Canada's Nuclear Regulator

Environmental Protection Review Report:
McArthur River Operation

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Environmental Protection Review Report: McArthur River Operation

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Revision history

The following table identifies the revision history of this document.

Revision number	Change	Summary of changes	Date
000	Initial release	N/A	January 2023
001	Revision 1	Formatting revised to meet new accessibility requirements.	September 2023

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Executive summary

The Canadian Nuclear Safety Commission (CNSC) conducts environmental protection reviews (EPRs) for all nuclear facilities with potential interactions with the environment, in accordance with its mandate under the *Nuclear Safety and Control Act* to ensure the protection of the environment and the health and safety of persons. An EPR is a science-based environmental technical assessment conducted by CNSC staff. The fulfillment of other aspects of the CNSC's mandate is met through other oversight activities.

This EPR report was written by CNSC staff as a stand-alone document, describing the scientific and evidence-based findings from their review of Cameco Corporation's (Cameco's) environmental protection measures. Under its current uranium mine licence, UML-MINE-MCARTHUR.01/2023, Cameco is permitted to mine uranium ore at its McArthur River Operation in northern Saskatchewan. The McArthur River Operation is situated within historic Treaty 10 territory, and in the Homeland of the Métis, and is within the traditional territories of the Denesųłiné, Cree, and Métis peoples.

CNSC staff's EPR report focuses on items that are of Indigenous, public, and regulatory interest, such as potential environmental releases from normal operations, as well as on the risk of radiological and hazardous (non-radiological) substances to the receiving environment, valued components and species at risk.

This EPR report includes CNSC staff's assessment of documents submitted by the licensee from 2013 to 2021 and the results of CNSC staff's compliance activities, including the following:

- the results of Cameco's environmental monitoring, as reported in annual reports
- Cameco's 2015 McArthur River Operation environmental risk assessment
- Cameco's 2020 McArthur River Operation environmental risk assessment
- Cameco's 2019 McArthur River Operation preliminary decommissioning plan
- the results of the CNSC's Independent Environmental Monitoring Program
- the results from other environmental monitoring programs (such as the Eastern Athabasca Regional Monitoring Program) and/or health studies (including studies completed by other levels of government) in proximity to Cameco's McArthur River Operation

Based on their assessment and evaluation of Cameco's documentation and data, CNSC staff have found that the potential risks from the McArthur River Operation's radiological and hazardous releases to the atmospheric, terrestrial, aquatic and human environments are low to negligible, and that these releases are at levels similar to natural background. Furthermore, human health is not impacted by operations at the McArthur River Operation and the health outcomes are indistinguishable from health outcomes found in similar northern Saskatchewan communities. CNSC staff have also found that Cameco continues to implement and maintain effective environmental protection measures that meet regulatory requirements and adequately protect the environment and the health and safety of persons. CNSC staff will continue to verify Cameco's environmental protection programs through ongoing licensing and compliance activities.

CNSC staff's findings from this report may inform recommendations to the Commission in future licensing and regulatory decisions, as well as inform CNSC staff's ongoing and future compliance verification activities. CNSC staff's findings do not represent the Commission's

conclusions. The Commission's decisions will be informed by submissions from CNSC staff, the licensee, Indigenous Nations and communities, and the public, as well as through any interventions made during public hearings on licensing matters.

For more information on the Cameco's McArthur River Operation, visit the CNSC's web page and Cameco's web page. References used throughout this document are available upon request, subject to confidentiality considerations, and requests can be sent to ea-ee@cnsc-ccsn.gc.ca.

1.0 Introduction

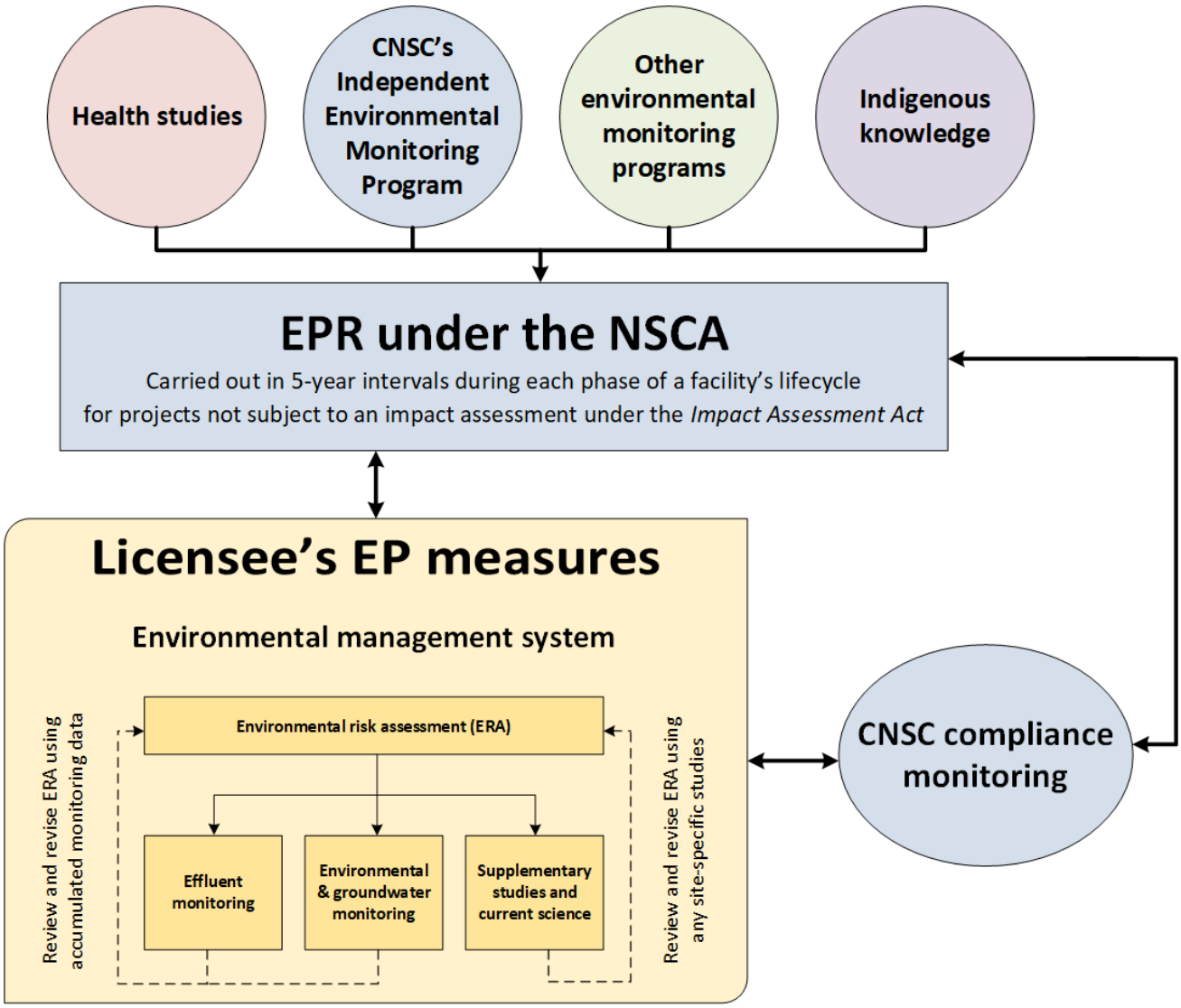
1.1 Purpose

The Canadian Nuclear Safety Commission (CNSC) conducts environmental protection reviews (EPRs) for all nuclear facilities with potential interactions with the environment, in accordance with its mandate under the *Nuclear Safety and Control Act* (NSCA) [1]. CNSC staff assess the environmental and health effects of nuclear facilities and/or activities during every phase of a facility's lifecycle. As shown in figure 1.1, an EPR is a science-based environmental technical assessment conducted by CNSC staff to support the CNSC's mandate for the protection of the environment and human health and safety as set out in the NSCA. The fulfillment of other aspects of the CNSC's mandate is met through other regulatory oversight activities and is outside the scope of this report. Each EPR is typically conducted every 5 years and is informed by the licensee's environmental protection (EP) program and documentation submitted by the licensees as per regulatory reporting requirements.

As per the CNSC's Indigenous Knowledge Policy Framework [2], the CNSC recognizes the importance of considering and including Indigenous knowledge in all aspects of its regulatory processes, including EPRs. CNSC staff are committed to working directly with Indigenous Nations and communities and knowledge holders on integrating their knowledge, values, land use information, and perspectives in the CNSC EPR reports, where appropriate and when shared with the licensee and the CNSC.

The purpose of this EPR is to document the outcome of CNSC staff's assessment of Cameco Corporation's (Cameco's) EP measures and CNSC staff's health science and environmental compliance activities for the McArthur River Operation. This review serves to assess whether Cameco's environmental protection measures at the McArthur River Operation meet requirements and adequately protect the environment and the health and safety of persons.

Figure 1.1: EPR framework



CNSC staff's findings may inform recommendations to the Commission in future licensing and regulatory decision making, as well as inform CNSC staff's ongoing and future compliance verification activities.

CNSC staff's findings do not represent the Commission's conclusions. The Commission is an independent, quasi-judicial administrative tribunal and court of record. The Commission's conclusions and decisions are informed by information submitted by CNSC staff, the licensee, Indigenous Nations and communities, and the public, as well as through any interventions made during public hearings on licensing matters. The information in this EPR report is intended to inform Indigenous Nations and communities, members of the public and interested stakeholders.

EPR reports are prepared to thoroughly document CNSC staff's assessment relating to a licensee's EP measures and are posted online for information and transparency. Posting EPR reports online,

separately from the documents drafted during the licensing process, allows interested Indigenous Nations and communities and members of the public additional time to review EP related information prior to any licensing hearing or Commission decisions. CNSC staff may use the EPR reports as reference material when engaging with interested Indigenous Nations and communities, members of the public, and interested stakeholders.

This EPR report is informed by documentation and information submitted by Cameco, compliance activities completed by CNSC staff from 2013 to 2021, as well as the following:

- regulatory oversight activities (section 2.0)
- CNSC staff's review of Cameco's 2019 McArthur River Operation preliminary decommissioning plan [3] (section 2.2)
- CNSC staff's review of Cameco's annual reports [4, 5, 6, 7, 8, 9, 10, 11, 12]
- CNSC staff's review of Cameco's McArthur River Operation environmental risk assessment 2015 [13] (section 3.2)
- CNSC staff's review of Cameco's 2020 McArthur River Operation environmental risk assessment [14] (section 3.2)
- the CNSC's Independent Environmental Monitoring Program (IEMP) results, including discussions with Indigenous Nations and communities (section 4.0)
- health studies with relevance to McArthur River Operation (section 5.0)
- data from other environmental monitoring programs (EMPs) in proximity to the McArthur River Operation site (section 6.0)

This EPR report focuses on topics related to the environmental performance of the facility, including atmospheric (emission) and liquid (effluent) releases to the environment, and the potential transfer of constituents of potential concern (COPCs) through key environmental pathways and associated potential exposures and/or effects on valued components (VCs), including human and non-human biota. VCs refer to environmental biophysical or human features that may be impacted by a project. The value of a component relates not only to its role in the ecosystem, but also to the value people place on it (for example, it may have scientific, social, cultural, economic, historical, archaeological, or aesthetic importance). The focus of this report is on radiological and hazardous substances associated with licensed activities undertaken at the McArthur River Operation, with additional information provided on other topics of Indigenous, public and regulatory interest, such as greenhouse gas (GHG) emissions. CNSC staff also present information on relevant regional environmental and health monitoring, including studies conducted by the CNSC or other governmental organizations.

1.2 Facility overview

This section of the report provides general information on the McArthur River Operation site, including a description of the site location and a basic history of site activities and licensing. This information is intended to provide context for later sections of this report, which discuss completed and ongoing environmental and associated regulatory oversight activities.

1.2.1 Site description

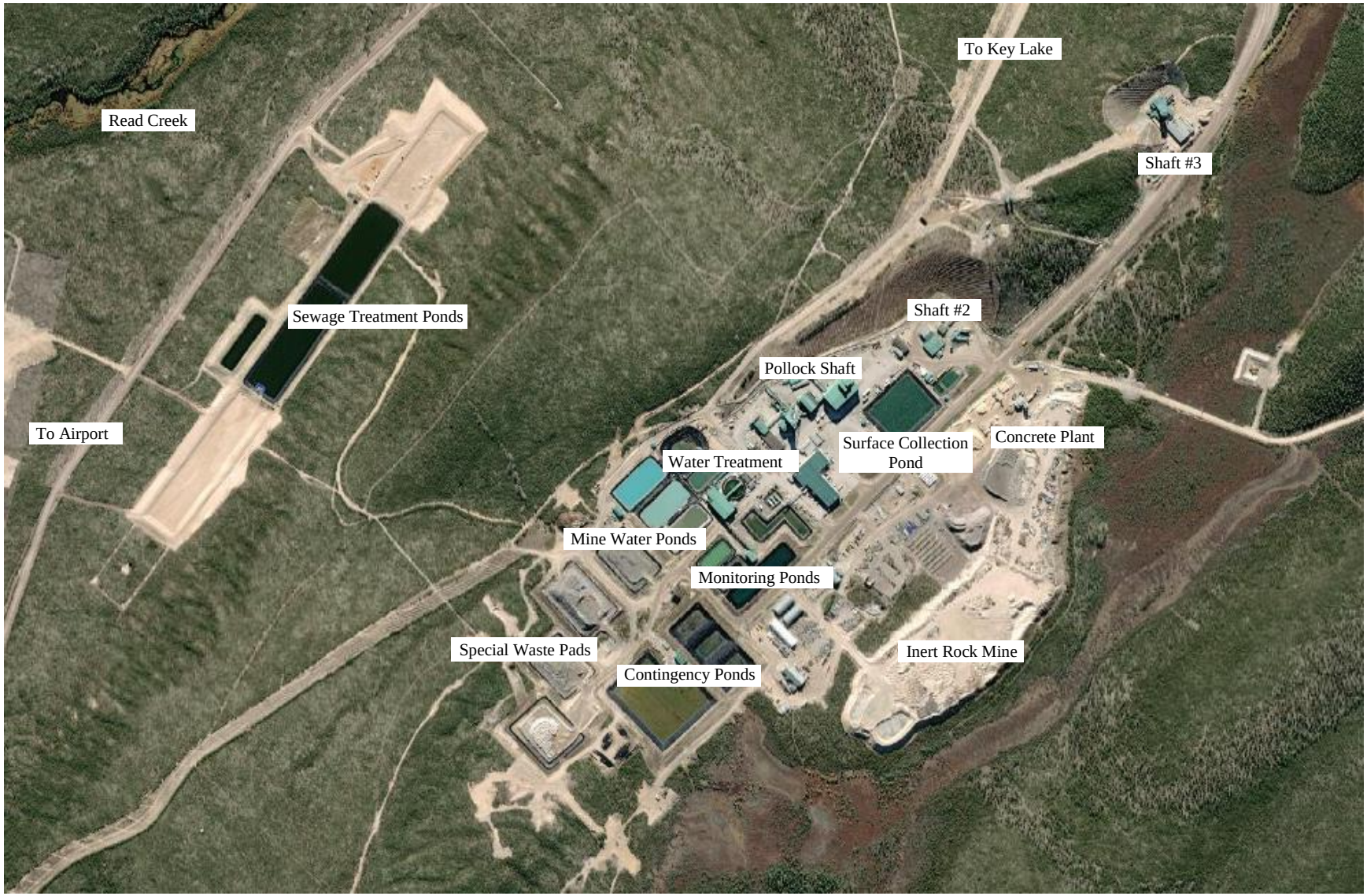
The McArthur River Operation is an underground uranium mine located within the Athabasca basin of northern Saskatchewan, approximately 620 kilometers (km) north of Saskatoon (figure 1.2). The facility is located within historic Treaty 10 territory, in the Homeland of the Métis, and is within the traditional territories of the Denesųłiné, Cree, and Métis peoples. The McArthur River Operation is owned by McArthur River Joint Venture, where the partners are approximately 70% Cameco and 30% Orano. Cameco is the operator and licensee.

The McArthur River Operation consists of an underground uranium mine, primary ore processing, ore slurry loading, waste management facilities, a water treatment plant, effluent storage ponds, surface freeze plants, administration offices, camp infrastructure, and warehouses (figure 1.3).

The McArthur River Operation is situated in a sparsely populated and largely undeveloped region of Saskatchewan. The nearest community is the northern village of Pinehouse, located 280 km away by an all-weather road. Other active uranium mine and mill facilities are located in the region, including Cameco's Cigar Lake Operation, Key Lake Operation, and Rabbit Lake Operation, as well as Orano Canada Inc.'s McClean Lake facility.

Figure 1.2: Location of the McArthur River Operation [3]

Figure 1.3: Aerial view of the McArthur River Operation [15]



1.2.2 Facility operations

Construction of the McArthur River Operation began in 1997 and ore production began in late 1999. High-grade ore is mined underground, pumped to the surface in slurry form and transported by haul truck to Cameco's Key Lake Operation, approximately 80 kilometers away, for processing into uranium ore concentrate. There is no tailings management facility at McArthur River, since all ore is processed at the Key Lake Operation.

Current licence activities

Cameco is currently permitted to undertake the activities outlined in the licence, UML-MINE-MCARTHUR.01/2023 [16] and the licence conditions handbook (LCH) [17]. Cameco is authorized to:

- operate and modify an underground uranium mine, including an associated underground ore-treatment system, to a maximum output of 9.6 million kilograms (kg) of uranium per year
- transfer, by use of a surface load-out system, the treated uranium ore to another facility authorized by the CNSC to accept the nuclear substance
- prepare hazardous non-nuclear materials for use in the mining and treatment of the uranium
- implement and maintain a program for the appropriate treatment of all wastes arising from any part of the facility, including those containing nuclear substances
- possess, transfer, use, store, import and dispose of nuclear substances and radiation devices required for use in the facility or as part of the operation of the facility.

In 2018, the McArthur River Operation stopped active mining of high-grade uranium ore and the mining facility was placed, and remains, in safe care and maintenance. Operations such as the water treatment plant continue to operate. In 2022, Cameco announced their intent to begin the process of transitioning the McArthur River Operation from care and maintenance to production.

2.0 Regulatory oversight

The CNSC regulates nuclear facilities and activities in Canada to protect the environment and the health and safety of persons in a manner that is consistent with applicable legislation and regulations, environmental policies, and Canada's international obligations. The CNSC assesses the effects of nuclear facilities and activities on human health and the environment during every phase of a facility's lifecycle. This section of the EPR report discusses the CNSC's regulatory oversight of Cameco's EP measures for McArthur River.

To meet the CNSC's regulatory requirements and according to the licensing basis for the McArthur River Operation, Cameco is responsible for implementing and maintaining EP measures that identify, control and (where necessary) monitor releases of radiological and hazardous substances, and the effects on human health and the environment. These EP measures must comply with, or have implementation plans in place to comply with, the regulatory requirements found in Cameco's licence and licence conditions handbook. The relevant regulatory requirements for Cameco's McArthur River Operation are outlined in this section of the report.

2.1 Environmental protection reviews and assessments

To date, 1 federal environmental assessment (EA) has been carried out for the McArthur River Operation, as indicated in table 2.1. Subsection 2.1.1 provides a description of the most recent EA conducted under the Federal Environmental Assessment and Review Process (EARP) [18], *Canadian Environmental Assessment Act (*CEAA 1992) [19], predecessor to the *Canadian Environmental Assessment Act, 2012* (CEAA 2012) [20]. In 2019, the *Impact Assessment Act of Canada* (IAA) [21] came into force replacing CEAA 2012. Cameco's current activities do not require an impact assessment under the IAA's *Physical Activities Regulations* [22]. The purpose of any one of these assessments is to identify the possible impacts of a proposed project or activity and to determine whether those effects can be adequately mitigated to protect the environment and the health and safety of persons.

This stand alone EPR report is the first developed for the McArthur River Operation. CNSC staff have previously publicly documented evaluations and assessments of Cameco's EP performance for the McArthur River Operation through the EP sections found in licensing Commission member documents (CMDs) and as part of the Uranium Mines and Mills Regulatory Oversight Reports (RORs).

Table 2.1: Federal EA completed for McArthur River

Project	Applicable EA process and/or legislation	EA start date	EA decision date
McArthur River Project	Joint Federal/Provincial Panel on Uranium Mining in Northern Saskatchewan appointed under EARP	1995	1997

2.1.1 Environmental assessments completed under EARP and CEAA 1992

Original Environmental Assessment for the McArthur River Operation

In 1991, the Joint Federal-Provincial Panel on Uranium Mining Developments in Northern Saskatchewan was appointed pursuant to the federal EARP [18] and the *Environmental Assessment Act* (Saskatchewan) to conduct a review of several proposed uranium mines, including the McArthur River Project. Although CEAA 1992 was enacted in 1995, CEAA 1992 had provisions to continue the assessment under EARP [19].

In 1995, the Environmental Impact Statement for the McArthur River Project [23] and addendum [24] was submitted to meet the guidelines issued by the Joint Federal-Provincial Panel. In 1997, the Joint Federal-Provincial Panel recommended the approval of the McArthur River Project with conditions including improvements to monitoring of environmental impacts [25].

In 1997, the Atomic Energy Control Board, the CNSC's predecessor, supported the Joint Panel's recommendation and proceeded with the licensing process [26].

2.2 Planned end state

The following section provides high-level information on the end-state currently planned for the McArthur River Operation site following decommissioning activities. This section is informed by Cameco's preliminary decommissioning plan (PDP) for the McArthur River Operation. The PDP is important to consider as part of CNSC staff's ongoing oversight for the assessment of environmental and health effects of nuclear facilities and activities during every phase of a facility's lifecycle.

A PDP is required to be developed by the licensee and submitted to the CNSC for review and acceptance as early as possible in the lifecycle of the facility or the conduct of the licensed activities. The PDP is progressively updated, where needed, to reflect the appropriate level of detail required for the respective licensed activities. The PDP is developed for planning purposes only and the associated cost estimate is used to develop dedicated decommissioning funding in the form of a financial guarantee. The PDP does not authorize decommissioning and does not provide sufficient details for the assessment of environmental impacts during decommissioning. Prior to the commencement of any decommissioning activities and to support an application for a licence to decommission, a detailed decommissioning plan is required to be developed by the licensee and submitted to the CNSC for review and acceptance.

The PDPs for nuclear facilities are updated at least every 5 years, or considering notable changes relevant to decommissioning, by the licensee and reviewed by CNSC staff. The decommissioning strategy and end-state objectives for the McArthur River Operation are documented in the McArthur River Operation preliminary decommissioning plan [3].

Cameco has prepared the PDP based on a 'decommission tomorrow' scenario. The PDP describes that surface infrastructure will be dismantled in place and wastes will be disposed of either on-site or at approved off-site disposal facilities. Radioactive wastes generated from decommissioning will be placed in underground workings or at an approved off-site storage facility (such as Key Lake). Non-radioactive wastes generated from decommissioning will be landfilled on-site. There will not be any radiological material or waste exceeding site-specific decommissioning end-state objectives remaining on surface.

The PDP also notes that the two mineshafts will be backfilled with clean waste rock material and capped with reinforced concrete. The PDP describes that environmental monitoring will be conducted during all decommissioning stages and Cameco has estimated a 10-year post-active decommissioning environmental monitoring period. Cameco intends for the decommissioned McArthur River Operation site to be transferred into the province of Saskatchewan's Institutional Control Program once it has been confirmed that decommissioning objectives and criteria have been met and that the site is in a stable or improving condition. Cameco expects that the site will be suitable for certain traditional land uses following acceptance into the provincial institutional control program.

Cameco submitted an update of the McArthur River Operation preliminary decommissioning plan in January 2018. The revised PDP was reviewed and accepted by CNSC staff in May 2019. An updated revised PDP was submitted in December 2022 and is currently under review by CNSC staff. Un PPD mis à jour a été soumis en décembre 2022 et fait actuellement l'objet d'un examen par le personnel de la CCSN.

2.3 Environmental regulatory framework and protection measures

The CNSC has a comprehensive EP regulatory framework which includes the protection of people and the environment and considers both radiological and hazardous substances as well as physical stressors (such as noise). Public dose is considered under the EP framework. The focus of this section of the EPR Report is on the EP regulatory framework and the status of Cameco's environmental protection program (EPP) for the McArthur River Operation. The results derived from Cameco's EPP are detailed in section 3.0 of this report.

