Rook I Project

Environmental Impact Statement

TSD IX: Transportation Risk Assessment Report

TRANSPORTATION RISK ASSESSMENT - TECHNICAL SUPPORTING DOCUMENT FOR THE ROOK I PROJECT

REPORT PREPARED FOR:

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Ecometrix | Environmental INTELLIGENCE

TRANSPORTATION RISK ASSESSMENT - TECHNICAL SUPPORTING DOCUMENT FOR THE ROOK I PROJECT

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EXECUTIVE SUMMARY

Ecometrix Incorporated (Ecometrix) was retained by NexGen Energy Ltd. (NexGen) to complete the assessment of the risks associated with transportation related to the proposed NexGen Rook I Project (Project), including consideration of the accidental release of hazardous materials to the environment. This report details that assessment.

Proposed Project

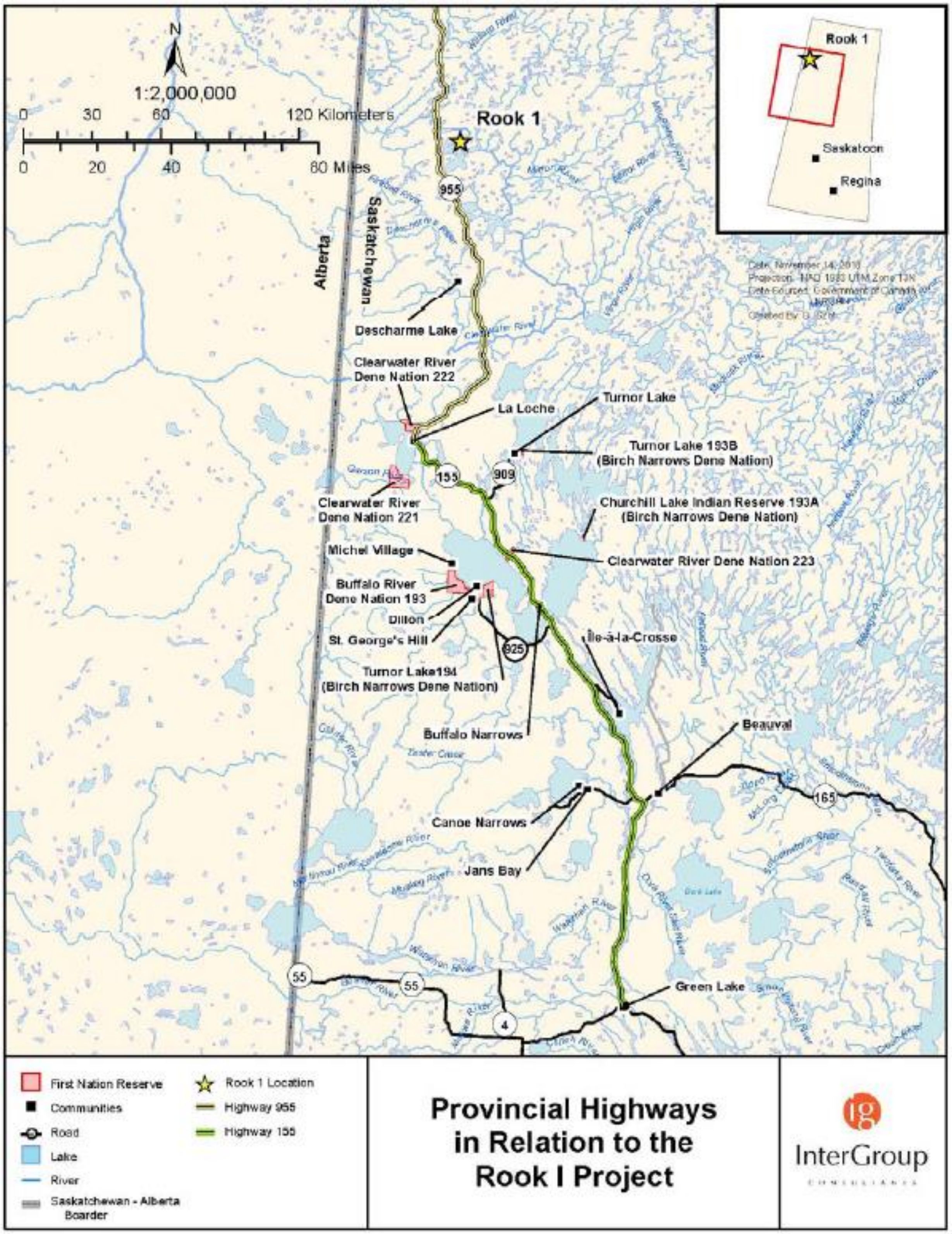
The Project is a proposed new uranium mining and milling operation that is 100 percent (%) owned by NexGen. The Project would be located in northwestern Saskatchewan, approximately 40 kilometres (km) east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon. The Project would reside within Treaty 8 territory and within the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake and along the upper Clearwater River system. Access to the Project would be from an existing road off Highway 955.

Objective and Scope of the Assessment

The objective of the assessment was to evaluate the potential health and environmental effects resulting from transportation accidents and consequent release of contaminants that may be associated with the Project. The transportation risk assessment, which is a part of the assessment of accidents and malfunctions, is intended to provide a clear identification of the potential transportation-associated hazards that fall outside the range of “typical” day-to-day events.

The temporal extent of the evaluation includes all Project phases (i.e., Construction, Operations, Decommissioning and Reclamation [i.e., Closure]). The spatial extent of the evaluation includes two sections of highway, one along Highway 955 and the second along Highway 155. The spatial extent along Highway 955 spans from the intersection of the access road and Highway 955 to the intersection of Highway 955 and Highway 155 at La Loche. The spatial extent along Highway 155 spans from the intersection of Highway 955 and Highway 155 to the intersection of Highway 155 and Highway 55 at Green Lake (Figure ES-1). The spatial extent was informed by evaluation of the existing traffic volumes, identification of incremental increases in traffic associated with the proposed Project, and understanding of transportation emergency response times.

Figure ES-1: Provincial Highways in Relation to the Rook I Project



Assessment Methodology

The assessment was conducted consistent with the United States Department of Energy (USDOE) resource handbook for transportation risk assessment. The handbook data are specific to the United States; however, the framework is universal and has been used previously in the assessment of transportation of radioactive materials in northern Saskatchewan.

The four basic steps in the process of risk assessment for the transportation risk assessment are as follows:

- **Scenario identification**: involves the identification of transportation accident scenarios with the potential for release of hazardous materials into the ground, atmosphere, and/or water. These scenarios may involve fires which emit toxic chemicals associated with smoke as well. In addition to hazardous material release, the accident scenarios may involve physical interactions with humans and wildlife.

- **Probability analysis:** involves the estimation of the probability (i.e., likelihood) of the accident scenarios occurring within a specific time period or in specified circumstances. On a scale of increasing likelihood, scenarios were categorized as highly unlikely, unlikely, likely, very likely, and almost certain as shown in Table ES-1.

Table ES-1: Likelihood Ratings

Rating	Likelihood	Likelihood Note
1	Highly unlikely	<1 occurrence in 1,000 years
2	Unlikely	≤1 occurrence in 100 years and >1 occurrence in 1,000 years
3	Likely	≤1 occurrence in 10 years and >1 occurrence in 100 years
4	Very likely	≤1 occurrence in 1 year and >1 occurrence in 10 years
5	Almost certain	>1 occurrence in 1 year

- **Effects analysis:** includes quantitative evaluation of the potential effects of a transportation accident scenario to human health or the environment. The effects analysis of the transportation accidents scenarios includes the assessment of fate and transport of the released contaminants and the exposure to the selected receptors. On a scale of increasing consequences, scenarios were categorized as negligible, minor, moderate, major, and catastrophic as shown in Table ES-2. The risk assessment considered the hierarchy of controls (i.e., elimination, substitution, engineering, administrative, personal protective equipment) that would be implemented as part of the Integrated Management System to prevent, eliminate, and reduce hazards and mitigate the risks associated with activities throughout the Project lifespan.

Table ES-2: Consequence Index

Rating	Consequence	Description
1	Negligible	No measurable biophysical environmental effects, or medical treatment not required
2	Minor	Short-term (i.e., less than one month in duration) minor effect on small area, or minor first aid injuries with no lost time
3	Moderate	Reversible or repairable effect (i.e., less than one year in duration) off site, or reversible injuries with lost time
4	Major	Extended-range, long-term effect (i.e., 10 years in duration) off site, or severe injuries with long-lasting effects and/or disability
5	Catastrophic	Long-lasting (e.g., more than 10 years in duration) or irreversible environmental effects, fatalities, or multiple disabilities

- **Risk estimation and ranking:** includes the estimation of the overall risk for a given transportation accident and is the product of the probability of occurrence and consequence (risk = probability of occurrence * consequence). A risk evaluation was completed for transportation accident scenarios by evaluating the likelihood and consequence to determine a risk level. The resulting risk levels are defined according to the risk matrix in Figure ES-2.

Figure ES-2: Hazard Analysis Risk Matrix

Likelihood		Consequence				
		1	**2**	**3**	**4**	**5**
		Negligible	**Minor**	**Moderate**	**Major**	**Catastrophic**
5	**Almost certain**	low	moderate	moderate	high	high
4	**Very likely**	low	low	moderate	high	high
3	**Likely**	low	low	moderate	moderate	high
2	**Unlikely**	low	low	low	moderate	high
1	**Highly unlikely**	low	low	low	moderate	moderate

Transportation Accident Scenarios

A number of transportation accident scenarios were selected for the risk assessment. A transportation accident may result in release of hazardous materials to ground, water, and/or air. In addition to the hazardous material release, the accident may involve physical impact to members of the public and wildlife along the transportation route.

For the purpose of this assessment, the following five release scenarios were assessed:

1. aquatic release scenario involving uranium concentrate and other hazardous materials;
2. terrestrial release scenario involving uranium concentrate and other hazardous materials;
3. vehicle fire and atmospheric release scenario involving uranium concentrate and smoke from hydrocarbon fire;
4. vehicle-human accident scenario along the transportation route; and
5. vehicle-wildlife accident scenario.

The following water crossing locations were selected for the assessment of surface water release:

- Clearwater River at Highway 955;
- Canoe River at Highway 155;
- Beaver River at Highway 155; and
- Churchill Lake at Highway 155 (Buffalo Narrows).

Hazardous Materials Selected

The analysis of the potential effects from a transportation accident involving hazardous materials requires information regarding the type, quantity, transportation method, and characteristics of the hazardous materials transported from/to the site. The following hazardous materials were selected for the assessment based on review of Project information:

- uranium concentrate;
- hydrogen peroxide;
- diesel fuel;
- liquified natural gas (LNG); and
- molten sulphur.

Based on the release characterization provided in this study, it was decided that for the non-radiological contaminants considered, the consequences of the associated releases are bounded by the potential consequences of the diesel fuel release. Therefore, the release of diesel fuel to the aquatic environment was selected as a surrogate for the non-radiological contaminant scenarios.

A potential transportation accident that results in a hydrocarbon fire would emit smoke to the atmosphere; therefore, smoke is also considered for the assessment. In this scenario, it is assumed that the fire does not spread.

Transportation Setting

As indicated above, the spatial extent of the evaluation includes sections of Highway 955 and Highway 155.

- Highway 155 extends north and north-west for approximately 300 km from the intersection with Highway 55 near Green Lake, and terminates near La Loche, where Highway 955 begins.
- Highway 955 extends for approximately 270 km north of La Loche and ends near the southern tip of Carswell Lake and the former Cluff Lake Mine. The Project is approximately 154 km from La Loche off Highway 955 and is accessed by a private 13 km all-season road.

Traffic volumes on Highway 155 and Highway 955 are as much as 5 to 20 times less than those on Highway 55, and much lower (i.e., 15 to 60 times less) compared to other provincial highways. As such, the percent increase in traffic volume on Highways 155 and Highway 955 due to Project-related traffic would be larger than those for other highways. In addition, the distance of these two highways from major population centres such as Regina or Saskatoon results in longer emergency response time to transportation accidents. The emergency response capabilities that can be deployed to attend the traffic accidents on other major highways is more timely, due to closer proximity to larger population centres.

The above information provides the rationale for the inclusion of the spatial extent of the transportation risk assessment. The above information also provides the rationale for not extending the transportation risk assessment beyond the Highway 155 and Highway 55 junction at Green Lake. Project-related traffic is not considered to be a material incremental increase above existing conditions beyond Green Lake (i.e., Highway 55). Additionally, emergency response times to traffic accidents on Highway 155 and Highway 955 may be longer than that on Highway 55.

Conclusions

The results of the risk assessment are summarized in Table ES-3. With the exception of the risk of a vehicle-human accident, the risk associated with the other scenarios evaluated was determined to be low. Although the vehicle-human accident scenario is a very unlikely occurrence, due to the catastrophic nature of the potential effects (e.g., fatality), the risk was evaluated as moderate.

Table ES-3: Summary of the Transportation Accident Risk Assessment

Accident Scenario	Probability	Consequence	Risk
Aquatic release	Highly unlikely	Moderate	Low
Terrestrial release	Likely	Minor	Low
Vehicle fire and atmospheric release	Unlikely to highly unlikely[1]	Minor	Low
Vehicle-human accident	Highly unlikely	Major-catastrophic	Moderate
Vehicle-wildlife accident	Very likely	Minor	Low

1) Probabilities given for both the typical (unlikely) and worst-case (highly unlikely) weather scenarios. Consequence and overall risk are the same in both cases.

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ABBREVIATIONS AND UNITS OF MEASURE

Abbreviations

Acronym	Definition
AEGL	Acute Exposure Guideline Level
ALARP	as low as reasonably practicable
ATSDR	Agency for Toxic Substances and Disease Registry
ARF	airborne release fraction
CNSC	Canadian Nuclear Safety Commission
DR	damage ratio
ERP	Emergency Response plan
ERPG	Emergency Response Planning Guidelines
ETP	effluent treatment plant
STP	sewage treatment plant
Hwy	highway
LNG	liquefied natural gas
LPF	leak path factor
MAR	material-at-risk
NexGen	NexGen Energy Ltd.
No.	number
NPAG	non-potentially acid generating
OECD	Organisation For Economic Co-Operation and Development
PAC	Protective Action Criteria
PAG	potentially acid generating
PAH	polycyclic aromatic hydrocarbon
PM	particulate matter
Project	Rook I Project
RBE	relative biological effectiveness
RF	respirable fraction
SI	screening index
TRV	toxicity reference value
U_3O_8	triuranium octoxide
UGTMF	underground tailings management facility
USDOE	United States Department of Energy
USDOT	United States Department of Transportation
WRSA	waste rock storage area

Units of Measure

Units	Definition
%	percent
µg/L	micrograms per litre
µGy/h	micrograys per hour
µL/L	microlitres per litre
µm	micrometre
Bq/d	becquerels per day
cm	centimetre
cm/s	centimetres per second
d/kg	days per kilogram
g/cm^3	grams per cubic centimetre
g/h	grams per hour
g/kg	grams per kilogram
g/m^3	grams per cubic metre
g/s	grams per second
h	hour
kg	kilogram
kg fuel/h	kilograms of fuel per hour
kg/h	kilograms per hour
$kg/h/m^2$	kilograms per hour per square metre
km	kilometre
km/h	kilometres per hour
L	litre
Lbs	pounds
m	metre
m/s	metres per second
m^2	square metre
m^3	cubic metre
m^3/s	cubic metres per second
m^3/kg	cubic metres per kilogram
mg/kg	milligrams per kilogram
mg/kg/d	milligrams per kilogram per day
mg/L	milligrams per litre
mg/m^3	milligrams per cubic metre
mGy/d	milligrays per day
mL	millilitre
min	minute
MVkm	million-vehicle-kilometre
t	tonne

1.0 INTRODUCTION

Ecometrix Incorporated (Ecometrix) was retained by NexGen Energy Ltd. (NexGen) to complete the assessment of the risk associated with transportation of hazardous materials used or produced at the NexGen Rook I Project (Project), a proposed uranium mining and milling operation in northwestern Saskatchewan. The risk assessment of transportation of hazardous materials along the transportation route is a part of the overall assessment of accidents and malfunctions. The potential Project-related accidents and malfunctions that may occur during any phase of the Project and transportation-related accidents along the access road to its intersection Highway 955 were assessed separately and the results were documented in Technical Support Document (TSD) VIII, Accidents and Malfunctions Report. This report documents the hazardous material transportation risk assessment including the characterization of the transportation route, identification of hazardous materials considered in the assessment, methodology for the assessment, identification of accident scenario, the probability of these scenarios and their effects, and an overall characterization of risk related to the scenarios.

1.1 Background Information

The Project is a proposed new uranium mining and milling operation that is 100% owned by NexGen. The Project would be located in northwestern Saskatchewan, approximately 40 km east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon. The Project would reside within Treaty 8 territory and within the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake and along the upper Clearwater River system. Access to the Project would be from an existing road off Highway 955.

Further Project-related information is provided in Section 2.0, Project Information.

1.2 Regulatory Context

In Canada, federal *Transportation of Dangerous Goods Regulations* (SOR/2001-286), consolidated to include amendment SOR/2019-101 (Emergency Response Assistance Plan), govern the transportation of dangerous goods, including Class 7 radioactive materials. More specifically, the Canadian Nuclear Safety Commission (CNSC; 2015) issues licences and certificates for certain types of packaging and transport of nuclear substances as stipulated in the *Packaging and Transport of Nuclear Substances Regulations* (2015). These regulations are based on the International Atomic Energy Agency's Regulations for the Safe Transport of Radioactive Material (IAEA 2012). The CNSC licences and certificates include:

- licence to transport Category I, II, or III nuclear material;
- licence to transport nuclear substances while in transit;
- licence to transport nuclear substances contained in large objects;
- licence to transport nuclear substances when the transport cannot meet all of the regulatory requirements;
- licence to transport nuclear substances that require a multilateral approval of shipments;

- licence to transport nuclear substances that require a special use vessel; and
- certificates for the design of packages and special form radioactive material.

1.3 Overall Scope and Objective of the Assessment

The objective of the assessment was to evaluate the potential human health and environmental effects resulting from transportation accidents and consequent release of contaminants that may be associated with the Project. The transportation risk assessment, which is a part of the assessment of accidents and malfunctions, is intended to provide a clear identification of potential transportation-associated hazards that fall outside the range of "typical" day-to-day events.

The temporal extent of the evaluation includes all Project phases (i.e., Construction, Operations, Closure).

The spatial extent of the evaluation includes two sections of highway, one along Highway 955 and the second along Highway 155. The spatial extent along Highway 955 spans from the intersection of the access road and Highway 955 to the intersection of Highway 955 and Highway 155 at La Loche. The spatial extent along Highway 155 spans from the intersection of Highway 955 and Highway 155 to the intersection of Highway 155 and Highway 55 at Green Lake. The spatial extent was informed by evaluation of the existing traffic volumes, identification of incremental increases in traffic associated with the proposed Project, and understanding of transportation emergency response times.

1.4 Report Format

Following this introductory section, the remainder of this report is organized as follows:

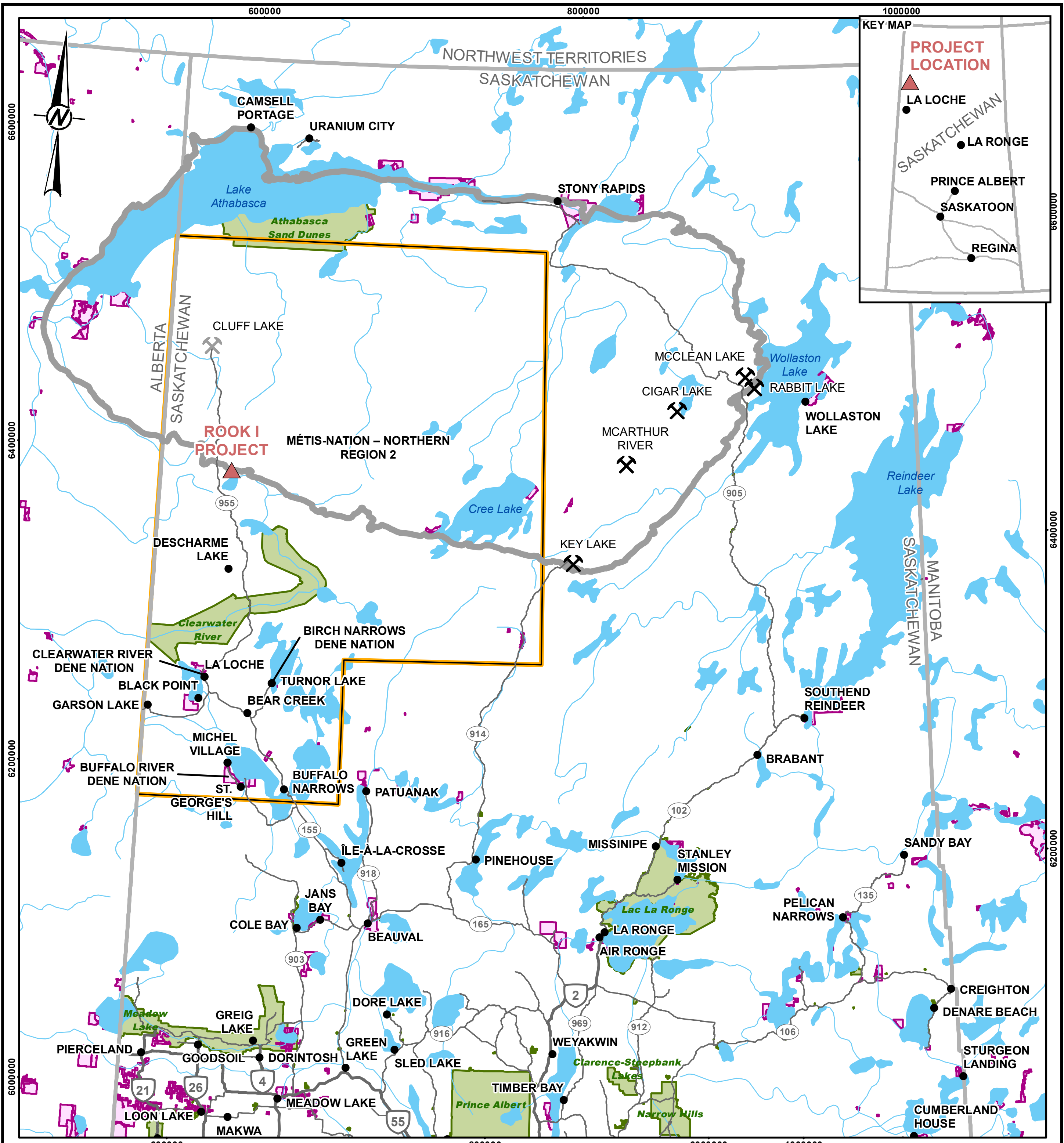
- Section 2.0: provides Project-related information;
- Section 3.0: provides the assessment methodology;
- Section 4.0: describes risk controls related to NexGen management programs considered for the assessment;
- Section 5.0: describes the hazardous materials considered in the assessment as well as transportation route and its setting;
- Section 6.0: presents an overview of the postulated transportation accident scenarios;
- Section 7.0: presents the review of receptors and toxicity benchmarks used in the risk assessment;
- Section 8.0: presents the assessment of probabilities of the transportation accident scenarios;
- Section 9.0: presents the assessment of the fate and transport of chemicals released during postulated transportation accident scenarios and their effects on the environment;
- Section 10.0: presents the overall risk characterization for the transportation accident scenarios;
- Section 11.0: provides a summary and the conclusions of the transportation risk assessment; and
- Section 12.0: provides a list of references cited in this report.

2.0 PROJECT INFORMATION

The following subsections present Project-related information that provide context to the transportation risk assessment.

2.1 Rook I Project Location

The Project would be located approximately 40 km east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon (Figure 2-1). The Project would reside within Treaty 8 territory and the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake, along the upper Clearwater River system. Patterson Lake is at the interface of the Boreal Shield and Boreal Plain ecozones. Access to the Project would be from an existing road off Highway 955 (Figure 2-2), with on-site worker accommodation serviced by fly-in/fly-out access.



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KILOMETRES

LEGEND

- ● POPULATED PLACE
- ⚒ URANIUM MINING FACILITY (ACTIVE)
- ⚒ URANIUM MINING FACILITY (DECOMMISSIONED)
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- WATERCOURSE
- ATHABASCA BASIN BOUNDARY
- INDIAN RESERVE
- PROVINCIAL PARKS
- WATERBODY
- ▲ PROJECT LOCATION
- MÉTIS NATION-SASKATCHEWAN NORTHERN REGION 2

REFERENCE(S)

1. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
2. PARKS OBTAINED FROM IHS MARKIT CANADA ULC.

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LOCATION OF THE ROOK I PROJECT

CONSULTANT

wsp

PROJECT		20144150	PHASE	3314 - 6
DESIGN	JMC	2022-02-28	SCALE AS SHOWN	REV. 0
GIS	NO	2022-02-28	**FIGURE 2-1**	
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REVIEW	MM	2022-02-28		

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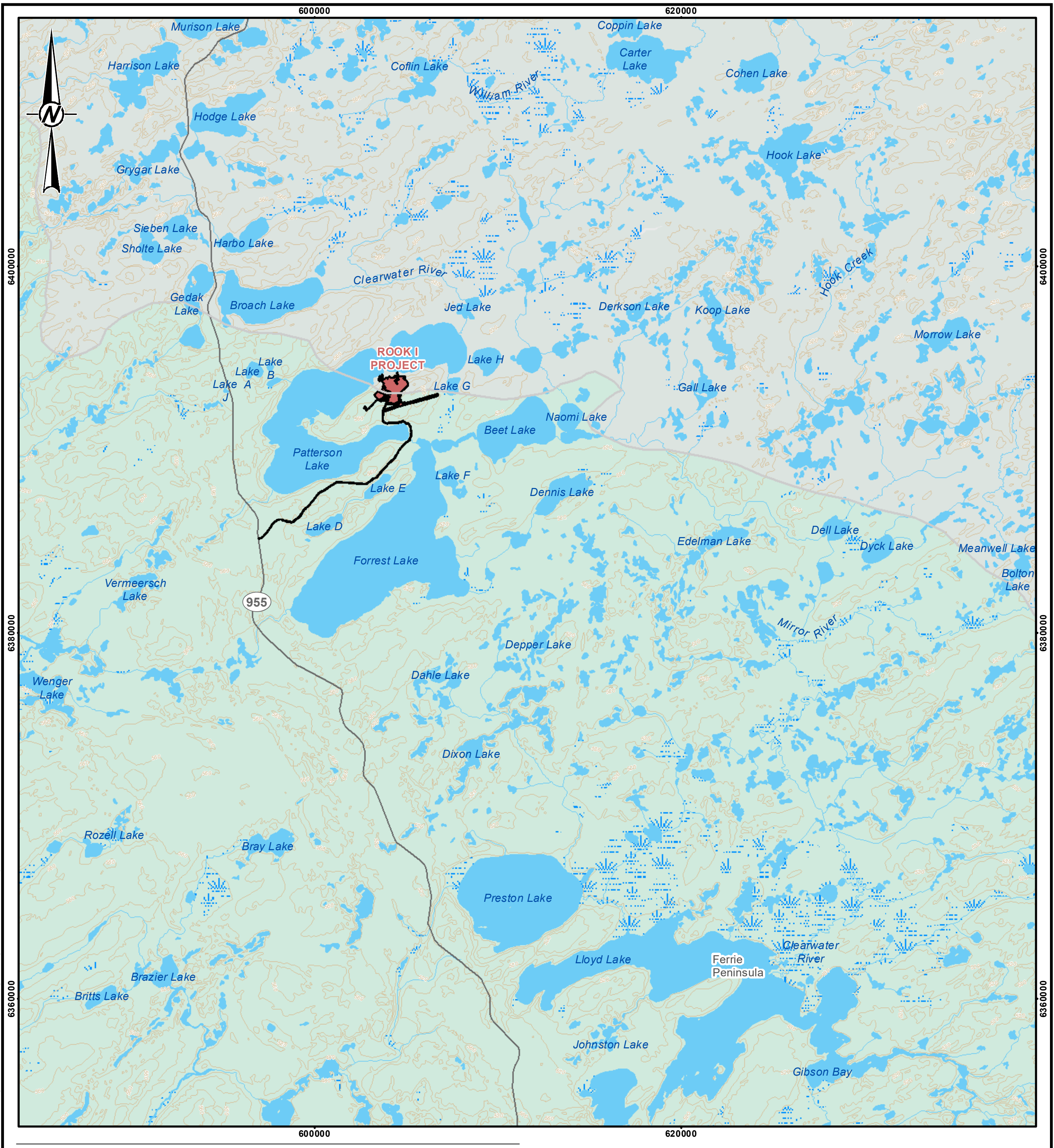

0 5 10

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LEGEND

—	ELEVATION CONTOUR (20 m INTERVAL)
—	SECONDARY HIGHWAY
—	WATERCOURSE
⬜	ATHABASCA BASIN
🟦	WATERBODY
⋯	WETLAND
🟩	WOODED AREA
🟥	PROPOSED PROJECT FOOTPRINT

REFERENCE(S)
1. PROJECT FEATURES OBTAINED FROM NEXGEN, APRIL 6, 2021.
2. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

REGIONAL AREA OF THE ROOK I PROJECT

CONSULTANT

wsp

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REVIEW	MM	2023-10-25		

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2.2 Rook I Project Timeline

The timeline over which potential transportation accident scenarios have been considered includes the period of time from the initiation of Construction to the completion of Closure. The lifespan of the Project is anticipated to be 43 years, as summarized in Table 2-1.

