AT CANADIAN THERMAL GENERATING STATIONS* (1)

Station	Coal Pile Base	Coal Pile Sprays Source and Annual Volume (m^3)	Annual Coal Pile Runoff (m^3)	Coal Pile Run-off, Collection and Treatment System	Coal Pile Run-off, Receiving Body
Battle River	None	None	Unknown	Collection only	Battle River Reservoir
H.R. Milner	None	None	Unknown	Collection only	Smokey River
Sundance	Clay	None	Unknown	Collection only	Sundance Cooling Pond
Wabamum	Clay	None	Unknown	Collection only	Lake Wabamum
Queen Elizabeth	Clay/6 m sand	None	Unknown	None	--
Estevan	Clay	Souris River	Unknown	None	Souris River
Selkirk	None	None	Unknown	None	Red River
Brandon	None	None	Unknown	None	Assiniboine River
Lakeview	Packed clay on shale	Lake Ontario 4.6×10^4	1.3×10^5	Collection, lime treatment and sedimentation	Lake Ontario
Nanticoke	6 m clay on rock	Lake Erie 3.2×10^5	Unknown	Collection and pumping to ash lagoon	--
Lambton	None	St. Clair River 1.0×10^4	Unknown	Collection and pumping to ash storage area	--
R.L. Hearn	None	Lake Ontario 2.4×10^4	Unknown	Coal pile is centre graded	--
Trenton	Gravel	None	Unknown	None	Unknown
Lingan	Glacial till covered with gravel	None	Unknown	Collection only	Indian Bay via CCW discharge
Grand Lake	None	None	Unknown	Periodic addition of lime	Grand Lake
Dalhousie	Material with low permeability	None	Unknown	Collection and treatment	Eel Bay

* Current data not available for the following stations:
Poplar River G.S.
Boundary Dam G.S.
Thunder Bay G.S.
Glace Bay G.S.

drying of coal, high winds, and high activity on the coal pile. This problem was resolved by applying water to the pile using water wagons. The resulting thin layer of ice was found to be acceptable with no problems resulting from the frozen coal. This approach for dust suppression during the winter could be less successful in areas of Canada with a more severe climate. Frozen coal can impede the operation of coal feed equipment and cause severe operating problems.

Waste lubricating oil is also used for dust suppression at Nanticoke. The oil is applied to haul roads using a modified water wagon. The resulting coal surface has no crust but the small coal particles are well retained on the coal pile surface. No adverse operational effects from the oil use have been reported (13). It was concluded by Ontario Hydro that the waste oil is an effective, long-lasting dust suppressant for use on pile sides and permanent haul roads.

Based on inventory data, as shown on Table 5 (1), 11 of 16 stations reported that cole pile drainage was collected. At four stations the water was blended with other wastewater, presumably providing some form of treatment. Only one station operates a wastewater treatment plant that is primarily intended for coal pile drainage. One other station chemically treats all station wastewaters, including coal pile drainage, in one central treatment facility. Four of the stations which did not have runoff collection systems were located in the relatively dry regions of Saskatchewan and Manitoba.

2.4 Acid Generation

It is widely believed that the low pH, high solids and high levels of dissolved metals in acid mine drainage are, in part, due to microbiological activity. This is particularly true for drainage from coal mines where the coal contains high levels of sulphur. There are similar biological considerations in the oxidation of stored coals.

Highly acidic coal pile drainage from eastern coals, which contain high sulphur concentrations, result from the percolation of rainfall through the stored coal. The water quality of the drainage is affected by the leaching of oxidation bearing minerals that predominate in coal ore pyrite and marcasite, both of which are iron sulphide ores (14). Marcasite is unstable and degrades into pyrite. The oxidation of pyrite results in the production of ferrous ion and acidity as shown in the following equation (15):

$$2\,FeS_2(s) + 7O_2 + 2\,H_2O \rightarrow 2\,Fe^{+2} + 4H^+ + 4SO_4^{-2} \qquad (1)$$

The ferrous ion then undergoes oxidation to the ferric state in a rate-limiting step in the production of acidity:

$$4\,Fe^{+2} + O_2 + 4H^+ \rightarrow 4Fe^{+3} + 2H^+ + 2OH^- \qquad (2)$$

Ferric ion then hydrolizes to form insoluble ferric hydroxide thus producing more acidity:

$$Fe^{+3} + 3H_2O \rightarrow Fe\,(OH)_3\,(s) + 3H^+ \qquad (3)$$

or oxidizes pyrite directly, thus producing more ferrous ion and acidity:

$$Fe\,S_2\,(s) + 14\,Fe^{+3} + 8H_2O \rightarrow 15\,Fe^{+2} + 2SO_4{}^{-2} + 16H^+ \qquad (4)$$

The stoichiometry of these reactions reveals that, for every mole of ferrous sulphide oxidized, there is a net increase of two moles of hydrogen ion. This net increase in acidity provides hydrogen ions for further oxidation of ferrous ion and subsequent acid production (14).

Abiotic oxidation, which does not involve living organisms, occurs relatively slowly at pH values greater than 4. The natural environments in which most organisms thrive have concentrations of hydrogen ions near 10^{-7} M or pH 7.0. Although extremes in pH are toxic to many organisms, there are also certain acidophilic or "acid loving" organisms which require extremely acid conditions with pH values of 3 or less for growth (16).

Below pH 4, oxidation is believed to be caused by the metabolic activities of "acid loving" members of the thiobacilli species. The acidophilic, chemoautrophic bacteria most widely associated with this are Thiobacillus ferrooxidans, Thiobacillus thiooxidans and Metallogenium sp., which are most active at pH 2.0 to 4.5 and use CO_2 as their carbon source (16). They are the main contributors to the oxidation of ferrous iron to the ferric iron state, which is the rate-limiting step in the oxidation sequence. Their presence indicates rapid pyrite oxidation and is usually accompanied by coal pile waters of low pH, and high iron, manganese, and total dissolved solids. These bacteria have been estimated to accelerate the oxidation of pyritic materials by a factor of 10^6 (17).

T. thiooxidans is capable of producing metabolic energy from the oxidation of sulphur or sulphide minerals with concomitant production of sulphuric acid. The species can grow in the pH range of 0.9 to 4.5. T. ferrooxidans is capable of oxidizing reduced sulphur compounds as well as ferrous iron to ferric iron. Sulphuric acid is also produced, with the optimum pH for elemental sulphur oxidation being about 5.0. The optimum pH for the oxidation of iron by Metallogenium has been found to be 3.5 to 5.0. It has been proposed that there is a pH-dependent succession of iron oxidizing bacteria which initially involves Metallogenium at pH 3.5 to 5.0, followed by T. ferrooxidan at pH values below 4.0 (18).

Walsh (19) stated that when chemical oxidation is rapid, biological catalysis is not effective in providing the bacteria with the energy required for anabolic activity. The specific level of catalysis by the bacteria is a function of seasonably varying flow-through rates, population levels and also the chemistry of the coal itself. Eighty percent of the pyrites can be removed from coal samples in three to four days by iron autotrophs. These are simple organisms which derive metabolic energy from the oxidation of iron and rely on inorganic sources for their carbon and nitrogen requirements (18). In the case of a predominantly alkaline-associated mineralization, iron bacteria catalysis will be minimal but sulphur bacteria catalysis may be important (17).

Other consituents in coal pile drainage, such as dissolved metals and dissolved organics, are produced by secondary reactions of sulphuric acid with minerals and organic compounds present in the coal. Such secondary reactions are dependent upon the method of coal preparation and cleaning before storage; climate, including rainfall and temperature; concentration of $CaCO_3$ and other neutralizing substances in the coal; concentration and form of trace metals in the coal; and residence time of the water in the coal pile.

A number of authors have suggested that there is a relationship between the sulphur content of coal and the concentration of contaminants in coal pile discharges. Table 6 shows the proximate analyses and coal ranks of the fuels used at coal-fired stations in Canada. It is very evident that the sulphur content can be related to coal rank for the coals presently in use at steam electric generating stations. Sub-bituminous, lignite and reject coals have an average sulphur content of about 0.4 percent, while the bituminous coal sulphur content averages 3.2 percent. From a geographical perspective, the more eastern the coal pile the higher the sulphur content. Maritime coals contain about ten times more sulphur than the coals stored in Alberta.

2.5 Characterization of Coal Pile Drainage

The characteristics of coal pile drainage from coal-burning generating plants differ greatly because of such factors as the chemical composition of the coal, amount of rainfall, and quality of rainfall. This type of data is a prerequisite to the assessment of

TABLE 6 PROXIMATE ANALYSES OF COALS USED AT CANADIAN THERMAL GENERATING STATIONS (1,2)

	Proximate Analysis of Coal (%)					Rank of Majority of Coal Burned
Station	Moisture	Ash	Volatiles	Fixed Carbon	Sulphur	
Battle River	27.0	11.0	27.8	34.2	0.4	SB
H.R. Milner	4.9	62.1	11.6	21.4	0.4	R
Sundance	20.4	13.6	29.5	36.5	0.21	SB
Wabumum	21.4	13.5	29.0	36.1	0.23	SB
Queen Elizabeth	27.6	9.0	30.3	31.1	0.5	SB
Estevan	35.2	10.73	25	31	0.5	L
Selkirk	33.5	9.0	25.4	32.2	0.5	L
Brandon	33.4	7.9	26.3	32.4	0.4	L
Lakeview	6.3	8.2	35.7	49.8	1.7	B
Nanticoke	6.2	8.2	35.7	49.8	2.4	B
Lambton	7.0	8.5	34.5	50.0	2.1	B
R.L. Hearn	7.1	8.3	34.3	50.3	2.4*	B
Trenton	9.2	12.3	N/A	N/A	3.2	B
Lingan	7	12	33	44	4.0	B
Grand Lake	2	13.2	32	48	4.8	B
Dalhousie	9	24	27	40	4.8	B

NOTE:

B	Bituminous
SB	Sub-bituminous
L	Lignite
R	Reject coal from metallurgical coal

* Ontario Hydro has subsequently indicated that sulphur content had been reduced to 1.4 percent.

the environmental consequences of discharging the wastewater to the receiving body (20), and also in the design and operation of treatment plants for this wastewater stream.

2.5.1 Canada. The chemical characteristics of specific coal pile leachates and runoffs have previously been investigated by several electric utilities in Canada.

As part of the background studies for the Poplar River Generating Station, coal leachate tests were conducted by the University of Wisconsin, Water Chemistry Laboratory. The results of the tests on the lignite coal from Saskatchewan which will be used at that station are shown in Table 7. Leachates from this coal are relatively low in sulphate, reflecting the low sulphur content of the lignite coal. The concentrations of most metals in the leachate are also quite low; the mean concentration of trace components is less than 0.5 mg/L. Although it is commonly believed that leachate from western coals does not contain high concentrations of elements it should be noted that this leachate contained 15 mg/L of boron. This would make the water unfit for drinking or irrigation (31).

In a study commissioned by the New Brunswick Electric Power Commission, the leachate from stockpiled coal at the Dalhousie Generating Station was characterized. The results are shown in Table 8. The bituminous coal used at this station is supplied by the Minto mine and is characteristically high in sulphur. The resulting coal pile leachate has a very low pH of 1.2, an extremely high iron concentration of 17 600 mg/L, and a sulphate concentration of 49 600 mg/L. The concentration of total arsenic in the leachate is reported to be 40 mg/L.

The runoff from the coal pile at Lingan Generating Station is periodically analyzed for major water pollution parameters whenever the collection lagoon overflows (Personal Communication, Robin Day, Lingan TGS, Lingan). The characteristics of a runoff sample gathered on April 25, 1980, are shown in Table 9. The bituminous coal stored at this station is supplied from an adjacent mine and contains a characteristically high level of sulphur which is the likely cause of the low pH of the runoff, as discussed in Section 2.4.

Studies conducted by Ontario Hydro have contributed to the overall understanding of coal pile leachates and runoffs under Canadian conditions. Coal pile runoff from stored coal at the Nanticoke Generating Station was studied as part of a major water use investigation (32). This study identified the coal pile runoff as a major contributor to the mineral enrichment of the ash lagoon water, particularly due to the high levels of leachable iron, sulphate and acidity.

Both coal pile runoff and leachate at Ontario Hydro's Lakeview Generating Station have been studied in detail over the past five years (33,34). Table 10 illustrates the nature of the coal pile runoff over the period of May to November 1975 (12). During the period of the study, the coal stored on-site was from Pennsylvania and contained 2.5

TABLE 7 RESULTS OF LIGNITE COAL LEACHATE TESTS - POPLAR RIVER GENERATING STATION*

	Mean Concentration (mg/L)
Major and Minor Components	
Na	118.0
K	4.86
Mg	33.6
Ca	36.9
B	15.0
SO_4	435.5
Trace Components	
Mn	0.187
Fe	0.477
Sr	0.706
V	0.016
Cr	0.018
Co	0.12
Ni	0.12
Cu	0.015
Zn	0.015
Cd	0.015
Al	0.231
Pb	0.12
As	0.12
Se	0.12
Zr	0.016
Sb	0.12

* Personal Communication, D.W. Draper, Environment Canada.

percent sulphur. This coal is washed before shipment. A definite decrease in the acidity, iron and sulphate content of the leachate was observed in samples collected in October and November. However, there was essentially no change in other elemental concentrations. Table 11 shows a comparison of coal pile runoff for August and November (33). Acidic leachate was found even during the winter whenever a flow was observed; however, during most of the winter the ditches were frozen and no flow was evident.

The dissolved solids, iron and sulphate concentration of the drainage were correlated to the total acidity in the runoff. Leachates were periodically analyzed for

TABLE 8 COAL PILE LEACHATE AT DALHOUSIE GENERATING STATION*

Parameter	Concentration (mg/L except pH)
pH	1.2
Sulphate	49 600
Phosphorus	300
Arsenic	40
Chromium	2.0
Copper	8.0
Iron	17 600
Lead	0.2
Nickel	7.8
Zinc	14.5
Mercury	< 0.0001

* Personal Communication, C. Doiron, New Brunswick Electric Power Commission.

TABLE 9 COAL PILE RUNOFF QUALITY AT LINGAN GENERATING STATION

Parameter	Concentration
pH	2.8
Suspended Solids	2 310 mg/L
Total Solids	3.82 mg/L
Conductivity	200 MS

trace elements. The results are shown in Table 12 (12). Also shown are the concentrations of phenol and chemical oxygen demand (COD). The chemical oxygen demand of the sample was almost completely accounted for by the presence of ferrous iron in the leachate.

One problem with coal pile drainage pointed out in the Lakeview studies was the occurrence of high concentrations of suspended solids. The suspended solids content of the runoff was determined to be as high as 30 000 mg/L; however, the majority of samples had suspended solids between 100 and 500 mg/L (12). The highest suspended

TABLE 10 COAL PILE DRAINAGE AT LAKEVIEW GENERATING STATION, MAY TO NOVEMBER, 1975 (12)

Parameter	Concentration (mg/L except pH)		
	Average	High	Low
pH	2.7	2.9	2.4
Acidity (as $CaCO_3$)	1 500	2 850	300
Dissolved Solids	6 500	11 600	4 600
Sulphate	4 100	6 900	1 100
Iron	420	1 000	150
Calcium	400	540	200
Sodium	300	440	140
Magnesium	170	440	9
Chloride	160	190	110
Aluminum	62	75	48
Silica	22	64	12
Manganese	7	12	3.4
Potassium	5	10	1.6

solids concentrations were observed in the high flow rate drainage from heavy storms of greater than 15 mm rainfall. The relationship between flow rate and suspended solids content is shown in Figure 2. Frequently, high suspended solids were evident during low flow conditions as a result of vehicle washing or unloading of coal from a ship. A floating scum was frequently observed in the runoff collection ditch around the coal pile.

The composition of rainfall runoff from the coal pile was also investigated in this study as this is considered to be the main contributor of the total mass emission from the pile (12). Except during heavier rainfalls, there was little change in the drainage composition. The most significant feature of heavier rainfall was the reduced level of contaminants during the later stage of the runoff. The quality of the runoff generally returned to normal levels within 24 hours after the rainfall ended.

A slight increase in the concentrations of acidity, iron, sulphate and trace metals was observed at the beginning of a rainfall. This was attributed to the flushing action of the rain which washes out accumulated pools of concentrated leachate in the

TABLE 11 SEASONAL VARIATION OF POLLUTANT CONCENTRATIONS IN COAL PILE RUNOFF AT LAKEVIEW GENERATING STATION (33)

Parameter	Monthly Average Concentrations August 1975	 November 1975
pH (units)	2.7	2.8
Acidity (meq/L)	32	18
Dissolved Solids	7 700	5 400
Iron	470	220
Sulphate	4 600	3 300
Sodium	330	340
Calcium	490	480
Magnesium	170	170
Potassium	2.8	7.6

Note: All analyses expressed in mg/L except where noted.

coal pile and drainage ditches. The decreased levels of contaminants toward the end of a rainfall event are likely due to the dilution of the leachate with surface runoff rather than a complete flushing of the pile. The authors of the study suggested that the two effects tended to cancel each other so that the flow-proportioned composite samples were essentially similar to the average base flow leachate (12).

A rigourous statement of the relationship between storm intensity and amount of runoff could not be made by the authors (12). In general, for the coal pile at Lakeview, the fraction of rainfall appearing as runoff increased with the total volume of rainfall. Short intense storms returned less often than longer, less intense storms of equivalent total rainfall volumes. The rainfall intensity, previous meteorological conditions and pile size have a significant effect on the amount of runoff from a particular storm. The large pile volume allows the pile to behave like a sponge, which tends to decrease the net return of precipitation for all but the largest storms. Based on calculated evapo-transpiration rates over the study period, there was a net loss of water from the pile during the summer months. Further, it was estimated that about 20 percent of the water entering the pile as rain or applied water left the coal pile as drainage (12).

TABLE 12 TRACE ELEMENT CONCENTRATIONS IN COAL PILE DRAINAGE AT LAKEVIEW GENERATING STATION, MAY TO NOVEMBER, 1975 (12)

	Concentration (mg/L)		
Parameter	Maximum	Minimum	Number of Analyses
Nickel	2.8	0.2	8
Copper	1.6	<0.2	7
Cobalt	0.4	0.09	12
Chromium	0.4	0.02	6
Zinc	0.3	0.2	5
Lead	0.2	<1	3
Arsenic	0.1	0.02	5
Selenium	0.02	<0.005	5
Antimony	0.01	<0.005	5
Cadmium	0.002	<1	8
Vanadium	< 1		4
Molybdenum	< 1		2
Beryllium	< 1		4
Phenols	0.012	<0.001	5
COD	161	37	11

Other elements <1 mg/L: Bromine, Barium, Europium, Fluorine, Lutetium, Scandium, Silver, Tantalum, Thorium, Titanium.

2.5.2 United States. A number of studies have been conducted in the United States to characterize both the organic and inorganic chemical constituents in coal pile runoff.

Most of the characterization studies have been conducted to quantify the inorganic constituents in coal pile drainage. The most definitive study on the subject was conducted by Wachter and Blackwood (21) who characterized coal pile drainage from both freshly-mixed and aged coals from six regions in the United States. Samples were collected beneath a rainfall simulator and were analyzed for a wide range of chemical constituents. A representative coal pile for the United States was defined to characterize the drainage runoff effluent levels from all sources. Table 13 shows the average coal pile drainage by coal region in the United States based on these simulations.

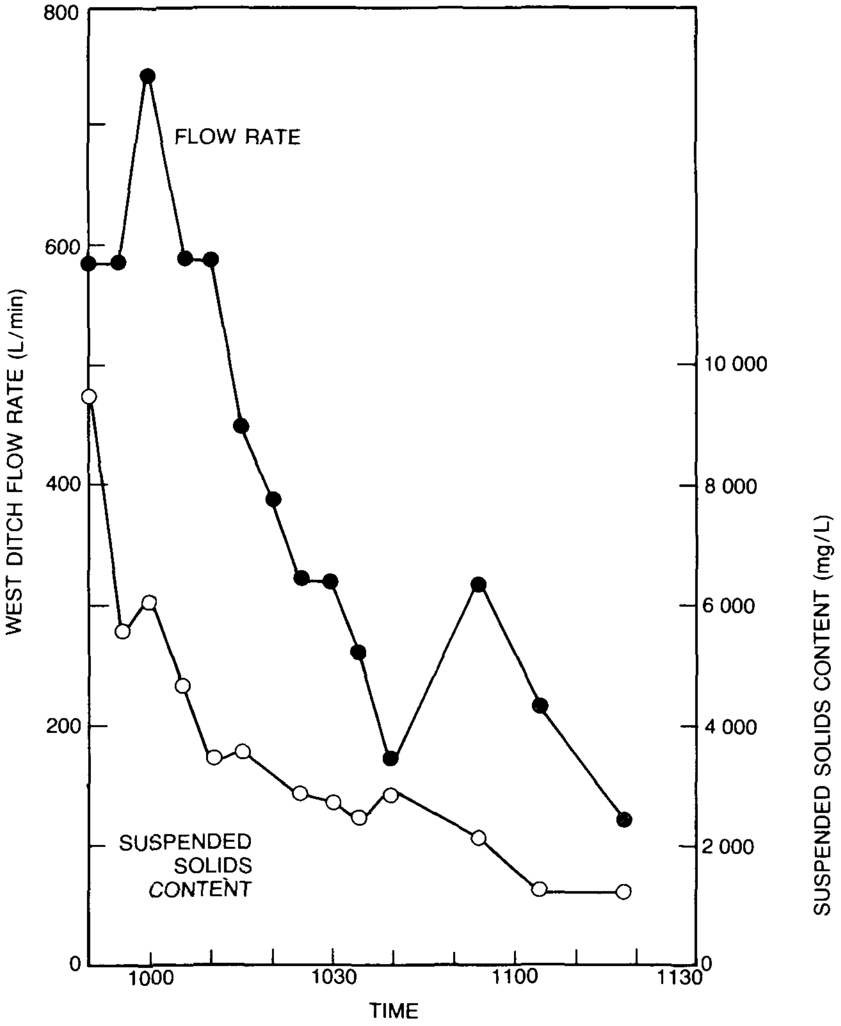

FIGURE 2 COAL PILE DRAINAGE AT LAKEVIEW GENERATING STATION (12)
(6 mm rainfall September 21, 1977)

TABLE 13 AVERAGE CONSTITUENT CONCENTRATIONS IN SIMULATED COAL PILE RUNOFF BY COAL REGION (21)

	Concentration (mg/L)					
Parameter	Appalachian	Great Northern Plains	Interior Eastern	Interior Western	Western	Southwestern
Total Suspended Solids	1521	1282	1264	1853	2486	1538
Total Dissolved Solids	259	430	1136	5539	1900	356
Sulphate	66	1598	648	4860	240	190
Iron	3.1	1.5	9.1	1131	8.2	5.5
Manganese	0.03	0.14	0.44	17.9	0.4	0.04
Free Silica	12.3	NDL[a]	0.8	86.3	NDL	NDL
Cyanide	< 0.001	NDL	0.002	NDL	NDL	NDL
BOD_5	< 5.0	< 7.5	NDL	< 1.2	< 2.5	< 7.5
COD	1407	1324	1556	1053	1826	769
Nitrate	0.12	0.14	0.33	0.09	1.8	0.16
Total phosphate	NDL	NDL	NDL	NDL	NDL	NDL
Antimony	2.1	NDL	7.5	10.3	14.0	6.5
Arsenic	23	1.8	4.1	10.1	5.6	4.1
Beryllium	NDL	NDL	NDL	NDL	NDL	NDL
Cadmium	NDL	NDL	NDL	0.05	0.005	NDL
Chromium	NDL	NDL	NDL	0.03	0.04	NDL
Copper	0.02	NDL	NDL	2.2	NDL	0.02
Lead	0.05	0.05	0.06	0.33	0.07	0.05
Nickel	0.06	0.02	0.09	10.2	0.05	0.03
Selenium	23.8	NDL	12.5	25.2	15.0	21.5
Silver	NDL	NDL	NDL	NDL	NDL	NDL
Zinc	0.008	0.17	0.14	25.0	0.15	0.04
Mercury	< 0.001	0.003	NDL	0.004	0.005	0.002
Thallium	NDL	NDL	NDL	NDL	NDL	NDL
pH[b]	6.28[b]	6.93[b]	7.62[b]	2.81[b]	7.24[b]	6.60[b]
Chloride	0.33	NDL	NDL	2.3	NDL	NDL
Total organic carbon	251.7	373.2	380.1	90.5	318.4	158.7

[a] No detectable level.

[b] Negative logarithm of hydrogen ion concentration.

COAL REGIONS OF THE UNITED STATES AS DEFINED IN ABOVE TABLE

Region	States included
Appalachian	Pennsylvania, Ohio, West Virginia, Maryland, Virginia, Eastern Kentucky, Tennessee, Alabama, Georgia.
Interior-Eastern	Illinois, Indiana, Western Kentucky, Michigan.
Interior-Western	Iowa, Missouri, Nebraska, Kansas, Oklahoma, Arkansas, Texas.
Western	Wyoming, Idaho, Utah, Colorado, New Mexico, Arizona, Washington.
Southwestern	Utah, Colorado, Arizona, New Mexico.
Great Northern Plains	Montana, North Dakota, South Dakota.

The site-specific nature of coal pile runoff is apparent in the results of this study. For example, the pH of drainage from western coal, which has a low sulphate concentration, is 7.24, while interior western coal, which has a sulphate concentration of about 20 times greater, has a pH of 2.81. The concentration of zinc ranges from 25 mg/L in the interior western coal to 0.008 mg/L in the Appalachian coal.

The authors also concluded that large, aged coal stockpiles located in areas of frequent rainfall generate much higher concentrations of most effluent parameters.

Table 14 shows the chemical constituents of runoff from a production-weighted simulated coal pile. This characterization takes into account the relative volumes of coal produced in each region of the United States. Based on the simulation, runoff can be characterized as containing high levels of total suspended and dissolved solids, sulphates, COD, arsenic, nickel and selenium.

Metry (22) conducted a simulation study using low-sulphur western U.S. coal to generate coal pile runoff. Distilled water was allowed to percolate through a 1.8-m, 0.079-m diameter glass column filled with coal and the leachate was collected and analyzed. The results are shown in Table 15. The leachate was simulated under wet aerobic, intermediate aerobic and anaerobic conditions. Based on this laboratory experimentation, the acid-producing capacity of the coal is less than the alkalinity-producing capacity under all conditions. This balance between acid-producing capacity and inherent alkalinity is most important in the production of acidic leachate. Such acidic conditions are observed in eastern coals containing a high pyrite sulphur content.

The highest TDS and iron concentrations were produced under wet/dry-intermediate aerobic conditions; however, anaerobic conditions produced the highest pH and alkalinity.

Differences between this simulated leachate from a low-sulphur western U.S. coal (Table 15) and the production-weighted simulated runoff for all the U.S. (Table 14) are evident. The simulated western leachate generally had lower TDS, iron, manganese and zinc concentrations and a higher pH than the coal production-weighted simulated runoff.

A simulation study by Boston and Boegly (23) involved laboratory and field-scale leaching experiments on coals from the Western United States. As with other studies, a wide variation in leachate characteristics was evident. Results of analyses of the simulated eastern coal leachates are shown in Table 16.

TABLE 14 COAL PRODUCTION-WEIGHTED EFFLUENT CONCENTRATIONS IN SIMULATED RUNOFF (21)

Effluent Parameter	Concentration (mg/L)
Total Suspended Solids	1551
Total Dissolved Solids	754
Sulphate	401
Iron	39
Manganese	0.69
Free Silica	10.1
Cyanide	< 0.001
BOD$_5$	< 3.8
COD	1436
Nitrate	0.31
Total Phosphate	NDL[a]
Antimony	4.6
Arsenic	15.7
Beryllium	NDL
Cadmium	0.002
Chromium	0.004
Copper	0.08
Lead	0.06
Nickel	3.1
Selenium	19.9
Silver	NDL
Zinc	0.08
Mercury	0.001
Thallium	NDL
pH	6.78[b]
Chloride	0.27
Total Organic Carbon	280

[a] No detectable level.
[b] Negative logarithm of hydrogen ion concentration.

A number of studies have been conducted to characterize runoff from actual coal piles. A study by Brookman et al (24) compared the runoff quality from coal piles during dry weather (leachate) and wet weather (runoff). Results of this study are shown in Table 17. The dry weather leachate was more variable in terms of pollutant concentration with the exception of total dissolved solids, which were found at concentrations up to five times higher in the runoff.

A comparison between the simulated runoff from an Appalachian coal shown in Table 13 and the actual runoff from coal piles in Pennsylvania, shown in Table 17,

TABLE 15 LEACHATE SIMULATION FROM LOW-SULPHUR WESTERN U.S. COAL (22)

Effluent Parameter (mg/L except pH)	Test No. 1 Wet Aerobic Conditions	Test No. 2 Wet/Dry-Intermediate Aerobic Conditions	Test No. 3 Anaerobic Conditions
Total Dissolved Solids	490	1720	592
pH	7.4	7.2	8.0
Alkalinity	54	37.5	124
Iron	0.65	12	0.85
Vanadium	< 2	< 2	< 2
Lead	< 0.1	< 0.1	< 0.1
Zinc	0.15	0.2	0.23
Cadmium	< 0.05	< 0.05	< 0.05
Chromium	< 0.05	< 0.05	< 0.05
Manganese	< 0.05	0.08	< 0.05
Strontium	0.2	0.33	0.26
Copper	0.12	0.15	0.1
Lithium	< 0.05	< 0.05	< 0.05

indicates that the simulated runoff was much less concentrated than the actual runoff. Iron, manganese and sulphate levels were about 200, 300 and 24 times greater in the actual runoff compared to the simulated runoff. Also, the pH was about 4 units more acidic in the actual runoff. Only the TSS was adequately simulated by Wachter (21) based on this comparison. The simulation by Boston and Boegly, shown in Table 16, generated leachates that more closely matched the characteristics of leachates from eastern coals in terms of pH, sulphates and iron.

The results of six other characterization studies of coal pile drainage are summarized in Table 18. Ferraro (25) investigated the runoff from a coal transfer facility in Southeastern Ohio. The site covered 3.04 ha, and medium to high-sulphur pH (2 to 4% by weight) coal was stored. The runoff from the site varied considerably in chemical constituents. Chu et al (26) investigated the chemical characteristics of many waste

TABLE 16 SIMULATED LEACHATES FROM EASTERN U.S. COALS (23)

Parameter	Illinois	Kentucky	Pittsburgh	Ohio
pH	2.2	2.1	2.9	7.9
Conductivity (µmhos/cm)	15 200	10 500	1 730	7 570
Sulphate	21 500	22 300	1 240	8 810
Iron	7 710	9 850	296	< 0.10
Arsenic	0.147	9.05	0.016	N/A
Barium	< 0.2	< 0.2	< 0.2	N/A
Cadmium	0.268	0.166	0.010	N/A
Chromium	0.438	0.724	0.011	N/A
Lead	0.014	0.012	0.008	N/A
Selenium	0.438	0.829	< 0.020	N/A
Silver	0.00035	0.00005	< 0.00005	N/A
Mercury	0.00012	0.0002	0.00008	N/A

Note: N/A - not analyzed.
All analyses in mg/L except as indicated.

streams, one of which was coal pile runoff at operating Tennessee Valley Authority (TVA) generating stations. The highly acidic runoff from coal storage piles at two plants was analyzed. Anderson and Youngstrom (27) studied coal pile runoff from stored coal at the Cornell University heating plant. The drainage area investigated covered 0.60 ha and was located in central New York State.