Cameco's EPP for the McArthur River Operation was designed and implemented in accordance with REGDOC-2.9.1, *Environmental Protection: Environmental Principles, Assessments and Protection Measures* (2017) [27], as well as the CSA Group's environmental protection standards listed below. The implementation status for these items is shown in table 2.2.

Table 2.2: Status of EP measures to implement regulatory documents and standards

Regulatory document or standard	Status
CSA N288.4-10, Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills [28]	Implemented
CSA N288.5-11, Effluent Monitoring Program at Class I Nuclear Facilities and Uranium Mines and Mills [29]	Implemented
CSA N288.6-12, Environmental Risk Assessment at Class I Nuclear Facilities and Uranium Mines and Mills [30]	Implemented
CSA N288.7-15, Groundwater Protection Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills [31]	Implemented
CSA N288.8-17, Establishing and Implementing Action Levels for Releases to the Environment from Nuclear Facilities [32]	Implemented
CNSC REGDOC-2.9.1, Environmental Protection: Environmental Principles, Assessments and Protection Measures, version 1.1 (2017) [27]	Implemented

CNSC staff confirm that Cameco has implemented programs that are in compliance with the relevant EP regulatory documents and standards.

Licensees are also required to regularly report on the results of their EPPs. Reporting requirements are specified in REGDOC-3.1.2, *Reporting Requirements, Volume I: Non-Power Reactor Class I Nuclear Facilities and Uranium Mines and Mills* [33], the *Radiation Protection Regulations* [34] (for example, for action levels (ALs) or dose limit exceedances), and the LCH.

Cameco is required to submit annual reports as per REGDOC-3.1.2. These reports are reviewed by CNSC staff for compliance verification, as well as trending. Summaries of the effluent monitoring results contained in Cameco's annual reports are available on Cameco's McArthur River Operation webpage [35].

CNSC staff regularly report on the licensee performance to the Commission for activities conducted at the McArthur River Operation. For example, CNSC staff's RORs are a standard mechanism for updating the Commission, Indigenous Nations and communities, and the public on the operation and regulatory performance of licensed facilities. Previous RORs are available on the CNSC regulatory oversight report web page [36]. CNSC staff may also report to the Commission on events, such as unplanned releases to the environment, through an initial event report.

2.3.1 Environmental protection measures

To meet the CNSC's regulatory requirements under REGDOC-2.9.1 (2017) [27], Cameco is responsible for implementing and maintaining EP measures that identify, control, and monitor releases of radioactive and hazardous substances from the McArthur River Operation, as well as the effects of these substances on human health and the environment. EP measures are an important component of the overall requirement for licensees to make adequate provision to protect the environment and the health of persons.

This subsection and the following ones under section 2.3 summarize Cameco's EPP for the McArthur River Operation and the status of each specific EP measure, relative to the requirements or guidance outlined in the latest regulatory document or CSA Group standard. Section 3.0 of this EPR report summarizes the results of these programs or measures against relevant regulatory limits and environmental quality objectives or guidelines, and discusses, where applicable, any notable trends.

Cameco is required to implement an environmental management system (EMS) that conforms to REGDOC-2.9.1 (2017) [27], and to submit an EPP for the McArthur River Operation. Cameco's EPP includes the following components to meet the requirements and guidance as outlined in REGDOC-2.9.1, (2017) [27]:

- EMS
- environmental risk assessment (ERA)
- effluent and emissions control and monitoring
    - air emissions and liquid effluent monitoring
- environmental monitoring program (EMP)
    - ambient air monitoring
    - terrestrial monitoring
    - surface water monitoring
    - groundwater monitoring

2.3.2 Environmental management system

An EMS refers to the management of an organization's environmental policies, programs, and procedures in a comprehensive, systematic, planned, and documented manner. It includes the organizational structure as well as the planning and resources to develop, implement and maintain an EP policy. An EMS requires a facility to continuously improve its EPP; this includes periodic updates to the ERA. The results from the ERA updates determine whether the facility's effluent monitoring and EMPs are effective. The EMS serves as a management tool to integrate all of a licensee's EP measures in a documented, managed, and auditable process, in order to:

- identify and manage non-compliances and corrective actions within the activities, through internal and external inspections and audits
- summarize and report on the performance of these activities both internally (licensee management) and externally (Indigenous Nations and communities, the public, interested stakeholders, and the Commission)
- train personnel involved in these activities
- ensure the availability of resources (that is, qualified personnel, organizational infrastructure, technology, and financial resources)
- define and delegate roles, responsibilities, and authorities essential to effective management

Cameco established and implemented an EMS for the McArthur River Operation in accordance with REGDOC-2.9.1, (2017) [27], and is also registered and certified under the International Organization for Standardization (ISO) standard 14001:2015 (a standard that helps an organization achieve the intended outcomes of its EMS). CNSC staff review Cameco's annual internal audits, management reviews; and environmental goals, targets, and objectives to ensure compliance with REGDOC-2.9.1, (2017).

While the CNSC does not consider ISO 14001 certification as part of the criteria for meeting the requirements of REGDOC-2.9.1 (2017) [27], the results of these third-party audits are reviewed by CNSC staff as part of the compliance program. As part of their review of the annual reports on EP, CNSC staff also review the status of Cameco's annual goals, targets, and objectives and implementation of the EMS.

The results of these reviews demonstrate that Cameco's EMS for the McArthur River Operation meets CNSC requirements as outlined in REGDOC-2.9.1, (2017) [27]. The implementation of the EMS ensures that Cameco continues to improve environmental performance at the McArthur River Operation.

2.3.3 Environmental risk assessment

An ERA of nuclear facilities is a systematic process used by licensees to identify, quantify, and characterize the risk posed by contaminants and physical stressors in the environment on human and other biological receptors, including the magnitude and extent of the potential effects associated with a facility. The ERA serves as the basis for the development of site-specific EP control measures and EMPs. The results of these programs, in turn, inform and refine future revisions of the ERA.

In 2020, Cameco submitted an updated ERA to the CNSC for the McArthur River Operation [14]. The ERA included an ecological risk assessment and a human health risk assessment (HHRA) for radiological and hazardous contaminants and physical stressors. CNSC staff reviewed Cameco's ERA and found it to be compliant with CSA N288.6-12, [30] and found that human health and the environment in the vicinity of the McArthur River Operation remain protected.

Cameco's findings from the 2020 ERA are summarized in table 2.3. CNSC staff review the ERA and found that effects to ecological and human health due to releases of COPCs to the air and water from the McArthur River Operation were found to be negligible. The next ERA update is anticipated in 2025.

Table 2.3: Summary of ERA findings for the McArthur River Operation [14]

Type	Humans	Aquatic and terrestrial biota
Radiological	No adverse impacts expected from radiological COPCs released from the McArthur River Operation.	No adverse impacts expected from radiological COPCs released from the McArthur River Operation.
Hazardous	No adverse impacts expected from hazardous COPCs released from the McArthur River Operation.	No adverse impacts expected from hazardous COPCs released from the McArthur River Operation.
Physical stressors	No adverse impacts expected from physical stressors released from the McArthur River Operation.	No adverse impacts expected from physical stressors released from the McArthur River Operation.

2.3.4 Effluent and emissions control and monitoring

Controls on environmental releases are established to provide protection to the environment and to respect the principles of sustainable development and pollution prevention. The effluent and emissions prevention and control measures are established based on industry best practice, the application of optimization (such as in design) and of as low as reasonably achievable (ALARA) principles, the Canadian Council of Ministers of the Environment (CCME) guidelines, and results of the licensee's ERAs.

The McArthur River Operation's current EPP [37] was reviewed and accepted by CNSC staff. It contains licence limits and site-specific ALs to control radiological and hazardous effluents and emissions. Limits in CNSC's licences for uranium mines and mills are adopted from schedule 4 of the *Metal and Diamond Mining Effluent Regulations* (MDMER) [38].

Under section 4 of CNSC's *Uranium Mines and Mills Regulations* [39], Cameco is required to implement an environmental code of practice (ECOP) as part of its effluent monitoring program. The objectives of an ECOP are to ensure that releases to the environment are kept ALARA, and that any events which could indicate a potential loss-of-control are identified to ensure that corrective actions can be taken, if warranted. The ECOP contains ALs that serve as an early warning of a potential loss of control to prevent a licence limit exceedance. ALs are derived from actual performance data from the mine water treatment plant. This follows the methodology outlined in CSA N288.8-17 [32]. The ECOP also must contain actions that would be taken if an

AL were to be exceeded, such as reporting the incident to the CNSC within 24 hours, immediately performing an investigation to determine whether a loss of control has occurred, taking immediate action to restore the effectiveness of the EPP, and submitting a report to the CNSC explaining the actions taken to correct the situation and prevent recurrence. In addition, Cameco has internal administrative levels that are set lower than the ALs.

The McArthur River Operation effluent monitoring program was reviewed and accepted by CNSC staff in March 2022 and is in compliance with REGDOC-2.9.1 (2017) [27] and the relevant standards, including CSA N288.5-11 [29].

Based on compliance activities, CNSC staff have found that the effluent monitoring program currently in place for the McArthur River Operation continues to protect human health and the environment.

2.3.5 Environmental monitoring program

The CNSC requires each licensee to design and implement an EMP that is specific to the monitoring and assessment requirements of the licensed facility and its surrounding environment. The program is required to:

- measure contaminants in the environmental media surrounding the facility or site
- determine the effects, if any, of the facility or site operations on people and the environment
- serve as a secondary support to emission monitoring programs to demonstrate the effectiveness of emission controls

More specifically, the program must gather the necessary environmental data to calculate public dose and demonstrate compliance with the public dose limit found in the *Radiation Protection Regulations* [34] of 1 millisievert (mSv) per year. The program design must also address the potential environmental interactions identified at the facility or site. Hazardous substances are the major focus at the McArthur River Operation as monitoring has indicated they are more abundant in effluent, though radionuclides are included within monitoring activities associated with liquid discharges and air emissions. Cameco's EMP for the McArthur River Operation consists of the following components:

- ambient air monitoring (radon and particulates)
- soil and lichen monitoring
- aquatic biota monitoring (fish and benthic invertebrates)
- sediment monitoring
- surface water monitoring
- groundwater monitoring

Monitoring frequency is specified in the EMP. Ambient air, surface water, and groundwater monitoring is conducted regularly throughout each year, while soil, lichen, blueberry, aquatic biota and sediment monitoring are conducted every 3 or 6 years depending on the sampling media and location. Cameco's EMP also contains a requirement to perform annual inspections of buildings, structures, liners or piping that act as containment systems and geotechnical inspections of water drainage facilities, containment ponds, monitoring ponds, containment pads and other retaining structures.

Cameco is required to maintain its EMP, to comply with REGDOC-2.9.1 (2017) [27] and relevant standards, including CSA N288.4-10 [28].

Based on compliance activities, CNSC staff have found that the Cameco is compliant with REGDOC-2.9.1 (2017) [27] and continues to implement and maintain an effective EMP for the McArthur River Operation that adequately protects the environment and the health and safety of persons.

2.4 Reporting of environmental releases under other federal or provincial legislation

A core element of the CNSC's requirement for an EMS is the identification of all regulatory requirements applicable to the facility, whether pursuant to the NSCA or other federal or provincial legislation. The EMS must ensure that programs are in place to respect these requirements.

2.4.1 Greenhouse gas emissions

While there are a range of broadly applicable federal environmental regulations (for example, petroleum products storage tanks, environmental emergency regulations), the management of GHG emissions has been identified as a national priority.

Under the federal *Canadian Environmental Protection Act, 1999* (CEPA 1999) [40], Cameco is required to monitor GHG emissions [41]. Nuclear facilities that emit more than the emission reporting threshold (that is, 10,000 tonnes of CO_2 equivalent) on an annual basis must report its GHG emissions to Environment and Climate Change Canada (ECCC).

In 2017, the reporting threshold was lowered from 50,000 tonnes CO_2 equivalent to 10,000 tonnes CO_2 equivalent. As a result, the McArthur River Operation reported GHG emissions to ECCC in 2017, 2018, 2019, and 2020. The emission data can be found on ECCC's Greenhouse Gas Reporting Program web page [42]. As of July 2022, the 2021 results are not yet available.

The CNSC maintains a collaborative working relationship with ECCC through a formal Memorandum of Understanding (MOU) [43], which includes a notification protocol. An exceedance of the GHG emissions threshold would be included under this notification protocol. This ensures a coordinated regulatory approach is achieved to meet all federal requirements associated with EP, including GHGs.

2.4.2 Halocarbons

In accordance with the *Federal Halocarbon Regulations, 2022* [44], Cameco is required to provide a semi-annual halocarbon release report to ECCC on the release of halocarbons of an amount greater than 10 kg but less than 100 kg from any system, container, or equipment at the McArthur River Operation. In the event of a release that surpasses 100 kg, Cameco would be required to report the releases to ECCC within 24 hours and ECCC would inform the CNSC through the notification protocol of the MOU. Cameco would then be required to submit a follow-up report within 30 days of the release detailing the circumstances leading to the release and the corrective and preventative actions taken to prevent a reoccurrence.

Between 2013 and 2021, Cameco reported 2 halocarbon releases of 10 kg of R-22 refrigerant and 10.2 kg of R-410 refrigerant in 2014, 1 halocarbon release of 10.2 kg of the R-410A refrigerant

in 2016, and 1 halocarbon release of 10.9 kilograms of the R-22 refrigerant in 2021. The releases were in accordance with ECCC's *Federal Halocarbon Regulations* [44], and therefore, CNSC staff found that there was little environmental impact from the R-410A and R-22 releases.

2.4.3 National Pollutant Release Inventory

Under the authority of CEPA 1999 [40], Cameco is required to report emissions of pollutants from the McArthur River Operation to the National Pollutant Release Inventory (NPRI) [45] if they are above the reporting threshold [46]. Additional information about the NPRI can be found in section 6.3 of this report.

2.4.4 Other environmental compliance approvals

Cameco holds an approval to operate pollutant control facilities issued by the Saskatchewan Ministry of the Environment for the McArthur River Operation [47]. The approval contains requirements for air emission monitoring, air quality monitoring, effluent monitoring, surface water monitoring, waste management, inspections, event and compliance reporting, decommissioning, and reclamation. The approval also contains effluent quality limits and authorized concentrations of contaminants in ambient air quality standards.

Emissions from the McArthur River Operation throughout the current licensing period have been in compliance with the facility's approval to operate pollutant control facilities and CNSC's regulatory requirements. More information on these emissions can be found in sections 3.1.1, 3.1.2, and 3.1.3 of this report.

3.0 Status of the environment

This section provides a summary of the status of the environment around the McArthur River Operation. It starts with a description of the radiological and hazardous releases to the environment (section 3.1), followed by a description of the environment surrounding the McArthur River Operation and an assessment of any potential effects on the different components of the environment as a result of exposure to these contaminants (section 3.2).

CNSC staff regularly review the potential effects to environmental components through annual reporting requirements and compliance verification activities, as detailed in other areas of this report. This information is reported to the Commission in the sections on EP in licensing CMDs and annual RORs.

3.1 Releases to the environment

Radioactive and hazardous substances that have the potential to cause an adverse effect to ecological or human receptors are identified as COPCs. Once COPCs are emitted from a facility or licensed site, they are considered a release to the environment. The ways in which COPCs could find their way to the different receptors considered by the ERA are called ‘exposure pathways’.

Figure 3.1 illustrates a conceptual model of the environment around the McArthur River Operation, to show the relationship between releases (airborne emissions or waterborne effluent) and human and ecological receptors. This graphic is meant to provide an overall conceptual model of the releases, exposure pathways and receptors for the McArthur River Operation, and thus, should not be interpreted as a complete depiction of the McArthur River Operation and its surrounding environment. The specific releases and COPCs associated with the McArthur River Operation are explained in detail in the following subsections.

Figure 3.1: Conceptual model of the environment around the McArthur River Operation

3.1.1 Licensed release limits

All operating uranium mines and mills in Canada are in northern Saskatchewan and are regulated at both the provincial and federal level. At the provincial level, the Saskatchewan Ministry of Environment issues an Approval to Operate a Pollutant Control Facility licence, which sets out release limits adopted from Saskatchewan's *Mineral Industry Environmental Protection Regulations* [48]. At the federal level, under the *Fisheries Act* [49], metal and diamond mines must adhere to the requirements of the MDMER [38] which contain release limits that are enforced by ECCC. In addition, under the NSCA, uranium mines and mills are issued a CNSC licence, which includes licence limits from the MDMER.

Table 3.1 shows the current MDMER-based licence limits for waterborne effluent applicable to the McArthur River Operation.

Table 3.1: Authorized licence limits for waterborne effluent at the McArthur River operation, adopted from the MDMER [38]

Deleterious substance	Maximum authorized monthly mean concentration [(a)]	Maximum authorized concentration in a composite sample [(b)]	Maximum authorized concentration in a grab sample [(c)]
Arsenic (mg/L)	0.30	0.45	0.60
Copper (mg/L)	0.30	0.45	0.60
Lead (mg/L)	0.10	0.15	0.20
Nickel (mg/L)	0.50	0.75	1.00
Zinc (mg/L)	0.50	0.75	1.00
Un-ionized ammonia (mg/L)	0.50	N/A[(d)]	1.00
Total suspended solids (mg/L)	15.00	22.50	30.00
Radium-226 (Bq/L)	0.37	0.74	1.11
Acid balance (H_3O^+) reported as pH	In a range of 6.0 to 9.5	In a range of 6.0 to 9.5	In a range of 6.0 to 9.5
Acutely lethal effluent [(e)]	0%	0%	0%

(a) "Monthly Mean Concentration" means the average value of the concentrations in composite or grab samples collected over a calendar month, in accordance with the MDMER **[38]**.

(b) Based on the LCH [17], a "composite sample" means (i) a quantity of undiluted effluent consisting of a minimum of three equal volumes of effluent, or three volumes proportionate to flow, that has been collected at approximately equal time intervals over a sampling period of not less than 7 hours, and not more than 24 hours, or (ii) a quantity of undiluted effluent collected continually at an equal rate, or at a rate proportionate to flow, over a sampling period of not less than 7 hours, and not more than 24 hours.

(c) Based on the LCH [17], a "grab sample" means a quantity of undiluted effluent collected at any given time.

(d) N/A stands for "not available".

(e) "Acutely lethal" [38], in respect of an effluent, means that the effluent at 100 percent concentration kills
a) more than 50 percent of the rainbow trout subjected to it for a period of 96 hours, when tested in accordance with the acute lethality test set out in section 14.1;
b) more than 50 percent of the threespine stickleback subjected to it for a period of 96 hours, when tested in accordance with the acute lethality test set out in section 14.2; or
c) more than 50 percent of the Daphnia magna subjected to it for a period of 48 hours, when tested in accordance with the acute lethality test set out in section 14.3

There are currently no MDMER limits for selenium, uranium, and molybdenum, and thus, there are no limits for these parameters in the CNSC licence issued for the McArthur River Operation. The limits for selenium and uranium provided in section 3.1.3 (table 3.2) come from the Province of Saskatchewan and are presented here to put the CNSC's regulatory expectations into perspective. While licensees must meet other federal and provincial regulatory requirements, the CNSC reserves the right to place more stringent expectations where deemed necessary. As such, the CNSC has required uranium mine and mill licensees to implement additional treatment technologies and process optimization techniques, where necessary. REGDOC 2.9.1 (2017) [27] requires licensees to demonstrate the application of the principles of ALARA and *best available technology economically available* (BATEA), and to ensure site-specific environmental protection related to selenium, uranium, and molybdenum. As a result, releases have been substantially lower than those authorized by the Province of Saskatchewan. Further information on controls of selenium and molybdenum can be found in section 3.1.3 of this report.

The CNSC has an interim objective for uranium releases of 0.1 mg/L, which is used as a benchmark to demonstrate the current application of ALARA and BATEA. This value is based on a 2006 review of uranium treatment within the uranium mine and mill sector [50], which was prepared under contract for the CNSC.

No provincial or federal licence limits currently exist for molybdenum. In the 2000s, the CNSC required that uranium mines and mills with high molybdenum releases upgrade their effluent management and water treatment processes to treat molybdenum. This resulted in a significant reduction of molybdenum loadings to the environment. In the absence of a licence limit, uranium mine and mill licensees have implemented administrative and ALs to effectively manage and control molybdenum.

In the absence of a CNSC limit for selenium, the CNSC requires all uranium mines and mills to manage selenium releases to the environment. For the McArthur River Operation, selenium is controlled using a target that is equal to the site-specific ERA upper bound concentration of 0.003 mg/L. This value is derived from the site's ERA modelling. The CNSC also requires the uranium mines and mills to demonstrate continuous improvement by applying process optimization techniques that reduce the concentrations of molybdenum, selenium, and uranium in effluent. If a uranium mine or mill facility cannot achieve the selenium site-specific targets, the CNSC will require the facility to go into adaptive management. This ensures that the licensee takes corrective actions to mitigate an identified unreasonable risk or a potential unreasonable risk to the environment to a level accepted by the CNSC. More information about adaptive management is available in draft REGDOC-2.9.2, *Controlling Releases to the Environment* [51]. The selenium site specific ERA upper bound concentration is currently being met for the McArthur River Operation.

Draft REGDOC-2.9.2 was recently developed by CNSC staff and was presented to the Commission in September 2022. Should REGDOC-2.9.2 be approved by the Commission as drafted and become part of the licensing basis, formal licence release limits will be required for selenium, uranium, and molybdenum, as applicable.

3.1.2 Airborne emissions

Cameco controls and monitors airborne emissions from the McArthur River Operation to the environment under its EPP. This program is based on CSA N288.5-11 [29] and includes monitoring of both radiological and hazardous emissions.

The sources of possible airborne releases at the McArthur River Operation include:

- material handling and transfers of waste rock, aggregate, sand and fines stockpiles
- vehicle travel on unpaved areas, site roads and haul roads
- grading of unpaved roads
- concrete batch plant operations
- wind erosion of waste rock, aggregate, sand and fines stockpiles
- diesel and propane fuel combustion
- underground mine ventilation exhaust
- emissions from waste stockpiles (radon emissions)
- fugitive sources of radon

The emission sources have the potential to emit:

- particulate matter (PM) from the underground ventilation exhaust (that is, total suspended particulate (TSP), PM less than 10 microns in diameter (PM_{10}) and PM less than 2.5 microns in diameter ($PM_{2.5}$)
- gaseous COPCs from fuel combustion (that is, nitogen oxides (NO_x), sulphur dioxide (SO_2) and carbon monoxide (CO))
- metals from the underground mine ventilation exhaust (that is, arsenic, cobalt, copper, lead, molybdenum, selenium, uranium and zinc)
- radon gas from the underground mine ventilation exhaust and waste rock stockpiles

There are mitigation measures in place at the McAthur River Operation to reduce airborne releases to the environment. For example, watering roads and the airstrip reduce emissions from road dust and installing exhaust gas scrubbers to underground vehicles and mobile equipment reduce air emissions. Also, emissions from the fly ash and cement silos of the concrete batch plant are filtered to remove particulates prior to release.

Note that there are no measured airborne emissions data presented in this report because there is no mill at the McArthur River Operation. Cameco estimates airborne releases from the McArthur River Operation and reports the values that are above the reporting threshold to the NPRI.

Air emissions sources identified for the McArthur River Operation were modelled in the McArthur River Air Quality Modelling Assessment [52]. The results showed that there were no significant risks to the environment and persons from the identified emission sources.

3.1.2.1 Findings

Based on CNSC staff's review of the results of McArthur River Operation's EPP and the McArthur River Air Quality Modelling Assessment [52], CNSC staff have found that Cameco's air emissions to the environment from the McArthur River Operation are very low. CNSC staff

have also found that Cameco continues to provide adequate protection of people and the environment from air emissions.

3.1.3 Waterborne effluent

Cameco controls and monitors liquid (waterborne) effluent from the McArthur River Operation to the environment under its implementation of the EPP. This program is based on CSA N288.5-11 [29], and includes monitoring of radiological and hazardous releases.

The mine water treatment plant, summarized in the Mining Facility Licensing Manual [53], treats wastewater generated by the facility, such as from drainages, sumps and the underground mine. One exception is sewage, which is treated by the sewage treatment system.

