October 2013

APPENDIX 3.4

Peace-Athabasca Delta Assessment

REPORT

Project Number: 13-1346-0001

Golder Associates

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1.0 INTRODUCTION

The Environmental Impact Assessment (EIA) completed for the Pierre River Mine (PRM) predicted that there will be no adverse cumulative effects on the Peace-Athabasca Delta (PAD) from the PRM in combination with other developments in the Oil Sands Region. As part of the December 2011 sufficiency review submissions, Environment Canada requested additional review of the effects of sediment on water quality in the PAD, and Parks Canada requested an assessment of incremental and cumulative effects on the PAD. Based on these comments and others received through the review process for this EIA, Shell agreed in the January 18, 2012 letter to the Joint Review Panel to provide an assessment of the PAD. This appendix provides context for understanding the cumulative effects assessment for the 2013 Planned Development Case (PDC) of air quality, hydrology and surface water quality as it relates to the PAD. Discussion is also provided about the incremental effects of PRM on the PAD.

1.1 Location

The PAD is located in northeastern Alberta at the western end of Lake Athabasca where the Peace, Athabasca and Birch rivers converge (Figure 1.1-1). About 80% of the PAD is in Wood Buffalo National Park.

The PAD has a drainage basin of about 600,000 km^2, which includes most of northern Alberta and parts of northern British Columbia and Saskatchewan (Parks Canada 2010); it comprises:

- three main deltas, including:
    - Birch River Delta (168 km^2);
    - Peace River Delta (1,680 km^2); and
    - Athabasca River Delta (1,960 km^2).
- numerous interconnected channels (both active and inactive) and shallow, open-water areas; the largest of these include:
    - Lake Claire;
    - Baril Lake;
    - Mamawi Lake; and
    - Richardson Lake.

The southern extent of the PAD is approximately 65 km downstream of PRM.

LEGEND

● HYDROMETRIC STATIONS

➡ FORWARD FLOW DIRECTION

➡ REVERSE FLOW DIRECTION

▨ PEACE-ATHABASCA DELTA AREA

REFERENCE

DATUM: NAD83 PROJECTION: UTM ZONE 12 . IMAGE OBTAINED FROM GOOGLE EARTH, USED UNDER LICENSE. GOOGLE EARTH IMAGE IS NOT TO SCALE.

15 0 15

SCALE KILOMETRES

PROJECT

PIERRE RIVER MINE PROJECT

TITLE

LONG-TERM HYDROLOGY MONITORING STATIONS IN THE PEACE-ATHABASCA DELTA

Shell Canada Limited

PROJECT	13.1346.0001.6105		FILE No. 13134600016105A001	
DESIGN	MA	22 Aug. 2013	SCALE AS SHOWN	REV. 0
CADD	PSR	22 Aug. 2013	**FIGURE: 1.1-1**	
CHECK	MB	22 Aug. 2013		
REVIEW	WES	22 Aug. 2013		

1.2 Scope

For this assessment, existing conditions, historical trends, as well as an environmental evaluation of PRM effects and the 2013 PDC, were assessed for air quality, hydrology and surface water quality. Changes to key issues and indicators are evaluated in the context of the PAD for identified key indicators, as well as from the results of the PDC assessment completed. The assessment also provides context on whether the PAD warrants inclusion in aquatics Regional Study Areas for EIAs in the region.

The scope of this assessment was limited to existing information that could be obtained from publicly available sources, such as the Regional Aquatics Monitoring Program (RAMP), Alberta Environment and Sustainable Resource Development (ESRD) and Environment Canada. Consequently, the spatial representation of the assessment was focused on parts of the PAD that have been most intensively monitored. For example, RAMP has monitored sediment quality in the Athabasca River Delta for over a decade, so these locations provided the most comprehensive dataset upon which to base an analysis. It is anticipated that Environment Canada will be implementing additional monitoring in the PAD at locations further downstream.

2.0 AIR QUALITY

This section provides context for understanding the cumulative effects assessment of air quality as it relates to the PAD. The following sections discuss the existing air quality conditions in the PAD as well as the environmental evaluation based on the 2013 PRM Application Case and the 2013 PDC.

The existing air quality in the PAD was assessed using continuous air quality monitoring data from the Wood Buffalo Environmental Association Fort Chipewyan air monitoring station, which is the closest station to the PAD. The effects of emissions from PRM and other regional projects on air quality in the PAD were assessed using dispersion modelling for two assessment cases, namely 1) 2013 PRM Application Case (i.e., existing and approved projects combined with PRM); and 2) 2013 PDC (existing, approved and planned projects, including PRM). Dispersion modelling results are presented for the communities of Poplar Point (IR 201G) and Fort Chipewyan, which are located in the vicinity of the PAD.

2.1 Historic Data and Existing Conditions

The Wood Buffalo Environmental Association Fort Chipewyan air quality monitoring station is located on the shore of Lake Athabasca outside the community of Fort Chipewyan. The following compounds are measured hourly: sulphur dioxide (SO_2), ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2), oxides of nitrogen (NO_X) and particulate matter with a mean diameter less than 2.5 µm ($PM_{2.5}$). These monitoring data were obtained from the Clean Air Strategic Alliance (CASA 2013).

A summary of the air quality conditions in Fort Chipewyan from 1999 to 2012 is shown in Table 2.1-1. The following comments refer to data presented in Table 2.1-1:

- SO_2 concentrations: The monitored maximum 1-hour, 24-hour and annual concentrations are 64.2 µg/m^3, 26.5 µg/m^3 and 1.1 µg/m^3, respectively. The monitored concentrations are well below the Alberta Ambient Air Quality Objectives (AAAQO) of 450 µg/m^3, 125 µg/m^3 and 20 µg/m^3, respectively (ESRD 2013).
- NO_2 concentrations: The monitored maximum 1-hour and annual concentrations are 79.0 µg/m^3 and 2.9 µg/m^3, respectively. These concentrations are well below the AAAQOs of 300 µg/m^3 and 45 µg/m^3. There is no AAAQO for 24-hour NO_2 (ESRD 2013).
- $PM_{2.5}$ concentrations: The maximum 1-hour and the maximum 24-hour monitored $PM_{2.5}$ concentrations have exceeded the 1-hour Alberta Ambient Air Quality Guideline (AAAQG) and the 24-hour AAAQO several times over the monitoring period. According to Kindzierski (2010) these high concentrations (i.e., greater than 200 µg/m^3 for 1-hour averaging period) are due to natural events such as forest fires and wind-blown dust.
- O_3 concentrations: The monitored maximum 1-hour O_3 concentration is 84 ppb, which is above the 1-hour AAAQO of 82 ppb (ESRD 2013). There was only one exceedance of the AAAQO over the monitoring period. The Canada-wide Standard (CWS) for 8-hour O_3 is 65 ppb (CCME 2000). Achievement of the CWS is based on the 4th highest 8-hour measurement annually, averaged over three consecutive years. Monitoring data shows that the CWS has been met over the monitoring period.

Table 2.1-1 Fort Chipewyan Air Quality

Compound	Parameter	AAAQO	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
SO_2	Maximum 1-hour [µg/m^3]	450	46.4	34.1	64.2	46.6	51.6	47.2	49.8	47.2	52.4	49.8	47.2	52.4	31.4	52.4
	Maximum 24-hour [µg/m^3]	125	9.0	6.6	25.1	17.8	24.2	13.8	26.5	15.8	20.0	11.5	11.4	22.2	14.8	13.8
	Annual Average [µg/m^3]	20	1.1	0.6	0.9	1.0	1.1	0.9	0.9	0.8	0.9	0.7	0.7	0.9	0.7	0.6
NO_2	Maximum 1-hour [µg/m^3]	300	55.1	52.9	44.2	63.8	48.2	48.9	56.5	58.3	58.3	52.7	48.9	45.2	79.0	47.6
	Maximum 24-hour [µg/m^3]	–	14.7	16.5	14.3	14.4	19.0	18.7	17.1	15.7	40.9	26.4	20.0	21.1	21.2	25.1
	Annual Average [µg/m^3]	45	2.2	1.9	1.7	1.6	2.0	1.9	1.4	1.6	2.9	2.3	2.1	2.0	2.0	1.7
$PM_{2.5}$	Maximum 1-hour [µg/m^3]	80(a)	–	16.4	57.8	**118.8**	48.6	76.0	**97.3**	**214.4**	**144.0**	**89.4**	22.6	**268.8**	**406.5**	**1,243.0**
	Maximum 24-hour [µg/m^3]	30	–	10.0	14.3	25.0	18.6	27.2	**36.2**	**46.4**	**96.4**	**45.8**	14.5	**68.2**	**382.7**	**191.0**
	# of days >AAAQO µg/m^3	–	–	0	0	0	0	0	1	4	2	2	0	9	4	5
	Annual Average [µg/m^3]	–	–	4.1	4.4	2.4	2.4	2.4	2.4	2.6	2.3	2.6	2.3	3.7	3.2	5.5
O_3	Maximum 1-hour [ppb]	82	60.0	51.0	55.0	65.0	63.0	63.0	53.0	66.0	57.0	59.0	55.0	62.0	**84.0**	60.0
	Maximum 8-hour [ppb]	–	53.3	48.7	52.5	64.5	58.4	57.0	51.5	61.5	53.4	56.5	52.3	53.5	64.6	55.3
	4th highest 8-hour [ppb]	65(b)	51.8	47.6	52.0	59.0	57.4	55.0	51.3	59.0	52.8	55.3	50.8	53.1	64.3	53.6
	Annual Average [ppb]	–	27.1	27.5	28.9	28.1	29.5	30.0	26.3	28.4	27.1	26.9	25.4	27.4	28.6	28.2

(a) Alberta Ambient Air Quality Guideline for 1-hour $PM_{2.5}$ (AENV 2011).

(b) Canada–wide Standard for 8-hour averaging period. Compliance with the 8-hour CWS is based on the 4th highest measurement annually, averaged over three consecutive years.

– = No criteria available.

Note: Bold values are higher than AAAQO.

2.2 Environmental Evaluation

The 2013 PRM Application Case and 2013 PDC predictions of SO_2, NO_2, carbon monoxide (CO) and $PM_{2.5}$ for Poplar Point and Fort Chipewyan are shown in Table 2.2-1. The modelling methods are detailed further in the EIA, Volume 3, Appendix 3.8, and in Appendix 3.2 of this submission. Poplar Point is located about 40 km south of the PAD and Fort Chipewyan is located on the northeastern edge of the PAD. The range of predictions from Poplar Point and Fort Chipewyan are considered representative of future air quality conditions over the PAD. The change in predicted concentrations due to PRM emissions is minimal and the predictions for all assessment cases are well below the applicable AAAQOs.

Table 2.2-1 Air Quality Predictions in the Peace-Athabasca Delta

Parameter[a]	Poplar Point (IR 201G)		Fort Chipewyan[b]		AAAQO[c]
	2013 PRM Application Case	2013 PDC	2013 PRM Application Case	2013 PDC	
Maximum 1-hour SO_2	27.8	31.8	17.2	19.2	**450**
Maximum 24-hour SO_2	14.1	17.5	9.9	12.4	**125**
Annual average SO_2	1.5	1.8	0.6	0.8	**20**
Maximum 1-hour NO_2	56.5	59.4	69.0	73.9	**300**
Annual average NO_2	7.1	8.3	3.2	3.5	**45**
Peak 1-hour CO	220.9	241.6	390.7	405.7	**15,000**
Peak 8-hour CO	149.8	181.3	239.5	252.3	**6,000**
Maximum 24-hour $PM_{2.5}$	7.5	9.3	13.3	14.5	**30**

(a) The peak predictions are the highest predictions from the model. The maximum 1-hour predictions exclude the eight highest 1-hour predictions and the maximum 24-hour predictions exclude the first highest 24-hour prediction from the model per the Alberta Air Quality Model Guideline (AENV 2009). The eight highest hours are included in the annual average predictions.

(b) These results include community background concentrations that represent the contribution due to local activities within the community.

(c) AAAQO = Alberta Ambient Air Quality Objectives (ESRD 2013).

2.3 Summary

The Fort Chipewyan air quality monitoring data were reviewed to determine the existing air quality conditions in the PAD. Model predictions of SO_2, NO_2, CO and $PM_{2.5}$ at Poplar Point and Fort Chipewyan for the 2013 PRM Application Case and the 2013 PDC were provided to determine the impact of regional and PRM emissions in the PAD.

The Fort Chipewyan monitoring data shows that the maximum concentrations of SO_2 and NO_2 are well below the applicable ambient air quality objectives. There was one exceedance of the 1-hour O_3 AAAQO. The high $PM_{2.5}$ concentrations are likely caused by natural events such as forest fires and wind-blown dust.

Dispersion modelling was completed to predict the effect of regional and PRM emissions of SO_2, NO_2, CO and $PM_{2.5}$ on air quality at Poplar Point and Fort Chipewyan. Model results showed that the predictions for all compounds and all assessment cases were well below the applicable AAAQOs.

3.0 HYDROLOGY

The key indicators selected to provide focus for the PAD evaluation on hydrology were flows and water levels in the PAD. These key indicators were used to quantify and evaluate the 2013 PDC effects of the PRM in conjunction with existing and approved developments, and planned (publicly disclosed) developments in the Oil Sands Region. An evaluation of potential cumulative effects for PAD hydrology is discussed in terms of effects pathways including:

- flow regulation;
- water withdrawals; and
- climate change.

A detailed discussion of key issues and associated key indicators for hydrology included in the assessment is provided in the EIA, Volume 4A, Sections 6.4.2.2 and 6.4.2.6.

3.1 Historic Data, Existing Conditions and Trends

The PAD is formed by the Peace, Athabasca and Birch rivers at the western end of Lake Athabasca (Figure 1.1-1). The specific hydrologic variables that are discussed include flows and water levels in the PAD. Sources of hydrologic data include records of long-term monitoring stations operated by Environment Canada’s Water Survey Division. Statistics of annual, seasonal, monthly and daily flows were derived from available data. Hydrologic statistics for the PAD are summarized in Tables 3.1-1 and 3.1-2. The locations of long-term monitoring stations are shown in Figure 1.1-1. Additional details of climate and hydrology of the PAD, a discussion of historical trends, and graphs of water levels and flows for key waterbodies (i.e., Lake Athabasca) and watercourses are provided in Attachment A.

Table 3.1-1 Flow Statistics for Tributary Watersheds of the Peace-Athabasca Delta

Parameter	Athabasca River Fort McMurray Station (07DA001)(a)	Athabasca River Embarras Airport Station (07DD001)(b)	Richardson River Near the Mouth (07DD002) (c)	Birch River below Alice Creek (07KE001) (d)	Peace River at Peace Point (07KC001)(e)(g)	Slave River at Fitzgerald (07NB001)(f)(g)
Drainage area [km^2]	133,000	155,000	2,700	9,860	293,000	606,000
Mean annual discharge [m^3/s]	618	666	16.6	37.6	2,084	3,450
Maximum daily discharge [m^3/s]	4,700	4,751	41.6	394	12,600	11,200
Lowest daily discharge [m^3/s]	75	80	8.8	0.142	272	530
100-year daily discharge [m^3/s]	5,452	5,420	42.0	478	14,869	11,091
50-year daily discharge [m^3/s]	4,920	4932	41.3	443	13,453	10,237
20-year daily discharge [m^3/s]	4,224	4,284	39.8	392	11,548	9,129
10-year daily discharge [m^3/s]	3,694	3,783	38.3	346	10,063	8,297
5-year daily discharge [m^3/s]	3,145	3,257	36.2	294	8,504	7,452
2-year daily discharge [m^3/s]	2,324	2,454	31.8	204	6,128	6,217

(a) Based on recorded flows by Environment Canada for the period 1957 to 2010.

(b) Based on recorded flows by Environment Canada for the period 1971 to 1984 and derived flow series based on data recorded at Fort McMurray Station for the periods 1957 to 1970 and 1985 to 2010.

(c) Based on recorded flows by Environment Canada for the period 1970 to 2010.

(d) Based on recorded flows by Environment Canada for the period 1967 to 2010.

(e) Based on recorded flows by Environment Canada for the period 1959 to 2010.

(f) Based on recorded flows by Environment Canada for the period 1921 to 2010.

(g) Includes regulated flows from W.A.C. Bennett Dam.

Source: Environment Canada 2011.

Table 3.1-2 Water Levels Recorded in the Peace-Athabasca Delta

Station Name	Station ID	Period of Record	Mean Water Level	Maximum Water Level	Minimum Water Level	Maximum Fluctuation[a]
			[m amsl]	[m amsl]	[m amsl]	[m]
Lake Claire near outlet to Prairie River	07KF002	1970 to 2010	209.27	210.77	208.04	2.73
Mamawi Lake Channel at Old Dog Camp	07KF003	1971 to 2010	208.81	211.37	206.46	4.91
Lake Athabasca at Fort Chipewyan	07MD001	1930 to 2010	208.86	211.33	205.63	5.70
Lake Athabasca near Crackingstone Point	07MC003	1956 to 2010	208.79	210.64	207.31	3.33
Rivière Des Rochers above Slave River	07NA001	1960 to 2010	207.42	210.96	204.69	6.28
Rivière Des Rochers east of Little Rapids	07NA007	1960 to 2010	208.51	210.34	206.16	4.18
Rivière Des Rochers west of Little Rapids	07NA008	1960 to 2010	207.40	210.30	204.76	5.54

(a) Water level statistics are derived based on recorded daily water level data by Environment Canada.

Sources: Environment Canada 2011.

3.1.1 Flows and Ice Jams

Flow in the PAD complex is typically northward but can reverse when water levels on the Peace River are higher than those of the more southerly lake and river systems. The hydrology of the delta is heavily influenced by inflows from the Athabasca River and the complex river ice regime. The biological productivity and diversity of this extensive riparian landscape depends on periodic flooding and drying cycles. Deltaic landscapes, such as the PAD, are intimately affected by temporal and spatial variability in river discharge and flooding. The Peace River ice jams are considered a critical component sustaining the ecology of the PAD by raising the water levels enough to create flow reversals in some of the delta channels and refreshing many of the lakes and wetlands.

After the W.A.C. Bennett Dam for hydroelectric power production was constructed in 1968, perceived effects of flow regulation of the Peace River on the PAD led to several environmental studies to assess the hydrological and ecological consequences. Several studies conducted for the PAD concluded that ice-jamming is the most effective mechanism for producing extremely high backwaters capable of recharging perched watersheds, in particular, the elevated region of the Peace River Delta where productive wetlands are situated. By contrast, the historic high, open-water flow events generated by the Peace River basin were insufficient to cause greater than bankfull flow conditions within the Peace River Delta. Even without the influence of flow regulation on the Peace River, overflow of the lower Peace River would have been a rare occurrence during ice-free conditions. However, the unregulated Athabasca River occasionally produces localized overland flow in the Athabasca River Delta under both open-water and ice jam conditions.

3.1.2 Drainage

The fluvial hydrology of the PAD is highly variable because of its extremely low topography and temporally variable water levels and discharges of the Peace and Athabasca rivers and Lake Athabasca. Both rivers originate in the Rocky Mountains and exhibit nival flow regimes driven by seasonal snowmelt (Wolfe et al. 2006).

In addition to the Athabasca River, the Peace River and the Birch River deltas, the PAD also encompasses Lake Claire (about 1,200 km^2) and Mamawi Lake (about 170 km^2). These lakes are linked to Lake Athabasca (7,800 km^2) by the Prairie River and Chenal des Quatre Fourches, and drain into the Peace and Slave rivers by the Rivière des Rochers, Revillion Coupé and Chenal des Quatre Fourches (Peters et. al. 2006).

The system normally drains northward to the Slave River. However, when the Peace River stage is higher than the level of the central lakes, typically during spring ice breakup and summer high discharge events, flow in the connecting channels reverses into the delta lakes as shown in Figure 1.1-1 (PAD-PG 1973).

Construction of the W.A.C. Bennett Dam on the Peace River and the filling of Williston Lake behind the dam led to low flows in the Peace River from 1968 to 1971. These low flows prevented flooding in the delta, raising concerns about the ecological integrity of the delta in the absence of the annual flood (Mitchell and Prepas 1990; MRBB 2004). Permanent weirs were constructed in 1975 and 1976 on the Rivière des Rochers and Revillion Coupé, a distributary of the Rivière des Rochers. According to studies conducted during the 1980s by the Peace-Athabasca Delta Implementation Committee, these weirs nearly restored peak summer water levels in the lakes and delta, and counteracted many of the effects that regulation of the Peace River had on the delta (Mitchell and Prepas 1990; MRBB 2004). The weirs do not affect water levels in the Peace River, however, and perched basins in the Peace River Delta that were dependent on regular flooding have been lost (Mitchell and Prepas 1990).

The Athabasca sector of the delta consists of the Athabasca River and its four major distributary channels that bring water into Lake Athabasca and several other surrounding lakes and channels. The distributary channels are (from west to east) the Embarras River, the Fletcher Channel, the Goose Island Channel and the Big Point Channel. A breakthrough channel formed in 1982 (PADTS 1996) that now connects the Embarras River to Mamawi Lake. Past studies (PADTS 1996) estimate that the Embarras River captures on average about 10% of the Athabasca River flow entering the delta, with the breakthrough channel taking about 58% of the Embarras River's flow during normal conditions.

Sources of water flowing into Lake Athabasca include the Athabasca, Fond du Lac and Birch rivers, in addition to smaller tributaries and seasonal flows from the Peace River. The Athabasca River and its tributaries contribute the largest proportion of the annual inflow to Lake Athabasca (53%). The Fond du Lac River, arising in Wollaston Lake, Saskatchewan, flows through several lakes before discharging into the eastern end of Lake Athabasca. The Fond du Lac River contributes about 21% of the total inflow to the lake and the delta. Inflow to the south side of the lake and delta, such as Richardson, Old Fort, William and McFarlane rivers, provide less than 6% of the total inflow. Another river, the Birch River, flowing through Lake Claire and Mamawi Lake into the western side of Lake Athabasca, provides less than 3%. Part of the time, flow from the Birch River system bypasses Lake Athabasca, as water levels in the PAD change. Miscellaneous inflows and direct runoff from the catchment area account for the final 18% of the total inflow. The Peace River flows from Williston Lake (the reservoir created by the W.A.C. Bennett Dam in British Columbia in 1968) to its delta located northwest of Fort Chipewyan. Water flow from the Peace River to Lake Athabasca is seasonal.

Lake Athabasca is drained by the Rivière des Rochers, which carries the bulk of the outflow and the Chenal des Quatre Fourches. The volume of outflow leaving Lake Athabasca via these two channels is largely dependent on water levels in Peace River. During the flood season, high flows in the Peace River have historically provided a natural barrier to the outflow of water from Lake Athabasca, thus allowing the PAD to be flooded. The water level in Lake Athabasca would rise an average of about 1.7 m during spring and summer and then recede during fall and winter (Muzik 1991).

The Peace sector of the PAD is incised by two major channels, the Rivière des Rochers on the east and the central Chenal des Quatre Fourches, plus the Revillon Coupe, a smaller subsidiary channel of the Rivière des Rochers. These channels usually flow north, but they also undergo transient flow reversals at times of high relative water level in the Peace River as shown in Figure 1.1-1. Flow reversal tends to occur when water levels in the Peace River exceed those in Lake Athabasca, which normally occurs because of ice jams during the spring breakup period and during periods of sustained high flows produced by runoff from the Peace River headwaters (Leconte et al. 2001). Spring flooding of the PAD is governed by ice jams in the Peace River that restrict and reverse outflow from Lake Athabasca, resulting in a backup of water in the lake, which, in turn, floods the delta.

3.2 Environmental Evaluation

3.2.1 Effects of Flow Regulation

An analysis of available hydrometric data in the PAD shows that regulation has increased flows during the fall and winter seasons and reduced the spring/summer peak flows at Peace Point and associated water levels within the PAD (see Attachment A for details). For example, results of preliminary analyses show that the average June flow has been reduced by about 50% from 7,500 to 3,400 m^3/s following regulation, while average winter (December to March) flows have increased by about 200% from 500 to 1,500 m^3/s. The changes from the regulation effects of the W.A.C. Bennett Dam are listed in Table 3.2-1. Historically, monthly mean flows reached their maximum values in June and their minimum values in December. Analysis of the data before and after the dam suggests there has been a change in flow regimes during these two periods. There has been a reduction in mean flows for June and an increase in mean flows for December.

Table 3.2-1 Difference in Flow Statistics on the Peace River

Parameters	Pre-Bennett Dam[a]	Post-Bennett Dam[b]	Percent Change
Mean Annual [m^3/s]	2,300	2,100	-9%
2-year [m^3/s]	10,000	5,400	-46%
5-year [m^3/s]	11,000	7,400	-32%
10-year [m^3/s]	11,500	8,800	-23%
Mean Summer [m^3/s]	3,500	2,400	- 31%
Mean Winter [m^3/s]	500	1,500	+ 200%

[a] As measured at Peace Point (07KC001) for the Period from 1960 to 1967.

[b] As measured at Peace Point (07KC001) for the Period from 1972 to 2010.

Source: Environment Canada 2011.

Prowse et al. (2002) and Prowse and Conly (2002) provide a succinct review of the results of the multi-component research program initiated by the Northern River Basins Study (NRBS) to assess how flow regulation in the Peace River could affect the PAD's aquatic ecosystem. While the NRBS studies were underway, another major research program, the Peace-Athabasca Delta Technical Studies (PADTS 1996), was initiated by a multi-agency group representing governments and Aboriginal communities living in the PAD and dependent on its resources for traditional lifestyles (Prowse and Conly 2002). The NRBS studies indicate that the regulation of the Peace River has shifted the pattern of seasonal flows and dampened flow extremes, creating a less variable annual flow regime. Increased winter releases from the reservoir created by the dam have delayed ice cover formation downstream of the dam. Higher ice levels that accompany increased winter flows are thought to reduce the frequency and magnitude of ecologically important ice-induced floods that occur during the spring. In general, the higher the freeze-up cover, the greater the flows the river can pass without breaking.

Prowse and Conly (1998) noted that the frequency of ice-induced backwater flooding of perched basins has declined since the 1970s. They state that flow regulation seems to have produced only minor changes in factors such as ice thickness and strength, and not to have reduced the flow at the time of breakup. Prowse and Lalonde (1996) suggest that an important source of spring flow affecting breakup at Peace River originates from tributaries downstream of the regulated headwaters. Prowse and Conly (1998) suggest that, since the mid-1970s, spring runoff has declined in the downstream portions of the Peace River watershed that is unaffected by regulation. This decline has been linked to a decrease in the magnitude of the winter snowpack. Elevated ice levels and winter flows resulting from regulation have further reduced the potential for tributary runoff to produce severe breakup floods. Thus, the absence of a high order event between 1974 and 1992 seems to be related to the combined effect of flow regulation and the reduced snowpacks in the unregulated portions of the Peace River watershed. Since the construction of the dam in 1968, about 24% of the drainage area is captured by Williston Lake at the dam (Leconte et al. 2001).

With large-scale drying of the PAD beginning in the 1970s, engineering structures (weirs) were built to restore water levels within the PAD. The focus was on open-water conditions. Referencing the Peace-Athabasca Delta Technical Studies (PADTS 1996), Leconte et al. (2001) states that two weirs were installed in 1975 and 1976 to restrict the northward outflow of water and mitigate the effects of the Peace River flow regulation on the PAD complex. The fixed crest weirs were constructed on the Rivière des Rochers and Revillon Coupe (Prowse and Lalonde 1996). Although these measures have been largely successful in restoring the natural summer peak water levels within the PAD, average summer and minimum water levels have also been raised (Aitken and Sapach 1994). The Peace-Athabasca Delta Technical Studies (PADTS 1996) state that open-water floods from the Peace River were unlikely to flood the ecologically sensitive perched basins within the PAD (Prowse and Conly 2002). It was concluded that the weirs, designed for control of open-water flood conditions, do not influence the recharge of perched basins flooded from the Peace River (PADTS 1996).

Peters et al. (2006) conducted a systematic examination of the effect of flow regulation using one-dimensional hydraulic modelling, analysis of satellite images and Digital Elevation Model-derived flood maps of historically notable events (both ice jam and open-water flood events). Hydraulic modelling was used to remove the effect of regulation and produce a naturalized (no dam and no weirs) water-level. Comparison of the regulated and naturalized (1976 to 1996) data at Peace River below Chenal des Quatre Fourches near Rocky Point showed that the winter water levels were on average more than 1 m higher after flow regulation and the summer peak level was on average similarly lower. The estimated difference between the regulated and naturalized channel levels was relatively minor (winter about 0.3 m and summer about 0.1 m; within model error) at the Athabasca River near Jackfish Creek. The results indicate that the influence of flow regulation varies seasonally and decreased with distance from the Peace River.

3.2.2 Effects of Water Withdrawals

A summary of current water licence allocations and projected annual allocations of all existing and approved, and planned oil sands developments for surface water withdrawals from the Athabasca River and its tributary streams and the return flows is provided in the EIA, Volume 4A, Section 6.4.7 and also in Appendix 2. Considering the variability in the cumulative annual water requirement from the Athabasca River prior to closure of all mines, the predicted maximum cumulative annual average water requirement is about 25.4 m^3/s, including 6.0 m^3/s for the non-oil sands users and 1.74 m^3/s for the PRM. The predicted maximum cumulative instantaneous peak withdrawal depends on the total existing and planned pump intake capacities and is estimated to be about 34.6 m^3/s, of which 4.17 m^3/s is attributable to PRM.

The following sections discuss potential effects to PAD features from the 2013 PDC cumulative water withdrawals.

3.2.2.1 Effects to Distributary Channels

Andrishak and Hicks (2010) developed a one-dimensional hydrodynamic network model of the Athabasca Delta and assessed the anthropogenic water withdrawal schemes on the flow distributions among the major Athabasca Delta distributary channels. Analyses completed using the Hydrologic Engineering Center’s River Analysis Systems model show that flows of about 2,500 to 3,000 m^3/s on the Athabasca River entering the PAD are expected to result in bankfull stage. The lower bound of this range is about the one- in two-year flood and close to the median summer peak flow over the period of record.

Andrishak and Hicks (2010) used a withdrawal rate of 20 m^3/s in their analyses to assess the effect of such withdrawals on the frequency of flow cut-off to the distributary channels. The 20 m^3/s value is arbitrary and represents about a 20% reduction of the average minimum winter flow on the Athabasca River. This withdrawal rate results in a reduction of about 2 cm in the average mean daily simulated Lake Athabasca water level, with a corresponding reduction in simulated lake outflow of about 19 m^3/s. The model also indicated that the most sensitive area to flow reductions is the Fletcher Channel, for which complete flow cut-off frequency has increased from 31% to 48% within the 48 years considered as the historic period.

The analysis completed by Andrishak and Hicks (2010) assumed that a withdrawal rate of 20 m^3/s will occur during the winter period as well as during the open-water flow period. However, during the winter periods (weeks 1 to 14 and weeks 49 to 52) the maximum allowable withdrawal rate is 10 m^3/s for red zone condition and 14 m^3/s for yellow zone condition, and is governed by the *Phase 1 Water Management Framework* developed by Alberta Environment and Fisheries and Oceans Canada (AENV and DFO, 2007). Hence, the effect of water withdrawal on Lake Athabasca and distributary channels will be considerably less than the estimates provided by Andrishak and Hicks (2010) during the winter low flow period for red and yellow zone flow conditions.

Using the flow distribution profiles developed by Andrishak and Hicks (2010) for distributary channels and maximum allowable withdrawal rates provided by the *Phase I Water Management Framework* (AENV and DFO 2007) as an upper bound, the effects of water withdrawals on distributary channels were re-evaluated and the results are shown in Figures 3.2-1, 3.2-2 and 3.2-3. Using the plots for winter flows in the three figures as an example, the solid light green lines in each figure show the split in winter flows as percentages between the Athabasca and Embarras rivers under no water withdrawal conditions, and the red dash lines represent the percentage of winter flows including water withdrawals. The spacing between these two lines on two of the figures indicates that the percentage of flow directed to the Embarras River (Figure 3.2-1) decreases by less than 1% and the percentage of flow directed to Fletcher Channel (Figure 3.2-2) decreases by less than 1.3%. The percentage reductions during open-water periods, which are the differences between percentage of open-water flows without water withdrawals represented by solid blue lines and the percentage of open-water flows including water withdrawals represented by the green dotted lines, are less than those during the winter periods. The effects of winter water withdrawals on Goose Island distributary channel (reductions vary from 1.6% to 4.1%) and Big Point distributary channel (reductions vary from 1.9% to 11%) are higher than the effects on Embarras River and Fletcher Channel.

Golder (2011) completed water level measurements at three selected locations in the Athabasca Delta: Cree Creek on the Embarras River distributary, Fletcher Channel and Limon Lake. A one-dimensional hydraulic model developed by Andrishak and Hicks (2010) was used to assess the potential effects of water withdrawals from the Athabasca River on water levels, and consequently on riparian areas, beaver and muskrat habitat. The one-dimensional model was then used to develop a new series of daily water level predictions when water is withdrawn from the Athabasca River according to the “Phase 2 Framework Committee Report Option H Water Management Rules” (CEMA, 2010). The study was limited to open-water conditions.