Table 2-1: Rook I Project Phases

Phase	Description		Duration (Years)
Construction	Construction includes site preparation; mine, process plant, and additional infrastructure development; transportation of people and materials to and from the Project; and all activities associated with commissioning the Project up until Operations commences.		4
Operations	Operations includes all activities associated with mining and processing ore; tailings management; management of waste rock, domestic waste, and hazardous materials; water management; release of treated effluent; site maintenance; progressive reclamation; and transportation of staff and materials to and from the Project up until Decommissioning and Reclamation commences.		24
Decommissioning and Reclamation Phase (i.e., Closure)	Includes two stages:		15
	Active Closure Stage	Active closure includes active decommissioning and reclamation activities that occur post-Operations such as backfilling mine workings, removal of physical infrastructure, recontouring and revegetating disturbed areas, waste disposal or removal, and any other activities required to achieve decommissioning objectives and return the site to a safe and stable condition prior to the Transitional Monitoring Stage.	5
	Transitional Monitoring Stage	Transitional Monitoring Stage would continue until monitoring and reporting verifies that the performance criteria have been met. Once performance criteria have been fully demonstrated, an application to be released from the CNSC licence would be submitted to the CNSC for approval. Once that is achieved, and upon Provincial approval, the land would be transferred under Provincial management through the Institutional Control Program. Stage is nominally 10 years; however, NexGen acknowledges this is dependent on the achievement of performance criteria.	10

CNSC = Canadian Nuclear Safety Commission.

2.3 Key Support Facilities

The Project would include the following key facilities to support the extraction and processing of uranium ore from the Arrow deposit for transportation off site:

- underground mine development;
- process plant buildings, including uranium concentrate packaging facilities;
- paste tailings distribution system;
- underground tailings management facility (UGTMF);
- potentially acid generating (PAG) waste rock storage area (WRSA);
- non-potentially acid generating (NPAG) WRSA;
- special waste rock[1] and ore storage stockpiles;
- surface and underground water management infrastructure, including water management ponds, effluent treatment plant (ETP), and sewage treatment plant (STP);
- conventional waste management facilities and fuel storage facilities;
- ancillary infrastructure, including maintenance shop, warehouse, administration building, and camp;
- airstrip and associated infrastructure; and
- access road to Project and site roads.

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[1] Special waste rock is mine rock that is mineralized with insufficient grade to be considered ore (i.e., greater than 0.03% of triuranium octoxide [U_3O_8] and less than 0.26% U_3O_8). All special waste would be temporarily stored in the special waste rock stockpile.

3.0 ASSESSMENT METHODOLOGY

The assessment of transportation risks is designed to provide a clear definition of the potential Project-associated hazards that fall outside the range of "typical" day-to-day events and to provide a framework for quantifying the risks associated with these hazards.

The assessment was conducted consistent with the United States Department of Transportation (USDOT) resource handbook for transportation risk assessment (USDOT 2002). The handbook data are specific to the United States, but the framework is universal and has been used previously in the assessment of transportation of radioactive materials in northern Saskatchewan.

The four basic steps in the process of risk assessment for the transportation risk assessment are outlined in Section 3.1 through Section 3.24.

3.1 Scenario Identification

The identification of transportation accident scenarios with the potential for the release of hazardous materials to the ground, atmosphere, and/or water. These scenarios may involve fire, which emits toxic chemicals associated with smoke. In addition to hazardous material release, the accident scenarios may involve physical interactions with humans and wildlife.

3.2 Probability Analysis

Probability analysis involves the estimation of the probability (i.e., likelihood) of the accident scenarios occurring within a specific time period, or in specified circumstances. On a scale of increasing likelihood, scenarios were categorized as highly unlikely, unlikely, likely, very likely, and almost certain as shown in Table 3-1.

Table 3-1: Likelihood Ratings

Rating	Likelihood	Likelihood Note
1	Highly unlikely	<1 occurrence in 1,000 years
2	Unlikely	≤1 occurrence in 100 years and >1 occurrence in 1,000 years
3	Likely	≤1 occurrence in 10 years and >1 occurrence in 100 years
4	Very likely	≤1 occurrence in 1 year and >1 occurrence in 10 years
5	Almost certain	>1 occurrence in 1 year

< = less than; > = more than; ≤ = less than or equal to.

The detailed description of the probability assessment for each hazard scenario is provided in Section 8.0.

3.3 Effects Analysis

The effects analysis involves the quantitative evaluation of the potential effects of a transportation accident scenario to human health or the environment. On a scale of increasing consequence, scenarios were categorized as negligible, minor, moderate, major, and catastrophic as shown in Table 3-2.

Table 3-2: Consequence Index

Rating	Consequence	Description
1	Negligible	No measurable biophysical environmental effects, or medical treatment not required
2	Minor	Short-term (i.e., less than one month in duration) minor effect on small area, or minor first aid injuries with no lost time
3	Moderate	Reversible or repairable effect (i.e., less than one year in duration) off site, or reversible injuries with lost time
4	Major	Extended-range, long-term effect (i.e., 10 years in duration) off site, or severe injuries with long-lasting effects and/or disability
5	Catastrophic	Long-lasting (i.e., more than 10 years) or irreversible environmental effects, fatalities, or multiple disabilities

The detailed description of the effect assessment for each hazard scenario is provided in Section 9.0.

3.4 Risk Estimation and Ranking

The estimation of the overall risk for a given transportation accident is the product of the probability of occurrence and consequence (risk = probability of occurrence * consequence). A risk evaluation was carried out for transportation accident scenarios by evaluating the likelihood and consequence to determine a risk level.

The resulting risk levels are defined according to the matrix shown in Figure 3-1.

Figure 3-1: Hazard Analysis Risk Matrix

Likelihood		**Consequence**				
		1	**2**	**3**	**4**	**5**
		Negligible	**Minor**	**Moderate**	**Major**	**Catastrophic**
5	**Almost certain**	low	moderate	moderate	high	high
4	**Very likely**	low	low	moderate	high	high
3	**Likely**	low	low	moderate	moderate	high
2	**Unlikely**	low	low	low	moderate	high
1	**Highly unlikely**	low	low	low	moderate	moderate

For the purpose of the assessment, risks were identified as being low where the screening evaluation considered the risk as generally being acceptable, as the risk of these scenarios can be effectively managed through application of planned controls. Low-risk scenarios have a consequence of negligible to moderate with the likelihood ranging from highly unlikely to almost certain.

Risks were identified as being moderate where the screening evaluation considers the risk as generally being tolerable. In some cases, a moderate-risk scenario can encompass the risk of several screened scenarios for each effect category (e.g., toxic release, fire). In these cases, a moderate-risk scenario can be forwarded as a bounding scenario for more detailed analysis. Moderate-risk scenarios have minor to catastrophic consequence with the likelihood ranging from highly unlikely to almost certain. In many cases, risk-reduction activities would reduce the risk associated with these scenarios to As Low As Reasonably Practicable (ALARP). Under this condition, the risk may be characterized as tolerable.

Risks were identified as being high where the screening evaluation considered the risk as generally being unacceptable. High-risk scenarios have major to catastrophic consequence with the likelihood ranging from unlikely to almost certain.

4.0 CONSIDERATIONS FOR THE TRANSPORTATION ACCIDENT ASSESSMENT

NexGen would develop and operate the Rook I Project in a manner that mitigates potential adverse effects on the human health and biophysical environment to the extent possible. NexGen would verify that all work to be completed during the Project would meet, or exceed, the regulatory requirements stipulated by the province of Saskatchewan, the CNSC, and other regulatory authorities. Through complying with all regulations and standards and engagement with Indigenous Peoples, local communities, and other stakeholders, and by embracing the application of technology and best practices, NexGen is focused on achieving high standards in all facets of the business and across its Project lifespan that would serve to mitigate potential Project-related effects, including those that may be associated with postulated transportation accident scenarios.

As part of this commitment, NexGen would adopt a hierarchy of controls (i.e., elimination, substitution, engineering, administrative, personal protective equipment) as part of the Integrated Management System to prevent, eliminate, and reduce hazards and mitigate the risks associated with activities throughout the Project lifespan. In practice, these controls would be implemented and their effectiveness monitored via management system processes defined in topic-specific programs which include, but may not be limited to:

- Integrated Management System Manual;
- Health and Safety Program;
- Radiation Protection Program;
- Environmental Protection Program;
- Waste Management Program;
- Emergency Preparedness and Response Program;
- Fire Protection Program;
- Security Program;
- Training Program;
- Contractor Management Program;
- Indigenous and Public Engagement Program;
- Construction Management Program;
- Commissioning Management Program; and
- Asset Management Program.

The processes outlined in these programs would be described in more detailed topic-specific plans, procedures, and work instructions developed for the Project. This would include processes related to the following:

- transportation planning and management;
- driver training;
- traffic control, such as speed limits and signage;
- radiation exposure monitoring and protection;
- spill and emergency response;
- environmental monitoring;
- regulatory notification and external communication; and
- transportation emergency response.

These plans, procedures, and work instructions would be implemented throughout the life of the Project, and together would help to mitigate the likelihood of occurrence of transportation accident scenarios.

5.0 TRANSPORTATION OF HAZARDOUS MATERIALS

The assessment of transportation accident scenarios requires the identification of the hazardous materials transported and characterization of the transportation route, transportation frequencies, and quantity of hazardous materials.

5.1 Hazardous Materials

The analysis of the potential effects from a transportation accident involving hazardous materials requires information regarding the type, quantity, transportation method, and characteristics of the hazardous materials transported from/to the site.

The following hazardous materials were selected for the assessment based on review of Project information (NexGen 2021):

- uranium concentrate;
- hydrogen peroxide;
- diesel fuel;
- liquified natural gas (LNG); and
- molten sulphur.

A potential transportation accident that results in a hydrocarbon fire would emit smoke to the atmosphere. Thus, smoke is also considered for the assessment.

Further consideration of uranium concentrate as a hazardous material is provided below for reference.

5.1.1 Uranium Concentrate

Uranium concentrate has a uranium content of about 84.8%[2]. It has uranium-238, uranium-234, and uranium-235 present in natural abundances. The short-lived decay products of uranium-238 (i.e., thorium-234, protactinium-234m, protactinium-234, and uranium-234) and uranium-235 (i.e., thorium-231) are assumed to be in equilibrium with their respective parents. The activities of these radionuclides in uranium concentrate are shown in Table 5-1 (Momeni et. al. 1979).

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[2] (Uranium, 3x238) / (uranium + oxygen, 3x238 + 8x16)

Table 5-1: Radionuclides Present in Uranium Concentrate

Radionuclide	Half Life	Branch Percentage
Uranium-238	4.47×10^9 year	n/a
Thorium-234	24.1 d	100% uranium-238
Protactinium-234m	1.16 min	100% uranium-238
Protactinium-234	6.7 h	0.16% uranium-238
Uranium-234	2.45×10^5 year	100% uranium-238
Uranium-235 (4.6% of uranium-238)	7.04×10^8 year	n/a
Thorium-231	1.063 d	100% uranium-235

n/a = not applicable.

Studies conducted for the McClean Lake uranium mill in northern Saskatchewan analyzed the particle size distribution for three calcined uranium concentrate samples using a Beckman Coulter LS Particle Size Analyzer[3]. Table 5-2 provides a summary of particle size distribution from these studies.

Table 5-2: Uranium Ore Concentrate Particle Size Distribution

Calcined Samples (Three Samples)		
Size Category (µm)	Average Size (µm)	Percentage
<5	2.5	4.0
5-15	8.6	14.7
15-25	19	46.1
25-35	30	32.8
35-55	44	2.5

Note: Calcined uranium concentrate was provided courtesy of Cameco Corporation Key Lake Operation during the assessment of accidents and malfunctions for the Millennium Mine Project.
< = less than.

The solubility of calcined samples from the McClean Lake Operation in northern Saskatchewan was analyzed over 72 or 24 hours. The Organisation for Economic Co-operation and Development Guideline for Testing of Chemicals; Water Solubility (OECD, 27 July 1995), flask method, was followed for these tests. The results are shown in Table 5-3. Based on data on the solubility of McClean Lake samples, a solution of about 0.125 g of uranium concentrate in 250 mL of water would lead to a uranium concentration of 4,800 µg/L within 72 hours. Bulk and particle densities of uranium concentrate were considered at 2.1 g/cm^3 and 9.6 g/cm^3.

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[3] This information was obtained from Cameco Corporation during the assessment of accidents and malfunctions for the Millennium Mine Project, and has been included with permission from Cameco Corporation.

Table 5-3: Solubility of Calcined Uranium Concentrate

Sample Source	Sample No.	Estimated Solubility (g/L) by Test Duration		
		24h	48h	72h
McClean Lake (calcined uranium concentrate)	1	0.0035	0.0045	0.0046
	2	0.0060	0.0071	0.0067
	3	0.0053	0.0062	0.0090
	4	0.0038	0.0036	0.0039
	5	0.0070	0.0068	0.0064
	16-20 (average)	0.003-0.008 (0.005)	No data	No data

Calcined uranium concentrate would be packed into standard 205 L (45 gallon) steel drums for shipping. The gross weight of each drum would be 450 kg (990 Lbs). It is projected that there would be about 90 to 100 drums packaged per mill-operating day, which requires two trips made per day (NexGen 2021). According to the International Atomic Energy Agency regulations for the safe transport of radioactive material (IAEA 2012) and the federal *Packaging and Transport of Nuclear Substances Regulations*, uranium concentrate is considered Low Specific Activity material (LSA-I) and is to be packaged in Industrial Package Type 1 (IP-1). The package is designed so that it can be transported easily and safely, can be properly secured in or on the conveyance during transport, have robust lifting attachments, nuts, bolts, and other securing devices, and can withstand ambient temperature and pressure during air transport.

5.1.2 Fuel and Chemicals

The information related to the fuel and chemicals transported to the site is summarized in Table 5-4.

Table 5-4: Chemicals Transported to the Rook I Project Site

Item	Value
Fuel tanker truck capacity	30 m^3
Fuel tanker truck trip per day	10 each for gasoline and diesel
LNG tanker truck capacity	48 m^3
LNG tanker truck trips per day	3
Daily volume of hydrogen peroxide consumption	18,289 L (approximately 18.3 m^3)
Hydrogen peroxide tanker truck capacity	11,350 L to 18,900 L
Hydrogen peroxide tanker truck trip per day	0.97 to 1.61
Daily volume of molten sulphur consumption	50,280 L
Molten sulphur tanker truck capacity	25 t
Molten sulphur tanker truck trip per day	3.5 per day
Daily volume of organic solvent consumption	Minimal
Organic solvent tanker truck capacity	40 t
Organic solvent tanker truck trip per day	Minimal

Source: NexGen 2021.
LNG = liquified natural gas.

Based on the released characterization provided in Section 9.1.3, it was decided that for the non-radiological contaminants considered, the consequences of the associated releases are bounded by the potential consequences of the diesel fuel release. Therefore, the release of diesel fuel to the aquatic environment was selected as a surrogate for the non-radiological contaminant scenarios.

5.2 Transportation Quantities

The determination of site-generated traffic was developed using estimates of trip generation based on expected activity levels for the Project as documented in the Traffic Impact Study Report prepared by Stantec (2019). This exercise considered the various activities and needs associated with each Project phase. From this information, the various traffic activities were combined to represent the following categories for ease of reference: expendables, labour, construction equipment/materials, one-time equipment deliveries, and exports. The data for each of these high-level categories were then broken down further by trips per day, trips per week, and one-time trips for all Project phases, as summarized in Table 5-5, Table 5-6, and Table 5-7. Daily trips represent regularly scheduled activities that occur on a daily basis, weekly trips represent regularly scheduled activities that occur on a weekly basis, and one-time trips represent trips associated with deliveries or services that would not be required on a regular basis.

To avoid overestimating traffic volumes, the traffic schedule, broken down into trips per day, trips per week, and one-time trips, are reported independent of one another in Table 5-5, Table 5-6, and Table 5-7. For example, daily trips were not included in the number of weekly trips or one-time trips. It is noted that there are a relatively high number of estimated one-time trips (i.e., 1,970) during the Construction and Decommissioning and Reclamation (i.e., Closure) phases; these individual one-time trips represent shipments of site infrastructure components that would be constructed on or removed from site, as well as all supporting equipment required for Construction and Closure.

Table 5-5: Traffic Generation for Construction

Category	Generation		
	Trips/Day	Trips/Week	One-Time Trips
Expendables	24	11	0
Labour	0	50	0
Construction equipment/materials	0	1	1,970
Total	**2**	**62**	**1,970**

Table 5-6: Traffic Generation for Operations

Category	Generation		
	Trips/Day	Trips/Week	One-Time Trips
Expendables	26	18	0
Labour	10	0	0
One-time equipment deliveries	0	0	182
Exports	2	0	0
Total	**38**	**18**	**182**

Table 5-7: Traffic Generation for Closure

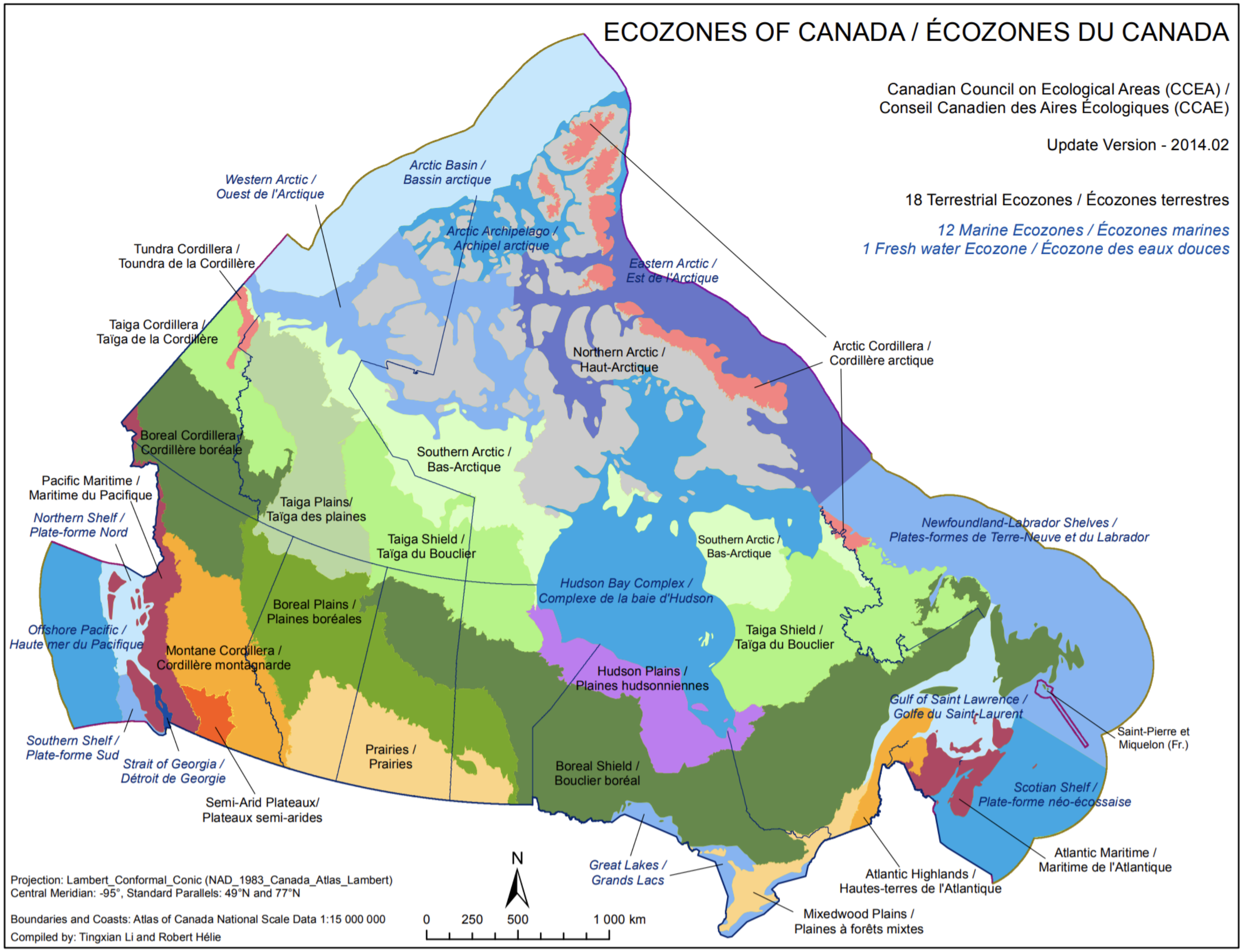
Category	Generation		
	Trips/Day	Trips/Week	One-Time Trips
Expendables	24	11	0
Labour	0	0	0
One-time equipment deliveries	0	0	1,970
Total	**24**	**11**	**1,970**

5.3 Transportation Setting

The transportation route is mostly outside the Project biophysical local study area and regional study area. Therefore, the baseline information for locations of the accident scenarios is not available. Alternatively, information from Ecological Framework of Canada's ecozone (CCEA 2014, Ecozones n.d.), where the transportation route is located, was used to understand the environment surrounding the route. The route is located in northern Saskatchewan. It is mainly located within the Boreal Plains Ecozone (CCEA 2014; Figure 5-1).

Based on the information provided on the Ecological Framework of Canada (Ecozones n.d.), the Boreal Plains Ecozone forms part of the flat Interior Plains of Canada with subdued relief consisting of low-lying valleys and plains. Most of the ecozone is associated with boreal forest composed of white and black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), and jack pine (*Pinus banksiana*), with tamarack (*Larix laricina*) in some peatlands. Aspen and poplar (*Populus*) are the most common broadleaf trees, with birch also occurring in some areas. Lakes and wetland areas such as sloughs and marshes are areas of rich vegetation. In poorly drained areas, extensive bogs have developed with ground and tree lichens. The most prominent local wildlife species include timber wolf (*Canis lupus*), black bear (*Ursus americanus*), moose (*Alces alces*), woodland caribou (*Rangifer tarandus caribou*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), and beaver (*Castor canadensis*). Typical bird species include gray jay (*Perisoreus canadensis*), common loon (*Gavia immer*), white-throated sparrow (*Zonotrichia albicollis*), American redstart (*Setophaga ruticilla*), Canada warbler (*Cardellina canadensis*), and ovenbird (*Seiurus aurocapilla*). Game birds found in the region include species of grouse (*Canachites canadensis*), geese, ducks, and ptarmigan. Common fish in lakes and streams include walleye (*Sander vitreus*), lake whitefish (*Coregonus clupeaformis*), northern pike (*Esox lucius*), burbot (*Lota lota*), perch (*Perca flavescens*), and scattered populations of trout.

Figure 5-1: Ecozones of Canada



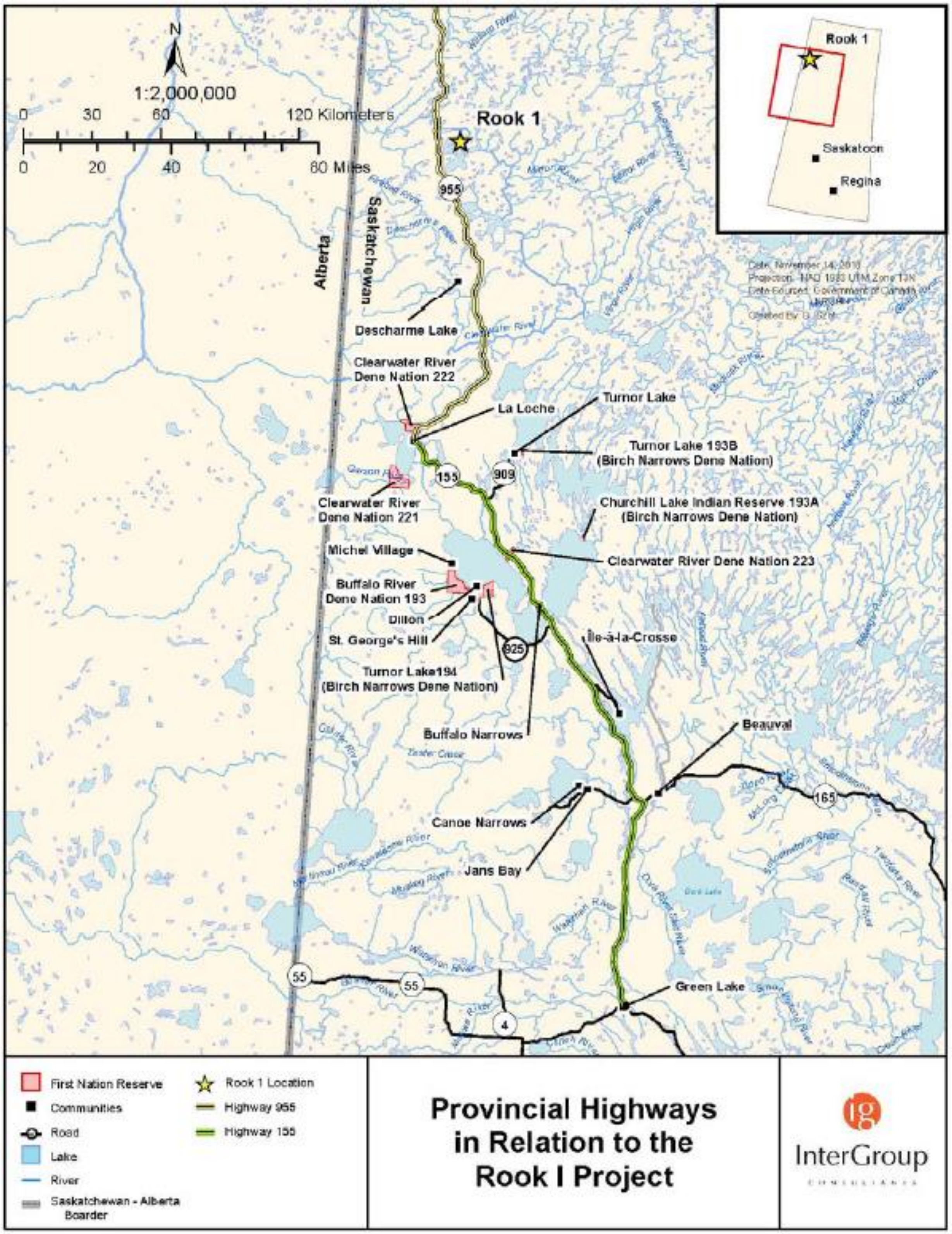
5.4 Transportation Route

Highway 155 extends north and northwest for approximately 300 km from the intersection with Highway 55 near Green Lake, and terminates near La Loche, where Highway 955 begins. Highway 955 extends for approximately 270 km north of La Loche and ends near the southern tip of Carswell Lake and the former Cluff Lake Mine. The proposed Project is approximately 154 km from La Loche off Highway 955 and is accessed by a private 13 km all-season road (Figure 5-2).

Traffic volumes on Highway 155 and Highway 955 are as much as 5 and to 20 times less than those on Highway 55, and much lower (i.e., 15 to 60 times less) compared to other provincial highways of comparable size. As such, the incremental increase in traffic volume on these highways due to Project-related traffic would be larger than those for other such highways. In addition, the distance of these two highways from major population centres such as Regina or Saskatoon results in slower emergency response to transportation accidents. The emergency response capabilities that can be deployed to attend the traffic accidents on other major highways is more timely due to closer proximity to larger population centres. The above information provides the rationale for the inclusion of the spatial extent of the transportation risk assessment.

The above information also provides the rationale for not extending the transportation risk assessment beyond the Highway 155 and Highway 55 junction at Green Lake. Project-related traffic is not considered to be a material incremental increase above existing conditions. Additionally, emergency times to traffic accidents on Highway 155 and Highway 955 may be longer than that on Highway 55.

Figure 5-2: **Provincial Highways in Relation to the Rook I Project**



5.4.1 Water Crossings, Communities, and Intersections

The statistics for transportation accidents are presented as the frequencies per vehicle-km travelled. Thus, the analysis of the probability of accident scenarios requires information about the length of portions of the route that are vulnerable to the accident and subsequent contaminant release. The water crossings, communities along the transportation route, and intersections were identified to inform selection of the location of the postulated transportation accident scenarios.

The transportation route from the access road and Highway 955 junction to Highway 155 and Highway 55 junction at Green Lake (454 km) crosses over or passes by (i.e., within 30 m of) 33 waterbodies (Table 5-8), enters five communities (Table 5-9), and intersects nine other Saskatchewan highways (Table 5-10). Figures showing the features in Table 5-8, Table 5-9, and Table 5-10 are provided in Appendix A - Water Features, Appendix B - Communities, and Appendix C - Intersections, respectively.

Table 5-8: Transportation Route Water Features

No.	Hwy	Distance from Access Road-Highway 955 intersection (km)	Name	Feature	Length (m)	Length plus Buffer (m)[(a)]
1	955	6.3	Unnamed creek	Water crossing	50	110
2	955	26.9	Unnamed creek	Water crossing	70	130
3	955	50.9	Unnamed creek	Water crossing	100	160
4	955	57.8	Unnamed creek	Water crossing	15	75
5	955	68.1	Unnamed creek	Water crossing	20	80
6	955	69.6	Unnamed creek	Water crossing	30	90
7	955	70.0	Unnamed creek	Water crossing	50	110
8	955	79.7	Unnamed creek	Water crossing	70	130
9	955	91.0	Clearwater River	Water crossing	110	170
10	955	105.0	Unnamed creek	Water crossing	15	75
11	955	124.0	Unnamed creek	Water crossing	10	70
12	955	137.5	Unnamed creek	Water crossing	110	170
13	955	143.3	Unnamed creek	Water crossing	360	420

No.	Hwy	Distance from Access Road-Highway 955 intersection (km)	Name	Feature	Length (m)	Length plus Buffer (m)[(a)]
14	155	154.6	Unnamed creek	Water crossing	10	70
15	155	194.2	Bear Creek	Water crossing	15	75
16	155	202.4	Unnamed creek	Water crossing	65	125
17	155	220.2	Unnamed creek	Water crossing	15	75
18	155	255.1	Churchill Lake	Vicinity	100	160
19	155	258.0	Kisis Channel	Water crossing	200	260
20	155	295.7	Unnamed creek	Water crossing	250	310
21	155	300.8	Unnamed creek	Water crossing	50	110
22	155	302.2	Unnamed creek	Water crossing	10	70
23	155	311.0	Unnamed creek	Water crossing	10	70
24	155	313.9	Lac Île-à-la-Crosse	Vicinity	110	170
25	155	318.7	Unnamed creek	Water crossing	150	210
26	155	322.9	Canoe River	Water crossing	50	110
27	155	326.0	Unnamed creek	Water crossing	30	90
28	155	349.8	Unnamed creek	Water crossing	200	260
29	155	391.6	Unnamed creek	Water crossing	10	70
30	155	412.2	Waterhen River	Water crossing	50	110
31	155	427.9	Beaver River	Water crossing	70	130
32	155	438.1	Cowan River	Water crossing	45	105
33	155	451.7	Unnamed creek	Water crossing	15	75
				Total	**2,465**	**4,445**

a) Buffer includes 30 m on both side of the water feature.

