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Impacts of Coal-Fired Generating Stations and Coal Mines Across Canada
II. Thallium, Mercury, Heavy Metals, Organics, and Toxicities in Sediments.

BY:

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NWRI Contribution No: 98-265

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

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MANAGEMENT PERSPECTIVE

Title: Impacts of coal-fired generating stations and coal mines across Canada. II. Thallium, mercury, heavy metals, organics, and toxicity in sediments

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EC Priority/Issue: This is part of Environment Canada's Action Plan (Conserving Canada's Ecosystems) and Environmental Effects Monitoring Initiatives. It deals with the impacts of coal mining and coal-fired power plants.

Current Status: Elevated concentrations of some contaminants and toxicities were observed, when compared to those in uncontaminated sediments.

Next Steps: Detailed toxicity tests along with chemical analyses be followed-up for the sediments from the Prince colliery, Battle River, Phalen colliery, Trenton power plant, and Salmon Harbor mine. In addition, all the sites identified to contain high Tl concentrations in waters (Cheam et al. 1998) should be included.

Abstract

Thirty two sediment samples were collected from selected sites at coal mines and coal-fired power plants across Canada. Elevated concentrations of some contaminants and toxicities were observed, when compared to those in uncontaminated sediments. The samples from the Souris River upstream, the Trenton power plant ash lagoon cenospheres, the Salmon Harbor mine lake water, and the Phalen colliery surface runoff contain several high concentrations of metals. The sediment from the Phalen colliery surface runoff brook has very high Cd and Fe concentrations. The Prince colliery downstream discharge contains elevated concentrations of PAHs; the Souris River upstream sample also has fairly high PAHs concentrations.

Five sediment samples of five liters each were selected for the toxicity tests. Even though the sediments physical characteristics were not ideally suited for the tests as most contain a significant amount of pebbles and twigs, toxic effects were nevertheless observed in all species except *Hexagenia limbata*. The Battle River and Prince mine sediments would be classified as toxic to *Chironomus riparius* and *Hyalella azteca*. The Battle River sediment is also toxic to *Tubifex tubifex*.

Introduction

Coal is Canada's most abundant fossil fuel. Its production and consumption exceed 78 and 55 million tonnes, respectively (Table 1, Canadian Coal Statistics 1997). Across the country there are thirty five active coal mines and twenty five coal-fired generating stations (Tables 2 and 3). Clearly, coal is important to the Canadian economy, and its exports are worth $2 billion (Natural Resources Canada 1994). However, the effects of coal production and consumption may be detrimental to the environment. For example, Smith and Carson (1977) reported that the air emissions from the 415 American coal-burning power plants in highly populated regions form the largest collective source of thallium (Tl) discharge into the atmosphere. The impacts of the Canadian coal industries on the surrounding waters have been recently studied, which show that it is the type of coal used and/or the local geochemical contributions, rather than amount used, that contribute to some of the very high thallium concentrations observed (Cheam et al. 1998a).

This report is the second one in this series, describing the impacts of coal mining and combustion in term of contaminant concentrations and toxicity in sediments collected from selected sites near various mines and power plants. Trace metals including Tl and Hg, organic contaminants including PAHs and PCBs, together with toxicity to four invertebrate species will be described.

Experimental

Study Design and Sediment Sampling

Of the 35 active Canadian coal mines, 80% are located in the three western provinces of British Columbia, Alberta, and Saskatchewan (Table 2). About 50% of the coal-burning power plants are in the western provinces (Alberta, Saskatchewan, and Manitoba), and 50% in Ontario, New Brunswick, and Nova Scotia (Table 3). While collecting sediment samples from all these localities would be ideal, this study selected a subset of localities for initial examination. The subset was evenly distributed among the mines and power plants. In all, thirty two sediment samples, instead of twenty seven as originally planned, were collected.

A mini ponar sampler (1-2 L) or an Eckman sampler was used to collect the samples. All containers, bags, spoons, and other utensils used were cleaned with 30% nitric acid. As in the case of water collection, at each sampling locality (a mine or a generating station / power plant), there are oftentimes 3 relevant sampling sites, basically at water intake such as upstream of a river, at water discharge and at downstream. Additional samples such as those from settling lagoons, nearby lakes and rivers are also included if available. Table 4 lists all the selected sites and the particulars of the samples collected.

Sediment Handling

After collection and bagging, sediment samples were immediately refrigerated in an ice box and kept cool until freeze drying. For inorganic and organic parameters, bottles of

150 ml size were used to contain wet sediments. All samples were then freeze-dried, crushed, sieved, and sub-sampled for the analysis of heavy metals, Hg, Tl, and organics (15-60 g). For toxicity tests and for each site, five one-liter replicate samples (for five replicate tests) were collected and placed into plastic bags, and refrigerated at 4°C until use.

Analytical Methods

Thallium was determined by a Laser-Excited Atomic Fluorescence Spectrometric (LEAFS) method recently developed (Cheam et al. 1998b). A weight of 0.1 g of each sediment was used and dissolved via the simple cold dissolution procedure; it uses 2.5 ml of concentrated nitric acid and 2.5 ml of concentrated hydrofluoric acid, followed by a dilution. The detection limit is 0.5 ng/g of thallium.

For mercury determination, about 0.2 g of each sediment was weighed into a microwave Teflon bottle followed by the addition of 5 ml of HNO_3. The mixture was let stand over the weekend and was microwaved. Three and a half milliliters of the digested solution was pipetted into a volumetric flask, diluted to 100 ml, preserved by BrCl, and analysed by a cold vapor atomic absorption method with a detection limit is 2 ng/L of mercury for aqueous solutions.

For heavy metals, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Tl and Zn, a semi-closed acid digestion was used to decompose 0.5 g sediment utilizing a 75 ml teflon beaker recently described (Cheam et al. 1998b). Five milliliters of HF and 5 mL of HNO_3 were added to the sediment and digested on a hot plate to dryness. Then 0.1 M HNO_3 and 2 mL of aqua regia as well as 2 mL of 30% hydrogen peroxide were added to the residue and digested for one more hour. The solution was then diluted to 50 mL and analyzed with an ICP spectrometer.

