Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

Report, General

Environmental Risk Assessment of Chalk River Laboratories

Environmental Protection Program

ENVP-509220-REPT-003
Revision 0

2019 January

UNRESTRICTED

286 Plant Road
Chalk River, Ontario
Canada K0J 1J0

janvier 2019

ILLIMITÉE

286, rue Plant
Chalk River (Ontario)
Canada K0J 1J0

EXECUTIVE SUMMARY

The present Environmental Risk Assessment (ERA) report updates the 2012 ERA [1] in accordance with Canadian Standards Association (CSA) N288.6 Standard [2] cited in the Chalk River Laboratories (CRL) Licence Condition Handbook [3], using more recent environmental data (to the end of 2017), including available information from environmental effects monitoring (EEM) and follow-up studies. Specific objectives, consistent with the standard, are:

(1) To evaluate the risk to relevant human and ecological receptors resulting from exposure to contaminants and stressors related to the CRL site and its activities; and

(2) To recommend further monitoring or assessment as needed based on the results, to confirm risks or reduce uncertainties in the assessment.

The present ERA is organized into Management Units (MUs) to align with the recent organization of the CRL Site into MUs to better plan for remediation. The boundaries of the MUs are shown in Figure 1.

The scope of the ERA encompasses current CRL operations, and the human health and ecological effects potentially arising from these operations. Current releases of contaminants, and potential impacts of other stressors to the environment are considered. Past practices or events outside of operational facilities are considered where they may have resulted in a contaminant release or receptor exposure today. The ERA is a living document and is based on currently available information; it should be noted that characterization of the CRL site is on-going, and new contaminants of potential concern may be identified as work progresses – new data will be considered in the next iteration of the ERA. Proposed future operations are not considered here, but have been addressed in project-specific environmental assessments.

The natural environment to be considered in this ERA includes all locations outside operational areas, (e.g., Waste Management Area (WMA)-B, and the Controlled Area are not considered), both on-site and off-site (e.g., the Ottawa River) that may be subject to adverse impacts arising from CRL site operations. Atmospheric, groundwater or surface water plumes leaving operational areas (i.e., extending outside the fence line of a WMA) are within scope of the ERA. Biota exposure to radionuclide contaminants in soil inside the fence line are considered for non-operational areas (WMA-A, the Liquid Dispersal Areas, and WMA-F).

An updated Site Description is presented, which includes:

- an overview of the facilities decommissioned and new facilities constructed;
- descriptions of the engineered site, facilities, and systems;
- descriptions of effluents from the facilities and environmental monitoring activities; and
- descriptions of the natural and physical environments.

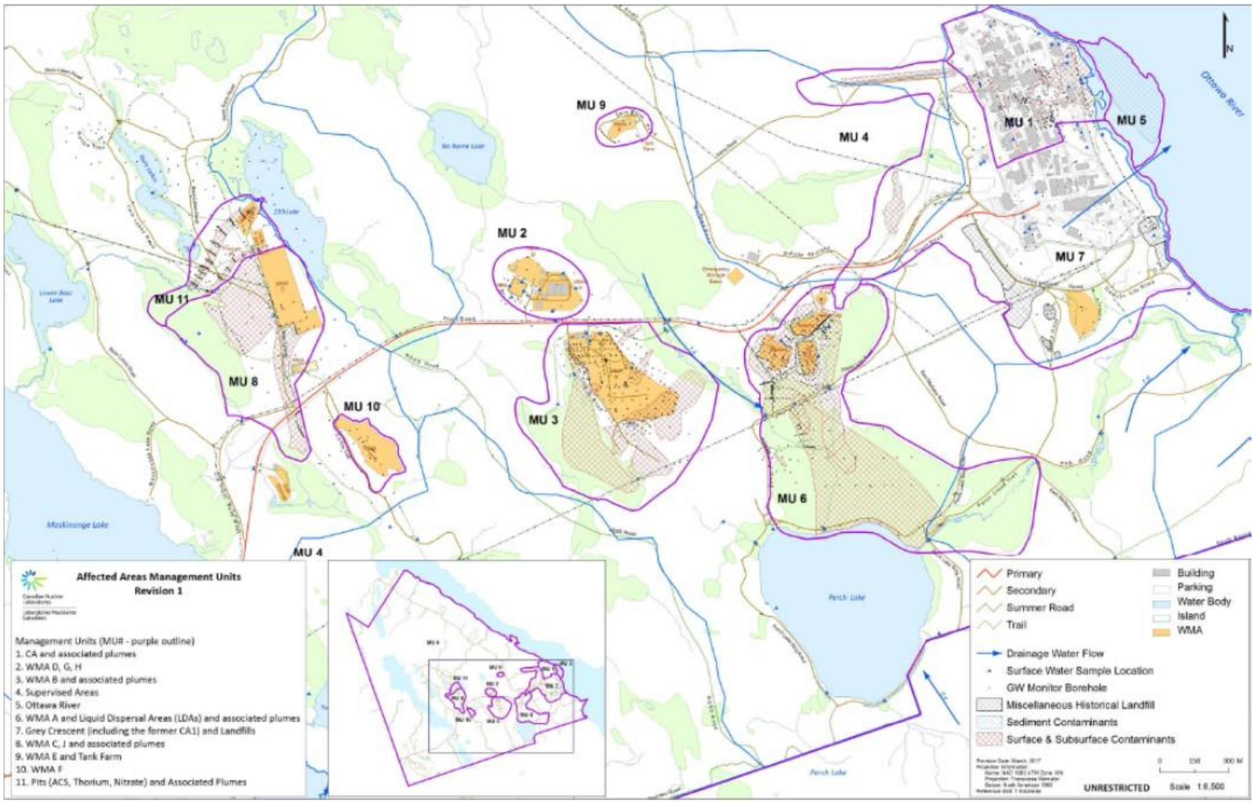

Figure 1. Map of CRL site outlining boundaries of Management Units.

Human Health Risk Assessment

The Human Health Risk Assessment (HHRA) focuses on the potential for health effects to the public from the release of contaminants from the CRL site to the environment. The HHRA assesses the dose to critical groups, i.e., those individuals most likely to receive the greatest dose from radiological and non-radiological contaminants of potential concern (COPCs) because of their location of residency and considering relevant exposure pathways. In the HHRA, the total dose to off-site members of the public was calculated conservatively by summing the dose to the most sensitive critical group for each pathway, thereby resulting in a dose to a hypothetical individual living off-site.

Workers on the CRL site are potentially exposed to environmental contaminants, both chemical and radiological, but these exposures are considered and controlled through CNL's Occupational Health and Safety Program and the Radiation Protection Program. Worker and visitor exposures on the CRL site are not addressed in the HHRA as these exposures are less than worker doses in both magnitude and duration. Radiation doses to workers and visitors are monitored as per regulatory Radiation Protection Program requirements.

Off-site members of the public are potentially exposed to low levels of airborne or waterborne releases. All potential critical groups are considered in the calculation of Derived Release Limits

(DRLs) for the site [4] which are based on CSA N288.1-14 [5], where bounding critical groups were identified. This HHRA uses measured radionuclide concentrations in environmental media, including foodstuffs, to calculate the radiation dose to critical groups. Radiation dose is also calculated based on effluent releases as a percentage of the DRLs for the various radionuclides.

Balmer Bay receptors, located 6.8-km northwest and upstream of the site, receive the highest total dose from airborne contaminants from CRL (based on % of DRL and environmental monitoring results) as they are in the predominant NW-SE wind direction. Chalk River residents are slightly closer to the CRL site, but less exposed since they are not in the predominant wind directions. The most exposed farm residents are at the Sheenboro farm, approximately 10.5-km southeast of the CRL site, on the Québec side of the Ottawa River. The Balmer Bay residential and Sheenboro farm receptors were considered for assessment in the HHRA [6].