The mine water treatment plant consists of multiple stages that include:

- the primary water treatment plant to remove radium-226 and solids. The plant consists of reaction tanks where barium chloride, ferric sulphate, lime and sulphuric acid are added to the effluent to precipitate contaminants through a clarifier. For molybdenum and selenium removal, the circuit is operated at a low pH with the addition of ferric sulphate. The effluent is then fed to the secondary water treatment plant clarifier underflow tank.
- the secondary water treatment plant to precipitate and remove radium-226 and other metals. The effluent is pumped to reaction tanks where ferric sulphate, sulphuric acid, barium chloride and lime are added to precipitate radium-226, heavy metals and suspended solids. Then, the effluent is fed to a final polishing stage consisting of sand filters to remove any remaining fine particulates.
- monitoring ponds, where treated water is pumped, a composite sample is taken as the pond fills up, and treated water is discharged to the environment provided that lab results indicate that COPCs in the sample are within licence limits and internal targets, otherwise the treated water is recycled back to the mine water treatment plant for further treatment. A composite sample is a quantity of effluent consisting of three equal volumes of effluent, or three volumes proportional to flow, that has been collected at approximately equal time intervals over a period of between 7 to 24 hours.
- the contingency water treatment system that is used to treat mine water in case of an emergency mine water inflow into the underground mine.

The effluent treated by the mine water treatment plant is batch released to a muskeg receiving area. The effluent flows through the muskeg for approximately 500 m before reaching an open ditch channel. The water from the channel flows on the surface and then through the Read Creek discharge channel for approximately 420 m before it enters Read Creek. As treated water is pumped from the monitoring ponds to the environment, it is sampled again to confirm that it meets the release criteria. If the results are outside of release criteria, the release is immediately stopped and the water is pumped back to a collection pond to be returned to the mine water treatment plant for further treatment. Cameco also records the flow rate and total volume of each batch release from the McArthur River Operation. With this information, the Cameco calculates and reports the total mass loadings of COPCs to the environment.

Cameco is required to monitor temperature, conductivity, pH, metals (arsenic, copper, lead, molybdenum, nickel, selenium, uranium, unionized ammonia and zinc) and radionuclides (radium-226, thorium-230, polonium-210, and lead-210) in the effluent released at both of the McArthur River Operation's discharge points (Read Creek and Shaft #3).

Cameco is also required by the MDMER to perform quarterly acute lethality testing on the treated effluent at the final point of discharge using rainbow trout (*Oncorhynchus mykiss*) and water fleas (*Daphnia magna*) as test organisms in accordance with ECCC's procedures [38]. These are are recognized standard aquatic toxicity tests used in concert with effluent limits to assess compliance with the MDMER. Acute lethality, as defined in the MDMER, means that the effluent at 100% concentration kills more than 50% of the rainbow trout over a 96-hour test period or more than 50% of the water fleas over a 48-hour test period. During the current licensing period (2013 to 2021), results showed that the treated effluent discharged from the McArthur River Operation met the MDMER acute lethality requirements.

3.1.3.1 Effluent from mine water treatment plant

Table 3.2 summarizes the annual monthly mean concentrations of liquid effluent discharged from 2013 to 2021, at the end of the pipe before dilution occurred. In addition to licence limits, Cameco has established liquid effluent ALs for important COPCs, such as uranium, molybdenum, and selenium, and internal control levels (also known as administrative levels) for the McArthur River Operation. Exceedances of licence limits and ALs are required to be reported to the CNSC, documented, investigated, and appropriate corrective actions are taken where warranted. As shown in table 3.2, all of the COPCs in the effluent discharged from the mine water treatment plant are below regulatory limits.

In March 2018, there was a radium-226 AL exceedance at the mine water treatment plant. At that time, ALs were exceeded when the average concentration in 10 consecutive discharged effluent ponds exceeds an administrative level. These exceedances were identified during a routine duplicate sample analysis. The duplicate sample analyzed by the Saskatchewan Research Council indicated higher radium-226 concentrations than the duplicate sample analyzed by Cameco at the McArthur River Operation. The discrepancy between the two analyzed samples was attributed to an operational change, as detailed in the next paragraph.

In 2018, the McArthur River Operation transitioned from operation to care and maintenance, which resulted in uranium ore production stopping at the McArthur River Operation. This caused a change in the influent chemistry and the amount of reagent necessary to bring the water to concentrations acceptable for release. The adjustment in the volume of reagent used to account for the change in influent chemistry resulted in excess reagent remaining in the effluent which suppressed the analysis result of radium-226.

Upon discovery of the AL exceedance of radium-226, Cameco notified the CNSC, performed an investigation, and implemented corrective actions, such as adjusting their methodologies to treat and to analyze radium-226. Cameco used the Key Lake laboratory for radium-226 analysis for pond releases until the issue was resolved. Cameco also increased the frequency of sampling in receiving waters at the McArthur River Operation and did not observe an increase in radium-226 concentrations. CNSC staff reviewed the event and are satisfied with Cameco's response and found that there was no impact on the environment or health and safety of persons resulted from this AL exceedance.

Table 3.2: Annual average waterborne releases from the McArthur River Operation mine water treatment plant compared with applicable release limits (2013 – 2021) [4, 5, 6, 7, 8, 9, 10, 11, 12]

Parameter	Licence limit	2013	2014	2015	2016	2017	2018	2019	2020	2021
Arsenic (mg/L)	0.3	0.0017	0.0020	0.0029	0.0011	0.0007	0.0001	0.0001	0.0001	0.0001
Copper (mg/L)	0.3	0.0011	0.0014	0.0011	0.0011	0.0006	0.0004	0.0005	0.0006	0.0005
Lead (mg/L)	0.1	0.0001	0.0008	0.0009	0.0009	0.0001	0.0001	0.0001	0.0001	0.0001
Nickel (mg/L)	0.5	0.0012	0.0034	0.0035	0.0033	0.0015	0.0016	0.0017	0.0015	0.0022
Zinc (mg/L)	0.5	0.0014	0.0022	0.0016	0.0016	0.0019	0.0011	0.0032	0.0019	0.0024
pH [a]	6.0 to 9.5	7.2	7.3	7.3	7.3	7.2	7.5	7.4	7.4	7.4
Radium-226 (Bq/L)	0.37	0.052	0.058	0.065	0.082	0.068	0.063	0.052	0.049	0.029
Total suspended solids (mg/L)	15	1	1	1	1	1	1	1	1	1
Un-ionized ammonia (mg/L) [b]	0.5	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Selenium (mg/L)	0.6 [c]	0.0014	0.0024	0.0025	0.0037	0.0019	0.0002	0.0003	0.0003	0.0003
Uranium (mg/L)	2.5 [d]	0.0107	0.0095	0.0089	0.0055	0.0048	0.0049	0.0093	0.0073	0.0082
Molybdenum (mg/L)	N/A [e]	0.1878	0.1865	0.1458	0.185	0.1393	0.0192	0.0084	0.0094	0.0089

a) pH is taken from every discharge samples. It is not measured in monthly composite samples.
b) Un-ionized ammonia was added to the MDMER in 2021.
c) This is the provincial limit that is not in the CNSC licence.
d) This is the provincial limit that is not in the CNSC licence. As discussed in subsection 3.1.1, in the absence of a CNSC licence limit for uranium, the CNSC uses the interim objective for uranium of 0.1 mg/L as a benchmark to demonstrate the application of ALARA and BATEA.
e) Refer to subsection 3.1.1 for an explanation of why no provincial or federal licence limits currently exist for molybdenum.

Table 3.3 summarizes the annual waterborne loadings to the environment before dilution for the period of 2013 to 2021. The data shows that the loadings remained stable during the operational period from 2013 to 2017. The loadings of some parameters (for example, molybdenum and selenium) decreased after the McArthur River Operation was placed in care and maintenance in 2018.

Table 3.3: Annual waterborne loadings from the Mine Water Treatment Plant (2013 – 2021) [4, 5, 6, 7, 8, 9, 10, 11, 12]

Parameter	2013	2014	2015	2016	2017	2018	2019	2020	2021
Arsenic (kg)	3.78	3.05	2.37	1.60	1.80	0.24	0.24	0.23	0.23
Copper (kg)	2.38	2.55	1.88	2.06	1.43	1.04	1.07	1.41	1.07
Lead (kg)	0.23	0.28	0.28	0.27	0.26	0.24	0.24	0.25	0.25
Nickel (kg)	2.70	3.36	3.18	3.37	3.72	3.99	4.01	3.35	4.99
Zinc (kg)	3.26	6.09	4.86	5.16	4.19	2.70	7.39	4.39	5.36
Radium-226 (MBq)	117.7	87.4	152.9	151.6	161.5	150.9	125.8	114.9	65.3
Total suspended solids (kg)	-	-	-	-	-	-	-	2922	2465
Un-ionized ammonia (kg)	-	-	-	-	-	-	-	23.4	55.1
Selenium (kg)	3.29	4.11	5.18	5.44	3.86	0.63	0.65	0.69	0.55
Uranium (kg)	24.42	22.85	21.19	12.66	12.88	15.66	20.79	19.62	17.75
Molybdenum (kg)	426.91	412.79	336.43	450.37	361.37	38.28	26.97	22.79	19.16

3.1.3.2 Effluent from shaft #3

Table 3.4 summarizes the annual monthly mean concentrations of liquid effluent from Shaft #3 discharge from 2013 to 2021, at the end of the pipe before dilution occurred. Clean water from Shaft #3 has been approved for direct discharge to the environment. In addition to licence limits, Cameco has established internal control levels at the McArthur River Operation. As shown in table 3.4, all of the COPCs in the effluent discharged from the Shaft #3 discharge are below regulatory limits.

Table 3.4: Annual average waterborne releases from the McArthur River Operation Shaft #3 discharge compared with applicable release limits (2013 – 2021) [4, 5, 6, 7, 8, 9, 10, 11, 12]

Parameter	Licence limit	2013	2014	2015	2016	2017	2018	2019	2020	2021
Arsenic (mg/L)	0.3	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001
Copper (mg/L)	0.3	0.0002	0.0005	0.0005	0.0010	0.0002	0.0003	0.0002	0.0002	0.0002
Lead (mg/L)	0.1	0.0001	0.0001	<0.0001	0.0001	<0.0001	0.0001	<0.0001	<0.0001	0.0003
Nickel (mg/L)	0.5	0.0017	0.0016	0.0014	0.0019	0.0012	0.0014	0.0013	0.0011	0.0011
Zinc (mg/L)	0.5	0.0172	0.0195	0.0289	0.0384	0.0090	0.0193	0.0185	0.0191	0.0209
pH [a]	6.0 to 9.5	7.2	7.2	7.0	7.0	7.2	7.3	7.2	7.1	7.1
Radium-226 (Bq/L)	0.37	0.107	0.100	0.110	0.112	0.103	0.116	0.098	0.086	0.088
Total suspended solids (mg/L)	15	1	1	1	1	1	1	1	1	1
Un-ionized ammonia (mg/L) [b]	0.5	-	-	-	-	-	-	<0.01	<0.01	<0.01
Selenium (mg/L)	0.6 [c]	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001
Uranium (mg/L)	2.5 [d]	0.0010	0.0008	0.0008	0.0008	0.0009	0.0009	0.0008	0.0008	0.0017
Molybdenum (mg/L)	N/A [e]	0.0062	0.0061	0.0060	0.0055	0.0050	0.0054	0.0038	0.0044	0.0049

(a) pH is taken from every discharge samples. It is not measured in monthly composite samples.
(b) Un-ionized ammonia was added to the MDMER in 2021.
(c) This is the provincial limit that is not in the CNSC licence.
(d) This is the provincial limit that is not in the CNSC licence. As discussed in subsection 3.1.1, in the absence of a CNSC licence limit for uranium, the CNSC uses the interim objective for uranium of 0.1 mg/L as a benchmark to demonstrate the application of ALARA and BATEA.
(e) Refer to subsection 3.1.1 for an explanation of why no provincial or federal licence limits currently exist for molybdenum.

Table 3.5 summarizes the annual waterborne loadings to the environment before dilution for the period of 2013 to 2021. The loadings of some of the parameters (for example, radium-266) have been increasing due to an increase in the volume of clean water released compared to previous year.

Table 3.5: Annual waterborne loadings discharged from the Shaft #3 discharge (2013 – 2021) [4, 5, 6, 7, 8, 9, 10, 11, 12]

Parameter	2013	2014	2015	2016	2017	2018	2019	2020	2021
Arsenic (kg)	0.0363	0.0338	0.0130	0.0096	0.0454	0.0590	0.0436	0.0515	0.0480
Copper (kg)	0.0886	0.1806	0.0796	0.1017	0.0488	0.1187	0.0911	0.1062	0.0961
Lead (kg)	0.0439	0.0470	0.0130	0.0096	0.0214	0.0334	0.0436	0.0515	0.1193
Nickel (kg)	0.5437	0.5354	0.1773	0.1857	0.2466	0.4721	0.5752	0.5811	0.5292
Zinc (kg)	6.02	6.69	3.86	3.73	1.68	5.92	7.60	9.12	10.68
Radium-226 (MBq)	38.1	34.5	14.3	10.8	20.6	37.0	42.3	43.6	41.4
Total Suspended Solids (kg)	-	-	-	-	-	-	-	721.1	577.3
Un-ionized ammonia (kg)	-	-	-	-	-	-	-	0.39 [a]	4.80
Selenium (kg)	0.0718	0.0676	0.0260	0.0192	0.0429	0.0500	0.0436	0.0515	0.0480
Uranium (kg)	0.3568	0.2788	0.0991	0.0762	0.1953	0.2992	0.3574	0.3820	0.7189
Molybdenum (kg)	2.20	2.08	0.76	0.53	1.01	1.77	1.65	2.26	2.33

a) The December 2020 un-ionized ammonia value represents data collected in December 2020. It does not represent a full year of data.

3.1.3.3 Selenium and molybdenum in effluent

As described in section 3.1.1, both selenium and molybdenum have been the focus of increased regulatory oversight by the CNSC. This is because ERAs completed in the mid-2000s indicated that releases of selenium and molybdenum have the potential to cause adverse environmental effects. As a result of this finding and upon request by the Commission [54, 55], licensees added administrative controls and upgrades to their effluent treatment systems, and improved engineering controls and treatment technologies to reduce effluent releases. These actions have been successful to date for the uranium mining sector, where molybdenum and selenium releases have substantially decreased since the mid-2000s and continue to be effectively controlled and closely monitored.

In this latter context and in response to the increase in selenium and molybdenum, Cameco implemented process optimization techniques in the mine water treatment plant at the McArthur River Operation to more effectively control selenium and molybdenum in effluent. This resulted in more stable loadings to the environment.

3.1.3.4 Findings

CNSC staff have found that Cameco's reported liquid effluent discharged from the McArthur River Operation to the Read Creek watershed remained below CNSC's licence limits throughout the reporting period (2013 to 2021). CNSC staff also found that the treated effluent met the requirements for acute lethality testing to aquatic organisms in the receiving environment.

CNSC staff are satisfied that the McArthur River Operation is taking the appropriate above-mentioned measures to effectively control and reduce concentrations and loadings of molybdenum, uranium, and selenium in waterborne effluent.

3.2 Environmental effects assessment

This section presents an overview of the assessment of predicted effects from licensed activities on the environment and the health and safety of persons. CNSC staff reviewed Cameco's assessment of current and predicted effects on the environment and health and safety of persons due to licensed activities included in the ERA (see subsection 2.3.3). The ERA was performed in a stepwise manner as follows:

- quantify the releases (of COPCs) to the environment from current (section 3.1) and future activities
- identify the environmental interactions of the current and expected releases of COPCs, and COPC exposure pathways in the environment
- identify predicted COPC exposure for ecological and human receptors
- identify potential effects to receptors
- determine whether the environment and the health and safety of persons are and will continue to be protected

To inform this section of the report, CNSC staff reviewed Cameco's ERA [14], along with Cameco's 2020 Environmental Performance Report [56], previous ERA predictions and reviews [13, 57] and the McArthur River Operation annual reports submitted between 2013 and 2021, inclusively [4, 5, 6, 7, 8, 9, 10, 11, 12].

While CNSC staff conducted a review for all environmental components, only a selection of components is presented in detail in the following subsections. The environmental components were selected based on regulatory requirements, facility type, and geographic context, as well as those that have historically been of interest to the Commission, Indigenous Nations and communities, and the public.

3.2.1 Atmospheric environment

An assessment of the atmospheric environment requires Cameco to characterize both the meteorological conditions and the ambient air quality at the McArthur River Operation site.

3.2.1.1 Meteorological conditions

Meteorological conditions, such as temperature, wind speed, wind direction and precipitation, are monitored to assess the extent of the atmospheric dispersion of contaminants emitted to the atmosphere, the rates of contaminant deposition, and to determine predominant wind directions, which are used to identify critical receptor locations from the air pathway.

The McArthur River Operation is in the Athabasca Plain ecoregion of the Boreal Shield ecozone of northern Saskatchewan. The climate in this region is typical of the continental sub-arctic region and is characterized by short, cool, and moist summers, and very cold, dry winters. This ecozone is classified as having a sub-humid high boreal climate. The average frost-free period is approximately 90 days.

Meteorological data for modelling contaminant dispersion was generated from the North American mesoscale model that was modified using data gathered from the McArthur River Airport Automated Weather Observing Station in 2018 for air dispersion modelling.

3.2.1.2 Ambient air quality

ERA predictions

In the 2020 ERA, Cameco predicted and assessed the potential impacts to ambient air quality at McArthur River Operation. ERA predictions found potential air quality effects from the McArthur River Operation are related to short term exceedances of TSP, PM10, and PM2.5 air quality standards for the historical operations, future operations, and decommissioning scenarios; however, off-property exceedances are limited to the area near landfill/site entrance road and did not extend beyond 450 m from the lease boundary. In addition, due to the conservative assumptions built into this assessment, it is likely that the predicted concentrations and exceedances noted will be less than what was predicted by the model.

Ambient air monitoring

Cameco conducts ambient air quality monitoring to confirm that airborne emissions from the McArthur River Operation are within the ERA predictions and remain at levels that are protective of the environment.

The McArthur River Operation ambient air monitoring consists of 2 high-volume samplers located around the Operation which are used to monitor TSP and emissions from site operations. The TSP collected is further analyzed to determine the concentration of adsorbed metals and radionuclides in the captured dust. Radon-222 is monitored at 10 locations around the Operation using track-etch detectors. In addition, on-site meteorological stations are used to monitor site specific weather patterns at the Operation (figure 3.2).

Figure 3.2: Air and terrestrial monitoring locations at the McArthur River Operation [56]

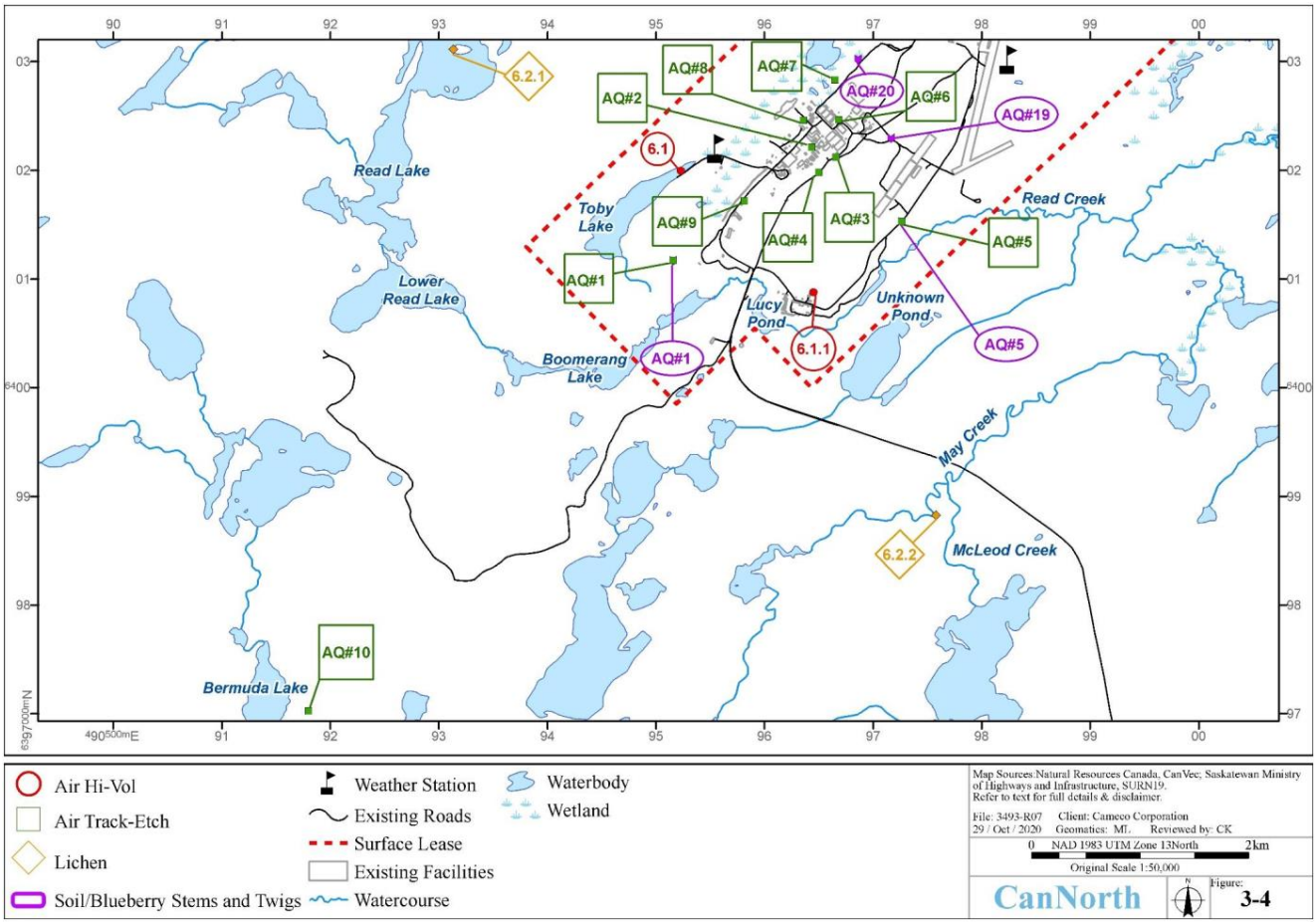


Table 3.6 shows that the average and maximum radon-222 concentrations in ambient air between 2015 and 2019 generally remained below the maximum recorded reference value of 30 becquerel per cubic meter (Bq/m^3), except for the monitoring location next to Shaft #3 exhaust stack, which reported a maximum concentration of 162.8 Bq/m^3 in 2015. The increase in radon-222 levels at Shaft #3 during this time is likely due to maintenance work that was being completed at Shaft #2, causing temporary ventilation changes at Shaft #3. The mean radon-222 levels at this station remain lower than the maximum level reported at the reference station.

Table 3.6: Summary statistics of radon-222 (Bq/m³) levels from 2015-2019 [56]

Track-Etch detectors (2015-2019)	Average	Maximum
AQ#10 – Bermuda Lake (reference station)	9	30[(a)]
AQ#1 – Toby Lake	6.7	10
AQ#2 – Next to Diesel Tanks	8.2	14.8
AQ#3 – Beside Pond C	9.7	18.5
AQ#4 – Walking Road over Hill	8.5	14.8
AQ#5 – Airport Road	7.2	11.1
AQ#6 – Old Camp Area	9.3	18.5
AQ#7 – East of Ore Zone Pond	7.2	11
AQ#8 – West of Coverall A	7.4	11.1
AQ#9 – Shaft # 3	23.4	162.8
Maximum reference statue value = 30		

(a) Maximum recorded value at the reference site between 2015-2019

Table 3.7 and 3.8 show summary statistics of adsorbed COPCs of dust captured at the 2 high-volume sampling locations (6.1 and 6.1.1) The measured arithmetic mean concentrations of metals are each well below the established Ambient Air Quality Criteria (AAQCs), which are referenced from the Ontario Ministry of Environment, Conservations and Parks in the absence of criteria from the Province of Saskatchewan.