Table 5-9: Communities Along the Transportation Route

No.	Hwy	Distance from Access Road-Highway 955 intersection (km)	Name	Feature	Exposure Length (m)
1	955	154	La Loche community	Vicinity	430
2	155	194.3	Bear Creek community	Vicinity	300
3	155	252.9	Buffalo Narrows	Vicinity	3,400
4	155	358.7	Beauval community	Vicinity	900
5	155	453.0	Green Lake	Vicinity	600
				Total	**5,630**

Table 5-10: Major Intersections and Road Features

No.	Hwy	Distance from Access Road-Highway 955 intersection (km)	Location	Feature
1	955	0	Access road, Highway 955 intersection	Intersection
2	155	154.1	Highway 955, 155 intersection	Intersection
3	155	198.3	Highway 909, 155 intersection	Intersection
4	155	255.3	Highway 155 sharp turn	Intersection
5	155	259.4	Highway 155, Buffalo Narrows airport road intersection	Intersection
6	155	267.1	Highway 909, 155 intersection	Intersection
7	155	299.7	Highway 908, 155 intersection	Intersection
8	155	354.0	Highway 965, 155 intersection	Intersection
9	155	359.2	Highway 165, 155 intersection	Intersection
10	155	453.6	Highway 55, 155 intersection	Intersection

The specifications of Highway 155 and Highway 955 are provided in the Transportation and Logistics Study, Logistics Review Report (Stantec 2019).

6.0 TRANSPORTATION ACCIDENT SCENARIOS

The transportation accident assessment is a part of the assessment of accidents and malfunctions, in which a number of scenarios were selected for quantitative assessment. Similarly, a number of transportation accident scenarios were selected to evaluate potential Project-related transportation risks. A transportation accident may result in the release of hazardous materials to ground, water, and/or atmosphere. In addition to the hazardous material release, the accident may involve physical impact to members of the public and wildlife along the transportation route.

Release scenarios were derived from previous experience at similar operations, a traffic study completed for the Project (Stantec 2019), engagement with Joint Working Groups, features of transportation route including proximity to population centres and surface water bodies, and relevant acts and regulations (Section 1.2).

During initial discussions, Joint Working Groups have shown initial interest in:

- assessing the consequence of a traffic-related accident on the highway north of La Loche where there are peat bog areas (rather than only at key water crossings, for example);
- traffic planning and ongoing communication with communities;
- emergency response planning integrated with the communities; and
- the poor condition of the highway north of Green Lake.

For the purpose of this assessment, the following five release scenarios were assessed:

1. an aquatic release scenario;
2. a terrestrial release scenario;
3. a vehicle fire and atmospheric release scenario;
4. a vehicle-human accident scenario; and
5. a vehicle-wildlife accident scenario.

Two of the five scenarios selected as the focus of the assessment (Aquatic Release Scenario, Section 6.1; Terrestrial Release Scenario, Section 6.2), could be initiated by single vehicle or vehicle-vehicle accidents, or alternatively, by vehicle-human interactions. The assessment of these scenarios is focused on the potential environmental consequences and related public and wildlife risks. However, these scenarios could also result in direct injuries or fatalities to those involved in the accidents and/or members of the public, as highlighted in during Joint Working Group engagement (BRDN-JWG 2021). A scenario specific to vehicle-human interaction has been assessed (Vehicle-Human Accident Scenario, Section 6.4). Although this scenario does not identify a specific location along the transportation route, it is assumed to be relevant at key locations such as those perceived to be of higher concern (i.e., the bridge crossing and sharp turn along Highway 155 in Buffalo Narrows).

Brief descriptions of these scenarios are provided in Section 6.1 through Section 6.5.

6.1 Aquatic Release Scenario

In this postulated scenario, the contents of the uranium concentrate drums or other hazardous material containers would be released to surface water following a traffic accident with breach of drums or containers. The accident could be the result of running off the road, roll over, or collision with other vehicles. The following water crossing locations were selected for the assessment of postulated surface water release:

- Clearwater River at Highway 955;
- Canoe River at Highway 155;
- Beaver River at Highway 155; and
- Churchill Lake at Highway 155 (Buffalo Narrows).

6.2 Terrestrial Release Scenario

In this postulated scenario, the contents of the uranium concentrate drums or other hazardous material containers would be released on land following a traffic accident with breach of drums or containers. The accident could be the result of running off the road, roll over, or collision with other vehicles. The release during winter and summer seasons is analyzed separately as the behaviour of the released materials is different during winter when the land is frozen and summer when there is a potential for soil and groundwater contamination.

6.3 Atmospheric Release Scenario

In this postulated scenario, the transportation truck catches fire following a traffic accident. The accident could be the result of running off the road, roll over, or collision with other vehicles. If the uranium concentrate drums breach and are exposed to fire, there is a potential for atmospheric release of uranium concentrate particles. If the fire involves the released hydrocarbons (e.g., diesel, gasoline, solvent), smoke with toxic components would be released to the atmosphere.

The driver of the truck, first responders, and members of the public residing in the communities along the transportation route could potentially be at risk of exposure.

6.4 Vehicle-Human Accident Scenario

In this postulated scenario, a vehicle-pedestrian accident involving a Project-related vehicle and a member of the public within the communities along the transportation route was analyzed.

6.5 Vehicle-Wildlife Accident Scenario

In this postulated scenario, a vehicle-wildlife accident involving a Project-related vehicle along the transportation route was analyzed.

7.0 RECEPTORS AND TOXICITY BENCHMARKS

The analysis of the potential effects from a transportation accident on human health and the environment requires the identification of both human and ecological receptors, as well as the toxicological benchmarks used for the effects assessment. Potential receptors and relevant toxicity benchmarks are described below.

7.1 Selected Ecological and Human Receptors

7.1.1 Ecological Receptors

The following aquatic indicator taxa, which are representative of species that are typical of the assessment study area, were considered in the transportation risk assessment for evaluating releases to the aquatic environment:

- aquatic plants;
- benthic invertebrates; and
- forage fish and predatory fish.

Hazardous materials released due to accidents on land, particularly in more remote areas where there may be a delay in responding to a spill, could be accessible to wildlife; thus, may pose a risk to wildlife. In the aquatic environment, long-term elevated concentrations due to residual materials that may remain in place at the release location following remediation activities may result in exposure to terrestrial taxa that have a strong affinity to water. These taxa are both primarily linked to the terrestrial environment, in consideration of traffic-related releases to ground, and have a strong affinity to water, in consideration of traffic-related releases to the aquatic environment. The following terrestrial indicator taxa, which are representative of species that are typical of the assessment study area, are also considered in the transportation risk assessment:

- sandpiper (*Calidris alpina*);
- moose (*Alces alces*); and
- meadow vole (*Microtus pennsylvanicus*).

7.1.2 Human Receptors

The human receptors considered for this assessment include the following:

- the driver of the vehicle that is the subject of the accident;
- the first responders attending the accident; and
- members of the public residing in the communities along the transportation route.

7.2 Toxicity Benchmarks

The following subsections define relevant benchmarks used to assess the potential effects of the transportation accident scenarios described in Section 6.0. The following benchmarks presented are specific to the effects of the scenarios with consideration of the interactions of the scenarios with the environment presented in Section 9.0, Fate and Transport Assessment.

- uranium:
    - atmospheric environment; and
    - aquatic environment.
- radioactivity:
    - aquatic and terrestrial environment.
- smoke:
    - atmospheric environment.

7.2.1 Uranium

7.2.1.1 Atmospheric Environment

The Agency for Toxic Substances and Disease Registry (ATSDR) provides evaluations of toxicity for numerous agents, including uranium. In its 2013 report *Toxicological Profile for Uranium* (ATSDR 2013), the ATSDR reports that “natural and depleted uranium have the identical chemical effect on your body. The health effects of natural and depleted uranium are due to chemical effects and not to radiation.” The 2013 report by ATSDR further notes that “neither the National Toxicology Program, International Agency for Research on Cancer, nor the Environmental Protection Agency have classified natural uranium or depleted uranium with respect to carcinogenicity.”

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2017) indicates that the relative importance of chemical and radiological toxicity of uranium depends on a number of factors, notably, the degree of enrichment of uranium-234 and uranium-235. The chemical toxicity from uranium exposure is mainly exhibited as damage to the kidneys and is assumed not to occur below a threshold concentration. While uranium is a radioactive substance, for natural and depleted uranium, the risks from intake of uranium are related to its chemical toxicity, and the potential for such effects is the basis for the hazard and risk assessments described in this report.

Exposure limits for emergency scenarios are defined by a hierarchy of threshold concentrations for one-hour exposure. These include the Acute Exposure Guideline Level (AEGL; NOAA 2022a), the Emergency Response Planning Guideline (ERPG; NOAA 2022b), and the Temporary Emergency Exposure Limit (NOAA 2022c). Temporary Emergency Exposure Limits are intended for use until AEGLs and ERPGs are adopted for chemicals and have similar definitions as the corresponding ERPG levels. The ERPGs and AEGLs are defined for three levels.

The three levels of the AEGLs are defined as follows:

AEGL-1	The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible on cessation of exposure.
AEGL-2	The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
AEGL-3	The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

The three AEGL levels have not been established for uranium oxide or uranium concentrate.

The Emergency Response Panning Guideline is intended to be a planning tool to help anticipate human adverse effects on the general public caused by toxic chemical exposure. These guidelines are only available for a one-hour exposure duration and are not designed for hypersensitive individuals.

The three levels of the ERPGs are defined as follows:

ERPG-1	The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing effects other than mild transient adverse health effects, or perceiving a clearly defined, objectionable odour.
ERPG-2	The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.
ERPG-3	The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects.

The most commonly used benchmarks for emergency release scenarios are ERPG-2 and AEGL-2. Emergency Response Panning Guideline values for uranium oxide and uranium concentrate developed by the American Industrial Hygiene Association are provided in Table 7-1 (AIHA 2013).

Table 7-1: Emergency Response Planning Guidelines for Uranium Oxide and Uranium Concentrate

Chemical	ERPG-2	ERPG-3
Uranium oxide	10 mg/m^3	30 mg/m^3
Uranium concentrate	10 mg/m^3	50 mg/m^3

ERPG = Emergency Response Planning Guidelines.

7.2.1.2 Aquatic Environment

The maximum acceptable concentration (MAC) is 20 µg/L for total natural uranium in drinking water (Health Canada 2019). The guideline is based on the chemical toxicity of naturally occurring uranium.

Canadian Water Quality Guidelines for the protection of aquatic life for uranium (total recoverable, unfiltered) are 15 µg/L and 33 µg/L for long-term exposure and short-term exposure, respectively (CCME 1987).

Uranium exposure to benthic invertebrates from sediments was assessed against the toxicity benchmarks from Thompson et al. (2005). The Lowest Effect Level (LEL) and Severe Effect Level (SEL) concentrations are 2,296 µg/g (mg/kg) and 5,874 µg/g (mg/kg), respectively.

The water quality guidelines for drinking water and protection of aquatic life are not developed for emergency situations; however, they can be conservatively used during transient situations following an accident.

7.2.1.3 Terrestrial Environment

The Toxicity Reference Values (TRVs) used for the semi-aquatic ecological receptor (sandpiper) are for chronic exposure, since exposure to sandpiper includes sediment-related pathways. The selected TRV for moose and meadow vole is an acute threshold since these species would potentially be exposed to the spilled uranium concetrate in water and soil for a short period of time. These are listed in Table 7-2.

Table 7-2: Toxicity Reference Values for Semi-Aquatic and Terrestrial receptors

Receptor	TRV (mg/kg/d)	Reference
Sandpiper (Semi-Aquatic)	16	Haseltine and Sileo (1983)
Meadow Vole (Terrestrial)	11.4	Domingo et al. (1987)
Moose (Terrestrial)	11.4	Domingo et al. (1987)

7.2.2 Radioactivity

Radiation Protection Regulations, SOR/2000-203, govern the annual effective dose equivalent limits for individual members of the public exposed to the radioactivity resulting from industrial activities such as uranium mining and milling facilities. The effective dose limit for the general public is 1 mSv per calendar year.

The assessment of effects on ecological species from exposure to radioactive constituents involves estimation of the combined (total) dose that a receptor may receive from radionuclides taken into the body, as well as from exposure to radiation fields in the external environment. In addition, it is standard practice to take into account differences in the effects of alpha, beta and gamma radiation. Radiation effects on biota depend not only on the absorbed dose, but also on the relative biological effectiveness (RBE) of the particular radiation (i.e., alpha, beta or gamma radiation). For example, alpha particles can produce observable damage at lower absorbed doses than gamma radiation. Thus, in order to estimate the potential harm to non-human biota from a given absorbed dose, the absorbed dose is multiplied by an appropriate radiation weighting factor. This in turn is derived from an experimentally determined RBE.

There is uncertainty concerning the most appropriate RBE values for assessing risks to non-human biota. The RBE values depend on the radiation quality, the biota under consideration, the endpoint being considered and the reference photon energies. The RBE values selected to develop protection criteria correspond to the endpoint being protected (e.g., health of a population). For this assessment, an RBE of 2 was used for "low beta" and an RBE of 10 was used for alpha components to represent their greater relative effectiveness (CSA 2022).

The Canadian Standard N288.6, which addresses *Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills* (CSA 2022), recommends an RBE of 10 to be applied to the component of internal dose from alpha emitters. This assessment follows this recommendation. The standard also recommends that radiation dose benchmarks for quantitative effects assessment follow guidelines set by United Nations Scientific Committee on the Effects of Atomic Radiation (2008; i.e., 100 micrograys per hour [μGy/h] for terrestrial biota and 400 μGy/h for aquatic biota). Therefore, the benchmarks used in the assessment are 2.4 milligrays per day (mGy/d) for terrestrial biota and 9.6 mGy/d for aquatic biota.

7.2.3 Smoke and its Toxic Components

Carbon monoxide and polycyclic aromatic hydrocarbons (PAHs) were considered with reference to potential toxic effects of smoke dispersion. Particulate matter (PM), especially respirable fractions (RFs) of PM, was not considered for the assessment because no safe level for PM has been established by the various regulatory organizations, including the World Health Organization (WHO 2014). Therefore, the assessment of PM consequences does not provide useful information for emergency response planning. The mitigation of PM should be based on an ALARP basis. The criteria for accidents and emergency situations are presented as AEGL levels. Where AEGL levels are not available, Protective Action Criteria (i.e., PAC-1, PAC-2, and PAC-3) for toxic releases are used. The ERPG-2, AEGL-2, and PAC-2 are the most commonly used criteria for emergency response planning purposes. The AEGLs and PACs for carbon monoxide and PAHs are provided in Table 7-3.

Table 7-3: Temporary Emergency Exposure Limits for Smoke Contaminants

Chemical	AEGL-2	AEGL-3	PAC-2[(a)]	PAC-3[(a)]
Carbon monoxide	83 ppm	330 ppm	n/a	n/a
PAHs equivalent	n/a	n/a	1.3 mg/m^3	7.9 mg/m^3

n/a = not available; AEGL = Acute Exposure Guideline Level; PAC = Protective Action Criteria; ppm = parts per million; PAH = polycyclic aromatic hydrocarbon.

a) PAC-2 = Irreversible or other serious health effects that could impair the ability to take protective action; PAC-3 = Life-threatening health effects.

8.0 PROBABILITY ASSESSMENT

The probability of transportation accidents is derived using transportation accident statistics from various jurisdictions and is described below. Given the low traffic volume on the highways being evaluated compared to province-wide averages, the general statistics can be considered more accurate.

8.1 Transportation Volume and Accident Statistics

To select the appropriate dataset to estimate accident probabilities, the historical accident datasets relevant to the study area were reviewed. The focus of this review was on accidents involving heavy trucks, since uranium concentrate drums or other hazardous materials would be transported by commercial trucks and tractors pulling one multi-axle semi-trailer.

8.1.1 Provincial Data

For this analysis, publicly available accident data provided by Saskatchewan Government Insurance (SGI) from 2007 to 2014 in the province of Saskatchewan were reviewed (SGI 2018). Table 8-1 presents the total number of accidents involving heavy trucks for Saskatchewan from 2007 to 2014.

Table 8-1: Total Number of Accidents in Saskatchewan Involving Heavy Trucks, 2007 to 2014

Jurisdiction	2007	2008	2009	2010	2011	2012	2013	2014
Saskatchewan	1,604	1,601	1,599	1,583	1,753	1,703	2,076	1,679

Source: SGI 2018.

In order to estimate the probability of accidents on the transportation route, province-wide accident frequencies are required to be normalized, and values adjusted to a common scale. A number of factors can be considered for normalizing accident data, including population, vehicle distance travelled, number of registered vehicles, and number of licensed drivers. Among these factors, the vehicle distance travelled was chosen for this assessment, as it the most commonly used means for normalizing traffic accidents. Table 8-2 summarizes the total distance travelled by commercial trucks to transport goods in Saskatchewan, retrieved from Canadian Vehicle Survey of Statistics Canada.

Table 8-2: Total Distance Travelled (Million-Vehicle-Kilometres) by Trucks in Saskatchewan, 2007 to 2014

Jurisdiction	2007	2008	2009	2010	2011	2012	2013	2014
Saskatchewan	1,957	1,883	1,928	1,923	2,057	2,086	2,110	2,057

Source: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310009701.

Based on the available accident frequencies and vehicle distance travelled data, the truck accident rates were calculated for Saskatchewan (Table 8-3).

Table 8-3: Truck Accident Rate in Saskatchewan (Per Million-Vehicle-Kilometre), 2007 to 2014

Jurisdiction	2007	2008	2009	2010	2011	2012	2013	2014
Saskatchewan	0.82	0.85	0.83	0.82	0.85	0.82	0.98	0.81

The information shown in the above table indicates that the truck accident rates in Saskatchewan from 2007 to 2014 (i.e., 0.81 to 0.98 per million-vehicle-kilometre [MVkm] distance travelled) are relatively low compared with the Canada-wide rate (i.e., 1.1 per MVkm distance travelled; Transport Canada 2016) and are consistent with the United States rate (0.98 per MVkm distance travelled; NHTSA 2015).

The accident rates referenced above that are used to derive accident frequency / probability in Section 8.2 (Accident Frequency Calculation) are not specifically adjusted to account for the incremental change in traffic numbers associated with the Project, as accident rates are not expected to be affected by this change. Accident rates are generally consistent year-over-year and there is not a direct relationship between traffic volume and accident rate. Moreover, drivers and operators who would be associated with the Project were assumed to have the same skill level as the general public on which the accident data are based. This is a conservative assumption as the transportation of materials for the Project would be conducted by professional drivers bound by both speed limits and adherence to strict safety practices. Together, these factors provide a conservative rationale for use of existing data to assess accident frequency / probability.

According to SGI (2018) truck accident statistics, approximately 90% of the accidents are minor in nature and result in no injuries, with property damage only. However, McSweeney et al. (2004) indicate that if a truck sustains major damage, even at even low speeds, the drums/containers inside the truck may breach.

8.1.2 Regional Statistics

A summary of the SGI data (SGI 2018) collected on average annual daily traffic, annual travel (MVkm), truck average annual daily traffic, and annual truck travel (MVkm) by control section for Highway 155 in 2018 by Saskatchewan Government Insurance indicates that the annual travel is 51 MVkm. The same dataset for Highway 955 shows that the annual travel is 10 MVkm. The total number of accidents was 59 for Highway 155 and 8 for Highway 955 in 2018 (SGI 2018). Based on these data, the accident rates for Highway 155 and Highway 955 were 1.16 and 0.8 accidents per MVkm, respectively.

The information in the Saskatchewan Government Insurance report indicates that 15.6% of the rural traffic collisions involved wildlife and only 0.4% of the rural traffic collisions involved pedestrians. It was also reported that only 0.1% of all traffic accidents involved vehicle fire or explosion.

8.2 Accident Frequency Calculation

The accident frequency (and then probability) is calculated using the following equation:

$$\text{Accident frequency (per year)} = \text{Number of trips per year} \times \text{Travel distance (km)} / 1{,}000{,}000 \times \text{Accident rate (per MVkm)}$$

Based on the transportation route length considered (454 km), the number of vehicle travels per year provided in Section 5.2, Transportation Quantities, and the transportation accident rates estimated above (Section 8.1), the frequency of accidents for each postulated accident scenario were calculated and summarized in Table 8-4. In Table 8-4, conditional probabilities are the fraction of different types of the accidents (e.g., damage only, fire, vehicle-human, vehicle-wildlife).

Table 8-4: Summary of Annual Accident Frequencies

Accident Scenario	Trips per Year	Exposure Distance (km)(a)	Exposed (MVkm)	Traffic Accident Frequency (Per Year)(b)	Conditional Probability	Scenario Frequency (Per Year)
Aquatic release (uranium concentrate)	800	4.4	0.004	2.85×10^{-3}	0.1	2.85×10^{-4}
Aquatic release (other hazardous materials)	2,400	4.4	0.01	8.55×10^{-3}	0.1	8.55×10^{-4}
Terrestrial release	3,200	454	1.45	$1.18 \times 10^{+0}$	0.1	1.18×10^{-1}
Vehicle fire and atmospheric release	800	454	0.36	2.94×10^{-1}	0.01	2.94×10^{-3}
Vehicle-human accident	10,843	454	4.92	$3.99 \times 10^{+0}$	0.004	1.60×10^{-2}
Vehicle-wildlife	10,843	454	4.92	$3.99 \times 10^{+0}$	0.156	6.22×10^{-1}

a) The exposure distance was calculated in Section 5.4.1, Table 5-8.
b) Based on the accident rate of 0.81 accident per MVkm.
MVkm = million-vehicle-kilometre.

It is important to note that while accident frequency is used interchangeably with accident probability, they are not the same. Although similar for very low accident frequencies, for higher accident rates, the relationship between accident rates and probability should be considered in a more formal sense because the difference may be important. For this analysis, the probability of at least one release occurring during one year is given by the following equation:

$$P = 1 - exp^{-lt}$$

Where: *P* represents probability, *l* represents the frequency per year, and t represents the time interval when the probability is calculated.

The annual probabilities of accident scenarios for each postulated scenario are summarized in Table 8-5. Note that for frequencies of <0.01/year, probability is approximately the same as frequency.

It should be noted that since the focus of the assessment is the risk of transportation of dangerous goods (e.g., uranium concentrate), which occurs during the operation phase, the probabilities during 24 years of operation were also calculated.

Table 8-5: Summary of Annual Accident Probabilities

Accident Scenario	Scenario Frequency (Per Year)	Annual Scenario Probability	Operational Lifetime Probability[(a)]
Aquatic release (uranium concentrate)	2.85×10^{-4}	2.85×10^{-4}	6.82×10^{-3}
Aquatic release (other hazardous materials)	8.55×10^{-4}	8.55×10^{-4}	2.03×10^{-2}
Terrestrial release	1.18×10^{-1}	1.11×10^{-1}	9.41×10^{-1}
Vehicle fire and atmospheric release	2.94×10^{-3}	2.94×10^{-3}	6.81×10^{-2}
Vehicle-human accident	1.60×10^{-2}	1.58×10^{-2}	3.18×10^{-1}
Vehicle-wildlife accident	6.22×10^{-1}	4.63×10^{-1}	9.9×10^{-1}

a) Assumed 24 years of operations.

9.0 FATE AND TRANSPORT ASSESSMENT

The fate and transport assessment calculates the concentrations of released contaminants for postulated transportation accident-related releases to the aquatic environment, to ground, and to the atmosphere.

9.1 Aquatic Release Scenario

9.1.1 Fate and Transport Assessment Methods

A traffic accident, collision, roll over, or runoff near surface waterbodies, river crossings, or on bridges could potentially result in a release of uranium concentrate into surface water. A spill of uranium concentrate to a river or a large lake may have transient (i.e., short-term), as well as long-term implications. In the short term, the quality of water may be affected in a way that makes it unsuitable for drinking or supporting aquatic life. In the long term, the released material would require removal and the impacted area would require remediation. Depending on the removal extent and efficiency, the long-term quality of sediment may be affected, resulting in undesirable exposure of benthic invertebrates and other biota consuming the affected sediment, or in contact with sediment, directly or indirectly.

NexGen would develop a Ground Transportation Emergency Response Plan (GTERP) that would be implemented during all phases of the proposed Project and would be activated during emergencies. The GTERP would include provisions for mitigating the effects of surface water, terrestrial, and atmospheric release emergencies as well as remediation and recovery provisions.

For the purposes of this assessment, short-term water quality is defined as the time when the affected water is diluted enough to meet the water quality guideline for uranium. This period varies between waterbodies, but is usually in the order of days to weeks. The dissolution of uranium concentrate in 5%, 25%, and 100% of the river flow by volume was assessed for minimum, average, and maximum water flowrates for each river. Consideration of 5%, 25%, and 100% is to allow the assessment of the sensitivity of the calculated concentrations with the extent of dilution in the short term.

Long-term concentrations in water were also estimated to account for transfer of the settled uranium from sediment to water. The long-term release rate is based on the concentration estimated for porewater quality. It was assumed that only the top 5 cm of the sediment bed is contaminated. If the contamination were to affect deeper sediments, the average concentration of the sediments would be lower and the diffusion of contaminants to the water column slower. Therefore a 5 cm sediment depth was considered conservative, and used in the assessment.

The effect on sediment quality was assessed through estimating the area over which uranium concentrate particles would settle onto existing sediments. This required the estimation of a settling velocity (for different particle sizes) and travel distance before settling (in longitudinal and lateral dimensions for different flow rates). In the absence of experimental data for the settling velocity of each particle size, Stoke’s Law was used to calculate the settling velocity. Concentrations in the sediment were estimated using the results of the particle dispersion analysis.

It was assumed that uranium concentrate that settles close to the spill site (i.e., within the first 15 m) would be removed through a post-accident remediation program with a removal efficiency of 95%. This assumption was based on the expectation that most of the uranium concentrate released would remain in relatively close proximity to the release location, given the high particle density of uranium concentrate (8.3 g/cm^3) that results in a high settling velocity (USDOE 2001). Figure 9-3, Figure 9-6, Figure 9-10, and Figure 9-14 indicate that more than 95% of the sediments would settle within 15 m of the released location. In the far field (i.e., farther than 15 m), no uranium concentrate removal was assumed. This assumption implies that only 5% of the uranium concentrate is dissolved and transported away from the release site. If the remediation criteria is set at no-effect uranium concentration of 2,296 µg/g, the residual uranium content in the 5 cm of sediments in an area of 15 m by 15 m is about 26 kg. This is a very small fraction of the total amount released. Therefore, 95% recovery is a reasonable assumption.

A similar approach was adopted to estimate the concentrations in the lake sediment, except that the assumption of constant width of the flow is not relevant for lakes. It was assumed that 95% of uranium concentrate that settles within the first 30 m would be removed, with no removal at a greater distance from the release site. This is based on a conservative assumption that no clean up is conducted beyond 30 m, and 95% removal of settled particles can be achieved within a small area of 30 m.

Porewater quality within the affected sediment was estimated based on concentrations in sediment and using a sediment-to-water partition coefficient of 3.5 m^3/kg (SENES 2010).

9.1.2 Uranium Concentrate Release Characterization

Uranium concentrate drums similar to those that would be used for the Project have been subject to performance tests. For example, the drum design has passed the free drop test from 1.2 m, during which the drums sustained structural compression, but maintained their seal integrity and did not allow any of the contents to be released. The design has also passed the stacking test with a weight of five times the mass of the actual package for a period of 24 hours (Greif 2004). The stacking test results showed that packages are watertight as long as the lid is in place properly. The performance of drums similar to those used for uranium concentrate shipment during transportation accidents was determined by McSweeney et al. (2004). The authors concluded that, based on drum deformations performed in a previous analysis, if a drum experienced a crush force of 100,000 Lbs, then the deformation of the drum would cause the lid to detach from the drum.

Using this drum failure mechanism, and assuming the drums weigh 450 kg (990 Lbs) and are arranged four across in the truck in a single layer without stacking:

- at a speed of less than 60 km/h, the front 25% of the drums would fail;
- at 60 to 97 km/h, 55% would fail, at 145 km/h, 75% would fail; and
- at greater than or equal to 193 km/h, all would fail.

These results show that if the truck sustains major damage at even low speeds, the drums inside the truck may breach.

Assuming Project-related transport of 100 drums in two shipments per day, each shipment would have 49,560 Lbs (22,500 kg) of uranium concentrate (100/2 x 450 kg x 1 Lb / 0.454 kg = 49,600 Lbs). If 25% of this amount is released, the total release weight would be equivalent to approximately 12,400 Lbs (5,625 kg) of uranium concentrate.

The short-term dissolved release rate was estimated using solubility data presented previously. The solubility of calcined uranium concentrate was considered at an average value of 4.8 g/m^3 over the first 72 hours. It was conservatively assumed that such concentrations applied to a cross section of water defined by the lateral footprint of the spill and a depth of water column of 10 cm. Under these assumptions, the affected area immediately following a release would be in the order of tens of square metres. Thus, the water column would pass over the released uranium concentrate in several seconds in rivers and a few minutes in lakes. Since the mechanism for vertical movement of the dissolved uranium concentrate is diffusion, it is not expected that the dissolved uranium concentrate diffuses more that a few centimetres in the water column at the water-solids interface; thus, the assumed 10 cm depth is conservative.