The receptors that receive the highest total dose from waterborne contaminants from CRL (based on % of DRL and results of environmental monitoring) are riverside residents at Harrington Bay, 8.6-km downriver on the Québec side of the Ottawa River, and residents at Petawawa and Pembroke, 17.9- and 30.1-km downriver, respectively. Residents in these communities were considered as receptors for assessment in the HHRA.

The public dose estimates for the Balmer Bay receptors (0.087 $mSv \cdot y^{-1}$ for an adult and 0.084 $mSv \cdot y^{-1}$ for an infant) are well below the public dose limit of 1 $mSv \cdot y^{-1}$ [6]. Therefore, public health is protected. The radiation dose from CRL is very low and represents a fraction of the natural background dose, even when extreme diets are modelled. When considering a diet consisting entirely of local venison or fish from the Ottawa River, results show this would have little effect on the total radiation dose to the public. Since residents at Balmer Bay are protected, other population groups near CRL that receive lower radiation doses are also protected. With the shut-down of the National Research Universal (NRU) reactor on March 31, 2018, the radiation dose from noble gases, particularly ^{41}Ar, that have been major contributors to the external dose (gamma) from immersion in air, will be greatly reduced.

Non-radionuclide releases to air were also considered from a human health perspective. Acid gases, NO_x and SO_x, and particulate matter (PM_{10}, $PM_{2.5}$), from various sources on site, have near-source concentrations in the built-up area of the site that exceeded Ontario Ambient Air Quality Criteria (OAAQC) [7]. Atmospheric concentrations of Hg, Pb, NO_x, N_2O, $PM_{2.5}$, PM_{10}, SO_2 and SF_6 off-site at Balmer Bay were far below OAAQC and were not considered further.

The potential risk of health effects from exposure to radiation and mercury (Hg) in Ottawa River bottom sediment near the Process Outfall is negligible. Nevertheless, in the remote possibility that members of the public are exposed to elevated radionuclide or Hg concentrations in Ottawa River sediment, the potential risk was investigated [8]. All plausible scenarios of exposure resulted in radiation doses considered trivial (10 to 100 $\mu Sv \cdot y^{-1}$) by the International Atomic Energy Agency (IAEA) [9] and Hg uptake rates were a small fraction (<4%) of the Tolerable Daily Intake.

Ecological Risk Assessment

In the present ERA, the potential for effects to biota is assessed through the use of generic receptors that represent pathways of exposure and groups of organisms. This is because there are too many species to assess them all individually and the data are not available to accurately assess many species. Species-specific parameters for a variety of environmental conditions are generally lacking. For example, in most Ecological Risk Assessments (EcoRAs), fish are divided into two groups, pelagic (e.g., the walleye) or benthic (e.g., the brown bullhead), representing different pathways, i.e., either feeding from the water column or the bottom (benthic invertebrates and radiation exposure from sediment) with the same parameter values representing all pelagic fishes and another set of parameter values representing all benthic fishes.

Ecological receptors of interest, the radiological and non-radiological COPCs (and stressors), locations of exposure to COPCs, and relevant exposure pathways have been identified in previous CRL ERAs with a few minor changes in the present ERA. Selected ecological receptors represent a cross-section of taxonomic groups, habitats, feeding habits and trophic levels so that effects can be extrapolated to ecologically similar species.

The difference in assessing non-Species at Risk (SAR) valued components (VCs) and SAR VCs is in the benchmark that is used. For non-SAR, a low-effect value such as an EC_{20} (i.e., concentrations at which effects are observed in 20% of the population) is ideally used as the benchmark, whereas a No-Observed-Effect-Level is preferred for SAR. Reference organisms of approximately the same size and representing similar food-chain pathways and diets can act as surrogates for SAR or the potential effects of a contaminant can be calculated directly to the SAR using data representative of that species, when available.

Accumulation of contaminants is modelled with the use of bioaccumulation factors (BAFs). Concentrations of most metals and radionuclides decrease up the food chain, whereas most organic compounds increase (biomagnify) up the food chain. Cs-137 is an exception as it biomagnifies up the food chain to walleye, a top predator, in the Ottawa River. The use of site-specific BAFs generally provides a reasonably accurate estimate of the accumulation of a given contaminant in higher-trophic level receptors and site-specific values were used where available. Where site-specific data were not available, generic values were used.

Concentrations of contaminants in CRL media (surface water, sediment, soil) were updated based on recent site monitoring data and measured concentrations were compared to benchmark values. Where updated measured concentrations were not available, or partitioning calculations were not possible, risk quotients (RQs) were carried over from the 2012 ERA to the present ERA. Benchmarks used to assess the potential for radiological effects to sensitive species were 100 $\mu Gy \cdot h^{-1}$ (2.4 $mGy \cdot d^{-1}$) for terrestrial organisms and 400 $\mu Gy \cdot h^{-1}$ (9.6 $mGy \cdot d^{-1}$) for aquatic organisms [2][10], and individual radionuclide ecological effects concentration benchmarks for terrestrial and aquatic sites (Table 4-4). Benchmark values for non-radiological COPCs were taken from applicable federal and provincial guidelines for environmental quality, literature toxicological data and the upper range of background concentrations (Table 4-7).

Groundwater within a source area was not considered as an exposure medium, except in the area of groundwater discharge. Physical stressors considered in the EcoRA included entrainment/impingement effects at the cooling water intake, and traffic on site roads. Habitat alterations are considered in individual project assessments.

Risk quotients (RQ) were calculated for each relevant receptor at each assessment location. RQs > 1 indicate a potential for adverse effects, but do not demonstrate that there is an effect. RQs based on maximum exposure concentrations may overestimate the risk for mobile species such as fish, birds and mammals, which may average their exposure through their movements. In addition, RQs local upper limit background concentrations may be overly conservative, since these concentrations are usually below the effect level.

Potential Effects

Most locations around the CRL site have radiation doses below the benchmark values (RQ < 1). The few locations where the benchmarks are exceeded (RQ > 1) are mainly associated with the ^{90}Sr groundwater plumes such as those emanating from the WMAs, discharging to wetlands. Areas with elevated radiation levels, and RQs > 1, are small and potential effects are not expected to mobile species at the population level. Non-radiological contaminants with RQs > 1 are more common and widespread. Although RQs are > 1, the exceedances do not demonstrate adverse effects, but indicate that further assessment is required. Some exceedances may be due to naturally high local background conditions, as well as releases from WMAs which may, or may not have an adverse effect.

A brief synopsis of each MU follows in terms of the potential for adverse effects from radiological and non-radiological COPCs.

Management Unit #1 (MU #1):

MU #1 is the Controlled Area, an area of approximately 20 ha where most of the radioactive work takes place. MU #1 is home to five nuclear reactors of which only the Zero Energy Deuterium-2 is still operational. The National Research eXperimental (NRX), Maple 1 and Maple 2 and the NRU reactors are all in a Safe-Shutdown-State. A number of laboratories and support facilities, e.g., Powerhouse, Waste Treatment Centre, hot cell facilities, radioisotope laboratories, nuclear materials storage, various workshops, and maintenance shops are located here.

