Cameco Blind River Refinery

ENVIRONMENTAL RISK ASSESSMENT FOR THE CAMECO BLIND RIVER REFINERY

November 2016

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Environmental Risk Assessment for the Cameco Blind River Refinery

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1 INTRODUCTION

1.1 Background

Cameco operates a uranium refinery near Blind River, Ontario. The Blind River Refinery (BRR) processes natural uranium concentrates, along with small quantities of scrap natural uranium bearing materials such as uranium dioxide (UO_2) and natural uranium metal, into natural uranium trioxide (UO_3). More detailed characterization of the BRR is presented in Section 2.

Arcadis Canada Inc. (Arcadis) has been contracted to update the existing Environmental Risk Assessment (ERA) for the site; provide updated plume delineation and field verification, along with sediment sampling; and provide a review of the existing BRR soil monitoring program.

This report contains the updated ERA for the BRR.

1.2 Objectives of the Present Study

The objective of the present study is to complete an Environmental Risk Assessment (ERA) for the BRR, including Human Health Risk Assessment (HHRA) and Ecological Risk Assessment (EcoRA) in order to assess risks to human and non-human receptors from radiological and non-radiological contaminants related to current operations at the BRR, and, to account for:

(i) Newly acquired data from environmental monitoring and other studies (e.g. updated DRL [SENES 2013]);

(ii) Changes in ecological risk assessment guidance (e.g. publication of CSA N288.6 guidance on ERA [CSA 2012]); and,

(iii) Any potential changes to the BRR site or its surroundings since completion of the prior ERA in 2006.

The receptors in this HHRA are based on the most recent DRL (SENES 2013) for consistency.

Overall, this ERA is based on data provided to Arcadis as of March 2015, in addition to sediment data collected in May of 2015 (see Section 2.5 for further discussion).

1.3 Report Organization

This report is structured as follows, based on the CSA (2012) recommended outline for ERAs:

Section 2 provides a characterization of the Site, including a description of the study area, engineered and natural environment, hydrogeology, and data currently available from monitoring programs and site investigations.

Section 3 describes modelling activities undertaken.

Section 4 presents the methodology and results of screening for contaminants of potential concern (COPCs).

Section 5 presents the Human Health Risk Assessment (HHRA), including selection of receptors, conceptual model for HHRA, methodology and results.

Section 6 presents the Ecological Risk Assessment (ERA), including selection of receptors, conceptual model for EcoRA, methodology and results.

Section 7 summarizes the conclusions and recommendations resulting from this study.

2 SITE CHARACTERIZATION

2.1 Location and Boundaries

Cameco operates a uranium refinery near Blind River, Ontario. The facility is located in northern Ontario on the north shore of Lake Huron, about midway between Sudbury and Sault Ste. Marie (see Figure 2.1).

Figure 2.1 Cameco Blind River Refinery - Location

The property is 636 acres in total, which includes a secured area of 28 acres, where the facility is located and where the CNSC licensed activities are carried out. Cameco has a lease arrangement for an additional 481 acres to the east of the existing property boundary (Figure 2.2). The property boundary on the north is approximately the CP railway line. It is bounded on the west by the Mississagi River and extends south to the North Channel of Lake Huron (Figure 2.3).

Figure 2.2 Cameco Blind River Refinery – Site Area & Boundaries

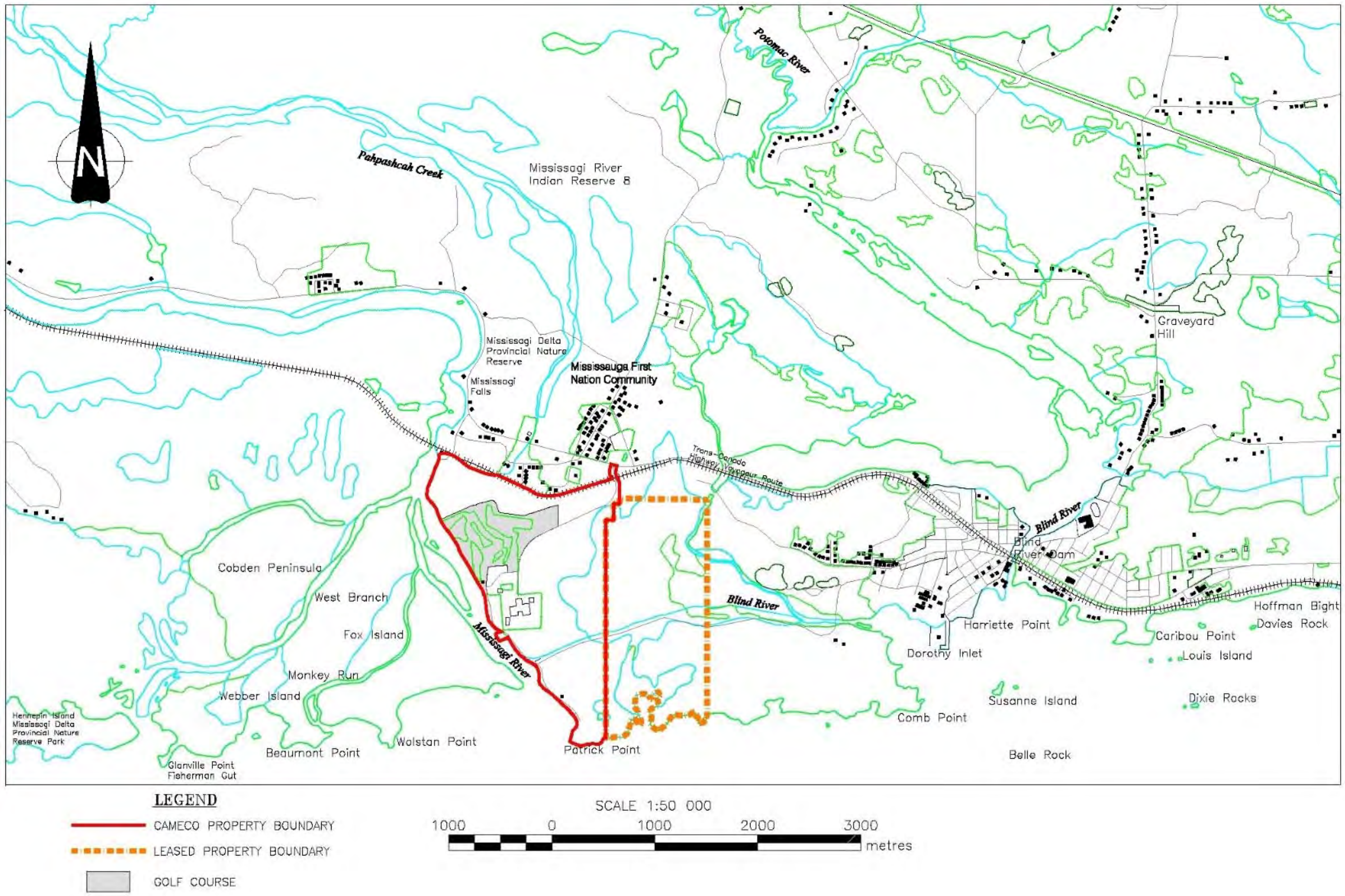


Figure 2.3 Cameco Blind River Refinery – Proximity to Lake Huron & Mississagi River

There are few permanent residences directly to the east or west of the property; however, there are small rural communities located along Highway 17 to the north. Much of the general surrounding area is vegetated or wet lands with little agricultural activity as is typical for northern Ontario.

2.2 Operations

The Blind River Refinery (BRR) processes natural uranium concentrates, along with small quantities of scrap natural uranium bearing materials such as uranium dioxide (UO_2) and natural uranium metal, into natural uranium trioxide (UO_3). The refinery has an on-site incinerator to burn radioactively contaminated combustible materials that cannot otherwise be disposed of or recycled. The contaminated incinerator ash is [redacted] sent off-site to another licensed facility for uranium recovery. The incinerator is located inside of the secured area, on the south side of the main building, just west of the powerhouse.

The BRR has a comprehensive liquid effluent treatment system to process effluents generated from the operation. [redacted]

The original facility design from the 1980s included three outdoor lagoons, but a fourth lagoon (the Effluent Lagoon) was installed in the late 1990s. These four lagoons are used to hold process effluent and stormwater before release to Lake Huron. The Effluent Lagoon (see Figure 2.4) and the Monitor Lagoon (see Figure 2.5) are the largest, [redacted]. The Stormwater Lagoon (see Figure 2.6) and Treatment Lagoon (see Figure 2.7) are smaller, [redacted].

Figure 2.4 Effluent Lagoon (SENES 2012)

Figure 2.5 Monitoring Lagoon (SENES 2012)

Figure 2.6 Stormwater Lagoon (SENES 2012)

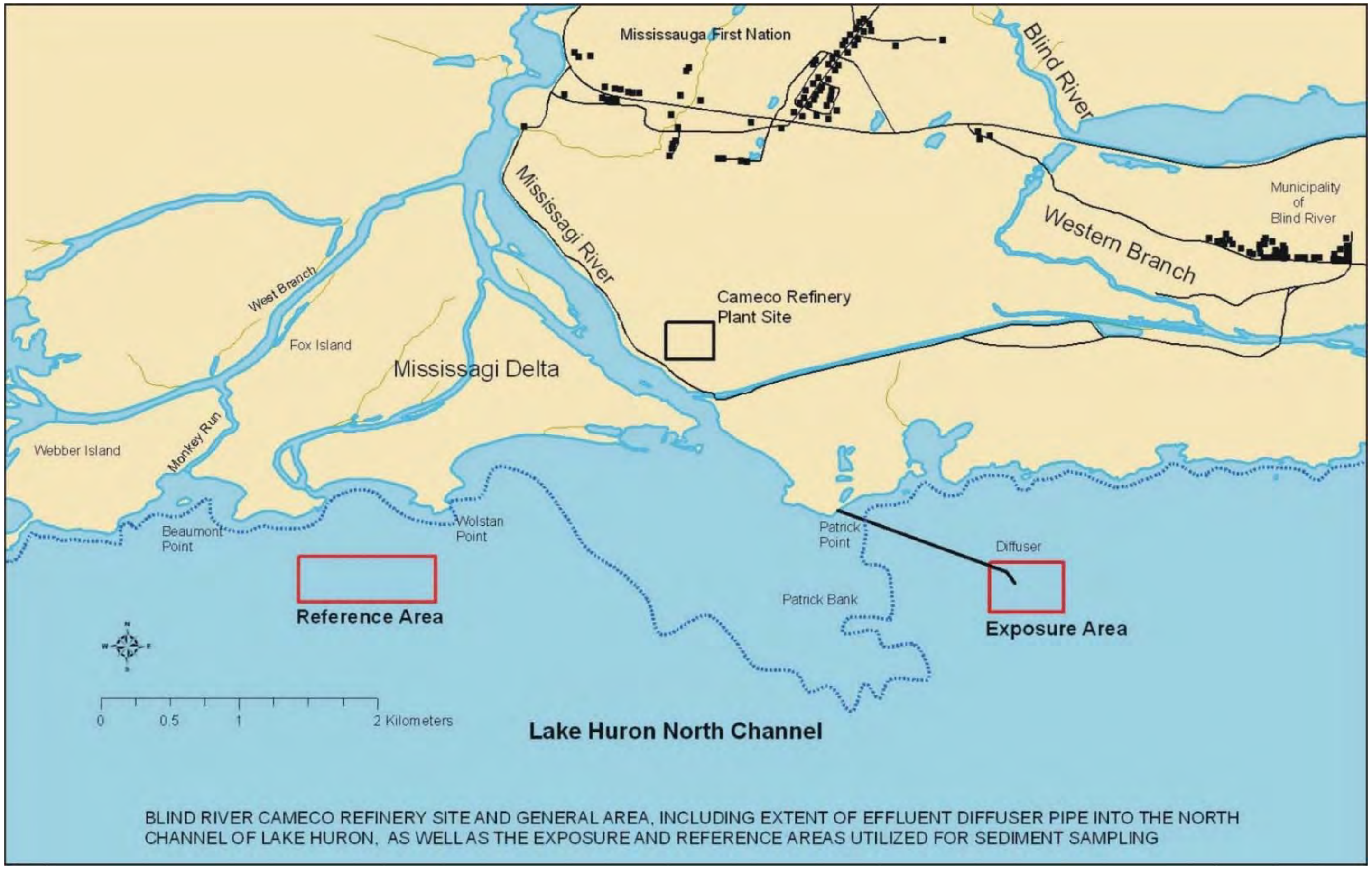
Figure 2.7 Treatment Lagoon (SENES 2012)

The Effluent Lagoon and Monitor Lagoon are the primary lagoons which collect the treated effluent, while the Stormwater Lagoon, as its name implies, collects stormwater, runoff and snow melt. The Treatment Lagoon is primarily an overflow lagoon for stormwater, but is used occasionally for collecting process water.

The Effluent and Monitor lagoons are drained by gravity flow into a sump below the effluent house building, which subsequently pumps the discharge to Lake Huron (see Figure 2.8). [redacted] When one-third full, water from the Stormwater Lagoon is transferred to either the Effluent or Monitor Lagoon; thus, the Stormwater Lagoon is drained on a regular basis.

The bottoms of three of the lagoons (Monitor, Treatment and Effluent) are covered by a plastic liner, which was installed to inhibit algae growth. These three lagoons are periodically cleaned (two to three times per year depending on the build-up of algae) after draining to remove all algal deposits and other debris that accumulates on the liners. The Stormwater Lagoon has a plastic liner as well, but also has an overlying layer of sand, gravel and clay which prevents cleaning of this Lagoon and permits growth of aquatic vegetation.

Figure 2.8 BRR Discharge to Lake Huron (SENES 2006a)



2.3 Natural and Physical Environment

2.3.1 Geology & Hydrogeology

The geology and hydrogeology of the BRR site has been investigated as part of previous studies including:

- Golder (2007) *Evaluation of Groundwater Monitoring Program – Cameco Blind River Uranium Refinery;*
- Golder (2008a) *Blind River Geological Conceptual Model; and,*
- Golder (2008b) *Monitoring Well Installation at Cameco Blind River Uranium Refinery.*

Golder (2008a) describes the geology of the site based on previous site investigations as well as data from historical boreholes and boreholes drilled as part of the 2008 investigation itself. As outlined in Golder (2008a), borehole records show the site to be underlain by a sequence of predominantly sand and silt overburden deposits up to 33 m in thickness (average thickness 17 m where boreholes progressed to bedrock or assumed bedrock refusal), above crystalline bedrock. The bedrock, where proven, is described as greyish green medium to coarse grained diabase (dolerite). The overburden deposits comprise of six primary lithological units. Shallow subsurface soils show some variability, predominantly described as brown medium to fine sand, but also in places described as silty sand and in others encompassing sandy gravel fill. This surficial unit is typically beneath the lower sand horizon in some areas (see Golder 2008a for specific locations). However, the base of the overburden deposit sequence and typically comprises silty clay or silt over glacial till (described as compact sandy silt, trace gravel). The distribution of the lower parts of the sequence across the site is not uniform. Any one of all three of the lower silt horizons are noted to be absent at some locations. In particular, the glacial till unit may occur immediately beneath the lower sand horizon or may be absent. Contacts between the lithological units in the overburden deposits, with the possible exception of the upper glacial till, are considered likely to be transitional rather than representative of a distinct surface of geological change. For more detailed discussion on the geology of the site, and the 3D stratigraphic model, the reader is referred to the original Golder (2008a) study.

Site hydrogeology is discussed in Golder (2007) and Golder (2008b). Golder (2007) included the development of groundwater elevation contours based on measured groundwater elevations in BRR wells. Using measured data from 2002 to 2007 the water table was estimated to be located within the sand unit between approximately 1.5 and 4 mbgs, and groundwater flow direction was interpreted to be southwest toward the Mississagi River. The horizontal hydraulic gradient for the shallow groundwater flow system within the sand unit was estimated to range from 0.0009 to 0.0029. A generally downward hydraulic gradient was noted in the areas of BH9, BH10, and BH13. Later, in Golder (2008b), the hydraulic conductivity for the sand unit was calculated to be 0.0022 cm/s (based on a geometric mean of data). Golder (2008b) estimated the horizontal hydraulic gradient for the shallow groundwater flow system to be 0.003 m/m, and the average groundwater velocity to be 1.5 m/yr for the silty fine sand unit and 6.9 m/yr for the sand unit. It is noted that higher groundwater velocities are possible for the deeper groundwater flow system, given that hydraulic conductivity is higher in the deeper sand unit. Golder (2008b) also estimated groundwater elevation contours.

2.3.2 Terrestrial Environment

Adjacent Lands (within ~2 km radius)

As shown in Figure 2.3, the terrestrial environment surrounding the BRR is predominantly forested. Figure 2.16(a & b) shows aerial photographs of the site and surrounding area which illustrate the extent of the naturalized forest area. A large area to the east of the BRR is forested lowland, referred to as the 'bog' (Figure 2.9, green outlined area). There is an 18-hole golf course, operated by the Town of Blind River, located just north/northwest of the secured area.

As discussed in SENES (2007), the BRR site lies near the northern edge of the Great Lakes St. Lawrence Forest. In the adjacent lands (i.e. within ~2 km), vegetation communities generally fall into three community classes: Fen, Forest, and Cultural. In addition, manicured grass field surrounds the site. Forests include dry oak-pine mixed forest, dry-fresh white cedar mixed forest, and coniferous plantations. The reader is referred to the original SENES (2007) study for detailed descriptions and vegetation mapping of the terrestrial environment. As a consequence of having a diversity of plant species and vegetation communities, a high diversity of fauna is expected, including several amphibians, reptiles, birds, and mammals.

It is of note that the southern portion of the property, below the canal, is predominantly mixed forest of second growth, interrupted nearly throughout by rock outcroppings. Also, the northeast corner of the BRR property has been influenced by gravel excavation, relatively recent cutting, and activity associated with the adjacent Blind River mill yard.

Surrounding Lands (within ~25 km radius)

SENES (2007) provides detailed descriptions of the surrounding terrestrial environment, within a 25 km radius of the BRR site. Brief summaries are included here, though the reader is referred to the original SENES (2007) study for in-depth descriptions.

Overall, the BRR is in the Central Region of Ontario and lies within the Great Lakes-St. Lawrence Forest Region, a forest zone that extends across Ontario. The Central Region is south of the Boreal Forest and north of the Carolinian Forest of Southern Ontario. It is noted for its diverse mix of conifer and hardwood forest ecosystems. Hardwood mixed wood stands are widespread across the landscape, with trembling aspen, largetooth aspen, white birch, white spruce, eastern white cedar, balsam fir, red maple, eastern white pine and red pine.

The lands east and west of the BRR are of importance. Ecosystems identified through a search of the MNR Natural Heritage Information Centre (NHIC) as part of SENES (2007) are as follows:

- Mississagi Bay Shoreline Marsh, a Candidate Life Science for Area of Natural and Scientific Interest (ANSI);
- Mississagi Delta Provincial Park (PP) and Nature Reserve (NR), a Candidate Life Science for Area of Natural and Scientific Interest (ANSI); and,

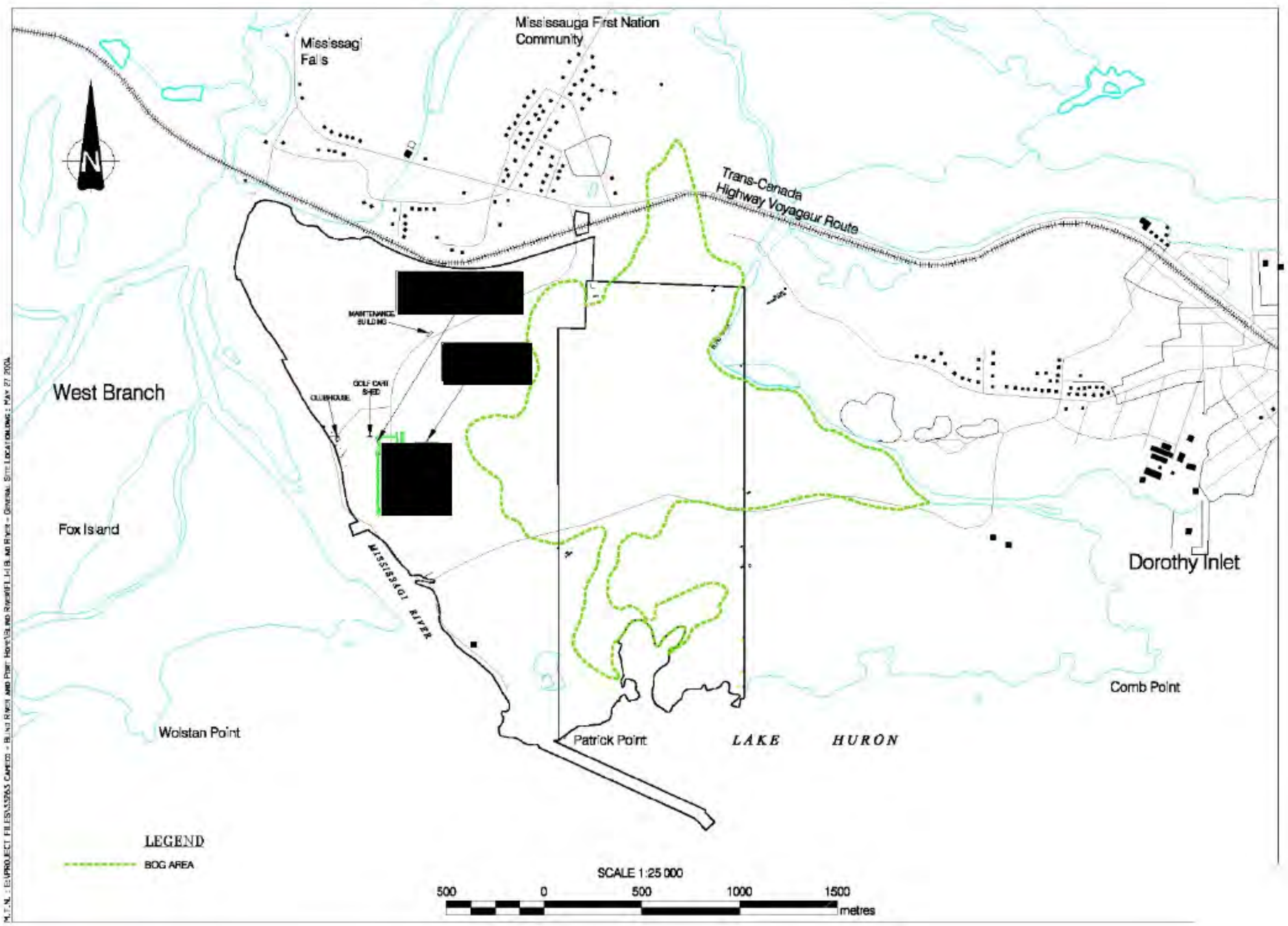
- Marsh Bay Wetland – Island 9, a Provincially Significant Wetland (PSW).

The Mississagi Bay Shoreline Marsh is an extensive 75 ha area of shallow and deep shoreline marshes along the coast of the North Channel. There are meadow marshes on wet coble and sand beaches along the shore, as well as extensive shallow and deep marshes.

The Mississagi Delta Provincial Nature Reserve protects 2,395 ha of sand delta at the mouth of the Mississagi River as well as a chain of offshore bedrock (gneissic) islands known as the French Islands. It is located west of the BRR, within a few kilometres. The delta is made of a number of islands by several active river channels. Old remnant flooded channels with wetland vegetation characterize the delta islands as well as the mainland. The area itself is located within the Great Lakes Heritage Coast Signature Site, one of nine such areas featured in the Ontario's Living Legacy Land Use Strategy. The Nature Reserve is an important staging and breeding area for waterfowl. Use of the park is restricted to trails, signs and low-intensity recreational activities.

Marsh Bay Island 9 is a 254 ha Provincially Significant Wetland (PSW), more specifically a coastal wetland complex. It is located a few kilometres east of the BRR. It is made of six individual wetlands, composed of four wetland types (<1% bog, 23% fen, 32% swamp and 45% marsh).

Figure 2.9 BRR Bog Area (SENES 2006a)



2.3.3 Aquatic Environment

As discussed in SENES (2007), waters in the vicinity of the Cameco facility include:

- the southern section of Mississagi River and Delta;
- the southern section of Blind River, western branch; and,
- the shallow offshore area of the North Channel known as the Blind River Bank.

The Mississagi River drains into the North Channel on the western boundary of the land on which Cameco currently operates the BRR. The river is approximately 150 m from the Site Study Area. Mean monthly flow at the Mississagi mouth is approximately 100 m^3/sec, but varies from a monthly average of 285 m^3/sec in May to less than 70 m^3/sec during the summer. River mouth average velocity is 6 cm/sec, varying from 14 cm/sec in the spring to less than 4 cm/sec in the summer (MacLaren PlanSearch 1981). The Mississagi River Delta is an exceptional delta environment divided into a number of islands by several active channels. Off the Mississagi River at Patrick Point on the North Channel is a shallow sandy bottom referred to as Patrick Bank.

The Blind River western branch marks the eastern boundary of the general area on which the BRR is located. This branch does not physically make contact with any portion of the facility boundary. The river has a low flow rate throughout the year and is quite turbid. Occasionally, wind action is strong enough to reverse the direction of water flow upstream.

The North Channel is one of three discrete water masses of Lake Huron, along with Georgian Bay and Lake Huron proper. The North Channel is a shallow enclosed passage with prominent bays and headlands imposed by the northern shoreline of Manitoulin Island. Blind River Bank is a large and shallow area of the North Channel extending from Mississagi Bay located west of the Mississagi Delta to the offshore Mississagi Island, and well east of the North Passage (South of the inland Lauzon Lake). Cameco's effluent outfall and diffuser is located on the Blind River Bank, east and adjacent to the near surface Patrick Bank, 650 m southeast from Patrick Point at the mouth of the Mississagi River.

2.3.4 Meteorological Statistics and Climate Setting

Meteorological mechanisms govern the dispersion, transformation and eventual removal of pollutants from the atmosphere. This section summarizes the climatic parameters in the study area and provides an overview of the meteorological elements such as wind speed and wind direction, temperature and precipitation.

The local meteorology near the Cameco Blind River facility is characterized by the surface meteorological data set collected from the Killarney automated meteorological station and Gore Bay station presented in Figure 2.10.

Figure 2.10 Meteorological Station Locations

Temperature

Temperature data have been summarized for the 2011 to 2015 period, from data provided by the Killarney automated meteorological station (Table 2.1) and Gore Bay climate station (Table 2.2). These data are compared to long-term data from the 30-year period, the Canadian climate normals (1971 to 2000) for the Gore Bay station, provided by Environment Canada (Table 2.3). As it can be seen from these tables, differences in average daily temperatures, daily maximum and minimum temperatures and extreme temperatures throughout the seasons are small between the two stations and periods.

The daily temperature at Killarney ranges from a high of 19.2°C in July to a low of -10.5°C in February, with the average annual temperature of 5.5°C. The daily maximum temperature ranges from a high of 22.5°C in July to -6.2°C in February, with extreme maximum temperature of 31.5°C in July. The daily minimum temperature at Killarney is lowest in January (-14.8°C) and highest in July, 15.8°C, with extremes of -29.4°C in January. Table 2.2 shows the highest daily temperature of 19.8°C at Gore Bay in July and the lowest one in February (-10.3°C), with extreme maximum temperature of 33.3°C in July and extreme minimum temperature of -34.3°C in February. The average daily temperature at Gore Bay in the thirty-year period (1971 to 2000) ranges between 19.1°C in July and -10.0°C in January, with extreme maximum temperature of 36.2°C in July and extreme minimum temperature of -36.9°C in January. The average annual temperature observed at Killarney and Gore Bay from 2011 to 2015 (5.5°C and 5.9°C) is very similar to the Gore Bay climate normal (1971 to 2000) of 5.2°C. Average daily temperatures are below 0°C from December through March at both stations in the past 5-year period (2011 to 2015) as well as in 30-year climate normals for the Gore Bay station.

Table 2.1 Temperature Normals, Killarney, Ontario, 2011 to 2015

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Daily Average Temperature (°C)	-9.8	-10.5	-4.8	2.7	10.9	16.3	19.2	18.5	15.0	9.1	2.4	-3.4	5.5
Daily Maximum Temperature (°C)	-5.3	-6.2	-0.6	6.1	14.7	19.5	22.5	21.4	18.3	11.9	5.3	0.04	9.0
Daily Minimum Temperature (°C)	-14.2	-14.8	-9.1	-0.7	7.2	12.9	15.8	15.5	11.7	6.2	-0.6	-6.7	2.0
Extreme Maximum Temperature (°C)	7.4	5.7	7.3	20.6	24.4	27.4	**31.5**	27.4	26.8	22.8	13.1	11.5	31.5
Extreme Minimum Temperature (°C)	**-29.4**	-29.1	-23.9	-10.2	0.6	6.6	10.3	9.8	2.8	-3.5	-16.6	-25.1	-29.4

Note: Bolded values represent the extreme temperature conditions
Source: Environment Canada (http://climate.weatheroffice.ec.gc.ca/climateData/)

Table 2.2 Temperature Normals, Gore Bay, Ontario, 2011 to 2015

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Daily Average Temperature (°C)	-9.7	-10.3	-5.6	3.1	11.4	16.3	19.8	19.0	14.9	8.9	2.3	-3.1	5.9
Daily Maximum Temperature (°C)	-4.7	-5.5	-0.6	7.4	16.7	21.5	24.8	23.5	19.6	12.6	5.5	0.2	10.4
Daily Minimum Temperature (°C)	-14.7	-15.1	-10.7	-1.5	6.0	11.1	14.6	14.3	10.1	5.1	-1.0	-6.3	1.4
Extreme Maximum Temperature (°C)	9.1	5.4	8.2	19.0	25.3	28.7	**33.3**	30.3	28.5	24.3	18.3	11.5	33.3
Extreme Minimum Temperature (°C)	**-34.3**	-33.8	-28.7	-10.6	-1.5	3.5	7.5	8.1	-0.1	-2.7	-14.2	-26.8	-34.3

Note: Bolded values represent the extreme temperature conditions
Source: Environment Canada (http://climate.weatheroffice.ec.gc.ca/climateData /)

Table 2.3 Temperature Climate Normals, Gore Bay, Ontario, 1971 to 2000

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Daily Average Temperature (°C)	-10.0	-9.3	-3.9	3.9	10.8	15.4	19.1	18.5	13.6	7.7	1.6	-5.3	5.2
Daily Maximum Temperature (°C)	-5.1	-4.2	0.9	8.8	16.3	20.7	24.2	23.2	17.7	11.3	4.7	-1.4	9.8
Daily Minimum Temperature (°C)	-14.8	-14.3	-8.7	-1.1	5.3	10.0	13.9	13.7	9.4	4.0	-1.5	-9.2	0.6
Extreme Maximum Temperature (°C)	8.3	8.3	16.7	27.5	29.5	31.7	**36.2**	34.4	33.3	23.9	18.3	14.3	36.2
Extreme Minimum Temperature (°C)	**-36.9**	-36.5	-30.6	-20.6	-5.6	-7.3	5.6	2.3	-2.0	-5.0	-22.8	-30.5	-36.9

Note: Bolded values represent the extreme temperature conditions
Source: Climatic data files from Environment Canada (http://climate.weatheroffice.ec.gc.ca/climate_normals/)

Figure 2.11 and Figure 2.12 illustrate the distribution of daily maximum temperatures and daily minimum temperatures at Killarney and Gore Bay in the period 2011 to 2015, and climate normals for Gore Bay (1971 to 2000). The very similar seasonal pattern in the temperature on both figures indicate that the most recent 5-year temperature data is well representative of the climatic temperatures in the region.

Figure 2.11 Daily Maximum Temperature

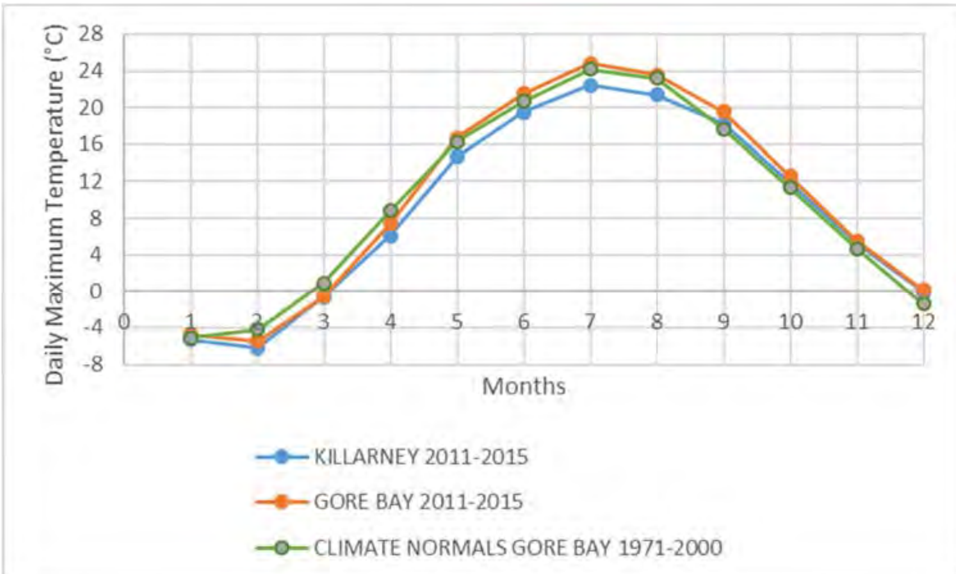
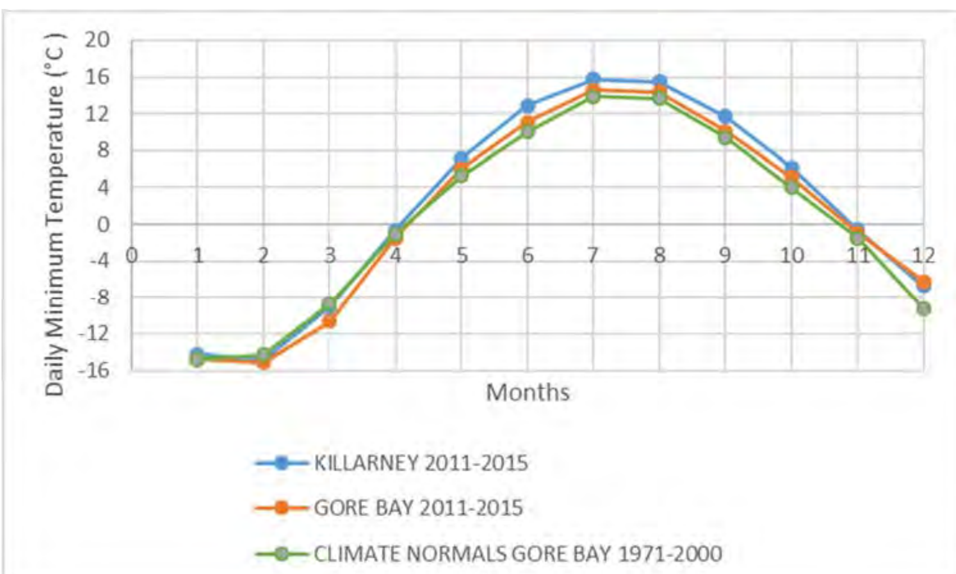


Figure 2.12 Daily Minimum Temperature



Precipitation

Precipitation data for the period 2011 to 2015 were available only from the Gore Bay climate station as total precipitation data (i.e. including both rain and snowfall). Table 2.4 presents a summary of precipitation data for the Gore Bay station for the 2011 to 2015 period. The average annual precipitation measured in this 5-year period was 793 mm. The highest mean monthly precipitation was in October (107 mm) and the greatest precipitation in a 24-hour period occurred also in October (66.2 mm). Number of days with measurable precipitations (i.e. precipitation >=0.2 mm) ranges from 21.2 in January to 6.6 in July. Figure 2.13 shows the annual total precipitation distribution at Gore Bay in the period 2011 to 2015.

Table 2.5 summarizes the thirty-year precipitation normals for the Gore Bay station for the 1971 to 2000 period provided by Environment Canada. The average annual precipitation measured within 30-year period was 808 mm, with approximately 77% of the total annual precipitation fell as rain. The highest mean monthly rainfall was in October (88.2 mm), while the greatest rainfall in the 24 hours occurred in August (83.1 mm). The greatest snowfall in 24 hours occurred in November (50.0 cm). Snowfall has occurred in every month except from June to September. The total number of days with measurable precipitations was similar to the 2011 to 2015 period (159.3 comparing to 155.2). Comparison of precipitation data from the most recent 5-year period (2011 to 2015) with the climate normals 1971 to 2000 shows similar precipitation pattern and seasonal distribution.

Figure 2.13 Annual Precipitation (mm), Gore Bay, 2011 to 2015

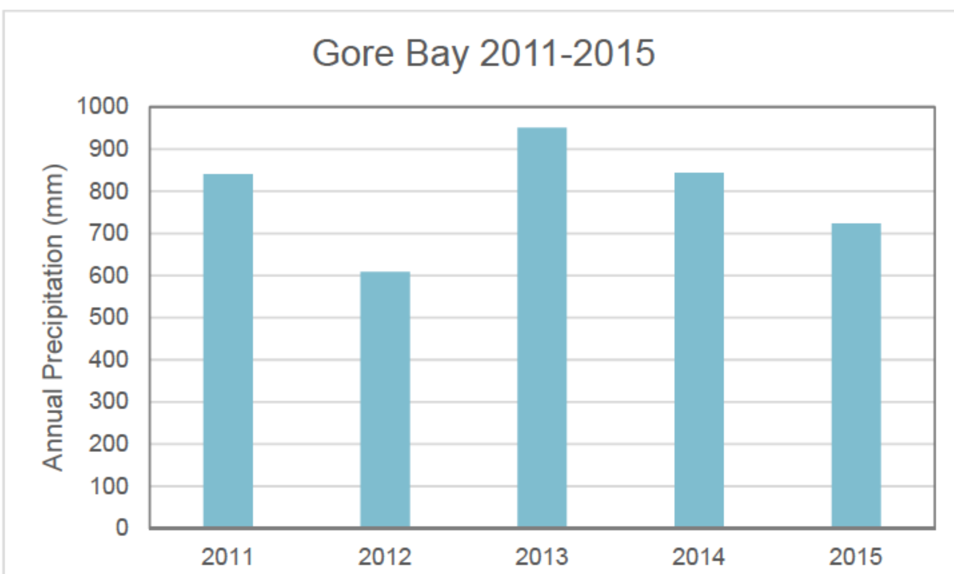


Table 2.4 Precipitation Normals, Gore Bay, Ontario, 2011 to 2015

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Average Monthly Precipitation (mm)	52	22	37	89	60	68	61	75	84	107	77	59	793
Extreme Daily Precipitation (mm)	26	21	21	39	33	27	39	40	53	**66**	24	52	66
Number of days with measurable precipitation*	21.2	15.8	13.8	12.2	8.6	10.0	6.6	9.6	9.0	15.8	14.8	17.8	155.2

Note: Bolded values represent the extreme temperature conditions; * Days with precipitation >=0.2 mm

Source: Environment Canada (http://climate.weatheroffice.ec.gc.ca/climateData /

Table 2.5 Precipitation Climate Normals, Gore Bay, Ontario, 1971 to 2000

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Average Monthly Rainfall (mm)	11.7	4.8	37.7	50.6	66.6	66.1	52.0	75.0	86.3	86.3	62.4	25.5	625.0
Average Monthly Snowfall (cm)	67.1	47.3	34.5	14.1	0.7	0.0	0.0	0.0	0.0	2.0	29.0	72.6	267.3
Average Monthly Precipitation (mm)	53.7	35.7	64.9	63.5	67.2	66.1	52.0	75.0	86.3	88.2	85.5	70.8	808.9
Average Snow Depth (cm)	32.0	34.0	22.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	14.0	9.0
Extreme Daily Rainfall (mm)	26.8	46.2	35.8	41.4	39.4	51.1	49.0	**83.1**	61.5	49.0	44.2	41.7	83.1
Extreme Daily Snowfall (cm)	36.0	23.1	37.3	25.4	8.1	0.0	0.0	0.0	0.0	9.7	**50.0**	39.1	50.0
Extreme Daily Precipitation (mm)	45.8	46.2	35.8	41.4	39.4	51.1	49.0	**83.1**	61.5	49.0	51.6	41.7	83.1
Extreme Snow Depth (cm)	**109.0**	**109.0**	107.0	36.0	3.0	0.0	0.0	0.0	0.0	6.0	37.0	90.0	109.0
Number of days with measurable precipitation*	8.4	12.6	12.4	12.2	11.3	11.5	9.4	11.2	12.8	13.9	15.2	18.5	159.3

Note: Bolded values represent the extreme temperature conditions; * Days with precipitation >=0.2 mm

Source: Climatic data files from Environment Canada (http://climate.weatheroffice.ec.gc.ca/climate_normals/

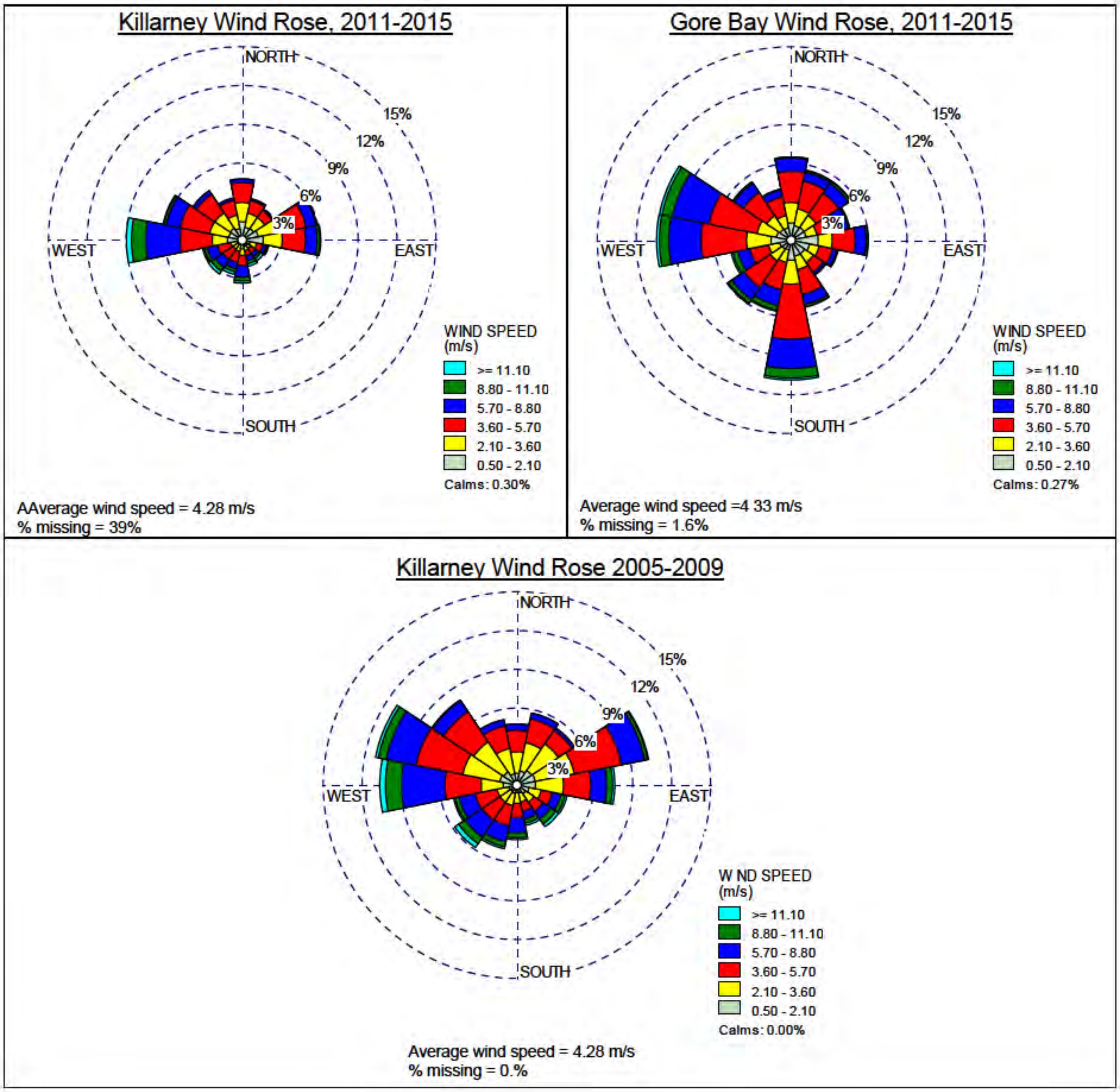
Wind

Wind direction is reported as the direction from which the wind blows and is based on surface (i.e. 10 m) observations. In general terms, if the wind doesn't blow toward a receptor, human or environmental, there will be no air quality impact.

However, the wind does blow in all directions with certain directions occurring more frequently than others. These are known as the prevailing wind directions. Ambient contaminant concentrations typically decrease with increasing wind speed as a result of dilution. When wind speed is high there is good dispersion; with a low wind speed local ambient contaminant concentrations near the ground can be much higher due to poor dispersion. Higher wind speeds also induce greater mechanical turbulence as a result of flows around obstacles on the surface (topography, buildings, etc.).

Figure 2.14 presents the frequency distribution of hourly surface wind speed and direction at the Killarney station and Gore Bay station in the period from 2011 to 2015 in the form of a wind rose. The hourly surface wind speed and direction observed at the Killarney stations in this period were missing approximately 39% of data. As is illustrated in Figure 2.14, the prevailing annual wind direction was from the W, occurring 9 % of the time. The average wind speed was 4.28 m/s. Calm wind conditions were observed to occur at 0.3% of the time. The hourly surface wind speed and direction observed at the Gore Bay station in the period from 2011 to 2015 was more completed, with less than 2% of missing hourly data. The prevailing annual wind directions at Gore Bay were from the S, W and WNW, occurring 10.8 %, 10.4% and 10.4% of the time, respectively. The average wind speed was 4.33 m/s. Calm wind conditions were observed to occur at 0.27% of the time. The frequency distribution of the wind speed and direction from the MOE site specific pre-processed 5-year meteorological surface data that was used in air dispersion modelling (from 2005 to 2009) is also presented in Figure 2.14. The source of the meteorological data was the wind data from Killarney with missing data filled with Gore Bay then Sudbury data. The prevailing annual wind directions were from the WNW, W and ENE, occurring 11.1%, 10.6 % and 10.4 % of the time, respectively. The average wind speed was 4.28 m/s.

Figure 2.14 Wind Rose Plots



2.4 Key Prior Risk Assessments & Environmental Studies

- *Ecological Risk Assessment (SENES, 2004)*

An ecological risk assessment (EcoRA) of BRR was completed in 2004 (SENES 2004). The ERA followed a tiered approach, based on the guidelines of the Canadian Council of Ministers of the Environment (CCME). The report was prepared for and accepted by the CNSC. The report concluded that routine releases of both radioactive and non-radioactive chemicals from the refinery are not expected to significantly impact the aquatic or terrestrial environment, based on a conservative Tier 1 assessment.

- *Effluent Plume Delineation, Field Verification, and Sediment Sampling (SENES, 2006a)*

In 2006 the BRR was requested by the CNSC to measure the dispersal and accumulation of contaminants in sediments from an effluent diffuser in order to validate prior EcoRA estimates by SENES (2004).

To investigate sediment quality, an initial effluent plume delineation was performed using the Cornell Mixing Zone Expert System (CORMIX) model. This modeling exercise allowed characterization of effluent dilution at known concentrations in order to plan where to locate the sediment sampling stations. Following a field verification of the plume geometry and dilution characteristics, sediment sampling was performed based on the known effluent plume specifications. Sediment sampling involved establishing reference sampling locations (upgradient, not influenced by the plume) and exposure sampling locations (downgradient; influenced by the plume). Sediment samples were obtained and analyzed for several parameters including both radionuclides and chemical parameters. The measured concentrations of all parameters in the Reference and Exposures Areas were below guideline values (or below reference conditions, in the case of radionuclides). Prior to this field assessment, the ERA estimated sediment concentrations of three parameters of potential concern (Cu, Pb, Zn) using water concentrations and water-sediment distribution coefficients (Kds). The estimated concentration values were conservative by overestimating the actual (measured) concentrations by a factor ranging from 2.5 to 5.6.