For PAHs and n-Alkanes, the freeze-dried sediment samples were soxhlet-extracted using 300 mL of dichloromethane (DCM) for at least sixteen hours. The extracts were then reduced to 1-2 mL by vacuum distillation on a rotary evaporator. They were then quantitatively transferred to 15 mL graduated centrifuge tubes with DCM and brought to a volume of 1.0 mL by evaporation with nitrogen in a heated water bath. Aliquots of 100 µL were taken as sub-samples from each extract for capillary GC/MS quantitation of PAHs and n-Alkanes. Chemstation data analysis reports were generated after Select Ion Monitoring (SIM mode) data acquisition was obtained for the external sixteen priority pollutant PAH standard provided by Supelco Canada, CAT NO. 4-8905, and for the sample extracts. Benzo[e]Pyrene and Perylene concentrations were obtained by using the Benzo[a]Pyrene response. The quantitation of these two additional compounds often aid in the data interpretation. The n-alkane external standard was also provided by Supelco Canada under a custom order which contained a mix of carbon number range from C12 to C26. Further confirmation data of the target compounds was obtained by SCAN acquisition from M/z 40 to 450 a.m.u. The method detection limit is 200 pg/g for both PAHs and n-Alkanes.

The remaining nine hundred µL of the soxhleted sediment extracts were solvent exchanged to hexane and then cleaned-up for PCBs analysis as follows. Each extract was quantitatively transferred to 200 mL separatory funnels with 20 mL of hexane and then base extracted three times with 40 mL of 0.1M potassium carbonate in distilled water.

The basic water phases were discarded. The hexane neutral fraction, containing non polar organic compounds such as PCBs and organochlorines, was then dried through sodium sulphate using vacuum with several hexane rinses. The extract was then reduced to 2 mL. The clean-up of the extract was accomplished by silica gel column fractionation (10g of 60-200 mesh silica gel/hexane slurry in 2.5 cm by 21 cm fritted-bottom glass columns). Three sample fractions were obtained by elution with 80 mL hexane (F1), 85 mL 20% DCM/hexane (F2), 100 mL 50% DCM/methanol (F3). Each fraction was reduced to approximately 2 mL on a rotary evaporator, quantitatively transferred to a 15 mL graduated centrifuge tube, and brought to a final volume of 0.9 mL with hexane. Fraction one and two was separately treated with mercury metal to reduce possible sulphur content and then analyzed by the analytical technique of dual capillary column gas chromatography with dual electron capture detection (GC/ECD). (The third fraction generally containing oxygenated organic compounds was not analysed by this technique.) Chemstation pascal reports were generated for signals 1 and 2 which were calibrated against the National Research Council (NRC) CLB1-A,B,C,D 51 congener mix external standard. The concentrations of each compound quantitated in the sample extracts were then compared between signals 1 and 2 and if they were equal to or less than 30% by difference then the compound was confirmed and the least of the two values was reported. In addition, chromatographic windows were selected to represent no less than three PCB congener peaks which were then used for a pictorial overlay representation, known as "finger printing". The method detection limit is 0.5 ng/g for total PCBs. The PCBs results were not confirmed by GC/MS.

Toxicity tests

Detailed procedures have been described previously (Reynoldson et al. 1991;1994). Briefly, culture water was added to the sediment producing a slurry, which was then poured through a 250μm mesh screen, instead of 500μm mesh screen (Reynoldson et al. 1991), to remove large debris and endemic species that may be present. Sediment was then allowed to settle for 24 hours. The water was decanted and used as the overlying water in the tests. Most sediments did not pass through the sieve, however. As a result, the *Tubifex tubifex* test could not be performed on the Salmon Harbour sample. There were a large number of endemic worms present in this sample that made it difficult to identify *T. tubifex*. Total ammonia readings were taken at the completion of the tests.

The physical characteristics of the sediments are briefly summarized below.

Site	Code	Comments
Souris River - Upstream	209S	Fine sediment (clay/silt); Passed through sieve except small portion of rep 3.
Souris River - Downstream	211S	Similar to upstream sediment; Approximately 1/4 of sediment did not pass through sieve.
Battle River G. S.	28S & 34S	Small pebbles, humicy-high organic content; Did not pass through sieve.
Prince Mine	141S	Pebbles, larger stones; Did not pass through sieve.
Salmon Harbour	128S	Vegetation; Did not pass through sieve.

Chironomus riparius : The 10-day survival and growth test was performed. The endpoints were expressed as percent survival and average growth given in mg dry weight per individual organism per replicate. Overall means and standard deviations are also included.

Hexagenia spp. : The 21-day survival and growth test was done, and the endpoints were expressed as above.

Hyalella azteca : The 28-day survival and growth test was done, and the endpoints were expressed as above.

Tubifex tubifex : The 28-day adult survival and reproduction test was carried out. The endpoints were expressed as a) the number of adults surviving out of 4; b) the number of cocoons produced per individual adult worm and the percentage of those cocoons that hatched; and c) the number of youngs produced per individual adult worm.

Results and Discussion

Thallium, Mercury and Other Heavy Metals

Table 5 shows the concentrations of thallium in all the sediment samples, as well as the concentrations of mercury in ten of the samples which had been chosen for toxicity tests as well as for analyses of organic parameters (see below). The concentrations of thallium are in general similar to other concentrations reported around the globe for sediments (Cheam 1998; Cheam et al. 1998b), except one high concentration in sample 69S, the Main Tailings Pond of the Obed Mountain Coal. This sample has a concentration of 3.39 μg/g, which is higher than the 2.6 μg/g, the highest concentration reported for the sediment reference materials from around the Great Lakes (Cheam et al. 1998b); and is higher than 2.9 μg/g, the Tl concentration in a Chinese Stream sediment reference material (Govindaraju 1994). Other fairly high concentrations, ~ 1 μg/g, were found in the samples 7S (Sundance generating station, ash slurry); 13S2 (Keephills generating station, ash lagoon cenopheres); 43S (Genesee mine, mine drainage); 72S (Line Creek mine, Settling pond); and 132S (Phalen Colliery, surface runoff brook). Most of the Tl concentrations are, however, below 1 μg/g, as found in the world's sediment reference materials (Cheam 1998).