The analyses of coal pile runoff at seven unnamed generating stations, likely in the United States, have also been presented (28). Chu et al (26) studied the runoff from two TVA stations while Cox et al (14) reported on the coal pile runoff of a third TVA generating station. Weeter (29) canvassed 80 utility companies in the U.S. using a questionnaire to compile data on coal pile drainage. The results of this study represent the broadest information base on coal pile drainage for the U.S. steam electric generating industry.

An examination of Table 18 illustrates two important facts. The characteristics of coal pile drainage are highly variable and reflect the large differences in coals currently stored in the U.S.

TABLE 17 POLLUTANT CONCENTRATIONS IN LEACHATE AND RUNOFF FROM COAL PILES IN PENNSYLVANIA (24)

Effluent Parameter (mg/L except pH)	Runoff Condition	
	Dry	Wet
Total Suspended Solids	12 - 19 000	1 700 - 13 000
Total Dissolved Solids	2 300 - 21 700	2 300 - 115 000
Iron	160 - 23 500	700 - 1 400
Aluminum	20 - 1 800	70 - 100
Manganese	2 - 100	9 - 15
Sulphate	90 - 57 000	1 600 - 2 700
Total Alkalinity @ $CaCO_3$	--	--
Total Acidity @ $CaCO_3$	200 - 38 000	1 900 - 2 900
pH	1.48 - 3.37	2.35 - 3.36

Coal source: Pennsylvania and West Virginia.

Average Analysis:		
	Sulphur	1.84%
	Iron	0.35%
	Manganese	0.003%
	Aluminum	0.56%

The simulated leachate from coal as generated by Wachter and Blackwood (21) and Metry (22) is generally not representative of actual coal pile waters. It would appear that runoff cannot be adequately simulated either for eastern high-sulphur or western low-sulphur coals.

As pointed out by McFall (30), the effect of snowmelt from a coal pile may be important. Coal piles that have snow resting on them will produce leachates with different characteristics than those subjected to rainfall only. Ferraro (25) presented data of the analysis of snowmelt runoff from a coal in the Northwest United States (Table 19). A comparison between this runoff and the simulated runoff from a western coal as presented by Wachter and Blackwood (21) indicates that the snowmelt runoff apparently has 50 times less TSS and much lower concentrations of iron and manganese. This

TABLE 18 COAL PILE DRAINAGE CHARACTERIZATION FOR U.S. COALS

Parameter	Reported Concentration or Range (mg/L)	Number of Samples	Reference
pH	2.1 - 3.2	5	25
	2.0 - 2.9	2	26
	2.2 - 5.8	-	27
	2.1 - 6.6	7	28
	2.3 - 3.1	12	15
	1.5 - 7.6	204	29
Total Suspended Solids	550 - 810	2	26
	22 - 610	4	28
	38 - 680	12	15
	2 - 19 000	190	29
Total Dissolved Solids	1 500 - 3 200	2	26
	9 332 - 14 948	-	27
	720 - 28 970	4	28
	270 - 8 200	12	15
	90 - 115 000	177	29
Sulphate	447.6 - 10 107	4	25
	2 600	1	26
	525 - 19 000	5	28
	1 800 - 6 200	12	15
	1 - 57 000	168	29
Acidity	114.5 - 7 700	4	25
	270 - 1 700	2	26
	375 - 8 250	-	27
	8.84 - 21 700	3	28
	700 - 4 800	12	15
	0 - 38 000	155	29
Iron	26 - 2 702.1	5	25
	510 - 830	2	26
	10 - 5 250	-	27
	0.06 - 4 700	6	28
	23 - 590	12	15
Total	0.17 - 93 000	95	29
Dissolved	0.01 - 4 410	15	29
Manganese	27 - 110	2	26
	45 - 72	-	27
	1.8 - 12.0	12	15
	0 - 100	25	29
Alkalinity	0 - 3 641	4	28
	0 - 608	34	29

TABLE 18 COAL PILE DRAINAGE CHARACTERIZATION FOR U.S. COALS (CONT'D)

Parameter	Reported Concentration or Range (mg/L)	Number of Samples	Reference
Hardness	600 - 980	2	26
	130 - 1 851	3	28
	90 - 3 850	130	29
Oil/Grease	0 - 36.7	53	29
DO	6.7 - 8.6	28	29
TOC	2 - 39	13	29
BOD	< 0.5	6	29
COD	9	1	26
	7.6 - 1 836	21	29
Turbidity	330	1	26
	2.77 - 505	3	28
Conductivity (µmho/cm)	2 100 - 2 400	2	26
	2 200 - 6 400	12	15
Phenol	< 0.005 0	5	29
Chloride	0	1	26
	3.6 - 481	2	28
	15 - 660	12	15
Calcium	240 - 350	2	26
	110 - 720	12	15
Magnesium	0.023 - 1.2	2	26
	0 - 89	3	28
	22 - 130	12	15
Sodium	4.1	1	26
	160 - 1 260	2	28
Ammonia	0 - 1.35	3	28
Nitrate	0.3 - 0.9	2	28
Silicon (Dissolved)	91	1	26
	1 - 45	11	15
Phosphorus	1.2	1	28
Aluminum	190	1	26
	1 200	1	28
	20 - 92	11	15
Antimony	< 0.1 - 0.5	10	15
Arsenic	0.009 - 0.01	2	26
	0.006 - 0.046	9	15

TABLE 18 COAL PILE DRAINAGE CHARACTERIZATION FOR U.S. COALS (CONT'D)

Parameter	Reported Concentration or Range (mg/L)	Number of Samples	Reference
Barium	0.1	1	26
	< 0.1 - 0.5	11	15
Beryllium	< 0.01	1	26
	< 0.01 - 0.03	11	15
Cadmium	< 0.001 - 0.006	2	26
	< 0.001 - 0.003	12	15
Chromium	< 0.005	2	26
	0.1 - 7.5	-	27
	0 - 15.7	4	28
	< 0.005 - 0.010	12	15
Copper	0.18 - 0.56	2	26
	0.1 - 6.1	-	27
	1.6 - 1.8	2	28
	0.07 - 0.46	12	15
Lead	< 0.01 - 0.023	2	26
	< 0.01	12	15
Mercury	< 0.0002 - 0.027	2	26
	0.0019 - 0.0073	12	15
Nickel	0.32 - 1.7	2	26
	0.15 - 0.49	12	15
Selenium	0.003 - 0.03	2	26
	< 0.001 - 0.006	10	15
Titanium	< 1	1	26
	< 1	12	15
Zinc	1.0 - 3.7	2	26
	2.4 - 26.0	-	27
	0.006 - 12.5	7	28
	1.1 - 5.1	12	15

suggests that for western coal, the snowmelt runoff is less concentrated than rainfall runoff.

Ferraro (25) related the lack of actual data on runoff from Western United States coals to the high evaporation rates and minimal rainfall in most western states. During his study, none of the utilities contacted had any data on coal pile rainfall runoff quality.

TABLE 19 SAMPLE OF SNOWMELT RUNOFF FROM COAL IN THE NORTHWEST UNITED STATES (25)

Parameter	Concentration
pH	6.8 units
Conductance	374 µmho/cm
Iron	0.79
Aluminum	0.40
Manganese	0.06
Alkalinity (to pH 4.3)	51.6
Total Suspended Solids	58

Note: All analyses expressed in mg/L except where noted.

Wachter and Blackwood (21) also simulated coal runoff samples with high trace organic contaminants contents and analyzed them for organic substances on the U.S. Environmental Protection Agency priority pollutants list. The complete list of the priority pollutants is shown in Appendix I. Results are shown in Table 20. No phenolic compounds were observed at concentrations greater than 1 µg/L. The background level of di-iso-octylphthalate (DiOP) was higher than in the coal leachate and was assumed to have resulted from contamination from the plastic liners used in the sample pans. Based on the dilution that would occur due to rainfall runoff, the levels of organics were reported to be 10^{-6} to 10^{-11} lower than hazardous levels for the receiving waters.

2.6 Coke Storage in Canada

Metallurgical coke is made by the destructive distillation of bituminous coal in the absence of air. This process is carried out at temperatures as high as 1100°C, driving off volatile components and both surface and combined water from the coal.

Most coke production in Canada is associated with steel manufacturing and, as a result, the majority of stockpiled coke is stored on-site at four major steel-making facilities. Table 21 shows the approximate weights and pile areas of coal and coke at the four largest steel-making plants in Canada.

Large volumes of coke are not normally stored in piles at the steel-making facilities due to the value of the product. As shown in Table 21 about 40 times more coal than coke is stored at the four major steel plants. Although the coal piles are generally

TABLE 20 ORGANIC CONCENTRATIONS IN SIMULATED RUNOFF (21)

Compound	Concentration (µg/L) Coal Leachate	Background	Source Level
2-Chloronaphthalene	16	2	14
Acenaphthene	22	7	15
Fluorene	21	7	14
Fluoranthene	24	8	16
Benzidine	18	4	14
Di-iso-octylphthalate (DiOP)	95	405	-310*
Benzo (ghi) perylene	52	8	44

* Negative level due to higher concentration in the background sample, believed due to contact with plastic for longer period of time than leachate sample; DiOP is a plasticizer.

TABLE 21 STOCKPILED COAL AND COKE AT CANADIAN STEEL-MAKING FACILITIES*

Steel Mill	Coal Storage		Coke Storage	
	tonnes x 10^{-3}	ha	tonnes x 10^{-3}	ha
1	1 361	33.6	3.5	0.57
2	907	12.5	48	2.69
3	2 721	12.1	45	0.56
4	272	N/A	7	0.13
TOTAL	5 261	58.2**	135	3.95

* Personal Communication, J. Haskill, EPS, Environment Canada, Ottawa.
** Total of storage areas for 3 mills only

N/A: Not available

the same order of magnitude of size as coal piles at steam electric stations, the coke storage piles are about one-tenth the size.

Generally, less concern exists about the management of coke piles because coke has distinctly different properties from coal. Coke is generally larger in particle size and contains less water and volatiles. It is widely believed that runoff from coke piles contains fewer chemical contaminants and, because of the larger, more unreactive particles, coke is much less likely to ignite spontaneously. Usually, coke is stockpiled anywhere that is convenient, without pile liners, dust suppression sprays, runoff collection or runoff treatment. At the steel-making facilities visited during this study, runoff from coke piles was allowed to enter the surface drainage system for the rest of the site.

2.7 Characterization of Coke Pile Runoffs

The quality and quantity of runoff from coke storage piles in the U.S. were reported in a study by Brookman et al (35). Two sites were investigated, one in Houston, Texas, from May 1975 to September 1976, and the second in Fantana, California, for all of 1975. Table 22 compares the average concentrations of pollutants in coal and coke pile runoff from storage areas at the two sites.

The coal storage area at Site 1 showed much higher values for most pollutants than the same area at Site 2. During dry days up to 1.9×10^5 litres of water were sprayed on the pile to prevent wind erosion of coal fines. These retained fines likely increased the concentrations of TSS and total iron in the runoff compared to sites without such systems. Further, the water used for dust suppression consisted of recycled cooling water which the authors suggested was the source of the high TDS, ammonia and phenol concentrations.

Generally, coke pile runoff contained lower concentration of pollutants than coal pile runoff. The levels of TDS, dissolved iron and ammonia for the coke pile at Site 2 were higher than in the runoff from the coal pile at the same site.

2.8 Summary

Based on the review of the technical literature, it is apparent that the coal pile drainage problem is intimately linked to the coal characteristics, meteorological conditions and the overall management scheme for the stored coal. The characteristics and quantity of coal pile drainage are in part dependent on the pile shape, age and degree of compaction. These factors are also important in other pile considerations such as spontaneous combustion. The overriding factor governing the nature of the coal pile discharge appears to be the type and properties of the stored coal.

TABLE 22 AVERAGE CONCENTRATION OF POLLUTANTS IN STORM RUNOFF AT TWO STEEL-MAKING FACILITIES (35)

		Concentration (mg/L)		
Pollutant	Site	Coke Pile Runoff	Coal Pile Runoff	Coke Pile/ Coal Pile
TSS	1	505	4 187	0.12
	2	392	853	0.46
TDS	1	745	2 289	0.33
	2	959	471	2.04
Total Iron	1	32.3	39.3	0.82
	2	12.6	18	0.70
Dissolved Iron	1	0.1	N/D	-
	2	1.0	0.2	5.00
Phenols	1	0.06	0.39	0.15
	2	0.03	0.01	3.00
Total Cyanide	1	0.01	N/D	-
	2	0.55	N/D	-
Ammonia	1	2.1	56*	0.04
	2	29.3	0.33*	88.79
Sulphate	1	N/A	N/A	-
	2	129	232	0.56

* High concentrations of ammonia may be due to the source of dust suppression water which was applied to the pile. See discussion in Section 2.7.

It is widely believed that acid generation in coal piles is due to biological activity and is related to the sulphur content of the coal. This is consistent with the understanding of the acidity generation mechanism in coal refuse piles and metal sulphide ore mining tailings. Biological activity can increase acid generation by 10^6 times.

Only limited study has been given to quantifying the presence of organics in coal pile waters. Very low concentrations of U.S. EPA Priority Pollutants were found in one study.

Both simulated and actual coal pile drainage have been analysed for inorganic chemical constituents. Generally, the simulated runoff contained lower concentrations of contaminants and did not model natural coal pile discharges acceptably. Coal pile discharges are highly variable; however, certain trends are apparent. Western coals, which contain less sulphur than eastern coals, produce discharges that contain lower levels of contaminants, metals and trace elements. Eastern coals produce the most concentrated discharges due primarily to biologically-produced acidity. Leachates are more concentrated in terms of contaminants than rainfall runoff. Snowmelt from western coal piles was found to be less contaminated than rainfall or leachate. Discharges from coke piles contain lower concentrations of contaminants than from coal piles.

Three areas have not been adequately addressed in the literature. Runoff due to snowmelt and aqueous discharges from coal piles during winter conditions have not been assessed. Rainfall runoff from western low-sulphur coals has not been characterized for existing piles exposed to natural climatic conditions. Little data exists in the literature on the presence of trace organics in coal pile discharges.

Based on the review of the literature, some general characteristics of coal and coke pile drainages in Canada could be predicted. The sampling program for this study was designed to obtain samples that would highlight the anticipated differences between coal and coke pile drainage characteristics across Canada.

3 SAMPLING METHODOLOGY

During the sampling program, seven sites were visited. Discharges from coal piles at five steam electric generating stations and two coke piles at steel-making facilities were sampled. Table 23 summarizes the details of the sampling program at the selected sites. The program was designed to sample runoff and water in the pile at both coke and coal piles during rainfall events and following periods of no rain. This provided data on the characteristics of coal and coke pile runoff and leachate.

At one site, discrete samples were taken during a storm to monitor changes in runoff quality with storm duration. Also, at one coke and one coal pile, discharges from a number of positions around the piles were discretely sampled to observe spatial differences in discharge.

In this section of the report the sites are briefly described and the sampling procedures used at each location are presented. For each of the sites weather data for the month previous to the day of sampling is presented in detail in Appendix II. The weather conditions at the time of sampling are mentioned in each sampling site description.

3.1 Lingan Thermal Generating Station

The Lingan Generating Station is operated by the Nova Scotia Power Corporation and is located at Lingan, near Sydney, Nova Scotia. The nominal capacity is 300 MW, generated by two equally-sized units which were commissioned in 1979 and 1980. Typical analyses of the bituminous coal used at the station are shown below:

Moisture	9 - 10%
Ash content	4 - 22% (12% average)
Volatiles	33%
Fixed carbon	55%
Sulphur content	1.3%
Heat value	23.3 - 27.9 MJ/kg

More comprehensive analyses of the coal are shown in Table 24. Coal used at the site is supplied from a nearby mine and is delivered to the site by unit train.

The coal pile covers approximately 0.9 ha and has a height of 15 m. The pile volume is 1.4 x 10^5 m^3 (1). The coal is piled on a layer of trash coal which itself is

TABLE 23 SUMMARY OF SAMPLING PROGRAM

Site of Sampling	Location	Type of Fuel Stored	Date of Sampling (1980)	Comment
Lingan Generating Station	Sydney, N.S.	Bituminous high-sulphur coal	July 22	Discrete sample from runoff collection lagoon following period of no rainfall.
			August 19	Discrete sample from runoff collection lagoon following a relatively rainy period.
Dalhousie Generating Station	Dalhousie, N.B.	Bituminous high-sulphur coal	August 13/ September 18	Discrete samples taken from runoff collection ditch during a relatively rainy period. Sample taken August 13 was analyzed for metals. Sample on September 18 was analyzed for trace organics.
Lakeview Generating Station	Mississauga, Ontario	Bituminous low-sulphur coal	July 29	Discrete sample taken from runoff collection ditch during period of no rain.
			September 2	20 discrete samples taken during rainfall event from runoff collection ditch. Analysis completed on composite of samples.
Algoma Steel Limited	Sault Ste. Marie, Ontario	Coke	July 24	Eight discrete samples taken from impounded water on pile. Analysis conducted on composite of discrete samples.
Stelco Steel Company	Nanticoke, Ontario	Coke	September 13	Discrete sample taken from pile runoff during rainstorm.
Battle River Generating Station	Forestburg, Alberta	Sub-bituminous low sulphur coal	August 7	Five discrete samples taken from water trapped in the coal pile. Analysis conducted on composite of the samples.
Milner Generating Station	Grande Cache, Alberta	Sub-bituminous low-sulphur coal, rejects and dewatered tailings	August 8	Discrete sample taken of rainfall runoff from coal pile during a rainstorm.

TABLE 24 ANALYSES OF TYPICAL CAPE BRETON COAL - LINGAN GENERATING STATION*

Parameter	Concentration**
Ash Content	5 - 25%
Silicon	85 000 - 114 000
Aluminum	79 000 - 106 000
Iron	22 000 - 35 000
Titanium	3 600 - 5 400
Phosphorus	1 300 - 2 600
Manganese	1 400 - 7 200
Calcium	10 000 - 24 000
Magnesium	1 200 - 6 600
Sodium	370 - 1 900
Potassium	4 600 - 13 000
Sulphur	800 - 6 000

* Personal Communication, R.Day, Lingan GS, Lingan, N.S. Analyses were performed on ashed coal sample. This method may underestimate concentrations of elements present in coal.

** Concentration reported in mg/kg unless otherwise noted.

located on a gravel and crushed rock base. Coal can be stored on the stacker reclaimer for transfer into the generating station after a few days. Alternatively, the coal can be accumulated on another part of the pile where it can remain in storage for up to 11 months. This alternate coal supply is used in the event of an interruption in the delivery of coal.

Discharges from any part of the coal storage area are collected in a ditch around the perimeter of the pile which drains into an unlined collection lagoon as shown in Figure 3.

Samples were taken twice from the collection lagoon. On July 22, 1980, a sample was taken following five days of no rainfall. The preceding weeks were slightly drier than normal as well. The second sampling took place on August 19, 1980. Rainfall occurred in the area on each of the first 17 days of August with the total rainfall being normal for the area. Eight discrete samples were taken from the collection lagoon on

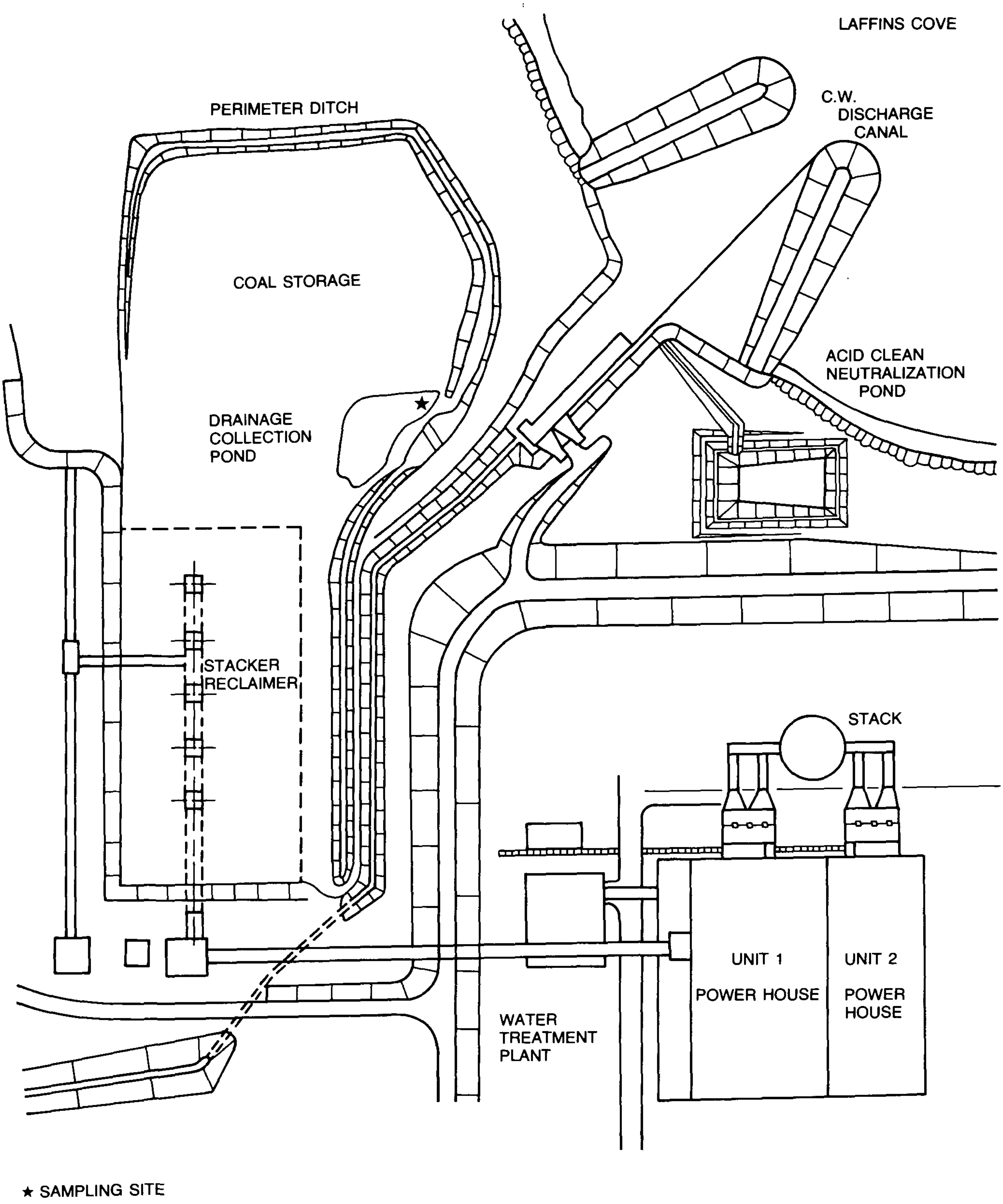

FIGURE 3 COAL STORAGE AREA - LINGAN G.S.

August 17, 22, 26, 29, and September 3, 9, 16 and 23. These samples were analyzed to determine changes in the lagoon water over that period.

3.2 Dalhousie Generating Station

This generating station is located on Eel Bay, near Dalhousie, New Brunswick, and is operated by the New Brunswick Electric Power Commission. The station has a nominal generating capacity of 323 MW. Unit 1 is oil-fired with a capacity of 110 MW and was commissioned in 1968. Unit 2 is coal-fired and was commissioned in 1979. The coal burned at the station is mined at the Minto Coalfield and is transported by rail, then by truck, to the on-site storage area. Analyses of the typical bituminous coal used in the station are shown below:

Moisture	9%
Ash content	18% - 22%
Volatiles	27%
Fixed carbon	40%
Sulphur content	4.8%
Heat value	23.26 MJ/kg

Results of more detailed analyses of the coal are shown in Table 25. Figure 4 shows the on-site storage area. The coal pile occupies 1.5 ha and is 4.6 m in height. About 6.9 x 10^4 m^3 of coal are maintained in storage (1). Runoff from the pile is collected in a ditch around the perimeter, and then flows to the station's liquid waste treatment system.

Two samples were gathered from the coal pile drainage collection ditch. On August 13, 1980, when the sample was taken, there was a light steady rainfall. Weather data from the nearby Charlo Airport indicated that measurable rainfall occurred on 22 of the 30 days prior to the sampling. This sample was analyzed for all parameters except non-volatile trace organics. A second sample, taken on September 18, 1980, was collected during a period of no rainfall and was analyzed for trace organics.

3.3 Lakeview Thermal Generating Station

Ontario Hydro operates the Lakeview Station, which is located on Lake Ontario in Mississauga, Ontario. The station has a total installed capacity of 2 441 MW which is generated by six 300-MW units and two 310-MW units, commissioned between 1962 and 1969, and three combustion turbine units which contribute 21 MW. Analyses of

TABLE 25 ANALYSIS OF COAL AT DALHOUSIE GENERATING STATION*

Element	Concentration in Coal (mg/kg)
Silicon	260
Aluminum	110
Iron	500
Titanium	5.2
Phosphorus	19
Calcium	74
Magnesium	1
Sulphur	15
Sodium	2.5
Potassium	5.7

* Personal correspondence, C. Doiron, NBEPC, Fredericton, N.B. Analyses were performed on ashed coal sample. This method may underestimate concentrations of elements present in coal.

typical washed bituminous coal burned at the station are shown below:

Moisture	6.3%
Ash content	8.2%
Volatiles	35.7%
Fixed carbon	49.8%
Sulphur content	1.7%
Heat value	29.8 MJ/kg

The results of more detailed analyses of the coal stored at the station are shown in Table 26. The coal is delivered from suppliers in Pennsylvania and West Virginia to the station by ship. Sufficient coal is stockpiled on the site to supply the station during the winter and spring when coal cannot be delivered.

The coal pile covers 13 ha with a height of 30 m (Personal Communication, A.G. Castellan, Ontario Hydro, Toronto, Ontario). The coal pile volume is 3.9 x 10^6 m^3 (1). The coal pile is located on a layer of packed clay over shale. A ditch around the pile collects the runoff and routes it to a sump adjacent to the runoff pumphouse as shown in Figure 5. The runoff is pumped to concrete lagoons for storage, treatment and reuse. Coal pile drainage is treated by lime addition with sedimentation occurring in the lagoons.

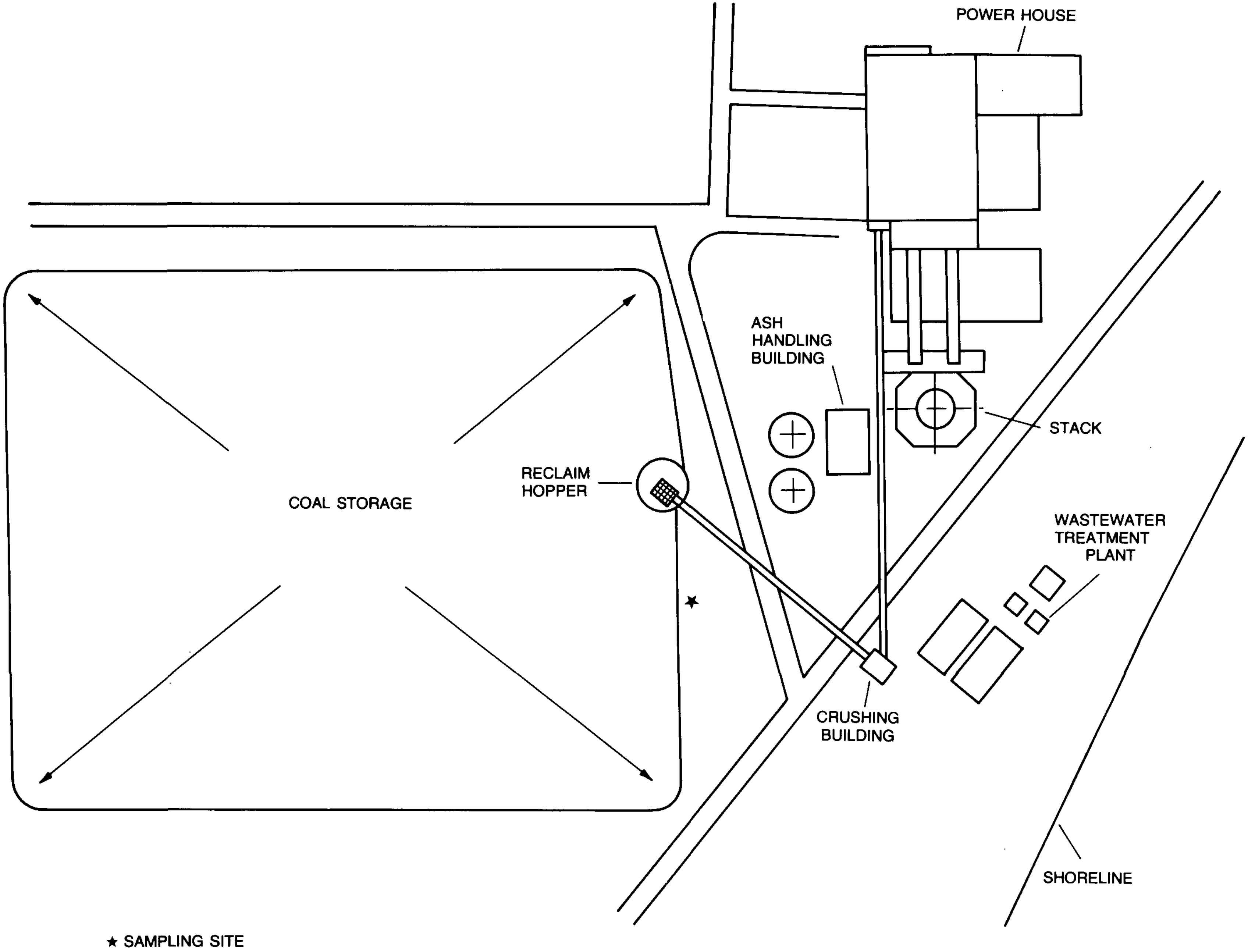

FIGURE 4 COAL STORAGE AREA - DALHOUSIE G.S.

TABLE 26 DRY BASIS CONCENTRATIONS OF ELEMENTS IN COAL - LAKEVIEW GENERATING STATION (36)

Element	Number of Analyses	Average Concentration* (mg/kg)
Barium	56	147
Calcium	35	3 958
Cesium	56	0.8
Magnesium	22	417
Potassium	56	1 223
Rubidium	46	13
Sodium	24	506
Strontium	56	118
Aluminum	24	11 040
Beryllium	58	0.88
Dysprosium	46	1.0
Europium	56	0.3
Hafnium	56	0.7
Lanthanum	56	4.8
Lutetium	54	0.2
Samarium	56	1.0
Tantalum	56	0.3
Terbium	56	0.3
Thorium	56	1.4
Uranium	24	0.7
Ytterbium	56	0.4
Chromium	59	12
Cobalt	59	3.3
Copper	55	5.8
Iron	56	6 377
Manganese	56	24
Nickel	56	4.0
Scandium	56	3.1
Silver	56	1.7
Titanium	24	555
Vanadium	56	20
Bromine	56	14
Chlorine	56	1 174
Fluorine	69	77
Iodine	24	1.1
Antimony	56	0.50
Arsenic	59	12.4
Boron	37	16
Cadmium	61	0.27
Gallium	56	9.5
Lead	61	6.0
Mercury	74	0.35
Selenium	58	2.70
Zinc	19	27

* Average concentration of all washed bituminous coals used at four coal-fired stations operated by Ontario Hydro, representative of the coal used at Lakeview G.S.

