AREVA

Kiggavik Project
Final Environmental Impact Statement

Tier 3 Technical Appendix 10A: Transportation Risk Assessment

Attachment B

Assessment of Risk and Consequence of Transportation Incidents Involving Uranium Ore Concentrates along Ground Transportation Routes in Canada

September 2014

RISK ASSESSMENT
TRANSPORTATION OF
URANIUM ORE CONCENTRATE (UOC)
IN CANADA

Prepared for:

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EXECUTIVE SUMMARY

Uranium ore concentrate (UOC), commonly referred to as yellowcake, that is produced in Northern Saskatchewan is packaged in 205 L steel drums, loaded in sea-cans or transport trailers, and transported by road to North American receivers and by road/rail combination to shipping ports for destinations in Europe, Asia and South America. This assessment examines the potential risk and consequence for the transportation of UOC in Canada via ground transportation routes. The results of this assessment can be used for planning purposes to minimize the risk and to inform AREVA's Emergency Response Assistance Plan.

Transportation Routes

The existing ground transport routes include the following:

- truck transport from northern Saskatchewan to Saskatoon, Saskatchewan, and then to the Blind River Refinery (Cameco Corporation) in Ontario;
- truck transport from Saskatoon to the United States border with North Dakota at North Portal in Saskatchewan or Emerson in Manitoba from where the UOC will be trucked to the Metropolis Works Plant (ConverDyn) in Illinois; and,
- truck transport from Saskatoon to Regina, Saskatchewan, from where the UOC will be transported via Canadian Pacific (CP) Rail west to the Vancouver Port in British Columbia or east to the Montreal Port in Quebec.

Risk Assessment Methodology and Accident Scenarios

Consistent with the traditional definition of risk, which is the product of the consequence and the probability of a hazardous event, the risk assessment conducted in this study includes the calculation of both the probability and the consequences of the identified hazardous events. The risk is then calculated using a risk matrix and the ratings for both the probability and the consequence of each hazardous event. Transportation of UOC in the vicinity of surface water bodies and population centres along the routes is the potential source of hazard. Hazard identification identified the following transportation accident scenarios for risk assessment of aquatic and terrestrial release of UOC:

- Spill of UOC into major rivers;
- Spill of UOC into a generic small lake;
- Spill of UOC into larger lakes:
- Spill of UOC on land from truck accident;
- Spill of UOC on land from train accident;
- Spill of UOC on land followed by airborne release (truck accidents);

- Spill of UOC on land followed by airborne release (train accidents);
- Spill of UOC on land followed by fire and airborne release (truck accidents);
- Spill of UOC on land followed by fire and airborne release (train accidents).

For aquatic releases, the releases to large rivers, large lakes and harbours and small lakes were assessed. The following five rivers and five lakes were selected as case studies:

- Columbia River (British Columbia)
- North Saskatchewan River (Saskatchewan)
- Assiniboine River (Manitoba)
- Kaministiquia River (Ontario)
- Mississagi River (Ontario)
- Vancouver Harbour (British Columbia)
- Wollaston Lake (Saskatchewan)
- Lac La Ronge (Saskatchewan)
- Lake of the Woods (Ontario)
- Lake St. Louis (Quebec)

Probability Assessment of Accident Scenarios

The probabilities of the identified transportation accidents are derived from transportation accident statistics from various jurisdictions as well as conditional probabilities for breaches and releases to the land and to the surface water bodies. Canada-wide transportation accident statistics along with the statistics from the province of Saskatchewan and the United States for both general transportation and transportation of dangerous goods (TDG) were analysed.

The analysis indicated that the frequency of truck rollover and crash along the routes are 3.16×10^{-4} and 3.55×10^{-4} per km per tonne of UOC, respectively. The frequency of a main-track rail accident along the route was calculated at 1.3×10^{-4} per km per tonne of UOC. Considering the route length and transportation volume, the frequencies of releases were calculated and summarized in the following table.

Route	Destination	Frequency of Accidents Per Year, Near Water	Frequency of Accidents Per Year, Near Population Centre
Rd-1	Blind River, Ontario	1.55×10^{-5}	7.59×10^{-5}
Rd-2	Metropolis, Illinois	1.58×10^{-5}	4.31×10^{-5}
Rd-3	Metropolis, Illinois	1.06×10^{-5}	1.12×10^{-4}
Rl-1	East rail (France, Argentina)	9.95×10^{-5}	2.01×10^{-4}
Rl-2	West rail (China)	2.99×10^{-5}	7.85×10^{-6}

In summary, the results of the probability assessment showed that:

- The probability of accidents involving transportation of dangerous goods is smaller than the probability of general transportation accidents.
- The accident rate for trains is slightly less than the accident rates for truck transport when compared on a per million tonne-km basis.
- The probability of release of UOC to surface water ranged from $1x10^{-5}$ to $1.5x10^{-5}$ during one year for the identified truck transportation routes.
- The probability of release of UOC to surface water ranged from $1x10^{-5}$ to $3x10^{-5}$ during one year for the identified train transportation routes.
- The probability of release of UOC to land at the vicinity of population centres ranged from $4x10^{-5}$ to $1x10^{-4}$ during one year for the identified truck transportation routes.
- The probability of release of UOC to land at the vicinity of population centres ranged from $8x10^{-6}$ to $2x10^{-4}$ during one year for the identified train transportation routes.

Overall the probability of an accident that could result in the release of UOC to the environment during ground transport was estimated to be very unlikely.

Receptors and Benchmarks

Assessment of the consequences requires the selection of the appropriate human and ecological receptors in the study area. The study area is vast and includes the following ecological zones:

- Mixedwood Plains:
- Boreal Shield
- Boreal Plains
- Prairies

- Montane Cordillera
- Pacific Maritime:

Aquatic, semi-aquatic, and terrestrial ecological receptors were considered for the assessment. The following aquatic receptors were selected for all ecological zones within the study area:

- Aquatic Plants
- Benthic Invertebrates
- Forage Fish
- Predatory Fish
- Amphibians

Semi-aquatic and terrestrial receptors selected for various ecological zones are summarised in the following table:

Species	Mixedwood Plains	Boreal Shield	Boreal Plains	Prairies	Montane Cordillera	Pacific Maritime
Semi-Aquatic						
Sandpiper (spotted, semi-palmated)	✓	✓	✓	✓	✓	✓
Scaup (lesser)	✓	✓	✓	✓	✓	✓
Merganser (common, red-breasted)	✓	✓	✓	✓	✓	✓
Mallard	✓	✓	✓	✓	✓	✓
Peregrine falcon						✓
Muskrat	✓	✓	✓	✓	✓	✓
Terrestrial						
Willow Ptarmigan					✓	✓
Ruffed Grouse	✓	✓	✓	✓	✓	✓
Deer (mule, white-tailed)	✓	✓	✓	✓	✓	✓
Meadow vole	✓	✓	✓	✓	✓	✓
Squirrel (Arctic ground squirrel, eastern grey squirrel)	✓	✓	✓	✓	✓	✓
Woodland caribou		✓	✓			
Barren-ground caribou		✓	✓			

Human receptors included workers and members of the public. Workers included the truck driver, emergency response personnel, and workers handling the UOC drums at transfer locations. Members of the public that are living in close proximity to accident locations may be exposed to the airborne release of UOC particles.

The health effect benchmarks considered for this assessment included the surface and drinking water quality guidelines, sediment quality guidelines, short-term toxicity benchmarks, toxicity benchmarks for chronic effects for long-term exposure, and emergency response planning guidelines for short-term exposure of members of the public for airborne release of UOC particles.

Fate and Transport Modelling

Assessment of the consequences of the accident scenarios requires the calculation of concentration of contaminants of concern in the environmental media (e.g. water, air) and exposure media (e.g. food). The radionuclides present in UOC and considered for ecological receptors included U-238, Th-234, Pa-234, Pa-234m, U-234, U-235 and Th-231. For calculation of the water concentrations, the source terms for releases need to be characterized. The source term characterization was done with the following considerations:

- 75% breach for release to water
- Dilution in 5%, 25%, and 100% of the flow

For sediment, it was assumed that the UOC that settles close to the spill site will be removed through a post-accident clean-up program; however, it is likely that some residual UOC will be present in sediment subsequent to remediation and this was accounted for in the assessment.

Two types of UOC, calcined and un-calcined, were considered for the calculations. The solubility and particle size distribution of both calcined and un-calcined UOC were measured and used in the fate and transport calculations.

The differential settling of various particle size fractions of UOC for turbulent flow was used to predict the settlement of various particles and concentration of UOC in sediments. The solubility was used to calculate the water concentrations. The concentrations were calculated for short-term and long-term exposures. The short-term concentrations represent the water and sediment quality following the accidents. The short-term period was calculated to be less than two weeks following a release.

Key categories used for consequence assessment include health and safety, radiation exposure, and environment. The assessment of environmental effects included the assessment of the consequences of the accident scenarios on representative small and large lakes, rivers, and urban areas.

Consequence Assessment for Aquatic Releases

The consequence assessment included the calculation of exposure to various ecological and human receptors and benchmarking against selected toxicological reference values.

Overall, the detailed calculations showed that there was minimal difference between the results for calcined and un-calcined UOC. Two types of exceedances were identified for ecological receptors, one for population effect, and the less substantial one for individual effects. Short-term water quality impacts and sediment impacts in a limited area (generally defined as 0.2 ha in rivers, and 5% of the surface area for lakes) were found to affect individuals but not the populations of the ecological receptors.

The majority of the adverse effects on water quality were predicted to be short-term events, not long-term events. In the short term, there is the potential for effects on sensitive zooplankton species but population level impacts were not identified for the scenarios examined.

Sediment concentrations were found to be adversely impacted; this would result in effects on benthic invertebrates that reside in sediment. Generally the spatial extent of the impact would be limited; however, in some of the scenarios considered, there is the potential for population-level effects for the benthic invertebrate community (Columbia River as well as Lake of the Woods and Vancouver Harbour).

The threshold limit values for semi-aquatic receptors were exceeded, primarily due to the intake of residual UOC in sediment. These exceedances were mostly limited to the individual level directly downstream; however in the case of the Columbia River as well as Lake of the Woods and Vancouver Harbour population-level effects are possible.

Drinking the water immediately after the spill (defined by short-term water concentrations) would not cause terrestrial receptors any substantial impact. However, concentrations of uranium in such water may exceed the drinking water quality guideline for human consumption in Lac La Ronge and Lake Saint-Louis in the short-term.

In addition to these results, it was found that the accidental release of UOC to a small lake will result in compromised water and sediment quality of the lake to the extent that the water body loses its value as a habitat and will need remediation. The minimum lake size where the water quality would meet the guideline of 15 µg/L (SENV 2006) following the release of one container of UOC (about 4000 kg of UOC or 3500 kg of uranium) is a 2.3 million m^3 lake. There are many lakes smaller than this threshold along the transportation route. With respect to sediment, assuming that UOC would mix in the top layer of sediment, the minimum size lake for the sediment quality to meet the appropriate guideline is 3.3 ha.

The following table summarizes the results of exposure assessment for all receptors in all accident locations.

Parameter	RD-1 / RD-3 Assiniboine River	RI-1 Columbia River	RI-2 Kaministiquia River	RD-1 North Saskatchewan River	RD-1 Mississagi River	RD-1 Lac La Ronge	RD-1 Lake of the Woods	RI-1 Vancouver Harbour	RI-2 Lake Saint-Louis	RD-1 Wollaston Lake
Water-short	✗	✗	✗	✗	✗	✗	☑	☑	✗	✗
Water-long	□	□	□	□	□	☑	☑	☑	☑	☑
Aquatic										
Benthic Invertebrate	✗	☒	✗	✗	✗	✗	☒	☒	✗	✗
Semi-aquatic										
Muskrat	□	□	□	□	□	✗	☒	☒	✗	✗
Merganser	□	□	□	□	□	✗	☒	☒	✗	✗
Mallard	□	□	□	□	□	✗	☒	☑	☑	✗
Scaup	□	□	□	□	□	✗	☒	☒	✗	✗
Sandpiper	□	□	□	□	□	✗	☒	☒	✗	✗
Falcon	□	□	□	□	□	□	□	☑	□	☑
Terrestrial										
Grouse	☑	☑	☑	☑	☑	☑	☑	□	☑	□
Vole	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Deer	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ptarmigan	□	☑	□	□	□	□	□	☑	□	☑
Squirrel	□	□	□	□	□	□	□	□	□	☑
Caribou-B	□	□	□	□	□	□	□	□	□	☑
Caribou-W	□	□	□	□	□	□	□	□	□	☑
Public										
Short-term Drinking Water	□	□	□	□	□	☒	☑	☑	☒	□
Long-term Drinking water and fish	□	□	□	□	□	☑	☑	☑	☑	□

Note: ☒: exceeds TRV, ✗ exceeds TRV with some individuals affected but population-level effects not expected; ☑: does not exceed TRV, □: not applicable

Consequence Assessment for Terrestrial Releases

The assessment of the consequences for terrestrial release of UOC included the calculation of the gamma dose to the workers and calculation of the exposure and impact of inhalation of released UOC particles following an accident scenario to the workers and members of the public.

The calculated effective dose rates for the workers were between 0.0025 and 0.0029 mSv/hr for various scenarios. Given that the exposure time for any worker is limited to a few hours, the total effective doses for these workers were well below the regulatory limit for both nuclear energy workers and members of the public.

It should also be noted that during the milling operations, radium is effectively removed from uranium oxides and disposed along with the mine tailings. The residual radium activity concentration in UOC is too small to support significant radon emanation from the released UOC. Therefore, the dose due to radon inhalation was not calculated in this assessment.

The assessment of the impact of the dust inhalation following an accident by the driver or a member of the emergency response team showed that the radiological dose (0.164 mSv) was below the benchmarks of 1 mSv per year. For chemical toxicity, the dose was approximately two orders of magnitude smaller than the value of 3 μg uranium per g of kidney.

The results of the air dispersion models for airborne emission of UOC following a traffic accident indicated that the maximum uranium concentration in air is a small fraction of ERPG level 2 benchmark for both fire and no-fire scenarios (0.05-0.2% and 0.2-1.2%, respectively). Therefore no impact to members of the public is expected.

Summary of the Results

Overall, the consequence assessment for release to surface water indicates that the effects for release to large lakes and rivers are minor (except for a few lakes where the effects could be moderate to major). The effects to small lake systems could be major to severe (according to the risk categorization matrix). However, the probability of such releases and impacts are extremely small, resulting in low to moderate risk. A moderate risk is considered to be As Low As Reasonably Practicable (ALARP) given all regulatory oversight, the preventive and mitigative measures for transportation of dangerous goods, particularly class 7 material.

The calculation of the total effective doses to the truck driver and members of the emergency response team (unprotected) attending the accidents shows that the total effective doses are well below all regulatory limits. In addition, the dust inhalation following an accident by the driver or first responders showed that both chemical and radiological doses were far below their respective benchmarks. The results of the inhalation impact analysis to members of the public indicated that the maximum uranium concentration in air is much less than the ERPG level 2 benchmark for both fire and no-fire scenarios. Overall, it was concluded that the impact of transportation accidents, resulting in the release of UOC to land is minor. Given the low probability of such accidents, the risk from such accidents is deemed to be low.

The results of the risk assessment for the accidental release during UOC transport to both surface water and land are summarized in the following table.

Scenario Description	Probability Rating [a]	Consequence Rating [b]	Risk [c]
Spill of UOC into major rivers	Highly Unlikely	Moderate	Negligible Risk
Spill of UOC into a generic small lake	Highly Unlikely	Severe	Moderate Risk
Spill of UOC into larger lakes	Highly Unlikely	Major [d]	Moderate Risk
Spill of UOC on land from truck accident	Highly Unlikely	Moderate	Negligible Risk
Spill of UOC on land from train accident	Highly Unlikely	Moderate	Negligible Risk
Spill of UOC on land followed by airborne release (truck accidents)	Highly Unlikely	Minor	Negligible Risk
Spill of UOC on land followed by airborne release (train accidents)	Highly Unlikely	Minor	Negligible Risk
Spill of UOC on land followed by fire and airborne release (truck accidents)	Highly Unlikely	Minor	Negligible Risk
Spill of UOC on land followed by fire and airborne release (train accidents)	Highly Unlikely	Minor	Negligible Risk

Notes:

a Probability ratings are based on AREVA probability rating table.

b Consequence ratings are based on the AREVA consequence rating table

c Risk is estimated based on Table 1.3 AREVA risk matrix

d For the majority of large lakes the consequence of releases are moderate, for other lakes the risk is negligible.

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1.0 INTRODUCTION

Uranium ore concentrates (UOC), commonly referred to as yellowcake, currently produced in Northern Saskatchewan is packaged in 205 L steel drums, loaded in sea-cans or transport trailers, and transported by road to North American receivers and by road/rail combination to shipping ports for destinations in Europe, Asia and South America. The UOC proposed to be produced at the Kiggavik mine and mill in Nunavut will be flown to Points North, Saskatchewan, for further ground transport.

There is a risk of an accident inherent in the transportation of any material. Any accident presents the potential for contaminant releases to air, soil and/or water. This assessment examines this potential risk and consequence for the transportation of UOC in Canada. The results of this assessment can be used for planning purposes to minimize the risk and to inform AREVA's Emergency Response Assistance Plan.

1.1 BACKGROUND INFORMATION

The UOC (yellowcake) produced in northern Saskatchewan uranium mill is transported to North American refineries and to shipping ports for delivery abroad. UOC proposed to be produced in future will be transported similarly. The existing ground transport routes are shown in Figure 1.1 and involve the following:

- truck transport from northern Saskatchewan to Saskatoon, Saskatchewan, and then to the Blind River Refinery (Cameco Corporation) in southern Ontario;
- truck transport from Saskatoon to the United States border with North Dakota at North Portal in Saskatchewan or Emerson in Manitoba from where the UOC will be trucked to the Metropolis Works Plant (ConverDyn) in Illinois; and,
- truck transport from Saskatoon to Regina, Saskatchewan, from where the UOC will be transported via Canadian Pacific (CP) Rail west to the Vancouver Port in British Columbia or east to the Montreal Port in Quebec.

For the proposed Kiggavik Project in Nunavut, UOC is proposed to be transported from the mine site via aircraft to Points North in northern Saskatchewan. From Points North airstrip, ground transportation of UOC would be via transportation routes established for existing northern Saskatchewan mines. The proposed air transport of UOC from Kiggavik to Points North was examined within the Kiggavik Project Environmental Impact Statement (AREVA 2014, Volume 10, Technical Appendix 10A).

The assessment of risks of potential accidents associated with the transportation of UOC includes a consequence assessment addressing the potential effects to environmental and human health.

The environmental effects assessment considers representative small and large lakes, rivers, remote wilderness areas, and urban areas.

Figure 1.1 Potential UOC Transportation Routes

1.2 OBJECTIVE

The scope of this project is the assessment of the risk of an accident and the subsequent consequences for the transportation of UOC in Canada.

The consequence assessment will address the potential effects to environmental and human health. The assessment of environmental effects will consider accident scenarios impacting representative small and large lakes, rivers, remote wilderness areas, and urban areas. Representative ecological receptors will be selected for each of these scenarios. The human receptors will include transport workers, emergency responders and members of the public.

Overall the steps included in the assessment are:

- Describe the key attributes of each of the transportation routes (e.g. length, population centres, proximity to natural areas and water bodies, water crossings, etc.);
- Develop the appropriate accident scenarios. The scenarios cover a range of severity (minor to major release of UOC) and geographic locations;
- Define the probability of an accident based on the latest transportation accident statistics and the conditional probability of container failure;
- Identify the appropriate receptors (people and ecological receptors) for the scenarios and the appropriate toxicity benchmarks;
- Model the fate and transport of UOC following a release to air, land and water;
- Estimate the potential exposure to receptors following a release and determine the consequence of this exposure;
- Rate the risk according to the AREVA 4×4 risk matrix. Potential opportunities to mitigate high risk scenarios will be identified.

1.3 METHODOLOGY FOR RISK ASSESSMENT

The literature review related to the risk analysis methodologies revealed that, the terms risk analysis[1], risk assessment[2], modelling risk[3], quantitative risk assessment[4], risk estimation[5], risk evaluation[6] have all been used loosely for studies related to the risk of transport of dangerous goods (TDG). Although these studies cover a wide range of scopes from very narrow focus on one aspect of risk to studies which provide a more comprehensive framework, the great majority of the methodologies provided in these studies can be accommodated within the traditional definition of risk, which is the product of the consequence and the probability of a hazardous event[7]. Accordingly,

Risk = Accident probability x Accident consequences

The Center for Chemical Process Safety (CCPS 2008) provides guidelines to conduct risk assessment for all modes of transportation of dangerous goods. In consistency with its classical risk assessment framework and the above definition of the risk, the CCPS framework suggests that hazard analysis and identification, probability assessment, consequence assessment, and risk calculation are the elements of a comprehensive risk assessment (CCPS 2008).

[1] e.g. Abkowitz *et al*. 2004, Kawprasert and Barkan 2010.
[2] e.g. Bagheri *et al*. 2011, Barilla *et al*. 2009.
[3] e.g. Bagheri *et al*. 2012, Kokkinos *et al.* 2012.
[4] e.g. Brandsæter, and Hoffmann 2010, Hall *et al.* 2004, Hamouda *et al*. 2004.
[5] e.g. Dennis 1996, Olekszyk 1993.
[6] e.g. English *et al*. 2007, Qiang *et al.* 2011.
[7] e.g. Erkut and Verter, V. 1997, barilla 1999, CCPS 2008.

Assessment of the probability of the event occurring is based on the criteria shown in Table 1.1. Assessment of the potential consequences of the event occurring is based on the criteria shown in Table 1.2. Key categories used for consequence assessment include health and safety, radiation exposure, and environment. A risk matrix is used to rate the risk of identified accident scenarios (Table 1.3).

Table 1.1 Criteria for Assessing Probability

	Likelihood	**Comments**	**Probability of Event occurring within 40 yrs**
Almost Certain	> 1 in 10 Years	It is likely that the event has occurred at the site if the facility is more than a few years old	Greater than 98.5%
Likely	1 in 10 to 1 in 100 years	Might happen in a career	Between 98.5% and 44%
Unlikely	1 in 100 to 1 in 1000 years	Conceivable – has never happened in this facility but has probably occurred in a similar plant somewhere else	Between 44% and 4%
Highly Unlikely	< 1 in 1000 years	Essentially Impossible	Less than 4%

Table 1.2 Criteria for Assessing Consequences

Category	Consequence Rating			
	1	2	3	4
Health & Safety Risk	Minor: Nuisance and irritation, ill health leading to temporary discomfort, first aid treatment, minor cuts and bruises, eye irritation from dust, area exceeds internal administrative level.	Moderate: Some loss of hearing, dermatitis, asthma, upper limb disorder, minor disability, medical aid required, lacerations, burns, concussions, serious sprains, minor fractures, area exceeds a Threshold Limit Value	Major: Deafness, ill-health leading to major disability, medical aid required, lost limb injury, amputation, major muscle strain, major fracture, poisoning, multiple injuries, area routinely exceeds a Threshold Limit Value	Severe: Life-shortening diseases, acute fatal diseases, ill health leading to permanent disability, fatality, area exceeds a Threshold Limit Value and causes harm to individual.
Radiation Exposure Risk	Minor: Area exposure rate or dose exceeds an internal administrative level.	Moderate: Area exposure rate or dose exceeds regulatory action levels.	Major: Area exposure rate or dose exceeds regulatory dose limit.	Severe: Dose exposure exceeds regulatory emergency dose limit.
Environmental Risk	Minor: Incident, spill or occurrence reportable to regulators, measurable impacts to the environment is localized, exceeds administration level	Moderate: Incident, spill or occurrence reportable to regulators, measurable impact to the environment causes harm but limited to site, exceeds regulatory action level requiring an official investigation	Major: Incident, spill or occurrence causes extensive harm beyond property, impacts have short term or reversible effects, exceeds regulatory limits	Severe: Life shortening incident, spill or occurrence causes ecosystem to be impaired, either long term or irreversible effect to the environment, public inquiry

Table 1.3 Risk Rating Matrix

Likelihood		**Consequence**			
		1	**2**	**3**	**4**
		Minor	**Moderate**	**Major**	**Severe**
4	Almost certain: > 1 in 10 yrs	2	3	4	4
3	Likely: 1 in 10 to 1 in 100 yrs	2	3	3	4
2	Unlikely: 1 in 100 to 1 in 1000 yrs	1	2	2	3
1	Highly unlikely: < 1 in 1000 yrs	1	1	2	2

Where:
4– High Risk
3– Moderate Risk
2 – Low Risk
1 – Negligible Risk

1.4 URANIUM ORE CONCENTRATE CHARACTERISTICS

Uranium ore concentrate (UOC), commonly referred to as yellowcake, has a uranium content (U_3O_8) of about 84.8%. It is assumed to have U-238, U-234 and U-235 present in natural abundances. The short lived-decay products of U-238 (Th-234, Pa-234m, Pa-234 (which has a relative concentration of 0.16% of U-238) and U-234) and U-235 (Th-231) are assumed to be in equilibrium with their respective parents. The activities of these radionuclides in UOC can be derived using the branch ratios as shown in Table 1.4.

Table 1.4 Radionuclides Present in UOC

Radionuclide	Half Life	Branch Percentage
U-238	4.47×10^9a	-
Th-234	24.1 d	100% U-238
Pa-234m	1.16 min	100 % U-238
Pa-234	6.7 h	0.16 % U-238
U-234	2.45×10^5a	100% U-238
U-235 (4.6% of U-238)	7.04×10^8 a	-
Th-231	1.063 d	100% U-235

The particle size distribution for three UOC calcined samples and five un-calcined samples were measured using a Beckman Coulter LS Particle Size Analyzer. Table 1.5 provides a summary of particle size distribution information for these samples.

Table 1.5 UOC Particle Size Distribution

Calcined Samples [1] (3 Samples)			Un-Calcined [2] (5 Samples)		
Size Category (µm)	Average Size (µm)	Percentage	Size Category (µm)	Average Size (µm)	Percentage
<5	2.5	4.0	<5	1.1	14.2
5-15	8.6	14.7	5-15	9	18.1
15-25	19	46.1	15-50	29	56.8
25-35	30	32.8	50-200	110	7.8
35-55	44	2.5	200-400	266	2.8

1. Calcined UOC provided courtesy of Cameco Corporation Key Lake Operation
2. Un -calcined UOC provided courtesy of Cameco Corporation Rabbit Lake Operation

Solubility of UOC was measured in un-calcined samples from Rabbit Lake over a period of 72 hours. Calcined samples from McClean Lake were analyzed over 72 or 24 hours for solubility. The OECD Guideline for Testing of Chemicals; Water Solubility (adopted 27.07.95), flask method, was followed for these tests. The results are shown in Table 1.6. Bulk and particle densities of UOC were considered at 2.1 and 9.6 g/cm^3 based on previous studies completed for the Kiggavik project.

Based on more detailed data on the solubility of McClean Lake samples, solution of about 0.125 g of UOC in 250 mL of water will lead to a uranium concentration of 4800 µg/L. This is translated to a solubility of about 1% for the calcined product. Solubility of the un-calcined product is also estimated at about 1%.

Table 1.6 Solubility of UOC (g U_3O_8/L)

Sample Source	Sample No.	Time (hr)		
		24	48	72
Rabbit Lake (un-calcined)	1	0.0049	0.0043	0.0047
	2	0.0044	0.005	0.0051
	3	0.0034	0.0026	0.0031
	4	0.0066	0.0061	0.0061
	5	0.0026	0.0029	0.0029
McClean Lake (calcined)	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 to 20 (average)	0.003 to 0.008 (0.005)	-	-

2.0 HAZARD IDENTIFICATION AND ACCIDENT SCENARIOS

Canadian regulations for transportation of dangerous goods classify the uranium ore concentrate as Class 7 dangerous goods (Transportation of Dangerous Goods Regulations, Part 2)[8]. Therefore transportation of UOC by various modes of transportation is regulated. The road and rail transportation routes for hauling UOC from northern Saskatchewan to various destinations cross many surface water bodies, run alongside many surface water bodies, and go through several major population centres. Therefore, transportation accidents that potentially could result in release of UOC and subsequent exposure to human and ecological receptors are potential hazard scenarios.

2.1 TRANSPORTATION MODES ROUTES

Road and rail transportation routes from Northern Saskatchewan to various destinations within Canada include the segments shown in Table 2.1.

Table 2.1 Transportation Route Segments

Segment	From	To	Highways	Distance (km)
1	Points North Landing, SK	Saskatoon	905→102 →2 →11	839
2	Saskatoon	Regina Gateway Rail Terminal, Pinkie Road	11 →Trans-Canada 1	263
3	Saskatoon	Cameco, Blind River	11 →Trans-Canada 1 →Ontario 17	2379
4	Saskatoon	Cameco, Blind River (alternate)	16 →Trans-Canada 1 →Ontario 17	2322
5	Saskatoon	US border toward ConverDyn, Metropolis Il.	11→6 →39 -- US interstates	1657
6	Saskatoon	Emerson MB toward ConverDyn, Metropolis Il.	11→Trans-Canada 1 →MB 75 →US interstates	1714
7	Regina Gateway Rail Terminal, Pinkie Road	Port of Montreal	CP rail line (east)	3222
8	Regina Gateway Rail Terminal, Pinkie Road	Port of Vancouver	CP rail line (west)	1790

Three roads transportation routes and two rail transportation routes were defined and shown for the probability assessment. These routes comprise the segments shown in Table 2.1.

[8] http://www.tc.gc.ca/eng/tdg/clear-part2-339.htm

Table 2.2 Transportation Routes

Route	From	To	Segments	Distance (km)
Rd-1	Points North Landing, SK	Cameco, Blind River	2 + 4	3,260
Rd-2	Saskatoon	US border toward ConverDyn, Metropolis Il.	6 - 3	1,394
Rd-3	Saskatoon	Emerson MB toward ConverDyn, Metropolis Il.	7 - 3	1,451
Rl-1	Regina Gateway Rail Terminal, Pinkie Road	Port of Vancouver	9	1,790
Rl-2	Regina Gateway Rail Terminal, Pinkie Road	Port of Montreal	8	3,222

Table 2.3 shows the number of shipments and capacities of shipments for each destination.

Table 2.3 Number of Shipments and Capacities of Shipments

Destination	Mode	Number of Shipments per year	Number of Drums per Container	Kg U per Container	Total Tonnes U per Year
Blind River, Ontario	Truck (trailer Van)	34	43-45	16,305	554
Metropolis, Illinois	Truck (trailer Van)	95	40-42	15,120	1,436
East rail (France, Argentina)	Train (ISO Container)	94	35	12,975	7,318
West rail (China)	Train (ISO Container)	24	35	12,975	1,868

2.1.1 Route Rd-1

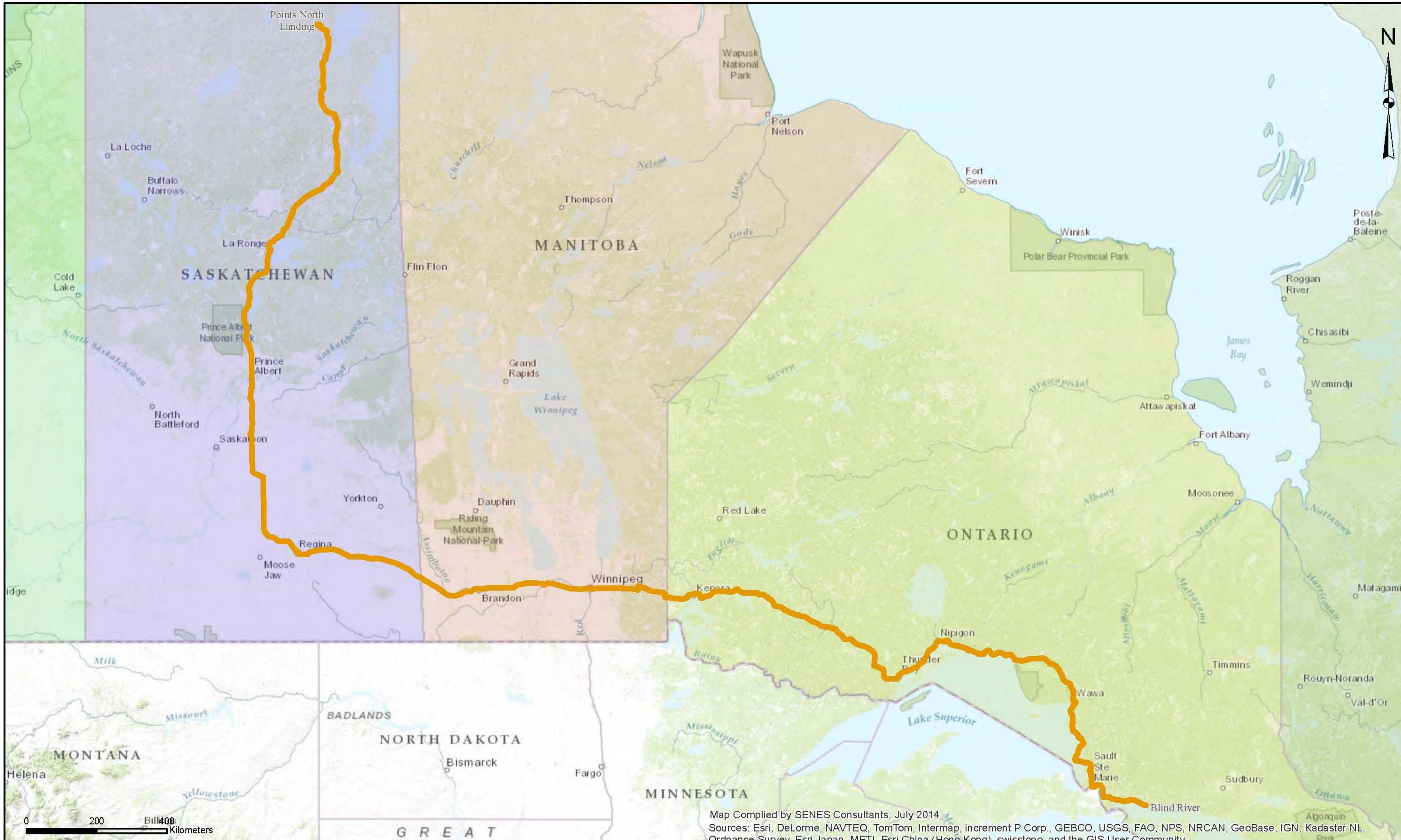
Route Rd-1 starts from Points North Landing, Saskatchewan and ends at Cameco’s Blind River Refinery.