Radiological COPCs

Groundwater contamination from the NRX rod bay leak has resulted in a ^{90}Sr plume that extends 330 m from the rod bay to the shoreline of the Ottawa River. The leakage of radiologically contaminated bay water into the soils and groundwater beneath the facility continued until September 2006, when water remaining in the B204A Bays was successfully removed. In 2017, the ^{90}Sr concentration in groundwater near the shoreline was 84 Bq·L^{-1}

(RQ=0.46 to the snail), hence no ecological effects are expected. This is supported by two on-site studies [11] [12] on the breeding and reproductive success of tree swallows that colonized nest boxes in the area of the plume. Accumulation of ^{90}Sr by tree swallows feeding on insects in the area of the plume resulted in a RQ < 1.

In the 2012 ERA, alder trees growing over the NRX plume had a RQ of 1.1 based on a radiation dose of 2.61 $mGy \cdot d^{-1}$, which is below the No-Observed-Adverse-Effect-Level for plants [13]. The RQ of 1.1 is not an indication of a harmful effect to alder trees. The area of elevated gross beta activity is relatively small, i.e., extending about 40 m along the shoreline north of the Gray Dock.

A tritium plume also extends from the NRU rod bays to the shoreline. In 2017, tritium concentrations in nearshore wells in a transect across the plume had a maximum tritium concentration of 109 $kBq \cdot L^{-1}$ and a mean of 67 $kBq \cdot L^{-1}$ resulting in RQs well below one, therefore, no ecological effects are expected.

The chimney swift (*Chaetura pelagica*) is classified as threatened in Canada under the Species at Risk Act and in Ontario under the Endangered Species Act. At CNL, the chimney swift roosts in the Molybdenum Processing Facility (MPF) stack annually over a period of 16 weeks with between 60 and 600 individuals present at any one time. The chimney swift does not breed in the MPF stack. While the MPF facility was operating, chimney swift birds residing in the stack received low levels of radiation from noble gas emissions (a conservative dose assessment of the receptor's night-time occupancy of the MPF stack during the summer resulted in a RQ of well below 1). In October 2016, molybdenum (Mo) processing activities ceased thereby eliminating the source of noble gas emissions and associated radiation dose.

Non-radiological COPCs

In MU #1, non-radiological COPCs with RQs > 1 were noted at the following locations:

- undiluted 4F6 Man Hole effluent includes chloride (Cl), copper (Cu), iron (Fe) and phosphorus (P),
- Storm Outfall 030 effluent includes *E. coli*, and
- Sanitary Outfall effluent includes aluminum (Al), Cu, nickel (Ni), P, vanadium (V), ammonium, total residual chlorine (TRCl) and total suspended solids (TSS).

Elevated Cl likely reflects runoff of road salt during storm events. Due to a large-scale restructuring of storm water management at CRL during 2018, Storm Outfall 040 was directed to the Process Outfall, and Storm Outfall 030 was rerouted to 010 Stream holding pond. These changes, as well as the construction of a new Sewage Treatment Facility, are predicted to make a positive impact on effluent concentrations in these locations and will be assessed in upcoming monitoring reports and future ERAs.

Airborne releases of sulphate (SO_2) result in RQs > 1 up to the 300-m point of impingement in the SE direction, within the built-up area/waterfront area, therefore, there is a potential for effects from SO_2 from the Power House stack on a local scale. Within the built-up/waterfront area of the site where the landscape has been altered by human disturbance, the diversity of natural biota is diminished. No obvious adverse effect is seen in the local vegetation in this area. In 2017, the source of SO_2 emissions (burning #6 fuel oil) was replaced with burning of natural gas, thus emissions are expected to decrease well below benchmark values by the end of 2018

Management Unit #2 (MU # 2)

MU #2 includes WMA-D, -G, and –H, which are all operating, above-ground waste storage facilities.

No radiological and non-radiological COPCs had RQs > 1.

Management Unit #3 (MU #3)

MU #3 includes WMA-B and associated plumes discharging to Spring B Forest and West Swamp, Perch Lake Inlet 1 and seeps near Main Stream. The plumes result from historic discharges to unlined sand trenches. WMA-B also contains asphalt-lined and capped trenches, rectangular concrete bunkers, tile holes, and special burials. Currently operating facilities include cylindrical concrete bunkers, newer tile holes and the Fuel Packaging and Storage facility.

Radiological COPCs

Sr-90 is the primary radionuclide of concern in MU #3. A groundwater ^{90}Sr plume from WMA-B discharges to the surface at Spring B, a forested wetland area. The ^{90}Sr plume is intercepted by the Spring B pump and treat groundwater treatment facility, which greatly reduces the ^{90}Sr concentration in water released into the stream. Contamination is highly focussed along the Spring B Forest channel. Further downgradient, in West Swamp, surface flow does not follow a clearly defined channel, but water (and contaminant) movement is towards the southeast corner of the swamp and the stream that drains to Perch Lake Inlet 1. The area with a RQ > 1 for soil is limited to a small strip of land along Spring B with an area of about 0.1 ha [14].

In 2015, a maximum gross beta activity in West Swamp vegetation samples of 1,680 $Bq \cdot g^{-1}$ dw was in an alder tree adjacent to Spring B Forest Stream. This represents a radiation dose of about 10.3 $mGy \cdot d^{-1}$ and a RQ of 4.3. This dose is in the range where minor effects first start to appear in sensitive plant species, whereas the alder, being a deciduous tree, is considered to be a more resistant species.

Maximum RQs were calculated for gross beta to the snail in Spring B (RQ=4.0 in a groundwater discharge location, 6.1 in surface water and 3.4 in sediment). Considering the small area (0.1 ha) of elevated radiation in Spring B Forest, and the fact that most benthic invertebrates, including the snail, are fairly radioresistant, population level effects are unlikely. Due to the relatively long half-life of ^{90}Sr of 28.8 years, it is anticipated that RQs will exceed one for several decades in this small area.

Non-radiological COPCs

In MU #3, non-radiological COPCs with RQs > 1 were noted at the following locations:

- Spring B Forest water includes Cl, lithium (Li), uranium (U) and phenolics,
- Spring B Forest sediment includes arsenic (As), Cl, Fe, Ni, (lead) Pb, strontium (Sr), U and zinc (Zn),
- West Swamp water includes barium (Ba), Cl and Li,
- West Swamp sediment includes Al, Ba, Cl, Li, Pb and Sr,
- Perch Lake Inlet 1 in water includes Ba, Cu, Fe, Li, Pb, phenolics, solvent extractable (oil and grease), TCFM, V and Zn,
- Perch Lake Inlet 1 sediment includes Ni and V, as well as Pb and Zn for the ingestion pathway,
- Discharge of the solvent plume at seep SS-1 near Main Stream resulted in RQs > 1 for TCE and chloroform.

Further assessment is required to better characterize these COPCs and determine whether adverse effects are occurring.

Management Unit #4 (MU #4)

MU #4 is the area in the Outer Supervised Area that does not contain any WMAs that fall under facility authorization. There are a number of legacy sites within MU #4, as well as operating support facilities (i.e., the CRL Firing Range) and locations for proposed new infrastructure. MU #4 has an area of 3,580 ha, representing the majority of the CRL site, which is mainly unaltered by CNL operations and remains in its natural state.

Radiological COPCs

No radiological contaminants exceed their respective benchmarks (RQ < 1).

Non-radiological COPCs

In MU #4, non-radiological COPCs with RQs > 1 were noted at the following locations:

- O-3 Swamp water and sediment include elevated Cl concentrations,
- Main Stream above Plant Road water includes Cl, Cu, Li, P, phenolics, and TCFM,
- Main Stream above Plant Road sediment include Cl, Cu, P, Sr and TCFM.