The study results indicate that the effects of water withdrawals on the wetted perimeter seem to be most noticeable (2% to 5% reduction) for the Limon Lake site and least noticeable site (0 to 1% reduction) for the Fletcher Channel. The three sites studied, Cree Creek, Fletcher Channel and Limon Lake, will see a minor reduction in the number of days when connection to the Athabasca River or distributaries is broken if the recommended withdrawal limits are implemented. However, all of the sites will continue to receive water at times throughout the open-water season and the impacts on the beaver and muskrat populations in these regions are not expected to be detrimental. Although changes are expected in water levels, the amount of wetted perimeter, and connectivity of the study sites to the Athabasca River, these changes are expected to be minor in magnitude and are not expected to result in measurable changes to muskrat and beaver populations in the region.

3.2.2.2 Effects to Perched Basins

During open-water periods, the perched basins in the Athabasca Delta are affected by flood flows that spill over the banks of the distributary channels (i.e., flows more than about 2,500 m^3/s). This is about the one- in two-year flood in the Athabasca River based on recorded data (Figure 3.2-4 provides plots of flows in the Athabasca River).

Applying the allowable maximum water withdrawal rate from the Athabasca River prescribed by the *Phase I Water Management Framework* (AENV and DFO 2007) does not change the frequency of flooding as shown in Figure 3.2-5, and will result in negligible decrease in the depth of flooding.

Figure 3.2-1 Effects of Water Withdrawals on Distributary Channels — Embarras River

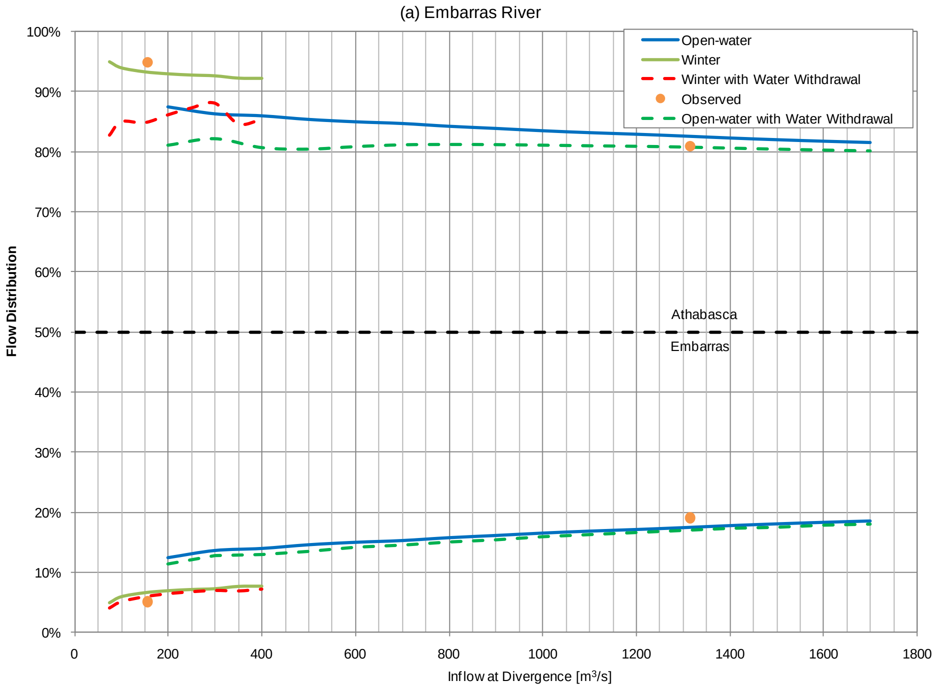


Figure 3.2-2 Effects of Water Withdrawals on Distributary Channels — Fletcher Channel

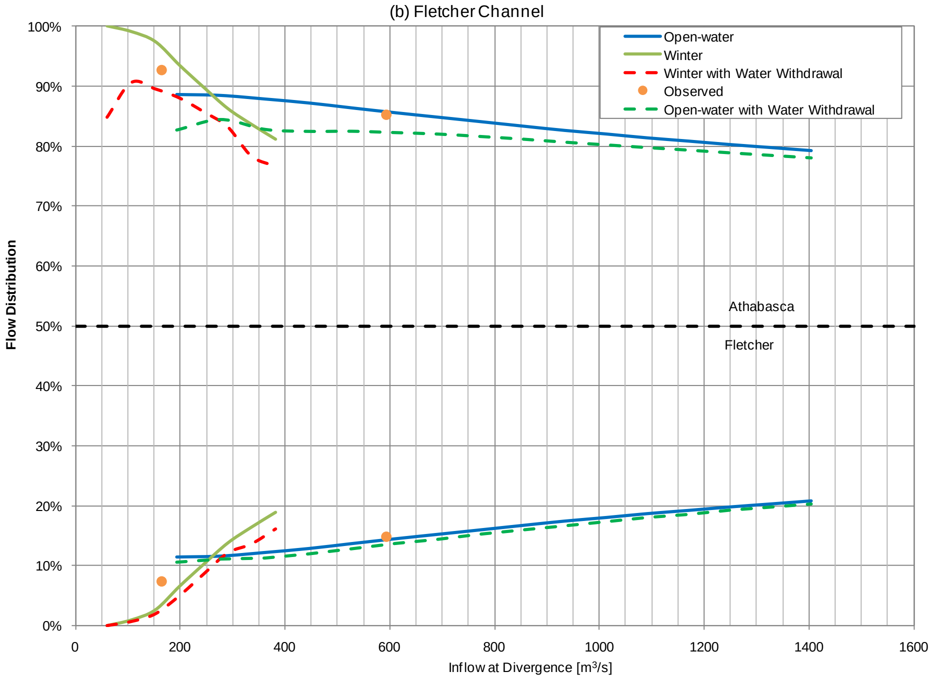


Figure 3.2-3 Effects of Water Withdrawals on Distributary Channels — Goose Island and Big Point

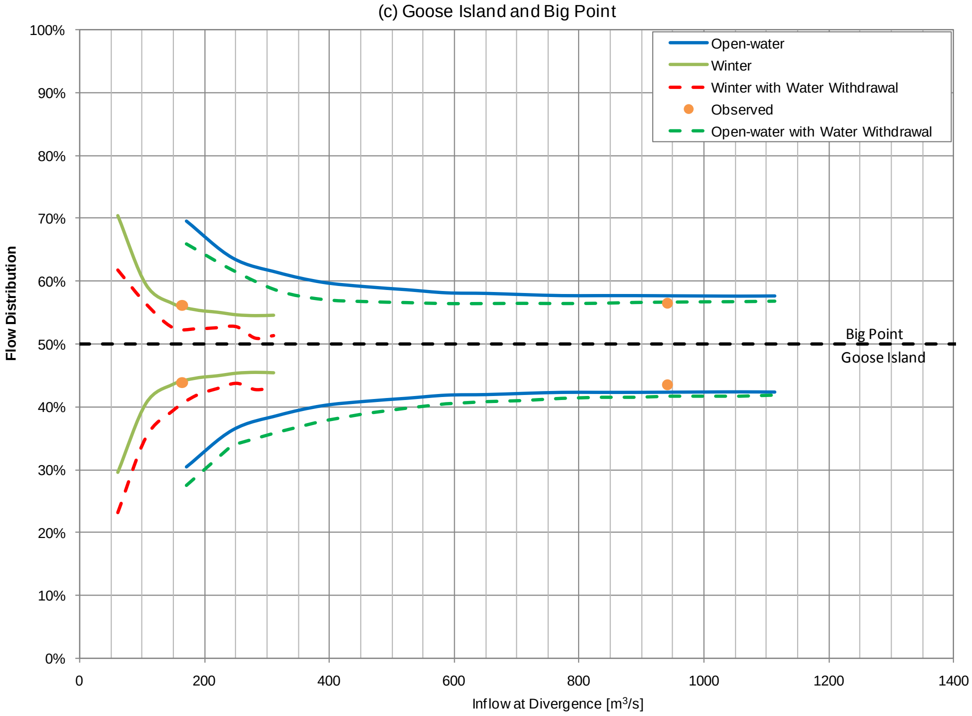


Figure 3.2-4 Recorded Athabasca River Flows

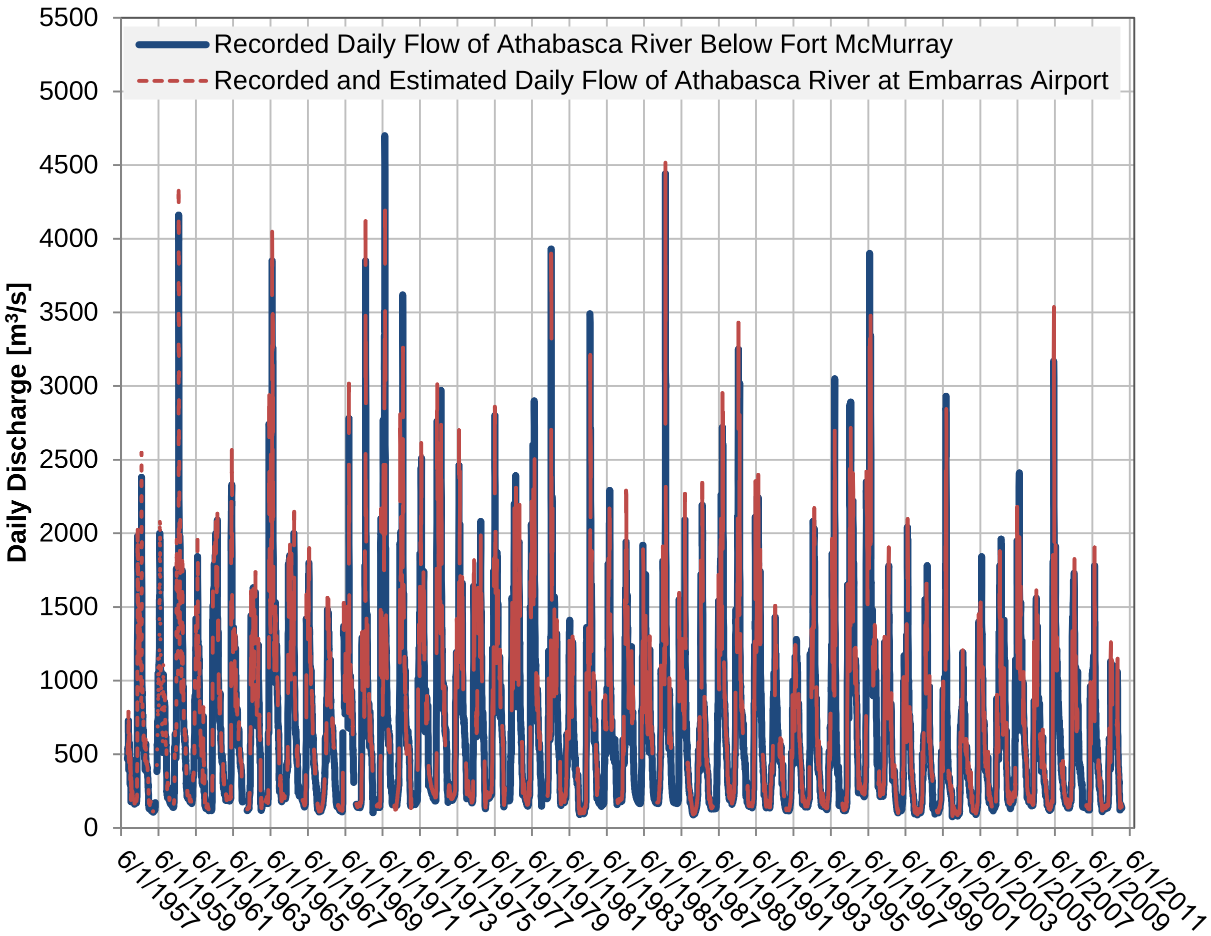
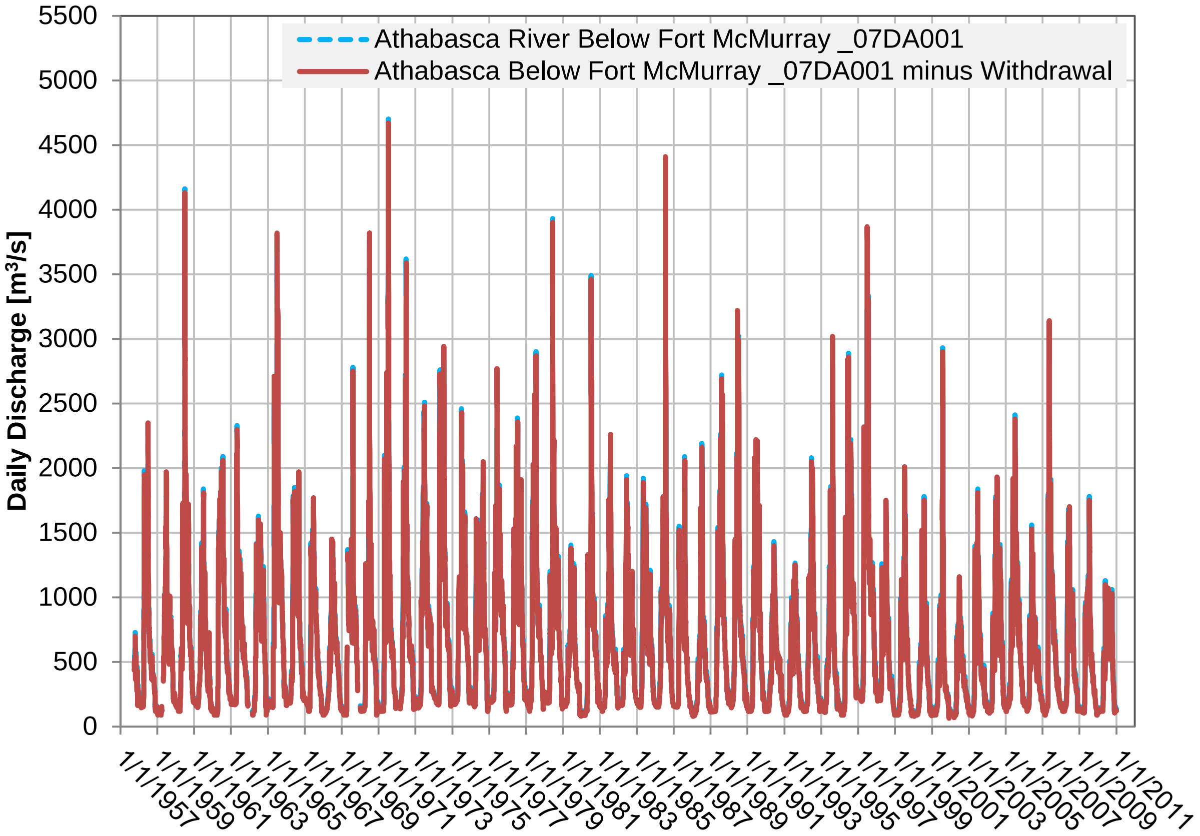


Figure 3.2-5 Athabasca River Flow – Considering Water Withdrawals



3.2.2.3 Effects to Peace-Athabasca Delta Water Levels

The possible changes in water levels in the PAD including Lake Athabasca were evaluated using the open-water flood level of July 1971 measured on Lake Athabasca River at Fort Chipewyan as an indicator (Table 3.2-2). The July 1971 flood is the largest flood recorded on Athabasca River for the last 50 years. Based on recorded water levels at Old Fort and near Crackingstone Point during this event, the Lake Athabasca water level change from June 29, 1971 to end of July 1971 was about 0.61 m. The volume of water that flowed to PAD over this period was about 6.85 billion m^3. Assuming an area of about 9,760 km^2 for the PAD including Lake Athabasca (i.e., 7,800 km^2 for Lake Athabasca and 1,960 km^2 for the Athabasca River Delta), this volume translates to a depth of about 0.7 m. This is comparable to the average change in Lake Athabasca water level during the June to July period (i.e., 0.61 m) assuming the balance of inflow from other tributary watersheds is equivalent to the outflow that occurred from the lake during that period. The maximum allowable withdrawal of 30 m^3/s from the Athabasca River as stipulated in the *Phase I Water Management Framework* (AENV and DFO 2007) will reduce the volume of water that will flow to PAD to 6.78 billion m^3, which in turn means a reduction of less than 1 cm in water level in the PAD, as shown in Table 3.2-2.

Considering only the maximum withdrawal rate for PRM, the reduction of water level in the Athabasca River Delta due to PRM will be less than 0.1 cm.

3.2.3 Effects of Climate Change

In the conclusions of the Northern River Basins Study (NRBS 1996), recommendations were made that it is important to understand the climate-hydrology interactions within this region. Pietroniro et al. (2006) investigated the potential effects of climate change on the flows and water levels using WATFLOOD, a conceptual distributed hydrological model capable of simulating river flows over a long period of time. To study climate change in the PAD, Pietroniro et al. (2006) used downscaled climate change scenarios as inputs into the WATFLOOD modelling system.

Pietroniro et al. (2006) found that under the selected climate change scenarios, water levels in lakes Athabasca, Claire and Mamawi peaked on average, 40 to 50 days earlier than at present. The effects on lake levels from various climate change scenarios vary:

- The Commonwealth Scientific and Industrial Research Organization Model and Hadley Centre Climate Prediction and Research Model predict increases of 0.25 m and 0.1 m, respectively, in spring levels for Lake Athabasca.
- The General Circulation Model based on European Centre for Medium Range Weather Forecasts, Geophysical Fluid Dynamic Laboratory Model and Canadian Circulation Model predict spring level decreases of 0.4 m, 0.25 m and 0.15 m, respectively.

All Global Climate Model scenarios predicted higher winter levels in the PAD system, which would result in elevated pre-melt spring levels in the PAD. Increased precipitation and temperatures in winter would increase thaw events and result in a higher variability in water levels.

In the rivers within the PAD, it was predicted that spring peak water levels in the rivers in the future would be lower by up to 1.0 m and occur 20 to 30 days earlier. Average annual peak elevations will vary from +0.1 to 0.6 m, depending on the Global Climate Model scenarios. Lower levels are also predicted in the Peace and Athabasca rivers with decreases averaging 0.5 m and 0.2 m, respectively.

Prowse et al. (2006) investigated the effects of climate change on the potential for ice jam-related floods in the PAD. It was predicted that major floods would require a total winter snowpack of at least 150 mm at Grande Prairie and intense spring heating to generate a large ice jam flood. Using these benchmarks it was predicted that the frequency of ice jams would be further reduced in the future, mainly because of the reduced snowpack. A reduced snowpack is anticipated to result from the advent of mid-winter thaws, which would be more frequent (Romolo et al. 2006). In fact, Wolfe et al. (2006) found that flooding frequency in the PAD has been highly variable in the past 300 years but in decline for many decades beginning as early as the late nineteenth century, well before the Peace River regulation. Therefore, there is some evidence to show that the ice jam-related flooding frequency will potentially decrease in the future because of climate change.

The effects of potential climate change on the Athabasca River flows and water levels (i.e., a major tributary river to Athabasca portion of the Delta) were assessed as part of the 2013 assessment for PRM. Detailed results are provided in Appendix 4.

Four out of the five climate scenarios selected to represent the range of reasonably possible future climate regimes from a number of General Circulation Models (GCMs) show increase flows and water levels in the lower reach of Athabasca River in winter and spring (Appendix 4, Table 3-3 and 3-4). Hence, the predicted effect of potential climate change on the Athabasca sector of the PAD could increase in water level in winter and spring season except for the scenario of warmer and drier (predicted by CNRMCM3 SR-A2), which could result in decreased water levels in the PAD.

For the summer season, flows and water levels in the lower reach of Athabasca River will decrease for most climate change scenarios except for cooler and wetter scenarios (predicted by INMCM3.0 SR-A2) that will result in increased summer flows and water levels. Hence, the predicted potential effect of climate change on the Athabasca sector of the PAD may be decreased water levels.

Water levels in the Athabasca sector of the PAD are expected to increase under cooler climate scenarios (predicted by INMCM3.0 SR-A2 and BCM2.0 SR-B1) and are expected to decrease under warmer climate scenarios in the fall season.

Table 3.2-2 Changes From Water Withdrawals on Water Level in the Athabasca River Delta

Date	Athabasca River at Embarras Airport Station (07DD001) [m^3/s]	Daily Volume [Mm^3]	Daily Volume after Maximum Allowable Withdrawal Rate [Mm^3]	Recorded Lake Athabasca Water Level [m amsl]	
				Old Fort Station (07DD011)	Crackingstone Point Station (07MC003)
29-Jun-71	2,020			208.794	208.736
30-Jun-71	2,340	188	186	208.785	208.742
01-Jul-71	2,490	209	206	208.788	208.758
02-Jul-71	2,490	215	213	208.837	208.770
03-Jul-71	2,340	209	206	208.904	208.782
04-Jul-71	2,150	194	191	208.858	208.809
05-Jul-71	2,060	182	179	208.934	208.828
06-Jul-71	2,120	181	178	208.959	208.843
07-Jul-71	2,370	194	191	208.965	208.837
08-Jul-71	2,920	229	226	208.907	208.867
09-Jul-71	3,230	266	263	208.934	208.882
10-Jul-71	3,230	279	276	208.995	208.889
11-Jul-71	3,230	279	276	208.956	208.904
12-Jul-71	3,370	285	283	208.895	208.931
13-Jul-71	3,430	294	291	208.910	208.931
14-Jul-71	3,400	295	292	208.965	208.943
15-Jul-71	3,540	300	297	209.163	208.940
16-Jul-71	3,910	322	319	209.123	208.965
17-Jul-71	4,190	350	347	209.099	209.020
18-Jul-71	4,130	359	357	209.154	209.068
19-Jul-71	3,820	343	341	209.169	209.123
20-Jul-71	3,430	313	311	209.239	209.160
21-Jul-71	3,090	282	279	209.297	209.184
22-Jul-71	2,830	256	253	209.355	209.199
23-Jul-71	2,580	234	231	209.468	209.212
24-Jul-71	2,340	213	210	209.306	209.251
25-Jul-71	2,170	195	192	209.288	209.276
26-Jul-71	2,060	183	180	209.373	209.273
Total Volume [billion m^3]		6.85	6.78	N/A	N/A
Equivalent Depth in Athabasca River Delta [m]		0.70	0.69	N/A	N/A
Maximum Change in Lake Water Level [m]				0.683	0.540
Average Change in Lake Water Level [m]				0.612	

Source: Environment Canada (2011).

N/A = Not Applicable.

3.3 Summary

The effects of the PRM in conjunction with existing, approved and planned developments (i.e., 2013 PDC) in the Athabasca Oil Sands Region on water level changes and flooding in the PAD are negligible. As negligible surface water quantity effects are predicted in the Athabasca River, including its divergence with the Embarras River, the spatial extent of the aquatics Regional Study Area in the EIA was verified to be appropriate.

4.0 SURFACE WATER QUALITY

The surface water quality evaluation of potential effects to the PAD included the potential for changes in constituent concentrations, thermal regime, dissolved oxygen and sediment quality. The potential for changes was evaluated by examining several lines of evidence. First, all available water quality data from within and near the PAD were compiled to establish historical and existing conditions. Second, reports from government and other sources were reviewed, and the trends and conclusions highlighted in these reports were considered. Third, model results from the EIA were considered in the context of potential effects beyond the modelling domain (i.e., extending downstream to the PAD). Finally, temporal trends of sediment concentrations were calculated to evaluate changes in sediment quality.

4.1 Historic Data, Existing Conditions and Trends

4.1.1 Water Quality

Historical water and sediment quality data in the PAD were obtained from the following sources:

- Environment Canada;
- Alberta Environment's Water Data System;
- Regional Aquatics Monitoring Program (RAMP); and
- Northern River Basin Study (NRBS).

Historical water quality data in the PAD were collected between 1967 and 2010. Water quality data collected in the Peace River at Peace Point, about 25 km north of the PAD, were included in this evaluation because data were not available in the Peace River within the PAD. Samples collected at this location represent water quality in the Peace River upstream from the mouth. Limited water quality data were found in Lake Athabasca, the Peace River Delta, Lake Claire and Birch River Delta. The available information provided a general overview of water quality in surface waters within the PAD. Water quality data for these waters were sorted by geographic location and compared to aquatic guidelines.

Temporal trends upstream of the PAD were presented in previous monitoring reports for the Athabasca River at Old Fort (Hebben 2009) and at the 27 Baseline station, and in Peace River at Peace Point (Glozier et al. 2009). The studies were completed at locations relatively close to the PAD and were considered representative of temporal trends in the PAD. A general overview of the temporal trends is summarized herein.

Few literature sources relating to sediment quality in the PAD were available. Data were limited to sediment quality in the Athabasca River at the mouth, Athabasca River Delta and Lake Athabasca. Sediment quality data were also sorted by geographic location and compared to sediment quality guidelines.

Temporal trends analyses were completed on sediment quality constituents using the same RAMP sediment dataset used by Timoney and Lee (2011). This analysis is discussed in more detail in Section 4.1.2.

4.1.1.1 Conventional Parameters

Water in the PAD was generally alkaline and well oxygenated based on the median values of field measurements (Attachment B, Tables B-1 to B-3). The minimum and maximum pH levels in the Athabasca River Delta were outside of the guideline pH ranges for the protection of aquatic life (pH range of 6.5 and 8.5; AENV

1999). The minimum pH level (pH of 5.4) in the delta was measured at one of the Alberta Environment monitoring stations in March 1988. The pH level could be an immediate occurrence at the sampling time or a possible outlier; total alkalinity in the sample was high (142 mg/L). The second lowest pH (pH of 6) was also lower than the acute and chronic ranges of the guidelines.

Minimum concentrations of Dissolved Oxygen (DO) observed in the Athabasca River Delta, Rivière Des Rochers and Birch Lake were below the acute and chronic guidelines for the protection of aquatic life (5 mg/L and 6.5 mg/L; AENV 1999). Total Suspended Solids (TSS) concentrations were elevated in these waters compared to concentrations considered harmful to aquatic life (TSS concentration greater than 25 mg/L, from Newcombe and MacDonald 1991).

Major ions concentrations ranged from moderately low to high as indicated by conductivity levels and Total Dissolved Solids (TDS) concentrations (Attachment B, Tables B-1 to B-3). Concentrations of major ions and TDS are known to increase along the lower reach of the Athabasca River because of inputs from geological weathering and saline groundwater (Glozier et al. 2009). Waters in the PAD were moderately soft and likely not sensitive to acid deposition, with the exception of the western portion of Lake Athabasca. Major ion concentrations were lower in the western portion of Lake Athabasca compared with other waters in the PAD. The lake had soft water and lower levels of alkalinity. Higher sulphate concentrations were observed in Lake Claire and Birch River Delta compared with other waters in the PAD. Fluoride was generally high in the PAD, with maximum concentrations often above the chronic aquatic guideline.

Nutrient levels were moderate to high in waters in the PAD based on median concentrations of Total Nitrogen (TN) and Total Phosphorus (TP) (Attachment B, Tables B-1 to B-3). Maximum concentrations of TN and TP were above the chronic guidelines for the protection of aquatic life (1.0 mg/L and 0.05 mg/L, respectively from AENV 1999) in most of the waterbodies and watercourses of the PAD.

Trophic status in waters in the PAD was variable. As median TP concentrations in waterbodies in the PAD ranged from 0.041 to 0.071 mg/L (Attachment B, Tables B-1 to B-3), the waterbodies in the PAD were likely in the mesotrophic to eutrophic range according to Vollenweider and Kerekes (2002) and Wetzel (2001), and eutrophic according to Canadian Council of Ministers of the Environment (CCME 2004). Maximum levels of chlorophyll *a* in the waterbodies of Athabasca River Delta and Birch River Delta were indicative of mesotrophic to eutrophic conditions (Mitchell and Prepas 1990). The west portion of Lake Athabasca was the exception and was likely oligotrophic based on TP concentrations.

Median concentrations of TP in the watercourses in the PAD ranged from 0.033 to 0.051 mg/L (Attachment B, Tables B-1 to B-3) and were likely indicative of mesotrophy based on the classification system in Dodds et al. (1998) and CCME (2004).

4.1.1.2 Total Metals

Median concentrations of total metals were below guidelines in waters in the PAD with few exceptions (Attachment B, Tables B-1 to B-3). Total metals that were above the relevant chronic guideline for the protection of aquatic life include:

- aluminum in the Athabasca River Delta and Peace River;
- chromium in the Athabasca River downstream of Old Fort and Athabasca River Delta;

- copper in the Peace River;
- iron in the Athabasca River downstream from Old Fort, Athabasca River Delta, Peace River and Lake Athabasca; and
- mercury in the Athabasca River Delta.

The median total aluminum concentration was above the acute guideline for the protection of aquatic life in waters in the PAD (0.75 mg/L from U.S. EPA 2002). The concentrations that were above the acute guideline were found to be directly related to the naturally high sediment loads in these rivers and were deemed unlikely to have negative effects on aquatic life (Glozier et al. 2009). Guideline exceedances for other total metals were also thought to be related to naturally high suspended sediment in the Athabasca River, although causative factors were not specifically examined (Hebben 2009).

4.1.1.3 Organic Compounds

Organic compounds were generally below both detection limits and applicable guidelines (Attachment B, Tables B-1 to B-3). Low concentrations of total naphthenic acids and total recoverable hydrocarbons were consistently observed throughout the PAD. At all sites except the Birch River Delta, maximum concentrations of total phenolics exceeded the chronic guidelines for the protection of aquatic life (0.004 mg/L from CCME 1999).

4.1.1.4 Long-Term Temporal Trends

Studies by Hebben (2009) and Glozier et al. (2009) were reviewed to provide an overview of temporal trends in waters at the upstream boundaries of the PAD. A summary of parameters that showed trends at a p-value of 0.05 at these locations is presented in Table 4.1-1 and discussed below.

In both the Peace and Athabasca rivers, pH levels, DO, TSS and turbidity showed an increase over the study period. Based on the trends detected at the upstream boundaries, levels of these parameters in the PAD are expected to have also increased over the study periods.

Major ions followed few detectable trends in both rivers. When concentrations were flow-adjusted, temporal trends of major ions shifted from no trend to decreasing and from increasing to no trend. The cause of the decreasing trends in major ion concentrations after flow adjustment is unclear (Glozier et al. 2009).

Nutrients generally increased substantially in both rivers over the studied time frame (Table 4.1-1). When concentrations were flow adjusted, temporal trends of TP changed from no trend to increasing in the Athabasca River at Old Fort, which indicates that TP might have also increased in the PAD over this period. The increasing trends in flow-adjusted TP might have been because of decreased flow in the Athabasca River (Glozier et al. 2009).

Total metals generally decreased or did not change in both rivers over time, with some exceptions. Concentrations of total aluminum and arsenic increased in the Athabasca River at Old Fort. This increasing trend was likely associated with the increased TSS. After evaluating temporal trends in the Peace and Athabasca rivers, Glozier et al. (2009) concluded that:

- total metals in the Athabasca River appeared to be largely of natural origin;
- concentrations of metals did not increase in the Peace River; and

- the transport of metals associated with sediment load into depositional environments is likely not an issue in the PAD.

Table 4.1-1 Temporal Trends for Water Quality Parameters

Parameter	Athabasca River at Old Fort(a) (Between 1987 and 2008)		Athabasca River at 27 Baseline(b) (Between 1989 and 2006)		Peace River at Peace Point(b) (Between 1989 and 2006)
	Concentration Trend	Flow-adjusted Trend	Concentration Trend	Flow-adjusted Trend	Concentration Trend
Conventional Parameters					
Temperature	↓	↔	NA	NA	NA
Dissolved oxygen	↔	↔	↑	↔	↑
pH	↑	↑	↑	↑	↑
Conductivity	↔	↓	↔	↓	↔
Turbidity	↑	↑	↔	↑	↔
Total suspended solids	↑	↑	↔	↑	↔
Dissolved organic carbon	↔	↔	↔	↔	↓
Major Ions					
Total alkalinity	↔	↔	↔	↓	↔
Bicarbonate	↔	↔	↔	↓	↔
Calcium	↔	↔	↔	↓	↔
Chloride	↔	↓	↔	↓	↓
Fluoride	↔	↔	↑	↔	↔
Potassium	↔	↔	↑	↑	↔
Sodium	↔	↔	↔	↔	↓
Sulphate	↔	↔	↑	↔	↑
Nutrients					
Total ammonia	↑	↔	↑	↔	↔
Nitrite + nitrate	↑	↔	↑	↔	↑
Total phosphorus	↔	↑	↑	↑	↔
Total Metals					
Aluminum	↑	↑	NA	NA	NA
Arsenic	↔	↑	↔ (c)	↔ (c)	NA
Copper	↓	↔	↓	↔	↔
Iron	NA	NA	↓	↔	↔
Lead	↔	↔	↓	↓	↓
Nickel	NA	NA	↓	↔	↔
Molybdenum	↓	↔	NA	NA	NA
Zinc	NA	NA	↓	↔	↔

(a) Results of temporal trend analysis completed by Hebben (2009) are presented.

(b) Results of temporal trend analysis completed by Glozier et al. (2009) are presented.

(c) Temporal trend for dissolved arsenic is included because total arsenic is not available.

Notes: NA = Not available.
↑ = Increasing trend, significant at a p-value of 0.05.
↓ = Decreasing trend, significant at a p-value of 0.05.
↔ = Any trends not reporting significance at a p-value of 0.05.

4.1.2 Sediment Quality

A literature review was conducted for data sources relating to sediment quality in the PAD. Information was limited to the sediment quality in the Athabasca River, Athabasca River Delta and Lake Athabasca (Bourbonniere et al. 1996; RAMP 2010).