- *Ecological Risk Assessment (as part of EA) (SENES, 2006b)*

In 2006, a Canada-wide standard for emissions of dioxins and furans from incinerators came into effect, and based on test work and sampling completed at that time, the incinerator operated at the BRR would not have been able to consistently meet the new dioxin and furans emissions limits without the addition of pollution abatement equipment. The BRR site had also accumulated an inventory of waste oils that were slightly contaminated with uranium, making them unsuitable for conventional waste oil recycling. As well, the BRR produces a uranium-bearing organic recyclable material called regeneration product, which is sent off-site to another processing facility for uranium recovery. As a result of these factors, Cameco proposed to install pollution control systems for incinerator exhaust to ensure compliance with the Ontario Ministry of the Environment's Guideline. An EcoRA was completed (SENES 2006b) as part of larger Environmental Assessment (EA) to determine the effects of baseline operation, and of the proposed incinerator modifications (and other proposed changes, such as production increases) on the environment. The SENES (2006b) EcoRA again followed a tiered approach based on CCME guidance.

The SENES (2006) EcoRA concluded that the routine releases of both radioactive and non-radioactive chemicals from the Blind River facility are not expected to significantly impact the aquatic or terrestrial environment based on a conservative Tier 1 assessment.

- *Ecological Risk Assessment of Wildlife Near Lagoons (SENES, 2012)*

As part of the liquid effluent treatment system at the BRR, there are four outdoor lagoons on-site which hold process effluent and stormwater before discharging to Lake Huron. There have been a number of waterfowl, amphibian and reptile sightings on and around these lagoons. Due to the presence of wildlife, Cameco had voluntarily initiated an EcoRA to determine:

(i) if there are any risks to the wildlife; and,
(ii) if there is a need for mitigation measures to reduce exposures and risks.

The SENES (2012) EcoRA considered exposure of aquatic biota (aquatic plants and phytoplankton), amphibians, reptiles and waterfowl (with diets of aquatic plants and/or phytoplankton) to contaminants in the lagoons. Water concentrations and estimated intakes and doses were compared to toxicity reference values (TRVs) that were considered to be protective of ecological species. Conservative assumptions were applied so as to not underestimate the exposures and potential risks.

The assessment determined that there are not expected to be any adverse effects to aquatic plants, amphibians, reptiles and waterfowl present in and around the four lagoons. Therefore, there was no need to implement any mitigation measures at these lagoons.

- *Derived Release Limits (SENES 2013)*

At present, SENES (2013) contains the most recent Derived Release Limits (DRLs) for the BRR. Prior to this version, DRLs were established or revised in 2004, 2001, 1986, and 1983.

As a regulatory requirement, DRLs are calculated to predict the radionuclide release rates that would result in a dose of 1 mSv/y to a reasonably maximum exposed member of the public. Although uranium is the principal radionuclide of interest at the BRR, other long-lived radionuclides present as contaminants in the feedstock for the facility and are released from the facility. The doses from these radionuclides are included in the dose from uranium when the DRL for uranium releases are calculated. The DRLs also consider doses from accumulation of radioactivity in soil attributable to operations from 1983-2009. SENES (2013) notes that there has been a large decrease in the uranium releases to air from the refinery operations over time. The DRL focusses on radiological doses to the human receptors, namely, off-site members of the public. The DRL identifies and describes the relevant human receptors in the surrounding area.

The estimated DRL for water releases is 16,000 g U/h. This is a lower DRL than the 2004 value primarily due to higher transfer factor from water to fish flesh than that used in 2004. The DRL for gamma radiation emissions from materials stored within the fenceline is an incremental value of 2.0 μSv/h at the Golf Course monitoring location.

The DRLs for the Blind River facility are much higher than the current release rates. Environmental concentrations attributable to the facility were found to be close to, or within the natural variation in, background levels at many of the receptor locations. The SENES (2013) DRL report concludes that current operations are having only small effects on the environment and result in minor levels of dose to the potential representative human receptors. Under current operations all human receptors have a dose of less than 10 μSv/y.

- *Assessment of Flooding Potential at the Blind River Facility (AMEC, 2009)*

An assessment of the flood potential of BRR was completed by AMEC in 2009. The report was prepared based on some of the elements consistent with the guidelines of the International Atomic Energy Agency (IAEA) and Canadian Nuclear Safety Commission (CNSC) which address the need for the assessment of potential flood hazards associated with coastal flooding by storm surges, waves and seiches. The report concluded that BRR is not at risk from flooding from either Lake Huron or the Mississagi River and has a very low risk associated with wave and riverine based flooding. [redacted]

- *Assessment of Flooding on the Mississagi River (Hatch, 2012)*

In 2012, a study was completed to develop an understanding of the potential for flooding at the BRR from an extreme flood event on the Mississagi River. The study found that the BRR is not at risk from flooding from a significant flood event on the Mississagi River or from an extreme event like the spring probable maximum flood. Combination of spring probable maximum flood with potential breaching of the upstream earth embankment dams could potentially inundate the BRR with water at the south and north end of the site. Installation of additional flood protection (e.g. berms) has been initiated following this study.

2.5 Available Environmental Data

The follow environmental data were included in this ERA.

2.5.1 Groundwater Quality Data

Groundwater quality data are primarily available from BRR's groundwater monitoring program (GWMP), from 2012 to 2014.

Additional information on the GWMP and the groundwater conceptual model for the site was provided via the following reference documents:

1. BRR (2014a) *Environmental Monitoring Program – Cameco Corporation – Fuel Services Division – Blind River Refinery Facility*;

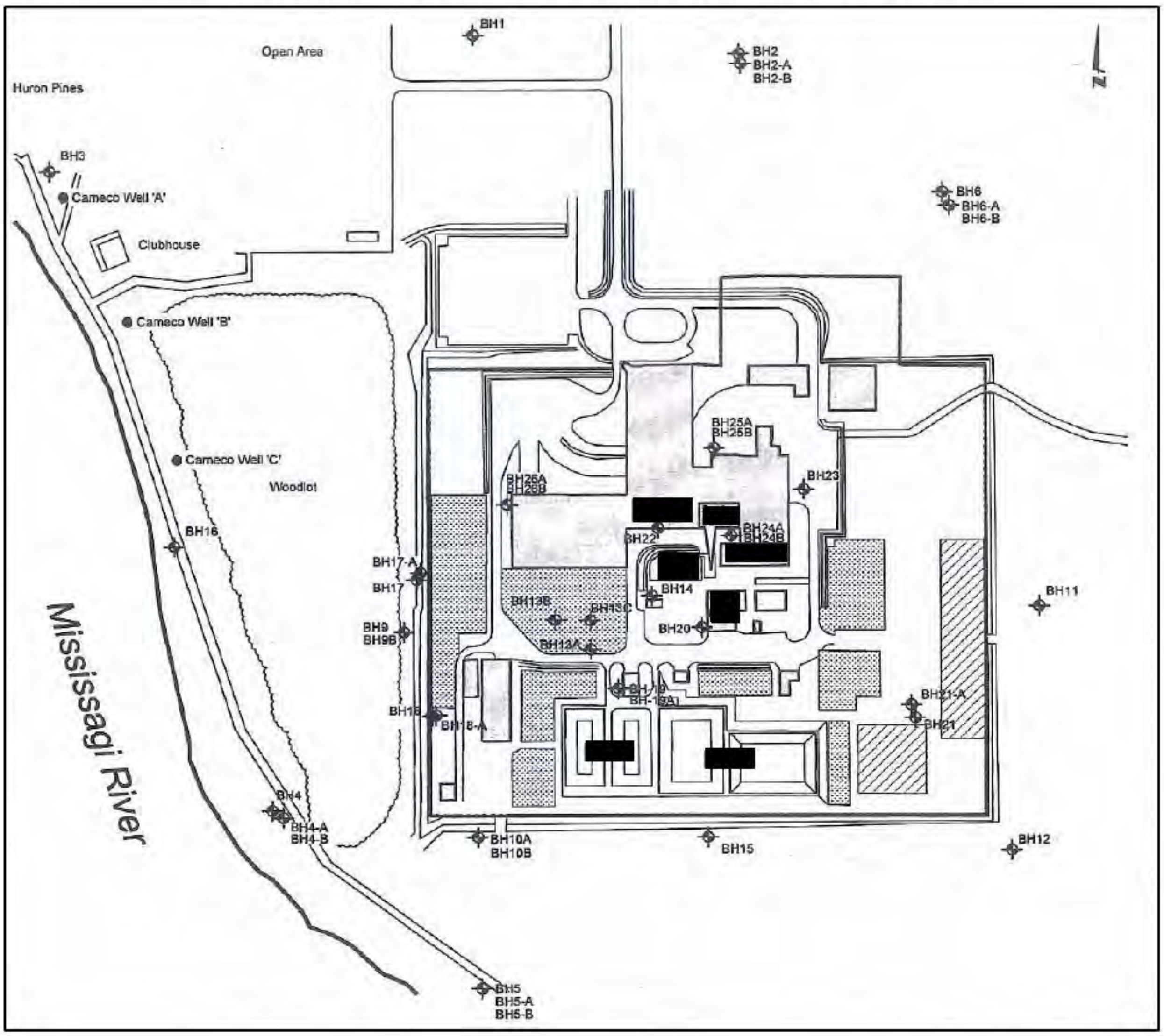
2. Golder (2007) *Evaluation of GWMP - Cameco Blind River Uranium Refinery - Blind River, Ontario*;

3. Golder (2008) *Blind River Geological Conceptual Model*; and,

4. Golder (2008) *Monitoring Well Installation at Cameco Blind River Uranium Refinery, Blind River, Ontario.*

The 2012-2014 groundwater quality data from the BRR GWMP are used for this study, as it represents the most recent data available. These data encompass several analytes, including select metals (U, As), general physical and parameters, major ions, ammonia, tributyl-phosphate (TBP), and Ra-226. The current GWMP at the BRR is shown in Figure 2.15.

Figure 2.15 Groundwater Monitoring Locations (BRR 2014)



2.5.2 Soil Quality Data

Soil quality data are available from the following sources:

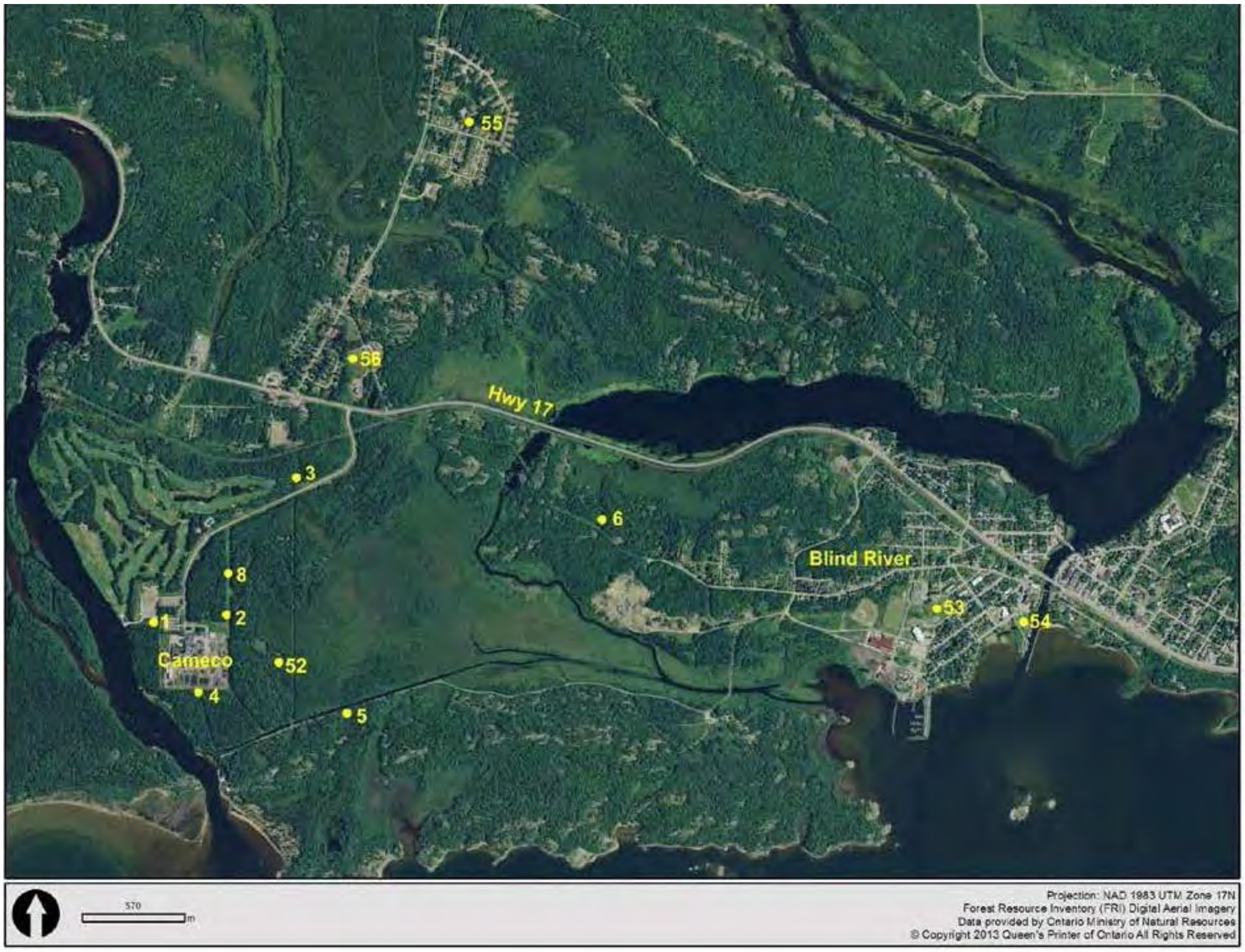
- BRR soil uranium monitoring data from 2011 to 2014;
- MOE soil uranium monitoring data from the 2012 *MEMORANDUM: Soil and Tree Foliage Survey in the Vicinity of Cameco's Blind River Refinery, Blind River, Ontario, 2012* (MOE 2012); and,
- Golder (2008) *Monitoring Well Installation at Cameco Blind River Uranium Refinery, Blind River, Ontario* – select locations, obtain during groundwater well installation.

Soil data from the BRR monitoring program and MOE (2012) are used for this study as they are the most recent data available, and because data are obtained from several off-site monitoring locations as shown in Figure 2.16 (including nearby stations adjacent to the BRR active site boundaries, and, distant stations in or near receptor locations such as camps, residential subdivisions, recreational areas, or occupational areas). Data from the BRR monitoring program and MOE (2012) focus on uranium.

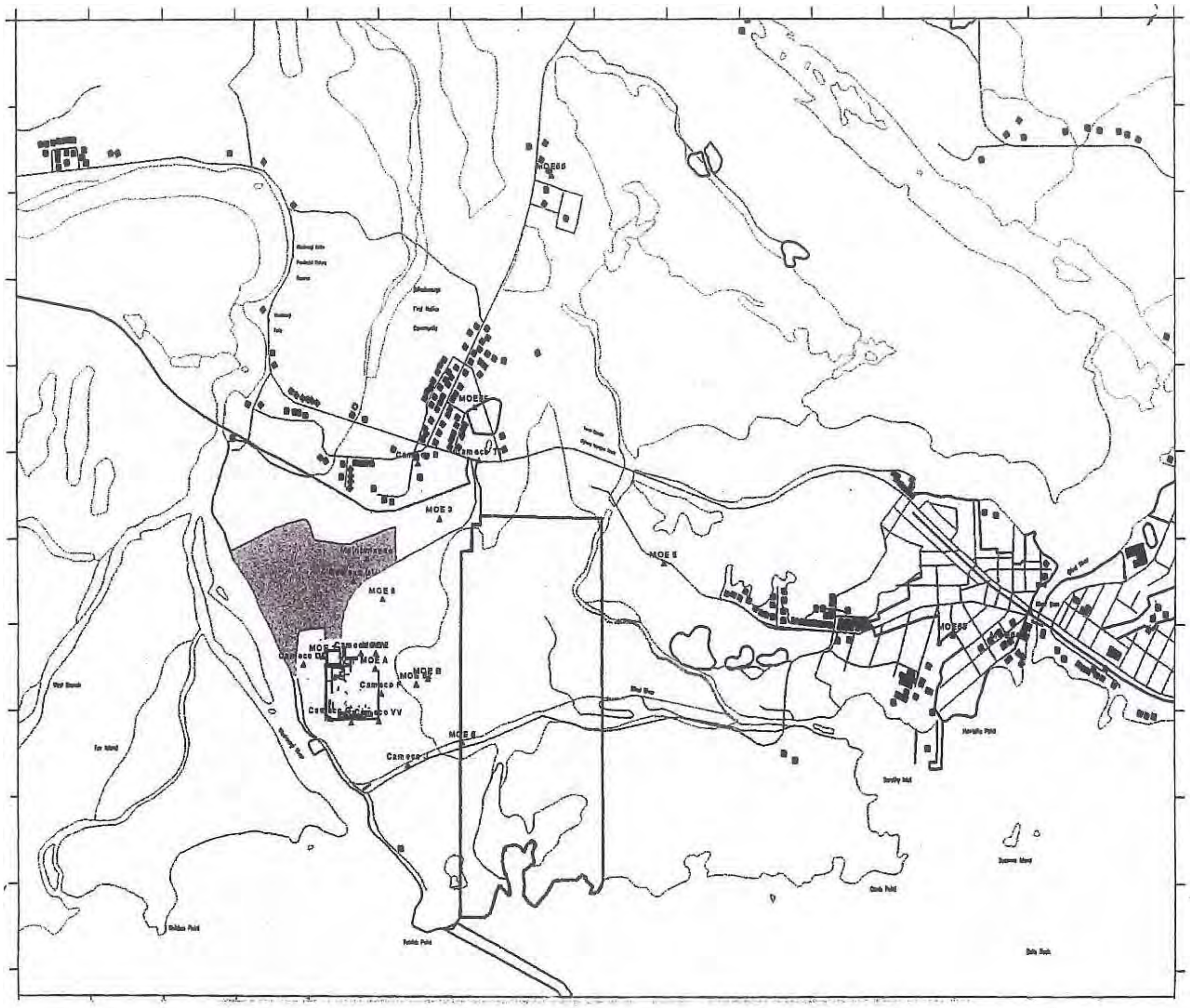
Figure 2.16 Soil Sampling Locations

a) MOE (2012) Soil Sampling Locations Near the BRR *(reproduced from MOE (2012))*

b) MOE (2012) Soil Sampling Locations At Distance from the BRR *(reproduced from MOE (2012))*



c) **BRR Soil Monitoring Locations** *(reproduced from (BRR 2014))*



2.5.3 Surface Water Quality Data

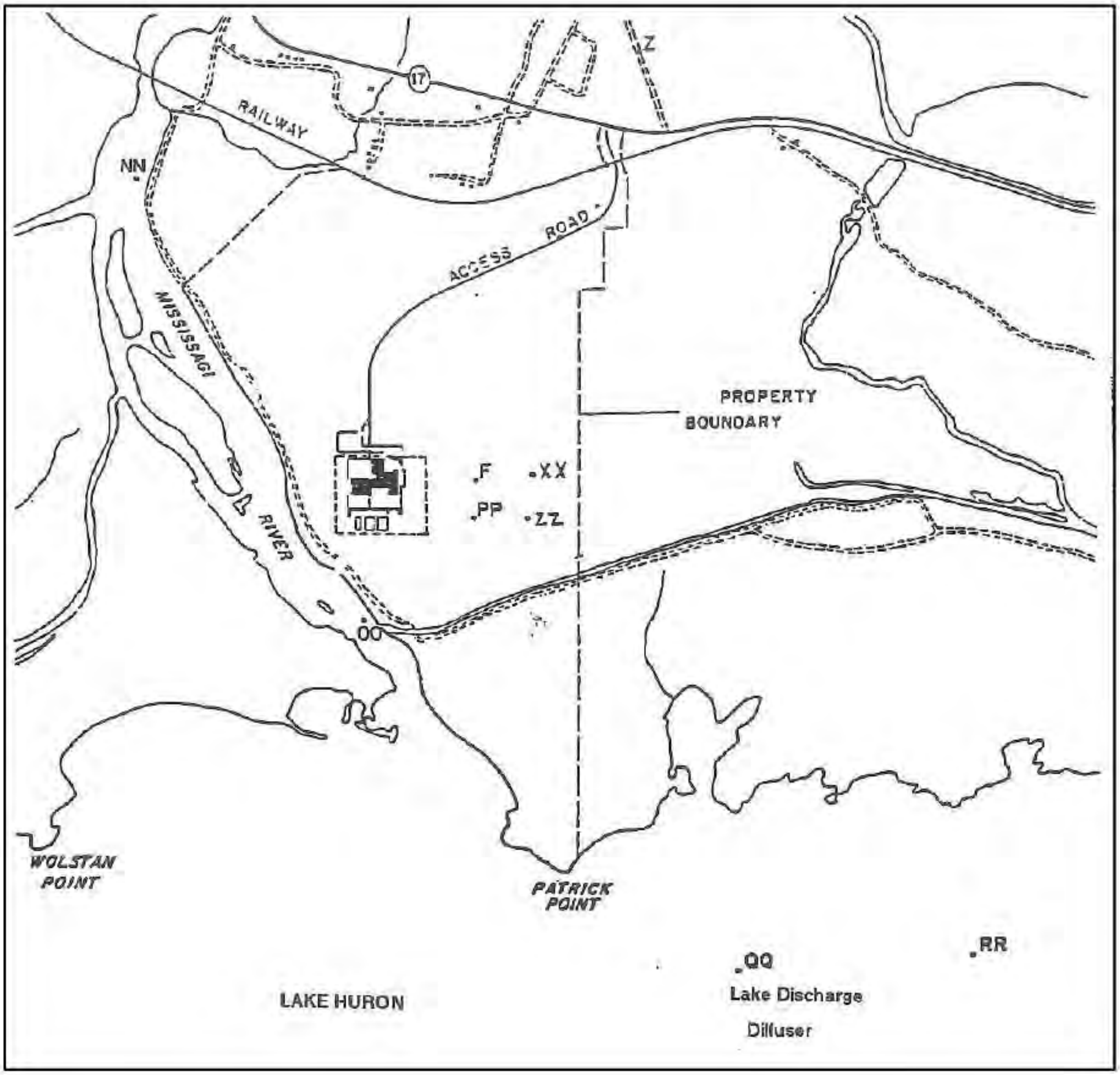
Surface water quality data are available from the BRR environmental monitoring program, for 2013 to 2014. Surface water quality data are obtained from three main locations (see Figure 2.17):

1. River – obtained from the nearby Mississagi River, including an upstream and a downstream sampling location;
2. Lake – obtained from Lake Huron; and,
3. Bog – obtained from each of the 4 bog monitoring locations on the BRR property.

The 2013-2014 surface water quality data from the BRR surface water monitoring program are used for this study. Surface water quality analytes include Ra-226, ammonia, uranium, general physical/chemical properties, TBP, and phosphorus.

Figure 2.17 Surface Water Sampling Locations

(Reproduced from BRR (2014a))



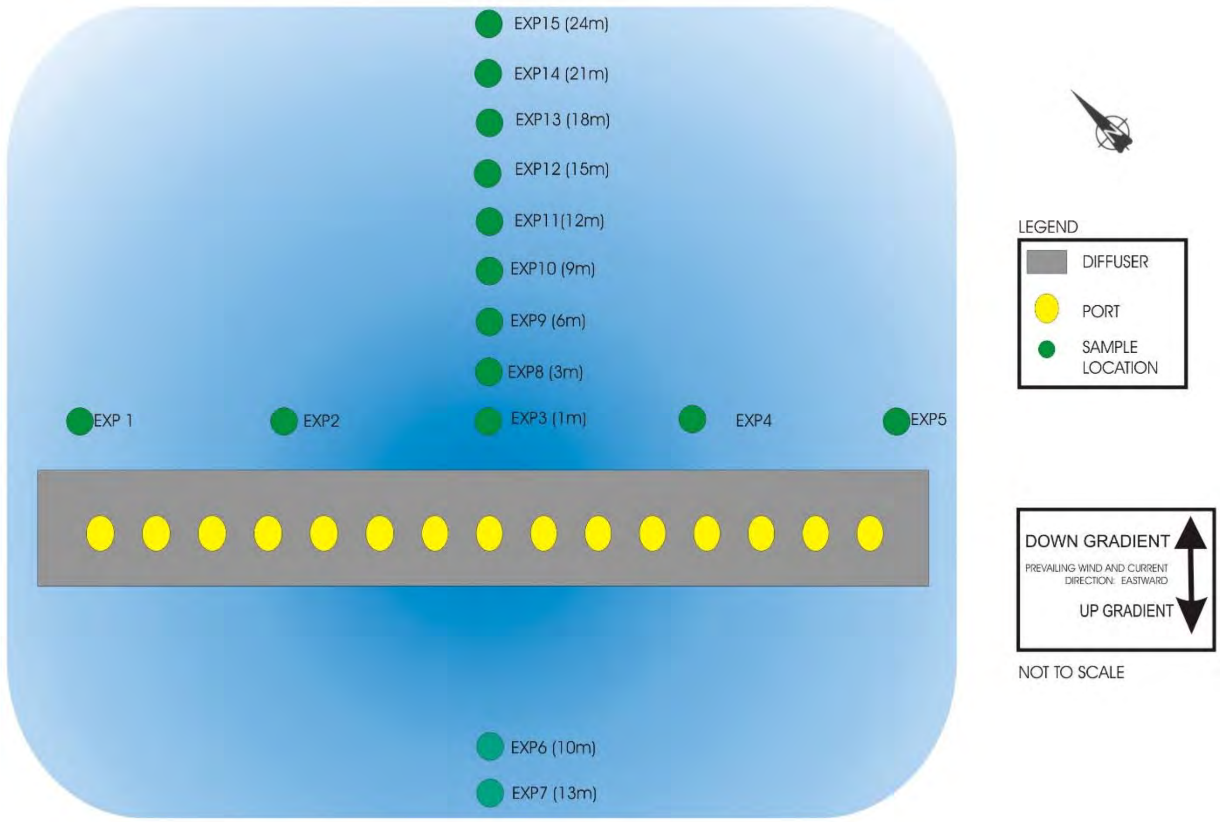
2.5.4 Sediment Quality Data

Sediment quality data are available from the Arcadis (2015a) *Plume Modelling, Delineation and Sediment Study*. These *sediment data were obtained from sediment sampling and analysis activities performed in May of 2015*. Samples were obtained from a total of 20 sediment sampling locations. Fifteen (15) of these locations are found in the vicinity of the diffuser, representing an area potentially influenced by effluent releases (referred to as 'Exposure Locations'). Five (5) of these locations are positioned approximately 4 km upgradient from the diffuser, representing background (reference) conditions which are not influenced by effluent releases (referred to as 'Reference Locations') (see Figure 2.18 and Figure 2.19). For more information, the reader is referred to the Arcadis (2015a) *Plume Modelling, Delineation and Sediment Study.* Historical sediment quality data are also available from the past SENES (2006) *Effluent Plume Delineation and Sediment Quality at Cameco, Blind River Refinery* study.

The 2015 sediment data from Arcadis (2015a) are used in this study. Sediment quality data include the following analytes: metals mercury, uranium, phosphorus, ammonia, nitrate and nitrite, select radionuclides, PAHs, PHCs, and PCBs.

Figure 2.18 Sediment Sampling Locations (Arcadis 2015a)

Figure 2.19 Sediment Sampling – 'Exposure' Locations (Arcadis 2015a)



2.5.5 Air Quality Data

Air quality data from the SENES (2015) Consolidated Emission Summary and Dispersion Modelling Report - Cameco Blind River Refinery study, encompassing emissions data from 2014, are used in this study. Emissions to air, extracted from this report, are summarized and screened for COPCs in Table 4.3. Air quality analytes include nitrogen oxides, carbon monoxide, uranium, suspended particulate matter, fluorides, and magnesium.

2.5.6 Discharge (Liquid Effluent) Quality Data

Liquid effluent data from the BRR monitoring program, covering 2014, are used in this study. The location of the BRR effluent discharge diffuser is shown in Figure 2.8. Several effluent samples are obtained each month, and analytes include: select metals, ammonia, general chemical and physical parameters, select biological analytes (e.g., E.coli), and tributylphosphate (TBP).

2.5.7 Gamma Measurement Data

Overall, gamma measurement data are available from 2 sources:

1. Quarterly gamma measurements at air monitoring (HiVol) locations, from the BRR monitoring program; and,
2. Monthly gamma measures at the fenceline, from BRR annual compliance reports (BRR 2014b, 2014c, 2014d, 2014e).

Gamma measurements from 2014, from the BRR monitoring program, are used in this study. These gamma data are BRR gamma data are obtained on a quarterly basis (i.e. four sets of gamma data, one for each quarter). This includes measurements for each of the following 5 locations:

1. **South East Yard**: located inside the facility perimeter fence, at the south-east corner of the yard.
2. **East Yard**: located inside the facility perimeter fence, directly east of the main aisle.
3. **Golf Course**: located north-west of the facility at the southern end of the golf course, between the putting green and the river, inside a locked and fenced area.
4. **Hydro Yard**: located approximately 1 km north of the BRR, inside a secured OPG equipment yard.
5. **Town Sewage Treatment Plant**: located in the Town of Blind River, at the sewage treatment plant property, inside a locked fenced area.

However, fenceline gamma measurement data from BRR annual compliance reports are also used for comparison purposes.

2.5.8 Radionuclide Data

Overall, radionuclide measurement data are limited to Ra-226 in groundwater (Figure 2.15) and surface water (Figure 2.17), as obtained from the BRR environmental monitoring program, along with select radionuclides in sediment (Arcadis 2015a). Table 2.6 summarizes the availability of *measured* radionuclide data across the different environmental media. All available measured radionuclide data are included in the ERA.

Where measured data are not available, radionuclide levels can be inferred using a combination of specific activity considerations (Lowe 2004) along with secular equilibrium assumptions (discussed below in Section 2.5.8.1), or, by considering known radionuclide and U_{nat} ratios in effluent releases based on the SENES (2013) DRL (discussed below in Section 2.5.8.2).

Table 2.6 Available Radionuclide and U_{nat} Measurement Data

	Pb-210	Po-210	Ra-226	Th-230	U-238	U_{nat}
Soil	-	-	-	-	-	✓
Groundwater	-	-	✓	-	-	✓
Surface Water	-	-	✓	-	-	✓
Air	-	-	-	-	-	✓
Sediment	✓	✓	✓	✓	-	✓

Notes
Based on U-238 decay chain.
✓ indicates where measured data are available for a particular radionuclide.
' – ' indicates where measured data are not available for a particular radionuclide.

2.5.8.1 Secular Equilibrium

Measured uranium concentration data (U_{nat}; which are available for all environmental media) can be used to infer the level of U-238 through specific activity conversion (Lowe 2004). From this, the levels of other radionuclides in the U-238 decay chain can be estimated using secular equilibrium assumptions. Measured Ra-226 levels can also be used to infer the levels of other radionuclides in its decay chain through secular equilibrium assumptions. This is a *very* conservative method, used for Tier 1 EcoRA investigations (see Section 6.2.4).

2.5.8.2 Radionuclide Ratios

Though measured data are absent for certain radionuclides in certain environmental media, these levels can be estimated based on the known levels of radionuclides in facility emissions. In this method, the known levels of radionuclides in *facility releases* (airborne effluent, and liquid effluent) are examined and the ratios between them – as well as their ratios to natural uranium - are noted. Then, these same ratios are applied to corresponding *environmental media*, starting from the measured amount of natural uranium in each medium.

The DRL report (BRR 2013; [redacted]) is the primary source of information used in this method, as it presents estimates of the radionuclide content of facility releases relative to natural uranium. These estimates are based on actual measured data from air and liquid releases from the facility, and therefore, this represents a more realistic (and less conservative) approach. This method is used for HHRA investigations (Section 5) as well as Tier 2 EcoRA investigations (Section 6.2.4).

The ratios of radionuclides in facility effluents are related to corresponding environmental media as follows:

- To estimate levels of radionuclides in *air*: the air U_{nat} concentration was used to correlate U-238; then the ratio of U_{nat} in airborne *effluent* to each given radionuclide in airborne *effluent*, was used to estimate the levels of other radionuclides in *air*.

- To estimate levels of radionuclides in *surface water (SW)*: the SW U_{nat} concentration was used to correlate U-238; then the ratio of U_{nat} in liquid *effluent* to each given radionuclide in liquid *effluent*, was used to estimate the levels of other radionuclides in *SW*.

- To estimate levels of radionuclides in soil: the same ratio-method for air was used (i.e., using airborne *effluent* rad. ratios) since soil concentrations are driven by deposition, and therefore air concentrations.

Again, it is important to note that the method discussed above (i.e. applying effluent ratios) is *only* used in the absence of measured radionuclide data. Wherever radionuclide levels are measured directly in environmental media, those measured data are used preferentially.

It should be noted that when the measured Ra-226 value for surface water in the environment is compared to the calculated value using the estimated ratios, there is a discrepancy. This is most likely due to the inclusion of background concentrations in the measured value, which would not be included in the calculated value.

The resulting radionuclide activity concentrations used in the HHRA are outlined in Table 5.13; the resulting radionuclide activity concentrations used in the EcoRA are outlined in Table 6.8.

3 MODELLING

3.1 Air Dispersion Modelling

Air dispersion modelling was completed as part of the SENES (2015) *Consolidated Emission Summary and Dispersion Modelling Report - Cameco Blind River Refinery* study, encompassing emissions data from 2014.

Air dispersion modelling was conducted in order to estimate airborne concentrations of effluent constituents at receptor locations. The US EPA AERMOD atmospheric dispersion model was used. A 5-year meteorological dataset was used; the source of the meteorological data has the winds from Killarney with missing data filled with Gore Bay then Sudbury data. Cloud cover is mostly Gore Bay data while the precipitation is from the Sudbury Airport. A nested receptor grid, centered around the BRR site, was used. For more detailed discussions, the reader is referred to the original SENES (2015) study.

Predicted air concentrations of uranium are presented in Figure 3.1. Predicted uranium air deposition is presented in Figure 3.2.

Figure 3.1 Modelled Air Uranium Concentrations (μg/m³)

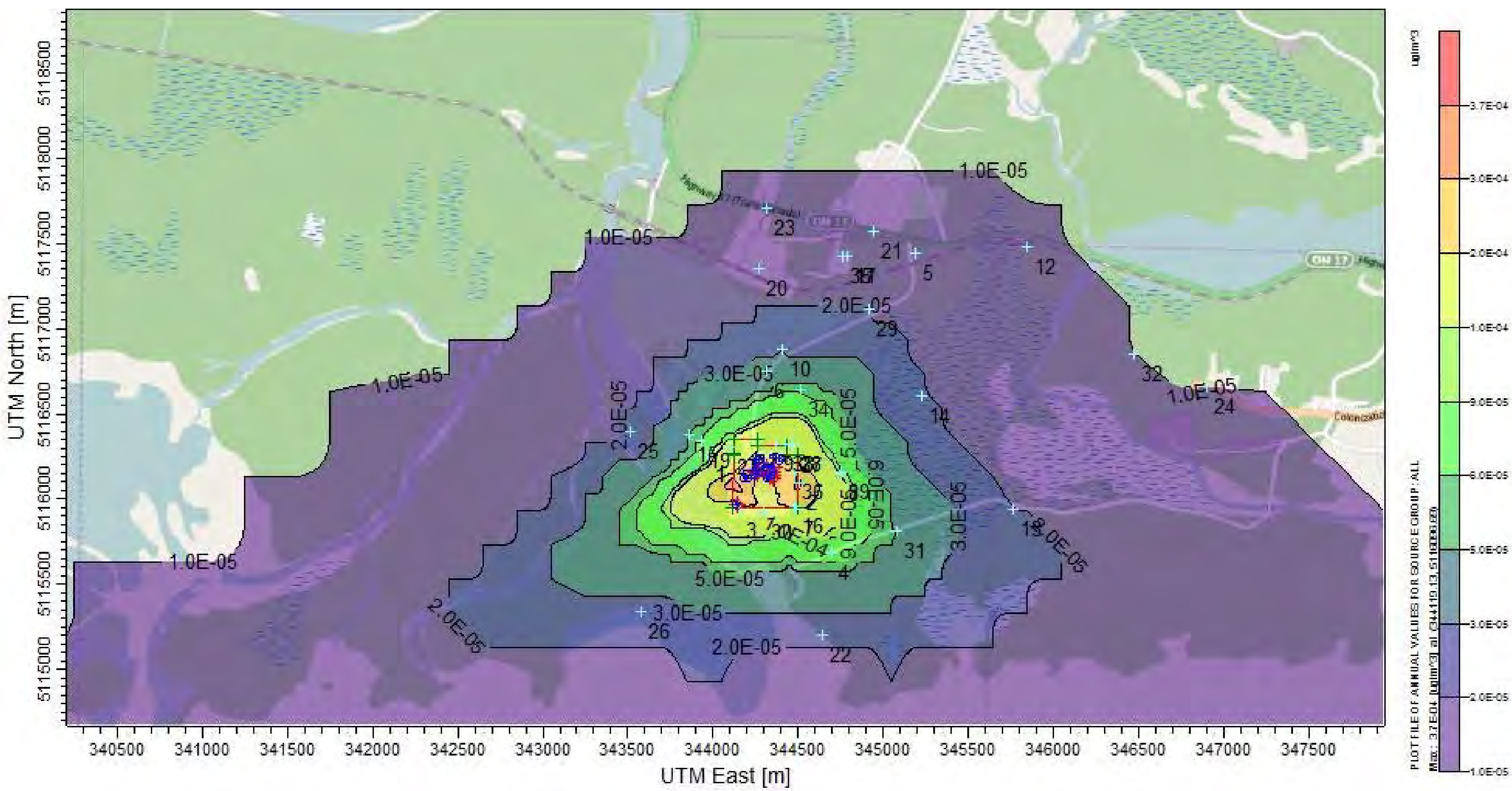
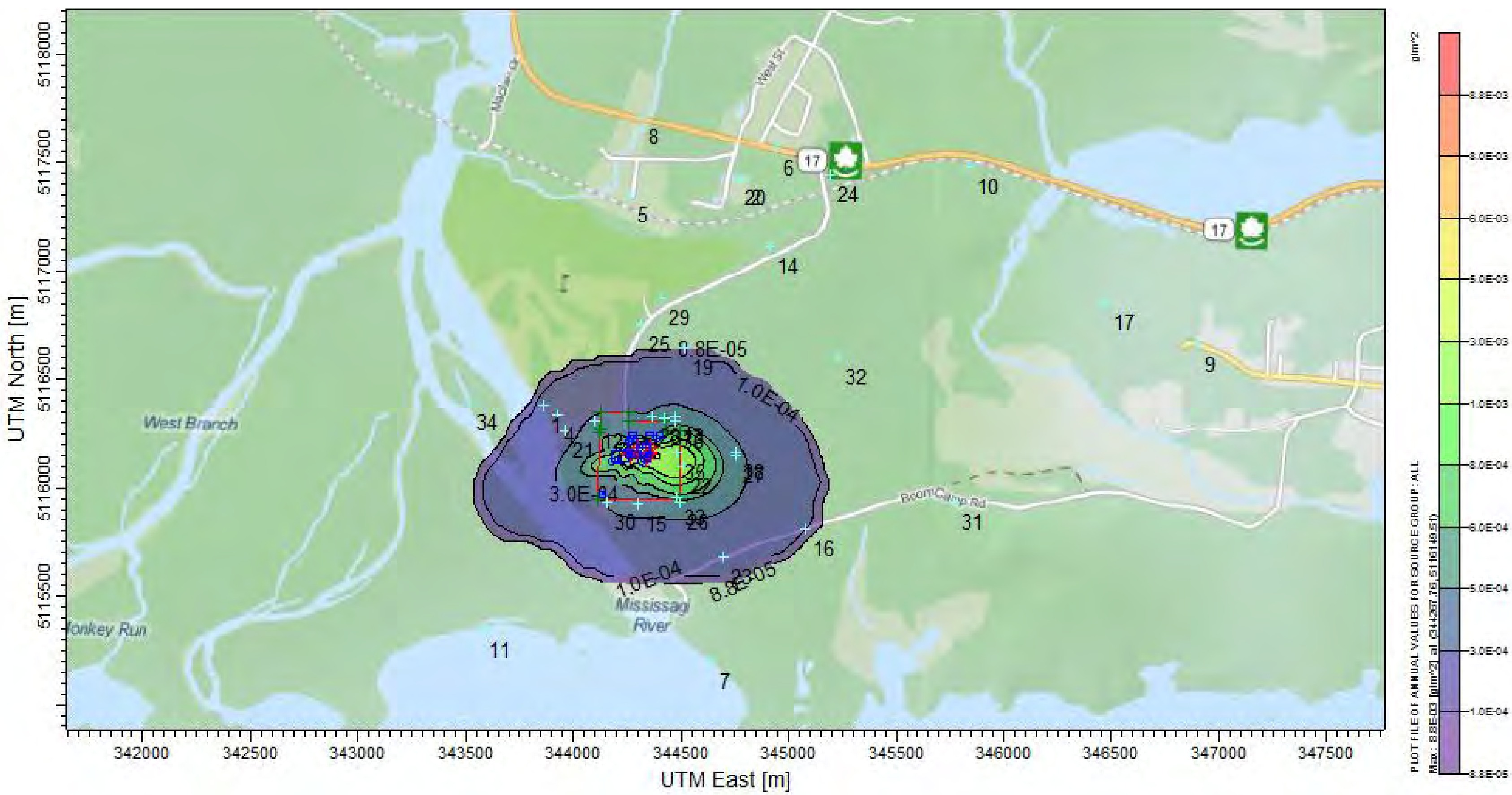


Figure 3.2 Modelled Air Uranium Deposition (g/m²)



3.2 Liquid Effluent Release Modelling

Liquid effluent release modelling was completed as part of the SENES (2015a) *Plume Modelling, Delineation & Sediment Study,* based on liquid effluent quality data from 2014. Overall, modelling predicts the effluent plume that results from release of liquid effluents from the submerged diffuser into the Lake Huron North Channel.

The Cornell Mixing Zone Expert System (CORMIX) (Doneker & Jirka, 2007) was used for analysis and prediction of the discharged effluent. Several input parameters are used to characterize the effluent, the outfall diffuser geometry, and the conditions of the ambient aquatic receiving environment. An effluent flow rate of [redacted] m^3/hr was used for modelling purposes, along with an effluent temperature of [redacted]°C. Modelling conservatively assumes that the effluent experiences no loss or reduction (e.g. degradation or decay). Several scenarios were modelled using different combinations of model inputs (e.g. different wind velocities, current velocities, etc.) in order to investigate the influence of each factor. For detailed discussion on model inputs and results, the reader is referred to the original Arcadis (2015a) study. It should be noted that CORMIX does not account for conductivity. Conductivity was used in the field verification component of the study to delineate the extent of the plume. The measured concentrations were found to be lower than the modelled concentrations, reflecting the conservative (i.e. cautious) nature of the CORMIX calculations (Arcadis 2015a).

The resulting plume prediction for 'Scenario 1' (near-worst-case lake current velocity; conservative wind velocity; and, stratified lake temperature profile) are shown in Figure 3.3.

Figure 3.3 CORMIX Plume Modelling Results for 'Scenario 1' (Arcadis 2015a)

4 PRELIMINARY SCREENING - CONTAMINANTS OF POTENTIAL CONCERN

This section contains the preliminary screening process used to review measurement data from the different environmental media in order to identify Contaminants of Potential Concern (COPCs) that will require further evaluation in the risk assessment.

Overall, the screening process involves two steps:

1. **Preliminary screening** to identify an overall list of COPCs (documented in this section); and
2. **Secondary screening (where necessary)** to determine which COPCs to include in the HHRA and which to include in the EcoRA.

The preliminary screening step (documented in this section) is conducted by comparing maximum concentrations in environmental media to screening criteria from available standards (see Sections 4.2 to 4.7 for the hierarchies used). This step allows for the development of an initial list of COPCs; however, several screening criteria are based on the lowest concentration that is protective of human health *or* ecological species. Therefore, where this occurs, secondary screening steps are carried out later to further distinguish between COPCs requiring evaluation as part of the human health assessment, and those requiring evaluation as part of the ecological assessment.

In general, preliminary screening identifies COPCs (i.e. those analytes that are carried forward for further evaluation in the ERA) if the analyte satisfied one of the following 3 conditions:

1. The maximum concentration exceeds the corresponding screening criterion; or
2. a) There are measurable concentrations; and

   b) corresponding screening criteria are not available; and

   c) toxicity benchmarks are available; or
3. They were identified in other relevant connected environmental media as COPCs (i.e., at levels exceeding screening criteria in those connected media) and are related to current site operations.

If an analyte is present in measurable concentrations, but screening criteria and toxicity data are not available, then the analyte is not considered for further assessment since the lack of toxicity data prevents meaningful assessment.

If an analyte does not have a corresponding screening criterion, but also has non-detect levels in media, then it is generally not considered for further evaluation. An exception to this rule exists if the analyte has been identified in a relevant connected media at measurable levels that exceed those criteria (due to the potential for the analyte to transfer between media). However, in such circumstances, a decision is made on a case-by-case basis based on the complexity of the site and the interaction of the different environmental media.

If an analyte *does* have a corresponding screening criterion, and has non-detect levels in media but at an MDL that is greater than the screening criterion, then it is generally included for further assessment; however, again in such circumstances a decision is made on a case-by-case basis based on the complexity of the site and the interaction of the different environmental media.

It is important to note however, that variations to the general procedure above may exist for select environmental media. Rationale for the screening decision for each analyte is provided in the screening tables.

Air:

Air screening follows the overall screening procedure outlined above using concentrations at the point of impingement (POI). The results of air screening are shown below in their respective sub-section.

Soil:

Soil screening follows the overall screening procedure outlined above, the results of soil screening are shown below in their respective sub-section. It is important to note that soil data are limited to uranium measurements only. Since soil data are limited to uranium (which is directly relevant to site operations) and has been identified as a COPC in surface water, uranium has been identified as a COPC for inclusion in both EcoRA and HHRA.

Soil: *measured concentrations in on-site groundwater are compared to screening criteria. Due to its direct relevance to site operations, and it being identified as a COPC in other media, it has been included for further evaluation.*

Groundwater:

Groundwater screening follows the overall screening procedure outlined above. The results of groundwater screening are shown below in their respective sub-section. Those analytes that exceed their corresponding criteria are identified as COPCs.

Groundwater: *measured concentrations in on-site groundwater are compared to screening criteria. Analytes that exceed their corresponding criteria are identified as COPCs. For perspective, where information on background levels is readily available it has been included.*

<u>*Surface Water:*</u>

Surface water screening follows the overall screening procedure outlined above; where maximum measured surface water concentrations are compared to their corresponding screening criteria. Analytes that exceed their corresponding criteria are identified as COPCs. Where additional rationale is incorporated and interpreted for screening, it is noted within the screening tables.

Surface Water: *maximum measured concentrations (regardless of location) are compared to screening criteria. Analytes that exceed their corresponding criteria are identified as COPCs.*

<u>*Sediment*</u>

Sediment screening follows the overall screening procedure outlined above; where maximum measured surface water concentrations are compared to their corresponding screening criteria. Analytes that exceed their corresponding criteria are generally identified as COPCs, though, where additional rationale is incorporated and interpreted for screening, it is noted within the screening tables.

