International Journal of Coal Geology 43 (2000) 357–372
International Journal of coal geology
www.elsevier.nl/locate/ijcoalgeo

Metals and polyaromatic hydrocarbons in the drinking water of the Sydney Basin, Nova Scotia, Canada: a preliminary assessment of their source

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Accepted 18 August 1999

Abstract

Twenty-five drinking water samples collected from the household property and from the Sydney Regional Municipality well bores and lakes were analyzed to evaluate the various inorganic parameters, level of concentrations of the priority elements and polyaromatic hydrocarbons (PAHs). The pH of the majority of the water samples was below the guidelines adopted by Health and Welfare Canada (1996), although the drinking waters supplied by the Sydney Regional Municipality were within the guidelines. Only three water samples (13 and 14: Point Aconi area and 16: Port Morien fish plant) have elevated concentrations of various PAHs compared to the detection limit. Eight samples have higher concentrations of manganese and two samples (number 7: Sydney Airport and number 1: RCMP Office; Reserve Mines) have higher concentrations of priority elements (especially lead) than the recommended guidelines (> 0.05 mg/l). These priority elements and the PAHs in the drinking water samples may have originated from the leaching of the individual coal seams within that part of the Sydney Basin. Other potential sources of these elements and PAHs (Power Plant disposal, Sydney Tar Pond, metalliferous rocks, hydrocarbon reservoir rocks) are not located close enough to the sampling sites of the water samples. Therefore, they are not considered the source of these elements and PAHs. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: drinking water; priority metals; PAHs; Sydney coals; Nova Scotia

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PII: S0166-5162(99)00067-1

1. Introduction

1.1. Background information

Since the beginning of this century, we have been living in a sophisticated chemical world (Stewart, 1990). In this chemical world, the pollutants that occur in our ecosystem can be differentiated into two categories: natural and synthetic. The natural pollutants are derived from the decay of plant substances, flow of water through rocks that contain fossil fuel (coal, petroleum, tar sand, oil shale, etc.), and transportation as air/water-borne components derived from volcanic eruptions or forest fires. Similar compounds, as those released naturally, may also be derived as a synthetic by-product from anthropogenic sources. Therefore, in a natural ecosystem (especially in the aquatic regime), pollutants can be derived from a number of two sources. The sources of some of the pollutants are complex and are often difficult to predict.

The distribution of inorganic elements in the aquatic environments is universal. They occur as suspended particulates or dissolved as elements, ions, or complex molecules. Some of them are toxic and carcinogenic to humans and other biohabitats. As discussed earlier, these elements or compounds are derived from the both natural (geogenic) and anthropogenic sources. Polynuclear aromatic hydrocarbons (PAHs) that contain two to eight fused aromatic rings are stable, bioaccumulative, toxic, and some are carcinogenic. PAHs are often adsorbed into organic particulates (Bouchez et al., 1996a,b). In an aquatic environment, PAHs are present in both dissolved and suspended particulate states. Similar to the inorganic elements, PAHs are derived from both natural (geogenic) and industrial sources. As an anthropogenic source, PAHs enter the aquatic environment as airborne dust and as precipitation derived from the anthropogenic sources. These include fossil fuel utilization (power generation), effluent or atmospheric discharge from other chemical industries such as coal coking, aluminum production through old technology, iron smelting, petroleum refining, tar paper production, wood preservation operations, and as part of asphalt pavement leachate (Environment Canada, Atlantic Region, 1995; Bouchez et al., 1996a,b; Howard, 1997). Bouchez et al. (1996a; b) showed that a ratio of phenanthrene and anthracene greater than 25 indicates a petroleum origin of the PAHs and smaller than 10 indicates a pyrolytic origin.

According to the Clean Air Amendment Act of 1980, 15 elements are considered as potentially toxic and hazardous to human habitat and health (U.S. Statutes at large, 1990). These elements are antimony (Sb), arsenic (As), beryllium (Be), cadmium (Cd), chlorine (Cl), cobalt (Co), chromium (Cr), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), phosphorous (P), selenium (Se), uranium (U), and thorium (Th). Health and Welfare Canada (1993a, b, 1996) has guidelines for the maximum concentration of the following elements in the drinking water: As, Ba (Barium), B (Boron), Cd, Cl (chlorine as chloride), Cr, Cu (copper), Fl (fluorine as fluoride), Fe (iron), Hg, Mn, Na (sodium), Pb, U, Zn (zinc). US EPA and Environment Canada have specified 16 PAHs as priority pollutants. These compounds are acenaphthylene, acenaphthene, anthracene, benz[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, benzo[*g,h,i*]perylene, chrysene, dibenz[*a,h*]anthracene, fluoranthene, fluorene, indeno-

[1,2,3-*cd*]pyrene, naphthalene, phenanthrene, pyrene. However, Environment Canada (1991); Environment Canada (1996) has strict guidelines only for benzo[*a*]pyrene. The biotic fate and toxicokinetics of PAHs are mainly documented for aquatic organisms and laboratory animals (Germain et al., 1993). However, because of the lipophilic characteristics of PAHs, they can easily be adsorbed through the food chain. In Canada, the ecotoxicity threshold (in milligrams per liter) data is documented only for 13 PAHs (Germain et al., 1993). Seven of these PAHs are known to be carcinogenic (Jwel-It Joint Venture, 1996). The carcinogenic effect of the other PAHs has not yet been documented. The carcinogenic PAHs are benz[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*g,h,i*]perylene, benzo[*e*]pyrene, chrysene, dibenz[*a,h*]-anthracene, and indeno[1,2,3-*cd*]pyrene (Jwel-It Joint Venture, 1996).