Bottom sediments in the PAD were predominantly silt and sand. In the west portion of Lake Athabasca, the bottom sediment was predominantly clay.

Metals and Polycyclic Aromatic Hydrocarbon (PAH) concentrations in sediments were below guideline values in the PAD with some exceptions (Attachment C, Table C-1). Arsenic and chromium concentrations in the Athabasca River Delta were occasionally above the CCME (1999) Interim Sediment Quality Guideline (ISQG; 5.9 mg/kg and 37.3 mg/kg, respectively). In one sample, the chromium concentration was also above the CCME probable effect level of 90 mg/kg. In the west portion of Lake Athabasca, arsenic and cadmium concentrations were above the CCME (1999) ISQG (0.6 mg/kg for cadmium).

Concentrations of C1-napthalenes were often above the ISQG (0.0202 mg/kg) in the Athabasca River Delta (Attachment C, Table C-1). Phenanthrene was above the ISQG (0.0419 mg/kg) in one sample from the west portion of Lake Athabasca (Bourbonniere et al. 1996).

Concentrations of total recoverable hydrocarbons ranged from 600 to 1,400 mg/kg in the Athabasca River Delta, and from 500 to 900 mg/kg in the Athabasca River at the mouth (Attachment C, Table C-1). As noted in RAMP (2010), the highest concentrations of hydrocarbons in Athabasca River sediments have historically been measured upstream of oil sands development at a baseline station.

4.1.2.1 Long-Term Temporal Trends

Long-term temporal trends for PAH concentrations in PAD sediments were analyzed by Timoney and Lee (2011). Based on an analysis of RAMP data, they found that PAH concentrations in PAD sediments over all areas had increased by 0.05 mg/kg/yr between 1999 and 2009, and found no change at a group of upstream reference sites. The analysis by Timoney and Lee (2011) was restricted to total PAH. The study by Timoney and Lee (2011) is useful as a screening-level analysis, but it is difficult to draw meaningful conclusions from total PAH concentrations lumped from several sites.

For the evaluation presented herein, trends in individual constituents at individual stations were analyzed. The same RAMP sediment dataset used by Timoney and Lee (2011) was used in this analysis. From this dataset, results from the site on the Athabasca River downstream from Fort McMurray (ATR-DC-W) were selected as reference data for a site upstream from the oil sands development. This site had the longest record (1998 to 2004) of any of the upstream reference sites, but was still downstream from urban effects from Fort McMurray, such as municipal wastewater and urban runoff.

Two sites downstream from all oil sands development were selected for intensive analysis: on the Athabasca River at Embarras divergence (site ATR-ER) and site BPC-1 in the Peace-Athabasca Delta. These two sites had the most years of sediment data (2000 to 2009) of any of the lower river and delta sites. Site ATR-ER provided a measure of constituents moving into the delta from the Athabasca River, and Site BPC-1 was furthest out in the delta. Site BPC-1 is located within Big Point Channel, which is recognized as a “primary depositional environment for sediment carried in the Athabasca River” (Environment Canada 2011). Therefore, effects of sediment deposition in the Peace-Athabasca Delta would not be expected beyond this reach. All individual species of PAH and metals were tested, as these were the constituents identified in two recent papers on contaminant transport from the oil sands developments (Kelly et al. 2009, 2010). Associated variables such as total organic carbon, and some major ions that were also in the dataset were tested, but no trends were found in these other variables.

The long-term temporal trends analysis was completed on 70 constituents: 45 individual PAH species, 23 metals, total PAH and total organic carbon. Data were obtained from the RAMP long-term sediment monitoring stations, which include Athabasca River downstream of Fort McMurray at Donald Creek (ATR-DC-W) as a reference station, the Athabasca River at Embarras divergence (ATR-ER) and three stations in the PAD (BPC-1, GIC-1 and FLC-1).

A nonseasonal Mann-Kendall test was used to test for monotonic trends. Then slopes were calculated to provide an estimate of the approximate magnitude of significant monotonic trends. Procedures in the water quality statistics package WQHYDRO (Aroner 2011) were used for all trend and slope analysis. As recommended by Ward et al. (1990), a 0.10 level of significance was used in all trend analysis. Samples that were below the detection limit were replaced by half of the detection limit before inputting the data.

Statistically significant trends in individual PAH species and metals are summarized in Table 4.1-2, and selected significant trends are plotted in Attachment D, Figures D-1 to D-4. There were no significant trends detected for other variables.

Levels of C3- and C1-fluorene (Attachment D, Figure D-1), C4-phenanthrenes/anthracenes (Attachment D, Figure D-2), and both dimethyl- and methyl-biphenyl increased at two or more sites downstream of oil sands development, but no trend was detected at the upstream reference site (Table 4.1-2). C4-naphthalenes, C2-fluoranthenes/pyrenes and C4-dibenzothiophenes also increased at single sites downstream of oil sands development, again with no trend detected at the upstream reference site. Fluorene and phenanthrene/anthracene are dominant components of bitumen (Kelly et al. 2009). Accordingly, the increasing trends found downstream from oil sands developments might reflect increased rates of bitumen input to the Athabasca River during the sampling period; however, a conclusive determination cannot be made based on the available information.

Fluorene concentrations at all sites downstream from oil sands developments were below the CCME (1999) ISQG for the protection of aquatic life (0.021 mg/kg), and well below the probable effect concentration of 0.144 mg/kg throughout the period of record. A single value at the upstream site exceeded the ISQG for fluorene. Similarly, the highest naphthalene value at the single site where naphthalene increased significantly (BPC-1) was at the ISQG of 0.0346 mg/kg, and well below the probable effects level of 0.391 mg/kg. Other CCME sediment guidelines are for individual PAH rather than the alkylated PAH species that demonstrated increasing trends. Accordingly, it is not possible to evaluate whether the other PAH that increased have exceeded guidelines.

Table 4.1-2 Temporal Trends for Constituents With Significant Change

Parameters	Upstream Oil Sands Development	Downstream Oil Sands Development			
	Athabasca River downstream from Fort McMurray	Athabasca River at Embarras Divergence	Athabasca Delta		
	ATR-DC-W	ATR-ER	BPC-1	GIC-1	FLC-1
	1998 to 2004	2000 to 2009	2000 to 2009	2001 to 2009	2001 to 2009
Metals					
Aluminum	-	↓	↔	-	-
Arsenic	-	↓	↔	-	-
Barium	-	↓	↔	-	-
Chromium	-	↓	↔	-	-
Cobalt	-	↓	↔	-	-
Copper	-	↓	↔	-	-
Mercury	-	↓	↓	-	-
Nickel	-	↓	↔	-	-
Strontium	-	↓	↔	-	-
Zinc	-	↓	↔	-	-
Polycyclic Aromatic Hydrocarbons					
Acenaphthylene	↔	↓	↓	↔	↔
C1-benzo[a]anthracenes/ chrysenes	↑	↔	↓	↓	↔
C1-fluoranthenes/pyrenes	↔	↑	↔	↔	↔
C1-fluorenes	↔	↑	↑	↔	↑
C2-benzo[a]anthracenes/ chrysenes	↑	↔	↔	↓	↔
C2-fluoranthenes/pyrenes	↔	↑	↔	↔	↔
C3-fluorenes	↔	↑	↑	↔	↔
C4-dibenzothiophenes	↔	↔	↑	↔	↔
C4-naphthalenes	↔	↔	↑	↔	↔
C4-phenanthrenes/ anthracenes	↔	↑	↑	↔	↑
Dimethyl-biphenyl	↔	↔	↑	↔	↑
Methyl-biphenyl	↔	↔	↑	↔	↑
Total PAH	↔	↔	↔	↔	↔

Notes: - = Trend analysis was not completed because no significant trends were observed both at Athabasca River at Embarras divergence (ATR-ER) and BPC-1 in the Athabasca Delta.
↑= Increasing trend, significant at an α-value of 0.1; ↓= Decreasing trend, significant at an α-value of 0.1.
↔ = Any trends not reporting significance at an α-value of 0.1.

Acenaphthylene (Attachment D, Figure D-3) and C1-benzo[a]anthracenes/chrysenes (Attachment D, Figure D-4) levels declined significantly at two of the sites downstream of oil sands development, and C2-benzo[a]anthracenes/chrysenes declined at one downstream site (site GIC-1). Alkylated chrysene is a dominant component of bitumen (Kelly et al. 2009), which, in contrast to the increasing trends of fluorene and phenanthrene/anthracene, might reflect decreased rates of bitumen input to the Athabasca River during the sampling period. However, the reasons for increasing or declining levels cannot be definitively determined from the available data.

Acenaphthylene declined significantly from an unusually high concentration in 2000 (Attachment D, Figure D-3), which could reflect some analytical or sampling concern. Timoney and Lee (2011) found that discharge was not significantly correlated with total PAH at mainstem sites. However, individual PAH species might behave differently, and some have a greater propensity to adsorb to particulate material. Hebben (2009) found reach-specific differences in flow trends in the Athabasca River, with a declining trend in the Lower Athabasca and no trend near Fort McMurray. Constituents affected by flow might behave differently in different reaches.

An increasing trend in C1-benzo[a]anthracenes/chrysenes was detected at the upstream reference site (site ATR-DC-W). The reason for this increasing trend at site ATR-DC-W cannot be determined from the available data. A likely source would be a bitumen outcrop on the Athabasca River, as documented in RAMP (2010). Other possible inputs at this site include urban runoff from Fort McMurray or natural sources such as forest fires. Only six years of data are available from this site, and apparent trends might disappear over a longer sampling period. Aside from this one trend at the upstream reference site, no increasing trends were detected for any of the carcinogenic substituted forms of PAH such as benzo[a]pyrene, at any site.

No significant trend in total PAH was found at any site. While this finding might seem to contradict the findings of Timoney and Lee (2011), their work and the current study used different methods of data preparation and analysis, and the findings are not directly comparable. For example, the current study substituted values half the detection limit for values below detection limits, while Timoney and Lee (2011) substituted the exact detection limit. Both forms of substitution might introduce a bias to total PAH, as the exact value below detection limits is unknown.

No increasing trend in total metal concentration was found at the PAD site that was tested (site BPC-1, Table 4.1-2). However, a variety of metals, including aluminum, arsenic, barium, chromium, cobalt, copper, mercury, nickel, selenium and zinc declined in concentration in sediments from the Athabasca River downstream from oil sands developments (site ATR-ER). Accordingly, these sediment results provide no evidence of increased transport of these metals from oil sands development areas, as described in Kelly et al. (2010). Metal concentrations are often strongly influenced by flow effects on particulate metals, and the declining flow trend documented by Hebben (2009) might complicate any interpretation of sediment metal concentrations. Accordingly, these metal trends should be interpreted with caution.

4.1.2.2 Sediment Toxicity

Several toxicity test samples were collected from the Athabasca River and Athabasca Delta by RAMP (RAMP 2010). Toxicity testing included the organisms *Chironomus tentans*, *Hyalella azteca* and *Lumbriculus variegates.* The survival values were often less than 100% compared to the laboratory control (Attachment C, Tables C-1 to C-2), but reductions in survival were small and survival values were greater than 100% nearly as often. These results suggest that the sediment samples collected in the Athabasca River and Athabasca Delta were nontoxic to slightly toxic to the test organisms compared to control samples.

4.2 Environmental Evaluation

4.2.1 Effects on Water Quality

Oil sands development activities that might affect water quality in the PAD include:

- diversion of flow from the Athabasca River upstream from the PAD; and
- activities that might affect water quality in the Athabasca River.

The hydrology evaluation indicated that no significant temporal trend was observed in flows in the PAD, and that surface water withdrawals from the Athabasca River will result in negligible changes in flows in the PAD. Therefore, the effects of water withdrawals from the Athabasca River on water quality in the PAD were not evaluated further.

The effects of PRM activities on water quality in the Athabasca River were predicted to be negligible, with all parameter concentrations predicted to be within 10% of baseline concentrations or below applicable aquatic health thresholds, as discussed in the EIA, Volume 4A, Section 6.5.7.2. Although the changes in water quality in the Athabasca River upstream from the PAD were predicted to be negligible, the parameters that might have increased from upstream to the mouth in the Athabasca River were qualitatively evaluated further, as described below.

Results of a cumulative effect assessment completed in the Athabasca River (Squires et al. 2009) found increasing trends as one moves downstream from the headwaters to the mouth in Athabasca River for chloride, total organic carbon, sodium, turbidity and TP. However, the concentrations of these parameters did not show significant temporal increasing trends or decreasing trends over the past 20 years in the PAD, with the exception of TP and turbidity (Section 4.1.1.4). Total metals concentrations have not shown increasing trends and high total metals were primarily of natural origin in the Athabasca River. Total metals related to the potential sediment loading from the PRM are discussed in Section 4.1.1.2.

Levels of TP in the waterbodies and watercourses in the PAD may have increased over the past 20 years (Sections 4.1.1.1 and 4.1.1.4). The primary source of the TP input in the Athabasca River was unknown because several potential sources might have contributed to the increasing trend, including pulp mills, large growth in municipal population, as well as the oil sands (Glozier et al. 2009). However, the modelling of TP concentrations in the Athabasca River upstream of the PAD indicated that cumulative inputs from all oil sands developments are expected to result in increases in TP concentrations of about 3% (Appendix 2, Section 3.3.3).

Mitigation measures described in the EIA, Volume 4A, Section 6.5.7.3, such as creating polishing ponds, a compensation lake and pit lakes, will be implemented to reduce or eliminate changes in TSS, and hence turbidity, in receiving watercourses. Polishing ponds will be tested before release to the receiving environment to verify acceptability of release waters for parameters defined under PRM's *Environmental Protection and Enhancement Act* approval. As a result of these measures, sediment yield, TSS and turbidity are not predicted to change in the Athabasca River or the PAD as a result of PRM.

Based on the analysis presented above, potential effects of PRM activities and other developments on water quality concentrations in the PAD are expected to be negligible.

4.2.2 Effects on Thermal Regime

Oil sands development activities that might affect the thermal regime in the PAD are as follows:

- diversion of flow from the Athabasca River upstream of the PAD; and
- activities that might affect water quality in the Athabasca River (EIA, Volume 4A, Section 6.5.2.5).

The hydrology assessment predicted that surface water withdrawals from the Athabasca River will result in negligible changes in overall flows, including low flow in the PAD (Section 3.2.2). The water quality assessment (EIA, Volume 4A, Section 6.5.7) predicted negligible changes in thermal regime in the Athabasca River at any location. Therefore, the effects of PRM activities on the thermal regime in the PAD are expected to be negligible and were not evaluated further.

4.2.3 Effects on Dissolved Oxygen Levels

Development activities that might affect DO concentrations in the PAD are as follows:

- diversion of flow from the Athabasca River upstream of the PAD; and
- activities that might affect water quality in the Athabasca River (EIA, Volume 5, Section 4.6).

The hydrology assessment predicted that surface water withdrawals from the Athabasca River will result in negligible changes in flows in the PAD (Section 3.2.2). Based on the literature review, the DO level in the PAD might have increased slightly over the past 20 years (Section 4.1.1.4). In addition, a model developed by Alberta Environment indicates that the range of withdrawals from the Athabasca River is unlikely to exert a measurable influence on DO (McEachern 2010). The water quality assessment (see the EIA, Volume 4A, Section 6.5.7) predicted negligible changes in DO concentrations in the Athabasca River at any location. Therefore, the effects of PRM activities on DO concentrations in the PAD are expected to be negligible and were not evaluated further.

4.2.4 Effects on Sediment Quality

Changes to sediment quality in the PAD might occur through either of the following two pathways because of Project activities:

- direct inputs of sediment that could be transported down the Athabasca River and deposited in the PAD; and
- changes in water quality concentrations that will interact with sediments through partitioning and other reactions.

Changes in suspended sediment inputs and runoff quality from PRM might change the sediment quality of waterbodies and watercourses within the PAD. The potential effects of each of these pathways were qualitatively assessed, as described below:

- Transport of metals associated with sediment load into a depositional environment like the PAD was examined by Glozier et al. (2009). Total metal concentrations appear to be largely of natural origin, with flow decreasing in the Athabasca River overall, and concentrations not increasing over the past 20 years.
- Spatial and temporal comparisons of sediment quality monitoring by RAMP do not indicate any consistent trends over time in concentrations of metals (Section 4.1.2.1), nor do they indicate any consistent, regional differences in sediment quality between baseline and test stations. These results do not show any relationships between sediment chemistry and composition of benthic invertebrate communities (RAMP 2010).
- Analysis of sediment cores taken from the west portion of Lake Athabasca indicate that PAH concentrations in lake sediments are generally consistent through time and lower than levels observed in other Canadian lakes (Bourbonniere et al. 1996).

- Monitoring of watercourses with and without oil sands development has shown considerable natural or background concentrations of hydrocarbons and other compounds (Colavecchia et al. 2004; Headley et al. 2001, 2002, 2005; Tetreault et al. 2003).
- A weak tendency was observed for naphthalene and fluorene to increase in concentration from the main body of the Athabasca River to the Athabasca River Delta channels, although lower molecular weight compounds of PAH have a tendency to increase in concentration from upstream sources to downstream depositional area. There is no evidence of effects on these substances from the oil sands developments (Evans et. al. 2002).
- A significant increasing trend was observed in some PAH sediment concentrations and reducing trends observed in others (Section 4.1.2.1). The cause of these changes cannot be determined from the limited data and the current RAMP sampling design. There are no sediment data from these stations before development began. Accordingly, it is not possible to discern whether the observed trends in sediment PAH and metals are within the ranges that would occur naturally.
- Polishing ponds, wetlands and pit lakes created for PRM will be implemented to trap eroded, suspended and bed-transported particulate material. These water systems will have sufficiently long residence times to enhance settling of solid materials and associated metals. Polishing ponds will be tested to verify acceptability of release waters for constituents defined under PRM's *Environmental Protection and Enhancement Act* approval.

Sampling of sediments at a suitable upstream reference station is required to evaluate spatial and temporal changes at stations downstream from oil sands development. Sampling of sediment stations upstream and downstream from development is recommended to be sampled concurrently. As part of ongoing improvements to RAMP, an enhanced sediment quality monitoring program will be developed in consultation with Alberta Environment and Environment Canada to monitor long-term temporal and spatial trends in sediment concentrations in the Athabasca River Delta and at appropriate locations upstream from oil sands developments. After considering the reviewed literature together with the lack of change in modelled water concentrations, and mitigation measures to be employed, the potential cumulative effects of PRM activities on sediment quality in the PAD are expected to be negligible.

4.3 Summary

The environmental evaluation of surface water and sediment quality changes to the PAD indicated that changes due to PRM in conjunction with existing, approved and planned developments would be negligible. This conclusion was based on multiple lines of evidence, including a literature review of existing studies, an analysis of data from those studies, and model results from the EIA. As effects on water and sediment quality were predicted to be negligible upstream of and within the PAD, the spatial extent of the aquatics Regional Study Area in the EIA was verified to be appropriate.

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ATTACHMENT A

Hydrological Baseline Information

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TABLES

FIGURES

1.0 HYDRO-CLIMATIC REGIME OF THE PEACE-ATHABASCA DELTA

1.1 Climate

With the exception of the Fort Chipewyan climate station, climate data specific to the Peace-Athabasca Delta (PAD) is limited to a few seasonal lookout stations with short periods of record on a limited number of climate parameters. The Fort McMurray Airport climate station, although located about 200 km to the south of the PAD, is a long-term station that monitors several climate parameters. Data from the Fort McMurray Airport climate station can be used to supplement information from the seasonal stations closer to the PAD.

1.1.1 Temperature

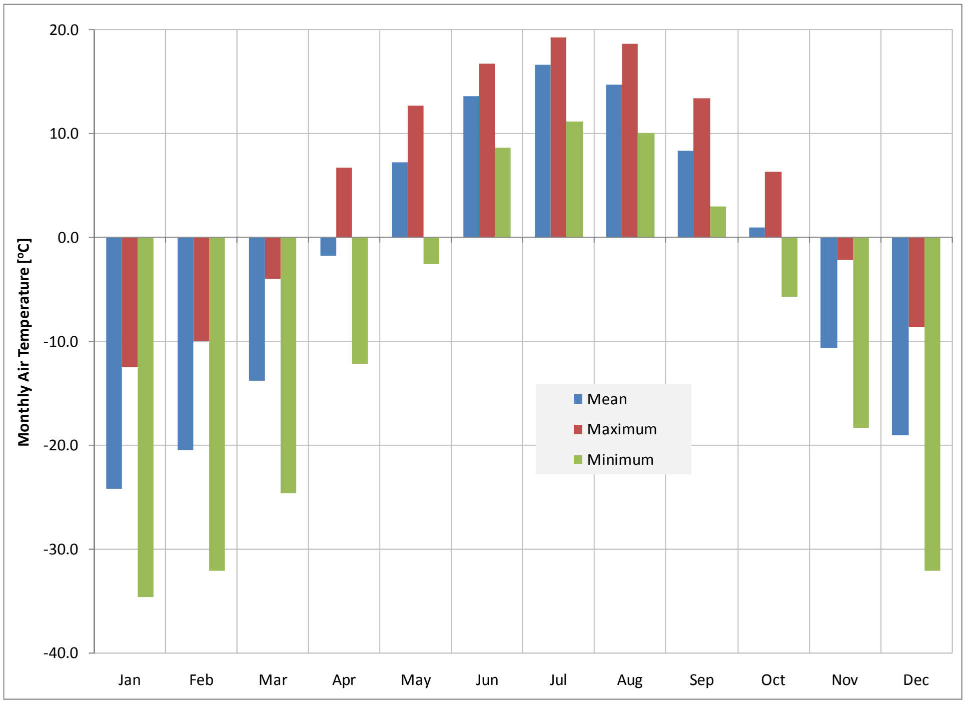
The Fort Chipewyan climate monitoring station is the only station located close to the PAD that has continuous records of air temperature. The small variation in air temperature between Fort Chipewyan and the seasonal stations suggests similar air temperature regimes throughout the region. Differences in air temperature between stations can be attributed to differences in elevation. Analysis of long-term data at the Fort Chipewyan climate station indicates a general trend of increasing temperatures in recent decades up to the present time.

Long-term climate records are available at the Fort Chipewyan climate station, which was operational from 1883 to 2007. The Fort Chipewyan climate data can be used to provide an approximate overview of the temperature, precipitation, and evaporation statistics for the PAD. Mean monthly air temperatures range from -24.2°C in January to 16.7°C in July. Mean annual air temperature is estimated at about -2.4°C. Plots of maximum, minimum and mean monthly air temperature data recorded at Fort Chipewyan climate station are shown in Figure A-1.

1.1.2 Precipitation

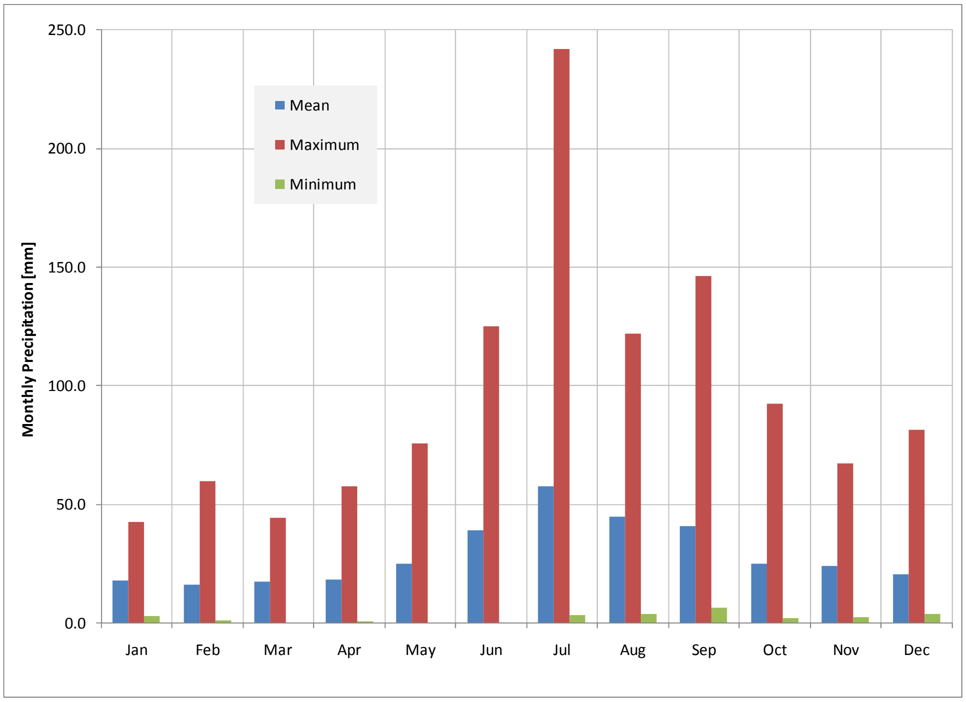
Based on an analysis of recorded data from Fort Chipewyan, average annual precipitation in the PAD is about 370 mm, about 40% of which accumulates as winter snowfall. The average monthly precipitation for June, July and August is about 39 mm, 58 mm and 45 mm, respectively, occurring primarily as rainfall. Plots of maximum minimum and mean monthly precipitation data recorded at Fort Chipewyan climate station are shown in Figure A-2.

Figure A-1 Monthly Air Temperature – Fort Chipewyan Climate Station



Source: Based on recorded data by Environment Canada (2012).

Figure A-2 Monthly Precipitation – Fort Chipewyan Climate Station



Source: Based on recorded data by Environment Canada (2012).

1.1.3 Evaporation

Many lakes in the PAD and wetlands that are perched above surrounding waterways are shallow and less than 1.5 m deep (Peters et al. 2001). In general, water drawdown is expected to occur annually because of average evaporation losses exceeding average precipitation. Estimated annual evaporation from small ponds is about 450 mm, and within perched basins, where groundwater contributions are only through levees and can be treated as negligible (Nielsen 1972), these numbers indicate that perched lakes and ponds have an annual water deficit of about 80 mm/yr.

Using the solar radiation and relative humidity data at Fort McMurray as inputs to the Morton evaporation model (Morton et al. 1985), average annual potential evaporation is estimated to be about 820 mm for the oil sands region. Average annual lake evaporation is estimated to be about 595 mm for shallow lakes less than 2 m deep. Average annual potential evapotranspiration is estimated to be about 795 mm, which is almost as high as average annual potential evaporation. The actual areal evapotranspiration averages about 312 mm per year, which is less than the potential evaporation rate. The areal evapotranspiration from areas around perched waterbodies might be considerably less because of the less frequent flooding of these areas.

1.2 Hydrology

The flow and water level gauging stations at which hydrometric data has been or continues to be collected by Environment Canada in the vicinity of the PAD are listed in Table A-1.

Table A-1 Hydrometric Monitoring Stations in the Vicinity of the Peace-Athabasca Delta

Station No.	Station Name	Drainage Area [km^2]	Type of Data	Monitoring Period	
				Start	End
07NB001	Slave River at Fitzgerald	606,000	Water level	2002	2010
07NB001	Slave River at Fitzgerald	606,000	Streamflow	1921	2010
07KC001	Peace River at Peace Point	293,000	Water level	2002	2010
07KC001	Peace River at Peace Point	293,000	Streamflow	1959	2010
07KC005	Peace River below Chenal Des Quatre Fourches	N/A	Water level	1972	2010
07NA007	Rivière Des Rochers east of Little Rapids	N/A	Water level	1960	2010
07NA008	Rivière Des Rochers west of Little Rapids	N/A	Water level	1960	2010
07NA001	Rivière Des Rochers above Slave River	N/A	Water level	1960	2010
07KE001	Birch River below Alice Creek	9,860	Streamflow	1967	2010
07MC003	Lake Athabasca near Crackingstone Point	271,000	Water level	1956	2010
07MD001	Lake Athabasca at Fort Chipewyan	271,000	Water level	1930	2010
07KF002	Lake Claire near Outlet to Prairie River	N/A	Water level	1970	2010
07KF003	Mamawi Lake Channel at Old Dog Camp	N/A	Water level	1971	2010
07DD003	Embarras River below divergence	N/A	Streamflow	1987	2010
07KF015	Embarras River Breakthrough to Mamawi Lake	N/A	Streamflow	1987	2010
07DD002	Richardson River near the mouth	2,700	Streamflow	1970	2010
07DA001	Athabasca River below Fort McMurray	133,000	Streamflow	1957	2010
07DD001	Athabasca River at Embarras Airport	155,000	Streamflow	1971	1984
07DD011	Athabasca River near Old Fort	156,000	Water level	1975	2010

N/A = Not available.

Source: Based on recorded data by Environment Canada (2012).

1.2.1 Slave River

The Slave River is the primary outflow channel from the PAD. Flows on the Slave River have been monitored at Fitzgerald, located about 150 km downstream of the PAD, since 1921. The total drainage area of the Slave River, referenced to the Fitzgerald hydrometric station 07NB001 is 606,000 km^2. The years from 1960 to 1967 represent the period of natural flow records. Maximum flows historically occurred in June with an average of 7,700 m^3/s.

The mean annual discharge estimate for the Slave River at Fitzgerald is about 3,914 m^3/s for the monitoring period prior to 1967 and about 3,363 m^3/s after 1972. The mean annual discharge in the Slave River at Fitzgerald is more than five times the mean annual discharge in the Athabasca River near Fort McMurray. The lowest daily flow recorded on the Slave River at Fitzgerald station was 530 m^3/s in 1953. The water level in Slave River at Station 07NB001 varied from 200.52 to 203.19 m amsl according to recorded daily data from 2002 to 2010 as shown in Figure A-3.

1.2.1.1 Effect of the W.A.C. Bennett Dam

The average winter, spring and summer flows on the Slave River indicate a statistically significant difference between the pre-dam and post-dam flow series recorded at Station 07NB001 due to regulation of the Peace River from the W.A.C Bennett Dam. Mean winter flows between January and March have increased by about 57% between the pre- and post-construction periods. In contrast, mean summer flows between July and September have been reduced by about 25% between the same periods (Figure A-4).

1.2.2 Peace River

The largest river flowing into the PAD complex is the Peace River. Flows on the Peace River have been monitored since 1960 at Peace Point, located just a few kilometres upstream of the PAD. The total drainage area of the Peace River, referenced to the Peace Point hydrometric station 07KC001 is 293,000 km^2 (Table A-1). The years from 1960 to 1967 represent the period of natural flow records. Maximum flows historically occurred in June with an average of 7,500 m^3/s and a standard deviation of 1,200 m^3/s. During this period the Peace River experienced flood flows averaging 8,800 m^3/s for 10 days, volumes that were sufficient to prevent water from flowing out of Lake Athabasca and the PAD system, and often created a southward flow of water that added to the volume of water already in the PAD system (Muzik 1991).

Recorded water levels at Peace Point (2002 to 2010) show a maximum fluctuation of about 11.05 m and recorded water levels below Chenal des Quatre Fourches (1972 to 2010) show a maximum fluctuation of about 7.26 m (Figure A-5).