Sediment: *maximum measured concentrations (regardless of location) are compared to screening criteria. Analytes that exceed their corresponding criteria are identified as COPCs, additional rationale is incorporated and interpreted for select parameters.*

4.1 Gamma Measurements & Radionuclides – Preliminary Screening

For the purposes of this ERA, all radionuclide and gamma measurement data are screened-in (i.e., are identified as stressors), and will undergo further risk evaluation for both HHRA and EcoRA.

4.2 Groundwater - Preliminary Screening

Preliminary screening of groundwater data is presented in Table 4.1, where maximum measured concentrations from the BRR GWMP are compared to groundwater screening criteria from MOE (2011) *Soil, Groundwater and Sediment Standards* (Table 2 values). Where available, information on typical background levels of analytes in groundwater is used for comparison and interpretation.

The MOE (2011) Table 2 values (for potable water, not within 30 m of a Water Body) were chosen. This is consistent with prior site investigations such as Golder (2008), which mentions that the active site areas are beyond 30 m from the Mississaugi River. Soil sampling and screening comparisons performed by the MOE (MOE 2012) for the BRR are also based on standards for potable water beyond 30 m of a water body. Our proposed approach is therefore consistent with these prior studies.

Table 4.1 Groundwater: Preliminary Screening

Category	Parameter	Units	Screening Criteria	Max. Groundwater Value	Evaluate as a COPC?	Comments
INORGANICS & GENERAL CHEMISTRY	pH	units	N/A	5.28 - 7.75	No	Will influence toxicity but not a COPC
	Conductivity	uS/cm	N/A	1,880	No	Will influence toxicity but not a COPC
	Alkalinity	mg/L $CaCO_3$	N/A	271	No	Will influence toxicity but not a COPC
	Carbonate (CO_3)	g/L CO_3	N/A	867	No	Will influence toxicity but not a COPC
	HCO_3	mg/L $CaCO_3$	N/A	271	No	Will influence toxicity but not a COPC
	OH	µmol/L	N/A	4	No	Will influence toxicity but not a COPC
	Sulphate (SO_4)	mg/L	NA	540	No	Measurable levels in groundwater; no screening criterion. Within the typical range of concentrations in groundwater of between 1 and 1000 mg/L (WHO 1996)
	Chloride (Cl)	µg/L	790,000	210,000	No	Less than screening criterion.
	Nitrite (NO_2)	as N mg/L	NA	0.31	No	Measurable levels in groundwater, no MOE screening criterion available. Within the range of local BRR background levels of between 0.05 - 0.91 mg/L (Golder 2007).
	Nitrate (NO_3)	as N mg/L	NA	7.4	No	Measurable levels in groundwater, no MOE screening criterion available. Within the typical range of concentration in groundwater of between 0.01 and 10 mg/L (WHO 1996).
	Ammonia (Total)	as N mg/L	NA	4.1	**Yes**	Measurable levels in groundwater; no MOE screening criterion available.
	TOC	mg/L	N/A	20	No	Will influence toxicity but not a COPC
	Hardness	mg/L $CaCO_3$	N/A	9,108	No	Will influence toxicity but not a COPC
METALS	As	µg/L	25.00	5.7	No	Less than screening criterion.
	Ca	µg/L	NA	95,000	No	Measurable levels in groundwater; no MOE screening criterion. Within the lower range of background concentrations in groundwater of between 1 and 1000 mg/L (WHO 1996). Not within the range of local BRR background of 15.4 to 19.8 mg/L (Golder 2007), but based on limited number of measurements from 2002 to 2006.

Category	Parameter	Units	Screening Criteria	Max. Groundwater Value	Evaluate as a COPC?	Comments
METALS	K	µg/L	NA	3,400	No	Measurable levels in groundwater; no MOE screening criterion. Within the typical range of concentrations in groundwater of between 0.01 and 10 mg/L (WHO 1996). Within the range of local BRR background of 0.2 to 4.7 mg/L (Golder 2007), but based on limited number of measurements from 2002 to 2006.
	Mg	µg/L	NA	16,000	No	Measurable levels in groundwater; no MOE screening criterion. Within the lower range of background concentrations in groundwater of between 1 and 1000 mg/L (WHO 1996). Not within the range of local BRR background of 2.27 to 3.20 mg/L (Golder 2007), but based on limited number of measurements from 2002 to 2006.
	P	µg/L	NA	191	No	Measurable levels in groundwater, no MOE screening criterion available. Exceeds typical range of phosphate (as P) concentrations in groundwater of between 0.0001 - 0.1 mg/L (WHO 1996) [i.e. 0.1 - 100 µg/L]. Within range of local BRR background levels of between 80 – 530 µg/L (Golder 2007).
	U	µg/L	20.00	8.9	**Yes**	Less than screening criterion, but, directly relevant to site operations; identified as a COPC in other connected media.
Rad	Ra-226	Bq/L	NA	0.03	**Yes**	MOE criterion not available. Relevant to site operations. Identified as a COPC in other connected media.
Organics	TBP - Tributyl Phosphate	mg/L	NA	3	**Yes**	Measurable levels in groundwater (0.6, 0.7, 0.8, and 3 mg/L) with no associated screening criterion. Identified as a COPC in other connected media.

Notes:

MOE (2011) Site Condition Standards: TABLE 2- Standards potable, not within 30 m of a Water Body

[a] Environment Canada 2014 - Federal Interim Groundwater Quality Guidelines

[b] Health Canada 2012 - Federal Drinking Water Quality Guidelines

ND - non-detect

NA - Not Available

N/A - Not applicable: not associated with toxicity but can affect the effectiveness of other COPCs.

Based on the preliminary screening in Table 4.1, the following preliminary COPCs were identified:

1. Ammonia (Total)
2. U
3. Radionuclides
4. TBP

4.3 Surface Water – Preliminary Screening

Preliminary screening of surface water data is presented in Table 4.2. Maximum measured concentrations (regardless of location) were compared to the following hierarchy of screening criteria:

- MOE (1999) *Provincial Water Quality Objectives (PWQOs); and,*
- CCME (2015a, online) *Water Quality Guidelines for the Protection of Aquatic Life; (*wherever MOE (1999) values were not available).

Table 4.2 Surface Water: Preliminary Screening

Category	Parameter	Units	Surface Water Screening Criteria	Maximum Surface Water Value	Evaluate as COPC?	Comment
Field Parameters & General Chemistry	pH	units	6.5-8.5 [1]	3.77 - 7.98	No	Will influence toxicity but not a COPC
	Conductivity	µS/cm	NA	112	No	Will influence toxicity but not a COPC
	Ammonia (Total)	as N mg/L	12.5 [2]	2	No	Less than screening criterion.
	Nitrate (NO_3)	as N mg/L	13 [2]	2	No	Less than screening criterion.
	Ammonia (un-ionized)	µg/L	19 [2]	2.6	No	Less than screening criterion.
	TOC	mg/L	NA	7	No	Measurable levels in surface water; no screening criterion available. Will influence toxicity but not a COPC. Toxicity data not available.
Metals	P	µg/L	4 [2]	1.01	No	Less than MOE PWQO screening criterion; less than lowest CCME trigger range (4 µg/L). Considered a natural element in the earth's crust, and as such, is ubiquitous in environmental media.
	U	µg/L	5 [1]	7.4	**Yes**	Exceeds screening criterion. Is relevant to site operations. For perspective, is less than the CCME freshwater criterion of 15 µg/L.
Rad	Ra-226	Bq/L	1 [1]	0.02	Yes	Less than screening criterion, but related to site operations. All radionuclides included.
Organics	TBP	µg/L	0.6 [1]	600	Yes	Non-detect, however, MDL (0.6 mg/L) is much higher than screening criterion (0.6 µg/L). Detected in groundwater using an MDL of 0.6 mg/L.

Notes:
[1] MOE (1999) Provincial Water Quality Objectives.
[2] CCME (2015a, online) Water Quality Guidelines for Protection of Aquatic Life.
Ammonia (total): for comparison against a CCME criterion, the CCME criterion must first be derived based on pH and temperature data. The derivation uses the maximum pH and temperature data, regardless of location, in order to produce the most conservative (restrictive) criterion.
Ammonia (un-ionized): for comparison against the MOE (1999) criterion, total ammonia must be converted into un-ionized ammonia based on pH and temperature data. The conversion uses the maximum pH and temperature data, regardless of location, in order to produce the most conservative (i.e. highest) estimated concentration.

Based on the preliminary screening in Table 4.2, the following surface water COPCs were identified:

1. U;
2. Radionuclides;
3. Tributyl Phosphate (TBP).

4.4 Air – Preliminary Screening

The preliminary air quality screening is presented in Table 4.3, showing:

- total, site-wide emission rates (aggregate);
- maximum concentrations in air, based on either 1-hour, 24-hour, or 12-month (annual) averaging periods, derived using AERMOD model results as reported in SENES (2015);
- air quality screening criteria obtained from MOE *Summary of Standards and Guidelines to support Ontario Regulation 419/05 – Air Pollution – Local Air Quality*;
- a comparison between air quality screening criteria and maximum air concentrations (shown as a percentage);
- the overall decision as to whether or not to identify each compound as a COPC requiring further evaluation in the risk assessment; and
- notable comments or supporting rationale, where necessary.

Table 4.3 Air: Preliminary Screening (based on SENES 2015)

Contaminant	CAS No.	Aggregate Emission Rate (g/s)	Averaging Period	AERMOD Maximum Ground-level Concentration (µg/m^3)	Screening Criteria (µg/m^3)	% of Criteria (%)	Evaluate as COPC?	Comments
Nitrogen Oxides (NOx)	10102-44-0	2.17E+00	1-hr	1.96E+02	400	49%	No	Less than screening criterion
Nitrogen Oxides (NOx)	10102-44-0	2.17E+00	24-hr	4.10E+01	200	21%	No	Less than screening criterion
Carbon Monoxide (CO)	630-08-0	7.50E-01	24-hr	3.90E+01	6000	1%	No	Less than screening criterion
Uranium (U)	7440-61-1	7.70E-05	Annual	5.00E-04	0.03	2%	Yes	Less than screening criterion. Identified as a COPC in other relevant connected media. Directly relevant to site operations.
Suspended Particulate Matter (SPM)	-	6.80E-02	24-hr	1.06E+00	120	1%	No	Less than screening criterion
Fluorides (as HF; growing season)	7664-39-3	1.90E-03	24-hr	5.20E-02	0.86	6%	No	Less than screening criterion
Fluorides (as HF; growing season)	7664-39-3	1.90E-03	24-hr	5.20E-02	1.72	3%	No	Less than screening criterion
Magnesium	7439-95-4	2.80E-04	24-hr	5.10E-03	0.2	3%	No	Less than screening criterion

Overall, as shown in Table 4.3 below, only uranium was identified as a COPC in air.

4.5 Soil - Preliminary Screening

Preliminary screening of soil data is presented in Table 4.4. Maximum measured concentrations (regardless of location) were compared to screening criterion from both MOE (2011) (Table 2 values; see discussion below) and CCME (2015b; online) for perspective.

Similar to the discussion for groundwater (see Section 4.2), soil criteria from MOE (2011) Table 2 (i.e. for sites *not* within 30 m of a waterbody) were chosen. This is consistent with prior site investigations such as Golder (2008), which mentions that the active site areas are beyond 30 m from the Mississaugi River. Soil sampling and screening comparisons performed by the MOE (MOE 2012) for the BRR are also based on standards for potable water beyond 30 m of a water body. Our proposed approach is therefore consistent with these prior studies.

Table 4.4 Soil: Preliminary Screening

Category	Parameter	Units	Screening Criteria			Toxicity Data Available?	Max. Soil Concentration	Evaluate as COPC?	Comments
			Applicable CCME Standard[1]		MOE (2011) Table 2 Standard[2]				
Metals	U	µg/g	23		33	Y	22.1	**Yes**	Less than screening criterion, but directly relevant to site operations. Identified as a COPC in other relevant connected media (surface water).

Notes:

[1] CCME (2015b online) – Soil Quality Guidelines for the Protection of Environmental and Human Health.

[2] MOE (2011) Table 3a - Full Depth Generic Site Condition Standards in a Non-Potable Ground Water Condition.

Based on the preliminary screening in Table 4.4, uranium was identified as a COPC, to be included in further risk evaluations as part of the HHRA and ERA.

4.6 Sediment – Preliminary Screening

Table 4.5 presents a comparison of maximum sediment concentrations to corresponding screening criteria. Screening criteria were obtained from the following hierarchy of sources:

1. MOE (2011) *Table 1 – Full Depth Background Site Condition Standards*;
2. MOE (2008a) *Guidelines for Identifying, Assessing, and Managing Contaminated Sediments in Ontario: An Integrated Approach;*
3. CCME (2015c, online) *Sediment Quality Guidelines for the Protection of Aquatic Life*;
4. Thompson (2005) *Derivation and Use of Sediment Quality Guidelines for Ecological Risk Assessment of Metals and Radionuclides Released to the Environmental from Uranium Mining and Milling Activities in Canada; and*
5. RIVM (2001) *Maximum permissible concentrations for protection of ecosystem health (5th percentile of NOEC distributions).*

Table 4.5 Sediment: Preliminary Screening

Parameter	Units	Screening Criteria		Maximum Sediment Concentration	COPC?	Comments
Ammonia (Total)	µg/g	NA		<20	N	Non-detect concentrations in sediment; no corresponding screening criterion.
Metals						
Ag	µg/g	0.5	1	<0.2	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Al	µg/g	NV	1	5500	N	Measurable concentrations in sediment, no corresponding screening criterion. Not associated with BRR effluents.
As	µg/g	6	1	<1	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Ba	µg/g	29	1	18	N	Less than corresponding screening criterion.
Be	µg/g	NV	1	<0.2	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Bi	µg/g	NA		<1	N	Non-detect concentrations in sediment, no corresponding screening criterion.
B	µg/g	NV	1	<5	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Ca	µg/g	NA		3700	N	Ubiquitous, naturally occurring element in sediment.
Cd	µg/g	0.6	1	<0.1	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Co	µg/g	50	1	4.5	N	Less than corresponding screening criterion.
Cr	µg/g	26	1	29	**Yes**	Greater than corresponding screening criterion.
Cu	µg/g	16	1	9.7	N	Less than corresponding screening criterion.
Fe	µg/g	20000	2	28000	N	Ubiquitous, naturally occurring element in sediment.
Hg	µg/g	0.2	1	<0.05	N	Non-detect concentrations in sediment, MDL is less than screening criterion.

Table 4.5 Sediment: Preliminary Screening (Cont'd)

Parameter	Units	Screening Criteria		Maximum Sediment Concentration	COPC?	Comments
K	µg/g	NA		410	N	Ubiquitous, naturally occurring element in sediment.
Mg	µg/g	NA		2800	N	Ubiquitous, naturally occurring element in sediment.
Mn	µg/g	460	2	160	N	Less than corresponding screening criterion.
Mo	µg/g	13.8	4	<0.5	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Na	µg/g	NA		300	N	Ubiquitous, naturally occurring element in sediment.
Ni	µg/g	16	1	14	N	Less than corresponding screening criterion.
P	µg/g	NA		530	N	Ubiquitous, naturally occurring element in sediment.
Pb	µg/g	31	1	3.3	N	Less than corresponding screening criterion.
Se	µg/g	1.9	4	<0.5	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Sb	µg/g	NV	1	<0.2	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Sn	µg/g	NA		<5	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Sr	µg/g	NA		14	N	Measurable concentrations in sediment, no corresponding screening criterion. Not associated with BRR effluents.
Tl	µg/g	NV	1	<0.05	N	Non-detect concentrations in sediment, no corresponding screening criterion.
U	µg/g	32	4	0.64	**Yes**	Less than corresponding screening criterion, but directly relevant to site operations, and identified as a COPC in other relevant connected media (surface water).
V	µg/g	27.3	4	98	**Yes**	Greater than corresponding screening criterion.
Zn	µg/g	120	1	24	N	Less than corresponding screening criterion.

Table 4.5 Sediment: Preliminary Screening (Cont'd)

Parameter	Units	Screening Criteria		Maximum Sediment Concentration	COPC?	Comments
Radionuclides						
Pb-210	Bq/g	0.5	4	<0.1	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Po-210	Bq/g	0.6	4	0.039	N	Less than corresponding screening criterion.
Ra-226	Bq/g	0.1	4	<0.1	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Ra-228	Bq/g	NA		<0.1	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Th-228	Bq/g	NA		<0.1	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Th-230	Bq/g	NA		<0.8	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Th-234	Bq/g	NA		<0.05	N	Non-detect concentrations in sediment, no corresponding screening criterion.
U-235	Bq/g	NA		<0.1	N	Non-detect concentrations in sediment, no corresponding screening criterion.
PAHs						
Acenaphthene	µg/g	0.00671	3	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Acenaphthylene	µg/g	0.00587	3	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Anthracene	µg/g	0.22	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Benzo(a)anthracene	µg/g	0.32	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Benzo(a)pyrene	µg/g	0.37	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Benzo(b/j)fluoranthene	µg/g	NA		<0.005	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Benzo(k)fluoranthene	µg/g	0.24	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Benzo(g,h,i)perylene	µg/g	0.17	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.

Table 4.5 Sediment: Preliminary Screening (Cont'd)

Parameter	Units	Screening Criteria		Maximum Sediment Concentration	COPC?	Comments
Chrysene	µg/g	0.34	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Dibenz(a,h)anthracene	µg/g	0.06	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Fluoranthene	µg/g	0.75	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Fluorene	µg/g	0.19	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Indeno(1,2,3-cd)pyrene	µg/g	0.2	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
1-Methylnaphthalene	µg/g	NA		<0.005	N	Non-detect concentrations in sediment, no corresponding screening criterion.
2-Methylnaphthalene	µg/g	NA		<0.005	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Naphthalene	µg/g	0.0346	3	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Phenanthrene	µg/g	0.56	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
Pyrene	µg/g	0.49	1	<0.005	N	Non-detect concentrations in sediment, MDL is less than screening criterion.
PHCs & BTEX						
Benzene	µg/g	NA		<0.02	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Toluene	µg/g	NA		<0.02	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Ethylbenzene	µg/g	NA		<0.02	N	Non-detect concentrations in sediment, no corresponding screening criterion.
o-Xylene	µg/g	NA		<0.02	N	Non-detect concentrations in sediment, no corresponding screening criterion.
p+m-Xylene	µg/g	NA		<0.04	N	Non-detect concentrations in sediment, no corresponding screening criterion.
Total Xylenes	µg/g	NA		<0.04	N	Non-detect concentrations in sediment, no corresponding screening criterion.
F1 (C6-C10)	µg/g	NA		<10	N	Non-detect concentrations in sediment, no corresponding screening criterion.

Table 4.5 Sediment: Preliminary Screening (Cont'd)

Parameter	Units	Screening Criteria		Maximum Sediment Concentration	COPC?	Comments
F1 (C6-C10) BTEX	µg/g	NA		<10	N	Non-detect concentrations in sediment, no corresponding screening criterion.
F2 (C10-C16 Hydrocarbons)	µg/g	NA		<10	N	Non-detect concentrations in sediment, no corresponding screening criterion.
F3 (C16-C34 Hydrocarbons)	µg/g	300	6	82	N	Less than corresponding screening criterion.
F4 (C34-C50 Hydrocarbons)	µg/g	NA		<50	N	Non-detect concentrations in sediment, no corresponding screening criterion.
PCBs						
Aroclor 1016	µg/g	0.007	2	<0.01	N *(see comments)*	All PCB results show non-detect concentrations in sediment, including Total PCBs which has a MDL that is less than the corresponding MOE Total PCB criterion. [redacted]
Aroclor 1221	µg/g	NA		<0.01		
Aroclor 1232	µg/g	NA		<0.01		
Aroclor 1242	µg/g	NA		<0.01		
Aroclor 1248	µg/g	0.03	2	<0.01		
Aroclor 1254	µg/g	0.06	2	<0.01		
Aroclor 1260	µg/g	0.005	2	<0.01		
Aroclor 1262	µg/g	NA		<0.01		
Aroclor 1268	µg/g	NA		<0.01		
Total PCB	µg/g	0.07	1	<0.01		

Notes:
1 MOE (2011) Soil, Groundwater and Sediment Standards - Table 1 values.
2 MOE (2008) Sediment Quality Guidelines.
3 CCME (2015c; online) Sediment Quality Guidelines for the Protection of Aquatic Life.
4 Thompson, Kurias, Mihok (2005) - Derived Sediment Screening Levels: Table 1.
5) RIVM (2001).
6) MOE (2011) Soil component for soil invertebrates (surrogate).
NV – 'No Value' designation from MOE (2011).
NA - Not Available

4.7 Summary - Preliminary Screening

The individual COPC lists generated by preliminary screening of each environmental medium are combined and presented in Table 4.6 below.

Table 4.6 Summary of Preliminary Screening COPCs

Category	Parameter	Soil	Groundwater	Surface Water	Sediment	Air
Major Ions	Ammonia (Total)	nd	Y			nd
	Ammonia (un-ionized)	nd	See Ammonia (total)		nd	nd
TBP	TBP	nd	Y	Y	nd	nd
Metals	Cr	nd	nd	nd	Y	nd
	V	nd	nd	nd	Y	nd
	U	Y	Y	Y	Y	Y
Rad	Ra-226	Y (All radionuclides included as COPCs)				

Notes

Y - Screened In: Indicates a parameter that has been identified as a COPC.

Blanks - Screened Out: Indicates where a parameter was screened, and not identified as a COPC.

nd - Indicates instances where data for a particular parameter are not available in the given environmental medium. Screening comparison cannot be completed for this medium.

Given the analytes that have been identified as COPCs through primary screening, a secondary screening process is not necessary – all the identified COPCs will undergo further risk evaluation in both the HHRA and EcoRA. For uranium, this is the case because of its direct relevance to site operations and emissions, and the fact that the maximum measured surface water concentration exceeds the corresponding surface water criterion. For all other identified COPCs, this is the case because they are found in measurable levels but corresponding screening criteria are not available.

It is important to note that all radionuclides identified in environmental media are considered COPCs, and will undergo further evaluation (see Table 2.6 for available radionuclide data).

5 HUMAN HEALTH RISK ASSESSMENT

A HHRA is the evaluation of the probability of health consequences to humans caused by the presence of chemical contaminants at a Site. To assess this probability it is necessary to take receptor characteristics, exposure pathways and mitigating circumstances into consideration. The assessment of levels of unacceptable risk is evaluated using: toxicological information associated with the particular contaminants of concern; chemical and physical Site conditions; and known characteristics of the people interacting with the Site or connected media.

The requirement for, approach to, and scope of, a HHRA is based on a fundamental understanding of: site conditions, including the nature, extent and distribution of the radiological and chemical hazards; the potential exposure pathways; and opportunities for human receptors that will frequent, use or populate the Site. The following sections describe the HHRA and its components.

5.1 Problem Formulation

5.1.1 Receptor Selection & Characterization

For consistency, the receptors included in the HHRA are derived primarily from those outlined in the BRR DRL (SENES 2013). However, additional pathways have been included for select receptors to better represent their interaction with key environmental media - including for example, swimming. Six human receptor groups have been included in the HHRA; five of these are members of the public (with different age variants), and one is a worker receptor representing on-site BRR personnel (adult age group only).

Under CSA N288.6 (2012), HHRAs apply to off-site receptors (i.e., members of the public) and on-site non-nuclear energy workers (non-NEWs) that are not covered under the facility's radiation protection program or health and safety program. At the BRR facility, all workers are trained as NEWs, regardless of position or job function; this includes technologists and maintenance workers (Cameco 2015). Therefore, for the purpose of this HHRA, on-site BRR workers are identified, but do not undergo quantitative evaluation as part of this assessment.

Table 5.1 presents the complete list of human receptors along with their descriptions.

Table 5.1 HHRA: Identification of Human Receptors

<table>
<tr><th>No.</th><th colspan="3">Type of Receptor</th><th>Receptor Name</th><th>Description</th><th>Age Variants</th></tr>
<tr><td>1A</td><td>Off-Site</td><td>Resident</td><td>Member of the Public</td><td>Resident (Lantain St.)</td><td rowspan="4">A local resident(s), present full-time (8566 hours per year at their residence) who:
• consumes local fish caught from the Lake (excluding infants);
• consumes wild game harvested from the local area (excluding infants);
• consumes wild fowl harvested from the local area (excluding infants);
• consumes drinking water;
• consumes backyard grown produce;
• spends time indoors;
• spends time outdoors recreating at the Boom Camp location (assessed separately via the 'Boom Camp' receptor).
Resident receptors are also assessed for gamma exposure from the BRR facility.</td><td rowspan="6">Rad*:
-Infant
-Child
-Adult

Non-Rad*:
-Infant
-Toddler
-Child
-Teen
-Adult</td></tr>
<tr><td>1B</td><td>Off-Site</td><td>Resident</td><td>Member of the Public</td><td>Resident (MFN)</td></tr>
<tr><td>1C</td><td>Off-Site</td><td>Resident</td><td>Member of the Public</td><td>Resident (Railway)</td></tr>
<tr><td>1D</td><td>Off-Site</td><td>Resident</td><td>Member of the Public</td><td>Resident (Col. St.)</td></tr>
<tr><td>2</td><td>Off-Site</td><td>Seasonal Resident</td><td>Member of the Public</td><td>Cottager</td><td>A seasonal cottager receptor located on the shore of the lake. Engages in fishing activities (consumption of local fish), and can experience a fall from the boat into the water. Not assessed for swimming activities, as these are encompassed by the Boom Camp receptor. Does not garden or hunt, and therefore does not consume local garden produce or locally harvested wild game. The cottager receptor is present only seasonally (16% of the year; 1403 hours per year), and therefore does not experience exposures across a full year. Cottager receptors are also assessed for direct external gamma exposure from the BRR facility.</td></tr>
<tr><td>3</td><td>Off-Site</td><td>Part-Time Resident</td><td>Member of the Public</td><td>Boom Camp</td><td>Represents the portion of time that resident receptors spend recreating at the Boom Camp location (200 hours per year, for resident, golf, and hydro worker receptors). Assessed for:
• swimming;
• consumption of drinking water;
• time spent outdoors (200 hours per year);
• direct external gamma exposure from the BRR facility.</td></tr>
</table>

Table 5.1 HHRA: Identification of Human Receptors (Cont'd)

No.	Type of Receptor			Receptor Name	Description	Age Variants
4	Off-Site	Seasonal Commercial Worker	Member of the Public	Golf Worker	A seasonal worker receptor located at the nearby golf course. This receptor is assumed to come into contact with soil (at their location), as well as outdoor air/particulate, but not groundwater. This receptor is assumed to be potentially present only seasonally (1200 hrs per year). The golf worker receptor does not engage in swimming activities. Local food ingestion pathways (fish, produce, wild game) are excluded as these activities do not take place at the golf course location (exposure via these pathways is encompassed by the resident receptor variants). The golf worker receptor is assessed for direct external gamma exposure from the BRR facility.	**Rad & Non-Rad:** Adult only
5	Off-Site	Full-Time Commercial Worker	Member of the Public	Hydro Worker	A full-time hydro worker receptor located at the in-town hydro yard. This receptor is assumed to come into contact with soil (at their location), as well as outdoor air/particulate, but not groundwater. This receptor is assumed to be present for 2000 hrs per year, representing occupational-based exposure. The hydro worker receptor does not engage in swimming activities. Local food ingestion pathways (fish, produce, wild game) are excluded as these activities do not take place at the hydro course location (exposure via these pathways is encompassed by the resident receptor variants). The hydro worker receptor is assessed for direct external gamma exposure from the BRR facility.	

Table 5.1 HHRA: Identification of Human Receptors (Cont'd)

No.	Type of Receptor			Receptor Name	Description	Age Variants
6	On-Site	On-Site Worker	On-Site Worker	On-Site BRR Worker	An on-site worker with the potential to be involved in a variety of activities, including: • short-term soil subsurface investigations or construction activities; and • collection of groundwater samples. This receptor is assumed to come into contact with soil and groundwater (anywhere on-site) for short periods of time. This receptor is assumed to be potentially present in the long-term (i.e., for several years), therefore warranting assessment of chronic effects. The on-site worker receptor does not engage in swimming activities. Local food ingestion pathways (fish, produce, wild game) are excluded as these activities do not take place at the BRR facility (exposure via these pathways is encompassed by the resident receptor variants). On-site worker receptors are also assessed for direct external gamma exposure from the BRR facility.	

* Age groups recommended for radiological assessment as per CSA N288.1 (2014). Age groups recommended for non-radiological assessment as per CSA N288.6 (2012).

5.1.2 HHRA COPCs

As outlined in Section 4, the following analytes were identified as COPCs:

- Ammonia (in groundwater);
- Uranium;
- TBP;
- Chromium;
- Vanadium; and,
- Radionuclides and gamma radiation.

Chromium and vanadium are identified as COPCs due to the fact that the maximum measured level in sediment exceeds their corresponding screening criteria (26 µg/g for chromium; 27.3 µg/g for vanadium). However, it is important to note that chromium and vanadium are not components of facility releases (liquid or airborne) from the BRR and are not associated with BRR site operations.

Figure 5.1 and Figure 5.2 present measured sediment concentrations of chromium and vanadium, from 2015 (Arcadis 2015a), along with historical sediment concentration data from SENES (2006a) for perspective.

Figure 5.1 Chromium Concentrations in Sediment (µg/g)

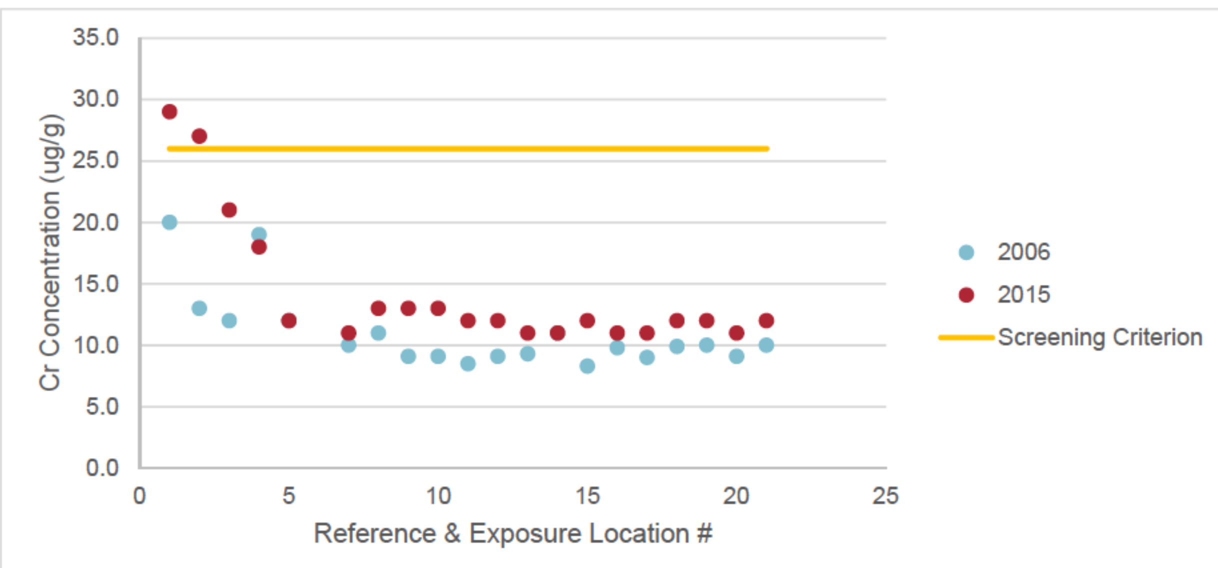
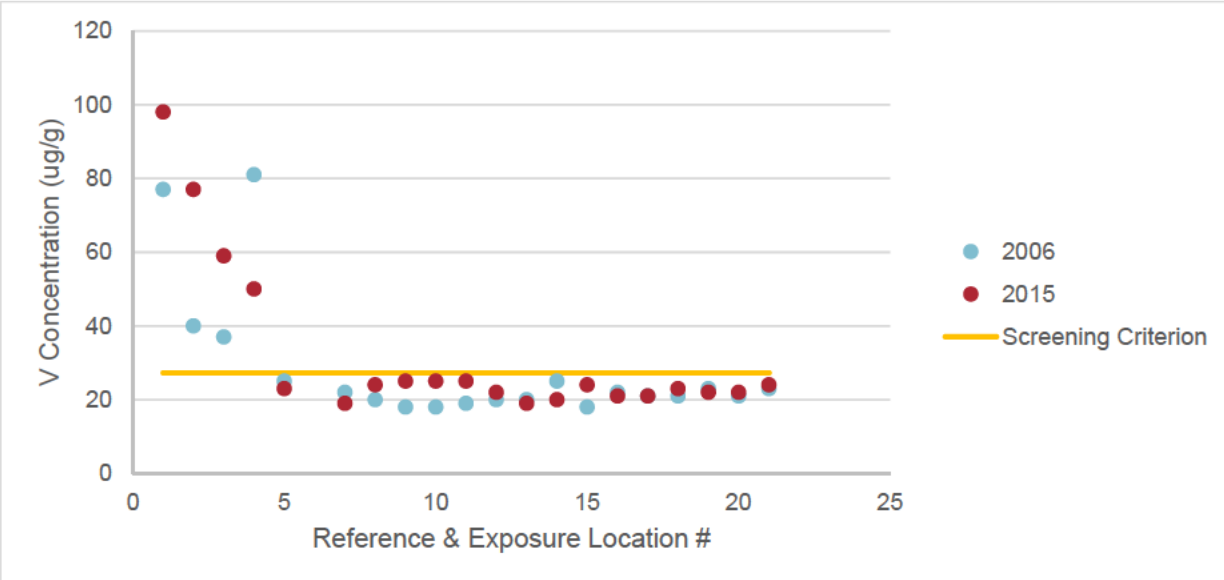


Figure 5.2 Vanadium Concentrations in Sediment (µg/g)



In both figures, the 5 left-most data points indicate measurements obtained from the up gradient Reference Locations which represent background conditions, whereas the remaining 15 data points are measurements obtained from Exposure Locations (see Section 2.5.4). For both chromium and vanadium, data indicate that concentrations in the vicinity of the BRR site (i.e. at the exposure locations) are much lower than those observed at reference locations (i.e. background conditions), and, are also below their respective screening criteria. Therefore, since concentrations at Exposure Locations are less than local background concentrations at Reference Locations, and are less than the corresponding screening criteria, chromium and vanadium have been excluded from further assessment.

Therefore, the following have been identified as requiring further assessment in the HHRA:

- Ammonia;
- Uranium;
- TBP; and,
- Radionuclides and gamma radiation.

5.1.3 HHRA Exposure Pathways

The next step is to examine the potential pathways of exposure and identify the ways in which human receptors could be exposed to COPCs and radiological stressors present in the different environmental media, as identified in Section 3 (preliminary COPC identification).

In general, human receptors may come into contact with contaminants through four primary exposure routes: dermal exposure, incidental ingestion (of for example, soil), ingestion of contaminated food, and inhalation (though inhalation is likely to be minimal in comparison to other pathways, since all exposures occur outdoors). Therefore, a complete exposure pathway consists of a contaminant source, a release mechanism, one or more transport mechanisms, a point of exposure (receptor), and an exposure route for intake into the human body.

For gamma and other external radiation, exposure can occur externally without one of the four primary exposure routes. As a result, external radiation dose rates are included in this HHRA.

It is important to note that the pathways included for human receptors are based primarily on the BRR DRL (SENES 2013) for consistency; however, additional pathways have been included for select receptors in order to better represent the environmental media they may be exposed to.

5.1.3.1 Soil Exposure Pathways

Based on the types of receptors, their characteristics, and their behaviours as described in Section 5.1.1, human receptors may come into contact with soil, resulting in the following potential soil exposures:

- Dermal exposure to soil;
- Incidental ingestion of soil; and,
- Inhalation of airborne particulates that contain contaminated soil [on-site worker receptor (Receptor No. 6) only].

Detailed breakdowns of soil exposure pathways, distinguishing between on-site worker receptors and off-site members public, are presented in Table 5.2.

5.1.3.2 Groundwater Exposure Pathways

Based on the type of receptors, their characteristics, and their behaviours as described in Section 5.1.1, certain (though not all) human receptors may come into contact with contaminated groundwater resulting in the following groundwater exposures:

- Dermal exposure to groundwater [on-site worker receptor (Receptor No. 6) only];
- Incidental ingestion of groundwater [on-site worker receptor (Receptor No. 6) only]; and,
- Consumption of groundwater as drinking water (for select receptors only, see Table 5.2 and Table 5.4).

Detailed breakdowns of groundwater exposure pathways, distinguishing between on-site worker receptors and off-site members public, are presented in Table 5.2.

5.1.3.3 Air Exposure Pathways

Though air screening did not identify any COPCs that exceed their corresponding air concentration criteria, uranium has been included for air inhalation assessment due to its relevance to site operations, and because it has been identified as a COPC in other relevant connected media. Air pathways include:

- Inhalation of outdoor air; and,
- Inhalation of indoor air.

A detailed breakdown of all exposure pathways, distinguishing between on-site worker receptors and off-site members public, is presented in Table 5.2.

5.1.3.4 Surface Water Exposure Pathways

Based on the type of receptors, their characteristics, and their behaviours as described in Section 5.1.1, certain (though not all) human receptors may come into contact with contaminated surface water resulting in the following surface water exposures:

- Dermal exposure to surface water while swimming;
- Incidental ingestion of surface water while swimming;
- Dermal exposure to surface water due to falling into the lake;
- Incidental ingestion of surface water due to falling into the lake; and,
- Consumption of surface water as drinking water (for select receptors only, see Table 5.2 and Table 5.4).

Detailed breakdowns of surface water exposure pathways, distinguishing between on-site worker receptors and off-site members public, are presented in Table 5.2.

5.1.3.5 Contaminated Food Exposure Pathways

Based on their characteristics and behaviour as described in Section 5.1.1, off-site receptors (members of the public), may come into contact with contaminated foods resulting in exposure to soil contaminants. The contaminated food intakes included in this HHRA are based on those included in the BRR DRL (SENES 2013) for consistency. This includes:

- Consumption of fish caught locally (and resulting ingestion of surface water COPCs taken up by the fish);

- Consumption of garden produce grown in off-site soil (and resulting ingestion of off-site soil COPCs taken up by the vegetation);
- Consumption of wild game harvested locally (and resulting ingestion of soil COPCs taken up by the game species); and,
- Consumption of wild fowl harvested locally (and resulting ingestion of soil COPCs taken up by the bird species).

As described in Section 5.1.1, locally obtained fish, garden produce, game, and fowl comprise only a portion of the total dietary intake of the receptor. The proportions of locally obtained foods used in this study are outlined in Table 5.5.

Detailed breakdowns of the food ingestion exposure pathway, distinguishing between the different human receptors, are presented in Table 5.2.

5.1.3.6 Sediment Exposure Pathways

Based on the type of receptors, their characteristics, and their behaviours as described in Section 5.1.1, certain (though not all) human receptors have sediment exposure pathways in the radiological HHRA, consistent with CSA N288.1. These radiological HHRA pathways include:

- Incidental ingestion of sediment while swimming/recreating along shoreline beaches; and,
- External radiation exposure from sediment deposits while swimming/recreating along shoreline beaches (also listed in Section 5.1.3.8 below).

Detailed breakdowns of surface water exposure pathways, distinguishing between on-site worker receptors and off-site members public, are presented in Table 5.2.

5.1.3.7 Gamma Radiation Exposure Pathway

Based on the characteristics and behaviour as described in Section 5.1.1, human receptors that are present in or near the BRR may experience external gamma exposure.

Gamma radiation doses are assessed based on direct external gamma radiation exposure. The dose rate from gamma radiation is added to the dose rate estimated from radionuclides in environmental media.

In general, worker radiation doses are addressed under the BRR radiation protection program.

5.1.3.8 External Radiation Exposure

Based on the characteristics and behaviour as described in Section 5.1.1, human receptors could potentially receive a radiological external dose from the following pathways, depending on their activities and location:

- Immersion in surface water (from swimming; falling into water; and bathing);
- External dose from soil deposits;
- External dose from sediment (during swimming or shoreline recreating); and,
- Direct gamma radiation (as discussed in Section 5.1.3.7).

5.1.3.9 Summary of Inactive/Non-Applicable Exposure Pathways

Based on the receptor descriptions and the defined activities they engage in, the following exposure pathways are not applicable:

- *<u>External Exposure from Immersion in air (Radiological)</u>*

In many cases immersion in air is not a dominant contributor to overall radiological dose. The external dose contributed by air immersion is typically low enough to be neglected; only when specific conditions exist - such as confined spaces (where radionuclide levels can accumulate) or elevated concentrations of radionuclides in air – does the dose contribution from air immersion increase and warrant consideration. Furthermore, air COPC screening shows that air concentrations are below their corresponding criteria. Therefore, external radiological dose from air immersion can be excluded from further assessment.

- *<u>Inhalation of Groundwater Vapours (Indoor or Outdoor)</u>*

Inhalation of vapours from groundwater have been excluded since receptors are located either outdoors or in a ventilated indoor setting (in the case of the on-site BRR worker receptor) and *not* in spaces where vapours could accumulate.

- *<u>Inhalation of Soil Vapours (Indoor or Outdoor)</u>*

Inhalation of vapours from soil have been excluded since uranium - the only identified soil COPC – is not volatile.

- *<u>Dermal Exposure to Suspended Sediments While Swimming/Recreating Along Shoreline Beaches</u>*

Exposure from dermal contact can occur from direct contact with bulk sediments as well as with suspended sediments in the water column. As dermal absorption is a function of the adherence of sediment to exposed skin, exposure (adherence) from dermal contact with suspended sediments while swimming in surface water is expected to be negligible and was not considered.

- *Inhalation of Suspended Sediment Particulate While Recreating Along Shoreline Beaches*

Exposure from inhalation of particulates (e.g., wind-entrained sediments) is expected to be negligible. In soil risk assessments, dust generation is assumed to occur only on days without precipitation (i.e., when soil is dry); in this assessment, the sediment to which the receptors are exposed is assumed to always be wet at the shoreline and thus exposure via this pathway was therefore not considered. None of the COPCs in sediment are volatile and thus exposure via inhalation of volatile vapours was also not evaluated.

- *Ingestion of Suspended Sediment via Lake Drinking Water Ingestion*

Resident receptors are assumed to use groundwater as drinking water; and as a result, they do not experience exposure via ingestion of suspended lake sediments in drinking water. All other receptors are assumed to obtain their drinking water from the lake. It was assumed that the water would be drawn from a deeper part of the lake with minimal suspended sediment and thus ingestion of suspended sediment in drinking water is not considered an active exposure pathway.

- *Dermal Exposure to Suspended Lake Sediment Via Domestic Water Use*

Resident receptors are assumed to use groundwater as domestic water; and as a result, they do not experience exposure via dermal contact (bathing) with suspended lake sediments in domestic water. Use of lake surface water for domestic water use is not associated with receptors other than the resident, and therefore, dermal contact with suspended sediment via bathing water is not considered an applicable pathway.

- *Inhalation of Soil Particulate/Dust (specifically to public receptors)*

Off-site member of the public receptors are not assessed for soil particulate/dust inhalation as part of their activities; though they *are* assessed for inhalation of outdoor air (based on modelled concentrations from BRR emissions).

The on-site worker receptor (Receptor No. 6) is assessed for inhalation of soil particulate/dust as part of their activities, which is conservative (i.e. results in a higher inhalation dose than from inhalation of outdoor air).

5.1.3.10 Summary of Active HHRA Exposure Pathways

Exposure pathways related to each environment medium (soil, groundwater, surface water, and sediment) are described in their respective sections above. An overall summary of exposure pathways for is presented in Table 5.2.

Table 5.2 HHRA Exposure Pathways

(See Section 5.1.3.9 for inactive/non-applicable pathways - not shown in table below).

	RECEPTORS					
	Resident	Cottager	Boom Camp	Golf Worker	Hydro Worker	On-Site Worker (BRR)
PATHWAYS	No. 1 A-D	No. 2	No.3	No. 4	No. 5	No. 6
Dermal contact with soil	N *(Assessed as part of boom camp receptors)*	N *(Assessed as part of boom camp receptors)*	Y	Y	Y	Y
Dermal contact with groundwater	N	N	N	N	N	Y
Dust inhalation	N *(dust limited to on-site workers; off-site receptors assessed for air inhalation)*	N *(dust limited to on-site workers; off-site receptors assessed for air inhalation)*	N *(dust limited to on-site workers; off-site receptors assessed for air inhalation)*	N *(dust limited to on-site workers; off-site receptors assessed for air inhalation)*	N *(dust limited to on-site workers; off-site receptors assessed for air inhalation)*	Y
Incidental ingestion of soil	N	Y	Y	Y	Y	Y
Incidental ingestion of groundwater	N	N	N	N	N	Y
Inhalation of outdoor air	N	Y *(Assumed outdoor air; conservative)*	Y	Y	Y	N *(Assessed for dust inhalation)*
Inhalation of indoor air	Y		N	N	N	N
Drinking water intake	Y *(DW assumed to be GW)*	Y *(DW assumed to be lake SW)*	Y *(DW assumed to be lake SW)*	Y *(DW assumed to be lake SW)*	Y *(DW assumed to be lake SW)*	Y *(DW assumed to be lake SW)*
Dermal exposure to surface water while swimming	N *(Assessed as part of boom camp receptor)*	N *(Assessed as part of boom camp receptor)*	Y	N *(Not engage in swimming activities)*	N *(Not engage in swimming activities)*	N *(Not engage in swimming activities)*
Incidental ingestion of surface water while swimming	N *(Assessed as part of boom camp receptor)*	N *(Assessed as part of boom camp receptor)*	Y	N *(Not engage in swimming activities)*	N *(Not engage in swimming activities)*	N *(Not engage in swimming activities)*
Dermal exposure to surface water while falling into water	N *(Assessed as part of cottager receptor)*	Y	N *(Assessed as part of cottager receptor)*	N	N	N
Incidental ingestion of surface water while falling into water	N *(Assessed as part of cottager receptor)*	Y	N *(Assessed as part of cottager receptor)*	N	N	N
Ingestion of local fish	Y	Y	N	N	N	N
Ingestion of local backyard produce	Y	N	N	N	N	N
Ingestion of wild game (harvested locally)	Y	N	N	N	N	N
Ingestion of wild fowl (harvested locally)	Y	N	N	N	N	N
External exposure from immersion in surface water [swimming, bathing, falling into water] (radiological)	N *(bathes using GW)*	Y *(swimming, bathing)*	Y *(swimming)*	N	N	N
External exposure from soil deposits (radiological)	N	Y	Y	Y	Y	Y
Direct gamma (radiological)	Y	Y	Y	Y	Y	Y
External exposure from sediment (radiological)	N	N	Y	N	N	N
Incidental ingestion of sediment (radiological)	N	N	Y	N	N	N

Notes:
DW – Drinking water, GW – Groundwater, SW – Surface water.

5.1.4 HHRA Conceptual Site Model (CSM)

The overall HHRA study boundaries are based on knowledge of the site and surrounding area, and includes a range of known and potential contamination sources. Figure 5.3 presents the location of human receptors, based on their locations in the BRR DRL (SENES 2013). Figure 5.4 outlines the many environmental media included in this study, along with the exposure pathways that link these environmental media to human receptors. Figure 5.5 and Figure 5.6 present a graphical conceptual site model, based on the known COPCs and their locations, identified receptors, and relevant exposure pathways.