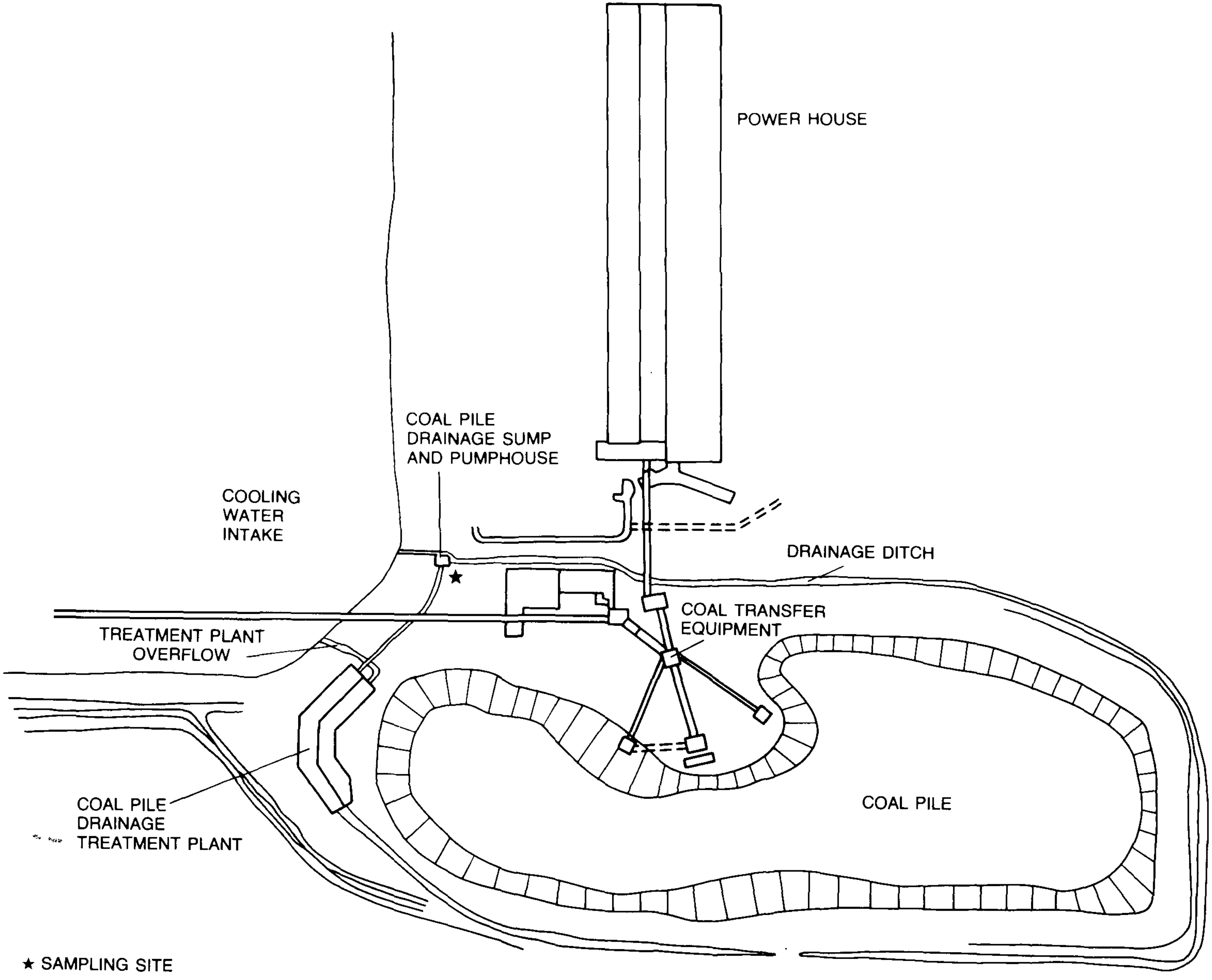

FIGURE 5 COAL STORAGE AREA - LAKEVIEW G.S.

Since the wastewater is treated for internal reuse, e.g., for dust suppression on the coal pile, particularly efficient treatment is not necessary.

Sampling at this site occurred on July 29, 1980, and September 2, 1980. The first sampling was preceded by three days of no rainfall and five days of very light rain. On the day prior to sampling 27.2 mm of rainfall were recorded. The discharge from the pile was sampled from the sump adjacent to the coal pile drainage pumphouse. The second sample was a composite of 20 discrete samples that were taken at 15-minute intervals during a rainfall on September 2. Sampling began at 1100 h and continued for five hours. The first runoff sample was taken at 1145 h when runoff from the rainfall began flowing into the pumphouse sump. The total rainfall from the storm was 2.7 mm. All samples were taken from the sump adjacent to the coal pile drainage pumphouse.

3.4 Algoma Steel Corporation

The Algoma Steel Corporation operates an integrated steel-making facility on the St. Joseph River in Sault Ste. Marie, Ontario. The annual production of raw steel is more than 3.0×10^6 tonnes. At this complex, coke is manufactured from coal. Annual production of coke is about 1.3×10^6 tonnes. About 8.2×10^4 tonnes of coke were in storage on the site. Average results of analyses of the blended coal supplied to the coke ovens and the resultant coke are presented in Table 27. Figure 6 shows the coke storage area and sampling locations.

Samples of coke pile water were taken on July 24. Eight discrete water samples were taken from various positions in and around the coke pile. A composite of these was prepared on which all analyses were performed. Rain was recorded on two days in the week prior to the sampling, including a light rain on the previous day. Generally rainfall for the month of June was much higher than normal while in July rainfall was 30 percent below normal.

3.5 Steel Company of Canada

Stelco's Lake Erie Works are located 65 km from Hamilton near Nanticoke, Ontario. The steel-making facility began production during June 1980 with an eventual rated capacity of 1.17×10^6 tonnes per year. As the coke battery was not to become operational until 1981, all coke stored on the site was being produced at Stelco's Hilton Works in Hamilton.

TABLE 27 ANALYSES OF COAL AND COKE AT ALGOMA STEEL LIMITED*

		Analyses (%)		
Parameter		Blended Coal to Coke Ovens		Coke to Blast Furnace
Volatile matter		31.14		0.85
Fixed carbon		62.63		91.14
Ash		6.26		8.04
Sulphur		0.83		0.61
Particle size	>0.6 cm	7.1	9.0 cm	2.0
	<0.3 cm	81.7	5.0 cm	42.4
			<2.5 cm	4.0
Iron		0.15		0.42
Manganese		0.05		0.05
Calcium		0.13		0.19
Silicon		1.23		1.44
Magnesium		0.07		0.11
Aluminum		0.98		1.21
Potassium		0.03		0.06
Titanium		0.07		0.09

* Personal communication, J. Freimen, Algoma Steel, Sault Ste. Marie, Ontario. Average analysis for first eight months of 1980.

Table 28 presents analyses of coal used in the production of coke while Table 29 shows the composition of the stored coke. The coke storage area and runoff collection system are shown in Figure 7. The coke is piled on a layer of crushed rock which covers the clay subsoil. Runoff from the stored coke is collected in a series of drainage ditches around the coke piles. The runoff eventually flows to one of a series of collection lagoons for reuse in the steel-making facility.

Sampling at this site was conducted on September 13, 1980, several hours after the start of a rainstorm. The day on which the samples were taken was preceded by a prolonged period of dry weather.

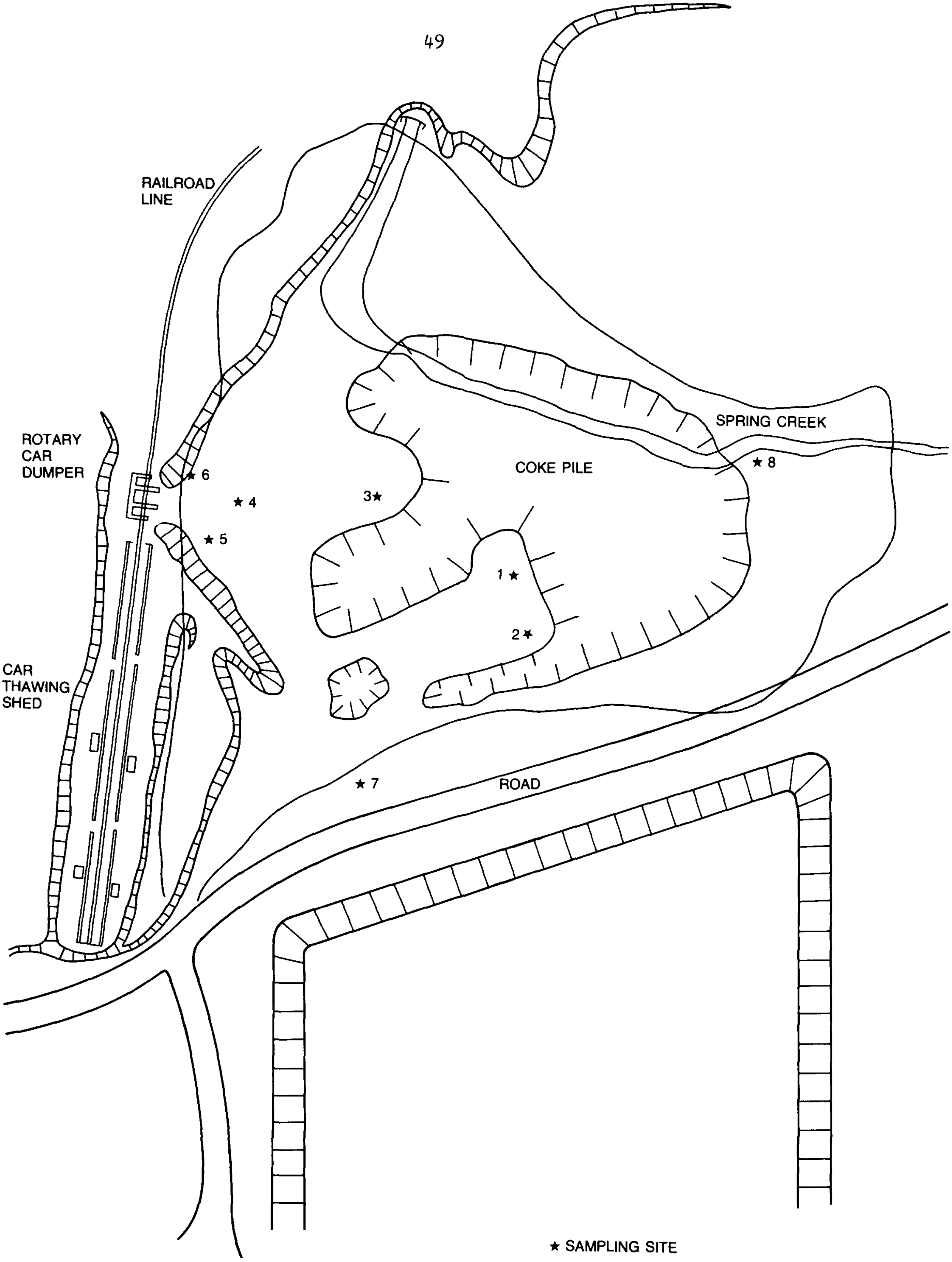

FIGURE 6 COKE STORAGE AREA - ALGOMA STEEL COMPANY

TABLE 28 ANALYSIS OF COAL USED FOR MANUFACTURING COKE - STELCO, LAKE ERIE WORKS*

Parameter	Dry Weight (mg/kg)
Ag	< 0.2
Al	7690
As	< 1
Ba	75
Be	1.2
Ca	1560
Cd	< 10
Co	< 3
Cr	31
Cu	13
Fe	6050
Hg	0.044
Mg	462
Mn	263
Mo	< 50
Ni	8
P	70
Pb	4
Sr	74
Ti	37
V	21
Zn	11
F**	< 2
Cl^-**	250
$SO_4^=$**	852
NO_3^-**	53
Moisture	7.3%
Sulphur Range in Coal Blend	0.8 to 0.9%

* Personal Communication, A. Schuldt, Stelco, Hamilton, Ontario.

** Sample was extracted with a carbonate - bicarbonate buffer.

TABLE 29 COMPOSITION OF COKE IN STORAGE AT THE LAKE ERIE WORKS*

Parameter	Concentration Range (%)
Fixed Carbon	91 - 92
Ash	7 - 9
Moisture	5 - 15
Volatile matter	<1.0
Al	0.5 - 0.7
Ca	0.2 - 0.5
Fe (total)	0.8 - 1.0
K	0.04 - 0.6
Mg	0.03 - 0.05
Mn	0.02 - 0.05
Na	0.01 - 0.04
P	0.01 - 0.03
S	0.6 - 0.9
Si	1.9 - 2.6

* Personal communication, A. Schuldt, Stelco, Hamilton, Ontario.

3.6 Battle River Generating Station

The Battle River Generating Station has a nominal generating capacity of 360 MW and is operated by Alberta Power Limited. The station has four units with capacities and commissioning years as shown below:

Unit	Capacity	Year Commissioned
1	30 MW	1956
2	30 MW	1964
3	150 MW	1969
4	150 MW	1976

The station is located near Forestburg, Alberta, on a man-made reservoir on the Battle River. An analysis of the sub-bituminous coal burned at the station is shown below:

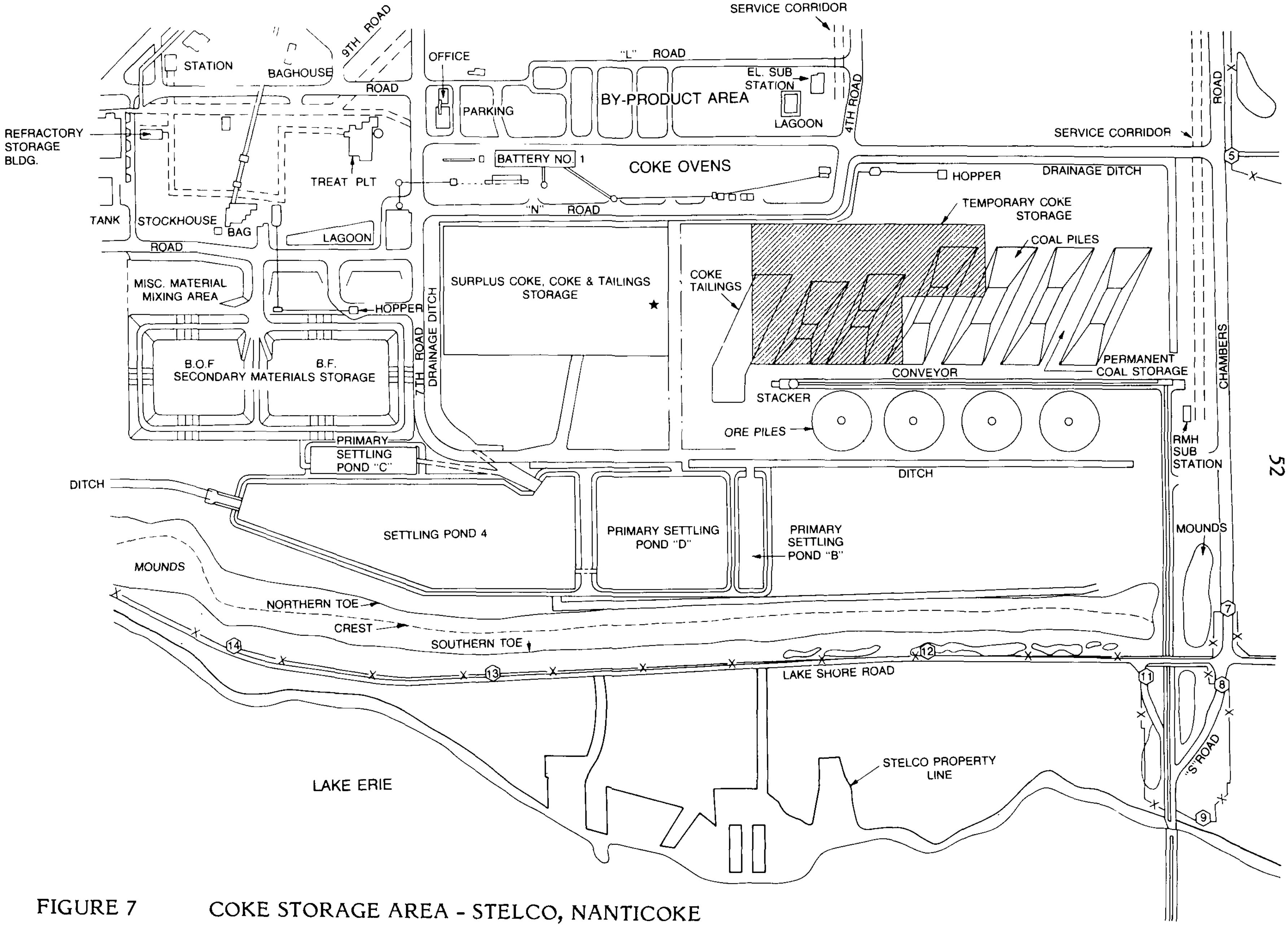

FIGURE 7 COKE STORAGE AREA - STELCO, NANTICOKE

★ SAMPLING SITE

Moisture	20%
Ash content	16%
Volatiles	42%
Fixed carbon	44%
Sulphur	0.3%
Heat value	24.2 MJ/kg

Table 30 provides a more detailed analysis of trace elements in the coal that is stored and burned at the station.

The coal is delivered by mine truck from nearby strip mining operations. It is stored on a stacker-reclaimer system adjacent to the powerhouse as shown in Figure 8. The coal pile is 7.6 m in height and occupies 0.33 ha. The total volume of the pile is 2.8 x 10^4 m^3 (1). The coal is stockpiled for no more than seven days. A second smaller pile is located near unit one for use in that unit only.

Runoff from either coal pile accumulates in a low area surrounding the pile. During heavy rainfalls, runoff from around the stacker-reclaimer area enters the plant storm sewer system which eventually discharges into the station treatment facility. Water trapped in the coal pile at this station was sampled on August 7, 1980. Although no rainfall was recorded at the station on 13 of the 16 days previous to sampling, measurable rainfall was recorded on the two days immediately prior to the sampling. Water impounded in the pile was sampled at five locations around the coal pile stacker-reclaimer area. One sample was taken from the trapped water adjacent to the coal pile for unit 1, as well as one sample from the drains in the stacker-reclaimer tunnel.

3.7 Milner Generating Station

The H.R. Milner Generating Station is operated by Alberta Power Limited and is located on the Smoky River near Grande Cache, Alberta. The station has one unit rated at a capacity of 150 MW which was commissioned in 1973. The station burns a highly variable mixture of natural gas, run-of-mine coal and rejects from a nearby metallurgical coal mine. The fuel is highly variable but analyses of the bituminous coal burned are shown below:

Moisture	6.93%
Ash content	50.5%
Volatiles	7.82%

TABLE 30 ANALYSIS OF COAL BURNED AT BATTLE RIVER GENERATING STATION*

Element	Concentration (mg/kg)** October 10, 1979
Silver	14.6
Arsenic	0.988
Boron	28.9
Beryllium	0.600
Cadmium	3.06
Cobalt	3.01
Chromium	4.67
Copper	3.63
Iron	4618.0
Magnesium	1015.0
Manganese	48.8
Molybdenum	8.61
Nickel	3.10
Lead	9.17
Tin	18.4
Zinc	9.53
Selenium	< 0.100
Sulphur	5250.0
Mercury	0.45

* Personal communication, W. Symington, Alberta Power Limited, Edmonton, Alta.

** The samples were individually prepared, digested and analyzed for the trace and heavy metals. The results are reported as mg/kg by weight of the air-dried samples.

Fixed carbon	34.75%
Sulphur content	0.27%
Heat value	12.5 MJ/kg

Table 31 presents more detailed results of analyses of the coal burned at the station. The coal is delivered from an adjacent mine and coal processing plant by conveyor or mine truck and is stored on a stacker-reclaimer. The coal pile is rather

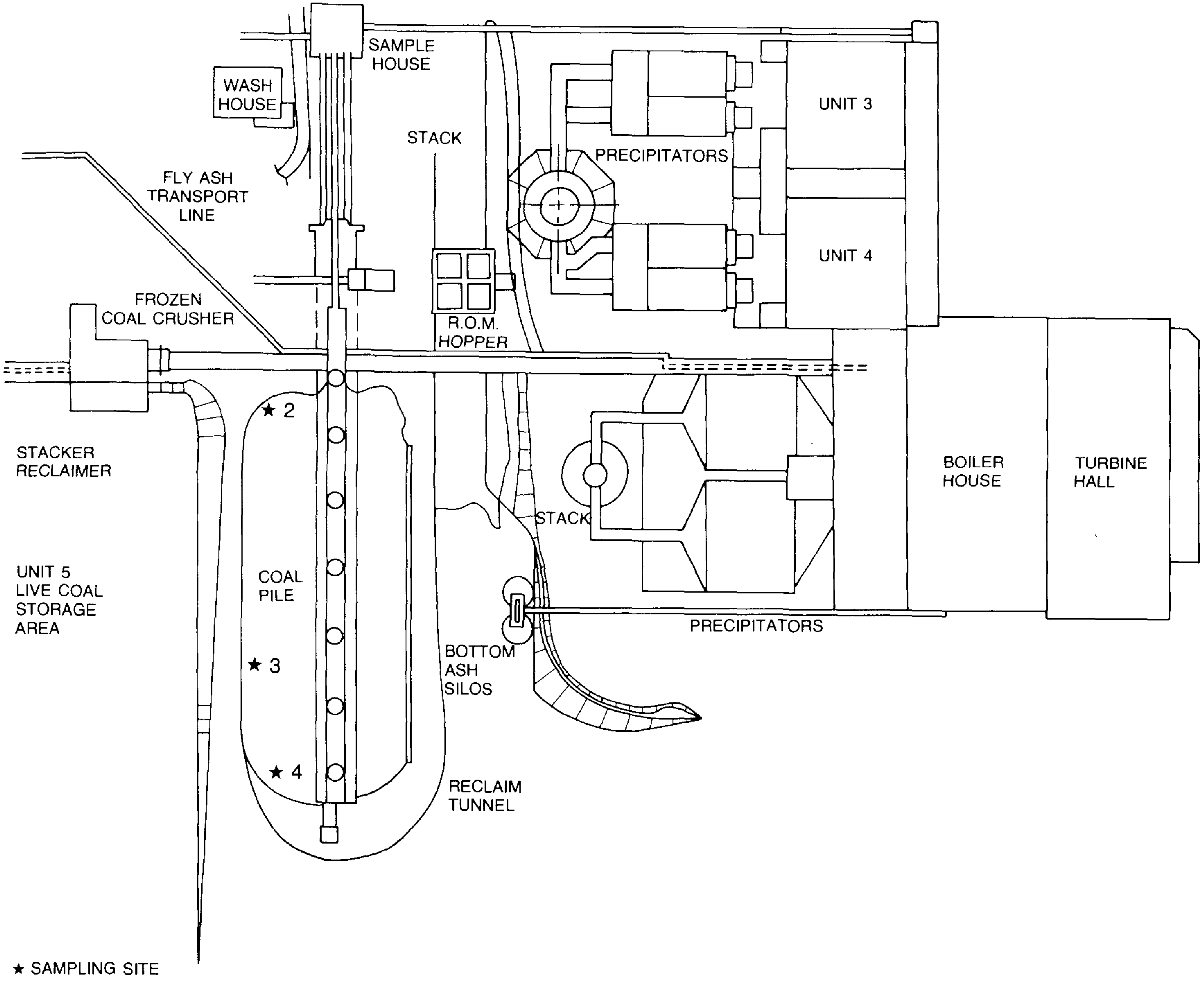

FIGURE 8 COAL STORAGE AREA - BATTLE RIVER G.S.

TABLE 31 ANALYSIS OF COAL BURNED AT MILNER GENERATING STATION*

Element	Concentration (mg/kg)**
Silver	26.9
Arsenic	5.98
Boron	72.6
Beryllium	2.32
Cadmium	12.5
Cobalt	19.4
Chromium	53.9
Copper	38.2
Iron	16 297.0
Magnesium	4 458.0
Manganese	96.5
Molybdenum	45.1
Nickel	22.9
Lead	45.3
Tin	89.5
Zinc	89.2
Selenium	1.53
Sulphur	3 668.0
Mercury	0.63

* Personal communication, W. Symington, Alberta Power Limited, Edmonton, Alberta.

** The samples were individually prepared, digested and analyzed for the trace and heavy metals. The results are expressed as mg/kg by weight of the air-dried samples.

poorly defined as shown in Figure 9. The 19-ha pile is estimated to be 15 m in height and has a volume of 2.8 x 10^6 m^3 (1). Runoff from the coal pile is collected in a drainage ditch on the lower side of the pile. The water eventually flows into the wastewater lagoons used for treatment of the station's aqueous wastes.

Sampling at this site was conducted on August 8, 1980. Rainfall was recorded at the station on 10 of the 12 previous days although only a light rain was falling on the day of sampling.

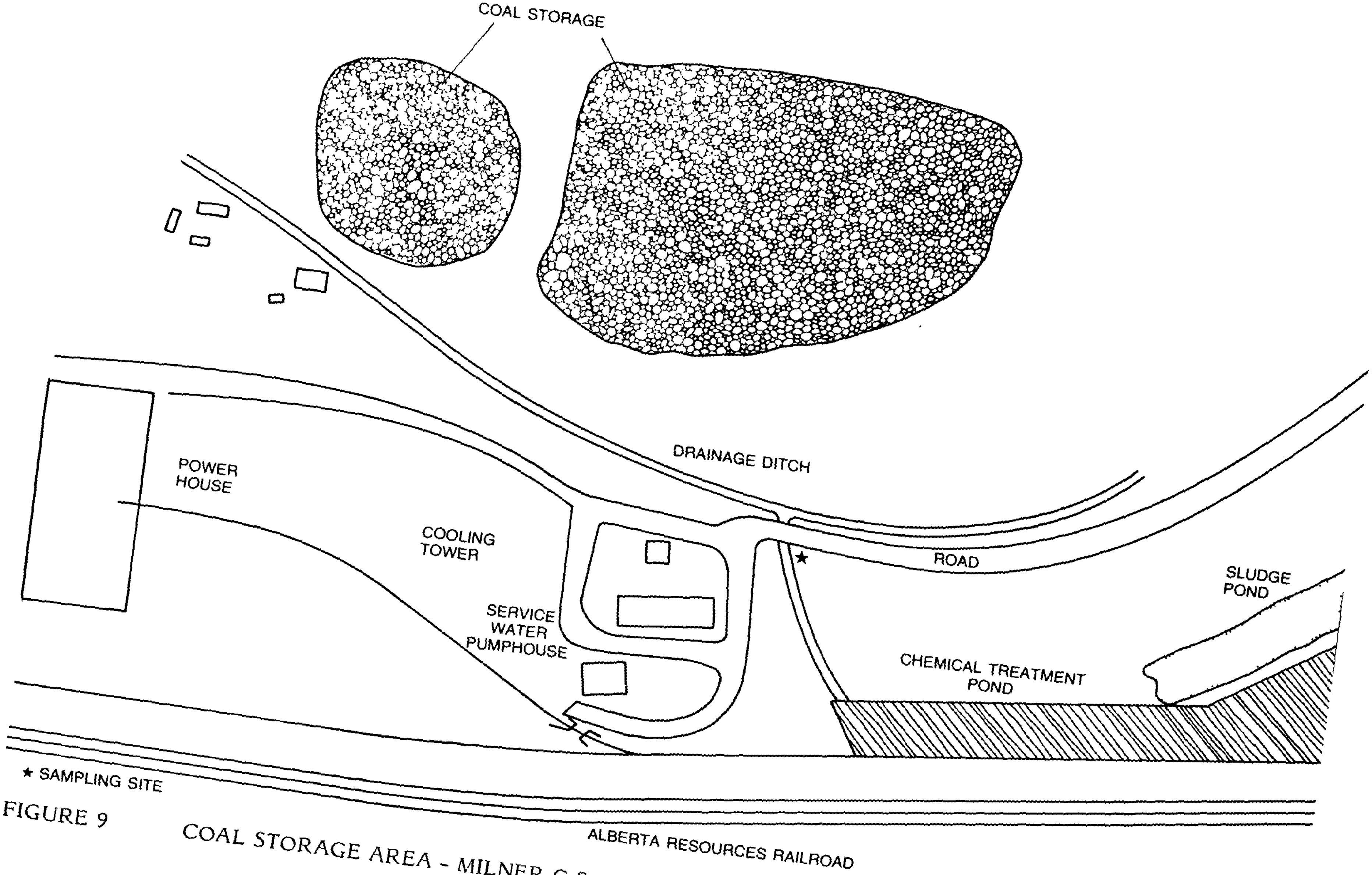

FIGURE 9 COAL STORAGE AREA - MILNER G.S.

3.8 Sample Preservation and Analysis

Samples collected for analysis were preserved using methods currently recommended by the U.S. Environmental Protection Agency (37). All samples were refrigerated prior to analysis in the laboratory. Holding times between sample collection and sample analysis were less than specified by the U.S. EPA (37).

Generally, laboratory analyses were performed using procedures outlined in Standard Methods for the Examination of Water and Wastewater (38). Aliquots for metal analyses were prepared using the digestion for total metals procedure. This involves the addition of sulphuric acid, followed by nitric acid, evaporation until near dryness, and gentle refluxing with nitric acid until a light-coloured residue remains. All metals, with the exception of boron, were quantified by atomic absorption spectrophotometry. Analyses for boron were by the carmine method (38). More detailed descriptions of the methodologies used in the quantification of inorganics, gross organics and metals are presented in Appendix III. Purgeable organics, base/neutral extractables, acid extractables and pesticides/PCB's were analyzed using gas chromatograph/mass spectrophotometric techniques. Procedures used for the analysis of trace organics and purgeable organics were those recommended by the U.S. EPA (39).

4 CHARACTERISTICS OF COAL AND COKE PILE DISCHARGES

Results of the analyses of samples taken at the seven sites across Canada are presented in this section. This data is presented in three groups: inorganics, gross organics and metals; purgeable organics group of the priority organic pollutants; base/neutral extractables, acid extractable organics and pesticides.

4.1 Inorganics, Gross Organics and Metals

Results of the analyses of the coal and coke pile drainage samples for inorganics, gross organics and total metals are shown in Table 32. Coal samples analyzed for trace organics from Dalhousie Generating Station were collected by personnel of Environment Canada, Environmental Protection Service, Atlantic Region. Inorganic analysis results are averages of previous analytical studies and were provided by C. Doiron of the New Brunswick Electric Power Commission.

From the results shown in Table 32, the coal pile drainage samples from the eastern sites can be characterized as being acidic with a pH of between 1.0 and 3.0. Biological activity in the coal pile produces sulphuric acid from the iron sulphide in the coal. The acidity of the aqueous stream results in the solubilization of metals from the coal into the pile drainage. The mechanism of acid generation is more completely discussed in Section 2.

The drainage samples from eastern coal piles contained high concentrations of total solids. The concentration of total solids is relatively constant between the sites. Due to the low pH in the pile drainage, about 80 percent of the total solids are present as dissolved solids. The acidic nature of these discharges from the eastern sites is responsible for relatively high concentrations of metals such as cobalt, iron, manganesse and zinc. The highest concentrations of arsenic, iron, manganese and zinc were found in the discharges into the coal pile drainage lagoon at Lingan Generating Station. Discharges from the coal pile at Lakeview Generating Station contained the highest concentrations of total suspended solids, turbidity, oil and grease and total organic carbon.