Figure A-3 Recorded Daily Flows and Water Levels for Slave River at Fitzgerald

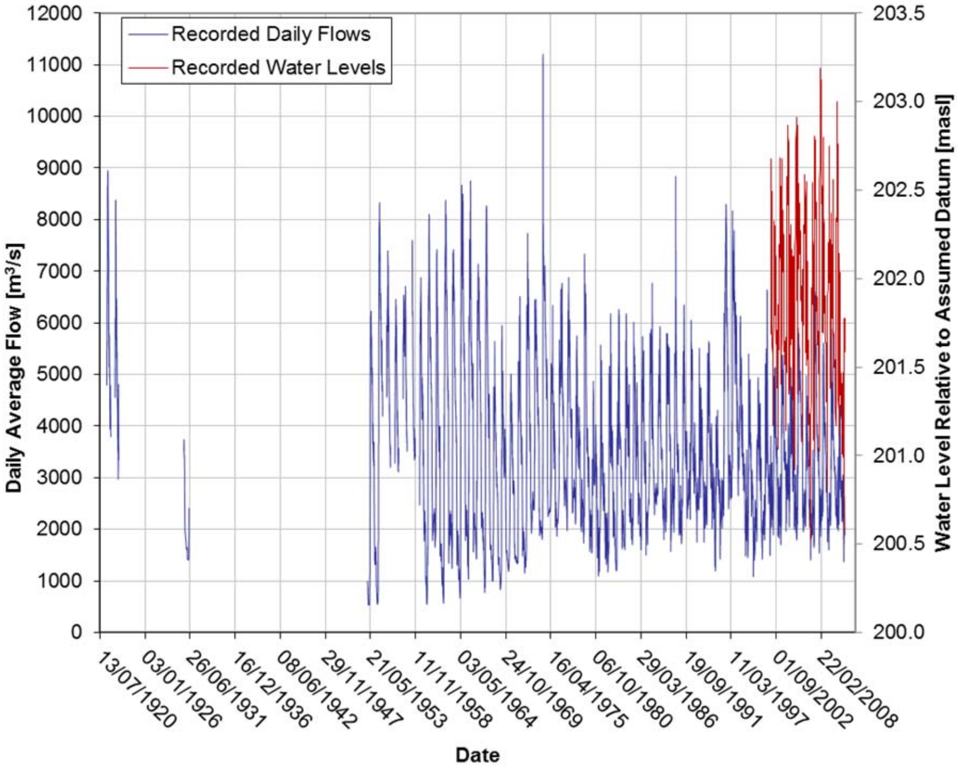


Figure A-4 Mean Seasonal Flows on the Slave River at Fitzgerald

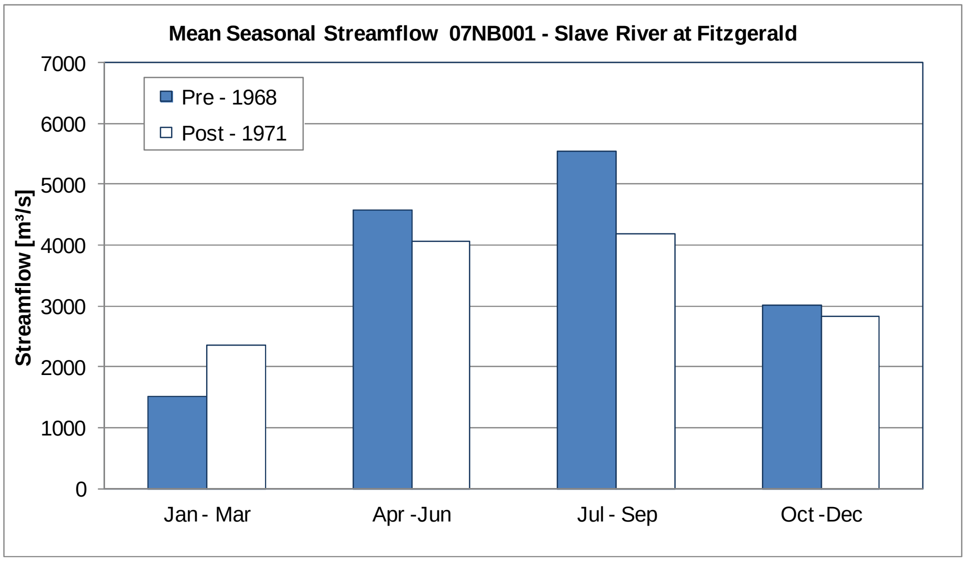
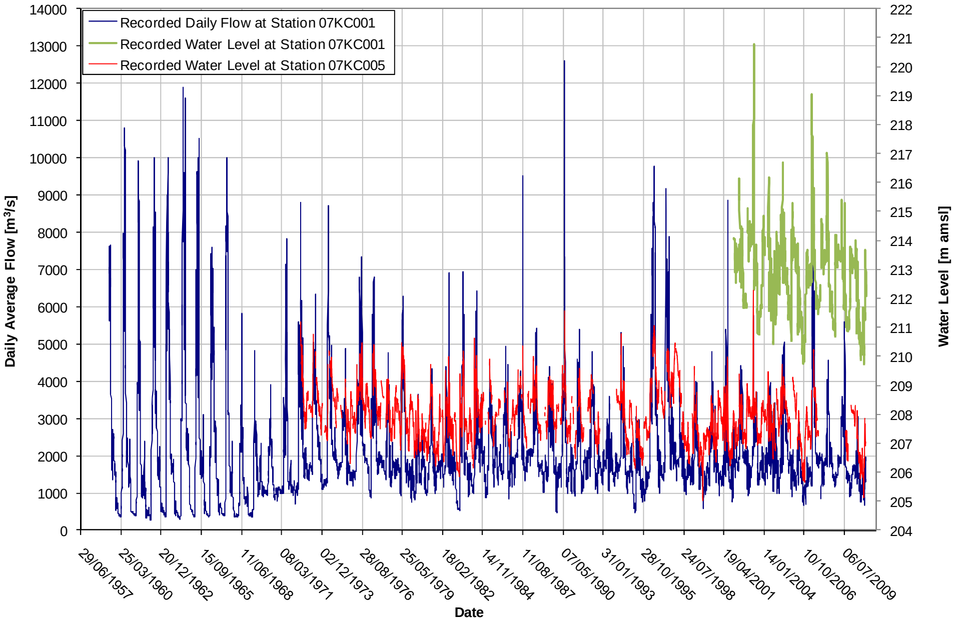


Figure A-5 Recorded Daily Flows and Water Levels for Peace River



1.2.2.1 Effect of the W.A.C. Bennett Dam

The mean annual discharge estimate for the Peace River at Peace Point is about 2,300 m^3/s from 1960 to 1967 and about 2,100 m^3/s from 1972 to 2010. The mean annual discharge in the Peace River at Peace Point is about four times the mean annual discharge in the Athabasca River at Embarras. The mean seasonal flows at the Peace Point station for two periods, pre-1968 that corresponds to the period prior to the construction of the dam on the Peace River and post-1971 that corresponds to the period after the construction, are shown in Figure A-6. Mean winter flows between January and March have increased substantially between the pre- and post-construction periods. In contrast, mean spring flows between April and June have been reduced by a large amount.

1.2.3 Lake Athabasca

Water levels in Lake Athabasca have been recorded at Fort Chipewyan (1930 to 2010) and at Crackingstone Point (1956 to 2010). Maximum water levels in the lake occurred in July 1935. The water level varied from 205.63 to 211.33 m amsl based on recorded data near Old Fort and from 207.31 to 210.64 m amsl based on recorded data near Crackingstone Point (Figure A-7).

Figure A-6 Mean Seasonal Flows on the Peace River at Peace Point

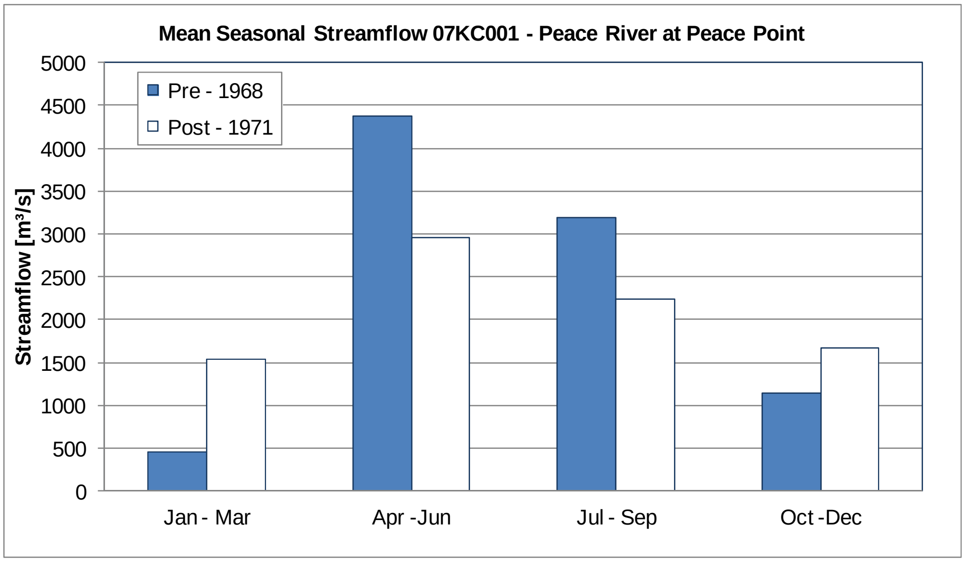
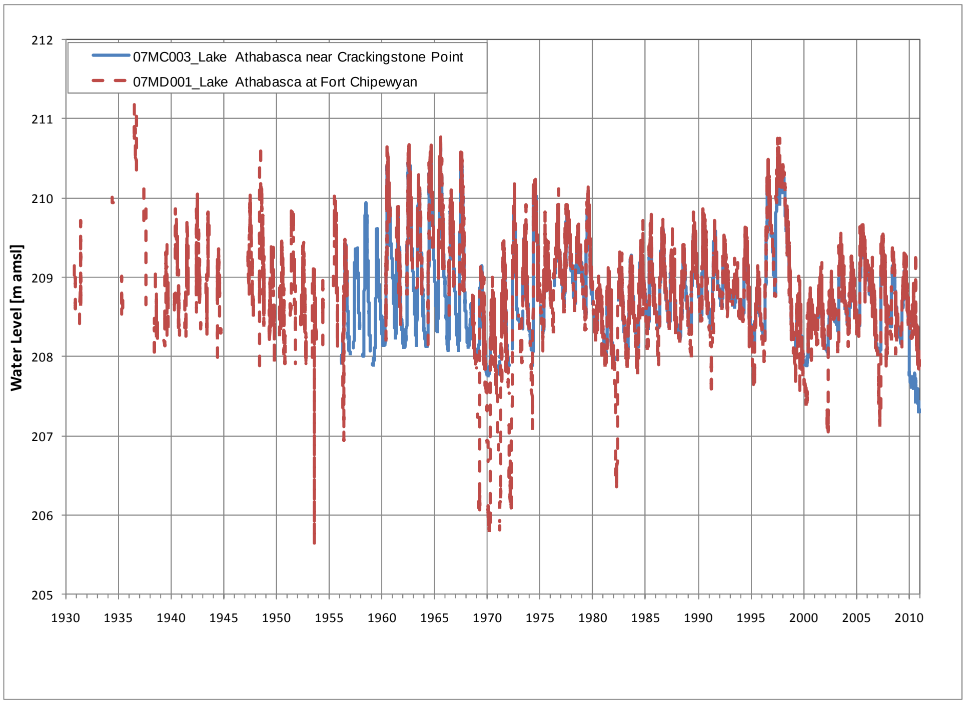


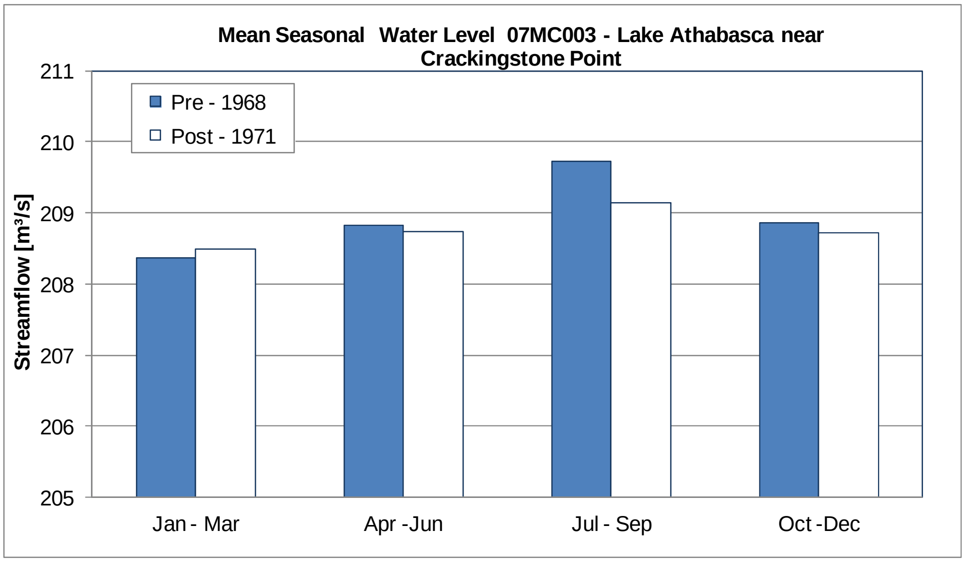
Figure A-7 Daily Water Levels for Lake Athabasca



1.2.3.1 *Effect of the W.A.C. Bennett Dam*

The mean seasonal water levels at the Crackingstone monitoring station are shown in Figure A-8 for two periods, the pre-1968 period prior to the construction of the W.A.C Bennett Dam on the Peace River, and the post-1971 period after the construction. The average seasonal water levels decrease during the July to September period because of the effects of the regulation of the Peace River from the dam. The differences during the other seasons are not as evident. A statistically significant decrease of about a half-metre is evident in the average open-water levels during the May to October period because of the effects of the regulation of the Peace River by the dam.

Figure A-8 Mean Seasonal Water Levels in Lake Athabasca Near Crackingstone Point



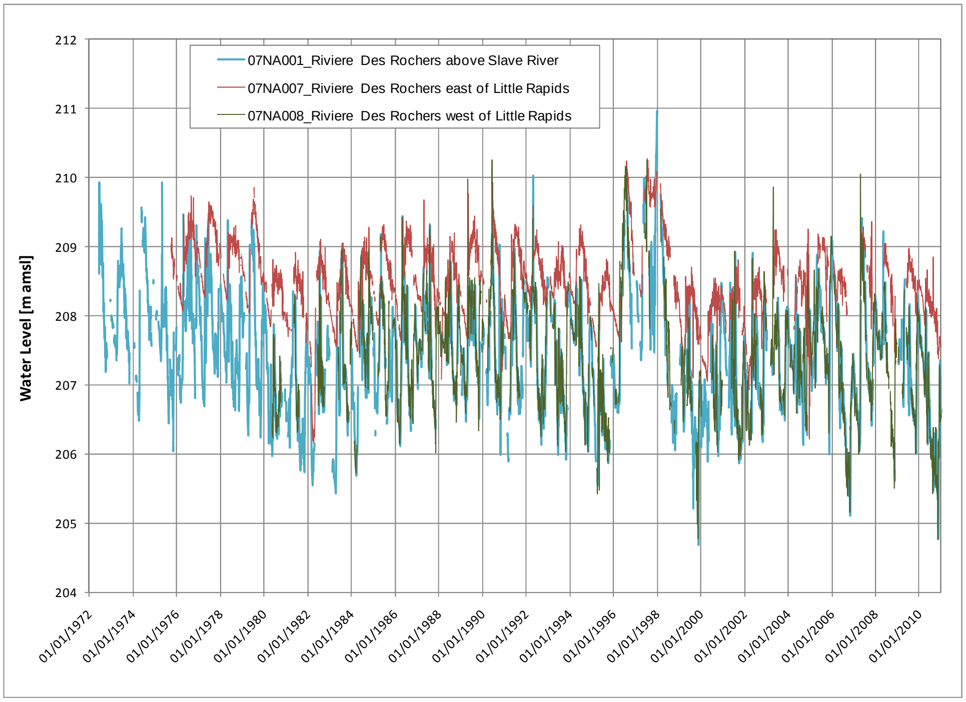
1.2.4 Distributary Channels in the Peace-Athabasca Delta

Two of the more prominent distributary channels in the PAD are currently gauged by Environment Canada: Rivière des Rochers (water level) that flows between Lake Athabasca and Peace River, and Embarras River (flow) between Athabasca River and Lake Athabasca. Although the data records for Rivière des Rochers start from 1960, almost all the data prior to 1971 is missing. Nevertheless, the data on the distributary channels and the water level data on Lake Athabasca and Peace River can be used to assess the flow patterns within the delta during the flood and low flow periods.

1.2.4.1 *Rivière des Rochers – Water Levels*

Water levels in Rivière des Rochers have been recorded at three stations (07NA001, 07NA007 and 07NA008 [1960 to 2010]). The water level varied from 204.69 to 210.96 m amsl based on recorded data at Rivière des Rochers above Slave River, and from 206.16 to 210.34 m amsl based on recorded data at Rivière des Rochers east of Little Rapids (Figure A-9).

Figure A-9 Daily Water Levels for Rivière des Rochers

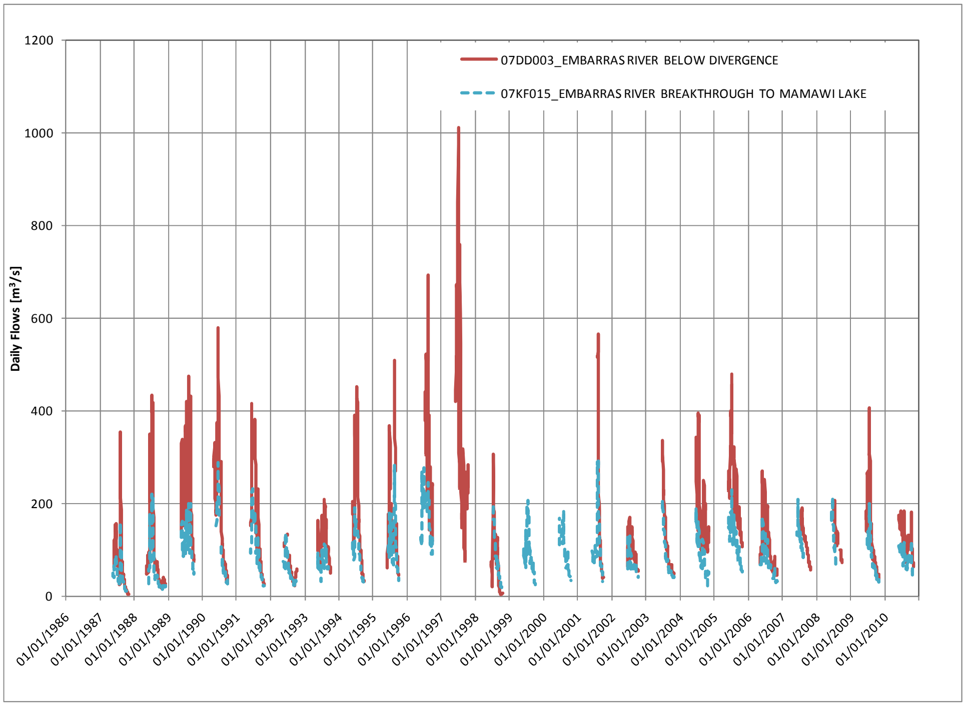


1.2.4.2 Embarras River Flows

Flows in Embarras River have been recorded at two stations (07DD003 and 07KF015 [1987 to 2010]). Average recorded outflow for Embarras River Breakthrough to Mamawi Lake is about 90 m^3/s. The maximum outflow for Embarras River Breakthrough to Mamawi Lake is controlled by Mamawi Lake water level. As a result, during high flood flows most of the flow will be directed to Lake Athabasca instead of going through the Breakthrough channel as shown in Figure A-10.

Past studies (Andrishak and Hicks 2010; PADTS 1996) estimate that the Embarras River captures on average about 10% of the Athabasca River flow entering the delta, with the breakthrough channel taking about 58% of the Embarras River's flow during normal conditions.

Figure A-10 Daily Flows for Embarras River



1.2.5 Athabasca River

1.2.5.1 Flows

The second largest river flowing into the PAD complex is the Athabasca River. The river flows are distributed through the delta and into Lake Athabasca through a series of rivers and channels.

The head watershed of the Athabasca River is situated in the Rocky Mountains of Alberta near Mount Columbia (elevation 3,747 m amsl). The river generally flows northeast through the province of Alberta, and passes by, or through Jasper, Hinton, Whitecourt, Athabasca and Fort McMurray before emptying into Lake Athabasca (elevation 208 m amsl), which outflows through the Mackenzie River system to the Arctic Ocean. The drainage area of the Athabasca River at its inlet into Lake Athabasca is about 160,000 km^2. The major tributaries to the lower Athabasca River between Fort McMurray and Lake Athabasca include the Beaver, MacKay, Ells, Muskeg, Steepbank, Firebag and Richardson rivers. Two Environment Canada hydrometric stations are located on the lower Athabasca River: Station 07DA001 (Athabasca River below Fort McMurray) and Station 07DD001 (Athabasca River at Embarras Airport; Table A-1).

The mean annual discharge estimates for the Athabasca River from 1957 to 2010 are 618 m^3/s at the Fort McMurray station and 666 m^3/s at Embarras Airport station. The Embarras Airport station estimate is derived from recorded flows from 1971 to 1984, as well as estimates for periods of missing data that are based on the ratio of mean monthly flows at the two stations.

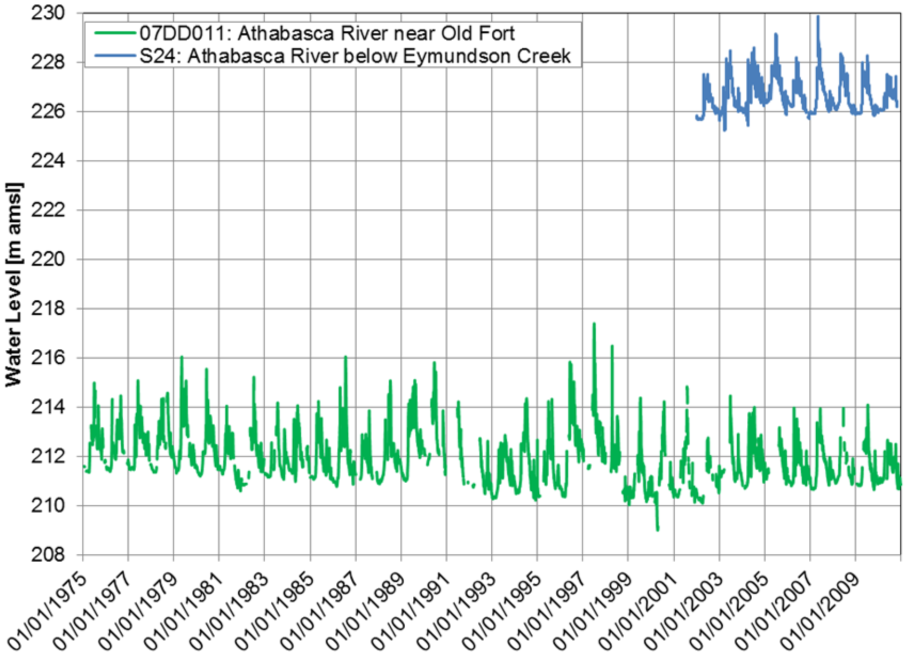
A frequency analysis of annual maximum daily discharge series from 1957 to 2010 at the two hydrometric stations on the lower Athabasca River indicates that the 2-year, 10-year and 100-year flood peak discharges are 2,324, 3,694 and 5,452 m^3 at the Fort McMurray Station, and 2,454, 3,783 and 5,420 m^3 at the Embarras Airport station. The maximum daily flows at the two stations are 4,700 m^3/s in 1971 (recorded) at the Fort McMurray station and 4,751 m^3/s in 1986 (derived) at the Embarras station.

The low flow period for the Athabasca River is the winter months, typically between November and March. The lowest daily flow recorded on the Athabasca River at the Fort McMurray station was 75 m^3/s in 2001. The 10-year 7-day low flow (7Q10) is estimated to be 101 m^3/s near Fort McMurray and 105 m^3/s at the Embarras Airport station. Plots of daily flows at these two stations are provided in Appendix 3.4, Figure 3.2-1 of this submission. Details of flow statistics for Athabasca River flows are provided in the EIA, Volume 4A, Section 6.4.3.

1.2.5.2 Water Levels

Water level measurements for Athabasca River are available at two locations: Athabasca River at S24 Regional Aquatics Monitoring Program (RAMP) station (1995 to 2010) and Athabasca River near Old Fort (Station 0700011 [1975 to 2010]). Based on recorded data, water level at the S24 RAMP station varied from 225.25 to 229.88 m amsl and water level at the station near Old Fort varied from 209.00 to 217.39 m amsl (Figure A-11).

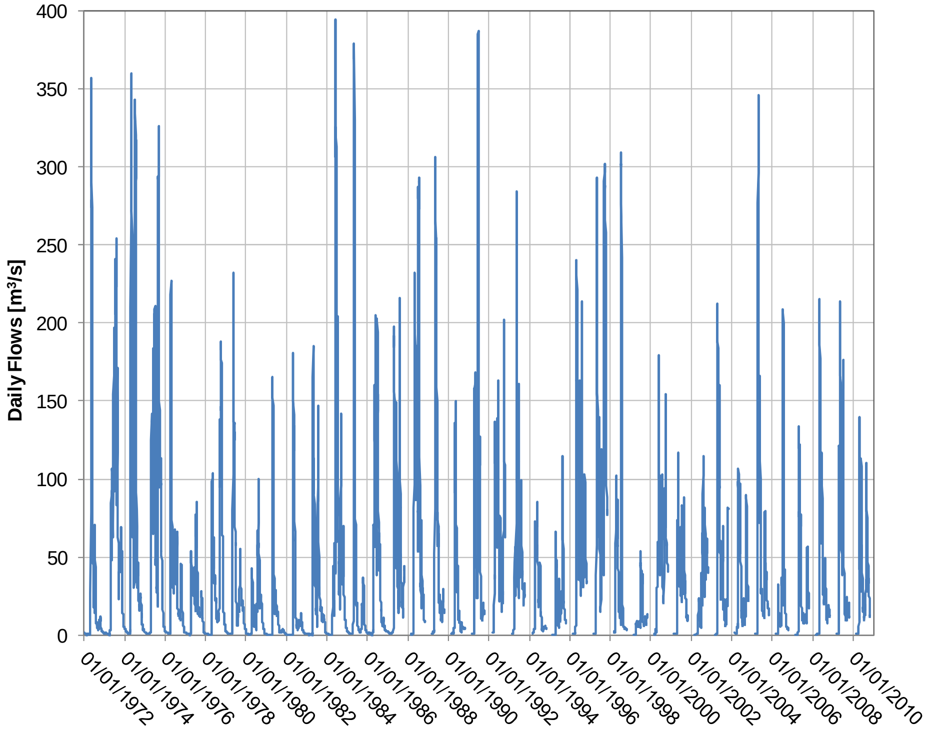
Figure A-11 Daily Water Levels for Athabasca River



1.2.6 Birch River

Flows in Birch River below Alice Creek (Station 07KE001) have been recorded from 1967 to 2010. The average annual flow based on recorded data is about 37.6 m^3/s. The highest and lowest flows recorded for Birch River below Alice Creek are 394 m^3/s and 0.142 m^3/s, respectively (Figure A-12).

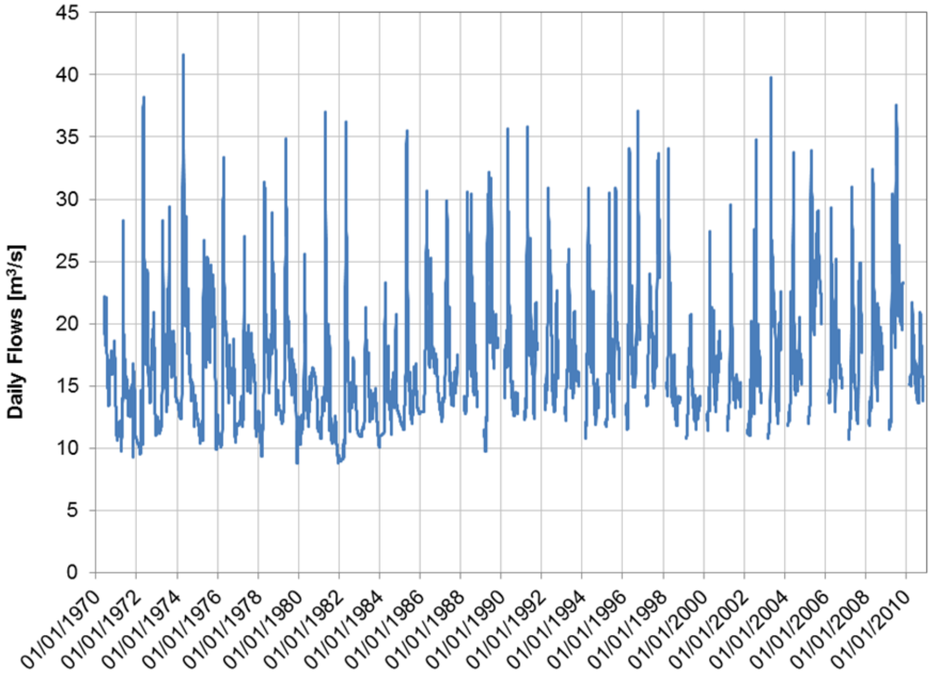
Figure A-12 Daily Flows for Birch River Below Alice Creek



1.2.7 Richardson River

Flows in Richardson River near the mouth (Station 07DD002) have been recorded from 1970 to 2010. Average annual flow based on recorded data is about 16.6 m^3/s. The highest and lowest flows recorded for Richardson River near the mouth are 41.6 m^3/s and 8.8 m^3/s, respectively. Plots of daily flows are provided in Figure A-13.

Figure A-13 Daily Flows for Richardson River Near the Mouth



1.3 Flooding Mechanism in the Peace-Athabasca Delta

Given the importance of floods to the perched basins within the PAD for maintaining hydro-ecological conditions essential for habitats, it is important to understand the underlying flooding mechanisms and various flood types within the region. A review of reports and journal articles (e.g., Andrishak and Hicks 2010, Farley and Cheng 1986; Jacques 1989; NRBS 1996; PAD-IC 1987; PAD-PG 1973; PADTS 1996; Peters et al. 2006; Prowse and Lalonde 1996; Prowse et al. 1996; Prowse and Conly 1998; Timoney 2002; Wolf et al. 2006) indicates that recharge of the PAD basins results from high backwaters induced by ice jams rather than from open-water flows, and that several distinct flood regimes are present.

Despite more than three decades of hydrological investigation, a comprehensive study that combines intra-delta hydrometric data and flood mapping has never been completed to properly establish the full range of flood conditions that affect the complex aquatic ecosystem of the PAD (Peters et al. 2006). The most comprehensive study was recently completed by Peters et al. (2006) using available satellite imagery and field hydrometric measurements of historically important extreme events, supplemented with information derived using a digital-elevation model and a hydraulic model. River and lake high waters generated under ice jam and open-water conditions were evaluated by producing a naturalized (no-dam and no-weirs) water level record. A one-dimensional hydraulic model was employed to remove the effects of regulation.

The study by Peters et al. (2006) concluded that ice jamming is the most effective mechanism for producing extremely high waters capable of recharging perched basins, in particular the elevated region of the Peace delta where productive wetlands are situated. In contrast, the historical high, open-water flow events generated by the

Peace Basin were insufficient to cause greater than bankfull flow conditions within the Peace delta. Even without the influence of flow regulation, overflow of the lower Peace River would have been a rare occurrence during ice-free conditions. However, the unregulated Athabasca River occasionally produces localized overland flow in the Athabasca delta under both open-water and ice jam conditions.

1.4 Waterbodies in the Peace-Athabasca Delta

Waterbodies in the PAD span a wide hydrological spectrum ranging from perennially open-drainage basins that are hydraulically connected to river channels under all flow conditions, to perennially closed-drainage or isolated basins that are influenced by river waters only at times of extensive flooding, such as that induced during major ice jam floods (Wolfe et al*.* 2006). Many of these waterbodies are perched above the open-water system and are dependent on occasional floodwater to maintain a viable water depth for aquatic wildlife, such as muskrat and waterfowl (Peters et al*.* 2001). In non-flood years, the balance of precipitation input, evaporation losses and (to a lesser extent) groundwater flow controls the water levels in the perched basins. An intermediate class of restricted drainage basins can also be defined as those that have intermittent channelized or overbank river connection during elevated flow conditions, including major floods during the summer.

All the waterbodies in the three classes (i.e., open-drainage, restricted-drainage and closed-drainage) gain water from direct precipitation and catchment runoff, and lose water through evaporation and outflow (except closed-drainage basins that lack an outflow under normal water level conditions). However, the relative importance of individual fluxes can differ markedly among basins, depending on the nature and frequency of river connection and variations in local runoff generation and hydro-climate. River flow dominates water budgets of open-drainage basins under most conditions, whereas the balance of precipitation, runoff and evaporation usually determines the budgets of closed-drainage basins, other than during brief episodes of inflow during overland flooding (Wolfe et al*.* 2006). The restricted-drainage basins, hydrologically lying between these two extremes, have highly variable water budgets. Leconte et al*.* (2001) note that, because regional evaporation is generally greater than precipitation (Prowse et al. 1996), these hydrologically disconnected lakes are dependent on periodic flooding to sustain their high primary plant production, on which most of the PAD's wildlife rely for food and shelter (Carbyn et al*.* 1993).

In summary, the perched basins in the PAD are sensitive ecosystems that depend primarily on periodic spring ice jam-induced floods for water and nutrient replenishment.

1.5 Flood Zones in the Peace-Athabasca Delta

The relief, channel network, wetlands and small lakes of the PAD are poorly understood owing to the flatness and hydrological complexity of the system. Several studies attempted to classify the PAD according to flood stages, flood mechanism and origin of floodwaters (Jaques 1989; Peters et al. 2006; Prowse and Demuth 1996; Townsend 1972). Peters et al. (2006) classified the PAD into three zones based on relief, dominant channel and lake hydrology: (a) perimeter Peace River Delta; (b) perimeter Athabasca River Delta; and (c) central delta lakes.

These three zones have coalesced at the west arm of Lake Athabasca to form several large shallow lakes in the centre of the PAD, including Lake Claire, Baril Lake and Mamawi Lake. The lakes are from less than 1 m deep to 3 m deep (Prowse and Conly 2002). Topographic relief in the PAD seldom exceeds 1 m above the surface of the major PAD lakes, except for levees and islands of bedrock from the Precambrian Shield located primarily in the northeast (Prowse and Conly 2002).

1.5.1 Peace River Delta Zone

The Peace River Delta zone is found in the north portion of the PAD with most of the landscape above 212 m amsl (i.e., the highest elevations in the PAD). Flooding of the perched basins in this zone is predominantly from backwater flooding from ice jam in the Peace River.

1.5.2 Athabasca River Delta Zone

The Athabasca River Delta zone is found in the south portion of the PAD and lies largely below 212 m amsl. Flooding of the perched basin in this zone is from overbank flow from ice jam or open-water floods in the Athabasca River.