Figure 5.3 Human Receptor Locations (BRR DRL - SENES 2013)

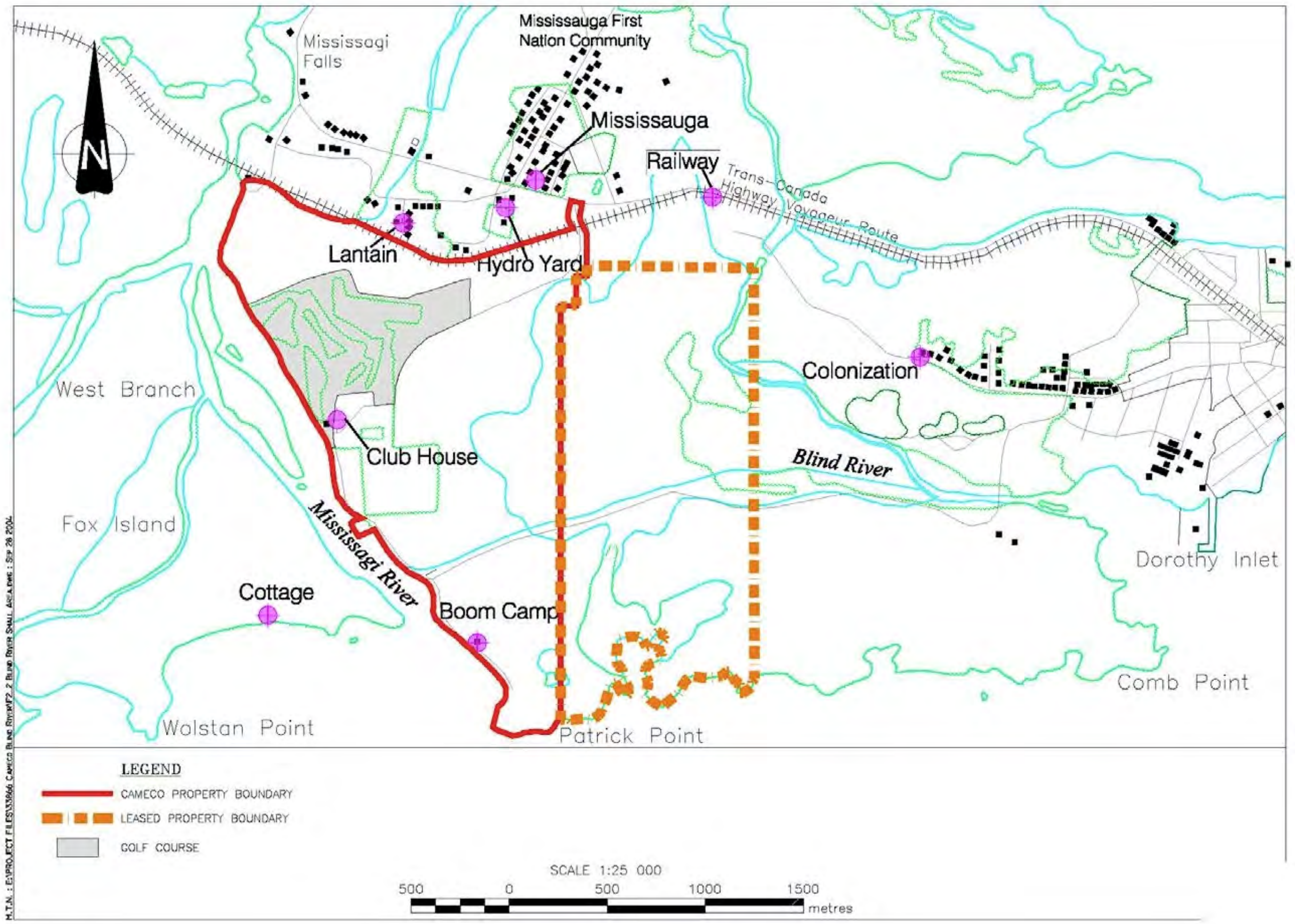


Figure 5.4 Human Receptor Pathways

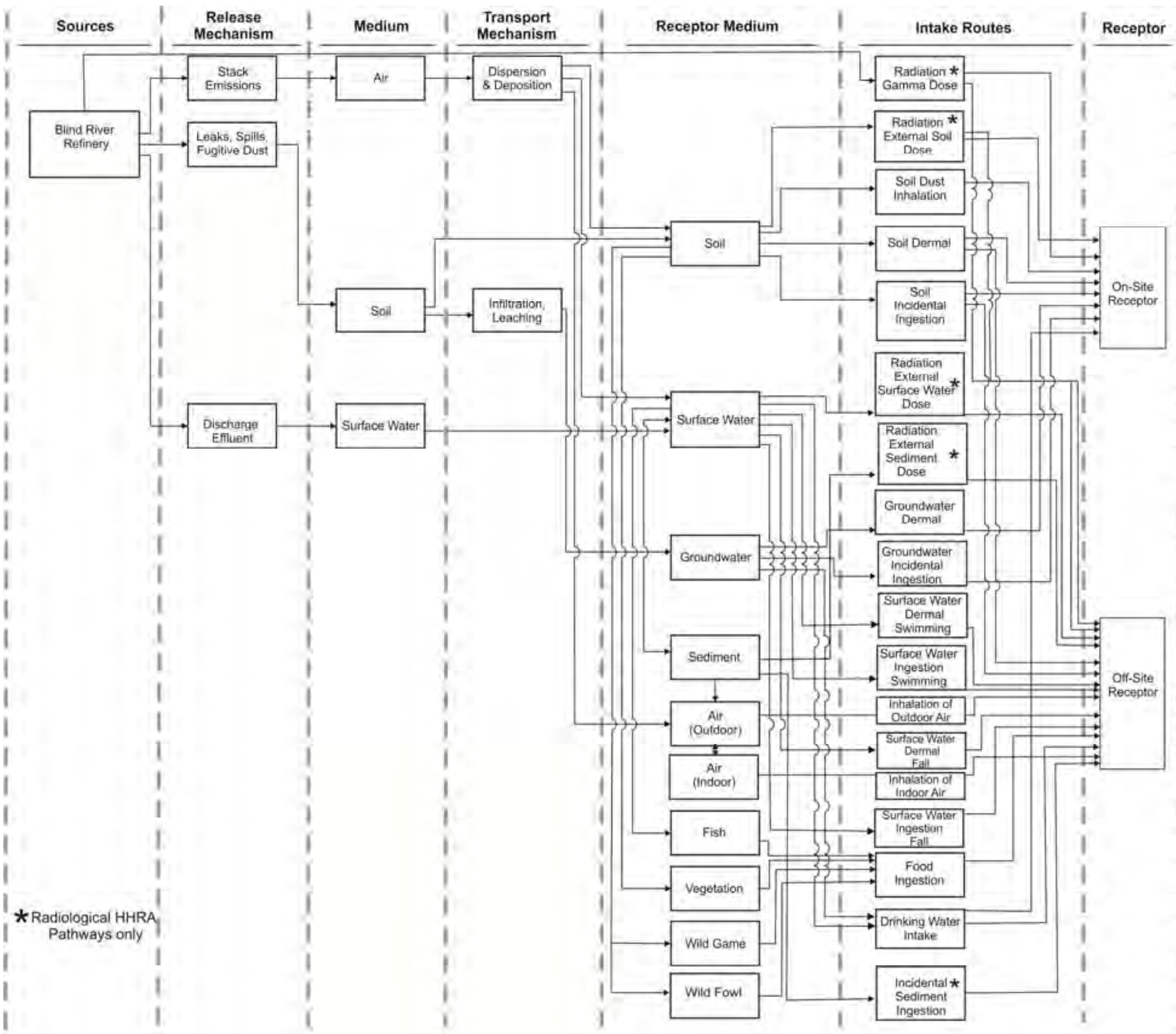
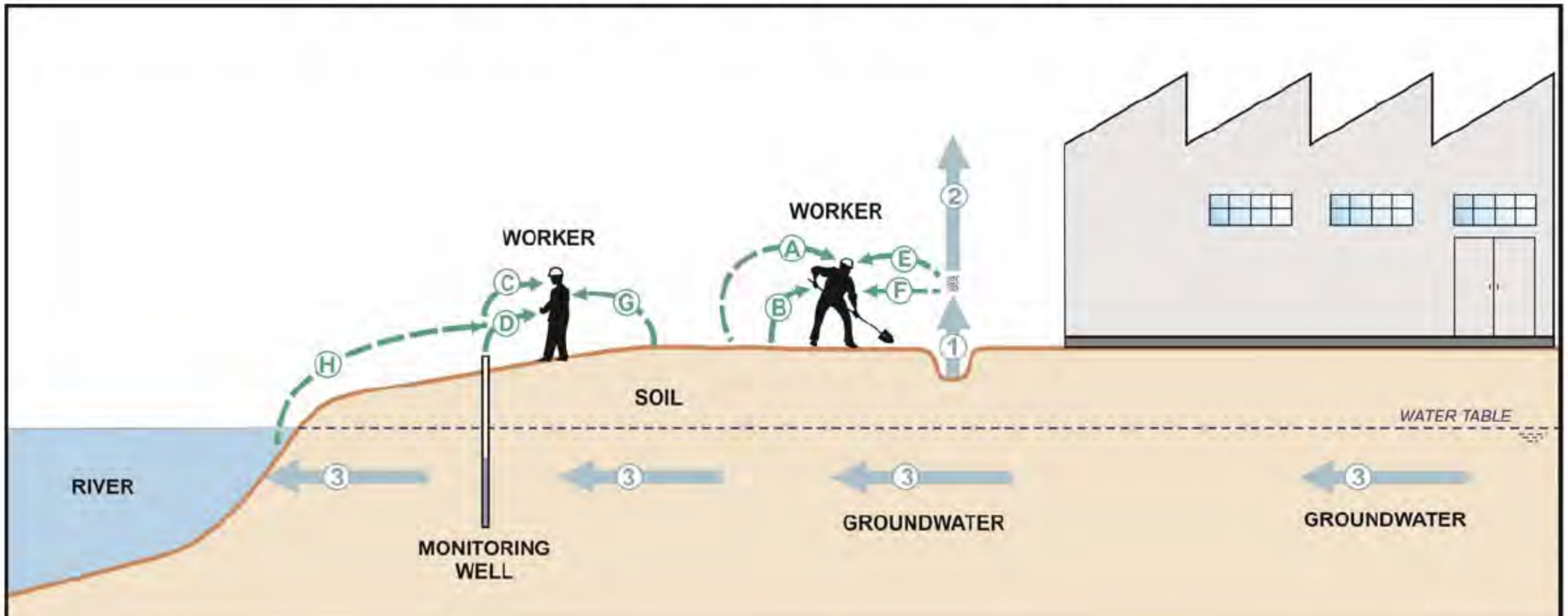


Figure 5.5 HHRA Conceptual Site Model – On-Site Worker (BRR) Receptor



ENVIRONMENTAL FATE PROCESS:

1. RESUSPENSION
2. AIR DISPERSION/MIXING
3. MIGRATION OF GROUNDWATER

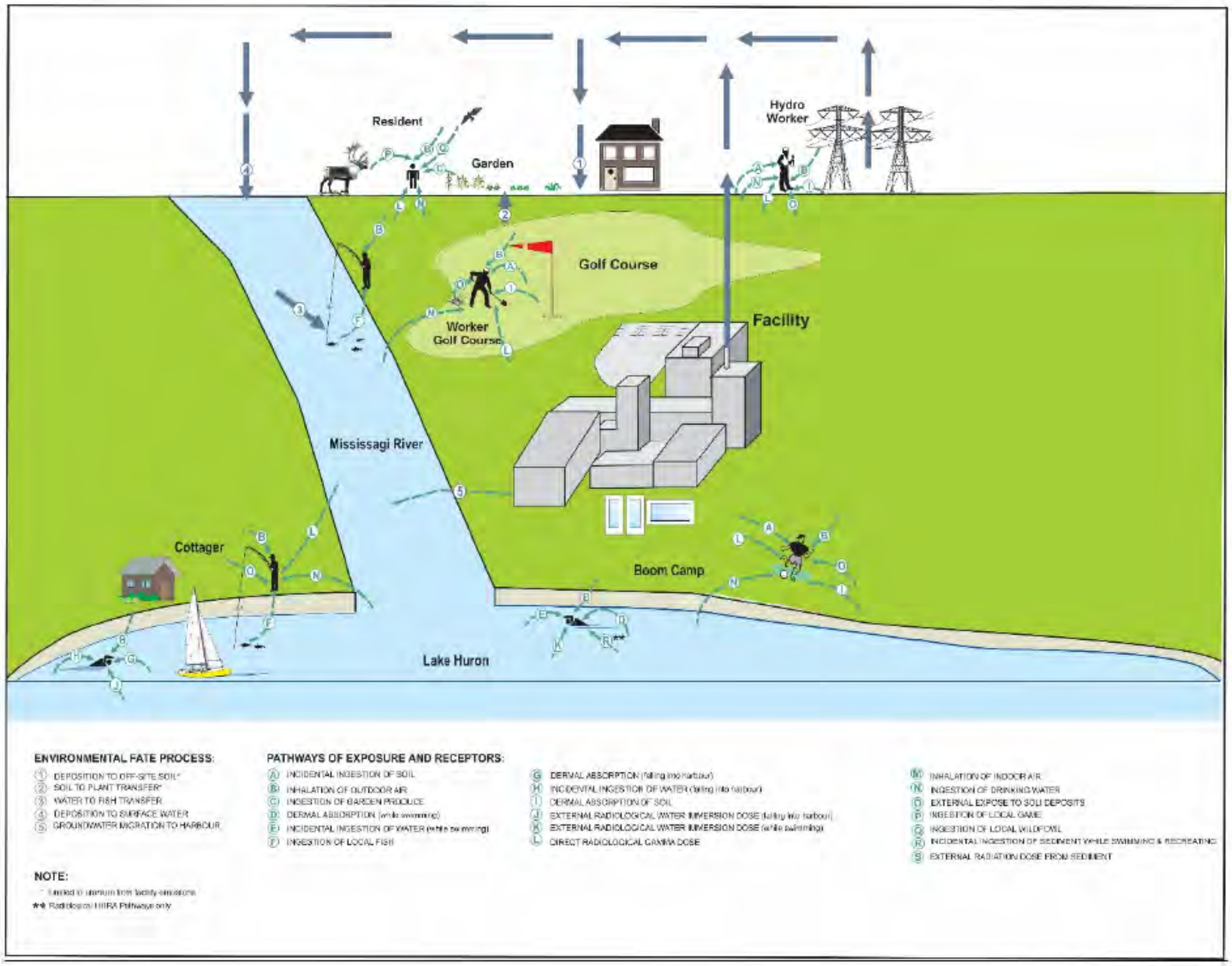
PATHWAYS OF EXPOSURE AND RECEPTORS:

- (A) INCIDENTAL INGESTION OF SOIL
- (B) DERMAL CONTACT WITH SOIL
- (C) INCIDENTAL INGESTION OF GROUNDWATER
- (D) DERMAL CONTACT WITH GROUNDWATER
- (E) INHALATION OF SOIL/DUST PARTICULATE
- (F) DIRECT GAMMA (RADIOLOGICAL)
- (G) External Dose From Soil Deposits
- (H) Ingestion of Surface Water as Drinking Water

NOTE:

Figure is a conceptual representation of site model and not to scale

Figure 5.6 HHRA Conceptual Site Model – Off-Site Member of the Public Receptors



Problem Formulation Checklist

Table 5.3 presents the problem formulation checklist for the HHRA, consistent with CSA (2012).

Table 5.3 HHRA – Problem Formulation Checklist

(See Sections 5.1.1 and 5.1.2 for further discussion)

a) Land Use

Land Use		
X	*Agricultural*	No agricultural land use identified within study area.
✓	*Residential*	Facility site and immediately adjacent land is industrial, though residential lands are located nearby. Pathways included for nearby residents.
X	*Commercial*	No commercial land is identified within the site or immediately adjacent lands.
✓	*Industrial*	Facility site and immediately adjacent lands identified as industrial.
✓	*Parkland*	The Boom Camp recreational area can be considered parkland. As such, receptor activities and pathways associated with this usage have been included.

b) Receptor Groups

Receptor Groups		
✓	*Public*	Members of the public, including nearby residents, represented in the study.
✓	*Employees*	Facility workers included in the study.
✓	*Construction*	Construction worker receptors not specified, however the hydro worker receptor (Receptor No. 5) activities/duties include soil sub-surface activities in order to address soil exposures (see Table 5.6)..
✓	*First Nations*	The Mississaugi First Nation is located on the northern extent of the residential grouping north of the BRR. As such, consumption of fish, wild game, and wild fowl have been included in this HHRA and are based on ingestion rates for First Nations peoples (see Table 5.6).

c) Critical Receptors

Critical Receptors		
✓	*Infant*	Worker receptors (Receptor No. 4, 5, and 6) are assumed to be adults only. Public receptors (Receptor No. 1, 2, and 3) include all 5 recommended age groups for non-radiological HHRA and 3 recommended age groups for radiological HHRA (CSA 2012).
✓	*Toddler*	
✓	*Child*	
✓	*Teen*	
✓	*Adult*	

d) Exposure Pathways

Exposure Pathways		
✓	*Incidental Soil Ingestion*	Included for relevant receptors (Receptor No. 2 - 6).
✓	*Soil dermal absorption*	Included for relevant receptors (Receptor No. 3 - 6).
✓	*Soil dust inhalation*	Included for on-site BRR worker receptors (Receptor No. 6).
X	*Soil vapour inhalation*	Not applicable. No volatile COPCs identified (see Section 5.1.3.9).
✓	*Groundwater incidental ingestion*	Included for on-site BRR worker receptors (Receptor No.6).
✓	*Groundwater dermal absorption*	Included for on-site BRR worker receptors (Receptor No.6).
X	*Groundwater vapour inhalation*	Not applicable. No volatile COPCs identified (see Section 5.1.3.9).
✓	*Drinking water ingestion*	Drinking water ingestion included for all receptors (source of drinking water varies, see Table 5.4).
✓	*Surface water incidental ingestion*	Included for relevant public receptors (Receptor No. 2, 3).
✓	*surface water dermal absorption*	Included for relevant public receptors (Receptor No. 2, 3).
✓	*Ingestion of local fish*	Included for resident receptors (Receptor No. 1).
✓	*ingestion of garden produce*	Included for resident receptors (Receptor No. 1).
✓	*Ingestion of wild game*	Included for resident receptors (Receptor No. 1).
✓	*Ingestion of wild fowl*	Included for resident receptors (Receptor No. 1).
✓	*Sediment incidental ingestion*	Included for boom camp public receptor, radiological only (Receptor No. 3).
✓	*Air inhalation*	Included for public receptors (Receptor No. 1 - 5); either indoor air or outdoor air, see Table 5.4.
✓	*External soil rad.*	Included for relevant receptors (Receptor No. 2 – 6).
✓	*External surface water rad.*	Included for public receptors that may swim, fall into, or bath using, surface water (Receptor No. 2, 3).
X	*External air rad.*	Excluded (see Section 5.1.3.9).
✓	*External sediment rad.*	Included for relevant public receptors that swim and recreate near shoreline (Receptor No. 3).
✓	*Direct gamma rad.*	Included for all receptors.

5.2 Exposure Assessment

5.2.1 Exposure Locations

The environmental media that a given human receptor is exposed to differs based on their location. For example, both worker and public receptors have the potential for exposure to soil, but the soil a worker receptor is exposed to different than the soil the public receptor is exposed to since these receptors occupy different locations.

Table 5.4 provides a tabular outline of each human receptor, the assessment areas they are associated with, and the corresponding environmental media they may be exposed to, based on the descriptions of the receptors and their behaviours presented in Table 5.1 (for worker receptors, this includes the nature of their duties).

For surface water, exposure is limited to the river and the lake (in other words, the on-site bog is excluded). Bog data are excluded because it is located within the BRR property boundary, within which access is restricted. Therefore, members of the public could not reasonably access bog surface water locations. Consistent with the BRR DRL (SENES 2013), on-site BRR worker receptors are exposed to lake surface water as drinking water, for the purposes of this HHRA.

Table 5.4 Human Receptors, Exposure Locations and Media

<table>
<tr><th>Receptor</th><th>Location</th><th>Environmental Media</th><th>Uptake/Exposure Route</th><th>Tier 1</th><th>Tier 2</th></tr>
<tr><td rowspan="8">1A Resident</td><td rowspan="8">Lantain</td><td rowspan="4">Soil</td><td>Consumption - Backyard Produce</td><td rowspan="4">Max. Measured Soil Concentration (regardless of location)</td><td rowspan="4">95th Percentile Measured Soil Concentration (regardless of location)</td></tr>
<tr><td>Consumption - Wild Game</td></tr>
<tr><td>External Exposure from Soil (Rad. Only)</td></tr>
<tr><td>Consumption - Wild Fowl</td></tr>
<tr><td>Surface Water</td><td>Consumption - Fish</td><td>Max. Measured Lake or River Concentration (regardless of location)</td><td>95th Percentile Measured Lake or River Concentration (regardless of location)</td></tr>
<tr><td>Air</td><td>Inhalation (indoor air)</td><td>½ Max. Modelled Air Conc (regardless of location)</td><td>N/A</td></tr>
<tr><td>Groundwater</td><td>Consumption - Drinking Water</td><td>Max. Measured GW Concentration (regardless of location)</td><td>95th Percentile Measured GW Concentration (regardless of location)</td></tr>
<tr><td>Gamma</td><td>External - Direct (Rad. Only)</td><td>Max. Measured Gamma Rate (regardless of location)</td><td>N/A</td></tr>
</table>

Table 5.4 Human Receptors, Exposure Locations and Media (Cont'd)

Receptor	Location	Environmental Media	Uptake/Exposure Route	Tier 1	Tier 2
1B Resident	*MFN*	Soil	Consumption - Backyard Produce	Max. Measured Soil Concentration *(regardless of location)*	95th Percentile Measured Soil Concentration *(regardless of location)*
			Consumption - Wild Game		
			External Exposure from Soil *(Rad. Only)*		
			Consumption - Wild Fowl		
		Surface Water	Consumption - Fish	Max. Measured Lake & River Concentration *(regardless of location)*	95th Percentile Measured Lake & River Concentration *(regardless of location)*
		Air	Inhalation (indoor air)	½ Max. Modelled Air Conc *(regardless of location)*	N/A
		Groundwater	Consumption - Drinking Water	Max. Measured GW Concentration *(regardless of location)*	95th Percentile Measured GW Concentration *(regardless of location)*
		Gamma	*External - Direct (Rad. Only)*	Max. Measured Gamma Rate *(regardless of location)*	N/A
1C Resident	*Railway*	Soil	Consumption - Backyard Produce	Max. Measured Soil Concentration *(regardless of location)*	95th Percentile Measured Soil Concentration *(regardless of location)*
			Consumption - Wild Game		
			External Exposure from Soil *(Rad. Only)*		
			Consumption - Wild Fowl		
		Surface Water	Consumption - Fish	Max. Measured Lake & River Concentration *(regardless of location)*	95th Percentile Measured Lake & River Concentration *(regardless of location)*
		Air	Inhalation (indoor air)	½ Max. Modelled Air Conc *(regardless of location)*	N/A
		Groundwater	Consumption - Drinking Water	Max. Measured GW Concentration *(regardless of location)*	95th Percentile Measured GW Concentration *(regardless of location)*
		Gamma	*External - Direct (Rad. Only)*	Max. Measured Gamma Rate *(regardless of location)*	N/A

Table 5.4 Human Receptors, Exposure Locations and Media (Cont'd)

Receptor	Location	Environmental Media	Uptake/Exposure Route	Tier 1	Tier 2
1D Resident	*Colonization St.*	Soil	Consumption - Backyard Produce Consumption - Wild Game External Exposure from Soil *(Rad. Only)* Consumption - Wild Fowl	Max. Measured Soil Concentration *(regardless of location)*	95th Percentile Measured Soil Concentration *(regardless of location)*
		Surface Water - Lake	Consumption - Fish	Max. Measured Lake & River Concentration *(regardless of location)*	95th Percentile Measured Lake & River Concentration *(regardless of location)*
		Air	Inhalation (indoor air)	½ Max. Modelled Air Conc *(regardless of location)*	N/A
		Groundwater	Consumption - Drinking Water	Max. Measured GW Concentration *(regardless of location)*	95th Percentile Measured GW Concentration *(regardless of location)*
		Gamma	*External - Direct (Rad. Only)*	Max. Measured Gamma Rate *(regardless of location)*	N/A
2 Cottager	*Lake Shore, SW of River.*	Soil	Incidental Ingestion External Exposure from Soil *(Rad. Only)*	Max. Measured Soil Concentration *(regardless of location)*	N/A
		Surface Water - Lake	Fall into water - Dermal Fall into water - Incidental Ingestion Consumption – Fish Consumption - Drinking Water *External - Immersion (Rad. Only)*	Max. Measured Lake & River Concentration *(regardless of location)*	95th Percentile Measured Lake & River Concentration *(regardless of location)*
		Air	Inhalation (indoor air)	½ Max. Modelled Air Conc *(regardless of location)*	N/A
			Inhalation (outdoor air)	Max. Modelled Air Conc *(regardless of location)*	
		Gamma	*External - Direct (Rad. Only)*	Max. Measured Gamma Rate *(regardless of location)*	N/A

Table 5.4 Human Receptors, Exposure Locations and Media (Cont'd)

Receptor	Location	Environmental Media	Uptake/Exposure Route	Tier 1	Tier 2
3 Boom Camp	*River Shore*	Soil	Dermal External Exposure from Soil *(Rad. Only)* Incidental Ingestion	Max. Measured Soil Concentration *(regardless of location)*	95th Percentile Measured Soil Concentration *(regardless of location)*
		Surface Water - Lake	Swim - Dermal Swim - Incidental Ingestion *External - Immersion (Rad. Only)* Consumption - Drinking Water	Max. Measured Lake & River Concentration *(regardless of location)*	95th Percentile Measured Lake & River Concentration *(regardless of location)*
		Air	Inhalation (outdoor)	Max. Modelled Air Concentration *(regardless of location)*	N/A
		Gamma	*External - Direct (Rad. Only)*	Max. Measured Gamma Rate *(regardless of location)*	N/A
		Sediment	External Dose *(Rad. Only)* Incidental Ingestion *(Rad. Only)*	Max. Measured Sediment Concentration *(regardless of location)*	N/A
4 Golf Worker	*Golf Course Club House*	Soil	Incidental Ingestion External Exposure from Soil *(Rad. Only)* Dermal	Max. Measured Soil Concentration *(regardless of location)*	N/A
		Surface Water - Lake	Consumption - Drinking Water	Max. Measured Lake & River Concentration *(regardless of location)*	95th Percentile Measured Lake & River Concentration *(regardless of location)*
		Air	Inhalation (outdoor)	Max. Modelled Air Concentration *(regardless of location)*	N/A
		Gamma	*External - Direct (Rad. Only)*	Max. Measured Gamma Rate *(regardless of location)*	N/A
5 Hydro Worker	*In-Town Hydro Site*	Soil	Incidental Ingestion External Exposure from Soil *(Rad. Only)* Dermal	Max. Measured Soil Concentration *(regardless of location)*	N/A
		Surface Water - Lake	Consumption - Drinking Water	Max. Measured Lake & River Concentration *(regardless of location)*	95th Percentile Measured Lake & River Concentration *(regardless of location)*

Table 5.4 Human Receptors, Exposure Locations and Media (Cont'd)

Receptor	Location	Environmental Media	Uptake/Exposure Route	Tier 1	Tier 2
		Air	Inhalation (outdoor)	Max. Modelled Air Concentration *(regardless of location)*	N/A
		Gamma	*External - Direct (Rad. Only)*	Max. Measured Gamma Rate *(regardless of location)*	N/A
6 On-Site Worker	*BRR Facility*	Soil	Incidental Ingestion	Max. Measured Soil Concentration *(regardless of location)*	N/A
			Dermal		
			External Exposure from Soil *(Rad. Only)*		
			Inhalation of Particulate/Dust		
		Surface Water - Lake	Consumption - Drinking Water	Max. Measured Lake & River Concentration *(regardless of location)*	95^{th} Percentile Measured Lake & River Concentration *(regardless of location)*
		Groundwater	Dermal	Max. Measured GW Concentration *(regardless of location)*	N/A
			Incidental Ingestion		
		Air	Inhalation dose accounted for using dust/particulate inhalation.	-	N/A
		Gamma	*External - Direct (Rad. Only)*	Max. Measured Gamma Rate *(regardless of location)*	N/A

Notes:
Drinking water sources for each receptor are consistent from those used in the BRR DRL (SENES 2013).

5.2.2 Exposure Factors, Durations & Frequencies

Table 5.5 presents the exposure factors for the HHRA (both non-radiological and radiological). Intake rates for fish, wild game, and wild fowl vary considerably from one source to the next. The BRR DRL (SENES 2013) uses values from HC (1994) which are indicative of ingestion rates for First Nations, these are typically higher (i.e. more conservative) than ingestion rates for non-First Nation peoples. Overall, the most conservative combination of exposure values between CSA N288.6 (CSA 2012) and the BRR DRL (SENES 2013) are used in the assessment and values that are not adopted are shaded in gray. References and brief rationale for each particular value are provided in the table.

Table 5.6 presents the exposure durations for the HHRA. The overall time frames used for human receptors are taken from the BRR DRL (SENES 2013). These are shown in part (a) of the table. However, for non-radiological HHRA calculations following the CSA (2012) methodology, these annual time fractions must be converted into equivalent hours, days, and weeks. These converted equivalent values are shown in part (b) of the table for each receptor (only the applicable pathways for each receptor are shown).

Table 5.5 HHRA Exposure Factors & Durations

a) Non-Radiological HHRA Exposure Factors *(HC (2010) unless otherwise noted; consistent with CSA (2012))*

Age Group[a]	Infant	Toddler	Child	Teen	Adult	Worker
Exposure Factors						
Age	0-6 months	7 months – 4 years	5-11 years	12-19 years	≥ 20 years	≥ 20 years
Age group duration (yrs)	0.5	4-5	7	8	61	30
Averaging time for carcinogens (yrs)	80	80	80	80	80	56
Body weight (kg)	8.2	16.5	32.9	59.7	70.7	70.7
Inhalation Rate (m^3/d)	2.2	8.3	14.5	15.6	16.6	1.4 m^3/hr
Exposed skin area – swimming (cm^2)	3,620	6,130	10,140	15,470	17,640	17,640
Exposed skin area – soil (hands & arms) (cm^2)	870	1,320	2,070	3,030	3,390	3,390
Incidental Soil Ingestion Rate (g/d)	0.02	0.08	0.02	0.02	0.02	0.1
Soil Loading (g/cm^2/event)	0.0001	0.0001	0.0001	0.0001	0.0001	0.001
Dermal event (ev/d)	1	1	1	1	1	1
Incidental Ingestion Rate while swimming (L/h) [b]	0.05	0.05	0.05	0.05	0.05	0
Drinking Water Ingestion Rate (L/d)	0.3	0.6	0.8	1	1.5	0
Incidental Groundwater Ingestion Rate (L/d)	0	0	0	0	0	0.01
Food - Local Fractions & Intakes						
Fish - Total Ingestion Rate[c] (g/d)	*0*	*56*	*90*	*104*	*111*	
Fish - Total Ingestion Rate (First Nations)[c] (g/d)	0	95	170	200	220	0
Fish - Local Fraction	*1.0 (most conservative in CSA (2014), following CSA (2012))*					
Fish – Local Ingestion Rate (g/d)	0	95	170	200	220	0
Produce – Total Ingestion Rate (g/d)[d]	155	172	259	347	325	0
Produce – Local Fraction[e]	*0.25 (most conservative in CSA (2014), following CSA (2012))*					
Produce – Local Ingestion Rate	39	43	65	87	81	0
Game – Total Ingestion Rate (g/d)	0	85	125	175	270	0
Game – Local Fraction	*0.5 (BRR DRL - SENES 2013; more conservative than CSA (2014), following CSA (2012))*					
Game – Local Ingestion Rate (g/d)	0	43	63	88	135	0
Fowl - Total Ingestion Rate (g/d)[e]	0 [e]	12.6 [e]	15.9 [e]	20.2 [e]	20.2 [e]	0
Fowl - Local Fraction [e]	*0.5 (BRR DRL - SENES 2013; more conservative than CSA (2014), following CSA (2012))*					
Fowl - Local Ingestion Rate (g/d)	0	6.3	8.0	10.1	10.1	0

Notes:
[a] In the radiological assessment, three age groups were considered based on CSA (2014); these age groups correspond to the Infant, Child and Adult age groups presented above.
[b] Water ingestion rate while swimming: 0.05 L/hr from U.S. EPA 1989 (value for non-competitive swimming).
[c] HC (2004) PQRA Guidance.
[d] HC (2010) PQRA, values for root vegetables plus other vegetables.
[e] Data from BRR DRL (SENES 2013): values derived for 1-yr old have been applied to the toddler (to match age range); values derived for adult have been applied to the teen (conservative, versus applying child values to teen); infants 0-6 months old assumed not to consume local wild fowl.
Shaded values – not used in the assessment as they are less conservative than values from other sources.

b) Radiological HHRA Exposure Factors *(CSA (2014) unless otherwise noted; consistent with CSA (2012))*

Age Group[a]	Infant	Child	Adult	Ref.
Exposure Factors				
Age	0-5 months	6-15 years	16-70 years	N288.1 (2014) – Following N288.6
Inhalation Rate (m^3/hr)	0.31	0.89	0.96	N288.1 (2014) Table 19 (95th Percentile) – Following N288.6
Inhalation Rate (m^3/hr)	*0.38*	*0.6*	*0.66*	*BRR DRL – HC 2004 (PQRA) or 1993.*
Incidental Ingestion Rate while swimming (L/h) [b]	0.05	0.05	0.05	US EPA 1989 – Following N288.6
Exposed skin area - swimming (cm^2)	7,200	14,600	21,900	N288. 1 (2014) Table 22 – Following N288.6
Incidental Soil Ingestion Rate (g/d)	0.204	0.185	0.02	N288. 1 (2014) Table 20 (95th Percentile) – Following N288.6
Incidental Soil Ingestion Rate (g/d)	*0.08*	*0.02*	*0.02*	*BRR DRL – HC 2004 (PQRA) or 1993.*
Drinking Water Ingestion Rate (L/d)	0.837	1.32	2.96	N288. 1 (2014) Table 21 (95th Percentile) – Following N288.6
Drinking Water Ingestion Rate (L/d)	*0.6*	*0.8*	*1.2*	*BRR DRL – HC 2004 (PQRA) or 1993.*
Food - Local Fractions & Intakes				
Fish - Total Ingestion Rate (g/d)	*56*	*90*	*111*	*SENES 2013 – based on HC 1994; more conservative than CSA (2014)*
Fish - Total Ingestion Rate - First Nations (g/d)	95	170	220	HC 2010 default for non-rad HHRA; more conservative than CSA (2014)
Fish - Local Fraction	0.5	0.5	0.5	BRR DRL (SENES 2013)
Fish - Local Ingestion Rate (g/d)	*Product of Total Ingestion Rate multiplied by Local Fraction*			
Produce - Total Ingestion Rate (g/d) [c]	342	726	1132	N288.1 (2014) Table G.9c – Following N288.6; more conservative than SENES (2013).
Produce - Local Fraction[d]	0.25	0.25	0.25	N288.1 (2014) – Following N288.6; more conservative than SENES (2013).
Produce - Local Ingestion Rate (g/d)	*Product of Total Ingestion Rate multiplied by Local Fraction*			
Game - Total Ingestion Rate (kg/y)	6.28	9.51	14.9	SENES 2013 – based on HC 1994; more conservative than N288.1 (2014)
Game - Total Ingestion Rate (g/d)	85	125	270	HC 2010 default for non-rad HHRA; more conservative than N288.1 (2014)
Game - Local Fraction	0.5	0.5	0.5	BRR DRL (SENES 2013) more conservative than N288.1 (2014); CSA (2012).
Game - Local Ingestion Rate (g/y)	*Product of Total Ingestion Rate multiplied by Local Fraction*			
Fowl - Total Ingestion Rate (g/y)	12.6	15.9	20.2	BRR DRL (SENES 2013) – based on HC 1994
Fowl - Local Fraction	0.5	0.5	0.5	BRR DRL (SENES 2013)
Fowl - Local Ingestion Rate (g/y)	*Product of Total Ingestion Rate multiplied by Local Fraction*			

Notes:
[a] In the radiological assessment, three age groups based on CSA (2014); these age groups correspond to the Infant, Child and Adult age groups.
[b] Water ingestion rate while swimming: 0.05 L/hr from U.S. EPA 1989 (value for non-competitive swimming).
[c] CSA (2014) values for fruit and berries, vegetables, and potatoes.
[d] CSA (2014) highest (most conservative) local fraction among fruit and berries, vegetables, and potatoes.
Shaded values – not used in the assessment as they are less conservative than values from other sources.

Table 5.6 HHRA Exposure Durations

a) Overall Exposure Time based on SENES (2013)

Receptor No.	Receptor Name	Residence (indoors)	Hydro	Golf Course	Boom Camp (outdoors)	BRR Facility
1A-D	Resident [a]	8566			200	
2	Cottager [b]	1403				
3	Boom Camp				200	
4	Golf Worker [d]	7366		1200	200	
5	Hydro Worker [c]	6566	2000		200	
6	On-Site Worker	6566			200	2000

Notes:
[a] Resident receptors and Boom Camp Receptors: Assumed to spend 10% of their time (200 hours) outdoors, at Boom Camp for recreational activities; and 90% of their time (8566 hours) indoors at their residence location.
[b] Cottage Receptor: Assumed to spend 16% of the year at the cottage location (exposure location); i.e. 16% of 8766 (a full year) is 1403 hours.
[c] Golf Course/Club Worker Receptor: Assumed to be a seasonal worker, with 1200 hours per year exposure time.
[d] Hydro Worker: Assumed to be a full-time worker, with 2000 hours per year exposure time.

b) Exposure Durations & Frequencies for HHRA

Receptor No.	Receptor Name	Time-based Exposures	Associated Activities	Pathways	Units	Infant	Toddler	Child	Teen	Adult
1A-D	RESIDENT	Time spent exposed to **indoor** air	**Time Indoors**	***Inhalation***	*(h/d)*	23.53	23.53	23.53	23.53	23.53
					(d/week)	7	7	7	7	7
					(weeks/y)	52	52	52	52	52
		Indoor Gamma exposure*	**Time Indoors**	***Direct Gamma***	*(h/d)*	23.53	23.53	23.53	23.53	23.53
					(d/week)	7	7	7	7	7
					(weeks/y)	52	52	52	52	52
		Exposure Duration (y)				0.5	4-5	7	8	61
		Averaging Time (y)		*Carcinogens*		80	80	80	80	80
				Non-carcinogens		1	1	1	1	1
2	COTTAGER	Time spent exposed to SW	**Fall into water**	***Dermal Inc. Ingestion Immersion****	*(h/d)*	0.00	0.20	0.20	0.20	0.20
					(d/week)	0	1	1	1	1
					(weeks/y)	0	1	1	1	1
			Bathing	***Immersion****	*(h/d)*	0.33		0.33		0.33
					(d/week)	7		7		7
					(weeks/y)	52		52		52
		Time spent exposed to soil	**Time Outdoors**	***Inc. Ingestion (Conservative)***	*(h/d)*	13.64	13.64	13.64	13.64	13.64
					(d/week)	3	3	3	3	3
					(weeks/y)	20	20	20	20	20
		Time spent exposed to **outdoor** air	**Time Outdoors**	***Inhalation***	*(h/d)*	13.64	13.64	13.64	13.64	13.64
					(d/week)	3	3	3	3	3
					(weeks/y)	20	20	20	20	20
		Time spent exposed to **indoor** air	**Time Indoors**	***Inhalation***	*(h/d)*	9.74	9.74	9.74	9.74	9.74
					(d/week)	3	3	3	3	3
					(weeks/y)	20	20	20	20	20
		Indoor Gamma exposure*	**Time Indoors**	***Direct Gamma***	*(h/d)*	9.74	9.74	9.74	9.74	9.74
					(d/week)	3	3	3	3	3
					(weeks/y)	20	20	20	20	20
		Outdoor Gamma exposure*	**Time Outdoors**	***Direct Gamma***	*(h/d)*	13.64	13.64	13.64	13.64	13.64
					(d/week)	3	3	3	3	3
					(weeks/y)	20	20	20	20	20
		Exposure Duration (y)				0.5	4-5	7	8	61
		Averaging Time (y)		*Carcinogens*		80	80	80	80	80
				Non-carcinogens		1	1	1	1	1
3		Time spent exposed to SW	**Swimming**	***Dermal***	*(h/d)*	0.55	0.55	0.55	0.55	0.55

Receptor No.	Receptor Name	Time-based Exposures	Associated Activities	Pathways	Units	Infant	Toddler	Child	Teen	Adult
	BOOM CAMP			***Inc. Ingestion Immersion****	*(d/week)*	7	7	7	7	7
					(weeks/y)	52	52	52	52	52
		Time spent exposed to sediment	**Swimming/ Recreating**	***Incidental Ingestion External (Rad)***	*(h/d)*	1 hr/d from May to October (CSA 2014, N288.1)				
					(d/week)					
					(weeks/y)					
		Time spent exposed to soil	**Time Outdoors**	***Dermal Inc. Ingestion***	*(h/d)*	0.55	0.55	0.55	0.55	0.55
					(d/week)	7	7	7	7	7
					(weeks/y)	52	52	52	52	52
		Time spent exposed to **outdoor** air	**Time Outdoors**	***Inhalation***	*(h/d)*	0.55	0.55	0.55	0.55	0.55
					(d/week)	7	7	7	7	7
					(weeks/y)	52	52	52	52	52
		Outdoor Gamma exposure*	**Time Outdoors**	***Direct Gamma***	*(h/d)*	0.55	0.55	0.55	0.55	0.55
					(d/week)	7	7	7	7	7
					(weeks/y)	52	52	52	52	52
		Exposure Duration (y)				0.5	4-5	7	8	61
		Averaging Time (y)		*Carcinogens*		80	80	80	80	80
				Non-carcinogens		1	1	1	1	1
4	GOLF WORKER	Time spent exposed to soil	**Time Outdoors**	***Dermal Inc. Ingestion (Conservative)***	*(h/d)*					10.00
					(d/week)					6
					(weeks/y)					20
		Time spent exposed to **outdoor** air	**Time Outdoors**	***Inhalation***	*(h/d)*					10.00
					(d/week)					6
					(weeks/y)					20
		Outdoor Gamma exposure*	**Time Outdoors**	***Direct Gamma***	*(h/d)*					10.00
					(d/week)					6
					(weeks/y)					20
		Exposure Duration (y)				0.5	4-5	7	8	61
		Averaging Time (y)		*Carcinogens*		80	80	80	80	80
				Non-carcinogens		1	1	1	1	1

Receptor No.	Receptor Name	Time-based Exposures	Associated Activities	Pathways	Units	Infant	Toddler	Child	Teen	Adult
5	HYDRO WORKER	Time spent exposed to soil	Time Outdoors	*Dermal Inc. Ingestion (Conservative)*	*(h/d)*					8.00
					(d/week)					5
					(weeks/y)					50
		Time spent exposed to **outdoor** air	Time Outdoors	*Inhalation*	*(h/d)*					8.00
					(d/week)					5
					(weeks/y)					50
		Outdoor Gamma exposure*	Time Outdoors	*Direct Gamma*	*(h/d)*					8.00
					(d/week)					5
					(weeks/y)					50
		Exposure Duration (y)				0.5	4-5	7	8	61
		Averaging Time (y)		*Carcinogens*		80	80	80	80	80
				Non-carcinogens		1	1	1	1	1
6	ON-SITE WORKER	Time spent exposed to soil	Time Outdoors	*Dermal Inc. Ingestion (Conservative)*	*(h/d)*					8.00
					(d/week)					5
					(weeks/y)					50
		Time spent exposed to **outdoor** air	Time Outdoors	*Inhalation*	*(h/d)*					8.00
					(d/week)					5
					(weeks/y)					50
		Time spent exposed to GW	GW Monitoring	*Dermal Inc. Ingestion*	*(h/d)*					8.00
					(d/week)					5
					(weeks/y)					50
		Outdoor Gamma exposure*	Time Outdoors	*Direct Gamma*	*(h/d)*					8.00
					(d/week)					5
					(weeks/y)					50
		Exposure Duration (y)				0.5	4-5	7	8	30
		Averaging Time (y)		*Carcinogens*		80	80	80	80	80
				Non-carcinogens		1	1	1	1	1

* - Radiological only

5.2.3 Exposure Point Concentrations (Levels)

As outlined in Table 5.4, there are many different environmental media that human receptors could potentially be exposed to. The following tables present the concentrations (or dose rates, for gamma) that are associated with the various environmental media. These summary statistics are used as exposure point concentrations in subsequent exposure calculations.

5.2.3.1 Non-Radiological

For Tier 1 exposure calculations, the maximum concentration in any particular environmental medium is used, regardless of its location. One exception is noted for surface water: where the maximum concentration is selected from among lake and river data, i.e. data from the on-site bog are not included in the selection. Bog data are excluded because the bog is located within the BRR property boundary, which has controlled access. Therefore, members of the public could not reasonably access bog surface water locations.

For Tier 2a exposure calculations, 95^{th} percentile concentrations in corresponding environmental medium are used. As mentioned above, surface water data from the bog are excluded.

Among groundwater TBP concentration data, as shown in Table 5.9 a single maximum concentration measurement of 3 mg/L was identified. However, this particular maximum value is suspect since it is well outside of the range of all other groundwater TBP measurements from 2012-2014. In addition, Cameco BRR has noted that the 3 mg/L value was not reproducible. Given these observations, the 3 mg/L TBP measurement is likely an outlier value. In Tier 1 assessment the 3 mg/L maximum measurement is used as the groundwater exposure concentration, for conservatism. In Tier 2a assessment the 95^{th} percentile is used as the groundwater exposure concentration, which has a similar effect as giving less weight to the outlier value. The 95^{th} percentile TBP concentration including the 3 mg/L was compared to the 95^{th} percentile TBP concentration excluding the 3 mg/L value, and the two results were found to be essentially equal.

Table 5.7 HHRA – Air Exposure Point Concentrations

COPCs	Units	Location	Max.
Uranium	µg/m^3	Outdoor	0.0005
Uranium	µg/m^3	Indoor	0.00025*

*Indoor air assumed equal to 50% of outdoor air (BRR DRL, SENES 2013).

Table 5.8 HHRA – Soil Exposure Point Concentrations

(All soil locations)

COPCs	Units	N	N < MDL	% < MDL	Min.	Max.	Arith. Mean	Geo. Mean	Std. Dev.	95th Perc.
Uranium	µg/g	140	140	0	0.09	22.10	2.05	0.99	3.35	8.06

Table 5.9 HHRA – Groundwater Exposure Point Concentrations

(All groundwater locations; see discussion above)

COPCs	Units	N	N < MDL	% < MDL	Min.	Max.	Arith. Mean*	Geo. Mean*	Std. Dev.*	95th Perc.*
Ammonia	mg/L as N	267	30	11	0.03	4.1	0.52	0.24	0.70	1.27
Uranium	µg/L	267	169	63	0.2	8.9	0.45	0.30	0.77	1.47
TBP	mg/L	140	135	96	0.6	3	0.62	0.61	0.20	0.60

*Non-detect values in database taken to be equal to their detection limits.

Table 5.10 HHRA – Surface Water Exposure Point Concentrations

(Lake and River; bog excluded, see Section 5.2.1)

COPCs	Units	N	N < MDL	% < MDL	Min.	Max.	Arith. Mean*	Geo. Mean*	Std. Dev.*	95th Perc.*
Uranium	µg/L	20	7	35	0.2	0.8	0.32	0.28	0.17	0.61
TBP	mg/L	8	8	100	<0.6	<0.6	N/A	N/A	N/A	N/A

*Non-detect values in database taken to be equal to their detection limits.