In Europe, the list of the priority PAHs differs from the USA and Canada. They have specified that the sum of the concentration for six PAHs (benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, indeno[1,2,3-*cd*]pyrene, benzo[*g,h,i*]perylene, and fluoranthene) must not exceed 200 ng per liter of water. In the EPA list of priority PAHs, dibenz[*a,h*]anthracene is included. Europeans do not include this PAH.

1.2. Origin of pollutants from natural source

In coal seams, metallic and nonmetallic elements are associated both as a mineral species or bonded with the organic matter (Gluskoter et al., 1977; Swaine and Goodarzi, 1995). Similarly, some of the low-molecular-weight PAHs is an inherent component in a peat stage of coalification. The formation of three- to six-ring PAHs within the coal matrix is accompanied by a change in rank of coal (from lignite to bituminous) because of aromatization reactions. Coal seams and associated rocks (sandstones and shales) act as aquifers and, therefore, contain an enormous volume of groundwater. Coal seams also contain inherent water in a bonded state. This water is released from the coal seams during compaction and dehydration. Aquifers such as coal seams are often recharged. The water in these temporary aquifers is dynamic and flows towards more porous rocks (e.g., sandstones and limestones). This is accomplished through faults and other conduits. Moreover, inorganic elements/compounds and PAHs entered sandstone aquifers through leaching of coal seams and other sedimentary rocks (Pagenkopf, 1978; Masters, 1995). Often these waters flow from reservoirs to other underground but stratigraphically higher aquifers above or to lakes and rivers through seepage as a result of pressure gradient. However, the current study does not include hydrogeology and groundwater geochemistry and are considered as preliminary.

1.3. Objectives

The objectives of this paper are: (a) to quantify the amount of selected elements, other inorganic parameters, and PAHS in the drinking waters of the Greater Sydney area in Nova Scotia, Canada; and (b) to find out the possible origin of these components in the water.

2. Samples and analytical methods

2.1. Samples

Twenty-five water samples from various villages and towns in the Greater Sydney areas, Cape Breton County, Nova Scotia were collected during the summer and fall of 1997 (Mukhopadhyay, 1997a) (Table 1). The water samples were selected from the following sources: (a) individual houses/factories/shops who get their drinking water supply from their own well bores; (b) from the drinking water of individual homes supplied by the City of Greater Sydney; and (c) from river, lakes, and well bores that were used by the various municipalities to supply drinking water to individual homes. Fig. 1 shows the location of the samples.

Usually polyethylene bottles with polyethylene caps are used for the sampling of metals (except for Hg). These bottles were treated with a preservative (nitric acid) before or immediately after sampling and were kept in a refrigerator. However, for the analysis of PAHs, amber glass bottles are essential to prevent changes due to ultraviolet

Table 1
Location and depth of water samples from the Sydney Basin, Nova Scotia, Canada

Sample no.	Location	Depth (m)	Comment
1	Reserve Mines, RCMP Office	~15.3	Police population drinks; smell of H_2S
2	Radar Base, Sydney	183	400–500 people drink
3	New Waterford Pump House	Lake Water	3500 people drink
4	MacKie’s Lane, Sydney	~ 30.5	14 homes
5	Correctional Centre, Sydney	Unknown	Inmates and guards drink; smell of H_2S
6	UCCB, Marconi Campus	61	University population drinks
7	Sydney Airport, Reserve Mines	~ 60	Airport population drinks
8	Sand Lake, Glace Bay Town Water	surface	Glace Bay population drinks
9	Port Morien Pumphouse	30.5	People from five homes drink
10	Donkin Pumphouse	~ 30.5	Donkin population drinks
11	Scotsburn Dairy Farm, Point Morien	~15.5	Cattle + people from five home drink
12	Birch Grove Pumphouse	~ 30.5	Birch Grove population drinks
13	Pumphouse, Prince Mine	~ 35.5	Mine area population drinks
14	Point Aconi Pumphouse	surface	Point Aconi population drinks
15	Harold Barro’s wellbore, Donkin Mine area	~15.5	Population from two homes drinks
16	Hopkins Fish Plant, Port Morien	~ 30.5	Fish plant workers drink
17	North Sydney Pumphouse	surface	North Sydney population drinks
18	Sydney River Irving Gas Station	~ 30.5	Water is connected Sydney Steel Plant
19	Sydney Community Water Treatment Plant	surface	Sydney population drinks, started 1996
20	Sydney Town old water supply	surface	Sydney population drank before 1996
21	Sydney City Water well in the Field #1A	~ 30.5	Sydney population drinks, Started 1996
22	Rita’s Kwik Way, Lingan Mine	~ 30.5	Resturant population drinks
23	Bayside canteen, Gardiner Mines	~ 30.5	Resturant population drinks
24	Christiansen and Son’s Dairy Farm, Gardiner Mines	~ 30.5	Dairy population drinks
25	George MacQueen, Glace Bay	~15.5	People from two homes drink