The release scenario is applied to various locations as detailed below.

9.1.3 Non-Radiological Release Characterization

For non-radiological releases, it was conservatively assumed that the entire cargo would be released during a transportation accident event. Based on information provided in Table 5-4, for the purposes of the assessment, the following was assumed:

- Diesel fuel (30 m^3 release): The released diesel would form a sheen on top of water with a thickness of approximately 1 μm. While as much as 15% of the diesel would dissolve in the water column (NOAA 2006), up to 30% would evaporate from the surface of water (Silver and Mackay 1984). The rest of the fuel, which is predominantly heavier components, would stay afloat or be adsorbed into the soil or shallow sediments along the river and downstream lake banks.

- Gasoline (30 m^3 release): The released gasoline would form a sheen on top of water with a thickness of approximately 1 μm. While as much as 25% of the gasoline would dissolve in the water column, up to 70% would evaporate from the surface of water (Silver and Mackay 1984). The rest of the fuel, which is predominantly heavier components, would stay afloat or be adsorbed into the soil or shallow sediments along the river and downstream lake banks.

- Organic solvents (40 t release): The released solvent would behave similarly to diesel fuel, as discussed above.

- Liquified natural gas (48 m^3 release): The release would most likely undergo a phenomenon called cold explosion. The released liquified natural gas would evaporate quickly and be released to the atmosphere (Melhem and Ozog 2006).

- Hydrogen peroxide (approximately 18.3 m^3 release): Hydrogen peroxide and water are miscible liquids. Thus, upon release, the entire volume of hydrogen peroxide would mix with water. Hydrogen peroxide is a reactive oxygen species that decomposes slowly when exposed to light in natural environment, and rapidly in the presence of organic compounds. Decomposition releases hydroxyl radicals that rapidly react with organic compounds in the environment. The typical products of hydrogen peroxide decomposition (i.e., water and oxygen) do not harm organisms in fresh water. Organisms in small, confined waterbodies could be affected by hydrogen peroxide itself, or by reactive hydroxyl radicals formed when it reacts with metal catalysts in the water such as iron (II) sulfate (Schmidt et al. 2006). This would need to occur before hydrogen peroxide decomposes or dilutes to background levels in the environment. In a study conducted by Rach et al. (1997), fish were exposed to hydrogen peroxide concentrations ranging from 100 microlitres per litre (µL/L) to 5,000 µL/L (ppm) for 15-minute or 45-minute treatments every other day for four consecutive treatments to determine the sensitivity of various species and life stages of fish. It was found that except for walleye, most species of fish tolerated hydrogen peroxide of greater than 1,000 ppm with no adverse effects. Walleye was sensitive at concentrations as low as 100 µL/L. Given the anticipated rate of dilution of the release of hydrogen peroxide, possible effects on fish would be spatially limited and short-lived.

- Molten sulphur (25 t release): When molten sulphur is released into cold surface water, brownish amorphous or plastic sulphur is produced by the rapid cooling process. The amorphous form has long, coiled polymeric molecules that make it elastic. The solubility of this substance is extremely low and can be considered to not be released into the water column through the dissolution process.

Based on the release characterization above, the effects of releases of liquified natural gas, hydrogen peroxide, and molten sulphur were not analyzed further.

Based on the release characterization for the non-radiological contaminants considered, the consequences of the associated releases are bounded by the potential consequences of the diesel fuel release. The release of diesel fuel to the aquatic environment was selected as a surrogate for the non-radiological contaminant scenarios. The release scenario was applied to various locations as detailed below.

9.1.4 Release to the Clearwater River

9.1.4.1 River Flow Data

The Clearwater River originates in the northern forest region of northwestern Saskatchewan and joins the Athabasca River in northeastern Alberta. Historical level and flow rate data for the Clearwater River up to 1995 are available from Environment Canada.

The crossing where the hypothetical truck accident occurs is located 91 km south of the access road junction on Highway 955 (Figure 9-1). The river width at the crossing is about 80 m. The closest hydrometric gauging station is station 06AF005 (near Waterhen River). The variation in flow of the Clearwater River at this station over 15 years is shown in Figure 9-2. Minimum, average, and maximum flows considered for this assessment are 5% of the flow variation (13.3 m^3/s), average flow (21.9 m^3/s), and 95% of the flow variation (35.5 m^3/s), respectively. Corresponding river depths are 0.6 m, 1.1 m, and 2.1 m, respectively.

Figure 9-1: The Clearwater River Crossing Location

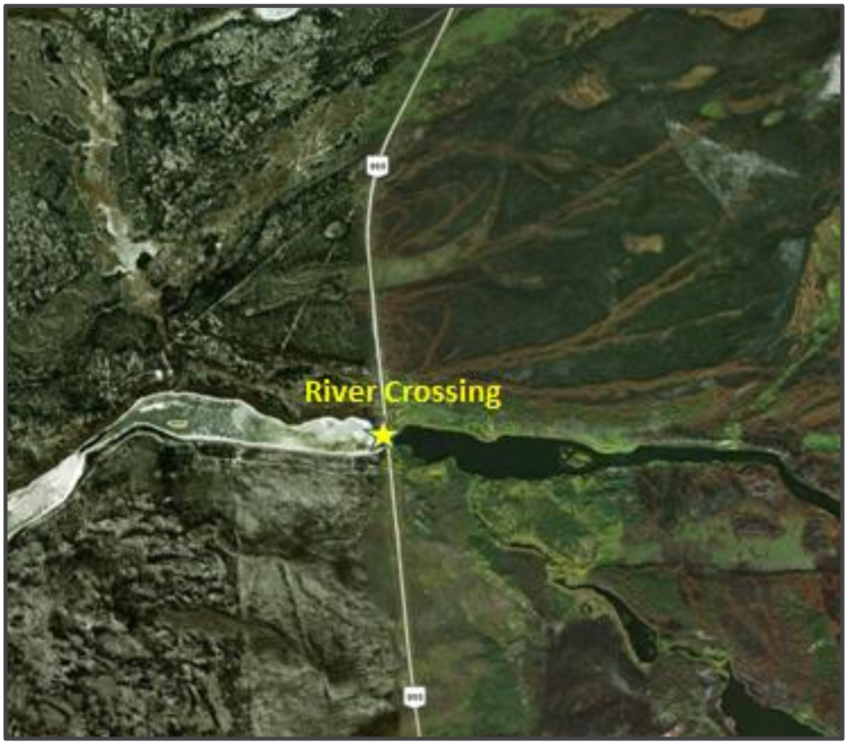
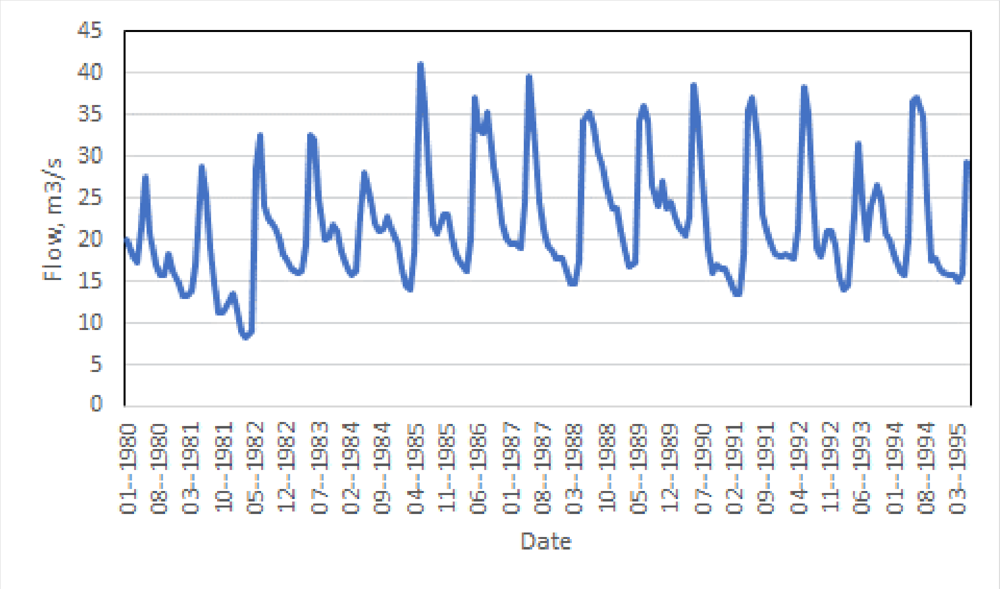


Figure 9-2: Historical Monthly Flow of the Clearwater River at Station 06AF005



Source: Saskatchewan Government, Waste Security Agency, n.d.

9.1.4.2 Uranium Concentrate Fate and Transport Results

Concentrations in sediment were estimated through calculation of the distance travelled by the uranium concentrate after a spill and the area affected. Detailed description of the methods and example calculations are provided in Appendix D, Descriptions of Methods and Sample Calculations.

Figure 9-3 illustrates the implications of the distribution of deposited uranium concentrate mass for remediation planning. The results indicate that most (i.e., 98% of the mass) of the uranium concentrate would settle within a short distance of the release, even under high flow conditions (i.e., within approximately 10 m of the release point), due to relatively low water velocity (i.e., less than 0.28 m/s) in the river. This indicates that the hypothetical spill would be confined to a small area and expected to be effectively recovered. Under high flow conditions (i.e., worst-case), the maximum estimated distance for the deposition of particulates less than 5 µm is approximately 17 m from the crossing.

Sediment quality results are shown in Table 9-1 for post-remediation conditions. The results presented in the table are predicted concentrations of uranium concentrate for three flow conditions in the Clearwater River (i.e., 5% [minimum], average [mean], and 95% flow variation [maximum]) as described in Section 9.1.4.1. In general, using the results of the assessment, the minimum predicted uranium concentrations in the river sediments occur under high flow conditions, where the smaller particles (i.e., less than 5 µm) would be deposited over a larger area.

Porewater quality within the affected sediment of the Clearwater River was estimated based on weighted-average concentrations in sediment and using a sediment-to-water partition coefficient of 3.5 m^3/kg (SENES 2010). The results are shown in Table 9-1. During minimum flow conditions, the affected volume is smaller, resulting in a higher concentration. Higher flow conditions result in a greater footprint and hence lower concentration.

Figure 9-3: Distribution of Deposited Uranium Concentrate by Distance Downstream of the Clearwater River Crossing

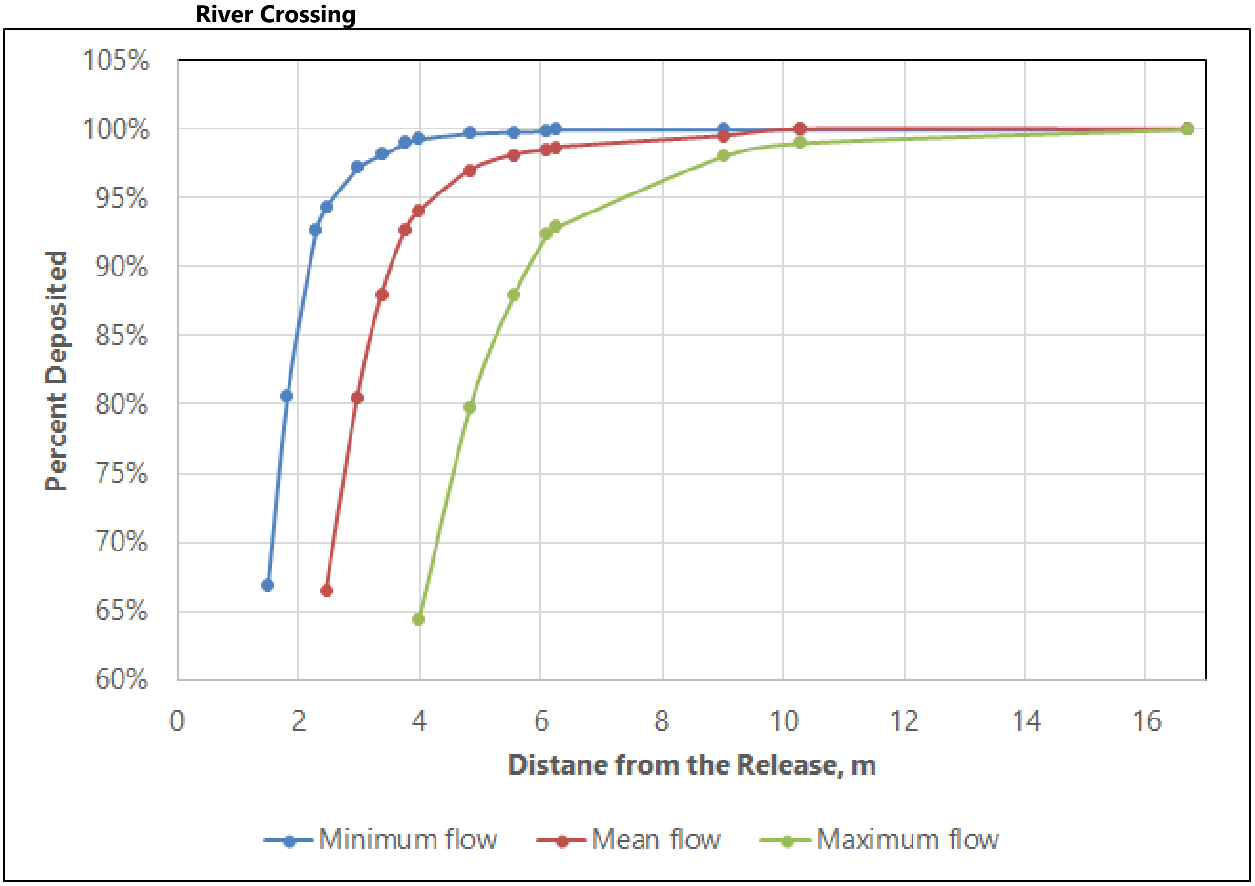


Table 9-1: Estimated Post-Remediation Concentrations of Uranium Concentrate in Sediment and Porewater Downstream of the Clearwater River Crossing

Flow	Affected Distance (m)	Average Concentration in Sediment (µg/g) (ww)	Average Concentration in Sediment (µg/g) (dw)	Average Concentration in Porewater (µg/L)
Minimum	7	1.18×10^4	3.92×10^4	41
Average	11	8.3×10^3	2.76×10^4	29
Maximum	17	5.7×10^3	1.9×10^4	20

The concentrations reported in the table is based on 95% recovery of the released uranium concentrate.
ww = wet weight.
dw = dry weight = ww/((1-0.7) x ww), assuming 70% water and 30% solids.

Concentrations of uranium concentrate in water for the three flow conditions were estimated as short- and long-term concentrations using information on uranium solubility provided in Section 5.1.1 and concentrations in porewater provided in Section 9.1.1, respectively. The results are shown in Table 9-2. The short-term period for the Clearwater River is estimated at about a week, even if no settling is taken into account. The short-term water concertation is a result of the dissolution of the released uranium concentrate into the water shortly after the release (i.e., within a day or two), and long-term concentration is a result of porewater diffusion following the remediation. Therefore, the assumption of seven days for short-term concentration is conservative.

Table 9-2: Estimated Concentrations of Uranium Concentrate in Water Downstream of the Clearwater River Crossing

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Flow (µg/L)	Mean Flow (µg/L)	Max Flow (µg/L)	Min Flow (µg/L)	Mean Flow (µg/L)	Max Flow (µg/L)	Min Flow (µg/L)	Mean Flow (µg/L)	Max Flow (µg/L)
Short-term[(a)]	18,916	10,318	5,404	3,783	2,064	1,081	946	516	270
Long-term[(b)]	n/a	n/a	n/a	n/a	n/a	n/a	0.44	0.167	0.06

a) Estimated at seven days after the spill.
b) Post-remediation.
n/a = not applicable (mixing in 5% and 25% of flow is not relevant for long-term concentrations).

9.1.4.3 Hydrocarbon Fate and Transport Results

Diesel fuel is considered a non-persistent oil. It would lose about 30% of its volume due to evaporation within 48 hours. Small diesel spills would usually evaporate and disperse within a day or less in the aquatic environment. This is particularly true for typical spills from a fishing vessel (2 m^3 to 20 m^3), even in cold water; thus, there is seldom any oil on the surface for responders to recover. Diesel fuel is much lighter (i.e., density between 0.83 and 0.88 g/cm^3) than water, so it is not possible for diesel to sink and accumulate on the benthic environment as pooled or free oil, unless adsorption occurs on sediments (NOAA 2006). Diesel dispersed in the water column can adhere to fine-grained suspended sediments (adsorption), which then settle out and get deposited on the lake or river bottom. This process is more likely to occur near river mouths where fine-grained sediment is carried in by rivers. This process is not likely to result in measurable sediment contamination for small spills. The residual diesel is completely degraded within one to two months. Therefore, surface water remediation for small-scale diesel spills is not feasible (NOAA 2006).

Nevertheless, a small-scale spill still poses a threat to aquatic organisms and particularly birds if they are exposed to diesel fuel. Fish, invertebrates, and vegetation that come in direct contact with a diesel spill may be killed (NOAA 2006). However, small spills in open water are so rapidly diluted that fish kills are unlikely events unless the spill is in confined in shallow water. Diesel spills can affect marine birds by direct contact. Mortality is caused by ingestion during preening.

The theoretical maximum size of a 1 µm thick diesel fuel sheen that can be created by a 30 m^3 spill is 3×10^7 m^2. However, due to evaporation and dissolution of the majority of the spilled diesel, the size of the sheen is typically much smaller, particularly in slow-moving surface waterbodies. The average water velocity in the Clearwater River is 0.24 m/s. At this velocity, the spill would travel about 20 km in a day. Considering the lifetime of diesel fuel, the diesel sheen could travel as much as 40 km from the bridge over the Clearwater River. The effects would be transient (within a day or two); however, some damage to aquatic biota, and potentially birds, would occur within this area. Due to short-term exposure, irreversible population-level damage is not expected.

9.1.5 Release to the Canoe River

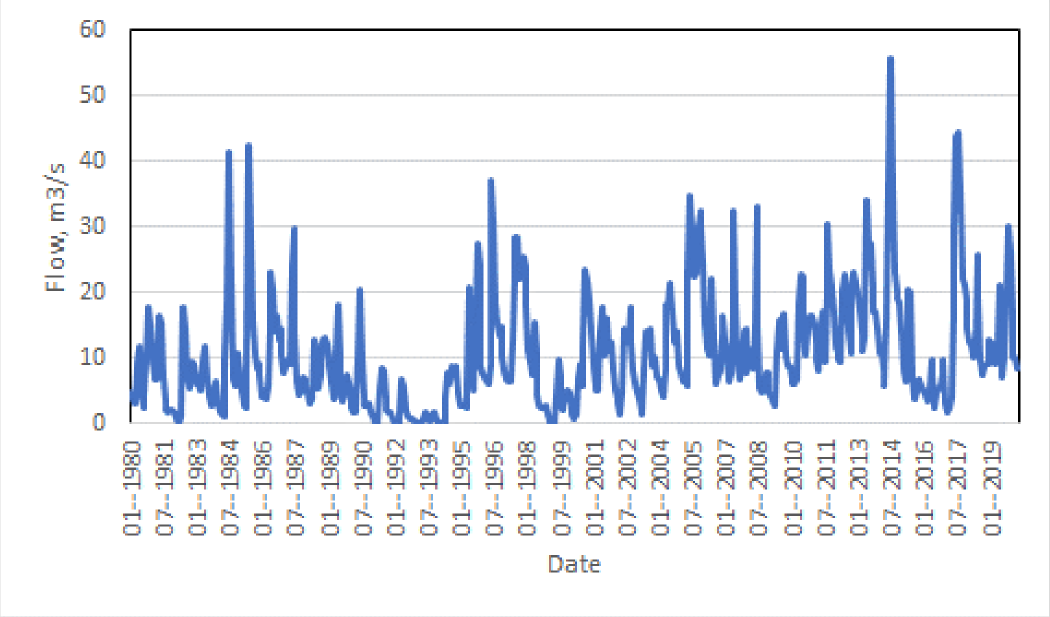
9.1.5.1 River Flow Data

The Canoe River originates from Canoe Lake in northeastern Saskatchewan west of Highway 155, runs northeast, and flows into Lac Île-à-la-Crosse on the Churchill River. The total length of the Canoe River is approximately 35 km.

The crossing where the hypothetical truck accident occurs is located 322 km south of the access road junction on Highway 155 (Figure 9-4). The river width at the crossing is approximately 60 m. The closest hydrometric gauging station is station 06BB005, near Beauval. The variation of flow in Canoe River at this station over 39 years is shown in Figure 9-5. Minimum, average, and maximum flows considered for this assessment account for 5% of the flow variation (0.73 m^3/s), average flow (10.7 m^3/s), and 95% of the flow variation (28.1 m^3/s), respectively. Corresponding river depths were 1.9 m, 2.3 m, and 2.7 m, respectively.

Figure 9-4: The Canoe River Crossing Location

Figure 9-5: **Historical Monthly Flow of the Canoe River**



Source: Saskatchewan Government, Water Security Agency n.d.

9.1.5.2 Uranium Concentrate Fate and Transport Results

Concentrations of uranium concentrate in sediment were estimated through the calculation of the distance travelled by the uranium concentrate after a spill and the area affected. A detailed description of the methods and example calculations are provided in Appendix D.

Figure 9-6 illustrates the implications of the deposited distribution of uranium concentrate mass for remediation planning. The results indicate that most (i.e., 98% of the mass) of the uranium concentrate would settle within a short distance of the release, even under high flow conditions in the Canoe River (i.e., within approximately 10 m of the release point) due to a low water velocity (less than 0.18 m/s) in the river. Due to the high density of uranium concentrate particles, which results in low mobility, and a small, affected area, a large portion of the released solids is assumed to be recovered from the spill location. Under high flow conditions (i.e., worst-case), the maximum estimated distance for the deposition of particulates less than 5 µm is approximately 18 m from the crossing.

Sediment quality results are shown in Table 9-3 for post-remediation conditions. The results presented in Table 9-3 are predicted concentrations of uranium concentrate for three flow conditions in the Canoe River (i.e., minimum, average, and maximum) as described in Section 9.1.5.1. In general, using the results of the assessment, the minimum predicted uranium concentrations in river sediments occur under high flow conditions where the smaller particles (less than 5 µm) are deposited over a larger area.

Porewater quality within the affected sediments of the Canoe River was estimated based on weighted-average concentrations in sediment and using a sediment-to-water partition coefficient of 3.5 m^3/kg (SENES 2010). The results are shown in Table 9-3. During minimum flow conditions, the affected volume is smaller, resulting in a higher concentration. Higher flow conditions result in a greater footprint and hence lower concentration.

Figure 9-6: Distribution of Deposited Uranium Concentrate by Distance Downstream of the Canoe River Crossing

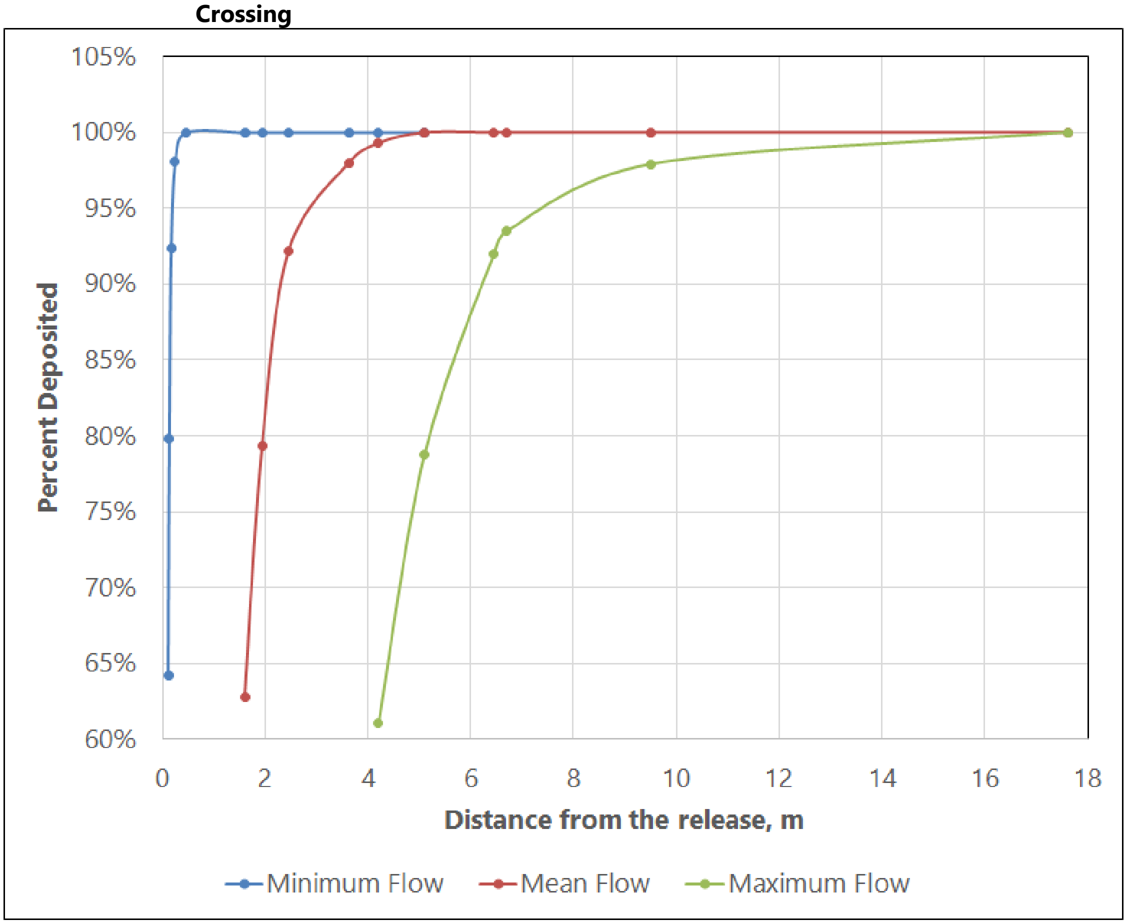


Table 9-3: Estimated Post-Remediation Concentrations of Uranium Concentrate in Sediment and Porewater Downstream of the Canoe River Crossing

Flow	Affected Distance (m)	Average Concentration in Sediment (µg/g) (ww)	Average Concentration in Sediment (µg/g) (dw)	Average Concentration in Porewater (µg/L)
Minimum	1	3.38×10^4	1.13×10^5	118.2
Average	7	1.13×10^4	3.76×10^4	39.4
Maximum	18	5.45×10^3	1.82×10^4	19.1

The concentrations reported in the table is based on 95% recovery of the released uranium concentrate.
ww = wet weight.
dw = dry weight = ww/((1-0.7) x ww), assuming 70% water and 30% solids.

Concentrations in water for the three flows were estimated for short and long-term concentrations using information on uranium solubility provided in Section 5.1.1 and concentrations in porewater provided in Section 9.1.1, respectively. The results are shown in Table 9-4. The short-term period for the Canoe River is estimated at about a week, even if no settling is considered.

Table 9-4: Estimated Concentrations of Uranium Concentrate in Water Downstream of the Canoe River Crossing

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Flow (µg/L)	Mean Flow (µg/L)	Max Flow (µg/L)	Min Flow (µg/L)	Mean Flow (µg/L)	Max Flow (µg/L)	Min Flow (µg/L)	Mean Flow (µg/L)	Max Flow (µg/L)
Short-term[(a)]	7,965	6,579	5,605	1,593	1,316	1,121	398	329	280
Long-term[(b)]	n/a	n/a	n/a	n/a	n/a	n/a	0.527	0.145	0.06

a) Estimated at one week after the spill.
b) Post-remediation.
n/a = not applicable; mixing in 5% and 25% of flow is not relevant for long-term concentrations.

9.1.5.3 Hydrocarbon Fate and Transport Results

The distance between the Canoe River crossing and Lake Lac Île-à-la-Crosse is approximately 3 km (Figure 9-7). The average water velocity in the Canoe River is 0.08 m/s. At this velocity, the spill would reach the lake in about 10 hours. Beyond this time, the plume of diesel would disperse across the western part of the lake, and would cover approximately a maximum of 1.35×10^7 m^2 of the lake area before diminishing farther. The effects would be transient (i.e., within a day or two); however, some effects to aquatic biota, and potentially birds, would occur within this area. Due to short-term exposure, irreversible population level damage is not expected.

Figure 9-7: The Canoe River and Lac Île-à-la-Crosse

9.1.6 Release to the Beaver River

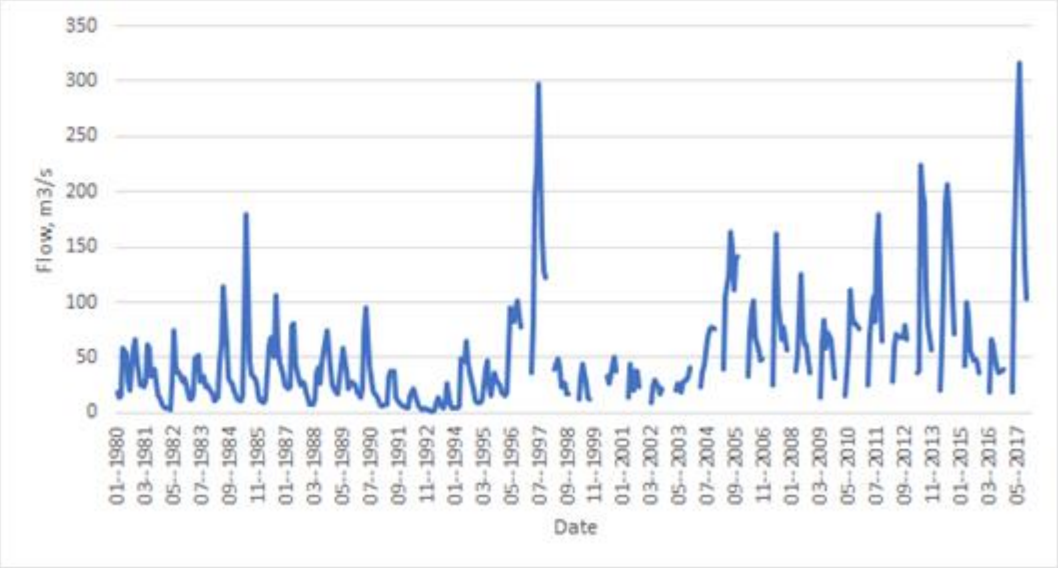
9.1.6.1 River Flow Data

The Beaver River is in east-central Alberta and central Saskatchewan. It flows east through Alberta and Saskatchewan and then turns sharply north to flow into Lac Île-à-la-Crosse on the Churchill River, which flows into Hudson Bay. The Beaver River has a catchment area of 14,500 km^2 in Alberta. The total length is 491 km.