The concentration of mercury, on the other hand, are much lower than thallium (Table 5). This concentration differential is similar to the one found by Lentz in 1993 for the concentrations found in a massive sulfide deposit at Bathurst, New Brunswick. Also this difference occurs in most of the world's sediment reference materials (Cheam 1998). Similarly, the earth's crust content is 450-600 ppb of Tl, compared to only 200 ppb for Cd and 80 ppb of Hg (CRC Handbook 1992-93; Korenman 1963). The crustal rocks concentrations of Tl is also higher than that of Hg and Cd -- 530 ppb of Tl vs. 150 ppb of Cd, and 67 ppb of Hg (Winter 1998). Theses crustal concentrations give the Tl/Hg ratios of 5.6 to 7.9, whereas the ratios for the 10 samples investigated range from 6 to 39, with a mean value of 13 and a median value of 10. The ratio values suggest there is a definite enrichment of Tl by at least 25%, or even as high as 117%.

For the Souris River, Saskatchewan sediments, the concentrations of Tl and Hg are higher in the upstream samples than the downstream samples (Table 5), which is rather surprising. The same is true for heavy metals (Table 6). To verify the findings, new fresh and duplicate samples from the same locations were recently collected and analyzed for heavy metals. The new results confirm the higher concentrations in the upstream sediment compared to downstream. This is in fact true for organic compounds as well as toxicity to various organisms (Tables 7-10) to be discussed below. Also, for water samples, the upstream samples likewise contain higher Tl content than downstream (Cheam et al. 1998a). It seems therefore that the so-called "upstream" sediment samples (49° 07.337' latitude N., 103° 01.397' longitute W.) may represent the outflow of the cooling water from the Boundary Dam power plant.

It is also interesting to note that the Battle River upstream sediments also contain higher concentrations than the downstream sediments for all the groups of chemicals, except perhaps Tl and Hg; we have no explanation for this. The Phalen colliery sediments contain, by far, the highest content of Cd (16.2 µg/g, the closest being <3.4 µg/g) and Fe (17%, the closest being 5.8%) among all the studied sediments, and could be very interesting sediments to be used in future toxicity tests. Unfortunately, this wasn't known at the sampling time, and the sediments were not collected. Sample 122S (Trenton power plant, ash lagoon cenospheres), sample 128S (8200 Salmon Harbor mine, lake water), and sample 132S (Phalen colliery, surface runoff brook) contain several high concentrations of metals (Table 6) compared to other sites.

Polycyclic Aromatic Hydrocarbons

The sixteen priority pollutants of the Polycyclic Aromatic Hydrocarbons (PAHs) were measured using GC/MS responses. In addition, two 252 PAH isomers, benzo[e]pyrene and perylene, were also quantitated using the benzo[a]pyrene response (Table 7). The concentration of total PAHs in sample 141s (Prince Colliery, downstream discharge) is high as it is in the same order of magnitude as that of Hamilton Harbor suspended sediments (RAP 1988; Mayer and Nagy 1992). The diversity and high levels of the PAHs in samples 141s, 209s and 128s compared to the other sites seem to suggest that these sites may be affected by industrial inputs associated with coke production (Mayer and Nagy 1992). The compound anthracene was difficult to confirm in these samples due to the complexity of the matrix; for example in sample 141s, the anthracene result might be high by 10%. Also the naphthalene results may be low by 20-50% due to the possible loss during the freeze-drying process (Fox et al. 1991).

n-Alkanes

The determination of n-alkanes is necessary in that it helps to determine the types of sediments, whether they are of biological or petroleum origins. According to Bray and coworkers (Bray and Evans 1961; Cooper and Bray 1963), the types can be inferred by determining the carbon preference index (CPI) from the odd-carbon and even- carbon data in the sediments of interest. The CPI is defined for the number of carbon up to 26 as

$$CPI = \frac{1}{2}\,[A/B + A/C] \quad \text{where}$$

$$A = \sum_{13}^{n-1} \text{odd-carbon alkanes,}$$

$$B = \sum_{14}^{n} \text{even-carbon alkanes, and}$$

$$C = \sum_{12}^{n-2} \text{even-carbon alkanes}$$

The CPI's for biological systems range about 2.5 - 5.5, whereas the CPI's of about 1 indicate crude oil or petroleum systems. In our case, the CPI's range from 0.8 to 1.7 (Table 8) with an average of 1.3 ± 0.3, which clearly indicates non-biological origins.

Sample 141S (Prince Colliery, d/s discharge) contains the highest total n-alkanes of 32 μg/g, but the smallest CPI of 0.8, which signifies an industrial system, thus corroborating with the PAHs results discussed above. Likewise, Sample 209S (Souris

River u/s) contain fairly high n-alkane concentration of 7 μg/g, and is of industrial sources.

Polychlorinated Biphenyls

The analysis of PCBs showed that the concentrations are very low, and only very few congeners were detected. In fact, of the 360 congeners analyzed (40 congeners per sample times 9 samples), only 36 congeners were detected sparingly as above or close to the detection limit of 20 pg/g (Table 9).

Toxicity to Organisms

Reynoldson et al. (1997) reported on sediment toxicity targets in the recently published biological sediment guidelines for the Laurentian Great Lakes. In this report, they established toxicity limits for determining toxicity of ten test endpoints. Using the sediments from the Great Lakes reference sites for their study, they classified sediments as non-toxic, potentially toxic, and toxic, based on the percentage of survival and growth of three different organisms, namely, *Chironomus riparius, Hyalella azteca,* and *Hexagenia spp. (Hexagenia limbata).* As well, the survival and reproduction targets were established for the oligochaete worm *Tubifex tubifex*, based on % survival, % hatch, # cocoons/adult, and # youngs/adult. These guidelines are used here to determine the toxicity of the sediment samples.