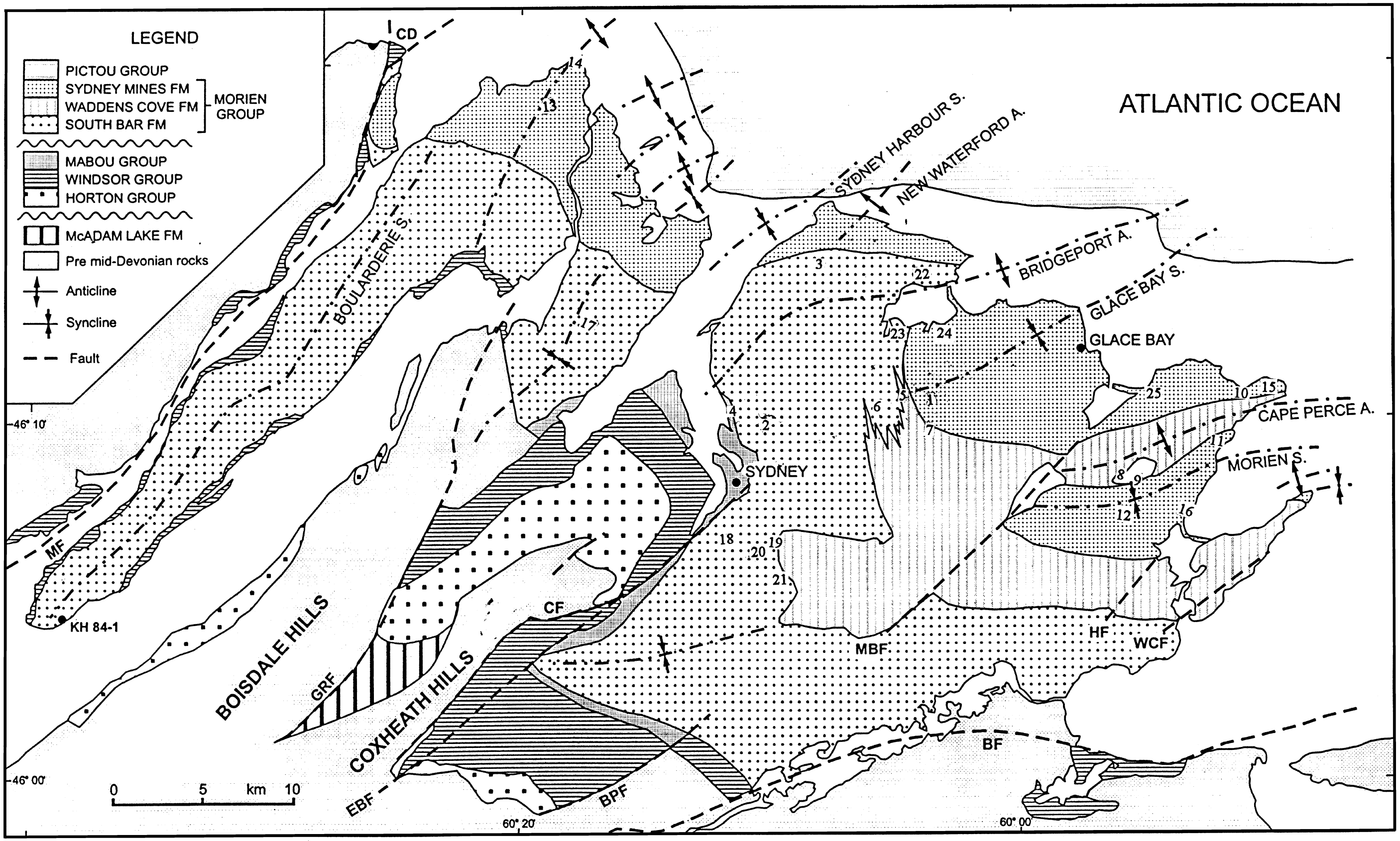


Fig. 1. Geological map of the Sydney Basin and the location of the samples (after Pascucci et al., in preparation; modified after Boehner and Giles, 1986).

Table 2

Analytical data on inorganic geochemistry and dissolved organic carbon in the water samples from the Sydney Basin along with the detection limit and recommended guidelines