The crossing where the hypothetical truck accident occurs is located 427 km south of access road junction on Highway 155 (Figure 9-8). The river width at the crossing is about 65 m. The closest hydrometric gauging station is station 06AG001 (below Waterhen River). The variation of flow of the Beaver River at this station over 39 years is shown in Figure 9-9. Minimum, average, and maximum flows considered for this assessment are 5% of the flow variation (5.5 m^3/s), average flow (50.9 m^3/s), and 95% of the flow variation (154 m^3/s), respectively. Corresponding river depths were 1.2 m, 1.7 m, and 2.3 m, respectively.

Figure 9-8: The Beaver River Crossing Location

Figure 9-9: Historical Monthly Flow of the Beaver River



Source: Saskatchewan Government, Waste Security Agency n.d.

9.1.6.2 Uranium Concentrate Fate and Transport Results

Concentrations in sediment were estimated through calculation of the distance travelled by the uranium concentrate after a spill, and the area affected. Detailed description of the methods, and example calculations are provided in Appendix D.

Figure 9-10 illustrates the implication of this distribution of deposited uranium concentrate mass for any remediation planning. The results indicate that most (i.e., 98% of the mass) of the uranium concentrate would settle within a short distance of the release, even under high flow conditions in the Beaver River (i.e., within approximately 48 m of the release point) due to a relatively moderate water velocity (i.e., less than 1 m/s) in the river. This indicates that the hypothetical spill would be confined to a small area and is expected to be effectively recovered. Under high flow conditions (i.e., worst-case), the maximum estimated distance for the deposition of particulates less than 5 µm is approximately 89 m from the crossing.

Sediment quality results are shown in Table 9-5 for post-remediation conditions. The results presented in the table are predicted concentrations of uranium concentrate for three flow conditions (i.e., minimum, average, maximum) as described in Section 9.1.6.1. In general, using the results of the assessment, the minimum predicted uranium concentrate concentrations in the river sediments occurred under high flow conditions, where the smaller particles (less than 5 µm) are deposited over a larger area.

Porewater quality within the affected sediment of the Beaver River was estimated based on weighted-average concentrations in sediment and using a sediment-to-water partition coefficient of 3.5 m^3/kg (SENES 2010). The results are shown in Table 9-5. During minimum flow conditions, the affected volume is smaller resulting in a higher concentration. Higher flow conditions result in a larger footprint but also lower concentrations.

Figure 9-10: **Distribution of Deposited Uranium Concentrate by Distance Downstream of the Beaver River Crossing**

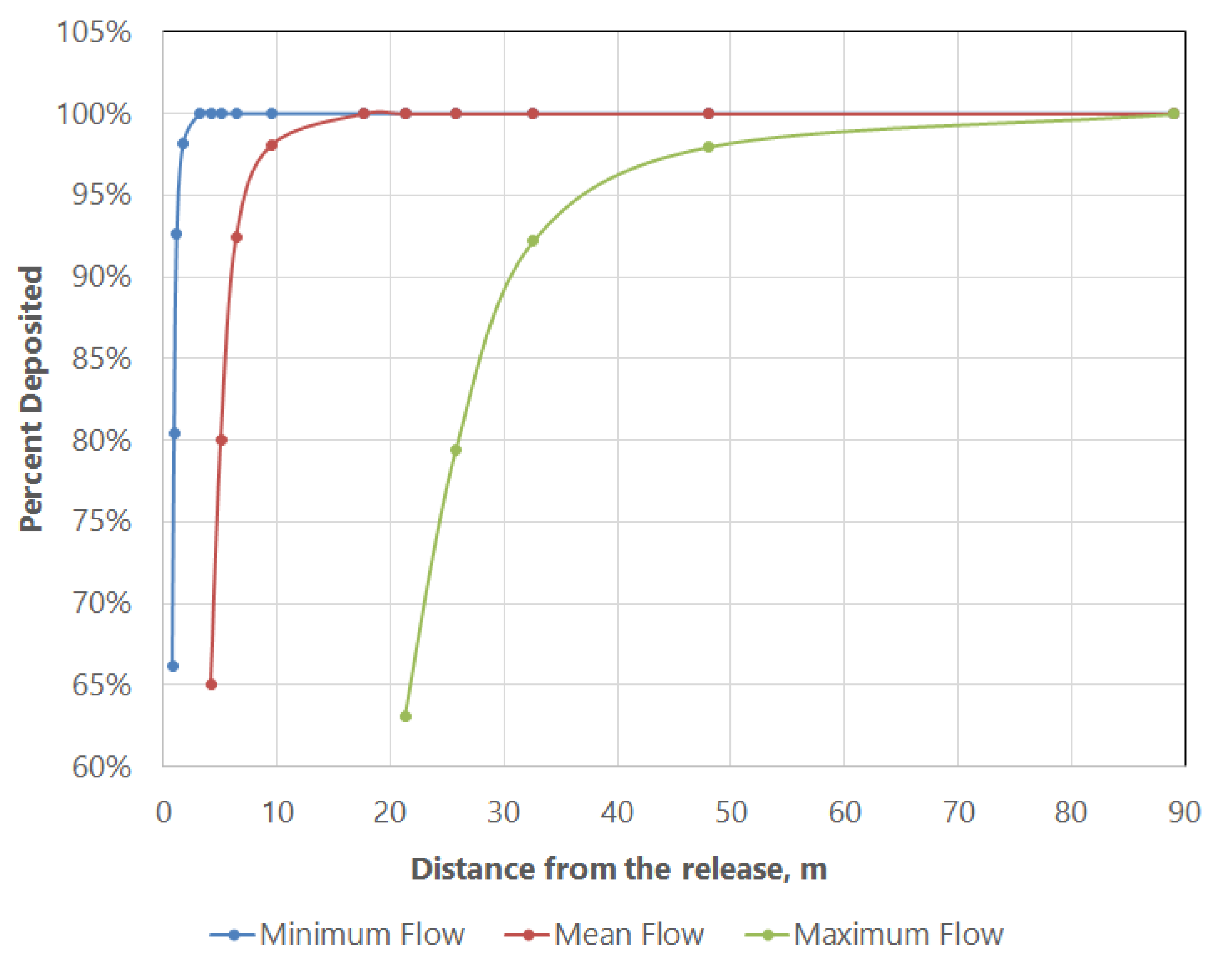


Table 9-5: **Estimated Post-Remediation Sediment and Porewater Quality Downstream of the Beaver River Crossing**

Flow	Affected Distance (m)	Average Concentration in Sediment (µg/g) (ww)	Average Concentration in Sediment (µg/g) (dw)	Average Concentration in Porewater (µg/L)
Minimum	1	1.77×10^4	5.89×10^4	62
Average	17	1.23×10^4	4.11×10^4	43
Maximum	89	5.47×10^3	1.82×10^4	19

The concentrations reported in the table are based on 95% recovery of the released uranium concentrate.
ww = wet weight.
dw = dry weight = ww/((1-0.7) x ww), assuming 70% water 30% solids.

Concentrations in water for the three flows were estimated for short- and long-term concentrations using information on uranium solubility provided in Section 5.1.1 and concentrations in porewater provided in Section 9.1.1, respectively. The results are shown in Table 9-6. The short-term period for the Beaver River is estimated at about a week, even if no settling is assumed.

Table 9-6: Estimated Water Quality Downstream of the Beaver River Crossing

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Flow (µg/L)	Mean Flow (µg/L)	Max Flow (µg/L)	Min Flow (µg/L)	Mean Flow (µg/L)	Max Flow (µg/L)	Min Flow (µg/L)	Mean Flow (µg/L)	Max Flow (µg/L)
Short-term[(a)]	11,640	8,217	6,073	2,328	1,643	1,215	582	411	303.7
Long-term[(b)]	n/a	n/a	n/a	n/a	n/a	n/a	0.4	0.088	0.147

a) Estimated at one week after the spill.
b) Post-remediation.
n/a = not applicable (mixing in 5% and 25% of flow is not relevant for long-term concentrations).

9.1.6.3 Hydrocarbon Fate and Transport Results

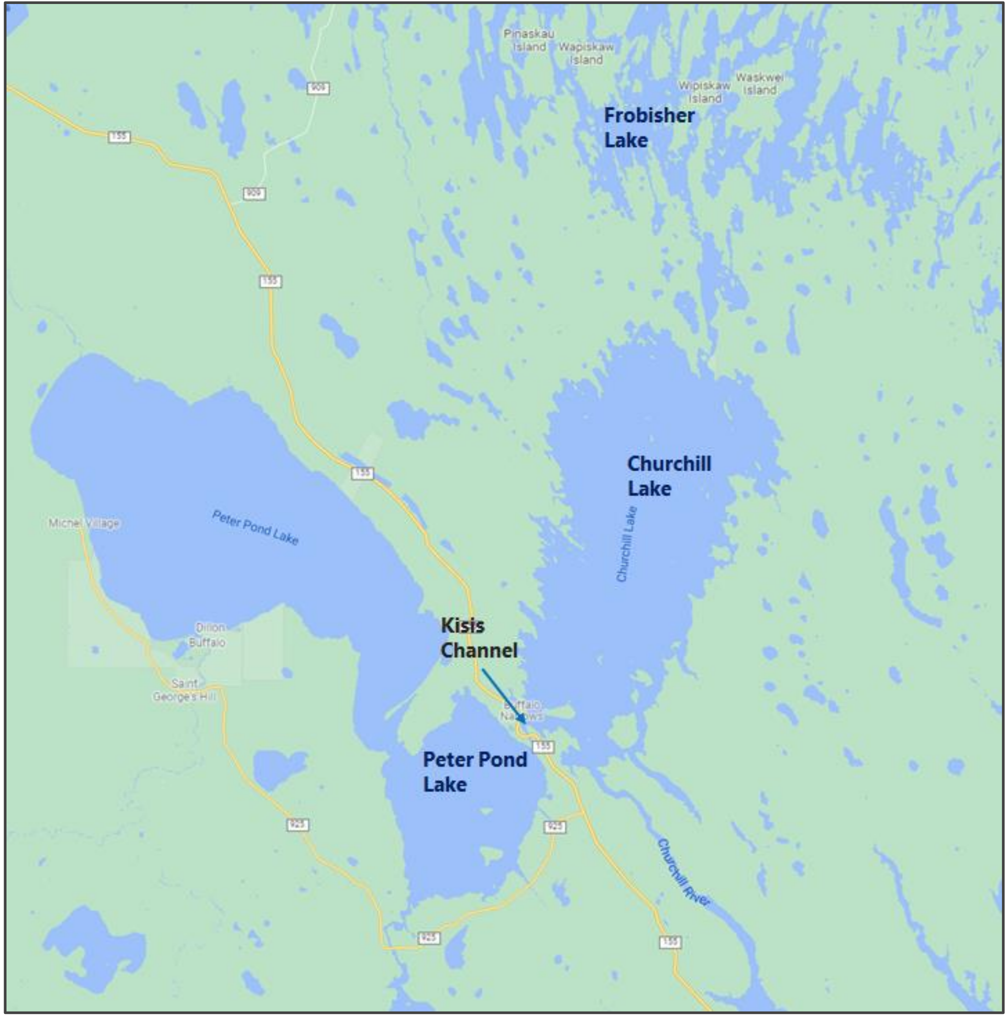
The theoretical maximum size of a 1 µm diesel fuel sheen that can be created by a 30 m^3 spill is 3×10^7 m^2. However, due to evaporation and dissolution of the majority of the spilled diesel, the size of the sheen would be much smaller, particularly in slow-moving surface waterbodies. The average water velocity in the Beaver River is 0.28 m/s. At this velocity, the spill would travel about 24 km in a day. Considering the lifetime of diesel fuel, the diesel sheen could travel as much as 48 km from the bridge over the Beaver River. The effects would be transient (i.e., lasting a day or two); however, some damage to aquatic biota, and potentially birds, could occur within this area. Due to short-term exposure, irreversible population level damage is not expected.

9.1.7 Release to Churchill Lake

9.1.7.1 Lake Bathymetry

Churchill Lake is a glacial lake in northwestern Saskatchewan. Frobisher Lake flows in from the north, while Peter Pond Lake flows in from the southwest through the Kisis Channel. Highway 155 crosses this channel at the village of Buffalo Narrows (Figure 9-11).

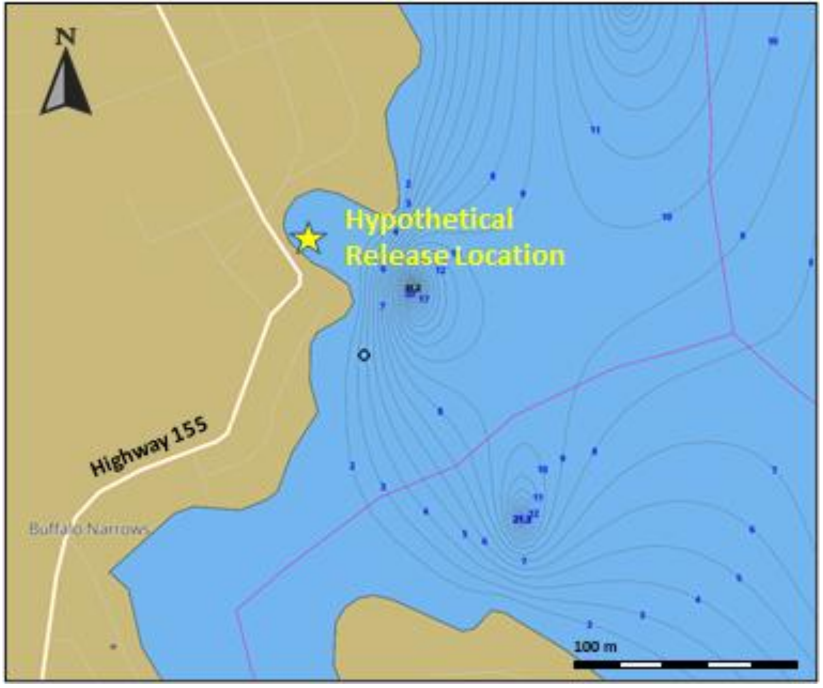
Figure 9-11: Churchill Lake Location



The location where a hypothetical truck accident may occur is a small bay in the southern part of the lake next to Buffalo Narrows (Figure 9-12). The closest hydrometric gauging station is station number 06AB003 (at Buffalo Narrows), reporting lake level. This small bay is very shallow as the water depth is less than 2 m as far as 150 m from the location where Highway 155 passes by the lake. Beyond this point, the water depth increases to a maximum of 31 m at around 350 m from the shoreline (Figure 9-13).

Figure 9-12: Churchill Lake at Highway 155

Figure 9-13: Churchill Lake Bathymetry Near the Hypothetical Release Location



9.1.7.2 Uranium Concentrate Fate and Transport Results

Concentrations in sediment were estimated through calculation of the distance travelled by uranium concentrate after a spill, and the area affected. Detailed description of the methods and example calculations are provided in Appendix D.

Figure 9-14 illustrates the implications of the distribution of spilled uranium concentrate mass for remediation planning. The results indicate that most (i.e., 98% of the mass) of the uranium concentrate would settle within a short distance, even under high water velocity in Churchill Lake (i.e., within approximately 8 m of the release point) due to a relatively low water velocity (i.e., low compared to a river, at less than 0.4 m/s) and lack of circulation in the bay. This indicates that the hypothetical spill would be confined to a small area and is expected to be effectively recovered. Under high water velocity conditions (i.e., worst-case), the maximum estimated distance for the deposition of particulates less than 5 µm is approximately 15 m from the shoreline.

Sediment quality results are shown in Table 9-7 for post-remediation conditions. The results presented in the table are a summary of the three water velocity conditions for the predicted concentrations in Churchill Lake sediments. In general, using the results of the assessment, the minimum predicted uranium concentrations in the lake sediments occur under high water velocity conditions, where the smaller particles (less than 5 µm) are deposited over a larger area.

Porewater quality within the affected sediment of Churchill Lake was estimated based on weighted-average concentrations in sediment and using a sediment-to-water partition coefficient of 3.5 m^3/kg (SENES 2010). The results are shown in Table 9-7. During minimum water velocity conditions, the affected volume is smaller, resulting in a higher concentration. Higher water velocity conditions result in a greater footprint and hence lower concentration.

Figure 9-14: Distribution of Deposited Uranium Concentrate by Distance in Churchill Lake

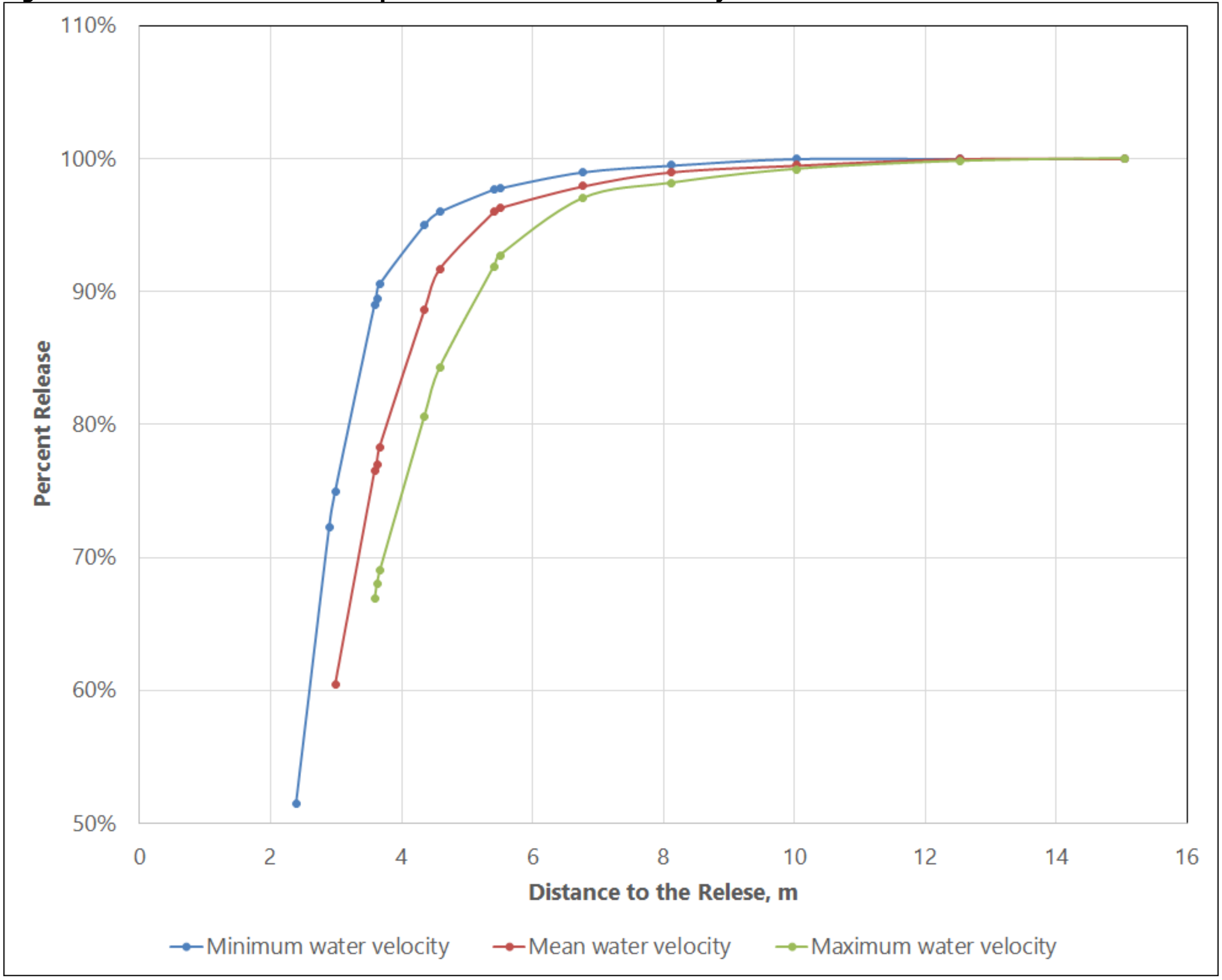


Table 9-7: Estimated Post-Remediation Sediment and Porewater Quality in Churchill Lake

Flow	Affected Distance (m)	Average Concentration in Sediment (µg/g)	Average Concentration in Sediment (µg/g)	Average Concentration in Porewater (µg/L)
Minimum	10	4.07×10^3	1.23×10^4	14
Average	12.5	3.55×10^3	1.18×10^4	12
Maximum	15	2.96×10^3	9.88×10^3	10

The concentrations reported in the table is based on 95% recovery of the released uranium concentrate.
ww = wet weight.
dw = dry weight = ww/((1-0.7) x ww), assuming 70% water 30% solids.

Concentrations in water for the three flows were estimated for short- and long-term concentrations using information on uranium solubility provided in Section 5.1.1 and concentrations in porewater provided in Section 9.1.1, respectively. The results are shown in Table 9-8. The short-term period for Churchill Lake is estimated at about a week, even if no settling is taken into account.

Table 9-8: Estimated Water Quality Downstream of Churchill Lake

Duration	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Min. Flow (µg/L)	Mean Flow (µg/L)	Max. Flow (µg/L)	Min. Flow (µg/L)	Mean Flow (µg/L)	Max. Flow (µg/L)	Min. Flow (µg/L)	Mean Flow (µg/L)	Max. Flow (µg/L)
Short-term(a)	12,106	2,421	1,101	2,421	484	220	605.3	121.1	55
Long-term(b)	n/a	n/a	n/a	n/a	n/a	n/a	0.07	0.017	0.009

a) Estimated at one week after the spill.
b) Post-remediation.
n/a = not applicable (mixing in 5% and 25% of flow is not relevant for long-term concentrations).

9.1.7.3 Hydrocarbon Fate and Transport Results

The theoretical maximum size of 1 µm thick diesel fuel sheen that can be created by a 30 m^3 spill is 3×10^7 m^2. Given that the majority of diesel would dissolve and evaporate (55%) in less than two days, the maximum affected size would be 1.35×10^7 m^2. The average water velocity in Churchill Lake is 0.07 m/s. At this velocity, the plume would travel about 6 km in a day. Considering the lifetime of diesel fuel, the diesel sheen could travel as much as 12 km from the spill location. The effects would be transient (i.e., lasting a day or two); however, some damage to aquatic biota, and potentially individual birds, could occur within this area. Due to short-term exposure within a day or two, irreversible population level damage is not expected.

9.2 Terrestrial Release Scenarios

9.2.1 Uranium Concentrate Fate and Transport Results

The area affected by terrestrial release of uranium concentrate is expected to be small. Considering the size of the trucks, the area would be expected to be on the order of tens of square metres.

Securing the spill location to prevent wildlife access could be achieved within a day. Before the remediation and recovery operations, emergency response procedures would limit access to the contaminated area. Because of the small area of contamination, restricted access, and short-term exposure time before remediation (i.e., one or two days), no long-term effects on the environment would be expected.

If the release were to occur during a rain event, runoff is expected to contaminate a larger area. However, due to low solubility of uranium concentrate, the dissolution would be minimal, thus potential for groundwater contamination is not expected. In either case, the contaminated site could be cleaned up to the background level, or to a safe level that would be developed as a post-accident remediation criterion.

9.2.2 Hydrocarbon Fate and Transport Results

The fate of liquid materials released to ground is affected by several factors including:

- the slope of the ground;

- soil porosity;
- permeability of the ground and rate of penetration into the ground; and
- the volume of the release.

The areas surrounding the transportation route are mainly outside the Project biophysical local study area and regional study area and were not characterized as part of the Project-specific baseline environment program. Nevertheless, regional data on which to base a general characterization for the areas sufficient for the needs of the assessment are available. According to the Ecological Framework of Canada, the soil in the Boreal Plains Ecozone is characterized as grey Luvisols, developed in loamy conditions under a forest canopy with a porosity ranged from 42% to 68%. Lakes and wetland areas, such as sloughs and marshes, are areas of rich vegetation. In poorly drained areas, extensive bogs have developed. For this assessment, a porosity of 45% was selected. Continental glaciation flattened the landscape and left behind a variety of glacial deposits consisting of level to gently rolling plains.

The area along the transportation route is dominated by luvisolic soil. The organic topsoil layer directly at surface is very thin. In some areas, the route is exposed to muskegs with a thick layer of organic material. Hydraulic conductivity in the sandy surficial material ranges from 1×10^{-6} m/s to 7×10^{-5} m/s. The hydraulic conductivity of peats in muskegs is one order of magnitude less (Dai and Sparling 1972).

In a series of experiments during a study contracted by the USDOE, Simmons and Keller (2005) showed that the penetration rate of spilled liquid into soil depends on many factors, including slope, soil permeability, soil wettability, surface roughness, and initial moisture content of soil. In this study, experimental results were fitted into the Green-Ampt model (Simmons and Keller 2005). The results showed that, for most cases, the penetration rates ranged from 0.07 cm/s to 0.1 cm/s for silt loam and sandy soils (air porosity of 30% to 45%) with slopes of 2.4% and 4.8%. In most experiments, the final moisture content of 60% was reached after the front head of the spills disappeared. Given that the porosity of the areas around the transportation route are likely to be greater, this penetration rate of 0.1 cm/s is expected to be a conservative value for this assessment. At this penetration rate, a pool of released liquid with a depth of 30 cm would have penetrated the ground surface in 300 s (i.e., 5 minutes).

Assuming that the liquid content of the soil (water + diesel) increases from 20% to 60% for the maximum diesel release of 30 m^3, approximately 75 m^3 of the soil could be contaminated, as calculated below:

- 60% – 20% = 40% of additional liquid; and
- 30 m^3 / 0.4 = 75 m^3 of soil.

If the soil is completely saturated following the spill (from 20% to 100% liquid content), for the maximum diesel release of 30 m^3, 37.5 m^3 of the soil could be contaminated:

- 100% – 20% = 80% of additional liquid; and
- 30 m^3 / 0.8 = 37.5 m^3 of soil.

Based on the above discussion on water penetration rate, a conservative penetration time of 15 minutes was made. Based on this assumption, the maximum depth of contamination could be 90 cm (for penetration rate of 0.1 cm/s):

- depth = 900 s × 0.1 cm/s = 90 cm = 0.9 m.

For the penetration rate of 0.07 cm/s over 15 minutes, the depth of contamination could be 63 cm:

- depth = 900 s × 0.07 cm/s = 63 cm = 0.63 m.

The surface area affected by the spill can be calculated as follows:

- area = 75 m^3 / 0.9 m= 83 m^2, (60% saturation and depth of 0.9 m);
- area = 37.5 m^3 / 0.63 m = 60 m^2, (100% saturation and depth of 0.63 m);
- area = 75 m^3 / 0.63 m = 119 m^2, (60% saturation and depth of 0.63 m); and
- area = 37.5 m^3 / 0.9 m = 42 m^2, (100% saturation and depth of 0.9 m).

From the above calculation, the size of affected area would range from about 42 m^2 to 119 m^2. Shallow groundwater flow is generally affected by local-scale topography, which is represented by level to gently rolling plains around the transportation route. There is a potential for groundwater contamination within the area of soil contamination.

The velocity of groundwater at this location can be calculated as follows:

- $V = K \times I/n$, where V is groundwater velocity, K is horizontal hydraulic conductivity, I is the horizontal hydraulic gradient, and n is the effective porosity.

Assuming that porosity is 0.45, hydraulic conductivity ranges from 7×10^{-5} m/s to 1×10^{-7} m/s, and hydraulic gradient ranges from 0.02 to 0.1, a range of groundwater velocity can be calculated as follows:

- $V_{max} = 7 \times 10^{-5}$ m/s × 0.1 / 0.45 = 1.5×10^{-5} m/s
- $V_{min} = 1 \times 10^{-7}$ m/s × 0.02 / 0.45 = 4.4×10^{-9} m/s

The wide range of the calculated velocities is a result of variation of soil conditions and the slope of the surface. The distance that the groundwater can travel under these extreme (i.e., conservative) conditions ranges from 0.15 m to 100 m. During this time period, no major migration of groundwater is expected. Thus, the contamination of soil and shallow groundwater is expected to be limited to a small area near the release location.

During the cold season when the soil is frozen, no penetration of spilled material is expected. Therefore, no soil or groundwater contamination is expected. However, due to large spread of the released materials, the remediation is expected to take longer.

9.3 Atmospheric Release Scenarios

9.3.1 Assessment Methods

Airborne release of uranium concentrate particles following an accident (both with and without fire) could adversely affect the air quality of the areas surrounding the accident location. Air dispersion modelling was conducted to calculate the concentration of uranium in air at various distances from the accident location.

For air dispersion modelling, the Areal Locations of Hazardous Atmospheres (ALOHA) model was used (NOAA 2013). The ALOHA model is a stand-alone software application developed and supported by the Emergency Response Division, a division within the National Oceanic and Atmospheric Administration in collaboration with the Office of Emergency Management of the US Environmental Protection Agency. The primary purpose of the ALOHA model is to provide emergency response personnel estimates of the spatial extent of some common hazards associated with chemical spills or releases (NOAA 2013).