Figure 2.1 shows a map of route Rd-1. The total length of the route is 3,260 km. The route passes through population centres including Saskatoon, Regina, Winnipeg, Thunder Bay, Sault Ste. Marie, and approximately 100 towns and communities. The total length of the route within population centres is approximately 204.5 km. It crosses over 140 water bodies. These water bodies include small unnamed creeks to large rivers including Montreal River, South Saskatchewan River, Assiniboine River, Red River, Eagle River, and Mississagi River. The total length of the route exposed to rivers, including a 100 m buffer zone, is 19.2 km.

The route passes near a large number of water bodies. The total length of route passing within 30 m of water bodies is approximately 22.5 km. It also goes through 10 provincial and national parks with the total exposed length of approximately 139.4 km.

The exposure features of the route Rd-1 are summarized in Appendix A.

Figure 2.1 Map of Route Rd-1



2.1.2 Route Rd-2

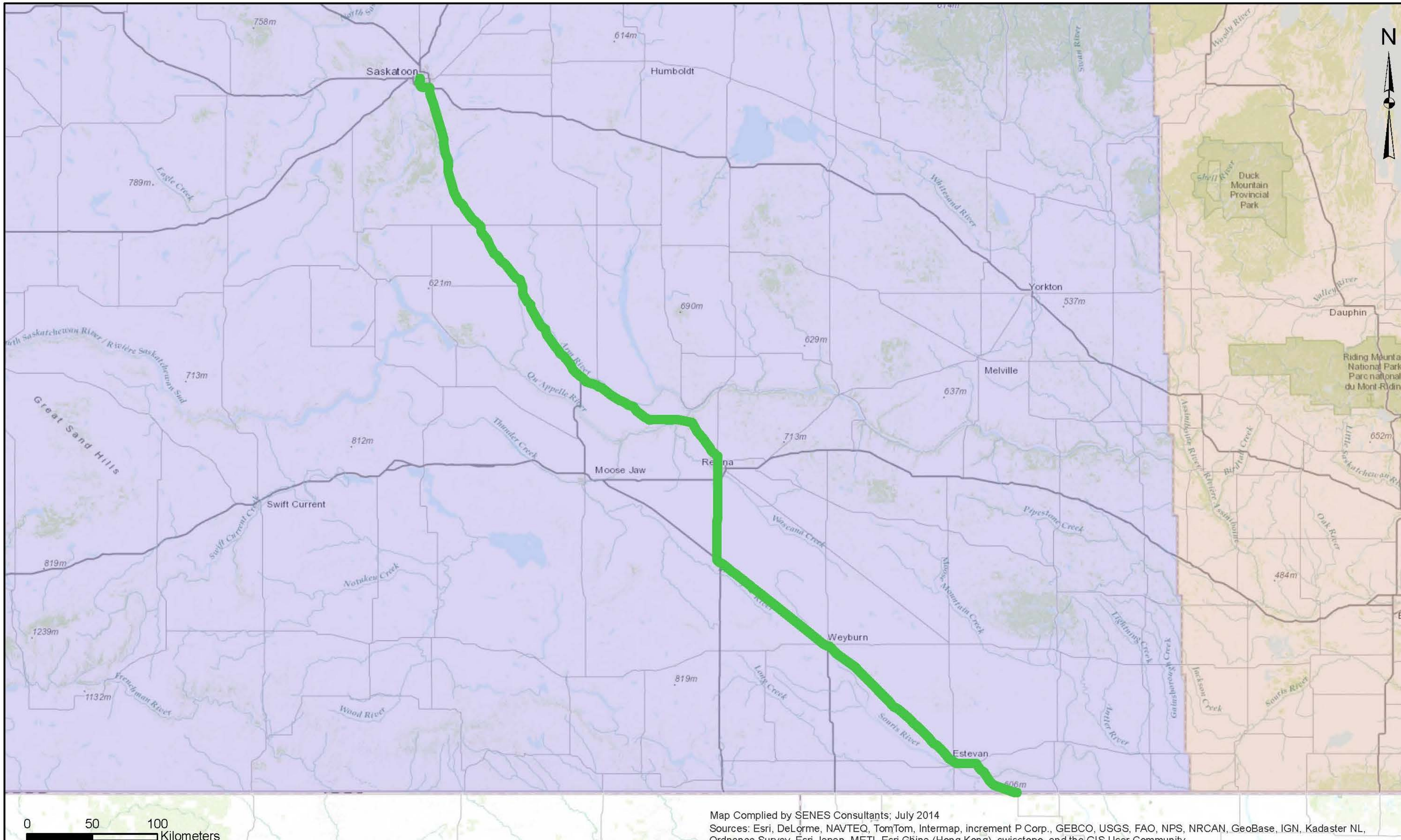
Route Rd-2 starts from Saskatoon and ends at the US border toward Honeywell's ConverDyn refining and conversion facility in Metropolis, Illinois.

Figure 2.2 shows a map of route Rd-2. The total length of the route is 1,400 km. The route passes through a number of population centres including Saskatoon and Regina and approximately 20 towns and communities. The total length of the route exposed to the population centres is approximately 44 km. It crosses over 10 water bodies. These water bodies include small unnamed creeks to large rivers including the South Saskatchewan River. The total length of the route exposed to rivers, including a 100 m buffer zone, is approximately 1.3 km.

The route passes near a large number of water bodies. The total length of route passing within 30 m of water bodies is approximately 4 km.

The exposure features of the route Rd-2 are summarized in Appendix A.

Figure 2.2 Map of Route Rd-2



2.1.3 Route Rd-3

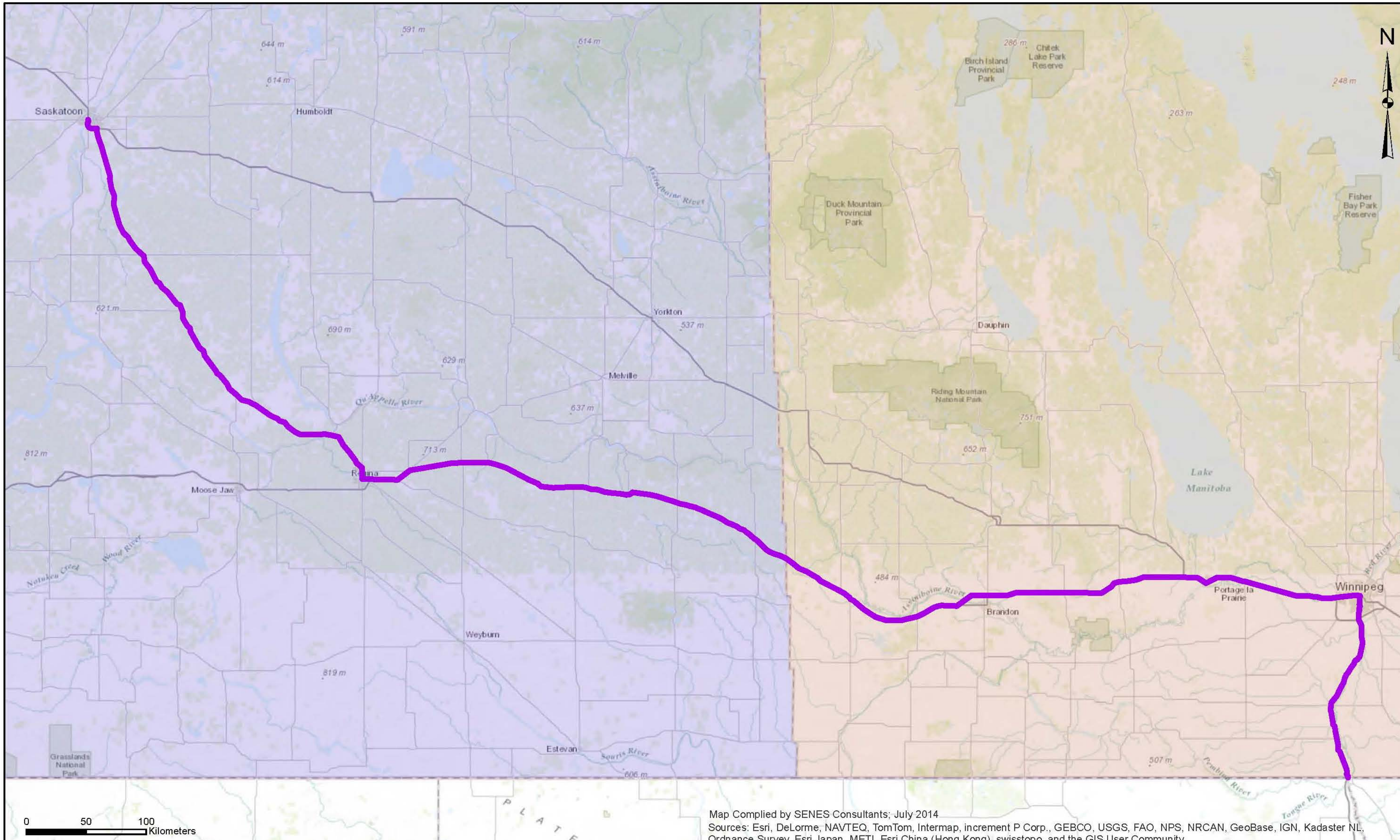
Route Rd-3 starts from Saskatoon and ends at the US border near Emerson, Manitoba, toward Honeywell's ConverDyn uranium refining and conversion facility in Metropolis, Illinois.

Figure 2.3 shows a map of route Rd-3. The total length of the route is 1,450 km. The route passes through a number of population centres including Saskatoon, Regina, Winnipeg, and approximately 50 towns and communities. The total length of the route exposed to the population centres is approximately 117 km. It crosses over 15 water bodies. These water bodies include small unnamed creeks to large rivers including the South Saskatchewan River and Assiniboine River. The total length of the route exposed to rivers, including a 100 m buffer zone, is approximately 1.9 km.

The route passes near a large number of water bodies. The total length of route passes within 30 m of water bodies is approximately 9 km. It also goes through Grand Valley Provincial Park with the exposed length of approximately 1 km.

The exposure features of the route Rd-3 are summarized in Appendix A.

Figure 2.3 Map of Route Rd-3



2.1.4 Route Rl-1

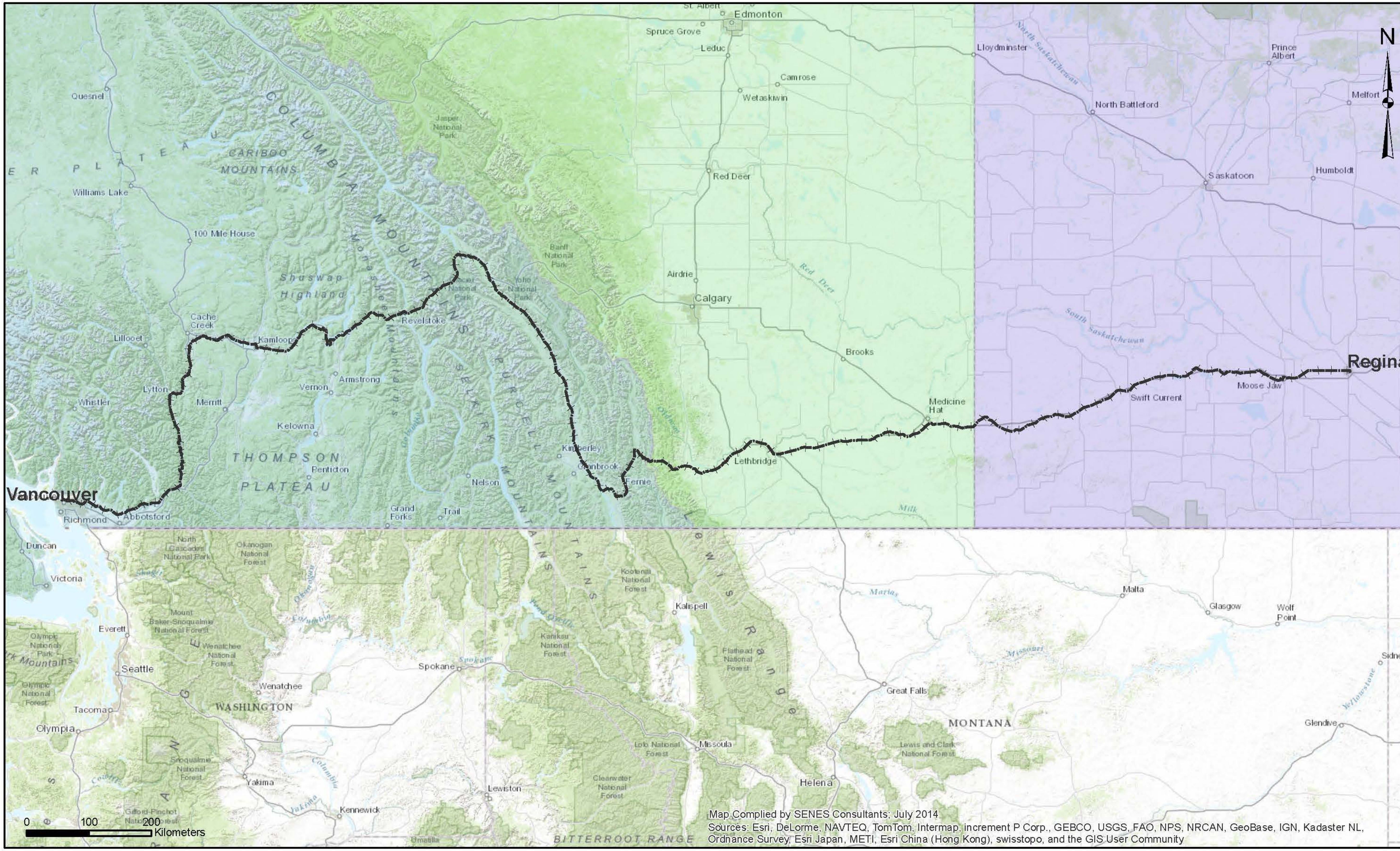
Route Rl-1starts from Regina Gateway Rail Terminal and ends at the Port of Vancouver.

Figure 2.4 shows a map of route Rl-1. The total length of the route is approximately 1,800 km. The route passes through many population centres including Regina, Moose Jaw, Lethbridge, Kamloops, Vancouver, and approximately 130 towns and communities. The total length of the route exposed to the population centres is approximately 211 km. It crosses over 80 water bodies. These water bodies include small unnamed creeks to large rivers including Cootenay River, Columbia River, Eagle River, and Fraser River. The total length of the route exposed to rivers, including a 200 m buffer zone, is approximately 20.5 km.

The route passes near a large number of water bodies. The total length of route passes within 30 m of water bodies is approximately 84 km. It also goes through more than 20 provincial and national parks and conservation areas with the total exposed length of approximately 85 km.

The exposure features of the route Rl-1 are summarized in Appendix A.

Figure 2.4 Map of Route Rl-1



2.1.5 Route Rl-2

Route Rl-2 starts from Regina Gateway Rail Terminal and ends at the Port of Montreal.

Figure 2.5 shows a low-resolution map of route Rl-2. The total length of the route is approximately 3,200 km. The route passes through many population centres including Regina, Winnipeg, Thunder Bay, Sault Ste. Marie, and, approximately 160 towns and communities. The total length of the route exposed to the population centres is approximately 322 km. It crosses over 130 water bodies. These water bodies include small unnamed creeks to large rivers including Assiniboine River, Red River, Eagle River, Spanish River, Sturgeon River, Ottawa River, Rideau River, and St. Lawrence River. The total length of the route exposed to rivers, including a 200 m buffer zone, is approximately 36 km.

The route passes near a large number of water bodies. The total length of route passes within 30 m of water bodies is approximately 87 km. It also goes through more than 20 provincial and national parks and conservation areas with the total exposed length of approximately 133 km.

The exposure features of the route Rl-2 are summarized in Appendix A.

Figure 2.5 Map of Route Rl-2

2.2 TRANSPORTATION PACKAGES AND QUANTITIES

UOC to be transported includes both calcined and uncalcined products. Both types will be transported in 208 L steel drums containing approximately 450 kg of uranium.

According to the IAEA regulations for the safe transport of radioactive material (IAEA 2005) and the Canadian Packaging and Transport of Nuclear Substances Regulations (2000), yellowcake is considered Low Specific Activity material (LSA-I) and is to be packaged in Industrial Package Type 1 (IP-1). The package shall be 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.

The UOC drum design has passed the free drop test from 1.2 meters, during which the drums sustained structural compression, but maintained their sealed integrity and did not allow any of the contents to be released. It has also passed the stacking test with a weight of 5 times the mass of the actual package for a period of 24 hours (Greif 2004). The packages are watertight as long as the lid is in place properly.

The internal dimensions of 20 foot ISO sea-containers, containing 35 drums of UOC are 590 cm (L) by 235 cm (W) by 239.3 cm (H) with the wall thickness of 0.65 cm (Bluefreight 2009). The overall transport capacity of ISO containers are 13,000 kg U.

The trailer vans transporting UOC to the Blind River Refinery has a capacity of 44 drums or 16,300kg U and those transporting UOC to ConverDyn has a capacity of 41 drums or 15,120 kg U.

The Transportation modes, means, and types of UOC for route segments are shown in Table 2.4.

Table 2.4 Transportation Characteristics

Segment	Type of UOC	Transport Mode	Means of transport
1	Calcined and uncalcined concentrate	Truck / trailer	Trailer Van
2	Calcined and uncalcined concentrate	Truck - B train	20' ISO Sea Container
3	Calcined and uncalcined concentrate	Truck - B train	20' ISO Sea Container
4	Calcined and uncalcined concentrate	Truck / trailer	Trailer Van
5	Calcined and uncalcined concentrate	Truck / trailer	Trailer Van
6	Calcined and uncalcined concentrate	Truck / trailer	Trailer Van
7	Calcined and uncalcined concentrate	Truck / trailer	Trailer Van
8	Calcined and uncalcined concentrate	Rail	20' ISO Sea Container
9	Calcined and uncalcined concentrate	Rail	20' ISO Sea Container

2.3 SELECTED SCENARIOS

The following scenarios for transportation accidents were defined for risk assessment:

1. Spill of UOC into major rivers, the following rivers were selected for this assessment:
    - Assiniboine River (Manitoba);
    - Columbia River (British Columbia);
    - Kaministiquia River (Ontario);
    - North Saskatchewan River (Saskatchewan);
    - Mississagi River (Ontario);
2. Spill of UOC into a generic small lake;
3. Spill of UOC into larger lakes, the following lakes were selected for this study:
    - Wollaston Lake (Saskatchewan)
    - Lac La Ronge (Saskatchewan);
    - Lake of the Woods (Ontario);
    - Vancouver Harbour (British Columbia);
    - Lake St. Louis (Quebec);
4. Spill of UOC on land from truck accident;
5. Spill of UOC on land from train accident;

6. Spill of UOC on land followed by airborne release (truck accidents);
7. Spill of UOC on land followed by airborne release (train accidents);
8. Spill of UOC on land followed by fire and airborne release (truck accidents);
9. Spill of UOC on land followed by fire and airborne release (train accidents).

While site clean-up is expected to occur; it is unlikely to recover 100% of the released material (e.g. residual UOC will be present in sediment subsequent to remedial activities). The risk assessment of the above scenarios were conducted for both calcined and un-calcined UOC.

3.0 PROBABILITY ASSESSMENT

As UOC is packaged in steel drums and loaded in sea-cans or transport trailers, in addition to a transportation accident, there are a number of subsequent events that must occur for a release of UOC to reach the environment. The probability and severity of damage to a container is a function of the severity of the accident, the form and amount of force applied to the container and the ability of the container to withstand these forces. The probability of a release can then be described symbolically as the product of conditional probabilities:

Probability of release = (Probability of accident) × (conditional probability of damage to the containment)

The probability of transportation accidents is derived using transportation accident statistics from various jurisdictions.

3.1 TRANSPORTATION ACCIDENT STATISTICS

3.1.1 Highway Transportation

Accident statistics reported for Canada, the U.S. and Saskatchewan were reviewed for selecting appropriate statistics to use in the current assessment.

3.1.1.1 Canada-wide Statistics

Transport Canada (TC) estimated that in 2012, dangerous goods were shipped or received at over 40,000 business sites across Canada. Data pertaining to the exact number of shipments or the actual weight (tonnage) of dangerous goods that were transported in 2012 are not available. TC estimates that (by weight), in 2012, 70% of dangerous goods were transported by road. This is followed by rail transport (24% by weight) and marine transport (6% by weight). Less than 1% (by weight) of dangerous goods was transported by air in 2012.[9]

Statistics related to the transport of (and associated accidents related to) dangerous goods by the predominant transportation modes (road, rail and marine) and a discussion on their applicability to this project are provided below.

Statistics Canada has made data available for all freight transportation on roads in terms of total vehicle kilometers (with and without dangerous goods) for the period 2000 through 2009. Only the period 2004 – 2009 is selected for analysis, since data for this period are the most relevant for

[9] Transportation in Canada 2012. Overview Report.

purposes of this analysis as this period includes only truck transport of dangerous goods. Data for dangerous goods transportation in buses and in vehicles up to 4.5 tonnes are not included in this period (data collection for these modes of transport was discontinued after 2003).

Data for truck transportation (with and without dangerous goods) for the period 2004 – 2009 are shown below.[10]

From Table 3.1, it can be concluded that on average, dangerous goods transportation (in terms of vehicle kilometres of truck movement) account for about 7.6% of all truck transportation in Canada.

Table 3.1 Truck Transportation of Dangerous Goods in Canada

Year	Truck transportation (Million vehicle kilometers)			
	With dangerous goods	Without dangerous goods	Total	% With dangerous goods
2004	2,071	25,555	27,626	7.5%
2005	1,880	25,679	27,558	6.8%
2006	2,124	26,930	29,054	7.3%
2007	2,813	29,028	31,841	8.8%
2008	2,248	28,741	30,989	7.3%
2009	2,333	27,139	29,473	7.9%
Average				**7.6%**

Data for freight movement (in terms of tonne-kilometres transported) on Canadian roads were collated from annual statistical addenda provided by Transport Canada and are summarized below in Table 3.2.

[10] Statistics Canada CANSIM Table 405-0077.

Table 3.2 Truck Transportation of Goods in Canada

Year	Tonne-Kilometres (millions)[a]	Vehicle-Kilometres (millions)[b]	Tonne-km / Vehicle-km
2004	232,375	27,626	8.41
2005	224,910	27,558	8.16
2006	225,105	29,054	7.75
2007	224,839	31,841	7.06
2008	223,802	30,989	7.22
2009	208,532	29,473	7.08 Average (2004 – 2009) = 7.61
2010	221,766		
2011	224,325		

Notes:
a – data from TC Statistical Addendum (2007 through 2012).
b – data for 2004 through 2009 from Statistics Canada CANSIM Table 405-0077.

While data in terms of million tonne-km for truck movement are available for the period 2004 – 2011, data in million vehicle-km for truck transport are available only for the period 2004 – 2009. From Table 3.2 above, we conclude that the ratio of million tonne-km to million vehicle-km for truck transport is more or less constant and varies between 7 and 8.4. The average value of 7.61 is utilized to extrapolate data for million vehicle-km for truck transport for 2010 and 2011 (reported in Table 3.2).

In the ten-year period between 2003 through 2012, there has been an overall drop in the total number of reportable road accidents involving dangerous goods. However, there is no clear pattern for the total number of reportable road accidents involving dangerous goods for the period 2009 – 2012.

Data for the total number of reportable road accidents involving dangerous goods are shown in Table 3.3 below.

Assuming that 7.6% of all goods transported in 2011 were dangerous (from Table 3.1), the road transportation of dangerous goods in 2011 would represent 7.6% x 224,325 million tonnes-km = 17,049 million tonnes-km. The reportable in-transit road accidents that occurred in 2011 (Table 3.3) were 89 out of a total of 91 accidents. The corresponding accident rate can be derived as 0.005 [= 89 / 17,049] accidents per million tonnes-kilometres travelled.

Table 3.3 Dangerous Goods Reportable Accidents in Canada – Road Transportation

Year	In transit	Handling, loading and unloading	Temporary storage	Total
2002	169	1	0	170
2003	100	1	0	101
2004	106	0	0	106
2005	127	2	0	129
2006	100	1	1	102
2007	109	14	3	126
2008	112	3	0	115
2009	74	3	1	78
2010	94	0	1	95
2011	89	1	1	91
2012	82	0	2	84

Statistics Canada also reported that, in 2011, there were six collisions and 5.4 overturns that affected the means of containment related to dangerous goods. The corresponding collision rate can be derived as 3.5×10^{-4} [= 6 / 17,049] collisions per million tonnes-kilometres travelled. Assuming that the 5.4 overturns in 2011 refer to roll-overs, the roll-over accident rate can be derived as 3.2×10^{-4} [= 5.4 / 17,049] roll-overs per million tonnes-kilometres travelled.

In addition, in 2011, of the 91 reportable dangerous goods accidents that occurred, 56 accidents involved a spill, 26 involved a leak, four involved a spill and fire, one involved a spill and leak and four involved spill, leak, fire and explosion.

Crude petroleum oil, gasoline and fuel oils comprise close to 77% of all dangerous goods transported by road in Canada. In terms of accidents, in 2012, 64% of dangerous goods accidents involved flammable liquids (Class 3), 18% involved corrosives (Class 8) and 9% involved gases (Class 2). Overall, the number of reportable accidents specifically involving radioactive materials (Class 7) is very low. Data from Statistics Canada indicates that in the 10-year period of 2003 – 2012 there were only 2 accidents involving radioactive materials (Class 7), one each in 2008 and 2010, out of a total of 1,315 reported accidents during the same period. None of these accidents resulted in breach of containment and release of radioactive materials.

3.1.1.2 Saskatchewan Statistics

Data on accidents specific to the province of Saskatchewan were obtained from the Saskatchewan Auto Fund division of the Saskatchewan Government Insurance (SGI) as well as from Statistics Canada. Data for million vehicle-km traveled by trucks[11] (only available through 2009) as well as accidents[12] are summarized in Table 3.4 for the province of Saskatchewan.

Table 3.4 Accident Statistics Involving Transportation of Goods - Saskatchewan

Year	Million Vehicle-Km of Transportation		Number of Accidents based on Impact			Total Accidents = C + D + E = F	Accident Rate	
	Trucks 4.5 tonnes to 14.9 tonnes = A	Trucks 15 tonnes and over = B	Property Damage Only = C	Personal Injury = D	Fatal = E		Accidents / Million Vehicle-km = F / (A + B)	Accidents / Million tonne-km = F / {(12 x A) + (25 x B)}
2000	319	985	1,070	313	37	1,420	1.09	0.05
2001	478	987	1,079	288	33	1,400	0.96	0.05
2002	161	1,005	948	286	21	1,255	1.08	0.05
2003	295	1,011	1,021	286	26	1,333	1.02	0.05
2004	372	1,134	1,041	285	21	1,347	0.89	0.04
2005	361	1,142	1,131	304	32	1,467	0.98	0.04
2006	469	1,293	1,193	302	30	1,525	0.87	0.04
2007	516	1,212	1,245	283	28	1,556	0.90	0.04
2008	494	1,156	1,260	272	19	1,551	0.94	0.04
2009	529	1,224	1,259	264	23	1,546	0.88	0.04
2010	No data	No data	1,206	263	31	1,500	NA	NA
2011	No data	No data	1,329	313	33	1,675	NA	NA
2012	No data	No data	1,249	324	34	1,607	NA	NA
Average (2000 – 2009)							**0.96**	**0.04**

An average accident rate (for the 10-year period of 2000 – 2009) of 0.96 accidents per million vehicle-km is estimated. Assuming a payload of 12 tonnes for smaller trucks and a payload of 25 tonnes for larger ones, this metric translates to an average accident rate for the same period of 0.04 accidents per million tonne-kilometres.

It is noted that, in the 8-year period (2005 – 2012) for which data have been made available by SGI for accidents related to collisions involving the transportation of dangerous goods, radioactive materials (Class 7) have been involved only on two occasions (one each in the years 2005 and 2007). No accidents have been reported in Saskatchewan involving the transportation

[11] Statistics Canada CANSIM Table 405-0058.
[12] Saskatchewan Traffic Accident Facts (Annual Reports made available by SGI).

of radioactive materials in the past five years (2008 – 2012). On average, for the period 2005 – 2012, there have been about 27 collisions involving the transportation of dangerous goods.

Data on the number of trucks that were fatally involved in a rollover for the period 2008 – 2012 are shown in Table 3.5.[13] It reveals that in a majority of cases (except for the year 2005), the driver was impaired and/or did not make use of a seatbelt.

Table 3.5 Rollovers and Rollover Rates in Saskatchewan (2005 – 2009)

Year	Number of rollovers	Impaired conditions	No Seatbelt	Rollovers / Million Vehicle-Km	Rollovers / Million Tonne-Km
2005	3	1	1	0.002	1×10^{-4}
2006	9	2	6	0.005	2×10^{-4}
2007	5	3	2	0.003	1×10^{-4}
2008	21	16	16	0.013	6×10^{-4}
2009	3	2	3	0.002	8×10^{-5}
Average (2005 – 2009)				**0.005**	$\mathbf{2 \times 10^{-4}}$

The 5-year average (2005 – 2009) for the rollover rates in Saskatchewan are: 0.005 rollovers / million vehicle-km and 2×10^{-4} rollovers / million tonne-km. It is noted that these rollovers include all types of trucks and not just trucks transporting dangerous goods.

For the same time period (2005 – 2009), data for head-on collisions involving trucks are presented in Table 3.6.

Table 3.6 Head-on Collisions and Head-on collision Rates in Saskatchewan (2005 – 2009)

Year	Number of head-on collisions	Impaired conditions	No Seatbelt	Head-on collisions / Million Vehicle-Km	Head-on collisions / Million Tonne-Km
2005	2	0	1	0.001	6×10^{-5}
2006	13	5	5	0.007	3×10^{-4}
2007	7	3	4	0.004	2×10^{-4}
2008	14	6	3	0.008	4×10^{-4}
2009	1	0	1	0.0005	2.7×10^{-5}
Average (2005 – 2009)				**0.004**	$\mathbf{2 \times 10^{-4}}$

[13] For all years, rollover data are provided only for those accidents that involved a fatality.

The 5-year average (2005 – 2009) for the rate of head-on collisions in Saskatchewan is 0.004 head-on collisions / million vehicle-km and 2 x 10^{-4} head-on collisions / million tonne-km. It is noted that these head-on collisions include all types of trucks and not just trucks transporting dangerous goods.