Coal pile drainage samples from the western sites were neutral with the pH ranging from 6.0 to 8.5. Western Canadian coal contains lower concentrations of sulphur than Eastern Canadian coal. This reduces the amount of biologically-generated acidity thus producing a neutral pile discharge. These western coal pile drainage samples also contained high concentrations of total solids. The mean concentration of suspended solids

TABLE 32 INORGANICS, GROSS ORGANICS AND METALS IN COAL AND COKE PILE DRAINAGE

	Lingan Generating Station	Lingan Generating Station	Dalhousie Generating Station	Lakeview Generating Station	Lakeview Generating Station	Algoma Steel Limited	Steel Company of Canada, Nanticoke	Battle River Generating Station	Milner Generating Station
DATE SAMPLED - 1980	July 22	Aug. 19	*	July 29	Sept. 2	July 24	Sept. 13	Aug. 7	Aug. 8
FUEL TYPE	Bituminous Coal	Bituminous Coal	Bituminous Coal (averages)	Bituminous Coal	Bituminous Coal	Coke	Coke	Sub-Bituminous Coal	Rejects/ Dewatered Tailings
pH	2.5	2.1	1.2	2.7	2.9	9.7	7.7	6.3	8.3
Total Solids	4 820	5 720	N/A	5 300	6 040	1 900	1 500	21 100	2 440
Total Dissolved Solids	4 750	5 540	N/A	4 910	4 870	985	1 480	2 300	330
Total Suspended Solids	70	180	N/A	390	1 170	925	20	18 800	2 110
Turbidity (NTU)	15	7.8	N/A	480	310	70	14	9 500	1 100
Oil and Grease	2.1	1.5	N/A	9.3	4.9	3.3	< 1.0	3.7	11.9
Total Organic Carbon	3.0	2.0	N/A	97	120	108	< 0.5	2 200	310
Chemical Oxygen Demand	21.2	42.9	N/A	567	1 680	619	31.1	8 990	2 470
Hardness as $CaCO_3$	800	860	N/A	1 920	2 030	675	870	7 200	2 400
Alkalinity as $CaCO_3$ to pH 4.5	-	-	N/A	-	-	80	110	340	180
Free Mineral Acidity as $CaCO_3$	1 400	1 500	N/A	710	490	-	-	-	-
Total Sulphur as $SO_4^=$	6 400	3 700	N/A	2 700	5 300	610	80	1 600	150
Sulphate	6 500	3 600	49 600	2 700	4 900	700	72	1 400	130
Chloride	630	580	N/A	220	170	120	100	17	2.2
Fluoride	0.5	0.4	N/A	0.8	1.4	1.1	1.5	4.5	0.3
Inorganic Phosphate as PO_4^{-3}	1.2	6.1	N/A	4.2	2.2	0.7	< 0.02	22	2.7
Total Phosphate as PO_4^{-3}	1.2	6.1	N/A	4.2	2.2	1.2	< 0.02	23	3.1
Ammonia as NH_4^+	2.0	0.6	N/A	0.3	1.0	0.3	1.2	1.0	< 0.1
Cyanide as CN^- (μg/L)	< 20	< 20	N/A	< 20	< 20	< 20	< 20	< 20	< 20
Thiocyanate as SCN^- (μg/L)	< 0.5	< 0.5	N/A	< 0.5	< 0.5	< 0.9	< 1.0	< 0.5	< 0.5
Phenol (μg/L)	4.5	4.0	N/A	< 1.0	8.0	3.5	6.0	3.5	< 1.0
Aluminum	56	60	N/A	30	35	3.0	< 1.0	360	160
Antimony	1.7	1.7	N/A	< 0.2	1.2	0.6	1.6	4.4	< 0.2
Arsenic	0.750	0.650	40	0.073	0.030	0.008	< 0.002	0.242	0.040
Barium	< 0.1	< 0.1	N/A	< 0.1	< 0.1	< 0.1	< 0.1	0.15	< 0.1
Beryllium	0.03	0.01	N/A	< 0.01	< 0.01	0.02	< 0.01	0.06	< 0.01
Boron	0.23	0.23	N/A	0.54	0.44	0.88	9.75	4.33	0.95
Cadmium	0.10	0.12	N/A	< 0.01	0.06	< 0.01	0.09	0.23	< 0.01
Calcium	84	27	N/A	170	140	100	55	180	40
Chromium	< 0.05	< 0.05	2.0	< 0.05	< 0.05	< 0.05	< 0.05	1.30	0.20
Cobalt	0.69	0.85	N/A	0.28	0.37	< 0.03	0.14	0.47	< 0.03
Copper	0.48	0.56	8.0	0.38	0.54	3.40	< 0.01	8.2	3.00
Iron	560	500	17 600	370	190	12	0.70	98	45
Lead	< 0.1	< 0.1	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Lithium	0.2	0.3	N/A	0.2	0.2	0.4	0.3	0.9	0.2
Magnesium	56	72	N/A	180	200	32	96	140	34
Manganese	17.5	21.3	N/A	7.50	9.20	1.61	0.09	3.70	4.40
Mercury (μg/L)	< 1	< 1	< 0.1	1.2	< 1	< 1	< 1	2.7	< 1
Molybdenum	< 0.1	< 0.1	N/A	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Nickel	1.2	1.6	7.8	0.55	0.65	0.45	0.15	1.6	0.55
Potassium	2.8	2.9	N/A	6.3	8.1	50	12.4	45	26
Selenium	< 0.02	< 0.02	N/A	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Silica as SiO_2	21	22	N/A	74	77	57	11	4 100	45
Silver	0.04	0.03	N/A	0.02	0.03	0.02	0.03	0.09	< 0.01
Sodium	410	450	N/A	150	210	40	43	480	31
Strontium	2.3	1.3	N/A	2.6	1.9	1.3	2.4	5.3	1.3
Thallium	< 0.2	< 0.2	N/A	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Thorium	< 0.06	< 0.06	N/A	< 0.06	< 0.06	< 0.06	< 0.06	0.13	< 0.06
Titanium	< 0.3	< 0.3	N/A	< 0.3	< 0.3	< 0.3	< 0.3	18	18
Uranium (μg/L)	5	< 5	N/A	< 5	< 5	< 5	< 5	66	90
Vanadium	< 0.1	< 0.1	N/A	< 0.1	0.2	< 0.1	< 0.1	0.8	< 0.1
Zinc	5.0	5.4	14.5	4.6	4.9	1.0	0.28	4.0	1.4
Zirconium	< 0.05	< 0.05	N/A	< 0.05	< 0.05	< 0.05	< 0.05	< 0.37	< 0.05

Notes: All analyses reported in mg/L unless otherwise stated.
N/A - not analyzed.

* Personal communication, C. Doiron, N.B.E.P.C., Fredericton, N.B.

in the Battle River Generating Station sample was about 100 times greater than that from the eastern sites. However, these very high suspended solids levels may be due, in part, to sampling location (see 4.4.2).

Unlike the discharge samples from the eastern sites, most of the solids present in the western samples were in suspended form, primarily in the form of coal fines. Only about 15 percent of the total solids were in dissolved form.

Discharge samples from the coal piles at the western sites contained high concentrations of boron, mercury, silicon, silver, sodium and strontium.

Discharge samples from the two coke piles investigated were slightly alkaline with pH values of 7.7 and 9.7. The drainage samples from these piles were generally less contaminated than coal pile drainage samples. For example, the concentrations of total solids in the discharges from the coke piles were about 50 percent of the levels in discharges from the coal piles.

The coal pile discharge sample from Lingan Generating Station on July 22, 1980, was obtained during a dry period. The second sample from the site was taken on August 19, 1980, during a relatively rainy period. Although the weather conditions prior to sampling were distinctly different, the coal pile leachate and the runoff collected in the lagoon were similar. This may be attributable to the equalizing effect of the coal pile drainage collection lagoon, which tends to average out changes in the pile discharges.

At Lakeview Generating Station the sample of pile discharge obtained on July 29, 1980, was collected following a relatively dry period. The second sample taken on September 2, 1980, was obtained during a rainstorm. The analytical results do not indicate distinct differences between the leachate and runoff samples at this site.

At the two western sites there was a distinct difference between the leachate-type sample collected at Battle River Generating Station on August 7, 1980, and the runoff sample from Milner Generating Station which was obtained on August 8, 1980. The leachate sample was collected following a dry period while the runoff sample was taken during a light rainstorm. The leachate sample contained higher concentrations of most parameters. The concentrations of oil and grease and uranium, and the pH level were lower in the leachate sample from Battle River Generating Station. This may be due to the different coals stored at each site. At the Battle River Generating Station the coal pile is composed of sub-bituminous coal from the nearby mine while at Milner Generating Station the fuel is dewatered tailings and rejects from the adjacent coal processing plant. The coal processing may change the nature of the coal rejects and hence the drainage from the stored fuel.

Discharges from the coke pile at Algoma Steel taken on July 24, 1980, were sampled during a relatively dry period and should represent a leachate-type sample. The sample of the discharge from the coke pile at Stelco was obtained during a rainstorm and would represent a runoff sample. The coke pile leachate sample generally contained high concentrations of most parameters compared to the runoff sample. This reflects the longer contact time between the rainfall and the coke. Exceptions include phenol, boron, magnesium and strontium, which were indicated in higher concentrations in the runoff at Stelco than in the leachate at Algoma.

4.2 Purgeable Organics

Results of analyses for purgeable organics in pile drainage are shown in Table 33. Four organics, benzene, chloroform, methylene chloride and toluene, were indicated in more than three samples at greater than trace concentrations (greater than one microgram per litre).

Benzene was indicated in concentrations ranging from a trace (less than 1 µg/L) to 2.6 µg/L in eight of the nine samples. Chloroform was indicated in each sample at concentrations ranging from a trace to 15.5 µg/L. Methylene chloride was indicated in seven of the nine samples in concentrations of 1.7 to 22.0 µg/L. Six of the nine samples indicated toluene at concentrations from a trace to 1.8 µg/L.

Some trends were observed for the presence of purgeable organics in the samples. Generally, eastern coal samples indicated higher levels of the purgeable organics than western coals, and concentrations in runoff discharges were higher than in leachate discharges. For the western coals, the leachate-type sample showed slightly greater concentrations of benzene and methylene chloride. Runoff-type samples from coke piles also showed higher levels of chloroform, methylene chloride and toluene than leachate-type samples. No clear distinction between the overall presence of purgeable organics in discharge from coke versus coal piles was apparent.

4.3 Base Neutral Extractables, Acid Extractables and Pesticides

Results of analyses of coal and coke pile drainage for base/neutral extractables, acid extractables and pesticides are shown in Table 34. A complete list of the organic contaminents that were analyzed for is shown in Appendix I.

None of the organic compounds in the acid group or pesticide group were detected in any sample. Although low concentrations of polynuclear aromatics, nitrosa-

TABLE 33 PURGEABLE ORGANICS IN COAL AND COKE PILE DRAINAGE

	Lingan Generating Station	Lingan Generating Station	Dalhousie Generating Station	Lakeview Generating Station	Lakeview Generating Station	Algoma Steel Limited	Steel Company of Canada, Nanticoke	Battle River Generating Station	Milner Generating Station
DATE SAMPLED - 1980	July 22	Aug. 19	Aug. 13	July 29	Sept. 2	July 24	Sept. 13	Aug. 7	Aug. 8
FUEL TYPE	Bituminous Coal	Bituminous Coal	Bituminous Coal	Bituminous Coal	Bituminous Coal	Coke	Coke	Sub-Bituminous Coal	Rejects/ Dewatered Tailings
Acrolein	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Acrylonitrile	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Benzene	Trace	2.6	1.04	1.1	2.6	Trace	N.D.	1.6	1.3
Bromodichloromethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Bromoform	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Bromomethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Carbon Tetrachloride	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Chlorobenzene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Chloroethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
2-Chloroethylvinyl Ester	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Chloroform	Trace	9.3	Trace	3.7	15.5	2.6	4.6	Trace	Trace
Chloromethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Bis-chloromethyl Ether	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Di Bromochloromethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Di Chlorodifluoromethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
1,1-Dichloroethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
1,2-Dichloroethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	Trace	N.D.
1,1-Dichloroethylene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Trans-1,2-Dichloroethylene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
1,2-Dichloropropane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
1,2-Dichloropropylene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	Trace	N.D.	N.D.	N.D.	N.D.	N.D.
Methylene Chloride	1.7	22.0	N.D.	3.6	18.3	2.6	6.8	2.3	N.D.
1,1,2,2-Tetrachloroethane	Trace	N.D.	N.D.	Trace	Trace	N.D.	N.D.	N.D.	N.D.
1,1,2,2-Tetrachloroethene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Toluene	Trace	1.8	N.D.	N.D.	1.5	N.D.	Trace	Trace	Trace
1,1,1-Trichloroethane	Trace	1.0	N.D.	N.D.	N.D.	Trace	Trace	Trace	N.D.
1,1,2-Trichloroethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Trichloroethylene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Trichlorofluoromethane	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Vinyl Chloride	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

Notes: N.D. - Not Detected
Trace - Less than one microgram per litre.

All analyses expressed as micrograms per litre.

TABLE 34 TRACE ORGANICS IN COAL AND COKE PILE DRAINAGE

	Lingan Generating Station	Lingan Generating Station	Dalhousie Generating Station	Lakeview Generating Station	Lakeview Generating Station	Algoma Steel Limited	Steel Company of Canada, Nanticoke	Battle River Generating Station	Milner Generating Station
DATE SAMPLED - 1980	July 22	Aug. 19	Sept. 18	July 29	Sept. 2	July 24	Sept. 13	Aug. 7	Aug. 8
FUEL TYPE	Bituminous Coal	Bituminous Coal	Bituminous Coal	Bituminous Coal	Bituminous Coal	Coke	Coke	Sub-Bituminous Coal	Rejects/ Dewatered Tailings
Acid Group	ND	ND	ND	ND	ND	ND	ND	ND	ND
Base Neutral Group									
Nitrosamines									
Nitrosodiphenylamine	ND	ND	ND	ND	ND	ND	ND	ND	10
Phthalate Esters									
Butylbenzylphthalate	ND	ND	ND	ND	ND	ND	ND	ND	24
Di-n-butylphthalate	210	25	15	ND	10	ND	23	ND	ND
Diethylphthalate	190	ND	15	100	ND	ND	25	ND	ND
Bis-(2-ethylhexyl) phthalate	ND	20	ND	ND	10	ND	ND	15	ND
Other Compounds									
Nitrobenzene	ND	ND	ND	ND	ND	ND	ND	15	ND
Pesticides	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note: All analyses expressed in µg/L

ND - not detected

mines and haloethers were detected, their concentrations ranged between trace and 15 µg/L. Only the phthalate esters group of organics were indicated in most of the samples at concentrations between trace and 260 µg/L. During sample collection, handling and preservation, only glass containers and laboratory equipment were used to avoid possible contamination of the samples by contact with plastic or polythene equipment which might have affected the analytical results.

4.4 Variability of Coal and Coke Pile Drainage

Additional samples of coal and coke pile drainage from Lingan Generating Station, Lakeview Generating Station, Algoma Steel and Battle River Generating Station were collected to investigate the temporal and spatial variations in discharges from coal and coke piles.

4.4.1 Temporal Variability. The temporal variability of coal pile drainage was studied at two sites in Eastern Canada. Eight samples from the coal pile drainage lagoon at Lingan Generating Station were collected over a six-week period from August 19 to September 23, 1980. Results of analyses of these samples are shown in Table 35. The coefficients of variability for the analyses range from 22.6 to 59.1, which indicates that the characteristics of the coal pile drainage were relatively constant over the period of investigation. Again, this lack of variation may be due to the equalizing effect of the lagoon which tends to average out extreme variations in the quality of the discharges.

There were some trends in the variations of concentrations of parameters from the summer through the early fall. The pH of the discharge remained relatively constant; however, concentrations of acidity, dissolved solids, sulphate, iron, nickel, zinc and copper tended to increase from August through September while the suspended solids tended to decrease over the same period. The decrease in suspended solids concentration in the lagoon may be caused by the conversion of suspended solids to dissolved solids due to the low pH of the coal pile discharge.

The temporal variation in coal pile drainage during a rainfall event was investigated at Lakeview Generating Station where ten discrete samples were taken at 30-minute intervals during a 2.7-mm rainstorm on September 2, 1980.

Table 36 presents the variations in the concentrations of ten parameters with the duration of the storm. The concentration of suspended solids was highest at the beginning of the storm and decreased as the rainfall continued. This suggests that most of the suspended solids were washed from the coal pile at the beginning of the rainfall, which

TABLE 35 VARIATION IN COAL PILE DRAINAGE LAGOON - LINGAN GENERATING STATION

	Parameter (mg/L except pH)									
Date Sampled (1980)	pH	Acidity as $CaCO_3$	Suspended Solids	Dissolved Solids	Sulphate as SO_4	Iron	Nickel	Zinc	Copper	Chromium
August 19	2.40	1 580	72	5 540	2 900	600	1.40	5.1	0.74	<0.05
August 22	2.40	1 660	105	5 870	3 380	625	1.75	2.9	0.62	<0.05
August 26	2.45	1 670	80	5 990	3 380	630	1.90	3.0	0.62	<0.05
August 29	2.45	1 730	79	6 140	3 450	605	1.75	2.9	0.64	<0.05
September 3	2.40	1 980	14	6 250	3 500	630	1.93	3.5	1.62	<0.05
September 9	2.40	2 330	32	7 320	4 000	830	2.10	3.8	1.58	<0.05
September 16	2.35	3 330	53	9 700	5 400	1 300	3.0	5.5	2.17	0.08
September 23	2.40	3 250	33	9 370	5 000	1 600	3.6	4.5	2.58	0.23
Mean	-	2 191	59	7 023	3 876	853	2.18	3.9	1.32	-
Standard Deviation	-	719	31	1 636	876	385	0.74	1.02	0.78	-
Coefficient of Variability (%)	-	32.8	52.5	23.3	22.6	45.1	33.9	26.2	59.1	-

TABLE 36 VARIATION IN RUNOFF QUALITY - LAKEVIEW GENERATING STATION

	Parameter (mg/L except pH)									
Time of Sample, Sept. 2, 1980	pH	Acidity as $CaCO_3$	Suspended Solids	Dissolved Solids	Sulphate as SO_4	Iron	Nickel	Zinc	Copper	Chromium
11:45	3.30	260	5 600	3 560	2 010	250	1.25	3.6	5.0	0.64
12:15	3.00	370	4 570	3 820	2 150	250	0.85	2.5	4.9	<0.05
12:45	2.90	330	1 920	4 190	2 640	201	0.90	2.1	0.64	<0.05
13:15	2.90	575	828	4 900	2 990	190	0.90	2.5	0.56	<0.05
13:45	3.00	505	464	5 000	2 990	225	1.15	2.3	0.40	<0.05
14:15	3.00	575	782	5 150	3 060	225	1.25	3.0	3.67	<0.05
14:45	3.00	565	404	5 240	3 190	215	1.32	3.3	3.43	<0.05
15:15	3.30	575	204	5 300	3 130	210	1.32	3.1	4.25	<0.05
15:45	3.25	280	756	3 420	2 010	140	1.2	2.3	3.61	<0.05
16:15	3.10	550	732	5 200	3 540	110	1.25	3.2	4.43	<0.05
Mean		459	1 626	4 578	2 771	202	1.14	2.8	3.09	-

confirms the observations of other authors that the concentration of suspended solids is dependent on rainfall intensity and duration.

The concentrations of dissolved solids, acidity and sulphate appear to follow a common trend. Each of these was present in the runoff at low levels initially followed by gradual increases. This can be attributed to the flushing action of the rainfall on accumulated pools of concentrated leachate in the coal pile and drainage ditches (12).

The concentrations of iron, zinc, nickel and copper fluctuated in a common way during the sampling period. Each started at a relatively high concentration followed by a gradual reduction in concentration. This decrease in concentration may have been due to the dilution of the pile runoff with surface runoff which had not contacted the piled coal. This surface runoff would be less contaminated since it had not been flushed through the pile (12).

4.4.2 Spatial Variability. To determine the variability in coke and coal pile leachate parameters with position in the stockpile, multiple discrete samples at one coke and one coal pile were obtained. Eight samples from different locations around the coke pile at Algoma Steel were taken on July 24, 1980. The exact locations of the sampling sites are shown in Figure 6. The results of the analyses are shown in Table 37.

The spatial variation in coke pile leachate is evident from the coefficients of variability, which range from about 80 to over 200 percent. The wide range of the parameters analyzed is partly due to the method of sampling. For example, if the pools of water in the pile were disturbed while the sample was being taken, the total and suspended solids would be present in higher concentrations. Likewise, as the concentration of coke fines increased, the chemical oxygen demand would also increase in the sample.

Samples 1, 2 and 3 were most representative of the leachate from the stored coke as they were taken from locations on the interior of the pile. The other sampling locations were around the perimeter of the pile area and could be subject to contamination from dust from passing trucks and rail traffic which may alter the true nature of the leachate. For example, the pH of the leachate is more likely to be around 8.0 as found at sampling sites 1, 2 and 3 than alkaline as suggested by the analyses of samples 4, 5, 6 and 7. The latter four sites were around the pile perimeter and would be more subject to contamination not associated with the piled coke.

TABLE 37 SPATIAL VARIATION IN COKE PILE LEACHATE - ALGOMA STEEL CORPORATION

	Parameter (mg/L except pH)					
Position in Pile*	pH	Total Solids	Dissolved Solids	Suspended Solids	Chemical Oxygen Demand	Sulphate as SO_4
1	7.90	3 250	1 100	2 150	4 168	490
2	7.95	1 080	708	372	383	460
3	8.50	2 300	2 130	170	110	1 260
4	11.55	736	552	184	142	300
5	11.60	1 230	532	698	458	300
6	10.83	808	632	176	248	310
7	11.35	684	556	128	15.6	210
8	8.30	96	16	80	21.8	30
Mean	--	1 273	778	495	693	420
Standard Deviation	--	1 017	621	698	1 413	368
Coefficient of Variability (%)	--	79.9	79.8	141	204	87.6

* Sites shown in Figure 6.

Samples were also taken from four locations around the coal pile and from the stacker-reclaimer sump at Battle River Generating Station on August 7, 1980. The actual sampling locations are shown in Figure 8. Results of the analyses of these samples are shown in Table 38. The coefficients of variability of the analyses range from 56.3 to 98.2 which indicates relatively low variation between the five sites sampled.

As with the samples taken at Algoma Steel, the sampling methodology greatly affects the concentration of suspended solids in the sample. If the ponded water around the pile was disturbed during sampling a higher solids concentration would result. Also, sampling sites 3 and 4 were close to construction activity at the station which may be in part responsible for the higher concentrations of suspended solids in these samples. The high concentration of suspended solids in sample 3 is likewise responsible for the high COD concentrations in that sample.

TABLE 38 SPATIAL VARIATION IN COAL PILE DRAINAGE - BATTLE RIVER GENERATING STATION

	Parameter (mg/L except pH)					
Sampling Location*	pH	Suspended Solids	Total Solids	Sulphate as SO_4	Iron as Fe	Chemical Oxygen Demand
1	6.60	4 500	8 000	840	235	2 200
2	6.95	2 950	7 900	2 550	100	1 200
3	6.40	43 100	48 500	970	1 010	21 417
4	6.50	15 800	18 600	750	365	5 240
Sump in Stacker-Reclaimer	7.00	30 000	37 000	1 530	575	14 300
Mean		19 270	24 000	1 328	457	8 871
Standard Deviation		17 172	18 122	747	355	8 709
Coefficient of Variability (%)		89.1	75.5	56.3	77.7	98.2

* See Figure 8 for locations of sampling sites.

5 PHYSICAL-CHEMICAL TREATABILITY STUDIES

5.1 Literature Review

The treatment of aqueous discharges from coal storage piles has been described by a number of authors. These studies have concentrated on treating coal pile waters from eastern U.S. coals which are highly acidic and contain many dissolved metals. Much of the work in this area was in response to effluent guidelines promulgated by the United States Environmental Protection Agency, which defined the two major problems as the pH and suspended solids in discharges from coal storage areas.

Brenman (40) outlined a general approach that could be taken to treat coal pile waters. Large detention/equalization basins are used to collect the wastewater before treatment. The treatment scheme required to produce an effluent consistent with U.S. EPA guidelines includes pH adjustment to neutral conditions, flocculation and sedimentation in a solids contact clarifier. Chemicals such as lime, alum and polyelectrolytes are added to the waste to enhance settling.

Wachter and Blackwood (21) summarized present treatment technology for effluents from coal storage areas at steam electric generating stations. Process steps include collection, neutralization and settling by gravity. Methods currently practiced to control the problem include construction of collection ditches around the pile, storage of coal in bins and hoppers with runoff collected in ditches around the pile, installation of a hard surface over the area to direct drainage to a sump, and establishment of vegetable covers around the stockpile to control erosion and sedimentation (21).

Table 39 lists the biological treatment methods applicable to water pollutants from coal stockpiles while Table 40 shows possible physical/chemical treatment processes. Although these processes are theoretically possible, it is unlikely that any one, other than coagulation, flocculation and sedimentation would ever be used.

Several authors (25, 41, 42) reported that runoff from coal piles can be treated by collection, flocculating with lime and an anionic polyelectrolyte followed by sedimentation. Kanaletz and Hess (41) found that flocculation with lime and/or an anionic polyelectrolyte followed by pH neutralization with sulphuric acid, after solids separation by sedimentation, was necessary.

Results of studies by Ferraro (25) again showed that lime neutralization was the simplest, most cost-effective treatment; however, sodium hydroxide or soda ash could

TABLE 39 BIOLOGICAL TREATMENTS FOR COAL STOCKPILE WATER POLLUTANTS (21)

	Pollutant				
Treatment Technique	BOD	COD	TOC	TSS	Nitrate
Aerobic:					
Activated sludge	x	x	x	x	
Trickling filters	x	x	x	x	
Aerated lagoons	x	x	x	x	
Aerated ponds	x	x	x	x	
Activated sludge modifications	x	x	x	x	
Anaerobic:					
Sludge digestion	x	x		x	x
Contact process	x	x		x	x
Aerobic filter	x	x		x	x
Anaerobic ponds	x	x		x	x
Anaerobic-aerobic ponds	x	x	x	x	x

also be used. Tests on recycling of treated sludge confirmed that high-density sludge could be produced with coal pile runoff, thereby reducing the sludge volume.

Weeter (29) conducted a study to assess the availability of data on coal pile drainage by contacting 80 utilities in the United States. The author summarized the effects of various treatment approaches for coal pile drainage, as shown in Table 41. The author concluded that sedimentation alone was not an effective method to treat the wastewater and that chemical treatment was required to produce an acceptable effluent. It should be noted that the removal of heavy metals and organics using chemical treatment was not evaluated.

A simulation study by Metry (22) provided the only previous insight into the treatability of leachates from western low-sulphur coals. In the experiment, distilled water was allowed to percolate through a 1.9-m, 50-mm diameter glass column filled with coal. The leachate was collected and analyzed. The treatment processes investigated were coagulation using ferric chloride and/or lime and/or polymer, settling in a flocculation clarifier, filtration in a pressure sand filter, filtration in a diatomaceous earth filter, and vacuum filtration using diatomaceous earth as a precoat material. The author con-

TABLE 40 PHYSICAL/CHEMICAL TREATMENTS FOR COAL STOCKPILE WATER POLLUTANTS (21)

	Pollutant																						
Treatment	BOD	COD	TOC	TSS	TDS	Phosphate	Sulphate	Acidity	Nitrate	Lead	Nickel	Chromium	Arsenic	Zinc	Mercury	Cadmium	Iron	Calcium	Manganese	General Heavy Metals	Copper	Chlorides	Cyanide
Coagulation, flocculation, precipitation				x	x	x				x	x	x		x	x	x	x	x	x	x	x		
Carbon adsorption	x	x	x	x		x				x													
Filtration	x	x		x	x	x																	
Sedimentation	x	x		x		x														x			
Chemical oxidation reduction							x										x		x				
Chlorination	x	x					x										x		x			x	x
Ozonation	x	x															x		x				x
Reverse osmosis	x	x			x	x	x		x	x	x	x	x	x		x	x	x	x	x	x	x	
Ion exchange	x	x			x	x	x		x	x	x	x	x	x	x	x	x		x	x	x		
Electrodialysis					x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	
Dissolved air flotation and foam separation	x	x		x							x	x											
Neutralization								x															
Magnetic separation	x	x		x		x														x			
Wet air combustion	x	x	x																				
Evaporation					x						x	x									x		
Freezing					x																		

TABLE 41 EFFECT OF VARIOUS TREATMENT METHODS ON COAL PILE DRAINAGE IN THE UNITED STATES (29)

	Parameters in Violation of Criteria or Regulations	
Treatment Systems	Prior to Treatment	After Treatment
Sedimentation	pH	pH
	TSS	TSS
	SO_4	SO_4
	Fe (total)	Fe (total)
	Mn	Mn
	Cu	Cu
	Zn	Zn
Chemical Treatment (Alum, Sodium Hydroxide, Sedimentation)	pH	
	TSS	
	Fe (total)	
	Alkalinity	

cluded that gravity settling of suspended coal fines could be effective when a combination of lime and polymer was used; further, this process would also remove heavy metals in the leachate. Gravity thickening of slurries containing coal fines was not possible. Chemically-aided thickening was possible if lime and polymer were used as conditioning agents, and sand filtration or mixed media filtration were not effective in capturing the suspended coal fines in leachate and contaminated runoff water.

McCormick (43) reported on treatability studies conducted on coal pile runoff from the Milliken Generating Station in New York State. Runoff from the 2.5-ha coal pile was highly coloured, and had a pH of 2.0 to 2.5 with an acidity of 10 000 to 20 000 mg/L. Both batch and continuous bench scale testing were conducted to select the most suitable neutralizing procedure. The test procedures consisted of adding a neutralizing chemical to an untreated coal pile drainage sample and then aerating and mixing the sample to promote oxidation of the ferrous iron and to provide good contact for the neutralization to proceed as rapidly as possible. Table 42 summarizes the performance of lime, sodium hydroxide and ammonium hydroxide.

Removal efficiencies for iron and aluminum in each case exceeded 99.8 percent. However, reductions in total dissolved solids were 88 percent using lime, 25 percent with sodium hydroxide, and 29 percent using ammonium hydroxide.

TABLE 42 RESULTS OF TREATABILITY STUDIES ON COAL PILE WATERS AT MILLIKEN GENERATING STATION (43)

		Neutralization to pH 7.0		
	Untreated Waste	Lime Neutralization	Sodium Hydroxide Neutralization	Ammonium Hydroxide Neutralization
Conductivity (µmhos/cm)	11.0×10^3	3.3×10^3	9.9×10^3	17.0×10^3
TDS	34 490	4 150	26 200	24 900
Sulphate	19 200	3 200	20 200	19 600
Calcium	450	515	365	345
Magnesium	560	395	500	385
Iron (total)	5 000	< 0.5	< 0.5	< 0.5
Aluminum	1 000	< 2	< 2	< 2

Note: All analyses expressed in mg/L except where noted.

The author concluded that the most practical treatment method was neutralization using lime. Although limestone is less expensive per unit weight than lime, treatment with limestone was not considered because of longer reaction times, and hence larger reactors and higher capital costs.