Table 3.7: Summary statistics of metals and radionuclides in suspended particulate at Station 6.1.1 (permanent residence) from 2015-2019 [56]

Constituent	Units	Mean	Maximum	Annual AAQC
Arsenic	ng/m^3	0.07	0.22	60
Copper	ng/m^3	5.65	9.4	10000
Nickel	ng/m^3	0.63	1.1	40
Lead	ng/m^3	0.82	2.7	100
Selenium	ng/m^3	0.030	0.08	2000
Uranium	ng/m^3	0.22	0.072	60
Zinc	ng/m^3	15.6	47	24000
Radium-226	mBq/m^3	0.01	0.02	13
Lead-210	mBq/m^3	0.3	0.53	21
Polonium-210	mBq/m^3	0.09	0.15	28
Thorium-230	mBq/m^3	0.01	0.01	8.5

Table 3.8: Summary statistics of metals and radionuclides in suspended particulate at Station 6.1 (Toby Lake) from 2015-2019 [56]

Constituent	Units	Mean	Maximum	Annual AAQC
Arsenic	ng/m^3	0.08	0.21	60
Copper	ng/m^3	6.92	14	10000
Nickel	ng/m^3	0.65	1.1	40
Lead	ng/m^3	0.91	3	100
Selenium	ng/m^3	0.03	0.08	2000
Uranium	ng/m^3	0.26	0.8	60
Zinc	ng/m^3	16.982	47	24000
Radium-226	mBq/m^3	0.01	0.4	13
Lead-210	mBq/m^3	0.31	0.63	21
Polonium-210	mBq/m^3	0.09	0.16	28
Thorium-230	mBq/m^3	0.01	0.08	8.5

3.2.1.3 Findings

Based on the review of Cameco's ERA and the results of the atmospheric monitoring program for McArthur River Operation, CNSC staff have found that airborne emissions from the McArthur River Operation remain within the ERA predictions and below available air quality guidelines, and therefore, ambient air quality remains at levels protective of human health and the environment.

3.2.2 Terrestrial environment

An assessment of potential effects on terrestrial biota at the McArthur River Operation and the surrounding area consists of characterizing the local habitat and species (including considering federal species at risk) and assessing the possibility of their exposure to radiological and hazardous substances that may be disruptive to ecological receptors.

3.2.2.1 Soil quality

The objective of the soil monitoring program is to assess the potential influences of atmospheric emissions of COPCs on soil chemistry in proximity to the McArthur River Operation. There are four soil quality monitoring stations situated at different distances and directions from the mine site and are co-located with blueberry monitoring stations (figure 3.2). Soil samples are monitored for sulphate, arsenic, copper, lead, nickel, uranium, zinc, lead-210, polonium-210, radium-226, and thorium-230.

The soil monitoring results are displayed in table 3.9. Over the monitoring period there were no exceedances of available guidelines. Soil concentrations at station AQ#5 were elevated in 2021, compared to historical data, but no immediate cause has been identified. As this station is located directly alongside a main road, it is possible some of the road material was washed down into the sampling plot. Soil quality during the current licensing period has been conducted in 2015, 2018, and 2021. Sampling is then scheduled to continue on a 6-year cycle to align with the lichen sampling cycle, with the next round of sampling scheduled for 2027.

Table 3.9: Soil monitoring results at the McArthur River Operation 2015-2021 [12]

Parameter	Units	Guideline [58]	Station AQ#1			Station AQ#5			Station AQ#19			Station AQ#20		
			2015	2018	2021	2015	2018	2021	2015	2018	2021	2015	2018	2021
Sulphate	µg/g	-	<50	<50	90	<50	<50	70	<50	<50	<50	<50	50	60
Arsenic	µg/g	12	0.3	0.4	0.7	0.3	0.5	1.8	0.3	0.5	0.4	0.3	0.3	0.7
Copper	µg/g	63	0.5	<0.5	1.6	0.7	0.9	5.9	0.9	0.7	6	0.7	0.8	1
Lead	µg/g	140	1.4	1.5	2.4	1.7	2	4.2	1.7	2.5	1.3	1.7	1.8	2.1
Nickel	µg/g	45	0.4	0.3	1.4	0.7	1	8.4	0.4	0.7	0.4	0.3	0.4	0.9
Uranium	µg/g	23	0.6	0.4	0.4	0.4	1	9.3	1.4	0.6	0.6	0.5	0.3	0.4
Zinc	µg/g	250	2.5	1.7	4.7	3	2.9	11	3.5	3.3	2.7	3.9	3.4	4.3
Lead-210	Bq/g	-	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.06	<0.04	<0.04	<0.04	<0.04	<0.04
Polonium-210	Bq/g	-	0.02	0.03	0.04	0.02	0.03	0.16	0.06	0.04	0.03	0.06	0.04	0.04
Radium-226	Bq/g	-	0.03	<0.01	0.02	0.01	0.02	0.14	0.03	<0.01	<0.01	0.02	<0.01	0.02
Thorium-230	Bq/g	-	<0.02	<0.02	0.02	<0.02	<0.02	0.06	<0.02	<0.02	0.02	<0.02	<0.02	0.02

Blueberry plants are common in northern Saskatchewan and both their availability and propensity to accumulate metals and radionuclides from the soil make them a useful tool in monitoring the terrestrial environment. The objective of the blueberry monitoring program is to assess the potential influences of atmospheric emissions of COPCs via uptake by vegetation near the McArthur River Operation. There are four blueberry stem and twig monitoring stations co-located with soil monitoring locations (figure 3.2). Alongside soil, blueberry stem and leaves/twig samples were analyzed for several constituents (table 3.10). Since 2015 constituents have remained stable or have decreased. Concentrations of COPCs have also remained below available foliage background values for the area. Blueberry sampling during the current licensing period has been conducted in 2015, 2018, and 2021. Sampling is then scheduled to continue on a six-year cycle, with the next round of sampling scheduled for 2027.

Table 3.10: Blueberry monitoring results at the McArthur River Operation 2015-2021 [12]

Parameter	Units	Background [14]	Station AQ#1			Station AQ#5			Station AQ#19			Station AQ#20		
			2015	2018	2021	2015	2018	2021	2015	2018	2021	2015	2018	2021
Arsenic	µg/g	0.5	<0.05	<0.05	<0.05	0.13	0.17	0.08	0.06	0.06	<0.05	<0.05	<0.05	<0.05
Nickel	µg/g	1.4	1.4	1.6	0.66	2.2	2.8	2.4	1.1	2.3	0.66	0.88	1.3	0.71
Uranium	µg/g	0.9	0.07	0.09	0.02	0.73	1.2	0.43	0.27	0.23	0.12	0.3	0.12	0.13
Lead-210	Bq/g	0.3	0.044	0.13	0.04	0.03	0.05	0.02	0.03	0.04	0.04	0.05	0.07	0.05
Polonium-210	Bq/g	0.2	0.019	0.084	0.018	0.02	0.02	0.017	0.01	0.029	0.014	0.03	0.026	0.023
Radium-226	Bq/g	0.05	0.016	0.013	0.0068	0.03	0.04	0.025	0.02	0.0089	0.056	0.01	0.013	0.022
Thorium-230	Bq/g	0.005	<0.0007	0.0006	<0.0006	0.007	0.008	0.006	0.003	0.002	0.002	0.003	0.001	0.001

Lichens are also monitored as an indicator of airborne emissions due to their tendency to accumulate metals and radionuclides in their tissue. Lichen tissue analysis has been completed at the McArthur River Operation since 1997. An objective of the lichen sampling program is to monitor any changes in COPC concentrations at established locations at the McArthur River Operation. Results indicate COPCs in lichens have remained stable or decreased between 2015 and 2021. There are two licenced lichen sampling stations: Read Creek, Station 6.2.1, situated on an island in Read Lake (reference location), and May Creek, Station 6.2.2, situated along May Creek (exposure location). Both stations are shown on figure 3.2. Lichen sampling was completed in 2015 and 2021 in the most recent licensing period (table 3.11).

Table 3.11: Lichen monitoring results at the McArthur River Operation 2015-2021 [12]

Parameter	Units	Station 6.2.1 - Reference		Station 6.2.2 - Exposure	
		2015	2021	2015	2021[(a)]
Arsenic	µg/g	0.7	<0.05	0.12	-
Copper	µg/g	0.69	0.54	0.61	-
Lead	µg/g	0.2	0.17	0.33	-
Nickel	µg/g	0.22	0.17	0.86	-
Uranium	µg/g	0.09	0.04	0.36	-
Zinc	µg/g	9.9	7.2	6.5	-
Lead-210	Bq/g	0.23	0.24	0.28	-
Polonium-210	Bq/g	0.18	0.19	0.22	-
Radium-226	Bq/g	0.0041	0.001	0.0071	-
Thorium-230	Bq/g	0.0014	0.0008	0.004	-

(a) Sampling could not be completed as sampling site had recently been burned by a forest fire

3.2.2.2 Terrestrial habitat and species

The McArthur River Operation is located within the Athabasca Plain Ecoregion, characterized by short, cool summers and long, cold winters [14] and forms part of continuous coniferous forest that extends from northwestern Ontario to Great Slave Lake in the Northwest Territories. Jack pine, shrubs, and lichens are dominant, but some paper birch, white and black spruce, balsam fir and trembling aspen occur on warmer, south facing sites. Forest fires are common in this ecoregion, and most coniferous stands tend to be young [59].

For the ERA, 16 species were selected to represent a wide range of species and potential exposure pathways and includes herbivores, omnivores, and carnivores from terrestrial and aquatic bird and mammal species.

Terrestrial species at risk

In Saskatchewan, the following legislation applies to species at risk: *The Wild Species at Risk Regulations* [60], which is integrated with the federal *Species at Risk Act* (SARA) [61]. In 2017, Cameco conducted a comprehensive review of wildlife species at risk that may be found in Cameco's northern operation area, including the McArthur River Operation [14]. Table 3.12 lists the 16 terrestrial species at risk that were identified as potentially present around the McArthur

River Operation, along with whether they were observed in the area and how they were assessed in the ERA.

Table 3.12: Status of terrestrial species at risk present around the McArthur River Operation [14]

Category	Common Name	SARA status	Assessment notes
Birds	Bank swallow	Threatened	Not observed at study area
Birds	Barn swallow	Threatened	Not observed at study area
Birds	Canada warbler	Threatened	Not observed at study area
Birds	Common nighthawk	Threatened	Observed in study area; assessed via surrogate (rusty blackbird)
Birds	Evening grosbeak	Special Concern	Not observed at study area
Birds	Horned grebe	Special Concern	Not observed at study area
Birds	Olive-sided flycatcher	Threatened	Observed in study area; assessed via surrogate (rusty blackbird)
Birds	Peregrine falcon	Special Concern	Not observed at study area
Birds	Red-necked phalarope	Special Concern	Not observed at study area
Birds	Rusty blackbird	Special Concern	Observed in study area; assessed in the ERA
Birds	Short-eared Owl	Special Concern	Not observed at study area
Birds	Yellow Rail	Special Concern	Not observed at study area
Mammals	Little brown myotis (bat)	Endangered	Not observed at study area
Mammals	Northern myotis (bat)	Endangered	Not observed at study area
Mammals	Wolverine	Special Concern	Not observed at study area
Mammals	Woodland caribou	Threatened	Observed in study area; assessed in the ERA

ERA predictions

The most recent assessment of potential effects on terrestrial biota near the McArthur River Operation was provided in the 2020 ERA [14]. As discussed in subsection 2.3.3, the ERA fully complied with requirements of CSA N288.6-12, [30] and incorporated recent environmental monitoring data.

Cameco selected a total of 16 terrestrial receptors for the assessment based on knowledge of the McArthur River Operation site and its surrounding environment, and relevant field observations. They include both terrestrial and aquatic birds and mammals. The 4 species at risk identified as potentially occurring in the area (that is, common nighthawk, olive-sided flycatcher, rusty blackbird, and woodland caribou) are also included as terrestrial receptors, or assessed through appropriate surrogates. The chosen ecological receptors listed in table 3.13 reflect a variety of diets or feeding habits, cover a variety of trophic levels, and are representative of the potential species present in the area.

Table 3.13: Terrestrial receptors selected for assessment in the 2020 ERA [14]

Receptor type	Receptor	Comment
Terrestrial Bird	Bald Eagle	n/a
Terrestrial Bird	Willow Ptarmigan	n/a
Terrestrial Bird	Common Nighthawk	Rusty blackbird is surrogate
Terrestrial Bird	Olive-sided Flycatcher	Rusty blackbird is surrogate
Terrestrial Bird	Osprey	Bald eagle considered as surrogate as has the same diet
Terrestrial Bird	Rusty Blackbird	n/a
Aquatic Bird (Waterfowl)	Mallard	n/a
Aquatic Bird (Waterfowl)	Common Merganser	n/a
Aquatic Bird (Waterfowl)	Lesser Scaup	n/a
Terrestrial Mammal	Masked Shrew	n/a
Terrestrial Mammal	Snowshoe Hare	n/a
Terrestrial Mammal	Moose	n/a
Terrestrial Mammal	Caribou (Woodland)	n/a
Terrestrial Mammal	Caribou (Barren-Ground)	Woodland caribou is surrogate
Terrestrial Mammal	Grey Wolf	n/a
Terrestrial Mammal	Black Bear	n/a
Terrestrial Mammal	Lynx	Grey wolf is surrogate
Terrestrial Mammal	Red Fox	n/a
Aquatic Mammal	Muskrat	n/a
Aquatic Mammal	Beaver	n/a
Aquatic Mammal	Mink	n/a

Exposure to radiological substances

The potential radiological effects to ecological receptors were assessed by comparing the estimated radiation dose received by each ecological receptor from radiological COPCs through all applicable pathways (namely external and internal exposure due to radionuclides in air, soil, water, sediment, diet, and gamma radiation) to the recommended benchmark values (that is, dose limits to non-human biota).

The overall radiation dose, which included all internal and external doses from all exposure pathways, were significantly below the radiological dose benchmarks recommended in CSA 288.6-12 [30], which is 100 µGy/h for terrestrial receptors, as well as the more conservative benchmark of 41 µGy/h (1mGy/d) used for species at risk. This result indicates negligible potential for adverse effects and no need for further (detailed) assessment.

Exposure to hazardous substances

The potential hazardous effects to ecological receptors were assessed by comparing the estimated exposure concentration received by each ecological receptor from hazardous COPCs through all applicable pathways (namely exposure to hazardous contaminants in air, soil, lichen, vegetation, water, sediment, and diet) to the recommended benchmark values (that is, toxicity reference values for non-human biota).

Predicted intakes of non-radionuclides for terrestrial-based receptors (that is, bear, woodland caribou, eagle, fox, hare, moose, ptarmigan, shrew, and wolf) were below respective lowest observed adverse effect level based toxicity reference values for the expected scenario. There were also no potential issues identified for receptors with an aquatic-based diet (that is, beaver, mallard, merganser, mink, muskrat, and scaup).

Terrestrial environment monitoring

Terrestrial monitoring consisted of monitoring soil, blueberries, and lichen. The details of their respective sampling programs are discussed above in section 3.2.2.1 for soil quality.

3.2.2.3 Findings

Based on the review of Cameco's ERA and the results of the environmental monitoring program for the McArthur River Operation, CNSC staff have found that the terrestrial environment remains protected from radiological and hazardous releases from the McArthur River Operation.

3.2.3 Aquatic environment

An assessment of potential effects on aquatic biota at the McArthur River Operation and the surrounding area consists of characterizing the local habitat and species (including considering designated species at risk) and assessing the possibility of their exposure to radiological and hazardous substances.

3.2.3.1 Surface water quality

The McArthur River Operation area is drained by the Read Creek drainage basin which lies within the Waterbury Lake drainage basin, part of the larger Athabasca River system. Read Lake

and Boomerang Lake form the headwaters of the Read Creek drainage. Read Creek is a tributary of May Creek which discharges into Little Yalowega Lake before flowing into Yalowega Lake. Flows then travel through Carlson Creek, the McArthur River, and the Whitford River, ultimately reaching Waterbury Lake. The local area is characterized by hilly drumlin topography interspersed with a series of interconnected lakes, peatlands, and isolated ponds. A dendritic drainage pattern has developed in the region, with local streamflow patterns controlled by surficial features such as drumlins and eskers. Surface water quality at the McArthur River Operation is influenced by treated effluent and dewatering sources from stations 2.1 and 2.7, respectively (figure 3.3).

The main activities influencing the surface water hydrology near the McArthur River Operation are the use of freshwater from Toby Lake and the release of treated effluent and clean Shaft #3 water into the Read Creek drainage. Treated effluent is discharged from the mine water treatment plant pump house through a 1,250 m pipeline to a muskeg receiving area adjacent to Shaft #3. The effluent meanders preferentially through the muskeg for approximately 500 m before reaching a conveyance channel. Water from the channel flows on the surface for approximately 25 m to 30 m before braiding into smaller channels and pools for another 20 m. At this point the water flows through the Read Creek conveyance channel for approximately 420 m and then enters Read Creek.

The McArthur River Operation conducts an extensive water quality monitoring program within the Read Creek drainage on a monthly or quarterly basis, depending on the station for physical properties, nutrients, inorganic ions, metals, and radionuclides. Several monitoring stations have been established in the area to assess possible influence of the mining operations on water quality. Surface water monitoring stations are shown in figure 3.3.

Figure 3.3: McArthur River Operation surface water sampling and hydrology monitoring stations [14]

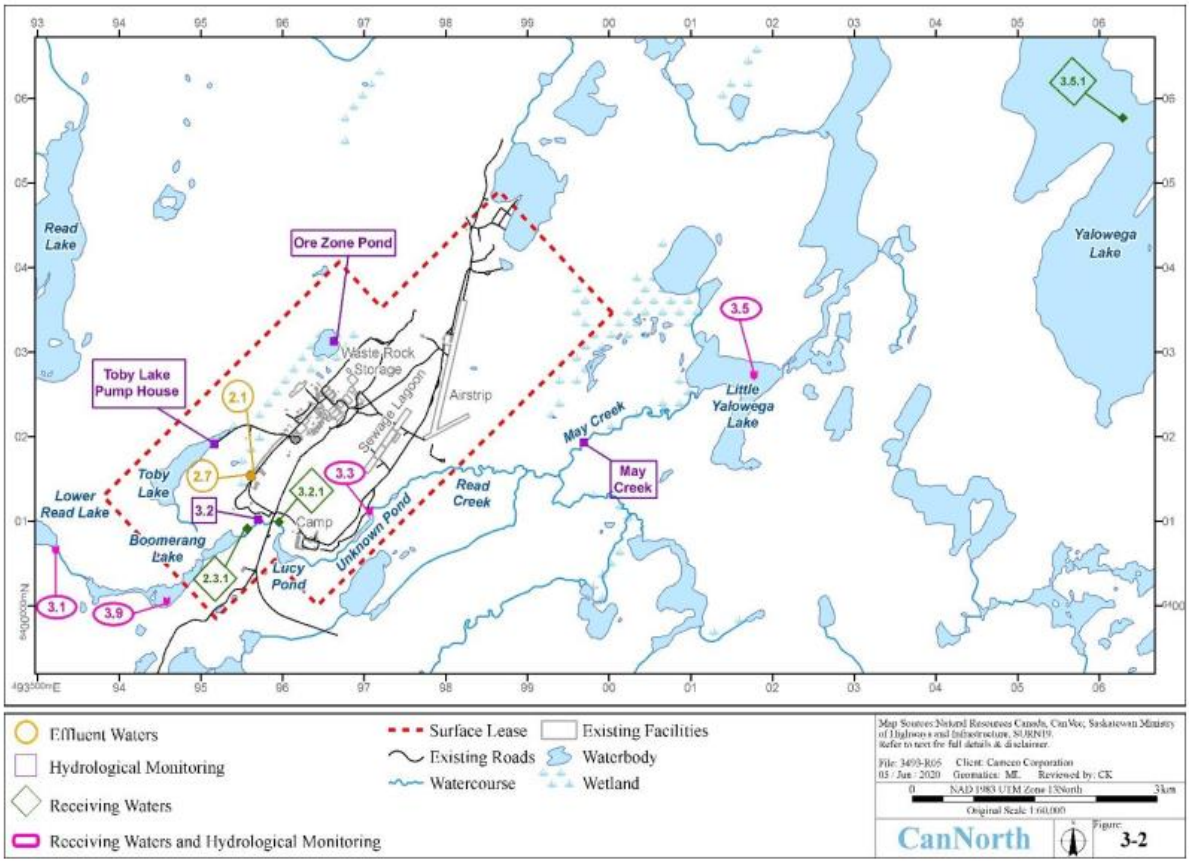


Table 3.14 and 3.15 contain the annual monthly mean concentrations of key COPCs with available water quality guidelines in surface water in Read Creek and Boomerang Lake Outflow, respectively. Annual monthly mean concentrations of COPCs from 2013 to 2020 were below the Saskatchewan Environmental Quality Guidelines (SEQGs) which are protective of aquatic life [62]. CNSC staff have reviewed the surface water quality results for all exposure stations, confirmed they were below the SEQG and/or reference station concentrations, and concluded that there is minimal risk to the environment.

Table 3.14: Water quality at Station 3.2.1 – Read Creek [12]

Parameter	SEQG	2017	2018	2019	2020	2021
Arsenic (mg/L)	0.005	0.0002	0.0001	0.0001	0.0001	0.0001
Cadmium (mg/L)	0.00004	<0.00001	<0.00001	0.00001	0.00001	<0.00001
Cobalt (mg/L)	0.00078[(a)]	0.0001	0.0001	<0.0001	<0.0001	0.0001
Copper (mg/L)	0.002[(b)]	<0.0002	<0.0002	0.0002	<0.0002	<0.0002
Molybdenum (mg/L)	31	0.0158	00041	0.0023	0.0011	0.0015
Nickel (mg/L)	0.025[(c)]	0.0002	0.0002	0.0002	0.0001	0.0002
Lead (mg/L)	0.001[(d)]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (mg/L)	0.001	0.0002	0.0001	0.0001	<0.0001	<0.0001
Uranium (mg/L)	0.015	0.0006	0.0007	0.0007	0.0005	0.0004
Zinc (mg/L)	0.03	0.0006	0.0012	0.0013	0.0008	0.0010
Lead-210 (Bq/L)	N/A[(e)]	0.02	<0.02	0.02	0.02	<0.02
Polonium-210 (Bq/L)	N/A[(e)]	0.006	0.006	0.005	0.005	0.005
Radium-226 (Bq/L)	0.11	0.008	0.010	0.009	0.006	0.006
Thorium-230 (Bq/L)	N/A[(e)]	<0.01	<0.01	<0.01	<0.01	<0.01

(a) Cobalt value is from the Federal Environmental Quality Guidelines [63] and is hardness dependant: 0.00078 mg/L when hardness is 52 mg/L to 0.0018 mg/L when hardness is 396 mg/L.
(b) Copper objective: 0.002 mg/L where hardness is 0 – 120 mg/L; 0.003 mg/L where hardness is 120 – 180 mg/L; 0.004 mg/L where hardness is > 180 mg/L.
(c) Nickel objective: 0.025 mg/L where hardness is 0 – 60 mg/L; 0.065 mg/L where hardness is 60 – 120 mg/L; 0.110 mg/L where hardness is 120 – 180 mg/L; 0.150 mg/L where hardness is > 180 mg/L.
(d) Lead objective: 0.001 mg/L where hardness is 0 – 60 mg/L; 0.002 mg/L where hardness is 60 – 120 mg/L; 0.004 mg/L where hardness is 120 – 180 mg/L; 0.007 mg/L where hardness is > 180 mg/L.
(e) There are no SEQGs for lead-210, polonium-210 and thorium-230, and therefore, CNSC staff assess trends over time.