Accident rates at junctions (road intersections) tend to be more severe. During 2005 to 2009, about 54% of the collisions with personal injuries occurred at intersections. During the same period, 26% of the most severe accidents (fatal collisions) took place at intersections.

3.1.1.3 U.S. Statistics

The United States Department of Transportation (DOT) statistical data (DOT, 2007) for hazardous material transportation in 2007 showed that total hazardous materials shipment by trucks was 104 billion ton-miles or 151 billion tonne-km (Table 3.7). DOT statistics also indicated that in 2007 there were 322 hazardous material related highway accidents in the U.S. The rate of hazardous materials accidents were calculated as 322/151,000 = 0.002 accidents per million tonnes-km travelled (Table 3.8).

Table 3.7 U.S. Hazardous Materials Shipments by Transportation Mode, 2007

Transportation mode	Tons		Ton-miles	
	(millions)	Percent	(billions)	Percent
Truck	1,202.8	53.9	104.0	32.2
Rail	129.7	5.8	92.2	28.5
Water	149.8	6.7	37.1	11.5

U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, U.S. Department of Commerce, Census Bureau, 2007 Commodity Flow Survey, Hazardous Materials (Washington, DC: December 2009), table CF0700H01, available at http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=&-ds_name=CF0700H01&-_lang=en as of Mar. 9, 2010.

Table 3.8 Hazardous Materials Accidents Data

Transportation Mode	2003	2004	2005	2006	2007	2008	2009	2010
Air Accident-related	0	0	9	7	7	8	2	2
Highway Accident-related	300	281	323	308	322	302	251	321
Rail Accident-related	42	47	51	44	54	27	37	37
Water Accident-related	0	0	0	0	0	0	0	1

1975-85: U.S. Department of Transportation, Research and Special Programs Administration, Office of Hazardous Materials Safety, Hazardous Materials Information System Database, 1999.
1990-2010: Ibid., Pipeline and Hazardous Materials Safety Administration, Office of Hazardous Material Safety, available at http://www.phmsa.dot.gov/hazmat/library/data-stats/incidents as of Dec. 20, 2011.

DOT statistics also indicate that the frequencies of rollovers and truck crashes during transportation of hazardous materials were 6.7×10^{-4} and 8.1×10^{-4} accidents per million ton-miles, respectively (3.8×10^{-4} to 4.6×10^{-4} accidents per million tonne-km). The U.S. DOT reported that in 2007 less than 0.1% of the hazardous materials shipped were class 7 hazardous materials (Table 3.9).

Table 3.9 U.S. Hazardous Materials Shipments by Hazard Class, 2007

Hazard class	Description	Metric tonnes		Tonne kilometers	
		Millions	Percent	Billions	Percent
Class 1	Explosives	3	0.1	<1	<0.1
Class 2	Gases	206	11.2	118	17.1
Class 3	Flammable liquids	1,443	78.6	387	56.3
Class 4	Flammable solids	17	0.9	12	1.7
Class 5	Oxidizers and organic peroxides	12	0.7	15	2.2
Class 6	Toxic (poison)	9	0.5	12	1.8
Class 7	Radioactive materials	<1	<0.1	<1	<0.1
Class 8	Corrosive materials	94	5.1	95	13.8
Class 9	Miscellaneous dangerous goods	52	2.8	49	7.1
Total		**1,836**	**100.0**	**688**	**100.0**

Notes: 1 metric tonne = 1.1023 short tons; 1 tonne kilometer = 0.6849 ton miles. Numbers and percents

Source: U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics and U.S. Department of Commerce, Census Bureau, 2007 Commodity Flow Survey, Hazardous Materials (Washington, DC: February 2010), table 1a, available at www.bts.gov/publications/commodity_flow_survey/ as of August 22, 2011.

3.1.1.4 Site Data

Saskatchewan Ministry of Highways and Infrastructure and SGI show no recorded incidents for Hwy 905 portion of the haul route. Data provided by AREVA for the McClean Lake site indicates that for the period 1996 – 2013, a total of 19,936 truck trips were made into/out of the site. Out of these, only 1,117 trips involved the transportation of UOC (representing about 5.6% of all trips).

Data provided also indicates that in this time period (1996 – 2013), there were only 21 truck incidents in total, of which only two were roll-overs. Both rollovers occurred on Hwy 905: one involved a loaded truck (in 2002) and the other was an empty truck (in 2005). There were no fatalities during any of the incidents.

3.1.1.5 Comparison of Selected Statistics

A comparison of statistics provided above is shown in Table 3.10. The U.S. DOT data have been developed specifically from a large database on the transport of hazardous materials. In addition, there is a differentiation between the types of the accidents, which allows for a more detailed assessment. The Canadian and Saskatchewan data are less specific. For example, data for rollover and head-on collisions indicated are for all trucks (and not specifically involving dangerous goods' transportation), thereby providing liberal estimates (and adequate cushioning effects for comparison). The accident rate for rollover and crash are very similar for all selected statistics. For this study, Canada-wide statistics will be selected.

Table 3.10 Selected Accident Statistics involving Dangerous Goods (accidents per million tonne-kilometres)

Jurisdiction	All Accidents	Roll-over	Head-on Collision
Canada	0.005	3.16×10^{-4}	3.55×10^{-4}
USA	0.0021	4.6×10^{-4}	5.6×10^{-4}
Saskatchewan	0.0045	2×10^{-4}	2×10^{-4}

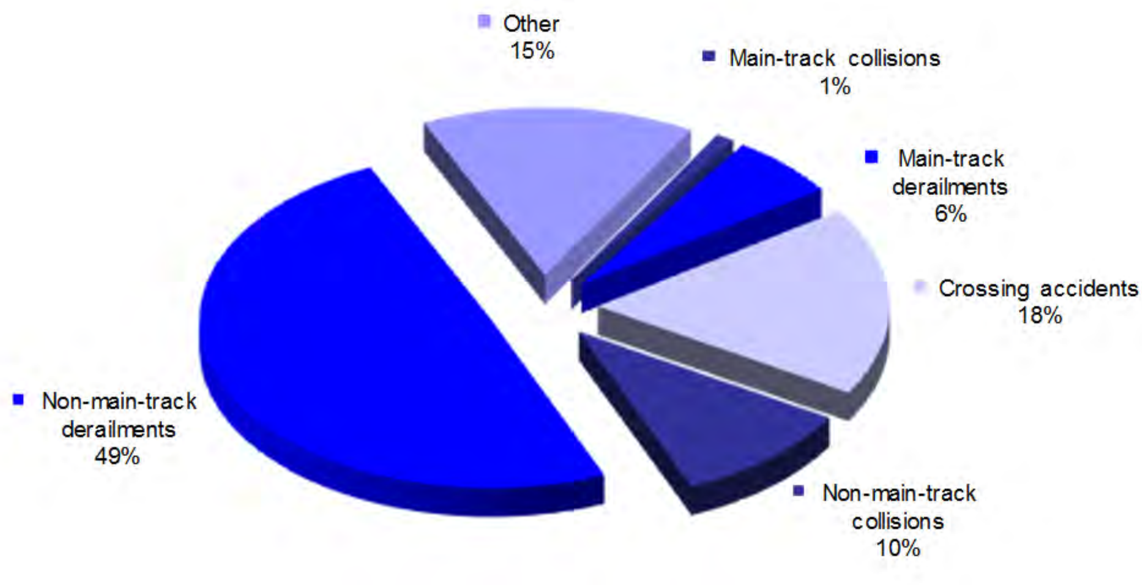
3.1.2 Rail Transport

3.1.2.1 Canada-wide Statistics

Data from Transport Canada have been utilized to study accident rates involving dangerous goods transported by rail in Canada. It is noted that out of all dangerous goods-related rail accidents, only a fraction involves reportable accidents and only a sub-set of reportable accidents involves 'In-Transit' accidents.

Railway association of Canada reported that in 2006, there were total of 1170 rail transportation incidents in Canada. Transport Canada also reported that approximately 655 billion tonne-km of goods were transported for the same year. Figure 3.1 shows that only 7 percent of rail accidents were main-track accidents. These accidents can produce enough impact to breach the hazardous materials containments.

Figure 3.1 Percentage of Rail Accidents by Type, Source: Transportation Safety Board of Canada (2012)



The rail accident rates in Canada can be calculated as: 1,170*0.07/ 655,000 = 0.00013 accidents per million tonne-km travelled.

Data for the 10-year period of 2003 – 2012 for the total number of reportable rail accidents involving dangerous goods are shown in Table 3.11 below by the different phases of transport.

The 5-year (2008 - 2012) average accident rates involving dangerous goods transported via rail are estimated as 1.0 dangerous goods accident per million train km (for all accidents) and 0.031 reportable in-transit dangerous goods accidents per million train km (or 31 reportable in-transit dangerous goods accidents per billion train km). It is noted that for 2012, there were less than 15 reportable in-transit dangerous goods accidents per billion train km.

Table 3.11 Dangerous Goods Reportable Accidents by Phases of Transport – Rail Transportation

Year	In transit	Handling, loading and unloading	Temporary storage	Railyard operations	Total
2003	5	0	0	0	5
2004	9	0	0	0	9
2005	8	0	0	0	8
2006	4	0	0	0	4
2007	6	1	1	1	9
2008	5	0	0	1	6
2009	5	0	0	0	5
2010	5	0	0	0	5
2011	3	0	0	0	3
2012	2	0	0	0	2

Relevant data for the period 2008 – 2012 and are shown in Table 3.12.

Table 3.12 Dangerous Goods Reportable Accidents by Phases of Transport – Rail Transportation

Year	Total Accidents	Million Train-Km (MTK)	Total Accidents per MTK	Dangerous Goods Involved in Accidents		DG Accidents per MTK	
				All Accidents	Reportable In Transit DG Accidents	All Accidents	Reportable In Transit DG Accidents
2008	1,179	145.4	8.1	151	6	1.0	0.04
2009	1,043	125.4	8.3	132	5	1.1	0.04
2010	1,076	134.6	8.0	141	5	1.0	0.04
2011	1,021	136.3	7.5	116	3	0.9	0.02
2012	1,012	137.8	7.3	119	2	0.9	0.01
5-year average (2008 - 2012)				**131.8**	**4.2**	**1.0**	**0.031**

Reportable dangerous goods accidents classified based on the dangerous goods class for rail transportation for the 10-year period of 2003 – 2012 are tabulated below, during which there have been no reportable DG accidents involving radioactive materials (Class 7).

Table 3.13 Reportable Accidents by DG Class – Rail Transportation

Year	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Total
2003	0	17	15	0	0	0	0	3	0	35
2004	0	13	10	0	5	2	0	3	1	34
2005	0	6	2	0	0	0	0	4	0	12
2006	0	3	5	0	0	0	0	6	0	14
2007	0	1	3	0	2	0	0	7	1	14
2008	0	2	1	0	1	0	0	2	0	6
2009	0	18	8	0	0	0	0	0	0	26
2010	0	7	0	0	3	2	0	2	0	14
2011	0	1	4	0	1	0	0	3	0	9
2012	0	0	2	0	0	0	0	0	0	2
Total	**0**	**68**	**50**	**0**	**12**	**4**	**0**	**30**	**2**	**166**

3.1.2.2 U.S. Statistics

The United States Department of Transportation (DOT) statistical data (DOT, 2007) for hazardous material transportation in 2007 showed that total hazardous materials shipment by train was 92 billion ton-miles or 134 billion tonne-km (Table 3.7). DOT statistics also indicated that in 2007 there were 54 hazardous material related rail accidents (main-track) in the U.S. The rate of hazardous materials accidents were calculated as 54/134,000 = 0.0004 accidents per million tonnes-km travelled (Table 3.8).

3.1.2.3 Comparison of Selected Statistics

For this study, Canada-wide statistics will be selected. The rail accident rates calculated for U.S. is three times larger than that of Canada. The difference can attributed to the difference in reporting criteria for rail accidents involving dangerous goods. Since Canada-wide accident rates are more specific for the type of accidents, this rate was selected for this study.

3.2 ACCIDENT FREQUENCY CALCULATION

Based on the transportation route length and their various exposure characteristics provided in Section 2.1, and the transportation accident rates estimated in Section 3.1, the frequency of accidents for various transportation routes were calculated as follows.

Route Rd-1

The frequency of rollover and crash along the route:
3,260 * ($3.16 \times 10^{-4} + 3.55 \times 10^{-4}$) = 2.19 accidents per million tonnes

The frequency of rollover and crash near water bodies:
41.7 * ($3.16 \times 10^{-4} + 3.55 \times 10^{-4}$) = 0.028 accidents per million tonnes

The frequency of rollover and crash within population centres:
204.5 * 3($3.16 \times 10^{-4} + 3.55 \times 10^{-4}$) = 0.137 accidents per million tonnes

Route Rd-2

The frequency of rollover and crash along the route:
1,400 * ($3.16 \times 10^{-4} + 3.55 \times 10^{-4}$) = 0.94 accidents per million tonnes

The frequency of rollover and crash near water bodies:
16.9 * ($3.16 \times 10^{-4} + 3.55 \times 10^{-4}$) = 0.011 accidents per million tonnes

The frequency of rollover and crash within population centres:
44.1 * ($3.16 \times 10^{-4} + 3.55 \times 10^{-4}$) = 0.030 accidents per million tonnes

Route Rd-3

The frequency of rollover and crash along the route:
1,450 * ($3.16 \times 10^{-4} + 3.55 \times 10^{-4}$) = 0.97 accidents per million tonnes

The frequency of rollover and crash near water bodies:
11.1 * ($3.16 \times 10^{-4} + 3.55 \times 10^{-4}$) = 0.0074 accidents per million tonnes

The frequency of rollover and crash within population centres:
116.7 * ($3.16 \times 10^{-4} + 3.55 \times 10^{-4}$) = 0.078 accidents per million tonnes

Route Rl-1

The frequency of main-track rail accident along the route:
1,800 * 1.3×10^{-4} = 0.234 accidents per million tonnes

The frequency of main-track rail accident near water bodies:
104.8 * 1.3×10^{-4} = 0.0136 accidents per million tonnes

The frequency of main-track rail accident within population centres:
211.4 * 1.3 x 10^{-4} = 0.0275 accidents per million tonnes

Route Rl-2

The frequency of main-track rail accident along the route:
3,200 * 1.3 x 10^{-4} = 0.416 accidents per million tonnes

The frequency of main-track rail accident near water bodies:
123.1 * 1.3 x 10^{-4} = 0.016 accidents per million tonnes

The frequency of main-track rail accident within population centres:
123.1 * 1.3 x 10^{-4} = 0.0042 accidents per million tonnes

Using the amount of uranium shipped for each route the frequencies for all accidents along the routes were calculated and summarised in Table 3.14. It was assumed that each rollover, truck crash, and major rail accident result in containment breach.

Table 3.14 Summary of Accident Frequencies

Route	Destination	Tonnes U per Year	Frequency of Accident per Million Tonnes, Near Water	Frequency of Accidents Per Year, Near Water	Frequency of Accident per Million Tonnes, Near Population Centre	Frequency of Accidents Per Year, Near Population Centre
Rd-1	Blind River, Ontario	554	0.028	1.55E-05	0.137	7.59E-05
Rd-2	Metropolis, Illinois	1,436	0.011	1.58E-05	0.03	4.31E-05
Rd-3	Metropolis, Illinois	1,436	0.0074	1.06E-05	0.078	1.12E-04
Rl-1	East rail (France, Argentina)	7,318	0.0136	9.95E-05	0.0275	2.01E-04
Rl-2	West rail (China)	1,868	0.016	2.99E-05	0.0042	7.85E-06

The results of the probability assessment showed that:

- The probability of accidents involving transportation of dangerous goods is smaller than the probability of general transportation accidents.
- The accident rate for trains is slightly less than the accident rates for truck on per million tonne mile basis.

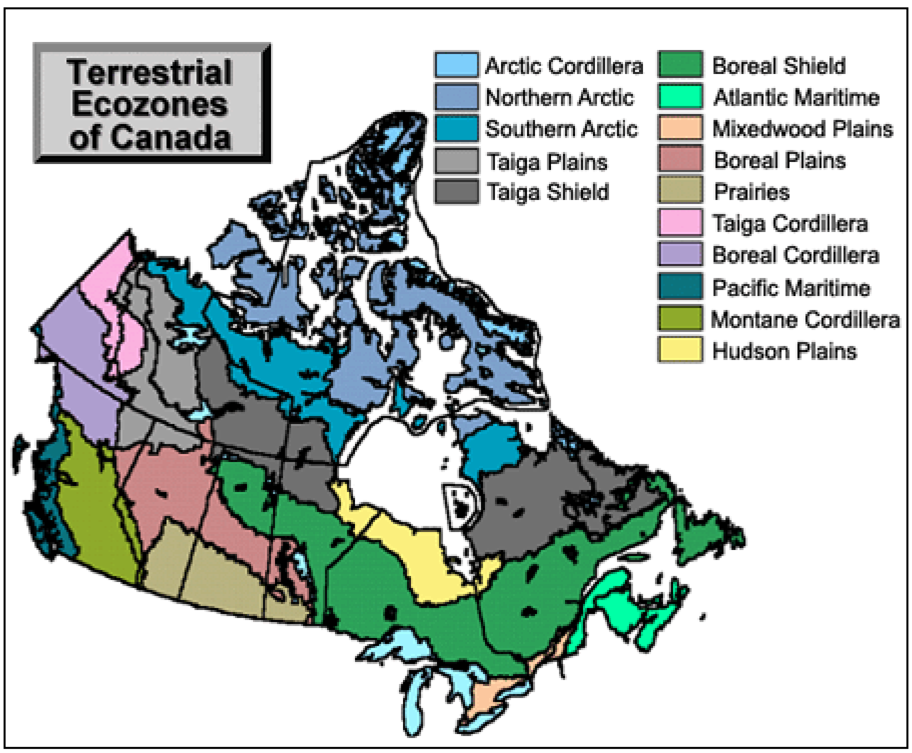
- The probability of release of UOC to surface water ranged from 1×10^{-5} to 1.5×10^{-5} during one year for the identified truck transportation routes
- The probability of release of UOC to surface water ranged from 3×10^{-5} to 1×10^{-5} during one year for the identified train transportation routes. Greater probability of train accidents compared with truck accidents is attributed to the longer train routs and greater exposure to surface water.
- The probability of release of UOC to land at the vicinity of population centres ranged from 4×10^{-5} to 1×10^{-4} during one year for the identified truck transportation routes
- The probability of release of UOC to land at the vicinity of population centres ranged from 8×10^{-6} to 2×10^{-4} during one year for the identified train transportation routes
- Overall the probability of release of UOC to the environment was calculated to be very unlikely.

4.0 RECEPTORS AND TOXICITY REFERENCE VALUES

4.1 STUDY AREA

The study area extends from northern Saskatchewan to the U.S.A. border in the south and from the west coast of British Columbia to as far east as Montreal in southern Quebec. Given the vastness of the study area, it transcends several political domains within Canada as well as terrestrial ecozones, or areas with similar land features, vegetation and animal life. With respect to political domains the study area roughly includes Ontario and Quebec, the length of Alberta and Saskatchewan, southern portion of Manitoba and central and southern portions of British Columbia, including the west coast (see Figure 1). With respect to ecozones, the study area roughly includes portions of the Mixedwood Plains in the vicinity of Lake Ontario in southern Ontario and Montreal in southern Quebec, the Boreal Shield running throughout southern Ontario and northwest from there into Manitoba and Saskatchewan, the Boreal Plains and Prairies in the Prairie provinces, the Pacific Maritime and Montane Cordillera in British Columbia, and the Taiga Plains, Taiga Shield and Southern Arctic in the northern territories (see Figure 4.1). Ecozones relevant to the study area are described below based on information provided on the Ecological Framework of Canada website (available at ecozones.ca).

Figure 4.1 Terrestrial Ecozones of Canada



Source: Ecological Framework of Canada website at ecozones.ca.

Mixedwood Plains: The small area of the Mixedwood Plains ecozone is bounded by three Great Lakes in southern Ontario and extends along the St. Lawrence shoreline to Quebec City. Despite being the smallest Canadian terrestrial ecozone, it contains over half of the nations endangered and threatened species including the American ginseng (threatened), Henslow's sparrow (endangered), eastern massasauga rattlesnake (threatened), and spiny softshell turtle (threatened). Vast tracks of forest once blanketed most of the Mixedwood Plains but very little of the original forest remains today due to the effects of agriculture, logging and urbanization. Presently, the ecozone's forests consist of 12.8% mixedwood, 2.1% deciduous, and 0.2% coniferous trees. Vibrant wildflowers and shrubs such as trilliums, clover, black-eyed Susans, goldenrod, and wild raspberry decorate the forests; successional species such as staghorn sumac, highbrush cranberry, red-osier dogwood and willow are found in thickets and abandoned fields; and, aquatic plants such as cattail, water lilies, sedges, and purple loosestrife are found in the few remaining wetland areas. Forests and grasslands support a wide variety of terrestrial organisms in the Mixedwood Plains including characteristic mammals such as white-tailed deer, black bear, eastern cottontail, and grey and black squirrels. Foxes and wolves make appearances outside urban settings, while coastal wetlands and tributaries provide crucial habitat for beaver and muskrat. The St. Lawrence River and its marine habitats support a diverse collection of aquatic species, including Atlantic tomcod, northern pike, baleen whales and the endangered beluga whale.

Boreal Shield: The Boreal Shield represents the areas where the Canadian Shield and the boreal forest overlap. The Boreal Shield encompasses approximately 10% of Canada's freshwater and hosts countless small and large lakes as well as the headwaters of some of Canada's largest rivers (e.g., Nelson, Churchill, Rupert and St. Lawrence Rivers). While cool temperatures, a short growing season, frequent forest fires, and acidic soils challenge plant life in the ecozone, approximately 88% of the area is forested by a few adaptable trees such as black and white spruce, jack pine and balsam fir. Broadleaf trees such as paper birch, trembling aspen and poplar occur further south and species characteristic of more temperate climates such as yellow birch, sugar maple, black ash, and eastern white cedar commonly occur in the southeastern parts of the ecozone. Throughout the Boreal Shield, these forests are mixed with innumerable bogs, marshes and other wetlands. Characteristic mammals of the Boreal Shield include white-tailed deer, moose, woodland caribou, wolf, black bear, lynx, snowshoe hare, fisher, martin and striped skunk. The numerous wetlands, ponds, lakes and rivers also provide habitat for beaver, mink and muskrat as well as migratory ducks and geese in the spring. Among the most common waterfowl that summer here are the bufflehead, American black duck, wood duck, ring-necked duck and Canada goose. Also found are the boreal owl, great horned owl, evening grosbeak, and blue jay while the white throated-sparrow is the most common songbird associated with this ecozone.

Boreal Plains: The Boreal Plains 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, balsam fir, jack pine as well as tamarack in some peatlands. Aspen and poplar 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, black bear, moose, woodland caribou, mule deer, elk and beaver. Typical bird species include gray jay, common loon, white-tailed sparrow, American redstart, Canada warbler, and ovenbird. Game birds found in the region include species of grouse, geese, ducks and ptarmigan. Common fish in lakes and streams include walleye, lake whitefish, northern pike, burbot, perch, and scattered populations of trout.

Prairies: As with the Boreal Plains, the Prairies also forms part of the Interior Plains of Canada and is characterized by subdued relief consisting of low-lying valleys and plains sloping eastward. The Prairies is dominated by farmland which covers nearly 94% of the land base. Due to the effects of agriculture practices, little of the natural vegetation remains within the Prairies making it home to high numbers of threatened and endangered wildlife species. The natural vegetation is generally dominated by spear grass, wheat grass, and blue grama grass while sagebrush is also abundant. Intermittent sloughs and ponds on the plains offer major breeding, staging, and nesting grounds for migratory waterfowl (e.g., lesser scaup, Canada goose) using the Central North American flyway. The Prairies ecozone offers unique habitat for black-tailed prairie dog, while its southern region is home to the short-horned lizard and western rattlesnake. Manitoba provides habitat for black bear, moose, sharp-tailed grouse, beaver, and red fox. Also present are various species of frog and toad while local fish include walleye, lake whitefish, and northern pike. Considering its area and population, the Prairies ecozone has a disproportionate number of threatened and endangered wildlife species including the peregrine falcon, mountain plover, piping plover, burrowing owl, and whooping crane.

Montane Cordillera: Exhibiting some of the driest, wettest, coldest, and hottest conditions anywhere in the country, the Montane Cordillera is the most diverse terrestrial ecozone in Canada. Much of the region is rugged and mountainous and the vegetative cover varies widely with alpine environments containing various herbs, lichen and shrubs, and subalpine regions being dominated by tree species. Three forest groups emerge with decreasing elevation including a marginal band at upper elevations characterized by Engelmann spruce, alpine fir and lodgepole pine; a second zone characterized by ponderosa pine, interior douglas fir, lodgepole pine and trembling aspen in much of the southwest and central portions; and, another featuring western hemlock, western red cedar, interior douglas fir, and western white pine in the southeast. Grasslands featuring bunchgrasses and other grasses and shrubs appear in the valley bottoms and on plateaus in south-central British Columbia and in smaller areas in the Kootenays of southeastern British Columbia. Ungulates such as mountain goat, moose, caribou and mule deer are common throughout the middle and upper elevations while rocky mountain elk, bighorn sheep, white-tailed deer and stone sheep are found less frequently. Grizzly bear and black bear are the most common large mammals. The conifer forests are also important habitat for fur-bearers such as marten, fisher, red squirrel and wolverine and a diverse collection of birds that feed on conifer seeds, bark insects and small mammals. Common birds include pileated woodpecker, northern flicker, Clark's nutcracker and red cross-bill while the mountain plover, sage thrasher, and burrowing owl are endangered species. Several other bird species are also classified under SARA including the peregrine falcon which is of special concern.

Pacific Maritime: The Pacific Maritime ecozone includes the Coast Mountains, British Columbia's marine islands, plus a small corner of southwestern Yukon. The forest ecosystems found here vary with elevation and precipitation with western hemlock forests dominating in low-lying coastal areas; subalpine mountain hemlock forests commonly found in higher elevations; and, small areas of dry douglas fir forests occurring on the leeward side of the mountains. Characteristic land mammals of this area include the black-tailed deer, black and grizzly bears, mountain lion (or cougar), fisher, and American pika. Bird species unique to this area include the American black oyster catcher, tufted puffin, chestnut-backed chickadee and, in southern regions only, the California and mountain quail. Other representative birds are the northern saw-whet owl, northern pygmy owl, Steller's jay, bald eagle and blue grouse. The area's many islands, estuaries and fiords provide critical habitat for countless migrating shorebirds and waterfowl, including the trumpeter swan and sandhill crane. Typical marine mammals include the northern sea lion, northern fur seal, harbour seal, and a host of whales such as the giant beaked whale, sperm whale, grey whale, killer whale, Pacific pilot whale and blue whale. The endangered sea otter has been reintroduced to the northwest coast of Vancouver Island. Several species of salmon and their spawning streams are located throughout the ecozone. Pacific herring and Pacific halibut are also found here. Common freshwater species include the cutthroat trout, dolly varden, and steelhead.

4.2 SELECTED RECEPTORS

Different scenarios will be defined based on whether an accident occurs near a waterbody, sensitive terrestrial environments or in population centres. These different scenarios require the characterization of a variety of receptors.

Receptors of interest are chosen based on the following considerations: their presence in the impacted areas; their ecological and cultural significance to the area; and, whether they are likely to be impacted by a spill event. The selected aquatic and terrestrial receptors and their habitats are discussed below.

Terrestrial plants and soil invertebrates are not identified as receptors. These classes of biota could be affected by a spill to land but would be localized to the direct area of the spill. These impacts could be removed and these classes of receptors are quickly reproducing and would be expected to re-establish. Overall, it is not expected that an accident would lead to population-level effects on these receptors.

4.2.1 Ecological Receptors

4.2.1.1 Aquatic Environment

The following aquatic species typically occurring in most freshwater lake ecosystems will be considered in the impact assessment:

- Aquatic Plants
- Benthic Invertebrates
- Forage Fish
- Predatory Fish
- Amphibians

Aquatic Plants: Aquatic plants in most lake ecosystems (e.g., pondweed) constitute the majority of the primary producer biomass. Aquatic plants are consumed by several species of aquatic based animals thereby forming a link between aquatic and terrestrial ecosystems. Besides being an important food resource, aquatic plants provide habitat to aquatic organisms.

Benthic Invertebrates: Due to the association of benthic invertebrates with sediments in aquatic ecosystems, they are at greatest risk in terms of sediment contamination. Benthic invertebrates both live and feed within sediments and therefore may be exposed to constituents through ingestion of sediment bound constituents and also through exposure to interstitial waters within the sediment. In addition, benthic invertebrates may also reside in the water column where exposure to constituents may also occur.

Benthic invertebrates provide a link between aquatic and terrestrial ecosystems. Many species feed on decaying organic matter and thereby form an important link between the decomposer level and primary consumers. Furthermore, midge larvae are a main food source for small/juvenile fish and larger omnivorous fish. The adults are capable of flight and are frequently consumed by birds and bats. This life stage provides an important link between aquatic and terrestrial ecosystems in the region.

Fish: Ecological receptors at the secondary consumer level include forage fish (e.g., lake whitefish or white sucker), which feed primarily on benthic invertebrates and are an important food source of larger predatory fishes. Tertiary consumers are found at the top end of the aquatic food chain and consist of larger piscivorous (predatory) fish species such as northern pike. These predatory fish consume other fish species. Predatory fish are also an important component of the human food chain.

Amphibians: Amphibians include frogs and toads, newts and salamanders, and caecilians which superficially resemble large earthworms. Amphibians play an important role in ecosystems as both predator and prey. Adult amphibians typically feed on small, slow moving prey such as beetles, caterpillars, earthworms and spiders.

4.2.1.2 Terrestrial Species

As was noted previously, there is the potential for accidents to the aquatic environment and terrestrial environment. If there is a spill to water, terrestrial receptors that are semi-aquatic could be affected. Accidents on land, particularly in more remote areas where there may be a delay in responding to a spill, could pose a risk through soil exposure. Therefore, two different types of terrestrial species are identified. Furthermore, due to the range of ecozones, a range of receptors have been identified as shown in Table 4.1.

Given the vast geographical extent of the study area, it is expected that several species that have been classified under the federal Species at Risk Act (SARA) or the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) will likely occur within the study area. While it is not possible to include all potential species at risk in the assessment, the peregrine falcon and the barren-ground caribou, which are both classified as "Special Concern" under SARA and COSEWIC, will be assessed. Furthermore, a number of receptors with similar dietary components that would encompass the characteristics of many species at risk have also been selected as receptors in the evaluation.

Table 4.1 Wildlife Receptors Selected for Assessment

Species	Description	Mixedwood Plains	Boreal Shield	Boreal Plains	Prairies	Montane Cordillera	Pacific Maritime
Semi-Aquatic							
Sandpiper (spotted, semi-palmated)	Avian – shorebird that primarily consumes aquatic invertebrates	✓	✓	✓	✓	✓	✓
Scaup (lesser)	Avian – duck that consumes primarily benthic invertebrates	✓	✓	✓	✓	✓	✓
Merganser (common, red-breasted)	Avian – duck that consumes primarily fish	✓	✓	✓	✓	✓	✓
Mallard	Avian – dabbling duck, consumes aquatic vegetation and benthic invertebrates	✓	✓	✓	✓	✓	✓
Peregrine falcon	Avian – raptor that consumes fish						✓
Muskrat	Mammal – consumes primarily aquatic vegetation	✓	✓	✓	✓	✓	✓
Terrestrial							
Willow Ptarmigan	Avian – consumes primarily vegetation					✓	✓
Ruffed Grouse	Avian – consumes primarily vegetation	✓	✓	✓	✓	✓	✓
Deer (mule, white-tailed)	Mammal – medium size, consumes terrestrial vegetation	✓	✓	✓	✓	✓	✓
Meadow vole	Mammal - small, consumes terrestrial vegetation	✓	✓	✓	✓	✓	✓
Squirrel (Arctic ground squirrel, eastern grey squirrel)	Mammal - small, consumes terrestrial vegetation	✓	✓	✓	✓	✓	✓
Woodland caribou	Mammal – large, consumes terrestrial vegetation (lichen)		✓	✓			
Barren-ground caribou	Mammal – large, consumes terrestrial vegetation (lichen)		✓	✓			

4.2.1.2.1 Semi-Aquatic Wildlife

For spills that may occur in the aquatic environment, receptors that are common to ecozones throughout the study area have been selected to represent semi-aquatic wildlife that would use and reside on the waterbody, including both mammalian and avian receptors.