Waste treatment studies were performed on coal pile runoff from Dallman and Lakeside Generating Stations in Springfield, Illinois, and were reported by Browne and Wyness (44). These consisted of laboratory-scale jar tests and included sedimentation, pH adjustment, coagulant addition, polymer addition and combinations of these treatments. Specifically, treatment methodologies were 30-minute sedimentation, addition of 25 to 50 mg/L of lime, addition of alum or ferric sulphate at concentrations of 12 to 50 mg/L or the addition of 0.5 to 1.0 mg/L anionic polymer. Results of the treatment studies are shown in Table 43. Sedimentation alone or lime addition alone with sedimentation were not effective in lowering suspended solids and iron to levels required for discharge as permitted by the U.S. EPA. However, the addition of alum and an anionic polymer did produce an acceptable effluent.

5.2 Coal Pile Drainage Treatment in Canada

Treatability studies of coal pile drainage have been conducted by at least two utilities in Canada. A treatability study for the New Brunswick Electric Power

TABLE 43 TREATMENT OF COAL PILE RUNOFF AT DALLMAN AND LAKESIDE GENERATING STATIONS (44)*

Parameter	Influent	Effluent
Suspended Solids (mg/L)	7 780	12
Iron (mg/L)	109	0.1
Aluminum (mg/L)	174	0.2
Turbidity (JTU)	100	6
Color	300	20
pH (units)	7.9	7.5

* Results of laboratory-scale treatability tests using additions of alum and anionic polymer.

Commission was completed on a runoff sample from coal stored at the Dalhousie Generating Station (Personal Communication, C. Doiron, NBEPC). Initially, lime, sodium hydroxide, alum, and polyelectrolytes, separately or in some combination, were studied. Results of the study showed that the optimum treatment was obtained when only lime was added to the runoff. Alum treatment (aluminum sulphate) was not used since it would only aggravate the already high sulphate concentration in the wastewater. When sodium hydroxide was used, the separated supernatant liquor was only nine percent of the total volume and as a result this treatment was considered unsatisfactory. A combination of lime addition followed by sodium hydroxide likewise gave unsatisfactory results. Aeration of the sample was found to have only a marginal effect on the settleability of the sludge; however, it was an effective means of chemical mixing.

Following the selection of lime as the best settling aid, the optimum pH in terms of metal removal was determined. Based on the concentrations of iron, zinc and sulphate in the resulting supernatant, it was found that a final pH value between 7.5 and 9.0 was required for effective treatment. In one test, sufficient lime was added to increase the pH to over 10.0. No supernatant liquor separated from this sample even after standing overnight. The effect of treating the coal pile waters with lime at pH 9 is shown in Table 44. The resultant supernatant liquor exceeded the suggested criteria for the testing.

The use of polyelectrolytes, in conjunction with lime treatment, was also evaluated. Two polymers, Purifloc A-23, an anionic polymer, and Hercofloc 859, a

TABLE 44 TREATABILITY OF COAL PILE LEACHATE AT DALHOUSIE GENERATING STATION*

Parameter	Untreated Coal Pile Leachate	Supernatant Liquor Shaken Sample	Filtered Sample
pH	1.2	7.7	7.7
Sulphate	49 600	1 575	1 575
Total Phosphorus	300	< 0.02	< 0.02
Total Arsenic	40	< 0.003	< 0.003
Total Chromium	2.0	< 0.04	< 0.04
Total Copper	8.0	< 0.04	< 0.04
Total Iron	17 600	0.74	< 0.05
Total Lead	0.2	< 0.05	< 0.05
Total Nickel	7.8	< 0.08	< 0.08
Total Zinc	14.5	< 0.02	< 0.02

Note: All analyses expressed in mg/L except pH.

* Personal Communication, C. Doiron, N.B.E.P.C., Fredericton, N.B.

cationic polymer, were studied in a dosage range of 50 to 200 mg/L. When compared to the control using only lime addition, only a minimal improvement on settleability was observed.

It was concluded from this study that optimal results were attained when lime alone was used to treat the wastewater to a final pH value of 7.5 to 9.0. Good separation of solids occurred using this approach; however, final filtration through a sand filter was advised. Aeration did not have any effect.

Studies by the Research Division of Ontario Hydro have addressed both the suspended solids and chemical contaminant problems of coal pile drainage at the Lakeview Generating Station (12, 34). Sedimentation tube experiments on the suspended coal dust in the runoff revealed that, although the larger size particles settled rapidly, a fine suspension remained after extended settling periods. Plots of the settling rates for initial concentrations of 20 000 mg and 5 500 mg/L are shown in Figure 10. More than half the particles had a settling velocity of greater than 0.6 cm/min. The residual concentration of suspended solids was generally above 200 mg/L; however, runoff with an initial

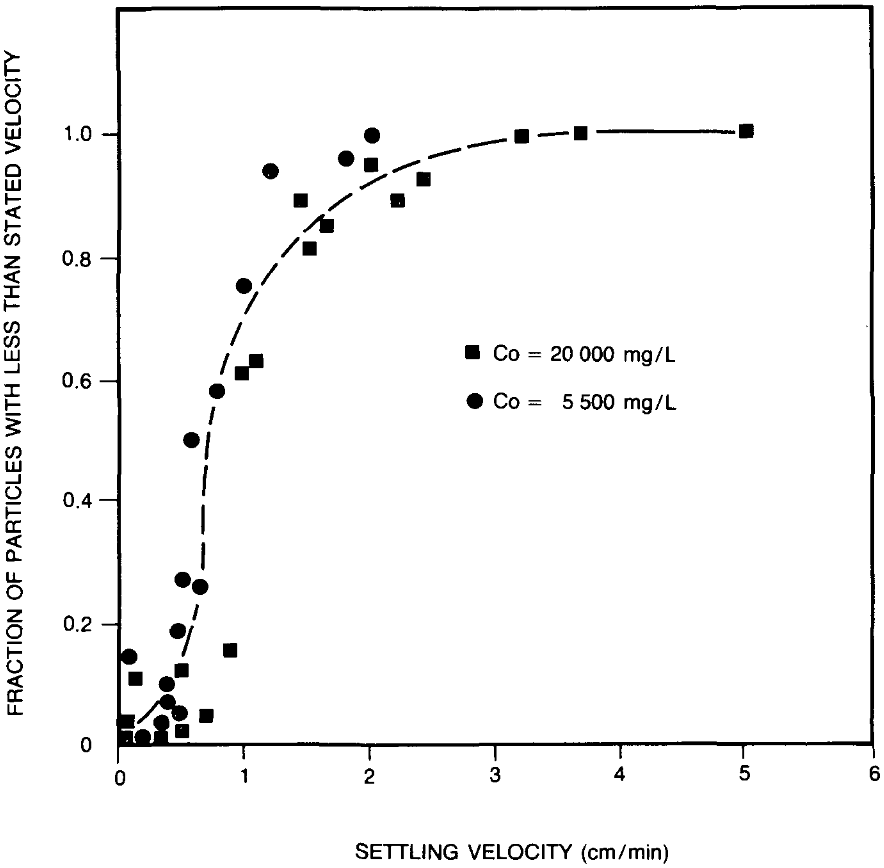

FIGURE 10 SETTLING RATE OF SUSPENDED SOLIDS IN COAL PILE DRAINAGE - LAKEVIEW G.S. (34)

concentration of less than 1 000 mg/L had little tendency to settle (12). Dosages as low as 1 mg/L of nonionic polymer increased the settling rate markedly, leaving a supernatant that contained less suspended solids but which was still turbid.

In another study, at the same site, Ontario Hydro studied the neutralization of the coal pile runoff, which was shown to reduce excess acidity and iron content and produced sufficient floc to trap all coal fines and produce a clear supernatant (34). The settling rate of the precipitated solids averaged 3 cm/min. The precipitated solids had a one-percent solids content and a one-hour settled volume of 15 percent.

Polyelectrolytes were used in an attempt to improve the sedimentation of the treated coal pile drainage. Although a nonionic polymer did not improve the solids settling, an anionic polyelectrolyte noticeably improved sedimentation (34). To increase the sludge solids content and to relieve calcium sulphate supersaturation, the sludge from previous neutralizations was recycled and added with the lime required for neutralization.

After six cycles and seeding of the recycled sludge with calcium sulphate, an increase in the solids content of the sludge was evident. The settling rate of the neutralized samples remained constant in spite of the increased solids content of the slurry.

Only one generating station in Canada, Lakeview Generating Station, operates a treatment facility exclusively for its coal pile drainage. At Dalhousie G.S. the coal pile drainage is mixed with other station wastewaters and is chemically treated at a central facility before discharge. At Lakeview G.S. water from the west ditch is pumped via a transfer station to a concrete lagoon while the east ditch drains by gravity. Automatic lime dosing equipment in the transfer station partially neutralizes the wastewater prior to the lagoon. Final pH adjustment is made in the lagoon. The treated effluent is reused in the station for coal pile dust suppression and, since there is no discharge to the environment, the treatment standards for the wastewater are not stringent.

The treatment lagoon has two cells so that one cell can be cleaned out while the other is in service. One end of the cell is sloped to allow the accumulated dewatered solids to be removed easily. Underdrains at the bottom facilitate the dewatering of settled solids. The solids are returned to the coal pile for eventual disposal; they can be burned along with the coal or disposed of as landfill.

As necessary, inflows to the lagoon can be further neutralized by the addition of excess lime at the transfer station either in the available flow to the lagoon or by returning some of the lagoon liquid. Drawdown is decanted from below the surface so that the floating scum in the lagoon is not disturbed. Treated water from the lagoon is used for coal pile spraying to reduce dust problems.

Routine operating practice for the plant has not been established since the treatment system is not fully commissioned. The coal pile waters are considered fully treated when the pH has been raised to 9 but the optimum operation of the plant and efficiency of contaminant removal is still under investigation.

The operation of the coal pile drainage treatment plant at Lakeview Generating Station is assessed by sampling and analyzing both untreated coal pile waters and the treated effluent. The performance of the plant in terms of the removal of wastewater parameters and metals is shown in Table 45 while the effects on organic contaminants are presented in Table 46.

High reductions in the concentration of metals such as aluminum, iron and copper, which precipitate at neutral pH due to hydroxide formation, are evident. Lesser reductions in non-amphoteric elements such as arsenic and boron were observed. There

TABLE 45 PERFORMANCE OF COAL PILE DRAINAGE TREATMENT PLANT AT LAKEVIEW GENERATING STATION

Parameter	Untreated	Treated*	Removal Efficiency (%)
pH	2.8	8.7	-
TOC	15	15	0
Total Solids	5 540	4 520	18
Total Dissolved Solids	5 420	4 450	18
Total Suspended Solids	110	60	45
Hardness as $CaCO_3$	1 990	2 160	+8.5**
COD	170	95	44
Alkalinity as $CaCO_3$	-	21	-
FMA as $CaCO_3$	480	-	-
Oil & Grease	< 1	< 1	-
Turbidity (NTU)	11	17	+55
Total Sulphur as Sulphate	3 400	2 600	24
Sulphate	3 600	2 300	36
Chloride	528	372	30
Fluoride	0.7	0.5	29
Ammonia as NH_4^+	2.4	1.4	42
Phenol (µg/L)	3	3	0
Cyanide as CN^- (µg/L)	20	< 20	-
Thiocyanate as SCN^- (µg/L)	< 0.5	< 0.5	-
Inorganic Phosphate as PO_4^{-3}	0.30	< 0.05	-
Total Phosphate as PO_4^{-3}	1.7	0.40	76
Aluminum	6.5	1.5	77
Antimony	0.3	< 0.2	-
Arsenic	0.033	0.017	48
Barium	< 0.1	< 0.1	-
Beryllium	< 0.01	0.02	-
Boron	0.35	0.30	14
Cadmium	< 0.01	< 0.01	-
Calcium	35.7	209	+485
Chromium	< 0.05	< 0.05	-
Cobalt	0.08	< 0.03	-
Copper	0.41	0.18	56
Iron	49	2.7	94
Lead	< 0.1	< 0.1	-
Lithium	0.1	0.1	0
Magnesium	50.0	24.0	52
Manganese	2.49	0.08	97
Mercury (µg/L)	< 1	< 1	-
Molybdenum	< 0.1	< 0.1	-
Nickel	0.3	< 0.1	-
Potassium	2.1	2.6	+23
Selenium	< 0.02	< 0.02	-
Silica as SiO_2	20	1.2	94
Silver	0.02	0.02	0
Sodium	430	430	0
Strontium	2.3	1.7	26
Thallium	< 0.2	< 0.2	-
Thorium	< 0.06	< 0.06	-
Titanium	< 0.3	< 0.3	-
Uranium (µg/L)	< 5	< 5	-
Vanadium	< 0.1	< 0.1	-
Zinc	0.81	0.72	11
Zirconium	< 0.05	< 0.05	-

Note: All results in mg/L except where noted.

* Treatment consists of pH adjustment to approximately 9.0 and sedimentation.

** Signifies increase in concentration due to treatment.

TABLE 46 REMOVAL OF TRACE ORGANICS - LAKEVIEW G.S.

Parameter	Untreated (μg/L)	Treated (μg/L)	Removal Efficiency (%)
Purgeable Organics:			
Benzene	Trace	ND	-
Bromodichloromethane	ND	Trace	+- *
Chloroform	93.0	94.0	+1
Methylene Chloride	52.0	67.0	+29
Toluene	1.7	1.9	+12
1,1,1-Trichloroethane	1.3	1.4	+8
Base Neutral Group:			
Polynuclear Aromatics:			
Anthracene	12	13	+8
Fluorene	36	ND	-
Phenanthrene	12	ND	-
Phthalate Esters:			
Di-n-butylphthalate	70	40	43
Diethylphthalate	0	115	+-
Other Compounds:			
2,6-Dinitrotoluene	0	23	+-

ND not detectable.

* + signifies increase in concentration due to treatment.

was an increase in the concentrations of hardness and calcium due to the treatment of the coal pile drainage. These increases result from the additions of lime, $Ca(OH)_2$, during the neutralization stage of the treatment process. The turbidity and concentration of potassium also increased as a result of the treatment process. To achieve the treatment criteria presented in Appendix IV, additional removal of total suspended solids, iron and zinc would be necessary.

Table 46 indicates the effect of the treatment system on organics. The treated effluent contained about the same concentrations of purgeable organics as the untreated coal pile discharge. Of the base neutral group, polynuclear aromatics, phthalate esters and 2,6-dinitrotoluene were present in the treated effluent. With the exception of di-n-bitylphthalate, the concentrations of trace organics appear to have been reduced or remained the same. The di-n-butylphthalate concentration is indicated as having increased 43 percent due to treatment. The concentrations of all trace organics in the treated effluent were less than 115 µg/L.

5.3 Treatability of Coal Pile Discharges

Samples of coal pile drainage from Lingan G.S., Battle River G.S. and Milner G.S. were collected during the sampling program and were used in the bench-scale physical-chemical treatability studies. The following treated effluent criteria were selected as the basis for assessment of chemical dosages and treatment requirements:

Wastewater Parameter	Criteria
pH	6.5-9.5
chromium	0.5 mg/L
copper	0.5 mg/L
iron	1.0 mg/L
nickel	0.5 mg/L
zinc	0.5 mg/L
suspended solids	25 mg/L

Treatability tests were conducted using a bench-scale six-gang multiple stirrer following ASTM standard recommended procedures (45). Samples were flash-mixed at 100 rpm for one minute following the addition of the primary coagulant. The stirrer speed was reduced to a minimum to keep the floc particles uniformly suspended during a five-minute slow mix period. Subsequently, the stirrer paddles were removed from the beakers and the samples were allowed to settle under quiescent conditions for 30 minutes. Using a siphon, a sample was withdrawn from the supernatant liquor for analysis.

5.3.1 Lingan Generating Station Sample. Based on the treatment schemes presented in the literature for low pH coal pile waters, pH adjustment to the neutral range to promote metal precipitation was selected as the initial treatment approach. The optimum pH for treatment was selected by neutralizing the coal pile waters using lime ($Ca(OH)_2$). Figure 11 shows the effect of pH on the concentration of suspended solids, iron, nickel, zinc and copper in the sample supernatant after 30 minutes of quiescent settling. The optimum pH was found to be 8.0.

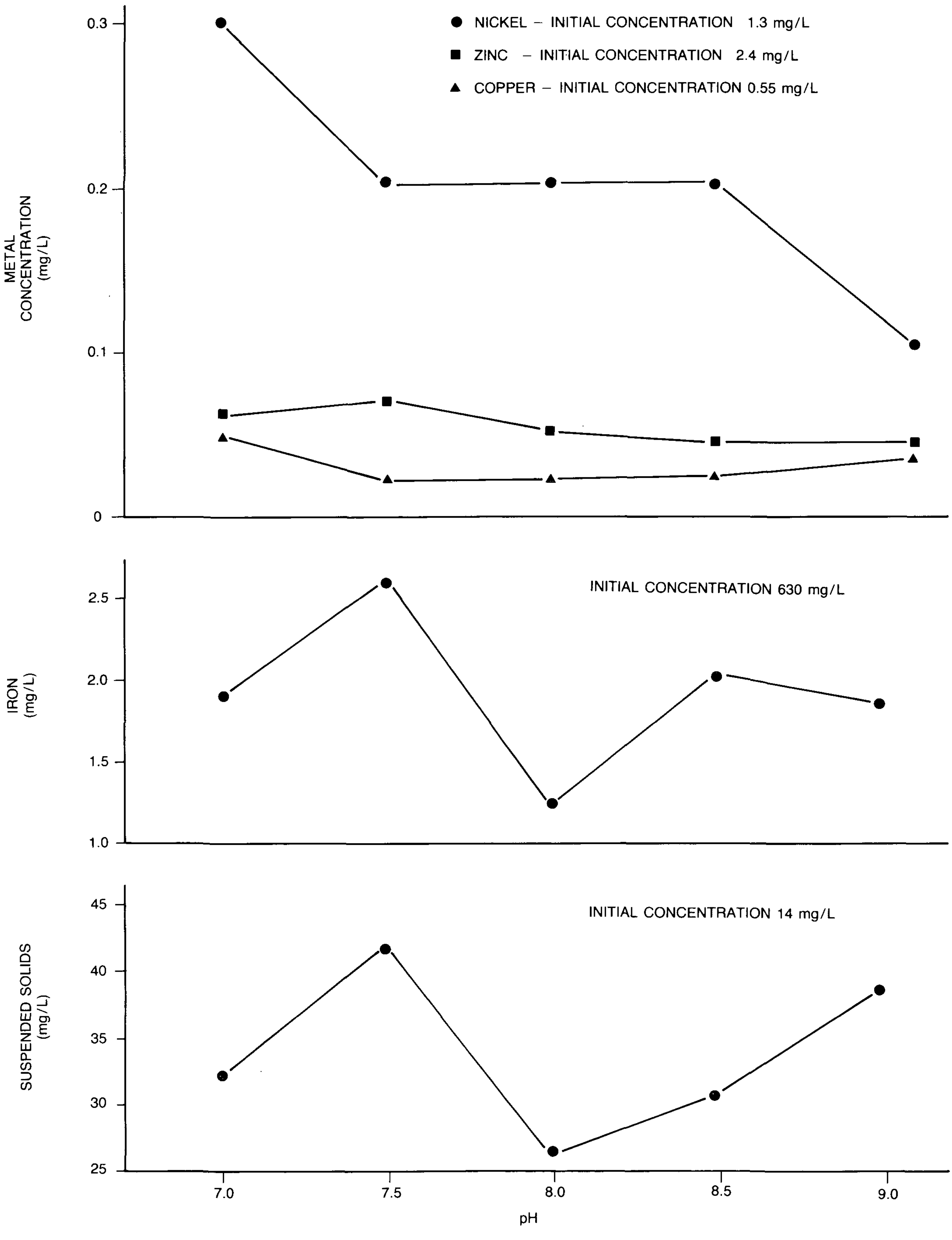

FIGURE 11 EFFECT OF pH ON COAL PILE DRAINAGE QUALITY - LINGAN G.S.

The effectiveness of sodium hydroxide as a neutralizing agent was also evaluated. In Table 47, the effectiveness of sodium hydroxide is compared with that of lime. The use of lime produced a larger, more rapidly settling floc and a lower sludge volume. Sodium hydroxide produced greater sludge volumes. The treated runoff quality attained in both cases was similar. Although sodium hydroxide offers some materials handling advantages over lime because it can be purchased and dosed as a liquid, lime is considerably less expensive ($0.0577/kg) than sodium hydroxide ($0.45/kg). Therefore, for treatment of the Lingan coal pile drainage sample, lime was selected as the more cost effective treatment approach.

TABLE 47 COMPARISON OF LIME AND SODIUM HYDROXIDE FOR NEUTRALIZATION OF COAL PILE DRAINAGE - LINGAN G.S.

Parameter	$Ca(OH)_2$	NaOH
pH	8.0	8.0
quantity added (mg/L)	2.4	1.7
relative floc size	medium	small
relative settling rate	rapid	medium rapid
sludge volume (%)	20	34
<u>Supernatant Quality</u>:		
chromium (mg/L)	<0.01	<0.01
copper (mg/L)	0.06	0.05
iron (mg/L)	1.54	9.45
nickel (mg/L)	<0.1	0.2
zinc (mg/L)	0.06	0.08
suspended solids (mg/L)	34	20

Adjustment of pH alone did not produce an acceptable effluent in terms of the suspended solids concentration. The use of high molecular weight anionic polyelectrolytes as flocculants to improve the removal of suspended metal hydroxide floc was investigated. After an initial screening of a variety of polymers, an anionic copolymer of acrylamide and acrylate with a molecular weight greater than 10^7 was selected as most effective.

Figure 12 shows the effect of the addition of the 20 percent anionic acrylate and 80 percent nonionic acrylamide copolymer on the total iron and suspended solids concentrations following pH adjustment to 8.0 with lime and 30 minutes of quiescent settling. The optimum concentration of the polymer was 0.25 mg/L. Although the removal of iron increased slightly at higher polymer dosages, the suspended solids concentration in the supernatant was adversely affected. This is a characteristic indication of an overdose of polymer.

Based on the laboratory-scale testing, the optimal treatment was found to consist of the adjustment of pH to 8.0 using lime and the addition of 0.25 mg/L of anionic polyelectrolyte as a coagulant aid. This treatment was performed on a composite of eight sequential samples from the coal pile drainage lagoon at Lingan G.S. The results are shown in Table 48. Comparison of these data with the treatment criteria indicates that the physical-chemical treatment produced an acceptable supernatant quality. The concentration of copper was reduced by 80 percent while the iron concentration was reduced by more than 99 percent, zinc 97 percent and suspended solids 99 percent following treatment. The concentration of nickel was reduced from 1.55 mg/L to less than 0.1 mg/L, while the concentration of chromium was below the detection limit before and after the treatment. High removals of total and dissolved solids, COD, turbidity, phosphate, cadmium, cobalt, manganese and silicon were also observed. The concentration of calcium and total hardness increased as a result of the treatment, as would be expected with the addition of 2.4 mg/L of $Ca(OH)_2$. Increases in the concentrations of lithium, sodium, magnesium and strontium may be associated with impurities in the industrial grade of lime used in the testing. Increases in the concentrations of other parameters such as oil and grease, ammonia and fluoride were not significant as these were present in concentrations close to their detection limits. Detection limits for these analyses are shown in Appendix III.

Table 49 shows the effects of the physical-chemical treatment on the purgeable and trace organics. With the exception of chloroform, all purgeable organics were indicated to be present in lower concentrations in the treated effluent than in the untreated waters. The indicated concentration of chloroform increased 180 percent. This apparent increase may have been due to analytical error or non-representative sampling, although the increase is large and the concentration is well above the detection limit. Considerably more study and refinement of the analytical procedure would be necessary to verify this result.

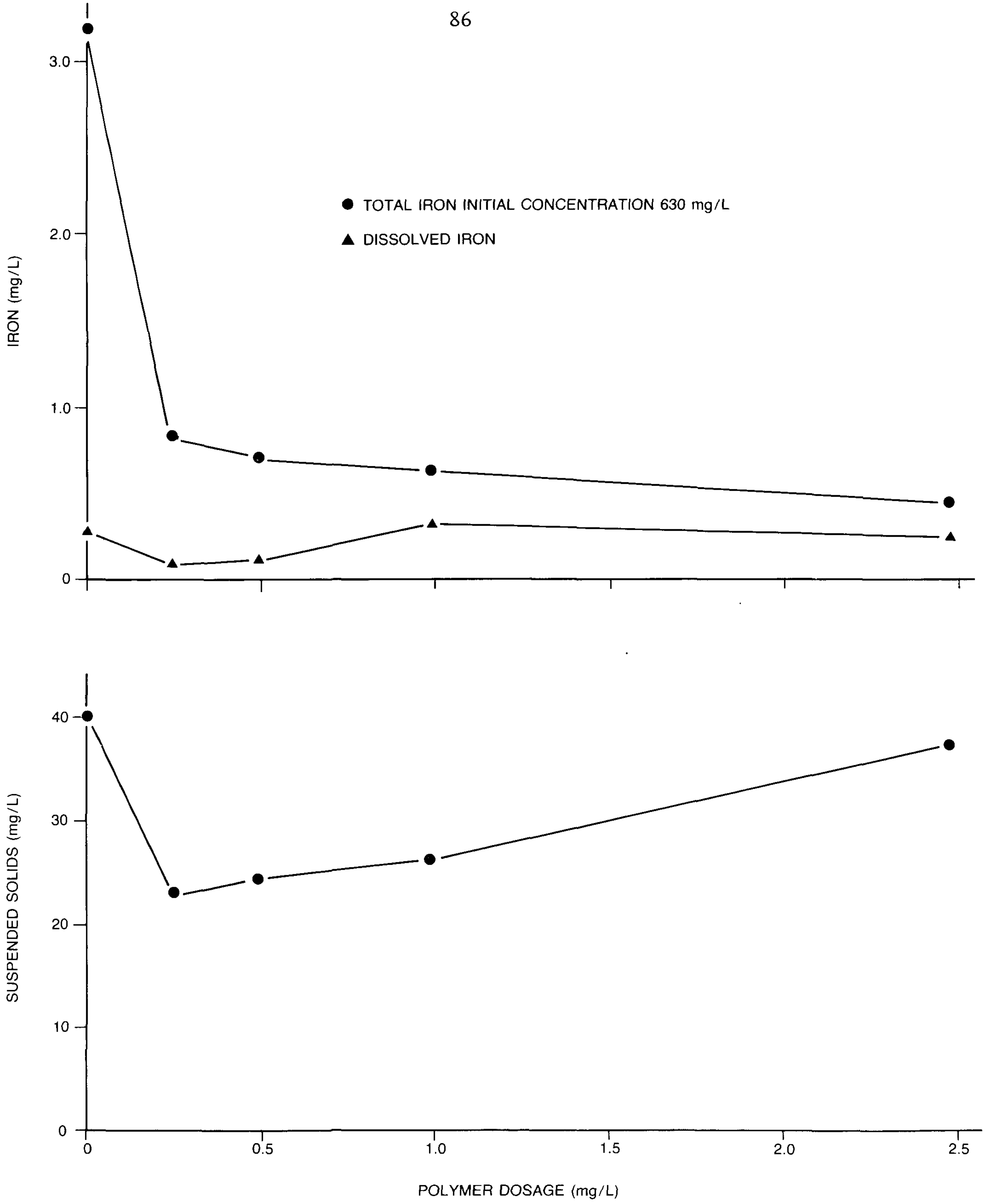

FIGURE 12 EFFECT OF POLYMER DOSAGE ON IRON AND SUSPENDED SOLIDS CONCENTRATIONS IN COAL PILE DRAINAGE - LINGAN G.S.

TABLE 48 OPTIMAL TREATMENT OF COAL PILE DRAINAGE AT LINGAN GENERATING STATION

Parameter	Untreated	Treated*	Removal Efficiency (%)
pH	2.1	8.2	-
TOC	2.0	1.0	50
Total Solids	5 720	992	83
Total Dissolved Solids	5 540	990	82
Total Suspended Solids	180	2	99
Hardness as $CaCO_3$	860	2 720	+216**
COD	42.9	3.9	91
Alkalinity as $CaCO_3$	-	29	-
FMA as $CaCO_3$	1 500	-	-
Oil & Grease	1.5	3.0	+100
Turbidity (NTU)	7.8	1.5	81
Total Sulphur as Sulphate	3 700	2 600	30
Sulphate	3 600	2 100	42
Chloride	580	768	+32
Fluoride	0.4	0.5	+39
Ammonia as NH_4^+	0.6	0.7	+17
Phenol (µg/L)	4.0	3	25
Cyanide as CN^- (µg/L)	< 20	< 20	-
Thiocyanate as SCN^- (µg/L)	< 0.5	< 0.5	-
Inorganic Phosphate as PO_4^{-3}	6.1	0.15	98
Total Phosphate as PO_4^{-3}	6.1	0.30	95
Aluminum	60	< 1.0	-
Antimony	1.7	< 0.2	-
Arsenic	0.650	< 0.002	-
Barium	< 0.1	< 0.1	-
Beryllium	0.01	< 0.01	-
Boron	0.23	0.23	-
Cadmium	0.12	0.03	75
Calcium	27	203	+652
Chromium	< 0.05	< 0.05	-
Cobalt	0.85	0.08	91
Copper	0.56	0.11	80
Iron	500	0.4	> 99
Lead	< 0.1	< 0.1	-
Lithium	0.3	0.3	0
Magnesium	72	80.0	+11
Manganese	21.3	1.61	92
Mercury (µg/L)	< 1	< 1	-
Molybdenum	< 0.1	< 0.1	-
Nickel	1.5	< 0.1	-
Potassium	2.9	1.3	55
Selenium	< 0.02	< 0.02	-
Silica as SiO_2	22	2.6	89
Silver	0.03	0.02	33
Sodium	450	480	+7
Strontium	1.3	2.3	+77
Thallium	< 0.2	< 0.2	-
Thorium	< 0.06	< 0.06	-
Titanium	< 0.3	< 0.3	-
Uranium (µg/L)	< 5	< 5	-
Vanadium	< 0.1	< 0.1	-
Zinc	5.4	0.16	97
Zirconium	< 0.05	< 0.05	-

Note: All results in µg/L except where noted.

* Treatment consists of adjustment of pH to 8.0 using lime and addition of 0.25 µg/L anionic copolymer of acrylamide and acrylate.

** signifies increase in concentration due to treatment.

TABLE 49 REMOVAL OF ORGANICS BY OPTIMUM TREATMENT OF COAL PILE DRAINAGE - LINGAN G.S.

Parameter	Untreated (µg/L)	Treated (µg/L)	Removal Efficiency (%)
Purgeable Organics:			
Benzene	2.6	trace	-
Chloroform	9.3	26.0	+180*
Methylene Chloride	22.0	21.1	4
Toluene	1.8	1.5	17
1,1,1-Trichloroethane	1.0	trace	-
Base Neutral Group:			
Phthalate Esters:	ND	38	+-
butylbenzlphthalate	ND	38	+-
Di-n-butylphthalate	25	88	+252
Diethylphthalate	ND	80	+-
bis-(2-ethyl hexyl) phthalate	20	95	+375
Other Compounds:			
2,4-Dinitrotoluene	0	27	+-

ND not detected.

* + signifies increase in concentration due to treatment.

Of the other trace organics, only the phthalate esters group and 2,4-dinitrotoluene were found in the treated sample. No acid extractables or pesticides were quantified. In all cases, the concentrations of the trace organics present in the raw sample were indicated to increase to well above the detection limits after the physical-chemical treatment.

It has been suggested that methylene chloride and phthalate esters can be present in such samples due to contamination (46). Phthalate esters are used as plasticizers in the manufacture of tubing while methylene chloride is used in the cleaning and preparation of laboratory equipment.