	pH	Conductivity[a] (umh/cm)	DOC (mg/l)	Hard[a] (mg/l)	Nitrate (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	Amm[a] (mg/l)	Na (mg/l)	K (mg/l)	Al (mg/l)	Ca (mg/l)	Mg (mg/l)	P (mg/l)	Fe (mg/l)	Mn (mg/l)
Detection limit[a]	0.1	1	0.5	0.1	0.05	1	2	0.05	0.1	0.1	0.01	0.1	0.1	0.101	0.02	0.002
Guidelines[a]	6.5–8.5				45	< 250	< 500		< 200						< 0.3	< 0.05
15	5.5	285	0.9	52.1	5.67	48.9	17	nd	27.8	4.3	0.12	9.5	6.9	0.51	nd	0.048
10	6.7	114.3	2.5	15.1	nd	24.8	4	nd	14.2	0.6	0.012	2.9	1.9	nd	0.24	0.25
25	7.4	315	0.9	111	nd	22.4	7	0.28	15	4.9	nd	31.1	8.2	nd	0.15	0.083
11	6.8	342	0.7	57.4	2.68	46.9	4	nd	43	4.6	nd	2.1	6.6	nd	nd	0.002
16	6.8	3500	0.9	512	nd	796	134	0.48	445	18.4	nd	103	61.8	0.26	2	2.1
9	5.5	61.2	2.5	6.9	nd	13	4	nd	7.4	0.4	0.088	1.1	1	nd	0.25	0.088
8	5.5	65.2	1.7	7.7	0.05	12.4	5	nd	7.3	0.4	0.087	1.1	1.2	nd	0.23	0.059
12	6.3	64.1	2.2	7.1	nd	13.1	3	nd	8.3	0.4	0.017	1.2	1	nd	0.33	0.027
24	5	160.5	1.1	48	4.2	17.9	9	nd	8	2.5	0.04	11.8	4.5	nd	nd	0.017
23	7.5	970	0.9	126	nd	178	nd	0.1	125	3.5	nd	42.5	4.8	0.12	0.063	0.074
22	5.2	129	1.5	24.1	0.74	16.2	19	nd	10.1	3.7	0.069	5.7	2.4	0.16	0.028	0.041
3	6	75.6	1.9	14.2	nd	11.7	9	nd	7.3	0.6	0.01	3.2	1.5	nd	0.23	0.058
7	6.8	303	1.5	48.8	nd	9.2	4	0.1	44.8	5.3	0.013	13.6	3.6	nd	3	0.77
1	6.7	368	0.9	52.2	nd	26.6	8	0.08	61.8	5.7	nd	14.8	3.7	0.11	0.13	0.11
5	7.7	345	0.6	74.5	nd	26.8	5	0.09	42.5	5.4	nd	22.6	4.4	0.11	nd	0.072
6	7.1	269	0.6	83.8	nd	20.4	6	nd	20.6	2.5	nd	25.3	5	0.1	0.47	0.43
2	7.1	316	0.6	127	nd	18.1	16	nd	15.6	1.4	nd	41.2	5.9	nd	nd	0.059
4	6	248	0.6	68.9	0.41	37	13	nd	14.1	2	nd	22	3.4	nd	nd	0.019
21	7.4	268	0.9	88.4	nd	22.2	7	nd	17.3	1.8	nd	27.5	4.8	nd	0.049	0.25
20	5.6	88.1	3.7	12.6	0.13	16.4	3	nd	9.4	1.2	0.051	3.4	1	nd	0.61	0.16
19	7.3	359	1.3	100	nd	44.9	9	nd	28.7	2.2	nd	31.8	5	0.1	0.022	0.24
18	6.3	136.3	4	35.9	nd	19.2	13	nd	9.7	0.5	0.032	11.4	1.8	0.18	0.067	0.054
17	6.3	85.5	2.1	11.9	nd	17.4	4	nd	10.8	0.4	0.01	2.8	1.2	nd	0.03	0.012
14	7.4	220	nd	56.8	nd	11	14	nd	22.5	1.6	nd	17.8	3	nd	0.028	0.15
13	7	647	0.7	123	nd	60.4	48	0.15	87.2	6	nd	34.3	9.1	0.12	0.043	0.37

nd = Not detected. Guidelines based on Health and Welfare Canada (1996).

[a] Guidelines for maximum acceptable concentration (MAC), interim maximum acceptable concentrations (IMAC), aesthetic objectives (AO) (after Health and Welfare Canada, 1996).

radiation. Therefore, five sets of water samples were collected in the following way for each sample:

- For pH and conductivity analysis — water collected in a clean bottle.
- For metal/nonmetal analysis — water collected in acid-treated plastic bottles.
- For various other inorganic analyses — water collected in treated plastic bottles.
- For mercury analysis — water collected in a specially treated (nitric acid + dichromate solution) glass bottle with Teflon liner.
- For PAHs analysis — water collected in an amber glass with Teflon lining.

All samples were kept cool at 4°C during and after collection using a cool pack and a refrigerator.