Table 5.11 HHRA – Tier 1 COPC Concentrations in Consumed Foods

COPC	Fish Concentration (µg/g FW)	Notes / Reference
U	0.000768	Calculated using TF from CSA N288.1 (2014) T A.25a (as shown in Table 6.16); max. surface water concentrations from Table 5.10 (i.e. excluding bog, due to limited access to public)
TBP	-	Literature-based transfer factor not available for TBP.
COPC	**Produce Concentration (µg/g FW)**	**Notes / Reference**
U	0.046	Soil-to-Plant: TF=0.01 kg/kg dw (Table G.3, CSA 2014) with max soil concentration (Table 5.8) and an assumed moisture content of 81%. Air-to-Plant: TF=8000 m^3/kg fw (Table A.5b -most conservative for all Ontario sites considered in CSA2014 - for generic fruits and vegetables, CSA 2014) with air concentration in Table 5.7.
COPC	**Wild Game Concentration (µg/g FW)**	**Notes / Reference**
U	0.00249	Based on EcoRA food chain transfer modelling for deer, which is based on max. measured uranium concentration in surface water (lake, river, and bog) and soil.
COPC	**Wild Fowl Concentration (µg/g FW)**	**Notes / Reference**
U	0.196	Based on EcoRA food chain transfer modelling for ruffed grouse, which is based on max. measured uranium concentration in surface water (lake, river, and bog) and soil.

Table 5.12 HHRA – Tier 2a COPC Concentrations in Consumed Foods

COPC	Fish Concentration (µg/g FW)	Notes / Reference
TBP	-	Literature-based transfer factor not available for TBP.
COPC	**Produce Concentration (µg/g FW)**	**Notes / Reference**
U	0.0193	Soil-to-Plant: TF=0.01 kg/kg dw (Table G.3, CSA 2014) with 95th percentile soil concentration (Table 5.8) and an assumed moisture content of 81%. Air-to-Plant: TF=8000 m^3/kg fw (Table A.5b -most conservative for all Ontario sites considered in CSA2014 - for generic fruits and vegetables, CSA 2014) with air concentration in Table 5.7
COPC	**Wild Game Concentration (µg/g FW)**	**Notes / Reference**
U	9.19E-04	Based on EcoRA food chain transfer modelling for deer, which is based on 95th percentile of measured uranium concentration in surface water (lake, river, and bog) and soil.
COPC	**Wild Fowl Concentration (µg/g FW)**	**Notes / Reference**
U	0.0717	Based on EcoRA food chain transfer modelling for ruffed grouse, which is based on 95th percentile of measured uranium concentration in surface water (lake, river, and bog) and soil.

5.2.3.2 Radiological

For radiological exposure calculations, measured radionuclide levels in any particular environmental medium are used, regardless of the location of each measurement (subject to the availability of radionuclide data). One exception is noted for surface water: where the maximum concentration is selected from among lake and river data, i.e. data from the on-site bog are not included in the selection. Bog data are excluded because the bog is located within the BRR property boundary, and members of the public would not reasonably access bog surface water for drinking or swimming.

For Ra-226, radionuclide measurements are available for select media and are used.

For U-238, U-234, and U-235, activity is correlated from measured $U_{natural}$ concentrations in environmental media (see section 5.2.3.1), following the methodology in Lowe (2004).

For other radionuclides – which do not have measured data – their concentrations in environmental media are estimated by applying known radionuclide ratios in effluent, as described in Section 2.5.8.2. The resulting radionuclide concentrations in environmental media and dietary intakes are shown in Table 5.13 and Table 5.14.

For the contact with contaminated soil deposits pathway, soil concentrations are evaluated on a contaminated surface area basis (Bq/m^2). To assess this pathway, maximum soil concentrations, available on a mass basis in Bq/gDW were converted from a mass concentration to a volume concentration using a density of 1600 kg/m^3 (US NRC (1977)). It was assumed, conservatively, that the contamination was contained with the top 1 cm of soil and using this assumption an activity by surface area was calculated.

$$Soil\ Conc\ \left(\frac{Bq}{m2}\right) = Soil\ Conc\left(\frac{Bq}{gDW}\right) \times 1000\ (\frac{g}{kg}) \times 1600(\frac{kg}{m^3}) \times 0.01(m)$$

Table 5.13 HHRA – Radionuclide Levels in Environmental Media

(See Section 2.5.8 for discussion on radionuclide levels in environmental media)

Radionuclide	Air Concentration (Bq/m^3)	Notes / Reference
Pb-210	7.10E-08	Estimated using ratios of U_{nat} to other radionuclides in airborne effluent. See discussion in Section 2.5.8.2.
Po-210	7.10E-08	Estimated using ratios of U_{nat} to other radionuclides in airborne effluent. See discussion in Section 2.5.8.2.
Ra-226	3.85E-08	Estimated using ratios of U_{nat} to other radionuclides in airborne effluent. See discussion in Section 2.5.8.2.
Th-230	9.20E-08	Estimated using ratios of U_{nat} to other radionuclides in airborne effluent. See discussion in Section 2.5.8.2.
U-234	6.18E-06	Specific Activity: Correlated from max. U_{nat} in air (from SENES 2015), using Lowe (2004)
U-235	2.85E-07	Specific Activity: Correlated from max. U_{nat} in air (from SENES 2015), using Lowe (2004)
U-238	6.18E-06	Specific Activity: Correlated from max. U_{nat} in air (from SENES 2015), using Lowe (2004)
Radionuclide	**Groundwater Concentration (Bq/L)**	**Notes / Reference**
Pb-210	3.92E-04	Estimated using ratios of U_{nat} to other radionuclides in liquid effluent. See discussion in Section 2.5.8.2.
Po-210	3.92E-04	Estimated using ratios of U_{nat} to other radionuclides in liquid effluent. See discussion in Section 2.5.8.2.
Ra-226	3.00E-02	Maximum measured groundwater concentration
Th-230	1.25E-03	Estimated using ratios of U_{nat} to other radionuclides in liquid effluent. See discussion in Section 2.5.8.2.
U-234	1.10E-01	Specific Activity: Correlated from max. U_{nat} in GW using Lowe (2004)
U-235	5.06E-03	Specific Activity: Correlated from max. U_{nat} in GW using Lowe (2004)
U-238	1.10E-01	Specific Activity: Correlated from max. U_{nat} in GW using Lowe (2004)
Radionuclide	**Soil Concentration (Bq/g dw)**	**Notes / Reference**
Pb-210	3.14E-03	Estimated using ratios of U_{nat} to other radionuclides in airborne effluent. See discussion in Section 2.5.8.2.
Po-210	3.14E-03	Estimated using ratios of U_{nat} to other radionuclides in airborne effluent. See discussion in Section 2.5.8.2.
Ra-226	1.70E-03	Estimated using ratios of U_{nat} to other radionuclides in airborne effluent. See discussion in Section 2.5.8.2.
Th-230	4.07E-03	Estimated using ratios of U_{nat} to other radionuclides in airborne effluent. See discussion in Section 2.5.8.2.
U-234	2.73E-01	Specific Activity: Correlated from max. U_{nat} in soil using Lowe (2004)
U-235	1.26E-02	Specific Activity: Correlated from max. U_{nat} in soil using Lowe (2004)
U-238	2.73E-01	Specific Activity: Correlated from max. U_{nat} in soil using Lowe (2004)

Radionuclide	Surface Water Concentration *(lake & river; excl. bog)* (Bq/L)	Notes / Reference
Pb-210	3.52E-05	Estimated using ratios of U_{nat} to other radionuclides in liquid effluent. See discussion in Section 2.5.8.2.
Po-210	3.52E-05	Estimated using ratios of U_{nat} to other radionuclides in liquid effluent. See discussion in Section 2.5.8.2.
Ra-226	9.00E-03	Maximum measured surface water concentration (lake & river)
Th-230	1.12E-04	Estimated using ratios of U_{nat} to other radionuclides in liquid effluent. See discussion in Section 2.5.8.2.
U-234	9.88E-03	Specific Activity: Correlated from max. U_{nat} in surface water (lake & river) using Lowe (2004)
U-235	4.55E-04	Specific Activity: Correlated from max. U_{nat} in surface water (lake & river) using Lowe (2004)
U-238	9.88E-03	Specific Activity: Correlated from max. U_{nat} in surface water (lake & river) using Lowe (2004)
Radionuclide	**Sediment Concentration *(Based on Kd)* (Bq/g dw)**	**Notes / Reference**
Pb-210	9.50E-06	Kd: Bechtel Jacobs (1998)
Po-210	5.28E-06	Kd: Bechtel Jacobs (1998)
Ra-226	6.66E-02	Kd: CSA N288.1 (2014), Table A.26
Th-230	2.13E-02	Kd: CSA N288.1 (2014), Table A.26
U-234	4.94E-04	Kd: CSA N288.1 (2014), Table A.26
U-235	2.28E-05	Kd: CSA N288.1 (2014), Table A.26
U-238	4.94E-04	Kd: CSA N288.1 (2014), Table A.26
Radionuclide	**Surface Water Concentration *(lake, river, & bog; for estimating wild game & wild fowl concentrations - Table 5.14)* (Bq/L)**	**Notes / Reference**
Pb-210	3.26E-04	Estimated using ratios of U_{nat} to other radionuclides in liquid effluent. See discussion in Section 2.5.8.2.
Po-210	3.26E-04	Estimated using ratios of U_{nat} to other radionuclides in liquid effluent. See discussion in Section 2.5.8.2.
Ra-226	0.02	Maximum measured surface water concentration (lake, river, and bog)
Th-230	1.04E-03	Estimated using ratios of U_{nat} to other radionuclides in liquid effluent. See discussion in Section 2.5.8.2.
U-234	9.14E-02	Specific Activity: Correlated from max. U_{nat} in surface water (lake, river, and bog) using Lowe (2004)
U-235	4.21E-03	Specific Activity: Correlated from max. U_{nat} in surface water (lake, river, and bog) using Lowe (2004)
U-238	9.14E-02	Specific Activity: Correlated from max. U_{nat} in surface water (lake, river, and bog) using Lowe (2004)

Table 5.14 HHRA – Radionuclide Levels in Dietary Intakes

Radionuclide	Fish Concentration (Bq/g FW)	Notes / Reference
Pb-210	8.80E-07	Calculated using TF from IAEA (2010) Table 57 (muscle); surface water concentrations from Table 5.13 (i.e. *excluding* bog, due to limited access to public)
Po-210	1.27E-06	
Ra-226	3.60E-05	Calculated using TF from CSA N288.1 (2014) T A.25a; surface water concentrations from Table 5.13 (i.e. *excluding* bog, due to limited access to public)
Th-230	6.72E-07	
U-234	9.48E-06	
U-235	4.37E-07	
U-238	9.48E-06	
Radionuclide	**Produce Concentration (Bq/g FW)**	**Notes / Reference**
Pb-210	1.86E-04	Calculated using TF from IAEA (2010) Table 17; soil concentrations from Table 5.13
Po-210	7.22E-05	
Ra-226	3.58E-05	Calculated using TF from CSA N288.1 (2014) T G.3 (Plant CR); soil concentrations from Table 5.13 and an assumed moisture content of 81%. Air-to-Plant:TF=8000 m^3/kg fw (Table A.5b -most conservative for all Ontario sites considered in CSA2014 - for generic fruits and vegetables, CSA 2014) with air concentration in Table 5.13.
Th-230	3.29E-06	
U-234	5.68E-04	
U-235	2.62E-05	
U-238	5.68E-04	
Radionuclide	**Wild Game Concentration (Bq/g FW)**	**Notes / Reference**
Pb-210	5.09E-06	Deer tissue concentration based on food-chain calculations; consumption of vegetation and surface water. Vegetation concentration calculated using TF as outlined in EcoRA; soil concentrations from Table 5.13. Surface water concentrations from Table 5.13 (i.e. *including* bog)
Po-210	1.62E-05	
Ra-226	3.50E-06	
Th-230	2.26E-07	
U-234	3.08E-05	
U-235	1.42E-06	
U-238	3.08E-05	
Radionuclide	**Wild Fowl Concentration (Bq/g FW)**	**Notes / Reference**
Pb-210	1.31E-04	Grouse tissue concentration based on food-chain calculations; consumption of vegetation, invertebrates, surface water. Vegetation and invertebrate concentrations calculated using TF as outlined in EcoRA; soil concentrations from Table 5.13. Surface water concentrations from Table 5.13 (i.e. *including* bog)
Po-210	1.87E-04	
Ra-226	1.30E-06	
Th-230	7.58E-07	
U-234	2.42E-03	
U-235	1.12E-04	
U-238	2.42E-03	

Notes:

* See Section 2.5.8 for broader overall discussion on estimating radionuclide levels in environmental media using existing measurement data.

5.2.3.3 External Gamma

Table 5.15 and Table 5.16 present gamma dose rate measurements from 2014 at fenceline monitoring stations and Hi-Vol monitoring stations (respectively). The locations of gamma monitoring stations are discussed in Section 2.5.7.

Table 5.15 HHRA – Measured Gamma Dose Rates at Fenceline Monitoring Stations

2014 – Q1: January to March (µSv/hr)			
Fenceline	**January**	**February**	**March**
East	0.42	0.43	0.38
North	0.6	0.27	0.23
South	0.44	0.36	0.34
West	0.79	0.89	1.13
2014 – Q2: April to June (µSv/hr)			
Fenceline	**April**	**May**	**June**
East	0.4	0.36	0.39
North	0.26	0.24	0.27
South	0.42	0.43	0.46
West	1.15	1	0.58
2014 – Q3: July to September (µSv/hr)			
Fenceline	**July**	**August**	**September**
East	0.28	0.3	0.3
North	0.22	0.27	0.28
South	0.29	0.34	0.33
West	0.47	0.52	0.52
2014 – Q4: October to December (µSv/hr)			
Fenceline	**October**	**November**	**December**
East	0.34	0.29	0.33
North	0.28	0.23	0.23
South	0.35	0.35	0.35
West	0.55	0.47	1.61

Table 5.16 HHRA – Measured Gamma Dose Rates at Hi-Vol Monitoring Stations

Location	Date/Time Out	Date/Time In	Total Time (Hrs)	Measured Dose (mSv)	Resulting Dose Rate (µSv/hr)
2014 – Q1 (January to March)					
S.E. Yard	Jan. 2 @ 15:15	April 2 @15:15	2160	0.5	0.23
East Yard	Jan. 2 @ 15:15	April 2 @15:15	2160	0.39	0.18
Golf Course	Jan. 2 @ 15:15	April 2 @15:15	2160	0.24	0.11
Hydro Yard	Jan. 2 @ 15:15	April 2 @15:15	2160	0.24	0.11
Town STP	Jan. 2 @ 15:15	April 2 @15:15	2160	0.24	0.11
2014 – Q2 (April to June)					
S.E. Yard	April 2 @15:15	June 26 @14:25	2039	0.51	0.25
East Yard	April 2 @15:15	June 26 @14:25	2039	0.47	0.23
Golf Course	April 2 @15:15	June 26 @14:25	2039	0.27	0.13
Hydro Yard	April 2 @15:15	June 26 @14:25	2039	0.27	0.13
Town STP	April 2 @15:15	June 26 @14:25	2039	0.27	0.13
2014 – Q3 (July to September)					
S.E. Yard	June 26 @14:25	Oct. 1 @ 13:30	2328	0.39	0.17
East Yard	June 26 @14:25	Oct. 1 @ 13:30	2328	0.44	0.19
Golf Course	June 26 @14:25	Oct. 1 @ 13:30	2328	0.29	0.12
Hydro Yard	June 26 @14:25	Oct. 1 @ 13:30	2328	0.26	0.11
Town STP	June 26 @14:25	Oct. 1 @ 13:30	2328	0.27	0.12
2014 – Q4 (October to December)					
S.E. Yard	Oct. 1 @ 13:30	Jan. 6 @ 14:00	2328.5	0.44	0.19
East Yard	Oct. 1 @ 13:30	Jan. 6 @ 14:00	2328.5	0.44	0.19
Golf Course	Oct. 1 @ 13:30	Jan. 6 @ 14:00	2328.5	0.27	0.12
Hydro Yard	Oct. 1 @ 13:30	Jan. 6 @ 14:00	2328.5	0.28	0.12
Town STP	Oct. 1 @ 13:30	Jan. 6 @ 14:00	2328.5	0.27	0.12

5.2.3.4 Sediment – Measured vs. Derived

This section compares derived sediment concentrations (based on surface water concentrations and distribution coefficients (Kds)) to measured sediment concentrations obtained from field sampling activities, for select COPCs and radionuclides.

Table 5.17 Comparison of Measured vs. Derived Sediment Concentrations

COPCs	Units	Min.	Max.	Arith. Mean	Geo. Mean	95th Perc.	Derived Sed. Conc (Max) [a]	Derived Sed. Conc (95th Percentile) [b]
Uranium	µg/g	0.39	0.64	0.50	0.50	0.59	0.04	0.0305
TBP	µg/g	[d]	[d]	[d]	[d]	[d]	[e]	[e]
Pb-210	Bq/g	<0.1	<0.1	NA	NA	NA	0.0027	0.002
Po-210	Bq/g	0.015	0.039	0.028	0.027	0.036	0.0015	0.0011
Ra-226	Bq/g	<0.1	<0.1	NA	NA	NA	0.0666	0.0525
Th-230	Bq/g	<0.8	<0.8	NA	NA	NA	1.877	1.431
U-234	Bq/g	[f]	[f]	[f]	[f]	[f]	0.0005	0.0004
U-235	Bq/g	<0.1	<0.1	NA	NA	NA	0.00002	0.00002
U-238	Bq/g	[f]	[f]	[f]	[f]	[f]	0.0005	0.0004

[a] Derived sediment concentration using Kd values; maximum SW concentrations from lake and river; specific activity conversion from measured U_{nat} to U-234, U-235, U-238; measured Ra-226; seqular equilibrium assumed for other radionuclides.
[b] Derived sediment concentration using Kd values; 95th percentile SW concentrations from lake and river; activity conversion from measured U_{nat} to U-234, U-235, U-238; measured Ra-226; seqular equilibrium assumed for other radionuclides.
[c] Surface water data not available for vanadium.
[d] TBP not measured in sediment.
[e] Kd for TBP not available.
[f] Not measured in sediment.

Table 5.17 indicates that measured uranium concentrations are higher than their corresponding Kd-based estimates. For radionuclides – excluding Po-210 – measured data show entirely non-detect results with MDLs that are higher than the corresponding Kd-estimated values; further interpretation is difficult, though these results indicate that the low Kd-estimated concentrations are not unreasonable. For Po-210, measured levels are higher than the corresponding Kd-estimated levels; this indicates that it is more appropriate to use measured concentrations of Po-210 rather than Kd-estimated concentrations.

For perspective, the maximum measured Po-210 level in sediment (0.039 Bq/g) can be compared to the most conservative (most restrictive) SENES (2006b) sediment No-Effect Concentration (NEC) (36.8 Bq/g) for ecological receptors. From this comparison it is clear that the even the maximum measured Po-210 level is 943x less than the estimated NEC in sediment.

Supplemental radiological HHRA results based on measured levels of radionuclides and uranium are presented in Table 5.23 and Table 5.24, and are discussed in Section 5.4.4.1.

5.2.4 Radiological Dose Calculation Methods

5.2.4.1 Internal Dose from Inhalation

The radiological dose from inhalation is calculated for each radionuclide using Equation 5-1, based on the methodology from CSA (2012):

$$D_{inh} = IR \times DC_{inh} \times C_{air} \times OF_i \qquad (5\text{-}1)$$

Where:

D_{inh}	=	internal radiation dose from inhalation [Sv/yr]
IR	=	inhalation rate [m^3/yr]
DC_{inh}	=	inhalation dose coefficient [Sv/Bq]
C_{air}	=	concentration in air [Bq/m^3]
OF	=	occupancy factor (fraction of time exposed) [unitless]

5.2.4.2 Internal Dose from Incidental Ingestion of Groundwater

The radiological dose from incidental ingestion of groundwater is calculated for each radionuclide using Equation 5-2, based on the incidental soil ingestion methodology from CSA (2012):

$$D_{gw} = I_{gw} \times EF_{gw} \times DC_f \times C_{gw} \qquad (5\text{-}2)$$

Where:

D_{gw}	=	internal radiation dose from incidental ingestion of groundwater [Sv/yr]
I_{gw}	=	incidental groundwater ingestion rate [L/d]
EF_{gw}	=	days per year in which the incidental ingestion could occur [d/yr]
DC_f	=	internal dose coefficient for intake by ingestion [Sv/Bq]
C_{gw}	=	concentration in groundwater [Bq/L]

5.2.4.3 Internal Dose from Incidental Ingestion of soil or Sediment

The radiological dose from incidental ingestion of soil is calculated for each radionuclide, following Equation 5-3 (CSA 2012):

$$D_s = I_s \times EF_s \times DC_f \times C_s \qquad (5\text{-}3)$$

Where:

D_s	=	internal radiation dose from incidental ingestion of soil [Sv/yr]
I_s	=	incidental soil ingestion rate [kg/d]
EF_s	=	days per year in which the incidental ingestion could occur [d/yr]

DC_f = internal dose coefficient for intake by ingestion [Sv/Bq]
C_s = concentration in soil [Bq/kg]

5.2.4.4 Internal Dose from Ingestion of Contaminated Foods

The radiological dose from ingestion of contaminated food is calculated for each radionuclide, following Equation 5-4 (CSA 2012):

$$D_f = \rho_f \times g_f \times I_f \times DC_f \times C_f \quad (5\text{-}4)$$

Where:

D_f = internal radiation dose from ingestion of contaminated food [Sv/yr]
ρ_f = adjustment factor for food processing (assumed to be 1) [unitless]
g_f = fraction of food from contaminated source (assumed to be 1) [unitless]
I_s = food ingestion rate [kg/yr]
DC_f = internal dose coefficient for intake by ingestion [Sv/Bq]
C_s = concentration in soil [Bq/kg]

5.2.4.5 External Dose from Immersion in Surface Water

The radiological external dose from immersion in surface water (while swimming, or falling into the water) is calculated for each radionuclide, following Equation 5-5 (CSA 2012):

$$D_{wi} = DC_{wi} \times (OF_w + D_c \times \rho \times OF_w' + \rho \times OF_w'') \times C_{wi} \quad (5\text{-}5)$$

Where:

D_{wi} = external radiation dose from immersion in water [Sv/hr]
DC_{wi} = external dose coefficient for immersion in contaminated water [Sv/yr per Bq/L]
OF_w = fraction of the year spent immersed in surface water [unitless]
D_c = Correction factor to account for finite size of bathtub – not applicable for immersion in surface water body [unitless]
ρ = correction factor to account for processes that may remove radionuclides from water (e.g., sedimentation, water treatment plant, etc.) – assumed no removal [unitless]
OF_w’ = fraction of time spent bathing [unitless]
OF_w” = fraction of time spent swimming in pool – not applicable, swimming assumed to occur in surface water (assumed equal to zero) [unitless]
C_{wi} = surface water concentration for immersion [Bq/L]

5.2.4.6 External dose from contaminated ground deposits

$$Dose_g = f_o \times f_r \times [f_u + (1 - f_u) \times S_g] \times DC_g \times C_g$$

Where:

f_o = fraction of total time spent by the individual at the exposure location [unitless[
f_r = dose reduction factor to account for non-uniformity of the ground surface [unitless]
f_u = time spent outdoors at the exposure location as a fraction of total time spent at that location [unitless]
S_g = shielding factor for groundshine, or fraction of the outdoor groundshine dose received indoors due to shielding by buildings [unitless]
DC_g = effective dose coefficient for an infinite plane ground deposit [$Sv \bullet a^{-1} \bullet Bq^{-1} \bullet m^2$]
C_g = activity in ground surface [$Bq \bullet m^{-2}$]

5.2.4.7 External Dose from contaminated shoreline sediment (beach sand)

$$Dose_s = OF_s \times W \times DC_s \times DF_s$$

Where:

OF_s = shoreline occupancy factor, or fraction of time an individual spends on contaminated shoreline (unitless)
W = shore-width factor that describes the shoreline exposure geometry (unitless)
DC_s = dose coefficient for a sediment uniformly contaminated to a depth of 5 cm ($Sv \bullet a^{-1} \bullet Bq^{-1} \bullet kg$ dw)
DF_s = dilution factor for shoreline deposits that allows for non-equilibrium between suspended sediment and shoreline deposits (unitless)

5.2.5 Dose Coefficients

Radiological assessment involves the use of dose coefficients (DCs) that convert levels of radionuclides in environmental media or intakes into radiation doses to human receptors. In the case of external exposure to gamma radiation, on-site monitoring measurements were used.

The DCs used in the radiological HHRA calculations were selected from literature references using the following hierarchy, consistent with CSA (2012). DCs for worker external air and water immersion doses - i.e., US EPA 1993a, as recommended in CSA (2012) - are not required since these pathways are not applicable to on-site worker receptors (see Table 5.4).

1. *On-Site Worker Receptors (non-NEWs) (See Section 5.1.1)*

    a. ICRP 68 (1994)

2. *Off-Site Member of the Public Receptors (See Section 5.1.1):*

    a. CSA N288.1 (2014); and

    b. ICRP 72 (1995).

Table 5.18 summarizes the DCs that were selected for the HHRA calculations.

Table 5.18 HHRA – Dose Coefficients

(a) On-Site Worker Receptors (ICRP #68, 1994)

COPCs	Inhalation	Ingestion
	Sv/Bq	*Sv/Bq*
Pb-210	1.10E-06	6.80E-07
Po-210	3.00E-06	2.40E-07
Ra-226	1.60E-05	2.80E-07
Th-230	4.00E-05	2.10E-07
U-234	8.50E-06	4.90E-08
U-235	7.70E-06	4.60E-08
U-238	7.30E-06	4.40E-08

Notes:

Pb-210 includes Bi-210;

Ra-226 includes Pb-214, Bi-214, Po-218 and Po-214.

(b) Off-Site Member of the Public Receptors

Radionuclide	Effective Dose Coefficients for Ingestion (in Sv/Bq)			
	Infant	Child	Adult	Ref
Pb-210	3.61E-06	2.20E-06	6.91E-07	ICRP 72 (1995), for ages 1 yr, 5 yr and Adult
Po-210	8.80E-06	4.40E-06	1.20E-06	ICRP 72 (1995), for ages 1 yr, 5 yr and Adult
Ra-226	9.60E-07	8.00E-07	2.80E-07	CSA N288.1 (2014), Table C.2
Th-230	4.10E-07	3.10E-07	2.10E-07	ICRP 72 (1995), for ages 1 yr, 5 yr and Adult
U-234	1.30E-07	7.40E-08	4.90E-08	CSA N288.1 (2014), Table C.2
U-235	1.30E-07	7.10E-08	4.70E-08	CSA N288.1 (2014), Table C.2
U-238	1.20E-07	6.80E-08	4.50E-08	CSA N288.1 (2014), Table C.2
Radionuclide	Effective Dose Coefficients for Immersion in Water (in Sv/y per Bq/m3)			
	Infant	Child	Adult	Ref
Pb-210	6.13E-12	6.13E-12	6.13E-12	U.S. EPA (1993a), Table III.2 (Adult values)
Po-210	2.85E-14	2.85E-14	2.85E-14	U.S. EPA (1993a), Table III.2 (Adult values)
Ra-226	1.20E-09	9.22E-10	9.22E-10	CSA N288.1 (2014), Table C.5
Th-230	1.24E-12	1.24E-12	1.24E-12	U.S. EPA (1993a), Table III.2 (Adult values)
U-234	5.71E-13	4.39E-13	4.39E-13	CSA N288.1 (2014), Table C.5
U-235	5.86E-10	4.51E-10	4.51E-10	CSA N288.1 (2014), Table C.5
U-238	3.27E-12	2.52E-12	2.52E-12	CSA N288.1 (2014), Table C.5
Radionuclide	Effective Dose Coefficients for Inhalation (in µSv per Bq)			
	Infant	Child	Adult	Ref
Pb-210	1.80E+01	1.10E+01	5.60E+00	ICRP 72 (1995): 1 yr, 5 yr and Adult - Type S
Po-210	1.40E+01	8.60E+01	4.30E+00	ICRP 72 (1995): 1 yr, 5 yr and Adult
Ra-226	1.10E+01	4.90E+00	3.50E+00	CSA N288.1 (2014) Table C.1
Th-230	3.50E+01	2.40E+01	1.40E+01	ICRP 72 (1995): 1 yr, 5 yr and Adult - Type S
U-234	1.10E+01	4.80E+00	3.50E+00	CSA N288.1 (2014) Table C.1
U-235	1.00E+01	4.30E+00	3.10E+00	CSA N288.1 (2014) Table C.1
U-238	9.40E+00	4.00E+00	2.90E+00	CSA N288.1 (2014) Table C.1
Radionuclide	Effective Dose Coefficients for External Dose from Soil (in Sv/yr per Bq/m^2)			
	Infant	Child	Adult	Ref
Pb-210	NA	NA	NA	Not Available
Po-210	NA	NA	NA	Not Available
Ra-226	6.93E-08	5.33E-08	5.33E-08	CSA N288.1 (2014) Table C.4 (+)
Th-230	NA	NA	NA	Not Available
U-234	2.41E-11	1.85E-11	1.85E-11	CSA N288.1 (2014) Table C.4
U-235	6.38E-09	4.91E-09	4.91E-09	CSA N288.1 (2014) Table C.4 (+)
U-238	4.77E-09	3.67E-09	3.67E-09	CSA N288.1 (2014) Table C.4 (+)
Radionuclide	Effective Dose Coefficients for External Dose from Sediment (in µSv/yr per Bq/kgDW)			
	Infant	Child	Adult	Ref
Pb-210	NA	NA	NA	Not Available
Po-210	NA	NA	NA	Not Available
Ra-226	1.97E+00	1.51E+00	1.51E+00	CSA N288.1 (2014) Table C.6 (+)
Th-230	NA	NA	NA	Not Available
U-234	1.02E-04	7.83E-05	7.83E-05	CSA N288.1 (2014) Table C.6
U-235	1.61E-01	1.24E-01	1.24E-01	CSA N288.1 (2014) Table C.6
U-238	2.76E-05	2.12E-05	2.12E-05	CSA N288.1 (2014) Table C.6

Notes:

Pb-210 includes Bi-210;

Ra-226 includes Pb-214, Bi-214, Po-218 and Po-214;

U-238 includes Th-234 and Pa-234m.

5.2.6 Non-Radiological Dose Calculation Methods

5.2.6.1 Incidental Ingestion of Soil

The non-radiological dose from incidental ingestion of soil is calculated for each COPC following Equation 5-7, based on CSA (2012):

$$D_s = \frac{C_s \times IR_s \times AF_{GIT} \times D_1 \times D_2 \times D_3}{BW \times LE}$$

(5-7)

Where:

D_s = dose from incidental ingestion of soil [mg/kg/d]

C_s = concentration of COPC in soil [mg/kg]

IR_s = incidental soil ingestion rate [kg/d]

AF_{GIT} = absorption factor for gastrointestinal tract (assumed equal to 1) [unitless]

D_1 = days per week exposed, divided by 7 days [d/d]

D_2 = weeks per year exposed, divided by 52 weeks [wk/wk]

D_3 = total years exposed to site (for carcinogens only) [yr]

BW = receptor body weight [kg]

LE = Life expectancy (for carcinogens only) [yr]

As shown in Table 5.5, an averaging time of 1 is used for assessing chronic exposure, whereas an averaging time of 0.5 is used for assessing short-term exposure (along with the appropriate short-term TRVs). In present calculations chronic exposure is assessed, and therefore the averaging time fraction is excluded.

5.2.6.2 Incidental Ingestion of Groundwater

The non-radiological dose from incidental ingestion of groundwater is calculated for each COPC, following Equation 5-8 (CSA 2012):

$$D_s = \frac{C_{gw} \times IR_{gw} \times AF_{GIT} \times D_1 \times D_2 \times D_3}{BW \times LE}$$

(5-8)

Where:

D_{gw} = dose from incidental ingestion of groundwater [mg/kg/d]

C_{gw} = concentration of COPC in groundwater [mg/L]

IR_{gw} = incidental groundwater ingestion rate [L/d]

AF_{GIT} = absorption factor for gastrointestinal tract (assumed equal to 1) [unitless]

D_1 = days per week exposed, divided by 7 days [d/d]

D_2 = weeks per year exposed, divided by 52 weeks [wk/wk]

D_3 = total years exposed to site (for carcinogens only) [yr]

BW = receptor body weight [kg]

LE = Life expectancy (for carcinogens only) [yr]

5.2.6.3 Ingestion of Contaminated Food

The non-radiological dose from ingestion of contaminated food is calculated for each COPC, following Equation 5-9 (CSA 2012):

$$D_{f\_ing} = \frac{[\sum(C_{food\_i} \times IR_{food\_i} \times RAF_{GIT} \times D_1)] \times D_2}{BW \times LE \times 365} \tag{5-9}$$

Where:

D_{f_ing} = dose from contaminated food ingestion [mg/kg/d]

C_{food_i} = concentration of COPC in food item "i" [mg/kg]

IR_{food_i} = ingestion rate of food item "i" [kg/d]

RAF_{GIT} = relative absorption factor for the gastrointestinal tract, for a particular COPC, in food item "i" (assumed equal to 1) [unitless]

D_1 = days per year over which the consumption of food "i" occurs [d/yr]

D_2 = total years exposed to site (for carcinogens only) [yr]

BW = receptor body weight [kg]

LE = Life expectancy (for carcinogens only) [yr]

365 = total days per year (constant) [d/yr]

For the purposes of this study, consumption of contaminated foods is assumed to occur 365 days per year (D1). Therefore, mathematically D1 (numerator) and 365 (denominator) in the equation above can be omitted.

Concentrations of COPCs in consumed foods are shown in Table 5.11.

5.2.6.4 Incidental Ingestion of Surface Water While Swimming

The non-radiological dose from incidental ingestion of surface water while swimming (or falling into the harbour) is calculated for each COPC, following Equation 5-10 (CSA 2012):

$$D_{sw} = \frac{C_{sw} \times IR_{sw} \times ET \times EF \times ED}{BW \times AT} \tag{5-10}$$

Where:

D_{sw}	=	dose from incidental ingestion of surface water while swimming or falling into the harbour [mg/kg/d]
C_{sw}	=	concentration of COPC in surface water [mg/L]
IR_{sw}	=	incidental surface water ingestion rate [L/hr]
ET	=	exposure time [hours/event]
EF	=	exposure frequency [events/yr]
ED	=	exposure duration [yrs]
BW	=	receptor body weight [kg]
AT	=	averaging time (i.e., period over which the exposure is averaged) [d]

5.2.6.5 Soil Dermal Uptake

The non-radiological dose from dermal soil uptake is calculated for each COPC, following Equation 5-11. Equation 5-11 is based on the calculation methods of Health Canada (2010) and US EPA (2004), with terms included for averaging time (for carcinogenic COPC calculations), consistent with CSA (2012):

$$D^{s}_{dermal} = \frac{C_s \times SA \times SL \times RAF \times EF_s \times {D_2}/{7} \times {D_3}/{52} \times D_4 \times CF}{BW \times AT} \tag{5-11}$$

Where:

D^{s}_{dermal}	=	exposure to COC in soil through the dermal pathway [mg/(kg-d)]
C_s	=	soil concentration [mg/kg]
SA	=	exposed skin surface area [cm^2]
SL	=	soil loading to exposed skin [(mg)/(cm^2 event)]
RAF	=	dermal absorption factor [-]

EFs	=	exposure frequency to soil [events/d]
$D_2/7$	=	days per week exposed/7 days [d/d]
$D_3/52$	=	weeks per year exposed/52 weeks [wk/wk]
D_4	=	total years exposed to site (for carcinogenic COC only) [yr]
BW	=	receptor body weight [kg]
AT	=	averaging time (for carcinogenic COC only) [yr]
CF	=	conversion factor 1.0×10^{-6} [kg/mg]

The value for the soil loading to exposed skin is based on the soil adherence value, which represents the amount of soil retained on the skin, and the skin surface area. Several studies have attempted to determine the soil adherence value and are summarized in U.S. EPA (2004). Health Canada (2010) provides separate adherence factors for hands and other surfaces which are summed to provide a total exposed skin surface area.

Table 5.19 summarizes the dermal absorption fractions used in the calculations of dermal exposure to soil. Values were obtained according to the following hierarchy:

1. Health Canada (2010b);
2. OMOE (2011);
3. US EPA (2004);
4. Default value of 10% (Health Canada, 2010b).

Table 5.19 HHRA – Dermal Absorption Factors

COPC	Dermal Absorption Factors [unitless]
Uranium	0.1 [a]

Note:
[a] Health Canada (2010b)

5.2.6.6 Surface Water & Groundwater Dermal Uptake

The non-radiological dose from dermal uptake of water (groundwater or surface water) is calculated for each COPC, following the general Equation 5-12 (based on US EPA 2004, consistent with CSA 2012). However, this calculation varies depending on the COPC by way of the absorbed dose term (i.e., DA_{ev} in the Equation 5-12 below), which is calculated using different methods for inorganic COPCs versus organic COPCs:

$$D^{w}_{dermal} = \frac{DA_{ev} \times SA \times EF_{w} \times {D_2}/{7} \times {D_3}/{52} \times D_4}{BW \times AT} \tag{5-12}$$

Where:

D^{w}_{dermal}	=	exposure to COC in water through the dermal pathway [mg/(kg-d)]
DA_{ev}	=	absorbed dose per event [mg/cm²/event]
SA	=	exposed skin surface area [cm²]
EF_w	=	exposure frequency to water [events/d] {assumed to be 1 event per day}
$D_2/7$	=	days per week exposed/7 days [d/d]
$D_3/52$	=	weeks per year exposed/52 weeks [wk/wk]
D_4	=	total years exposed to site (for carcinogenic COC only) [yr]
BW	=	body weight [kg]
AT	=	averaging time (for carcinogenic COCs only) [yr]

<u>Inorganic COPCS - DA_{ev}</u>

For inorganic COPCs, the skin has a limited capacity to reduce the transport rate and the viable epidermis does not act as a barrier. Therefore, the absorbed dose (DA_{ev}) can be calculated from Equation 5-13:

$$DA_{ev} = \frac{K_p \times C_w \times t_{ev}}{CF} \tag{5-13}$$

Where:

DA_{ev}	=	absorbed dose per event [mg/cm²/ev]
K_p	=	dermal permeability coefficient in water [cm/h]
C_w	=	concentration in water [µg/L]
t_{ev}	=	event duration [h/ev]
CF	=	conversion factor $1x10^{-6}$ [conversion from µg/L to mg/cm³]

In this study, the exposure times used in dermal uptake equations are those presented in Table 5.5 and Table 5.6.

Organic COPCS - DA_{ev}

For organic COPCs, the calculation is dependent on the contact time and the time required to reach steady state. Equations 5-14 and 5-15 are used to estimate the absorbed dose (DA_{ev}):

If $t_{ev} \leq t^*$
$$DA_{ev} = 2 \times FA \times K_p \times \frac{C_w}{CF} \sqrt{6\,\tau\,\frac{t_{ev}}{\pi}} \qquad (5\text{-}14)$$

If $t_{ev} > t^*$
$$DA_{ev} = FA \times K_p \times \frac{C_w}{CF} \left[\frac{t_{ev}}{1+B} + 2\tau \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right] \qquad (5\text{-}15)$$

Where:

FA	=	fraction absorbed [-]
τ	=	lag time [h]
t_{ev}	=	event time (duration) [h]
t*	=	time to reach steady state [h]
CF	=	conversion factor 1×10^{-6} [(mg/cm^3)/(µg/L)]
B	=	ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis

In this study, the exposure times used in dermal uptake equations are those presented in Table 5.5 and Table 5.6. For highly lipophilic chemicals or for chemicals that have a long lag time, some of the chemical dissolved into skin may be lost due to desquamation during that absorption period. The fraction absorbed (FA) term has been included to account for this loss of chemical due to desquamation. The conservative default for this parameter is 1 (i.e., assuming no loss due to desquamation), which is used in this assessment. However, alternative values can be obtained on a chemical-specific basis from U.S. EPA (2004).

An empirical predictive correlation is provided to estimate the permeability coefficient for organics:

$$\log K_p = -2.80 + 0.66 \log K_{ow} - 0.0056\, MW \qquad (5\text{-}16)$$

Where:

K_{ow}	=	octanol-water partition coefficient
MW	=	molecular weight [g/mole]

Chemicals with very large and very small K_{ow} values are outside of the range of the empirical relationship; however, the relationship can be used as a preliminary estimate (U.S. EPA 2004).

Assuming that the thickness of the stratum corneum is 0.001 cm the following equation can be used to determine the lag time:

$$\tau = 0.105 \times 10^{(0.0056\,MW)} \qquad (5\text{-}17)$$

For longer exposure durations, the absorbed dose is restricted by the permeability of the viable epidermis and the stratum corneum, and thus B, the ratio of the permeability of the stratum corneum to that of the epidermis is an important factor in the equation. The value of B can be approximated by:

$$B = K_p \frac{\sqrt{MW}}{2.6} \qquad (5\text{-}18)$$

The calculation of the time to reach steady state (t*) is dependent on B according to the following equations:

If B ≤ 0.6 $$t^* = 2.4\tau \qquad (5\text{-}19)$$

If B > 0.6 $$t^* = 6\tau(b - \sqrt{b^2 - c^2}) \qquad (5\text{-}20)$$

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)} \qquad (5\text{-}21)$$

$$b = \frac{2(1 + B)^2}{\pi} - c \qquad (5\text{-}22)$$

Where:

b,c = correlation coefficients

Table 5.20 summarizes the dermal permeability coefficients (Kp values) used in the calculations of dermal exposure to surface water or groundwater.

Table 5.20 HHRA – Dermal Permeability Coefficients

(Groundwater & Surface Water)

COPC	Dermal Permeability Coefficient (K_p) (cm/h)	Notes & Reference
Ammonia	0.001	Default value for inorganics (US EPA 2004; Exhibit 3-1)
Uranium	0.001	Default value for inorganics (US EPA 2004; Exhibit 3-1)
TBP	0.02	Derived value for organics (following US EPA 2004 *empirical predictive Kd methodology*)

5.2.6.7 Inhalation

In general, the non-radiological dose from inhalation (of outdoor air, or dust/particulate in air) is calculated for each COPC, following Equation 5-23, consistent with CSA (2012). Equation 5-23 calculates a dose in mg/kg-d that is compared to a slope factor or reference dose TRV (depending on carcinogenic effects for a particular COPC). However, for many chemical compounds, TRVs for the inhalation pathway are expressed as reference concentrations (in mg/m^3). In such cases, Equation 5-24 is used to calculate exposure:

$$D_{sp} = \frac{C_s \times P_{air} \times IR_a \times AF_{INH} \times D_1 \times D_2 \times D_3 \times D_4}{BW \times LE} \tag{5-23}$$

Where:

- D_{sp} = dose from inhalation of soil dust/particulate [mg/kg/d]
- C_s = concentration of COPC in soil [mg/kg]
- P_{air} = particulate concentration in air [kg/m^3]
- IR_a = receptor air inhalation rate [m^3/d]
- AF_{NH} = absorption factor for inhalation (assumed equal to 1) [unitless]
- D_1 = hours per day exposed, divided by 24 hours [hr/hr]
- D_2 = days per week exposed, divided by 7 days [d/d]
- D_3 = weeks per year exposed, divided by 52 weeks [wk/wk]
- D_4 = total years exposed to site (for carcinogens only) [yr]
- BW = receptor body weight [kg]

LE = Life expectancy (for carcinogens only) [yr]

$$D_{sp} = \frac{C_s \times P_{air} \times D_1 \times D_2 \times D_3 \times D_4}{LE} \tag{5-24}$$

Where:

D_i = exposure from inhalation [mg/m^3]

C_s = concentration of COPC in soil [mg/kg]

P_{air} = particulate concentration in air [kg/m^3]

D_1 = hours per exposure event, divided by 24 hours [hr/hr]

D_2 = days per week exposed, divided by 7 days [d/d]

D_3 = weeks per year exposed, divided by 52 weeks [wk/wk]

D_4 = total years exposed to site (for carcinogens only) [yr]

LE = Life expectancy (for carcinogens only) [yr]

In the absence of measured air concentrations, concentrations of COCs associated with particulate in ambient air can be estimated from soil data using an assumed respirable (≤ 10 µm aerodynamic diameter) particulate concentration. For the maintenance and sub-surface workers who may be exposed to a higher concentration of particulates as a result of soil resuspension during typical activities, a respirable particulate concentration of 60 µg/m^3 (or 6.0x10^{-8} kg/m^3) is typically used (MOE 2009). For all other receptors, a value of 0.76 µg/m^3 (or 7.6x10^{-10} kg/m^3) as provided by Health Canada (2004) is typically used for areas with no construction activities.

In this study, air concentrations at receptor exposure locations have been estimated and are used directly. Therefore, the air inhalation calculation replaces C_s (mg/kg) and P_{air} (kg/m^3) in Equation 5-24 with the modeled air concentration (in µg/m^3), with the appropriate unit conversion.

5.2.7 Gamma Dose Estimates

Gamma dose rates are estimated based on measured gamma levels at monitoring stations (see Table 5.15 and Table 5.16). Gamma dose rates are included in the overall dose assessment, and are discussed in Section 5.4.3.2.

5.3 Toxicity Assessment

5.3.1 Non-Radiological COPCs - Toxicological Reference Values

Exposure to non-radionuclide contaminants (i.e. chemical contaminants) is conventionally assessed against Toxicity Reference Values (TRVs). Toxicity is the potential of a chemical to cause some type of damage, either permanent or temporary, to the structure or functioning of any part of the body. The toxicity depends on the amount of the chemical taken into the body (generally termed the intake or dose) and the length of time a person is exposed. Every chemical has a specific dose and duration of exposure that is necessary to produce a toxic effect in humans. Toxicity assessments generally involve the evaluation of scientific studies, based either on laboratory animal tests or on workplace exposure investigations, by a number of experienced scientists in a wide range of scientific disciplines in order to determine the maximum dose that a human can be exposed to without having an adverse health effect.

Toxicity assessments generally categorize adverse effects as short term (acute) or long term (chronic). This HHRA focuses on the assessment of long term (chronic) effects.

Carcinogenic TRVs

Carcinogenesis is generally assumed to be a "non-threshold" type phenomenon whereby it is assumed that any level of exposure to a carcinogen poses a finite probability of generating a carcinogenic response. Carcinogenic TRVs or slope factors are used to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen. The carcinogenic TRV is, therefore, the incremental lifetime cancer risk per unit of dose.

Non Carcinogenic TRVs

For many non-carcinogenic effects, protective biological mechanisms must be overcome before an adverse effect from exposure to the chemical is manifested. For this reason, scientists generally agree that there is a level (threshold) below which no adverse effects would be measurable or expected to occur. This is known as a "threshold" concept. Non-carcinogens are often referred to as "systemic toxicants" because of their effects on the function of various organ systems. These toxicity reference values are generally called reference doses (RfDs), tolerable daily intakes (TDIs) or acceptable daily intakes (ADIs) and are generally derived by regulatory agencies such as Health Canada and the United States Environmental Protection Agency (U.S. EPA). These TRVs are usually expressed as the quantity of a chemical per unit body weight per unit time (mg/kg-day) or as an air concentration (mg/m^3) and have generally been derived for sensitive individuals in the public using the most sensitive endpoint available. These factors involve the incorporation of “uncertainty factors” by regulatory agencies to provide protection for members of the public.

There are several regulatory sources that report TRVs for evaluation of effects from long-term (i.e., chronic) exposure. The main sources ued in this study are:

1. Health Canada;
2. Ontario Ministry of Environment (OMOE) – *citing CalEPA, IRIS, RIVM and others*;
3. Canadian Council of Ministers of the Environment (CCME);
4. US California EPA (CalEPA);
5. U.S. EPA Integrated Risk Information System (IRIS) database;
6. World Health Organization (WHO);
7. Netherlands National Institute of Public Health and the Environment (RIVM); and
8. Agency for Toxic Substances and Disease Registry (ATSDR).

Table 5.21 presents the human-health TRVs selected for use in this assessment.