Two atmospheric release scenarios were assessed:

- truck accident with fire, including:
    - uranium concentrate release; and
    - smoke.
- truck accident without fire, including:
    - uranium concentrate release.

9.3.2 Release Characterization

To characterize the source term of the uranium concentrate release, a widely accepted method proposed by USDOE (1994) was used to estimate the source terms. In this method, the airborne source term is estimated by the following five-component linear equation:

$$\text{Source term} = \text{MAR} \times \text{DR} \times \text{ARF} \times \text{RF} \times \text{LPF}$$

Where:

MAR = material-at-risk is the amount of chemical available to be affected by the postulated scenario. For facilities, processes, and activities, the MAR is a value representing some maximum quantity of chemical present or reasonably anticipated for the process or structure being analyzed.

DR = damage ratio is the fraction of the MAR affected by the initiating event(s) (e.g., fire, extreme winds, accident-generated conditions). The DR is estimated based on engineering analysis of the response of structural materials and materials-of-construction for containment to the type and level of stress/force generated by the event. These estimates often include a degree of conservatism due to simplification of phenomena to obtain a useable model.

ARF = airborne release fraction (or airborne release rate for continuous release) is the coefficient used to estimate the amount of a chemical released or suspended in air as an aerosol or gas and thus available for transport due to physical stresses from a specific accident. For discrete events, the ARF is a fraction of the material affected. For mechanisms that continuously act to release chemicals to the air, a release rate is required to estimate the potential airborne release from postulated accident conditions.

RF = respirable fraction is the fraction of airborne chemical particles that can be transported through air and inhaled into the human respiratory system and is commonly assumed to include particles 10 µm aerodynamic equivalent diameter and less. Other definitions of "respirable particles" have been presented by various groups at different times, but for present purposes, 10 µm and smaller particles were considered respirable. For gaseous chemicals, the RF is one.

LPF = leak path factor is the fraction of the chemical transported through some confinement deposition or filtration mechanism. There can be many LPFs for some accident conditions (e.g., the fraction leaked from the enclosure to the operating area around the enclosure or room, the fraction leaked from the room to the building-atmosphere interface).

During uranium concentrate processing, radium is effectively removed from uranium peroxide and disposed along with the mine tailings. The residual radium activity concentration in uranium concentrate is insignificant to support considerable radon emanation from the released uranium concentrate. Therefore, the dose due to radon inhalation was not calculated in this assessment.

9.3.2.1 Truck Accident with Fire

The source term components for this case are estimated as follows:

- MAR: contents of a trailer van (22,500 kg uranium concentrate).
- DR: assumed that 25% of the drums are breached (0.25; Section 9.1.2, Uranium Concentrate Release Characterization).
- ARF: assumed at 0.025 for release fraction of powder materials during fire or low velocity air movement (Table A.33 of USDOE 1994).
- RF: 0.1 based on Table 9-9.
- LPF: conservatively assumed to be 1.

The source term is calculated as follows:

- source term = MAR × DR × ARF × RF × LPF; and
- source term = 22,500 kg × 0.25 × 0.025 × 0.1 × 1 = 14.06 kg.

For one-hour average concentration, the release rate would be 14.06 kg/h or 3.91 g/s.

9.3.2.2 Truck Accident without Fire

The source term components for this case are estimated as follows:

- MAR: content of a trailer van (22,500 kg uranium concentrate).
- DR: assumed that 25% of the drums are breached (0.25) (see Section 9.1.2, Uranium Concentrate Release Characterization).
- ARF: the USDOE provides the ARF for impact disturbances. The ARF was selected as 0.001 based on the USDOE recommended value in the second row of Table 9-9.
- RF: assumed to be 0.1 based on the USDOE recommended value in the second row of Table 7.6.
- LPF: assumed a conservative value of 1.

Table 9-9: Airborne Release Fractions

Compound	State	Disturbance	Bounding ARF	Bounding RF
Powder	Loose, resting (no container)	Impact	1.0×10^{-2}	0.2
Powder	Contained (metal container, e.g., can)	Impact	1.0×10^{-3}	0.1
Powder	Loose, resting (no container)	Blowing wind	$1.34 \times 10^{-2} \times w + 5.43 \times 10^{-3}$	1

Source: USDOE 1994.
w = wind speed (m/s); ARF = airborne release fraction; RF = respirable fraction.

The source term is calculated as follows:

source term = MAR × DR × ARF × RF × LPF; and
source term = 22,500 kg × 0.25 × 0.001 × 0.1 × 1 = 0.56 kg.

For one-hour average concentration, the release rate would be 0.56 kg/h or 0.16 g/s.

9.3.2.3 Smoke

The release of smoke and its toxic compounds is a direct result of pool fire. For this assessment, it was postulated that, following a fuel or solvent truck accident, the flammable fluid is released and forms a flammable pool. It was conservatively assumed that the entire contents of the truck (40 m^3 for solvent) are released. Assuming a 10 cm deep pool, the area of the pool is calculated at 400 m^2. The combustion rate of this liquid pool is approximately 144 $kg/h/m^2$ (Mishra and Wehrstedt 2012). Thus, the initial combustion rate would be 57,600 kg/h. This rate would be reduced as the liquid pool becomes smaller as it burns. As mentioned previously, carbon monoxide and PAHs were considered for evaluating the toxic effect of the smoke dispersion. The emission factors for these two components are 18 and 0.0012 g/kg fuel burned, for carbon monoxide and PAHs, respectively (Aurell et al. 2017). Based on these values, and assuming maximum burn rate, the emission rates of these two substances are calculated as:

- carbon monoxide emission rate = 57,600 kg fuel/h × 18 g/kg = 1,037,000 g/h or 1,037 kg/h; and
- the PAHs emission rate = 57,600 kg fuel/h × 0.0012 g/kg = 69 g/h.

9.3.3 Fate and Transport of Atmospheric Releases

Air concentrations versus distance were calculated using the relevant source terms with results compared to the benchmarks provided in Section 6.0, Transportation Accident Scenarios, for the following two weather conditions:

- W1: Worst-case weather condition is 95th percentile wind speed and stability class F. Pasquill stability class F is a stable atmospheric condition that occurs most often during nighttime overcast conditions, with a windspeed of less than 2 m/s, typically 1.5 m/s. This represents the worst-case condition for dispersion of released materials (NOAA 2019).
- W2: Typical weather conditions are average wind speed and stability class D. Pasquill stability class D is a neutral atmospheric condition that occurs most often during slight to moderate daytime solar intensity and thin nighttime overcast conditions, with windspeed of around 5 m/s or slightly higher. This represents the average condition for dispersion of released materials (NOAA 2019).

The probability of W1 weather condition is less than 5% of the probability of weather condition W2.

The modelling results are summarized in Table 9-10 for the transport truck accident with fire and in Table 9-11 for the transport truck accident without fire.

Table 9-10: Atmospheric Release Modelling Results for a Truck Accident with Fire

Scenario	Weather Condition	Toxic Release End Point	Distance Measured from the Point of Release (m)		
			Uranium Concentrate	Carbon Monoxide	PAH (Eq.)
Transport truck accident with fire	W1-1.5F	AEGL-1 / ERPG-1	Not calculated	Not calculated	Not calculated
		AEGL-2 / ERPG -2	245	510	164
		AEGL-3 / ERPG -3	92	238	11
	W2-5.0D	AEGL-1 / ERPG-1	Not calculated	Not calculated	Not calculated
		AEGL-2 / ERPG -2	91	132	30
		AEGL-3 / ERPG -3	44	66	<10

< = less than; PAH = polycyclic aromatic hydrocarbons; ERPG = Emergency Response Planning Guidelines; AEGL = Acute Exposure Guideline Level; Eq. = Equivalent.

Table 9-11: Atmospheric Release Modelling Results for a Truck Accident without Fire

Scenario	Weather Condition	Toxic Release End Point	Distance Measured from the Point of Release of Uranium Concentrate (m)
Transport truck accident without fire	W1-1.5F	AEGL-1 / ERPG-1	Not calculated
		AEGL-2 / ERPG -2	53
		AEGL-3 / ERPG -3	23
	W2-5.0D	AEGL-1 / ERPG-1	Not calculated
		AEGL-2 / ERPG -2	<10
		AEGL-3 / ERPG -3	<10

< = less than; ERPG = Emergency Response Planning Guidelines; AEGL = Acute Exposure Guideline Level.

10.0 RISK CHARACTERIZATION

Risks associated with the transportation accidents assessed herein are characterized below.

10.1 Aquatic Release Scenarios

10.1.1 Risk Characterization for Aquatic Receptors

The assessment of effects on ecological receptors is made by comparing exposure estimates to the benchmarks provided in Section 7.0, Receptors and Toxicity Benchmarks. For example, intake (or dose) estimates are compared to non-radiological toxicity reference values (TRVs) and to dose rate guidelines for radionuclides to assess the risks of adverse health effects for each of the ecological receptors. For humans, the estimated exposure is compared to the drinking water quality guidelines. The adverse effects on the water quality are transient, and the accumulation of contaminants through the food chain is not expected for the accident scenarios. Therefore, the only credible exposure pathway for the human receptors is drinking water.

For ecological health, effects are considered on a population level as opposed to an individual level. Estimation of population-level effects is a complex task and involves scientific judgment.

The results of water and sediment quality predictions were used to assess exposures of ecological species (i.e., aquatic plants, benthic invertebrates, forage and predatory fish, sandpiper, meadow vole, and moose) to uranium.

In general, the approach taken for estimating the exposure of radiological and non-radiological contaminants to non-human biota is to model the intake of a contaminant by the biota (in mg/kg/d or becquerels per day [Bq/d]) and then use a transfer factor (d/kg) to obtain a body or flesh concentration where necessary. Many toxicity values for non-radiological contaminants are expressed as intake rates rather than tissue residues. Therefore, the assessment of non-radiological and radiological contaminants can be carried out in parallel, with the flesh concentrations used for estimating internal radiological dose, and intakes used for assessment of non-radiological contaminants. Detailed methods and example calculations are provided in Appendix D.

The comparison of intake (or dose) estimates to TRVs or dose rate guidelines is usually undertaken by the calculation of screening index values (also called hazard quotients). The screening index values provide an integrated description of the potential hazard, the exposure (or dose) response relationship, and the exposure evaluation.

The acute exposure to all aquatic species, with the exception of benthic invertebrates, was assessed. Since acute TRVs are generally not available for benthic invertebrates and they are exposed to both sediments and water, benthic invertebrate exposure was considered to be chronic. This assumption is conservative since chronic thresholds are lower than acute thresholds because they assume a longer exposure period.

In the assessment of population-level effects on benthic invertebrates, one of the key considerations in this predictive assessment is the scale of the effect. As discussed by the US Environmental Protection Agency (2003), if the area is large, the effects would be diluted. However, if the area is small, a small portion of the affected population or community may be affected, and effects are mostly reversible at the population level.

The results of the water quality predictions were used to assess exposures of a human receptor to chemical uranium as well as radionuclides. For the short-term assessment, the estimated uranium concentration in water was compared to the appropriate water quality benchmark and the estimated radiological dose was compared to the reference dose.

For the assessment of the exposure following a spill in rivers, the focus is placed on the estimated concentration following mixing in the entire river flow under average conditions. For lakes, the focus is placed on the estimated concentration following mixing in the small bay in Churchill Lake where the spill occurs under average water velocity conditions.

10.1.2 Release of Uranium Concentrate

10.1.2.1 Release to the Clearwater River

Table 10-1 provides estimated concentrations in the environmental media, contaminant intake by receptors, radiological dose to the receptors, and calculated SI values in the Clearwater River for average flow conditions following a spill of uranium concentrate. The SI values for short-term concentration in water, and concentration in sediment are above the reference value of 1 and are examined further below. The results of the ecological risk assessment indicate short-term ingestion of contaminated water resulting from an accident would not result in potential risks to sandpiper, meadow vole, or moose. No additional exceedance is observed under low or high flow conditions. These receptors represent terrestrial receptors with strong affinity to surface water. Therefore, the level of risk estimated for them is a conservative estimate of the level of the risk for all terrestrial receptors that could be exposed to the released contaminants.

Sediment: Concentrations in post-remediation conditions are expected to exceed the benchmark. Spilled uranium concentrate would spread over an approximately 10.3 m distance in the average flow condition, covering an area of approximately 824 m^2 (10.3 m × 80 m = 824 m^2 = 0.082ha). These results indicate that a spill of uranium concentrate could potentially affect the benthic invertebrate populations, but the spatial extent would be limited.

Water: In the evaluation of the potential effect, a comparison was made between the results of the estimated short-term concentration in water (5.2×10^{-1} mg/L) and the guideline (33 µg/L or 3.3×10^{-2} mg/L). The result of this comparison indicates that some aquatic species could be affected, but the effects would be transient (i.e., short-term) because the concentration would quickly drop to the long-term level of 1.7×10^{-4} mg/L.

Table 10-1: Consequences on Ecological Receptors for Average Flow in the Clearwater River

Exposure Media / Receptor	Exposure to Uranium Concentrate				Screening Index (SI) (as based on)		
	Concentration (mg/L or mg/kg)	Intake (mg/kg/d)	Internal Dose (mGy/d)	Equivalent Dose (mGy/d)	Concentration	Intake	Dose
Water: short-term	5.2×10^{-1}	n/a	n/a	n/a	15.6	n/a	n/a
Water: long-term	1.7×10^{-4}	n/a	n/a	n/a	0.005	n/a	n/a
Sediment (dw)	2.76×10^{4}	n/a	n/a	n/a	12	n/a	n/a
Sandpiper	2.85×10^{-2}	1.73×10^{2}	1.81×10^{-5}	1.81×10^{-5}	n/a	1.08	<0.001
Meadow vole	1.08×10^{-6}	1.0×10^{-1}	1.88×10^{-6}	1.88×10^{-6}	n/a	0.009	<0.001
Moose	8.42×10^{-4}	3.75×10^{-2}	1.45×10^{-3}	1.21×10^{-3}	n/a	0.004	<0.001

Benchmarks: Water: 0.033 mg/L (short-term); TRVs: 0.043, 0.17 and 0.73 (95th, 90th, and 80th protection levels. respectively); Sediment: 2,296 mg/kg dw (benthic invertebrates); Intake, mg/kg/d: 160 (sandpiper), 11.4 (meadow vole, moose); Dose: 2.4 mGy/d.
Yellow cells indicate the SI that exceeds one (i.e., values exceed the benchmarks).
n/a = not applicable; < = less than; SI = screening index; dw = dry weight; TRV = toxicity reference value;
mGy/d = milligrays per day.

10.1.2.2 Release to the Canoe River

Table 10-2 provides estimated concentrations in the environmental media, contaminant intake by receptors, radiological dose to the receptors, and calculated SI values in the Canoe River for average flow conditions, following a spill of uranium concentrate. As seen from the table, the SI values for short-term concentration in water and concentration in sediment are above the reference value of 1 and are examined further below. The results of the ecological risk assessment indicate short-term ingestion of contaminated water resulting from an accident would not result in potential risks to sandpiper, meadow vole, or moose. No additional exceedance is observed under low or high flow conditions.

Sediment: Concentrations in post-remediation conditions are expected to exceed the benchmark. Spilled uranium concentrate would spread over approximately 7 m in the average flow condition, covering an area of approximately 420 m^2 (7 m × 60 m = 420 m^2 = 0.042 ha). These results indicate that a spill of uranium concentrate could potentially affect the benthic invertebrate populations, but the spatial extent would be limited.

Water: In the evaluation of the potential effect, a comparison was made between the results of the estimated short-term concentration in water (3.3×10^{-1} mg/L) and the guideline (33 µg/L or 3.3×10^{-2} mg/L). The result of this comparison indicates that some aquatic species could be affected, but the effects would be transient (short-term) because the concentration would quickly drop to the long-term level of 1.45×10^{-4} mg/L.

Table 10-2: Consequences on Ecological Receptors for Average Flow in the Canoe River

Exposure Media / Receptor	Exposure to Uranium Concentrate				Screening Index (SI) (as based on)		
	Concentration (mg/L or mg/kg)	Intake (mg/kg/d)	Internal Dose (mGy/d)	Equivalent Dose (mGy/d)	Concentration	Intake	Dose
Water: short-term	3.3×10^{-1}	n/a	n/a	n/a	10	n/a	n/a
Water: long-term	$1.45 \times x10^{-4}$	n/a	n/a	n/a	0.004	n/a	n/a
Sediment (dw)	3.76×10^{4}	n/a	n/a	n/a	16	n/a	n/a
Sandpiper	1.8×10^{-2}	1.10×10^{2}	1.69×10^{-5}	1.69×10^{-5}	n/a	0.7	<0.001
Meadow vole	6.91×10^{-7}	6.6×10^{-2}	1.88×10^{-6}	1.88×10^{-6}	n/a	0.006	<0.001
Moose	5.33×10^{-4}	2.42×10^{-2}	1.21×10^{-3}	1.21×10^{-3}	n/a	0.002	<0.001

Benchmarks: Water, mg/L: 0.033 (short-term); TRVs: 0.043, 0.17 and 0.73 (95th, 90th, and 80th protection levels); Sediment, mg/kg dw: 2,296 (benthic invertebrates); Intake, mg/kg/d: 160 (sandpiper), 11.4 (meadow vole, moose); Dose, mGy/d: 2.4.
Yellow cells indicate the SI that exceeds one (i.e., values exceed the benchmarks).
n/a = not applicable; < = less than; SI = screening index; dw = dry weight; TRV = toxicity reference value;
mGy/d = milligrays per day.

10.1.2.3 Release to the Beaver River

Table 10-3 provides estimated concentrations in the environmental media, contaminant intake by receptors, radiological dose to the receptors, and calculated SI values in the Beaver River for average flow conditions, following a spill of uranium concentrate. As seen from the table, the SI values for short-term concentrations in water and sediment are above the reference value of 1 and are examined further below. The results of the ecological risk assessment indicate short-term ingestion of contaminated water resulting from an accident would not result in potential risks to sandpiper, meadow vole, or moose. No additional exceedance is observed under low or high flow conditions.

Sediment: Concentrations in post-remediation conditions are expected to exceed the benchmark. Spilled uranium concentrate would spread over approximately 17.6 m in the average flow condition, covering an area of approximately 1,144 m^2 (17.6 m × 65 m = 1,144 m^2 = 0.114 ha). These results indicate that a spill of uranium concentrate could potentially affect the benthic invertebrate populations, but the spatial extent would be limited.

Water: In the evaluation of the potential effect, a comparison was made between the results of the estimated short-term concentrations in water (4.1×10^{-1} mg/L) and the guideline (33 µg/L or 3.3×10^{-2} mg/L). The result of this comparison indicates that there some aquatic species could be affected, but the effects would be transient (short-term) because the concentration would quickly drop to the long-term level of 8.8×10^{-5} mg/L.

Table 10-3: Consequences on Ecological Receptors for Average Flow in the Beaver River

Exposure Media / Receptor	Exposure to Uranium Concentrate				Screening Index (SI) (as based on)		
	Concentration (mg/L or mg/kg)	Intake (mg/kg/d)	Internal Dose (mGy/d)	Equivalent Dose (mGy/d)	Concentration	Intake	Dose
Water: short-term	4.1×10^{-1}	n/a	n/a	n/a	12.4	n/a	n/a
Water: long-term	8.8×10^{-5}	n/a	n/a	n/a	0.003	n/a	n/a
Sediment (dw)	1.82×10^{4}	n/a	n/a	n/a	5	n/a	n/a
Sandpiper	6.86×10^{-3}	1.26×10^{-2}	1.56×10^{-5}	1.56×10^{-5}	n/a	0.87	<0.001
Meadow vole	2.54×10^{-7}	2.4×10^{-2}	1.88×10^{-6}	1.88×10^{-6}	n/a	0.007	<0.001
Moose	1.97×10^{-4}	8.47×10^{-3}	1.21×10^{-3}	1.21×10^{-3}	n/a	<0.001	<0.001

Benchmarks: Water, mg/L: 0.033 (short-term); TRVs: 0.043, 0.17 and 0.73 (95th, 90th, and 80th protection levels); Sediment, mg/kg dw: 2,296 (benthic invertebrates); Intake, mg/kg/d: 160 (sandpiper), 11.4 (meadow vole, moose); Dose, mGy/d: 2.4.
Yellow cells indicate the SI that exceeds one (i.e., values exceed the benchmarks).
n/a = not applicable; < = less than; SI = screening index; dw = dry weight; TRV = toxicity reference value;
mGy/d = milligrays per day.

10.1.2.4 Release to Churchill Lake

Table 10-4 provides estimated concentrations in the environmental media, contaminant intake by receptors, radiological dose to the receptors, and calculated SI values in the Churchill Lake for average flow conditions following a spill of uranium concentrate. As seen from the table, the SI values for short-term concentration in water and concentration in sediment are above the reference value of 1 and are examined further below. The results of the ecological risk assessment indicate short-term ingestion of contaminated water resulting from an accident would not result in potential risks to sandpiper, meadow vole, or moose. No additional exceedance is observed under low or high flow conditions.

<u>Sediment:</u> Concentrations in post-remediation conditions are expected to exceed the benchmark. Spilled uranium concentrate would spread over approximately 7 m in the average flow condition, covering an area of approximately 700 m^2 (7 m × 100 m = 700 m^2 = 0.07 ha). These results indicate that a spill of uranium concentrate could potentially affect the benthic invertebrate populations, but the spatial extent would be limited.

<u>Water:</u> In the evaluation of the potential effect, a comparison was made between the results of the estimated short-term concentration in water (1.2×10^{-1} mg/L) and the guideline (33 µg/L or 3.3×10^{-2} mg/L). The result of this comparison indicates that some aquatic species may be affected, but the effects would be transient (short-term) because the concentration would quickly drop to the long-term level of 1.7×10^{-5} mg/L.

Table 10-4: Consequences on Ecological Receptors for Average Flow in Churchill Lake

Exposure Media / Receptor	Exposure to Uranium Concentrate				Screening Index (SI) (as based on)		
	Concentration (mg/L or mg/kg)	Intake (mg/kg/d)	Internal Dose (mGy/d)	Equivalent Dose (mGy/d)	Concentration	Intake	Dose
Water: short-term	1.2×10^{-1}	n/a	n/a	n/a	3.7	n/a	n/a
Water: long-term	1.7×10^{-5}	n/a	n/a	n/a	0.0005	n/a	n/a
Sediment (dw)	1.18×10^{4}	n/a	n/a	n/a	8	n/a	n/a
Sandpiper	2.23×10^{-2}	1.39×10^{2}	1.75×10^{-5}	1.75×10^{-5}	n/a	<0.001	<0.001
meadow vole	8.63×10^{-7}	8.2×10^{-2}	1.88×10^{-6}	1.88×10^{-6}	n/a	0.002	<0.001
Moose	6.72×10^{-4}	3.0×10^{-2}	1.45×10^{-3}	1.21×10^{-3}	n/a	<0.001	<0.001

Benchmarks: Water, mg/L: 0.033 (short-term); TRVs: 0.043, 0.17 and 0.73 (95th, 90th, and 80th protection levels); Sediment, mg/kg dw: 2,296 (benthic invertebrates); Intake, mg/kg/d: 160 (sandpiper), 11.4 (meadow vole, moose); Dose, mGy/d: 2.4.
Yellow cells indicate the SI that exceeds one (i.e., values exceed the benchmarks).
n/a = not applicable; < = less than; SI = screening index; dw = dry weight; TRV = toxicity reference value;
mGy/d = milligrays per day.

10.1.2.5 Overall Risk of the Aquatic Release of Uranium Concentrate

As described in Section 8.0, the probability of aquatic release of uranium concentrate was estimated to be 2.85×10^{-4} per year. Based on the probability classifications in Section 3.2, Probability Analysis, this probability is classified as highly unlikely. Assessment results shown in Section 9.1 indicate that the aquatic release of uranium concentrate could result in short-term effects on aquatic biota (e.g., benthic invertebrates) at a limited spatial scale. Sediment contamination could have longer-term effects, though in very small areas close to the release location. The drinking water criterion would also be exceeded during a short period following uranium concentrate release to surface water.

Given the nature of the effects, and the above provisions, the consequence of this scenario is judged to be moderate. Using the risk matrix provided in Section 3.4, the risk of aquatic release of uranium is calculated as being low.

10.1.3 Release of Hydrocarbons

As described in Section 8.0, the probability of aquatic release of hazardous materials is 8.55×10^{-4} per year. Based on the probability classifications in Section 3.2, this probability is classified as highly unlikely. The assessment results shown in Section 9.1, Aquatic Release Scenarios, indicate that the aquatic release of diesel fuel may result in short-term effects on aquatic biota (e.g., benthic invertebrates) and potentially birds. In the case of a release to the lake, the spatial scale of contamination is larger than the release to rivers; however, the effects are expected to be short-term due to short life span of diesel fuel in surface water.

Given the nature of the effects, and the emergency response provisions mentioned in Section 9.1.1, the consequence of this scenario is judged to be minor. Using the risk matrix provided in Section 3.4, the risk of aquatic release of diesel fuel is calculated as being low.

10.2 Terrestrial Release Scenarios

As described in Section 8.0, the probability of a terrestrial release of hazardous materials is estimated to be 1.18 × 10^{-1} per year. Based on the probability classifications in Section 3.2, this probability is classified as likely. The assessment results shown in Section 9.2, Terrestrial Release Scenarios, indicated that the spatial extent of potential effects of a terrestrial release of hazardous materials would be limited to a small area close to the spill location.

Given the nature of the effects, and the emergency response provisions mentioned in Section 9.1.1, the consequence of this scenario is judged to be minor. Using the risk matrix provided in Section 3.4, the risk of terrestrial release of hazardous materials is calculated as being low.

10.3 Atmospheric Release Scenarios

As described in Section 8.0, the probability of a truck accident resulting in an atmospheric release of hazardous materials is estimated to be 2.94 × 10^{-3} per year. Based on the probability classifications provided in Section 3.2, this probability is classified as unlikely. The domino effects of fire and initiating of wildfire are less likely; therefore, this was not assessed in this study.

The assessment results shown in Section 9.3, Atmospheric Release Scenarios, for typical weather conditions (average wind speed, stability class D) indicated that the AEGL-2 or ERPG-2 concentrations would be exceeded within 91 m of the release location for uranium concentrate particles and within 132 m for carbon monoxide in the downgradient wind direction. Given the transient nature of the effects and the emergency response planning provisions mentioned in Section 9.1.1 that would include the use of personal protective equipment (e.g., self-contained breathing apparatus) by first responders whom are more likely to be closer to the exposure source than the general public, the consequence of this scenario is judged to be minor.

Using the risk matrix provided in Section 3.4, the risk of atmospheric release of hazardous materials is calculated as being low.

As a sensitivity case, the risk of the atmospheric release scenario can also be considered for the worst-case weather / air dispersion condition as described in Section 9.3.3, Fate and Transport of Atmospheric Releases. The probability of the release occurrence (2.94 x 10^{-03}) in combination with the worst-case weather condition (95th percentile wind speed and stability class F) that occurs at a probability of 5% relative to the typical weather condition results in an overall scenario probability of 1.47 x 10^{-04}. Based on the probability classifications provided in Section 3.2, this scenario would be classified as highly unlikely. Under the worst-case conditions, the AEGL-2 or ERPG-2 concentrations would be exceeded for a period of less than one hour within a 245 m distance from the release location for uranium concentrate particles and within 510 m distance for carbon monoxide in the downgradient wind direction. Using the same reasoning as above for the typical weather condition scenario, the consequence of the worst-case scenario is judged to be minor. Similar to the typical weather condition scenario, using the risk matrix provided in Section 3.4, the risk of atmospheric release of hazardous materials is calculated as being low.

10.4 Vehicle-Human Interactions

As described in Section 8.0, the probability of a vehicle-human interaction is 1.60×10^{-2} per year. Based on the probability classifications in Section 3.2, this probability is classified as likely. However, the probability of fatal accidents is much less than the probability of all accidents, and is judged to be highly unlikely. The consequence of a major injury and fatal accident is classified as major to catastrophic.

Using the risk matrix provided in Section 3.4, the risk of vehicle-human accident is calculated as being moderate. It is important that this risk is managed to ALARP. In practice, that means all traffic control measures, such as driver training, speed control, signage, assignment of crossing guard at intersections within communities during high traffic periods be considered, as appropriate. As the transportation route is largely outside of the Project's zone of control, NexGen can encourage these practices, but ultimately enforcement would be the responsibility of the Province of Saskatchewan.

10.5 Vehicle-Wildlife Interactions

As described in Section 8.0, the probability of vehicle-wildlife interactions is 6.22×10^{-1} per year. Based on the probability classifications in Section 3.2, this probability is classified as very likely. Although this accident may result in fatality of individual animals, population-level effects are not expected from vehicle-wildlife interactions; thus, the consequence of this scenario is judged to be minor.

Using the risk matrix provided in Section 3.4, the risk of vehicle-wildlife interactions is calculated as being low; however, it is important that this risk is managed to ALARP. In practice that involves the implementation of traffic control measures, such as driver training, speed control, and signage, to mitigate risk.

11.0 SUMMARY OF KEY RESULTS

This report considered the assessment of transportation risks associated with the Project during all Project phases. The assessment included both the assessment of probability of occurrence of the identified scenarios and the consequence of the effects of these scenarios on human health and the environment.

The results of the overall characterization of risk for the accident scenarios are summarized in Table 11-1. With the exception of the risk associated with a vehicle-human accident, which was calculated as moderate, the risk of other the scenarios evaluated was determined to be low.