Table 3.15: Water Quality at Station 2.3.1 – Boomerang Lake Outflow [12]

Parameter	SEQG	2017	2018	2019	2020	2021
Arsenic (mg/L)	0.005	0.0001	0.0001	0.0001	0.0001	0.0001
Cadmium (mg/L)	0.00004	0.00001	<0.00001	0.00001	<0.00001	<0.00001
Cobalt (mg/L)	0.00078[(a)]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Copper (mg/L)	0.002[(b)]	<0.0002	<0.0002	<0.0002	<0.0002	0.0002
Molybdenum (mg/L)	31	0.001	0.0005	0.0002	0.0002	0.0003
Nickel (mg/L)	0.025[(c)]	<0.0001	<0.0001	0.0001	<0.0001	<0.0001
Lead (mg/L)	0.001[(d)]	<0.0001	0.0001	0.0001	<0.0001	<0.0001
Selenium (mg/L)	0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Uranium (mg/L)	0.015	0.0002	0.0001	0.0001	<0.0001	0.0001
Zinc (mg/L)	0.03	<0.0005	0.0005	0.0014	0.0005	0.0006
Lead-210 (Bq/L)	N/A[(e)]	0.02	<0.02	0.02	0.02	0.03
Polonium-210 (Bq/L)	N/A[(e)]	0.006	0.005	<0.005	<0.005	0.005
Radium-226 (Bq/L)	0.11	0.006	0.005	0.005	0.005	0.006
Thorium-230 (Bq/L)	N/A[(e)]	<0.01	<0.01	<0.01	<0.01	0.02

(a) Cobalt value is from the Federal Environmental Quality Guidelines [63] and is hardness dependant: 0.00078 mg/L when hardness is 52 mg/L to 0.0018 mg/L when hardness is 396 mg/L.
(b) Copper objective: 0.002 mg/L where hardness is 0 – 120 mg/L; 0.003 mg/L where hardness is 120 – 180 mg/L; 0.004 mg/L where hardness is > 180 mg/L.
(c) Nickel objective: 0.025 mg/L where hardness is 0 – 60 mg/L; 0.065 mg/L where hardness is 60 – 120 mg/L; 0.110 mg/L where hardness is 120 – 180 mg/L; 0.150 mg/L where hardness is > 180 mg/L.
(d) Lead objective: 0.001 mg/L where hardness is 0 – 60 mg/L; 0.002 mg/L where hardness is 60 – 120 mg/L; 0.004 mg/L where hardness is 120 – 180 mg/L; 0.007 mg/L where hardness is > 180 mg/L.
(e) There are no SEQGs for lead-210, polonium-210 and thorium-230, and therefore, CNSC staff assess trends over time.

3.2.3.2 Sediment quality

Cameco collects sediment samples at exposure and reference stations every three years in accordance with the facility's EMP [37], the most recent of which was completed in 2021, no samples were collected in 2018, as the facility was conducting an investigation of cause (IOC) study under the MDMER during that phase (discussed further in section 3.2.3.3). Cameco submits the samples to an accredited laboratory, where they are analyzed for metals, radionuclides, nutrients and general chemistry. The results are then compared to the reference station concentrations and against the Canadian Interim Sediment Quality Guidelines for the Protection of Aquatic Life (ISQG) [58], the Canadian Probable Effects Level Sediment Quality Guidelines (PSQG) [58] and the Lowest Effects Levels (LEL) and Severe Effects Levels (SEL) derived for uranium mining areas in Canada [64].

Sediment sampling at the McArthur River Operation is completed in the near-field and far-field study areas of the Read Creek drainage and at associated reference locations. Under the Saskatchewan Approval to Operate, the far-field study area is sampled at Little Yalowega Lake and Yalowega Lake with Lower Read Lake included as the reference location. As part of the environmental effects monitoring (EEM) program, the near-field study area is sampled at Unknown Pond with West Boomerang Lake and Reference lakes 2 through 5 included as reference locations. The inclusion of multiple EEM reference areas provides added context to the exposure-reference comparisons, and is not a requirement under the EMP. Sediment chemistry is collected as part of the EMP and included as supporting information for the EEM benthic invertebrate community program. Sediment chemistry from the near-field environment is a necessary input for the completion of the ERA.

Two additional study areas were also sampled in the previous licensing period. East Boomerang Lake and Lucy Pond were sampled for supporting information as part of the 2015 EMP. East Boomerang Lake received treated effluent until 2014 when the Read Creek conveyance channel was commissioned; therefore, it is a former exposure area monitored for potential influences from the former muskeg receiving area. Lucy Pond provided additional near-field supporting information; however, no temporal data are available.

All areas sampled were dominated by silt and either fine sand or clay particles. These results suggest that the sediment in all study areas had similar physical properties and particle size content. Coarse sand had the most variable distribution between study lakes and ranged from lowest in Little Yalowega Lake to highest in Lucy Pond.

Overall, sediment results in 2021 were consistent with previous results in the near- and far-field study areas of the Read Creek drainage, the majority of COPCs have remained constant or have decreased in Little Yalowega Lake, while slite increases in cadmium, cobalt, copper, lead, nickel, tin, uranium, zinc, and radiological COPCs were noted in Unknown pond in 2021. Results for near-field exposure and far-field exposure locations are presented in tables 3.16 and 3.17, respectively.

Table 3.16: Mean concentrations of COPCs in sediments in Unknown Pond (near-field) (2009, 2012, 2015, 2021) [56, 65]

Parameter	REF[a]	ISQG[b]	PSQG[c]	LEL[d]	SEL[e]	2009	2012	2015	2021
Arsenic (µg/g)	2	5.9	17	9.8	346.4	5.8	7.6	6.2	4.6
Cadmium (µg/g)	0.3	0.6	3.5	-	-	0.2	0.4	0.2	0.3
Cobalt (µg/g)	1	-	-	-	-	3.3	4.6	4.3	4.7
Copper (µg/g)	1.8	35.7	19.7	22.2	268.8	5.4	2.3	2.8	3.5
Iron (µg/g)	9976	-	-	-	-	16400	11120	7980	12050
Lead (µg/g)	4.6	35	91.3	36.7	412.4	4.6	5.7	5.2	5.6
Molybdenum (µg/g)	0.8	-	-	13.8	1238.5	240	274	222	101
Nickel (µg/g)	2.8	-	-	23.4	484	4.9	5.9	4.7	7
Selenium (µg/g)	0.6	-	-	1.9	16.1	3.5	3.4	2.5	2.4
Tin (µg/g)	0.1	-	-	-	-	0.04	0.22	0.24	0.3
Uranium (µg/g)	1	-	-	104.4	5874.4	192	145	105	110
Zinc (µg/g)	15	123	315	-	-	32	38	32	34
Lead-210 (Bq/g)	0.37	-	-	0.9	20.8	0.6	0.56	0.41	0.49
Polonium-210 (Bq/g)	0.37	-	-	0.8	12.1	0.68	0.57	0.38	0.49
Radium-226 (Bq/g)	0.03	-	-	0.6	14.4	0.15	0.13	0.11	0.14
Thorium-230 (Bq/g)	0.01	-	-	-		0.04	0.02	0.02	0.03

(a) REF refers to the 1997-2015 mean concentration at the near-field reference areas.
(b) ISQG stands for the "Canadian Interim Sediment Quality Guidelines for the Protection of Aquatic Life [58].
(c) PSQG stands for the "Canadian Probable Effects Level Sediment Quality Guidelines" [58].
(d) LEL stands for "Lowest Effects Levels" [64].
(e) SEL stands for "Severe Effects Levels" [64].

Table 3.17: Mean concentrations of COPCs in sediments in Little Yalowega Lake (far-field) (2007, 2012, 2015, 2021) [56, 65]

Parameter	REF[a]	ISQG[b]	PSQG[c]	LEL[d]	SEL[e]	2007	2012	2015	2021
Arsenic (µg/g)	3.8	5.9	17	9.8	346.4	3.6	3.5	4.6	3.02
Cadmium (µg/g)	0.3	0.6	3.5	-	-	0.05	0.3	0.3	0.3
Cobalt (µg/g)	2.6	-	-	-	-	1.9	2.5	3	2.52
Copper (µg/g)	4.6	35.7	19.7	22.2	268.8	2.9	1.7	3	3.7
Iron (µg/g)	6180	-	-	-	-	12833	7900	16400	11640
Lead (µg/g)	6.1	35	91.3	36.7	412.4	4.5	4.6	4.8	4.1
Molybdenum (µg/g)	2.0	-	-	13.8	1238.5	109	134	94	25
Nickel (µg/g)	5.1	-	-	23.4	484	4.1	4.4	4.4	4.8
Selenium (µg/g)	1.6	-	-	1.9	16.1	1.7	1.9	2.2	1.9
Tin (µg/g)	0.2	-	-	-	-	0.1	0.1	0.2	0.2
Uranium (µg/g)	10	-	-	104.4	5874.4	10	14	16	16
Zinc (µg/g)	21	123	315	-	-	17	27	24	22
Lead-210 (Bq/g)	0.98	-	-	0.9	20.8	0.43	0.38	0.44	0.44
Polonium-210 (Bq/g)	0.92	-	-	0.8	12.1	0.47	0.42	0.39	0.38
Radium-226 (Bq/g)	0.02	-	-	0.6	14.4	0.05	0.04	0.07	0.052
Thorium-230 (Bq/g)	0.01	-	-	-		0.02	0.01	0.01	0.01

(a) REF refers to the 2015 mean concentration at Lower Read Lake.
(b) ISQG stands for the "Canadian Interim Sediment Quality Guidelines for the Protection of Aquatic Life [58]
(c) PSQG stands for the "Canadian Probable Effects Level Sediment Quality Guidelines" [58].
(d) LEL stands for "Lowest Effects Levels" [64] .
(e) SEL stands for "Severe Effects Levels" [64] .

The sediment quality predictions in the 2020 ERA indicated that there were no exceedances of benchmarks predicted for arsenic, molybdenum, nickel, selenium, and uranium under the expected scenario. The 95th percentile of molybdenum concentrations in Unknown Pond exceed the no effect level benchmark until year 2040. Conditions are expected to continue to improve following the use of ferric sulphate in the minewater treatment plant to increase molybdenum removal. Cadmium concentrations in sediments of Unknown Pond are predicted to exceed the benchmark (ISQG) value of 0.6 µg/g until the end of the simulation period at the 95th percentile level, but not under expected conditions, while remaining under the PEL for the entire simulation period. Cadmium concentrations in sediments of other waterbodies do not exceed either benchmark. For COPC with no no effect level benchmarks, there are no predicted exceedances of the LEL for copper, lead, radium-226, lead-210, or polonium-210, and no predicted exceedances of the ISQG for zinc.

3.2.3.3 Aquatic habitat and species

The aquatic environment surrounding the McArthur River Operation supports a wide variety of aquatic species. Within the 2020 ERA, the aquatic receptors (that is, fish, benthic invertebrates, zooplankton, phytoplankton, aquatic vegetation) were evaluated at various locations along Read Creek, Little Yalowega Lake, and Yalowega Lake. Lucy and Unknown ponds are shallow (mean depth of 1 m) and not expected to support a fish population during winter months. However, since fish can be present at other times during the year, fish were included in Unknown Pond, representing the near-field exposure zone of Lower Read Creek. The muskeg area was not considered to be a fully functioning aquatic community and was, therefore, not considered specifically for aquatic receptors. Recovery of this area from previous releases is being monitored by Cameco.

The primary fish species located within the waterbodies surrounding the McArthur River Operation are typical of lakes within the Athabasca Basin, benthic species include white sucker, lake chub, ninespine stickleback, yellow perch, and spottail shiner in Little Yalowega Lake, while a greater variety of benthic fish species was observed in Lower Read Creek, including arctic grayling, burbot, lake chub, longnose sucker, ninespine stickleback, slimy sculpin, spottail shiner, white sucker, and other sucker species. The primary predatory fish species present is the northern pike.

The boreal chorus frog and the wood frog were detected and captured during surveys at the site and were, therefore, considered in the assessment. No aquatic reptiles were identified around the site and were therefore not considered for assessment.

Aquatic species at risk

The northern leopard frog was the only aquatic species at risk identified to have potential habitat in the area within or immediately surrounding the McArthur River Operation. However, site surveys have never observed the northern leopard frog within the McArthur River Operation study area. A search by Cameco within the Species at Risk Public Registry [66] and a review of the Aquatic Species at Risk Map developed by Fisheries and Oceans Canada [67] confirmed the absence of federally-listed aquatic species at risk in the area. CNSC staff reviewed the identified species and these sources of information and concluded this information was correct.

ERA predictions

The most recent assessment of potential effects on aquatic biota near the McArthur River Operation was provided in the 2020 ERA [14]. As discussed in subsection 2.3.3, the ERA fully complied with requirements of CSA N288.6-12, [30] and incorporated recent environmental monitoring data.

Cameco selected a total of 5 aquatic receptor classes for the assessment based on knowledge of the McArthur River Operation site and its surrounding environment, and relevant field observations. They include primary producers, primary, secondary and tertiary consumers, and amphibians. The chosen ecological receptors reflect a variety of diets or feeding habits, cover a variety of trophic levels, and are representative of the potential species present in the area.

Exposure to radiological substances

The potential radiological effects to ecological receptors were assessed by comparing the estimated radiation dose received by each ecological receptor from radiological COPCs through all applicable pathways (namely external and internal exposure due to radionuclides in air, soil, water, sediment, and gamma radiation) to the recommended benchmark values (that is, dose limits to non-human biota).

The overall radiation dose, which included all internal and external doses from all exposure pathways, were significantly below the radiological dose benchmarks recommended in CSA 288.6-12 [30], which is 400 µGy/h for aquatic receptors. This result indicates no potential for adverse effects and no need for further (detailed) assessment.

Exposure to hazardous substances

The potential hazardous effects to ecological receptors were assessed by comparing the estimated exposure concentration received by each ecological receptor from hazardous COPCs through all applicable pathways (namely exposure to hazardous contaminants in air, soil, lichen, vegetation, water, sediment, benthic invertebrates, phytoplankton, zooplankton and aquatic vegetation) to the recommended benchmark values (that is, toxicity reference values for non-human biota).

For the assessment of potential negative effects of hazardous substances to various species in the aquatic environment, the mean and 95th percentile predicted water concentrations were considered in the context of species sensitivity distributions.

For the expected scenario, there were no exceedances of the water quality guidelines by the mean and 95th percentile predicted concentrations in Read Creek and further downstream. Despite being unliekly to support fish populations during the winter months, fish were considered in Unknown Pond, representing the near-field exposure zone of Lower Read Creek as fish can be present at other times during the year.

The predicted future fish concentrations are consistent with measured concentrations in Little Yalowega Lake and Yalowega Lake. Based on environmental data, and predicted concentrations of hazardous substances in water and fish tissue, there is no expected potential for negative effects on fish in the immediate downstream environment from the release of COPC from the McArthur River Operation.

The 2020 ERA indicated no predicted exceedances under the expected scenario. Benthic invertebrate communities were assessed in 2012 and 2015 at the near-field exposure waterbody Unknown Pond. Additionally, East Boomerang Lake was sampled as a near-field exposure area in 2012 and a former exposure area in 2015 for temporal comparisons. In the far-field study area, Little Yalowega Lake was sampled as the exposure area and Lower Read Lake was sampled as the reference area. Similar to the 2012 assessment, the 2015 analyses of the benthic invertebrate community in the McArthur River Operation study area found that the near-field exposure area differed little from the reference areas, and that the far-field exposure area was statistically different from its reference area, but that these differences have been present since 1997. As part of environmental effects monitoring under the MDMER, Cameco completed an IOC Study in 2019 investigating the confirmed differences in benthic invertebrate community composition [68]. The IOC concluded that the statistical differences present in the benthic invertebrate

community composition were not ecologically relevant and statistical differences were correlated with habitat variables (such as station depth, silt/clay content, and cadmium levels). Cadmium was the only parameter found at a statistically higher concentration at some of the reference areas, compared to the near-field exposure areas. Therefore, based on the results of the assessment coupled with the monitoring program, no effects on the benthic community in the receiving environment of McArthur River Operation are projected under the expected scenario.

Aquatic environment monitoring

Aquatic environment monitoring is necessary for uranium mines and mills to meet the requirements of the MDMER, as well as any additional requirements from the CNSC and the Saskatchewan Ministry of Environment. Cameco's aquatic environment monitoring programs are executed every three years in accordance with the facility's EMP [37]. Cameco collects and analyzes benthic invertebrate community, fish population and fish tissue chemistry data. Aquatic monitoring data were collected just before the current licensing period in 2012 [69], and during the current licensing period in 2015 [70] providing a comprehensive understanding of the aquatic environment surrounding the McArthur River Operation and its current environmental performance.

Between 2013 and 2022, the 2012 and 2015 studies identified confirmed differences in the benthic invertebrate communities and the fish populations at the McArthur River Operation. This led to the completion of an IOC study in 2019 [68], as discussed above.

3.2.3.4 Findings

Based on the review of Cameco's ERA and the results of the EMP for the McArthur River Operation, CNSC staff have found that the aquatic environment remains protected from radiological and hazardous releases from the McArthur River Operation. The only predicted exceedances of appropriate benchmarks occur under the expected scenario – 95^{th} percentile, which is unlikely to occur. CNSC staff continue to maintain oversight on environmental monitoring and risk assessment to ensure release to environment remain consistent or decrease over time.

3.2.4 Hydrogeological environment

The geological and hydrogeological environment of the McArthur River Operation area has been characterized through a series of studies [23] [24]. Assessment on the impacts to hydrogeological environment (in terms of groundwater flow and quality) is mainly based on the ongoing groundwater monitoring program in the McArthur River Operation area.

3.2.4.1 Geological conditions

The McArthur River Operation site lies within the southwest portion of the Churchill Structural Province of the Canadian Shield. The crystalline basement rocks underlying the deposit are members of the Aphebian age basement rocks of Wollaston Group, consisting of a lower assemblage of pelitic, semipelitic and arkosic gneisses, with minor interlayered calc-silicates and quartzites. The Wollaston Group basement rocks are unconformably overlain by flat lying, unmetamorphosed sandstones and conglomerates of the Helikian Athabasca Group. These sediments are over 500 m thick in the deposit area, which is overlain unconformably by the Quaternary glacial deposits forming large-scale drumlins on surface. Tectonically, the most

significant feature in the region is the graphitic P2 fault. The brittle, flat lying sandstone has been well fractured by the tectonic forces of the thrust fault and these fractures are water bearing.

3.2.4.2 Groundwater quantity and quality

The site geology is comprised of three major lithostratigraphic units (top to bottom):

- overburden or surficial deposits:
    - this unit is comprised of hummocky till plains, eskers and kames, and drumlins, typically ranging from 0 up to 90 m in thickness.
- Athabasca sandstone:
    - this unit is a major aquifer in the area.
- basement rock (consisting of the Wollaston Domain)

The groundwater monitoring network consists of a series of monitoring wells that are used to measure hydraulic head and monitor the groundwater quality around surface facilities. The intent of this program is to determine if surface activities are impacting the local groundwater quality and to monitor the extent of drawdown on the local shallow groundwater.

Cameco's groundwater monitoring program at site is a comprehensive network of 69 monitoring wells that provide good coverage in both shallow sandstone and glacial drift geological units, upstream and downstream of facilities on site. In addition to local facility monitoring wells, several regional monitoring wells are included, which provide data on background groundwater levels and quality. Groundwater sampling occurs on a semi-annual frequency, once during the spring/summer and once during the fall/early winter if sufficient water for sampling is available.

Groundwater monitoring at the McArthur River Operation is divided into ten different areas (figures 3.4 and 3.5), summarized below:

- Area 1: Up Gradient of Waste Rock Pad and Ponds
- Area 2: Waste Rock Pad and Ponds
- Area 3: Mine Terrace
- Area 4: Lay Down and Core Storage
- Area 5: Batch Plant and Clean Rock Storage
- Area 6: Sewage Lagoons / Sewage Treatment Plant
- Area 7: Landfill
- Area 8: Airport
- Area 9: Toby Lake
- Area 10: Regional

Figure 3.4: McArthur River Operation licensed groundwater monitoring wells (local location map) [56]