The following semi-aquatic terrestrial species that obtain their food and water primarily from the aquatic environment will be considered in the assessment: sandpiper, lesser scaup, merganser, mallard, peregrine falcon, and muskrat.

Sandpiper (spotted and semi-palmated): Sandpipers are small shorebirds that feed on small invertebrates. The semi-palmated sandpiper migrates through most of the study area to the Arctic where it breeds in the summer time while the spotted sandpiper breeds throughout the remainder of the study area.

Lesser Scaup, Merganser, and Mallard: Waterfowl (e.g., ducks, geese, swans) are connected to the aquatic environment, since their diet is almost entirely obtained from the aquatic environment. The following species were selected to take into account differences in the diets; merganser (consumes mainly fish), lesser scaup (consumes mainly benthic invertebrates), and mallard (consumes aquatic plants and benthic invertebrates). Furthermore, the different species may occur within different regions of the study area. For example the lesser scaup breeds throughout the study area west of Ontario; and, the merganser and mallard breed throughout the study area including the Boreal Shield in the eastern portion of the study area.

Peregrine Falcon: The peregrine falcon is crow-sized and hunts medium-sized birds and small mammals and is a species of “Special Concern” under SARA and COSEWIC. Within the study area the peregrine falcon breeds in the far north and along the Pacific coast and southern portion of British Columbia.

Muskrat: Muskrat are small animals that rely entirely on the aquatic environment for their diet and thus serve as a good indicator of potential impacts on the aquatic ecosystem.

4.2.1.2.2 Terrestrial Wildlife

Willow Ptarmigan: The willow ptarmigan are found throughout the north and most of British Columbia. These birds are herbivores and most commonly occur in areas within the open tundra that are heavily vegetated with grasses, moss, herbs, and shrubs.

Ruffed Grouse: Ruffed grouse are small terrestrial birds that typically occupy mixed deciduous and coniferous forests but also live along forested streams and in areas growing back from burning or logging. They feed almost exclusively on vegetation including leaves, buds, and fruits of ferns, shrubs or woody plants. The ruffed grouse occurs in all of the provinces included within the study area.

Deer (mule and white-tailed): The deer is an herbivore whose diet changes depending on the habitat and the season. The white-tailed deer eats green plants in the spring and summer, corn, acorns and other nuts in the fall, and buds, and twigs of woody plants in the winter. The mule deer eats relatively little grass, browsing primarily on woody vegetation, but also consumes various berries (including blackberry, blueberry, salal and thimbleberry) in the summer. Within the study area the white-tailed deer occurs throughout the Boreal Shield of southern Ontario, and the Boreal Plains and Prairies of the Prairie provinces. The mule deer occurs throughout the western portion of the study area, within the Boreal Plains and Prairies of Alberta and Saskatchewan and the Montane Cordillera and Pacific Maritime of British Columbia.

Meadow Vole: The meadow vole or meadow mouse is primarily terrestrial and remains active all year round dwelling both above and below the ground. Preferred habitats include moist fields of grass and sedge that provide thick protective cover. Their diet comprises grasses (including the seeds), sedges, other herbaceous plants, and tender tree bark. Roots, tubers, and other plant parts are cached in a burrow to eat during the winter. The meadow vole has a large geographic distribution in North America and occurs throughout the study area.

Arctic Ground Squirrel: Arctic ground squirrel is a small mammal that lives in alpine and arctic tundra and in Canada is found in northern British Columbia, the Yukon and the Northwest Territories. These squirrels typically consume browse and herbaceous vegetation and play a significant role in food chain effects since they are part of the diet of larger predatory species. As herbivores, they are mainly exposed to contaminants via atmospheric deposition on terrestrial vegetation.

Eastern Grey Squirrel: The eastern grey squirrel (*Sciurus carolinensis*) is a small mammal that is commonly found in the eastern regions of Canada. Introduction of this species to other areas has occurred and the eastern grey squirrel is now the most common squirrel in urban British Columbia. The eastern ground squirrel is a medium-sized tree squirrel (approximately 500 g). These squirrels typically feed mostly on nuts, flowers and buds of a variety of tree species.

Barren-ground Caribou: Barren-ground caribou is one of the most important wildlife species in the north, both biologically and culturally, and has traditionally been the primary food source for First Nations groups. Caribou are herbivores and are thus mainly exposed to contaminants via atmospheric deposition on terrestrial vegetation. Herbivores convert vegetable matter to animal protein, and in turn are consumed by omnivores and carnivores. The barren-ground caribou is classified as a species of "Special Concern" under SARA and COSEWIC.

Woodland Caribou: Woodland caribou are an important northern animal. Canadian populations of woodland caribou are listed under Canada's Species at Risk Act (SARA) as Threatened (Southern Mountain and Boreal). Caribou are herbivores and are thus mainly exposed to contaminants via atmospheric deposition on terrestrial vegetation. Caribou consume ground lichen as well as tree growing (arboreal) lichens and as a result they are most often associated with mature coniferous forests that provide substantial quantities of tree lichens.

4.2.1.2.3 Summary of Receptor Characteristics

Characteristics of terrestrial receptors (including semi-aquatic receptors) that will be used in the pathways analysis are provided in Table 4.2.

The exposure to semi-aquatic species (i.e., sandpiper, lesser scaup, merganser, mallard, peregrine falcon and muskrat) will be considered to be long-term due to the on-going consumption of contaminated sediments. Exposure to the remaining terrestrial species (i.e., willow ptarmigan, ruffed grouse, deer, meadow vole, squirrel and caribou) will be considered to be short-term (10 days) and it will be assumed that during this time only contaminated water and soil will be consumed.

Table 4.2 Terrestrial Ecological Receptor Characteristics

Receptor	Body weight (kg)	Food consumption* (kg dw/d)	Food consumption* (kg ww/d)	Water (L/d)	Intake (g/d)		Fraction of Food			
					Sediment	Soil	Aquatic plants	Benthic invertebrates	Fish	Other**
Semi-aquatic										
Sandpiper	0.037[a]	0.007[a]	0.033	0.01[a]	1.2[i]	-	0.05[b]	0.90[b]	-	0.05[b]
Lesser Scaup	0.707[a]	0.05[a]	0.25	0.05[a]	5.4[j]	-	0.10[a]	0.90[c]	-	-
Merganser	1.5[a]	0.08[a]	0.38	0.08[a]	1.5[k]	-	0.02[a]	0.08[a]	0.90[a]	-
Mallard	1.2[a]	0.06[a]	0.25	0.07[a]	2[a]	-	0.50[a]	0.45[a]	-	0.05[a]
Peregrine Falcon***	0.814[a]	0.05[a]	0.15	0.05[a]	-	2.4[j]	-	-	0.05[a]	0.95[a]
Muskrat	1.0[a]	0.07[a]	0.35	0.1[a]	2.4[l]	-	0.80[a]	0.15[a]	0.05[a]	-
Terrestrial										
Willow Ptarmigan	0.625[e]	0.04[e]	0.13	0.04[h]	-	3.8[m]	-	-	-	1
Ruffed Grouse	0.552[a]	0.03[a]	0.11	0.04[a]	-	3.3[m]	-	-	-	1
Deer	75[a]	2.25[a]	7.5	4.5[a]	-	45[a]	-	-	-	1
Meadow Vole	0.035[a]	0.003	0.012[a]	0.007[a]	-	0.08[a]	-	-	-	1
Arctic Ground Squirrel	0.8[f]	0.06[f]	0.19	0.1[h]	-	3[f]	-	-	-	1
Barren-ground Caribou	135[g]	3.9[g]	6.5	8[h]	-	194[j]	-	-	-	1
Woodland Caribou	105	4.8	8	9.5	-	240	-	-	-	1

* Conversion between wet weight and dry weight diets assume 80% moisture content of aquatic food items, 70% for terrestrial plants, 40% for lichen and 68% for other prey

** Other includes food items that are not included in the assessment such as terrestrial vegetation

*** Peregrine falcon considered to be present in both semi-aquatic and terrestrial environments

a Environment Canada (EC) 2012

b Diet adjusted from EC 2012 to be representative of a range of sandpipers and maximize the intake of benthic invertebrates

c Diet adjusted from EC 2012 to maximize the intake of benthic invertebrates

e For willow ptarmigan, the average body weight of 625 g and food items were taken from Hinterland Who's Who (CWF 1994), the food intake rate of 0.06 kg dw/kg BW/d is the same as the ruffed grouse

f There are a variety of squirrels present in the study area (e.g. eastern grey squirrel), the characteristics of this receptor were used to represent this class of species. The average body weight was taken to be 800 g (Torre 2013). The food intake rate was estimated using allometric equation provided in the Wildlife Exposure Factors Handbook (U.S. EPA 1993). The soil ingestion rate was adopted from the average for prairie dogs (5.2%) from Beyer et al. 1994.

g For barren-ground caribou, the average body weight was taken to be 135 kg (ADF&G 2014). The food intake rate was estimated using allometric equation provided in the Wildlife Exposure Factors Handbook (U.S. EPA 1993)

h Water intake estimated from allometric equation provided in the Wildlife Exposure Factors Handbook (U.S. EPA 1993)

i Average sediment ingestion of the four sandpiper species presented in Beyer et al. (1994) is 18% of the dry weight diet

j Beyer et al. (1994). In lieu of specific information used average of either all avian species (11%) including soil/sediment dwellers, avian species excluding shorebirds (5%) or mammals (5%)

k Adopted value for the ring-necked duck and blue winged teal (2%) from Beyer et al. 1994 due to similar feeding patterns

l Adopted value for the mallard (3%) due to similar feeding patterns

m Adopted value average for the woodcock and wild turkey (10%) from Beyer et al. 1994 due to similar feeding patterns

4.2.1.3 Summary of Receptors in Identified Scenarios

The previous sections outlined the receptors to be included in the assessment. These receptors were matched with the selected scenarios (Section 2.3) and Table 4.3 summarizes the receptors that were included in each of the scenarios.

Table 4.3 Ecological Receptors Assessed in each Selected Scenario

Accident Location	Ecozone	Aquatic Receptors	Semi-aquatic Receptors		Terrestrial Receptors		
			falcon	sandpiper, scaup, mallard, merganser, muskrat	ptarmigan	squirrel, caribou	grouse, deer, vole
Assiniboine River	Prairie	✓	×	×	×	×	✓
Columbia River	Montane Cordillera	✓	×	×	✓	×	✓
Kaministiquia River	Boreal Shield	✓	×	×	×	×	✓
North Saskatchewan River	Boreal Plain	✓	×	×	×	×	✓
Mississagi River	Boreal Plain	✓	×	×	×	×	✓
Lac La Ronge	Boreal Plain	✓	×	✓	×	×	✓
Wollaston Lake	Boreal Shield	✓	✓	✓	✓	✓	✓
Lake of the Woods	Boreal Shield	✓	×	✓	×	×	✓
Vancouver Harbour	Pacific Maritime	✓	✓	✓	✓	×	✓
Lake Saint-Louis	Mixed Wood Plain	✓	×	✓	×	×	✓
Land – Point North	Boreal Shield-	×	×	×	✓	✓	✓

Note: In locations where ptarmigan was assessed, grouse was not as these two species are very similar.

4.2.2 Human Receptors

Workers: Following a transportation accident, emergency response personnel who are responding to the accident, and workers involved in the cleanup will be selected as human receptors.

Members of the Public: Members of the public that are in close proximity to an accident may be exposed.

The potential effects of an UOC spill into a large lake will be assessed on individuals who may obtain drinking water and fish from that lake. No long-term exposure to contaminated soil is anticipated for any of the receptors because of the ability to remediate the soil, therefore, meat consumption will not be considered as an exposure pathway.

4.3 EXPOSURE CHARACTERIZATION

The estimation of exposure of valued ecosystem components (VECs) to potentially hazardous constituents involves the identification of constituents of potential concern (COPC) and exposure pathways and the prediction of exposure conditions. These factors are discussed below.

4.3.1 Constituents of Potential Concern (COPC)

Exposure to radionuclides will be assessed for radionuclides present in UOC. These include U-238, Th-234, Pa-234, Pa-234m, U-234, U-235 and Th-231. Some of these radionuclides are progenies of others, and depending on the dose coefficients used, they may be included in the assessment implicitly. Chemical toxicity will be assessed quantitatively for exposure to uranium in the spilled UOC.

4.3.2 Exposure Pathways

4.3.2.1 Ecological Receptors

Ecologically, exposure to COPC occurs through both direct and indirect pathways. Aquatic organisms for example receive direct exposure as a result of changes in COPC concentrations in the water and/or sediments. Indirect exposure occurs via consumption of water, sediment, and/or aquatic biota that have been affected by releases of COPC to the environment in treated effluent discharges, contaminated runoff or groundwater or as a result of accidental spills. Thus, different patterns of exposure and differential sensitivity to COPC by organisms in complex food webs can result in ecological impacts that cannot be estimated accurately from considerations of direct effects alone.

While numerous lakes and streams exist in the study area, it is not practical to assess the potential effects of a spill on this number of potential receptors. Thus, the assessment will focus on representative waterbodies based on size and proximity to communities.

In the case where UOC is released to a waterbody, dispersion through water and sediment will occur. As a result, aquatic species (aquatic plants, benthic invertebrates, fish) will be directly exposed to uranium and radioactivity in the water column and/or sediment. Exposure to semi-aquatic species (sandpiper, lesser scaup, merganser, mallard, peregrine falcon, and muskrat) will occur through the ingestion of water and consumption of sediment as well as aquatic species (i.e., aquatic plants, benthic invertebrates, fish).

The UOC released following potential accidents on land can be contained and remediated efficiently. However, it can pose a risk through soil exposure when occurring in the remote areas that may limit the quick access and mobilization of remediation equipment. Therefore, although accidents on land involving truck or rail transport are not considered to result in any substantial long-term exposure, the potential short-term exposure is evaluated. Exposure to terrestrial species (willow ptarmigan, ruffed grouse, deer, meadow vole, Arctic ground squirrel and barren-ground caribou) will occur through the ingestion of soil prior to the implementation of any clean-up procedures or remedial actions. It is assumed that the bioaccessibility of uranium contained in UOC ingested through soil is 1%. This conservative fraction was chosen based on the 0.2%

fraction recommended for slow processes involving uranium by the International Commission on Radiological Protection (ICRP 1994) and the low solubility of UOC in water (<1%).

Table 4.4 provides a summary of exposure assumptions for each ecological species included in the assessment. As seen from the table, exposure resulting from contaminated water is assumed to be of a short-term duration as high contaminant concentrations in water resulting from a spill would be diluted quickly. Subsequent to an accidental release it is expected that remediation of the sediment will occur; however, it is likely not feasible to recover 100% of the material. Exposure resulting from the residual UOC in the sediment is assumed to be of a long-term duration. All species are assumed to remain in the contaminated area for their respective duration of exposure (100%).

Table 4.4 Ecological Exposure Assumptions

Species	**Uranium Exposure**		**Radiological Exposure**		
	Pathway	**Exposure Duration**	**Internal Pathway**	**External Pathway**	**Exposure Duration**
Aquatic					
Aquatic Plants	Exposure to water	Short-term	Uptake from water	Leaves: water Roots: sediment	Long-term
Benthic Invertebrates	Exposure to water and sediment	Long-term	Uptake from water	Sediment	Long-term
Forage Fish	Exposure to water	Short-term	Uptake from water	Water and sediment	Long-term
Predatory Fish	Exposure to water	Short-term	Uptake from water	Water	Short-term

Table 4.5 Ecological Exposure Assumptions

Species	Uranium Exposure		Radiological Exposure		
	Pathway	Exposure Duration	Internal Pathway	External Pathway	Exposure Duration
Semi-aquatic					
Sandpiper	Uptake from water, aquatic plants, benthic invertebrates and sediments	Long-term	Uptake from water, aquatic plants, benthic invertebrates and sediments	Sediment	Long-term
Lesser Scaup Mallard	Uptake from water, aquatic plants, benthic invertebrates and sediments	Long-term	Uptake from water, aquatic plants, benthic invertebrates, sediments, and aquatic vegetation	Water	Long-term
Merganser	Uptake from water, aquatic plants, benthic invertebrates, fish and sediments	Long-term	Uptake from water, aquatic plants, benthic invertebrates, fish and sediments	Water	Long-term
Peregrine falcon	Uptake from water, fish and soil	Long-term	Uptake from water, fish and soil	--	Long-term
Muskrat	Uptake from water, aquatic plants, benthic invertebrates, fish and sediments	Long-term	Uptake from water, aquatic plants, benthic invertebrates, fish and sediments	Water and sediment	Long-term
Terrestrial					
Willow ptarmigan Ruffed grouse Deer Meadow vole Squirrel Caribou	Uptake from water and soil (1% U bioaccessibility)	Short-term	Uptake from water and soil	Soil	Short-term

Note: Short-term is generally taken to be less than 10 days.

4.3.2.2 Human Receptors

<u>Workers:</u> Following a transportation accident, emergency response personnel who are responding to the accident, and workers involved in the cleanup will be selected as human receptors.

<u>Members of the Public:</u> Following a release to land or air, members of the public may be exposed through inhalation of dust and external radiation. No long-term exposure to contaminated soil is anticipated for any of the receptors because of the ability to remediate the soil, therefore, meat consumption will not be considered as an exposure pathway.

The potential effects of an UOC spill into a large lake will be assessed on individuals who may obtain drinking water and fish from that lake.

The potential effects of an UOC spill into a waterbody will be assessed on individuals who may obtain their drinking water from that waterbody (i.e., a nearby community). As such, the assessment will focus on a toddler, a child and an adult resident of the community that are exposed to uranium and radionuclides in drinking water. The exposure duration is conservatively assumed to be one week as residents would quickly be warned to stop drinking water from that waterbody in the case of a spill. The potential for fish ingestion from a waterbody following a UOC spill will also be assessed.

4.4 TOXICITY REFERENCE VALUES (TRVS) FOR ECOLOGICAL SPECIES

For the assessment of potential effects on ecological species, toxicity reference values (TRVs) are used in risk assessments to judge whether the predicted (estimated) exposures (or doses or intakes) may potentially have an adverse effect on the species. A discussion of selected literature and the associated TRVs consulted for this assessment is provided in the following sections.

For the assessment of potential effects on human health, the exposure assessment will compare predicted uranium levels in the impacted water downstream of a spill site to drinking water quality guidelines, which are based on the protection of even the most sensitive individuals against adverse effects from continuous exposure. Radiation doses will be compared to CNSC and Health Canada dose limits.

4.4.1 Radioactivity

The assessment of effects on ecological species from exposure to radioactive constituents will involve estimation of the combined (total) dose that a VEC 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. These factors are discussed below.

4.4.1.1 Relative Biological Effectiveness (RBE)

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. In this assessment, the terms “RBE” and “radiation weighting factor” are used interchangeably. It should be noted that uncertainty remains 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 should correspond to the endpoint being protected (e.g., health of a population).

The recently approved Canadian Standard N288.6 which addresses *Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills* (CSA 2012) recommends an RBE of 10 to be applied to the component of internal dose from alpha emitters. This assessment will follow this recommendation.

4.4.1.2 Aquatic and Terrestrial Biota Radiation Benchmarks

The Canadian Standard N288.6 (CSA 2012) recommends that radiation dose benchmarks for quantitative effects assessment should follow UNSCEAR (2008), i.e., 100 $\mu Gy \bullet h^{-1}$ for terrestrial biota and 400 $\mu Gy \bullet h^{-1}$ for aquatic biota. Therefore, the benchmarks used in the assessment are 2.4 mGy/d for terrestrial biota and 9.6 mGy/d for aquatic biota.

4.4.2 Non-Radionuclides (Uranium)

For the non-radioactive constituents, toxicity reference values are based on exposure levels in the case of aquatic species and total intakes (or doses) for terrestrial species.

Since the exposure to many species is considered to be short-term as COPC concentrations in water would quickly be diluted and spills on land would quickly be contained or cleaned-up, acute toxicity reference values are used in many instances.

4.4.2.1 Aquatic Toxicity Reference Values

A Species Sensitivity Distribution (SSD) was developed for uranium through a review of available toxicity data on aquatic biota. Data on acute (short-term) exposure to uranium were obtained from literature, generally consistent with the information used to generate the generic CCME water quality guideline. Further details on the development of the uranium SSD are provided in Appendix B. The SSD is shown in Figure 4.2 and Table 4.5 summarizes the protection levels for aquatic species determined from the SSD.

Figure 4.2 Species Sensitive Distribution for the Protection of Aquatic Life – Uranium (Acute)

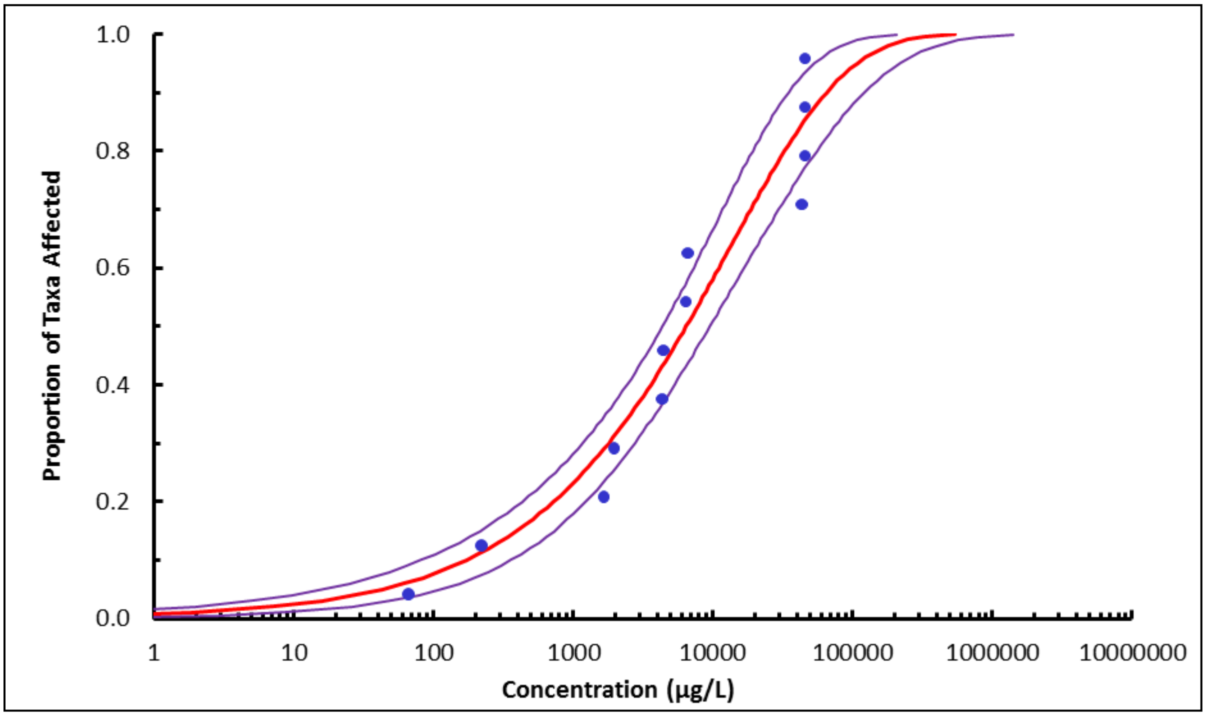


Table 4.5 Protection Levels Based on Uranium Species Sensitivity Distribution

Protection Level	Concentration (µg/L)			Species Affected at Central Tendency
	Central Tendency	Upper Prediction Interval	Lower Prediction Interval	
95%	43	114	16	--
90%	172	360	82	*Ceriodaphnia dubia*
80%	729	1234	431	*Ceriodaphnia dubia, Daphnia pulex*

The chronic exposure to benthic invertebrates will be assessed through the sediment exposure benchmarks.

4.4.2.2 Sediment Benchmarks

Uranium exposure to benthic invertebrates from sediments will be assessed against the toxicity benchmarks from Thompson *et al.* (2005), which are specific to uranium-bearing regions of Canada (e.g., northern Saskatchewan and northern Ontario) and are considered Canadian Nuclear Safety Commission (CNSC) working reference values. Thompson *et al.* (2005) used the Screening Level Concentration (SLC) approach to derive Lowest Effect Level (LEL) and Severe Effect Level (SEL) concentrations for nine metals and metalloids (arsenic, chromium, copper, lead, molybdenum, nickel, selenium, uranium and vanadium), which are naturally occurring substances often released to the aquatic environment during the mining and milling of uranium ore. The data were collected in uranium ore-bearing regions of northern Saskatchewan and Ontario where most Canadian decommissioned or operating uranium mines and mills are located. Benthic communities were considered to be not adversely affected if there was less than a 20% reduction in abundance and species richness relative to the reference. Benthic communities were considered to be severely affected if there was a greater than 40% reduction in these two indices. Two statistical methods were used by Thompson *et al.* (2005) to define the percentiles corresponding to LEL and SEL. A "weighted method" produced somewhat higher values than a "closest observation method". When the predictive ability of the sediment quality guidelines was assessed, all of the LELs derived using the weighted method, with the exception of the chromium LEL, were found to be highly reliable (>85% accuracy) in predicting sites unimpacted by uranium mining/milling. Caution is to be employed when using the SEL values as they may not be a reliable predictor of potential effects.

The LEL and SEL values for uranium are shown in Table 4.6. Also shown in this table is the results of toxicity testing on the growth and reproduction of *Hyalella azteca* and *Chironomus dilutus* (Liber et al. 2011). The LEL and SEL values were carried forward in the assessment; as the IC_{25} indicates, the LEL is a conservative level to use to determine potential effects.

Table 4.6 Sediment Quality Guidelines for Uranium

Benchmark	Uranium
Lowest Effect Level (LEL) (μg/g)	104.4[a]
Severe Effect Level (SEL) (μg/g)	5874.1 [a]
Inhibition Concentration IC_{25} - 25% decrease in growth (μg/g)	964 [b]

Source:
a Thompson *et al.* (2005)
b Liber et al. 2011

4.4.2.3 Semi-Aquatic and Terrestrial Species Toxicity Reference Values

The TRVs used for semi-aquatic ecological receptors (sandpiper, lesser scaup, merganser, mallard, peregrine falcon and muskrat) are for chronic exposure since exposure to these species will include sediment-related pathways over a relatively long period of time.

To determine possible effects on semi-aquatic ecological receptors, Lowest Observable Adverse Effect Level (LOAEL) and No Observable Adverse Effect Level (NOAEL) toxicity reference values will be used. NOAELs are generally used for screening level type assessments whereas

LOAELs are used to determine potential effects on ecological species in more comprehensive site-specific assessments when more realistic estimates of species exposures have been made (Sample *et al*., 1996).

In the absence of toxicity data for most of the terrestrial species, data for laboratory animals are generally used. For avian receptors, the test species are generally ducks or chicks. Existing data were collected from the U.S. DOE database by Sample *et al*. (1996).

Haseltine and Sileo (1983) conducted a study of black ducks with depleted metallic uranium, and derived a NOAEL of 160 mg U/(kg d) in a 10 week, sub-chronic study where no effects were observed at any dose level. A factor 10 was applied to derive a chronic NOAEL of 16 mg U/(kg d).

The muskrat is the only semi-aquatic mammal included in the assessment and the only mammal that will be evaluated for chronic exposure. Toxicity reference values for chronic uranium exposure in mammals were derived by Sample *et al.* (1996) from a study conducted by Paternain *et al.* (1989) examining reproduction in mice. Sample *et al.* (1996) derived a NOAEL of 3.1 mg U/(kg d) and LOAEL of 6.1 mg U/(kg d).

The selected TRV for deer, meadow vole, Arctic ground squirrel and barren-ground caribou is an acute one since these species will potentially be exposed to the spilled UOC (uranium) in water and soil for a short period of time. There are very few acute exposure laboratory studies related to uranium exposure for mammals. Studies by Domingo *et al.* (1987) in rats and mice obtained LD_{50} values of 114 and 136 mg U/(kg d). Domingo *et al*. (1987) also looked at reproductive endpoints in mice and derived a LOAEL of 3 mg/(kg d). This LOAEL, which is related to maternal reduced weight gain and food consumption and increased relative liver weight, is close to the chronic NOAEL discussed in the paragraph above and is not considered appropriate for use for the short-term exposure and therefore the LD_{50} value of 114 mg U/ (kg d) was considered as a basis for deriving a short-term TRV. An uncertainty factor of 10 was used to ensure the protection of individual species and thus a short-term uranium TRV for mammals of 11.4 mg U/(kg /d) is proposed. Table 4.7 summarizes the toxicity reference values that will be used in this study.

Table 4.7 Toxicity Reference Values for Exposure of Ecological Species to Uranium

Receptor	Guideline	Comment
Semi-aquatic		
Sandpiper, Lesser Scaup, Merganser and Mallard	NOAEL: 16 mg/kg-d	Chronic TRV (exposure to sediment-related pathways will be long-term)
Muskrat	NOAEL: 3.1 mg/kg-d LOAEL: 6.1 mg/kg-d	Chronic TRV (exposure to sediment-related pathways will be long-term)
Terrestrial		
Peregrine Falcon, Willow Ptarmigan and Ruffed Grouse	NOAEL: 160 mg/kg-d	Acute TRV
Deer, Meadow Vole, Arctic Ground Squirrel, and Barren-Ground Caribou	LOAEL:11.4 mg/kg-d	Acute TRV

4.5 TOXICITY REFERENCE VALUES (TRVS) FOR PEOPLE

The uranium Canadian drinking water quality guideline will be used as a benchmark for the assessment of human receptor exposure to uranium. The guideline value for uranium is 20 µg/L (Health Canada 2012).

For chronic exposure to uranium through the ingestion pathway for members of the public, the intake can be compared to a benchmark of 0.6 µg/kg-d (Health Canada 2010) which is based on hepatotoxicity observed in mice exposed to uranium in drinking water. If the oral exposure is of a short-term nature (1 – 14 days), then an acute TRV of 2 µg/kg-d can be used (ATSDR 2013), which was derived based on developmental effects.

In terms of exposure to contaminants in air following an accidental release, the U.S. EPA has derived Acute Exposure Guideline Levels (AEGLs) for a number of substances; however in terms of uranium, only uranium hexafluoride is included, which is not appropriate for this assessment. Emergency Response Planning Guidelines (ERPGs) are developed by the American Industrial Hygiene Association (AIHA). AIHA indicates that following a short-term release, ERPGs can be used to help protect the public when AEGLs are not available. The primary focus of the ERPGs is to provide guideline levels for once-in-a-lifetime, short term (typically 1 hour) exposure to a contaminant in air. ERPGs estimate how nearly all of the public (except for sensitive individuals) would react to a release. AIHA indicates that in areas with concentrations just above the ERPG-1, most people would experience temporary, non-disabling effects. In areas with concentrations just above the ERPG-2, people would experience significant—but not life-threatening—health effects.

AIHA determined there was insufficient information to develop an ERPG-1, the EPRG-2[14] for triuranium octaoxide (1344-59-8) is 10 mg/m^3 (AIHA 2013).

For radioactivity dose, the assessment of radiation exposures to members of the public is commonly based on estimation of the incremental (above-background) effects of the project or site. Such assessments consider the radiation dose received from direct exposure to gamma radiation as well as the dose received from the inhalation and ingestion of radionuclides.

The human receptor model converts radionuclide intake by the human receptors from the various pathways into a radiation dose. The CNSC radiation dose limit for a non-nuclear energy worker (NEW) or a member of public is 1 mSv/yr (1000 μSv/y) over natural background levels. The guideline for a NEW is 100 mSv for five years, i.e., an average of 20 mSv/y (CNSC 2000).

[14] ERPG-2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action. (AIHA 2013)

5.0 TRANSPORT AND FATE ANALYSIS FOR THE AQUATIC ENVIRONMENT

5.1 METHODOLOGY

A spill of UOC to a river or a large lake may have transient (short-term) as well as long-term implications. In the short-term, the quality of water may be impacted in a way that makes it unsuitable for drinking or supporting aquatic life. In the long term, the released material needs to be cleaned-up and the area remediated. Depending on the cleaning extent and efficiency, the long-term quality of sediment may be impacted resulting in undesirable exposure of benthic invertebrates and other biota consuming the impacted sediment directly or indirectly. The short-term period for water quality is defined as the time when the impacted water is diluted enough to meet the water quality guideline for uranium. This period varies between water bodies, but is usually in the order of days to weeks.