Road Kills

The effect of traffic on wildlife is likely one of the more significant effects CRL has on the local ecosystem. Typically, a few large mammals are killed by vehicles each year. From 2013 to 2017, 4 moose and 4 deer fatalities were recorded on Plant Road, the main access road to the plant site, compared to 4 moose, 11 deer and one bear fatalities during the 2007 to 2012 year period.

Turtles in a wetland bordering the road in the Maskinonge Lake area, cross the road during the spring and summer to look for places to lay their eggs in the gravel along the road. Since 2012, 31 turtles have been killed on the road (25 painted, 2 snapping, 1 northern map and 3

Blanding's turtles). Blanding's turtles, northern map turtles and snapping turtles are all listed under Schedule 1 of the Species at Risk Act. Mitigation measures to protect the turtles include signage to caution motorists at two turtle crossing areas, installation of silt barriers to reduce turtle access to the Plant Road, specially designed culverts for turtle crossing use, and an employee awareness/educational program about the turtles on site.

For long-lived, slow reproducing creatures, such as turtles (including SAR), traffic fatalities may have an impact on their populations over the long-term. In the case of larger mammals, the level of traffic mortality is not likely to be having an effect at the population level. Overall, the CRL site is largely unaffected by operations and acts as a nature reserve as public access is restricted and hunting and fishing is prohibited.

Road Salt

Roadways, parking areas and walkways are maintained in the winter months with the use of road salt. Road salt use during the winter months contributes to elevated Cl levels in surface water that could result in adverse effects to aquatic species along CRL roadways. It is assumed that elevated sodium (Na) and/or Cl concentrations will occur in groundwater and soils along CRL roadways and parking lots, similar to what can be expected along Ontario roadways in general.

Management Unit # 5 (MU #5)

MU #5 is the Ottawa River and its riverbed near the Process Outfall, which is an area that is readily accessible to the public. Throughout the Ottawa River, water concentrations of ^{137}Cs, ^{90}Sr and tritium are now about 3%, 4% and 2%, respectively, of maximum concentrations that occurred in the mid-1960s, following the peak in atmospheric nuclear weapon testing. Levels of radionuclides measured in Ottawa River water at Pembroke (30+ km downstream of CRL) are now close to background and pose no ecological risk to aquatic biota or the public.

A comprehensive characterization campaign beginning in the early 2000's revealed an area of river sediment with concentrations of a range of radiological and non-radiological contaminants elevated above background levels [15]. The area of contaminated sediment is 8 to 10 ha local to the CRL Process Outfall, and occurs at water depths of about 8 to 30 m. Radiological contaminants include fission and activation products from reactor operations, with the contamination occurring as dispersed "bulk sediment" contamination and as discrete active particles (minute pieces of nuclear fuel and corrosion products). Non-radiological constituents elevated in concentration and above ecological screening-levels within the radiological footprint include dioxin-like polychlorinated biphenyls (PCBs) and mercury.

Risk quotients for radionuclides were < 1 for all receptor organisms in both profundal and littoral habitats, including exposure to both natural and anthropogenic activity, however average mercury sediment concentrations resulted in an RQ of 3.

The potential effects of elevated contaminant levels to biota were assessed in the Ottawa River

Sediment ERA [15]. A weight of evidence assessment approach was used to provide a comprehensive understanding of the risks from the contaminants in Ottawa River sediment. Lines of evidence included: historical reviews of operations, sediment/contaminant characterization, determination of COPCs, evaluation of the physical characteristics and stability of the sediment, ^{210}Pb dating of sediment core profiles, studies of aquatic community structure, contaminant bioaccumulation and sediment toxicity tests.

Little potential for trophic transfer of sediment contamination to fish and fish-eating wildlife was found because of a predominately pelagic food web, low benthic biomass, and declining levels of sediment contamination. The only anthropogenic radionuclides presently detected in fish are ^{90}Sr and ^{137}Cs, and there is no difference in ^{90}Sr and ^{137}Cs concentrations in fish upstream and downstream of the CRL site. Methyl mercury (the bioavailable form that influences mercury biomagnification in the food web) concentrations are very low in Ottawa River surface water and the top 5-cm of sediment. Walleye mercury concentrations near CRL, and the evidence that walleye are pelagic feeders in the CRL reach of the river, indicates that any mercury biomagnification is a regional issue likely related to water concentrations influenced by atmospheric origin and natural mercury methylation processes in the watershed, not CRL's operations.

Despite elevated contaminant concentrations in Ottawa River sediments near the Process Outfall, benthic macroinvertebrate abundance and community structure does not appear to be different from upstream or downstream locations, and after 60 years of reactor operations, abundance of *Hexagenia* nymphs (a sensitive invertebrate to contamination) in the Ottawa River adjacent to CRL remains essentially unchanged from that prior to the NRX accident in 1952. Sediment toxicity test results for three benthic invertebrate taxa (*Hyalella azteca, Chironomus dilutus* and *Hexagenia* spp.) and the fathead minnow (*Pimephales promelas*) found no effect on survival or reproductive endpoints, and only minor impacts on growth for *D. dilutus* and *Hexagenia* spp. exposed to contaminated sediments.

For effluent releases to the Ottawa River from the Process Outfall (with dilution), TRCl had a RQ > 1 during chlorination events (~ 2 $h \cdot week^{-1}$). With the shutdown of NRU, the need for shock chlorination events has ceased. Therefore, TRCl should no longer be an issue in Process Outfall effluents in the future.

Contaminant concentrations in water, sediment and biota are declining in this area of the river due to radioactive decay and burial. Burial is the primary mechanism for decreasing contaminant/biota interactions for Hg, dioxin-like PCBs, metals and long-lived radionuclides through time. Overall, ongoing releases to the Ottawa River from CRL operations are having a negligible impact on the river, and with the shutdown of NRU in March 2018, releases have further declined.

Management Unit #6 (MU #6)

MU # 6 is within the Perch Lake Basin, and primarily consists of WMA-A and the Liquid Dispersal

Areas (LDAs), which include the Reactor Pits, Chemical Pit and the Laundry Pit, as well as the down-gradient receiving environments, i.e., South and East Swamps, Perch Lake and Creek. WMA-A and the LDAs are currently non-operational. A pump and treat system removes and treats ground water before it enters East Swamp, and a Funnel and Gate (passive system) remove ^{90}Sr from groundwater before it discharges to the surface in South Swamp.

WMA-A was used for storage of solids and dispersal of liquids beginning in 1946 in unlined, uncapped trenches. Waste emplacement operations in WMA-A were terminated in 1955, after which WMA-A was used as a surface storage area for contaminated and potentially contaminated reusable equipment until the mid-1970s. The surface of WMA-A was then cleaned-up and has been covered with approximately 3 m of cover material. In 2013, a permeable reactive barrier (South Swamp PRB) was installed to treat a ^{90}Sr plume emanating from the WMA-A.

The LDAs received liquid waste from holding tanks at B240 via a pair of underground pipelines (one to the LDA and one to WMA-A) over the period from 1953 to 2000. Reactor Pit 1 received low level radioactive waste water from the NRU and NRX reactors between 1953 and 1956, and cleanup water from the NRX storage bays and building sump in 1959. Lightly contaminated equipment, debris, scrap metal and excavated soil, rock and rubble from the CRL Active Area have been buried there. Groundwater flow beneath Reactor Pit 1 is to South Swamp and East Swamp. Reactor Pit 2 operated from 1956 to 2000 and was used to disperse low-level radioactive wastewater from the NRU and NRX reactors.

The Chemical Pit operated from 1956 to 1994 and received low-level radioactive liquid wastewater containing some chemicals originating from radioactive laboratories and various chemical processes on-site (e.g., acids, alkalis, and complexing agents). The Laundry Pit was used to disperse wastewater from the active area Laundry and Decontamination Centre and therefore contains small amounts of contaminated soil. Phosphorous and PO_4 are elevated above background in the groundwater, reflecting the past use of phosphate-based detergents.