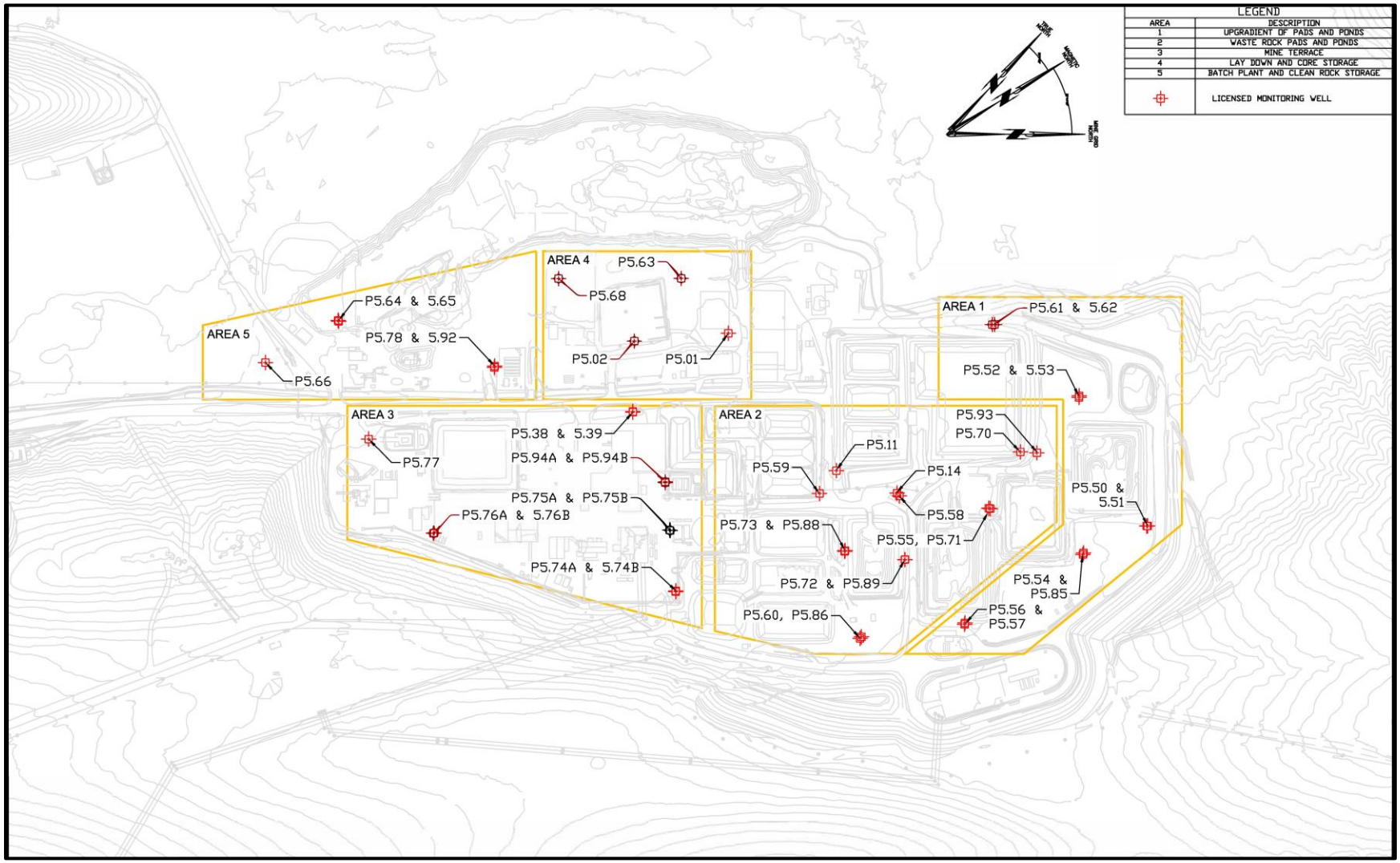
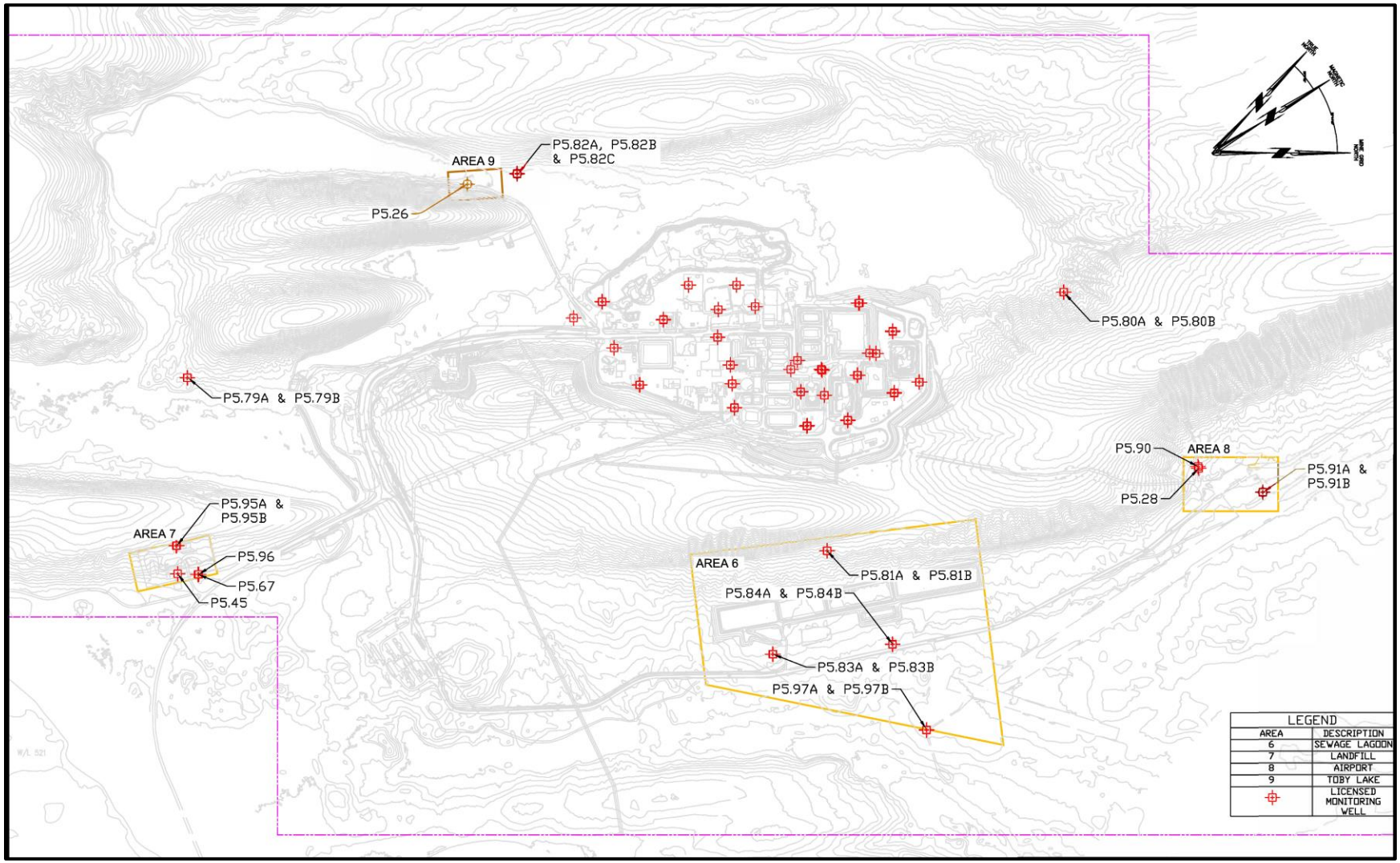
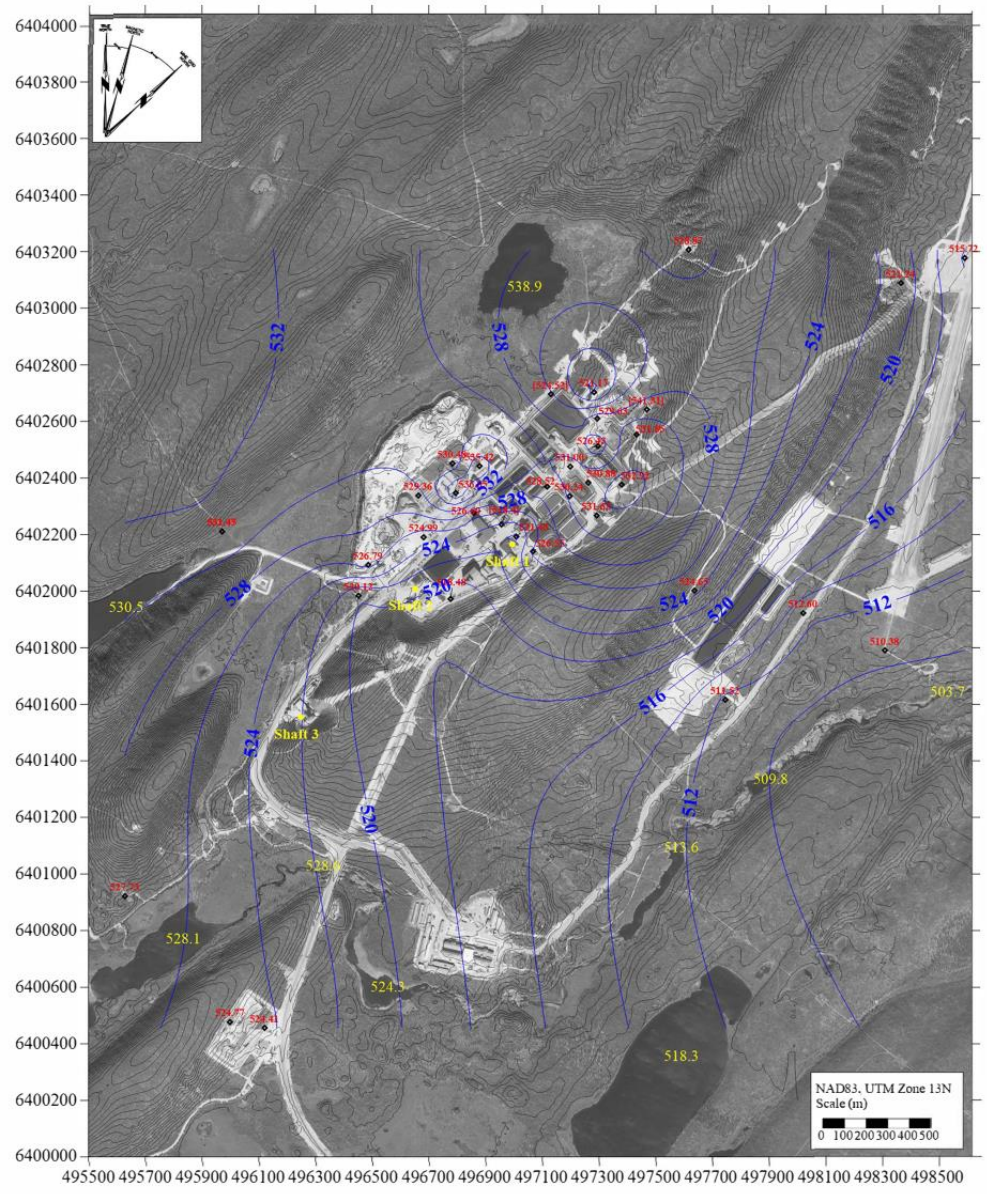


Figure 3.5: McArthur River Operation licensed groundwater monitoring wells (regional location map) [56]



Groundwater monitoring has determined that the primary flow path at the McArthur River Operation is from west to east, this remains the case except for areas that are affected by shaft drawdown (figure 3.6). The presence of three mineshafts onsite creates a localized drawdown cone, capturing groundwater from sources under the site. The drawdown cone extends west to near Toby Lake, however little (<0.5m) drawdown is observed in the wells in this vicinity. It extends as far north as the drumlin, separating the site property and airport facilities. Significant influences on nearby surface water body elevations due to shaft dewatering has not been noted on site. An overall downward gradient in flow exists in both the glacial drift and the entire sandstone sequence. Flow within the sandstone is dominated by the natural fracture network which exists.

Figure 3.6: McArthur River Operation shallow sandstone groundwater contour map [56]



Background groundwater quality at the McArthur River Operation site is characterized by a neutral to slightly acidic pH, very low major ion concentrations, with glacial drift bicarbonate concentrations slightly higher, on average, than observed in the sandstone. Considerable variability does exist in background groundwater quality for glacial till. This variability is due to a variety of environments being encountered, from upland drumlins to organic-rich lowland wetlands. Slight variations may also exist within fault expressions when compared to sandstone water quality.

Groundwater quality in Area 1, 6, 9 and 10 (figure 3.4 and 3.5) show background conditions. The western and southern portion of Site Area 5 are also similar to background. Groundwater quality in Area 2 is influenced by seepage from pads and ponds. Monitoring data suggests influences are more acute in the perched water within the glacial drift in this site area and appear to be more consistent with waste rock than ponds; however, differentiation between sources is difficult due to the similarity in the source water quality. Groundwater quality in Area 3 shows influences upgradient of the Pollock Shaft (Shaft #1) towards the waste rock pads and ponds. There is also indication that there are minor influences towards the lay down and core storage areas, likely due to core storage facilities. Area 4 shows minor influences that currently cannot be attributed to any one process or activity. Locations to the west of the batch plant in Area 5 show slight increases in calcium and magnesium as well as nickel and radium-266.

Findings

Based on CNSC staff's review of the groundwater conditions and monitoring results at the McArthur River Operation, CNSC staff found there are localized effects to groundwater from operations. However, based on the ERA conclusions, these effects are negligible and do not result in increased risk to people and the environment around the facility. CNSC staff have reviewed the ERA and agree with the conclusions of the ERA that the effects are negligible.

3.2.5 Human environment

An assessment of the human environment at the McArthur River Operation site consists of identifying representative persons located within or in proximity to the site, and determining whether radiological or hazardous COPCs could impact their health by breathing the air, being on the land, drinking and swimming in surface water, and eating plants, fish and wildlife from the McArthur River Operation area. In general, human receptors may be exposed to contaminants through four primary routes: dermal (skin), inhalation, incidental ingestion (soil) and ingestion of food and water. Representative persons are those individuals who, because of their location and habits, are likely to receive the highest exposures to radiological or hazardous substances from a particular source.

Cameco's 2020 ERA [14] included a HHRA to assess the risk to humans from both radioactive and hazardous substances released from activities at the McArthur River Operation. The risk assessment considered an adult camp worker at the McArthur River Operation and adult, child, and toddler age classes for a land resource user/trapper living at Little Yalowega lake for three months a year, a permanent resident, and a seasonal resident. Intake pathways to these receptors included incidental soil ingestion, contact with soil, inhalation and immersion in air, drinking water, immersion in water, and multiple food sources (traditional, store-bought, garden grown). These receptors were determined to be the most exposed individuals for potential radiological and hazardous contaminant exposures from operations at the McArthur River Operation.

3.2.5.1 Exposure to radiological substances

The CNSC's *Radiation Protection Regulations* [34] prescribe radiation dose limits to protect workers, the public, and Indigenous Nations and communities from exposure to radiation from licensed activities. Doses are either monitored by direct measurement or by estimation of the quantities and concentrations of any nuclear substance released as a result of the licensed activities, depending on the circumstances. The annual effective dose limit for a member of the public is 1 mSv per year.

The predicted maximum incremental dose resulting from the McArthur River Operation was 0.18 mSv per year for the camp worker and 0.15 mSv per year for the lodge resident toddler. The majority of incremental radiation dose for the camp worker was from radon exposure, while the trapper and resident receptors are mostly exposed via ingestion of fish and mallard ducks. All receptors assessed were well below the CNSC dose limit. CNSC staff reviewed Cameco's assessment and determined it was adequately conservative and risk to human health from radionuclide exposure from the McArthur River Operation was negligible.

3.2.5.2 Exposure to hazardous substances

In the McArthur River Operation HHRA [14], the exposure of representative receptors to hazardous substances (arsenic, cadmium, cobalt, copper, lead, molybdenum, nickel, selenium, uranium, and zinc) was evaluated by use of daily intake rates and compared to available toxicity reference values. Each receptor was assessed using pathways from drinking water, soil contact, inhalation and food obtained from local sources as well as store-bought foods. In addition, Cameco assessed the incremental exposure risk from carcinogenic non-radionuclides, such as arsenic, as well as exposure to airborne COPCs such as NO_2, SO_2, and dust.

The HHRA found that all non-radiological hazardous substances were below the appropriate toxicity reference values, with the exception of arsenic. However, the exceedance of arsenic was overwhelmingly driven by the generic Canadian intakes of supermarket foods (milk, cereal etc.) and contributions driven by the McArthur River Operation did not add perceptively to the overall exposure. No adverse effects are expected from hazardous substances to receptors assessed, as a result of the McArthur River Operation.

The exposure to carcinogenic non-radionuclides was assessed through incremental cancer risks resulting from arsenic exposure from the McArthur River Operation for a camp worker and a composite receptor (combined toddler, child, and adult exposure). The estimates in the assessment correspond to the incremental risk of an individual developing cancer over their lifetime as a result of exposure. For carcinogenic constituents, any level of exposure to a constituent results in an associated risk. Health agencies, such as Health Canada, have established a negligible risk factor at 1×10^{-5}, which is consistent with the recommendations of CSA N288.6-12, which states the sum of the risk levels for more than one pathways should not be greater than 1×10^{5} [30, 14]. All arsenic in the assessment was conservativley assumed to be in its most toxic form, even so the resultant maximum lifetime incremental cancer risk for the assessed receptors remained below 0.2 per 100,000 people, below the recommended guideline of 1×10^{-5} (1 per 100,000).

The exposure to airborne NO_2 and SO_2 was assessed through an incremental one hour maximum exposure and annual maximum exposure to these COPCs and compared to health-based criteria [71, 72]. Both NO_2 and SO_2 were below available guidelines, therefore negligible risk is

expected for these constituents. Dust exposure was assessed through exposure to PM_{10} and $PM_{2.5}$ resulted in an exceedance for the camp worker for 49 days and 64 days per year for PM_{10} and $PM_{2.5,}$ respectively. It should be noted that these are the maximum expected values and that the model employed conservative assumptions that all activities generating dust are operated concurently and at their maximum rates of production. It should also be noted that, while the dust criteria conservatively exceeded the health-based criteria, the exposures were about 40 times lower than the occupational exposure limit.

Since 2015, the four measured exceedances in air quality were attributable to prevalent smoke from forest fires in the area and a heavy presence of pine pollen [14]. Therefore, conservative background concentrations and conservative emissions estimates used in the air modelling assessment, along with the assumption of the worst-case conditions occurring simultaneously with unfavourable meteorological conditions, contribute to an overestimate of the predicted particulate matter exceedances.

3.2.5.3 Findings

In the last 5 years (2016 to 2020), the estimated radiological doses for the selected human receptors have remained constant between assessments [14] [28]. Over the last licensing period (2013 to 2021), estimated radiological doses to the public have also remained well below the annual public dose limit of 1 mSv per year, indicating that radiological releases from the McArthur River Operation pose a negligible risk to human health (that is, potential risk to humans is similar to health outcomes in similar northern communities).

For hazardous substances, CNSC staff's review of the HHRA indicated that hazardous releases from the McArthur River Operation pose a negligible risk to human health (that is, potential risk to humans is similar to health outcomes in similar northern communities).

Based on assessments conducted for the McArthur River Operation, including the review of the 2015 and 2020 ERA, annual reports, and annual environmental monitoring data, CNSC staff have found that impacts to the human environment from radiological and hazardous substances released from the McArthur River Operation are negligible, and that people living and working near the facility remain protected given the highly conservative assumptions of the dispersion modelling likely overestimates the results.

4.0 CNSC Independent Environmental Monitoring Program

The CNSC has implemented its IEMP as an additional verification that Indigenous Nations and communities, the public and the environment around licensed nuclear facilities are protected. It is separate from, but complementary to the CNSC's ongoing compliance verification program. CNSC staff's findings are supported by IEMP sampling and by the licensee EP data and ERA predictions. The IEMP involves taking samples from publicly accessible areas around the facilities, and measuring and analyzing the amount of radiological and hazardous contaminant substances in those samples. For the uranium mines and mills in northern Saskatchewan, a qualified contractor, with the assistance of CNSC staff if feasible, collects the samples and send them to an accredited laboratory for testing and analysis.

4.1 IEMP at the McArthur River Operation

In 2021, for the most recent campaign, a qualified contractor conducted IEMP sampling around the McArthur River Operation site. CNSC staff developed the 2021 site-specific sampling plan with input from relevant Indigenous Nations and communities to ensure meaningful results were obtained. The sampling plan focused on radiological and hazardous contaminants and considered Cameco's EMP and the CNSC's regulatory knowledge of the site.

The accredited contractor collected the following samples in publicly accessible areas outside the perimeter of the McArthur River Operation:

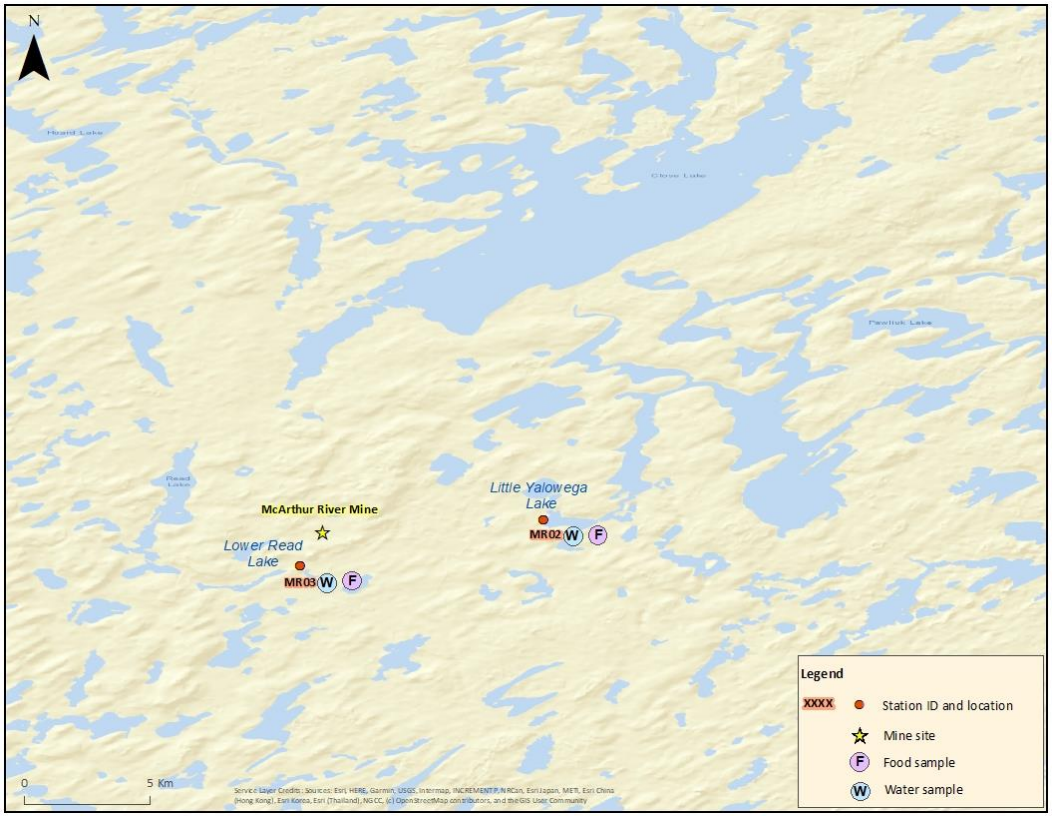
- water (2 locations, 3 samples per location)
- fish (2 locations, 3 samples of a benthic fish (lake whitefish) and 3 samples of a pelagic fish (northern pike) per location)
- Labrador tea (2 locations, 1 sample per location)
- blueberries (2 locations, 1 sample per location)

Samples collected were analyzed by qualified laboratory specialists in an accredited laboratory, using appropriate protocols. As requested by CNSC staff, the laboratory specialists measured radionuclides (radium-226, thorium-230, polonium-210 and lead-210), and hazardous substances (arsenic, copper, lead, molybdenum, nickel, selenium, uranium and zinc) in the collected samples. Water samples were also analyzed for ammonia, hardness, pH, and TSS. Labrador tea, and blueberry samples were also analyzed for moisture content in order for CNSC staff to convert the results from dry weight into wet weight to compare it against the screening levels.

Figure 4.1 provides an overview of the sampling locations for the 2021 IEMP sampling campaign around the McArthur River Operation. The IEMP results are published on the CNSC's IEMP web page [73].

In addition, in 2014, CNSC staff collected water samples at a reference station upstream of the effluent discharge point, and at an exposure station downstream of the effluent discharge point.

Figure 4.1: Overview of the 2021 sampling locations



4.2 Indigenous participation in the IEMP

It is a priority for the CNSC that IEMP sampling reflect Indigenous traditional land use, values and knowledge, where possible. In 2021, in advance of the IEMP sampling campaigns at McArthur River Operation, notification emails were sent to all Indigenous Nations and communities near the McArthur River Operation, inviting suggestions for species of interest, VCs or potential sampling locations where traditional practices and activities may take place.

In 2021, the CNSC met with English River First Nation (ERFN). These meetings provided CNSC staff with the opportunity to collaborate with Indigenous Nations and communities, to learn about their individual histories and cultures, and to address questions related to the operations at Cameco's McArthur River Operation. The following section summarize CNSC staff`s collaboration with ERFN during the 2021 sampling campaign.

4.2.1 Sampling with the English River First Nation

In June 2021, CNSC staff held teleconferences with ERFN to discuss the draft IEMP sampling plan. As part of their review, ERFN shared the draft IEMP sampling plan with a community elder. The community elder reviewed the draft sampling plan and concluded that the sampling locations and sampling media were acceptable to ERFN.

CNSC staff arranged with the accredited contractor to have a qualified and experienced member of ERFN join the sampling team. Unfortunately, the individual was unable to participate at the last moment. Due to the time constraints, the qualified contractor included a qualified and

experienced member of their staff, who is a member of the Lac La Ronge Indian Band, on their sampling team.

4.3 Summary of results

Most of the parameters in the samples measured during the 2021 IEMP sampling campaign were below available guidelines/screening levels. There were some exceedances of the CNSC's conservative screening levels in polonium-210 and selenium in fish tissue, at both the reference (far from site) and exposure (close to site) locations. All these exceedances were within the natural background of the region. CNSC staff performed a detailed assessment of the screening level exceedances and found that the environment is protected and that there are no anticipated health impacts. Results for all campaigns and the CNSC staff's assessment of the screening level exceedances are published on the CNSC's IEMP web page [73].

The CNSC's IEMP results in 2014 and 2021 are consistent with the results submitted by Cameco, supporting the CNSC's assessment that the licensee's EP program is effective. The IEMP results and conclusions are also consistent with the results and conclusions from the EARMP. The results add to the body of evidence that people and the environment in the vicinity of the McArthur River Operation are protected and that there are no anticipated health impacts.

5.0 Health studies

This section draws from the results of regional health studies, reports and other studies to provide further independent verification on whether the health of people living near, or working at the McArthur River Operation, in northern Saskatchewan, is protected. Various organizations, such as the Saskatchewan Health Authority and the Northern Inter-Tribal Health Authority (NITHA), monitor the health of people living near the McArthur River Operation. Disease rates of communities living near the McArthur River Operation are compared to similar populations to detect any potential health outcomes that may be of concern.

Cancer is the main health concern for occupational and environmental radiation exposures, and is thus the focus of health studies of workers and people living near nuclear facilities, such as the McArthur River Operation; however, all health outcomes were reviewed. The following subsections discuss several health studies and reports that have assessed the health of people living near the McArthur River Operation, including studies conducted by the CNSC to assess the health effects of workplace radiation exposure among Saskatchewan uranium workers.

CNSC staff continue to carefully monitor and conduct health studies to ensure the protection of human health. CNSC staff review any new publications and data related to the health of populations living near nuclear facilities. For additional information on health studies related to nuclear facilities, visit the CNSC's web page on health studies [74].

5.1 Population and community health studies and reports

5.1.1 Northern Saskatchewan Population Health Unit reports (latest 2019)

The Northern Saskatchewan Population Health Unit (PHU) monitors the health and living circumstances of the people of northern Saskatchewan. This includes changes in population and community characteristics, determinants of health, health service use, and the health status and well-being of northern Saskatchewan residents.

The Northern Saskatchewan Health Indicators reports developed by the PHU, provide an overview of the population of northern Saskatchewan. These reports include important community characteristics, determinants of health (that is, personal, social, economic and environmental factors that influence health status), and health status and well-being indicators. This information is important to put the communities' health into perspective.

The PHU published 2 Northern Saskatchewan Health Indicators reports, one in 2004 [75] and another one in 2011 [76], and updates and publishes health monitoring chapters on its Population Health Unit - Northern Saskatchewan website [77]. In addition, older reports (from 1998) are also available on the website for the Athabasca Health Authority, Keewatin Yatthé Regional Health Authority, and Mamawetan Churchill River Health Region.

Northern Saskatchewan Health Indicators report (August 2016) [78]

Community characteristics

Northern Saskatchewan is made up of the Keewatin Yatthé Health Region (KYHR) and Mamawetan Churchill River Health Region, and the Athabasca Health Authority . These are by geographical size the 3 largest health regions/authorities in Saskatchewan, together covering approximately 47% of the provincial surface area with over 70 communities and close to 40,000 individuals. The characteristics of the population of northern Saskatchewan are compared to the rest of the province (unless stated otherwise) to put people's health into perspective. The northern Saskatchewan geographical area encompasses all the uranium mine and mill facilities in Saskatchewan.