1.5.3 Central Delta Lake Zone

The central delta lake zone is found between the Peace River Delta and Athabasca River Delta. The lateral expansion of the central delta lake zone into inland areas is likely the primary mechanism for replenishing the low- to mid-elevation contiguous wetlands. The central delta lake zone occupies the central portion of the about 3,900 km^2 of the PAD and is connected to the main distributary streams such as Embarras River and to Lake Athabasca by a series of channels. A myriad of small lakes and wetlands also dot the inland areas surrounding the main hydrographic network.

1.6 Ice Jam Flooding

An ice jam flood is characterized by a large flood wave produced by the rapid melt of a deep snowpack, pushing and breaking the ice cover (increased resistance to flow), which might jam (reduction in channel cross-section) and temporarily raise the river water level. Hence, ice jamming produces extremely high backwaters with considerably less discharge than those generated under ice-free conditions (Prowse and Lalonde 1996). The 1974 and 1996 events are typical ice jam floods that occurred in the PAD. These events are described in the following sections and the observations provide insights into the spatial flooding patterns during such events.

1.6.1 1974 Ice Jam Flood Event

Dynamic spring breakups were recorded on the Athabasca River below Fort McMurray and Peace River at Peace Point on April 20 and 22, 1974. Based on information from local residents, flooding in the PAD occurred at the end of April because of massive ice jams that extended from Rocky Point on the Peace River to about 20 km down the Slave River (Peterson 1992).

The ice jam on Peace River resulted in backwaters elevations of about 215.46 m amsl on the Peace River below Chenal des Quatre Fourches and 201.96 m amsl at the confluence of the Peace River with the Rivière des Rochers on May 2 (Environment Canada 1998). The Peace River, which is normally within a bank width of 0.5 to 1 km, grew to more than a 5- to 10-km-wide floodplain (Peters et al. 2006). An ice jam also occurred within the Athabasca delta, with a peak level of 211.97 m amsl (Peterson 1992). Over a period of 10 to 14 days, overland sheet flow originating from the south and north perimeter delta channels spread to virtually all perched wetlands areas of the PAD, including the most isolated basins, forming a single large lake (Thorpe 1986). Drainage of the central delta lakes was delayed because of a temporary rock weir at the outflow of Mamawi Lake, which was partially washed away and removed the following year.

1.6.2 1996 Ice Jam Flood Event

Over an extended period from 1975 to 1995, there was no large-scale ice jam flooding in the PAD (Wolfe et al. 2006). Prowse and Conly (1998) note that the frequency of ice-induced backwater flooding of perched basins has declined since the 1970s. They suggest that the absence of a high-order flooding event in the PAD between 1974 and 1992 seems to be because of the combined effect of flow regulation on the Peace River and a decrease in spring runoff from the downstream portions of the Peace River basin unaffected by regulation. Elevated ice levels and winter flows resulting from regulation have further reduced the potential for tributary runoff to produce severe breakup floods.

The 1996 ice breakups were recorded on April 20 on Athabasca River below Fort McMurray and on April 24 on Peace River at Peace Point. The ice cover jammed near Moos Island in the Peace River and progressed up the Chenal des Quatre Fourches to Dog Camp and down to the confluence with the Slave River (Giroux 1997). Flood level in the Peace River reached about 214.18 m amsl near the Chenal des Quatre Fourches and about 212.02 m amsl at the Rivière des Rochers (Giroux 1997).

Ice jamming was observed on the lower Athabasca River in the meander downstream of the erosion control works and on the Embarras River below the breakthrough to Mamawi Creek (Giroux 1997). The ice jam in the lower Athabasca River produced a maximum water level of about 216.61 m amsl on the Embarras River below the divergence and about 211.52 m amsl on the Athabasca River above Jackfish Creek (Environment Canada, 1998). In comparison, the Peace River Delta zone is found in the north portion of the PAD with most of the landscape above 212 m amsl (i.e., the highest elevations in the PAD). The Athabasca River Delta zone is found in the south portion of the PAD and lies largely below 212 m amsl.

The backwater generated by above normal flows and ice jamming during the 1996 event was sufficiently elevated to spill channel flow onto floodplains and spread (over 5 to 10 days) onto the landscape (Prowse et al. 2002). Flood mapping based on a classified satellite image provided by Pietroniro et al. (1999) shows that a large portion of the PAD was inundated by the time the jams cleared in early May. A large number of the elevated perched basins east of the Claire River were replenished for the first time in over 20 years and most of the low-lying wetlands towards Mamawi and Richardson lakes were also flooded. The area north of Jackfish Creek received little water, if any (Giroux 1997) and ground surveys were not available to confirm if this area was flooded.

1.6.3 Comparison of 1974 and 1996 Ice Jam Events

The 1974 ice jam on Peace River resulted in backwaters elevations of about 215.46 m amsl (which is greater than the elevation of 212 m amsl of most of the surrounding landscape), and the extent of the inundation was larger than that of the 1996 event. Several key factors combined to divert greater volumes of channel water onto the perimeter landscape and central lakes in 1974 than in 1996 (Peters et al. 2006). For the 1974 event, an ice jam on the Slave River severely restricted outflow from the system, and maximum backwaters on the Peace River attained higher levels and were also driven by greater discharge. In addition, overland flow lasted several days longer during the 1974 event. Hence, the 1974 ice jam event was considered representative of the largest possible areal extent of inundation.

1.7 Open-Water Flooding

After the spring period ice jam events, flooding in the PAD can also occur because of large, rapid flood waves travelling through the perimeter delta channels and the expansion of lakes beyond their main shoreline. Open-water flood events on the Peace River and Athabasca River are described in the following sections. The observations provide insights into the effectiveness of flood events in replenishing the range of waterbodies, from perennially *open-drainage* basins through an intermediate class of *restricted-drainage* basins to perennially *closed-drainage* basins.

1.7.1 1990 Open-Water Flood Event on the Peace River

The recorded flows at Environment Canada gauging station at Peace Point (1959, 2010) indicate that the observed maximum flow during the 1990 open-water flood event on the Peace River occurred on June 17, 1990 (12,600 m^3/s). Using a one-dimensional hydraulic model, Peters et al. (2006) estimated that the water level on the lower Peace River peaked (mean daily) on June 17 to 18 at 214.60 m amsl at the Claire River, about 212.10 m amsl at the Chenal des Quatre Fourches, and about 210.43 m amsl at the Rivière des Rochers confluence. This event temporarily caused flow reversal in the connecting channel, but did not result in noticeable overbank flow into the river floodplain and adjacent wetlands, as seen on the June 29 Landsat^{TM} image (Peters 2003). This suggests that perched basins in the northern perimeter of the PAD are unlikely to be replenished by open-water flood events generated by the Peace River Basin (Peters et al. 2006; Prowse and Lalonde 1996).

1.7.2 1971 Open-Water Flood Event on the Athabasca River

The recorded flows for Athabasca River below Fort McMurray (1957 to 2010) indicate that the highest flow (4,700 m^3/s) on the Athabasca River during the 1971 open-water flood event occurred on July 17, 1971. Recorded flows at Environment Canada gauging station at Embarras Airport show that the highest flow at this location was about 4,190 m^3/s. The 1971 flood flow overwhelmed levees of the Athabasca River and caused erosion/transport of material towards the Embarras River (PAD-PG 1973). Maximum recorded water level on Athabasca River near Jackfish Creek was about 212.07 m amsl. Most of the Athabasca delta lies below this elevation and experienced localized flooding. Ambrock and Allison (1972) reported that nearby South Egg Lake was recharged and peaked at about 211.41 m amsl during this event.

Similar to what has been observed for the Peace delta, considerably more discharge is required to produce an open-water flood comparable to those generated by ice jamming in the Athabasca delta channels. However, the Athabasca River has fairly regularly (estimated at 1 in 5 years) generated open-water floods capable of overtopping the distributary channel banks (Peters 2003).

Using a one-dimensional hydraulic modelling, Peters et al. (2006) estimated that backwaters from Lake Athabasca, under a naturalized scenario, would not have influenced the peak flood-wave near Jackfish Creek because of the greater than 2 m difference in elevation. The low-lying northerly portions of the Athabasca River Delta are likely affected by Lake Athabasca expansion and associated backwaters in the delta channels, especially during abnormally high lake levels.

1.7.3 Central Delta Lakes Flooding During Open-Water Floods

Peters et al. (2006) used the water level measured on Lake Athabasca River at Fort Chipewyan as an indicator to evaluate flooding potential of the central delta lakes. Examination of recorded observed data at this site (averaged over 3 days to alleviate wind effects) indicated that the maximum level ranged from a low of 208.69 m amsl in 1945 to a high of 211.32 m amsl in 1935. These extremes occurred before regulation of flows on the Peace River. Since flow regulation, the highest Lake Athabasca level (210.48 m) occurred in 1996. A description and comparison of the 1935 and 1996 events is provided below.

1.7.3.1 1935 Flood Event

The peak lake level during the 1935 event occurred on July 14 and it was almost 1 m higher than observed levels during the 1996 event. Comparison of flood maps by Peters et al. (2006) revealed that the central delta lakes extended considerably farther inland during the 1935 event compared with the flood extent for the 1996 event. Lake Athabasca enlarged up to Lake Richardson and merged with Mamawi Lake and Lake Claire, forming one large body of water that inundated about 80% of the basins.

Lake expansion greater than 10 km inland did not recharge the areas north of Baril Lake and south of the Embarras River. Flooding of these isolated basins requires considerably more outflow constriction and river inflow to raise the lakes by an additional 2 m (Peters et al. 2006). Long-term (1810 to 1930) reconstruction of water level changes for Lake Athabasca by analysis of tree rings indicates that flooding has not happened in the last two centuries and that the 1935 water level represents the maximum areal extent of perched-basin inundation through lake expansion (Stockton and Fritts 1973).

1.7.3.2 1996 Flood Event

About four months after the 1996 spring ice jam flood event, the PAD experienced an open-water flooding into inland areas. This flooding occurred because of atypical circumstances. Williston Lake reservoir was lowered 3 m over a 6-week period in response to the discovery of a sinkhole in the crest of the W.A.C. Bennett Dam and wet hydro-climate conditions were prevalent in the contributing basins (Peters et al. 1999). Leconte et al. (2001), using a one-dimensional hydraulic model, estimated that the central lakes would have been almost 0.5 m lower under typical reservoir operation, but still at an above average lake level.

The sustained high discharges in the Peace River impeded outflow from outlet channels from the PAD and contributed some reverse flow to the large complex, raising Lake Athabasca by almost 1 m above the spring lake level to a maximum level of about 210.45 m amsl on August 16. A flood map developed by Peters et al. (2006), showed that the large central lakes expanded beyond their normal shorelines, overwhelming large areas of low-lying wetlands and inland lakes. Lake Athabasca inundated a large portion of the Athabasca River Delta north of Jackfish Creek. An estimated 55% of the inland basins were replenished. The remaining perched basins that were not affected by lake expansion were located within both elevated perimeters of the Peace and Athabasca river delta areas.

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ATTACHMENT B

Summary of Water Quality

Table B-1 Summary of Water Quality in the Athabasca River Delta and Lake Athabasca

Parameter	Units	Athabasca River Downstream of Old Fort				Athabasca River Delta				Lake Athabasca			
		Median	Minimum	Maximum	n	Median	Minimum	Maximum	n	Median	Minimum	Maximum	n
Field Measured													
pH	pH units	7.7	6.9	**9.3** (a)(b)	32	7.8	**5.4** (a)(b)	**10** (a)(b)	72	7.7	6.6	**8.8** (a)(b)	10
Specific Conductance	µS/cm	388	149	541	31	240	11	7,800	93	93	76	378	10
Temperature	°C	0.15	0.0	21	52	12	0.0	22	123	4.0	0.0	19	17
Dissolved Oxygen	mg/L	10	8.4	13	32	9.4	**3.5** (a)(b)	16	92	11	8.5	16	10
Dissolved Oxygen (Winkler)	mg/L	10	8.6	12	34	8.9	6.2	14	23	9.9	8.9	17	11
Conventional Parameters													
Biochemical Oxygen Demand	mg/L	0.55	0.2	3.2	12	1.0	<0.1	<2	13	0.5	-	-	1
Colour	TCU	23	18	24	4	23	4.0	100	39	6.5	2.0	23	16
Dissolved Organic Carbon	mg/L	6.9	4.7	12	57	7.5	<1	60	133	3.8	2.8	7.2	21
Hardness	mg/L	150	95	204	56	105	3.1	331	108	34	23	152	22
pH	pH units	7.9	7.2	8.4	57	7.9	**5.1** (a)(b)	8.4	155	7.7	7.1	8.1	22
Specific Conductance	µS/cm	420	233	598	57	258	<50	945	154	89	71	395	22
Total Alkalinity	mg/L	142	90	185	57	96	1.9	210	156	34	27	138	22
Total Dissolved Solids	mg/L	256	188	328	48	160	53	625	110	70	54	248	13
Total Dissolved Solids (Calculated)	mg/L	241	123	342	56	137	15	404	62	45	34	216	21
Total Organic Carbon	mg/L	7.2	5.2	12	21	10	<1	61	92	-	-	-	-
Total Suspended Solids	mg/L	5.0	<0.4	480	57	16	<0.4	518	145	19	<1	278	22
Major Ions													
Bicarbonate	mg/L	174	110	226	57	119	2.4	199	66	41	33	168	21
Calcium	mg/L	41	25	57	57	31	0.9	100	155	9.0	6.0	41	21
Carbonate	mg/L	<0.5	<0.5	<5	50	1.0	0.0	<5	24	-	-	-	-
Chloride	mg/L	30	6.0	62	57	8.3	0.8	106	156	4.0	3.3	24	21
Fluoride	mg/L	0.12	0.1	**0.33** (b)	57	0.1	0.01	**0.31** (b)	116	0.075	0.05	**0.37** (b)	22
Magnesium	mg/L	12	7.0	15	57	8.0	0.2	25	155	3.0	2.0	12	21
Potassium	mg/L	1.6	0.7	8.2	57	1.1	0.1	9.2	155	0.9	0.7	1.2	21
Sodium	mg/L	32	9.0	51	57	11	0.6	92	156	3.0	2.0	26	22
Sulphate	mg/L	37	15	54	57	22	1.8	120	154	5.0	<3	28	22
Sulphide	mg/L	<0.01	0.003	<0.01	14	<0.01	<0.001	<0.01	40	<0.001	-	-	1
Nutrients and Chlorophyll *a*													
Chlorophyll *a*	µg/L	0.6	0.2	24	56	3.1	0.3	65	50	1.5	0.2	3.9	9
Nitrate + Nitrite	mg/L	0.19	<0.001	0.63	57	0.036	<0.001	0.36	143	0.007	<0.001	0.21	25
Nitrogen - Ammonia	mg/L	0.09	0.01	0.2	48	<0.05	<0.01	<0.1	11	<0.01	<0.01	0.04	5
Nitrogen - Kjeldahl	mg/L	0.41	0.2	0.9	57	0.5	0.04	9.2	141	0.21	<0.05	0.8	23
Nitrogen - total	mg/L	0.59	0.27	**1.1** (b)	57	0.54	0.009	**9.2** (b)	147	0.22	<0.001	0.8	25
Phosphorus, dissolved	mg/L	0.015	0.004	0.057	56	0.011	0.002	0.12	62	0.005	0.003	0.017	24
Phosphorus, total	mg/L	0.033	0.015	**0.26** (b)	56	**0.051** (b)	0.008	**0.64** (b)	148	0.041	0.004	**0.33** (b)	24
General Organics													
Naphthenic acids	mg/L	<0.1	-	-	1	<1	<1	<1	5	-	-	-	-
Total Phenolics	mg/L	0.003	<0.001	**0.007** (b)	16	0.003	<0.001	**0.028** (b)	89	0.003	<0.001	**0.005** (b)	21
Total Recoverable Hydrocarbons	mg/L	0.36	<0.2	1.7	9	0.46	<0.1	2.2	66	0.35	<0.2	1.9	8
Total Metals													
Aluminum	mg/L	0.065	0.0081	**0.32** (b)	20	**1.7** (a)(b)	0.02	**6.9** (a)(b)	6	0.021	-	-	1
Antimony	mg/L	0.0002	0.000053	0.00073	13	0.00012	0.0001	<0.0008	3	-	-	-	-

Table B-1 Summary of Water Quality in the Athabasca River Delta and Lake Athabasca (continued)

Parameter	Units	Athabasca River Downstream of Old Fort				Athabasca River Delta				Lake Athabasca			
		Median	Minimum	Maximum	n	Median	Minimum	Maximum	n	Median	Minimum	Maximum	n
Arsenic	mg/L	0.00065	<0.0002	0.0025	24	0.0007	0.0002	**0.0078** (b)	53	0.0006	<0.0002	0.0043	21
Barium	mg/L	0.065	0.048	0.15	24	0.056	0.005	0.17	53	0.033	0.017	0.11	21
Beryllium	mg/L	0.000018	<0.000003	<0.0002	15	<0.001	0.00017	<0.001	6	-	-	-	-
Boron	mg/L	0.038	0.025	0.85	15	0.019	0.016	0.031	5	-	-	-	-
Cadmium	mg/L	0.000087	0.0000094	**0.0007** (b)	13	<0.0000691	<0.00001 [3]	<0.0002	3	-	-	-	-
Chromium	mg/L	**0.002** (b)	0.00013	**0.009** (b)	28	**0.002** (b)	<0.001	**0.022** (a)(b)	53	<0.001	<0.001	**0.015** (b)	21
Cobalt	mg/L	0.00035	0.000022	0.005	24	<0.001	<0.0002	0.004	52	<0.001	<0.001	0.008	21
Copper	mg/L	0.0021	<0.0002	**0.008** (b)	28	0.002	<0.001 (c)	**0.015** (b)	53	0.002	<0.001	**0.01** (b)	21
Iron	mg/L	**0.54** (b)	0.013	**0.9** (b)	19	**0.82** (b)	0.19	**13.9** (b)	27	**0.89** (b)	0.063	**9.9** (b)	13
Lead	mg/L	0.0011	0.000091	**0.071** (b)	20	0.0018	<0.0001 (c)	0.0027	6	-	-	-	-
Lithium	mg/L	0.0088	0.004	0.034	13	0.0074	0.0059	0.01	5	-	-	-	-
Manganese	mg/L	0.038	0.023	**0.094**	29	0.043	0.006	**0.40**	53	0.023	0.002	0.20	21
Mercury	mg/L	0.0000037	0.00000035	<0.00005 (c)	11	**0.000012** (b)	<0.0000012	**0.000022** (a)(b)	2	-	-	-	-
Molybdenum	mg/L	0.001	0.00051	0.007	24	<0.001	0.0004	0.003	52	<0.001	<0.001	0.003	21
Nickel	mg/L	0.002	0.0000064	0.015	24	0.003	0.0004	0.016	53	0.002	<0.001	0.012	21
Selenium	mg/L	<0.0002	<0.0002	0.00058	24	<0.0002	<0.0001	**0.0036** (b)	53	<0.0001	<0.0001	0.0002	21
Silver	mg/L	0.0000053	<0.0000005	<0.0001	12	0.000017	<0.000005	0.000028	2	-	-	-	-
Strontium	mg/L	0.3	0.24	0.54	13	0.22	0.19	0.24	5	-	-	-	-
Thallium	mg/L	0.000014	<0.0000003	0.0002	13	0.000087	0.00004	<0.0001	4	-	-	-	-
Titanium	mg/L	0.004	0.001	0.014	13	0.051	0.0063	0.14	5	-	-	-	-
Uranium	mg/L	0.0004	0.00027	0.0006	15	0.00059	<0.0001	0.0023	14	0.00075	<0.0005	0.0071	8
Vanadium	mg/L	0.0011	0.00032	0.009	24	0.002	<0.001	0.032	73	<0.002	<0.002	0.015	21
Zinc	mg/L	0.0057	<0.001	0.025	23	0.004	<0.001	**0.058** (b)	53	0.007	<0.001	**0.038** (b)	21
Dissolved Metals													
Aluminum	mg/L	0.0051	0.002	0.01	13	0.01	0.008	0.31	5	-	-	-	-
Antimony	mg/L	0.0001	0.000053	0.00046	13	<0.0008	0.000077	<0.0008	5	-	-	-	-
Arsenic	mg/L	0.00043	<0.0002	0.0005	13	0.0007	0.0003	0.008	20	-	-	-	-
Barium	mg/L	0.06	0.044	0.086	13	0.047	0.042	0.052	5	-	-	-	-
Beryllium	mg/L	<0.0002	<0.000003	<0.001	22	<0.001	0.0000099	<0.001	51	<0.001	<0.001	<0.001	21
Boron	mg/L	0.033	0.026	0.06	13	0.022	0.011	0.05	6	0.018	-	-	1
Cadmium	mg/L	0.000027	0.0000093	0.0004	11	<0.0001	<0.00001	<0.0001	5	-	-	-	-
Chromium	mg/L	0.00053	0.00013	0.002	12	0.0004	0.00034	0.0051	5	-	-	-	-
Chromium - hexavalent	mg/L	0.001	<0.001	0.003	6	0.003	<0.001	0.014	14	-	-	-	-
Cobalt	mg/L	0.000086	0.000022	0.0017	13	0.0001	0.00003	0.0002	5	-	-	-	-
Copper	mg/L	0.00082	<0.0002	0.0027	12	0.0015	0.0008	0.0018	5	-	-	-	-
Iron	mg/L	0.2	<0.01	0.76	42	0.14	0.068	0.47	5	-	-	-	-
Lead	mg/L	0.00029	0.000045	0.019	13	0.0001	0.000085	0.0003	5	-	-	-	-
Lithium	mg/L	0.0084	<0.004	0.011	13	0.0051	0.0039	0.0068	5	-	-	-	-
Manganese	mg/L	0.024	<0.004	0.059	41	0.007	0.0009	0.011	5	-	-	-	-
Mercury	mg/L	<0.00005	<0.00005	<0.00005	2	<0.000025	<0.00001	<0.00004	2	-	-	-	-
Molybdenum	mg/L	0.00076	0.00047	0.0026	13	0.0006	0.0001	0.0009	5	-	-	-	-
Nickel	mg/L	0.00057	0.0000063	0.0097	13	0.0011	0.0005	0.0024	5	-	-	-	-
Selenium	mg/L	0.0002	0.00014	0.00048	13	<0.0002	0.00015	<0.0005	18	-	-	-	-
Silver	mg/L	<0.00000075	<0.0000005	<0.0001	12	<0.00000275	<0.0000005	<0.000005	2	-	-	-	-

Table B-1 Summary of Water Quality in the Athabasca River Delta and Lake Athabasca (continued)

Parameter	Units	Athabasca River Downstream of Old Fort				Athabasca River Delta				Lake Athabasca			
		Median	Minimum	Maximum	n	Median	Minimum	Maximum	n	Median	Minimum	Maximum	n
Strontium	mg/L	0.29	0.24	0.44	13	0.19	0.18	0.25	5	-	-	-	-
Thallium	mg/L	0.000008	<0.0000003	0.0002	13	0.00004	0.0000086	<0.00005	4	-	-	-	-
Titanium	mg/L	0.0013	<0.001	0.01	13	0.0018	0.0014	0.013	5	-	-	-	-
Uranium	mg/L	0.00038	0.00025	0.0005	13	0.00033	0.0003	0.0005	5	-	-	-	-
Vanadium	mg/L	0.00054	0.00025	0.002	13	0.0005	<0.0001	0.0013	5	-	-	-	-
Zinc	mg/L	0.0034	0.0016	0.0078	12	0.002	0.001	0.003	5	-	-	-	-
Target PAHs and Alkylated PAHs													
Naphthalene	µg/L	<0.01	0.0017	<0.1	11	-	-	-	-	<1	<1	<1	3
Acenaphthene	µg/L	<0.01	0.0025	<0.1	11	-	-	-	-	<1	<1	<1	3
Acenaphthylene	µg/L	<0.01	0.0082	<0.1	11	-	-	-	-	<1	<1	<1	3
Anthracene	µg/L	<0.01	0.0014	<0.1 (c)	11	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
Dibenzo(a,h)anthracene	µg/L	<0.01 (c)	<0.01 (c)	<0.01 (c)	8	-	-	-	-	<5 (c)	<5 (c)	<5 (c)	3
Benzo(a)Anthracene	µg/L	<0.01 (c)	<0.01 (c)	<0.1 (c)	11	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
Chrysene	µg/L	<0.01 (c)	<0.01 (c)	<0.1 (c)	11	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
Benzo(a)pyrene	µg/L	<0.01 (c)	<0.01 (c)	<0.1 (c)	11	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
Benzo(b)fluoranthene	µg/L	<0.1 (c)	<0.1 (c)	<0.1 (c)	10	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
Benzo(k)fluoranthene	µg/L	<0.1 (c)	<0.1 (c)	<0.1 (c)	10	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
Benzo(g,h,i)perylene	µg/L	<0.01	<0.01	<0.2	11	-	-	-	-	<2	<2	<2	3
Fluoranthene	µg/L	<0.01	0.0012	<0.1 (c)	11	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
Fluorene	µg/L	<0.01	0.0069	<0.1	11	-	-	-	-	<1	<1	<1	3
Indeno(c,d-123)pyrene	µg/L	<0.01 (c)	<0.01 (c)	<0.1 (c)	11	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
Phenanthrene	µg/L	<0.01	0.0019	<0.1	11	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
1-Methyl-7-isopropyl-phenanthrene (Retene)	µg/L	<0.01	0.0012	<0.01	8	-	-	-	-	-	-	-	-
Pyrene	µg/L	<0.01	0.0017	<0.1 (c)	11	-	-	-	-	<1 (c)	<1 (c)	<1 (c)	3
Volatile Organics													
Benzene	µg/L	<0.1	<0.1	<1	11	<1	<1	<1	3	<1	<1	<1	2
Ethylbenzene	µg/L	<0.1	<0.1	<1	11	<1	<1	<1	3	<1	<1	<1	2
Toluene	µg/L	<0.1	0.030	<1	11	<1	0.0	<1	3	0.0	0.0	0.0	2
Xylenes	µg/L	<0.1	<0.1	1.04	7	-	-	-	-	-	-	-	-

(a) Concentration higher than the relevant acute aquatic life guideline.

(b) Concentration higher than the relevant chronic aquatic life guideline.

(c) Analytical detection limit higher than the relevant water quality guideline(s).

Notes: < = Less than; - = no data collected;
A value with "<" represents a concentration less than the relevant detection limit.
Bold values are higher than water quality guidelines.

Source: ESRD (2011); Environment Canada (2011); RAMP (2010).

Table B-2 Summary of Water Quality in the Birch River Delta

Parameter	Units	Lake Claire				Birch River Delta			
		Median	Minimum	Maximum	n	Median	Minimum	Maximum	n
Field Measured									
pH	pH units	-	-	-	-	7.6	6.9	8.5	5
Specific Conductance	µS/cm	-	-	-	-	360	22	9600	16
Temperature	°C	-	-	-	-	14	0.0	19	13
Dissolved Oxygen	mg/L	-	-	-	-	9.5	**4.5** (a)(b)	15	17
Conventional Parameters									
Dissolved Organic Carbon	mg/L	-	-	-	-	17	2.0	59	18
Hardness	mg/L	217	35	557	10	165	113	303	19
pH	pH units	7.8	5.7	8.3	10	7.8	7.1	8.3	29
Specific Conductance	µS/cm	428	78	1090	10	599	360	1200	29
Total Alkalinity	mg/L	89	18	117	10	99	24	193	29
Total Dissolved Solids	mg/L	-	-	-	-	349	240	792	18
Total Dissolved Solids (Calculated)	mg/L	258	38	842	10	350	214	464	11
Total Organic Carbon	mg/L	-	-	-	-	17	2.5	61	18
Total Suspended Solids	mg/L	-	-	-	-	30	2.8	432	18
Major Ions									
Bicarbonate	mg/L	112	22	146	9.0	114	82	139	11
Calcium	mg/L	72	9.6	190	10	49	31	126	29
Carbonate	mg/L	0.0	0.0	0.0	10	1.0	0.0	1.0	11
Chloride	mg/L	2.0	2.0	6.0	10	72	30	160	29
Fluoride	mg/L	0.1	0.1	**0.2** (b)	9	**0.19** (b)	<0.05	**0.45** (b)	27
Magnesium	mg/L	8.9	2.7	20	10	12	7.7	27	29
Potassium	mg/L	0.4	0.0	2.9	10	3.1	1.6	5.8	29
Sodium	mg/L	0.65	0.0	21	10	53	29	110	29
Sulphate	mg/L	102	2.0	560	10	91	48	268	29
Sulphide	mg/L	-	-	-	-	<0.01	<0.01 (c)	0.02	12

Table B-2 Summary of Water Quality in the Birch River Delta (continued)

Parameter	Units	Lake Claire				Birch River Delta			
		Median	Minimum	Maximum	n	Median	Minimum	Maximum	n
Nutrients and Chlorophyll *a*									
Chlorophyll *a*	µg/L	-	-	-	-	<1	<1	12	11
Nitrate + Nitrite	mg/L	-	-	-	-	0.052	<0.001	0.24	18
Nitrogen - Kjeldahl	mg/L	-	-	-	-	1.1	0.12	3.4	18
Nitrogen - total	mg/L	-	-	-	-	**1.2** (b)	0.13	**3.4** (b)	18
Phosphorus, total	mg/L	-	-	-	-	**0.071** (b)	0.032	**0.37** (b)	18
General Organics									
Total Phenolics	mg/L	-	-	-	-	<0.001	<0.001	<0.001	3
Total Recoverable Hydrocarbons	mg/L	-	-	-	-	1.2	<0.1	2.2	5.0

(a) Concentration higher than the relevant acute aquatic life guideline.

(b) Concentration higher than the relevant chronic aquatic life guideline.

(c) Analytical detection limit higher than the relevant water quality guideline(s).

Notes: < = less than; - = no data collected; d/s = downstream; a value with "<": less than the relevant detection limit.
A value with "<" represents a concentration less than detection limit.
Bold values are higher than water quality guidelines.

Source: ESRD (2011); Environment Canada (2011).