Considering the historical use of MU #6, it is one of the most affected areas on the CRL site. The LDAs were all intrusively characterized in 2017 and the results of soil analyses were considered in the present assessment.

Radiological COPCs

<u>South Swamp</u>

South Swamp is a small (1.5 ha) wetland located in the Perch Lake basin just south of WMA-A. South Swamp drains via South Swamp Stream (referred to as T-16 stream in the past) to Main Stream to Perch Lake by Perch Lake Inlet 2. Gross beta activity (primarily ^{90}Sr) has discharged to South Swamp since at least 1955, resulting in elevated concentrations in soil, vegetation, and surface water [16]. In 2017, RQs were > 1 for soil gross beta concentrations in about 38% of the area of South Swamp. Over the past 10 years, gross beta activity has been declining in South Swamp Stream.

A permeable reactive barrier was installed across the plume extending from WMA-A to South Swamp in 2013 reducing the groundwater gross beta concentration to less than 10 $Bq·L^{-1}$. In the present assessment, maximum gross beta concentrations in soil (RQ < 1) and trees (RQ=3.3 to the alder) occur just south of the permeable reactive barrier that is affected by releases from WMA-A. Gross beta concentrations in surface water averaged 400 $Bq·L^{-1}$ (RQ=1.2 to the aquatic snail) in 2013-2017. Surface and vegetation contamination in South Swamp is decreasing.

Decreases in South Swamp ^{90}Sr contamination as a result of the installation of the plume interception system are expected to become more evident over the next 15 years.

<u>East Swamp</u>

East Swamp has an area of approximately 7.7 ha and is located near the LDA. Groundwater flow from the Chemical Pit compound is south towards East Swamp. East Swamp is also contaminated, to a much lesser extent, by a second subsurface plume from Reactor Pit 2, which is a significant contributor to contamination at the East Swamp Stream weir. These contaminant plumes have been discharging to the wetland for nearly six decades [17].

Maximum ^{90}Sr concentrations in soil result in RQ=7.0 to the snail, whereas ^{90}Sr levels in leaves are at RQs < 1. Gross beta releases to East Swamp have been stable for several years, with gross beta activity at East Swamp Weir averaging 272 $Bq·L^{-1}$ (RQ < 1) over the 2007 to 2017 period. Gross beta activity at East Swamp Weir has been variable but stable.

Ambient radiation fields in East Swamp are decreasing due to radioactive decay of ^{60}Co and ^{137}Cs, and transport out of the wetland through East Swamp Stream.

Non-radiological COPCs

In MU #6, non-radiological COPCs with RQs > 1 were noted at the following locations:

- South Swamp water includes Ba, phenolics, TCE and TCFM
- South Swamp sediment includes Cl, Li, Sr and TCE. For the ingestion pathway, Al and Ba.
- East Swamp water includes Al, cadmium (Cd), Cu, Fe, PCBs, TCE, TCFM and V.
- East Swamp sediment includes Ni, tetrachloroethylene (PCE), Sr and TCE. For the ingestion pathway, Al exceeded its benchmark value.
- Chemical Pit seepage water includes Ba, Fe and mercury (Hg), whereas seepage sediment includes Fe, Pb, Hg, U and V.
- Perch Lake water includes Ba, which also exceeds ingestion dose benchmarks.
- Perch Lake Inlet 2 water includes Cu, Fe, PCBs, phenolics, solvent extractables and TCFM.
- Perch Creek water includes Cu, Li, PCBs and TCFM, whereas the sediment includes Cu and Li.

Further assessment is required to better characterize these COPCs and determine whether adverse effects are occurring within MU #6.

Management Unit #7 (MU #7)

MU #7 is an area of about 20 ha within the Ottawa Direct Basin that includes the Inner Supervised Area, which is occupied by non-nuclear facilities, office buildings, industrial facilities and site utilities, and the affected lands known as the "Grey Crescent" that was historically developed as disposal sites to accommodate waste from operational activities and conventional waste. With the exception of the Sanitary Landfill, which is currently in use for inactive wastes, landfills in the Grey Crescent are no longer accepting waste.

Contamination in MU #7 is mainly from non-radiological liquid and solid wastes. Further soil sampling to characterize the Electrical Yard Landfill found elevated metal concentrations in a small area. A risk assessment is presently in progress to assess the potential for adverse environmental effects from the metals.

Samples collected in 2014 from the Foundation Road Landfill had total uranium (U) soil concentrations ranging from 860 $\mu g \cdot g^{-1}$ dw to 430,000 $\mu g \cdot g^{-1}$ dw, which, when compared to the Canadian Soil Quality Guideline [18] of 300 $\mu g \cdot g^{-1}$ for industrial sites, results in a minimum RQ of 2.87.

Radiological COPCs

No radiological contaminants exceed their respective benchmarks (RQ < 1).

Non-radiological COPCs

Liquid effluent streams in MU #7 are given a dilution factor to account for the dilution that occurs when discharged to the Ottawa River. With a dilution factor applied, no COPC exceeded their benchmark values (RQs < 1) in Ottawa River nearshore streams. In the undiluted streams, RQs greater than 1 were noted at the following locations:

- Undiluted 010 Stream water includes Al, Ba, Cl, Cu, Li, Zn and solvent extractables.
- Undiluted 010 Stream sediment includes Al, Ba, Cu and Zn.
- Undiluted 020 Stream water includes Al, Ba and Li.
- Undiluted 020 Stream sediment includes Al, Ba and Sr.

Further assessment is required throughout MU #7 to better characterize the areas where these contaminants are found and determine whether adverse effects are occurring in these isolated areas.

Management Unit #8 (MU #8)

MU #8 is in the Maskinonge Lake Basin and includes WMA-C, WMA-J, as well as plumes emanating from WMA-C to the southern portion of Duke Swamp, and Bulk Storage Swamp. Only Fe concentrations (1,390 $\mu g \cdot L^{-1}$) in surface water at the confluence of Duke and Bulk Storage Stream exceeded benchmark values in 2017.

WMA-C was established in 1963 and originally utilized discrete sand trenches on the southern end and a continuous sand trench (Trench 30) on the north end, which was used for solid wastes between 1982 and 1995. A series of concrete well tiles were also used for the storage of small quantities of liquid wastes between 1963 and 1987. WMA-C received low-level radioactive and chemically contaminated solid wastes, and sewage sludge from the CRL Sewage Treatment Plant and animal carcasses from research and road kills until 2004. WMA-C has also been used for above ground storage of contaminated materials including sections of the NRX Reactor Stack, drums of liquid scintillation wastes (removed in 2008, now in WMA-H), suspect soils excavated from the Active Area, and steel containers filled with CRL sewage sludge filter cake (removed in 2011). In 2013, an engineered cover consisting of three layers was placed over the top of both the original compound and the extension to reduce water infiltration through the waste.

Groundwater flow at WMA-C is to Duke Swamp with a second flow path to Bulk Storage Swamp. The main COPCs in groundwater from WMA-C are tritium and volatile organic compounds. Tritium concentrations in surface waters near WMA-C are decreasing and are well below levels of concern, and are expected to decrease further in the next several years as a result of the application of the engineered cover.

WMA-J (formerly the Bulk Materials Landfill) is located between WMA-C and the Plant Road. WMA-J is a relatively new waste storage facility that came into operation in early 2011 for the long-term management of dewatered sewage sludge from the CRL Sanitary Sewage Treatment Plant.