As of 2015, northern Saskatchewan has a much larger proportion of young people. Between 28% to 32% of its population is under 15 years of age, while only between 5% to 7% of residents are 65 years of age or older. Most people (85%) in northern Saskatchewan identify themselves as Indigenous (approximately 68% as First Nations and 19% as Metis). Between 44% and 84% of the population in northern Saskatchewan reported having an Indigenous language as their mother tongue, and between 28% and 71% reported that an Indigenous language was the language they spoke most often at home.

Social determinants of health (SDOH)

Compared to the rest of Saskatchewan, the overall income was around 40% lower in northern Saskatchewan in 2010, and northern Saskatchewan had lower rates of people with any educational qualifications (such as in high school, trades, college, and university). The long-term unemployment rates in northern Saskatchewan range between 3.3% and 15.6%, which is 3 to 5 times higher than the provincial rate. Individuals who self-identify as Indigenous tend to have lower income than the overall region.

Only between 21% and 44% of private dwellings in northern Saskatchewan are owned by the household (compared with 70% provincially). Likewise, northern Saskatchewan has between 2.5 to 4.3 times the proportion of dwellings requiring major repair, and between 4.8 and 11.4 times the rates of crowding. Safe housing is an important issue in northern Saskatchewan.

Smoking rates in northern Saskatchewan have remained high over the last number of years. The overall smoking rate in northern Saskatchewan in 2013-2014 was 41%, which was elevated in comparison to many other northern regions in Canada. In addition, non-smoking individuals in northern Saskatchewan are more likely to be exposed to second-hand smoke in vehicles/public places or at home compared to their provincial counterparts. Northern Saskatchewan has similar rates of heavy drinking, active physical activity levels, fruit and vegetable consumption, breast feeding initiation, sense of community belonging, and life satisfaction compared to other northern regions in Canada.

Note that the SDOH vary greatly among communities in northern Saskatchewan. Some communities score as good as, or better, than the province, while other communities struggle with rates that are up to 25 times worse than the province.

Health status

Significantly fewer people in northern Saskatchewan off-reserve communities report perceiving their own *health status* and *mental health status* as very good or excellent compared to the province. However, the northern Saskatchewan off-reserve population indicate similar rates of life stress compared to the province. The percentage of northern Saskatchewan off-reserve

population reporting good to full functional health has remained relatively stable from 2009 to 2010 and from 2013 to 2014, decreasing slightly from 78 to 76%. Similar rates are seen in the province and other northern regions in Canada.

Yearly total mortality rates in northern Saskatchewan have remained relatively stable over the past 10 years. Northern Saskatchewan rates have also consistently remained statistically greater than the province [79].

From 2005 to 2014, the leading causes of death in northern Saskatchewan were, in order; injuries, cancer, circulatory diseases and respiratory diseases. However, in the KYHR, cancers were ahead of injuries as the leading cause of death. Some of the main specific causes of death in northern Saskatchewan include ischemic heart disease (IHD), intentional self-harm, lung cancer, motor vehicle collisions, cerebrovascular disease, and chronic obstructive pulmonary disease (COPD).

Injuries are the leading cause of death in most age groups in the north with intentional self-harm, motor vehicle traffic accidents, assault, and accidental poisonings being most common. In the older age groups, chronic disease becomes the leading causes of death with ischemic heart disease, lung cancer and diabetes being most common. Of all deaths in northern Saskatchewan, 57% were deemed avoidable.

Cancer rates for all cancers combined in northern Saskatchewan are lower for males, and similar for females when compared to southern Saskatchewan. From 2010 to 2014, the leading causes of cancer incidence (that is, new cancer cases) were breast, lung and colorectal cancer in females, and prostate, lung and colorectal cancer in males. However, lung cancer was by far the leading cause of cancer deaths for both sexes, followed by breast and colorectal cancer for females and colorectal and prostate cancer for males (2010 to 2014). Importantly, lung cancer rates (both cases and deaths) are greater in northern Saskatchewan compared to the province.

Cigarette smoking is the leading cause of lung cancer in northern Saskatchewan. The number of daily cigarette smokers is significantly higher in northern Saskatchewan compared to the provincial average. According to the First Nation Food Nutrition and Environment Study [80], the smoking rate in some northern Saskatchewan Indigenous communities is estimated to be approximately 4 times the provincial rate, at 79%. Therefore, the impact of tobacco use on cancer in northern Saskatchewan may be even greater than in the province as a whole due to a substantially higher smoking rate. [81]

The total number of children (aged 0 to 14 years) diagnosed with cancer in Saskatchewan from 1990 to 2016 was 833. This included 23 children from northern Saskatchewan (about 1 child or fewer a year), meaning that childhood cancer rates are low [82].

5.1.2 Northern Inter-Tribal Health Authority health reports (latest 2010-2015)

The NITHA is an Indigenous partnership organization between the Prince Albert Grand Council, Meadow Lake Tribal Council, Peter Ballantyne Cree Nation and Lac La Ronge Indian Band. NITHA provides and maintains health services and public health programs in 33 Indigenous

communities in northern Saskatchewan. NITHA's Public Health Unit provides advice and expertise for various public health programs, including population health assessment, disease surveillance, health promotion, health protection, and disease and injury prevention. NITHA's Public Health Unit also develops health-related resources, including health status reports, for its partner community members. These resources are available on the NITHA website [83]. According to the latest health status report from 2017, the leading causes of death for NITHA's partner communities from 2010 to 2015 were cancer (32%), heart diseases (16%), accidental deaths (15%) and diabetes (8%) [83]. Lung cancer was the most common cause of death from cancer, representing approximately 32% of all cancer deaths [84].

5.1.3 Saskatchewan health status reports (latest 2016)

The Province of Saskatchewan produces health status reports which describe the health of the population and offer regional and, where possible, national comparisons. The health status reports draw from a variety of sources of information, including the Saskatchewan Ministry of Health's administrative health services databases, vital statistics, census data, and survey data (such as from the Canadian Community Health Survey). According to the latest Saskatchewan Health Status Report [85], the leading causes of mortality in Saskatchewan in 2009 were circulatory diseases, cancer, injuries and respiratory disease. While the Province of Saskatchewan's website does not indicate when the latest report was published, the data used is older than 2011 (with most data ranging from 1995 to 2009).

A fact sheet on the prevalence of asthma, COPD, diabetes, IHD and heart failure in Saskatchewan from 2012 and 2013 [86] noted the prevalence of asthma was lowest in northern Saskatchewan compared to the province as a whole. However, the prevalence of COPD, diabetes, IHD and heart failure was much higher in northern Saskatchewan compared to the provincial rates.

5.1.4 Saskatchewan Cancer Agency (latest by health region 2017)

From 2014 to 2017, the Saskatchewan Cancer Agency (SCA) collaborated with the Federation of Sovereign Indigenous Nations and with Métis communities on a 3-year cancer surveillance program to gain insight into how to serve First Nation and Métis Nations and communities better [87]. In partnership with 5 Indigenous communities across the province, the SCA collected information within these communities to ensure that they had access to appropriate cancer care programs and services. Working closely with communities was essential to this project, particularly in northern Saskatchewan, where engaging community members is so important for proper communication on cancer prevention; for early detection; cancer awareness, education, and surveillance; and for finding ways to support cancer patients and their families [88]. Youth engagement was also an important focus of this work.

The SCA also conducts cancer control reports, which profile cancer for regional health authorities. The most recent Saskatchewan Cancer Control Report from 2017 [89] combines the 3 northernmost health authorities (namely Mamawetan Churchill River, Keewatin Yatthé and Athabasca) into 1 region called "the North". This region of the province is unique because its population is small and much younger than in the rest of the province. The northern Saskatchewan Health Indicators reports use the data in the Cancer Control Reports. Cancer is most common in people over age 50. In 2014, 90% of new cancer cases diagnosed were in

people aged 50 and over, with 96% of cancer deaths occurring among those aged 50 and over. This age group is growing in Saskatchewan and continues to comprise an increasing proportion of Saskatchewan's population. Thus, as the northern Saskatchewan population ages, one can expect to see more cancer cases and deaths. This has important implications for planning cancer screening, diagnostic and treatment services.

5.1.5 Saskatchewan First Nations 2018 Health Status Report

Overall, many Saskatchewan Indigenous Nations and communities continue to experience health disparities related to the SDOH [90]. These SDOH affect a community's health and wellness, and contribute to the majority of health challenges faced by Saskatchewan Indigenous Nations and communities. Specifically, poverty, inadequate and overcrowded housing conditions and food insecurity have contributed to the persistent burden of communicable and chronic diseases. Some of the highlights of this report are as follows:

Demographics: Overall, the registered Saskatchewan Indigenous population living in Indigenous Nations and communities has increased from 61,564 to 75,165 from 2006–2016. The northern Saskatchewan Indigenous population had an average growth rate of about 23.3% per year between 2006 to 2016, with an increase in population from 28,884 to 35,611.

About half of the Saskatchewan Indigenous population living in Indigenous Nations and communities is younger than 25 years of age, accounting for 51.2% of the Indigenous communities' population in 2016. This is projected to grow by 34% from 75,165 in 2016 to 100,577 in 2034.

SDOH: These are the economic and social factors that influence the health of individuals and communities.

- Approximately 41% of the people living in Saskatchewan Indigenous Nations and communities speak an Indigenous *language*; Cree (26%) and Dene (10%) were the most common languages spoken at home. Culture and language is as strong social determinants of health for Indigenous peoples in Canada so revitalization of Indigenous peoples' culture and language is considered significant to improve their health status.
- In 2015, 37% of the Indigenous households in Saskatchewan Indigenous Nations and communities were classified as *food insecure*: 27% of the households were moderately insecure and 10% were severely insecure.
- The percentage of severely *overcrowded households* in Saskatchewan Indigenous Nations and communities remained relatively high but unchanged between 2006 and 2016 (16.2 % and 16.6%, respectively). This compares to ~1% in people with non-Indigenous identities. In addition, households in Saskatchewan Indigenous Nations and communities in 2016 were 7.6 times more likely to need major repairs compared to households in non-Indigenous communities (51.1% and 6.7%, respectively).
- Saskatchewan Indigenous peoples ages 25 to 54 years attained higher levels of *education* in 2016 compared to 2006. About 56% of people in Indigenous Nations and communities had a high school diploma or equivalency certificate or greater in 2016.
- between 2006 and 2016, the median *income* for Indigenous peoples ages 25 to 54 year old in Saskatchewan Indigenous Nations and communities increased by 40. 2% from

$11,312 to $15,861 respectively. However, there is a large income gap between Indigenous Nations and communities and non-Indigenous populations (median income $50,253 in 2016) in Saskatchewan.

- in Saskatchewan Indigenous Nations and communities, the *employment* rates among Indigenous peoples ages 25 to 54 decreased between 2006 and 2016 from 45.2% to 37.7%. This compares to the decreas from 86.8% to 85.0% for non-Indigenous identity people for the same time period.

5.2 Health studies of uranium mine workers

The Saskatchewan Uranium Miners' Cohort (SUMC) Study is a 2-part project conducted by the CNSC, the Government of Saskatchewan and industry stakeholders in the early 2000s.

The CNSC, Government of Saskatchewan, University of Saskatchewan, and industry stakeholders are currently working in partnership to conduct the new Canadian Uranium Workers Study (CANUWS) [91], which will follow up on the health of about 80,000 past and present uranium workers, including miners, millers and processing workers. This new study will consider workers from previous Canadian uranium worker studies, as well as present day workers from northern Saskatchewan and Ontario.

The following subsections provide more information on the SUMC Study and the CANUWS.

5.2.1 Saskatchewan Uranium Miners' Cohort Study

Part 1 of the SUMC Study [92] [93] looked at the relationship between lung cancer (deaths and new cancer cases) and exposure to radon and its decay products in a group of Eldorado uranium workers who worked at the Beaverlodge and Port Radium uranium mine sites and Port Hope radium and uranium facility from 1932 to 1980. Workers' mortality and cancer incidence were followed until 1999. This study represents an update of the original Eldorado study group (or cohort) that looked at mortality at the Beaverlodge [94] and Port Radium [95] mine sites from 1950 to 1980.

Part 1 of the SUMC Study makes the following conclusions:

- Most past uranium workers were male and overall, uranium mining, milling, and processing workers were as healthy as the general Canadian male population.
- Lung cancer was the only disease that consistently showed significantly higher death and cancer incidence rates among uranium workers.
- Overall, the excess risk of lung cancer death and cancer incidence increased linearly with increasing radon exposure.
- There was no relationship between radon exposure and any other disease, other than lung cancer.

Part 2 of the SUMC Study [96] determined whether it was scientifically possible to assess the number of excess lung cancers from the relatively low radon exposure in modern miners from 1975 onward. The type of risk assessed was the increased risk of lung cancer resulting from radon exposure. The study considered factors such as smoking and residential radon exposure as potential confounding factors of the relationship between lung cancer and radon.

Part 2 of the SUMC Study made the following conclusions:

- Today's Saskatchewan uranium miners have radon exposures that are significantly lower than those of past miners because of dose limits, improved mining techniques and other radiation protection practices.
- By the year 2030, about 24,000 workers will have spent time working at a uranium mine. During the period under study, 141 miners are expected to develop lung cancer, primarily from tobacco smoking. Only 1 additional miner could expect to get lung cancer from exposure to radon in the workplace.
- It is not feasible to investigate the risk of excess lung cancer in modern miners because exposures are so low. It is also practically impossible to correct for the effects of smoking and residential radon, factors that could greatly affect the study results.

However, CNSC staff continue to monitor the occupational exposures of uranium miners to ensure they remain as low as reasonably achievable. The National Dose Registry maintains exposure records indefinitely.

5.2.2 The Canadian Uranium Workers Study

The CANUWS is a multi-year project initiated by CNSC staff in 2017 to assess the health effects of occupational radiation exposure among uranium workers [97]. The project involves researchers from the CNSC, Health Canada and the University of Saskatchewan. This retrospective cohort study will assess the information of over 80,000 Canadian uranium mine, mill and processing workers with occupational radiation exposures from 1932 to 2017. The study will follow-up on workers' mortality (1950 to 2017) and cancer incidence (1969 to 2017).

The main objective of the CANUWS is to study the relationship between radon and lung cancer, especially the potential health effects of low cumulative radon exposures and exposure rates. This is possible due to high-quality exposure measurements and the long-term follow-up of workers' health outcomes, with the consideration of workers employed after radiation protection measures were in place. The findings of the study will help to assess the adequacy of occupational radiation safety standards and support future licensing recommendations.

The CANUWS was planned to be completed by 2022-23; however this timeline may be extended because of delays in data linkage and data access as a result of the COVID-19 pandemic. In June 2022 CNSC staff presented an update of the study's progress to the Northern Saskatchewan Environmental Quality Committee. Additionally, annual study progress reports are communicated to interested parties, such as impacted workers and Indigenous Nations and communities.

5.3 Summary of health studies

Ongoing review and conduct of health studies and reports is an important component of ensuring that the health of people living near or working in nuclear facilities is protected. Overall, many Saskatchewan Indigenous Nations and communities continue to experience health disparities related to the SDOH [90] that affect a community's health and wellness, and that contribute to the majority of health challenges faced by Saskatchewan Indigenous Nations and communities.

The population and community health studies and reports indicate that the most common causes of death among the northern Saskatchewan population are cancer and heart disease, alongside injuries, respiratory diseases, and diabetes. This is similar to the rest of Canada, where heart

disease and cancer are the 2 leading causes of death. The exception is Nunavut, where heart and respiratory diseases are the leading causes of death [98].

In northern Saskatchewan, cancer is predominantly seen in people aged 50 years and older, which is not atypical given that cancer rates tend to increase as a population ages. Overall, cancer rates for all cancers combined in northern Saskatchewan are lower for males, and similar for females, when compared to southern Saskatchewan. However, lung cancer rates are greater in northern Saskatchewan compared to the provincial average, and lung cancer is the most common cause of cancer death in Indigenous Nations and communities in northern Saskatchewan. To put this into perspective, lung cancer is projected to continue to be the most commonly diagnosed cancer and the leading cause of cancer death in Canada in 2020, accounting for 1 in 4 of all cancer deaths [99]. Colorectal, breast, and prostate cancer are also leading causes of cancer incidence and mortality.

According to the Canadian Cancer Society, about 72% of lung cancer cases in Canada are due to smoking tobacco [99] [100]. Other factors include second-hand smoke, radon, asbestos, occupational exposure to certain chemicals, outdoor air pollution, family history and radiation. The number of daily smokers in northern Saskatchewan is significantly higher than the provincial average [78] [80]. Furthermore, the proportion of Saskatchewan residents who reported daily or occasional smoking was significantly higher than that of Canadian residents [101]. In Canada, exposure to indoor radon is the second leading cause of lung cancer [102]. Research from the Saskatchewan Cancer Agency has demonstrated that community work is essential to cancer control, particularly in northern Saskatchewan, where the focus should be on cancer prevention and education, and ways to support cancer patients and their families [89].

Studies of uranium workers help us assess workers' health and understand the relationship between workplace radiation and health. Part one of the SUMC showed that the overall health of workers employed at mines between 1932 and 1980 was similar to the general male population, except for lung cancer incidence and mortality, which were significantly greater in workers compared to the general male population. The risk of lung cancer increased linearly with increasing radon exposure. Part 2 of the SUMC demonstrated that assessing the risk of excess lung cancer resulting from radon exposure in modern miners from 1975 onward is not feasible because exposure is too low and correcting for the effects of smoking and residential radon would be practically impossible. However, strict radiation protection measures exist, including the ongoing monitoring of occupational exposure, to ensure the protection of uranium workers' health. Most recently, CNSC staff and other stakeholders started a new study of all past and present Canadian uranium workers. This large study will add to the understanding of the relationship between radon and lung cancer, especially at the low cumulative exposure and exposure rates of today's workers.

Based on exposure and health data, CNSC staff have not observed and do not expect any adverse health outcomes to northern Saskatchewan communities or workers resulting from the presence of the McArthur River Operation.

6.0 Other environmental monitoring programs

Several monitoring programs are carried out by other levels or bodies of government, and are reviewed by CNSC staff to confirm that the environment and the health and safety of persons around the facility in question are protected. A summary of the findings of these programs is provided below.

6.1 Cumulative Effects

A formal cumulative effects assessment is not a requirement within CNSC staff's assessments for EPRs as it is not a requirement under the NSCA and other regulatory documents. However, CNSC staff's assessments do consider the accumulation of COPCs within the environment because of the facility or activity through the cyclical nature of environmental risk assessments, the monitoring data in annual reports, data from the IEMP, and results from any regional monitoring programs and health studies. The CNSC has and continues to be involved in monitoring for cumulative effects and in regional monitoring outside of the potential influence of a single licensed facility or activity.

Licensees are required to meet onsite and near-field monitoring requirements associated with their provincial approvals and the federal regulations, including full life-cycle requirements. These programs focus on single operations with scheduled reports on performance submitted to the regulators. These activities are further supplemented by the CNSC's IEMP activities (see section 4.0), which focuses on local areas where Indigenous Nations and communities and members of the public could reasonably be expected to conduct recreational or traditional activities (that is, off-site accessible areas).

Despite the robustness of site monitoring programs and community and Indigenous engagement activities associated with the IEMP, concern related to overlapping effects from multiple sites remain. In response, over the years, several industry- and government-established community-based regional programs have developed.

The McArthur River Operation has been the focus of several environmental monitoring programs due to the long history of uranium mining and milling in the region. These include the site-specific licensee programs, the CNSC's IEMP campaigns within the area, and the further afield regional cumulative effects and community-based monitoring programs such as the Eastern Athabasca Regional Monitoring Program (EARMP) and the Community Based Environmental Monitoring Programs, completed under collaboration agreements between industry and Indigenous Nations and communities in the basin. The conclusion from these programs is that the environment and the health and safety of persons are protected.

6.2 Eastern Athabasca Regional Monitoring Program

Due to community concerns related to cumulative impacts from multiple operations, the EARMP was launched in 2011 with funding by the Government of Saskatchewan and industry (Cameco and Orano). The CNSC became a funding partner in 2017-18. The following year, the EARMP was extended with the signing of a 5-year funding agreement (from 2018-19 to 2022-23) between the CNSC, the Government of Saskatchewan, and the uranium mine and mill industry.

The EARMP is an environmental monitoring program designed to gather data on potential cumulative impacts downstream of uranium mine and mill operations. The EARMP is made up

of 2 programs: the community program and the technical program. The community program monitors the safety of traditionally harvested country foods. The technical program monitors the aquatic environment at reference and far-field stations to determine if there are any cumulative impacts to aquatic communities. Both components involve a high level of community involvement and communication and have been implemented by a local Indigenous-owned environmental consulting firm.

The technical program was established to monitor potential long-term changes in the aquatic environment downstream of uranium mining and milling operations where drainages from multiple discharges combined. Four cumulative assessment areas (one at each outlet of Wollaston Lake, Waterbury Lake, and Crackingstone Inlet on Lake Athabasca) and three reference areas (Cree Lake, Pasfield Lake and Ellis Bay on Lake Athabasca) were established. The complete suite of media and analyses were completed at these sites with additional supplemental data identified from Bobby's Lake (2009 and 2012) and Wollaston Lake Ivison Bay (at reference station #4 in 2008 and 2012). Sampling involved water, sediment and fish tissue for chemical analyses along with collections to characterize the benthic macroinvertebrate community composition. All of these remote locations are realistically only accessible via aircraft. Sampling campaigns were completed in 2011 and 2012 to establish a current baseline with an asssessment campaign completed in 2015. The assessment concluded there was little evidence of change from the baseline monitoring period and the assessment period [103].

The community program monitors the safety of traditionally harvested country foods through analysis of water, fish, berries and wild meat (namely grouse, rabbit, caribou and moose) from northern Saskatchewan communities. Samples are collected from areas identified by community members, who either assist in sample collection or provide samples from their own harvesting activities. The community based prgram has involved consistent annual sampling of water and fish with the additional media sampled on a cyclical basis since the establishment of the initial current baseline (2011-2012).

6.2.1 Findings

The results of the program showed that concentrations of COPCs have been relatively consistent over time and generally within the regional reference range. This indicates that there is no evidence of long-range transport of contaminants associated with uranium mining and milling. Thus, the EARMP concludes that water and country foods are safe for consumption. CNSC staff reviewed the EARMP technical reports and data and agree with the EARMP's conclusions.

The EARMP technical reports and data are available on the EARMP website [104].

6.2.2 Future of EARMP

With the 2022/23 fiscal year being the last year of the current EARMP funding agreement, the EARMP partners have been considering its future. Uranium mining and milling activities, regional and community monitoring programs, and resident and Indigenous expectations and capabailities regarding active participation and engagement in environmetal stewardship have all substantially changed since EARMP's inception in 2011. One of the current proposals is for the 2023/24 fiscal year to serve as a year of engagement with government (provincial and federal), industry and Indigenous representatives to discuss regional monitoring within the Athabasca Basin as a whole and the future of EARMP specifically. The goal is to optimize environmetal

monitoring and engagement activities to the benefit of those who work and live in the Athabasca Basin. CNSC staff are actively involved in discussions regarding the future of EARMP.

6.3 National Pollutant Release Inventory

As discussed in section 2.4 of this report, ECCC operates the NPRI [45], which is Canada's public inventory of pollutant releases, disposals and transfers, tracking over 320 pollutants from over 7,000 facilities across the country. Reporting facilities include factories that manufacture a variety of goods; mines; oil and gas operations; power plants; and sewage treatment plants. Information that is collected includes:

- releases from facilities to air, water or land
- disposals at facilities or other locations
- transfers to other locations for treatment and recycling
- facility activities, location and contacts
- pollution prevention plans and activities [105]

CNSC staff conducted a search of the NPRI database and found that the uranium mines and mills (namely Cigar Lake, Key Lake, McArthur River, Rabbit Lake and McClean Lake) are the only facilities from the Athabasca Basin that report to the NPRI. CNSC staff's review of the data did not find any trends or unusual results. Note that radionuclides are not included in the inventory of pollutants in the NPRI database. CNSC staff receive radionuclide loadings from the uranium mine and mill licensees through other means, such as annual and quarterly reports. This information has been used in this report, but the complete dataset is available for download on the CNSC's Open Government Portal [106].