Appendix V presents data on the recovery of various trace organics from a spiked sample. Recoveries of the spiked organic material were highly variable. Very poor recoveries were found for the nitrophenol group and reproducibility was low. The analytical method did not detect n-nitrosodiumethylamine, which decomposed in the gas chromatograph column, hexachlorocyclopentadiene, which polymerizes in the column, acrolein, or acrylonitrile. Anthracene and phenanthracene could not be distinguished; hence, the quantities reported represent either or both organics. The same applies for benzo (b) and benzo (k) fluoranthene. Problems were also encountered due to the formation of emulsions during the extraction stage which adversely affected trace organic recoveries. Further, it was difficult to determine whether, in general, the analytical data reflected changes in concentrations of the trace organics or a lack of reproducibility in the analytical method. Considerably more work is necessary to refine analytical techniques, to reduce possible contamination during sample collection, extraction and handling, and in general to improve the accuracy of trace organics analyses for wastewaters of this nature.

The cost of the treatment of the runoff water using lime at $0.0577/kg for pH adjustment and 0.25 mg/L of polyelectrolyte at $4.40/kg was approximately $0.14/m^3. This is the cost for chemicals only and does not include chemical transportation, treatment plant capital, operating or maintenance costs, chemical handling systems or sludge disposal.

5.3.2 Battle River Generating Station Sample. A composite sample of coal pile leachate from Battle River G.S. was collected during the sampling program and was used for bench-scale treatability studies. The coal pile drainage from this site contained high concentrations of suspended solids, in excess of 20 000 mg/L. Initial investigations of the treatment of the sample using chemical additions of calcium chloride, lime and a variety of polymeric coagulants indicated that the discharge was too concentrated to be treated using chemical addition and sedimentation. The sample could be flocculated; however, there was no separation of the flocculant solids from the liquid phase, even under extended quiescent settling conditions.

The sample collected from Battle River G.S. for testing was an extremely concentrated leachate. Comparison with a runoff sample from Milner G.S. indicated that the leachate was approximately ten times as concentrated as the runoff from a comparative coal pile area. The physical constraints on the coal pile collection system suggested that any leachate of this nature which might actually escape from the pile would undergo considerable dilution prior to any treatment process. Therefore, the effect of dilution of the concentrated leachate on the treatability was assessed. Table 50 presents the results of flocculation tests using two dosages of calcium chloride on the leachate sample diluted with varying proportions of deionized water. Even at the lowest dilution ratio (1:4), the leachate sample was treatable to produce a clear supernatant at a chemical dosage of 300 mg/L. However, at dilution ratios below about 1:9, the sludge volume after 30 minutes of quiescent settling approached 50 percent. There was no separation of the colloidal solids after extended quiescent settling (24 hours) of the diluted samples without chemical addition. As a dilution ratio of 1:9 produced an effluent sample similar to that collected at Milner G.S., this dilution was used for further assessment of the coal pile drainage treatability.

TABLE 50 EFFECT OF SAMPLE DILUTION ON TREATABILITY

Dilution:						
sample (mL)	50	75	100	50	75	100
deionized water (mL)	450	425	400	450	425	400
dilution ratio	1:9	1:6	1:4	1:9	1:6	1:4
Dosage of $CaCl_2 \cdot 2H_2O$ as $CaCl_2$ (mg/L)	150	150	150	300	300	300
Settling Rate	very slow	very slow	very slow	slow	very slow	very slow
Sludge Volume (%)	24	35	44	30	44	64
Supernatant Suspended Solids Concentration (mg/L)	156	296	440	8	68	*

* No separation of clear supernatant

Four chemical coagulants were evaluated on the diluted sample, ferric chloride ($FeCl_3$), lime ($Ca(OH)_2$), calcium chloride ($CaCl_2 \cdot 2H_2O$) and alum ($Al(SO_4)_3 \cdot 18H_2O$). The results of these treatments are shown in Table 51.

The use of ferric chloride greatly reduced the wastewater suspended solids concentrations; however, the resulting supernatant had a pH of 3.0 and there was an

TABLE 51 PERFORMANCE OF CHEMICAL COAGULANTS IN DILUTED SAMPLE FROM BATTLE RIVER G.S.

Chemical	Fe Cl_3	$Ca(OH)_2$	$Al_2(SO)_4)_3 \cdot 18H_2O$	$CaCl_2 \cdot 2H_2O$
Dosage (mg/L)	500 as Fe	250 as $Ca(OH)_2$	750 as Al	250 as $CaCl_2$
floc size	small	small	very small	small
settling rate	very slow	slow	slow	slow
sludge volume (%)	20	30	50	28
Supernatant (mg/L except pH):				
pH	3.0	8.4	4.5	7.4
suspended solids	< 2	2	22	12
iron	5.6	0.14	NA	0.7
copper	0.16	< 0.01	NA	0.03
nickel	0.6	0.10	NA	< 0.1
zinc	0.03	0.02	NA	0.27
chromium	0.01	< 0.01	NA	0.10

Note: NA - not analyzed

unacceptably high concentration of iron in the treated water. In a full scale system, an additional neutralization step would be necessary to achieve the treated effluent criteria.

The use of alum required relatively high dosages which formed a very small floc and produced a treated effluent which, after 30 minutes of quiescent settling, contained 22 mg/L of suspended solids. This was an order of magnitude higher than produced using the other coagulants. As with ferric chloride, the pH of the treated effluent was acidic (4.5), which would necessitate additional pH adjustment in a full scale treatment system.

Coagulation with either lime or calcium chloride resulted in a treated supernatant that met the treatment criteria. The addition of 250 mg/L of lime or 250 mg/L of calcium chloride produced similar settling rates and sludge volumes. Lime, as a primary coagulant, offered some advantages in terms of the removal of suspended solids, iron, copper, zinc and chromium. Calcium chloride produced a treated supernatant containing a lower concentration of nickel. The major disadvantage associated with lime was the effect on the treated effluent pH. Close control of the lime dosage rate would be necessary to ensure that an excessively alkaline effluent requiring additional acid addition for pH control was not discharged to the receiving waters. Calcium chloride addition resulted in an increase in the total dissolved solids content of the treated coal pile water.

On a chemical cost basis, the use of lime for treatment of the diluted Battle River coal pile leachate offered an advantage. Based on the chemical dosages given in Table 51, the costs associated with lime treatment, based on a chemical cost of \$0.0577/kg, are approximately \$0.014/m^3. The costs associated with calcium chloride, based on a chemical cost of \$0.10/kg, are approximately \$0.025/m^3. The chemical costs for the lime option would increase significantly if acid addition was required to control effluent pH. In addition, lime feed systems represent a substantial capital investment and often pose operational and maintenance problems. On this basis calcium chloride was selected as an attractive option for a coal pile discharge of this type.

The effect of calcium chloride dosage on the settled supernatant quality is shown in Figure 13. Although treatment at a dosage of 250 mg/L produced an acceptable effluent, the optimum chemical dosage was approximately 500 mg/L. The effect of the addition of calcium chloride at a dosage of 500 mg/L on the diluted drainage sample from Battle River G.S. is shown in Table 52. Comparison with the treatment criteria indicates that the physical-chemical treatment produced an acceptable supernatant quality. The concentration of copper was reduced 73 percent, iron 95 percent, and zinc 55 percent while the suspended solids were reduced by greater than 99 percent. The concentration of chromium was reduced from 0.13 to less than 0.05 mg/L, while the concentration of nickel was reduced from 0.17 to less than 0.1 mg/L. The concentrations of TOC, COD, turbidity, phosphate, aluminum, antimony, manganese and silicon were also significantly reduced by the treatment.

Increases in the concentrations of total dissolved solids, chloride and calcium are directly related to the addition of calcium chloride as a coagulant. Ammonia and sodium are present in calcium chloride as contaminants in significant concentrations. The other trace elements that apparently increased following treatment (boron, antimony, cadmium and cobalt) were present in the raw sample in such low concentrations that the increases were probably not statistically significant. The apparent increase in alkalinity may be related to a negative interference in the analytical method which occurs at high sample solids concentrations (38).

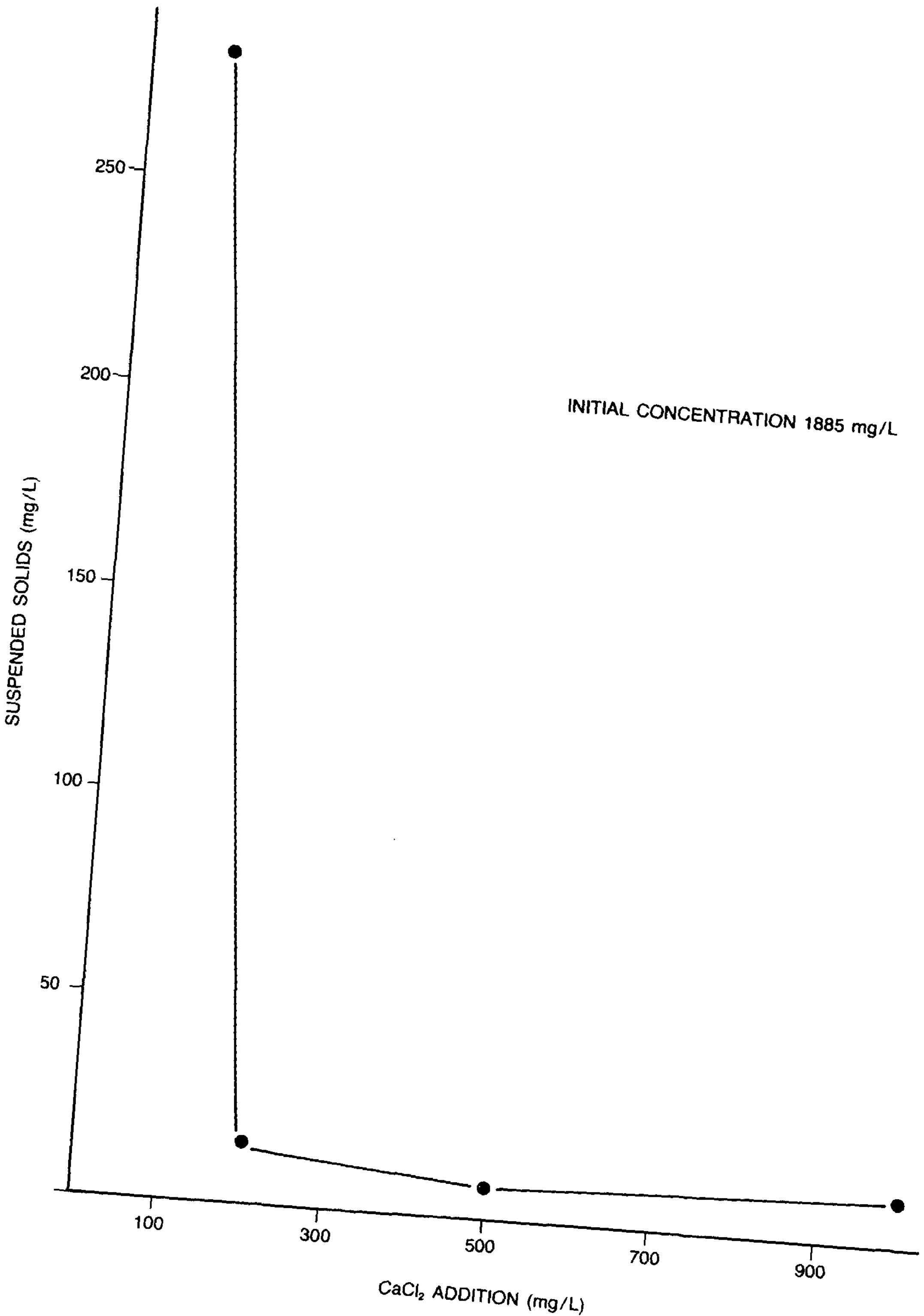

FIGURE 13 EFFECT OF $CaCl_2$ ADDITION ON SUSPENDED SOLIDS CONCENTRATION - BATTLE RIVER G.S.

TABLE 52 OPTIMAL TREATMENT OF COAL PILE DRAINAGE FROM BATTLE RIVER GENERATING STATION

Parameter	Concentration (mg/l except as noted) Untreated[a]	 Treated[b]	Removal Efficiency (%)
pH	7.0	7.9	-
TOC	220	3.0	99
Total Solids	2 110	804	62
Total Dissolved Solids	230	794	+245[c]
Total Suspended Solids	1 880	10.0	> 99
Hardness as $CaCO_3$	720	400	44
COD	899	18.4	98
Alkalinity as $CaCO_3$	34	90	+165
FMA as $CaCO_3$	-	-	-
Oil & Grease	< 1.0	< 1.0	-
Turbidity (NTU)	950	5.3	> 99
Total Sulphur as Sulphate	160	105	34
Sulphate	140	92	34
Chloride	1.7	246	+14 370
Fluoride	0.5	0.2	60
Ammonia as NH_4^+	0.1	0.7	+600
Phenol (µg/L)	< 1	4	-
Cyanide as CN^- (µg/L)	< 20	<20	-
Thiocyanate as SCN^- (µg/L)	< 0.5	< 0.5	-
Inorganic Phosphate as PO_4^{-3}	2.2	0.10	95
Total Phosphate as PO_4^{-3}	2.3	0.15	93
Aluminum	36	1.5	96
Antimony	0.4	0.8	+100
Arsenic	0.024	0.008	67
Barium	< 0.1	< 0.1	-
Beryllium	< 0.01	< 0.01	-
Boron	0.44	0.71	+66
Cadmium	0.02	0.07	+250
Calcium	18	75	+317
Chromium	0.13	< 0.05	-
Cobalt	0.05	0.12	+140
Copper	0.82	0.22	73
Iron	9.8	0.5	95
Lead	< 0.1	< 0.1	-
Lithium	< 0.1	< 0.1	-
Magnesium	14.4	8.00	44
Manganese	0.37	0.06	84
Mercury (µg/L)	0.27	0.25	7
Molybdenum	< 0.1	< 0.1	-
Nickel	0.17	< 0.1	-
Potassium	4.5	2.6	42
Selenium	< 0.02	< 0.02	-
Silica as SiO_2	410	4.8	99
Silver	0.03	0.03	0
Sodium	49	53	+8
Strontium	0.5	0.3	40
Thallium	< 0.2	< 0.2	-
Thorium	< 0.06	< 0.06	-
Titanium	1.8	< 0.3	-
Uranium (µg/L)	6.6	< 5	-
Vanadium	< 0.1	< 0.1	-
Zinc	0.4	0.18	55
Zirconium	< 0.05	< 0.05	-

[a] untreated sample was diluted with deionized water in ration 1:9.

[b] optimal treatment consists of the addition of 500 ml/L of $CaCl_2$.

[c] + signifies increase in concentration due to treatment.

The apparent effect of the treatment method on trace organics is shown in Table 53. Of the purgeable organics group, benzene, chloroform and methylene chloride concentrations appeared to be significantly increased due to the treatment. In three cases the concentrations were close to the detection limit, and for this reason the changes in concentration are not considered significant. Significant increases in the concentrations of benzene and methylene chloride at levels well above the detection limit suggest that these may represent actual changes in the concentrations of these compounds in the treated compared to the untreated samples. Further studies would be necessary to confirm these results. Of the other trace organics, no acid extractables or pesticides were indicated and only the phthalate esters and nitrobenzene were indicated to be present in either the raw or treated samples. Only the concentration of diethylphthalate is sufficiently above the detection limit to reduce the likelihood of analytical problems at low concentrations. As stated earlier, the lack of trace organics in the acid extractables groups and others may be related to problems with the trace organics analytical methods.

5.3.3 **Milner Generating Station Sample.** The treatability of the coal pile runoff sample from Milner G.S. was investigated to further define possible treatments for discharges. Based on the data from the treatability studies on the samples from Battle River G.S., the use of lime or calcium chloride with the possible addition of a polymer as a settling aid was investigated.

Table 54 shows the effect of the addition of lime to the runoff sample from Milner G.S. To obtain adequate suspended solids removal, the sample pH had to be increased to approximately 10.0, requiring a lime dosage of about 250 mg/L. Similarly, the addition of calcium chloride at dosages of up to 500 mg/L did not reduce the suspended solids concentration to less than 25 mg/L.

Jar tests were therefore conducted to assess the feasibility of improving suspended solids removal by the use of an organic polyelectrolyte in conjunction with calcium chloride and lime. The best treatments for each of these approaches are shown in Table 55. The use of lime alone did not remove sufficient suspended solids without creating a treated supernatant with an unacceptably high pH. With the exception of pH, the treated sample was acceptable in terms of supernatant quality. The addition of 500 mg/L of calcium chloride was found to be optimal for this treatment approach in terms of reduction of concentrations of metals; however, the addition of this coagulant did not produce an effluent that met the treatment criteria for suspended solids.

TABLE 53 REMOVAL OF ORGANICS BY OPTIMAL TREATMENT OF COAL PILE DRAINAGE - BATTLE RIVER G.S.

Parameter	Untreated (μg/L)	Treated (μg/L)	Removal Efficiency (%)
Purgeable Organics:			
Benzene	1.6	3.4	+113*
Chloroform	trace	79.0	+-
1,2-Dichloroethane	trace	ND	-
Methylene Chloride	2.3	61.0	+2 552
Toluene	trace	2.6	+-
1,1,1-Trichloroethane	trace	1.0	+-
Base Neutral Group:			
Phthalate esters:			
Di-n-butylphthalate	ND	10	+-
Diethylphthalate	ND	33	+-
bis-(2-ethylhexyl) phthalate	15	ND	-
Other compounds:			
Nitrobenzene	15	ND	-

ND not detected

* + signifies increase in concentration due to treatment.

TABLE 54 EFFECT OF LIME ADDITION TO RUNOFF FROM MILNER G.S.

Dosage as $Ca(OH)_2$ (mg/L)	50	100	150	200	250
Appearance of Floc	slow	slow	medium	medium	medium
Settling Rate	slow	slow	medium	medium	medium
Supernatant					
pH	8.4	8.4	9.5	9.6	10.3
suspended solids (mg/L)	326	332	126	44	4

TABLE 55 OPTIMAL TREATMENT USING THREE SETTLING AIDS AT MILNER G.S.

Settling Aid	Untreated	$Ca(OH)_2$	$CaCl_2{\cdot}2H_2O$	$CaCl_2{\cdot}2H_2O$ and polymer*	$Ca(OH)_2$ and polymer*
Dosage (mg/L)	-	250 as $Ca(OH)_2$	500 as $CaCl_2$	500 as $CaCl_2$ and 0.5	100 as $Ca(OH)_2$ and 0.5
settling rate	-	medium	slow	rapid	medium
Supernatant Quality:					
pH	8.5	10.3	8.2	8.1	8.6
suspended solids	2920	4	82	6	24
iron	23.2	0.28	0.35	0.14	0.14
chromium	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
copper	0.22	0.03	0.03	0.02	0.01
nickel	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
zinc	0.33	0.06	0.05	0.11	0.03

* 0.5 mg/L of high molecular weight anionic copolymer of acrylamide and acrylate.

The use of 500 mg/L of $CaCl_2$ and 0.5 mg/L of a high molecular weight anionic copolymer of acrylamide and acrylate produced a treated effluent that achieved the treatment criteria. The removal of suspended solids and iron exceeded 99 percent, while the concentration of copper was reduced by 91 percent and zinc by 67 percent. The concentration of chromium was below the detection limit before and after treatment.

The treatment criteria were also achieved with the addition of 100 mg/L of lime and 0.5 mg/L of the same polymer. More than 99 percent of the suspended solids and iron were removed and the concentration of zinc was reduced by 91 percent. The concentration of copper was reduced from 0.02 to less than 0.01 mg/L. In both treatments where polymer was added, the optimum dosage was found to be 0.5 mg/L.

The cost for chemicals only for the treatment using 500 mg/L of $CaCl_2$ at \$0.10/kg and 0.5 mg/L of anionic copolymer at \$4.40/kg was approximately \$0.07/m^3. This cost does not include capital, operating or maintenance costs of the treatment plant, costs of the chemical handling system or sludge disposal. The cost of treatment using 100 mg/L of lime at \$0.0577/kg and 0.5 mg/L of anionic copolymer at \$4.40/kg was \$0.03/m^3. Again these costs are for chemicals only. Although the results from both treatment approaches were similar, the lime and polymer addition method appears to be more cost-effective for a coal pile runoff of this type. However, long-term treatability studies would be necessary to precisely define the optimal flocculant and the most cost-effective combination of primary coagulant and flocculant.

6 COAL PILE WATER TREATMENT BY BLENDING WITH OTHER WASTE STREAMS

6.1 Literature Review

As mentioned in Section 5.3, coal pile drainage can be treated by lime or limestone neutralization followed by sedimentation. These processes can be costly and in some cases difficult to operate. Several authors have investigated the possibility of reusing coal pile runoff for other purposes in the generating station or of combining the runoff with other waste streams to allow self-neutralization and co-precipitation to occur.

Printz (47) discussed the reuse of coal pile runoff in the context of an overall water management plan for an electrical utility. It was suggested that coal pile runoff, after sedimentation and filtration, may be suitable for cooling tower system makeup, particularly when low-sulphur coals are used. A material balance would be necessary to determine the effects on cooling tower system operation. Existing makeup or sidestream precipitation softening will remove iron from the runoff, thus obviating the need for an external iron removal system if the runoff is introduced as feed to the softener. In the absence of a recirculating cooling water system, the wastes might be reused as makeup to a recycle bottom ash sluice or flue gas desulphurization system.

The combination of coal pile runoff and ash sluicing waters has been described by several authors. Breland (48) stated that ash lagoons are widely used for this purpose because they provide substantial retention time which results in self-neutralization, co-precipitation and gravity sedimentation.

A unique method of treating coal pile leachate from a small coal pile was described by Anderson (42). Runoff from a 10.9×10^3 tonne coal stockpile was collected in an equalization/retention tank and was pumped to a mixing tank where boiler blowdown was added. Automatic controls based on pH correlated the leachate feed rate to the available alkalinity in the boiler to produce a neutralizing effect. The neutralized coal pile leachate and boiler blowdown was discharged to the sanitary sewer to the city's wastewater treatment plant. The authors maintained that nutrient removal and solids settling at the municipal treatment plant should be improved slightly as a result of the ferrous and ferric iron discharges from the system.

Che et al (26) described the strategy of the Tennessee Valley Authority in dealing with their coal pile drainage problem. Discharges from the coal pile are routed through ash ponds before discharge. The ratio of coal pile drainage to total ash pond effluent averages from 0.001 to 0.012 at the twelve TVA power plants. It was believed that the concentration of iron as well as trace metals were lower due to the dilution with ash pond water and precipitation at neutral pH; however, this was still being investigated.

In an on-going detailed study of the coal pile drainage problem, Cox et al (14) reported on the experimental use of dry fly ash and fly ash sluice water for the treatment of coal pile waters. Fly ash consists primarily of metal oxides such as SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO and, when in contact with water, they will produce an alkaline solution. Conversely, sulphides will be oxidized in aerobic waters to sulphate and sulphuric acid yielding an acidic solution. The final pH of the solution depends on the ratio of alkaline metal to sulphate concentration in ash pond effluent (26). Metallic cations will precipitate as ash due to the high silica and alumina content of the ash (49). No results of this experimentation were presented in their report.

The possibility of mixing fly ash sluice water and coal pile drainage has also been investigated. Figure 14 illustrates the titration curve for an alkaline fly ash slurry with coal pile drainage while Figure 15 shows a titration curve for neutral fly ash slurry (14). By combining either alkaline or neutral fly ash sluice water in the proper volumetric ratio, the pH of the resulting combined waste can, in theory, be controlled. In practice, because the fly ash sluice water is a continuous effluent, while coal pile runoff is intermittent, it may be difficult to maintain the proper ratio of the two wastewater streams. Further, as shown in the figures, the final pH of the mixture also depends on the fly ash concentration in the slurry.

Figure 16 shows the relationship between the concentrations of dissolved metals and pH in the coal pile runoff. The effect of dilution was taken into consideration in the calculation of the dissolved metal concentration. The prime removal mechanism for metals was found to be precipitation as metal hydroxides. The significance of this figure is that it shows that the trace metals such as copper, iron, manganese, nickel and zinc in the coal pile drainage can be effectively removed in alkaline ash solutions at the optimal pH values (14).

The authors suggested that other trace metals that exist in significant concentrations in coal pile drainage such as beryllium, cadmium and chromium will also be removed at the optimum pH values. The optimum pH values can be selected by using an alkaline ash pond, by controlling the ash concentration during sluicing, maintaining the correct volumetric ratio of coal pile drainage to ash sluice water, or by choosing a suitable retention time in the ash pond. Concentrations of some trace metals such as

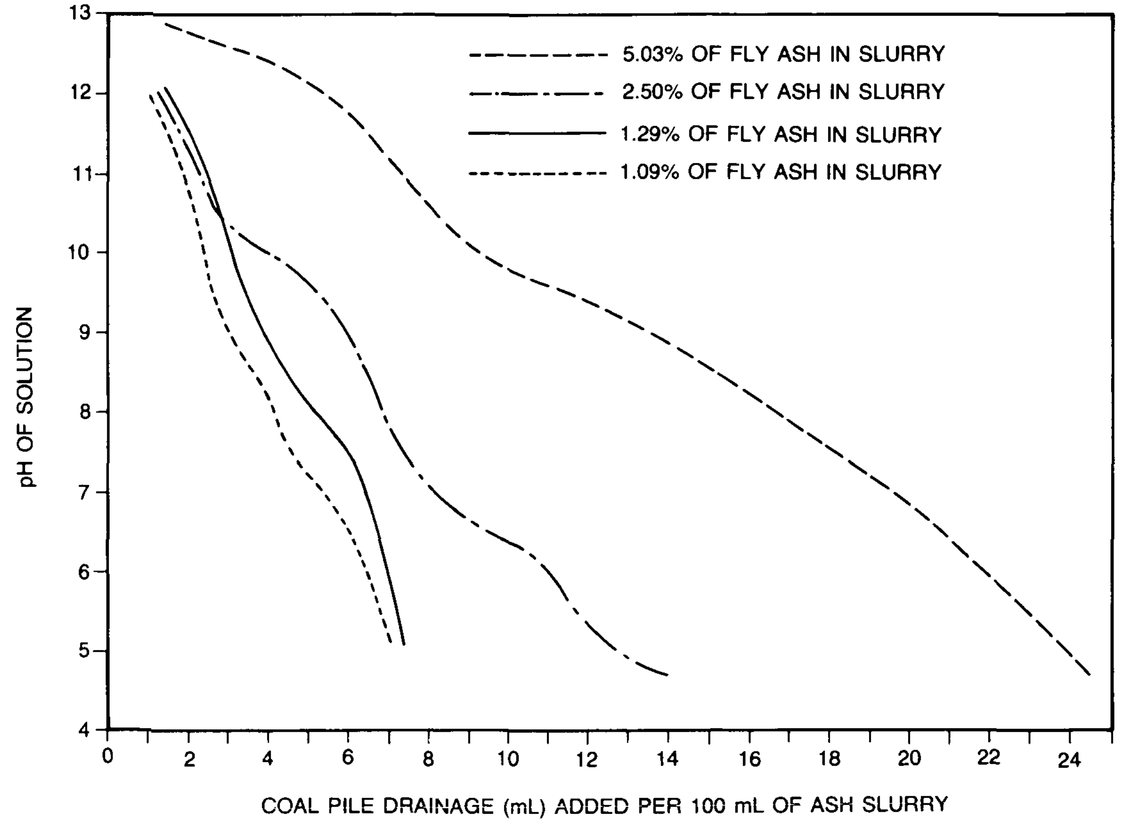

FIGURE 14 TITRATION CURVES FOR ALKALINE FLY ASH SLURRY WITH COAL PILE DRAINAGE (14)

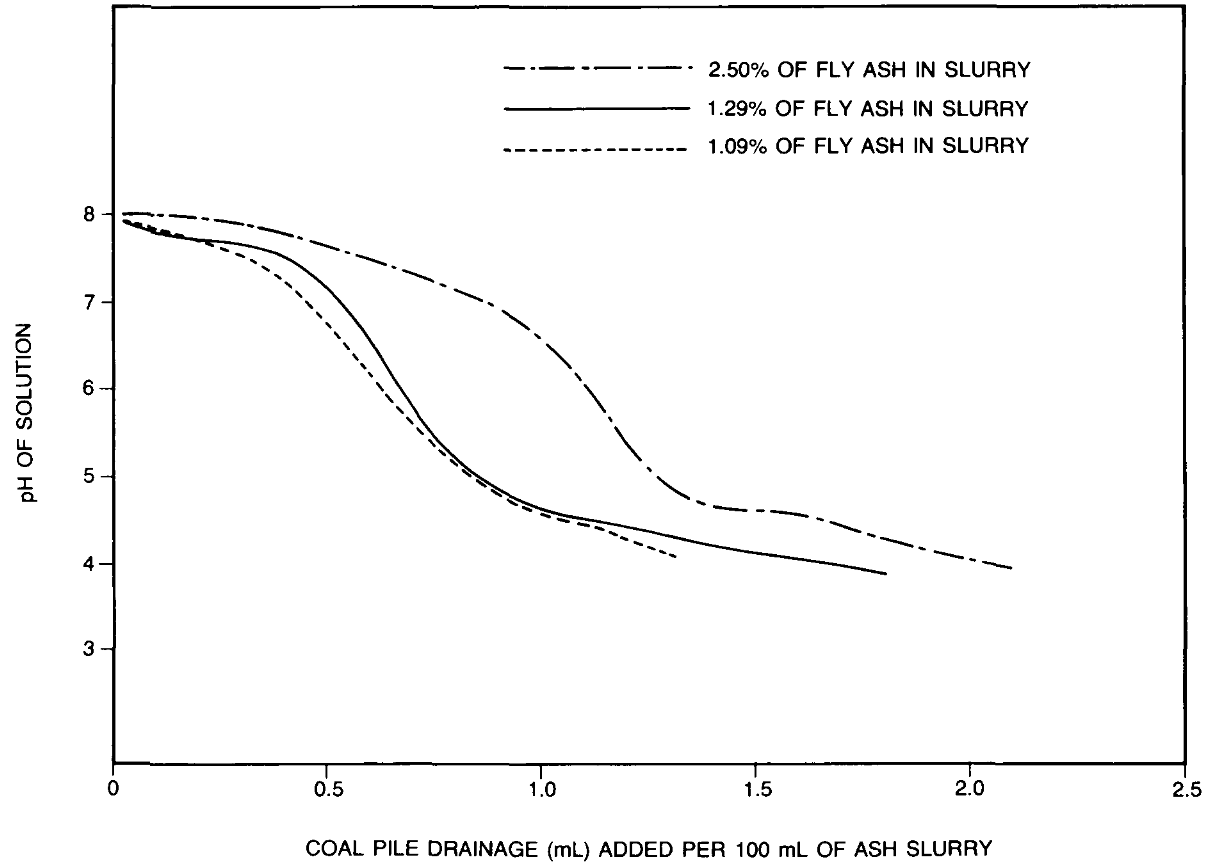

FIGURE 15 TITRATION CURVES FOR NEUTRAL FLY ASH SLURRY WITH COAL PILE DRAINAGE (14)

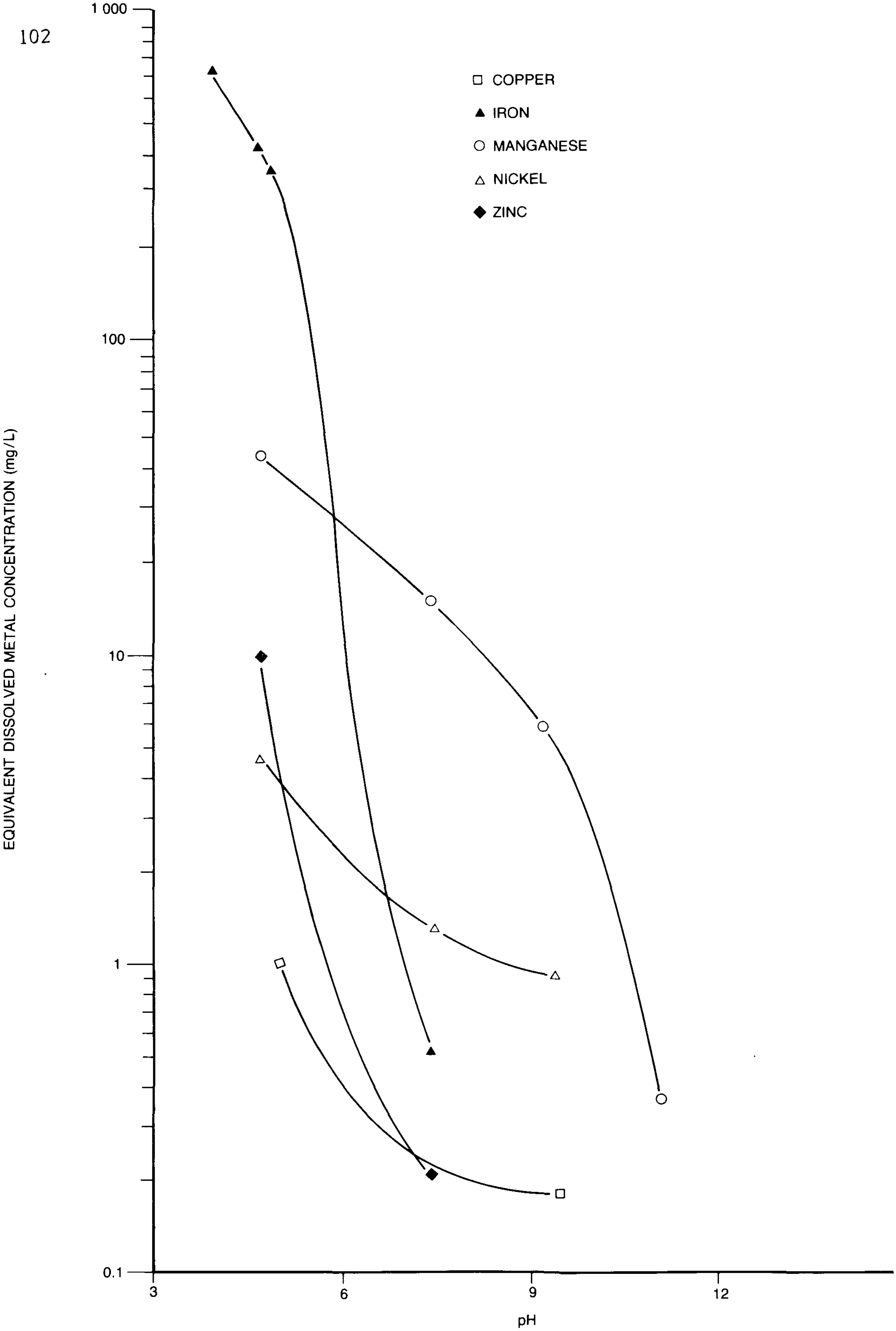

FIGURE 16 pH EQUIVALENT DISSOLVED METAL CONCENTRATION (14) arsenic and selenium are not functions of pH. Their removal by co-precipitation and adsorption in the ash pond is not well understood (14).