Table B-3 Summary of Water Quality in the Peace River Delta

Parameter	Units	Peace River				Rivière Des Rochers				Peace River Delta			
		Median	Minimum	Maximum	n	Median	Minimum	Maximum	n	Median	Minimum	Maximum	n
Field measured													
pH	pH units	-	-	-	-	7.7	6.9	**8.7** (a)(b)	19	-	-	-	-
Specific Conductance	µS/cm	-	-	-	-	172	2.0	2,000	40	-	-	-	-
Temperature	°C	-	-	-	-	7.6	0.0	21	68	-	-	-	-
Dissolved Oxygen	mg/L	12	7.4	18	95	9.7	**3.4** (a)(b)	16	40	-	-	-	-
Dissolved Oxygen (Winkler)	mg/L	-	-	-	-	12	8.6	14	16	-	-	-	-
Conventional Parameters													
Biochemical Oxygen Demand	mg/L	-	-	-	-	0.4	-	-	1	-	-	-	-
Colour	TCU	-	-	-	-	12	3.7	39	19	-	-	-	-
Dissolved Organic Carbon	mg/L	4.9	2.1	15	165	5.5	1.5	11	57	-	-	-	-
Hardness	mg/L	113	92	227	237	70	28	96	34	128	101	251	4
pH	pH units	8.0	6.9	**8.6** (a)(b)	242	7.7	6.8	8.4	78	7.9	7.3	8.4	4
Specific Conductance	µS/cm	239	152	500	232	176	79	323	78	371	250	510	4
Total Alkalinity	mg/L	96	60	190	241	65	16	98	78	110	87	140	4
Total Dissolved Solids	mg/L	152	146	158	2	111	57	184	68	-	-	-	-
Total Dissolved Solids (Calculated)	mg/L	130	111	263	157	90	41	133	26	142	142	320	3
Total Organic Carbon	mg/L	6.7	2.5	51	165	6.4	2.0	17	54	-	-	-	-
Total Suspended Solids	mg/L	43	1.0	2,170	202	32	0.8	413	81	107	-	-	1
Major Ions													
Bicarbonate	mg/L	116	74	224	158	75	38	108	25	137	137	177	3
Calcium	mg/L	33	20	63	239	20	8.0	33	78	32	17	73	4
Carbonate	mg/L	2.3	0.96	3.7	2	<2.75	<0.5	<5	2	0.0	0.0	1.0	3
Chloride	mg/L	1.9	0.6	32	239	7.6	1.6	26	78	2.6	2.0	47	4
Fluoride	mg/L	0.07	0.04	**0.88** (b)	195	0.08	<0.05	0.12	37	**0.17** (b)	**0.13** (b)	**0.2** (b)	3
Magnesium	mg/L	7.4	4.8	17	162	5.1	2.0	8.0	78	14	14	17	3
Potassium	mg/L	0.76	0.1	14	239	0.93	0.1	1.8	78	4.4	2.5	7.5	4
Sodium	mg/L	4.1	0.4	33	241	7.6	2.0	23	78	13	12	38	4
Sulphate	mg/L	21	9.6	67	239	11	3.0	44	78	38	5.7	123	4
Sulphide	mg/L	-	-	-	-	<0.01 [3]	<0.001	<0.01	20	-	-	-	-
Nutrients and Chlorophyll *a*													
Chlorophyll *a*	µg/L	16	-	-	1	1.0	0.4	6.3	18	-	-	-	-
Nitrate + Nitrite	mg/L	0.06	<0.002	4.0	227	0.038	<0.001	0.8	80	-	-	-	-
Nitrogen - Ammonia	mg/L	-	-	-	-	0.02	<0.01	0.09	3	-	-	-	-
Nitrogen - Kjeldahl	mg/L	0.45	<0.1	5.1	8	0.41	0.1	6.0	79	-	-	-	-
Nitrogen - total	mg/L	0.062	<0.002	**5.3** (b)	227	0.44	0.011	**6.1** (b)	82	-	-	-	-
Phosphorus, dissolved	mg/L	0.006	<0.002	0.06	165	0.007	0.002	0.015	31	-	-	-	-
Phosphorus, total	mg/L	0.047	0.002	**1.4** (b)	180	**0.051** (b)	0.008	**0.37** (b)	83	-	-	-	-
General Organics													
Total Phenolics	mg/L	-	-	-	-	0.002	<0.001	**0.022** (b)	68	-	-	-	-
Total Recoverable Hydrocarbons	mg/L	-	-	-	-	0.8	<0.1	3.8	53	-	-	-	-

Table B-3 Summary of Water Quality in the Peace River Delta (continued)

Parameter	Units	Peace River				Rivière Des Rochers				Peace River Delta			
		Median	Minimum	Maximum	n	Median	Minimum	Maximum	n	Median	Minimum	Maximum	n
Total Metals													
Aluminum	mg/L	**0.37** (b)	0.0019	**68.7** (a)(b)	125	0.024	-	-	1	-	-	-	-
Antimony	mg/L	0.0001	0.000033	0.00029	55	-	-	-		-	-	-	-
Arsenic	mg/L	0.0006	0.00017	**0.0094** (b)	55	0.00085	0.0002	0.0036	24	-	-	-	-
Barium	mg/L	0.08	0.024	0.41	163	0.043	0.025	0.12	24	-	-	-	-
Beryllium	mg/L	0.00005	<0.000001	0.0022	124	-	-	-		-	-	-	-
Boron	mg/L	0.0093	0.0022	0.033	55	-	-	-		-	-	-	-
Cadmium	mg/L	0.0001	0.000017	**0.0063** (a)(b)	102	-	-	-		-	-	-	-
Chromium	mg/L	0.0008	0.000055	**0.077** (a)(b)	125	0.002 (b)	<0.001	**0.008** (b)	25	-	-	-	-
Cobalt	mg/L	0.0005	0.00002	0.019	163	<0.001	<0.001	0.004	24	-	-	-	-
Copper	mg/L	**0.0024** (b)	0.0005	**0.056** (a)(b)	163	**0.003** (b)	<0.001	**0.009** (b)	25	-	-	-	-
Iron	mg/L	**0.92** (b)	0.0069	**61.7** [2]	124	**0.82** (b)	0.19	**5.34** (b)	16	-	-	-	-
Lead	mg/L	0.0009	0.000035	**0.046** [2]	163	0.0008	-	-	1	-	-	-	-
Lithium	mg/L	0.0054	0.001	0.12	124	-	-	-		-	-	-	-
Manganese	mg/L	0.029	0.00011	0.68	124	0.024	0.007	0.13	25	-	-	-	-
Molybdenum	mg/L	0.00079	<0.0001	0.0045	124	<0.001	<0.001	0.004	24	-	-	-	-
Nickel	mg/L	0.0023	<0.0002	0.064	163	0.0035	<0.001	0.011	24	-	-	-	-
Selenium	mg/L	0.00034	<0.00005	**0.0010** (b)	55	<0.0002	<0.0001	0.0002	24	-	-	-	-
Silver	mg/L	0.000019	<0.000001	**0.0039** (b)	71	-	-	-		-	-	-	-
Strontium	mg/L	0.14	0.052	0.35	124	-	-	-		-	-	-	-
Thallium	mg/L	0.000012	0.000002	0.00024	55	-	-	-		-	-	-	-
Uranium	mg/L	0.00055	0.00022	0.0025	55	0.00085	<0.0000004	0.0035	12	-	-	-	-
Vanadium	mg/L	0.0013	0.00022	**0.20**	163	<0.002	<0.001	0.014	58	-	-	-	-
Zinc	mg/L	0.0059	0.00023	**0.28** (a)(b)	163	0.009	<0.0006	0.027	25	-	-	-	-
Dissolved Metals													
Aluminum	mg/L	0.009	0.0005	0.42	81	-	-	-		-	-	-	-
Antimony	mg/L	0.000088	0.000036	0.00022	55	-	-	-		-	-	-	-
Arsenic	mg/L	0.0003	<0.0001	0.0012	156	0.0007	<0.0002	0.006	34	-	-	-	-
Barium	mg/L	0.051	0.033	0.098	81	-	-	-		-	-	-	-
Beryllium	mg/L	0.000005	<0.000001	<0.0005	81	<0.001	<0.001	<0.001	24	-	-	-	-
Boron	mg/L	0.01	<0.002	4.0	157	0.016	-	-	1	-	-	-	-
Cadmium	mg/L	0.000046	0.000015	<0.001	81	-	-	-		-	-	-	-
Chromium	mg/L	0.000099	0.000055	0.0096	81	-	-	-		-	-	-	-
Chromium - hexavalent	mg/L	-	-	-	-	<0.003	<0.001	0.01	15	-	-	-	-
Cobalt	mg/L	0.000037	0.000009	0.001	81	-	-	-		-	-	-	-
Copper	mg/L	0.0011	0.00048	0.005	81	-	-	-		-	-	-	-
Iron	mg/L	0.027	0.0037	0.87	81	-	-	-		-	-	-	-
Lead	mg/L	0.00013	<0.000005	0.005	81	-	-	-		-	-	-	-
Lithium	mg/L	0.0037	0.001	0.0097	81	-	-	-		-	-	-	-
Manganese	mg/L	0.0008	<0.00005	0.03	81	-	-	-		-	-	-	-
Molybdenum	mg/L	0.00098	0.00073	0.002	81	-	-	-		-	-	-	-
Nickel	mg/L	0.0014	0.00024	0.055	81	-	-	-		-	-	-	-
Selenium	mg/L	0.0003	<0.0001	0.00083	156	<0.0002	<0.0001	0.0004	15	-	-	-	-
Silver	mg/L	<0.000001	<0.000001	0.00001	55	-	-	-		-	-	-	-

Table B-3 Summary of Water Quality in the Peace River Delta (continued)

Parameter	Units	Peace River				Rivière Des Rochers				Peace River Delta			
		Median	**Minimum**	**Maximum**	**n**	**Median**	**Minimum**	**Maximum**	**n**	**Median**	**Minimum**	**Maximum**	**n**
Strontium	mg/L	0.13	0.11	0.35	81	-	-	-		-	-	-	-
Thallium	mg/L	0.000004	<0.000001	0.000017	55	-	-	-		-	-	-	-
Uranium	mg/L	0.0005	0.00039	0.001	55	-	-	-		-	-	-	-
Vanadium	mg/L	0.0003	0.00016	0.0016	81	-	-	-		-	-	-	-
Zinc	mg/L	0.0013	0.00008	0.047	81	-	-	-		-	-	-	-
Target PAHs and Alkylated PAHs													
Naphthalene	µg/L	-	-	-	-	<1	-	-	1	-	-	-	-
Acenaphthene	µg/L	-	-	-	-	<1	-	-	1	-	-	-	-
Acenaphthylene	µg/L	-	-	-	-	<1	-	-	1	-	-	-	-
Anthracene	µg/L	-	-	-	-	<1 (c)	-	-	1	-	-	-	-
Dibenzo(a,h)anthracene	µg/L	-	-	-	-	<5 (c)	-	-	1	-	-	-	-
Benzo(a)anthracene	µg/L	-	-	-	-	<1 (c)	-	-	1	-	-	-	-
Chrysene	µg/L	-	-	-	-	<1 (c)	-	-	1	-	-	-	-
Benzo(a)pyrene	µg/L	-	-	-	-	<1 (c)	-	-	1	-	-	-	-
Benzo(b)fluoranthene	µg/L	-	-	-	-	<1 (c)	-	-	1	-	-	-	-
Benzo(k)fluoranthene	µg/L	-	-	-	-	<1 (c)	-	-	1	-	-	-	-
Benzo(g,h,i)perylene	µg/L	-	-	-	-	<2	-	-	1	-	-	-	-
Fluoranthene	µg/L	-	-	-	-	<1 (c)	-	-	1	-	-	-	-
Fluorene	µg/L	-	-	-	-	<1	-	-	1	-	-	-	-
Indeno(c,d-123)pyrene	µg/L	-	-	-	-	<1	-	-	1	-	-	-	-
Phenanthrene	µg/L	-	-	-	-	<1 (c)	-	-	1	-	-	-	-
Pyrene	µg/L	-	-	-	-	<1 (c)	-	-	1	-	-	-	-

(a) Concentration higher than the relevant acute aquatic life guideline.

(b) Concentration higher than the relevant chronic aquatic life guideline.

(c) Analytical detection limit higher than the relevant water quality guideline(s).

Notes: < = less than; - = no data collected.
A value with "<" represents a concentration less than the relevant detection limit.
Bold values are higher than water quality guidelines.

Source: ESRD (2011); Environment Canada (2011).

REFERENCES

Environment Canada. 2011. *Water quality data provided from Environment Canada database*.

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ATTACHMENT C

Summary of Sediment Quality

Table C-1 Summary of Sediment Quality in the Athabasca River

Watershed	Unit	Athabasca River										
Site ID		**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**
Sampling Date		**15 Sep 2000**	**18 Oct 2001**	**17 Sep 2002**	**10 Sep 2003**	**11 Sep 2003**	**09 Sep 2004**	**12 Sep 2005**	**08 Sep 2007**	**06 Sep 2008**	**10 Sep 2008**	**19 Sep 2009**
Physical Properties												
% Clay	% clay	22	16	14	17	-	10	12	11	13	-	8.4
% Sand	% sand	36	50	57	45	-	61	56	57	51	-	64
% Silt	% silt	42	34	30	38	-	29	32	32	36	-	28
% Moisture	% moisture	-	-	-	30	-	32	30	32	42	-	33
CaCO$_3$ Equivalent	%	-	-	-	-	-	-	-	4.8	5.5	-	4.8
Inorganic Carbon	%	0.76	0.67	0.66	0.73	-	0.73	0.6	0.5	0.6	-	0.55
Texture	-	-	-	-	-	-	sandy loam	sandy loam	sandy loam	loam	-	sandy loam
Total carbon by combustion	%	1.9	1.7	1.1	2.0	-	1.5	1.6	2.1	2.4	-	1.6
Total organic carbon	%	1.1	1.0	1.1	1.3	-	0.8	1.0	1.6	1.7	-	1.0
Hydrocarbons and Organic Compounds												
AEP Total extractable hydrocarbons (C11-C30)	mg/kg	59	210	260	160	-	61	-	-	-	-	-
AEP Total hydrocarbons (C6-C50)	mg/kg	-	-	-	-	-	440	450	590	950	-	302
AEP Total recoverable hydrocarbons	mg/kg	500	500	900	700	-	500	-	-	-	-	-
AEP Total volatile hydrocarbons (C5-C10)	mg/kg	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	-	-	-	-
Benzene	mg/kg	-	-	-	-	-	<0.01	<0.005	<0.005	<0.005	-	<0.005
CCME Fraction 1 (BTEX)	mg/kg	-	-	-	-	-	<5	<5	<5	<5	-	<10
CCME Fraction 1 (C6-C10)	mg/kg	-	-	-	-	-	<5	<5	<5	<5	-	<10
CCME Fraction 2 (C10-C16)	mg/kg	-	-	-	-	-	28	11	24	39	-	<20
CCME Fraction 3 (C16-C34)	mg/kg	-	-	-	-	-	220	260	330	570	-	161
CCME Fraction 4 (C34-C50)	mg/kg	-	-	-	-	-	190	180	240	340	-	141
Ethylbenzene	mg/kg	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	-	<0.015
m+p-Xylene	mg/kg	-	-	-	-	-	-	-	-	-	-	<0.05
o-Xylene	mg/kg	-	-	-	-	-	-	-	-	-	-	<0.05
Toluene	mg/kg	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	-	<0.05
Xylenes	mg/kg	-	-	-	-	-	<0.01	<0.01	<0.02	<0.02	-	<0.1

Table C-1 Summary of Sediment Quality in the Athabasca River (continued)

Watershed	Unit	Athabasca River										
Site ID		ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER
Sampling Date		15 Sep 2000	18 Oct 2001	17 Sep 2002	10 Sep 2003	11 Sep 2003	09 Sep 2004	12 Sep 2005	08 Sep 2007	06 Sep 2008	10 Sep 2008	19 Sep 2009
PAHs												
% Moisture_PAH sample	%	30	30	26	-	-	27	26	28	-	28	28
Acenaphthene	mg/kg	<0.006	0.0003	0.001	0.001	-	0.001	0.001	0.001	-	0.001	0.001
Acenaphthylene	mg/kg	<0.005	<0.0005	<0.0004	<0.0001	-	<0.0004	<0.0005	<0.0001	-	<0.0002	<0.0001
Anthracene	mg/kg	<0.002	<0.001	<0.001	<0.0005	-	<0.001	0.001	<0.001	-	<0.001	<0.001
Benzo[a]pyrene	mg/kg	0.007	0.004	<0.007	0.006	-	0.005	0.007	0.005	-	0.006	*<0.003*
Benzo[b,j,k]fluoranthene	mg/kg	-	-	-	0.016	-	0.012	0.016	0.01	-	0.019	0.0087
Benzo[b,j,k]fluoranthenes	mg/kg	0.024	0.017	0.016	-	-	-	-	-	-	-	-
Benzo[g,h,i]perylene	mg/kg	0.015	0.0088	0.01	0.011	-	0.0097	0.01	0.0082	-	0.012	0.0073
Benz[a]anthracene	mg/kg	<0.002	0.003	0.002	0.003	-	0.002	0.004	0.002	-	0.003	*<0.002*
Benz[a]anthracene/Chrysene	mg/kg	-	-	-	-	-	-	-	-	-	-	-
Biphenyl	mg/kg	<0.0027	0.0028	0.0056	0.0058	-	0.005	0.0054	0.0044	-	0.005	0.0038
C1-Benzofluoranthenes/Benzopyrenes	mg/kg	-	-	-	-	-	-	-	-	-	-	0.036
C1-Benzofluoranthenes/Pyrenes	mg/kg	<0.0024	0.032	0.067	0.052	-	0.044	0.041	0.039	-	0.085	-
C1-Benzo[a]anthracenes/Chrysenes	mg/kg	0.12	0.15	0.18	0.18	-	0.13	0.18	0.04	-	0.06	0.039
C1-Dibenzothiophenes	mg/kg	0.0069	0.0075	0.018	0.017	-	0.012	0.013	0.0088	-	0.026	0.0073
C1-Fluoranthenes/Pyrenes	mg/kg	0.032	0.024	0.025	0.038	-	0.028	0.04	0.036	-	0.06	0.051
C1-Fluorenes	mg/kg	<0.003	0.0039	0.0052	0.014	-	0.0052	0.0064	0.011	-	0.019	0.0092
C1-Naphthalenes	mg/kg	**0.031**(a)	0.017	**0.023**(a)	**0.024**(a)	-	**0.023**(a)	**0.022** (a)	0.02	-	**0.024** (a)	0.017
C1-Phenanthrenes/Anthracenes	mg/kg	0.04	0.036	0.042	0.052	-	0.033	0.047	0.025	-	0.054	0.016
C2-Benzofluoranthenes/Benzopyrenes	mg/kg	<0.0038	0.019	0.016	0.024	-	0.024	0.023	0.012	-	0.035	0.017
C2-Benzo[a]anthracenes/Chrysenes	mg/kg	0.04	0.05	0.058	0.063	-	0.049	0.064	0.042	-	0.081	0.056
C2-Dibenzothiophenes	mg/kg	0.017	0.033	0.056	0.081	-	0.042	0.048	0.035	-	0.16	0.041
C2-Fluoranthenes/Pyrenes	mg/kg	0.067	0.051	0.048	0.069	-	0.054	0.067	0.07	-	0.13	0.1
C2-Fluorenes	mg/kg	<0.0027	0.022	0.02	0.054	-	0.017	0.02	0.021	-	0.044	0.018
C2-Naphthalenes	mg/kg	0.04	0.024	0.04	0.042	-	0.036	0.037	0.027	-	0.041	0.031
C2-Phenanthrenes/Anthracenes	mg/kg	0.032	0.037	0.051	0.071	-	0.035	0.042	0.033	-	0.094	0.031
C3-Dibenzothiophenes	mg/kg	0.064	0.086	0.068	0.13	-	0.053	0.088	0.059	-	0.25	0.08
C3-Fluoranthenes/Pyrenes	mg/kg	0.059	0.059	0.054	0.038	-	0.032	0.075	0.047	-	0.09	0.091

Table C-1 Summary of Sediment Quality in the Athabasca River (continued)

Watershed	Unit	Athabasca River										
Site ID		ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER
Sampling Date		15 Sep 2000	18 Oct 2001	17 Sep 2002	10 Sep 2003	11 Sep 2003	09 Sep 2004	12 Sep 2005	08 Sep 2007	06 Sep 2008	10 Sep 2008	19 Sep 2009
C3-Fluorenes	mg/kg	<0.0049	0.023	0.025	0.091	-	0.03	0.029	0.032	-	0.081	0.032
C3-Naphthalenes	mg/kg	0.029	0.029	0.038	0.046	-	0.037	0.03	0.025	-	0.047	0.025
C3-Phenanthrenes/Anthracenes	mg/kg	0.033	0.035	0.045	0.076	-	0.0027	0.047	0.042	-	0.15	0.043
C4-Dibenzothiophenes	mg/kg	<0.0026	0.042	0.11	0.12	-	0.12	0.14	0.087	-	0.31	0.11
C4-Naphthalenes	mg/kg	0.0066	0.03	0.027	0.058	-	0.027	0.022	0.024	-	0.055	0.019
C4-Phenanthrenes/Anthracenes	mg/kg	0.014	0.022	0.14	0.22	-	0.17	0.2	0.034	-	0.44	0.22
Chrysene	mg/kg	0.014	0.014	0.02	0.019	-	0.013	0.019	0.014	-	0.025	0.014
Dibenzothiophene	mg/kg	<0.001	0.0013	0.0024	0.0022	-	0.0016	0.0022	0.0016	-	<0.00217	0.0013
Dibenz[a,h]anthracene	mg/kg	<0.004	0.001	<0.005	0.002	-	0.002	0.003	<0.002	-	0.003	0.002
Dimethyl-Biphenyl	mg/kg	<0.0035	<0.00022	0.0086	0.0086	-	0.0079	0.0056	0.0071	-	0.0082	0.0085
Fluoranthene	mg/kg	0.004	0.003	0.004	0.004	-	0.003	0.016	0.003	-	0.005	0.002
Fluorene	mg/kg	<0.002	0.002	0.003	0.003	-	0.002	0.002	0.001	-	0.002	0.001
Indeno[1,2,3-c,d]-pyrene	mg/kg	0.011	0.006	0.004	0.0063	-	0.0055	0.0055	0.0053	-	0.0077	0.0039
Methyl Acenaphthene	mg/kg	0.0026	0.0013	<0.0003	0.00019	-	<0.00039	0.00022	<0.000287	-	0.0034	0.00017
Methyl-Biphenyl	mg/kg	<0.0021	<0.000094	<0.0003	0.0061	-	0.0055	0.0043	0.0046	-	0.0057	0.0041
Naphthalene	mg/kg	**0.037** (a)	0.005	0.009	0.008	-	0.009	0.008	0.007	-	0.008	0.006
Phenanthrene	mg/kg	0.01	0.01	0.02	0.02	-	0.01	0.02	0.01	-	0.02	0.01
Pyrene	mg/kg	0.009	0.007	0.011	0.009	-	0.007	0.017	0.008	-	0.012	0.007
Retene	mg/kg	0.033	0.081	0.059	0.04	-	0.034	0.051	0.031	-	0.078	0.064
Total Metals												
Aluminum	mg/kg	11,800	9,390	5,190	-	-	-	6,100	5,410	5,570	-	3,820
Antimony	mg/kg	<0.02	-	-	-	-	-	-	-	-	-	-
Arsenic	mg/kg	4.6	4.6	4.3	4.5	-	4.9	4.3	4.0	4.4	-	3.5
Barium	mg/kg	157	140	131	140	-	137	124	107	133	-	96
Beryllium	mg/kg	0.7	0.5	0.4	0.4	-	0.5	0.4	0.4	0.5	-	0.36
Bismuth	mg/kg	-	-	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	-	<0.5
Boron	mg/kg	20	12	4.0	-	-	-	9.0	8.0	9.0	-	5.1
Cadmium	mg/kg	0.2	0.2	0.2	0.2	-	0.2	0.2	0.2	0.2	-	0.2
Calcium	mg/kg	20,300	19,200	15,700	-	-	-	17,400	15,600	16,600	-	14,900

Table C-1 Summary of Sediment Quality in the Athabasca River (continued)

Watershed	Unit	Athabasca River										
Site ID		ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER	ATR-ER
Sampling Date		15 Sep 2000	18 Oct 2001	17 Sep 2002	10 Sep 2003	11 Sep 2003	09 Sep 2004	12 Sep 2005	08 Sep 2007	06 Sep 2008	10 Sep 2008	19 Sep 2009
Chromium	mg/kg	**61.3** (a)	17	12	9.9	-	14	15	9.5	13	-	8.8
Cobalt	mg/kg	7.1	6.8	6.7	7.3	-	7.3	6.3	6.5	6.6	-	5.7
Copper	mg/kg	13	10	10	13	-	12	9.3	9.0	11	-	7.4
Iron	mg/kg	17,400	14,200	13,900	-	-	-	15,000	12,000	15,400	-	12,700
Lead	mg/kg	7.2	6.2	6.2	7.5	-	7.4	6.6	5.9	7.5	-	5.7
Magnesium	mg/kg	7,550	6,570	5,890	-	-	-	5,840	6,020	5,890	-	5,130
Manganese	mg/kg	336	337	252	-	-	-	268	240	290	-	248
Mercury	mg/kg	0.05	0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05	-	<0.05
Molybdenum	mg/kg	1.9	0.5	0.3	0.4	-	0.4	0.4	0.4	0.4	-	0.31
Nickel	mg/kg	35	18	16	17	-	17	16	15	15	-	13
Potassium	mg/kg	2,250	1,530	810	-	-	-	1,070	900	1,000	-	620
Selenium	mg/kg	0.6	1.2	0.3	0.3	-	0.4	0.4	0.4	0.6	-	<0.2
Silver	mg/kg	0.2	<0.1	<0.1	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2
Sodium	mg/kg	257	157	60	-	-	-	200	200	200	-	200
Strontium	mg/kg	59	52	44	53	-	54	50	40	50	-	40
Thallium	mg/kg	0.18	0.15	0.11	0.16	-	0.19	0.16	0.1	0.16	-	0.14
Tin	mg/kg	-	-	-	<2	-	<2	<2	<2	<2	-	<2
Titanium	mg/kg	63	38	49	-	-	-	46	71	48	-	59
Total phosphorus	mg/kg	-	-	-	-	-	-	-	-	-	-	-
Uranium	mg/kg	1.0	0.8	0.7	0.81	-	0.77	0.83	0.77	1.0	-	0.68
Vanadium	mg/kg	34	23	14	14	-	22	19	16	21	-	13
Zinc	mg/kg	61	50	53	56	-	55	46	46	52	-	42
Toxicity												
Chironomus tentans - 10d growth	mg/organism	2.1	2.2	-	-	3.5	-	-	-	-	1.2	1.3
Chironomus tentans - 10d growth - % of Control	%	96	72	-	-	134	-	-	-	-	63	96
Chironomus tentans - 10d survival	# surviving	7.4	7.0	-	-	8.0	-	-	-	-	8.6	3.4
Chironomus tentans - 10d survival - % of Control	%	84	109	-	-	98	-	-	-	-	88	49
Hyalella azteca - 10d growth	mg/organism	0.05	0.2	-	-	-	-	-	-	-	-	-

Table C-1 Summary of Sediment Quality in the Athabasca River (continued)

Watershed	Unit	Athabasca River										
Site ID		**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**	**ATR-ER**
Sampling Date		**15 Sep 2000**	**18 Oct 2001**	**17 Sep 2002**	**10 Sep 2003**	**11 Sep 2003**	**09 Sep 2004**	**12 Sep 2005**	**08 Sep 2007**	**06 Sep 2008**	**10 Sep 2008**	**19 Sep 2009**
Hyalella azteca - 10d growth - % of Control	%	82	137	-	-	-	-	-	-	-	-	-
Hyalella azteca - 10d survival	# surviving	7.0	9.0	-	-	-	-	-	-	-	-	-
Hyalella azteca - 10d survival - % of Control	%	103	124	-	-	-	-	-	-	-	-	-
Hyalella azteca - 14d growth	mg/organism	-	-	-	-	0.09	-	-	-	-	0.29	0.28
Hyalella azteca - 14d survival	# surviving	-	-	-	-	10	-	-	-	-	9.2	9.4
Hyalella azteca - 14d growth - % of Control	%	-	-	-	-	82	-	-	-	-	123	135
Hyalella azteca - 14d survival - % of Control	%	-	-	-	-	103	-	-	-	-	110	104
Lumbriculus variegatus - 10d growth	mg/organism	1.3	13	-	-	0.7	-	-	-	-	-	-
Lumbriculus variegatus - 10d growth - % of Control	%	66	233	-	-	86	-	-	-	-	-	-
Lumbriculus variegatus - 10d survival	# surviving	19	6.0	-	-	20	-	-	-	-	-	-
Lumbriculus variegatus - 10d survival - % of Control	%	141	71	-	-	103	-	-	-	-	-	-

[a] Concentration higher than the interim sediment quality guideline (CCME 1999).

[b] Concentration higher than the probable effects level defined by CCME (1999).

[c] Analytical detection limit was higher than the relevant water quality guideline(s).

Notes: < = less than; - = no data collected; d/s = downstream.
A value with "<" represents a concentration less than the relevant detection limit.
Bold values are higher than the relevant sediment quality guidelines.

Source: RAMP (2010).

Table C-2 Summary of Sediment Quality in the Athabasca River Delta

Watershed	Unit	Athabasca River Delta									
Site ID		BPC-1	BPC-1	BPC-1	BPC-1	BPC-1	BPC-1	BPC-1	BPC-1	BPC-1	BPC-1
Sampling Date		31 Jul 1999	16 Sep 2000	17 Oct 2001	17 Sep 2002	11 Sep 2003	13 Sep 2005	09 Sep 2007	07 Sep 2008	09 Sep 2008	19 Sep 2009
Physical Properties											
% Clay	% clay	-	32	10	26	16	17	20	12	-	28
% Sand	% sand	-	10	64	23	39	39	38	36	-	16
% Silt	% silt	-	58	26	51	45	44	42	52	-	57
% Moisture	% moisture	-	-	-	-	31	29	46	27	-	56
$CaCO_3$ Equivalent	%	-	-	-	-	-	-	8.3	6.5	-	7.6
Inorganic Carbon	%	-	1.1	0.62	1.0	0.74	0.76	1.0	0.7	-	0.87
Texture	-	-	-	-	-	-	loam	loam	silt loam	-	silty clay loam
Total carbon by combustion	%	-	2.8	1.9	<0.01	1.4	1.9	2.4	2.0	-	3.1
Total organic carbon	%	-	1.7	1.2	<0.01	0.7	1.1	1.4	1.2	-	2.2
Hydrocarbons and Organic Compounds											
AEP Total extractable hydrocarbons (C11-C30)	mg/kg	-	81	200	54	150	-	-	-	-	-
AEP Total hydrocarbons (C6-C50)	mg/kg	-	-	-	-	-	310	330	140	-	527
AEP Total recoverable hydrocarbons	mg/kg	-	700	600	600	900	-	-	-	-	-
AEP Total volatile hydrocarbons (C5-C10)	mg/kg	-	<0.5	7.0	<0.5	<0.5	-	-	-	-	-
Benzene	mg/kg	-	-	-	-	-	<0.005	<0.005	<0.005	-	<0.01
CCME Fraction 1 (BTEX)	mg/kg	-	-	-	-	-	<5	<5	<5	-	<21
CCME Fraction 1 (C6-C10)	mg/kg	-	-	-	-	-	<5	<5	<5	-	<21
CCME Fraction 2 (C10-C16)	mg/kg	-	-	-	-	-	<5	23	<5	-	21
CCME Fraction 3 (C16-C34)	mg/kg	-	-	-	-	-	190	210	110	-	307
CCME Fraction 4 (C34-C50)	mg/kg	-	-	-	-	-	120	100	33	-	199
Ethylbenzene	mg/kg	-	-	-	-	-	<0.01	<0.01	<0.01	-	<0.031
m+p-Xylene	mg/kg	-	-	-	-	-	-	-	-	-	<0.1
o-Xylene	mg/kg	-	-	-	-	-	-	-	-	-	<0.1
Toluene	mg/kg	-	-	-	-	-	<0.01	<0.01	<0.01	-	<0.1
Xylenes	mg/kg	-	-	-	-	-	<0.01	<0.02	<0.02	-	<0.2
PAHs											
% Moisture_PAH sample	%	-	-	30	33	-	0.03	41	-	27	37
Acenaphthene	mg/kg	-	<0.01 (c)	<0.0002	0.001	0.001	0.001	0.001	-	0.001	0.001
Acenaphthylene	mg/kg	-	<0.008 (c)	<0.0004	<0.0003	<0.0001	0.0005	<0.0003	-	<0.0001	<0.0001
Anthracene	mg/kg	-	<0.003	<0.001	<0.001	<0.0005	0.001	<0.001	-	<0.001	*<0.0004*
Benzo[a]pyrene	mg/kg	-	0.006	0.004	0.004	0.006	0.006	0.005	-	0.004	0.005
Benzo[b,j,k]fluoranthene	mg/kg	-	-	-	-	0.014	0.017	0.013	-	0.016	0.017
Benzo[b,j,k]fluoranthenes	mg/kg	-	0.026	0.019	0.013	-	-	-	-	-	-
Benzo[g,h,i]perylene	mg/kg	-	0.02	0.011	0.0069	0.01	0.011	0.011	-	0.01	0.012
Benz[a]anthracene	mg/kg	-	<0.005	0.003	0.002	0.003	0.004	0.003	-	0.002	0.003
Benz[a]anthracene/Chrysene	mg/kg	-	-	-	-	-	-	-	-	-	-
Biphenyl	mg/kg	-	0.0054	0.0026	0.0072	0.0048	0.0074	0.006	-	0.0062	0.0075
C1-Benzofluoranthenes/Benzopyrenes	mg/kg	-	-	-	-	-	-	-	-	-	0.055
C1-Benzofluoranthenes/Pyrenes	mg/kg	-	<0.011	0.036	0.033	0.045	0.04	0.046	-	0.061	-
C1-Benzo[a]anthracenes/Chrysenes	mg/kg	-	0.25	0.18	0.19	0.15	0.18	0.048	-	0.035	0.057
C1-Dibenzothiophenes	mg/kg	-	0.018	0.0085	0.013	0.0079	0.014	0.01	-	0.012	0.012
C1-Fluoranthenes/Pyrenes	mg/kg	-	0.059	0.031	0.035	0.031	0.036	0.041	-	0.044	0.085
C1-Fluorenes	mg/kg	-	<0.003	0.005	0.0076	0.0082	0.0078	0.016	-	0.019	0.02