7.0 Findings

This EPR report focused on items of current Indigenous, public and regulatory interest, including airborne and waterborne releases from ongoing operations at the McArthur River Operation. CNSC staff have found that the potential risks from radiological and hazardous releases to the atmospheric, terrestrial, aquatic and human environments from the McArthur River Operation are low to negligible, and that the people and the environment remain protected.

7.1 CNSC staff's findings

CNSC staff's findings from this EPR report may inform and support staff recommendations to the Commission in future licensing and regulatory decisions that pertain to the McArthur River Operation. These findings are based on CNSC staff's technical assessments associated with Cameco's McArthur River Operation, such as the submitted ERA documentation and the conduct of compliance verification activities, including the review of annual and quarterly reports, and onsite inspections. CNSC staff also reviewed the results from various relevant or comparable health studies, and other environmental monitoring programs conducted by other levels of government, to substantiate their findings. CNSC staff also conducted IEMP sampling around the McArthur River Operation in 2021.

Based on their assessment of Cameco's documentation, CNSC staff have found that the potential risks from radiological and hazardous releases to the atmospheric, aquatic, terrestrial and human environments from the McArthur River Operation are low to negligible. The potential risks to the environment from these releases or stressors are similar to natural background, and the potential risks to human health are indistiguishable from health outcomes in similar northern communities. Therefore, CNSC staff have found that Cameco has and will continue to implement and maintain effective EP measures to adequately protect the environment and the health and safety of persons. CNSC staff will continue to verify and ensure that, through ongoing licensing and compliance activities and reviews, the environment and the health and safety of persons are protected.

8.0 Abbreviations

Units

Bq/L	becquerels per litre
Bq/m^3	becquerel per cubic meter
kg	kilogram
km	kilometer
m^3	cubic meters
mg/L	milligrams per litre
mSv	millisievert
µGy	microgray
µGy/h	microgray per hour

Acronyms

AAQC	Ambient Air Quality Criteria
AL	action level
ALARA	as low as reasonably achievable
BATEA	*best available technology economically available*
Cameco	Cameco Corporation
CANUWS	Canadian Uranium Workers Study
CCME	Canadian Council of Ministers of the Environment
CEAA (1992)	*Canadian Environmental Assessment Act, 1992*
CEAA (2012)	*Canadian Environmental Assessment Act, 2012*
CEPA (1999)	*Canadian Environmental Protection Act, 1999*
CNSC	Canadian Nuclear Safety Commission
CO	carbon monoxide
COPC	constituent of potential concern
COPD	chronic obstructive pulmonary disease
EA	environmental assessment
EARP	Environmental Assessment and Review Process
EARMP	Eastern Athabasca Regional Monitoring Program
ECCC	Environment and Climate Change Canada
ECOP	environmental code of practice

EEM	environmental effects monitoring
EMP	environmental monitoring program
EMS	environmental management system
EP	environmental protection
EPP	environmental protection program
EPR	environmental protection review
ERA	environmental risk assessment
ERFN	English River First Nations
GHG	greenhouse gas
HHRA	human health risk assessment
IAA	*Impact Assessment Act*
IEMP	Independent Environmental Monitoring Program
IHD	Ischemic Heart Disease
IOC	investigation of cause
ISO	International Organization for Standardization
ISQG	Canadian Interim Sediment Quality Guidelines for the Protection of Aquatic life
KYHR	Keewatin Yatthé Health Region
LEL	Lowest Effects Levels
LCH	licence conditions handbook
MDMER	*Metal and Diamond Mining Effluent Regulations*
MOU	Memorandum of Understanding
NITHA	Northern Inter-Tribal Health Authority
NOx	nitrogen oxides
NPRI	National Pollutant Release Inventory
NSCA	*Nuclear Safety and Control Act*
PDP	preliminary decommissioning plan
PHU	Population Health Unit
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 microns in diameter
PM_{10}	particulate matter less than 10 microns in diameter
PSQG	Canadian Probable Effects Level Sediment Quality Guidelines
ROR	regulatory oversight report

SARA	*Species at Risk Act*
SCA	Saskatchewan Cancer Agency
SDOH	social determinants of health
SEL	Severe Effects Levels
SEQG	Saskatchewan Environmental Quality Guidelines
SO_2	sulphur dioxide
SUMC	Saskatchewan Uranium Miners' Cohort
TSP	total suspended particulate
VC	valued component

9.0 References

[1] Government of Canada, "Nuclear Safety and Control Act (S.C. 1997, c.9)," amended January 1, 2017. https://laws-lois.justice.gc.ca/eng/acts/n-28.3/page-1.html#h-368751

[2] Canadian Nuclear Safety Commission, "Indigenous Knowledge Policy Framework," December 2021. https://nuclearsafety.gc.ca/eng/resources/aboriginal-consultation/indigenous-knowledge-policy.cfm

[3] Cameco Corporation, "McArthur River Operation Preliminary Decommissioning Plan," January 2019.

[4] Cameco Corporation, "McArthur River Operation: 2013 Annual Report," March 2014.

[5] Cameco Corporation, "McArthur River Operation: 2014 Annual Report," March 2015.

[6] Cameco Corporation, "McArthur River Operation: 2015 Annual Report," March 2016.

[7] Cameco Corporation, "McArthur River Operation: 2016 Annual Report," March 2017.

[8] Cameco Corporation, "McArthur River Operation: 2017 Annual Report," March 2018.

[9] Cameco Corporation, "McArthur River Operation: 2018 Annual Report," March 2019.

[10] Cameco Corporation, "McArthur River Operation: 2019 Annual Report," March 2020.

[11] Cameco Corporation, "McArthur River Operation: 2020 Annual Report," March 2021.

[12] Cameco Corporation, "McArthur River Operation: 2021 Annual Report," March 2022.

[13] EcoMetrix Incorporated, "McArthur River Operation Environmental Risk Assessment 2015," August 2015.

[14] Canada North Environmental Services, "McArthur River Operation Environmental Risk Assessment," December 2020.

[15] CNSC, "McArthur River Mine," http://nuclearsafety.gc.ca/eng/uranium/mines-and-mills/nuclear-facilities/mcarthur-river-lake/index.cfm

[16] CNSC, "UML-MINE-MCARTHUR.01/2023," June 2019.

[17] CNSC, "Licence Conditions Handbook – McArthur River Operation UML-MINE-MCARTHUR.01/2023," February 2020.

[18] Government of Canada, "The Federal Environmental Assessment and Review Process," 1987. https://publications.gc.ca/collections/collection_2017/acee-ceaa/En106-4-1987-eng.pdf

[19] Government of Canada, "Canadian Environmental Assessment Act (Repealed, 2012, c. 19, s. 66)," 1992. https://laws-lois.justice.gc.ca/eng/acts/c-15.2/index.html

[20] Government of Canada, "Canadian Environmental Assessment Act, 2012 (Repealed, 2019, c. 28, s. 9)," 2012. https://laws-lois.justice.gc.ca/eng/acts/C-15.21/

[21] Government of Canada, "Impact Assessment Act (c. 28, s. 1)," 2019. https://laws-lois.justice.gc.ca/eng/acts/I-2.75/

[22] Government of Canada, "Physical Activities Regulations (SOR/2019-285)," 2019. https://laws-lois.justice.gc.ca/eng/regulations/SOR-2019-285/FullText.html

[23] McArthur River Joint Venture, "Environmental Impact Statement McArthur River Project," 1995.

[24] McArthur River Joint Venture, "Addendum to the Environmental Impact Statement - McArthur River Project," June 1996.

[25] Joint Federal-Provincial Panel on Uranium Mining Developments in Northern Saskatchewan, "Panel Report - Report of the Joint Federal-Provincial Panel on Uranium Mining Developments in Northern Saskatchewan (McArthur River)," February1997. https://iaac-aeic.gc.ca/archives/pre-2003/76C904A0-1/default_lang=En_n=8D68F440-1.html

[26] CNSC, "BMD 97-125 - McArthur River Project Construction Licence," 1997.

[27] Canadian Nuclear Safety Commission, "REGDOC-2.9.1, Environmental Protection: Environmental Principles, Assessments and Protection Measures," 2017. http://www.nuclearsafety.gc.ca/eng/pdfs/REGDOCS/REGDOC-2-9-1-Environmental-Principles-Assessments-and-Protection-Measures-eng.pdf

[28] CSA Group, CSA N288.4-10, "Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills, Update No.2," May 2015.

[29] CSA Group, CSA N288.5-11, "Effluent Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills," May 2010.

[30] CSA Group, CSA N288.6-12, "Environmental Risk Assessment at Class I Nuclear Facilities and Uranium Mines and Mills," June 2012.

[31] CSA Group, CSA N288.7-15, "Groundwater Protection Programs at Class I Nuclear Facilities and Uranium Mines and Mills," June 2015.

[32] CSA Group, CSA N288.8-17, "Establishing and Implementing Action Levels for Releases to the Environment from Nuclear Facilities," February 2017.

[33] Canadian Nuclear Safety Commission, "REGDOC-3.1.2, Reporting Requirements, Volume I: Non-Power Reactor Class I Nuclear Facilities and Uranium Mines and Mills," 2018. http://www.nuclearsafety.gc.ca/eng/acts-and-regulations/regulatory-documents/published/html/regdoc3-1-2-v1/index.cfm

[34] Canadian Nuclear Safety Commission, "Radiation Protection Regulations (SOR/2000-203)," 2000. https://laws-lois.justice.gc.ca/eng/regulations/sor-2000-203/page-1.html

[35] Cameco Corporation, “McArthur River/Key Lake” 2022. https://www.cameco.com/businesses/uranium-operations/canada/mcarthur-river-key-lake .

[36] Canadian Nuclear Safety Commission, "Regulatory Oversight Reports," 2021. http://nuclearsafety.gc.ca/eng/resources/publications/reports/regulatory-oversight-reports/index.cfm

[37] Cameco Corporation, "McArthur River Operation Environmental Protection Program," November 2021.

[38] Governement of Canada, "Metal and Diamond Mining Effluent Regulations (SOR/2002-222)," amended June 24, 2022. https://laws-lois.justice.gc.ca/eng/regulations/sor-2002-222/FullText.html

[39] Government of Canada, "Uranium Mines and Mills Regulations (SOR/2000-206)," amended September 22, 2017. https://laws-lois.justice.gc.ca/eng/regulations/SOR-2000-206/index.html

[40] Government of Canada, "Canadian Environmental Protection Act, 1999 (c. 33)," amended May 1, 2021. https://laws-lois.justice.gc.ca/eng/acts/c-15.31/

[41] Government of Canada, "Notice with Respect to Reporting of Greenhouse Gases for 2016," December 2016. https://gazette.gc.ca/rp-pr/p1/2016/2016-12-10/html/notice-avis-eng.html

[42] Government of Canada, "Greenhouse Gas Reporting Program," 2022. https://climate-change.canada.ca/facility-emissions/

[43] Canadian Nuclear Safety Commission, "Memorandum of Understanding between Environment Canada and the Canadian Nuclear Safety Commission," 2003. http://www.nuclearsafety.gc.ca/eng/pdfs/MoU-Agreements/June-2012-MOU-between-CNSC-and-Environment-Canada_e.pdf

[44] Government of Canada, "Federal Halocarbon Regulations, 2022 (SOR/2022-110)," September 2022. https://laws-lois.justice.gc.ca/eng/regulations/SOR-2022-110/index.html

[45] Government of Canada, "National Pollutant Release Inventory," 2022. https://www.canada.ca/en/services/environment/pollution-waste-management/national-pollutant-release-inventory.html

[46] Government of Canada, "National Pollutant Release Inventory - Substance List by Threshold," 2022. https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/substances-list/threshold.html

[47] Saskatchewan Ministry of Environment, "Approval to Operate Pollutant Control Facilities PO17-024," February 2017.

[48] Government of Saskatchewan, "The Mineral Industry Environmental Protection Regulations, 1996 (c. E-10 Reg. 7)," March 1996. http://qp.gov.sk.ca/m/index.cfm?action=browse&p=1060

[49] Government of Canada, "Fisheries Act (R.S.C., 1985, c. F-14)," amended August 28, 2019. https://www.laws-lois.justice.gc.ca/eng/acts/F-14/

[50] SENES Consultants Limited, "Final Report: Uranium in Effluent Treatment Process - Prepared for the CNSC," March 2006.

[51] Canadian Nuclear Safety Commission, "REGDOC-2.9.2, Controlling Releases to the Environment (Draft)," March 2021. https://www.nuclearsafety.gc.ca/eng/pdfs/regulatory-documents/regdoc2-9-2/REGDOC-2_9_2_Controlling_Releases_to_the_Environment.pdf

[52] Cameco Corporation, "McArthur River Industrial Air Source Environmental Protection Plan," September 2019.

[53] Cameco Corporation, "McArthur River Operation Mining Facility Licensing Manual," September 2021.

[54] Canadian Nuclear Safety Commission, "Record of Proceedings, Including Reasons for Decision in the Matter of Cameco Corporation's Application to Amend the Key Lake Operation Uranium Mill Operationg Licence," January 2007.

https://nuclearsafety.gc.ca/eng/the-commission/pdf/2009-06-09-Decision-Cameco-KeyLake-Edocs3388649.pdf

[55] Canadian Nuclear Safety Commission, "Record of Proceedings, Including Reasons for Decision in the Matter of Cameco Corporation's Application to Renew the Operating Licence for the Key Lake Uranium Mill," June & September 2008. http://www.nuclearsafety.gc.ca/eng/the-commission/pdf/2008-09-17-Decision-Cameco-KeyLake-e-Final-Edocs3300287.pdf

[56] Canada Northern Environmental Services, "McArthur River Operation Environmental Performance Report," December 2020.

[57] Canadian Nuclear Safety Commission, "Technical Assessment of McArthur River Operation Environmental Risk Assessment 2015 and Environmental Performance report 2010 to 2014," 2015.

[58] Canadian Council of Ministers of the Environment, "Canadian Environmental Quality Guidelines," 1999. http://ceqg-rcqe.ccme.ca/

[59] Action et al., "The Ecoregions of Saskatchewan," Canadian Plains Research Centre, Regina, Saskatchewan, 1998.

[60] Government of Saskatchewan, "The Species at Risk Regulations," 1999. https://www.saskatchewan.ca/business/environmental-protection-and-sustainability/wildlife-and-conservation/wildlife-species-at-risk

[61] Government of Canada, "Species at Risk Act (S.C. 2002, c. 29)," 2002. https://laws-lois.justice.gc.ca/eng/acts/s-15.3/

[62] Government of Saskatchewan, "Saskatchewan Environmental Quality Guidelines," 2017. https://envrbrportal.crm.saskatchewan.ca/seqg-search/

[63] Government of Canada, "Canadian Environmental Protection Act, 1999, Federal Environmental Quality Guidelines Cobalt," 2017. https://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=92F47C5D-1#toc08

[64] Thompson P. A., Kurias J., & Mihok S., "Derivation and Use of Sediment Quality Guidelines for Ecological Risk Assessment of Metals and Radionuclides Released to the Environment from Uranium Mining and Milling Activities in Canada," *Environmental Monitoring and Assessment*, vol. 110, pp. 71-85, 2005.

[65] Cameco Corporation, "Comprehensive Aquatic Environmental Monitoring Report," June 2022.

[66] Government of Canada, "Species at Risk Public Registry," November 2020. http://www.sararegistry.gc.ca/

[67] Fisheries and Oceans Canada, "Aquatic Species at Risk Map," August 2019. https://www.dfo-mpo.gc.ca/species-especes/sara-lep/map-carte/index-eng.html

[68] CanNorth, "McArthur River Investigation of Cause Final Report," 2019.

[69] CanNorth, "McArthur River Operation 2012 comprehensive aquatic monitoring report," 2013.

[70] CanNorth, "McArthur River Operation 2015 comprehensive aquatic monitoring report," 2016.

[71] Canadian Environmental Protection Act Federal Provincial Advisory Committee Working Group on Air Quality Objectives and Guidelines (CEPA/FPAC WGAQOG), "National Ambient Air Quality Objectives for Particulate Matter Executive Summary: Part 1 - Science Assessment Document. Cat. No. H46-2/98-220.," 1998.

[72] California Air Resources Board, "Staff Report: Methodology for Estimating Premature Deaths Associated with Long-term Exposures to Fine Airborne Particulate Matter in California.," 2008.

[73] Canadian Nuclear Safety Commission, "Independent Environmental Monitoring Program (IEMP)," 2022. http://www.nuclearsafety.gc.ca/eng/resources/maps-of-nuclear-facilities/iemp/index.cfm

[74] Canadian Nuclear Safety Commission, "Health Studies," 2021. http://www.nuclearsafety.gc.ca/eng/resources/health/index.cfm

[75] Irvine J., Stockdale D., & Oliver R., "Northern Saskatchewan Health Indicators Report 2004, Prepared for the Athabasca Health Authority, Keewatin Yatthé Health Region and Mamawetan Churchill River Health Region, Population Health Unit," 2004. http://www.mcrhealth.ca/media/files/2004 Health Indicators Report revision1.pdf

[76] Irvine J., Quinn B., & Stockdale D., "Northern Saskatchewan Health Indicators Report 2011, Prepared for the Athabasca Health Authority, Keewatin Yatthé Health Region and Mamawetan Churchill River Health Region, Population Health Unit," 2011. http://www.mcrhealth.ca/media/files/Northern Saskatchewan Health Indicators Report 2011.pdf

[77] Northern Saskatchewan Population Health Unit, "Homepage – Population Health Unit," 2022. https://populationhealthunit.ca/

[78] Northern Saskatchewan Population Health Unit, "Northern Saskatchewan Health Indicators Report. August 2016. https://populationhealthunit.ca/health_monitoring_and_research.html

[79] Northern Saskatchewan Population Health Unit, "Northern Saskatchewan Health Indicators - Health Status: Mortality," November 2017. https://populationhealthunit.ca/mrws/filedriver/Health_Indicator_reports/Health_Status_-_Mortality.pdf

[80] Chan H.M., Fediuk K., Batal M., Sadik T., Tikhonov C., Ing A. & Barwin L., "First Nations Food, Nutrition and Environment Study (FNFNES): Results from Saskatchewan (2015)," 2018. The First Nations Food, Nutrition and Environment Study (2008–2018)—rationale, design, methods and lessons learned - PMC (nih.gov)

[81] Northern Saskatchewan Population Health Unit, "Northern Saskatchewan Health Indicators - Health Status: Chronic disease and Traffic Collisions," October 2019. https://populationhealthunit.ca/mrws/filedriver/Health_Status_-_Chronic_disease_and_MVTC_Oct_2019.pdf

[82] Irvine J., "Health Status Reporting in Northern Saskatchewan: Presentation to Northern Saskatchewan Environmental Quality Committee," July 2019.

[83] Northern Inter-Tribal Health Authority, "Health Status Report 2010-2015: Vital Statistics," 2017. http://www.nitha.com/wp-content/uploads/2017/12/Health-Status-Report-Chapter-3-Vital-Statistics.pdf

[84] Northern Inter-Tribal Health Authority, "Vital Statistics: NITHA, 2010-2015," http://www.nitha.com/wp-content/uploads/2017/12/Vital-Statistics-Infographic.pdf

[85] Government of Saskatchewan, "Saskatchewan Health Status Report, Chapter 5: Mortality," https://pubsaskdev.blob.core.windows.net/pubsask-prod/108313/108313-Mortality.pdf

[86] Government of Saskatchewan, "Prevalence of Asthma, Chronic Obstructive Pulmonary Disease (COPD), Diabetes, Ischemic Heart Disease (IHD) and Heart Failure in Saskatchewan 2021/2013," July 2016.

[87] Saskatchewan Cancer Agency, "Cancer Surveillance," 2022. http://www.saskcancer.ca/research-article/cancer-surveillance

[88] Saskatchewan Cancer Agency, "First Nations and Métis Cancer Surveillance Program – Improving Care, YouTube Video," March 2018. https://www.youtube.com/watch?v=3PdwcdKv5ko&feature=emb_title

[89] Saskatchewan Cancer Agency, "Saskatchewan Cancer Control Report – Profiling Cancer in Regional Health Authorities," 2017. http://www.saskcancer.ca/images/pdfs/research/epidemiology/Profiling Cancer in Regional Health Authorities 2017.pdf

[90] Indigenous Services Canada, "Saskatchewan First Nations 2018 Health Status Report," 2018. https://www.cps.sk.ca/iMIS/Documents/For Physicians/Indigenous Wellness/ISC_FNIHB_SFN_2018_Health_Status_Report-FINAL.pdf

[91] Canadian Nuclear Safety Commission, "Saskatchewan Uranium Miners Cohort Study," 2015. http://www.nuclearsafety.gc.ca/eng/resources/health/health-studies/feasibility-study-saskatchewan-uranium-miners-cohort-study.cfm

[92] Canadian Nuclear Safety Commission, "Updated Analysis of the Eldorado Uranium Miners' Cohort – Part I of the Saskatchewan Uranium Miners' Cohort Study (RSP-0205)," 2015. http://www.nuclearsafety.gc.ca/eng/resources/health/health-studies/eldorado/

[93] Lane R. S. D., Frost S. E., Howe G. R., & Zablotska L. B., "Mortality (1950–1999) and Cancer Incidence (1969–1999) in the Cohort of Eldorado Uranium Workers," *Radiation Research*, vol. 174, pp. 773-785, 2010.

[94] Howe G. R., Nair R. C., Newcombe H. B., Miller A. B., & Abbat J. D., "Lung Cancer Mortality (1950–80) in Relation to Radon Daughter Exposure in a Cohort of Workers at the Eldorado Beaverlodge Uranium Mine," *Journal of the National Cancer Institute*, vol. 77, pp. 357-362, 1986.

[95] Howe G. R., Nair R. C., Newcombe H. B., Miller A. B., Burch J. D., & Abbat J. D., "Lung Cancer Mortality (1950–80) in Relation to Radon Daughter Exposure in a Cohort of Workers at the Eldorado Port Radium Uranium Mine: Possible Modification of Risk by Exposure Rate," *Journal of the National Cancer Institute*, vol. 79, pp. 1255-1260, 1987.

[96] Canadian Nuclear Safety Commission, "Feasibility Study: Saskatchewan Uranium Miners Cohort Study (Part II of the Saskatchewan Uranium Miners' Cohort Study)," 2003. http://www.nuclearsafety.gc.ca/eng/resources/health/health-studies/feasibility-study-saskatchewan-uranium-miners-cohort-study.cfm

[97] Canadian Nuclear Safety Commission, "Update (January 2020 – September 2020) Canadian Uranium Workers Study (CANUWS)," September 2020.

[98] Statistics Canada, "Deaths, Causes of Death and Life Expectancy, 2016," June 2018. https://www150.statcan.gc.ca/n1/daily-quotidien/180628/dq180628b-eng.htm?wbdisable=true

[99] Canadian Cancer Statistics Advisory Committee, "Canadian Cancer Statistics: A 2020 Special Report on Lung Cancer," September 2020.

https://www.cancer.ca/~/media/cancer.ca/CW/cancer information/cancer 101/Canadian cancer statistics/Canadian-cancer-statistics-2020_special-report_EN.pdf?la=en

[100] Canadian Cancer Society, "Risk Factors for Lung Cancer," 2022. http://www.cancer.ca/en/cancer-information/cancer-type/lung/risks/?region=ab

[101] Statistics Canada, "Canadian Community Health Survey (CCHS) – 2015," https://www150.statcan.gc.ca/n1/daily-quotidien/170322/dq170322a-eng.htm

[102] Chen J., Moir D., & Whyte J., "Canadian Population Risk of Radon Induced Lung Cancer: A Re-Assessment Based on the Recent Cross-Canada Radon Survey," *Radiation Protection Dosimetry*, vol. 152(1-3), pp. 9-13, 2012.

[103] Canada North Environmental Services, "Eastern Athabasca Regional Monitoring Program 2015 Technical Report (Prepared for the Government of Saskatchewan)," 2015. https://www.icce-caec.ca/wp-content/uploads/2022/07/20152016TechnicalReport.pdf

[104] Eastern Athabaska Regional Monitoring Program, "Reports," 2022. https://www.earmp.ca/reports

[105] Environment and Climate Change Canada, "About the National Pollutant Release Inventory," 2021. https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/about-national-pollutant-release-inventory.html

[106] Government of Canada, "Radionuclide Release Dataset," 2021. https://open.canada.ca/data/en/dataset/6ed50cd9-0d8c-471b-a5f6-26088298870e