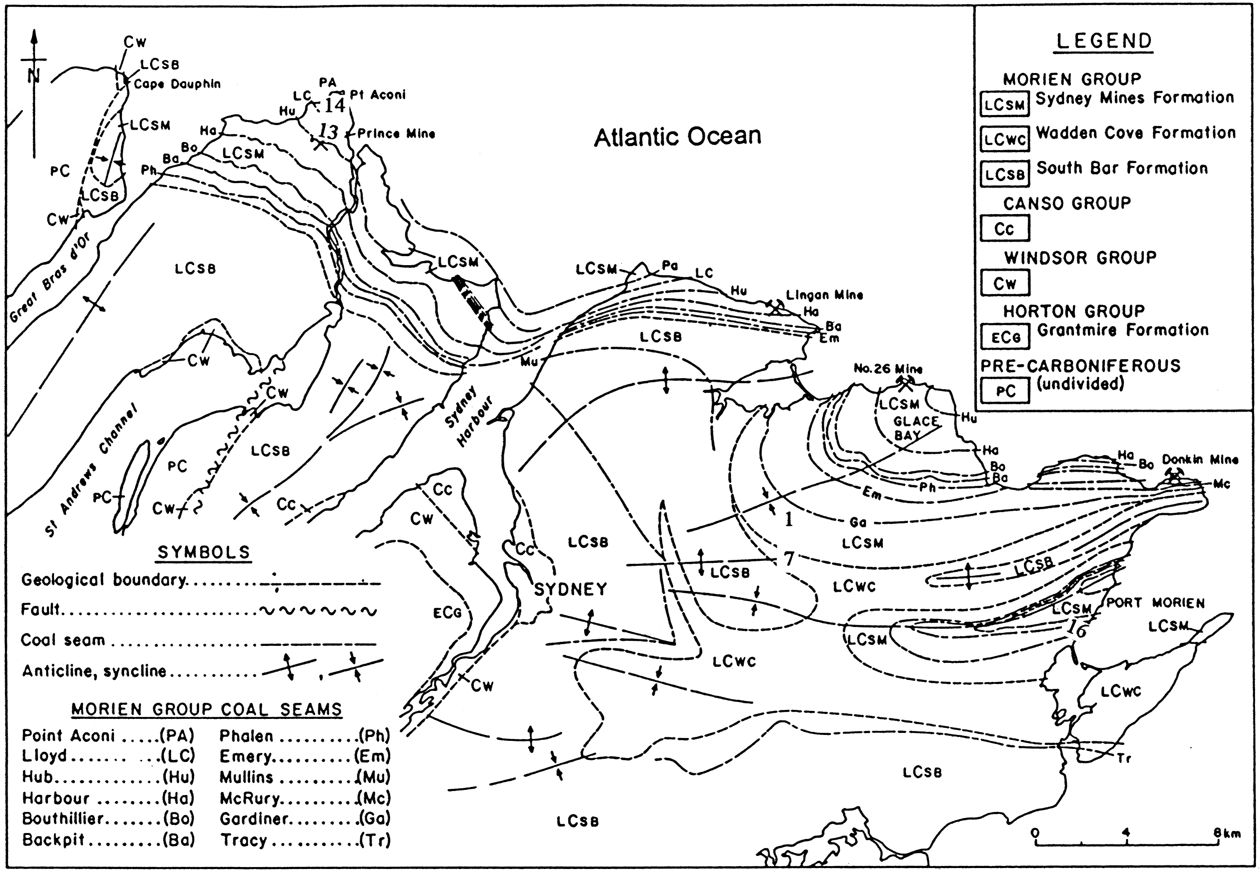
2.2. Analytical methods

The metal and inorganic analyses were performed according to US EPA, Environment Canada (1989), and Health and Welfare Canada (1993a, b) and standard methods (Stewart, 1990; Patnaik, 1996) using neutron activation analysis (NAA), inductively coupled plasma mass spectrometry (ICPMS), and X-ray fluorescence (XRF). The analytical method for PAHs was based on US EPA Method 8270 that involves solvent extraction of water samples and analysis by capillary gas chromatography mass spectrometry (GC–MS) (Phillips Analytical Services, 1996). The reporting limits of the elements and PAHs were evaluated using US Environmental Protection Agency (1987) protocol. The detection limits of various elements, inorganic ions, compounds and PAHs are shown in Table 2. The following surrogates and internal standards were used for quality control: acenaphthene-d10, acenaphylene-d8, anthracene-d10, chrysene-d12, naphthalene-d8, phenanthrene-d10, pyrene-d10, and *p*-terphenylene-d14.

3. Results and discussions

All the water samples were collected from the Sydney Basin, which lies within the Upper Carboniferous Sydney Mines Formation and the South Bar Formation of the Morien Group (Fig. 1). The geological age of the Morien Group ranges from Westphalian C and Stephanian (Hacquebard and Donaldson, 1969). There are 12 distinct coal seams present within Sydney Mines and South Bar formations (Fig. 2); other thin coal seams also occur within the group. All coals are of bituminous rank, with the majority of them being high to medium volatile bituminous (Hacquebard and Donaldson, 1969; Mukhopadhyay, 1992; Mukhopadhyay et al., 1998).

The analytical data for the various inorganic geochemical parameters/dissolved organic carbon, metals and concentration of PAHs in the 25 water samples are listed in Tables 2–4, respectively. The samples were clustered according to their position on the map of the Sydney Basin from east to west of the Sydney Basin. Accordingly, samples 15, 10, 25, 11, 16, 9, 8, and 12 are located in the eastern part of the basin whereas samples 17, 14, and 13 lie within the western part. The pH level of water 10 samples



Geological map of the Sydney coalfield

Fig. 2. Geological map of the Sydney Basin with distribution of selected coal seams (after Boehner and Giles, 1986).

Table 3
Metals in the water samples from the Sydney Basin along with the detection levels and recommended guidelines