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta									
Site ID		**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**
Sampling Date		**31 Jul 1999**	**16 Sep 2000**	**17 Oct 2001**	**17 Sep 2002**	**11 Sep 2003**	**13 Sep 2005**	**09 Sep 2007**	**07 Sep 2008**	**09 Sep 2008**	**19 Sep 2009**
C1-Naphthalenes	mg/kg	-	**0.04** [a]	0.018	**0.031** [a]	**0.021** [a]	**0.032** [a]	**0.028** [a]	-	**0.025** [a]	**0.032** [a]
C1-Phenanthrenes/Anthracenes	mg/kg	-	0.078	0.033	0.042	0.036	0.044	0.03	-	0.04	0.038
C2-Benzofluoranthenes/Benzopyrenes	mg/kg	-	<0.0043	0.026	0.013	0.022	0.021	0.021	-	0.021	0.03
C2-Benzo[a]anthracenes/Chrysenes	mg/kg	-	0.063	0.06	0.057	0.051	0.053	0.05	-	0.041	0.079
C2-Dibenzothiophenes	mg/kg	-	0.07	0.037	0.043	0.029	0.048	0.047	-	0.059	0.063
C2-Fluoranthenes/Pyrenes	mg/kg	-	0.11	0.064	0.058	0.053	0.053	0.075	-	0.084	0.17
C2-Fluorenes	mg/kg	-	<0.0078	0.03	0.03	0.03	0.024	0.027	-	0.021	0.038
C2-Naphthalenes	mg/kg	-	0.049	0.024	0.043	0.038	0.052	0.04	-	0.045	0.054
C2-Phenanthrenes/Anthracenes	mg/kg	-	0.089	0.038	0.056	0.044	0.0055	0.049	-	0.05	0.054
C3-Dibenzothiophenes	mg/kg	-	0.14	0.095	0.061	0.052	0.082	0.09	-	0.1	0.13
C3-Fluoranthenes/Pyrenes	mg/kg	-	0.1	0.07	0.051	0.038	0.059	0.051	-	0.054	0.14
C3-Fluorenes	mg/kg	-	<0.0084	0.019	0.036	0.042	0.033	0.048	-	0.034	0.055
C3-Naphthalenes	mg/kg	-	0.048	0.026	0.043	0.032	0.044	0.032	-	0.038	0.043
C3-Phenanthrenes/Anthracenes	mg/kg	-	0.074	0.032	0.059	0.043	0.05	0.065	-	0.067	0.06
C4-Dibenzothiophenes	mg/kg	-	<0.0052	0.064	0.1	0.06	0.13	0.13	-	0.14	0.15
C4-Naphthalenes	mg/kg	-	<0.004	0.022	0.025	0.027	0.03	0.028	-	0.022	0.035
C4-Phenanthrenes/Anthracenes	mg/kg	-	0.085	0.023	0.18	0.23	0.23	0.27	-	0.24	0.28
Chrysene	mg/kg	-	0.026	0.017	0.016	0.016	0.017	0.018	-	0.018	0.021
Dibenzothiophene	mg/kg	-	0.0025	0.0016	0.0021	0.0013	0.0021	0.0017	-	0.0022	0.0025
Dibenz[a,h]anthracene	mg/kg	-	<0.005	0.002	<0.002	0.002	0.003	<0.002	-	0.002	0.002
Dimethyl-Biphenyl	mg/kg	-	<0.0018	<0.00018	0.011	0.0076	0.009	0.009	-	0.0095	0.016
Fluoranthene	mg/kg	-	0.008	0.003	0.004	0.003	0.004	0.004	-	0.004	0.004
Fluorene	mg/kg	-	0.004	0.002	0.002	0.002	0.003	0.002	-	0.002	0.002
Indeno[1,2,3-c,d]-pyrene	mg/kg	-	0.015	0.0085	0.0043	0.0059	0.0073	0.006	-	0.006	0.0061
Methyl Acenaphthene	mg/kg	-	0.0041	0.0014	<0.0002	0.0001	<0.000265	<0.00228	-	0.0031	0.00028
Methyl-Biphenyl	mg/kg	-	<0.0048	<0.0001	<0.0003	0.0053	0.0069	0.0066	-	0.0071	0.0084
Naphthalene	mg/kg	-	0.024	0.005	0.012	0.007	0.012	0.009	-	0.007	0.009
Phenanthrene	mg/kg	-	0.03	0.01	0.02	0.01	0.01	0.02	-	0.02	0.02
Pyrene	mg/kg	-	0.019	0.009	0.011	0.008	0.01	0.011	-	0.01	0.011
Retene	mg/kg	-	0.065	0.041	0.051	0.096	0.053	0.046	-	0.044	0.071
Total Metals											
Aluminum	mg/kg	-	18,700	4,390	7,660	-	7,530	8,470	6,640	-	6,620
Antimony	mg/kg	-	<0.02	-	-	-	-	-	-	-	-
Arsenic	mg/kg	-	**6.2** [a]	4.7	4.9	3.8	4.3	4.6	4.1	0.0	5.3
Barium	mg/kg	-	215	142	166	132	149	163	148	-	145
Beryllium	mg/kg	-	0.9	0.5	0.6	0.4	0.5	0.6	0.5	-	0.59
Bismuth	mg/kg	-	-	-	-	<0.5	<0.5	<0.5	<0.5	-	<0.5
Boron	mg/kg	-	27	10	5.0	-	10	12	10	-	7.4
Cadmium	mg/kg	-	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.0	0.36
Calcium	mg/kg	-	26,800	19,700	24,100	-	20,400	26,400	26,000	-	23,600
Chromium	mg/kg	-	**92** [b]	16	16	10	15	15	14	-	17
Cobalt	mg/kg	-	9.1	7.8	8.1	7.0	6.8	8.0	7.0	-	8.2
Copper	mg/kg	-	20	11	14	12	11	13	13	-	16
Iron	mg/kg	-	22600	16100	17800	-	16100	17500	15300	-	20600

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta									
Site ID		**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**	**BPC-1**
Sampling Date		**31 Jul 1999**	**16 Sep 2000**	**17 Oct 2001**	**17 Sep 2002**	**11 Sep 2003**	**13 Sep 2005**	**09 Sep 2007**	**07 Sep 2008**	**09 Sep 2008**	**19 Sep 2009**
Lead	mg/kg	-	10	6.7	9.0	6.8	7.4	8.1	7.3	-	9.9
Magnesium	mg/kg	-	9,330	7,340	8,360	-	6,820	9,310	6,550	-	7,240
Manganese	mg/kg	-	523	367	445	-	310	458	321	-	573
Mercury	mg/kg	-	0.08	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05
Molybdenum	mg/kg	-	1.8	0.3	0.3	0.3	0.4	0.4	0.4	-	0.43
Nickel	mg/kg	-	50	19	21	16	17	19	16	-	22
Potassium	mg/kg	-	3,630	1,360	1,130	-	1,290	1,400	1,200	-	1,050
Selenium	mg/kg	-	0.8	1.2	0.4	0.2	0.3	0.5	0.4	-	0.64
Silver	mg/kg	-	0.1	<0.1	0.1	<0.2	<0.2	<0.2	<0.2	-	<0.2
Sodium	mg/kg	-	297	164	100	-	200	200	200	-	210
Strontium	mg/kg	-	80	56	65	51	57	62	61	-	68
Thallium	mg/kg	-	0.27	0.15	0.16	0.16	0.17	0.17	0.16	-	0.21
Tin	mg/kg	-	-	-	-	<2	<2	<2	<2	-	<2
Titanium	mg/kg	-	85	25	36	-	44	76	77	-	67
Total phosphorus	mg/kg	-	-	-	-	-	-	-	-	-	-
Uranium	mg/kg	-	1.3	0.8	0.9	0.8	1.0	0.88	0.96	-	0.92
Vanadium	mg/kg	-	50	21	18	14	22	23	22	-	19
Zinc	mg/kg	-	64	58	68	57	53	64	54	-	67
Toxicity											
Chironomus tentans - 10d growth	mg/organism	0.89	1.7	2.6	2.0	3.6	-	-	-	1.8	1.3
Chironomus tentans - 10d growth - % of Control	%	-	76	83	77	138	-	-	-	100	102
Chironomus tentans - 10d survival	# surviving	3.2	7.6	5.0	9.0	7.0	-	-	-	8.2	4.6
Chironomus tentans - 10d survival - % of Control	%	-	86	82	129	88	-	-	-	84	66
Hyalella azteca - 10d growth	mg/organism	0.048	0.06	0.1	0.1	-	-	-	-	-	-
Hyalella azteca - 10d growth - % of Control	%	-	100	77	100	-	-	-	-	-	-
Hyalella azteca - 10d survival	# surviving	6.6	7.4	8.0	9.0	-	-	-	-	-	-
Hyalella azteca - 10d survival - % of Control	%	-	109	105	113	-	-	-	-	-	-
Hyalella azteca - 14d growth	mg/organism	-	-	-	-	0.12	-	-	-	0.21	0.21
Hyalella azteca - 14d survival	# surviving	-	-	-	-	9.0	-	-	-	8.0	8.2
Hyalella azteca - 14d growth - % of Control	%	-	-	-	-	111	-	-	-	87	102
Hyalella azteca - 14d survival - % of Control	%	-	-	-	-	102	-	-	-	95	91
Lumbriculus variegatus - 10d growth	mg/organism	-	1.0	13	18	0.8	-	-	-	-	-
Lumbriculus variegatus - 10d growth - % of Control	%	-	52	230	93	95	-	-	-	-	-
Lumbriculus variegatus - 10d survival	# surviving	-	22	11	10	18	-	-	-	-	-
Lumbriculus variegatus - 10d survival - % of Control	%	-	157	126	100	91	-	-	-	-	-

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta								
Site ID		FLC-1	FLC-1	FLC-1	FLC-1	FLC-1	FLC-1	FLC-1	FLC-1	FLC-1
Sampling Date		17 Oct 2001	17 Sep 2002	10 Sep 2003	11 Sep 2003	13 Sep 2005	08 Sep 2007	06 Sep 2008	09 Sep 2008	19 Sep 2009
Physical Properties										
% Clay	% Clay	12	14	18	-	16	17	10	-	11
% Sand	% Sand	70	51	44	-	35	11	67	-	47
% Silt	% Silt	18	35	38	-	49	72	23	-	43
% Moisture	% Moisture	-	-	32	-	33	39	34	-	58
$CaCO_3$ Equivalent	%	-	-	-	-	-	7.2	4.5	-	6.9
Inorganic Carbon	%	0.62	0.75	0.72	-	0.8	0.8	0.5	-	0.79
Texture	-	-	-	-	-	silt loam	silt loam	sandy loam	-	loam
Total carbon by combustion	%	1.3	1.0	2.0	-	2.1	2.4	1.2	-	2.1
Total organic carbon	%	0.6	1.0	1.3	-	1.3	1.6	0.7	-	1.3
Hydrocarbons and Organic Compounds										
AEP Total extractable hydrocarbons (C11-C30)	mg/kg	500	270	140	-	-	-	-	-	-
AEP Total hydrocarbons (C6-C50)	mg/kg	-	-	-	-	730	510	160	-	661
AEP Total recoverable hydrocarbons	mg/kg	1400	600	1000	-	-	-	-	-	-
AEP Total volatile hydrocarbons (C5-C10)	mg/kg	5.3	<0.5	<0.5	-	-	-	-	-	-
Benzene	mg/kg	-	-	-	-	<0.005	<0.005	<0.005	-	<0.01
CCME Fraction 1 (BTEX)	mg/kg	-	-	-	-	<5	30	<5	-	<20
CCME Fraction 1 (C6-C10)	mg/kg	-	-	-	-	<5	30	<5	-	<20
CCME Fraction 2 (C10-C16)	mg/kg	-	-	-	-	18	23	<5	-	30
CCME Fraction 3 (C16-C34)	mg/kg	-	-	-	-	430	290	110	-	389
CCME Fraction 4 (C34-C50)	mg/kg	-	-	-	-	280	170	53	-	242
Ethylbenzene	mg/kg	-	-	-	-	<0.01	<0.01	<0.01	-	<0.03
m+p-Xylene	mg/kg	-	-	-	-	-	-	-	-	<0.1
o-Xylene	mg/kg	-	-	-	-	-	-	-	-	<0.1
Toluene	mg/kg	-	-	-	-	<0.01	<0.01	<0.01	-	0.12
Xylenes	mg/kg	-	-	-	-	<0.01	0.43	<0.02	-	<0.2
PAHs										
% Moisture_PAH sample	%	28	30	-	-	0.032	41	-	24	48
Acenaphthene	mg/kg	0.0005	0.001	0.001	-	0.001	0.001	-	<0.0005	0.001
Acenaphthylene	mg/kg	<0.0003	<0.0003	<0.0001	-	<0.0003	<0.0002	-	<0.0001	<0.0001
Anthracene	mg/kg	<0.001	<0.001	<0.001	-	<0.001	0.001	-	<0.0002	*<0.001*
Benzo[a]pyrene	mg/kg	0.004	<0.005	0.006	-	0.006	0.006	-	0.003	0.007
Benzo[b,j,k]fluoranthene	mg/kg	-	-	0.014	-	0.015	0.014	-	0.0069	0.02
Benzo[b,j,k]fluoranthenes	mg/kg	0.019	0.014	-	-	-	-	-	-	-
Benzo[g,h,i]perylene	mg/kg	0.0083	0.0072	0.0098	-	0.011	0.0097	-	0.0052	0.016
Benz[a]anthracene	mg/kg	<0.001	0.002	0.003	-	0.003	0.003	-	0.001	0.005
Benz[a]anthracene/Chrysene	mg/kg	-	-	-	-	-	-	-	-	-
Biphenyl	mg/kg	0.0015	0.0047	0.0056	-	0.0066	0.0063	-	0.0023	0.0089
C1-Benzofluoranthenes/Benzopyrenes	mg/kg	-	-	-	-	-	-	-	-	0.081
C1-Benzofluoranthenes/Pyrenes	mg/kg	0.017	0.02	0.048	-	0.038	0.052	-	0.027	-
C1-Benzo[a]anthracenes/Chrysenes	mg/kg	0.22	0.12	0.16	-	0.17	0.048	-	0.016	0.087
C1-Dibenzothiophenes	mg/kg	0.0063	0.011	0.0096	-	0.012	0.01	-	0.0051	0.017
C1-Fluoranthenes/Pyrenes	mg/kg	0.035	0.021	0.03	-	0.036	0.041	-	0.019	0.12

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta								
Site ID		**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**
Sampling Date		**17 Oct 2001**	**17 Sep 2002**	**10 Sep 2003**	**11 Sep 2003**	**13 Sep 2005**	**08 Sep 2007**	**06 Sep 2008**	**09 Sep 2008**	**19 Sep 2009**
C1-Fluorenes	mg/kg	0.0034	0.0041	0.0094	-	0.0077	0.014	-	0.0067	0.024
C1-Naphthalenes	mg/kg	0.014	0.019	**0.027** (a)	-	**0.031** (a)	**0.03** (a)	-	0.009	**0.046** (a)
C1-Phenanthrenes/Anthracenes	mg/kg	0.027	0.03	0.038	-	0.039	0.03	-	0.015	0.048
C2-Benzofluoranthenes/Benzopyrenes	mg/kg	0.0076	0.006	0.022	-	0.016	0.014	-	0.0087	0.039
C2-Benzo[a]anthracenes/Chrysenes	mg/kg	0.076	0.043	0.057	-	0.05	0.048	-	0.021	0.12
C2-Dibenzothiophenes	mg/kg	0.032	0.032	0.033	-	0.042	0.046	-	0.022	0.098
C2-Fluoranthenes/Pyrenes	mg/kg	0.077	0.032	0.056	-	0.052	0.074	-	0.037	0.24
C2-Fluorenes	mg/kg	0.011	0.015	0.031	-	0.023	0.03	-	0.0099	0.048
C2-Naphthalenes	mg/kg	0.019	0.03	0.044	-	0.048	0.041	-	0.015	0.069
C2-Phenanthrenes/Anthracenes	mg/kg	0.033	0.034	0.045	-	0.049	0.051	-	0.022	0.073
C3-Dibenzothiophenes	mg/kg	0.078	0.039	0.056	-	0.085	0.085	-	0.044	0.21
C3-Fluoranthenes/Pyrenes	mg/kg	0.08	0.03	0.036	-	0.059	0.054	-	0.025	0.22
C3-Fluorenes	mg/kg	0.017	0.018	0.053	-	0.03	0.052	-	0.016	0.08
C3-Naphthalenes	mg/kg	0.026	0.025	0.037	-	0.042	0.035	-	0.017	0.056
C3-Phenanthrenes/Anthracenes	mg/kg	0.032	0.027	0.041	-	0.047	0.068	-	0.028	0.1
C4-Dibenzothiophenes	mg/kg	0.068	0.063	0.07	-	0.12	0.12	-	0.06	0.27
C4-Naphthalenes	mg/kg	0.021	0.017	0.031	-	0.029	0.035	-	0.0099	0.044
C4-Phenanthrenes/Anthracenes	mg/kg	0.029	0.1	0.17	-	0.13	0.25	-	0.11	0.44
Chrysene	mg/kg	0.013	0.013	0.016	-	0.017	0.018	-	0.008	0.03
Dibenzothiophene	mg/kg	0.0011	0.0023	0.0015	-	0.002	0.0016	-	0.00081	NDR 0.0031
Dibenz[a,h]anthracene	mg/kg	<0.002	<0.004	0.002	-	0.002	<0.002	-	0.001	*<0.003*
Dimethyl-Biphenyl	mg/kg	<0.000092	0.0061	0.0085	-	0.0086	0.011	-	0.0042	0.016
Fluoranthene	mg/kg	0.004	0.003	0.004	-	0.004	0.004	-	0.002	0.006
Fluorene	mg/kg	0.001	0.003	0.002	-	0.003	0.001	-	0.001	0.003
Indeno[1,2,3-c,d]-pyrene	mg/kg	0.0067	0.0043	0.0054	-	0.0064	0.0068	-	0.003	0.008
Methyl Acenaphthene	mg/kg	0.0013	<0.0003	0.00013	-	0.00022	<0.000715	-	0.00092	0.00042
Methyl-Biphenyl	mg/kg	<0.00012	<0.0003	0.0061	-	0.0069	0.0065	-	0.0027	0.0099
Naphthalene	mg/kg	0.005	0.007	0.009	-	0.011	0.011	-	0.003	0.016
Phenanthrene	mg/kg	0.01	0.01	0.01	-	0.01	0.02	-	0.01	0.02
Pyrene	mg/kg	0.011	0.008	0.009	-	0.01	0.011	-	0.005	0.014
Retene	mg/kg	0.048	0.021	0.037	-	0.044	0.046	-	0.02	0.11
Total Metals										
Aluminum	mg/kg	11,000	5,810	-	-	8,220	7,890	4,520	-	4,950
Antimony	mg/kg	-	-	-	-	-	-	-	-	-
Arsenic	mg/kg	**6.2** (a)	4.1	4.5	-	5.0	5.3	3.2	-	4.1
Barium	mg/kg	140	150	142	-	160	173	108	-	124
Beryllium	mg/kg	0.6	0.4	0.5	-	0.5	0.5	0.3	-	0.41
Bismuth	mg/kg	-	-	<0.5	-	<0.5	<0.5	<0.5	-	<0.5
Boron	mg/kg	16	4.0	-	-	10	8.0	8.0	-	6.3
Cadmium	mg/kg	0.2	0.2	0.3	-	0.2	0.3	0.1	-	0.3
Calcium	mg/kg	14,800	18,900	-	-	21,700	26,800	14,500	-	22,500
Chromium	mg/kg	18	13	10	-	24	14	10	-	12
Cobalt	mg/kg	8.0	6.7	7.4	-	7.0	8.6	5.2	-	6.4

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta								
Site ID		**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**	**FLC-1**
Sampling Date		**17 Oct 2001**	**17 Sep 2002**	**10 Sep 2003**	**11 Sep 2003**	**13 Sep 2005**	**08 Sep 2007**	**06 Sep 2008**	**09 Sep 2008**	**19 Sep 2009**
Copper	mg/kg	9.0	10	13	-	12	14	6.2	-	11
Iron	mg/kg	15000	13800	-	-	17500	17300	11400	-	15500
Lead	mg/kg	6.4	6.9	7.7	-	8.0	8.5	5.0	-	7.2
Magnesium	mg/kg	5,540	6,840	-	-	7,220	8,310	4,570	-	6,970
Manganese	mg/kg	245	297	-	-	372	378	209	-	367
Mercury	mg/kg	0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	-	<0.05
Molybdenum	mg/kg	0.3	0.3	0.3	-	0.7	0.5	0.2	-	0.39
Nickel	mg/kg	19	17	17	-	21	21	11	-	16
Potassium	mg/kg	1,810	890	-	-	1,400	1,300	800	-	800
Selenium	mg/kg	1.0	0.3	0.2	-	0.4	0.5	<0.2	-	0.5
Silver	mg/kg	<0.1	<0.1	<0.2	-	<0.2	<0.2	<0.2	-	<0.2
Sodium	mg/kg	204	80	-	-	200	200	200	-	200
Strontium	mg/kg	50	50	55	-	61	80	38	-	55
Thallium	mg/kg	0.17	0.13	0.17	-	0.2	0.2	0.09	-	0.17
Tin	mg/kg	-	-	<2	-	<2	<2	<2	-	<2
Titanium	mg/kg	67	50	-	-	41	81	81	-	62
Total phosphorus	mg/kg	-	-	-	-	-	-	-	-	-
Uranium	mg/kg	0.8	0.8	0.83	-	1.0	0.89	0.66	-	0.83
Vanadium	mg/kg	29	15	15	-	22	21	17	-	16
Zinc	mg/kg	50	52	60	-	60	66	36	-	51
Toxicity										
Chironomus tentans - 10d growth	mg/organism	2.8	2.6	-	3.6	-	-	-	2.0	1.7
Chironomus tentans - 10d growth - % of Control	%	91	100	-	137	-	-	-	111	125
Chironomus tentans - 10d survival	# surviving	7.0	6.0	-	6.0	-	-	-	9.4	3.4
Chironomus tentans - 10d survival - % of Control	%	109	86	-	78	-	-	-	96	49
Hyalella azteca - 10d growth	mg/organism	0.1	0.1	-	-	-	-	-	-	-
Hyalella azteca - 10d growth - % of Control	%	98	100	-	-	-	-	-	-	-
Hyalella azteca - 10d survival	# surviving	9.0	9.0	-	-	-	-	-	-	-
Hyalella azteca - 10d survival - % of Control	%	121	113	-	-	-	-	-	-	-
Hyalella azteca - 14d growth	mg/organism	-	-	-	0.11	-	-	-	0.29	0.19
Hyalella azteca - 14d survival	# surviving	-	-	-	9.6	-	-	-	9.6	8.0
Hyalella azteca - 14d growth - % of Control	%	-	-	-	95	-	-	-	123	91
Hyalella azteca - 14d survival - % of Control	%	-	-	-	104	-	-	-	114	89
Lumbriculus variegatus - 10d growth	mg/organism	10	17	-	0.9	-	-	-	-	-
Lumbriculus variegatus - 10d growth - % of Control	%	178	87	-	106	-	-	-	-	-
Lumbriculus variegatus - 10d survival	# surviving	3.0	10	-	21	-	-	-	-	-
Lumbriculus variegatus - 10d survival - % of Control	%	29	100	-	108	-	-	-	-	-

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta							
Site ID		**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**
Sampling Date		**17 Oct 2001**	**17 Sep 2002**	**11 Sep 2003**	**13 Sep 2005**	**09 Sep 2007**	**07 Sep 2008**	**09 Sep 2008**	**19 Sep 2009**
Physical properties									
% Clay	% clay	20	22	20	28	12	15	-	14
% Sand	% sand	22	32	29	17	44	30	-	53
% Silt	% silt	58	46	51	56	44	54	-	34
% Moisture	% moisture	-	-	37	42	39	52	-	46
$CaCO_3$ Equivalent	%	-	-	-	-	7.1	7.6	-	5.1
Inorganic Carbon	%	0.83	0.87	0.76	0.87	0.8	0.9	-	0.58
Texture	-	-	-	-	silt loam	loam	silt loam	-	sandy loam
Total carbon by combustion	%	2.1	1.7	2.5	3.0	1.9	3.3	-	2.0
Total organic carbon	%	1.2	1.7	1.8	2.1	1.1	2.4	-	1.4
Hydrocarbons and Organic Compounds									
AEP Total extractable hydrocarbons (C11-C30)	mg/kg	250	350	240	-	-	-	-	-
AEP Total hydrocarbons (C6-C50)	mg/kg	-	-	-	560	310	380	-	392
AEP Total recoverable hydrocarbons	mg/kg	700	700	1,000	-	-	-	-	-
AEP Total volatile hydrocarbons (C5-C10)	mg/kg	10	<0.5	<0.5	-	-	-	-	-
Benzene	mg/kg	-	-	-	<0.005	<0.005	<0.005	-	<0.005
CCME Fraction 1 (BTEX)	mg/kg	-	-	-	<5	<5	<5	-	<10
CCME Fraction 1 (C6-C10)	mg/kg	-	-	-	<5	<5	<5	-	<10
CCME Fraction 2 (C10-C16)	mg/kg	-	-	-	<5	17	8.0	-	<20
CCME Fraction 3 (C16-C34)	mg/kg	-	-	-	360	180	280	-	216
CCME Fraction 4 (C34-C50)	mg/kg	-	-	-	200	110	88	-	176
Ethylbenzene	mg/kg	-	-	-	<0.01	<0.01	<0.01	-	<0.015
m+p-Xylene	mg/kg	-	-	-	-	-	-	-	<0.05
o-Xylene	mg/kg	-	-	-	-	-	-	-	<0.05
Toluene	mg/kg	-	-	-	<0.01	<0.01	<0.01	-	<0.05
Xylenes	mg/kg	-	-	-	<0.01	<0.02	<0.02	-	<0.1
PAHs									
% Moisture_PAH sample	%	0.034	29	-	0.04	32	-	32	32
Acenaphthene	mg/kg	0.001	0.001	0.001	0.002	0.001	-	0.001	0.001
Acenaphthylene	mg/kg	<0.0002	<0.0004	<0.0001	<0.0004	<0.0005	-	0.0001	<0.0001
Anthracene	mg/kg	<0.001	<0.001	0.001	<0.001	0.0004	-	<0.001	<0.001
Benzo[a]pyrene	mg/kg	0.006	<0.007	0.008	0.01	0.005	-	0.006	0.003
Benzo[b,j,k]fluoranthene	mg/kg	-	-	0.018	0.028	0.0087	-	0.019	0.011
Benzo[b,j,k]fluoranthenes	mg/kg	0.022	0.018	-	-	-	-	-	-
Benzo[g,h,i]perylene	mg/kg	0.0092	0.011	0.013	0.017	0.008	-	0.012	0.0081
Benz[a]anthracene	mg/kg	0.004	0.003	0.004	0.006	0.003	-	0.003	0.002
Benz[a]anthracene/Chrysene	mg/kg	-	-	-	-	-	-	-	-
Biphenyl	mg/kg	0.0024	0.0064	0.0064	0.0097	0.0049	-	0.0058	0.0042
C1-Benzofluoranthenes/Benzopyrenes	mg/kg	-	-	-	-	-	-	-	0.038
C1-Benzofluoranthenes/Pyrenes	mg/kg	0.026	0.04	0.06	0.065	0.042	-	0.069	-
C1-Benzo[a]anthracenes/Chrysenes	mg/kg	0.22	0.22	0.19	0.28	0.038	-	0.045	0.038
C1-Dibenzothiophenes	mg/kg	0.011	0.015	0.011	0.018	0.0086	-	0.015	0.0051
C1-Fluoranthenes/Pyrenes	mg/kg	0.037	0.023	0.039	0.056	0.032	-	0.052	0.059
C1-Fluorenes	mg/kg	0.0057	0.0069	0.016	0.012	0.011	-	0.016	0.012

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta							
Site ID		**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**
Sampling Date		**17 Oct 2001**	**17 Sep 2002**	**11 Sep 2003**	**13 Sep 2005**	**09 Sep 2007**	**07 Sep 2008**	**09 Sep 2008**	**19 Sep 2009**
C1-Naphthalenes	mg/kg	0.018	**0.026** [(a)]	**0.032** [(a)]	**0.044** [(a)]	**0.023** [(a)]	-	**0.028** [(a)]	0.018
C1-Phenanthrenes/Anthracenes	mg/kg	0.037	0.043	0.05	0.059	0.029	-	0.04	0.024
C2-Benzofluoranthenes/Benzopyrenes	mg/kg	0.0083	0.015	0.027	0.031	0.011	-	0.024	0.022
C2-Benzo[a]anthracenes/Chrysenes	mg/kg	0.1	0.07	0.064	0.077	0.036	-	0.059	0.05
C2-Dibenzothiophenes	mg/kg	0.046	0.054	0.043	0.065	0.034	-	0.061	0.04
C2-Fluoranthenes/Pyrenes	mg/kg	0.079	0.04	0.069	0.083	0.057	-	0.1	0.12
C2-Fluorenes	mg/kg	0.025	0.025	0.051	0.032	0.019	-	0.03	0.025
C2-Naphthalenes	mg/kg	0.023	0.04	0.056	0.072	0.036	-	0.044	0.033
C2-Phenanthrenes/Anthracenes	mg/kg	0.044	0.057	0.056	0.075	0.036	-	0.062	0.031
C3-Dibenzothiophenes	mg/kg	0.11	0.055	0.07	0.13	0.067	-	0.13	0.086
C3-Fluoranthenes/Pyrenes	mg/kg	0.086	0.039	0.042	0.086	0.041	-	0.051	0.095
C3-Fluorenes	mg/kg	0.022	0.035	0.077	0.052	0.032	-	0.038	0.037
C3-Naphthalenes	mg/kg	0.028	0.035	0.054	0.059	0.027	-	0.04	0.03
C3-Phenanthrenes/Anthracenes	mg/kg	0.042	0.037	0.051	0.083	0.053	-	0.089	0.037
C4-Dibenzothiophenes	mg/kg	0.091	0.096	0.09	0.2	0.091	-	0.2	0.11
C4-Naphthalenes	mg/kg	0.025	0.025	0.05	0.039	0.019	-	0.026	0.021
C4-Phenanthrenes/Anthracenes	mg/kg	0.038	0.11	0.2	0.35	0.18	-	0.32	0.16
Chrysene	mg/kg	0.021	0.021	0.021	0.027	0.013	-	0.022	0.013
Dibenzothiophene	mg/kg	0.0018	0.0024	0.0019	0.003	0.0014	-	<0.00186	0.0015
Dibenz[a,h]anthracene	mg/kg	<0.002	<0.005	0.003	0.004	<0.002	-	0.003	*<0.001*
Dimethyl-Biphenyl	mg/kg	<0.00011	0.0095	0.0096	0.012	0.0076	-	0.0087	0.013
Fluoranthene	mg/kg	0.004	0.005	0.005	0.006	0.003	-	0.005	0.003
Fluorene	mg/kg	0.002	0.003	0.002	0.004	0.001	-	0.002	0.001
Indeno[1,2,3-c,d]-pyrene	mg/kg	0.0063	0.006	0.0074	0.01	0.0042	-	0.0082	0.0044
Methyl Acenaphthene	mg/kg	0.0016	<0.0004	<0.000138	0.0036	<0.000267	-	0.0032	0.00018
Methyl-Biphenyl	mg/kg	<0.000076	<0.0003	0.0067	0.0096	0.0054	-	0.0063	0.005
Naphthalene	mg/kg	0.005	0.009	0.011	0.015	0.008	-	0.009	0.006
Phenanthrene	mg/kg	0.01	0.02	0.02	0.02	0.01	-	0.02	0.01
Pyrene	mg/kg	0.012	0.008	0.011	0.016	0.008	-	0.013	0.007
Retene	mg/kg	0.054	0.027	0.044	0.078	0.034	-	0.056	0.035
Total Metals									
Aluminum	mg/kg	4,890	6,470	-	11,600	5,520	8,370	-	4,630
Antimony	mg/kg	-	-	-	-	-	-	-	-
Arsenic	mg/kg	4.8	4.5	4.7	**6.6** [(a)]	3.9	5.7	-	4.2
Barium	mg/kg	169	150	156	207	130	164	-	105
Beryllium	mg/kg	0.7	0.5	0.5	0.8	0.3	0.6	-	0.41
Bismuth	mg/kg	-	-	<0.5	<0.5	<0.5	<0.5	-	<0.5
Boron	mg/kg	14	4.0	-	15	6.0	14	-	5.7
Cadmium	mg/kg	0.2	0.2	0.3	0.3	0.2	0.3	-	0.2
Calcium	mg/kg	22,400	20,700	-	26,600	23,000	21,200	-	16,100
Chromium	mg/kg	20	13	11	27	12	17	-	12
Cobalt	mg/kg	7.9	7.6	7.6	9.4	6.6	8.5	-	6.5
Copper	mg/kg	13	20	15	19	9.5	17	-	9.6
Iron	mg/kg	17500	15800	-	23300	15100	19200	-	15200

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta							
Site ID		**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**	**GIC-1**
Sampling Date		**17 Oct 2001**	**17 Sep 2002**	**11 Sep 2003**	**13 Sep 2005**	**09 Sep 2007**	**07 Sep 2008**	**09 Sep 2008**	**19 Sep 2009**
Lead	mg/kg	7.1	8.1	8.4	12	6.3	9.2	-	7.1
Magnesium	mg/kg	8,260	7,470	-	8,340	6,680	7,160	-	5,280
Manganese	mg/kg	410	380	-	523	287	356	-	360
Mercury	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05
Molybdenum	mg/kg	0.3	0.3	0.4	0.8	0.3	0.5	-	0.35
Nickel	mg/kg	21	19	19	26	15	20	-	16
Potassium	mg/kg	1,740	950	-	1,970	1,000	1,500	-	750
Selenium	mg/kg	1.1	0.4	0.4	0.7	0.3	0.6	-	0.33
Silver	mg/kg	<0.1	0.1	<0.2	<0.2	<0.2	<0.2	-	<0.2
Sodium	mg/kg	196	80	-	300	100	200	-	180
Strontium	mg/kg	64	57	59	82	60	67	-	47
Thallium	mg/kg	0.19	0.14	0.18	0.25	0.14	0.21	-	0.23
Tin	mg/kg	-	-	<2	<2	<2	<2	-	<2
Titanium	mg/kg	33	37	-	44	81	79	-	61
Total phosphorus	mg/kg	-	-	-	-	-	-	-	-
Uranium	mg/kg	0.9	0.8	0.89	1.3	0.78	1.1	-	0.61
Vanadium	mg/kg	25	16	16	31	17	27	-	15
Zinc	mg/kg	63	63	65	75	54	67	-	51
Toxicity									
Chironomus tentans - 10d growth	mg/organism	2.7	2.6	4.2	-	-	-	1.3	1.6
Chironomus tentans - 10d growth - % of Control	%	86	100	161	-	-	-	73	121
Chironomus tentans - 10d survival	# surviving	8.0	7.0	4.0	-	-	-	8.4	5.8
Chironomus tentans - 10d survival - % of Control	%	115	100	51	-	-	-	86	83
Hyalella azteca - 10d growth	mg/organism	0.1	0.1	-	-	-	-	-	-
Hyalella azteca - 10d growth - % of Control	%	94	100	-	-	-	-	-	-
Hyalella azteca - 10d survival	# surviving	10	7.0	-	-	-	-	-	-
Hyalella azteca - 10d survival - % of Control	%	126	88	-	-	-	-	-	-
Hyalella azteca - 14d growth	mg/organism	-	-	0.11	-	-	-	0.3	0.21
Hyalella azteca - 14d survival	# surviving	-	-	9.0	-	-	-	9.0	8.2
Hyalella azteca - 14d growth - % of Control	%	-	-	99	-	-	-	129	102
Hyalella azteca - 14d survival - % of Control	%	-	-	102	-	-	-	107	107
Lumbriculus variegatus - 10d growth	mg/organism	16	16	0.9	-	-	-	-	-
Lumbriculus variegatus - 10d growth - % of Control	%	229	86	110	-	-	-	-	-
Lumbriculus variegatus - 10d survival	# surviving	13	10	22	-	-	-	-	-
Lumbriculus variegatus - 10d survival - % of Control	%	134	100	110	-	-	-	-	-