Table 5.21 HHRA – TRVs

COPC	Pathway of Exposure*	Carc. vs. Non-Carc.**	Value	Units	Health Effect	Ref
Ammonia	oral	*See discussion below*				
	Inhalation	non-carc.	0.07	mg/m^3	Pulmonary function	ATSDR 2004
U	oral	non-carc.	6×10^{-4}	mg/(kg-d)	Degenerative lesions in kidney tubules	*Health Canada 2010b* *Based on ingestion exposure to soluble uranium (uranyl nitrate hexahydrate).*
	inhalation	non-carc.	4.0×10^{-5}	mg/m^3	Kidney effects	ATSDR 2013 *(more recent than the ATSDR 1999 reference in MOE 2011b).*
TBP	oral	carc.	0.009	$(mg/(kg\text{-}d))^{-1}$	Hyperplasia, ulceration, and hemorrhaging observed in bladder epithelial tissue	US EPA 2010
	oral	non-carc.	0.01	mg/(kg-d)		

Ammonia (oral/dermal pathways)

No oral or dermal toxicity values could be found for ammonia. However, data from human and animals suggest that that amount that may be tolerated may be substantial based on the existence of various efficient ways by which the human body can dispose of ammonia (WHO 1986; cited in ATSDR 2004). As such, it is unlikely that exposure to ammonia at the levels encountered in surface water and groundwater would cause undue risk.

Tributyl Phosphate (TBP)

TRV information for TBP are limited. An EC/HC (2009) *Draft Screening Assessment* on TBP is available which summarizes several toxicity studies, however, EC/HC (2009) offers no recommended quantitative TRV. In 2008, Cameco also completed a TBP study (BRR 2008) which outlines information on industrial hygiene, occupational health & safety, TBP's role in BRR operations, and a critique of publically available literature on TBP toxicity. However, the BRR (2008) study offers no recommended quantitative TRV. Ultimately, for the purposes of HHRA, among information obtained from scientific literature in the public domain, the US EPA's provisional peer reviewed toxicity values (PPRTVs) the US EPA offered the most credible quantitative TRV information.

As discussed in US EPA (2015b), PPRTVs are toxicity values derived for use in the US EPA's Superfund Program when TRV information is not available in US EPA's Integrated Risk Information System (IRIS). PPRTVs are derived after a review of the relevant scientific literature using the methods, sources of data and guidance for value derivation used by the EPA IRIS Program. All provisional peer-reviewed toxicity values receive internal review by EPA scientists and external peer review by independent scientific experts. PPRTVs differ in part from IRIS values in that PPRTVs do not receive the multi-program consensus review provided for IRIS values. This is because IRIS values are generally intended to be used in all EPA programs, while PPRTVs are developed specifically for the Superfund Program. The PPRTV electronic library contains toxicity values from two origins, both of which have undergone internal and external peer review.

Information in the PPRTV for TBP notes that data are sufficiently abundant to identify an association between TBP exposure and hyperplasia of the bladder epithelium. However, the exact mode of action (for bladder carcinogenesis specifically) is less clear and may be due to damage to the bladder epithelial cells resulting in regenerative hyperplasia and enhanced growth of initiated cells. Cell proliferation is believed to increase tumor formation through a number of possible mechanisms including: increased number of spontaneous initiations during cell replication; inhibition of apoptosis; promotion of clonal expansion; increased rate of neoplastic progression; selective growth advantage of initiated cells; and, reduced time available for DNA repair mechanisms. (US EPA, 2010)

5.3.2 Radiological Dose Limits

The radiological benchmarks used in this HHRA are based on the dose limits in the Nuclear Safety and Control Act Radiation Protection Regulations (CNSC 2000, see Table 5.22). These benchmarks were compared to the estimated doses in order to characterize risk.

Table 5.22 HHRA – Radiological Benchmarks

Receptor	Dose Limit	Reference
Member of the public	1 mSv/y	CNSC (2000) - *Nuclear Safety and Control Act*, Radiation Protection Regulations

5.4 Risk Characterization

Risk characterization involves the integration of the information from the exposure assessment and the toxicity assessment.

5.4.1 Radiological Risk Characterization

Radiological risk characterization involves comparing the total estimated dose (per year) to the dose limits outlined in Section 5.3.2. To facilitate identification of doses that exceed the dose limit, a screening index (SI) is calculated by dividing the estimated dose by the dose limit; in this way any resulting SI values greater than one represent a dose estimate that exceeds the dose limit.

5.4.2 Non-Radiological Risk Characterization

For this study, both non-carcinogens and carcinogens are included.

For many non-carcinogenic effects, protective biological mechanisms must be overcome before an adverse effect is manifested from exposure to the COC. This is known as a "threshold" concept. For non-carcinogenic COCs, the hazard quotient (HQ) is used to assess the potential for effects. Consistent with CSA (2012), HQs are calculated for threshold-acting chemicals on a *per medium basis.* It is important to note that TRVs specific to the dermal absorption pathway are largely not available. As such, oral toxicity data have been used as surrogates for the dermal pathway. Therefore it is appropriate to combine the oral and dermal exposures together (summed). In general, inhalation HQs are provided separately since effects resulting from inhalation exposure are generally for a different endpoint compared to the oral route. The inhalation HQs are summed with those from the oral and dermal pathways only if the endpoints for the different routes of exposure are the same. Overall, Equation 5-27 defines the HQ calculation procedure:

(5-27)

$$HQ_{OD_s} = \frac{D_{ING_s}}{TRV_o} + \frac{D_{DERMAL_s}}{TRV_d}$$

$$HQ_{OD_{gw}} = \frac{D_{ING_{gw}}}{TRV_o} + \frac{D_{DERMAL_{gw}}}{TRV_d}$$

$$HQ_i = \frac{D_{a,p} + D_{a,v}}{TRV_i}$$

Where:

HQ_{ODs}	=	HQ for oral ingestion (soil), including dermal contribution
HQ_{ODgw}	=	HQ for oral ingestion (groundwater), including dermal contribution
D_{INGs}	=	Dose from incidental soil ingestion
D_{INGgw}	=	Dose from incidental groundwater ingestion
$D_{DERMALs}$	=	Dose from dermal exposure to soil
$D_{DERMALgw}$	=	Dose from dermal exposure to groundwater
HQ_o	=	Hazard quotient – oral exposure [-]
HQ_i	=	Hazard quotient – inhalation exposure [-]
$D_{a,p}$	=	Dose from airborne soil particulate
$D_{a,v}$	=	Dose from airborne soil vapours
TRV_i	=	Toxicity Reference Value for inhalation exposure (RfC) [mg/m^3]
TRV_o	=	Toxicity Reference Value for oral exposure (RfD) [mg/(kg-d)]
TRV_d	=	Toxicity Reference Value for dermal exposure [mg/(kg-d)] *(TRV_d assumed equal to TRV_o)*

When all pathways of exposure and background sources are considered, if the HQ is below a value of 1.0, no potential exists for an adverse effect for the selected receptor. However, in this assessment there are potential pathways of exposure from other sources that have not been included (e.g., natural background levels in water, store-bought food, etc.). For this reason, the calculated HQ is compared to a more conservative value of 0.2, consistent with risk assessment practice (CSA 2012).

For carcinogenic COCs, an incremental lifetime cancer risk (ILCR) is calculated by multiplying the estimated dose (in mg/(kg-d)) by the appropriate slope factor (in $(mg/(kg\text{-}d))^{-1}$) for dermal and oral exposures, and the amortized air concentration (mg/m^3) by the appropriate unit risk (in $(mg/m^3)^{-1}$) for inhalation. This is shown in Equation (5-28). The estimate corresponds to an incremental risk of an individual developing cancer over a lifetime as a result of exposure. Risk is defined as follows:

$$Risk_o = \left(D_s \times TRV_o\right) + \left(D^s_{dermal} \times TRV_d\right) \qquad (5\text{-}28)$$

$$Risk_i = \left(D_{a,p} + D_{a,v}\right) \times TRV_i$$

Where:

TRV_o	=	TRV for carcinogenic effects from oral exposure (SF) $[(mg/(kg\text{-}d))^{-1}]$
TRV_d	=	TRV for carcinogenic effects from dermal exposure $[(mg/(kg\text{-}d))^{-1}]$ (assumed equal to TRV_o)
TRV_i	=	TRV for carcinogenic effects from inhalation (UR) $[(mg/m^3)^{-1}]$

The calculated risk is then compared to acceptable benchmarks. In this assessment, an incremental risk level of 1 x 10^{-6} (1 in 1,000,000) was used to assess carcinogenic effects, consistent with the OMOE (2011b) to represent an “essentially negligible” risk.

5.4.2.1 Addition Across Exposure Routes

Combining Oral and Dermal Exposures:

In an HHRA, it is generally acceptable to sum hazard quotients or risk levels across exposure routes when the adverse health effect has the same toxicological endpoint and mechanism of action.

In this assessment, it was considered that the mechanisms of action for the oral and dermal exposure routes (when toxicity values are available) are the same for all contaminants, and therefore HQs and risks were summed across the oral and dermal exposure routes.

Combining Oral, Dermal, and Inhalation Exposures:

Inhalation was also added to the oral and dermal total only if the endpoint and mechanism of action were the same as those for oral and dermal exposure. The inhalation TRVs outlined in Table 5.21 were reviewed for common endpoints and mechanisms of action. Of the identified COPCs for this HHRA, the following were found to have common endpoints and therefore their inhalation components can be combined with their dermal and oral components:

- Non-Carcinogenic Exposure: Uranium.
- Carcinogenic Exposure: None.

5.4.3 Risk Estimate Results

5.4.3.1 Radiological Risk

The following tables present the estimated radiological doses for worker and member of public receptors, based on their respective environmental media and exposure locations, along with a comparison to the dose limit outlined in Section 5.3.2).

Estimates are based on derived maximum levels in environmental media (i.e. groundwater, surface water, soil, and air) (see Sections 2.5.8 and 5.2.3).

Radiological: *Based on Kd-derived Sediment Concentrations*

Table 5.23 HHRA –Radiological Results – All Receptors [Kd Sed.]

Radionuclide	Resident			Boom Camp			Cottager			Golf Worker	Hydro Worker
	Adult	*Child*	*Infant*	*Adult*	*Child*	*Infant*	*Adult*	*Child*	*Infant*	*Adult*	*Adult*
Pb-210	1.41E-02	2.88E-02	2.28E-02	4.26E-05	5.09E-04	8.91E-04	5.37E-05	1.75E-04	2.33E-04	3.19E-05	3.79E-05
Po-210	1.13E-02	2.62E-02	2.70E-02	7.39E-05	1.02E-03	2.17E-03	1.12E-04	4.07E-04	6.27E-04	5.50E-05	6.51E-05
Ra-226	1.06E-02	1.44E-02	1.05E-02	3.40E-03	4.74E-03	4.31E-03	3.29E-03	4.54E-03	3.47E-03	3.04E-03	3.11E-03
Th-230	3.68E-04	2.71E-04	2.09E-04	3.23E-05	1.05E-04	1.42E-04	3.35E-05	3.94E-05	4.03E-05	2.89E-05	3.22E-05
U-234	9.32E-03	7.42E-03	7.57E-03	6.34E-04	1.78E-03	3.14E-03	5.90E-04	6.37E-04	8.83E-04	5.98E-04	6.53E-04
U-235	4.11E-04	3.28E-04	3.48E-04	4.38E-05	9.44E-05	1.65E-04	1.36E-04	1.39E-04	1.84E-04	2.40E-04	2.93E-04
U-238	8.55E-03	6.81E-03	6.98E-03	8.37E-04	1.89E-03	3.23E-03	2.33E-03	2.37E-03	3.14E-03	4.00E-03	4.87E-03
Total Dose (mSv/y)	5.46E-02	8.42E-02	7.55E-02	5.06E-03	1.01E-02	1.41E-02	6.54E-03	8.31E-03	8.57E-03	8.00E-03	9.06E-03
Dose Limit (mSv/y)	1	1	1	1	1	1	1	1	1	1	1
SI (-)	0.05	0.08	0.08	0.005	0.010	0.014	0.007	0.008	0.009	0.008	0.009

Bold & Shaded – Screening index indicates estimated dose that exceeds the dose limit.

Radiological: *Based on Measured Sediment Concentrations – where such data are available*

Table 5.24 HHRA – Radiological Results – All Receptors [Measured Sed.]

Radionuclide	Resident			Boom Camp			Cottager			Golf Worker	Hydro Worker
	Adult	*Child*	*Infant*	*Adult*	*Child*	*Infant*	*Adult*	*Child*	*Infant*	*Adult*	*Adult*
Pb-210	1.41E-02	2.88E-02	2.28E-02	4.26E-05	5.09E-04	8.91E-04	5.37E-05	1.75E-04	2.33E-04	3.19E-05	3.79E-05
Po-210	1.13E-02	2.62E-02	2.70E-02	7.39E-05	1.02E-03	2.17E-03	1.12E-04	4.07E-04	6.27E-04	5.50E-05	6.51E-05
Ra-226	1.06E-02	1.44E-02	1.05E-02	3.70E-03	5.05E-03	4.70E-03	3.29E-03	4.54E-03	3.47E-03	3.04E-03	3.11E-03
Th-230	3.68E-04	2.71E-04	2.09E-04	3.23E-05	1.05E-04	1.42E-04	3.35E-05	3.94E-05	4.03E-05	2.89E-05	3.22E-05
U-234*	9.32E-03	7.42E-03	7.57E-03	6.34E-04	1.78E-03	3.14E-03	5.90E-04	6.37E-04	8.83E-04	5.98E-04	6.53E-04
U-235	4.11E-04	3.28E-04	3.48E-04	1.22E-04	1.73E-04	2.67E-04	1.36E-04	1.39E-04	1.84E-04	2.40E-04	2.93E-04
U-238*	8.55E-03	6.81E-03	6.98E-03	8.38E-04	1.89E-03	3.23E-03	2.33E-03	2.37E-03	3.14E-03	4.00E-03	4.87E-03
Total Dose (mSv/y)	5.46E-02	8.42E-02	7.55E-02	5.44E-03	1.05E-02	1.45E-02	6.54E-03	8.31E-03	8.57E-03	8.00E-03	9.06E-03
Dose Limit (mSv/y)	1	1	1	1	1	1	1	1	1	1	1
SI (-)	0.05	0.08	0.08	0.005	0.011	0.015	0.007	0.008	0.009	0.008	0.009

Bold & Shaded – Screening index indicates estimated dose that exceeds the dose limit.

*U-234 and U-238 measured sediment data are not available. Concentrations based on measured U_{nat} in sediment, converted using specific activity conversion.

5.4.3.2 Gamma Dose

As discussed in the BRR DRL (SENES 2013), the external dose received from gamma radiation originating from the BRR decreases as distance from the facility increases (among other factors). From this, receptors located closest to the facility are expected to experience higher potential gamma dose rates; and, as discussed in SENES (2013), the gamma dose rate at residence locations can be assumed to be negligible (i.e. essentially zero) due to their distance. From this, gamma dose estimates in this HHRA focus on the golf course worker receptor – located north of the facility - as this is the closest public receptor.

The overall approach used to estimate gamma dose rates is based on that used in the BRR DRL (SENES 2013). This involves comparing gamma measurements from the fenceline to gamma measurements at distant stations. Because gamma measured at distant stations represents background levels (gamma contributions from the BRR are essentially zero at these locations), this provides an estimate of background gamma, which can be subtracted from measured fenceline gamma levels to determine the incremental gamma dose rate that can be attributed to the BRR.

Gamma measurement data from fenceline monitoring locations are presented in Table 5.15. Gamma measurement data from hi-vol monitoring stations is presented in Table 5.16. The locations of these monitoring stations are discussed in Section 2.5.7. Comparison between gamma measurements from the ‘eastern fenceline’ location to those from the ‘Town STP’ location shows a difference ranging from 0.16 to 0.32 µSv/hr (with an average difference of 0.23 µSv/hr). Comparison between gamma measurements from the ‘northern fenceline’ location to those from the ‘Hydro Yard’ location shows a difference ranging from 0.11 to 0.49 µSv/hr (with an average difference of 0.18 µSv/hr). Lastly, comparison between gamma measurements from the ‘northern fenceline’ location to those from the ‘Golf Course’ location shows a difference ranging from 0.10 to 0.49 µSv/hr (with an average difference of 0.17 µSv/hr).

Based on these results, the incremental gamma dose rate attributed to the BRR ranges from 0.11 to 0.49 µSv/hr (with an overall average of 0.19 µSv/hr) *<u>at the fenceline</u>*, and measured background gamma dose rates range from 0.11 to 0.13 µSv/hr. The DRL (SENES 2013) identified a nominal background level of 0.11 µSv/h for the Blind River area, with measured background gamma levels (from ‘Hydro Yard’ and ‘Town STP’ stations) also ranging from 0.11 to 0.13 µSv/hr).

From the above comparisons, an important observation is that all gamma measurements obtained <u>at the ‘Golf Course’</u> location range from 0.11 to 0.13 µSv/hr in 2014, which is equal to the range of measured background. Therefore, even at the golf course (which represents the highest expected gamma dose to a public receptor), there is essentially zero <u>incremental</u> gamma contribution from the BRR, despite measured fenceline levels during this same period.

5.4.3.3 Non-Radiological Hazard and Risk

The following tables present the estimated non-radiological hazard (non-carcinogenic) and risk (carcinogenic) results for worker and member of public receptors, based on their respective environmental media and exposure locations.

Tier 1 estimates are based on maximum concentrations in environmental media (i.e. groundwater, surface water, soil, and air) (see Section 5.2.3). Only those receptor-media combinations with estimated HQ or risk results that exceed their corresponding benchmark values are carried forward into tier 2 calculations (discussed below).

Tier 2a estimates are performed only for those receptor-media combinations whose HQ or risk results exceeded their corresponding benchmark values in Tier 1. Tier 2a estimates are based on 95th percentile concentrations (see Section 5.2.3) in the appropriate environmental media (i.e. only those media that were identified via Tier 1 results). For surface water, Tier 2a results indicated exceedances of the TBP benchmark for select receptors. Therefore, the assessment was further refined using a Tier 2b estimate by assuming 95th percentile *effluent* concentrations of TBP (2.7 mg/L) from 2014 BRR environmental monitoring program with a dilution factor of 500 (Arcadis 2015a).

Tier 1 – Non-Radiological:

Table 5.25 HHRA – T1 HQ & Risk – Resident Receptor (ID# 1A-D)

a) Air (inhalation – indoor air)

COPCs	HQ/Risk	Resident Receptor (ID# 1A-D)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (inhalation)	6.13E-03	6.13E-03	6.13E-03	6.13E-03	6.13E-03
Uranium	Risk (inhalation)	*N/A – Uranium not identified as a carcinogen*				

N/A – Not Applicable

b) Groundwater (drinking water ingestion)

COPCs	HQ/Risk	Resident Receptor (ID# 1A-D)				
		Infant	Toddler	Child	Teen	Adult
Ammonia	HQ (oral - ingestion)	NC	NC	NC	NC	NC
Ammonia	Risk (oral - ingestion)	*N/A – Ammonia not identified as a carcinogen*				
Uranium	HQ (oral - ingestion)	***5.4E-01***	***5.4E-01***	***3.6E-01***	***2.5E-01***	***3.1E-01***
Uranium	Risk (oral - ingestion)	*N/A – Uranium not identified as a carcinogen*				
TBP	HQ (oral - ingestion)	***1.1E+01***	***1.1E+01***	***7.3E+00***	***5.0E+00***	***6.4E+00***
TBP	Risk (oral - ingestion)	***6.2E-06***	***5.5E-05***	***5.7E-05***	***4.5E-05***	***4.4E-04***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

c) Soil (food ingestion – backyard produce, wild game, wild fowl)

COPCs	HQ/Risk	Resident Receptor (ID# 1A-D)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (oral - ingestion)	***3.6E-01***	***3.4E-01***	***2.4E-01***	1.7E-01	1.4E-01
Uranium	Risk (oral - ingestion)	*N/A – Uranium not identified as a carcinogen*				

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

N/A – Not Applicable

d) Surface Water (food ingestion - fish)

COPCs	HQ/Risk	Resident Receptor (ID# 1A-D)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (oral - ingestion)	N/A	7.4E-03	6.6E-03	4.3E-03	4. 0E-03
Uranium	Risk (oral - ingestion)	*N/A – Uranium not identified as a carcinogen*				
TBP	HQ (oral - ingestion)	NC				
TBP	Risk (oral - ingestion)	NC				

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

TPB – dose from fish ingestion not included: TF not available (see Table 5.11)

Table 5.26 HHRA – T1 HQ & Risk – Cottager Receptor (ID# 2)

a) Air (inhalation – outdoor air)

COPCs	HQ/Risk	Cottager Receptor (ID# 2)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (inhalation)	2.1E-03	2.1E-03	2.1E-03	2.1E-03	2.1E-03
Uranium	Risk (inhalation)	*N/A – Uranium not identified as a carcinogen*				

N/A – Not Applicable

b) Soil (incidental ingestion)

COPCs	HQ/Risk	Cottager Receptor (ID# 2)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (oral - ingestion)	1.5E-02	2.9E-02	3.7E-03	2.0E-03	1.7E-03
Uranium	Risk (oral - ingestion)	*N/A – Uranium not identified as a carcinogen*				

N/A – Not Applicable

c) Surface Water (drinking water ingestion; dermal uptake from falling into water)

COPCs	HQ/Risk	Cottager Receptor (ID# 2)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (oral + dermal)	4.9E-02	5.6E-02	3.9E-02	2.7E-02	3.2E-02
Uranium	Risk (oral + dermal)	*N/A – Uranium not identified as a carcinogen*				
TBP	HQ (oral + dermal)	***2.2E+00***	***2.2E+00***	***1.5E+00***	***1.0E+00***	***1.3E+00***
TBP	Risk (oral + dermal)	***1.2E-06***	***1.1E-05***	***1.1E-05***	***9.0E-06***	***8.7E-05***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

TPB – dose from fish ingestion not included: TF not available (see Table 5.11).

Table 5.27 HHRA – T1 HQ & Risk – Boom Camp Receptor (ID# 3)

a) Air (inhalation – outdoor air)

COPCs	HQ/Risk	Boom Camp Receptor (ID# 3)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (inhalation)	2.9E-04	2.9E-04	2.9E-04	2.9E-04	2.9E-04
Uranium	Risk (inhalation)	*N/A – Uranium not identified as a carcinogen*				

N/A – Not Applicable

b) Soil (incidental ingestion; dermal uptake)

COPCs	HQ/Risk	Boom Camp Receptor (ID# 3)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (oral - ingestion)	1.3E-01	***2.1E-01***	4.6E-02	3.1E-02	1.9E-01
Uranium	Risk (oral - ingestion)	*N/A – Uranium not identified as a carcinogen*				

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

N/A – Not Applicable

c) Surface Water (drinking water ingestion; dermal uptake - swimming; incidental ingestion - swimming)

COPCs	HQ/Risk	Boom Camp Receptor (ID# 3)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (oral + dermal)	5.4E-02	5.1E-02	3.4E-02	2.3E-02	2.9E-02
Uranium	Risk (oral + dermal)	*N/A – Uranium not identified as a carcinogen*				
TBP	HQ (oral + dermal)	***3.6E+00***	***3.3E+00***	***2.3E+00***	***1.7E+00***	***2.0E+00***
TBP	Risk (oral + dermal)	***1.3E-06***	***1.2E-05***	***1.2E-05***	***9.3E-06***	***8.9E-05***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

Table 5.28 HHRA – T1 HQ & Risk – Golf Worker Receptor (ID# 4)

a) Air (inhalation – outdoor air)

COPCs	HQ/Risk	Golf Worker Receptor (ID# 4)
		Adult
Uranium	HQ (inhalation)	1.7E-03
Uranium	Risk (inhalation)	*N/A – Uranium not identified as a carcinogen*

N/A – Not Applicable

b) Soil (incidental ingestion; dermal uptake)

COPCs	HQ/Risk	Golf Worker Receptor (ID# 4)
		Adult
Uranium	HQ (oral + dermal)	6.2E-02
Uranium	Risk (oral + dermal)	*N/A – Uranium not identified as a carcinogen*

N/A – Not Applicable

c) Surface Water (drinking water ingestion)

COPCs	HQ/Risk	Golf Worker Receptor (ID# 4)
		Adult
Uranium	HQ (oral + dermal)	2.8E-02
Uranium	Risk (oral + dermal)	*N/A – Uranium not identified as a carcinogen*
TBP	HQ (oral + dermal)	***1.3E+00***
TBP	Risk (oral + dermal)	***8.7E-05***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

Table 5.29 HHRA – T1 HQ & Risk – Hydro Worker Receptor (ID# 5)

a) Air (inhalation – outdoor air)

COPCs	HQ/Risk	Hydro Worker Receptor (ID# 5)
		Adult
Uranium	HQ (inhalation)	2.9E-03
Uranium	Risk (inhalation)	*N/A – Uranium not identified as a carcinogen*

N/A – Not Applicable

b) Soil (incidental ingestion; dermal uptake)

COPCs	HQ/Risk	Hydro Worker Receptor (ID# 5)
		Adult
Uranium	HQ (oral + dermal)	1.3E-01
Uranium	Risk (oral + dermal)	*N/A – Uranium not identified as a carcinogen*

N/A – Not Applicable

c) Surface Water (drinking water ingestion)

COPCs	HQ/Risk	Hydro Worker Receptor (ID# 5)
		Adult
Uranium	HQ (oral + dermal)	2.8E-02
Uranium	Risk (oral + dermal)	*N/A – Uranium not identified as a carcinogen*
TBP	HQ (oral + dermal)	***1.3E+00***
TBP	Risk (oral + dermal)	***8.7E-05***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

Tier 2 – Non-Radiological:

Table 5.30 HHRA – T2 HQ & Risk – Resident Receptor (ID# 1A-D)

a) Groundwater (drinking water ingestion)

COPCs	HQ/Risk	Resident Receptor (ID# 1A-D)				
		Infant	Toddler	Child	Teen	Adult
TBP	HQ (oral - ingestion)	***2.2E+00***	***2.2E+00***	***1.5E+00***	***1.0E+00***	***1.3E+00***
TBP	Risk (oral - ingestion)	***1.2E-06***	***1.1E-05***	***1.1E-05***	***9.0E-06***	***8.7E-05***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

b) Soil (food ingestion – backyard produce, wild game, wild fowl)

COPCs	HQ/Risk	Resident Receptor (ID# 1A-D)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (oral - ingestion)	1.5E-01	1.3E-01	9.5E-02	6.9E-02	5.7E-02
Uranium	Risk (oral - ingestion)	*N/A – Uranium not identified as a carcinogen*				

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

N/A – Not Applicable

Table 5.31 HHRA – T2a HQ & Risk – Cottager Receptor (ID# 2)

a) Surface Water (drinking water ingestion; dermal uptake from falling into water)

COPCs	HQ/Risk	Cottager Receptor (ID# 2)				
		Infant	Toddler	Child	Teen	Adult
TBP	HQ (oral + dermal)	***2.2E+00***	***2.2E=00***	***1.5E+00***	***1.0E+00***	***1.3E+00***
TBP	Risk (oral + dermal)	***1.2E-06***	***1.1E-05***	***1.1E-05***	***9.0E-06***	***8.7E-05***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

Table 5.32 HHRA – T2b HQ & Risk – Cottager Receptor (ID# 2)

a) Surface Water (drinking water ingestion; dermal uptake from falling into water)

COPCs	HQ/Risk	Cottager Receptor (ID# 2)				
		Infant	Toddler	Child	Teen	Adult
TBP	HQ (oral + dermal)	2.0E-02	2.0E-02	1.3E-02	9.0E-03	1.1E-02
TBP	Risk (oral + dermal)	1.1E-08	9.9E-08	1.0E-07	8.1E-08	7.9E-07

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

Table 5.33 HHRA – T2a HQ & Risk – Boom Camp Receptor (ID# 3)

a) Soil (incidental ingestion; dermal uptake)

COPCs	HQ/Risk	Boom Camp Receptor (ID# 3)				
		Infant	Toddler	Child	Teen	Adult
Uranium	HQ (oral - ingestion)	4.7E-02	7.6E-02	1.7E-02	1.1E-02	6.8E-02
Uranium	Risk (oral - ingestion)	*N/A – Uranium not identified as a carcinogen*				

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

N/A – Not Applicable

b) Surface Water (drinking water ingestion; dermal uptake - swimming; incidental ingestion - swimming)

COPCs	HQ/Risk	Boom Camp Receptor (ID# 3)				
		Infant	Toddler	Child	Teen	Adult
TBP	HQ (oral + dermal)	***3.6E+00***	***3.3E+00***	***2.3E+00***	***1.7E+00***	***2.0E+00***
TBP	Risk (oral + dermal)	***1.3E-06***	***1.2E-05***	***1.2E-05***	***9.3E-06***	***8.9E-05***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

Table 5.34 HHRA – T2b HQ & Risk – Boom Camp Receptor (ID# 3)

a) Surface Water (drinking water ingestion; dermal uptake - swimming; incidental ingestion - swimming)

COPCs	HQ/Risk	Boom Camp Receptor (ID# 3)				
		Infant	Toddler	Child	Teen	Adult
TBP	HQ (oral + dermal)	3.2E-02	3.0E-02	2.1E-02	1.6E-02	1.8E-02
TBP	Risk (oral + dermal)	1.2E-08	1.0E-07	1.1E-07	8.4E-08	8.0E-07

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

Table 5.35 HHRA – T2a HQ & Risk – Golf Worker Receptor (ID# 4)

a) Surface Water (drinking water ingestion)

COPCs	HQ/Risk	Golf Worker Receptor (ID# 4)
		Adult
TBP	HQ (oral + dermal)	***1.3E+00***
TBP	Risk (oral + dermal)	***8.7E-05***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)

N/A – Not Applicable

Table 5.36 HHRA – T2b HQ & Risk – Golf Worker Receptor (ID# 4)

a) Surface Water (drinking water ingestion)

COPCs	HQ/Risk	Golf Worker Receptor (ID# 4)
		Adult
TBP	HQ (oral + dermal)	1.1E-02
TBP	Risk (oral + dermal)	7.9E-07

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

Table 5.37 HHRA – T2a HQ & Risk – Hydro Worker Receptor (ID# 5)

a) Surface Water (drinking water ingestion)

COPCs	HQ/Risk	Hydro Worker Receptor (ID# 5)
		Adult
TBP	HQ (oral + dermal)	***1.3E+00***
TBP	Risk (oral + dermal)	***8.7E-05***

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

NC – Not Calculated (calculation could not be performed: key parameter values, concentration data, TRVs, or other such values are not available)
N/A – Not Applicable

Table 5.38 HHRA – T2b HQ & Risk – Hydro Worker Receptor (ID# 5)

a) Surface Water (drinking water ingestion)

COPCs	HQ/Risk	Hydro Worker Receptor (ID# 5)
		Adult
TBP	HQ (oral + dermal)	1.1E-02
TBP	Risk (oral + dermal)	7.9E-07

Shaded values indicate exceedance of corresponding HQ or Risk benchmark values.

5.4.4 Discussion

5.4.4.1 Radiological Risk

It is important to note that radiation doses to on-site facility workers are not generally part of an ERA, and are addressed through the facility's radiation safety program, according to CSA (2012).

To evaluate the risk to off-site public receptors, annual doses were estimated based on maximum measured radionuclide levels in environmental media (wherever such measured data are available), and through the use of radionuclide ratios (as discussed in Section 2.5.8.2) for Pb-210, Po-210 and Th-230. All estimated doses are well below the dose limit and, therefore, no undue impacts are expected to workers or members of the public.

Gamma dose rates were discussed in Section 5.4.3.2.

<u>*Supplemental Calculations: Measured vs. Kd-derived Sediment Concentrations.*</u>

Initial radiological HHRA calculations were performed based on sediment concentrations that were derived from surface water data using Kd distribution coefficients. Later, measured sediment data became available from Arcadis (2015a). A comparison of measured sediment concentrations to Kd-derived sediment concentrations is shown in Table 5.17 and discussed in Section 1.1.1.1. Additional radiological HHRA calculations were performed using the measured sediment concentrations, with the results presented in Table 5.23 and Table 5.24.

Similar to the radiological HHRA results based on *Kd-estimated sediment levels*, the radiological HHRA results based on *measured sediment concentrations* show that dose estimates are well below the dose limit.

5.4.4.2 Non-Radiological Risk

As shown in Section 5.4.3.2, risk and HQ results for specific receptor-media combinations were found to exceed their corresponding Tier 1 benchmark values. These receptor-media combinations were then carried forward for Tier 2a and Tier 2b calculations. Risk and HQ exceedances in the Tier 1, Tier 2a, and Tier 2b assessments are summarized in Table 5.39 below, for reference, to show the progression through the tiers.

Table 5.39 HHRA – Summary of HQ & Risk Results (T1 and T2)

Receptor Name	Rec. ID#	Age Group	HHRA TIER 1 – Exceedances				HHRA TIER 2a - Exceedances				HHRA TIER 2b - Exceedances
			Air (U)	*Soil (U)*	*SW (U, TBP)*	*GW (U, Ammonia, TBP)*	*Air (U)*	*Soil (U)*	*SW (U, TBP)*	*GW (U, Ammonia, TBP)*	
Resident	1	*Infant*		**U**		**U, TBP**				**TBP**	***No residual exceedances:*** *(see discussion below: TBP in groundwater)*
		Toddler		**U**		**U, TBP**				**TBP**	
		Child		**U**		**U, TBP**				**TBP**	
		Teen				**U, TBP**				**TBP**	
		Adult				**U, TBP**				**TBP**	
Cottager	2	*Infant*			**TBP**	n/a			**TBP**	n/a	***No residual exceedances:*** *(see discussion below: TBP in surface water, Tier 2b assessment)*
		Toddler			**TBP**	n/a			**TBP**	n/a	
		Child			**TBP**	n/a			**TBP**	n/a	
		Teen			**TBP**	n/a			**TBP**	n/a	
		Adult			**TBP**	n/a			**TBP**	n/a	
Boom Camp	3	*Infant*			**TBP**	n/a			**TBP**	n/a	
		Toddler		**U**	**TBP**	n/a			**TBP**	n/a	
		Child			**TBP**	n/a			**TBP**	n/a	
		Teen			**TBP**	n/a			**TBP**	n/a	
		Adult			**TBP**	n/a			**TBP**	n/a	
Golf Worker	4	Adult			**TBP**	n/a			**TBP**	n/a	
Hydro Worker	5	Adult			**TBP**	n/a			**TBP**	n/a	

From Table 5.39, it is clear that the Tier 2a HQ and risk results that exceed their corresponding benchmark values are related to:

1. **TBP in groundwater:** Resident Receptors; and,
2. **TBP in surface water:** Boom Camp, Cottager, Golf Worker, Hydro Worker Receptors.

Each of these is discussed below; additional information is introduced that is used to form subsequent Tier 2b investigation.

Resident Receptors: TBP in Groundwater

For the resident receptor, all residual Tier 2a groundwater-related HQ and risk exceedances for TBP are related to exposure through the assumed ingestion of groundwater as drinking water. However, groundwater measurement data are from within (or adjacent to) the BRR site, and not from residential areas where receptors would obtain their hypothetical groundwater drinking water.

A total of 140 TBP measurements were obtained across 2013 and 2014, from on-site groundwater. Of the 140 measurements, five (5) showed measurable TBP levels ranging from 0.6 mg/L to 3 mg/L. All five of these measurements occur among GW wells 'BH23', 'BH24', and 'BH25', which are located in the interior active area of the BRR site. Based on the DRL (SENES 2013), GW is assumed to be a potential source of drinking water only for off-site resident receptors. In 2007, the BRR contracted Golder to perform an evaluation of the BRR groundwater monitoring program (Golder, 2007). Among other findings, the Golder (2007) study identified that groundwater well 'BH6' is located approximately 100 m upgradient from the BRR site and represents un-impacted background groundwater conditions. All TBP measurement data obtained from BH6 show non-detect concentrations of TBP (based on the 2013-2014 dataset used in this study). A study by Golder in 2008 (Golder 2008b) further investigated the groundwater profile at the BRR site and determined that groundwater flow paths move diagonally – in general - from the northeast boundary of the site, toward the southwest boundary of the site, which is closest to the river. Groundwater well BH6 is located approximately northeast of the northeastern-most boundary of the site. So, given that:

- Measurable TBP levels are limited to select on-site areas (with restricted access) where groundwater is not used as a source of drinking water;
- Off-site resident receptors that may use groundwater as drinking water are located at distances much greater than 100 m *upgradient* from the BRR facility, see Figure 5.5 (i.e. TBP in groundwater cannot migrate upgradient toward the resident receptor locations); and,
- Upgradient background groundwater conditions do not contain measureable TBP concentrations.

It is therefore unlikely that resident receptors would be exposed to on-site groundwater TBP concentrations in drinking water, and as such, no adverse effects are expected.

Figure 5.7 Groundwater Drinking Water Visualization*

* Note: This is an approximate visualization of groundwater travel for illustrative purposes only.

All Receptors (excluding resident): TBP in Surface Water

All receptors, except the resident receptor, show HQ and risk results that exceed their corresponding benchmarks related to TBP in surface water in Tier 1 and Tier 2a. *These exceedances are due to the assumed use of surface water as drinking water. It is important to understand that all measured surface water concentration data from 2013 and 2014 (the data upon which this study is based) from all monitoring locations show non-detect levels of TBP*. However, these TBP measurements are performed using an MDL that is high relative to the concentrations that correspond to potential risk. The result is that even non-detect levels of TBP at the detection limits currently used are high enough to hypothetically produce undue risk.

To further refine the assessment, and avoid the need to use MDL concentrations, a Tier 2b assessment was performed using 95th percentile TBP concentration from the effluent lagoons, along with a dilution factor of 500 to account for rapid dilution when released from the effluent diffuser into the North Channel (Arcadis 2015a). Results from this Tier 2b assessment indicate no undue carcinogenic or non-carcinogenic risks to any receptors.

5.5 Uncertainties

Many areas of uncertainty attend a risk assessment. This is due to the fact that assumptions have to be made throughout the assessment either due to data gaps, environmental fate complexities or in the generalization of receptor characteristics. To be able to place a level of confidence in the results, an accounting of the uncertainty, the magnitude and type of which are important in determining the significance of the results, must be completed. In recognition of these uncertainties, several conservative assumptions were used throughout the assessment to ensure that the potential for an adverse effect would not be underestimated. The major assumptions are outlined below.

Exposure Point Concentrations

Measured concentrations of COPCs, and measured activities of radionuclides, were used wherever such data was available. For non-radiological COPCs, the HHRA uses the maximum and 95th percentile concentrations from throughout the year. The use of these concentrations assumes that receptors are exposed to these higher concentrations year-round when, in reality, there is both spatial and temporal variations in concentrations. Thus, exposures are likely overestimated in the assessment.

Radium-226 is the only radionuclide that is measured in surface water and groundwater. No radionuclides are measured in soil. Therefore, the activity concentrations of other radionuclides (Pb-210, Po-210, Th-230, U-238, U-234, and U-235) had to be estimated as outlined in Section 2.5.8. Although for HHRA this involves the use of specific activity estimates as well as the application of radionuclide ratios in facility effluents, these estimations use the maximum measured level of U_{nat} in environmental media as their starting point. It is therefore unlikely that the resulting doses would be underestimated given the use of maximum concentrations.

Transfer Factors

The concentration of COPCs and radionuclides in food (i.e. fish, produce, wild game (deer), and wild fowl (grouse)) had to be estimated using transfer factors from literature and pathways/intake calculations. There is some uncertainty involved in the use of transfer factors and data that are not site-specific; however, in the absence of measured concentrations in food, this approach provides the only method for estimating concentrations and for estimating transfer up the food chain.

Human Receptor Characterization

For all human receptors it is conservatively assumed that the incidental soil ingestion rate is constant, and that they ingest the corresponding amount of soil regardless of how much time they spend indoors (90% of the time). This would lead to a conservative overestimate of the dose they receive via this pathway.

The fraction of consumed fish that is caught locally has the potential to vary considerably. For this HHRA, it is conservatively assumed that *all* fish consumed has been caught locally (i.e. a location fraction of 1 is used).

This would lead to a conservative overestimate of the dose received through the fish ingestion pathway, for applicable receptors.

Toxicity Reference Values

The TRVs are selected to be very protective. The TRVs used in the assessment were obtained from reputable sources; nonetheless, they are always associated with uncertainty due to the extrapolation of testing on lab species (e.g., rats) to humans, and due to the extrapolation from a controlled laboratory setting to real-world conditions. The use of a single value for toxicity is another area of uncertainty. The factors used in the risk assessment represent risks from maximum dose-response estimates. Also, no adjustments were made for bioavailability, which can result in either an over- or under-estimation of exposure and thus leads to uncertainty in the risk assessment. Toxicity data were available for all COPC.

Risk Estimation – Multiple Contaminants

In this risk assessment, it was considered that the mechanisms of action for the oral and dermal exposure routes are the same for each specific contaminant and HQs were, therefore, summed across the oral and dermal exposure routes. This is a conservative approach to dealing with oral/dermal mechanisms of action and it is therefore unlikely that risk would be underestimated by using this approach. Furthermore, for uranium, the oral, dermal, and inhalation doses have been combined since there is evidence of a common mechanism of action.

When dealing with multiple contaminants, there is a potential for interaction with other contaminants that may be encountered at the site. In addition, other factors including smoking and lifestyle factors are known to compound health effects. Synergism, potentiation, antagonism or additivity of toxic effects may occur. A detailed quantitative assessment of these interactions is outside the scope of this study. Some of these interactions can be handled in a simple fashion. For chemical mixtures that show additive effects based on toxicity assessment, the HQ or risk values may be added together. The lifetime risk can be expressed individually for each chemical (and by site of action, if necessary) and then totalled as a group. In practical terms, at levels of exposure typically considered in the assessment, the dose-response relation is assumed to be linear and, thus, additivity of effects (strictly by organ) is reasonable. As the COPCs selected for this assessment do not have the same endpoint, no further consideration was given to potential interactions.

Summary

Table 5.40 provides a summary of the uncertainties discussed above. It can be seen from the table that, in general, uncertainties have been overcome by using conservative assumptions that are likely to lead to an over-estimate of exposures and thus the conclusions of the assessment would remain unchanged.

Table 5.40 HHRA – Summary of Uncertainties

Uncertainty	Likely Leads to Overestimate	Possibly Leads to Underestimate	Neither Overestimate or Underestimate
Use of transfer factors to estimate tissue concentrations	X		
Use of maximum or 95th percentile concentrations to characterize exposures	X		
Estimation of radionuclide concentrations not measured in the lagoons			X
Incidental soil ingestion rate assumed to be constant, despite time spent indoors	X		
Fraction of fish obtained locally	X		
Use of protective TRVs and maximum dose-response relationships	X		
Assuming 100% relative absorption for dermal uptake, and same mechanism of action as oral intake (i.e. combining exposures)	X		
Synergism, potentiation, antagonism, additivity of toxic effects (across multiple COPCs)		X	

6 ECOLOGICAL RISK ASSESSMENT

6.1 Problem Formulation

6.1.1 Receptor Selection and Characterization

The ecological receptors included in this EcoRA are obtained from the SENES (2006) EcoRA.

The study area encompassed by this EcoRA includes both terrestrial and aquatic environments characteristic of the northern shore of Lake Huron. Therefore, the following major biota groups warrant consideration:

- Freshwater aquatic environment:
  - Aquatic birds;
  - Aquatic mammals;
  - Amphibians;
  - Fish (benthic and pelagic);
  - Benthic invertebrates; and
  - Aquatic vegetation.
- Terrestrial environment:
  - Terrestrial birds;
  - Terrestrial mammals;
  - Terrestrial invertebrates; and
  - Terrestrial vegetation.

For each of the major biota groups mentioned above, a representative ecological receptor was selected (also referred to as an indicator species). The indicator species selected are those identified in the SENES (2006) EcoRA, which were selected based on:

- Knowledge of the BRR site and surrounding environment;
- Relevant environmental studies field observations;
- Accessibility of the environmental media; and,
- The potential species present in the area.

Table 6.1 presents the details of ecological receptor identification (reproduced from the SENES 2006 EcoRA) and selection.

Table 6.1 Identified Ecological Receptors

(Reproduced from SENES (2006) EcoRA)

Major Biota Group	Potential Indicator Species	Comments
Aquatic Receptors		
Fish	• Forage/ Benthic Fish*	Brown Bullhead Catfish used by EC/HC (2001) for Blind River
	• Predator/Pelagic Fish*	Lake Trout used in EA for Elliot Lake (SENES 1996)
Benthic Invertebrates	• Benthic Invertebrates*	EA for Elliot Lake (SENES 1996)
Aquatic Vegetation	• Macrophytes*	EC/HC (2001) for Blind River used Cladophora but field trip observation of macrophytes in the stormwater lagoon and bog.
Aquatic Birds	• Mallard	EC/HC (2001) for Blind River and the EA for Elliot Lake (SENES 1996)
	• Scaup	EA for Elliot Lake (SENES 1996)
	• Hooded Merganser	NHIC Database (MNR 2005) and field observations (SENES 2005)
	• Cormorant (Piscivore)	EC/HC (2001) for Blind River used osprey, but field observations of many cormorants.
Amphibians	• Northern Leopard Frog	Bruce A Restart TSD: Radiation and Radioactivity (SENES 2001)
Aquatic Mammals	• Beaver	EA for Elliot Lake (SENES 1996)
Terrestrial Receptors		
Terrestrial Invertebrates	• Earthworms	Bruce A Restart TSD: Radiation and Radioactivity (SENES 2001)
Terrestrial Vegetation	• Grass • Berries • Pine	DRL Report for Blind River (SENES 2004; 2013) and MOE (1989)
Terrestrial Birds	• Grouse (Herbivore)	EA for Elliot Lake (SENES 1996)
	• American Robin (Omnivore)	NHIC Database (MNR 2005) and field observations (SENES 2005)
	• Barred Owl (Carnivore)	NHIC Database (MNR 2005) and field observations (SENES 2005)
	• Bald Eagle (Piscivore)	EA for Elliot Lake (SENES 1996)
Terrestrial Mammals	• Deer	EA for Elliot Lake (SENES 1996)
	• Red Fox	EC/HC (2001) for Blind River
	• Black Bear	EA for Elliot Lake (SENES 1996)
	• Meadow Vole	NHIC Database (MNR 2005) and field observations (SENES 2005)
	• Coyote	NHIC Database (MNR 2005) and field observations (SENES 2005)

Notes:
* Assessed as general biota groups for radiological and non-radiological (chemical) EcoRA.

Therefore, based on the rationale provided in Table 6.1, the following 24 representative ecological receptors have been selected:

Aquatic Receptors:

1. Forage/ Benthic Fish
2. Predator/Pelagic Fish
3. Benthic Invertebrates
4. Macrophytes
5. Mallard
6. Scaup
7. Hooded Merganser
8. Cormorant (Piscivore)
9. Northern Leopard Frog
10. Beaver

Terrestrial Receptors

1. Earthworms
2. Grass
3. Berries
4. Pine
5. Grouse (Herbivore)
6. American Robin (Omnivore)
7. Barred Owl (Carnivore)
8. Bald Eagle (Piscivore)
9. Deer
10. Red Fox
11. Black Bear
12. Meadow Vole
13. Coyote

Overall, the selected indicator species are appropriate because they reflect a variety of diets/feeding habits, cover a variety of trophic levels, are representative of the biota expected to be found in the study area, and are of interest to the facility.

Ecological characterization tables have been developed for each receptor [redacted]. These profiles present receptor-specific information related to:

- Trophic level or ecosystem role (e.g., predators or prey species);
- Life history;
- Importance to humans;

- Size and body weight;
- Dietary composition;
- Food intake rate;
- Habitat;
- Habitat/home range spatial distribution and size;
- Time spent in area;
- Important behaviour and population dynamics (e.g., migratory); and
- Other useful information.