The effect of retention time was also evaluated in this study as the pH of the mixture of coal pile drainage and sluice water was observed to change with time. Testing showed that about 28 hours was required to change the pH of the solution from 4.35 to 7.0. This interval exists because the alkaline metal oxides dissolve continuously from the ash, and CO_2 from the air enters the solution. The change in pH may not occur if the fly ash does not contain alkaline metal hydroxides which can yield hydroxide ions to the solution.

Treatment of coal pile drainage by blending with fly ash pond supernatant was reported by Weeter (29). This technique was reported as quite effective in controlling problems caused by pH, total iron and total suspended solids. However, heavy metals and organics were not studied.

6.2 Feasibility of Blending Coal Pile Drainage with Ash Sluice Water at a Canadian Generating Station

It may be possible to blend coal pile drainage with ash sluice water to provide a convenient means of disposing of acidic coal pile drainage and eliminating the need for a treatment plant for this waste stream in some cases. In others, ash sluice water might be used to help neutralize coal pile drainage, and reduce the use of chemicals for pH adjustment of the wastewater.

The blending of coal pile drainage with ash slurry water was evaluated using slurries of bottom and fly ash and coal pile drainage from the Lakeview Generating Station. The slurries were prepared by mixing fly and bottom ash with deionized water to produce 0.5, 1.0 and 2.0 percent by weight fly ash slurries, and 2.0, 5.0 and 10.0 percent by weight bottom ash slurries.

Figure 17 shows the titration curve for the bottom ash slurries, and Figure 18 shows the titration curve for fly ash slurries. Because of the acidic nature of the coal pile drainage, it could be added to the alkaline slurries of fly and bottom ash to produce a mixture with a neutral pH. For example, 15 mL of coal pile drainage could be added to 100 mL of a 2.0 percent fly ash sluice water mixture, producing a mixture with a pH of 7.0. Thus a ratio of coal pile drainage to 2.0 percent fly ash slurry of 15:100 could be used to form a neutral mixture. Similar results could be achieved using bottom ash slurries; however, the ratio for coal pile drainage to a 2.0 percent slurry of bottom ash was determined to be 2.5:100.

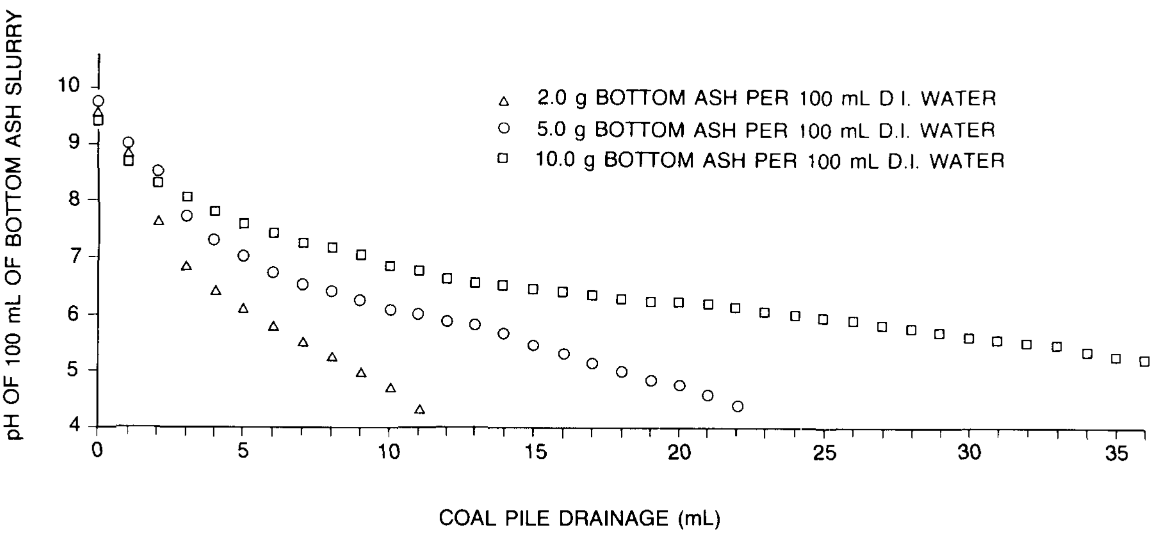

FIGURE 17 TITRATION CURVE OF BOTTOM ASH SLURRY AND COAL PILE DRAINAGE - LAKEVIEW G.S.

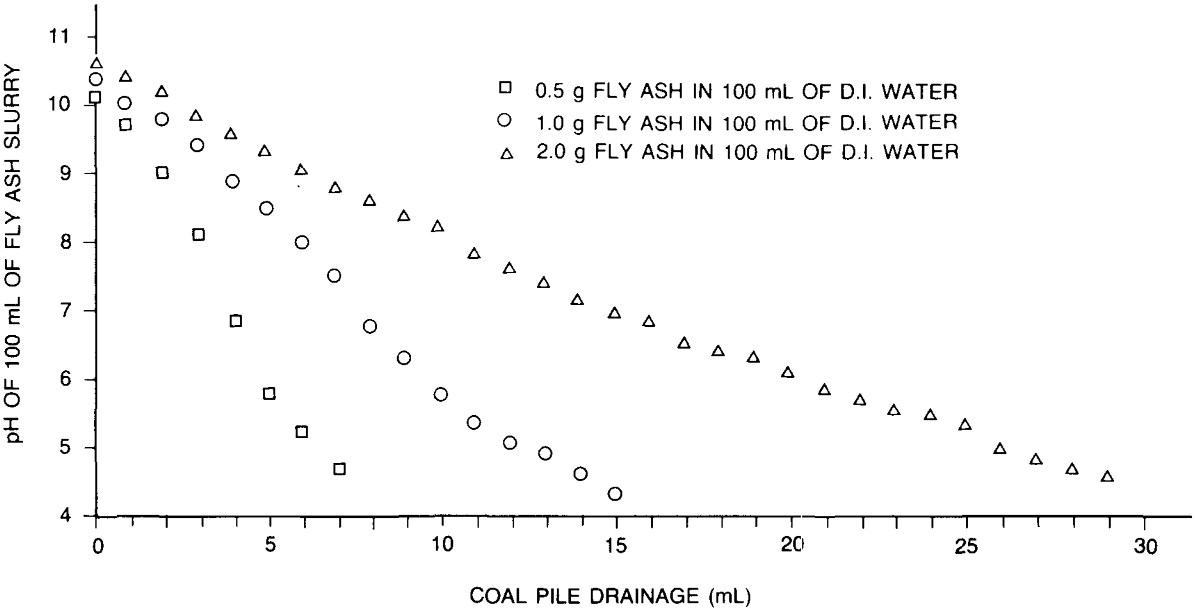

FIGURE 18 TITRATION CURVE OF FLY ASH SLURRY AND COAL PILE DRAINAGE - LAKEVIEW G.S.

Table 56 shows the effect of blending coal pile drainage with simulated ash sluice water from Lakeview Generating Station on the concentrations of metals in the mixture. The simulated fly ash sluice water was prepared by mixing 1 g of fly ash with 100 mL of deionized water. To this was added 8 mL of coal pile drainage yielding a mixture with a pH of 6.9 after 30 minutes of settling. In addition to the neutralization of the coal pile drainage there was some removal of the metals in the mixed solution. About 17 percent of the copper, 69 percent of the iron, and 38 percent of the zinc were removed as a result of mixing the two waste streams.

A similar experiment was completed using 5 g of bottom ash in 100 mL of deionized water to prepare a simulated bottom ash slurry. The results of the addition of 8 mL of coal pile drainage are also shown in Table 56. The pH of the blended wastewaters was 7.0. In addition to neutralization of the coal pile drainage, there were reductions of 60 percent in the copper concentration, 56 percent in iron and 36 percent in zinc.

The blending of fly ash and bottom ash sluice water with coal pile drainage from Lingan Generating Station was also considered. However, since the bottom ash sluice water had a pH of 3.5 and the fly ash sluice water had a pH of 3.2, neutralization of either of the ash slurries with the coal pile drainage would not be possible.

This work verified the work of Cox et al (14) in the United States. When alkaline ash sluice water streams are formed by the hydraulic transport of either bottom or fly ash, acidic coal pile drainage can be added to produce a mixture with a neutral pH. A higher ratio of coal pile drainage to fly ash sluice waters is required because fly ash streams tend to be more alkaline than those produced by sluicing bottom ash.

TABLE 56 EFFECT OF BLENDING COAL PILE DRAINAGE AND SIMULATED ASH SLUICE WATER - LAKEVIEW G.S.

	FLY ASH					BOTTOM ASH				
Parameter	Untreated Coal Pile Drainage	Simulated Sluice Water (a)	Unsettled Mixture (b)	Settled Mixture (c)	Removal (%)	Untreated Coal Pile Drainage	Simulated Sluice Water (d)	Unsettled Mixture (e)	Settled Mixture (f)	Removal (%)
pH	2.8	10.5	-	6.9	-	2.8	9.6	-	7.0	-
Chromium	<0.05	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05	-
Copper	0.41	0.03	0.06	0.05	17	0.41	0.02	0.05	0.02	60
Iron	49	2.52	5.96	1.82	69	49	1.26	4.8	2.1	56
Nickel	0.3	<0.1	<0.1	<0.1	-	0.3	<0.1	<0.1	<0.1	-
Zinc	0.81	0.11	0.16	0.10	38	0.81	0.06	0.11	0.07	36

Note: All analyses in mg/L except pH

(a) 1 g fly ash per 100 mL of deionized water.
(b) 1 g fly ash per 100 mL of deionized water and 8 mL of coal pile drainage.
(c) 1 g fly ash per 100 mL of deionized water and 8 mL of coal pile drainage following 30 minutes of settling.
(d) 5 g bottom ash per 100 mL of deionized water.
(e) 5 g bottom ash per 100 mL of deionized water and 8 mL of coal pile drainage.
(f) 5 g bottom ash per 100 mL of deionized water and 8 mL of coal pile drainage following 30 minutes of settling.

7 CONCLUSIONS AND RECOMMENDATIONS

A primary objective of these investigations was to illustrate characteristics and treatability of drainage from coal piles at Canadian steam electric generating stations and coke piles at Canadian steel mills. Based on a review of the technical literature, a selective field sampling and comprehensive analytical program and bench-scale treatatility studies, a number of conclusions and recommendations can be made.

7.1 Conclusions

1) The drainage samples from the coal piles at the Canadian steam electric generating stations in this study would not meet the effluent criteria used in this study if discharged. In order to achieve these, some form of treatment would be required.
2) The coal pile drainage samples from the eastern Canadian generating stations were highly acidic and contained excessive concentrations of dissolved iron and other metals.
3) The coal pile drainage samples from the western Canadian generating stations were more neutral in pH but also contained excessive concentrations of dissolved metals and tended to contain more suspended solids, consisting primarily of coal fines flushed from the coal stockpiles.
4) The drainage samples from coke piles at the Canadian steel mills in this study were characteristically slightly alkaline and generally contained significantly lower concentrations of inorganic and organic contaminants than the coal pile drainage samples.
5) Analyses completed during this study indicated that measurable amounts of base neutral extractable trace organics could be present in coal pile drainage from both eastern and western sites, and to a lesser extent in coke pile drainage. However, further investigation and refinement of analytical techniques is required to confirm the presence of these organic compounds.
6) The coal pile drainage samples collected for this study could be successfully treated to meet the criteria established for this study using relatively simple physical-chemical treatment technology.
7) Based on testing of an eastern coal pile drainage sample, the most cost-effective treatment involved pH adjustment using lime and the addition of an anionic polyelectrolyte as a coagulant aid.

8) Successful treatment of the western coal pile drainage samples involved the addition of either calcium chloride or lime as a primary coagulant. In some instances, an anionic polyelectrolyte was required to improve the settling properties of the particulates. The most cost-effective treatment method depends on the characteristics of the specific coal pile drainage.

9) Data indicated that several base neutral extractables, specifically the phthlate esters, were present in higher concentrations in the treated effluents than in the raw samples. It is possible that this increase was due to the method of treatment applied to the coal pile drainage samples, sample contamination, analytical procedures or other factors.

10) Bench-scale studies suggested that in situations where acidic coal pile drainage and alkaline ash slurry waters are present at a generating station, they can be blended to produce a mixture of neutral pH. This blending reduced the concentration of dissolved metals. Despite the operational problems associated with such a disposal scheme, it appears to be a feasible alternative to conventional treatment and discharge for coal pile drainage water.

7.2 Recommendations

Based on this study the following recommendation is made:

- The potential adverse environmental consequences of the discharge of untreated coal pile drainage to a receiving water body can be significantly reduced by technically feasible treatment methods; viable methods for the disposal of the wastewater by blending with other waste streams have been demonstrated and the direct reuse of the effluent for dust suppression on the coal pile is practicable. However, the physical-chemical treatment methods demonstrated during this study did not significantly reduce the concentrations of non-amphoteric elements such as arsenic and boron. Identification and optimization of treatment technology for the removal of elements of this nature from coal pile drainage is necessary.

During the study several areas of concern with respect to coal pile drainage which were outside the terms of reference of the study were identified. These were:

- The volumes of coal pile drainage were not estimated as part of this study. However, they are expected to be site-specific and related to coal supply, coal type, pile management and climatic conditions. Quantification of coal pile drainage is required to assess the mass loadings of this discharge and its significance at individual sites.

- The behaviour of coal piles during winter and spring thaw conditions should be investigated to more fully understand seasonal changes in coal pile discharges.
- It is likely that there will be increased use of lignite coals for generation of electricity in Canada. Discharge samples from lignite coal piles were not examined as part of this study. These coals are known to contain relatively high levels of boron and other elements. Although this coal will be utilized primarily in the more arid regions of Canada, it is possible that highly contaminated runoffs from such piles may occur during spring runoff. This should be investigated and suitable treatment methods demonstrated.
- It has been documented in the literature that radioactive substances are present in coal. Coal piles in Canada should be monitored for radionuclides to ascertain the extent of the presence of these radioactive substances in coal pile drainage.

In addition to these areas of concern relating directly to the study, other problem areas which were identified during this investigation include:

- The analytical procedures for determining trace organics on the U.S. Environmental Protection Agency priority pollutants list appear to be deficient for quantification of several trace organics, particularly nitrophenols of the acid extractable group. Further sampling and analysis should be conducted to verify the existing data and improved methods to analyze for organic contaminants in wastewaters of this type should be developed.
- Certain base neutral extractables, specifically phthlate esters, were indicated to be in higher concentrations in certain treated samples than in raw samples. Investigations should be conducted to confirm their presence and identify whether increases in the concentrations of some trace organics are associated with the method of treatment.

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APPENDIX I

TRACE ORGANIC CONTAMINANTS FROM THE U.S. EPA PRIORITY POLLUTANTS LIST

APPENDIX I TRACE ORGANIC CONTAMINANTS FROM THE U.S. EPA PRIORITY POLLUTANTS LIST

Trace organic contaminants from the U.S. Environmental Protection Agency's priority pollutants list and their detection limits are shown below (39).

ACID GROUP (Detection Limit 25 µg/L except where indicated otherwise):

p-Chloro-m-cresol
2-Chlorophenol
2,4-Dichlorophenol
2,4-Dimethylphenol
4,6-Dimethylphenol
4,6-Dinitro-o-cresol
2,4-Dinitrophenol (250 µg/L)
2-Nitrophenol
4-Nitrophenol
Pentachlorophenol
Phenol
2,4,6-Tricholorophenol

BASE NEUTRAL GROUP (Detection Limit 10 µg/L):

Polynuclear Aromatics:

Acenaphthene
Acenaphthylene
Anthracene
Benzo (a) anthracene
Benzo (b) fluoranthene
and/or
Benzo (k) fluoranthene
Benzo (ghi) perylene
Benzo (a) pyrene
Chrysene
Dibenzo (ah) anthracene
Fluoranthene
Fluorene
Indeno (1, 1 2-cd) pyrene
Naphthalene
Phenanthrene
Pyrene

Chlorinated Benzenes:

1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
1,2,4-Trichlorobenzene
Hexachlorobenzene

Nitrosamines:

N-nitrosodimethylamine
N-nitrosodiphenylamine
N-nitrosodi-n-propylamine

Phthalate Esters:

Butylbenzylphthalate
Di-n-butylphthalate
Diethylphthalate
Dimethylphthalate
Di-n-octylphthalate
bis-(2-ethylhexyl) phthalate

Haloethers:

4-Bromophenyl phenyl ether
bis(2-Chloroethoxy) methane
bis(2-Chloroethyl) ether
bis(2-Chloroisopropyl) ether
4-Chlorophenyl phenyl ether

Other Compounds:

Benzidine
2-Chloronaphthalene
3,3'-Dichlorobenzidine
2,4-Dinitrotoluene
2,6-Dinitrotoluene
1,2-Diphenylhydrazine
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Isophorone
Nitrobenzene

PESTICIDE GROUP (Detection Limit 10 μg/L):

Aldrin
alpha-BHC
beta-BHC
gamma-BHC (Lindane)
delta-BHC
Chlordane
4,4'-DDD
4,4'-DDT
alpha-Endosulfan
Endosulfan sulphate
Endrin
Endrin Aldehyde
Heptachlor
Heptachlor Epoxide
PCB'S
Toxaphene
Dieldrin
4,4'-DDE

APPENDIX II

PRECIPITATION AND TEMPERATURE DATA

APPENDIX II PRECIPITATION AND TEMPERATURE DATA

This appendix contains precipitation and temperature data for one month preceding sampling at each of the sampling locations. Data from the nearest Atmospheric Environment Weather Station is presented where on-site weather data was not available.

Sampling Site	Date of Sampling	Weather Data Reported
Lingan Generating Station	July 22, 1980	Sydney, N.S.
Lingan Generating Station	August 19, 1980	Sydney, N.S.
Dalhousie Generating Station	August 13, 1980	Charlo, N.B.
Lakeview Generating Station	July 29, 1980	Lakeview Water Treatment Plant, Mississauga, Ontario.
Lakeview Generating Station	September 2, 1980	Lakeview Water Treatment Plant, Mississauga, Ontario.
Algoma Steel Limited	July 29, 1980	Sault Ste. Marie, Ontario.
Stelco Canada	September 13, 1980	Texaco Nanticoke, Ontario.
Battle River Generating Station	August 7, 1980	On-site weather Station.
Milner Generating Station	August 8, 1980	On-site weather Station.

TABLE II-1 LINGAN GENERATING STATION, SYDNEY, N.S., JUNE, 1980*

	Temperature (°C)			Relative Humidity (%)		Precipitation (mm)	Average Wind (km/h)
Date	Max.	Min.	Mean	Max.	Min.		
1	19.4	9.2	14.3	100	62	3.6	23.3 SSW
2	18.6	4.8	11.7	100	68	0.8	23.5 N
3	8.1	0.7	4.4	93	71	0.2	21.1 N
4	9.8	0.7	5.3	100	66		10.8 N
5	7.7	5.0	6.4	100	81	0.2	19.3 N
6	8.5	4.3	6.4	93	81		31.1 N
7	12.3	4.4	8.4	93	62	TR	17.8 N
8	22.6	5.6	14.1	100	35	6.4	23.0 S
9	18.6	3.1	10.9	100	59	7.2	27.6 SSW
10	14.2	2.4	8.3	100	44		25.0 S
11	19.7	6.5	13.1	100	37	0.8	21.2 SW
12	17.4	6.6	12.0	87	39	TR	16.8 W
13	22.3	5.9	14.1	87	33		21.5 SW
14	25.7	9.7	17.7	94	33		29.4 SSW
15	19.5	10.5	15.0	100	88	12.2	17.3 S
16	17.1	5.4	11.3	100	71	1.0	26.9 W
17	16.2	3.8	10.0	87	41		13.1 W
18	16.2	1.6	8.9	87	48		14.7 SE
19	17.7	5.4	11.6	100	46	5.0	17.3 SSW
20	15.2	6.4	10.8	100	71	4.2	18.0 N
21	16.0	6.4	11.2	100	88	2.4	16.8 S
22	19.1	9.1	14.1	94	64		20.7 SW
23	21.0	8.0	14.5	100	60		7.3 SSW
24	27.2	8.5	17.9	93	42		12.8 SW
25	25.2	13.8	19.5	88	54	TR	10.4 SW
26	31.5	14.5	23.0	88	43		18.2 SSW
27	22.3	14.7	18.5	94	77	0.8	22.3 SSW
28	17.3	7.9	12.6	81	45	0.6	30.5 W
29	18.6	7.3	13.0	76	37		22.6 W
30	15.0	8.6	11.8	100	63	32.2	15.0 SW
Mean	18.0	6.7	12.4	94.5	57.0	77.6 (total)	19.9 SW

* Data from AES, Environment Canada, Weather Station at Sydney "A", N.S., Monthly Meteorological Summary.

TABLE II-2 LINGAN GENERATING STATION, SYDNEY, N.S., JULY, 1980*

	Temperature (°C)			Relative Humidity (%)		Precipitation (mm)	Average Wind (km/h)
Date	Max.	Min.	Mean	Max.	Min.		
1	11.9	8.8	10.4	100	93	TR	17.0 NNW
2	14.8	10.0	12.4	94	72	1.8	10.6 SSE
3	20.8	12.3	16.6	100	64	0.8	18.0 SW
4	25.4	9.1	17.3	100	57		14.8 SW
5	24.2	8.3	16.3	100	29		10.6 S
6	16.2	9.3	12.8	100	87	5.4	12.2 SE
7	15.7	8.8	12.3	94	72	TR	23.0 SW
8	17.4	9.3	13.4	94	55	0.2	19.2 WNW
9	14.7	10.6	12.7	100	88	18.4	19.8 SE
10	16.7	8.2	12.5	100	72	0.4	15.3 W
11	18.5	7.7	13.1	100	72	0.4	14.8 SSE
12	13.4	10.9	12.2	100	94	5.0	15.0 ESE
13	21.0	11.1	16.1	100	53	36.6	16.9 ESE
14	19.0	10.8	14.9	100	64		15.6 W
15	23.6	10.9	17.3	100	56	0.8	20.8 SW
16	23.7	14.4	19.1	100	83	2.4	19.3 SW
17	24.9	14.1	19.5	100	73	7.2	12.6 S
18	20.1	10.6	15.4	100	88		13.6 SW
19	25.6	10.7	18.2	100	47		14.4 W
20	24.6	14.4	19.5	100	57	TR	14.2 SW
21	26.1	14.4	20.3	100	65		6.4 ESE
22	23.9	14.0	19.0	100	73	TR	10.5 S
23	27.9	14.6	21.3	100	66	0.2	20.1 W
24	24.4	14.0	19.2	100	69		9.0 SW
25	15.8	13.8	14.8	100	100	7.1	19.9 NNE
26	27.5	14.1	20.8	100	45		22.0 WNW
27	20.3	13.0	16.7	100	68		7.5 NE
28	27.3	11.6	19.5	100	58		8.2 S
29	26.7	14.5	20.6	100	57	1.8	15.0 S
30	23.7	18.4	21.1	100	83	3.0	26.2 S
31	27.8	15.1	21.5	100	62		19.6 SW
Mean	21.4	11.9	16.7	99.4	68.5	91.5 (total)	15.5 SW

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* Data from AES, Environment Canada, Weather Station at Sydney "A", N.S., Monthly Meteorological Summary.

TABLE II-3 LINGAN GENERATING STATION, SYDNEY, N.S., AUGUST, 1980*

	Temperature (°C)			Relative Humidity (%)			
Date	Max.	Min.	Mean	Max.	Min.	Precipitation (mm)	Average Wind (km/h)
1	27.4	14.7	21.1	100	51		19.8 SW
2	28.5	15.9	22.2	100	45	1.2	10.5 SW
3	23.7	14.2	19.0	100	73	2.6	10.8 SSE
4	26.7	16.2	21.5	100	70	24.2	12.9 WSW
5	24.7	13.0	18.9	100	73	10.0	7.8 NE
6	21.1	13.3	17.2	100	68	0.4	8.2 N
7	19.0	15.4	17.2	100	94	3.6	13.0 SSE
8	26.3	17.5	21.9	100	61	2.4	14.6 WSW
9	24.0	16.0	20.0	100	65	1.8	14.1 SSW
10	20.2	13.5	16.9	94	68	0.4	27.3 SW
11	20.0	12.7	16.4	100	73		11.8 NW
12	22.3	12.4	17.4	100	64	26.0	15.1 SSW
13	16.7	14.0	15.4	100	94	1.8	18.3 ENE
14	19.0	12.7	15.9	94	68	0.2	17.0 NW
15	17.2	12.7	15.0	100	94	11.7	14.6 SSE
16	23.8	13.1	18.5	100	64	0.6	13.9 WSW
17	14.1	6.4	10.3	100	72	5.4	31.6 N
18	18.4	6.8	12.6	93	52		9.9 WSW
19	19.7	6.7	13.2	100	56		7.8 ESE
20	21.4	8.6	15.0	94	49		8.9 WSW
21	25.2	10.2	17.7	100	30		14.3 WSW
22	25.3	10.0	17.7	100	38		12.1 WSW
23	26.3	10.0	18.2	94	34		11.7 SW
24	21.2	12.8	17.0	88	68		23.3 N
25	17.4	9.6	13.5	94	68		21.0 N
26	20.9	7.0	14.0	100	56		5.8 S
27	22.8	13.0	17.9	100	78	0.4	10.8 SW
28	19.7	9.7	14.7	100	59	4.4	16.3 W
29	20.0	8.4	14.2	93	40		20.1 NW
30	20.5	7.3	13.9	93	46		13.7 WSW
31	23.3	9.5	16.4	100	69	0.2	22.5 SSW
Mean	21.8	11.7	16.8	98.0	62.6	97.3 (total)	14.8 WSW

* Data from AES, Environment Canada, Weather Station at Sydney "A", N.S., Monthly Meteorological Summary.

TABLE II-4 DALHOUSIE GENERATING STATION, CHARLO, N.B., JULY, 1980*

Date	Temperature (°C)			Relative Humidity (%)		Precipitation (mm)	Average Wind (km/h)
	Max.	Min.	Mean	Max.	Min.		
1	22.1	7.4	14.8	97	43		9.5 ENE
2	17.9	11.1	14.5	96	81	0.9	8.4 E
3	23.7	9.0	16.4	93	35		8.8 WSW
4	22.5	8.5	15.5	95	24		18.6 W
5	23.6	6.2	14.9	91	36	5.1	12.5 Svrl
6	14.3	9.8	12.1	100	82	71.1	17.0 NNW
7	16.0	6.3	11.2	95	55	3.0	14.8 NW
8	16.2	3.4	9.8	98	73	1.4	10.8 E
9	14.8	11.7	13.3	100	94	8.1	6.0 E
10	20.1	10.8	15.5	100	72	0.4	13.1 E
11	19.1	12.7	15.9	100	68	1.0	11.2 E
12	15.8	13.3	14.6	100	94	24.7	16.6 E
13	15.7	12.5	14.1	100	94	31.4	8.4 W
14	23.4	12.3	17.9	100	61	2.6	10.7 W
15	24.0	15.6	19.8	100	73	7.0	9.6 WSW
16	24.9	11.8	18.4	94	36		12.8 WSW
17	20.7	9.9	15.3	94	64	1.8	7.5 E
18	26.6	11.8	19.2	100	44	0.4	10.3 W
19	27.0	11.3	19.2	94	39		10.9 W
20	23.7	15.4	19.6	100	78	5.4	6.4 E
21	29.6	15.5	20.1	100	73	1.4	10.3 ENE
22	19.3	15.6	17.5	100	88	1.2	8.5 E
23	20.5	16.0	18.3	100	83	5.4	2.9 E
24	26.3	13.8	20.1	100	45	0.4	8.4 Svrl
25	24.6	13.0	18.8	100	65		7.8 ENE
26	24.1	9.4	16.8	94	33	1.0	12.4 W
27	20.9	7.9	14.4	93	64		12.0 E
28	19.5	15.4	17.5	100	82	4.9	9.1 E
29	24.9	14.1	19.5	100	61		9.3 E
30	23.5	17.6	20.6	100	78	24.8	7.5 E
31	25.0	16.9	21.0	94	61	3.0	15.5 WSW
Mean	21.5	11.8	16.7	98	54	206.4 (total)	10.6 E

* Data from AES, Environment Canada, Weather Station at Charlo (A) (YCL), N.B., Monthly Meteorological Summary.