<u>Duke Swamp</u>

Duke Swamp is a perennial wetland in the Maskinonge Lake basin, fed by groundwater discharge from Lake 233 that passes below the Nitrate Plant, Thorium Pit, Acid Solvent Pits, and WMA-C. Groundwater flow delivers tritium, low concentrations of ^{14}C and ^{60}Co, and halogenated volatile organic compounds to Duke Swamp from the narrow waste trenches in WMA-C. Groundwater plumes from the Thorium Pit and the Nitrate Plant (remediated by a permeable reactive barrier in MU #11) also discharge ^{90}Sr to the north end of Duke Swamp.

The installation of an impermeable cover on WMA-C in 2013 will significantly reduce releases of tritium, ^{14}C and ^{90}Sr to Duke Swamp. Tritium concentrations at Duke Stream Weir showed a substantial decrease in 2016 and continued to gradually decrease in 2017, with mean tritium concentrations of 4,149 $Bq \cdot L^{-1}$ measured at Duke Swamp Weir and 627 $Bq \cdot L^{-1}$ at Bulk Storage Stream Weir. Gross beta activity (^{90}Sr) has yet to show a response to the installation of the cover.

Radiological COPCs

Radiological contaminant levels are low with all RQs < 1.

Non-radiological COPCs

In MU #8, non-radiological COPCs with RQs > 1 were noted in the following area:

- Duke Swamp water includes Al, Li, TCFM and V.
- Duke Swamp sediment includes As, Cd, Cl, Pb, Ni, Sr and V.

Ongoing groundwater and surface water monitoring will confirm any changes in conditions in this area.

Management Unit # 9 (MU #9)

MU #9 includes WMA-E and the Waste Tank Farm. WMA-E is a non-operating facility that stores suspect and slightly contaminated soils, building materials, other bulk soils and building debris. In 2014, a Phase II Environmental Site Assessment for WMA-E concluded that there is only trace levels of radiological contamination and no significant leachable non-radiological contamination.

The Waste Tank Farm contains seven underground stainless steel storage tanks for radioactive waste solutions and sludge. Tank vent and access pipes are exposed at the surface. From 2012 to 2014, roughly 33.6 m^3 of liquid waste was removed from Tank 40D and processed through a mobile ion-exchange skid to remove ^{137}Cs. A residual heel of liquid waste/sludge of approximately 6.6 m^3 remains in the tank. Due to the unlined nature of Tanks 40D and 40E, plans are being developed to remove the remaining material from the tanks as soon as possible. Tanks 40F has recently been drained to less the 100 litres.

Radiological COPCs

No radiological contaminants exceed their benchmark values in MU #9 (RQ < 1).

Non-radiological COPCs

Not assessed in the present assessment, as no new data were available. Therefore, RQ < 1 for all non-radiological contaminants is carried forward from the 2012 ERA.

Management Unit #10 (MU #10)

MU #10 includes WMA-F in the Maskinonge Drainage Basin. WMA-F was developed to store wastes from remediation of contaminated sites at Port Hope, Ottawa, and Mono Mills, Ontario. The wastes contained Technologically Enhanced Naturally Occurring Radioactive Material, including contaminated soils, slags and building demolition debris resulting from uranium refining, niobium smelting and radium dial painting operations. The major contaminants of concern are As, Ra, Th and U.

In the 2012 ERA, the woodchuck (ground hog) was predicted to receive a radiation dose from radon inhalation in its burrow of 258 $\mu Gy \cdot h^{-1}$ (6,200 $\mu Gy \cdot d^{-1}$) (RQ=2.6). Groundwater monitoring has demonstrated that contaminant concentrations are not elevated beneath WMA-F, or downgradient of the facility. This situation has not changed since the 2012 ERA. 2018 characterization efforts will evaluate the presence of non-radiological COPC in WMA-F soil and will provide improved data on the radiological contaminants, including ^{226}Ra. Results will be available for evaluation in the next ERA.

Management Unit #11 (MU #11)

MU #11 is in the Maskinonge Lake Basin between Lake 233 and Duke Swamp and contains the three WMA's located immediately north of WMA-C: Acid, Chemical, Solvent Pits (ACS Pits), Thorium Pit and Nitrate Plant Pit and associated buildings, all of which are non-operating.

Groundwater flows from Lake 233 under the Nitrate Plant, Thorium and ACS Pits and discharges to the north end of Duke Swamp. Sr-90 plumes emanate from the Nitrate Plant and Thorium Pit and are intercepted by a Wall and Curtain PRB to remove ^{90}Sr from the groundwater before it enters the northern end of Duke Swamp. In Duke Swamp, the contaminated water flows northward along Lower Bass Creek to Lower Bass Lake to Maskinonge Lake. Gross beta concentrations in Lower Bass Creek have decreased from 5.7 Bq·L^{-1} in 2015 to 3.8 Bq·L^{-1} in 2017, which is well below the benchmark value of 183 Bq·L^{-1}.

The Nitrate Plant was a shielded pilot plant constructed to decompose (chemically stabilize and volume-reduce) ammonium nitrate solutions containing fission products generated from spent fuel reprocessing in the Plutonium Extraction Plant and operated from 1953 to 1954.

The Thorium Pit was operational from 1955 to 1960 for the dispersal of liquid waste solutions arising from thorium fuel cycle experiments conducted at CRL. The liquid waste contained natural thorium, thorium nitrate, ammonium nitrate, ^{144}Ce, ^{137}Cs, ^{90}Sr and ^{233}U. The inventory released from the Thorium Pit is a small fraction of the inventory released to the Nitrate Plant Plume. Radionuclide releases from the Thorium Pit have resulted in a ^{90}Sr plume that extends to Duke Swamp. In 2016, a maximum of 99 Bq·L^{-1} was measured in groundwater beta activity. Gross beta activity in vegetation is elevated where the ^{90}Sr plume from the Thorium Pit discharges to the surface in the northwest portion of Duke Swamp. Retention of ^{90}Sr by vegetation is low because there is a well-defined channel of only 80 m between the location of highest vegetation beta concentrations and the uppermost beaver dam on Lower Bass Creek, greatly reducing the opportunity for ^{90}Sr uptake.

The ACS Pits are a series of three small pits located north of WMA-C that operated from 1982 to 1987 for the dispersal of miscellaneous lab and processing wastes. One pit was used for dispersal of each waste type: inactive chemicals, acids and solvents.

Duke Swamp is the point of discharge for groundwater that flows from both MU #8 and MU #11; the potential effects of releases to Duke Swamp have been discussed and summarized in MU #8.

Concluding Remarks

The present ERA has demonstrated that radiation dose estimates to the public (0.086 mSv·y^{-1}) in the HHRA for the most sensitive human receptor are well below the regulatory limit of 1 mSv·y^{-1} and the 0.3 mSv·y^{-1} dose constraint. Therefore, public health is protected. Likewise, in the highly improbable scenario that a member of the public inadvertently exposes themselves to contaminated Ottawa River sediment from near the Process Outfall adhering to an anchor, the resultant radiation dose would be extremely small, as demonstrate by the hypothetical worst case scenarios.

For most of the CRL site, RQs for radiation exposure are less than one for nonhuman biota and there is little likelihood of adverse effects. For the few locations where radiological RQs are greater than one, there is the potential for an adverse effect, but this does not mean there is an effect. Radiological RQs > 1 are mainly associated with ^{90}Sr plumes such as the groundwater plume from the NRX rod bay to the Ottawa River, and the plumes from the WMAs that flow to swamps: Spring B and West Swamp, South Swamp, and East Swamp. RQs > 1 were calculated to the alder exposed to the NRX ^{90}Sr plume and the Spring B ^{90}Sr plume as well as to the snail and water shrew at Spring B.