	pH	As (mg/l)	Ba (mg/l)	Be (mg/l)	B (mg/l)	Cd (mg/l)	Cr (mg/l)	Co (mg/l)	Cu (mg/l)	Hg (mg/l)	Mo (mg/l)	Ni (mg/l)	Pb (mg/l)	Se (mg/l)	Sr (mg/l)	U (mg/l)	V (mg/l)	Zn (mg/l)
Detection limits[a]	0.1	0.002	0.005	0.005	0.005	0.0003	0.002	0.001	0.002	0.00005	0.002	0.002	0.0005	0.002	0.005	0.0001	0.0020	0.002
Guidelines[a]	6.5–8.5	0.025[a]	1[a]		5[a]	0.005[a]	0.05[a]	0.01[b]	1[a]	0.001[a]	0.005[b]	0.01[b]	0.01[a]	0.01[a]		0.1[a]		5[a]
Sample 15	5.5	nd	0.081	nd	0.043	nd	nd	nd	0.49	nd	nd	0.005	0.015	nd	0.12	nd	nd	0.071
10	6.7	nd	0.018	nd	0.01	nd	nd	nd	ltdl[a]	nd	nd	nd	0.0007	nd	0.02	nd	nd	0.006
25	7.4	nd	0.16	nd	0.03	nd	md	nd	0.003	nd	nd	nd	nd	0.66	nd	nd	nd	0.007
11	6.8	nd	0.064	nd	0.04	nd	nd	nd	0.15	nd	nd	nd	0.0018	nd	0.25	nd	nd	0.015
16	6.8	0.003	0.068	nd	0.15	nd	0.003	nd	0.003	nd	nd	nd	nd	nd	1.4	nd	0.006	0.016
9	5.5	nd	0.007	nd	0.005	nd	nd	nd	nd	nd	nd	nd	0.0005	nd	0.012	nd	nd	0.006
8	5.5	nd	0.008	nd	0.007	nd	0.034	nd	0.059	nd	nd	0.002	0.0005	nd	0.014	nd	nd	0.002
12	6.3	nd	0.011	nd	0.006	nd	nd	nd	0.009	nd	nd	nd	0.005	nd	0.01	nd	nd	0.019
24	5	nd	0.039	nd	0.011	nd	nd	nd	0.1	nd	nd	nd	0.0008	nd	0.035	nd	nd	0.012
23	7.5	nd	2.3	nd	0.044	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.8	nd	nd	0.004
22	5.2	nd	0.049	nd	0.03	nd	nd	nd	0.27	nd	nd	0.002	0.0016	nd	0.036	nd	nd	0.026
3	6	nd	0.005	nd	0.007	nd	nd	nd	0.1	nd	nd	nd	0.001	nd	0.026	nd	nd	0.1
7	6.8	nd	0.23	nd	0.041	nd	nd	nd	0.95	nd	nd	0.004	0.16	nd	0.33	nd	nd	0.27
1	6.7	nd	0.24	nd	0.041	nd	nd	nd	0.17	nd	nd	nd	0.019	nd	0.4	nd	nd	0.12
5	7.7	nd	0.33	nd	0.039	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.056	nd	nd	0.005
6	7.1	nd	0.14	nd	0.030	nd	nd	nd	0.014	nd	nd	0.003	0.0035	nd	0.4	nd	nd	0.042
2	7.1	nd	0.031	nd	0.027	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.27	nd	nd	0.038
4	6	nd	0.041	nd	0.02	nd	nd	nd	0.003	nd	nd	nd	.0006	nd	0.1	nd	nd	0.11
21	7.4	nd	0.11	nd	0.02	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.25	nd	nd	0.008
20	5.6	nd	0.012	nd	0.005	nd	nd	nd	0.077	nd	nd	nd	0.0019	nd	0.016	nd	nd	0.14
19	7.3	nd	0.16	nd	0.032	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.39	nd	nd	0.007
18	6.3	nd	0.023	nd	0.013	nd	nd	nd	0.3	nd	nd	nd	0.0025	nd	0.081	nd	nd	0.012
17	6.3	ltdl[a]	0.022	nd	0.006	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.014	nd	nd	0.011
14	7.4	ltdl[a]	0.07	nd	0.023	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.13	nd	nd	0.014
13	7	ltdl[a]	0.25	nd	0.047	nd	0.002	nd	0.002	nd	nd	nd	0.0008	nd	0.51	nd	nd	0.018

nd = Not detected. Guidelines based on Health and Welfare Canada (1996).

[a] Guidelines for MAC, IMAC, and AO.

[b] Interim assessment criteria (Environment Canada, 1991).

Table 4
Polyaromatic hydrocarbons (PAHs) in the water sample from the Sydney Basin along with the solubility of some compounds in water (at 25°C), their detection limit and recommended guidelines

PAHs (compound name)	Detection limit[a] (μg/l)	Guidelines (μg/l)	Solubility in water (mg/l)	15	10	25	11	16	9	8	12	24	23	22	3
Naphthalene	0.05	0.2[b]	31.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Perylene	0.01			nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1-Methylnaphthalene	0.01		27[c]	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-Methylnaphthalene	0.02		26[c]	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenaphthylene	0.01		3.93	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenaphthene	0.01		3.42	nd	nd	nd	nd	0.022	nd	nd	nd	nd	nd	nd	nd
Fluorene	0.01		1.98	nd	nd	nd	nd	0.018	nd	nd	nd	nd	nd	nd	nd
Phenanthrene	0.01	0.2[b]	1.29	nd	nd	nd	nd	0.025	nd	nd	nd	nd	nd	nd	nd
Anthracene	0.01		0.045	nd	nd	nd	nd	0.014	nd	nd	nd	nd	nd	nd	nd
Fluoranthene	0.01		0.21	nd	nd	nd	nd	0.014	nd	nd	nd	nd	nd	nd	nd
Pyrene	0.01	0.2[b]	0.135	nd	nd	nd	nd	0.041	nd	nd	nd	nd	nd	nd	nd
Benz[*a*]anthracene	0.01	0.01[b]	0.0057	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Chrysene	0.01		0.0018	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[*b*]fluoranthene	0.01	0.01[b]	0.014	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[*k*]fluoranthene	0.01	0.01[b]	0.0043	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[*a*]pyrene	0.01	0.01[a]	0.0012	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Indeno[1,2,3-*cd*]pyrene	0.01	0.1[b]	0.00053	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dibenz[*a*,*h*]anthracene	0.01	0.01[b]	0.0005	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[*g*,*h*,*i*]perylene	0.01		0.0007	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

PAHs (compound name)	Detection limit[a] (μg/l)	7	1	5	6	2	4	21	20	19	18	17	14	13
Naphthalene	0.05	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Perylene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1-Methylnaphthalene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-Methylnaphthalene	0.02	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenaphthylene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenaphthene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.014	0.014
Fluorene	0.01	0.011	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.01	0.011
Phenanthrene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.01	nd	0.019	0.03
Anthracene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Fluoranthene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.019
Pyrene	0.01	nd	nd	nd	nd	nd	nd	nd	0.012					
Benz[*a*]anthracene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.013
Chrysene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[*b*]fluoranthene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[*k*]fluoranthene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[*a*]pyrene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Indeno[1,2,3-*cd*]pyrene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dibenz[*a*,*h*]anthracene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[*g*,*h*,*i*]perylene	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

nd = Not detected; guidelines based on Health and Welfare Canada (1996). Sample numbers: 15, 10, 25 = Donkin Mine and Glace Bay; 11, 16, 9 = Port Morien; 8 = sandy lake, Port Morien; 24 and 23 = Gardiner Mines; 22 = close to Lingan Mine; 3 = New Waterford; 7, 1, 5, 6 = Reserve Mines and closeby areas; 2 and 4 = Sydney City area; 21, 20, 19, and 18 = Sydney City Area Water supply and Sydney River areas; 17 = North Sydney; 14 and 13 = Point Aconi area.