Table 10 shows the % survival and the growth of the test species *Chironomus riparius* in five different sediments from the various regions. It indicates that the sediments from the Battle River power plant and the Prince colliery would be classified as toxic, based on the % survival "toxic" limit of <60 (Reynoldson et al. 1997). However, on the growth basis, all five sediment types would be classified as non-toxic since all the five growth results fell within the non-toxic range of 0.21-0.49 mg dry weight (Reynoldson et al. 1997).

The sediments used would be indexed as non-toxic to *Hexagenia spp.* organisms as all the growth values fell within the non-toxic confine of 1.0-5.0 mg (Table 10). Furthermore, all the % survival values are greater than the non-toxic limit of >85.

Hyalella azteca were much affected by the Prince mine sediments as both the % survival and the growth are below the "toxic" limits, respectively, (36.7 << 58) and (0.1 < 0.11 mg) (Table 10). The high amount of ammonia of 9 ppm produced from these sediments, the highest ammonia content observed in the study, may have contributed to the observed high sediment toxicity. Also, the Prince mine sediments produce the highest ammonia content among all sediments and all organisms studied (Table 11). Additionally, an examination of the chemical data reveals that the very high content of the PAHs in these sediments (Table 7), as discussed above, may have contributed to the observed high toxicity. These sediments also contain the highest content of n-alkanes (Table 8). *Hyalella azteca*, on the other hand, are not as affected by the other sediments, except perhaps the Battle River sediments, which may be potentially toxic to *Hyalella* based on the % survival, 68, which is right at the edge of the "potentially toxic" range of 58-67.9 (Reynoldson et al. 1997).

Table 10 also shows the toxicity results for *Tubifex tubifex*. The sediments from Battle River generating station would be classified as toxic since the #cocoons/adult, 5.2, is below the toxic limit, <5.9; furthermore, the % survival as well as the #young/adult are within the "potentially toxic" limits of 84-87.9 and 3.6-11.9, respectively (Reynoldson et al. 1997). However, the chemical data (Tables 5-9) do not seem to corroborate with the toxicity results since the Battle River sediments contain no real high concentrations of any heavy metals, PAHs, n-alkanes, or PCBs relative to other sediments. In fact, the measured concentrations in the Battle River sediments, overall, are lower than those in the other four sediments. So it is interesting that the Battle River sediments are toxic to three out of four test species in spite of its relatively low concentrations. It could be that the Battle River sediments contain more toxic organic matter than the other sediments, or they could contain other highly toxic contaminants not measured in this study.

Summary and Recommendation

Thirty two sediment samples were collected from selected sites near the coal mines and coal-based power plants across Canada. Heavy metals including thallium and mercury, PAHs, n-alkanes, and PCBs were analyzed. In addition, the toxicity tests were performed using four different organisms, *Chironomus riparius, Hexagenia spp., Hyalella azteca, and Tubifex tubifex*. Some elevated concentrations and toxicities were observed. The samples from the Souris River upstream, the Trenton power plant ash lagoon cenospheres, the Salmon Harbor mine lake water, and the Phalen colliery surface runoff contain several high concentrations of metals (Table 6) compared to other sites. The sediment from the Phalen colliery surface runoff brook has very high Cd and Fe concentrations. The Prince colliery downstream discharge contains elevated concentrations of PAHs; the Souris River upstream sample also has fairly high PAHs concentrations. Even though the sediments physical characteristics were not readily suited for the toxicity tests as most contain a significant amount of pebbles and twigs, toxic effects were nevertheless observed in all species except the *Hexagenia limbata*. The Battle River and Prince mine sediments would be classified as toxic to *Chironomus riparius* and *Hyalella azteca*. The Battle River is also toxic to *Tubifex tubifex*.

Based on this study, it is recommended that detailed toxicity tests be done for the sediments from the Prince colliery, Battle River, Phalen colliery, Trenton power plant, and Salmon Harbor mine. In addition, the other sites identified to contain high Tl concentrations in waters (Cheam et al. 1998a) should be included; these are from the power plants at Belldune, Grand Lake, Lingan, Point Aconi, Point Tupper and Trenton.

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Table 1. The production, Consumption, Import, and Export of Coal, tonnes, in Canada

	Production	Consumption	Import	Export
British Columbia	27,892,747	200,817	---	27,278,581
Alberta	36,343,416	26,264,343	---	9,181,069
Saskatchewan	11,652,553	10,018,189	---	---
Manitoba	---	263,829	185,572	---
Ontario	---	13,877,042	11,393,496	---
Quebec	---	732,265	750,265	---
New Brunswick	170,958	1,326,676	1,150,622	---
Nova Scotia	2,632,994	3,051,199	--	49,924
Total	**78,692,668**	**55,734,360**	**13,479,955**	**36,509,574**

Table 2. List of all active coal mines in Canada (by province)

Principal Mines (1997 data/ The coal Association of Canada)

British Columbia	Owner
Quinsam	Quinsam Coal Corp.
Bullmoose	Teck Corporation
Quintette	Teck Corporation
Fording River	Fording Coal Ltd.
Greenhills	Fording Coal Ltd.
Line Creek	Line Creek Resources Ltd.
Elkview	Teck Corporation
Coal Mountain	Fording Coal Ltd.

Saskatchewan	Owner
Poplar River	Manalta Coal Ltd.
Utility	SaskPower
Boundary Dam	Luscar Ltd.
Costello	Manalta Coal Ltd.
Shand	Luscar Ltd.
Bienfait	Luscar Ltd.