Radiosensitivity of plants is in the order coniferous trees > deciduous trees > shrubs > herbaceous species > lichen and fungi. The benchmark of 2.4 $mGy{\cdot}d^{-1}$ adopted by the CSA N288.6-14 standard for terrestrial biota is more appropriate for terrestrial animals (mammals), not plants. As stated by UNSCEAR [10], chronic dose rates of < 400 $\mu Gy{\cdot}h^{-1}$ (< 10 $mGy{\cdot}d^{-1}$) should have only slight effects on sensitive plants (conifers), but would be unlikely to produce any significant deleterious effects on the wider range of plants present in natural plant communities. The radiation benchmark of 2.4 $mGy{\cdot}d^{-1}$ for terrestrial biota is a no-observed effect level for sensitive plant species, so it is unlikely that RQs > 1 in the present assessment represent adverse effects to the alder.

Likewise, for benthic invertebrates such as the snail, the effect level can be much higher than the aquatic benchmark of 9.6 $mGy{\cdot}d^{-1}$. Most aquatic invertebrates are relatively tolerant of radiation [13]. In the laboratory, a dose rate of 240 $mGy{\cdot}d^{-1}$ from ^{60}Co had no significant effect on reproduction, mortality or size of the snail [13]. Nevertheless, there are more radiologically sensitive benthic invertebrate species than the snail and RQs > 1 in a small area of elevated radiation may have adverse effects to such individuals. However, considering the small area of elevated radiation, it is unlikely that adverse effects would be seen at the population level. Further, high survival of the fathead minnow exposed to water from Maskinonge Lake, Perch Lake, Duke Swamp Weir, and Perch Creek for 60 days during the summer of 2013 demonstrates that the water at these locations is not toxic to fish [19].

Other studies looked at the potential for ^{90}Sr from groundwater plumes to accumulate in the tree swallow (*Tachycineta bicolor)*, an aerial insectivore. Tree swallow nestlings raised in a brood near a ^{90}Sr plume may feed on adult aquatic insects and flying terrestrial insects that are contaminated with ^{90}Sr. Near the NRX plume at the Ottawa River shoreline, gross beta activity was elevated in tree swallow nestlings (13.26 $Bq{\cdot}g^{-1}$), but well below the benchmark value (RQ < 1) [12]. A subsequent study [11], investigated the potential for radiation effects to tree swallows from elevated ^{90}Sr concentrations 7 to 14 times greater than background over a three year period at the NRX plume at the Ottawa River shoreline and at the north end of Perch Lake. Micronucleus frequency in blood cells from nestlings, reproductive success, nestling development, and female migratory return were assessed. Overall erythrocyte micronucleus frequency with ^{90}Sr/^{90}Y in tree swallow bone, clutch size in each nest, nestling mass at 12 days, sex ratio of nestlings and fledging rate were similar at ^{90}Sr elevated sites at radiation doses up to 16 $\mu Gy \cdot h^{-1}$ and control sites. An overall annual return rate of 43% for swallows was observed between 2015 and 2016, a rate that is considered excellent. Therefore, elevated ^{90}Sr concentrations observed on the CRL site are not having an adverse effect to insectivorous birds.

Studies of aquatic communities, contaminant bioaccumulation by biota and the toxicity of Ottawa River sediment have been conducted. Despite elevated anthropogenic radionuclides in Ottawa River sediments near the Process Outfall, benthic macroinvertebrate abundance and community structure does not appear to be different from upstream or downstream locations. A comparison of the present benthic invertebrate fauna with that prior to the NRX accident in 1952 found that after 60 years of reactor operations, *Hexagenia* spp. abundance in the Ottawa River adjacent to CRL remains essentially unchanged. Further, sediment toxicity test results for three benthic invertebrate taxa (*Hyalella azteca, Chironomus dilutus* and *Hexagenia* spp.) and the fathead minnow found no effect on survival or, in the case of *H. azteca,* reproduction. Other studies found there is little potential for trophic transfer of sediment contamination to fish and fish-eating wildlife. Only a small fraction of sediment bound radionuclides is bioavailable. The environmental studies performed to assess the potential effects of elevated sediment contaminant concentrations in the Ottawa River near the Process Outfall provide strong evidence that the CRL site is not having a major impact on the local environment.

Elevated radionuclide concentrations, mainly ^{90}Sr, are restricted to headwater areas, particularly swamps that are the recipients of groundwater plumes from WMAs. The highest ^{90}Sr concentrations are observed in Spring B Forest. Areas of elevated radioactivity are small (e.g., 0.1 ha for Spring B/West Swamp plume) and few receptors are affected. Furthermore, as noted above, the benchmarks used to assess the potential for adverse effects to the species that flagged are very conservative. Remediation efforts in intercepting the groundwater ^{90}Sr plumes will greatly reduce inputs to the surface environment. With the removal of source terms, radiological decay and dispersion of contaminants, concentrations will decrease to below effect levels within about 60 years.

Most RQ > 1 at the CRL site are associated with conventional contaminants, such as metals. A host of metals are present at elevated concentrations in association with wetlands, particularly Duke Swamp (Al, As, B, Ba, Cr, Li, Pb and V), downstream of wetlands in the Perch Creek watershed and in association with historic spills, storage facilities (i.e., Chemical Pit seepage), historic landfills and stormwater discharge. Naturally high background metal concentrations have been reported for the CRL site due to local geology. It is common for anaerobic groundwater to have elevated concentrations of redox sensitive metals, which, upon discharge to the surface, tend to precipitate out. Furthermore, wetland soils/sediments have elevated metal concentrations, because organic soil/sediment has a high cation exchange capacity. Metal concentrations are also naturally higher in organic-rich ecosystems such as those that predominate the CRL site. These factors and the history of the site in terms of storage of contaminated wastes, and the use of various locations for waste disposal has led to elevated contaminant concentrations in the environment. This is typical of most industrial sites, especially those that have operated for long periods like CRL. The nature of the elevated metal concentrations requires further assessment.

Airborne emissions are not of concern on a regional scale or off-site local scale, but SO_2 emissions have a RQ > 1 on-site up to 300 m in the south-east direction from the Power House. No adverse effects from SO_2 emissions are visible. It is anticipated that with completion of conversion from #6 fuel oil to natural gas, the 2018 Point of Impingement emissions at 100 m will be below the benchmark value (RQ < 1).

Evaluating the risk associated with each of the eleven MUs allows for the semi-objective division of the MUs into three groupings: high, intermediate, and low risk MUs. Based on the number of contaminants with RQs greater than one, both radiological and non-radiological, as well as the presence of VCs (including SAR), and any observed/measured ecological effects, the high risk areas are considered to be MUs #3, #4, #6, #8 and #11. Intermediate risk areas are MUs #1 and #7, and the lowest risk is assigned to MUs #2, #5, #9, and #10. Of those in the higher risk category, MU #4 is thought to have the greatest associated risk as the effect of road traffic on wildlife is likely one of the more substantial effects CRL has on the local ecosystem. The occurrence of traffic fatalities of SAR (mainly turtles) on Plant Road has an immediate effect on the local populations and the loss of only a few long-lived, slow reproducing individuals may have the potential to result in the local extinction of certain species from the site over the long-term. The other higher risk MUs (#3, #6, #8 and #11) all are associated with contaminant plumes from WMAs.