[a] Guidelines for MAC, IMAC, and AO.

[b] Interim assessment criteria (Environment Canada, 1991; Health and Welfare Canada, 1996).

[c] From Bouchez et al., 1996a,b.

(numbers 15, 9, 8, 12, 24, 22, 3, 4, 20, 18, and 17) is below the Canadian drinking water quality guidelines ($pH < 6.5$). With the exception of one sample (number 16, Port Morien area, eastern part of Sydney Basin), all samples have lower nitrate, chloride, sulfate, Na, K, Al, Ca, and Fe levels compared to the Canadian Guideline for Drinking Water Quality (Table 2). However, manganese concentration in most samples (except for samples 15, 11, 12, 24, 22, 6, 4, and 17) is higher than the recommended guidelines (> 0.05 mg/l) (Table 2). With the exception of two samples (number 7: Sydney Airport and number 1: RCMP Office; Reserve Mines), none of these samples has higher concentrations of toxic metals (Table 3). Samples 7 and 1 are located close to each other (Fig. 1). They have an elevated concentration (> 0.01 mg/l) of lead (Pb) compared to the recommended level of Health and Welfare Canada (1996) (Table 3). Sample number 7 also has higher concentration of manganese (Mn) than the recommended level. They have similar pH, conductivity and concentrations of Ba, B, and Sr. All samples contain Ba, B, Sr, and Zn but in lower concentrations than the recommended levels of Health and Welfare Canada (1996) for human intake. At this stage, the origin of these elements in the water samples is not definitive. Some of these elements may have been derived from the coal seams. It has been documented previously that most of these coal seams are sulfur-rich (1.5–10%) and have elevated concentrations of these priority elements (Mukhopadhyay, 1992; Mukhopadhyay et al., 1998). For example, samples 1 and 7 are close to the McRury, Gardiner and Tracy coal seams that contains abundant sulfur mostly in the form of pyrite. Lead, copper, and zinc are usually associated with pyrite as mineral galena (PbS) or solid solution with pyrite (Finkelman, 1994; Mukhopadhyay et al., 1998). The concentration of manganese in the water may also be related to clay mineral association. The elements Ba, B, and Sr may either be derived from seepage of paleowater from the marine Windsor Group (Mukhopadhyay et al., 1998) or from the trapped paleowater of the Windsor Group within the coal-bearing horizon (Tom Martel, personal communication, 1998).

At the bituminous coal rank stage, most coals have generated abundant bitumen that can be extracted and separated into various fractions by solvent extraction (Hunt, 1995). Usually the liquid chromatographic data suggests that the major fraction within the hydrocarbons in coal is aromatic hydrocarbons. The concentration of these compounds is possibly related to their solubility in water and photochemical degradation due to ultraviolet light. Both the solubility and photochemical degradation of PAHs are dependent on the number of aromatic rings. Accordingly, within the PAHs that are commonly associated within the solvent extractable component of coals in the high to medium volatile bituminous rank, naphthalene (two-ring) or phenanthrene (three-ring) have higher solubility and lower photochemical degradation properties compared to benzo[*a*]pyrene (five-ring aromatic structure) (Verschueren, 1996).

The separation of various aromatic compounds in coal by liquid chromatography has been documented by Radke et al. (1984). The GC–MS study of the aromatic fraction of the bitumen from two coal seams of the Cumberland Basin showed abundant concentrations of naphthalene, acenaphthene, phenanthrene, fluorene, fluoranthene and pyrene (Kruge, 1997). High concentrations of these two- to five-ring PAHs in the water have been documented in a hydrous pyrolysis of two coal seams from the Cumberland Basins during an artificial maturation experiment (Mukhopadhyay et al., 1993).

PAHs have not been detected in any of the water samples except for five samples (7, 13, 14, 16, and 20). Moreover, the concentrations of the PAHs in these five samples did not exceed the recommended guidelines of Health and Welfare Canada (1989, 1993a, b, 1996). Only three samples (13, 14, and 16) have more than three types of PAH compounds. Samples 13 and 14 (both from the Point Aconi area) and 16 (Port Morien) have elevated concentrations of acenaphthene, fluorene, and phenanthrene. Samples 13 and 16 have fluoranthene and pyrene; sample 16 contains anthracene. Some other samples (7, 20, and 18) contain small amounts of one single polyaromatic compound (Table 4). It is interesting to note that none of the water samples contains a stretched three-ring PAH such as anthracene, indicating that solubility plays an important role in the elevated concentrations of these PAHs. None of the PAHs that have solubility in water less than 0.1 mg/l (at 25°C) is present in the waters. However, the absence of naphthalene in these waters could not be explained at present.