Alberta	Owner
Smokey River	Smokey River Coal Ltd.
Obed	Luscar Ltd.
Highvale	TransAlta Utilities Corporation
Whitewood	TransAlta Utilities Corporation
Luscar	Luscar Ltd.
Gregg River	Manalta Coal Ltd.
Coal Valley	Luscar Ltd.
Genesee	Edmonton Power & Fording Coal Ltd
Vesta	Alberta Power Ltd.
Paintearth	Luscar Ltd.
Montgomery	Manalta Coal Ltd.
Sheerness	Luscar Ltd.

New Brunswick	Owner
N. B. Coal (Minto)	N. B. Coal Ltd.

Nova Scotia	Owner
Prince	Cape Breton Development Corp
Phalen	Cape Breton Development Corp

Minor Mines (Natural Resources Canada 1998)

Alberta
Dodds
Egg Lake

Nova Scotia
Stellarton
Thomas Brogan
Evans
Thorbourn

Table 3. List of Coal-based Electrical Generating Stations (by province)

Alberta	Owner
Sundance	TransAlta Utilities Corporation
Wabamun	"
Keephills	"
Battle River	Alberta Power Ltd.
H. R. Milner	"
Sheerness	" + TransAlta Utilities Corporation
Genesee	Edmonton Power

Ontario	Owner
Nanticoke	Ontario Hydro
Lakeview	"
Lambton	"
Thunder Bay	"
Atikokan	"

Saskatchewan	Owner
Boundary Dam	Saskpower
Poplar River	"
Shand	"

New Brunswick	Owner
Belledune	N. B. Power
Dalhousie	"
Grand Lake	"

Manitoba	Owner
Brandon	Manitoba Hydro
Selkirk	"

Nova Scotia	Owner
Lingan	N. S. Power
Glace Bay	"
Point Alconi	"
Trenton	"
Point Tupper	"

Table 4. Description of the selected sediment samples

SAMPLE LOCATION	SITE / SAMPLE DESCRIPTION	LATITUDE N.	LONGITUDE W	PARTICULARS*	SAMPLE ID
Wabamun G.S.,Alberta	Intake Water	53° 33.386'	114° 29.562'	Sediment	1S
	Ash Lagoon Effluent	53° 33.496'	114° 30.608'	Sediment	3S
Sundance G.S., Alberta	Ash Slurry	N/A	N/A	Sediment	7S
Keephills G.S., Alberta	Cooling Pond Screen Waste	53° 27.035'	114° 27.233'	Sediment	11S
	Ash Lagoon Slurry	53° 27.379'	114° 25.843'	Sediment	13S1
	Ash Lagoon Cenospheres	53° 27.379'	114° 25.843'	Sediment - harvested for use in makeup	13S2
Genesee G.S., Alberta	Discharge	N/A	N/A	Sediment	16S
Smoky River, Alberta	u/s Sheep Creek, 5km d/s HR Milner	54° 03.610'	119° 00.731'	Sediment	22S
	u/s H.R. Milner G.S. at Hwy. 40	53° 53.543'	119° 10.004'	Sediment	23S
Battle River G.S., Alberta	Battle River u/s	52° 29.335'	112° 11.009'	Sediment **and bio-assay replicates**	28S
	Battle River d/s	52° 27.244'	111° 55.102'	Sediment **and bio-assay replicates**	34S
Whitewood Mine, Alberta	Pit Water Discharge	53° 35.320'	114° 33.235"	Sediment	36S
Highvale Mine, Alberta	Pit 2 Drain	53° 28.197'	114° 31.774'	Sediment	37S
	Pit 3 Settling Pond - Outflow	53° 31.791'	114° 39.245'	Sediment	40S
Genesee Mine, Alberta	Mine Drainage	N/A	N/A	Sediment - at Hwy 770	43S
Coal Valley Mine, Alberta	Tailings Discharge	53° 04.602'	116° 47.555'	Sediment	44S
	Lovett River d/s	53° 00.019'	116° 39.335'	Sediment	48S
Gregg River Mine, Alberta	Plant Site Water Reservoir	53° 05.499'	117° 26.671'	Sediment	53S
Obed Mountain Coal, Alberta	E. Conveyor Settling Pond	53° 35.287'	117° 26.681'	Sediment	66S
	Main Tailings Pond (Upper)	53° 35.753'	117° 27.839'	Sediment	69S
	LSP2 - Coal Storage Drain	53° 35.753'	117° 27'839'	Sediment	70S
Line Creek Mine, British Columbia	Settling Pond	49° 57.597'	114° 44.833'	Sediment - Treatment system effluent - Dry at present	72S
Grand Lake G.S., New Brunswick	Lake	N/A	N/A	Sediment **and bio-assay replicates**	105S
Trenton G.S., Nova Scotia	Ash Lagoon Cenospheres	N/A	N/A	Sediment	122S
8200 Salmon Harbour Mine, New Brunswick	Lake Water	N/A	N/A	Sediment **and bio-assay replicates**	128S
Phalen Colliery, Nova Scotia	Surface Runoff Brook	46° 14.836'	60° 03.232	Sediment	132S
Prince Colliery, Nova Scotia	d/s Discharge	N/A	N/A	Sediment **and bio-assay replicates**	141S
Souris River, Saskatchewan	u/s Estevan, mines and generating stations	49° 07.337'	103° 01.397'	Duplicate Sediment **and bio-assay replicates**	209S dup1
Souris River, Saskatchewan	u/s Estevan, mines and generating stations	49° 07.337'	103° 01.397'	Duplicate Sediment **and bio-assay replicates**	209S dup2
Bienfait Mine, Saskatchewan	Pit Water Discharge	49° 06.153'	102° 45.692'	Sediment	210S
Souris River, Saskatchewan	d/s Estevan, mines and generating stations	49° 04.534'	102° 45.919'	Duplicat Sediment **and bio-assay replicates**	211S dup1
Souris River, Saskatchewan	d/s Estevan, mines and generating stations	49° 04.534'	102° 45.919'	Duplicat Sediment **and bio-assay replicates**	211S dup2

* "Sediment" refers to sediment samples intented for analysis of trace metals, Tl, and Hg.
* "Sediment **and bio-assay replicates**" refers to samples intended for toxicity tests and analysis of organics.