CRL has operated on the shore of the Ottawa River for seven decades, over which time radionuclides and conventional contaminants have been released from normal operations to the atmosphere and to the Ottawa River. In addition, the NRX accident in the early 1950s resulted in a substantial release of radioactive material and required the need to store or disperse radioactive liquid and solid wastes in WMAs, frequently without engineered containment. Despite this history of operation when standards were not as stringent as they are today, the present ERA has confirmed that, based on the currently available information, the potential for adverse effects to the environment from exposure to contaminants is limited to only a few locations on the CRL site. Further characterization and environmental effects monitoring are being planned to assess those locations where there is the potential for adverse effects.

Recommendations for the Monitoring Program

A set of recommendations have been developed to resolve data gaps, address uncertainty and increase transparency of ERA inputs and results prior to the next scheduled update. Recommendations are as follows:

1. In areas where radiation or chemical exposure exceed benchmarks and therefore there is

potential for adverse effects to biota, it is recommended that CNL continue monitoring these areas (through routine Environmental Monitoring and special investigations of soil and sediment where warranted) to confirm conclusions and analyze for trends. A weight of evidence approach is proposed to confirm if there is a risk in these areas. This may involve any, or all, of the following:

- a literature review of the subject (e.g., metal concentrations in wetlands and high organic sediment (peat)),
- review of present benchmarks for their relevance to the CRL site (e.g., confirm background concentrations and the potential for bioavailability of the contaminant),
- review of monitoring data trends for non-radiological and radiological parameters on-site, and
- planning appropriate field and/or laboratory studies to assess for significant adverse effects to biota as a result of elevated concentrations.

Studies will be performed following a graded approach, i.e., work would continue until CNL is satisfied that we have confidence in our understanding of these elevated concentrations and their potential risk to the environment, i.e., not all parameters may need the same level of investigation. CNL's goal is to determine if the potential effect is real, and if so, begin taking steps to mitigate it.

2. For a number of parameters, benchmark values based on toxicity were not available and the upper limit of background was used as the benchmark value. Since the upper limit of background is not based on toxicity, RQs > 1 derived from the use of the upper limit of background as the benchmark essentially indicate that the concentrations are elevated (or the upper limit of background is underestimated). It is recommended that CNL further evaluate elevated background concentrations for non-radiological contaminants and their potential for adverse effects. This would include better definition of background concentrations and assessment of contaminant availability for uptake by biota.
3. Where BAFs and exposure benchmarks are not available for COPCs to assess for potential risk (i.e., ingestion doses for American robin, painted turtle, great blue heron and water shrew), it is recommended that CNL address these data gaps. Again, a step-wise approach will be taken to assess and review present BAFs and benchmarks to determine their relevance to the CRL site, and further studies will fill data gaps; BAFs for surrogate species will be considered and used if relevant.
4. Once the Storm Water Management Project is complete, it is recommended that CNL re-evaluate the storm outfalls after 3 years of new data is collected.

References

[1] EcoMetrix Incorporated and Atomic Energy of Canada. *Environmental Risk Assessment of*

Chalk River Laboratories – 2012. 2013. ENVP-509220-REPT-001 Revision 0.

[2] Canadian Standards Association (CSA), *Environmental risk assessments at Class I nuclear facilities and uranium mines and mills*, CAN/CSA N288.6-12, 2012.

[3] Canadian Nuclear Safety Commission. 2018. Licence Condition Handbook NRTEOL-LCH-01.001 2028, Chalk River Laboratories Nuclear Research and Test Establishment Operating Licence NRTEOL-01.00/2028, Revision 0.

[4] Canadian Nuclear Laboratories (CNL), *Derived Release Limits (DRL's) for CNL's Chalk River Laboratories*, 2018. Regulatory Requirement Document CRL-509200-RRD-001, Revision 2.

[5] Canadian Standards Association (CSA), *Guidelines for calculating derived release limits for radioactive material in airborne and liquid effluents for normal operation of nuclear facilities*, CAN/CSA N288.1-14, 2014.

[6] Canadian Nuclear Laboratories (CNL), *Environmental monitoring in 2017 at Chalk River Laboratories*, 2018. Annual Safety Report CRL-509243-ASR-2017, Revision 0.

[7] Ontario's Ambient Air Quality Criteria. Standards Development Branch, Ontario Ministry of the Environment, 2012.

[8] Atomic Energy of Canada Ltd. (AECL), *Comprehensive Human Health Risk Assessment of Ottawa River Sediments near the CRL Process Outfall*. 2014. 175-121250-REPT-013 Revision 0.

[9] International Atomic Energy Agency (IAEA), *Principles for the Exemption of Radiation Sources and Practices from Regulatory Control*. IAEA Safety Series No. 89, 1988.

[10] United Nations Scientific Committee on Effects of Ionizing Radiation (UNSCEAR), *Annex E. Effects of Ionizing Radiation on Non-human Biota*. United Nations, New York, 2008.

[11] CANDU Owners Group (COG), *Dose-response relationships for non-human biota*. 2017. COG-16-3011.

[12] Atomic Energy of Canada Limited (AECL), *Transfer of Radionuclides from Contaminated Sediments into Tree Swallows via Emergent Aquatic Insects at the Chalk River Laboratories*. 2012. 175-121241-041-000.

[13] Bird, G.A., *Effects of Low Levels of Ionizing Radiation on Nonhuman Biota* in R.A. Meyers ed. Encyclopedia of Sustainability Science and Technology. New York, USA: Springer, 2012, Vol 8, pp. 5572-5619.

[14] Canadian Nuclear Laboratories (CNL), *Radiological Contamination in the West Swamp*. 2015. 3611-121250-REPT-009 Rev. 0.

[15] Canadian Nuclear Laboratories (CNL), *CRL Ottawa River Sediment Remediation – Ecological Risk Assessment*. 2014. 175-121240-REPT-002 Rev. 0.

[16] Canadian Nuclear Laboratories (CNL), *Radiological Contamination in the South Swamp, 2016 Groundwater Monitoring Program*. 2017. 3611-121250-REPT-00x Rev. 0.

[17] Canadian Nuclear Laboratories (CNL), *Radiological Contamination in the East Swamp, 2002 to 2012*. 2015. 3611-121250-REPT-006 Rev. 0.

[18] Canadian Council of Ministers of the Environment. 2007. *Soil Quality Guidelines for the Protection of Environment and Human Health*.

[19] Gagnaire, B., C. Adam-Guillermin, A. Festarini *et al*. 2017. *Effects of in situ exposure to tritiated natural environments: A multi-biomarker approach using the fathead minnow, Pimephales promelas*. Sci. Tot. Environ. 599-600: 597-611.

ACKNOWLEDGEMENTS

Thank you to all the groups and individuals that helped to bring this report together. Special mention to Richelle McCulligh, a Conestoga College student, who made a substantial contribution to the team.

Report Reviewed by and/or Received Input from:

George Dolinar
Christine Gallagher
Carla De Waele
Kaylin Lambert
Mary Kate Boileau
Annie Morin
Meghan Murrant
Chris Matasich
Matthew Bond
Kathryn Hogue
Renee Silke
Sohan Chouhan
Mokhles Rahman
Volodymyr Korolevych
David Rowan
Martin Klukas
Marc Hammell
Tracy Sanderson
Susan Miller
Craig Cochrane
Amy Festarini
Doug Killey
Jacob Eddy
Tammie Eve
Paul Leeson
Bruce Reavie
Brad Faught
Rob Roy MacGregor
Shelley Godin
Jamie Carr
Kevin Campbell
Kate Stephenson
Lucia Krivankova-Smal
Michelle Ball
Karl Reimer
Cole Merill
Allan Levoy
Mark Smith
Adrienne Ethier
Scott Clemow