It is important to understand that fish, amphibians, benthic invertebrates, and vegetation (both aquatic and terrestrial) are assessed based directly on environmental concentrations. Pathways of exposure (e.g., ingestion, inhalation, etc.) are not explicitly modelled (or needed) for these receptors. As a result, ecological characterization tables are not required for these receptors.

6.1.2 Assessment and Measurement Endpoints

Assessment endpoints

Indicator species are assessed using quantitative expressions referred to as “assessment endpoints”. These are expressions of the actual environmental values to be protected. In general, the assessment endpoints selected in this study are healthy populations of the identified indicator species within the study area.

Measurement endpoints

Typically, assessment endpoints (such as those outlined above) are qualitative in nature and do not lend themselves to direct measurement or quantification. Therefore, measurement endpoints are outlined, which are measurable or predictable expressions of the assessment endpoint.

The values of measurement endpoints will be dependent not only upon the species being protected, but also upon the level of protection provided. For example, a measurement endpoint suitable for ensuring reproductive success of a population may not be adequate to ensure the protection of each member of the population.

In this study, measurement endpoints are the screening index (SI): the ratio of an estimated exposure level (or an environmental concentration) divided by a corresponding TRV. The SI measurement endpoint is at the population level. As a result, when the chosen TRV encompasses long term effects based on survival (mortality), growth, or reproduction, then the measurement endpoint is closely linked to the assessment endpoint (healthy populations) and the necessary inferences can be made (i.e., one can infer the ‘healthiness’ of the population). So, where an estimated exposure level is less than the corresponding TRV (i.e., screening index less than 1), effects on a population of biota are not expected; however, where an estimated exposure level is greater than the corresponding criterion (i.e., screening index greater than 1), deleterious effects on the population of biota may or may not occur and further study may be required to determine potential effects.

6.1.3 EcoRA COPCs

As outlined in Section 1.0, the following analytes were identified as COPCs:

- Ammonia (in groundwater);
- Uranium;
- TBP;
- Chromium;
- Vanadium; and,
- Radionuclides.

As outlined in Section 5.1.2, chromium and vanadium have not been identified as requiring further assessment in the EcoRA since their concentrations at Exposure Locations are less than local background concentrations at Reference Locations, and, are less than their respective screening criteria.

Therefore, the following have been identified as requiring further assessment in the EcoRA:

- Ammonia (in groundwater);
- Uranium;
- TBP; and,
- Radionuclides.

6.1.4 EcoRA Exposure Pathways

Table 6.2 presents the active exposure pathways for the ecological receptors identified in Section 6.1.1. The exposure pathways are based on the known habitat needs, mobility, and diets of the ecological receptors, along with knowledge of the location of their respective habitats within the study area. *It is important to note that all surface dwelling biota (i.e. excluding submergent aquatic species, and terrestrial earthworms) are assessed for direct gamma dose, in addition to the pathways discussed below.*

Terrestrial vegetation and terrestrial invertebrates (earthworms) would be directly exposed to contaminated soil. Pathways of exposure (e.g., ingestion, inhalation, etc.) are not explicitly modelled (or needed) for these receptors. As a hypothetical case, an earthworm is used to assess groundwater, though aquatic and terrestrial biota do not have access to groundwater and its related COPCs.

Similarly, aquatic vegetation and pelagic fish would be directly exposed to contaminated surface water. Pathways of exposure (e.g., ingestion, inhalation, etc.) are not explicitly modelled (or needed) for this receptor.

Aquatic invertebrates (benthos) and benthic fish would be directly exposed to contaminated surface water and to sediment. Pathways of exposure (e.g., ingestion, inhalation, etc.) are not explicitly modelled (or needed) for these receptors.

Terrestrial mammals and birds are exposed through ingestion of food, including terrestrial vegetation and earthworms, as well as incidental ingestion of soil and ingestion of surface water. Higher trophic species (such as the bald eagle and red fox) will also consume lower trophic species (such as voles and robins), as part of their diet. It is assumed that terrestrial mammals and birds obtain all of their food from the site, which is conservative, given that many species have larger home ranges or forage areas than the small grass patch areas of the site. Terrestrial mammals will also receive an external dose from soil (radiological only).

Aquatic birds are exposed through ingestion of food, including aquatic vegetation and benthos, as well as ingestion of sediment and surface water. Aquatic birds will also receive an external dose from radionuclides in surface water. Higher trophic species such as the cormorant consume fish as part of their diet.

Aquatic mammals (i.e. beaver) are exposed through ingestion of food as well as ingestion of water and soil (through the ingestion of terrestrial vegetation). The beaver will also receive an external dose from surface water, sediment and vegetation as it spends the majority of its time in its lodge which is comprised of sediment and vegetation.

The following pathways have been identified as inactive, or are otherwise not applicable:

- *Inhalation*

As discussed in CSA N288.6 (2012), inhalation exposures are typically minor in relation to soil and food ingestion exposures, and can therefore be excluded from assessments. For particulate substances release to air and accumulating in the soil over time, the steady-state soil concentrations are usually high enough that soil and food ingestion components of dose are dominant.

- *Dermal uptake*

Dermal exposure is generally not a significant pathway of exposure for wildlife as fur and feathers are effective at blocking direct contact with skin.

- *Immersion in air (radiological only)*

External dose from immersion in air is minor, relative to soil and food ingestion exposure and can be ignored (particularly since noble gases are not identified as COPCs) (CSA 2012).

Table 6.2 EcoRA Exposure Pathways Summary

Receptor	Environmental Media Exposed	Modes of Exposure	Risk Calculation Method	
			Non-Radioactive	Radioactive
Fish	• surface water • sediment	• uptake from water; • immersion in water; • exposure to sediment (benthic fish, radiological only).	Comparison of surface water concentrations with corresponding benchmark values.	**Pelagic fish:** • Internal dose from water; • External dose from water. **Benthic fish:** • Internal dose from water; • External dose from water; • External dose from sediment.
Benthic Invertebrates	• surface water • sediment	• uptake from water; • immersion in water (radiological only); • immersion in sediment (radiological only).	Comparison of water concentrations with benchmark values.	• Internal dose from water; • External dose from water; • External dose from sediment.
Aquatic Plants	• surface water	• uptake from water; • immersion in water (radiological only).	Comparison of water concentrations with benchmark values.	• Internal dose from water; • External dose from water.
Terrestrial Invertebrates	• soil • groundwater	• uptake from soil; • immersion in soil (radiological only); • uptake from groundwater; • immersion in groundwater (radiological only).	Comparison of soil or groundwater concentrations with benchmark values.	• Internal dose from soil or groundwater; • External dose from soil or groundwater.
Terrestrial Birds	• soil • surface Water	• ingestion: - terrestrial vegetation; - terrestrial invertebrates; - soil; - surface water; - mammals and birds (owl; eagle). • direct exposure to soil (radiological only).	Comparison of dose from intake with benchmark values.	• Internal dose from ingestion. • External dose from soil. • Direct gamma

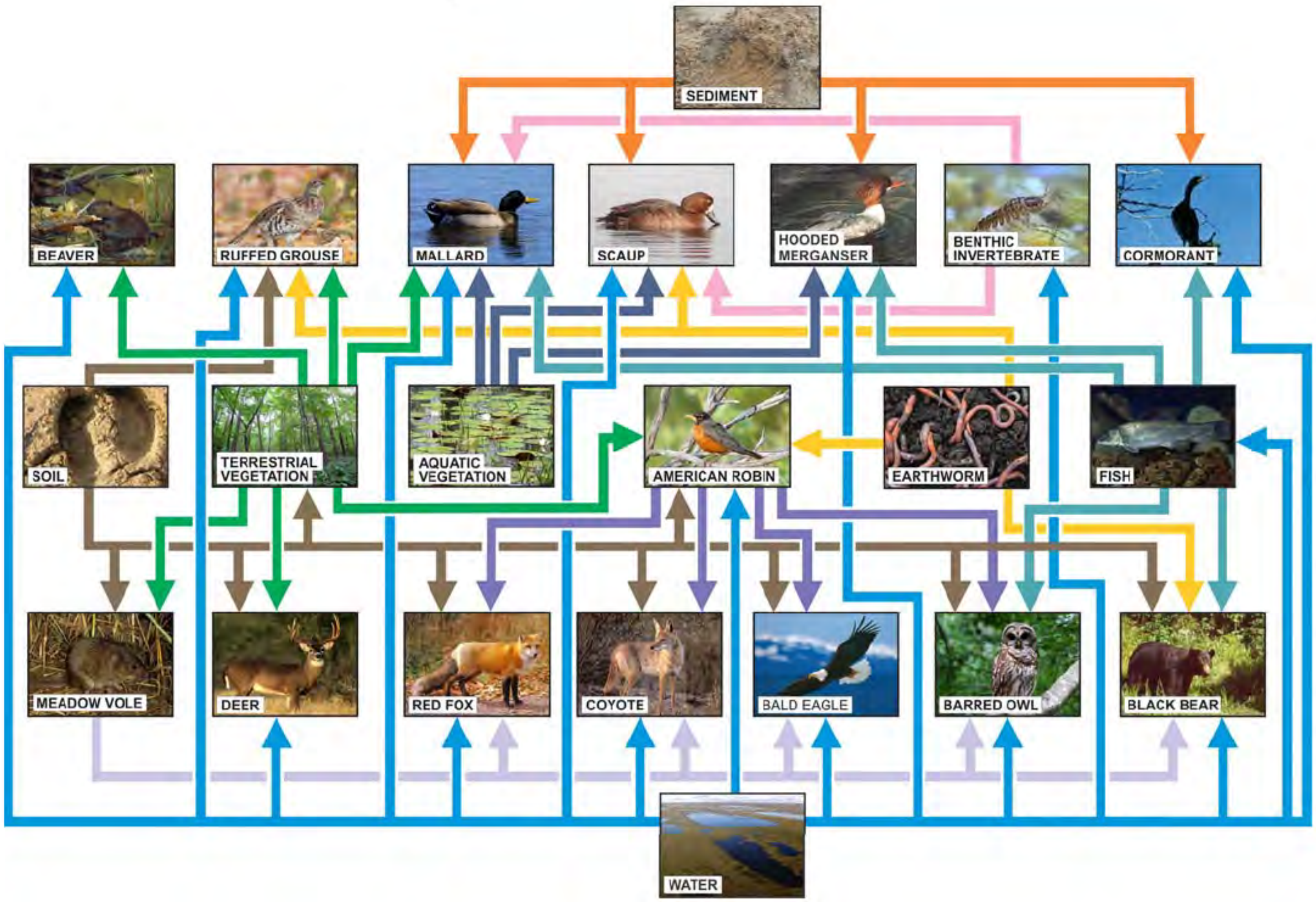
Table 6.2 EcoRA Exposure Pathways Summary (Cont'd)

Receptor	Environmental Media Exposed	Modes of Exposure	Risk Calculation Method	
			Non-Radioactive	Radioactive
Terrestrial Mammals	• soil • surface Water	• ingestion (as appropriate): - terrestrial invertebrates; - terrestrial vegetation; - soil; - surface water; - mammals and birds (fox, bear, coyote). • direct exposure to soil (radiological only).	Comparison of dose from intake with benchmark values.	• Internal dose from ingestion; • External dose from soil. • Direct gamma
Terrestrial Plants	• soil	• uptake from soil; • exposure to soil (radiological only).	Comparison of soil concentrations with benchmark values.	• Internal dose from soil; • External dose from soil. • Direct gamma
Aquatic Birds	• surface water • sediment	• ingestion (as appropriate): - surface water; - fish; - benthic invertebrates; - aquatic vegetation; - sediment. • immersion in surface water (radiological only).	Comparison of dose from intake with benchmark values.	• Internal dose from ingestion; • External dose from water. • Direct gamma
Aquatic Mammals	• surface water • sediment • Soil	• ingestion: - surface water; - benthic invertebrates; - aquatic vegetation; - soil. • immersion in surface water (radiological only).	Comparison of dose from intake with benchmark values.	• Internal dose from ingestion; • External dose from water. • External dose from sediment. • External dose from vegetation. • Direct gamma

6.1.5 EcoRA Conceptual Site Model (CSM)

The overall EcoRA study boundaries are based on knowledge of the site and surrounding area, and includes a range of known and potential contamination sources. Figure 5.3 presents a schematic CSM for the site, showing the environmental media included in this EcoRA along with the exposure pathways that link these environmental media to the identified ecological receptors. Note that direct gamma exposure is also assessed, for applicable receptors.

Figure 6.1 EcoRA Conceptual Site Model



6.2 Exposure Assessment

6.2.1 Exposure Points

The Tier 1 assessment relies on the conservative use of maximum concentrations in relevant environmental media, regardless of the location of the maximum measured concentrations.

For example: surface water concentration data are available from the river, lake, and bog. For those ecological receptors that receive a dose from surface water, the maximum concentration is used in all cases regardless of whether it is measured from the river, lake, or bog. Some receptors (e.g. pelagic fish) may not in fact reside in the bog, and would not be exposed to this maximum concentration, but such a combination represents a hypothetical (conservative) worst-case scenario.

The maximum concentrations of COPCs in environmental media are outlined in Section 6.2.4.

6.2.2 Exposure Factors for Receptors

Table 6.3 presents an overview of key exposure factors among the ecological receptors identified and described in Section 6.1.1. [redacted]

The exposure factors for ecological receptors were obtained preferentially from Module C (*Standardization of Wildlife Receptor Characteristics*) of the Environment Canada (2012) *FCSAP Ecological Risk Assessment Guidance*.

Soil and sediment ingestion rates, if not available in the FCSAP (2012) document, were for the most part obtained from a wildlife soil ingestion study completed by Beyer *et al.* (1994) in which the fractional soil composition of the diets (i.e., percentage of the dry weight food ingestion rate) of 28 wildlife species were estimated. Ingestion rates for animals not considered in the Sample study were estimated by using fractional compositions for other animals with similar diets.

When food and water intake and inhalation rates were not available directly from the above-mentioned sources, the following allometric equations from the U.S. EPA (1993b) were used:

Dry weight food Ingestion (g dw/d):

Birds = $0.648 * BW^{0.651}$ (BW in g)

Mammals = $0.235 * BW^{0.822}$ (BW in g)

Water Intake (L/d):

Birds = $0.059 * BW^{0.67}$ (BW in kg)

Mammals = $0.099 * BW^{0.9}$ (BW in kg)

Inhalation Rate (m^3/d):

Birds = $0.4089 * BW^{0.77}$ (BW in kg)

Mammals = $0.5458 * BW^{0.8}$ (BW in kg)

Table 6.3 Overview of Exposure Factors for Ecological Receptors

Parameter	Units	Ecological Receptor (Source)																											
		Black Bear		Beaver		Cormorant		Coyote		Deer		Bald Eagle		Red Fox		Ruffed Grouse		Mallard		Hooded Merganser		Barred Owl		American Robin		Scaup		Meadow Vole	
Body Weight	kg	68	1	20	2	2.1	3	14	4	75	1	4.7	1	3.8	1	0.552	1	1.2	1	1.47	5	0.72	6	0.079	1	0.707	1	0.0349	1
Water Intake Rate	L/d	4.08	1	3	2	0.0967	7	1.07	7	4.5	1	0.188	1	0.342	1	0.039	1	0.072	1	0.076	7	0.046	7	0.011	1	0.049	1	0.007	1
Inhalation Rate	m^3/d	83.1	7	12	7	1.4	7	4.5	7	46.9	7	2.3	7	3.7	7	0.46	7	0.9	7	0.55	7	0.31	7	0.059	7	0.7	7	0.0356	12
Soil Ingestion Rate	g(dw)/d	81.6	8	7.6	8			8.928	8	45	1	5.91	8	2.47	1	4.2	8					6.49	8	0.67	1			0.083	1
Sediment Ingestion Rate	g(dw)/d					3.9	8											1.98	1	2.775	8					2.47	8		
Food Ingestion Rate	g(ww)/d	6800	1	1000	9	522	3	930	7	7500	1	564	1	342	1	125	1	300	1	370	5	417	7	95.59	1	309	1	11.517	1
Fraction that is fish	-	0.05	1			1	3					0.65	1					0.025	1	0.8	10	0.05	6, 11						
Fraction that is benthos	-																	0.4	1							0.45	1		
Fraction that is aq. vegetation	-																	0.5	1	0.2	10					0.1	1		
Fraction that is small mammals	-	0.1	1					0.9	4			0.2	1	0.4	1							0.9	6, 11						
Fraction that is birds	-							0.1	4			0.15	1	0.2	1							0.05	6, 11						
Fraction that is invertebrates	-	0.05	1											0.25	1	0.15	1	0.025	1					0.4	1	0.45	1		
Fraction that is terrestrial vegetation	-	0.8	1	1	9					1	1			0.15	1	0.85	1	0.05	1					0.6	1			1	1

1 FCSAP (2012)
2 Beak (1995)
3 Weseloh (2000)
4 Takar (2001)
5 Environment Canada (1999)
6 Quimby (2000)
7 US EPA (1993b)
8 Beyer *et al.* (1994)
9 Mirka *et al.* (1996)
10 Corr (2005)
11 Sample, Opresko and Suter (1994)
12 MOE (2011b)

6.2.3 Exposure Durations and Averaging

Terrestrial Receptors

For Tier 1 and EcoRA calculations, it is conservatively assumed that ecological receptors spend their entire exposure duration within their exposure locations. In other words, there is no reduction to account for time spent outside of the exposure location.

For migratory species, risk calculations do *not* average a receptors exposure based on time away from the site during migration.

Aquatic Receptors

Similar to terrestrial EcoRA calculations, Tier 1 aquatic EcoRA calculations conservatively assume that all aquatic receptors spend their entire exposure duration within their exposure locations. In other words, there is no reduction to account for time spent outside of the exposure location.

6.2.4 Exposure Point Concentrations

Sections 6.1.3, 6.1.5, and 6.2.1 discuss the locations of ecological receptors, the environmental media that each receptor can be exposed to, and the pathway through which they can potentially be exposed.

The following tables present summary statistics for each environmental media, relevant to the identified receptors and pathways. These summary statistics are used as exposure point concentrations in subsequent exposure calculations.

Groundwater concentrations used in the hypothetical EcoRA groundwater earthworm calculations are the same as those presented in Table 5.10 for HHRA calculations. It is important to note that measurement data for total ammonia (i.e. as presented in 5.10) must be converted into unionized ammonia to allow for comparison to the TRV. The conversion from total ammonia to un-ionized ammonia is based on the pH and temperature of the water medium. In Tier 1 calculations the conversion uses the maximum measured pH and temperature, regardless of their locations, in order to produce the most conservative (i.e. highest) estimated unionized concentration of ammonia.

Table 6.4 EcoRA – Soil Exposure Point Concentrations

(All soil locations)

COPCs	Units	N	N < MDL	% < MDL	Min.	Max.	Arith. Mean	Geo. Mean	Std. Dev.	95th Perc.
Uranium	µg/g	140	140	0	0.09	22.10	2.05	0.99	3.35	8.06

Table 6.5 EcoRA – Groundwater Exposure Point Concentrations

(All groundwater locations)

COPCs	Units	N	N < MDL	% < MDL	Min.	Max.	Arith. Mean*	Geo. Mean*	Std. Dev.*	95th Perc.*
Ammonia	mg/L as N	267	30	11	0.03	4.1	0.52	0.24	0.70	1.27
Uranium	µg/L	267	169	63	0.2	8.9	0.45	0.30	0.77	1.47
TBP	mg/L	140	135	96	0.6	3	0.62	0.61	0.20	0.60

*Non-detect values in database taken to be equal to their detection limits.

Table 6.6 EcoRA – Surface Water Exposure Point Concentrations

(All surface water locations: lake, river, and bog)

COPCs	Units	N	N < MDL	% < MDL	Min.	Max.	Arith. Mean*	Geo. Mean*	Std. Dev.*	95th Perc.*
Uranium	µg/L	36	7	19	0.2	7.4	1.13	0.62	1.52	4.00
TBP	mg/L	8	8	100	<0.6	<0.6	N/A	N/A	N/A	N/A

*Non-detect values in database taken to be equal to their detection limits.

Table 6.7 EcoRA – Sediment Exposure Point Concentrations

(All sediment locations; from Arcadis (2015a))

COPCs	Units	N	N < MDL	% < MDL	Min.	Max.	Arith. Mean*	Geo. Mean*	Std. Dev.*	95th Perc.*
Uranium	µg/g	60	0	0	0.39	0.64	0.50	0.50	0.05	0.59
TBP	µg/g	0	-	-	-	-	-	-	-	-

*Non-detect values in database taken to be equal to their detection limits.

Table 6.8 EcoRA – Radionuclide Levels in Environmental Media

(See Section 2.5.8 for discussion on radionuclide levels in environmental media)

Radionuclide	Groundwater Concentration (Bq/L)	Notes / Reference
Pb-210	0.11	Assumed equal to U-238
Po-210	0.11	Assumed equal to U-238
Ra-226	0.03	Maximum measured groundwater concentration
Th-230	0.11	Assumed equal to U-238
U-234	0.11	Correlated from maximum measured U_{nat} concentration
U-235	0.00506	Correlated from maximum measured U_{nat} concentration
U-238	0.11	Correlated from maximum measured U_{nat} concentration
Radionuclide	**Soil Concentration (Bq/g dw)**	**Notes / Reference**
Pb-210	0.273	Assumed equal to U-238
Po-210	0.273	Assumed equal to U-238
Ra-226	0.273	Assumed equal to U-238
Th-230	0.273	Assumed equal to U-238
U-234	0.273	Correlated from maximum measured U_{nat} concentration
U-235	0.0126	Correlated from maximum measured U_{nat} concentration
U-238	0.273	Correlated from maximum measured U_{nat} concentration
Radionuclide	**Surface Water Concentration (Bq/L)**	**Notes / Reference**
Pb-210	0.0914	Assumed equal to U-238
Po-210	0.0914	Assumed equal to U-238
Ra-226	0.02	Maximum measured surface water concentration
Th-230	0.0914	Assumed equal to U-238
U-234	0.0914	Correlated from maximum measured U_{nat} concentration
U-235	0.00421	Correlated from maximum measured U_{nat} concentration
U-238	0.0914	Correlated from maximum measured U_{nat} concentration
Radionuclide	**Sediment Concentrations *(Based on Kd)* (Bq/g dw)**	**Notes / Reference**
Pb-210	0.0247	Kd: Bechtel Jacobs (1998)
Po-210	0.0137	Kd: Bechtel Jacobs (1998)
Ra-226	0.148	Kd: CSA N288.1 (2014), Table A.26
Th-230	17.366	Kd: CSA N288.1 (2014), Table A.26
U-234	0.0046	Kd: CSA N288.1 (2014), Table A.26
U-235	0.00021	Kd: CSA N288.1 (2014), Table A.26
U-238	0.0046	Kd: CSA N288.1 (2014), Table A.26

Notes:

* See Section 2.5.8 for discussion on estimating radionuclide levels in environmental media using existing measurement data.

6.2.4.1 Sediment – Measured vs. Derived

Section 5.2.3.4 presents a comparison of derived sediment concentrations (based on surface water concentrations and distribution coefficients (Kds) to measured sediment concentrations obtained from field sampling activities, for select COPCs and radionuclides. Results of the comparison indicate that measured uranium and measured Po-210 levels are considerably higher than the corresponding Kd-estimated levels.

See Table 5.17 for measured sediment exposure point concentrations, for radionuclides and non-radiological sediment COPCs.

EcoRA results based on measured levels of radionuclides and uranium are presented in Table 6.24 and Table 6.27, and discussed in Section 6.4.3.

6.2.4.2 Direct Gamma

Gamma dose rates used for radiological EcoRA are obtained from the BRR fenceline gamma monitoring program (BRR 2014b-e). A maximum measured quarterly fenceline dose rate of 1.61 µSv/h (equivalent to 0.0386 mGy/d) was recorded from the west fenceline monitoring station in Q3 of 2014; this maximum value was used for gamma dose calculation purposes, for all biota, as a conservative measure. Furthermore, it is conservatively assumed that all ecological receptors receive this dose rate for 24 h/d (i.e. 100% residency).

6.2.5 Non-Radiological Dose Calculation Methods

The COPCs identified through the screening process (see Section 3) are quantitatively evaluated for all ecological receptors (see Section 6.1.1), based on the identified pathways (see Section 6.1.3) and environmental media (see Section 6.2.1). Where sufficient data are not available, a qualitative assessment is undertaken.

For terrestrial vegetation and earthworms, toxicity is based on direct comparison to soil COPC concentrations; an examination of the intakes for these receptors is not necessary. Similarly, assessment of potential effects on aquatic biota via contact with surface water is based on direct comparison to surface water COPC concentrations; exposure modelling is not required.

For mammals and birds, COPC exposure is based on intakes, which are estimated by way of food chain intake calculations. In a broad sense, the total intake of any given COPC for a particular mammal or bird receptor is equal to the sum of intakes from all appropriate pathways, including: incidental ingestion of soil, incidental ingestion of surface water, and consumption of food (which varies based on the diet of a particular receptor). Equation 6-1 is used to calculate each of the intake routes as follows:

$$I_n = C_n \times IR_n \times f_{loc} \times CF \qquad (6\text{-}1)$$

Where:

I_n = intake of COC via pathway "n" where "n" can represent all exposure routes such as soil, vegetation, etc. [mg/d]

C_n = COC concentration in "n" media [mg/kg]

IR_n = intake rate of "n" by the receptor [g/d]

f_{loc} = fraction of time at site [-]

CF = conversion factor 1.0×10^{-3} [kg/g]

After summing the individual intakes, the total intake was divided by the body weight of the ecological receptor in order to compare the total COC intake to the toxicity reference value (which has the unit of mg/kg-d). This is consistent with CSA (2012) methodology for calculating intakes.

6.2.6 Radiological Dose Calculation Methods

For radionuclide COPCs, the resulting radiation dose involves both internal and external components, which are calculated separately. The total radiation dose, per radionuclide, is the sum of all internal and external doses. The overall radiation dose is the total sum of all internal external doses from all radionuclides.

6.2.6.1 Aquatic Biota – Internal & External Radiation Dose

For aquatic biota, internal dose calculation is performed for each radionuclide, following Equation 6-2 (CSA 2012):

$$D_{\text{int}} = DC_{\text{int}} \times C_{tissue} \tag{6-2}$$

Where:

D_{int} = internal radiation dose [µGy/hr]

DC_{int} = internal dose coefficient for radionuclide in tissue [µGy/hr per Bq/(kg fw)]

C_{tissue} = whole body tissue concentration [Bq/(kg fw)]

External dose calculation is performed for each radionuclide, following Equation 6-3 (CSA 2012):

$$D_{ext} = DC_{ext}\left[(OF_w + 0.5 \times OF_{ws} + 0.5 \times OF_{ss}) \times C_w + (OF_s + 0.5 \times OF_{ss}) \times C_s\right] \tag{6-3}$$

Where:

D_{ext} = external radiation dose [µGy/hr]

DC_{ext} = external dose coefficient for radionuclide in water or sediment [µGy/hr per Bq/kg; or µGy/hr per Bq/L]

OF_w = fraction of time spent immersed in surface water [unitless]

OF_s = fraction of time spent immersed in sediment [unitless]

OF_{ws} = fraction of time spent on the water's surface [unitless]

OF_{ss} = fraction of time spent on the sediment's surface [unitless]

C_w = surface water concentration [Bq/L]

C_s = sediment concentration [Bq/kg]

6.2.6.2 Terrestrial Biota – Internal & External Radiation Dose

For terrestrial biota, internal dose calculation is performed for each radionuclide, following Equation 6-4 (CSA 2012):

$$D_{\text{int}} = DC_{\text{int}} \times C_{tissue} \tag{6-4}$$

Where:

D_{int} = internal radiation dose [µGy/hr]

DC_{int} = internal dose coefficient for radionuclide in tissue [µGy/hr per Bq/(kg fw)]

C_{tissue} = whole body tissue concentration [Bq/(kg fw)]

External dose calculation is performed for each radionuclide, following Equation 6-5 (CSA 2012):

$$D_{ext} = DC_{ext} \times OF_{soil} \times C_{soil} \tag{6-5}$$

Where:

D_{ext} = external radiation dose [µGy/hr]

DC_{ext} = external dose coefficient for radionuclide in soil [µGy/hr per Bq/kg]

OF_{soil} = fraction of time spent immersed in soil [unitless]

C_{soil} = soil concentration [Bq/kg]

6.2.6.3 Radiation Weighting Factors

The radioecological weighting factor, also referred to as relative biological effectiveness (RBE), is the ratio of doses from different types of radiation needed to produce the same biological effect. For example,

$$\text{Alpha RBE} = \frac{\text{(Dose of gamma to produce a given effect)}}{\text{(Dose of alpha to produce the same effect)}}$$

The RBE is applied to un-weighted doses from alpha-emitting radionuclides; the weighted doses retain their original units (i.e., mGy/day). A RBE factor of 10 is used in this study for the alpha radiation component of internal dose from all alpha emitting radionuclides, following CSA (2012). Select DCs from Prohl (2003) already include an RBE of 10 (see below), whereas DCs from Amiro (1997) are not originally weighted. In this study, an RBE of 10 has been applied to DCs for all alpha emitting radionuclides, including DCs from Amiro (1997) and Prohl (2003).

6.2.6.4 Dose Coefficients

Radiation dose coefficients (DCs) have been selected from: (1) Prohl (2003), and (2) Amiro (1997), if an appropriate representative species could not be found in Prohl (2003), consistent with CSA (2012) guidance.

Prohl (2003) DCs

Prohl (2003) provides DCs from the FASSET program based on select reference organisms, which have been chosen based on broad taxonomic families of organisms that are known contributors to the proper functioning of an ecosystem. The following reference organisms are considered in Prohl (2003):

Terrestrial Reference Organisms:

- Woodlouse;
- Earthworm;
- Mouse;
- Mole;
- Weasel;
- Snake;
- Rabbit;
- Red fox;
- Row deer;
- Cattle;
- Small egg;
- Big egg;
- Herbivorous bird;
- Carnivorous bird.

Aquatic Reference Organisms Phytoplankton:

- Zooplankton;
- Crustacean;
- Insect larvae;
- Vascular plant;
- Gastropod;
- Amphibian;
- Bivalve mollusc;
- Pelagic fish;
- Benthic fish;
- Mammal;
- Bird.

Table 6.9 presents a comparison between Prohl (FASSET) (2003) reference organism classes and the identified ecological receptors.

Table 6.9 Comparison of Ecological Receptors to Reference Organisms (for DCs)

Prohl (2003) Reference Organism	Applicable Y/N	Ecological Receptor Equivalency	Comments
Terrestrial Biota			
Earthworm	Y	Earthworm	-
Mouse	Y	Meadow Vole	Representative species
Red fox	Y	Red Fox Coyote	-
Row Deer	Y	Deer	-
Cattle	Y	Black Bear	Representative species (closest match based on overall size)
Herbivorous bird (terrestrial)	Y	American Robin	Prohl (2003) DCs are based on organism size/dimensions, not diet. According to Prohl (2003), DCs for the 'carnivorous bird' reference organism are based on an organism equivalent in volume to a rabbit, whereas DCs for the 'herbivorous bird' reference organism are based on an organism with volume similar to a mouse. The herbivorous bird DCs are therefore chosen preferentially, since this more closely matches the size of a robin, and, the herbivorous bird DCs are generally more conservative than those derived for carnivorous birds.
Carnivorous bird (terrestrial)	Y	Barred Owl Ruffed Grouse Bald Eagle	Prohl (2003) DCs are based on organism size/dimensions. According to Prohl (2003), DCs for the 'carnivorous bird' reference organism are based on an organism approximately equivalent in size to a rabbit. The carnivorous bird/rabbit DCs therefore appropriately approximate the size of the owl, grouse and eagle receptors. See further discussion below.
Terrestrial Plants - Herb (Critical Organs)	Y	Terrestrial Vegetation	See discussion below.
Aquatic Biota			
Insect larvae	Y	Benthos	Benthos includes crustaceans such as crayfish, mollusks such as clams and snails, aquatic worms and the immature (larval) forms of aquatic insects such as stonefly and mayfly nymphs. Bivalve mollusk DCs were chosen. Compared to other benthos, bivalve mollusk DCs are equivalent or more conservative for internal radiation and less conservative for external radiation. However, as internal dose for benthos is many orders of magnitude higher than external dose, choosing bivalve mollusk as the representative species is a conservative assumption.
Gastropod			
Bivalve mollusc			
Vascular plant	Y	Aquatic Vegetation (generic)	Representative species.
Pelagic fish	Y	Pelagic Fish (generic)	Representative group.
Benthic fish	Y	Benthic Fish (generic)	Representative group.
Aquatic Bird	Y	Mallard Lesser Scaup Hooded Merganser Cormorant	Many representative species. Both predatory and herbivorous species are represented. Aquatic bird DCs will be used preferentially for these receptors, where available.

Overall, there is good alignment; however, there are two biota groups that warrant further discussion: terrestrial vegetation, and terrestrial birds.

Terrestrial Vegetation

For terrestrial vegetation, DCs for whole-body exposure are not available in Prohl (2003). Instead Prohl (2003) provides organ-specific terrestrial vegetation DCs (external) for selected critical organs of shrubs, trees and herbs (meristems and buds). By applying the DC for a sensitive critical organ to the estimated whole-body exposure, the resulting dose will have an inherent degree of conservatism. Therefore, the critical organ DC for the 'herb' reference organism was selected. Prohl (2003) does not provide internal DCs for terrestrial vegetation; internal DCs from Amiro (1997) were applied.

Terrestrial Birds

For terrestrial birds, DCs for internal exposure are not available from Prohl (2003). However, DCs from Prohl (2003) are derived primarily based on organism size, which is simplified and expressed ellipsoids or spheres of various sizes. Prohl (2003) lists the organism size for the 'herbivorous bird' reference organism as being equal to that of the 'mouse' reference organism. Similarly, Prohl (2003) lists the organism size for the 'carnivorous bird' reference organism as being equal to that of the 'rabbit' reference organism. Therefore, the Prohl (2003) internal exposure DCs for these two receptor pairs are interchangeable. As a result, the internal DCs for the 'mouse' reference organism are applied to the American Robin receptor, whereas the internal DCs for the 'rabbit' reference organism are applied to the Barred Owl, Ruffed Grouse, Bald Eagle and Cormorant receptor.

Amiro (1997) DCs

Two species, the Beaver and the Bald Eagle, did not have a clear representative species in Prohl (2003), due to their size and their habitat being a combination of aquatic and terrestrial. Earthworms that live in groundwater are also not clearly defined in Prohl (2003). To maintain conservatism, DCs from Amiro (1997) were chosen as they neglect organism geometry (i.e. assume infinite size) and therefore assume that all energies emitted by radionuclides from within the biota are absorbed by the biota, regardless of its actual size.

Summary

Table 6.10 presents the internal and external DCs selected for the ecological receptors.

Table 6.15 following the selected DC tables shows the reference key.

For external soil DC selection, the coyote, fox and meadow vole are burrowing animals and therefore DCs for biota that reside "in soil" were used preferentially over DCs for biota that reside "on soil".

Table 6.10 EcoRA: Dose Coefficients – Terrestrial Biota, Internal

Terrestrial Receptor	Radionuclide	Internal DCs (weighted) *(Gy/y per Bq/kgFW)*	Reference Information		
			Ref	Table	Species
Earthworm (soil)	U-234	2.37E-04	1	4	1
	U-235	2.28E-04	1	4	1
	U-238	2.10E-04	1	4	1
	Th-230	2.37E-04	1	4	1
	Ra-226	1.23E-03	1	4	1
	Pb-210	2.10E-06	1	4	1
	Po-210	2.72E-04	1	4	1
Black Bear	U-234	2.37E-04	1	4	2
	U-235	2.28E-04	1	4	2
	U-238	2.10E-04	1	4	2
	Th-230	2.37E-04	1	4	2
	Ra-226	1.23E-03	1	4	2
	Pb-210	2.28E-06	1	4	2
	Po-210	2.72E-04	1	4	2
Coyote	U-234	2.37E-04	1	4	4
	U-235	2.28E-04	1	4	4
	U-238	2.10E-04	1	4	4
	Th-230	2.37E-04	1	4	4
	Ra-226	1.23E-03	1	4	4
	Pb-210	2.28E-06	1	4	4
	Po-210	2.72E-04	1	4	4
Deer	U-234	2.37E-04	1	4	3
	U-235	2.28E-04	1	4	3
	U-238	2.10E-04	1	4	3
	Th-230	2.37E-04	1	4	3
	Ra-226	1.23E-03	1	4	3
	Pb-210	2.28E-06	1	4	3
	Po-210	2.72E-04	1	4	3
Red Fox	U-234	2.37E-04	1	4	4
	U-235	2.28E-04	1	4	4
	U-238	2.10E-04	1	4	4
	Th-230	2.37E-04	1	4	4
	Ra-226	1.23E-03	1	4	4
	Pb-210	2.28E-06	1	4	4
	Po-210	2.72E-04	1	4	4
Meadow Vole	U-234	2.37E-04	1	4	5
	U-235	2.28E-04	1	4	5
	U-238	2.10E-04	1	4	5
	Th-230	2.37E-04	1	4	5
	Ra-226	1.23E-03	1	4	5
	Pb-210	2.19E-06	1	4	5
	Po-210	2.72E-04	1	4	5

Table 6.10 EcoRA: Dose Coefficients – Terrestrial Biota, Internal (Cont'd)

Terrestrial Receptor	Radionuclide	Internal DCs (weighted) *(Gy/y per Bq/kgFW)*	Reference Information		
			Ref	Table	Species
Ruffed Grouse Barred Owl	U-234	2.37E-04	1	4	9
	U-235	2.28E-04	1	4	9
	U-238	2.10E-04	1	4	9
	Th-230	2.37E-04	1	4	9
	Ra-226	1.23E-03	1	4	9
	Pb-210	2.19E-06	1	4	9
	Po-210	2.72E-04	1	4	9
American Robin	U-234	2.37E-04	1	4	5
	U-235	2.28E-04	1	4	5
	U-238	2.10E-04	1	4	5
	Th-230	2.37E-04	1	4	5
	Ra-226	1.23E-03	1	4	5
	Pb-210	2.19E-06	1	4	5
	Po-210	2.72E-04	1	4	5
Beaver Bald Eagle	U-234	2.46E-04	2	7R	17
	U-235	2.36E-04	2	7R	17
	U-238	2.16E-04	2	7R	17
	Th-230	2.41E-04	2	7R	17
	Ra-226	2.46E-04	2	7R	17
	Pb-210	2.17E-07	2	7	17
	Po-210	2.73E-04	2	7R	17

Table 6.11 EcoRA: Dose Coefficients – Terrestrial Biota, External

Terrestrial Receptor	Radionuclide	External DCs *(Gy/y per Bq/kgDW)*	Reference Information		
			Ref	Table	Species
Terrestrial Vegetation	U-234	1.05E-09	1	3	8
	U-235	2.72E-07	1	3	8
	U-238	7.80E-10	1	3	8
	Th-230	1.14E-09	1	3	8
	Ra-226	2.89E-06	1	3	8
	Pb-210	3.16E-09	1	3	8
	Po-210	1.49E-11	1	3	8
Earthworm (soil)	U-234	2.54E-10	1	2	1
	U-235	2.54E-07	1	2	1
	U-238	1.31E-10	1	2	1
	Th-230	4.82E-10	1	2	1
	Ra-226	4.03E-06	1	2	1
	Pb-210	1.67E-09	1	2	1
	Po-210	2.02E-11	1	2	1
Black Bear	U-234	7.88E-11	1	1	2
	U-235	4.73E-08	1	1	2
	U-238	5.26E-11	1	1	2
	Th-230	1.05E-10	1	1	2
	Ra-226	8.77E-07	1	1	2
	Pb-210	2.45E-10	1	1	2
	Po-210	4.12E-12	1	1	2
Coyote Red Fox	U-234	3.85E-11	1	2	4
	U-235	8.23E-08	1	2	4
	U-238	6.49E-12	1	2	4
	Th-230	1.31E-10	1	2	4
	Ra-226	1.67E-06	1	2	4
	Pb-210	3.07E-10	1	2	4
	Po-210	7.54E-12	1	2	4
Deer	U-234	4.20E-10	1	1	3
	U-235	1.58E-07	1	1	3
	U-238	3.07E-10	1	1	3
	Th-230	4.91E-10	1	1	3
	Ra-226	2.02E-06	1	1	3
	Pb-210	1.31E-09	1	1	3
	Po-210	9.64E-12	1	1	3
Meadow Vole	U-234	9.64E-11	1	2	5
	U-235	2.01E-07	1	2	5
	U-238	2.02E-11	1	2	5
	Th-230	3.33E-10	1	2	5
	Ra-226	3.24E-06	1	2	5
	Pb-210	9.64E-10	1	2	5
	Po-210	1.58E-11	1	2	5

Table 6.11 EcoRA: Dose Coefficients – Terrestrial Biota, External (Cont'd)

Terrestrial Receptor	Radionuclide	External DCs *(Gy/y per Bq/kgDW)*	Reference Information		
			Ref	Table	Species
Ruffed Grouse Barred Owl	U-234	1.75E-10	1	1	7
	U-235	1.93E-07	1	1	7
	U-238	8.24E-11	1	1	7
	Th-230	3.68E-10	1	1	7
	Ra-226	2.28E-06	1	1	7
	Pb-210	1.05E-09	1	1	7
	Po-210	1.14E-11	1	1	7
American Robin	U-234	4.38E-10	1	1	6
	U-235	2.37E-07	1	1	6
	U-238	2.80E-10	1	1	6
	Th-230	6.14E-10	1	1	6
	Ra-226	2.80E-06	1	1	6
	Pb-210	1.58E-09	1	1	6
	Po-210	1.40E-11	1	1	6
Beaver Bald Eagle	U-234	1.21E-08	2	7	17
	U-235	9.95E-07	2	7	17
	U-238	9.48E-09	2	7	17
	Th-230	1.07E-08	2	7	17
	Ra-226	4.80E-08	2	7	17
	Pb-210	3.32E-08	2	7	17
	Po-210	5-16E-11	2	7	17

Table 6.12 EcoRA: Dose Coefficients – Aquatic Biota, Internal

Aquatic Receptor	Radionuclide	Internal DCs *(Gy/y per Bq/kgFW)*	Reference Information		
			Ref	Table	Species
Amphibian	U-234	2.37E-04	1	5R	10
	U-235	2.28E-04	1	5R	10
	U-238	5.00E-04	1	5R	10
	Th-230	2.37E-04	1	5R	10
	Ra-226	1.58E-03	1	5R	10
	Pb-210	2.02E-06	1	5	10
	Po-210	2.72E-04	1	5R	10
Aquatic Plants	U-234	2.37E-04	1	5R	15
	U-235	2.28E-04	1	5R	15
	U-238	4.65E-04	1	5R	15
	Th-230	2.37E-04	1	5R	15
	Ra-226	1.49E-03	1	5R	15
	Pb-210	4.82E-07	1	5	15
	Po-210	2.72E-04	1	5R	15
Earthworms (GW)	U-234	2.37E-04	1	4	1
	U-235	2.28E-04	1	4	1
	U-238	2.10E-04	1	4	1
	Th-230	2.37E-04	1	4	1
	Ra-226	1.23E-03	1	4	1
	Pb-210	2.10E-06	1	4	1
	Po-210	2.72E-04	1	4	1
Benthic Invertebrates	U-234	2.37E-04	1	5R	11
	U-235	2.28E-04	1	5R	11
	U-238	5.00E-04	1	5R	11
	Th-230	2.37E-04	1	5R	11
	Ra-226	1.58E-03	1	5R	11
	Pb-210	2.10E-06	1	5	11
	Po-210	2.72E-04	1	5R	11
Benthic Fish	U-234	2.37E-04	1	5R	12
	U-235	2.28E-04	1	5R	12
	U-238	5.00E-04	1	5R	12
	Th-230	2.37E-04	1	5R	12
	Ra-226	1.58E-03	1	5R	12
	Pb-210	2.10E-06	1	5	12
	Po-210	2.72E-04	1	5R	12
Pelagic Fish	U-234	2.37E-04	1	5R	13
	U-235	2.28E-04	1	5R	13
	U-238	5.00E-04	1	5R	13
	Th-230	2.37E-04	1	5R	13
	Ra-226	1.58E-03	1	5R	13
	Pb-210	2.10E-06	1	5	13
	Po-210	2.72E-04	1	5R	13
Cormorant Mallard Scaup Hooded Merganser	U-234	2.37E-04	1	5R	14
	U-235	2.37E-04	1	5R	14
	U-238	5.00E-04	1	5R	14
	Th-230	2.37E-04	1	5R	14
	Ra-226	1.58E-03	1	5R	14
	Pb-210	2.10E-06	1	5	14
	Po-210	2.72E-04	1	5R	14

Table 6.13 EcoRA: Dose Coefficients – Aquatic Biota, External Water

Aquatic Receptor	Radionuclide	External DCs *(Gy/y per m3)*	Reference Information		
			Ref	Table	Species
Amphibians	U-234	4.20E-12	1	6	10
	U-235	8.32E-10	1	6	10
	U-238	6.40E-10	1	6	10
	Th-230	4.38E-12	1	6	10
	Ra-226	8.77E-09	1	6	10
	Pb-210	9.64E-11	1	6	10
	Po-210	4.21E-14	1	6	10
Aquatic Vegetation	U-234	1.58E-11	1	6	15
	U-235	1.14E-09	1	6	15
	U-238	4.12E-09	1	6	15
	Th-230	2.02E-11	1	6	15
	Ra-226	1.40E-08	1	6	15
	Pb-210	1.67E-09	1	6	15
	Po-210	4.29E-14	1	6	15
Benthic Invertebrates	U-234	3.59E-12	1	6	11
	U-235	8.06E-10	1	6	11
	U-238	4.65E-10	1	6	11
	Th-230	3.86E-12	1	6	11
	Ra-226	8.59E-09	1	6	11
	Pb-210	6.49E-11	1	6	11
	Po-210	4.12E-14	1	6	11
Benthic Fish	U-234	3.07E-12	1	6	12
	U-235	7.27E-10	1	6	12
	U-238	2.80E-10	1	6	12
	Th-230	3.33E-12	1	6	12
	Ra-226	7.89E-09	1	6	12
	Pb-210	3.59E-11	1	6	12
	Po-210	3.86E-14	1	6	12
Pelagic Fish	U-234	3.42E-12	1	6	13
	U-235	7.88E-10	1	6	13
	U-238	3.86E-10	1	6	13
	Th-230	3.77E-12	1	6	13
	Ra-226	8.41E-09	1	6	13
	Pb-210	5.35E-11	1	6	13
	Po-210	4.03E-14	1	6	13
Beaver	U-234	1.75E-12	1	6	16
	U-235	6.31E-10	1	6	16
	U-238	1.84E-10	1	6	16
	Th-230	2.19E-12	1	6	16
	Ra-226	7.19E-09	1	6	16
	Pb-210	2.02E-11	1	6	16
	Po-210	3.51E-14	1	6	16

Table 6.13 EcoRA: Dose Coefficients – Aquatic Biota, External Water (Cont'd)

Aquatic Receptor	Radionuclide	External DCs *(Gy/y per m3)*	Reference Information		
			Ref	Table	Species
Cormorant Mallard Scaup Hooded Merganser	U-234	1.66E-12	1	6	14
	U-235	5.87E-10	1	6	14
	U-238	1.67E-10	1	6	14
	Th-230	2.02E-12	1	6	14
	Ra-226	6.83E-09	1	6	14
	Pb-210	1.75E-11	1	6	14
	Po-210	3.33E-14	1	6	14
Earthworm (GW)	U-234	8.09E-12	2	7	17
	U-235	6.64E-10	2	7	17
	U-238	6.32E-12	2	7	17
	Th-230	7.15E-12	2	7	17
	Ra-226	3.20E-11	2	7	17
	Pb-210	2.21E-11	2	7	17
	Po-210	3.44E-14	2	7	17

Table 6.14 EcoRA: Dose Coefficients – Aquatic Biota, External Sediment

Aquatic Receptor	Radionuclide	External DCs *(Gy/y per Bq/kgDW)*	Reference Information		
			Ref	Table	Species
Amphibians Benthic Invertebrates Benthic Fish Cormorant Mallard Scaup Merganser	U-234	1.21E-08	2	7	17
	U-235	9.95E-07	2	7	17
	U-238	9.48E-09	2	7	17
	Th-230	1.07E-08	2	7	17
	Ra-226	4.80E-08	2	7	17
	Pb-210	3.32E-08	2	7	17
	Po-210	5.16E-11	2	7	17
Aquatic Plants Pelagic Fish Beaver	*External sediment exposure not a pathway*				

Table 6.15 EcoRA: Dose Coefficients – Reference Key

Reference					
1	Pröhl, G. (Ed.). 2003. Dosimetric Models and Data for Assessing Radiation Exposures to Biota. FASSET Deliverable 3.				
2	Amiro, B.D. 1997. Radiological Dose Conversion Factors for Generic Non-Human Biota Used for Screening Potential Ecological Impacts. Journal of Environmental Radioactivity. 35:1, pp. 37–51.				
Table					
1	Table 3-9	Unweighted DCs for external exposure of organisms that live **on** soil for a homogeneously contaminated volume source; the thickness of the contaminated soil layer is 10 cm, the soil density is 1.6 g/cm³.			
2	Table 3-10	Unweighted DCs for external exposure of organisms that live **in** soil for a homogeneously volume source; the thickness of the contaminated soil layer is 50 cm, the soil density is 1.6 g/cm³, the organisms live at a depth of 25 cm.			
3	Table 3-11 (Volume Source)	External exposure for critical organs of plants. The values are given for meristem of grass and for buds of a shrub and a tree for a planar source with a surface roughness of 3 mm and volume source with a depth of 10 cm.			
4	Table 3-13	Weighted DCs for internal exposure. They are the weighted sum of the contributions of α-, lowβ- , β- and γ-radiation.			
5	Table 4-7	Freshwater—estuarine ecosystem DCC's for internal irradiation.			
5R	Table 4-7 * RBE = 10	Freshwater—estuarine ecosystem DCC's for internal irradiation.			
6	Table 4-8	Freshwater—estuarine ecosystem DCC's for external irradiation.			
7	Table 1	Dose Conversion Factors for Generic Plants and Animals			
7R	Table 1 * RBE = 10	Dose Conversion Factors for Generic Plants and Animals			
Species					
1	Earthworm	8	Herb	15	Vascular Plant
2	Cattle	9	Rabbit	16	Mammal
3	Row Deer	10	Amphibian	17	Generic
4	Red Fox	11	Bivalve Mollusc		
5	Mouse	12	Benthic Fish		
6	Herbivorous Bird	13	Pelagic Fish		
7	Carnivorous Bird	14	Bird		

6.2.7 Transfer Factors

To estimate intake up the food chain, concentrations of COPCs in terrestrial vegetation, earthworms and small mammals (as prey) are estimated using transfer factors (TFs) from literature sources. The associated tissue concentrations in terrestrial vegetation, earthworms and small mammals from all exposure pathways are estimated from soil concentrations as shown in Equation 6-6:

$$C_{biota} = C_{soil} \times TF_{soil-to-biota} \tag{6-6}$$

Where:

C_{biota} = COC concentration in biota (vegetation, earthworms, small mammals) [mg/(kg ww)]

C_{soil} = COC concentration in soil [mg/(kg dw)]

TF = transfer factor from soil-to-biota [(mg/(kg ww))/(mg/(kg dw))]

Soil-to-small mammal transfer factors are not always available for all COPCs. As an alternative, mammalian tissue concentrations can also be estimated from allometrically scaled feed-to-tissue transfer factors as shown in Equation 6-7:

$$C_{tissue} = I_{total} \times TF_{feed-to-tissue} \tag{6-7}$$

Where:

C_{tissue} = COC concentration in tissue of ingested animal [mg/(kg ww)]

I_{total} = intake of COC by ingested animal from all pathways ($\sum I_n$) [mg/d]

$TF_{feed-to-tissue}$ = allometrically scaled transfer factor from feed-to-tissue [d/kg]

Transfer factors from literature for feed-to-beef (cow) are available for many COPCs, which can then be allometrically scaled for the ingested mammal using the ratio of their body weight to that of the cow using Equation 6-8:

$$TF_{sm} = TF_{fb} \times \left(\frac{BW_{sm}}{BW_{cow}} \right)^{-0.75} \tag{6-8}$$

Where:

TF_{sm} = feed-to-tissue transfer factor for small mammal [d/(kg ww)]

TF_{fb} = feed-to-tissue transfer factor for beef [d/(kg ww)]

BW_{sm} = body weight of small mammal [kg]

BW_{cow} = 600, body weight of cow [kg] (CSA 2014 Table G.7)

Similarly, transfer factors from literature for feed-to-bird (poultry) can be allometrically scaled for the ingested birds using the ratio of their body weight to that of the poultry using Equation 6-9:

$$TF_{bird} = TF_{poultry} \times \left(\frac{BW_{bird}}{BW_{poultry}} \right)^{-0\ 75} \tag{6-9}$$

Where:

TF_{bird}	=	feed-to-tissue transfer factor for bird [d/(kg ww)]
$TF_{poultry}$	=	feed-to-tissue transfer factor for poultry [d/(kg ww)]
BW_{bird}	=	body weight of bird [kg]
$BW_{poultry}$	=	2, body weight of poultry [kg] (CSA 2014 Table G.7)

Table 6.16 presents the transfer factors selected for the EcoRA. For terrestrial plants, a moisture content of 81% was used for converting between dry weight (DW) and wet weight (WW or FW).