G. S. = GS = Coal-fired electrical generating station, or, simply, power plant

Colliery = is sometimes replaced by the word "mine"; for example "Prince Colliery" = "Prince Mine"

Table 5. Concentrations of Thallium and Mercury in Sediments

Sample Site	Site / Sample Description	Sample ID	Tl, µg/g	Hg, µg/g
Wabamun **GS**, Alberta	Intake Water	1S	0.52	
"	Ash Lagoon Effluent	3S	0.43	
Sundance **GS**, Alberta	Ash Slurry	7S	0.99	
Keephills **GS**, Alberta	Cooling Pond Screen Waste	11S	0.69	
"	Ash Lagoon Slurry	13S1	0.35	
"	Ash Lagoon Cenospheres	13S2	1.20	
Genesee **GS**, Alberta	Discharge	16S	0.52	
Smoky River, Alberta	u/s Sheep Creek, 5km d/s HR Milner	22S	0.39	
"	u/s H.R. Milner G.S. at Hwy. 40	23S	0.34	
Battle River **GS**, Alberta	Battle River u/s	28S	0.36	0.04
"	Battle River d/s	34S	0.47	0.04
Grand Lake **GS**, New Brunswick	Lake	105S	0.78	0.02
Trenton **GS**, Nova Scotia	Ash Lagoon Cenospheres	122S	0.89	
Souris River, Saskatchewan	u/s Estevan, mines and generating station	209S dup1	0.68	0.11
"	u/s Estevan, mines and generating station	209S dup2	0.68	0.10
"	d/s Estevan, mines and generating station	211S dup1	0.49	0.06
"	d/s Estevan, mines and generating station	211S dup2	0.45	0.07
Bienfait **Mine**, Saskatchewan	Pit Water Discharge	210S	0.54	
Whitewood **Mine**, Alberta	Pit Water Discharge	36S	0.47	
Highvale **Mine**, Alberta	Pit 2 Drain	37S	0.87	
"	Pit 3 Settling Pond - Outflow	40S	0.62	
Genesee **Mine**, Alberta	Mine Drainage	43S	1.04	
Coal Valley **Mine**, Alberta	Tailings Discharge	44S	0.47	
"	Lovett River d/s	48S	0.59	
Gregg River **Mine**, Alberta	Plant Site Water Reservoir	53S	0.52	
Obed Mountain **Coal**, Alberta	E. Conveyor Settling Pond	66S	0.25	
"	Main Tailings Pond (Upper)	69S	3.39	
"	LSP2 - Coal Storage Drain	70S	0.42	
Line Creek **Mine**, British Columbia	Settling Pond	72S	1.11	
8200 Salmon Harbour **Mine**, New Brunswick	Lake Water	128S	0.74	0.05
Phalen **Colliery**, Nova Scotia	Surface Runoff Brook	132S	1.25	0.06
Prince **Colliery**, Nova Scotia	d/s Discharge	141S	0.61	0.06

Table 6. Concentrations of Total Metals in Sediments

SAMPLE LOCATION	Sample #	Cd ug/g	Co ug/g	Cr ug/g	Cu ug/g	Fe %	Mn ug/g	Pb ug/g	Ni ug/g	Tl ug/g	Zn ug/g
Wabamun G.S.,Alberta	1S	<3.4	17.5	57.9	28.8	2.1	742	<2.5	28.8	<12.6	68.1
	3S	<3.4	9.72	39.9	20.3	1.7	180	<2.5	18.4	<12.6	46.2
Sundance G.S., Alberta	7S	<3.4	13.1	17.4	45.1	1.7	343	34.5	19.4	<12.6	33.4
Keephills G.S., Alberta	11S	<3.4	9.91	56.6	35.2	2.1	303	<2.5	27.7	<12.6	108
"	13S1	<3.4	13.5	21.9	28.3	2.1	348	<2.5	19.2	<12.6	18.6
"	13S2	<3.4	6.22	8.97	39.4	1.2	86.8	31.4	13.7	<12.6	19.5
Genesee G.S., Alberta	16S	<3.4	10.2	47.2	36.4	2.4	573	<2.5	21.9	<12.6	95.1
Smoky River, Alberta	22S	<3.4	7.79	35.7	19.2	1.7	221	<2.5	25.5	<12.6	70.9
"	23S	<3.4	8.87	40.3	19.3	1.6	208	3.72	17	<12.6	68.4
Battle River G.S., Alberta	28S	<3.4	5.34	28.37	8.56	1.64	297	<2.5	15.32	<12.6	42.83
"	34S	<3.4	3.25	22.34	4.91	1.18	280	<2.5	10.21	<12.6	28.6
Grand Lake G.S., New Brunswick	105S	<3.4	5.88	23.24	8.16	2.42	688	<2.5	12.47	<12.6	34.48
Trenton G.S., Nova Scotia	122S	<3.4	20.7	55.2	77.3	2.6	164	86.1	44.5	<12.6	156
Souris River, Saskatchewan	209S dup	<3.4	15	89.77	35.89	3.58	464	<2.5	43.1	<12.6	115
"	209S dup	<3.4	11.67	76.03	32.69	3.16	430	<2.5	34.8	<12.6	99.86
"	211S dup	<3.4	8.06	55.32	21.14	2.19	319	<2.5	21.57	<12.6	73.53
"	211S dup	<3.4	7.8	56.31	22.49	1.93	289	<2.5	20.54	<12.6	67.56

Table 6. (Continued)