The potential impact on water quality due to the release of UOC was modelled assuming that 25% of the UOC on a truck (about 4100 kg) or in an ISO container (about 3250 kg) was released at the time of the incident. This is a conservative assumption as the containers are built to withstand most accidents, and not to release any substantial amount of UOC. The short-term dissolved release rate was estimated using solubility data. Solubility of calcined UOC was considered at an average value of 5 g/m^3 over the first 72 hours, which is the average solubility of McClean Lake UOC samples. Solubility of un-calcined UOC was considered at 7 g/m^3 based on samples from Rabbit Lake. It was 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 1 m.

Long-term concentrations 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 pore-water quality in each scenario. It was 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 5 cm.

Impact on sediment quality as a result of a UOC spill into a river was assessed through estimating the area over which 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, Newton's equation was used. Concentrations in the sediment were estimated using the results of the particle dispersion analysis. UOC masses for each particle size were re-distributed to the defined areas so that the areas where coarser particles settle also receive finer particles. It was assumed that the UOC that settles close to the spill site will be removed through a post-accident clean-up program with a removal efficiency of 95% within the first 15 m with no removal in the further field. Long-term exposure of VECs was using post-remediation concentrations).

A similar approach was adopted to estimate the concentrations in the lake sediment, except that the assumption of uniformity of width is not relevant for lakes. A simplified representation of each lake was used to estimate the path of UOC particles through the lake. Additionally, it was assumed that 95% of the UOC that settles within the first 30 m will be removed, with no removal in the further field. Long-term exposure of VECs was assessed using post-remediation concentrations). The robustness of drums containing UOC, low solubility of UOC and high particle density, results in deposition of the great majority of the released UOC close to the accident location. Therefore, the large portion of the released UOC can be cleaned up following an accident.

Porewater quality for the impacted area was estimated using a sediment-to-water partition coefficient. Detailed methodology for transport and fate analysis is provided in Appendix C.

5.2 Fate of UOC Released to Rivers

5.2.1 Assiniboine River

The Assiniboine River, a tributary of the Red River, is a 1,070-kilometre river that runs through the prairies of Western Canada in Saskatchewan and Manitoba. The crossing where it is assumed that a hypothetical truck accident occurs is located north of Lido Plage, Manitoba (Figure 5.1). The river width at the crossing measures about 80 m. The closet hydrometric gauging station is station number 05MJ001 (at about 10 km downstream of the crossing). Minimum, average and maximum flows for the station are 21, 47 and 128 m^3/s, respectively. Corresponding river elevations were 230.8, 231.4 and 232.9 m. Using a base altitude of 229 m, the depths were estimated at 1.8, 2.4 and 3.9 m, respectively.

5.2.1.1 Sediment Quality

Sediment concentrations were estimated through calculation of the distance travelled by UOC after a spill, and the area impacted. Detailed description of the methodology, and example calculations are provided in Appendix C.

Figure 5.2 illustrates the implication of this distribution of UOC mass for any clean-up planning. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions in Assiniboine River (i.e. within ~32 m of the container). This indicates that the hypothetical spill would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 µm is approximately 60 and 90 m from the crossing for calcined and un-calcined products, respectively.

For the purposes of the current assessment, it was assumed that 95% of the solids that settle within 15 m of the spill site are potentially recoverable through remedial activities. Sediment quality results are shown in Table 5.1 for post remediation conditions. The results presented in the table are a summary of the three flow conditions for the predicted sediment concentrations in the Assiniboine River. In general, using the results of the assessment, the minimum predicted COPC concentrations in the river sediments occurred under high flow conditions, where the smaller particles (<5 µm) are deposited over a larger area.

Porewater quality within the impacted sediment of the Assiniboine River was estimated based on weighted-average sediment concentrations and using a sediment-to-water partition coefficient of 3.5 m^3/kg (SENES 2010). The results are shown in Figure 5.2. During minimum flow conditions, the impacted volume is smaller resulting in a higher sediment concentration. Higher flow conditions on the other hand, result in a greater footprint and hence lower concentration. Concentrations post-cleanup may not follow the same trend since the clean-up is limited to a distance of 15 m and while higher concentrated sediment in the vicinity of spill will be cleaned, sediment with lower concentrations further downstream will not, resulting in a higher overall concentration in the high flow conditions.

Water concentrations for the three flows were estimated for short and long term concentrations using information on uranium solubility and porewater concentrations, respectively. The results are shown in Table 5.2. The short-term period for Assiniboine River is estimated at about a week (see Appendix C for example calculation) even if no settling is taken into account.

Figure 5.1 Assiniboine River Crossing Location

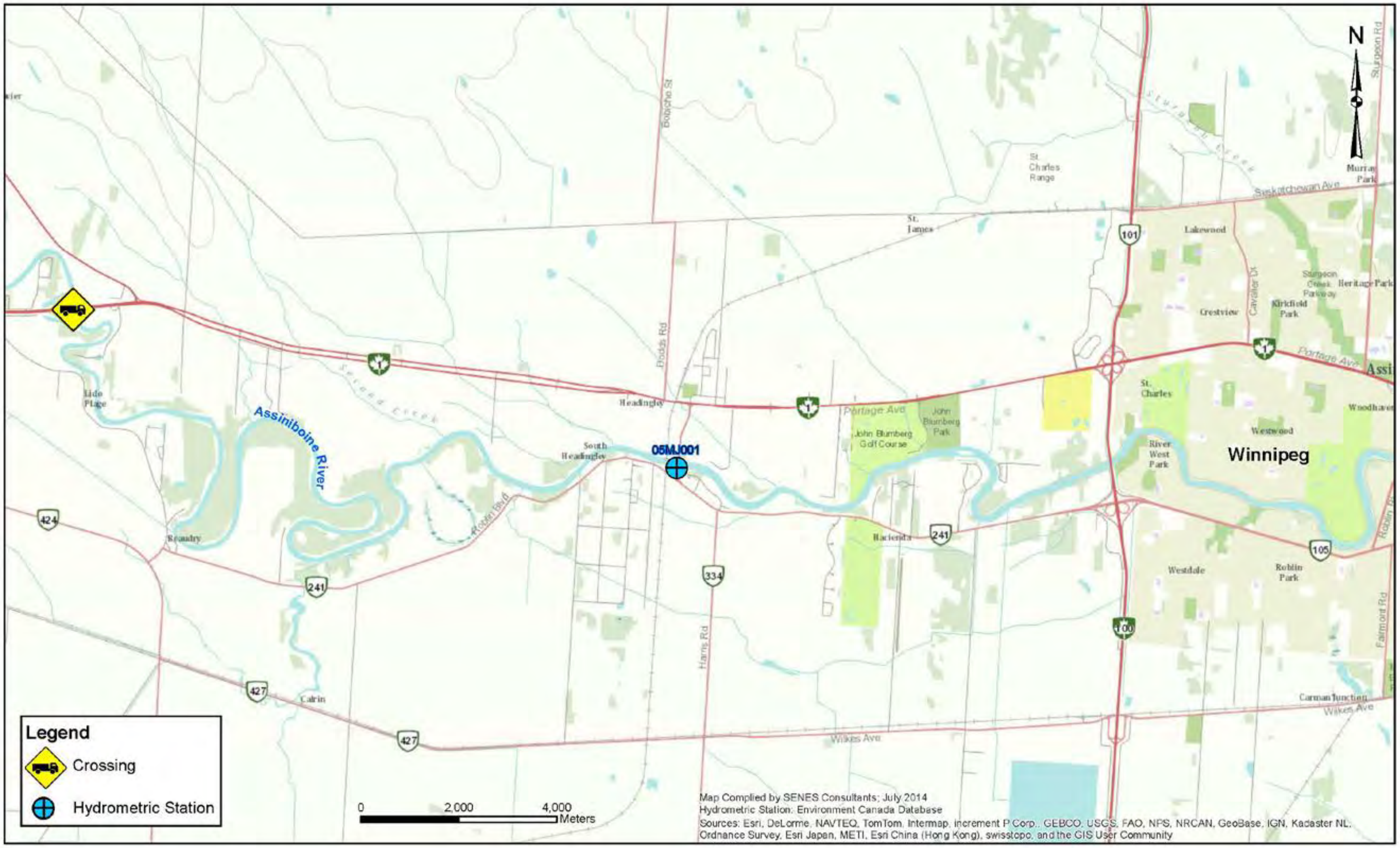
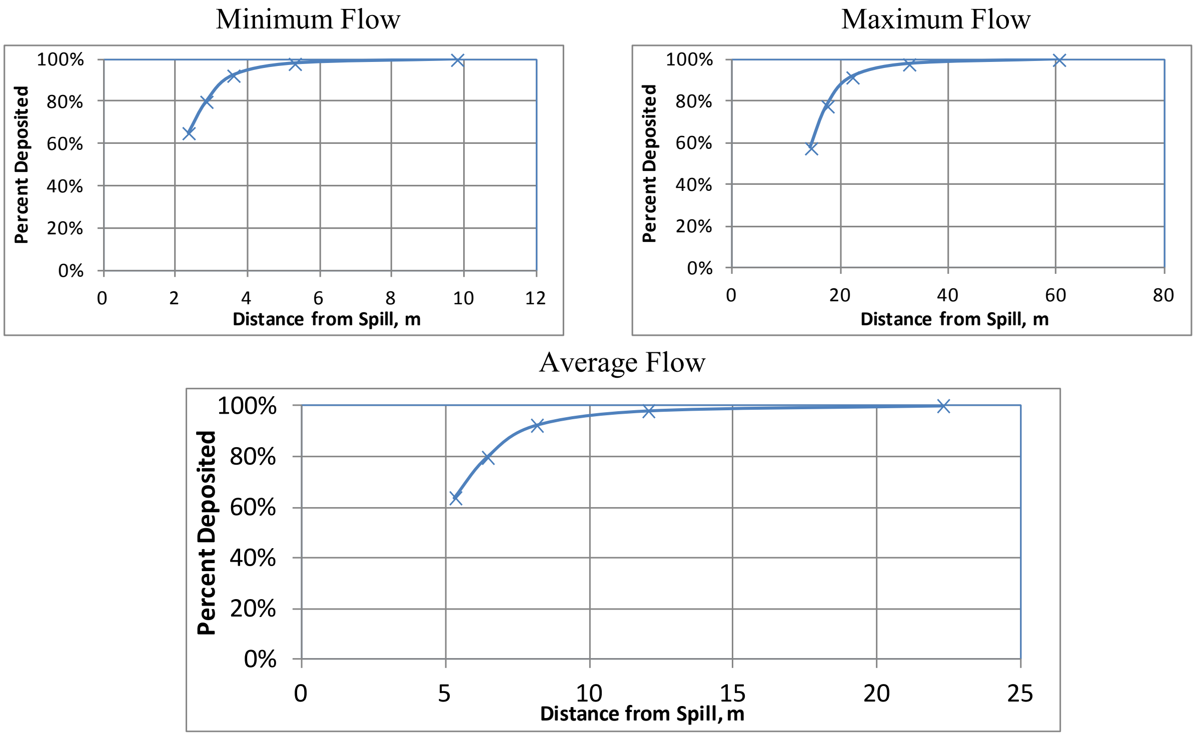
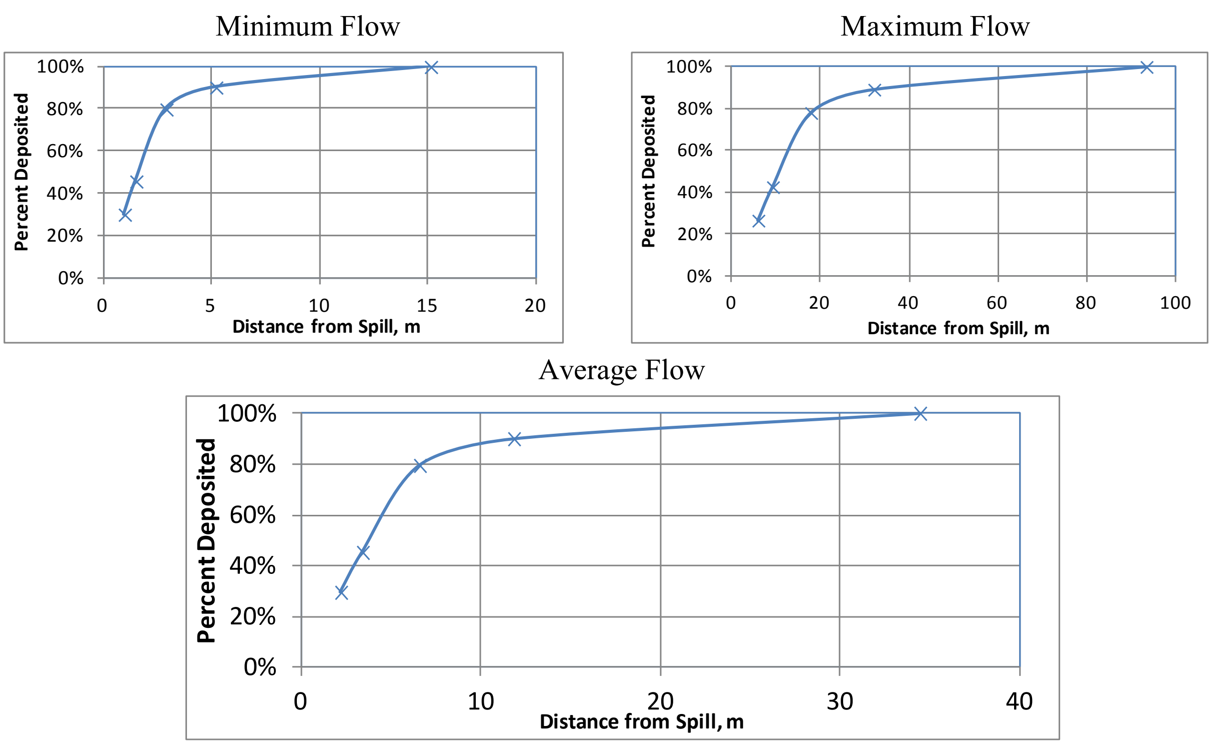


Figure 5.2 Distribution of Deposited UOC by Distance in Assiniboine River

a) Calcined product



b) Un-calcined product



Note: The horizontal scale is not the same for all figures.

Table 5.1 Estimated Post-Remediation Sediment and Porewater Quality in Assiniboine River

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	10	6718	24
Average	22	3417	12
Maximum	60	6376	22

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	15.1	11802	41
Average	34.4	7150	25
Maximum	93.2	9356	33

Table 5.2 Estimated Water Quality in Assiniboine River Crossing (µg/L)

a) Calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	6387	4763	2885	1277	953	577	319	238	144
Long-term*	n/a	n/a	n/a	0.34	0.13	0.14	0.08	0.032	0.036

b) Un-calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	8013	5976	3620	1603	1195	724	401	299	181
Long-term*	n/a	n/a	n/a	0.59	0.27	0.21	0.15	0.067	0.053

Note:
† Estimated at about one week
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

5.2.2 Columbia River

The Columbia River is the largest river in the Pacific Northwest region of North America and rises in the Rocky Mountains of British Columbia. The river is about 2,000 km long. The crossing where a hypothetical train accident may occur is located close to the community of Donald (Figure 5.3). The river width at the crossing is measured at about 80 m. The closest hydrometric gauging station is station number 08NB005 (about 2 km downstream of the crossing). Minimum, average and maximum flows for the station are 34, 172 and 508 m^3/s, respectively. River depth in summer has been reported between 6 and 10 m. Average depth was assumed at 8 m.

Figure 5.4 shows the estimated distances downstream of the spill location to which the solids are transported based on a turbulent flow assumption. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions in the river (i.e. within ~130 m of the container). Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 μm is approximately 240 and 370 m from the crossing for calcined and un-calcined products, respectively.

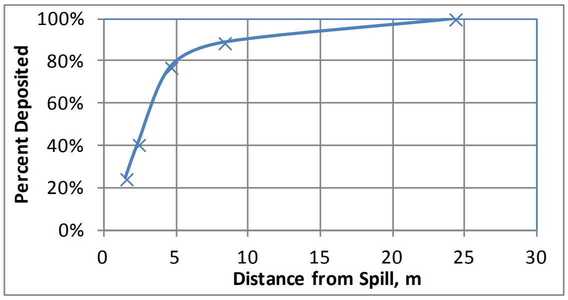
Sediment quality results are shown in Table 5.3 for post remediation conditions. The results presented in the table are a summary of the three flow conditions for the predicted sediment concentrations in the Columbia River. Porewater quality within the impacted sediment of the Columbia River was estimated using sediment-to-water partition coefficients (see Table 5.3). Water concentrations for the three flow conditions were estimated for short and long term periods using information on uranium solubility and porewater concentrations, respectively. The results are shown in Table 5.4. The short-term period for Columbia River is estimated at about a week even if no settling is taken into account.

Figure 5.3 Columbia River Crossing Location

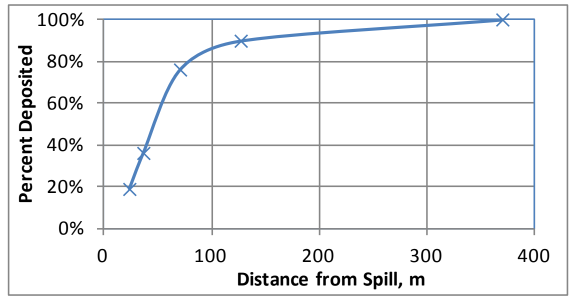
Figure 5.4 Distribution of Deposited UOC by Distance in the Columbia River

a) Calcined product

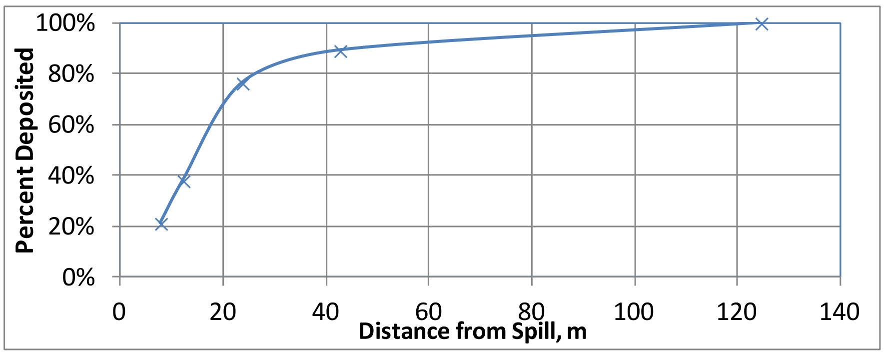
Minimum Flow



Maximum Flow

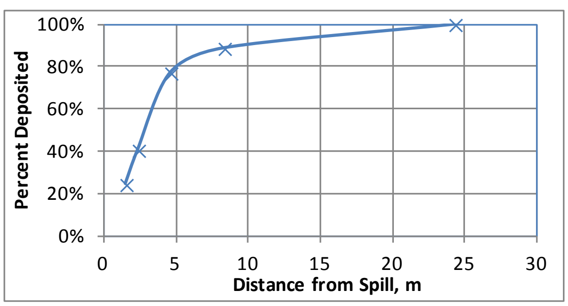


Average Flow

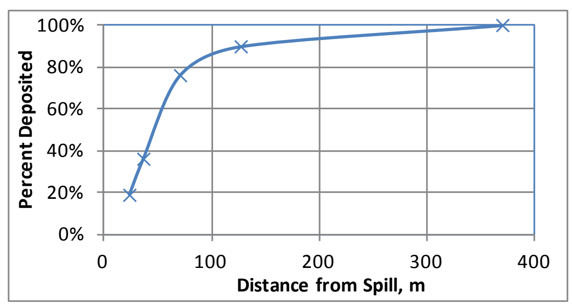


b) Un-calcined product

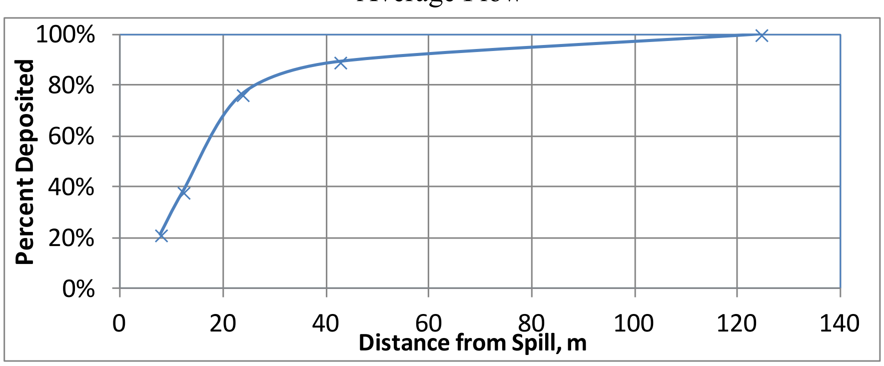
Minimum Flow



Maximum Flow



Average Flow



Note: The horizontal scale is not the same for all figures.

Table 5.3 Estimated Post-Remediation Sediment and Porewater Quality in the Columbia River

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	16	2189	7.7
Average	81	3327	11.6
Maximum	240	1784	6.2

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	24	4041	14.1
Average	124	4823	16.9
Maximum	369	2952	10.3

Table 5.4 Estimated Water Quality at Columbia River Crossing

a) Calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	3153	2364	1892	631	473	378	158	118	95
Long-term*	n/a	n/a	n/a	0.054	0.062	0.026	0.014	0.015	0.007

b) Un-calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	3955	2966	2373	791	593	475	198	148	119
Long-term*	n/a	n/a	n/a	0.1	0.089	0.044	0.025	0.022	0.011

Note:
† Estimated at about one week
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

5.2.3 Kaministiquia River

The Kaministiquia River (the Kam River) flows through western Ontario. The river divides into three channels as it enters Thunder Bay. The crossing where a hypothetical train accident may occur is located in the city of Thunder Bay (after the river has branched into two streams; Figure 5.5). The river width at the crossing measures about 150 m. The closest hydrometric gauging station is station number 02AB025 (at about 8 km downstream of the crossing- drainage area of 7739 km^2); however the monitoring of this station has been discontinued. Flow data for Kaministiquia River were prorated for drainage areas based on gauging Station 02AB006 at Kaministiquia. Drainage area at this station is 6467 km^2. Branching of the river was also taken into account, by allocating half of the estimated flow to each branch. Minimum, average and maximum flows for the station are 18, 25 and 37 m^3/s, respectively. Corresponding river depths were estimated at 0.9, 1.3 and 2.4 m, respectively.

Figure 5.6 shows the estimated distances downstream of the spill location to which the solids are transported based on a turbulent flow assumption. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions in the river (i.e. within ~5 m of the container). This indicates that the hypothetical spill would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 μm is approximately 9 and 14 m from the crossing for calcined and un-calcined products, respectively.

Sediment quality results are shown in Table 5.5 for post remediation conditions for the three flow conditions. Porewater quality within the impacted sediment of the Kaministiquia River was estimated using sediment-to-water partition coefficients (Table 5.5). Water concentrations for the three flow conditions were estimated for short and long term periods using information on uranium solubility and porewater concentrations, respectively. The results are shown in Table 5.6. The short-term period for Kaministiquia River is estimated at about a week even if no settling is taken into account.

Figure 5.5 Kaministiquia River Crossing Location

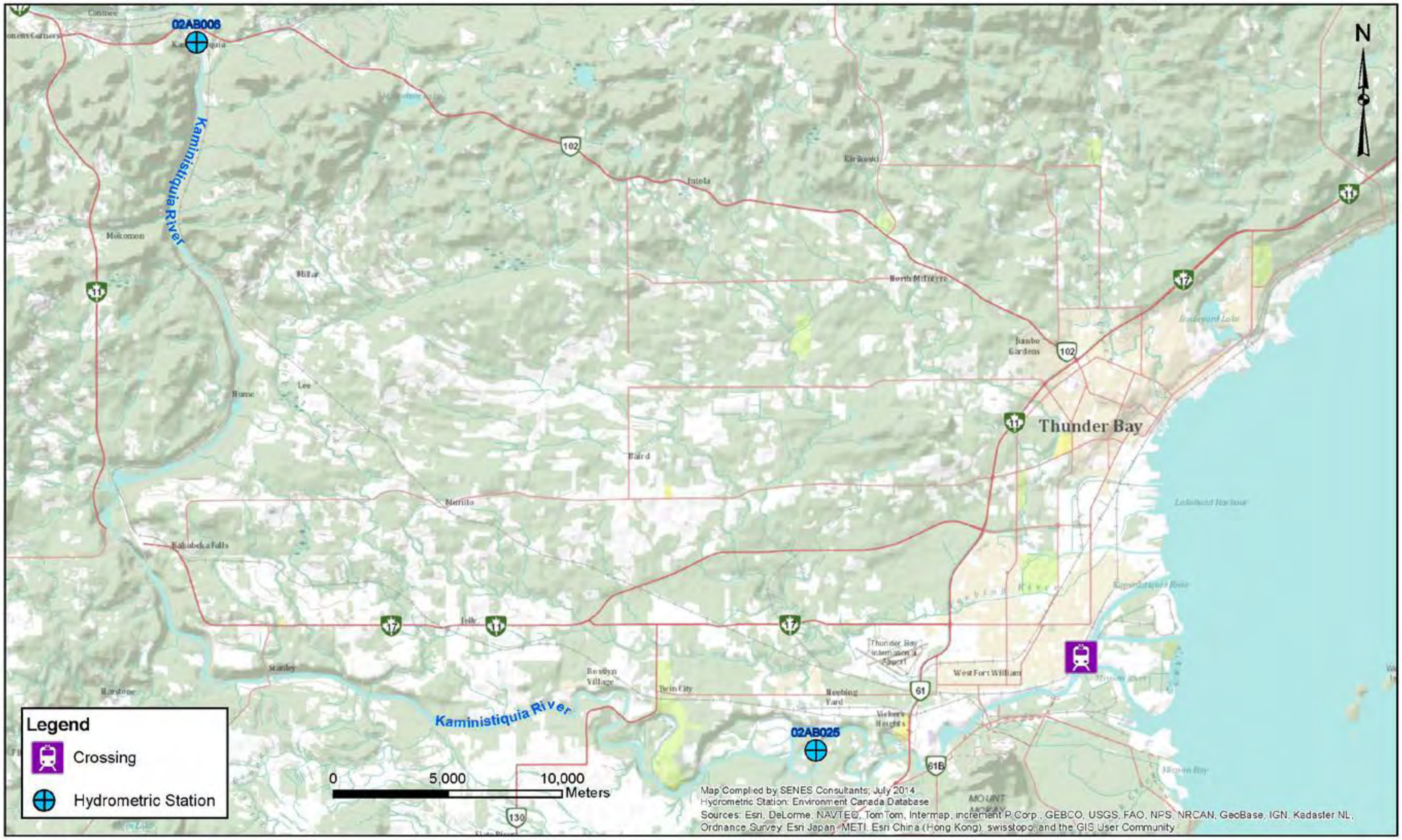
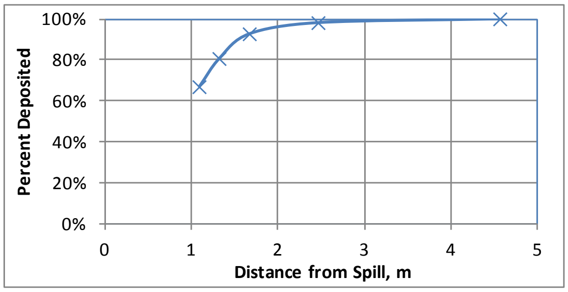


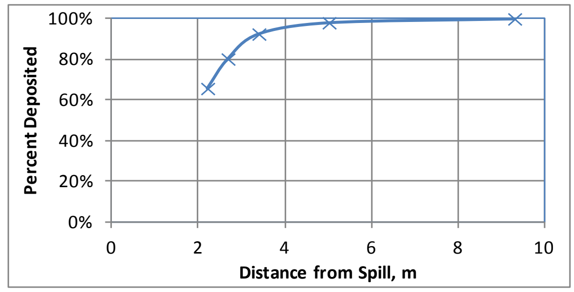
Figure 5.6 Distribution of Deposited UOC by Distance in Kaministiquia River

a) Calcined product

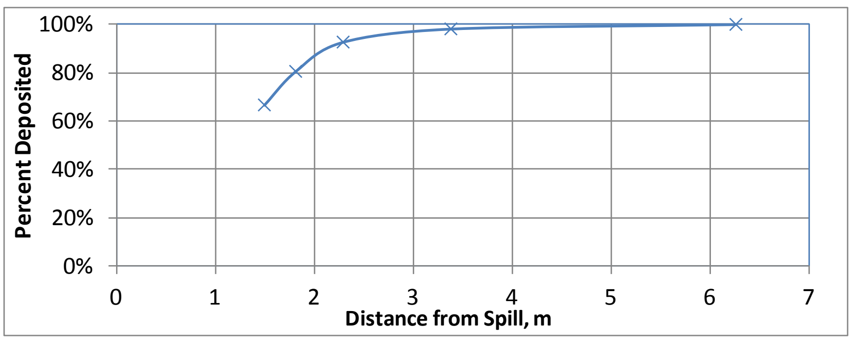
Minimum Flow



Maximum Flow

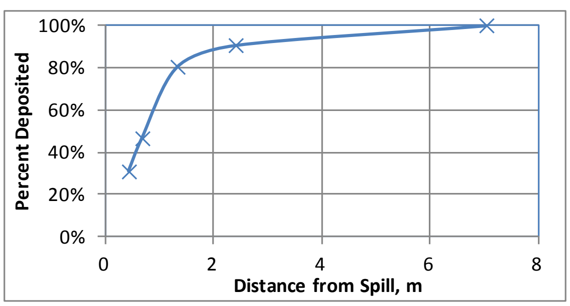


Average Flow

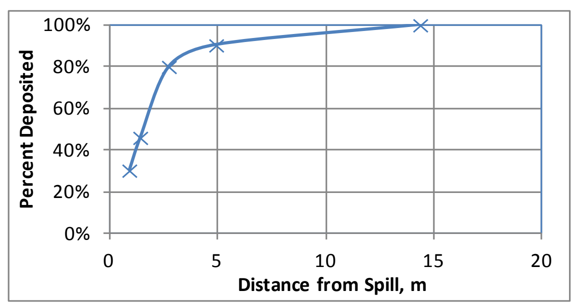


b) Un-calcined product

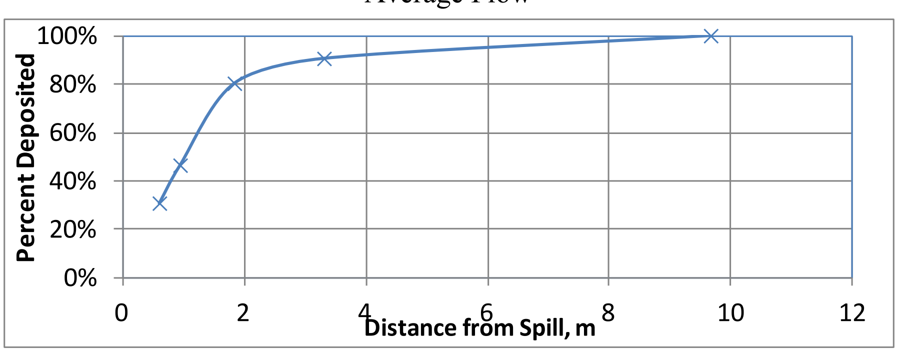
Minimum Flow



Maximum Flow



Average Flow



Note: The horizontal scale is not the same for all figures.

Table 5.5 Estimated Post-Remediation Sediment and Porewater Quality in Kaministiquia River

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	5	6810	24
Average	6	5279	18
Maximum	9	3784	13

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	7	12151	43
Average	10	9850	34
Maximum	14	7306	26

Table 5.6 Estimated Water Quality at Kaministiquia River Crossing

a) Calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	11391	7552	4229	2278	1510	846	570	378	211
Long-term*	n/a	n/a	n/a	0.61	0.31	0.13	0.15	0.08	0.031

b) Un-calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	14290	9474	5305	2858	1895	1061	714	474	265
Long-term*	n/a	n/a	n/a	1.09	0.58	0.24	0.27	0.15	0.061

Note:
† Estimated at about one week
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

5.2.4 North Saskatchewan River

The North Saskatchewan River flows east from the Canadian Rockies to central Saskatchewan. It is one of two major rivers that join to make up the Saskatchewan River. The river total length is about 1300 km.

The crossing where a hypothetical truck accident may occur is located in Prince Albert (Figure 5.7). The river width at the crossing is measured at about 300 m. The closest hydrometric gauging station is station number 05GG001 (at about 800 m upstream of the crossing). Minimum, average and maximum flows for the station are 111, 238 and 525 m^3/s, respectively. Corresponding river depths were estimated at 1, 3.0 and 5.5 m, respectively.