Table 11-1: Summary of the Transportation Accident Risk Assessment

Accident Scenario	Probability	Consequence	Risk
Aquatic release	Highly unlikely	Moderate	Low
Terrestrial release	Likely	Minor	Low
Vehicle fire and atmospheric release	Unlikely to highly unlikely[1]	Minor	Low
Vehicle-human accident	Highly unlikely	Major-catastrophic	Moderate
Vehicle-wildlife accident	Very likely	Minor	Low

1) Probabilities given for both the typical (unlikely) and worst-case (highly unlikely) weather scenarios. Consequence and overall risk are the same in both cases.

It is noted that the risk assessment considered the hierarchy of controls (i.e., elimination, substitution, engineering, administrative, personal protective equipment) that would be implemented as part of the Integrated Management System to prevent, eliminate, and reduce hazards and mitigate the risks associated with activities throughout the Project lifespan. Although the vehicle-human accident scenario is very unlikely, due to the catastrophic nature of the potential effects (e.g., fatality), the risk was evaluated as moderate. NexGen would reduce this risk as low as practicable by employing traffic control measures, particularly within communities, to ensure safe transport of hazardous materials.

12.0 REFERENCES

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Appendix A Water Features

Water Feature No 1 – Unnamed Creek

Water Feature No 2 – Unnamed Creek

Water Feature No 3 – Unnamed Creek

Water Feature No 4 – Unnamed Creek

Water Feature No 5 – Unnamed Creek

Water Feature No 6 – Unnamed Creek

Water Feature No 7 – Unnamed Creek

Water Feature No 8 – Unnamed Creek

Water Feature No 9 – Clearwater River

Water Feature No 10 – Unnamed Creek

Water Feature No 11 – Unnamed Creek

Water Feature No 12 – Unnamed Creek

Water Feature No 13 – Unnamed Creek

Water Feature No 14 – Unnamed Creek

Water Feature No 15 – Bear Creek

Water Feature No 16 – Unnamed Creek

Water Feature No 17 – Unnamed Creek

Water Feature No 18 – Churchill Lake

Water Feature No 19 – Kisis Channel & Bridge

Water Feature No 20 – Unnamed Creek

Water Feature No 21 – Unnamed Creek

Water Feature No 22 – Unnamed Creek

Water Feature No 23 – Unnamed Creek

Water Feature No 24 – Lac Île-à-la-Crosse

Water Feature No 25 – Unnamed Creek

Water Feature No 26 – Canoe River

Water Feature No 27 – Unnamed Creek

Water Feature No 28 – Unnamed Creek

Water Feature No 29 – Unnamed Creek

Water Feature No 30 – Waterhen River

Water Feature No 31 – Beaver River

Water Feature No 32 – Cowan River

Water Feature No 33 – Unnamed Creek

Appendix B Communities

Population Centre No 1 – La Loche

Population Centre No 2 – Bear Creek

Population Centre No 3 – Buffalo Narrows

Population Centre No 4 – Beauval, English River

Population Centre No 5 – Green Lake

Appendix C Intersections

Intersection No 1 – Access road - Highway 955 Intersection

Intersection No 2 – Highway 955 - 155 Intersection

Intersection No 3 – Highway 909 - 155 Intersection

Intersection No 4 – Highway 155 Sharp Turn

Intersection No 5 – Highway 155 - Buffalo Narrows Airport Road Intersection

Intersection No 6 – Highway 925 - 155 Intersection

Intersection No 7 – Highway 908 - 155 Intersection

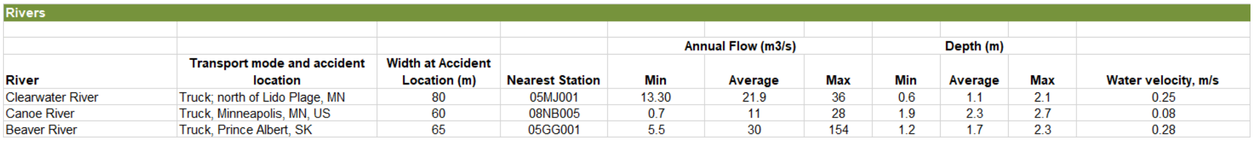
Intersection No 8 – Highway 965 - 155 Intersection

Intersection No 9 – Highway 165 - 155 Intersection

Intersection No 10 – Highway 55 - 155 Intersection

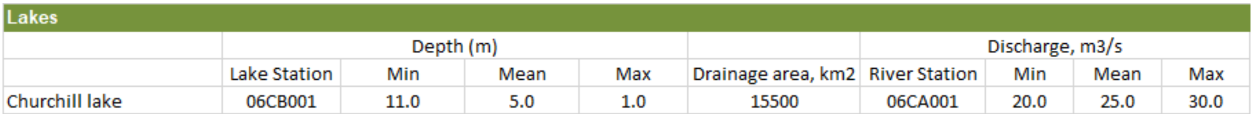
Appendix D Descriptions of Methods and Sample Calculations

Sample Fate and Transport Calculations:



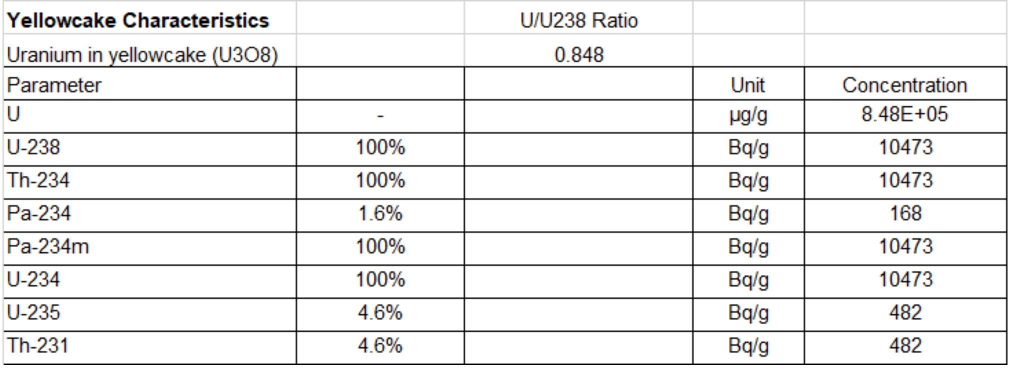
Rivers

				Annual Flow (m3/s)			Depth (m)			
River	**Transport mode and accident location**	**Width at Accident Location (m)**	**Nearest Station**	**Min**	**Average**	**Max**	**Min**	**Average**	**Max**	**Water velocity, m/s**
Clearwater River	Truck; north of Lido Plage, MN	80	05MJ001	13.30	21.9	36	0.6	1.1	2.1	0.25
Canoe River	Truck, Minneapolis, MN, US	60	08NB005	0.7	11	28	1.9	2.3	2.7	0.08
Beaver River	Truck, Prince Albert, SK	65	05GG001	5.5	30	154	1.2	1.7	2.3	0.28

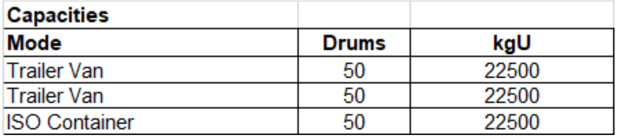


Lakes

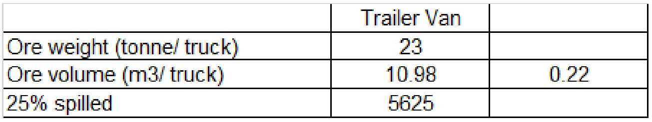
		Depth (m)					Discharge, m3/s		
	Lake Station	Min	Mean	Max	Drainage area, km2	River Station	Min	Mean	Max
Churchill lake	06CB001	11.0	5.0	1.0	15500	06CA001	20.0	25.0	30.0



Yellowcake Characteristics		U/U238 Ratio		
Uranium in yellowcake (U3O8)		0.848		
Parameter			Unit	Concentration
U	-		µg/g	8.48E+05
U-238	100%		Bq/g	10473
Th-234	100%		Bq/g	10473
Pa-234	1.6%		Bq/g	168
Pa-234m	100%		Bq/g	10473
U-234	100%		Bq/g	10473
U-235	4.6%		Bq/g	482
Th-231	4.6%		Bq/g	482



Capacities		
Mode	**Drums**	**kgU**
Trailer Van	50	22500
Trailer Van	50	22500
ISO Container	50	22500



	Trailer Van	
Ore weight (tonne/ truck)	23	
Ore volume (m3/ truck)	10.98	0.22
25% spilled	5625	

U Particle density (g/cm3):	9.6	Kiggavik	
Bulk density (g/cm3)	2.1	Kiggavik	
Water temperature (C)		10	assumed
Dynamic viscosity of water (g/m.s)		1.37	μ
Kinematic viscosity of water (m2/s)		1.37E-06	s
Porosity of sediment		0.70	assumed

icle Sizes and Settling Velocities (m/s)

For a laminar flow

Stoke's law

$$V_t = \frac{gd^2(\rho_p - \rho_m)}{18\mu}$$

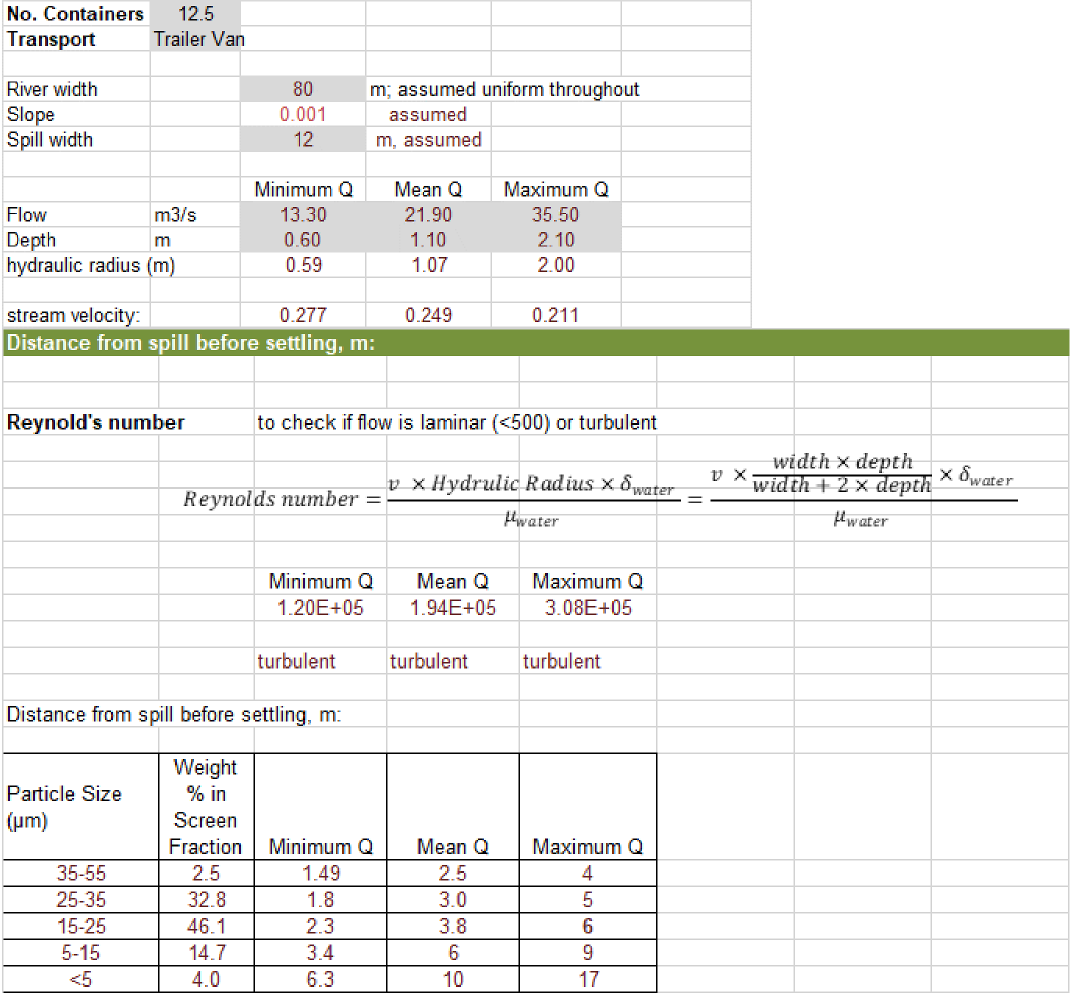
	Calcined		
Particle Size category (µm)	Particle Size (µm)	Weight % in Screen Fraction	Settling velocity (m/s)
35-55	44	2.5	0.007
25-35	30	32.8	0.003
15-25	19	46.1	0.001
5-15	8.6	14.7	0.0003
<5	2.5	4.0	0.000022

For a turbulent flow

$$\vartheta_s = \sqrt{\frac{10}{3} g \frac{(\rho_p - \rho_w)d}{\rho_w}}$$

	Calcined		
Particle Size category (µm)	Particle Size (µm)	Weight % in Screen Fraction	Settling velocity (m/s)
35-55	44	2.5	0.111
25-35	30	32.8	0.092
15-25	19	46.1	0.073
5-15	9	14.7	0.049
<5	3	4.0	0.027

Clearwater River



No. Containers	12.5			
Transport	Trailer Van			
River width		80	m; assumed uniform throughout	
Slope		0.001	assumed	
Spill width		12	m, assumed	
		Minimum Q	Mean Q	Maximum Q
Flow	m3/s	13.30	21.90	35.50
Depth	m	0.60	1.10	2.10
hydraulic radius (m)		0.59	1.07	2.00
stream velocity:		0.277	0.249	0.211

Distance from spill before settling, m:

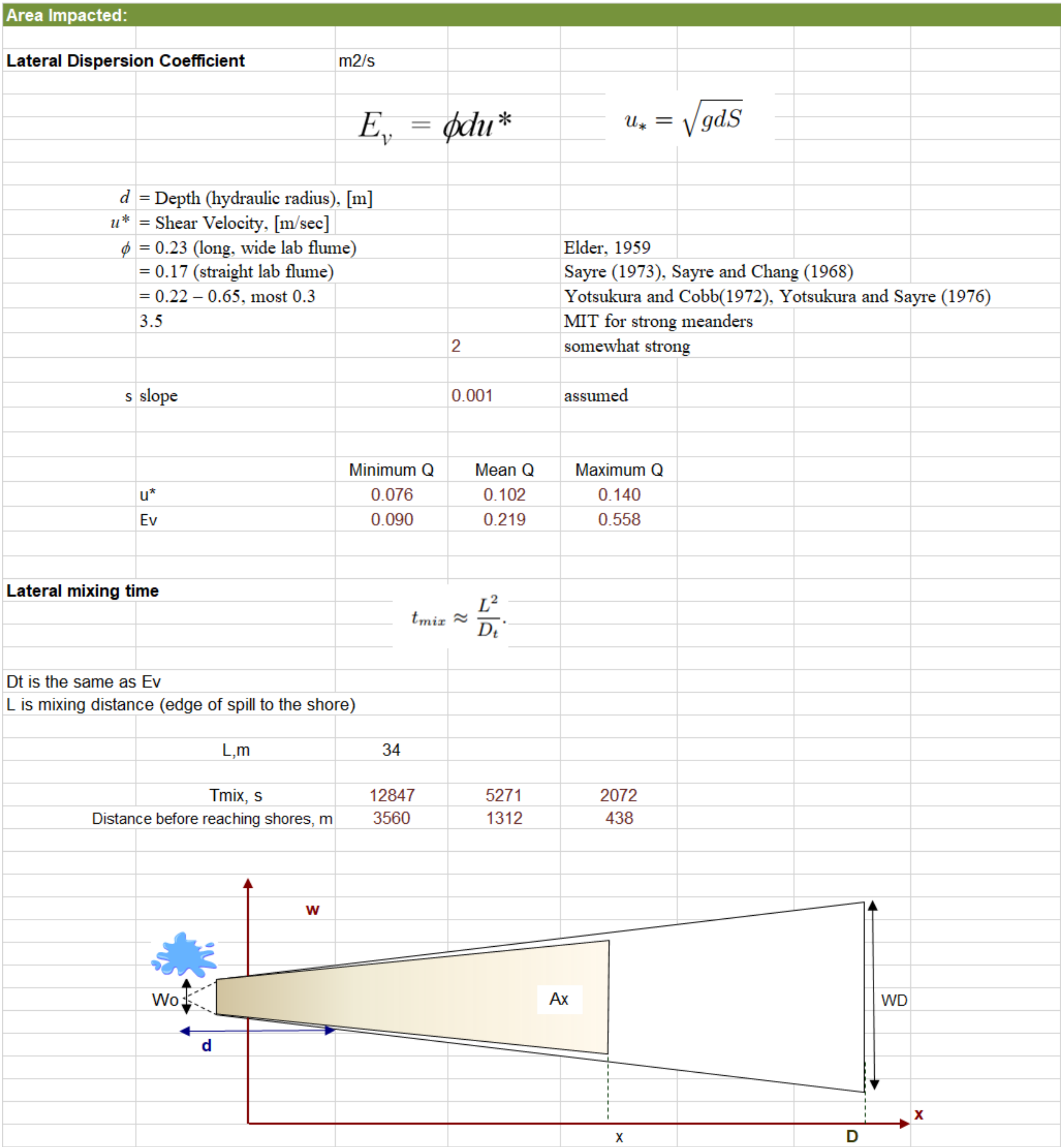
Reynold's number to check if flow is laminar (<500) or turbulent

$$Reynolds\ number = \frac{v\ \times Hydrulic\ Radius \times \delta_{water}}{\mu_{water}} = \frac{v\ \times \frac{width \times depth}{width + 2 \times depth} \times \delta_{water}}{\mu_{water}}$$

Minimum Q	Mean Q	Maximum Q
1.20E+05	1.94E+05	3.08E+05
turbulent	turbulent	turbulent

Distance from spill before settling, m:

Particle Size (µm)	Weight % in Screen Fraction	Minimum Q	Mean Q	Maximum Q
35-55	2.5	1.49	2.5	4
25-35	32.8	1.8	3.0	5
15-25	46.1	2.3	3.8	6
5-15	14.7	3.4	6	9
<5	4.0	6.3	10	17



Area Impacted:

Lateral Dispersion Coefficient m2/s

$$E_v = \phi d u^*$$

$$u_* = \sqrt{gdS}$$

d = Depth (hydraulic radius), [m]
u^* = Shear Velocity, [m/sec]

ϕ	= 0.23 (long, wide lab flume)		Elder, 1959
	= 0.17 (straight lab flume)		Sayre (1973), Sayre and Chang (1968)
	= 0.22 – 0.65, most 0.3		Yotsukura and Cobb(1972), Yotsukura and Sayre (1976)
	3.5		MIT for strong meanders
		2	somewhat strong
s	slope	0.001	assumed

	Minimum Q	Mean Q	Maximum Q
u*	0.076	0.102	0.140
Ev	0.090	0.219	0.558

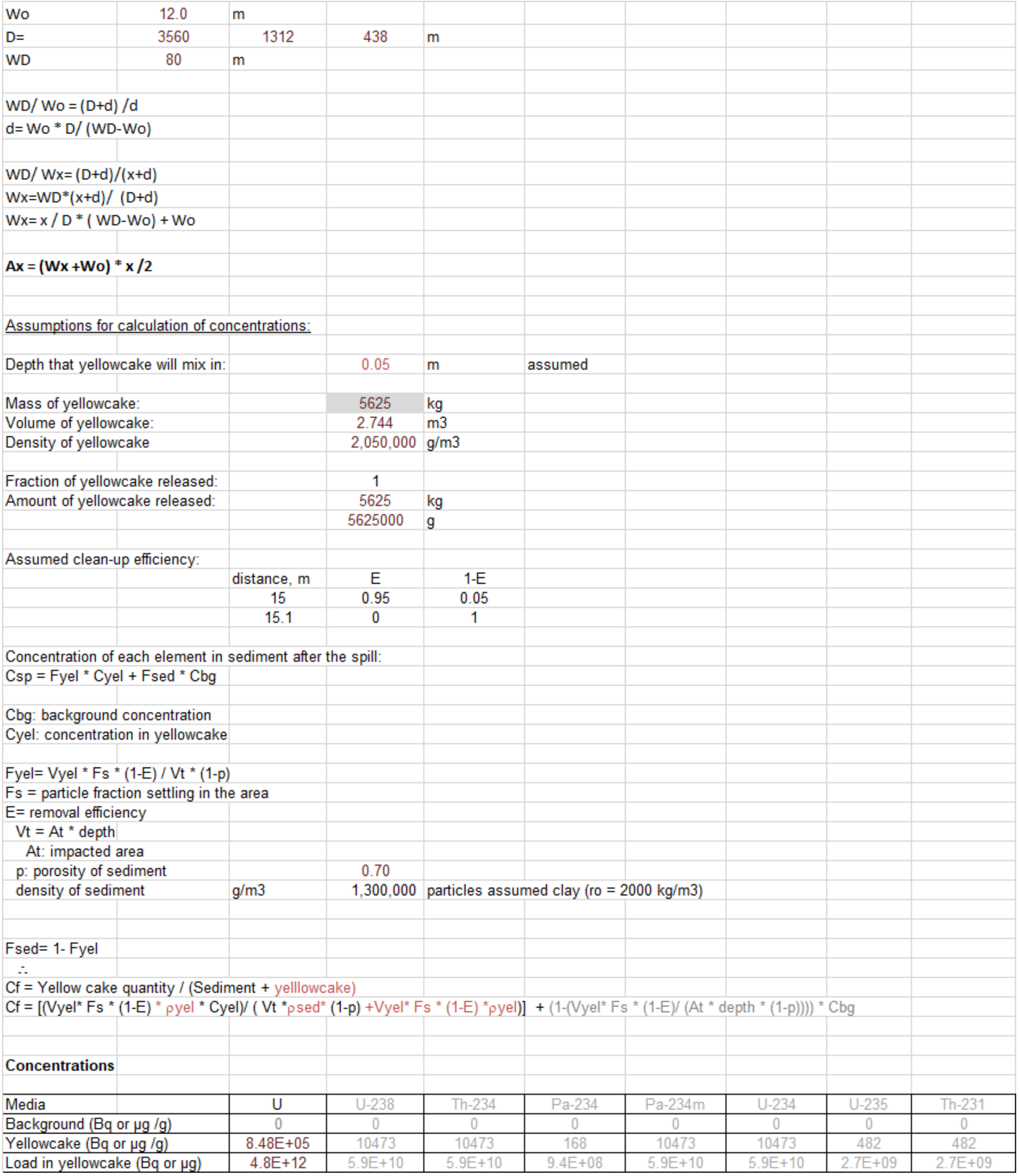
Lateral mixing time

$$t_{mix} \approx \frac{L^2}{D_t}.$$

Dt is the same as Ev
L is mixing distance (edge of spill to the shore)

L,m 34

Tmix, s	12847	5271	2072
Distance before reaching shores, m	3560	1312	438



Wo	12.0	m		
D=	3560	1312	438	m
WD	80	m		

WD/ Wo = (D+d) /d
d= Wo * D/ (WD-Wo)

WD/ Wx= (D+d)/(x+d)
Wx=WD*(x+d)/ (D+d)
Wx= x / D * (WD-Wo) + Wo

Ax = (Wx +Wo) * x /2

Assumptions for calculation of concentrations:

Depth that yellowcake will mix in: 0.05 m assumed

Mass of yellowcake: 5625 kg
Volume of yellowcake: 2.744 m3
Density of yellowcake 2,050,000 g/m3

Fraction of yellowcake released: 1
Amount of yellowcake released: 5625 kg
5625000 g

Assumed clean-up efficiency:

distance, m	E	1-E
15	0.95	0.05
15.1	0	1

Concentration of each element in sediment after the spill:
Csp = Fyel * Cyel + Fsed * Cbg

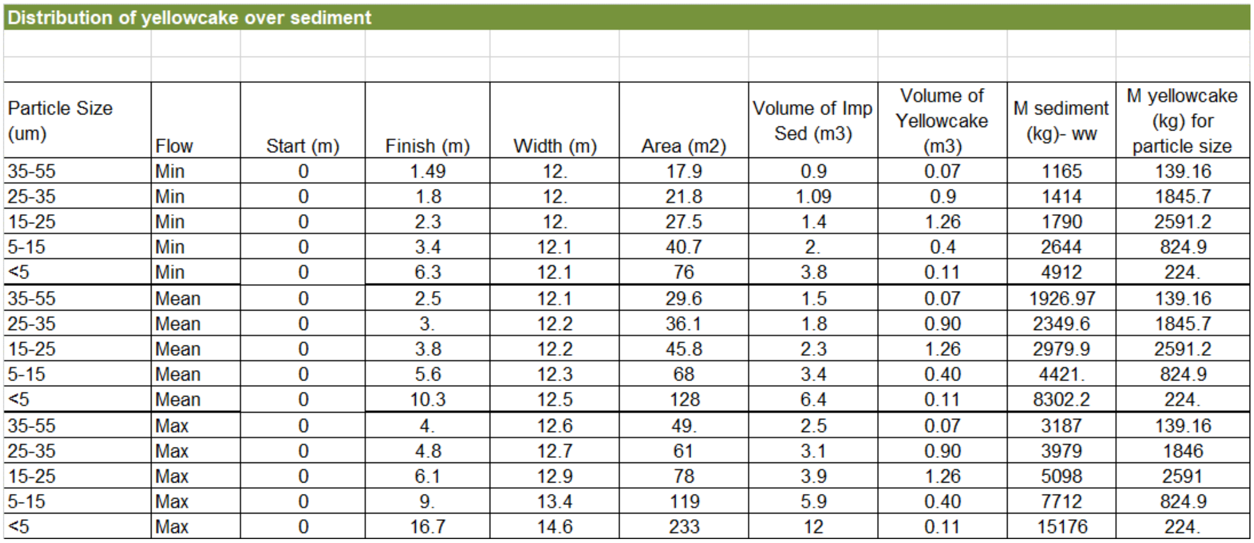
Cbg: background concentration
Cyel: concentration in yellowcake

Fyel= Vyel * Fs * (1-E) / Vt * (1-p)
Fs = particle fraction settling in the area
E= removal efficiency
Vt = At * depth
At: impacted area
p: porosity of sediment 0.70
density of sediment g/m3 1,300,000 particles assumed clay (ro = 2000 kg/m3)

Fsed= 1- Fyel
∴
Cf = Yellow cake quantity / (Sediment + yelllowcake)
Cf = [(Vyel* Fs * (1-E) * ρyel * Cyel)/ (Vt *ρsed* (1-p) +Vyel* Fs * (1-E) *ρyel)] + (1-(Vyel* Fs * (1-E)/ (At * depth * (1-p)))) * Cbg

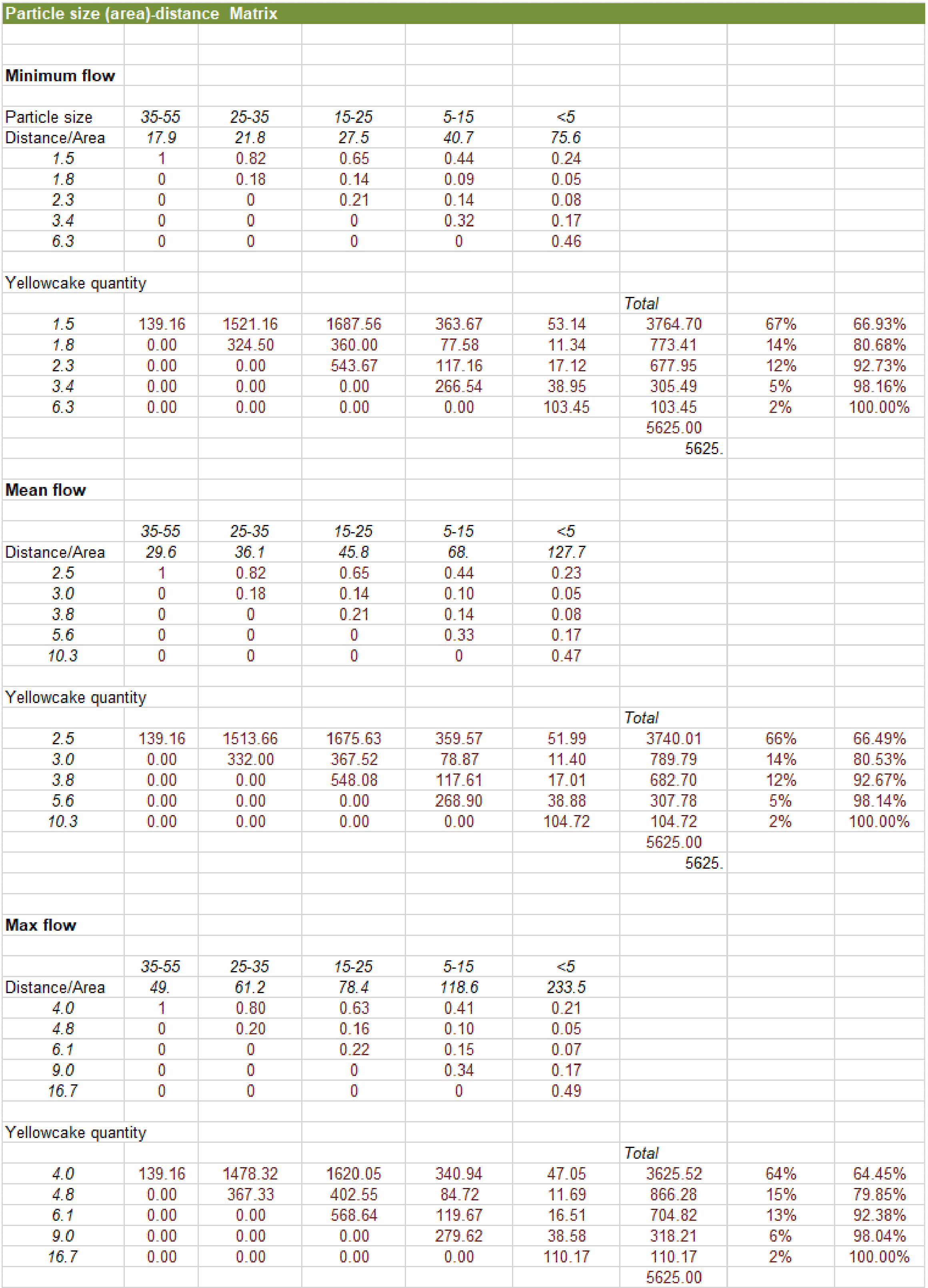
Concentrations

Media	U	U-238	Th-234	Pa-234	Pa-234m	U-234	U-235	Th-231
Background (Bq or µg /g)	0	0	0	0	0	0	0	0
Yellowcake (Bq or µg /g)	8.48E+05	10473	10473	168	10473	10473	482	482
Load in yellowcake (Bq or µg)	4.8E+12	5.9E+10	5.9E+10	9.4E+08	5.9E+10	5.9E+10	2.7E+09	2.7E+09



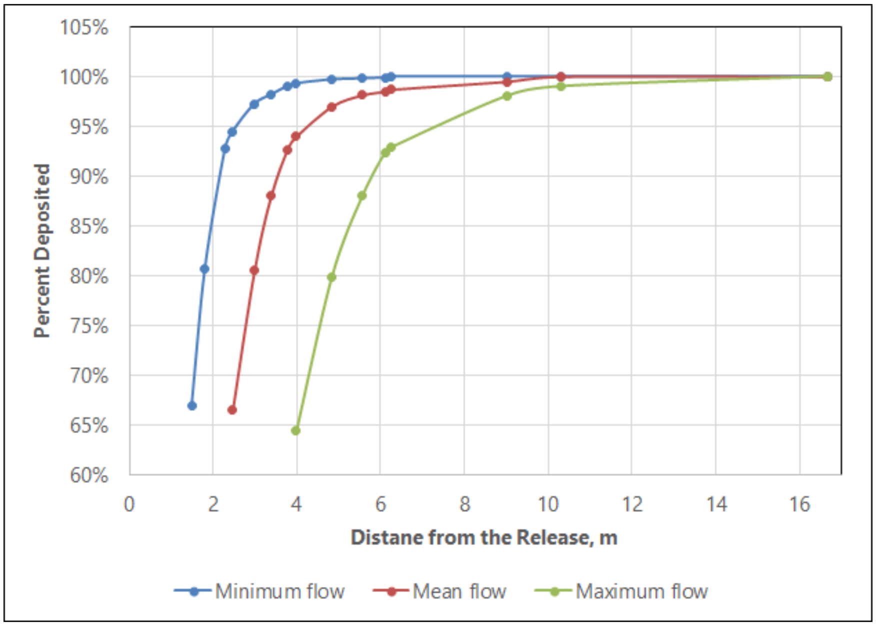
Distribution of yellowcake over sediment

Particle Size (um)	Flow	Start (m)	Finish (m)	Width (m)	Area (m2)	Volume of Imp Sed (m3)	Volume of Yellowcake (m3)	M sediment (kg)- ww	M yellowcake (kg) for particle size
35-55	Min	0	1.49	12.	17.9	0.9	0.07	1165	139.16
25-35	Min	0	1.8	12.	21.8	1.09	0.9	1414	1845.7
15-25	Min	0	2.3	12.	27.5	1.4	1.26	1790	2591.2
5-15	Min	0	3.4	12.1	40.7	2.	0.4	2644	824.9
<5	Min	0	6.3	12.1	76	3.8	0.11	4912	224.
35-55	Mean	0	2.5	12.1	29.6	1.5	0.07	1926.97	139.16
25-35	Mean	0	3.	12.2	36.1	1.8	0.90	2349.6	1845.7
15-25	Mean	0	3.8	12.2	45.8	2.3	1.26	2979.9	2591.2
5-15	Mean	0	5.6	12.3	68	3.4	0.40	4421.	824.9
<5	Mean	0	10.3	12.5	128	6.4	0.11	8302.2	224.
35-55	Max	0	4.	12.6	49.	2.5	0.07	3187	139.16
25-35	Max	0	4.8	12.7	61	3.1	0.90	3979	1846
15-25	Max	0	6.1	12.9	78	3.9	1.26	5098	2591
5-15	Max	0	9.	13.4	119	5.9	0.40	7712	824.9
<5	Max	0	16.7	14.6	233	12	0.11	15176	224.