SAMPLE LOCATION	Sample #	Cd ug/g	Co ug/g	Cr ug/g	Cu ug/g	Fe %	Mn ug/g	Pb ug/g	Ni ug/g	Tl ug/g	Zn ug/g
Bienfait **Mine**, Saskatchewan	210S	<3.4	7.96	36.5	16.7	1.2	284	11	13	<12.6	76.1
Whitewood **Mine**, Alberta	36S	<3.4	7.37	36.5	25.8	1.5	258	4.97	16.3	<12.6	158
Highvale **Mine**, Alberta	37S	<3.4	19	69.5	54.3	2.5	378	<2.5	42.5	<12.6	98.1
"	40S	<3.4	18.1	76.9	44.4	3.2	398	<2.5	38.4	<12.6	94.9
Genesee **Mine**, Alberta	43S	<3.4	17.1	77.7	54.6	3.1	369	<2.5	39.6	<12.6	170
Coal Valley **Mine**, Alberta	44S	<3.4	15.3	60.7	32.9	2.6	448	<2.5	33.8	<12.6	94.7
"	48S	<3.4	12.9	80	25.9	2.4	906	<2.5	33.5	<12.6	82.8
Gregg River **Mine**, Alberta	53S	<3.4	16.8	44.8	54.3	1.1	339	8.46	37	<12.6	196
Obed Mountain **Coal**, Alberta	66S	<3.4	8.66	39.1	24.7	1.4	417	7.68	20.3	<12.6	68.4
"	69S	<3.4	8.06	16.6	14.8	2.9	318	33.8	9.46	<12.6	105
"	70S	<3.4	4.69	23.8	17.5	0.95	194	10.2	11.9	<12.6	59.3
Line Creek **Mine**, British Columbia	72S	<3.4	7.35	52.4	31.5	0.92	153	9.51	22.9	<12.6	199
8200 Salmon Harbour **Mine**, New Br.	128S	<3.4	26.72	94.26	36.83	5.79	1972	<2.5	45.06	<12.6	132.6
Phalen **Colliery**, Nova Scotia	132S	16.2	21.3	39.9	30.8	**17.01**	640	54.5	37.6	<12.6	126
Prince **Colliery**, Nova Scotia	141S	<3.4	11.52	53.71	24.68	3.69	614	12.93	30.95	<12.6	109.3

Table 7. Concentrations, ng/g, of the 16 Priority PAHs and Benzo[e]Pyrene and Perylene

COMPOUND	M/z	Sample #	28S	34S	105S	128S	*141S	209S dup1	209S dup2	211S dup1	211S dup2
		Weight (g)	41.82	59.81	43.23	19.31	28.08	12.89	12.97	38.59	29.98
		Final Vol (ml)	1	1	1	1	1	1	1	1	1
NAPHTHALENE	128		13	2	11	704	4059	61	74	18	14
ACENAPHTHYLENE	152		2	0.2	MDL	13	359	26	8	1	1
ACENAPHTHENE	154		1	MDL	MDL	8	602	7	6	1	0.8
FLUORENE	166		2	0.3	0.4	36	756	105	12	6	3
PHENANTHRENE	178		9	2	5	326	3399	68	89	18	10
ANTHRACENE	178		1	MDL	MDL	NC	739	NC	NC	4	1
FLUORANTHENE	202		5	1	1	32	385	262	380	14	11
PYRENE	202		6	1	7	67	599	222	298	20	17
BENZO[a]ANTHRACENE	228		2	0.4	MDL	19	156	69	83	3	3
CHRYSENE	228		4	0.8	1	59	131	142	218	7	6
BENZO[b]FLUORANTHENE	252		5	2	MDL	26	22	103	137	7	6
BENZO[k]FLUORANTHENE	252		2	0.4	MDL	5	5	36	44	2	2
BENZO[a]PYRENE	252		2	0.7	MDL	14	28	30	32	2	1
INDENO[1,2,3-cd]PYRENE	276		MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL
DIBENZ[a,h]ANTHRACENE	278		MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL
BENZO[ghi]PERYLENE	276		MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL	MDL
TOTAL (ng/g)			54	10.8	25.4	1309	11240	1131	1381	103	76
BENZO[e]PYRENE (ng/g)	252		2	0.6	MDL	29	16	40	55	2	1
PERYLENE (ng/g)	252		26	9	MDL	MDL	2	16	20	9	7

* Results obtained after silica gel fractionation and sulfur clean-up. Unusually high Anthracene concentration (also high in samples 209sdup1 and dup2)

MDL = 200 pg/g

NC = not confirmed

Table 8. Concentrations, µg/g, of n-alkanes in Sediment Samples

		Sample #	28S	34S	105S	128S	*141S	209S dup1	209S dup2	211S dup1	211S dup2
		Weight (g)	41.82	59.81	43.23	19.31	28.08	12.89	12.97	38.59	29.98
		Final Vol (ml)	1	1	1	1	1	1	1	1	1
COMPOUND	C-No.		µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
n-C12	12		0.01	MDL	MDL	0.09	1.49	0.03	0.04	0.04	0.03
n-C13	13		0.02	MDL	MDL	0.09	1.74	0.04	0.05	0.03	0.03
n-C14	14		0.02	MDL	MDL	0.09	2.77	0.10	0.12	0.05	0.04
n-C15	15		0.03	0.01	0.01	0.09	1.10	0.20	0.23	0.08	0.06
n-C16	16		0.03	0.01	0.01	0.09	2.06	0.24	0.27	0.11	0.06
n-C17	17		0.17	0.04	0.02	0.15	2.11	0.92	1.21	0.28	0.19
n-C18	18		0.06	0.03	0.02	0.15	1.40	0.86	0.75	0.36	0.25
n-C19	19		0.08	0.04	0.03	0.21	1.87	1.09	0.86	0.41	0.32
n-C20	20		0.48	0.02	0.04	0.24	3.06	0.94	0.77	0.30	0.30
n-C21	21		0.08	0.02	0.04	0.25	2.31	0.96	0.53	0.03	0.29
n-C22	22		0.06	0.02	0.03	0.15	2.32	0.36	0.33	0.17	0.16
n-C23	23		0.19	0.06	0.01	0.15	2.28	0.42	0.39	0.46	0.39
n-C24	24		0.08	0.03	0.01	0.07	3.16	0.20	0.24	0.20	0.16
n-C25	25		0.06	0.03	0.01	0.31	1.89	0.53	0.66	0.67	0.55
n-C26	26		0.11	0.04	MDL	0.07	2.22	0.26	0.29	0.21	0.18
TOTAL (ug/g)			1.48	0.35	0.22	2.20	31.77	7.14	6.72	3.39	3.01
Carbon Preference Index (Mean CPI = 1.3 ± 0.3)			0.8	1.5	1.1	1.4	0.8	1.5	1.5	1.5	1.7