Figure 5.8 shows the estimated distances downstream of the spill location to which the solids are transported with settling rates based on a turbulent flow assumption. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions in the river (i.e. within ~35 m of the container). This indicates that the hypothetical spill would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 µm is approximately 65 and 100 m from the crossing for calcined and un-calcined products, respectively.

Sediment quality results are shown in Table 5.7 for post remediation conditions. The results presented in the table are a summary of the three flow conditions for the predicted sediment concentrations in the North Saskatchewan River. Porewater quality within the impacted sediment of the North Saskatchewan River was estimated using sediment-to-water partition coefficients (Table 5.7). Water concentrations for the three flow conditions were estimated for short and long term periods using information on uranium solubility and porewater concentrations, respectively. The results are shown in Table 5.8. The short-term period for the North Saskatchewan River is estimated at about a week even if no settling is taken into account.

Figure 5.7 North Saskatchewan River Crossing Location

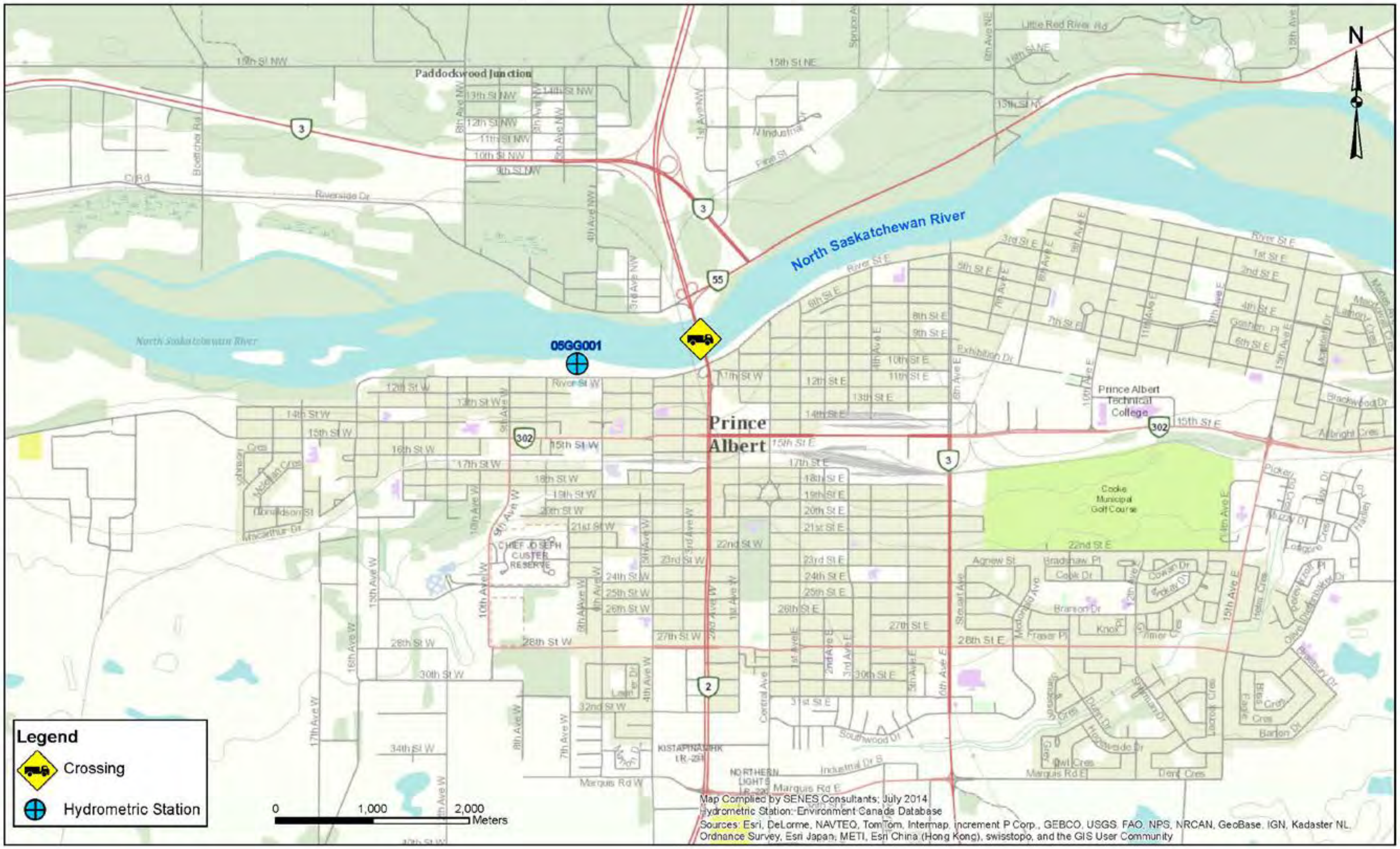
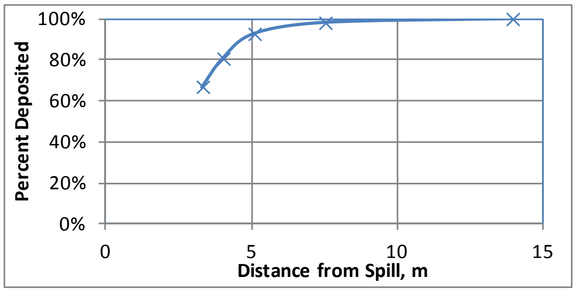


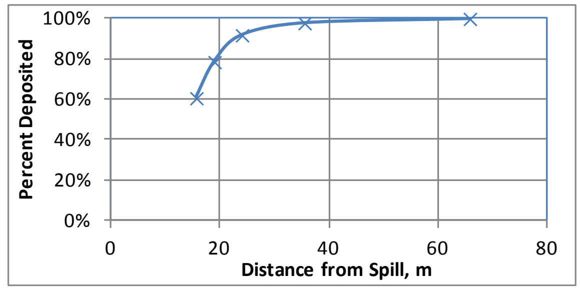
Figure 5.8 Distribution of Deposited UOC by Distance in North Saskatchewan River

a) Calcined product

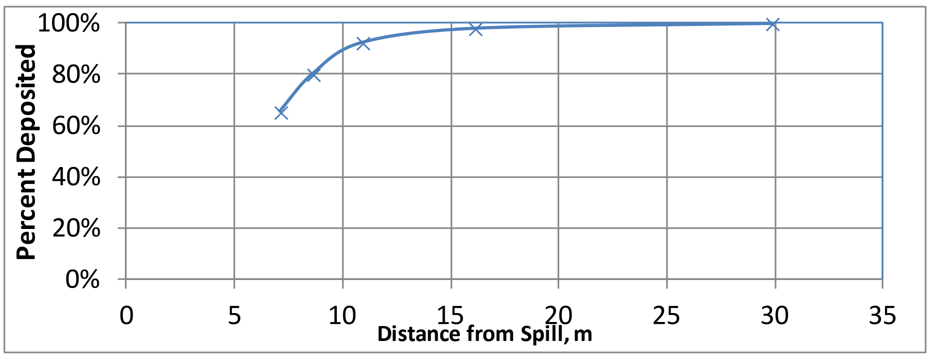
Minimum Flow



Maximum Flow

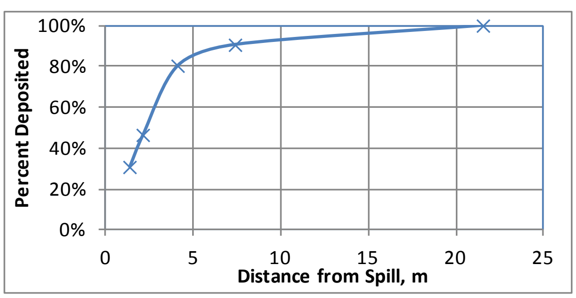


Average Flow

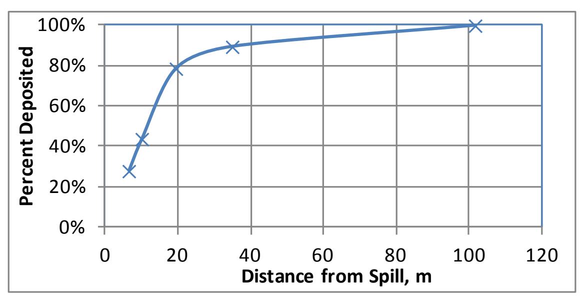


b) Un-calcined product

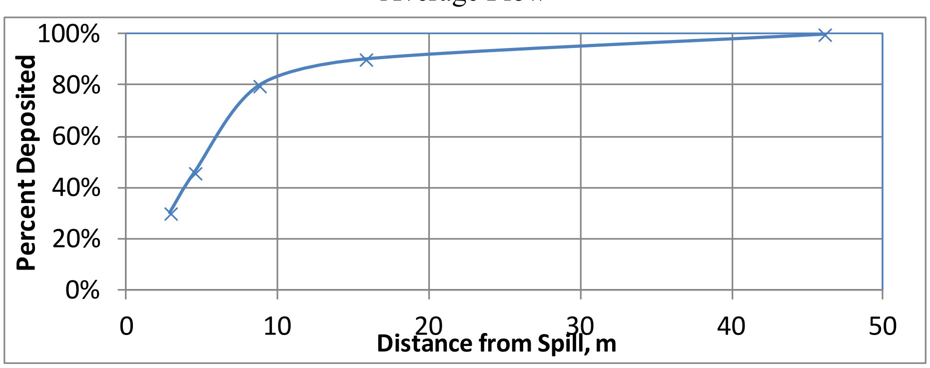
Minimum Flow



Maximum Flow



Average Flow



<u>Note:</u> The horizontal scale is not the same for all figures.

Table 5.7 Estimated Post-Remediation Sediment and Porewater Quality in North Saskatchewan River

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	14	5015	18
Average	30	2782	10
Maximum	66	7467	26

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	21	10222	36
Average	46	6143	21
Maximum	102	11706	41

Table 5.8 Estimated Water Quality at North Saskatchewan River Crossing

a) Calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	3027	1009	552	605	202	110	151	50	27.6
Long-term*	n/a	n/a	n/a	0.12	0.022	0.032	0.03	0.006	0.008

b) Un-calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	3797	1266	693	759	253	139	190	63.3	34.6
Long-term*	n/a	n/a	n/a	0.24	0.049	0.051	0.061	0.012	0.013

Note:
† Estimated at about one week
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

5.2.5 Mississagi River

The Mississagi River originates from Sudbury, Ontario and flows about 250 km to Lake Huron at Blind River. The crossing where a hypothetical truck accident may occur is located in Iron Bridge (Figure 5.9). The river width at the crossing is measured about 100 m. The closet hydrometric gauging station is station number 02CC008 (at about 18 km downstream of the crossing). Minimum, average and maximum flows for the station are 64, 114 and 225 m^3/s, respectively. Corresponding river depths were estimated at 3.3, 4.0 and 5.2 m, respectively.

Figure 5.10 shows the estimated distances downstream of the spill location to which the solids are transported with settling rates based on a turbulent flow assumption. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions in the river (i.e. within ~45 m of the container). This indicates that the hypothetical spill would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 µm is approximately 85 and 130 m from the crossing for calcined and un-calcined products, respectively.

Sediment quality results are shown in Table 5.9 for post remediation conditions. The results presented in the table are a summary of the three flow conditions for the predicted sediment concentrations in the Mississagi River. Porewater quality within the impacted sediment of the Mississagi River was estimated using sediment-to-water partition coefficients (Table 5.9). Water concentrations for the three flow conditions were estimated for short and long term periods using information on uranium solubility and porewater concentrations, respectively. The results are shown in Table 5.10. The short-term period for Mississagi River is estimated at about a week even if no settling is taken into account.

Figure 5.9 Mississagi River Crossing Location

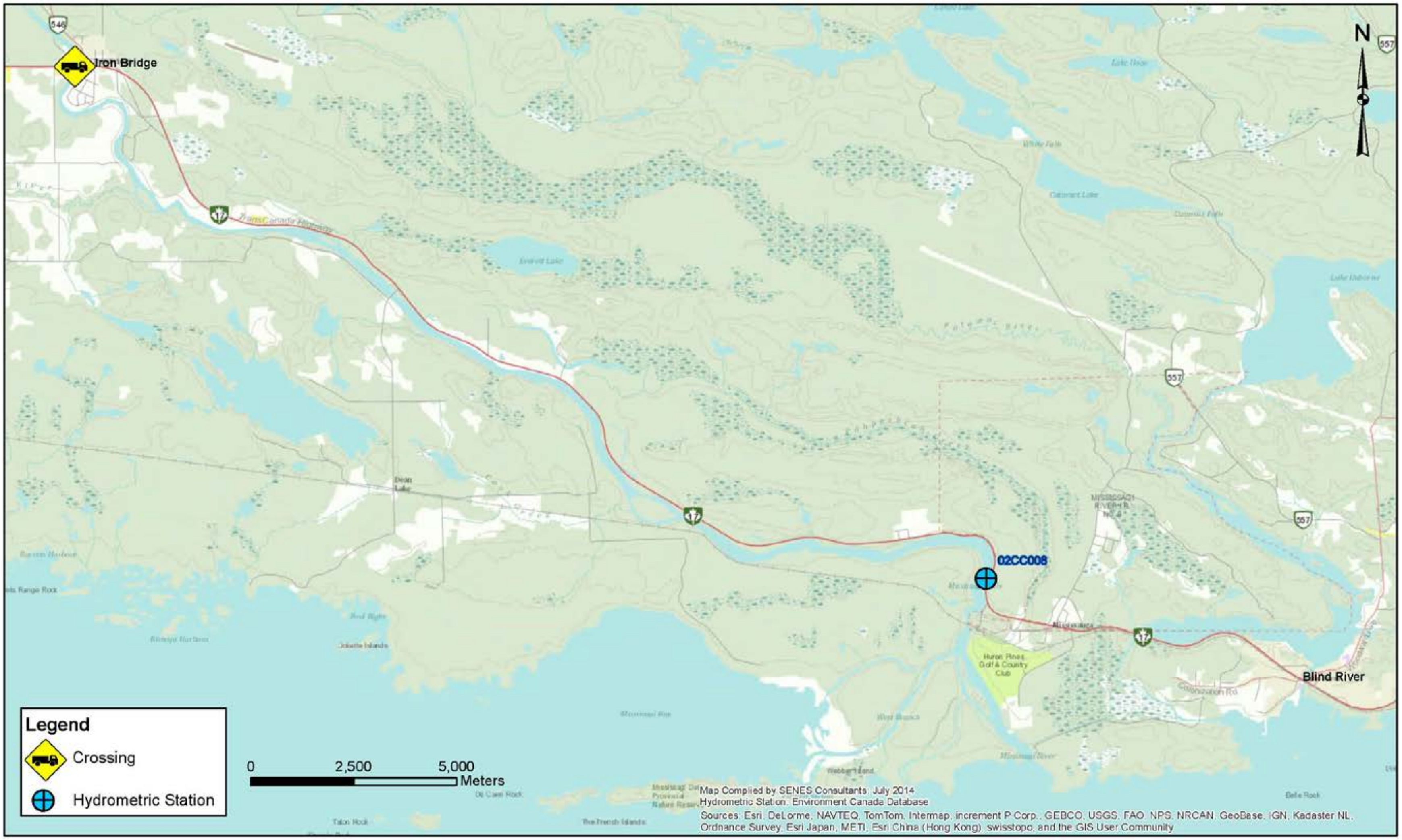
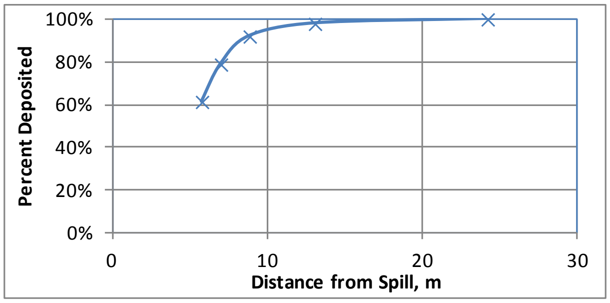


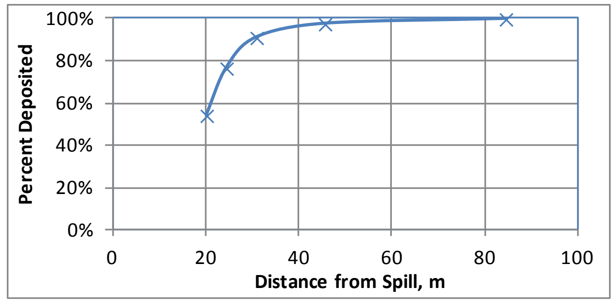
Figure 5.10 Distribution of Deposited UOC by Distance in Mississagi River

a) Calcined product

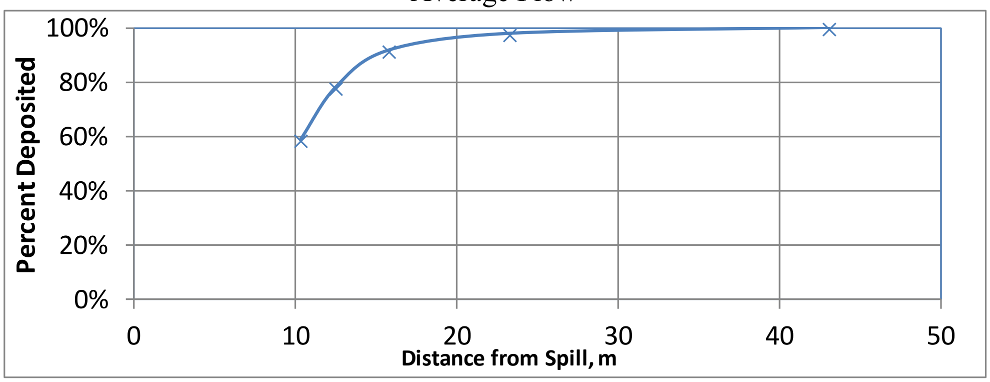
Minimum Flow



Maximum Flow

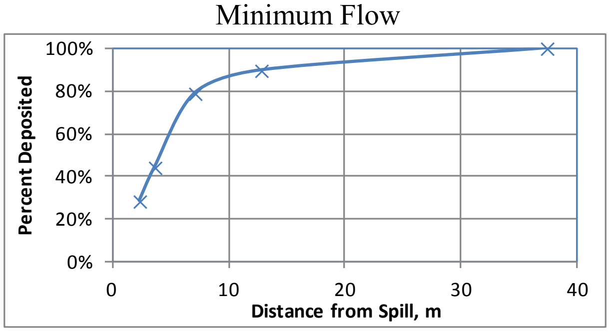


Average Flow

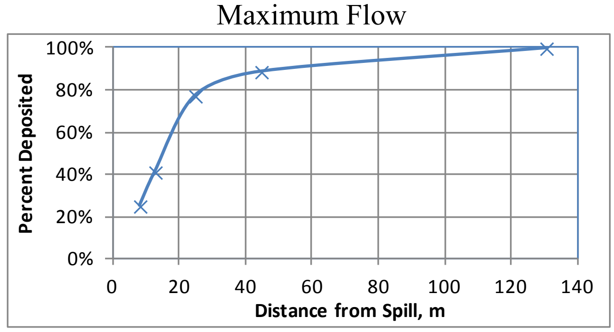


b) Un-calcined product

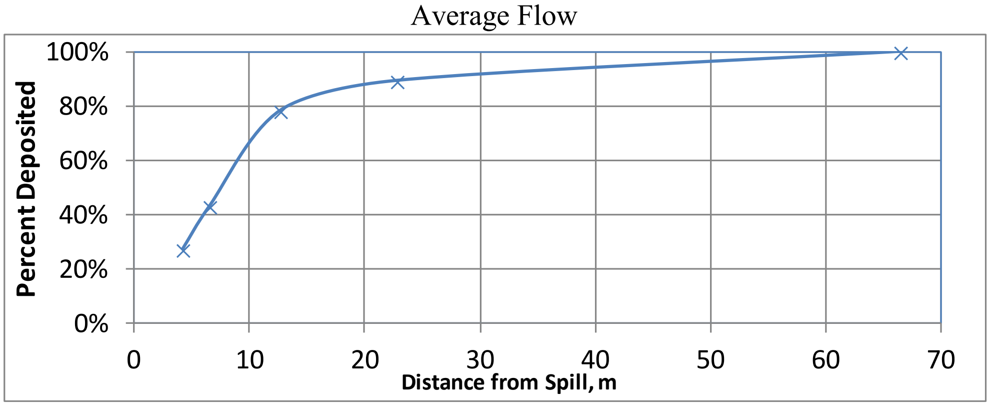
Minimum Flow



Maximum Flow



Average Flow



Note: The horizontal scale is not the same for all figures.

Table 5.9 Estimated Post-Remediation Sediment and Porewater Quality in Mississagi River

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	24	3171	11
Average	43	2894	10
Maximum	84	8346	29

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	37	6470	23
Average	66	4767	17
Maximum	130	12477	44

Table 5.10 Estimated Water Quality at Mississagi River Crossing

a) Calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	2740	2270	1761	548	454	352	137	113	88.1
Long-term*	n/a	n/a	n/a	0.07	0.052	0.12	0.017	0.013	0.029

b) Un-calcined product

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	3437	2848	2210	687	570	442	172	142	110
Long-term*	n/a	n/a	n/a	0.139	0.085	0.17	0.035	0.021	0.043

Note:
† Estimated at about one week
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

5.3 FATE OF UOC RELEASED TO SMALL LAKES

Release of UOC to a small lake is considered to deteriorate water and sediment quality of the lake to the extent that the water body loses its value as a habitat and will need remediation. Access of wildlife to the lake will be restricted from the time of the accident occurs until a time when the water and sediment have been properly remediated.

Assuming that dilution is the dominant dispersion and transport mechanism in small lakes, the size of water bodies delineating a "small lake" was estimated as follows:

For a UOC solubility of 1%, the minimum lake size where the water quality would meet the guideline of 15 µg/L (SENV 2006) following the release of one container of UOC (about 4000 kg of UOC or 3500 kg of uranium) is a 2.3 million m^3 lake. This is equivalent of 30 football fields filled with 10 m of water. Lakes larger than this volume would not be expected to have water quality that exceeds the guideline and for lakes smaller than this, the impact would extend downstream.

Assuming that UOC would mix in the top 5 cm of sediment, the minimum size lake for the sediment quality to meet the guideline of 104.4 µg/g (Thompson et al. 2005) is 3.3 ha.

These lake sizes were estimated as follows:

$$Lake\ volume = \frac{3500\ kg\ uranium \times 0.01\ soluble}{15\ \mu g/L} \times 10^6\ (\frac{\mu g}{kg} \times \frac{m^3}{L}) = 2.3\ \times\ 10^6\ m^3$$

and

$$Lake\ Area = \frac{3500\ kg\ uranium \times 0.99\ insoluble}{104.4 \frac{\mu g}{g\ dw} \times 10^{-6}\ \frac{g}{\mu g}\ \times 2000 \frac{kg\ dw}{m^3} \times 0.05\ m\ deep} = 3.3 \times 10^5\ m^2$$
$$= 3.3\ ha$$

The above estimates indicate that a release into a lake smaller than the above sizes will cause the water quality guidelines to be exceeded.

For reference, the sizes of a few selected lakes in the study area are shown in Table 5.11.

Table 5.11 Size of Selected Lakes -Context for the Size of a Small Lake

Lake	Volume (km^3)	Area (km^2)
Bright Lake, ON	0.06	12.3
Basswood Lake, ON	1.02	27
Columbia Lake, BC	0.075	25
Kamloops Lake, BC	3.7	52
Lake Newell, AB	0.32 (calculated from a mean depth of 4.8 m)	66
Lake Nipissing, ON	3.8	873.3
Shuswap Lake, BC	19.1	310
Windermere Lake, BC	0.05 (calculated using a mean depth of 3.4 m)	16

5.4 FATE OF UOC RELEASED TO LARGE LAKES

5.4.1 Lac La Ronge

Lac La Ronge is the fifth largest lake in Saskatchewan covering an area of about 1,414 km^2. It is a glacial lake approximately 250 kilometres north of Prince Albert.

The crossing where a hypothetical truck accident may occur is located on a bridge between the communities of Air Ronge and La Ronge (Figure 5.11). The closest hydrometric gauging station is station number 06CB001 (on the lake at about 1000 m from the bridge) reporting lake level. At this station, water elevations have been reported at 363.6, 364.0 and 364.4 masl for minimum, mean and maximum conditions. For an average water depth of 8 m, the datum is calculated at 356 m, resulting in minimum and maximum depths of 7.6 and 8.4 m, respectively. These values were assumed uniform throughout the lake. Station 06CA001 on the river 3 km upstream of the bridge was used for flow data. Minimum, average and maximum flows for the station are 5.3, 10.5 and 19.1 m^3/s, respectively.

Figure 5.12 shows the estimated distances downstream of the spill location to which the solids are transported with settling rates based on a turbulent flow assumption. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions (i.e. within ~6 m of the container). This indicates that the hypothetical spill would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 µm is approximately 11 and 17 m from the crossing for calcined and un-calcined products, respectively.

Sediment quality results are shown in Table 5.12 for post remediation conditions. The results presented in the table are a summary of the three flow conditions for the predicted sediment concentrations in Lac La Ronge. Porewater quality within the impacted sediment of Lac La

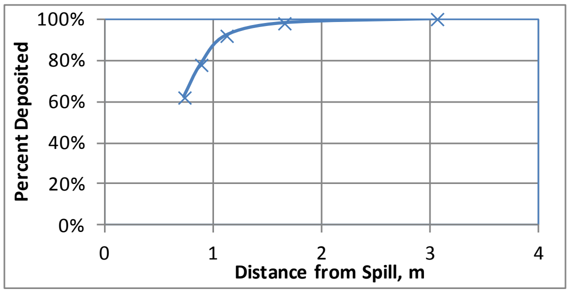
Ronge was estimated using sediment-to-water partition coefficients. Water concentrations were estimated for the three flow conditions for short and long term periods using information on uranium solubility and porewater concentrations, respectively. The short-term period for Lac La Ronge is estimated at a few months if no settling is taken into account. However, in reality all of the spilled material will be settled long before this estimated time, resulting in a transient time in the order of hours. It was assumed that 25% of all drums were compromised and released UOC into the lake. The results are shown in Table 5.13 for mixing in 5%, 25% and 100% of water flow.

Figure 5.11 Location of Crossing and Stations in Lac La Ronge

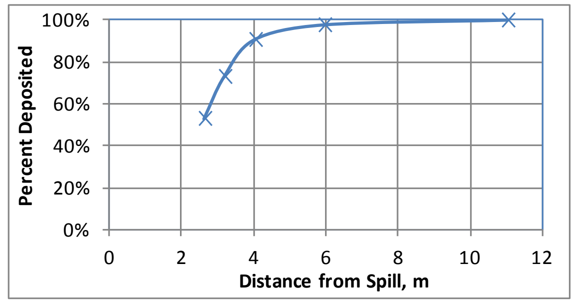
Figure 5.12 Distribution of Deposited UOC by Distance in Lac La Ronge

a) Calcined product

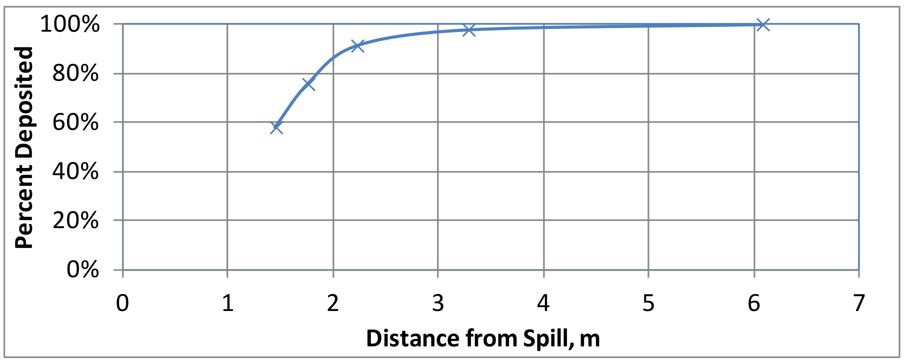
Minimum Flow



Maximum Flow

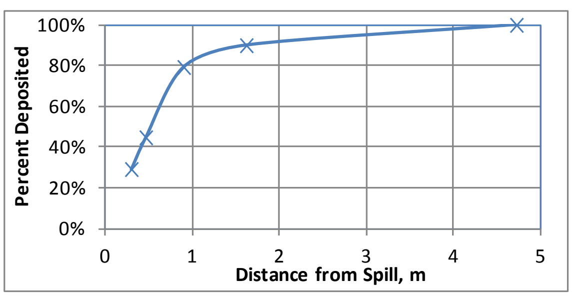


Average Flow

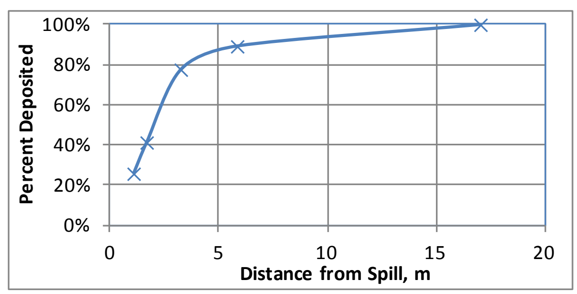


b) Un-calcined product

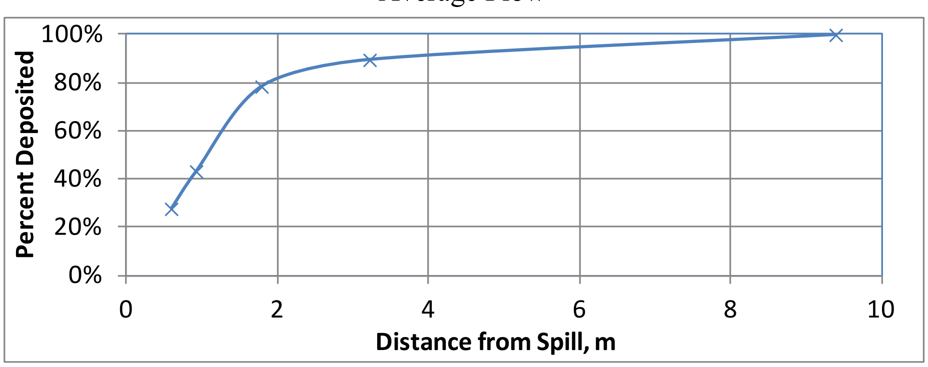
Minimum Flow



Maximum Flow



Average Flow



Note: The horizontal scale is not the same for all figures.

Table 5.12 Estimated Post-Remediation Sediment and Porewater Quality in Lac La Ronge

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	3	8125	28
Average	6	4920	17
Maximum	11	2910	10

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	5	17966	63
Average	9	12603	44
Maximum	17	8280	29

Table 5.13 Estimated Water Quality (µg/L) in Lac La Ronge Crossing

a) Calcined product

Duration	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	1826	1742	1657	365	348	331	91.3	87.1	82.8
Long-term*	n/a	n/a	n/a	0.12	0.07	0.04	0.029	0.017	0.009

b) Un-calcined product

Duration	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	2291	2186	2079	458	437	416	115	109	104
Long-term*	n/a	n/a	n/a	0.26	0.172	0.108	0.064	0.043	0.027

Note:
† Estimated at a few hours when settling is taken into account
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

5.4.2 Wollaston Lake

Wollaston Lake is one of the largest lakes in northern Saskatchewan and is unique in that it has two outflows, one to the Mackenzie River system in the west and the other to the Churchill River system in the east. Wollaston Lake has a surface area of 2286 km^2 and drains an area of about 23000 km^2. The water level of Wollaston Lake has been recorded since 1952. Over the period of record the maximum daily elevation was 28.99 m while the minimum daily elevation was 27.74 m, a difference of 1.26 m. Its depth reached 50 m in some areas.

A hypothetical truck accident may occur upstream of Hidden Bay of the lake on the Umpherville River (Figure 5.13). There is no hydrometric gauging station in close vicinity of this location, and discharge was estimated by using a run-off factor from the Thyme Hill River (station 06DB003). The estimated values are 2, 6.2 and 17 m^3/s for minimum, average and maximum flows, respectively. Average depth in Hidden Bay was considered to be 5 m with minimum and maximum depth considered at ±15% of the average value.