Particle size (area)-distance Matrix

Minimum flow								
Particle size	*35-55*	*25-35*	*15-25*	*5-15*	*<5*			
Distance/Area	*17.9*	*21.8*	*27.5*	*40.7*	*75.6*			
1.5	1	0.82	0.65	0.44	0.24			
1.8	0	0.18	0.14	0.09	0.05			
2.3	0	0	0.21	0.14	0.08			
3.4	0	0	0	0.32	0.17			
6.3	0	0	0	0	0.46			
Yellowcake quantity								
						Total		
1.5	139.16	1521.16	1687.56	363.67	53.14	3764.70	67%	66.93%
1.8	0.00	324.50	360.00	77.58	11.34	773.41	14%	80.68%
2.3	0.00	0.00	543.67	117.16	17.12	677.95	12%	92.73%
3.4	0.00	0.00	0.00	266.54	38.95	305.49	5%	98.16%
6.3	0.00	0.00	0.00	0.00	103.45	103.45	2%	100.00%
						5625.00		
						5625.		
Mean flow								
	35-55	*25-35*	*15-25*	*5-15*	*<5*			
Distance/Area	*29.6*	*36.1*	*45.8*	*68.*	*127.7*			
2.5	1	0.82	0.65	0.44	0.23			
3.0	0	0.18	0.14	0.10	0.05			
3.8	0	0	0.21	0.14	0.08			
5.6	0	0	0	0.33	0.17			
10.3	0	0	0	0	0.47			
Yellowcake quantity								
						Total		
2.5	139.16	1513.66	1675.63	359.57	51.99	3740.01	66%	66.49%
3.0	0.00	332.00	367.52	78.87	11.40	789.79	14%	80.53%
3.8	0.00	0.00	548.08	117.61	17.01	682.70	12%	92.67%
5.6	0.00	0.00	0.00	268.90	38.88	307.78	5%	98.14%
10.3	0.00	0.00	0.00	0.00	104.72	104.72	2%	100.00%
						5625.00		
						5625.		
Max flow								
	35-55	*25-35*	*15-25*	*5-15*	*<5*			
Distance/Area	*49.*	*61.2*	*78.4*	*118.6*	*233.5*			
4.0	1	0.80	0.63	0.41	0.21			
4.8	0	0.20	0.16	0.10	0.05			
6.1	0	0	0.22	0.15	0.07			
9.0	0	0	0	0.34	0.17			
16.7	0	0	0	0	0.49			
Yellowcake quantity								
						Total		
4.0	139.16	1478.32	1620.05	340.94	47.05	3625.52	64%	64.45%
4.8	0.00	367.33	402.55	84.72	11.69	866.28	15%	79.85%
6.1	0.00	0.00	568.64	119.67	16.51	704.82	13%	92.38%
9.0	0.00	0.00	0.00	279.62	38.58	318.21	6%	98.04%
16.7	0.00	0.00	0.00	0.00	110.17	110.17	2%	100.00%
						5625.00		



Estimated Sediment Quality

Distance	Flow	M sediment (kg)	M yellowcake for distance (kg)	U (µg/g)	U-238 (Bq/g)	Th-234 (Bq/g)	Pa-234 (Bq/g)	Pa-234m (Bq/g)	U-234 (Bq/g)	U-235 (Bq/g)
1.49	Min	1165	3765	32377	7997.1	7997.1	128.	7997.1	7997.1	367.9
1.8	Min	1414	773	14991	3702.8	3702.8	59.24	3702.8	3702.8	170.33
2.3	Min	1790	678	11649	2877.4	2877.4	46.04	2877.4	2877.4	132.36
3.4	Min	2644	305	4392	1084.8	1084.8	17.357	1084.8	1084.8	49.9
6.3	Min	4912	103	874	216.	216.	3.456	216.	216.	9.936
2.5	Mean	1927	3740	27982	6911.7	6911.7	110.59	6911.7	6911.7	317.9
3.0	Mean	2350	790	10667	2634.7	2634.7	42.15	2634.7	2634.7	121.19
3.8	Mean	2980	683	7903	1952.1	1952.1	31.234	1952.1	1952.1	89.8
5.6	Mean	4421	308	2760	681.6	681.6	10.906	681.6	681.6	31.36
10.3	Mean	8302	105	528	130.5	130.5	2.087	130.5	130.5	6.
4.0	Max	3187	3626	22564	5573.2	5573.2	89.17	5573.2	5573.2	256.4
4.8	Max	3979	866	7580	1872.3	1872.3	29.96	1872.3	1872.3	86.13
6.1	Max	5098	705	5150	1272.1	1272.1	20.35	1272.1	1272.1	58.51
9.0	Max	7712	318	1680	415.	415.	6.64	415.	415.	19.09
16.7	Max	15176	110	891	75.5	75.5	1.208	75.5	75.5	3.472
Max all				32377	7997.1	7997.1	128.	7997.1	7997.1	367.9

Predicted Sediment Quality
Weighted-average

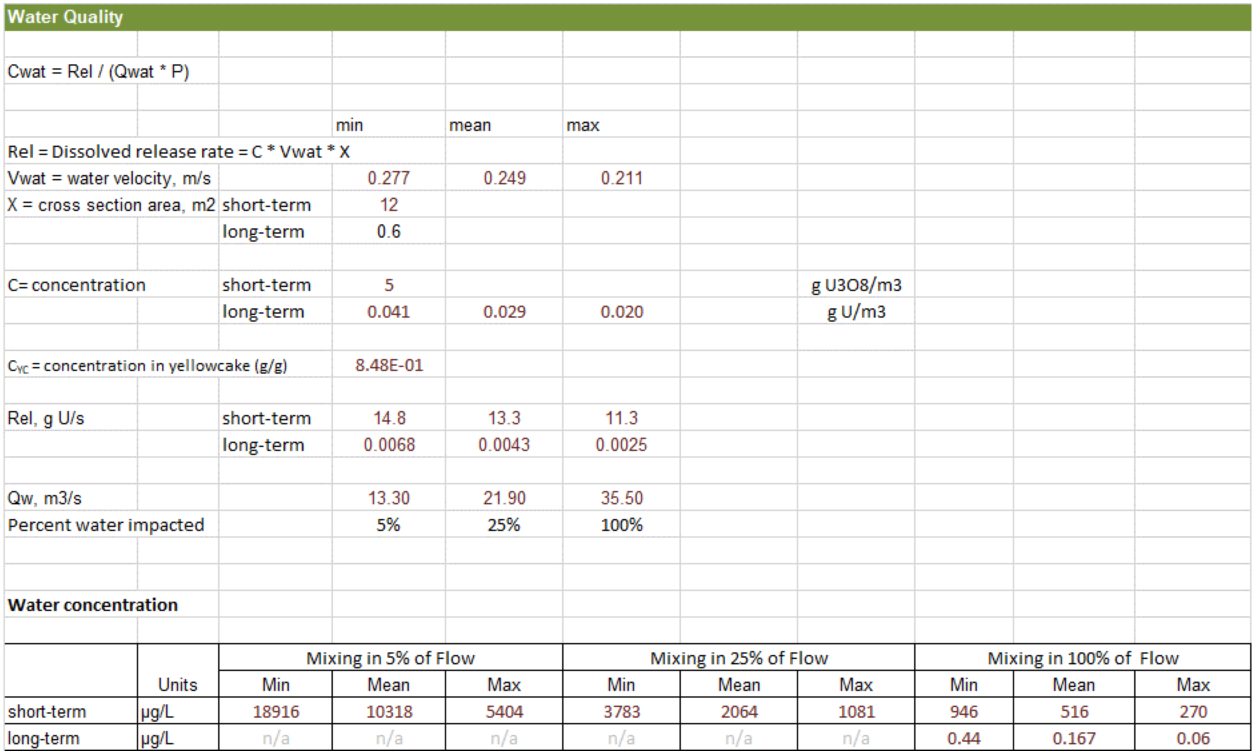
Flow	C, µg/g		
Minimum	11765	*10498*	
Average	8259	*8364*	
Maximum	5700	*6242*	*since clean-up extends to only 15 m, most of yellowcake in high flow (beyond 15 m) is not cleaned-up.*

Porewater Quality- Long-term

Weighted- Average Porewater Concentrations

Flow	Maximum	Units
Minimum	41	µg/L
Average	29	µg/L
Maximum	20	µg/L

Sediment-water partition coefficient		
3.5	m3/kg	SENES 2010 (Cigar Lake)



Water Quality

Cwat = Rel / (Qwat * P)

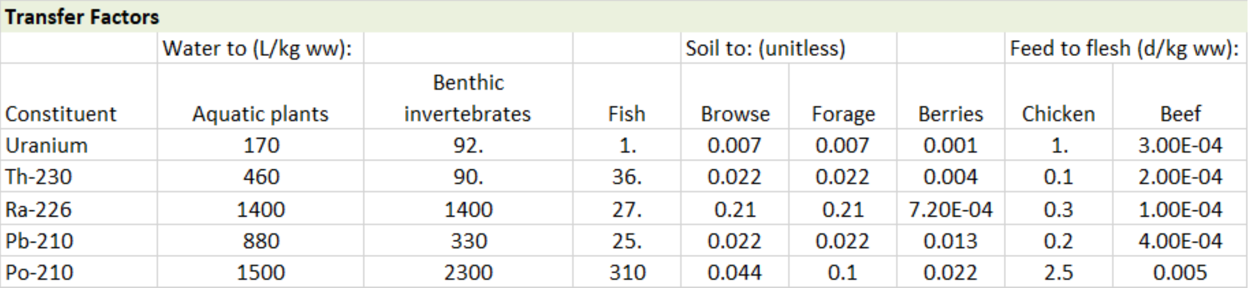
		min	mean	max	
Rel = Dissolved release rate = C * Vwat * X					
Vwat = water velocity, m/s		0.277	0.249	0.211	
X = cross section area, m2	short-term	12			
	long-term	0.6			
C= concentration	short-term	5			g U3O8/m3
	long-term	0.041	0.029	0.020	g U/m3
C_{YC} = concentration in yellowcake (g/g)		8.48E-01			
Rel, g U/s	short-term	14.8	13.3	11.3	
	long-term	0.0068	0.0043	0.0025	
Qw, m3/s		13.30	21.90	35.50	
Percent water impacted		5%	25%	100%	

Water concentration

		Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Units	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
short-term	µg/L	18916	10318	5404	3783	2064	1081	946	516	270
long-term	µg/L	n/a	n/a	n/a	n/a	n/a	n/a	0.44	0.167	0.06

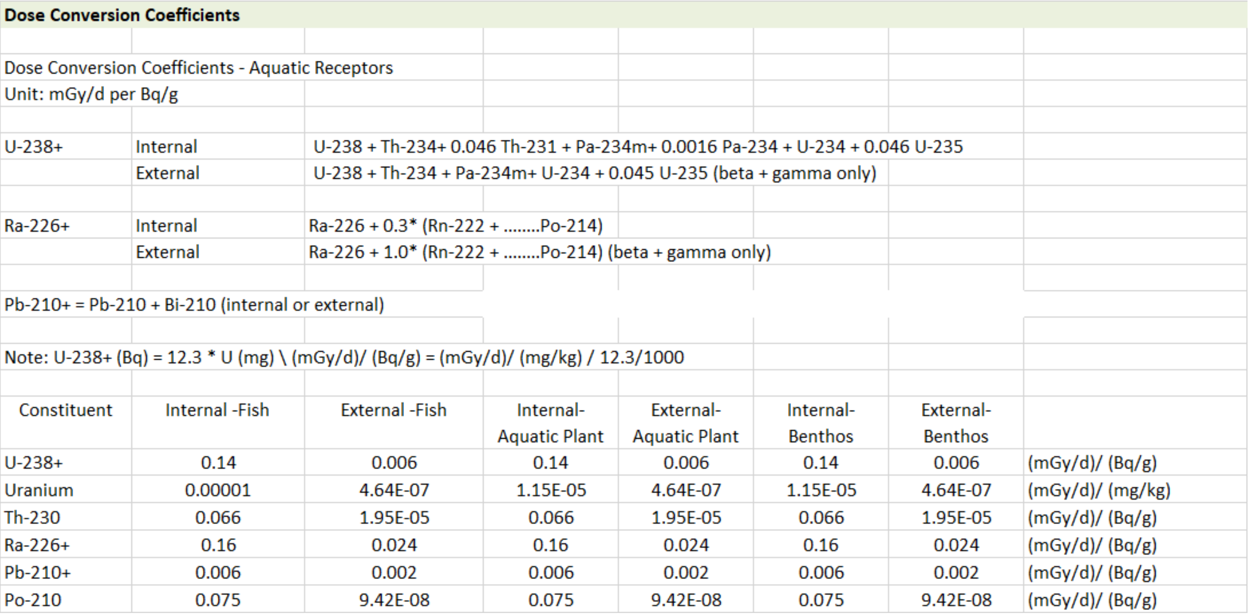
Exposure and Risk Characterization

Clearwater River



Transfer Factors

	Water to (L/kg ww):			Soil to: (unitless)			Feed to flesh (d/kg ww):	
Constituent	Aquatic plants	Benthic invertebrates	Fish	Browse	Forage	Berries	Chicken	Beef
Uranium	170	92.	1.	0.007	0.007	0.001	1.	3.00E-04
Th-230	460	90.	36.	0.022	0.022	0.004	0.1	2.00E-04
Ra-226	1400	1400	27.	0.21	0.21	7.20E-04	0.3	1.00E-04
Pb-210	880	330	25.	0.022	0.022	0.013	0.2	4.00E-04
Po-210	1500	2300	310	0.044	0.1	0.022	2.5	0.005



Dose Conversion Coefficients

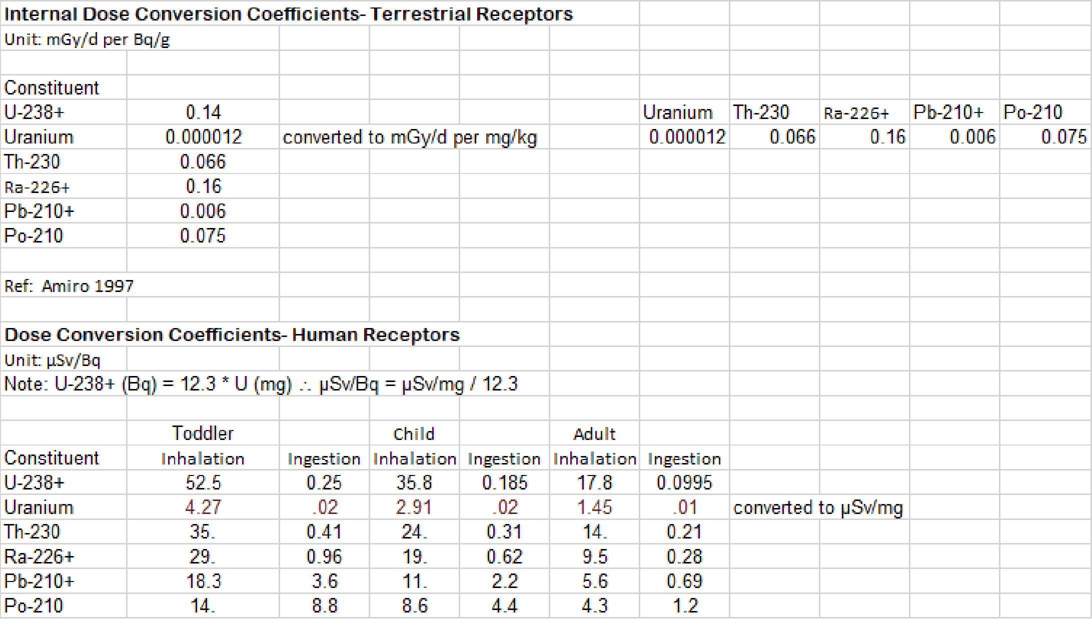
Dose Conversion Coefficients - Aquatic Receptors
Unit: mGy/d per Bq/g

U-238+	Internal	U-238 + Th-234+ 0.046 Th-231 + Pa-234m+ 0.0016 Pa-234 + U-234 + 0.046 U-235
	External	U-238 + Th-234 + Pa-234m+ U-234 + 0.045 U-235 (beta + gamma only)
Ra-226+	Internal	Ra-226 + 0.3* (Rn-222 + ...Po-214)
	External	Ra-226 + 1.0* (Rn-222 + ...Po-214) (beta + gamma only)

Pb-210+ = Pb-210 + Bi-210 (internal or external)

Note: U-238+ (Bq) = 12.3 * U (mg) \ (mGy/d)/ (Bq/g) = (mGy/d)/ (mg/kg) / 12.3/1000

Constituent	Internal -Fish	External -Fish	Internal-Aquatic Plant	External-Aquatic Plant	Internal-Benthos	External-Benthos	
U-238+	0.14	0.006	0.14	0.006	0.14	0.006	(mGy/d)/ (Bq/g)
Uranium	0.00001	4.64E-07	1.15E-05	4.64E-07	1.15E-05	4.64E-07	(mGy/d)/ (mg/kg)
Th-230	0.066	1.95E-05	0.066	1.95E-05	0.066	1.95E-05	(mGy/d)/ (Bq/g)
Ra-226+	0.16	0.024	0.16	0.024	0.16	0.024	(mGy/d)/ (Bq/g)
Pb-210+	0.006	0.002	0.006	0.002	0.006	0.002	(mGy/d)/ (Bq/g)
Po-210	0.075	9.42E-08	0.075	9.42E-08	0.075	9.42E-08	(mGy/d)/ (Bq/g)



Internal Dose Conversion Coefficients- Terrestrial Receptors

Unit: mGy/d per Bq/g

Constituent		
U-238+	0.14	
Uranium	0.000012	converted to mGy/d per mg/kg
Th-230	0.066	
Ra-226+	0.16	
Pb-210+	0.006	
Po-210	0.075	

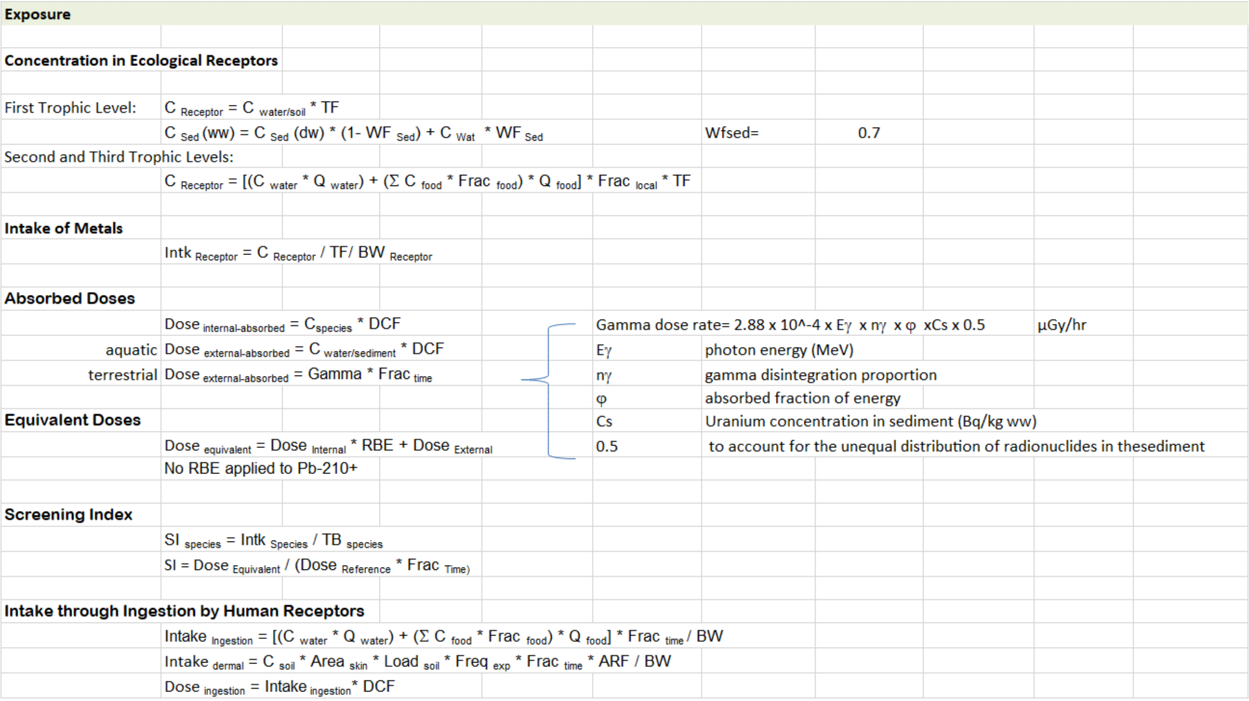
Uranium	Th-230	Ra-226+	Pb-210+	Po-210
0.000012	0.066	0.16	0.006	0.075

Ref: Amiro 1997

Dose Conversion Coefficients- Human Receptors

Unit: µSv/Bq
Note: U-238+ (Bq) = 12.3 * U (mg) ∴ µSv/Bq = µSv/mg / 12.3

	Toddler		Child		Adult		
Constituent	Inhalation	Ingestion	Inhalation	Ingestion	Inhalation	Ingestion	
U-238+	52.5	0.25	35.8	0.185	17.8	0.0995	
Uranium	4.27	.02	2.91	.02	1.45	.01	converted to µSv/mg
Th-230	35.	0.41	24.	0.31	14.	0.21	
Ra-226+	29.	0.96	19.	0.62	9.5	0.28	
Pb-210+	18.3	3.6	11.	2.2	5.6	0.69	
Po-210	14.	8.8	8.6	4.4	4.3	1.2	



Exposure

Concentration in Ecological Receptors

First Trophic Level: $C_{\text{Receptor}} = C_{\text{water/soil}} * TF$

$C_{\text{Sed}}(ww) = C_{\text{Sed}}(dw) * (1 - WF_{\text{Sed}}) + C_{\text{Wat}} * WF_{\text{Sed}}$ Wfsed= 0.7

Second and Third Trophic Levels:

$C_{\text{Receptor}} = [(C_{\text{water}} * Q_{\text{water}}) + (\Sigma\, C_{\text{food}} * Frac_{\text{food}}) * Q_{\text{food}}] * Frac_{\text{local}} * TF$

Intake of Metals

$Intk_{\text{Receptor}} = C_{\text{Receptor}} / TF / BW_{\text{Receptor}}$

Absorbed Doses

$Dose_{\text{internal-absorbed}} = C_{\text{species}} * DCF$

aquatic $Dose_{\text{external-absorbed}} = C_{\text{water/sediment}} * DCF$

terrestrial $Dose_{\text{external-absorbed}} = Gamma * Frac_{\text{time}}$

Gamma dose rate= 2.88 x 10^-4 x Eγ x nγ x φ xCs x 0.5		µGy/hr
Eγ	photon energy (MeV)	
nγ	gamma disintegration proportion	
φ	absorbed fraction of energy	
Cs	Uranium concentration in sediment (Bq/kg ww)	
0.5	to account for the unequal distribution of radionuclides in thesediment	

Equivalent Doses

$Dose_{\text{equivalent}} = Dose_{\text{Internal}} * RBE + Dose_{\text{External}}$

No RBE applied to Pb-210+

Screening Index

$SI_{\text{species}} = Intk_{\text{Species}} / TB_{\text{species}}$

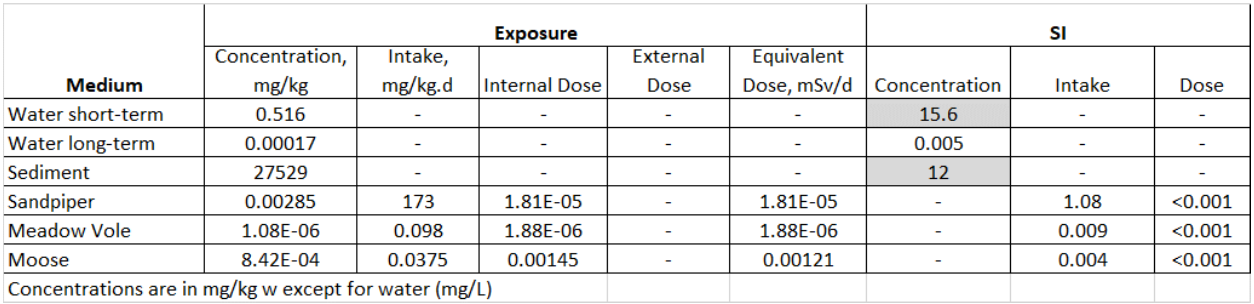
$SI = Dose_{\text{Equivalent}} / (Dose_{\text{Reference}} * Frac_{\text{Time}})$

Intake through Ingestion by Human Receptors

$Intake_{\text{Ingestion}} = [(C_{\text{water}} * Q_{\text{water}}) + (\Sigma\, C_{\text{food}} * Frac_{\text{food}}) * Q_{\text{food}}] * Frac_{\text{time}} / BW$

$Intake_{\text{dermal}} = C_{\text{soil}} * Area_{\text{skin}} * Load_{\text{soil}} * Freq_{\text{exp}} * Frac_{\text{time}} * ARF / BW$

$Dose_{\text{ingestion}} = Intake_{\text{ingestion}} * DCF$



Medium	Exposure					SI		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water short-term	0.516	-	-	-	-	15.6	-	-
Water long-term	0.00017	-	-	-	-	0.005	-	-
Sediment	27529	-	-	-	-	12	-	-
Sandpiper	0.00285	173	1.81E-05	-	1.81E-05	-	1.08	<0.001
Meadow Vole	1.08E-06	0.098	1.88E-06	-	1.88E-06	-	0.009	<0.001
Moose	8.42E-04	0.0375	0.00145	-	0.00121	-	0.004	<0.001

Concentrations are in mg/kg w except for water (mg/L)