* Results obtained after silica gel fractionation and sulfur clean-up
MDL = 200 pg/g

Table 9. Concentrations, ng/g, of total PCBs in Sediment Samples

Sample #	28S	34S	105S	128S	141S	209S dup1	209S dup2	211S dup1	211S dup2	Blank
Weight (g)	41.82	59.81	43.23	19.31	28.08	12.89	12.97	38.59	29.98	
PCB CONGENER	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	pg/µl
15/18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
54	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	0.440	0.236	0.156	0.807	0.113	0.000	0.000	0.608	0.000	0.000
52	0.000	0.000	0.000	0.000	0.000	8.552	0.000	2.807	0.000	0.000
49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40/103	0.297	0.196	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
121	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.242	0.000	0.000
60	0.000	0.116	0.000	0.151	0.000	0.514	0.730	0.000	0.000	0.317
101	0.000	0.000	0.000	1.121	0.000	2.380	2.958	0.000	0.000	0.000
86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
87	0.000	0.000	0.152	0.466	0.000	1.094	0.000	0.000	0.000	0.000
77/154	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
151	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
118	0.000	0.186	0.000	0.000	0.000	0.000	0.000	0.727	0.000	0.000
114/143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.262	0.000	0.000
153	0.484	0.000	0.173	0.620	0.000	0.000	0.000	0.000	0.000	0.000
105	0.000	0.000	0.000	0.000	0.108	0.000	0.000	0.000	0.000	0.000
141	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
137	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
138	0.000	0.000	0.000	0.000	0.179	0.000	0.000	0.000	0.000	0.000
129/159	0.000	0.159	0.000	0.000	0.000	0.062	0.000	0.000	0.000	0.000
187	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
182	0.000	0.000	0.000	0.000	0.000	0.000	0.185	0.000	0.000	0.000
183/128	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
185	0.000	0.000	0.000	0.000	0.000	0.047	0.000	0.000	0.000	0.000
156/202/171	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
173/201	0.000	0.014	0.000	0.000	0.000	0.000	0.104	0.000	0.000	0.000
180	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.048	0.000

Table 9. Continued

Sample #	28S	34S	105S	128S	141S	209S dup1	209S dup2	211S dup1	211S dup2	Blank
Weight (g)	41.82	59.81	43.23	19.31	28.08	12.89	12.97	38.59	29.98	
PCB CONGENER	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	pg/µl
191	0.000	0.000	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000
170	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.182	0.000	0.000
199	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
203/196	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
189	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
195/208	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
207	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
194	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
205	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
206	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
209	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total PCB (ng/g)	1.2	0.9	0.5	3.2	0.4	12.7	4.0	4.8	0.0	0.3

0.00 depicts < MDL of ~ 20 pg/g for individual congener

The PCBs results are not confirmed by GC/MS.

Table 10. Survival, Growth, and Reproduction of *Chironomus riparius, Hexagenia spp., Hyalella azteca,* and *Tubifex tubifex* in Sediments

	Chironomus riparius		*Hexagenia spp.*		*Hyalella azteca*		*Tubifex tubifex*			
Sediment Site*	% Survival	Growth, mg	% Survival	Growth, mg	% Survival	Growth, mg	% Survival	# Cocoons/Adult	% Hatched	# Young/Adult
Reference Values**										
Non toxic	>69	0.21 - 0.49	>85	1.0 - 5.0	>68	0.24 - 0.76	>88	7.2 - 12.3	40 - 78	12.0 - 45.6
Potentially toxic	60 - 68.9	0.14 - 0.20	80 - 84.9	0 - 0.9	58 - 67.9	0.11 - 0.23	84 - 87.9	5.9 - 7.1	30.8 - 39.9	3.6 - 11.9
Toxic	<60	<0.14	<80	--	<58	<0.11	<84	<5.9	<30.8	<3.6
Souris River - U/S	80.0	0.31	97.5	3.89	93.3	0.50	100	8.9	57.4	23.7
Souris River - D/S	89.3	0.32	98	4.29	89.3	0.64	100	8.5	**27.8**	13.1
Battle River G. S.	**16.0**	0.27	100	4.54	**68**	0.38	**87.5**	**5.2**	62.5	**5.7**
Prince Colliery	**40.0**	0.38	94	1.34	**36.7**	**0.10**	95	8.7	59.6	33.9
Salmon Harbour Mine	**66.7**	0.45	90	6.32	80	0.41	---	---	---	---

* U/S = upstream; D/S = downstream; G. S. = coal-based electrical generating station
** Reynoldson et al. 1997.
Note: --- Salmon Harbour not suitable for *T. tubifex* test due to large number of endemic worms.

Table 11. Ammonia content, ppm, measured during the toxicity tests

Sediment Site*	*Chironomus riparius*	*Hexagenia spp.*	*Hyalella azteca*	*Tubifex tubifex*
Souris River - U/S	sample lost	0.03	<0.01	nd
Souris River - D/S	sample lost	0.04	<0.01	nd
Battle River G. S.	nd	nd	<0.01	nd
Prince Colliery	2.8	0.6	9	2.6
Salmon Harbour Mine	0.85	0.06	<0.01	

* U/S = upstream; D/S = downstream; G. S. = coal-based electrical generating station
nd = non detectable

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