The crossing and therefore hypothetical location of an accident on Wollaston Lake is located on a river about 4 km east of Hidden Bay, and therefore, unless the estimated extent of impacted sediment reaches the lake, the accident is treated as a spill in a river. The river width at the location of crossing is measured at about 30 m.

Figure 5.14 shows the estimated distances downstream of the spill location to which the solids are transported with settling rates based on a turbulent flow assumption. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions (i.e. within ~14 m of the container). This indicates that the hypothetical spill would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 μm is approximately 26 and 40 m from the crossing for calcined and un-calcined products, respectively.

Sediment quality results are shown in Table 5.14 for post remediation conditions. The results presented in the table are a summary of the three flow conditions for the predicted sediment concentrations in Wollaston Lake. Porewater quality within the impacted sediment of Hidden Bay was estimated using sediment-to-water partition coefficients (Table 5.14). Water concentrations were estimated for the three flow conditions for short and long term periods using information on uranium solubility and porewater concentrations, and the results are shown in Table 5.15.

Figure 5.13 Crossing Location on Wollaston Lake

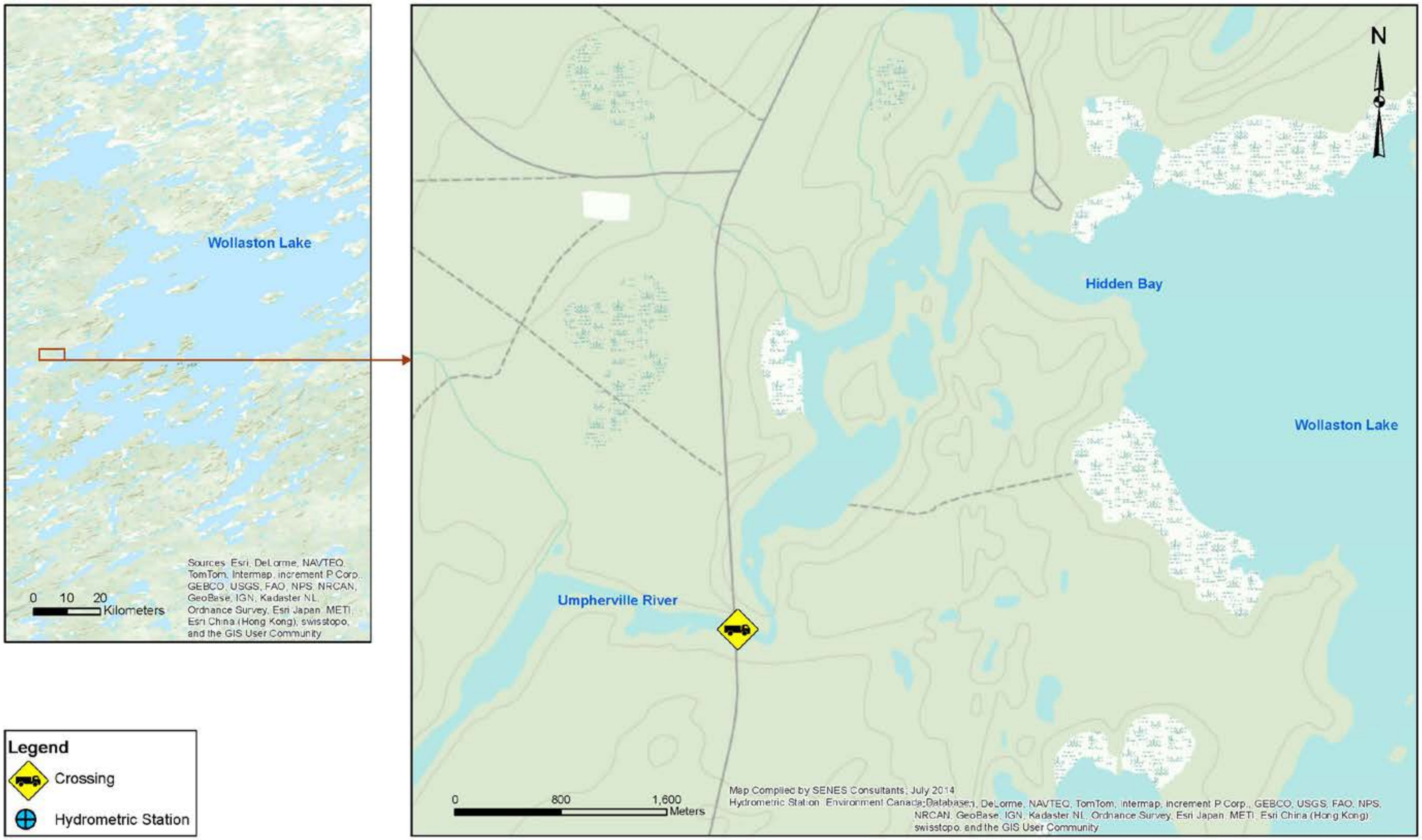
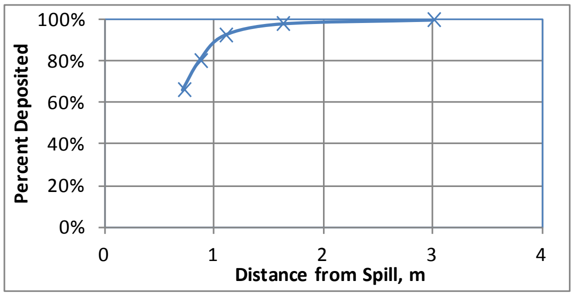


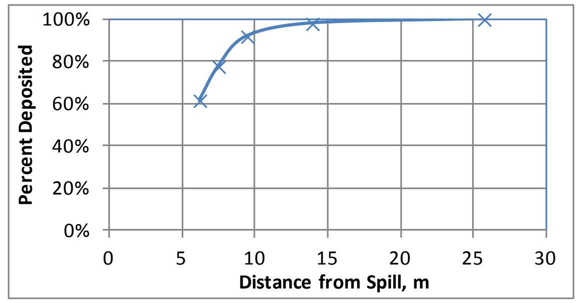
Figure 5.14 Distribution of Deposited UOC in Hidden Bay-of Wollaston Lake

a) Calcined product

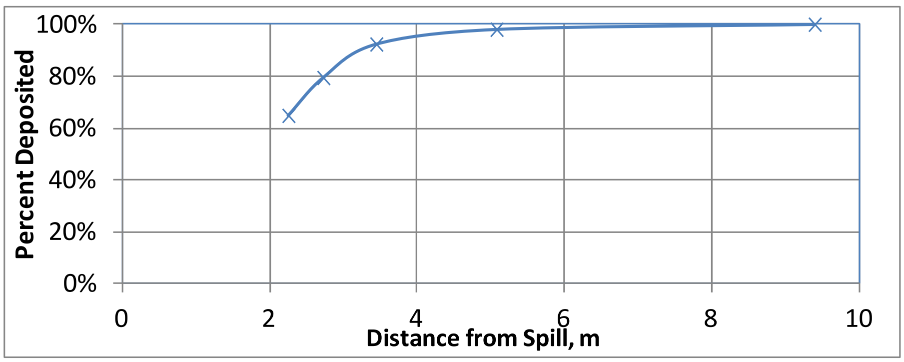
Minimum Flow



Maximum Flow

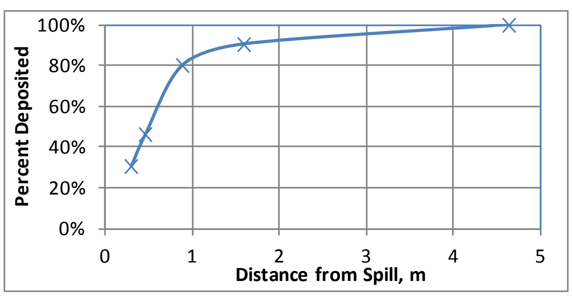


Average Flow

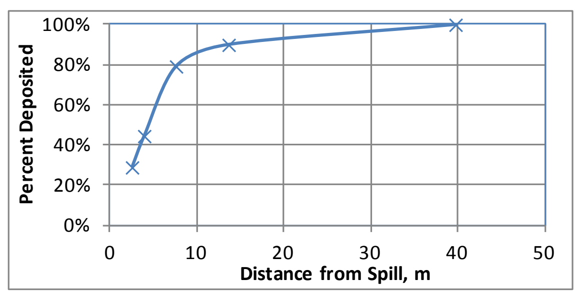


b) Un-calcined product

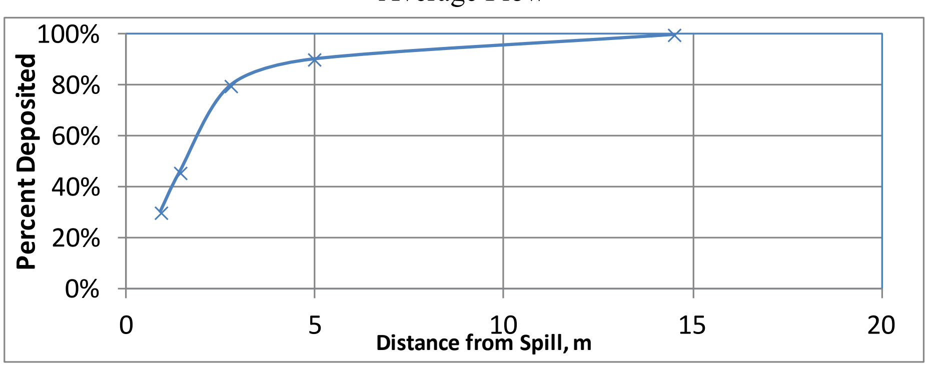
Minimum Flow



Maximum Flow



Average Flow



<u>Note:</u> The horizontal scale is not the same for all figures.

Table 5.14 Estimated Post-Remediation Sediment and Porewater Quality in Hidden Bay of Wollaston Lake

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	3	8127	28
Average	9	3420	12
Maximum	26	1433	5

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	5	18496	65
Average	14	10178	36
Maximum	40	5394	19

Table 5.15 Estimated Water Quality at Wollaston Lake Crossing

a) Calcined product

Duration	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	8545	7264	6316	1709	1453	1263	427	363	316
Long-term*	n/a	n/a	n/a	0.54	0.19	0.071	0.14	0.049	0.018

b) Un-calcined product

Duration	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	10721	9112	7924	2144	1822	1585	536	456	396
Long-term*	n/a	n/a	n/a	1.24	0.58	0.27	0.31	0.145	0.067

Note:
† Estimated at a few hours when settling is taken into account
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

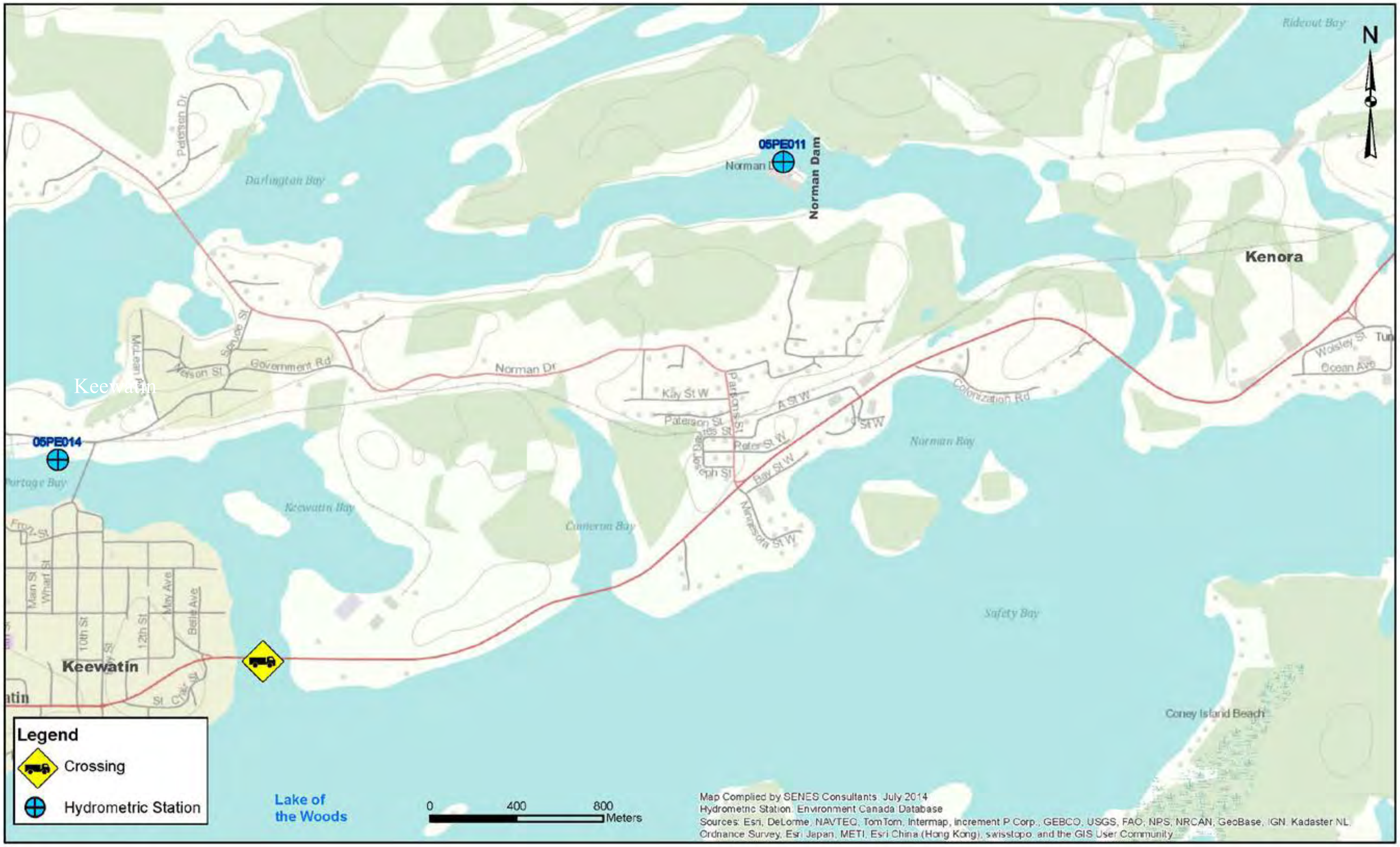
5.4.3 Lake of the Woods

Lake of the Woods occupies parts of Ontario and Manitoba as well as the U.S. state of Minnesota. It covers an area of 4350 km^2 (of which 3149 km^2 are in Canada) with maximum length and width measured at about 100 km each. The lake is fed by Rainy River from the south and drained to the northwest to the Winnipeg River.

The crossing where a hypothetical truck accident may occur is located on a bridge between Keewatin and Kenora (Figure 5.15). The closest hydrometric gauging station is station number 05PE014 in Keewatin Bay reporting lake level. At this station, minimum, mean and maximum elevations have been reported at 321.9, 322.7 and 323.45 masl, respectively. For an altitude of 317 m, these correspond to depths of 4.9, 5.7 and 6.4 m, respectively. Station number 05PE011 at the western outlet of the lake (above Norman Dam) reports flow at 184, 322 and 641 m^3/s for low, average and high flow conditions, respectively. Assuming that the lake discharges the same amount to the eastern outlet (to Rideout Bay), lake flows at this area were estimated at twice the values reported at station 05PE011.

In the absence of detailed information on lake currents, two scenarios were modeled, where spilled UOC impacts the enclosed water of Keewatin Bay (Figure 5.16) or it enters the main body of the Lake.

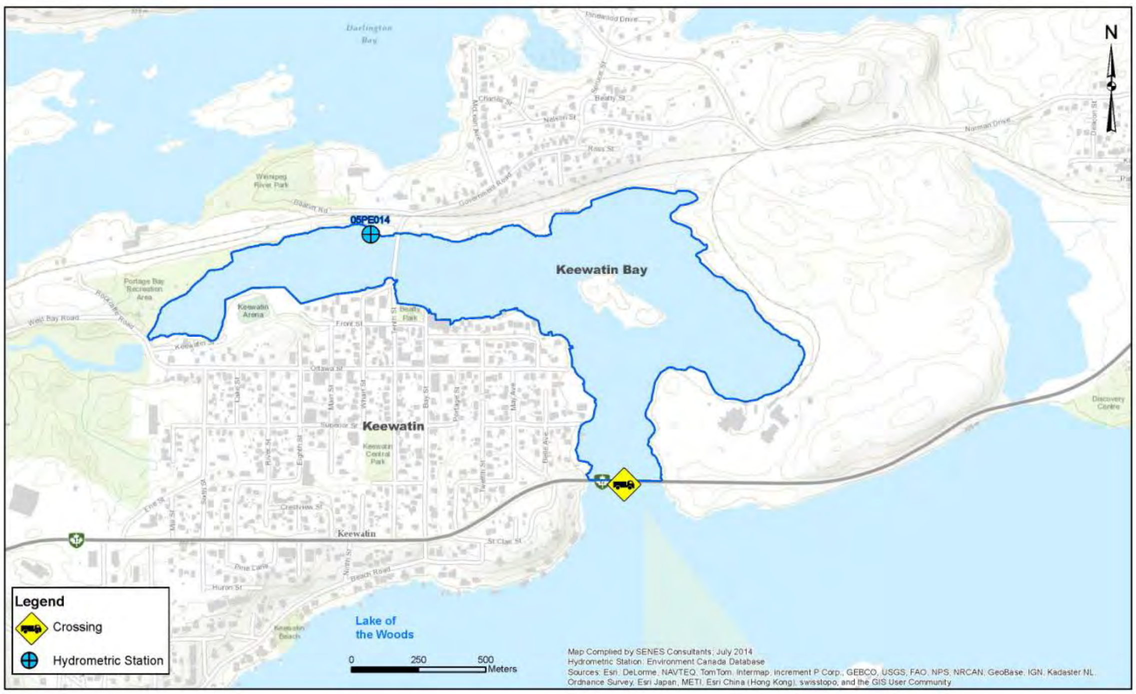
Figure 5.15 Location of Crossing and Stations in Lake of the Woods



5.4.3.1 Small Lake Model

Under the first scenario, water flow in the area was considered minimal and the bay was modeled as a small lake (see section 5.2.5). Since the bay volume (about 1.5x 10^6 m^3) is close to the threshold volume of a small lake (estimated at 2.3x 10^6 m^3), the enclosed area will be contaminated. The bay area (about 30 ha) is larger than the threshold area of a small lake (estimated at 3 ha), nonetheless, it is anticipated that a UOC spill will impact the sediment in a way that requires remediation of the whole area.

Figure 5.16 Schematic of Modeled Areas in Lake of the Woods- Small Lake Model



5.4.3.2 Large Lake Model

Figure 5.17 provides a schematic of the impacted area under the second scenario, where UOC is mixed with lake currents. The results for this scenario are provided below.

The lake width at the crossing is measured about 180 m. The lake widens to about 280 at a distance of about 120 m. The lake widens to about 6 km at a distance of 2 km. The main body of the lake measures about 100 km by 100 km. Water velocity varies significantly in the areas identified, and to accommodate these variations in estimating the area of impacted sediment, a schematic of the actual lake was used to represent three areas of the lake (Figure 5.18).

Figure 5.17 Schematic of Modeled Areas in Lake of the Woods - Large Lake Model

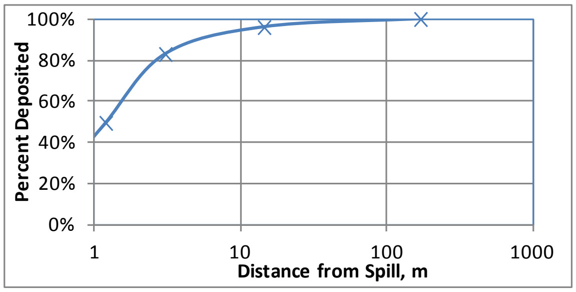
Figure 5.18 shows the estimated distances downstream of the spill location to which the solids are transported with settling rates based on a turbulent flow assumption. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions (i.e. within ~50 m of the container). This indicates that the hypothetical spill would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 µm is approximately 500 and 3400 m from the crossing for calcined and un-calcined products, respectively.

Sediment quality results are shown in Table 5.16 for post remediation conditions. The results presented in the table are a summary of the three flow conditions for the predicted sediment concentrations in Lake of the Woods. Porewater quality within the impacted sediment of Lake of the Woods was estimated using sediment-to-water partition coefficients (Table 5.16). Water concentrations were estimated for the three flow conditions for short and long term periods using information on uranium solubility and porewater concentrations, respectively, and the results are shown in Table 5.17.

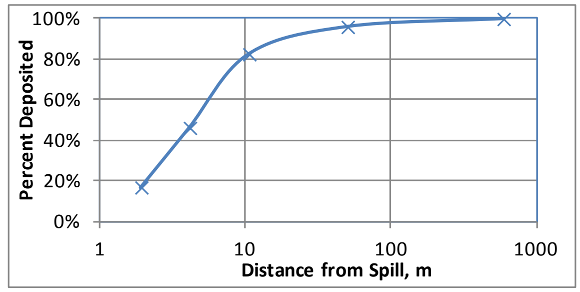
Figure 5.18 Distribution of Deposited UOC by Distance in Lake of the Woods

a) Calcined product

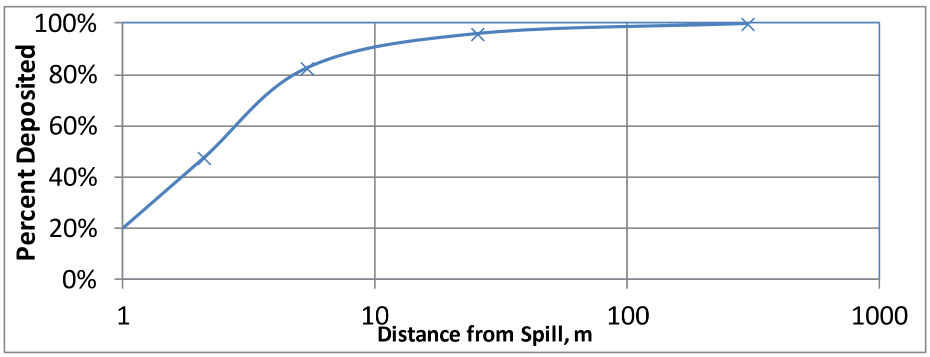
Minimum Flow



Maximum Flow

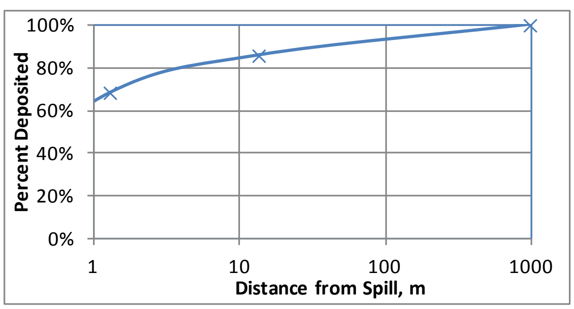


Average Flow

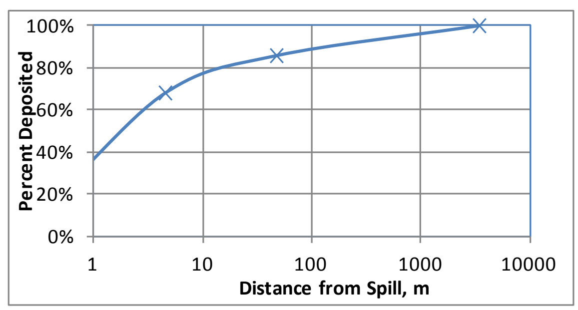


b) Un-calcined product

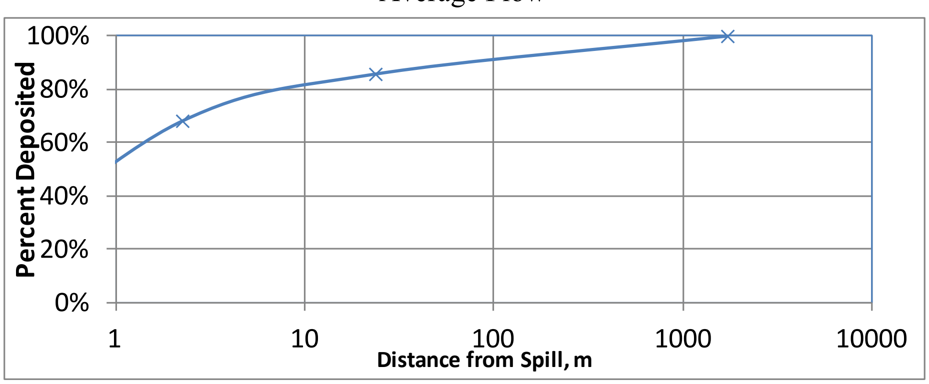
Minimum Flow



Maximum Flow



Average Flow



Note: The horizontal scale is not the same for all figures.

Table 5.16 Estimated Post-Remediation Sediment and Porewater Quality in Lake of the Woods

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	169	5270	18
Average	297	2840	10
Maximum	592	1314	5

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	964	16146	57
Average	1693	12262	43
Maximum	3367	7778	27

Table 5.17 Estimated Water Quality at Lake of the Woods Crossing

a) Calcined product

Duration	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	1.8	1.6	1.4	0.37	0.32	0.28	0.09	0.08	0.07
Long-term*	n/a	n/a	n/a	7.6E-05	3.5E-05	1.5E-05	1.9E-05	8.8E-06	3.6E-06

b) Un-calcined product

Duration	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	2.3	2.	1.8	0.46	0.4	0.35	0.12	0.1	0.088
Long-term*	n/a	n/a	n/a	2.3E-04	1.5E-04	8.6E-05	5.8E-05	3.8E-05	2.1E-05

Note:
† Estimated at a few days when settling is taken into account
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

5.4.4 Vancouver Harbour

Vancouver Harbour in British Columbia is defined as the waters to the east of Point Atkinson and consists of three water bodies, namely Inner Burrard Inlet, Port Moody Arm, and Indian Arm. Outer Burrard Inlet or English Bay downstream of the harbour may also be included in the assessment. The approximate length of the system is about 30 km with maximum width of about 4 km in English Bay.

A hypothetical train accident may occur in the harbour in downtown Vancouver where UOC is being transferred to ships (Figure 5.19). There is no hydrometric gauging station in close vicinity of this location, and discharge was estimated by adding discharges from various streams reporting to the harbor. These streams include Mosquito Creek, MacKay Creek, Lynn Creek, Seymour River, Noons Creek and Indian River. Some of these have hydrometric gauging stations, which were used in flow estimation. The estimated values are 22, 43 and 68 m^3/s for minimum, mean and maximum flows, respectively. Water level in the harbour has been reported between 10 and 45 m, with an average of 21 m.

Figure 5.20 shows the estimated distances downstream of the spill location to which the solids are transported with settling rates based on a turbulent flow assumption. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions (i.e. within ~150 m of the container). This indicates that the hypothetical spill would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 μm is approximately 1800 and 6900 m from the crossing for calcined and un-calcined products, respectively.

Sediment quality results are shown in Table 5.18 for post remediation conditions. The results presented in the table are a summary of the three flow conditions for the predicted sediment concentrations in Vancouver Harbour. Porewater quality within the impacted sediment of Vancouver Harbour was estimated using sediment-to-water partition coefficients. Water concentrations were estimated for the three flow conditions for short and long term periods using information on uranium solubility and porewater concentrations, respectively, and the results are shown in Table 5.19.

Figure 5.19 Transfer Location in Vancouver Harbour

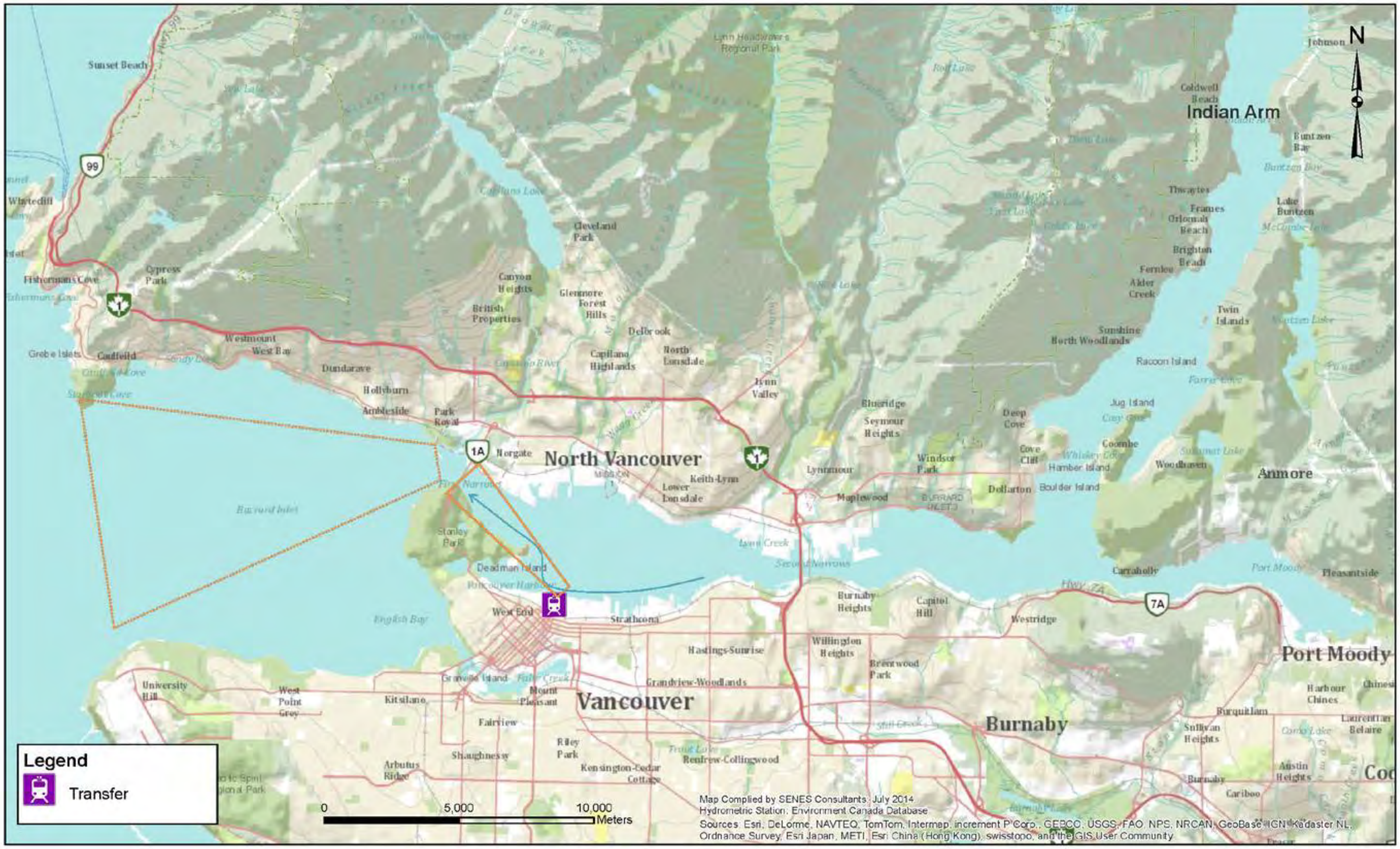
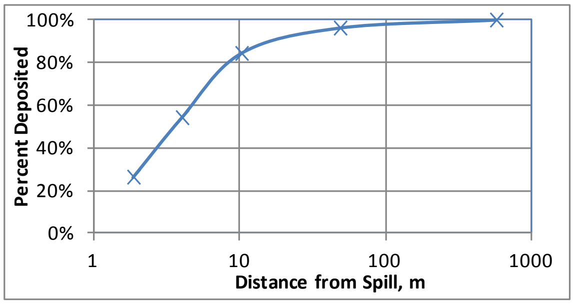


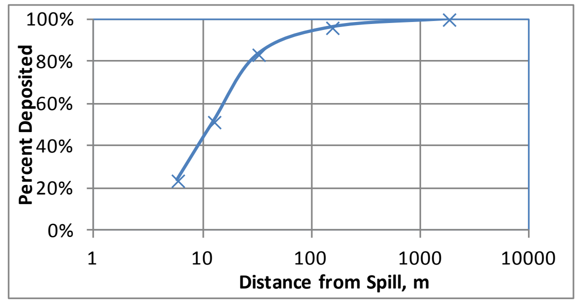
Figure 5.20 Distribution of Deposited UOC by Distance in Vancouver Harbour

a) Calcined product

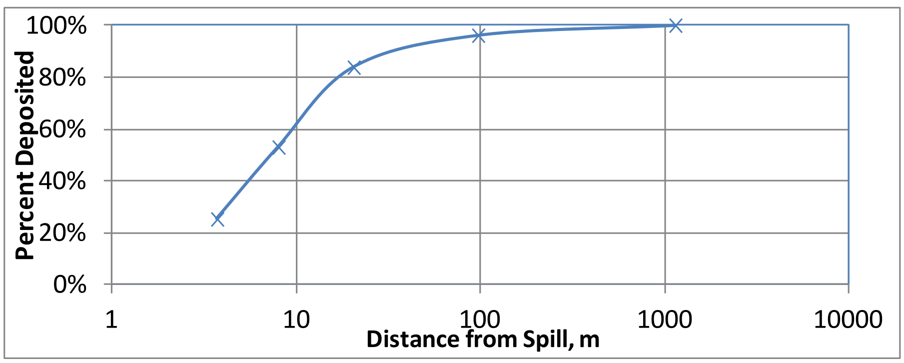
Minimum Flow



Maximum Flow

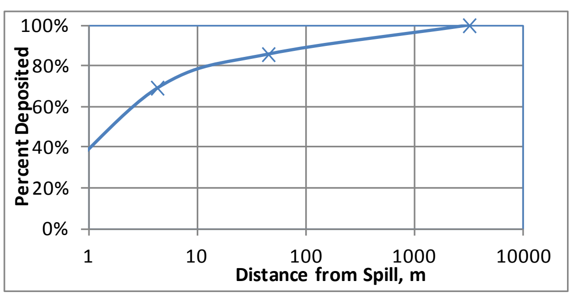


Average Flow

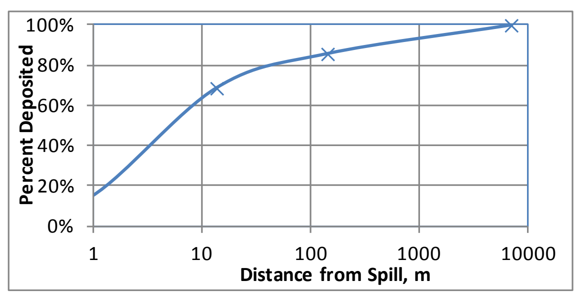


b) Un-calcined product

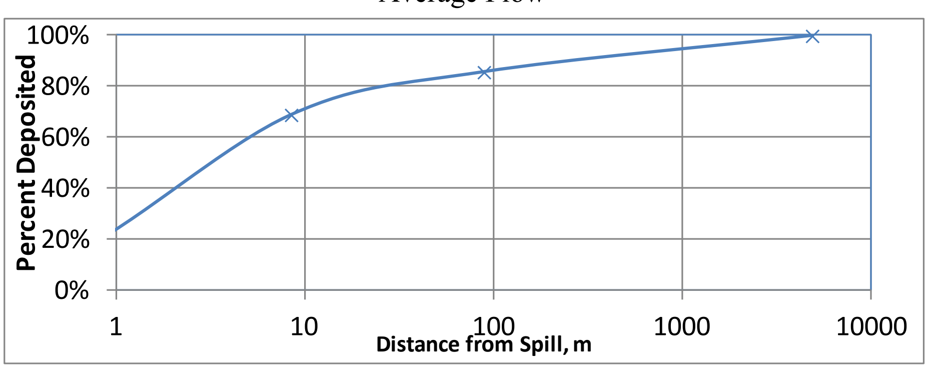
Minimum Flow



Maximum Flow



Average Flow



Note: The horizontal scale is not the same for all figures.