Table 6.16 EcoRA: Transfer Factors

a) Aquatic Receptors

Factor	U	Ref	Ra	Ref	Th	Ref	Pb	Ref	Po	Ref	TBP	Ref
Sediment-Water Kd (L/kg DW)	50	1	7400	1	190000	1	270	13	150	13	-	
Aquatic Veg-Water TF (L/kg FW)	1100	2	1200	2	2200	2	1900	5	2000	3	-	
Benthos-Water TF (L/kg FW)	110	14	900	14	110	14	22	6	20000	4	-	
Fish-Water TF (L/kg FW)	0.96	7	4	7	6	7	370	12	36	11	-	
Feed-to-Bird TF (d/kg FW)	0.75	9	0.03	9	0.01	9	0.8	8	2.4	10	-	
Feed-to-Mammal TF (d/kg FW)	0.00039	15	0.0017	15	0.00023	15	0.00070	16	0.005	17	-	

References:

1. CSA N288.1 (2014), Table A.26
2. CSA N288.1 (2014), Table A.25f
3. US DOE (2003), Table 2.14
4. US DOE (2003), Table 2.12
5. IAEA (2010), Table 55 (mean)
6. IAEA (2010), Table 56 (mean)
7. CSA N288.1 (2014), Table A.25a
8. US DOE (2003), Table 2.7
9. CSA N288.1 (2014), Table G.3, value for poultry meat
10. IAEA (2010), Table 34
11. IAEA (2010), Table 57 (mean), value for muscle as a value for whole body is not available
12. IAEA (2010), Table 57 (mean), value for whole body
13. Bechtel Jacobs (1998)
14. CSA N288.1 (2014), Table A.25e
15. CSA N288.1 (2014), Table G.3, value for beef meat
16. IAEA (2010), Table 30 (mean)
17. US DOE (2003), Table 2.6

b) Terrestrial Receptors

Factor	U	Ref	Ra	Ref	Th	Ref	Pb	Ref	Po	Ref	TBP	Ref
Soil-Water Kd (m^3/kgDW)	0.11	1	1.9	1	0.7	1	0.22	7	0.21	8	-	
Earthworm-Soil TF (g DW /g DW)	0.033	13	1	14	1	14	3.34	13	1	14	-	
Vegetation-Soil TF (g DW /g DW)	0.01	2	0.11	2	0.0033	2	0.31	9	0.12	10	-	
Feed-to-Bird TF (d/kg FW)	0.75	3	0.03	3	0.01	3	0.8	4	2.4	5	-	
Feed-to-Mammal TF (d/kg FW)	0.00039	6	0.0017	6	0.00023	6	0.00070	11	0.005	12	-	

<u>References:</u>

1. CSA N288.1 (2014), Table G.2 (sand)
2. CSA N288.1 (2014), Table G.3 (CR)
3. CSA N288.1 (2014), Table G.3, value for poultry meat
4. US DOE (2003), Table 2.7
5. IAEA (2010), Table 34
6. CSA N288.1 (2014), Table G.3, value for beef meat
7. IAEA (2010), Table 14 (mean - sand)
8. IAEA (2010), Table 14 (mean – all soils)
9. IAEA (2010), Table 17 (mean – grasses)
10. IAEA (2010), Table 17 (mean – pasture)
11. IAEA (2010), Table 30 (mean)
12. US DOE (2003), Table 2.6
13. Sample *et al.* 1998
14. Assumed equal to soil

6.3 Effects Assessment

6.3.1 Non-Radiological COPCs – Benchmark Values

Overall, ecological toxicity benchmark values for non-radiological COPCs were obtained based on the following hierarchies of sources. These hierarchies include credible, recognized references that are used in EcoRAs as common industry practice. The hierarchies generally incorporate CSA N288.6 guidance (CSA 2012) but in cases where N288.6 sources are considered outdated, values from more recent credible sources are used preferentially (with supporting rationale). More detailed descriptions of the methodologies used in selecting these toxicity benchmark values is presented in following subsections.

Terrestrial Vegetation & Invertebrates:

1. MOE (2011) values protective of soil invertebrates and plants, based on industrial land use;
2. CCME supporting documents for Canadian Soil Quality;
3. US EPA Ecological Soil Screening Levels (Eco-SSLs); and
4. Environment Canada (2013) Database of Guidelines.

Terrestrial Mammals & Birds:

1. MOE (2011) benchmark values;
2. US EPA Eco-SSLs; and
3. Sample *et al.* (1996).

Aquatic Birds:

1. Suter & Tsao (1996);
2. US EPA ECOTOX Database;
3. MOE (2011); and
4. EPA Eco SSLs.

Fish, Aquatic Vegetation and Aquatic Invertebrates:

1. US EPA ECOTOX Database;
2. Suter & Tsao (1996); and
3. CCME (2009, 2011, 2015).

6.3.1.1 Terrestrial Invertebrates and Vegetation

In selecting the TRVs for terrestrial vegetation and invertebrates (earthworms), a review was conducted of the MOE (2011b) rationale document, the soil quality standards of the CCME, the Eco-SSL documents of the U.S. EPA, along with values from the Environment Canada (2013) Database of Guidelines.

The MOE considers ecotoxicity criteria in the development of soil criteria, so that soil standards are protective of both human and ecological health. In the MOE update of their soil criteria (2011b), plant and soil invertebrate protection values for agricultural/residential/parkland and industrial/commercial land use were developed following the CCME (1996) protocol using current scientific literature data on toxicity to agricultural crops, native plant species and soil dwelling organisms. It is commonly acknowledged that the level of protection for plants and soil organisms can be less stringent for commercial/industrial land use than for agricultural/residential/parkland land use. However, in following the CCME (1996) protocol, this was problematic for no/lowest observable effects concentration (NOEC/LOEC) data (a combined NOEC/LOEC dataset was used for the agricultural/residential/parkland derivation, while an LOEC-only dataset was used for the commercial/industrial derivation which can throw out useful information and thereby drive the value down). To solve this issue, the MOE used a combined NOEC/LOEC dataset for both land uses, and selected the 25th and 50th percentile values as the agricultural/residential/parkland and industrial/commercial protection values, respectively. In situations where a value for plant and soil organism protection could not be developed for industrial/commercial land use, the MOE applied a factor of 2 to the agricultural/residential/parkland value. This was felt to be sufficiently protective for an industrial/commercial setting. It was determined that the above-described MOE approach was appropriate for use in the current assessment and thus, the MOE values for protection of plants and soil invertebrates were selected as the TRVs when available.

Following the above methodology, the MOE was able to develop components values for 20 constituents. The MOE also reviewed information from other jurisdictions and found that CCME ecological protection numbers and the numbers developed by the Netherlands would provide a suitable level of protection for Ontario. The Netherlands criteria were derived using the 50th percentile of the “No Observed Effect Distribution” (NOEC) of the data. The final selected values are presented in Table 6.17.

Table 6.17 EcoRA TRVs: Terrestrial Plants & Earthworms (mg/kg)

COPCs	Earthworm	Terrestrial Vegetation
Uranium	2,000 [a]	2,000 [a]

Notes:
[a] MOE (2011) direct soil contact protection value for *industrial* land use.
ND – no data.

Ammonia (in Groundwater)

As shown in Section 4.7, ammonia has been identified as a COPC in groundwater. For ecological risk assessment of ammonia in groundwater, it is important to understand that biota reside in surface water and surface soil, and do not have direct access to groundwater. For biota, exposure to groundwater occurs only once the groundwater has migrated into surface water. This is captured in the EcoRA through the use of measured surface water data, which implicitly include the contributions from groundwater.

Despite the above, groundwater quality can also be assessed (for perspective only) using a hypothetical terrestrial invertebrate (earthworm): where soil TRVs (expressed as a soil concentration) are obtained for the desired COPCs and converted - using a Kd value - into corresponding groundwater TRV concentrations. However, specifically for ammonia, an invertebrate soil TRV is not available, nor is a Kd value. As such, the conversion cannot be accomplished, and comparison cannot be made. Therefore, ammonia in groundwater cannot be assessed (for perspective) using the groundwater invertebrate method.

6.3.1.2 Mammals and Birds (terrestrial & aquatic)

In selecting the TRVs for mammals and birds, values were primarily obtained from the U.S. EPA Eco-SSLs and from Sample *et al.* (1996). Data from MOE (2011) were then used to fill any remaining data gaps.

Dose-based TRVs for wildlife were derived from a review of data presented in the documentation of U.S. EPA risk-based ecological soil screening levels (Eco-SSLs) for most analytes, and literature studies were reviewed for chronic dose values for analytes without Eco-SSL data. Endpoints involving growth and reproduction were considered to be relevant to assessment of wildlife populations. TRV were derived preferentially from LOAEL data. The use of LOAELs is consistent with CSA (2012), which states that selected benchmarks should correspond to the lowest exposure levels (e.g., LOAELs) associated with adverse effects. A comparison was made to mortality based endpoints to ensure that the derived TRV does not exceed a mortality endpoint. Where available, the LOAELs were paired with NOAELs for reference purposes.

An important aspect in TRV selection and derivation is the avoidance of allometric scaling. Historically, the results of toxicity tests on laboratory animals, which were typically limited to test species, were adjusted for other species by applying allometric equations for weight differences between test species and species of interest in the assessment. More recently, the allometric weight adjustment was found to be inappropriate for most analytes and ecological receptors. Therefore, the desired approach is instead to find toxicity data for species that most closely represent a given ecological receptor in a particular assessment (i.e., use of surrogates).

Tributyl Phosphate

TRVs for tributyl phosphate were not available for mammalian and avian receptors, based on a review of the hierarchies of sources presented in Section 6.3.1.

Uranium

In the present risk assessment, it is desirable to select TRV values based on test species that closely match the ecological receptor in terms of diet and overall organism size. However, the availability of toxicity data varies and at times a close match is not available. For uranium, only a single study was available for mammals (based on mice) and birds (based on black duck), and therefore, these studies were used for all mammals and birds (aquatic and terrestrial), respectively.

Final Selected TRVs

Table 6.18 presents the selected values for mammals.

Table 6.19 presents the selected values for birds.

Table 6.18 EcoRA TRVs: Mammals (mg/kg/d)

COPCs	Test Species	LOAEL Data	Final TRV	Ecological Receptor	Comments
Tributyl Phosphate	ND			Beaver	-
				Black Bear	
				Coyote	
				Deer	
				Meadow Vole	
U	Mouse	5.6	5.6	Beaver	Sample *et al.* (1996) Based on a single study NOAEL (LOAEL not available), with correction for unit conversion error in Sample *et al.* (1996).
				Black Bear	
				Coyote	
				Deer	
				Meadow Vole	

Notes:
ND – no data.

Table 6.19 EcoRA TRVs: Birds (mg/kg/d)

COPCs	Test Species	LOAEL Data	Final TRV	Ecological Receptor	Comments
Tributyl Phosphate	ND			American Robin	-
				Bald Eagle	
				Barred Owl	
				Cormorant	
				Hooded Merganser	
				Mallard	
				Ruffed Grouse	
				Scaup	
U	Black Duck	a	16	American Robin	Sample *et al.* (1996) Based on a single study NOAEL (LOAEL not available).
				Bald Eagle	
				Barred Owl	
				Cormorant	
				Hooded Merganser	
				Mallard	
				Ruffed Grouse	
				Scaup	

Notes:
ND – no data.

6.3.1.3 Aquatic Vegetation, Invertebrates, and Fish

In selecting the TRVs for aquatic biota, toxicity data were primarily obtained from the US EPA ECOTOX database, and water quality objectives/criteria from the CCME and US EPA. The ECOTOX database reports toxicity data for a wide range of aquatic species as well as laboratory and field studies. For most chemicals, ECOTOX includes toxicity data in literature from 1972 to the present. All data have been quality assured according to the U.S. EPA's criteria, and the system is updated quarterly (U.S. EPA 2012). CSA (2012) also supports the use of ECOTOX as a source of information. The following principles were applied in the data selection:

- Endpoints involving growth, reproduction and survival were considered to be relevant to persistence of aquatic populations (consistent with CSA 2012);
- Only freshwater toxicity studies were considered;
- Records without test duration, endpoint and exposure concentration were eliminated;
- Chronic toxicity data were preferred in the selection (favoured by CSA 2012 as well). When chronic data were not sufficient (minimum of 2), acute data were considered and converted to chronic values;
- Chronic EC20 concentrations were preferred (consistent with CSA 2012). If not reported, other endpoints were considered and adjusted to an estimated EC20 value (see discussion below).

If more than 20 chronic EC20 were available in each taxonomic group, a 5th percentile of the EC20 distribution was used as a recommended TRV; if there were less than 20 chronic EC20 values, the lowest EC20 was used as a recommended TRV for the taxonomic category. The lowest chronic EC20 or 5th percentile of chronic EC20s derived from the above process were compared with widely used TRVs in ecological risk assessment recommended by Suter and Tsao (1996), U.S. EPA, CCME or other government guideline documents. The more appropriate values were selected as the recommended TRV for each taxonomic category in this review.

Table 6.20 presents the final TRV values selected for aquatic biota.

Table 6.20 EcoRA TRVs: Aquatic Vegetation, Invertebrates, Fish and Amphibians (mg/L)

COPCs	Final TRV	Ecological Receptor	Reference
U	1.5	Fish (benthic)	VST (2004) and Liber *et al.* (2007). 31-day toxicity study involving fathead minnows with increasing water hardness produced EC25s for growth of 1.3, 1.5, 2 and 2 mg/L for water hardness of 15, 60, 120, and 240 mg/L $CaCO_3$, respectively. A value of 1.5 mg/L, corresponding to a water hardness of 60 mg/L, was selected.
	0.55	Fish (pelagic)	VST (2004) and Liber *et al.* (2007). 31-day toxicity study involving rainbow trout with increasing water hardness produced an EC25 for growth of 0.34 mg/L for water hardness of 5 mg/L $CaCO_3$, and an LC25 of 0.55 mg/L for water hardness of 60 mg/L $CaCO_3$. The value of 0.55 mg/L, corresponding to a water hardness of 60 mg/L, was selected.
	5.5	Aquatic Vegetation	VST (2004). 7-day uranium toxicity study on duckweed, using a growth endpoint, for different water hardness. The geometric mean of results for 60 mg/L $CaCO_3$ water hardness is 5.5 mg/L.
	0.027	Benthic Invertebrates	Liber *et al.* (2007). 28-day toxicity study on hyalella Azteca using a growth endpoint, based on a water hardness of 60 mg/L $CaCO_3$.
	0.55	Amphibians	Assessed based on pelagic fish
Tributyl Phosphate	0.1	Fish (benthic)	Mayer,F.L.,Jr., and M.R. Ellersieck (1986) 4-day toxicity study on fathead minnows produced an acute LC50 for mortality of 1.0 mg/L, converted to EC20 using a factor of 1/10.
	0.42	Fish (pelagic)	Dave,G., H. Blanck, and K. Gustafsson (1979) 5-day toxicity study on rainbow trout produced an acute LC50 for mortality of 4.2 mg/L, converted to EC20 using a factor of 1/10.
	0.44	Aquatic Vegetation	Kuhn,R., and M. Pattard (1990) 3-day toxicity study on green algae produced an acute EC50 for population of 1.1 mg/L, converted to EC20 using a factor of 2/5.
	0.24	Benthic Invertebrates	Yoshioka,Y., Y. Ose, and T. Sato (1986) 7-day toxicity study involving flatworm produced an EC50 for growth of 0.6 mg/L, converted to EC20 using a factor of 2/5.
	0.42	Amphibians*	Assessed based on pelagic fish

6.3.2 Radiological Dose Benchmarks

The recommended radiological dose benchmarks from CSA N288.6 (2012) are used in this study. Table 6.21 presents the final radiological dose benchmarks selected for both aquatic and terrestrial biota. For details regarding the dose benchmark selection process, the reader is referred to the CSA (2012) document.

Table 6.21 EcoRA Radiological Dose Benchmarks (mGy/d)

Category	Organism	Dose Rate Benchmark
Aquatic Biota	Fish (benthic & pelagic)	9.6 mGy/d
	Aquatic Vegetation	9.6 mGy/d
	Benthic Invertebrates	9.6 mGy/d
Terrestrial Biota	Terrestrial Animals	2.4 mGy/d
	Terrestrial Plants	2.4 mGy/d
Beaver [a]	Beaver [a]	2.4 mGy/d

Notes:
[a] While the beaver is considered an aquatic mammal, it spends a significant amount of time in terrestrial locations and consumes terrestrial vegetation. For this reason, the terrestrial benchmark was used, for conservatism.

6.4 Risk Characterization

This section presents the risk results (SIs) calculated for each receptor-COPC combination, based on a comparison of estimated exposures to the toxicity and radiation benchmarks outlined in Section 6.3.

6.4.1 Risk Results – Radiological

For aquatic receptors, Table 6.22 presents radiological dose estimates along with the corresponding dose benchmark and a SI comparison. For terrestrial receptors, Table 6.23 presents radiological dose estimates along with the corresponding dose benchmark and a SI comparison. These risk estimates are based on Kd-derived sediment concentrations, as discussed in Sections 1.1.1.1 and 6.4.3.1. Supplemental risk estimates based on measured sediment concentrations are presented in Table 6.24 for aquatic receptors directly exposed to sediment.

The dose contribution from radon and progeny was also included in the dose calculations for selected biota, i.e., those species that may spend a substantial portion of their time burrowed under (within) soil or sediment, and therefore may potentially be exposed to Rn-222 through their burrowing behaviour, or by otherwise residing within sediment or soil. In this ERA, the following biota were selected:

- Terrestrial Biota: Meadow Vole, Red Fox and Earthworm; and
- Aquatic Biota: Beaver and Benthic Invertebrate.

Additional radon contribution calculations are not necessary for benthic fish since benthic fish are present close to (i.e. immediately above) sediment, but not primarily *within* sediment. Benthic fish do receive an external dose from sediment though, and this *is* included in their dose and risk calculations.

The dose from radon to these species was assessed using methodology from Environment Canada/Health Canada (EC/HC 2003, PSL2). The EC/HC (2003) methodology calculates the dose contribution from radon (Rn-222) by relating it to radium (Ra-226). The methodology assumes that the activity of Rn-222 is 30% of Ra-226 for internal dose, and 100% of Ra-226 for external dose. Therefore, the internal dose from Rn-222 is estimated to be 30% of the internal dose from its parent radionuclide Ra-226, and the external dose from

Rn-222 is estimated to be 100% of the external dose from its parent radionuclide Ra-226. These estimated dose contributions are added to the total dose estimate.

For terrestrial biota, this is a particularly conservative approach, because by applying the radon contribution to the entire estimated dose of Ra-226, it assumes that the biota spends all of its time (i.e., its entire exposure time and duration) burrowed.

The dose contribution is calculated separately for internal and external dose fractions. The equations used to calculate the contribution from Rn-222 to all biota are listed below:

Internal Dose $_{\textit{Rn-222}}$***:*** Dose Contribution of Rn-222 = 30% of Internal Dose from Ra-226

External Dose $_{\textit{Rn-222}}$***:*** Dose Contribution of Rn-222 = 100% of External Dose from Ra-226

Total Dose from Rn-222: Rn-222 Dose = [Internal dose $_{\textit{Rn-222}}$] + [External dose $_{\textit{Rn-222}}$]

Table 6.22 EcoRA Radiological Dose (mGy/d) & SI Results (Aquatic)

Radionuclide	Amphibian	Aquatic Vegetation	Beaver	Benthic Fish	Benthos	Cormorant	Hooded Merganser	Mallard	Pelagic Fish	Scaup
Pb-210	1.9E-04	2.3E-04	2.5E-05	2.0E-04	2.0E-04	7.9E-05	1.3E-04	1.9E-04	1.9E-04	2.5E-04
Po-210	2.5E-03	1.4E-01	4.1E-04	2.5E-03	2.5E-03	3.1E-03	3.3E-02	6.5E-01	2.5E-03	1.0E+00
Ra-226	3.5E-04	9.8E-02	1.5E-04	3.6E-04	3.6E-04	7.8E-05	3.6E-04	1.2E-03	3.5E-04	2.6E-03
Rn-222 *	n/a	n/a	7.1E-05	n/a	1.1E-04	n/a	n/a	n/a	n/a	n/a
Th-230	3.6E-04	1.3E-01	1.3E-05	6.1E-04	6.1E-04	4.3E-04	5.2E-04	6.3E-04	3.6E-04	8.0E-04
U-234	5.7E-05	6.5E-02	1.9E-05	5.7E-05	5.7E-05	3.4E-05	4.6E-03	1.2E-02	5.7E-05	5.0E-03
U-235	2.5E-06	2.9E-03	3.5E-05	2.8E-06	2.8E-06	1.6E-06	2.1E-04	5.4E-04	2.5E-06	2.3E-04
U-238	1.2E-04	1.3E-01	1.6E-05	1.2E-04	1.2E-04	7.2E-05	9.7E-03	2.5E-02	1.2E-04	1.1E-02
Gamma (mGy/d)	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02
Total (mGy/d)	4.3E-02	6.0E-01	4.0E-02	4.3E-02	4.3E-02	4.3E-02	8.7E-02	7.3E-01	4.3E-02	1.1E+00
ENEV (mGy/d)	9.6	9.6	2.4	9.6	9.6	9.6	9.6	9.6	9.6	9.6
SI (-)	0.004	0.06	0.02	0.004	0.004	0.004	0.009	0.08	0.004	0.11

Note: n/a – not applicable.

* Rn-222 doses were calculated using equations in Section 6.4.1 and they are not included in the calculations shown in Appendix D.

Table 6.23 EcoRA Radiological Dose (mGy/d) & SI Results (Terrestrial)

Radionuclide	American Robin	Bald Eagle	Barred Owl	Black Bear	Coyote	Deer	Earthworm *(soil)*	Meadow Vole	Red Fox	Ruffed Grouse	Terrestrial Vegetation	Earthworm *(GW)*
Pb-210	3.4E-04	3.0E-05	4.0E-05	4.0E-06	8.2E-07	3.8E-06	7.9E-04	2.0E-06	4.3E-06	6.9E-05	2.4E-06	6.4E-07
Po-210	4.3E-02	7.3E-03	1.3E-02	1.4E-03	5.3E-04	1.1E-03	3.1E-02	5.3E-04	1.6E-03	1.2E-02	1.1E-08	8.2E-05
Ra-226	4.5E-03	5.4E-05	2.1E-03	2.6E-03	1.5E-03	3.0E-03	1.4E-01	3.2E-03	2.7E-03	2.4E-03	2.2E-03	1.0E-04
Rn-222 *	n/a	n/a	n/a	n/a	n/a	n/a	4.4E-02	2.7E-03	1.7E-03	n/a	n/a	3.0E-05
Th-230	1.3E-04	1.4E-05	2.5E-05	2.9E-05	6.5E-06	1.0E-05	2.7E-02	5.9E-06	2.8E-05	3.3E-05	8.5E-07	7.1E-05
U-234	1.5E-03	5.0E-04	1.9E-03	3.4E-05	1.2E-05	2.0E-05	8.8E-04	1.1E-05	1.3E-05	1.6E-03	5.8E-07	7.1E-05
U-235	7.3E-05	5.6E-05	9.2E-05	3.1E-06	3.4E-06	6.3E-06	4.8E-05	7.4E-06	3.4E-06	7.7E-05	2.7E-08	3.2E-06
U-238	1.3E-03	4.4E-04	1.7E-03	3.0E-05	1.0E-05	1.8E-05	7.8E-04	9.9E-06	1.1E-05	1.4E-03	5.8E-07	6.3E-05
Gamma (mGy/d)	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02
Total (mGy/d)	8.9E-02	4.7E-02	5.8E-02	4.3E-02	4.1E-02	4.3E-02	2.8E-01	4.5E-02	4.5E-02	5.7E-02	4.1E-02	3.9E-02
ENEV (mGy/d)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
SI (-)	0.04	0.02	0.02	0.02	0.02	0.02	0.12	0.02	0.02	0.02	0.02	0.02

Note: n/a – not applicable.

* Rn-222 doses were calculated using equations in Section 6.4.1 and they are not included in the calculations shown in Appendix D.

Table 6.24 EcoRA Radiological Dose (mGy/d) & SI Results (Aquatic) [Msrd. Sed.]

Radionuclide	Benthic Fish	Benthos	Cormorant	Hooded Merganser	Mallard	Scaup
Pb-210	2.0E-04	2.0E-04	8.0E-05	1.3E-04	1.9E-04	2.5E-04
Po-210	2.5E-03	2.5E-03	3.2E-03	3.3E-02	6.5E-01	1.0E+00
Ra-226	3.5E-04	3.5E-04	5.5E-05	3.4E-04	1.2E-03	2.6E-03
Rn-222*	n/a	1.1E-04	n/a	n/a	n/a	
Th-230	3.7E-04	3.7E-04	2.1E-05	1.4E-04	3.2E-04	2.2E-04
U-234	5.7E-05	5.7E-05	4.0E-05	4.6E-03	1.2E-02	5.0E-03
U-235	1.4E-04	1.4E-04	1.8E-04	3.8E-04	6.8E-04	4.9E-04
U-238	1.2E-04	1.2E-04	8.5E-05	9.7E-03	2.5E-02	1.1E-02
Gamma (mGy/d)	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02	3.9E-02
Total (mGy/d)	4.3E-02	4.3E-02	4.3E-02	8.7E-02	7.3E-01	1.1E+00
ENEV (mGy/d)	9.6	9.6	9.6	9.6	9.6	9.6
SI (-)	0.004	0.004	0.004	0.009	0.08	0.11

Notes: n/a – not applicable.

* Rn-222 doses were calculated using equations in Section 6.4.1 and they are not included in the calculations shown in Appendix D.

6.4.2 Risk Results – Non-Radiological

The following tables present the estimated non-radiological risk (SI) results for terrestrial receptors, based on their respective environmental media exposures and their corresponding benchmarks (see Section 6.3).

Tier 1 estimates are based on maximum concentrations in each environmental media, regardless of location. For surface water in particular, maximum concentrations were selected across all locations, including data from the river, lake, and bog. These risk estimates are based on Kd-derived sediment concentrations, as discussed in Sections 1.1.1.1 and 6.4.3.1.

Supplemental risk estimates based on measured uranium concentrations in sediment are presented in Table 6.27 for aquatic receptors directly exposed to sediment.

TIER 1: *Based on Kd-derived Sediment Concentrations*

Table 6.25 EcoRA – Non-Radiological Risk Results – Terrestrial Receptors (Tier 1)

COPC	American Robin	Bald Eagle	Barred Owl	Black Bear	Coyote	Deer	Earthworm (soil)	Earthworm (GW)	Meadow Vole	Red Fox	Ruffed Grouse	Terr. Vegetation
Tr butyl Phosphate	NC											
Uranium	1.70E-02	2.00E-03	1.29E-02	5.52E-03	2.85E-03	3.20E-03	1.11E-02	4.90E-04	1.21E-02	3.82E-03	1.13E-02	1.11E-02

Notes:
NC - Not Calculated. TRV data are not available for tributyl phosphate.

Table 6.26 EcoRA – Non-Radiological Risk Results – Aquatic Receptors (Tier 1)

COPC	Amphibian	Aquatic Vegetation	Beaver	Benthic Fish	Benthos	Cormorant	Hooded Merganser	Mallard	Pelagic Fish	Scaup
Tributyl Phosphate	**1.43**	**1.36**	NC	**6.0**	**2.50**	NC	NC	NC	**1.43**	NC
Uranium	1.35E-02	1.35E-03	2.07E-03	4.93E-03	2.74E-01	1.75E-04	2.58E-02	6.88E-02	1.35E-02	3.37E-02

Notes:
NC - Not Calculated. TRV data are not available for tributyl phosphate.
Shaded values in bold – Exceeds benchmark of 1.

TIER 1: *Based on Measured Uranium Concentrations in Sediment*

Table 6.27 EcoRA – Non-Radiological Risk Results – Aquatic Receptors (Tier 1) [Msrd. Sed.]

COPC	Benthic Fish	Benthos	Cormorant	Hooded Merganser	Mallard	Scaup
Uranium	4.93E-03	2.74E-01	2.06E-04	2.58E-02	6.89E-02	3.38E-02

Table 6.28 EcoRA – Non-Radiological Risk Results – Aquatic Receptors (Tier 2)

COPC	Amphibian	Aquatic Vegetation	Beaver	Benthic Fish	Benthos	Cormorant	Hooded Merganser	Mallard	Pelagic Fish	Scaup
Tributyl Phosphate	0.13	0.12	NC	0.54	0.23	NC	NC	NC	0.13	NC

Notes:
NC - Not Calculated. TRV data are not available for tributyl phosphate.
Shaded values in bold – Exceeds benchmark of 1.

6.4.3 Discussion of Risk Results

6.4.3.1 Radiological

As shown in Section 6.4.1, for all ecological receptors (terrestrial and aquatic), no radiological risk SIs were found to be greater than 1, and therefore, the estimated radiological doses to terrestrial receptors are less than the corresponding benchmark value. No undue effects are anticipated.

6.4.3.2 Non-Radiological

As shown in Section 6.4.2, for all aquatic receptors with TRV data available, non-radiological SIs for TBP were found to be greater than 1. TBP concentrations in surface water were all below the detection limit of 0.6 mg/L. However, as shown in Table 6.20, TBP TRVs for aquatic biota range from 0.1 mg/L for benthic fish to 0.44 mg/L for aquatic vegetation. Since the exceedance of benchmark values was driven by detection limit rather than by actual measurable concentrations, a Tier 2 estimate using 95th percentile effluent concentration of TBP (2.7 mg/L) with a dilution factor of 50 (Arcadis 2015a) within 2m from the release point. All the SIs were below 1 as shown in Table 6.28.

6.4.3.3 Supplemental EcoRA Calculations: Measured vs. Kd-derived Sediment Concentrations.

Initial EcoRA calculations were performed based on sediment concentrations that were derived from surface water data using Kd distribution coefficients. Later, measured sediment data became available from Arcadis (2015a). A comparison of measured sediment concentrations to Kd-derived sediment concentrations is shown in Table 5.17 and discussed in Section 5.2.3.4. Additional radiological EcoRA calculations were performed using the measured sediment concentrations, with the results presented in Table 6.24 and Table 6.27.

Overall, results show that measured sediment concentrations have little impact on EcoRA risk estimates (both radiological and non-radiological), with Tier 1 radiological and non-radiological EcoRA results showing no undue risk to any receptors.

6.4.3.4 Risk to Benthic Invertebrates from Exposure to Ammonia in Sediment

This study used the sediment quality data from the Arcadis (2015a) *Plume Modelling, Delineation and Sediment Study*. In the 2006 study, the risk to the benthic community from ammonia in the sediments showed higher ammonia concentrations in sediment from exposed areas when compared to the reference areas. There is no sediment benchmark for ammonia, however, ammonia in surface water was screened out (Table 4.2) as the maximum un-ionized ammonia concentration is 2.6 µg/L, below the criteria 19 µg/L.

In a study on sediment and porewater toxicity for ammonia and non-polar organic contaminants (Mehler 2010), ammonia toxicity units (TUs) based on overlying water concentrations were found to be up to 10-fold lower than porewater ammonia TUs. Since porewater was not measured, a simplistic extrapolation (assumes same pH and temperature in porewater and surface water) applying the factor of 10 to surface water concentrations was used to estimate the un-ionized ammonia concentration in porewater.

The estimated un-ionized ammonia concentration of 26 µg/L in porewater is below the TRV of 44 µg/L, derived from ECOTOX database (based on a 10-day Oligochaete worm study, Schubauer-Berigan 1995) following the methodology outlined in Section 6.3.1.3. Environment Canada (2001) presented a similar lowest EC20 of 0.051 mg/L for un-ionized ammonia for benthic invertebrates.

6.5 Uncertainties

Many areas of uncertainty attend a risk assessment. This is due to the fact that assumptions have to be made throughout the assessment either due to data gaps, environmental fate complexities or in the generalization of receptor characteristics. To be able to place a level of confidence in the results, an accounting of the uncertainty, the magnitude and type of which are important in determining the significance of the results, must be completed. In recognition of these uncertainties, conservative assumptions were used throughout the assessment to ensure that the potential for an adverse effect would not be underestimated. The major assumptions are outlined below.

Exposure Point Concentrations

Measured concentrations of COPCs, and measured activities of radionuclides, were used wherever such data was available. The exposure point concentrations used in the assessment are the maximum values associated with each environmental medium. The use of these concentrations assumes that receptors are exposed to these higher concentrations, regardless of the location of these concentrations relative to the location of the receptors. As a result, exposures are likely to be conservatively overestimated.

Furthermore, detection limits that are higher than screening criteria and/or TRVs result in additional uncertainties and overestimation in exposures.

Radium-226 is the only radionuclide that is measured in surface water and groundwater. No radionuclides are measured in soil. Therefore, the activity concentrations of other radionuclides (Pb-210, Po-210, Th-230, U-238, U-234, and U-235) had to be estimated as outlined in Section 2.5.8. For EcoRA this involves the use of specific activity conversions (based on maximum measured natural uranium levels) along with secular equilibrium assumptions. Although it is possible that this could lead to underestimates in exposures, this is very unlikely given the very conservative assumptions – in particular the use of secular equilibrium – that were applied when estimating concentrations/activities.

Receptor Occupancy & Home Ranges

All mobile receptors are assumed to be present for the entire year, despite any potential migratory behaviour. In addition, the home range of all mobile receptors is assumed to be limited to the location of these maximum concentrations, when in reality, several mobile receptors have large home ranges and the location of a maximum concentration might represent only a small portion of their overall range. Thus, exposures are likely to be conservatively overestimated.

Transfer Factors

Measured data from the site focus on environmental media and facility effluents, not tissue concentrations, Therefore, the concentrations/activities in biota had to be estimated using transfer factors from literature as well as food intake calculations. There is some uncertainty involved in the use of transfer factors and data that are not site-specific; however, in the absence of measured data, this approach provides the only method for estimating concentrations and for estimating transfer up the food chain.

Receptor Characterizations/Exposure Parameters

The characteristics of ecological receptors – mobile receptors in particular - represent another source of uncertainty since receptors will adjust and vary their diet and behavior according to the food and water sources available and regional conditions in general. The characteristics (e.g., body weight; food, water, and soil consumption rates, etc.) for all receptors were selected based on a review of available information in various credible literature sources. However, for some (though not all) literature sources, these parameters are obtained from studies involving animals in captivity, and therefore may not be fully representative of free-range animals in the wild. An underestimate of exposure might result from this – for example, by assuming a body weight that is greater than for animals in the wild - but there are other conservative assumptions that may compensate (e.g. assuming 100% of intake of a COPC is absorbed by the body).

Toxicity Reference Values

The TRVs used in the assessment were obtained from reputable sources; nonetheless, they are always associated with uncertainty due to the extrapolation of testing on lab species (e.g., rats) to field conditions as well as to the ecological receptors considered in this assessment. Additionally, toxicity information for a COPC was used regardless of its form in the test procedure, even though this may not be the same form used in the assessment (e.g., an oxide form compared to a more soluble form). It is difficult to determine the effect of these assumptions.

Another area of uncertainty in the risk assessment is the effect of multiple COPC. When dealing with toxic chemicals, there is potential interaction with other chemicals that may be found at the same location. It is well established that synergism, potentiation, antagonism or additivity of toxic effects occurs in the environment. A detailed quantitative assessment of these interactions is beyond the scope of the present study, and, for many COPC-receptor combinations there is not an adequate base of toxicological evidence to examine these interactions. This may result in an underestimate of the risk for some COPC combinations.

Likely the largest source of uncertainty is the limited availability of TRV data for TBP. While TRVs are available for TBP for aquatic biota, no TRV data could be found for terrestrial biota.

Summary

Table 6.29 provides a summary of the uncertainties discussed above. It can be seen from the table that, in general, the approaches or assumptions used to overcome uncertainties are likely to lead to an over-estimate of exposures and thus the conclusions of the assessment would remain unchanged.

Table 6.29 EcoRA – Summary of Uncertainties

Uncertainty	Likely Leads to Overestimate	Possibly Leads to Underestimate	Neither Overestimate or Underestimate
Use of maximum concentrations to characterize exposures	X		
Estimation of radionuclide activity concentrations for those radionuclides without measured data (i.e. use of specific activity and secular equilibrium, based on maximum measured U_{nat})	X		
Use of transfer factors to estimate tissue concentrations	X		
Use of literature characteristics for ecological receptors			X
Neglecting migratory behaviour, and home range fraction (I.e. assuming *all* ingested food, water, and soil is from within the study area)	X		
Use of laboratory-derived TRVs for chronic exposure and effects (see Section 6.3.1)	X		
Synergism, potentiation, antagonism, additivity of toxic effects		X	
Lack of TRV/toxicity data for TBP for terrestrial biota	*Identified as a gap in available literature information*		

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

7.1.1 HHRA Conclusions

Radiological HHRA:

The radiological human health risk component involved dose calculations based on maximum measured radionuclide levels in environmental media (wherever such measured data were available), as well as estimated levels of radionuclides (wherever measured data are absent) using radionuclide ratios – as described in Section 2.5.8.2. The resulting estimated doses are well below the dose limit and, therefore, no undue impacts are expected to workers or members of the public.

Non-Radiological HHRA:

The non-radiological human health risk component concluded that no undue risk is anticipated for human receptors.

Resident receptors that could potentially use groundwater as drinking water are located at distances much greater than 100 m *upgradient* from the BRR site, whereas measurable groundwater TBP concentrations are limited to select inaccessible on-site areas. As such, resident receptors are not expected to have access to on-site groundwater TBP concentrations, and therefore, no undue risk is anticipated.

It is important to understand that although HHRA results identified surface water TBP concentrations as being associated with undue risk, all surface water TBP measurement data show non-detect concentrations of TBP based on a detection limit of 0.6 mg/L. To further refine the assessment, a Tier 2b assessment was performed using measured concentrations from the effluent lagoons and accounting for the dilution occurring when released into the North Channel. Results from the Tier 2b assessment indicate no undue risks to any receptors.

7.1.2 EcoRA Conclusions

Radiological EcoRA:

The radiological component of the EcoRA identified no screening index results with values greater than 1 for terrestrial or aquatic receptors, and therefore, the estimated radiological doses to all ecological receptors (including direct gamma) are less than the corresponding benchmark. As a result, no undue effects are anticipated.

Non-Radiological EcoRA:

Similar to the HHRA results, EcoRA results also identified surface water TBP concentrations as being associated with undue risk as all surface water TBP measurement data show non-detect concentrations of TBP based on a detection limit of 0.6 mg/L. A Tier 2 assessment was performed using measured concentrations from the effluent lagoons and accounting for the dilution occurring when released into the North Channel. A more conservative dilution factor of 50 (achieved within 2m) was used compared to the 500 dilution factor used in HHRA to account for aquatic biota present in close proximity to the release point. Results from the Tier 2 assessment indicate no undue risks to any receptors.

7.1.3 Soil Monitoring

The existing BRR soil monitoring locations were reviewed and recommendations were provided as part of the Arcadis (2015b) *Review of Soil Monitoring Locations* study, including soil uranium measurement data from 2004 to 2013.

Overall, recommendations were made in regards to the positioning of soil monitoring stations, such as relocating or clearing around station 'F' (where the highest uranium concentrations are measured for most years), and on the current frequency at which soil sampling and analysis is performed. For more information, the reader is referred to the Arcadis (2015b) study.

7.1.4 Surface Water Monitoring

Overall, the results of the HHRA, EcoRA, and Arcadis (2015a) plume delineation study do not indicate a need to make modifications to the existing BRR surface water monitoring program.

7.2 Recommendations

The following recommendations are offered, based on the findings of this study:

1. Presently there is no information on local background levels of Ra-226, which may be naturally elevated. Completing a study to determine local background levels of radionuclides in environmental media would be beneficial, as it would help to provide perspective on the levels of radionuclides measured in surrounding environmental media in comparison to facility effluents.

2. It is recommended to update this ERA at least every 5 years, consistent with CSA N288.6 (2012) recommended update cycle.

3. The detection limit of 0.6 mg/L TBP in surface water samples is higher than the EcoRA TRVs for aquatic vegetation, fish and benthic invertebrates. It is recommended that TBP to be analyzed by a procedure with a lower detection limit, if possible.

4. It is recommended to include porewater sampling for ammonia in any future sediment sampling program so that field data will be available for future updates of the EcoRA. Furthermore, a lower ammonia detection limit than the one reported in the 2015 sediment sampling program (20 µg/g) should be utilized in future studies.

8 QUALITY ASSURANCE AND QUALITY CONTROL

Arcadis has an internal Quality Management System that has been certified to ISO 9001:2008. The Arcadis QMS was applied to the ERA process. It includes (but is not limited) the following elements that are required under CSA N288.6 (Section 10.2):

i. Data gathering: Sources (either Cameco internal monitoring data, or external references) documented. Where possible, obtained data in Excel to minimize copy errors.

ii. Data management: Shared data folder to ensure all team members have access to the most up-to-date information. Summary of data and sources in report. Document and e-mail naming convention to optimize version tracking.

iii. Data analysis: Use of QA'ed calculation models for HH Rad, Eco Rad, Eco NonRad. Use of QA'ed spreadsheet models for HH NonRad. Screening was QA'ed.

iv. Report preparation: Tracked changes, OneDrive, etc. to manage multiple inputs.

v. Record keeping: Bi-weekly tracking (at a minimum) to ensure project progress. Management of team resources to ensure staff are available when required, e.g., for QA or modelling.

Much of the data used in this assessment comes from previous Arcadis (formerly SENES) studies that were already reviewed and accepted by CNSC. Internal peer review is performed for all major aspects of the risk assessment, as seen in Table 8.1 below:

Table 8.1 Internal Peer Review of ERA

Section	Prepared By	Reviewed By	Example Findings
Screening	[redacted]	[redacted]	
Human Rad	[redacted]	[redacted]	Improvements made on receptor characteristics
Human NonRad	[redacted]	[redacted]	Updated U inhalation TRV Added dermal TRV for TBP
Eco Rad	[redacted]	[redacted]	Improvements made on receptor characteristics
Eco NonRad	[redacted]	[redacted]	Improvements made on receptor characteristics

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