In any coal-bearing region or in any city that has coal stockpiles and an abundance of rainfall, the PAHs and the priority metals can be released by leaching and can contaminate the drinking water aquifers. Verschueren (1996) has documented that concentrations of naphthalene and fluoranthene in a typical coal tar leachate vary between 0.004 (in the influent) or 0.025 (in the effluent) μg/l and 0.003 (in the influent) or 0.081 (in the effluent) μg/l, respectively. Phenanthrene concentrations in the soluble and suspended fractions of the coal leachate vary between 0.02 and 0.19 μg/l and 0.02 and 6.12 mg/kg, respectively. On the other hand, pyrene concentrations in the soluble and suspended fraction of the coal leachates vary between 0.02 to 0.33 μg/l and 0.02 to 3.89 mg/kg, respectively (Verschueren, 1996). All three samples (13, 14, and 16) that have elevated concentrations (compared to the detection limit) of various PAHs, are closely connected to the different coal seams within the Morien Group. The aquifer sandstone of the water sample 16 lies within the same stratigraphic unit as that of the Tracy and Gardiner coal seams and to other local seams such as the Blockhouse and the Gowrie. On the other hand, the aquifer for samples 13 and 14 are within the same stratigraphic unit of the Hub, Lloyd, and Point Aconi seams.

The origin of the PAHs and the priority metals in the drinking water of the Sydney Basin is not known. There are three possibilities that can relate to their origin.

◆ These waters have been contaminated through leaching of the combustion residues from the Sydney coke oven site (‘Tar Pond’) or from the disposal site of the two power plants (Lingan and Point Aconi) of the Nova Scotia Power (NSPI). Both Coke Oven Plant and NSPI from Sydney used coal seams from the Sydney Basin as their feedstock for coke production and power generation. However, the analyzed water samples were not located close enough to these areas to be affected by leaching to the groundwater.

◆ These waters have been contaminated through the leakage or flow of paleowater from the Windsor Group or leaching of the Windsor Group sedimentary strata that contain hydrocarbon reservoirs and source rocks. These waters may have been contaminated through leaching of other rocks containing metalliferous ore bodies. However, the present day drainage pattern possibly ruled out this possibility.

◆ The waters have been contaminated through leaching of the coal-bearing horizons. The coal seams are ubiquitous in these parts of the Sydney Basin. These coal seams have elevated concentrations of sulfur, pyrite, and other metals and nonmetals (Mukhopadhyay et al., 1998). These elements were possibly enriched due to leaching of the Windsor Group strata into the paleopeat mire during the early deposition of the coal. Moreover, these coal seams are high to medium volatile bituminous in rank and have high bitumen extract yield (Mukhopadhyay, 1997b, 1998, 1999). They may contain abundant concentrations of PAHs similar to the Carboniferous Cumberland Basin coals of Nova Scotia (Mukhopadhyay et al., 1993; Kruge, 1997). The origin of priority elements (especially Pb, Cu, and Zn) and PAHs in the drinking water samples is considered to be closely connected to the individual coal seams of that area within the Sydney Basin (Mukhopadhyay et al., 1998). Paleowater from the Windsor Group may also be linked to the enrichment of Ba, B, and Sr in these waters.

4. Conclusions

The paper deals with the quality of the drinking water in the Sydney and surrounding areas, Cape Breton County, Nova Scotia. Accordingly, 25 water samples were analyzed to evaluate the basic inorganic geochemical properties, and concentrations of the priority elements and PAHs in these waters. Based on these observations the following conclusions were made.

⇒ The majority of the water samples has pH below the standard guidelines of the Health and Welfare Canada (1996), although chloride and sulfate levels are within the recommended guidelines.

⇒ Within the priority element category and with the exception of Mn and Pb, water samples have low concentrations of all other elements and are within the guidelines of Health and Welfare Canada (1996). A large number of water samples, however, has elevated concentrations of Ba, B, Mn and Sr than the recommended guidelines. Two samples near the Reserve Mines area have higher concentrations of Pb that has possibly been mobilized due to low pH of the water. Most of samples have slightly elevated concentrations of Cu and Zn but within the recommended guidelines.

⇒ Except for benzo[*a*]pyrene, the concentrations of the PAHs have no proper guidelines by the Health and Welfare Canada (1996) for their maximum acceptable concentration (MAC). Three samples (two from the Point Aconi area and one from the Port Morien area) have some elevated concentrations of mainly two- to three-ring PAHs. Their concentrations may partly be related to the solubility of the PAHs in the waters.

⇒ The proximity of the metal- and PAH-enriched drinking water samples to the coal seams in these regions suggests that these components in the drinking water may have been contaminated. The leaching of the closely connected coal seams that contain priority metals and PAHs as a part of the deposition and maturation processes causes the contamination. Paleowater from the Windsor Group may also be linked to the enrichment of Ba, B, and Sr in these waters.

Acknowledgements

The authors acknowledge the help of Greg Penny/Albert Harriet, Public Water Works and Engineering Department of the City of Sydney, Cape Breton Regional

Municipality, Sydney, Nova Scotia and Terry MacPherson/Anna Steel of the Nova Scotia Department of Environment, Sydney, Nova Scotia for their help during the collection of water samples. The authors acknowledge the help of Phillips Analytical Services for their analytical data. The authors acknowledge Don MacNeil and Kevin Gillis of the Nova Scotia Department of Natural Resources, Sydney and Stellarton, Nova Scotia, for providing the geological information. The authors also thank Prof. M.A. Kruge, Southern Illinois University at Carbondale, IL, for fruitful scientific discussions. The authors acknowledge the help of two reviewers (Dr. T. Gentzis and M. Labonte) for their fruitful comments that greatly improved the manuscript.

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