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta									
Site ID		**ARD-1**	**ARD-2**	**ATR-OF**	**BEC**	**BPC-2**	**CC-1**	**EMR-1**	**EMR-2**	**FLB-1**	**JC-1**
Sampling Date		**31 Jul 1999**	**13 Sep 2005**	**12 Sep 2005**	**13 Sep 2005**	**13 Sep 2005**	**12 Sep 2005**	**12 Sep 2005**	**13 Sep 2005**	**16 Sep 2000**	**13 Sep 2005**
Physical Properties											
% Clay	% clay	22	22	13	19	24	17	19	43	32	19
% Sand	% sand	14	34	70	28	23	38	35	4.0	16	47
% Silt	% silt	64	44	17	53	52	45	46	53	52	34
% Moisture	% moisture	-	35	40	30	37	34	24	52	-	41
$CaCO_3$ Equivalent	%	-	-	-	-	-	-	-	-	-	-
Inorganic Carbon	%	0.79	0.7	0.33	0.77	0.75	0.74	0.86	0.82	0.88	0.38
Texture	-	-	loam	sandy loam	silt loam	silt loam	loam	loam	silty clay	-	loam
Total carbon by combustion	%	2.6	2.3	1.4	2.3	2.5	2.6	2.5	3.4	2.7	1.8
Total organic carbon	%	1.8	1.6	1.1	1.5	1.7	1.8	1.7	2.6	1.9	1.4
Hydrocarbons and Organic Compounds											
AEP Total extractable hydrocarbons (C11-C30)	mg/kg	-	-	-	-	-	-	-	-	82	-
AEP Total hydrocarbons (C6-C50)	mg/kg	-	590	1,100	480	460	510	620	580	-	520
AEP Total recoverable hydrocarbons	mg/kg	-	-	-	-	-	-	-	-	700	-
AEP Total volatile hydrocarbons (C5-C10)	mg/kg	-	-	-	-	-	-	-	-	<0.5	-
Benzene	mg/kg	-	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-	<0.005
CCME Fraction 1 (BTEX)	mg/kg	-	<5	<5	<5	<5	<5	<5	<5	-	<5
CCME Fraction 1 (C6-C10)	mg/kg	-	<5	<5	<5	<5	<5	<5	<5	-	<5
CCME Fraction 2 (C10-C16)	mg/kg	-	<5	44	<5	<5	12	22	<5	-	<5
CCME Fraction 3 (C16-C34)	mg/kg	-	350	620	290	280	290	360	390	-	320
CCME Fraction 4 (C34-C50)	mg/kg	-	240	450	190	180	210	240	190	-	200
Ethylbenzene	mg/kg	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01
m+p-Xylene	mg/kg	-	-	-	-	-	-	-	-	-	-
o-Xylene	mg/kg	-	-	-	-	-	-	-	-	-	-
Toluene	mg/kg	-	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.03	-	<0.01
Xylenes	mg/kg	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01
PAHs											
% Moisture_PAH sample	%	-	0.033	31	32	0.033	33	30	49	-	0.038
Acenaphthene	mg/kg	<0.001	0.002	<0.001	0.001	0.001	0.001	0.001	0.002	<0.005	0.001
Acenaphthylene	mg/kg	<0.004	0.001	<0.0003	<0.0003	<0.0003	<0.0002	<0.0002	<0.001	<0.004	<0.0002
Anthracene	mg/kg	<0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001
Benzo[a]pyrene	mg/kg	0.013	0.007	0.004	0.007	0.008	0.006	0.007	0.012	0.009	0.005
Benzo[b,j,k]fluoranthene	mg/kg	-	0.019	0.01	0.018	0.018	0.018	0.017	0.028	-	0.015
Benzo[b,j,k]fluoranthenes	mg/kg	0.03	-	-	-	-	-	-	-	0.027	-
Benzo[g,h,i]perylene	mg/kg	0.017	0.012	0.0072	0.013	0.013	0.012	0.012	0.02	0.018	0.0097
Benz[a]anthracene	mg/kg	0.004	0.004	<0.002	0.003	0.004	0.003	0.004	0.005	0.027	0.003
Benz[a]anthracene/Chrysene	mg/kg	-	-	-	-	-	-	-	-	-	-
Biphenyl	mg/kg	0.0078	0.0066	0.0037	0.0069	0.0077	0.0065	0.008	0.012	0.0056	0.0085
C1-Benzofluoranthenes/Benzopyrenes	mg/kg	-	-	-	-	-	-	-	-	-	-
C1-Benzofluoranthenes/Pyrenes	mg/kg	<0.015	0.05	0.032	0.047	0.053	0.049	0.041	0.073	<0.007	0.036
C1-Benzo[a]anthracenes/Chrysenes	mg/kg	0.036	0.23	0.15	0.2	0.21	0.21	0.17	0.3	0.23	0.14
C1-Dibenzothiophenes	mg/kg	0.017	0.025	0.0085	0.013	0.015	0.014	0.014	0.023	0.014	0.012
C1-Fluoranthenes/Pyrenes	mg/kg	0.043	0.048	0.028	0.047	0.042	0.048	0.041	0.072	0.063	0.027
C1-Fluorenes	mg/kg	<0.0037	0.0088	0.0036	0.0066	0.0083	0.0075	0.0081	0.013	<0.0043	0.0073

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta									
Site ID		**ARD-1**	**ARD-2**	**ATR-OF**	**BEC**	**BPC-2**	**CC-1**	**EMR-1**	**EMR-2**	**FLB-1**	**JC-1**
Sampling Date		**31 Jul 1999**	**13 Sep 2005**	**12 Sep 2005**	**13 Sep 2005**	**13 Sep 2005**	**12 Sep 2005**	**12 Sep 2005**	**13 Sep 2005**	**16 Sep 2000**	**13 Sep 2005**
C1-Naphthalenes	mg/kg	**0.035** (a)	**0.029** (a)	0.016	**0.03** (a)	**0.037** (a)	**0.029** (a)	**0.034** (a)	**0.053** (a)	**0.047** (a)	**0.031** (a)
C1-Phenanthrenes/Anthracenes	mg/kg	0.069	0.061	0.022	0.046	0.058	0.042	0.048	0.082	0.077	0.038
C2-Benzofluoranthenes/Benzopyrenes	mg/kg	<0.013	0.02	0.022	0.025	0.02	0.018	0.019	0.037	<0.003	0.0081
C2-Benzo[a]anthracenes/Chrysenes	mg/kg	0.015	0.063	0.072	0.068	0.054	0.076	0.064	0.095	<0.14	0.04
C2-Dibenzothiophenes	mg/kg	0.075	0.11	0.031	0.051	0.053	0.048	0.055	0.1	<0.0084	0.041
C2-Fluoranthenes/Pyrenes	mg/kg	-	0.068	0.06	0.076	0.063	0.076	0.071	0.12	0.11	0.04
C2-Fluorenes	mg/kg	<0.0027	0.034	0.011	0.021	0.03	0.02	0.023	0.04	<0.006	0.025
C2-Naphthalenes	mg/kg	0.043	0.05	0.03	0.05	0.058	0.047	0.056	0.087	0.054	0.048
C2-Phenanthrenes/Anthracenes	mg/kg	0.064	0.078	0.037	0.06	0.061	0.058	0.062	0.11	0.075	0.044
C3-Dibenzothiophenes	mg/kg	0.11	0.17	0.075	0.096	0.087	0.096	0.083	0.17	0.18	0.058
C3-Fluoranthenes/Pyrenes	mg/kg	-	0.079	0.057	0.078	0.07	0.099	0.069	0.12	0.089	0.023
C3-Fluorenes	mg/kg	-	0.055	0.025	0.031	0.035	0.034	0.037	0.051	<0.0038	0.019
C3-Naphthalenes	mg/kg	0.054	0.05	0.025	0.035	0.05	0.036	0.041	0.065	0.05	0.041
C3-Phenanthrenes/Anthracenes	mg/kg	0.071	0.087	0.033	0.059	0.057	0.058	0.055	0.1	0.075	0.04
C4-Dibenzothiophenes	mg/kg	-	0.2	0.13	0.15	0.14	0.15	0.13	0.19	<0.0039	0.087
C4-Naphthalenes	mg/kg	0.032	0.048	0.016	0.025	0.033	0.023	0.029	0.047	<0.0096	0.023
C4-Phenanthrenes/Anthracenes	mg/kg	0.35	0.34	0.24	0.3	0.26	0.3	0.27	0.45	0.025	0.14
Chrysene	mg/kg	0.027	0.023	0.012	0.021	0.022	0.021	0.018	0.031	0.004	0.015
Dibenzothiophene	mg/kg	<0.0028	0.0028	0.00097	0.002	0.0028	0.0019	0.0024	0.0039	<0.0047	0.0021
Dibenz[a,h]anthracene	mg/kg	<0.006	0.003	<0.003	0.003	0.002	0.003	0.003	0.004	< 0.007 [3]	0.002
Dimethyl-Biphenyl	mg/kg	<0.0017	0.0084	0.0036	0.0075	0.01	0.0063	0.0084	0.014	<0.0021	0.0092
Fluoranthene	mg/kg	0.007	0.005	0.002	0.004	0.005	0.004	0.004	0.007	0.006	0.004
Fluorene	mg/kg	0.003	0.003	0.002	0.003	0.004	0.002	0.003	0.006	0.005	0.004
Indeno[1,2,3-c,d]-pyrene	mg/kg	0.011	0.0072	0.0034	0.0072	0.0072	0.0065	0.0059	0.0096	0.013	0.0056
Methyl Acenaphthene	mg/kg	0.0034	0.0003	<0.000195	<0.00018	0.00022	<0.000233	<0.000198	0.00027	0.0026	<0.000674
Methyl-Biphenyl	mg/kg	<0.0021	0.0058	0.0024	0.0057	0.0083	0.0055	0.0067	0.011	<0.0025	0.0069
Naphthalene	mg/kg	0.019	0.011	0.007	0.011	0.012	0.011	0.013	0.018	0.022	0.011
Phenanthrene	mg/kg	0.03	0.02	0.01	0.02	0.02	0.02	0.02	0.03	0.02	0.01
Pyrene	mg/kg	0.015	0.01	0.007	0.012	0.013	0.011	0.012	0.018	0.019	0.008
Retene	mg/kg	-	0.074	0.064	0.11	0.046	0.056	0.073	0.13	0.067	0.039
Total Metals											
Aluminum	mg/kg	8,850	8,750	4,540	9,080	9,570	8,230	8,730	14,100	14,700	7,470
Antimony	mg/kg	-	-	-	-	-	-	-	-	<0.02	-
Arsenic	mg/kg	4.8	5.4	4.1	5.5	5.5	5.5	5.0	**8.2** (a)	5.8	5.0
Barium	mg/kg	166	167	94	178	174	160	171	236	187	129
Beryllium	mg/kg	<1	0.6	0.4	0.6	0.7	0.5	0.6	0.9	0.9	0.5
Bismuth	mg/kg	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5
Boron	mg/kg	13	12	8.0	12	13	12	12	16	21	10
Cadmium	mg/kg	<0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.2
Calcium	mg/kg	27,800	20,000	11,900	22,400	25,300	20,600	23,500	31,200	20,400	13,300
Chromium	mg/kg	25	21	8.9	23	22	27	20	27	**50.8** (a)	18
Cobalt	mg/kg	7.0	7.7	5.5	7.8	7.9	7.3	7.7	11	8.4	6.3
Copper	mg/kg	14	15	7.7	14	15	13	14	23	19	13
Iron	mg/kg	16800	19400	12100	19300	20300	18200	18800	27500	21200	16800

Table C-2 Summary of Sediment Quality in the Athabasca River Delta (continued)

Watershed	Unit	Athabasca River Delta									
Site ID		**ARD-1**	**ARD-2**	**ATR-OF**	**BEC**	**BPC-2**	**CC-1**	**EMR-1**	**EMR-2**	**FLB-1**	**JC-1**
Sampling Date		**31 Jul 1999**	**13 Sep 2005**	**12 Sep 2005**	**13 Sep 2005**	**13 Sep 2005**	**12 Sep 2005**	**12 Sep 2005**	**13 Sep 2005**	**16 Sep 2000**	**13 Sep 2005**
Lead	mg/kg	10	9.0	5.7	9.2	9.5	8.7	9.1	15	10	7.9
Magnesium	mg/kg	8,290	7,340	3,930	7,470	7,980	6,850	7,520	8,510	7,970	5,460
Manganese	mg/kg	413	368	238	374	422	372	396	744	403	387
Mercury	mg/kg	0.09	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.09	<0.05
Molybdenum	mg/kg	<1	0.6	0.4	0.6	0.7	0.9	0.5	0.7	0.8	0.5
Nickel	mg/kg	22	21	12	22	22	23	21	29	32	18
Potassium	mg/kg	1,400	1,490	820	1,550	1,610	1,440	1,500	2,230	2,770	1,290
Selenium	mg/kg	0.6	0.4	0.3	0.5	0.5	0.4	0.4	0.8	0.8	0.5
Silver	mg/kg	<1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.2	<0.2
Sodium	mg/kg	100	200	200	200	200	200	200	300	258	200
Strontium	mg/kg	69	61	39	67	72	63	67	107	64	45
Thallium	mg/kg	-	0.19	0.12	0.2	0.21	0.19	0.21	0.3	0.26	0.17
Tin	mg/kg	-	<2	<2	<2	<2	<2	<2	<2	-	<2
Titanium	mg/kg	26	52	51	42	67	51	52	31	45	52
Total phosphorus	mg/kg	-	-	-	-	-	-	-	-	-	-
Uranium	mg/kg	<40	1.1	0.65	1.5	1.1	1.1	1.1	1.6	1.2	0.8
Vanadium	mg/kg	21	24	15	25	25	23	24	35	39	20
Zinc	mg/kg	65	61	40	63	63	59	60	87	61	51
Toxicity											
Chironomus tentans - 10d growth	mg/organism	0.89	-	-	-	-	-	-	-	1.9	-
Chironomus tentans - 10d growth - % of Control	%	71	-	-	-	-	-	-	-	86	-
Chironomus tentans - 10d survival	# surviving	3.2	-	-	-	-	-	-	-	7.8	-
Chironomus tentans - 10d survival - % of Control	%	42	-	-	-	-	-	-	-	89	-
Hyalella azteca - 10d growth	mg/organism	0.048	-	-	-	-	-	-	-	0.06	-
Hyalella azteca - 10d growth - % of Control	%	98	-	-	-	-	-	-	-	95	-
Hyalella azteca - 10d survival	# surviving	6.6	-	-	-	-	-	-	-	8.4	-
Hyalella azteca - 10d survival - % of Control	%	72	-	-	-	-	-	-	-	124	-
Hyalella azteca - 14d growth	mg/organism	-	-	-	-	-	-	-	-	-	-
Hyalella azteca - 14d survival	# surviving	-	-	-	-	-	-	-	-	-	-
Hyallela azteca - 14d growth - % of Control	%	-	-	-	-	-	-	-	-	-	-
Hyallela azteca - 14d survival - % of Control	%	-	-	-	-	-	-	-	-	-	-
Lumbriculus variegatus - 10d growth	mg/organism	0.8	-	-	-	-	-	-	-	1.1	-
Lumbriculus variegatus - 10d growth - % of Control	%	63	-	-	-	-	-	-	-	56	-
Lumbriculus variegatus - 10d survival	# surviving	14	-	-	-	-	-	-	-	22	-
Lumbriculus variegatus - 10d survival - % of Control	%	122	-	-	-	-	-	-	-	158	-

(a) Concentration higher than the interim sediment quality guideline (CCME 1999).

(b) Concentration higher than the probable effects level defined by CCME (1999).

(c) Analytical detection limit was higher than the relevant water quality guideline(s).

Notes: < = less than; - = no data collected; d/s = downstream.
A value with "<" represents a concentration less than the relevant detection limit.
Bold values are higher than the relevant sediment quality guidelines.

Source: RAMP (2010).

REFERENCES

CCME (Canadian Council of Ministers of the Environment). 1999. *Canadian Environmental Quality Guidelines*. 1999 with updates to 2010. Winnipeg, MB.

RAMP (Regional Aquatics Monitoring Program). 2010. *Regional Aquatics Monitoring Program: 2009 Technical Report - Final*. Prepared for the RAMP Steering Committee by Hatfield Consultants Ltd., Kilgour and Associates Ltd. and Western Resource Solutions.

ATTACHMENT D

Temporal Trends for Selected Individual Polycyclic Aromatic Hydrocarbon Species

Figure D-1 C1-fluorene Concentrations in Sediments From the Athabasca River and Delta

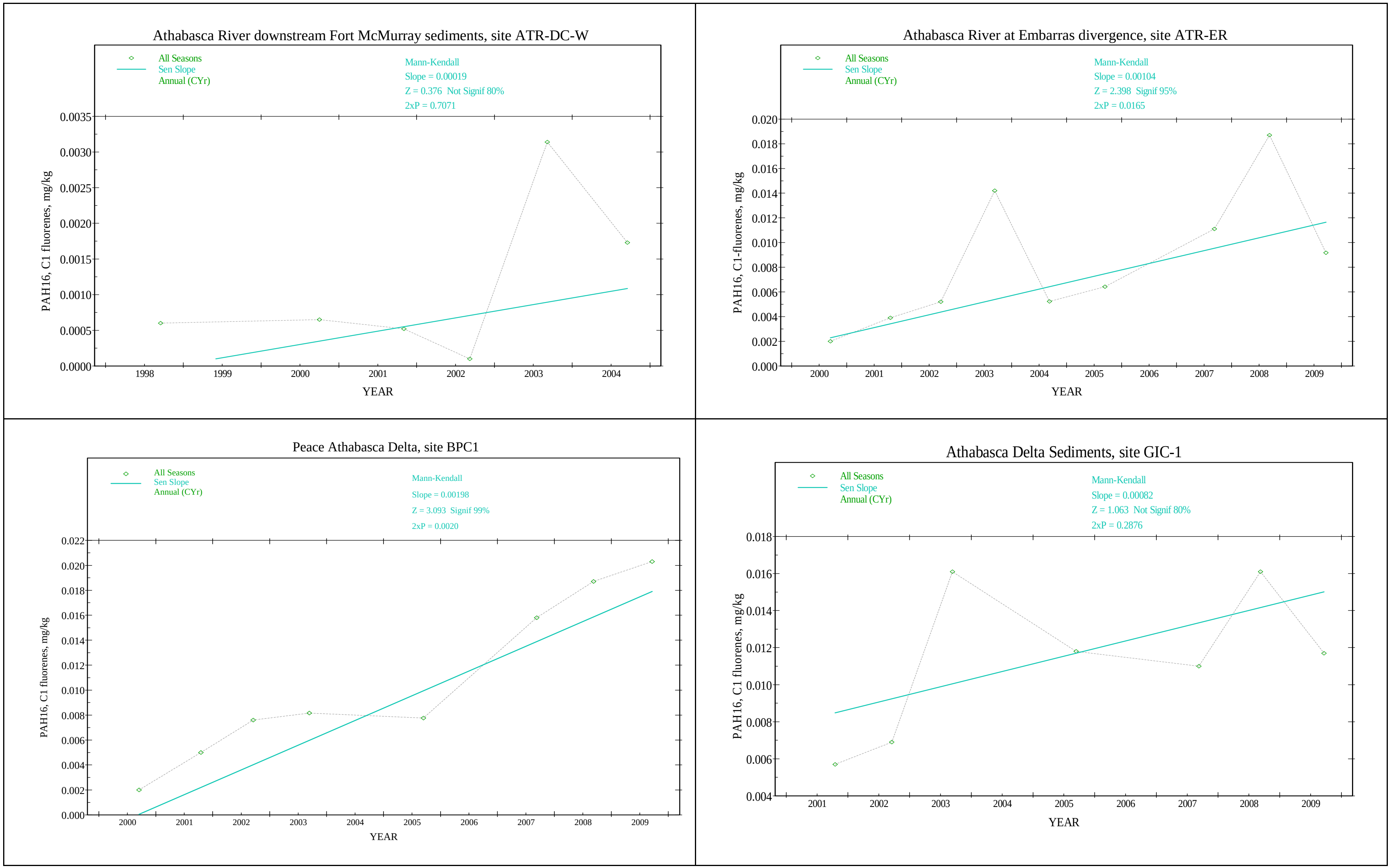
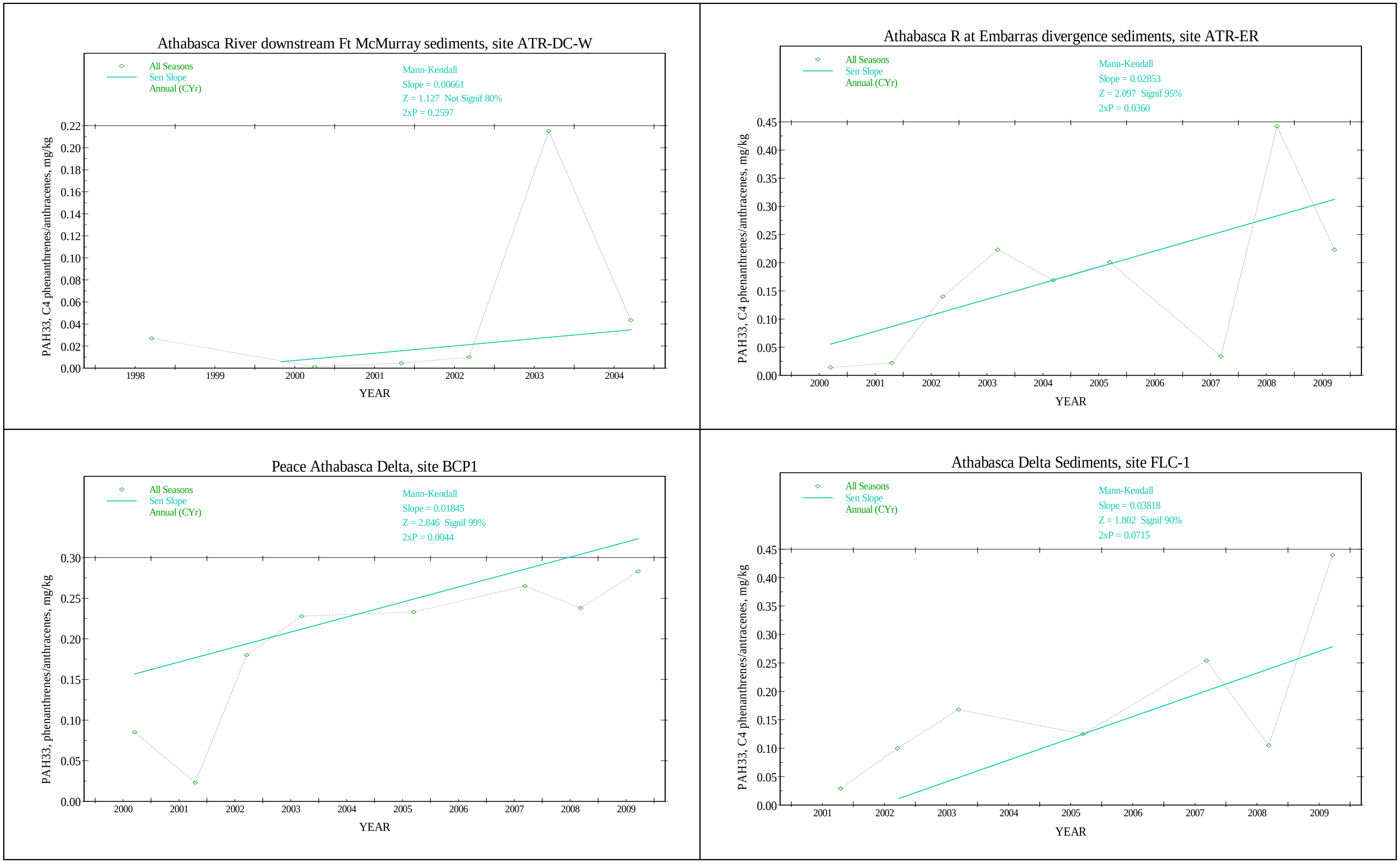


Figure D-2 C4-phenanthrene/anthracene Concentrations in Sediments From the Athabasca River and Delta



Athabasca River downstream Ft McMurray sediments, site ATR-DC-W

Athabasca R at Embarras divergence sediments, site ATR-ER

Peace Athabasca Delta, site BCP1

Athabasca Delta Sediments, site FLC-1

Figure D-3 Acenaphthylene Concentrations in Sediments From the Athabasca River and Delta

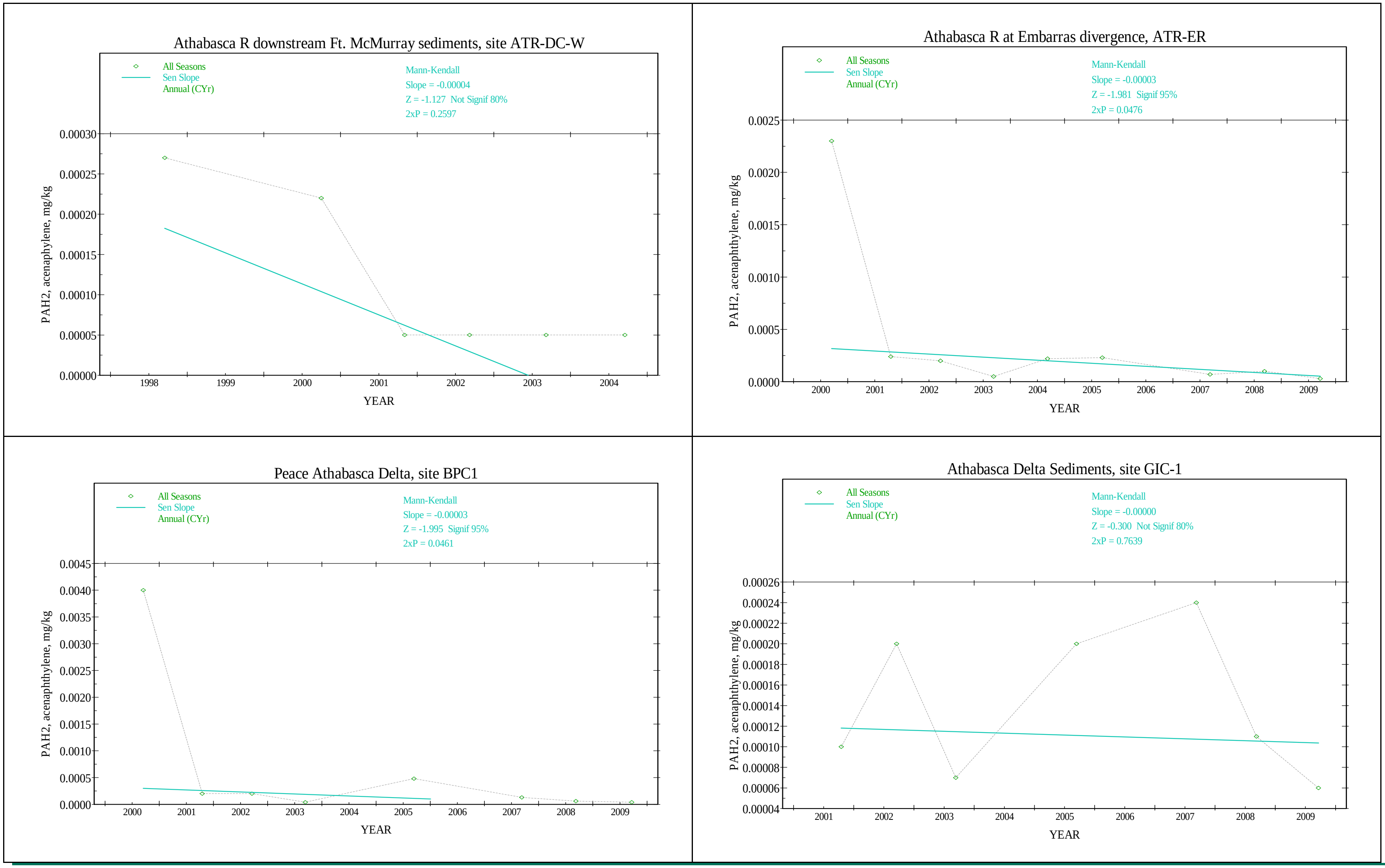
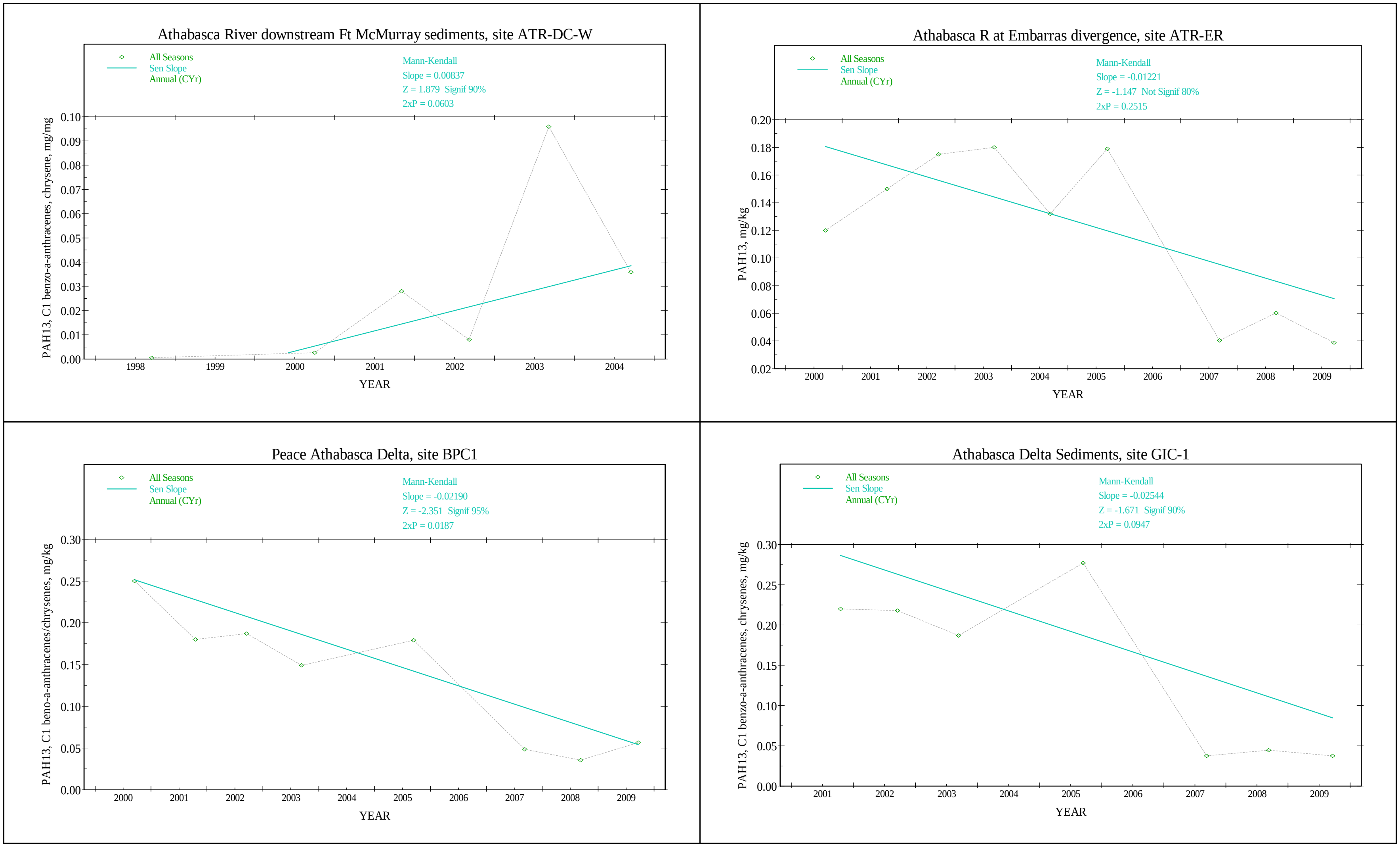


Figure D-4 C1-benzo[a]anthracene/chrysene Concentrations in Sediments From the Athabasca River and Delta



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