TABLE II-5 DALHOUSIE GENERATING STATION, CHARLO, N.B., AUGUST, 1980*

Date	Temperature (°C)			Relative Humidity (%)		Precipitation (mm)	Average Wind (km/h)
	Max.	Min.	Mean	Max.	Min.		
1	30.0	17.6	23.8	94	43		17.5 W
2	23.0	16.6	19.8	100	73	0.9	16.9 E
3	19.1	16.8	18.0	100	88	10.8	12.2 E
4	24.9	16.4	20.7	100	65	6.4	10.8 W
5	25.3	14.9	20.1	100	50		11.2 SW
6	20.2	15.5	17.9	100	88	TR	9.8 E
7	24.2	17.1	20.7	100	74	20.4	4.8 W
8	27.4	15.5	21.5	94	54	7.4	8.4 WSW
9	24.2	13.7	19.0	100	56	20.9	18.5 W
10	20.3	13.2	16.8	94	68		19.4 W
11	25.3	12.1	18.7	94	44		11.3 WSW
12	18.7	13.0	15.9	100	77	4.0	4.0 Svrl
13	16.7	13.7	15.2	100	94	3.1	3.7 W
14	19.5	12.5	16.0	100	73	1.4	12.5 E
15	16.6	14.1	15.4	100	94	25.3	12.8 E
16	19.9	11.2	15.6	100	59	18.4	12.6 W
17	23.0	9.8	16.4	88	47		14.9 WSW
18	25.3	11.0	18.2	94	47		10.1 W
19	19.5	14.8	17.2	94	78	2.2	12.1 E
20	20.7	11.2	16.0	100	64		8.9 E
21	25.6	9.4	17.5	100	50		7.3 SW
22	27.0	12.4	19.7	100	39		8.8 W
23	28.7	13.3	21.0	88	40		15.0 WSW
24	25.7	15.4	20.6	94	61		15.5 E
25	20.4	14.9	17.7	100	83	1.2	5.2 E
26	25.9	16.3	21.1	100	65		4.9 Svrl
27	24.8	13.9	19.4	94	50	1.4	14.1 W
28	21.1	9.0	15.1	100	40		14.7 W
29	21.3	7.4	14.4	93	38		14.9 W
30	24.7	5.8	15.3	94	38		7.8 W
31	21.4	11.4	16.4	100	78	3.4	6.4 WSW
Mean	22.9	13.2	18.1	97	62	127.2 (total)	10.9 W

* Data from AES, Environment Canada, Weather Station at Charlo (A) (YCL), N.B., Monthly Meteorological Summary.

TABLE II-6 LAKEVIEW GENERATING STATION, MISSISSAUGA, ONTARIO, JUNE, 1980*

Date	Temperature (°C)		Precipitation (mm)
	Maximum	Minimum	
1	18.0	9.0	12.2
2	19.0	8.5	3.6
3	21.0	12.0	6.0
4	20.8	12.5	
5	16.0	9.5	
6	16.0	10.2	2.4
7	17.0	12.0	9.7
8	14.0	9.0	
9	15.0	5.0	
10	12.5	5.5	
11	18.0	8.0	
12	16.0	9.5	
13	25.0	9.0	
14	24.0	11.0	11.0
15	20.0	14.0	
16	15.5	8.0	
17	16.5	6.0	
18	21.0	11.5	1.8
19	17.0	11.0	25.0
20	20.0	11.0	
21	25.0	9.5	
22	21.0	12.0	
23	27.0	12.0	
24	27.0	14.0	
25	30.0	14.0	
26	31.5	17.0	
27	24.0	16.0	
28	16.0	10.5	9.8
29	18.0	11.0	8.8
30	21.0	13.0	
Mean	20.1	10.7	90.3 (Total)

* Data from Lakeview Water Treatment Plant, Mississauga, Ontario.

TABLE II-7 LAKEVIEW GENERATING STATION, MISSISSAUGA, ONTARIO, JULY, 1980*

Date	Temperature (°C)		
	Maximum	Minimum	Precipitation (mm)
1	23.0	13.0	2.6
2	25.0	15.0	
3	23.0	12.0	
4	25.5	14.0	
5	29.0	16.0	
6	24.0	13.0	
7	22.0	12.0	10.0
8	28.0	14.0	
9	20.0	15.0	
10	26.0	13.2	
11	28.6	16.2	
12	28.5	13.8	
13	24.5	14.5	
14	26.0	15.5	1.0
15	29.5	16.5	24.0
16	29.0	21.0	
17	28.0	21.5	
18	24.0	18.0	
19	31.0	17.5	
20	27.0	17.0	13.0
21	29.0	18.0	1.2
22	22.0	15.0	3.8
23	26.0	11.0	
24	26.0	15.0	
25	30.0	17.0	
26	22.0	17.0	1.2
27	20.0	16.5	3.4
28	21.0	18.0	27.2
29	22.5	18.0	41.0
30	26.5	17.0	
31	22.0	15.0	
Mean	25.4	15.7	128.4 (Total)

* Data from Lakeview Water Treatment Plant, Lakeview, Ontario.

TABLE II-8 LAKEVIEW GENERATING STATION, MISSISSAUGA, ONTARIO, AUGUST, 1980*

	Temperature (°C)		
Date	Maximum	Minimum	Precipitation (mm)
1	29.5	20.5	
2	26.0	20.0	
3	26.5	19.0	
4	23.3	14.6	
5	28.0	20.5	
6	30.0	21.5	
7	29.0	21.0	
8	29.0	20.0	
9	26.6	21.0	
10	21.0	15.5	
11	21.4	17.0	20.0
12	26.0	17.0	
13	22.0	15.0	
14	28.0	19.0	3.6
15	23.0	17.0	
16	25.0	14.0	
17	24.0	14.5	
18	22.0	18.0	
19	24.0	17.0	
20	22.5	18.0	
21	22.0	19.5	
22	22.0	20.0	
23	25.0	18.0	
24	26.0	17.0	
25	25.5	17.0	
26	28.0	15.0	
27	31.5	20.5	2.0
28	20.0	17.0	1.1
29	22.0	18.0	
30	23.6	19.0	12.0
31	27.0	20.6	28.0
Mean	25.1	18.1	66.7 (Total)

* Data from Lakeview Water Treatment Plant, Mississauga, Ontario.

TABLE II-9 LAKEVIEW GENERATING STATION, MISSISSAUGA, ONTARIO, SEPTEMBER, 1980*

	Temperature (°C)		
Date	Maximum	Minimum	Precipitation (mm)
1	28.0	21.6	1.4
2	24.5	18.0	3.2
3	23.0	15.0	
4	24.0	13.0	
5	26.5	19.5	
6	25.0	16.0	
7	24.0	13.0	
8	20.5	15.0	
9	26.0	16.0	3.4
10	20.0	11.0	
11	25.0	12.0	
12	18.0	11.0	
13	17.0	11.0	11.0
14	22.5	14.0	TR
15	16.5	10.0	
16	17.5	10.0	1.0
17	21.0	8.0	2.6
18	14.0	5.0	
19	19.5	11.0	
20	25.0	14.5	
21	25.0	16.0	
22	25.5	16.5	16.3
23	17.0	10.0	
24	15.0	2.0	
25	15.5	4.0	2.5
26	11.5	8.5	
27	14.0	2.5	
28	15.0	6.0	
29	14.0	0.0	
30	20.0	8.5	
Mean	20.3	11.3	41.4 (Total)

* Data from Lakeview Water Treatment Plant, Mississauga, Ontario.

TABLE II-10 ALGOMA STEEL LIMITED, SAULT STE. MARIE, ONTARIO, JUNE, 1980*

	Temperature (°C)			Relative Humidity (%)		Precipitation (mm)	Average Wind (km/h)
Date	Max.	Min.	Mean	Max.	Min.		
1	16.5	-0.4	8.1	100	41	1.6	10.8 E
2	13.3	7.3	10.3	100	82	8.2	8.2 W
3	17.6	6.2	11.9	93	68		21.3 W
4	19.9	3.7	11.8	100	40		10.2 W
5	21.8	5.3	13.6	94	41	3.6	11.2 E
6	22.4	8.9	15.7	100	69	0.6	8.5 E
7	13.8	5.4	9.6	100	87	18.9	13.3 E
8	9.3	2.8	6.1	93	43	0.6	21.8 NW
9	8.6	0.0	4.3	93	61	0.2	20.6 NW
10	9.9	-1.4	4.3	93	50		22.5 W
11	16.5	3.4	10.0	93	29		13.5 W
12	24.8	2.7	13.8	93	34	1.0	11.5 E
13	18.9	12.9	15.9	100	72	35.3	11.6 S
14	20.4	10.8	15.6	94	72	6.6	9.3 W
15	15.4	3.5	9.5	93	47		15.2 NNW
16	16.4	1.6	9.0	87	41		10.3 W
17	22.3	5.7	14.0	94	46	0.2	16.5 S
18	15.3	7.3	11.3	87	55		17.3 W
19	14.6	7.6	11.1	94	59	2.8	13.6 NW
20	21.0	6.5	13.8	95	38		18.0 W
21	24.5	4.9	14.7	100	41	0.4	5.6 E
22	28.2	13.2	20.7	94	48	TR	6.7 E
23	31.0	13.8	22.4	94	43		6.3 E
24	32.5	11.7	22.1	100	41		5.5 S
25	32.7	17.0	24.9	88	49	3.0	10.3 SW
26	23.4	13.4	18.4	94	64	0.2	15.0 W
27	20.6	9.6	15.1	100	46		7.3 W
28	14.8	10.5	12.7	100	77	21.0	17.7 E
29	19.1	9.8	14.5	100	73	8.7	13.5 EW
30	21.0	9.2	15.1	100	56		16.3 W
Mean	19.6	7.2	13.4	96	54	112.9 (total)	13.0 W

* Data from AES, Environment Canada, Weather Station at Sault Ste. Marie "A", Ontario, Monthly Meteorological Summary.

TABLE II-11 ALGOMA STEEL LIMITED, SAULT STE. MARIE, ONTARIO, JULY, 1980*

	Temperature (°C)			Relative Humidity (%)		Precipitation (mm)	Average Wind (km/h)
Date	Max.	Min.	Mean	Max.	Min.		
1	19.3	8.9	14.1	94	67	6.9	11.8 W
2	23.9	7.0	15.5	88	31		11.5 W
3	29.0	6.8	17.9	93	37		9.0 S
4	28.8	10.2	19.5	94	52	0.3	9.4 E
5	20.8	9.3	15.1	100	56	2.1	17.3 W
6	24.0	10.1	17.1	100	47		14.0 W
7	23.0	10.7	16.9	100	73	TR	8.0 S
8	21.7	9.7	15.7	94	56		17.9 W
9	26.9	9.7	18.3	94	47		3.5 S
10	27.7	11.9	19.8	100	51		8.2 WNW
11	22.2	9.0	15.6	100	49		15.6 W
12	23.4	6.3	14.9	100	50	TR	4.8 E
13	27.6	10.8	19.2	100	44		5.7 W
14	22.7	14.1	18.4	100	83	17.8	6.1 E
15	24.8	13.1	19.0	100	69	TR	12.1 W
16	22.9	13.2	18.1	100	73	1.2	7.0 E
17	23.8	14.1	19.0	100	56		14.1 W
18	23.7	9.0	16.4	100	61	2.3	5.5 E
19	26.6	15.4	21.0	100	47		8.7 NW
20	24.0	15.7	19.9	94	73	6.1	4.6 E
21	23.7	14.3	19.0	100	61		15.3 W
22	21.9	14.2	18.1	100	68	1.6	15.4 W
23	23.6	10.8	17.2	100	50		14.5 W
24	27.6	9.9	18.8	100	45		10.3 SSW
25	21.6	14.2	17.9	100	73	8.2	9.2 W
26	20.4	9.2	14.8	100	56		7.2 NEW
27	24.4	7.4	15.9	100	57		4.0 W
28	26.8	9.7	18.3	100	47	2.8	6.4 SW
29	21.4	15.3	18.4	100	68		17.5 W
30	27.2	11.7	19.5	100	45		8.0 W
31	28.7	13.4	21.1	100	51	TR	7.8 SE
Mean	24.0	11.1	17.6	98	56	49.3 (total)	10.0 W

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* Data from AES, Environment Canada, Weather Station at Sault Ste. Marie "A", Ontario, Monthly Meteorological Summary.

TABLE II-12 STELCO CANADA, NANTICOKE, ONTARIO, AUGUST, 1980*

Date	Precipitation (mm)
1	
2	10.2
3	2.0
4	
5	5.3
6	
7	TR
8	0.3
9	
10	
11	4.4
12	0.5
13	
14	11.6
15	0.2
16	
17	
18	
19	0.2
20	
21	
22	8.3
23	
24	
25	
26	
27	
28	
29	
30	13.2
31	
Total	56.2

* Data from Nanticoke Texaco, Nanticoke, Ontario.

TABLE II-13 STELCO CANADA, NANTICOKE, ONTARIO, SEPTEMBER, 1980*

Date	Precipitation (mm)
1	1.2
2	32.6
3	0.3
4	
5	
6	
7	
8	
9	1.8
10	0.4
11	
12	
13	53.8
14	12.0
15	
16	3.8
17	4.8
18	0.2
19	
20	0.2
21	0.4
22	17.2
23	0.4
24	
25	10.4
26	
27	
28	
29	
30	
Total	139.5

* Data from Nanticoke Texaco, Nanticoke, Ontario.

TABLE II-14 BATTLE RIVER GENERATING STATION, FORESTBURG, ALBERTA, JULY 1980

Date of Month	Time of Observ-ation	Temperature (°C) Maximum Observed	Minimum Observed	After Reset	Precipi-tation (mm)
3	a.m.	26.5	4.5	12.0	15.2
4	a.m.	24.5	6.5	15.0	4.6
5	a.m.	21.5	7.5	11.0	5.1
6	a.m.	14.5	5.5	12.0	3.4
7	a.m.	23.5	7.0	21.5	0.3
8	a.m.	24.5	6.5	17.0	0.0
9	a.m.	22.0	6.5	17.0	0.0
10	a.m.	24.5	9.0	11.0	0.0
15	a.m.	26.5	5.0	13.5	2.4
18	a.m.	22.0	8.0	15.5	0.0
19	a.m.	18.5	5.5	18.0	0.0
20	a.m.	22.5	7.5	19.5	0.0
21	a.m.	23.5	6.5	12.5	Trace
22	a.m.	27.5	9.0	26.5	0.0
23	a.m.	28.5	11.0	16.0	2.6
24	a.m.	17.0	3.5	9.0	Trace
29	a.m.	23.0	4.5	18.0	5.2
30	a.m.	20.5	7.5	18.0	0.0
31	a.m.	27.5	9.5	27.0	0.0

TABLE II-15 BATTLE RIVER GENERATING STATION, FORESTBURG, ALBERTA, AUGUST 1980

Date of Month	Time of Observation	Temperature (°C)			Precipitation (mm)
		Maximum Observed	Minimum Observed	After Reset	
1	a.m.	27.5	10.0	17.5	
2	a.m.	23.0	11.0	12.5	Trace
3	a.m.	18.5	7.0	17.5	Trace
4	a.m.	21.5	6.0	15.5	
5	a.m.	17.5	10.0	8.5	Trace
6	a.m.	18.0	7.0	11.5	8.7
7	a.m.	17.0	7.5	9.5	10.6

TABLE II-16 MILNER GENERATING STATION, GRANDE CACHE, ALBERTA, JULY, 1980

Date of Month	Time of Observation	Temperature (°C)			Precipitation (mm)
		Maximum Observed	Minimum Observed	After Reset	
1	a.m.		10	12	
	p.m.	23	12	23	
2	a.m.	23	12	16	
	p.m.	24.5	16	24.5	
3	a.m.	27	13	16	
	p.m.	26	16	26	
4	a.m.	27.5	12	16	
	p.m.	22	16	22	
5	a.m.	25.5	14	16	
	p.m.	22	16	22	
6	a.m.	22.5	9.5	12	
	p.m.	17	12	17	
7	a.m.	17.5	9.5	12	
	p.m.	26	12	26	
8	a.m.	26.5	11.5	18	
	p.m.	27	18	27	
9	a.m.	27.5	12.5	18	
	p.m.	30.5	18	30.5	
10	a.m.	31	15	17	
	p.m.	28.5	17	28	
11	a.m.	28	13.5	17	
	p.m.	22.5	17	22.5	
12	a.m.	22.5	13	14	5.1
	p.m.	18.5	14	18.5	
13	a.m.	10.5	9	16	0.5
	p.m.	25.5	16	25	
14	a.m.	26	12	18.5	
	p.m.	26	18.5	2.6	
15	a.m.	27	14.5	15.5	8.2
	p.m.	21.5	15.5	21.5	
16	a.m.	21.5	13	14	1.0
	p.m.	21.5	14	21.5	

TABLE II-16 MILNER GENERATING STATION, GRANDE CACHE, ALBERTA, JULY, 1980 (Continued)

Date of Month	Time of Observation	Temperature (°C) Maximum Observed	Minimum Observed	After Reset	Precipitation (mm)
17	a.m.	21.5	9	14	6.6
	p.m.	17	14	17	
18	a.m.	17	9	12	
	p.m.	18	12	18	
19	a.m.	18	9.5	11	
	p.m.	13	11	13	
20	a.m.	13	6.5	17	
	p.m.	24.5	17	24.5	
21	a.m.	24.5	12.5	17	
	p.m.	27.5	17	27.5	
22	a.m.	27.5	13.5	23	
	p.m.	32	23	32	
23	a.m.	32	16	19	7.2
	p.m.	24	19	24	
24	a.m.	24	10	11	
	p.m.	21	11	21	
25	a.m.	21	9.5	11	
	p.m.	26	14.5	26	1.7
26	a.m.	26	14.5	16	
	p.m.	24.5	16	24.5	
27	a.m.	24.5	13.5	14	5.5
	p.m.	22	14	22	
28	a.m.	27.5	13.5	13.5	10.0
	p.m.	24.5	13.5	24	
29	a.m.	24.0	13.0	13	13.8
	p.m.	20	13	20	
30	a.m.	21.5	13	15	0.6
	p.m.	25.5	15	25	
31	a.m.	25	10	10	
	p.m.	27.5	10	27.5	

TABLE II-17 MILNER GENERATING STATION, GRANDE CACHE, ALBERTA AUGUST, 1980

Date of Month	Time of Observation	Temperature (°C)			Precipitation (mm)
		Maximum Observed	Minimum Observed	After Reset	
1	a.m.	27.5	15.5	17.5	
	p.m.	28.5	17.5	27	
2	a.m.	27.0	15.0	15	1.4
	p.m.	22.5	15	22	
3	a.m.	22	11	11.5	16.0
	p.m.	12	11	12	
4	a.m.	13	11	13	14.8
	p.m.	18.5	13	18.5	
5	a.m.	18.5	8	10	0.6
	p.m.	19	10	19	
6	a.m.	19	11	12.5	
	p.m.	15	12.5	15	
7	a.m.	15	11.5	13.5	2.8

APPENDIX III

ANALYTICAL METHODOLOGIES USED IN THE DETERMINATION OF INORGANICS, GROSS ORGANICS AND METALS

APPENDIX III ANALYTICAL METHODOLOGIES USED IN THE DETERMINATION OF INORGANICS, GROSS ORGANICS AND METALS

Generally, Standard Methods for the Examination of Water and Wastewater (38) was used to analyze the coal and coke pile drainage samples during this study.

Procedures used other than Standard Methods are referenced. Deviations from Standard Methods due to the nature of the samples and special measures taken to ensure the accuracy of results are described below.

Solids (total, dissolved and suspended):

Total and dissolved matter was determined as described in ASTM D-1888 (45). Suspended matter was then obtained by difference. Duplicate solid determinations were made on samples which were hygroscopic or highly turbid.

Hardness:

Interferences due to high concentrations of heavy metals can occur. To overcome this a cyanide inhibitor as described in Standard Methods (38) was used and determinations were made of two different sample dilutions.

COD:

Samples with suspended solids greater than 100 mg/L generally had high chemical oxygen demands. For this reason determinations were made using one or more dilutions.

Alkalinity:

A pH meter was used for all analyses. Suspended solids or precipitates produce an interference by causing a sluggish electrode response. In the case of those samples where electrode responses would not stabilize, samples were diluted. This is contrary to the standard procedure where samples are not filtered, diluted or concentrated. Use of an indicator may have eliminated this problem; however, some samples were too turbid or coloured for the indicator to be seen and for the sake of consistency the pH meter was used for all samples.

Free Mineral Acidity:

Suspended matter and precipitates cause a sluggish response of the electrode. These were not removed as they might contribute to the acidity of the sample. Samples were all diluted and composites were analyzed two or more times using different dilutions to determine the effect of dilution. Generally results of small volume samples were used as larger volume ones did not stabilize.

Oil and Grease:

Hexane was used as the solvent. Interferences will include any organic substances extractable in hexane.

Turbidity:

A Hach turbidity meter was used for this determination. Turbid samples were diluted one or more times until comparable results of different dilutions were obtained, that is until the concentration was in the linear range of the instrument.

Total Sulphur as Sulphate:

Following peroxide digestion, samples were analyzed by ion chromatography along with the undigested samples.

Sulphate, Chloride, Fluoride:

These analyses were completed using an ion chromatograph.

Ammonia:

Most ammonia determinations were completed using a modified Standard Methods procedure. Modifications included the use of sodium nitroprusside as catalyst instead of manganous sulphate and different concentrations of other reagents. Metals which interfere with the test were removed with EDTA as described in Standard Methods (38). Some highly turbid samples could not be analyzed using this procedure and determinations were made using the ion chromatograph.

Thiocyanate:

All samples were treated for hexavalent chromium as described in Standard Methods (38). This procedure also removed most of the turbidity permitting quantification using the spectrophotomer.

Inorganic Phosphate:

The term "inorganic phosphate" refers to condensed phosphates including pyrophosphate, tripolyphosphate and hexa meta phosphate. Recovery studies performed in the lab indicated that a ten-minute sulphuric acid digestion was sufficient to convert the condensed phosphates to ortho-phosphate. This procedure is a modification of the one described in Standard Methods for total acid-hyrolyzable phosphate which required a 90 minute sulphuric acid digestion.

Total Phosphate:

Procedure III for total phosphate involving a sulphuric acid ammonium persulfate digestion was used for all analyses (38).

Metals:

Aluminum, antimony, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, potassium, silver, sodium, strontium, titanium, vanadium and zinc were digested following the standard procedure for total metal analysis.

Aluminum, barium, strontium, and titanium had alkali metal added to samples after digestion to suppress ionization interference.

Chromium standards were heated under the same conditions as samples to ensure equivalent oxidation states.

Molybdenum and vanadium determinations were conducted on samples to which $Al(NO_3)_3 \cdot 9H_2O$ had been added. Adding this reagent in excess controls the interference due to high concentrations of aluminum.

Aluminum, barium, beryllium, molybdenum, titanium, and vanadium were analyzed by atomic absorption using a nitrousoxide acetylene flame. Lithium was analyzed by emission using the air-acetylene flame. All others listed above were analyzed by atomic absorption in an air-acetylene flame.

Arsenic and selenium determinations were completed using hyride generation with a low-temperature argon hydrogen flame.

Mercury was analyzed using the cold vapour technique. Silicon was analyzed photometrically after Na_2CO_3 fusion and was expressed as SiO_2. The recovery of this procedure may be reduced if quartz particulate such as sand was present in the sample.

The following are the detection limits for the determination of inorganics, gross organics and metals for this study, in mg/L except where other units are indicated.

pH	0.1 units
TOC	1
TDS	1

TSS	1
Hardness (titration)	5
COD	5
Alkalinity	1
FMA	1
Oil & grease (separatory funnel)	1
Turbidity	0.01 NTU
Total sulphur as sulphate	0.1
Sulfate	0.1
Chloride	0.1
Fluoride	0.1
Ammonia as NH_4^+	0.1
Phenol	0.001
Cyanide (distillation)	0.020
Thiocyanate	0.5
Inorganic phosphate	0.02
Total phosphate	0.02
Aluminum	1
Antimony	0.2
Arsenic	0.002
Barium	0.1
Beryllium	0.01
Boron	0.1
Cadmium	0.01
Calcium	0.01
Chromium	0.05
Cobalt	0.03
Copper	0.01
Iron	0.1
Lead	0.1
Lithium	0.1
Magnesium	0.01
Manganese	0.01
Mercury	0.001

Molybdenum	0.1
Nickel	0.1
Potassium	0.01
Selenium	0.002
Silica as SiO_2	2.1
Silver	0.01
Sodium	0.01
Strontium	0.1
Thallium	0.02
Thorium	0.06
Titanium	0.3
Uranium	0.0002
Vanadium	0.1
Zinc	0.01
Zirconium	0.020

Analyses of samples for zirconium, thallium, thorium and uranium were completed by Barringer Magenta Limited, Rexdale, Ontario.

Analyses of TOC were completed by Ontario Research Foundation, Mississauga, Ontario.

APPENDIX IV

TREATMENT CRITERIA

APPENDIX IV TREATMENT CRITERIA

Optimization of the treatment of the coal pile drainage samples was based on the following criteria:

Wastewater Parameter	Criteria
pH	6.5 - 9.5
iron	1.0 mg/L
copper	0.5 mg/L
nickel	0.5 mg/L
zinc	0.5 mg/L
chromium	0.5 mg/L
suspended solids	25. mg/L

APPENDIX V

TRACE ORGANIC ANALYSES - RECOVERY TESTS

APPENDIX V TRACE ORGANIC ANALYSES - RECOVERY TESTS

Purgeable Organics

U.S. EPA priority pollutants and internal standards were maintained during each set of analyses. The standard was run and the computer's relative retention times and response factors for each component of interest were updated to the accuracy of the identification and quantitation. Each sample was purged with internal standards (bromochloromethane and 1,4-dichlorobutane) and the Finnigan OWA 1030 dedicated computer aided in the "target" analysis. All possible measures were taken to prevent sample degradation and laboratory contamination (i.e., cold storage and rapid analysis).

A duplicate sample was "spiked" with the standard to check the purging efficiency of the sample matrix (see Table V-1). A check of instrument performance and calibration was carried out according to strict criteria.

Trace Organics

Recovery tests on eight trace organic compounds were also performed as a check on the analytical method. Table V-2 shows the recovery test results for base neutral and acid extractables. Table V-3 shows the recoveries for samples spiked with pesticides.

Note:

Analyses of purgeable organics were completed by Cantest Ltd., Vancouver, B.C.

Analyses of all other trace organics were conducted at the Wastewater Technology Centre, Environment Canada, Burlington, Ontario.

TABLE V-1 RECOVERY TESTS OF PURGEABLE ORGANICS ANALYSES

Parameter	Level of Spike Spiked (µg/L)	% Recovery	Detection Limit (µg/L)
Benzene	40	88	1.0
Bromodichloromethane	40	88	1.0
Carbon Tetrachloride	40	75	1.0
Chlorobenzene	40	93	1.0
Chloroethane	40	-	1.0
Chloroform	40	>100*	1.0
Dibromochloromethane	40	77	1.0
1,1-Dichloroethane	40	79	1.0
1,2-Dichloroethane	40	88	1.0
1,1-Dichloroethylene	40	80	1.0
trans-1,2-Dichloroethylene	40	91	1.0
1,2-Dichloropropane	40	79	1.0
1,2-Dichloropropylene	40	90	1.0
Ethylbenzene	40	85	1.0
Methylene Chloride	40	>100*	1.0
1,1,2,2-Tetrachloroethane	40	86	1.0
1,1,2,2-Tetrachloroethene	40	74	1.0
Toluene	40	81	1.0
1,1,1-Trichloroethane	40	89	1.0
1,1,2-Trichloroethane	40	80	1.0
Trichloroethylene	40	79	
Trichlorofluoromethane	40	70	

ND = Not Detected

* In Original Sample

TABLE V-2 RECOVERY TESTS OF TRACE ORGANICS ANALYSES

Parameter	Spiked Concentration (μg/L)	Lingan G.S.			Lingan G.S. (Treated)* October 30			Algoma Steel July 24		
		Raw Sample (μg/L)	Spiked Sample (μg/L)	Recovery** (%)	Raw Sample (μg/L)	Spiked Sample (μg/L)	Recovery (%)	Raw Sample (μg/L)	Spiked Sample (μg/L)	Recovery (%)
di-n-butyl phthalate	40	26.3	62	-503				ND	25	63
benzo-(ghi) perylene	80	ND	ND	0				ND	12	30
hexachlorobenzene	40	ND	ND	0				ND	24	60
benzopyrene	40	ND	ND	0				ND	26	65
pyrene	40	ND	29	73	ND	33	83	ND	25	63
diethylphthalate	40				ND	31	78			
bio-(2-ethylhexyl) phthalate	40				8	26	45			
pentachlorophenol	40	6	ND	-15				ND	ND	0

* Samples treated using optimum method described in Section 5.3 of this report.

** Recovery calculated using $\frac{\text{spiked sample - raw sample}}{\text{spike sample}} \times 100$.

TABLE V-2 RECOVERY TESTS OF TRACE ORGANICS ANALYSES (CONT'D)

Parameter	Spiked Concentration (µg/L)	Milner G.S. August 8 Raw Sample (µg/L)	Milner G.S. August 8 Spiked Sample (µg/L)	Milner G.S. August 8 Recovery* (%)	Lakeview G.S. September 2 Raw Sample (µg/L)	Lakeview G.S. September 2 Spiked Sample (µg/L)	Lakeview G.S. September 2 Recovery (%)	Dalhousie G.S. September 17 Raw Sample (µg/L)	Dalhousie G.S. September 17 Spiked Sample (µg/L)	Dalhousie G.S. September 17 Recovery (%)
di-n-butyl phthalate	40	24	13	-30	10	13	8	ND	35	88
benzo-(ghi) perylene	80	ND	ND	0	ND	ND	0	ND	ND	0
hexachlorobenzene	40	ND	13	33	ND	10	25	ND	23	58
benzopyrene	40	ND	ND	0	ND	7	18	ND	31	78
pyrene	40	ND	12	30	ND	9	23	ND	27	68
diethylphthalate	40									
bio-(2-ethylhexyl) phthalate	40									
pentachlorophenol	40	2	2	0	ND	ND	0			

* Recovery calculated using $\frac{\text{spiked sample - raw sample}}{\text{spike sample}}$ x 100.

TABLE V-3 RECOVERY OF SPIKED PESTICIDE SAMPLES

Compound Spiked	Spiked (µg/L)	Recovered (µg/L)	% Recovery
PCB	1.2	0.94	83
BHC	0.4	0.36	90
Heptachlor	0.4	0.38	95
Aldrin	0.4	0.38	95
Heptachlor Epoxide	0.4	0.38	95
ppDDE	0.4	0.42	105
Dieldrin	0.4	0.40	100
Endrin	0.8	0.72	90
Ensosulphan	0.4	0.42	105
ppDDD+endo B.	1.6	1.48	92.5
ppDDT	0.8	0.70	88
Endosulphan sulphate	0.8	0.84	105