Table 5.18 Estimated Post-Remediation Sediment and Porewater Quality in Vancouver Harbour

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	567	1616	5.7
Average	1127	840	2.9
Maximum	1788	933	3.3

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	3123	6295	22
Average	4838	3629	13
Maximum	6865	2305	8.1

Table 5.19 Estimated Water Quality at Vancouver Harbour Crossing

a) Calcined product

	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
Duration	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	86.5	41.2	19.2	17.3	8.2	3.8	4.3	2.1	0.96
Long-term*	n/a	n/a	n/a	0.001	2.71E-04	1.41E-04	2.74E-04	6.78E-05	3.51E-05

b) Un-calcined product

	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
Duration	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	108	51.7	24.1	21.7	10.3	4.8	5.4	2.6	1.2
Long-term*	n/a	n/a	n/a	0.004	0.001	3.5E-04	0.001	2.9E-04	8.7E-05

Note:
† Estimated at a few days when settling is taken into account
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

5.4.5 Lake Saint-Louis

Lake Saint-Louis in Quebec receives inflows from the Ottawa River as well as the St. Lawrence River. It covers an area of 148 km^2 and measures about 23 km by 6.5 km with an average depth of three meters. Mean discharge has been reported at 8400 m^3/s.

The crossing where a hypothetical train accident may occur is located on a bridge between L'Ile-Perrot and Montreal (Figure 5.21). Active hydrometric stations are located downstream of the lake (02OA016) as well as on the two major inflows, the Ottawa River (02KF005) and the Saint Lawrence River (02MC002). Flow at the crossing was estimated as the difference between flows at 02OA016 and 02MC002 divided by two to account for branching of Ottawa River before the crossing. This calculation led to minimum, mean and maximum flows of 295, 388 and 735 m^3/s. Minimum and maximum depths were assumed at ±15% of an average depth of three meters.

Figure 5.22 shows the estimated distances downstream of the spill location to which the solids are transported with settling rates based on a turbulent flow. The results indicate that most (96% for calcined and 85% for un-calcined products) of the UOC will settle within a short distance, even under high flow conditions (i.e. within ~37 m of the container). This indicates that the hypothetical spill would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e. worst-case), the maximum estimated distance for the deposition of particulates <5 µm is approximately 69 and 107 m from the crossing for calcined and un-calcined products, respectively.

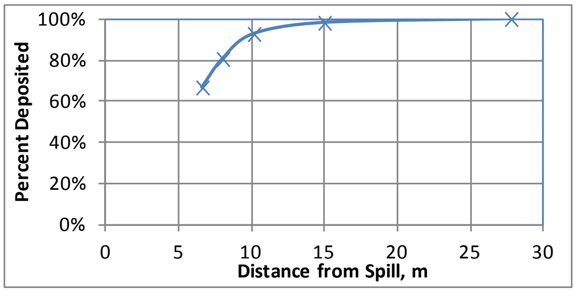
Sediment quality results are shown in Table 5.20 for post remediation conditions. Porewater quality within the impacted sediment of Lake Saint-Louis was estimated using sediment-to-water partition coefficients. Water concentrations were estimated for the three flow conditions for short and long term periods using information on uranium solubility and porewater concentrations, respectively, and the results are shown in Table 5.21.

Figure 5.21 Location of Crossing and Stations in Lake Saint-Louis

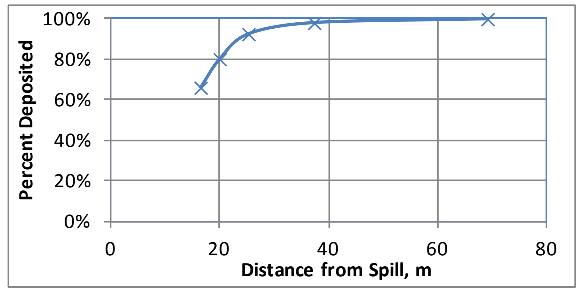
Figure 5.22 Distribution of Deposited UOC by Distance in Lake Saint-Louis

a) Calcined product

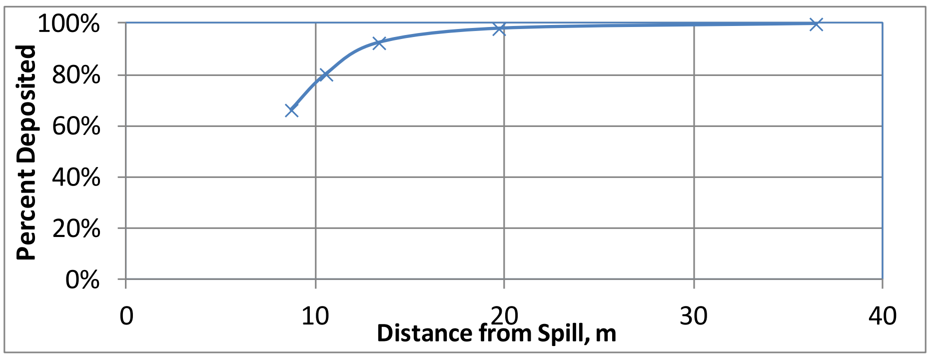
Minimum Flow



Maximum Flow

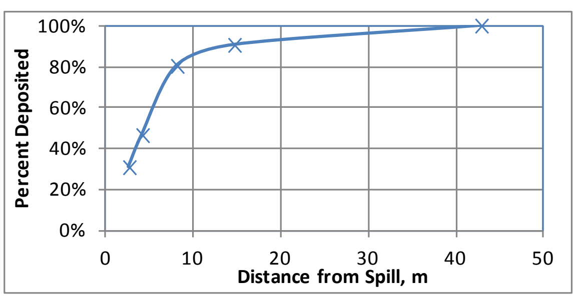


Average Flow

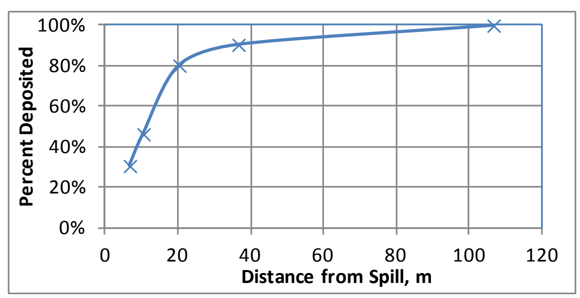


b) Un-calcined product

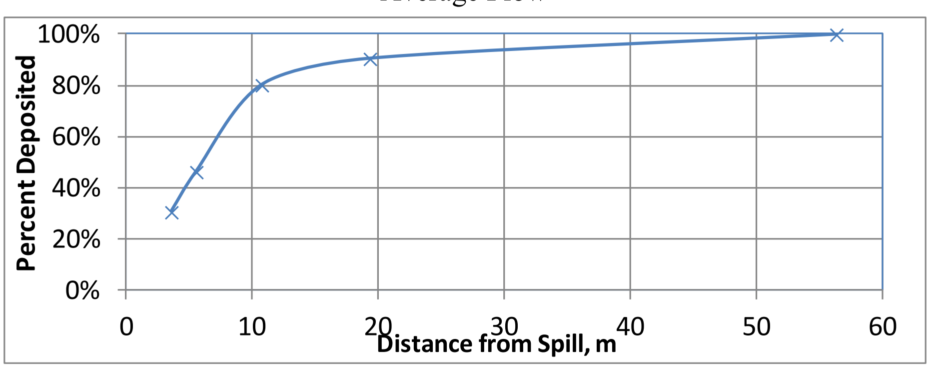
Minimum Flow



Maximum Flow



Average Flow



<u>Note:</u> The horizontal scale is not the same for all figures.

Table 5.20 Estimated Post-Remediation Sediment and Porewater Quality in Lake Saint-Louis

a) Calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	28	621	2.2
Average	36	485	1.7
Maximum	69	349	1.2

b) Un-calcined product

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	43	2587	9.1
Average	56	2084	7.3
Maximum	107	1368	4.8

Table 5.21 Estimated Water Quality at Lake Saint-Louis Crossing

a) Calcined product

Duration	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	1484	1261	1097	297	252	219	74	63	55
Long-term*	n/a	n/a	n/a	0.007	0.005	0.003	0.002	0.001	0.001

b) Un-calcined product

Duration	Mixing in 5% of Flow			Mixing in 25% of Flow			Mixing in 100% of Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	1861	1582	1376	372	316	275	93	79	69
Long-term*	n/a	n/a	n/a	0.03	0.021	0.012	0.008	0.005	0.003

Note:
† Estimated at a few hours when settling is taken into account
* Post remediation
n/a- mixing in 5% is not relevant for long-term concentrations

6.0 EXPOSURE AND RISK CALCULATIONS FOR SURFACE WATER RELEASE

6.1 SUMMARY OF METHODOLOGY

In this section, the potential exposure to people and the environment subsequent to an accident is assessed. The implication of this exposure is assessed through the risk calculations.

The assessment of effects to ecological receptors is made by comparing exposure estimates to TRVs (Section 4.4). For example, intake (or dose) estimates are compared to non-radiological TRVs and to dose rate guidelines for radionuclides to assess the risks of adverse health effects for each of the ecological receptors. For people, the estimated exposure is compared to TRVs specific to the protection of human health (Section 4.5).

The assessment of effects on ecological receptors is similar to that for human health in that potential receptors are identified, the toxicity of a COC is investigated, the exposure is estimated and a risk characterization is completed. A fundamental difference exists, however between the two. For people, consideration is given to effects on individuals, while for ecological health, effects are considered on a population-level. Estimation of population level impacts is a complex issue and involves some level of scientific judgement.

The results of water and sediment quality predictions were used to assess exposures of ecological species 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/d or Bq/d) and then use a transfer factor or TF (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 being important for estimating internal radiological dose; and intakes are used for assessment of non-radiological contaminants. Detailed methodology 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 (SI) values (may also be called hazard quotients or HQs). The SI values provide an integrated description of the potential hazard, the exposure (or dose) response relationship and the exposure evaluation. This approach is widely used as a key line of evidence in ecological assessments, particularly in screening-type assessments (EC 2012).

The acute exposure to all aquatic species, with the exception of benthic invertebrates was assessed. Since an acute TRV is not available for benthic invertebrates and they are exposed to both sediments and water, benthic invertebrate exposure was considered to be chronic.

In the assessment of population-level effects on benthic invertebrates, one of the key considerations in this predictive assessment is the scale of the impact. As discussed by U.S. EPA (2003), if the area is large, the effects will be diluted. However, if the area is small, the affected population or community may be too insignificant to prompt stakeholder concern or action. For this assessment, population-level impacts are judged to occur if more than 5% of a lake is affected or 0.2 hectares in river systems. In general, rivers are expected to support a less robust population of benthic invertebrates due to the lack of depositional habitat.

The results of the water quality predictions were used to assess exposures of a resident to chemical uranium as well as radionuclides. For 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 long-term assessment for people, the estimated uranium concentration in water and fish was used to calculate the intake of contaminants. As discussed in Section 4.5, estimated daily intake of uranium was compared with the human oral TRV of 0.0006 mg/kg-day (Health Canada 2009) and the estimated radiological dose was compared to the human reference dose of 1 mSv/yr (CNSC 2000).

6.2 RELEASE TO RIVERS

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 mean conditions. As demonstrated in Section 5.2, higher concentrations are possible with incomplete mixing within the river; however, this would represent a much smaller area of impact.

6.2.1 Assiniboine River

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in the Assiniboine River.

Table 6.1 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor selected for assessment in the Assiniboine River for average flow conditions for exposure to spill of both calcined and uncalcined products. As seen from the table, the SI values for short-term water and sediment concentrations are above the reference value of 1; these are examined further in the following discussion. 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 grouse, vole or deer. No additional exceedance is observed under low or high flow conditions.

Water: In the determination of the evaluation of the potential impact, a comparison was made between the results of the estimated short-term water quality and the results of the SSD. The concentration of 240 - 300 µg/L is between the 90^{th} and 80^{th} percentile protection level from the SSD. This indicates that there may be some sensitive zooplankton species that are affected, but wide-spread effects on aquatic biota due to the water concentration change in the short-term is not expected.

Sediment: Concentrations in post-remediation conditions (95% cleanup within 15 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.2 , spilled UOC would spread over a distance of approximately 30 m in the average flow condition, covering an area of approximately 1200 m^2 (0.12 ha). These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations following a spill but the spatial extent would be limited.

Table 6.1 Consequences on Ecological Receptors for Average Flow in Assiniboine River

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.24	-	-	-	-	7.2	-	-
Sediment- dw	11390	-	-	-	-	1.9- 109	-	-
Grouse	0.01	58	1.18E-05	-	1.18E-05	-	0.36	<0.001
Vole	5.00E-07	0.05	1.88E-06	-	1.88E-06	-	0.004	<0.001
Deer	3.22E-04	0.014	0.001	-	0.001	-	0.001	0.018

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.3	-	-	-	-	9.1	-	-
Sediment- dw	23833	-	-	-	-	4.1- 228	-	-
Grouse	0.012	72	1.21E-05	-	1.21E-05	-	0.45	<0.001
Vole	6.27E-07	0.06	1.88E-06	-	1.88E-06	-	0.005	<0.001
Deer	4.03E-04	0.018	0.001	-	0.001	-	0.002	0.018

Benchmarks: Water, mg/L: 0.033 (short-term); 0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th} protection levels)
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 160 (grouse), 11.4 (vole, deer) Dose, mSv/d: 2.4

6.2.2 Columbia River

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in the Columbia River.

Table 6.2 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor selected for assessment in the Columbia River for average flow conditions. As seen from the table, the SI values for short-term water and sediment concentrations are above the reference value of 1; these are examined further in the following discussion. 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 ptarmigan, grouse, vole or deer. No additional exceedance is observed under low or high flow conditions.

Water: In the determination of the evaluation of the potential impact, a comparison was made between the results of the estimated short-term water quality and the results of the SSD. The concentration of 120 - 150 µg/L is below the 90^{th} percentile protection level from the SSD. This indicates that there may be some sensitive zooplankton species that are affected, but the overall functioning of the ecowide-spread effects on aquatic biota due to the water concentration change in the short-term is not expected.

Sediment: Concentrations in post-remediation conditions (95% cleanup within 15 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.4 , spilled UOC would spread over a distance of about 80 m (calcined) and 125 m (un-calcined) in the average flow condition, covering an area of approximately 5000-8000 m^2 (0.5-0.8 ha). These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations following a spill.

Table 6.2 Consequences on Ecological Receptors for Average Flow in Columbia River

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.12	-	-	-	-	3.6	-	-
Sediment- dw	11089	-	-	-	-	1.9- 106	-	-
Grouse	0.005	28.6	1.13E-05	-	1.13E-05	-	0.18	<0.001
Vole	2.48E-07	0.024	1.88E-06	-	1.88E-06	-	0.002	<0.001
Deer	1.60E-04	0.007	0.001	-	0.001	-	<0.001	0.018
Ptarmigan	1.42E-06	0.008	1.07E-05	-	1.07E-05	-	<0.001	<0.001

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.15	-	-	-	-	4.5	-	-
Sediment- dw	16075	-	-	-	-	2.7- 154	-	-
Grouse	0.006	35.8	1.14E-05	-	1.14E-05	-	0.22	<0.001
Vole	3.11E-07	0.03	1.88E-06	-	1.88E-06	-	0.003	<0.001
Deer	2.00E-04	0.009	0.001	-	0.001	-	<0.001	0.018
Ptarmigan	1.78E-06	0.009	1.07E-05	-	1.07E-05	-	<0.001	<0.001

Benchmarks: Water, mg/L: 0.015 (short-term); 0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th} protection levels)
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 160 (grouse and ptarmigan), 11.4 (vole, deer) Dose, mSv/d: 2.4

6.2.3 Kaministiquia River

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in the Kaministiquia River.

Table 6.3 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor selected for assessment in the Kaministiquia River for average flow conditions. As seen from the table, the SI values for short-term water and sediment concentrations are above the reference value of 1; these are examined further in the following discussion. 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 grouse, vole or deer.

Water: In the determination of the evaluation of the potential impact, a comparison was made between the results of the estimated short-term water quality and the results of the SSD. The concentration of 380 - 470 µg/L is above the 90^{th} percentile protection level from the SSD but below the 80^{th} percentile protection level. This indicates that there may be some sensitive zooplankton species that are affected, but wide-spread effects on aquatic biota due to the water concentration change in the short-term is not expected.

Sediment: Concentrations in post-remediation conditions (95% cleanup within 15 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.6, spilled UOC would spread over a distance of about 6 m (calcined) and 10 m (un-calcined) in the average flow condition, covering an area of approximately 200 m^2 (0.02 ha). These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations following a spill but the spatial extent would be limited. In addition, due to the small scale of the affected area, this area can be cleaned up easily.

Table 6.3 Consequences on Ecological Receptors for Average Flow in Kaministiquia River

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.38	-	-	-	-	11.4	-	-
Sediment- dw	17597	-	-	-	-	3- 169	-	-
Grouse	0.015	91	1.25E-05	-	1.25E-05	-	0.57	<0.001
Vole	7.93E-07	0.08	1.88E-06	-	1.88E-06	-	0.007	<0.001
Deer	0.001	0.023	0.001	-	0.001	-	0.002	0.018

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.47	-	-	-	-	14.4	-	-
Sediment- dw	32834	-	-	-	-	5.6- 315	-	-
Grouse	0.019	114	1.29E-05	-	1.29E-05	-	0.72	<0.001
Vole	9.95E-07	0.09	1.88E-06	-	1.88E-06	-	0.008	<0.001
Deer	0.001	0.028	0.001	-	0.001	-	0.002	0.018

Benchmarks: Water, mg/L: 0.033 (short-term); 0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th} protection levels)
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 160 (grouse), 11.4 (vole, deer) Dose, mSv/d: 2.4

6.2.4 North Saskatchewan River

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in the North Saskatchewan River.

Table 6.4 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor selected for assessment in the North Saskatchewan River for average flow conditions. As seen from the table, the SI values for short-term water and sediment concentrations are above the reference value of 1; these are examined further in the following discussion. 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 grouse, vole or deer. No additional exceedance is observed under low or high flow conditions.

<u>Water:</u> In the determination of the evaluation of the potential impact, a comparison was made between the results of the estimated short-term water quality and the results of the SSD. The concentration of 50 - 60 µg/L is below the 95^{th} percentile protection level from the SSD. This indicates that there should not be substantial effects on aquatic biota due to the water concentration change in the short-term are not expected.

<u>Sediment:</u> Concentrations in post-remediation conditions (95% cleanup within 15 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.8, spilled UOC would spread over a distance of about 30 m (calcined) and 45 m (un-calcined) in the average flow condition, covering an area of approximately 400-600 m^2 (0.04-0.06 ha). These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations following a spill but the spatial extent would be limited.

Table 6.4 Consequences on Ecological Receptors for Average Flow in North Saskatchewan River

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.05	-	-	-	-	1.5	-	-
Sediment- dw	9275	-	-	-	-	1.6- 89	-	-
Grouse	0.002	12.2	1.10E-05	-	1.10E-05	-	0.08	<0.001
Vole	1.06E-07	0.01	1.88E-06	-	1.88E-06	-	<0.001	<0.001
Deer	6.81E-05	0.003	0.001	-	0.001	-	<0.001	0.018

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.06	-	-	-	-	1.9	-	-
Sediment- dw	20476	-	-	-	-	3.5- 196	-	-
Grouse	0.003	15.3	1.10E-05	-	1.10E-05	-	0.1	<0.001
Vole	1.33E-07	0.013	1.88E-06	-	1.88E-06	-	0.001	<0.001
Deer	8.54E-05	0.004	0.001	-	0.001	-	<0.001	0.018

Benchmarks: Water, mg/L: 0.033 (short-term); 0.043, 0.17 and 0.73 (95th, 90th and 80th protection levels)
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 160 (grouse), 11.4 (vole, deer) Dose, mSv/d: 2.4

6.2.5 Mississagi River

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in the Mississagi River.

Table 6.5 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor selected for assessment in the Mississagi River for average flow conditions for a spill of calcined and un-calcined products. As seen from the table, the SI values for short-term water and sediment concentrations are above the reference value of 1; these are examined further in the following discussion. 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 grouse, vole or deer. No additional exceedance is observed under low or high flow conditions.

Water: In the determination of the evaluation of the potential impact, a comparison was made between the results of the estimated short-term water quality and the results of the SSD. The concentration of 110 - 140 µg/L is below the 90^{th} percentile protection level from the SSD. This indicates that there may be some sensitive zooplankton species that are affected, but the overall functioning of the ecowide-spread effects on aquatic biota due to the water concentration change in the short-term is not expected.

Sediment: Concentrations in post-remediation conditions (95% cleanup within 15 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.10, spilled UOC would spread over a distance of about 40 m (calcined) and 66 m (un-calcined) in the average flow condition, covering an area of approximately 800-1500 m^2 (0.08-0.15 ha). These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations following a spill but the spatial extent would be limited.

Table 6.5 Consequences on Ecological Receptors for Average Flow in Mississagi River

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.11	-	-	-	-	3.4	-	-
Sediment- dw	9646	-	-	-	-	1.6- 92	-	-
Grouse	0.005	27.4	1.13E-05	-	1.13E-05	-	0.17	<0.001
Vole	2.38E-07	0.023	1.88E-06	-	1.88E-06	-	0.002	<0.001
Deer	1.53E-04	0.007	0.001	-	0.001	-	<0.001	0.018

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	0.14	-	-	-	-	4.3	-	-
Sediment- dw	15890	-	-	-	-	2.7- 152	-	-
Grouse	0.006	34.4	1.14E-05	-	1.14E-05	-	0.21	<0.001
Vole	2.99E-07	0.028	1.88E-06	-	1.88E-06	-	0.002	<0.001
Deer	1.92E-04	0.009	0.001	-	0.001	-	<0.001	0.018

Benchmarks: Water, mg/L: 0.033 (short-term); 0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th} protection levels)
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 160 (grouse), 11.4 (vole, deer) Dose, mSv/d: 2.4

6.3 RELEASE TO LAKES

6.3.1 Lac La Ronge

6.3.1.1 Ecological Receptors

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in Lac La Ronge.

Table 6.6 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor selected for assessment in Lac La Ronge for average flow conditions. Radioactivity resulting from background concentrations of radionuclides (i.e., uranium, radium-226, lead-210, polonium-210 and thorium-230) was also included in the calculations.

As seen from the table, the SI values for short-term water and sediment concentrations as well as semi-aquatic wildlife are above the reference value of 1; these are examined further in the following discussion. 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 terrestrial receptors (grouse, vole or deer). Radiological dose would not exceed the respective benchmarks for any of these ecological receptors. No additional exceedance is observed under low or high flow conditions.

<u>Water:</u> For the short-term water quality, comparison was also made between the predicted concentration and the results of the SSD. The concentration of 90-110 µg/L is above the 95th percentile protection level but below the 90th percentile. This indicates that substantial effects on aquatic biota due to the water concentration change in the short-term are not expected. The long-term uranium concentration is less than the Canadian water quality guidelines for protection of the aquatic life (15 µg/L), thus long-term adverse effects are not expected following clean up.

<u>Sediment:</u> Concentrations in post-remediation conditions (95% cleanup within 30 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.12, spilled UOC would spread over a distance of about 6 m (calcined) and 9 m (un-calcined)in the average flow condition, covering an area of approximately 125-200 m^2 (0.0125-0.02 ha). The LEL benchmark for sediment is a reliable predictor of uranium concentrations that will not adversely affect benthic invertebrates. These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations following a spill but the spatial extent would be limited.

<u>Semi-Aquatic Receptors</u>: A UOC spill would result in potential adverse effects to muskrat when considering both the NOAEL and LOAEL TRVs. The assessment of potential effects based on NOAELs is expected to be conservative. The spill could result in potential risks of adverse effects to merganser, scaup, mallard (only un-calcined) and sandpiper. The intakes are largely driven by the incidental ingestion of sediment. Considering the limited spatial extent of the contaminated sediment, population-level effects are unlikely but it is possible for animals directly downgradient of the spill to be affected.

Table 6.6 Consequences on Ecological Receptors for Average Flow in Lac La Ronge

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose *, mSv/d	Concentration	Intake	Dose
Water-short term	0.087	-	-	-	-	2.6	-	-
Water-long term	1.68E-05	-	-	-	-	0.001	-	-
Sediment- dw	16399	-	-	-	-	2.8- 157	-	-
Aquatic Plants-roots	0.003	-	3.30E-07	0.008	0.022	-	-	0.002
Aquatic Plants-leaves	0.003		3.30E-07	7.81E-12	0.014	-		0.001
Benthic Invertebrate	0.002	-	1.79E-07	0.008	0.022	-	-	0.002
Fish-Forage	1.68E-05	-	1.94E-09	0.008	0.022	-	-	0.002
Fish-Predatory	1.68E-05	-	1.94E-09	7.81E-12	0.014	-	-	0.001
Muskrat	0.033	111	2.46E-04	0.01	0.01	-	18.1- 35.6	0.004
Merganser	71.	47.3	0.008	-	0.008	-	2.96	0.01
Scaup	218	309	0.026	-	0.026	-	19.3	0.032
Mallard	9.8	8.1	0.001	-	0.001	-	0.51	0.002
Sandpiper	5.7	154	6.81E-04	0.003	0.004	-	9.6	0.005
Grouse	0.003	0.006	1.11E-05	-	1.11E-05	-	<0.001	<0.001
Vole	1.83E-07	0.017	1.88E-06	-	1.88E-06	-	0.002	<0.001
Deer	1.18E-04	0.005	0.001	-	0.001	-	<0.001	0.018

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose *, mSv/d	Concentration	Intake	Dose
Water-short term	0.11	-	-	-	-	3.3	-	-
Water-long term	4.31E-05	-	-	-	-	0.003	-	-
Sediment- dw	42011	-	-	-	-	7.2- 402	-	-
Aquatic Plants-roots	0.007	-	8.45E-07	0.02	0.034	-	-	0.004
Aquatic Plants-leaves	0.007		8.45E-07	2.00E-11	0.014	-		0.001
Benthic Invertebrate	0.004	-	4.57E-07	0.02	0.034	-	-	0.004
Fish-Forage	4.31E-05	-	4.97E-09	0.02	0.034	-	-	0.004
Fish-Predatory	4.31E-05	-	4.97E-09	2.00E-11	0.014	-	-	0.001
Muskrat	0.085	283	2.52E-04	0.025	0.025	-	46.4- 91.3	0.01
Merganser	182	121	0.021	-	0.021	-	7.6	0.026
Scaup	560	792	0.065	-	0.065	-	49.5	0.081
Mallard	25.	20.8	0.003	-	0.003	-	1.3	0.004
Sandpiper	14.6	394	0.002	0.008	0.01	-	24.7	0.012
Grouse	0.004	0.008	1.12E-05	-	1.12E-05	-	<0.001	<0.001
Vole	2.30E-07	0.022	1.88E-06	-	1.88E-06	-	0.002	<0.001
Deer	1.48E-04	0.007	0.001	-	0.001	-	<0.001	0.018

Benchmarks: Water, mg/L: 0.015 (long-term); 0.033 (short-term as well as aquatic plants and fish); 0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th} protection levels)
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 3.1 and 6.1 (muskrat), 16 (merganser, scaup, mallard, sandpiper), 160 (grouse), 11.4 (vole, deer)
Dose, mSv/d: 9.6 (aquatic receptors); 2.4 (semi-aquatic and terrestrial receptors)
* equivalent dose includes baseline dose, which may be the main contributor to dose for some species.

6.3.1.2 Human Receptors

Predicted short-term uranium concentrations following a UOC spill in Lac La Ronge (about 0.1 mg/L) would exceed the Canadian Drinking Water Quality Guideline (Health Canada 2008) for uranium (0.02 mg/L). The long-term water uranium concentration (incremental concentration of 0.02-0.04 µg/L) in the lake following a UOC spill would not exceed 0.02 mg/L. However, fish consumption is also contributing to the daily intake in the long-term exposure scenario. The uranium ingestion from drinking water and fish and hazard quotients (HQ) for long-term exposure were calculated and are shown in Table 6.7. The hazard quotients for adult, child, and toddler receptors were all below 1.

The radiation doses predicted for a child, toddler and adult ingesting water impacted by a UOC spill are summarized in Table 6.7. The short-term dose to a toddler and child would be higher than an adult. In all cases, however, the dose estimates are well below the Canadian Nuclear Safety Commission regulatory incremental dose limit of 1 mSv/yr for members of the public.

Table 6.7 Consequences for Human Receptors for Average Flow in Lac La Ronge

a) Calcined

Receptor	Exposure		HQ	
	Intake, mg/kg.d	Equivalent Dose, µSv/d	Intake	Dose
Toddler	6.78E-07	2.27E-07	0.001	<0.001
Child	5.41E-07	2.44E-07	<0.001	<0.001
Adult	4.15E-07	2.35E-07	<0.001	<0.001

b) Un-calcined

Receptor	Exposure		HQ	
	Intake, mg/kg.d	Equivalent Dose, µSv/d	Intake	Dose
Toddler	1.74E-06	5.82E-07	0.003	<0.001
Child	1.39E-06	6.25E-07	0.002	<0.001
Adult	1.06E-06	6.03E-07	0.002	<0.001

<u>Note:</u>
Benchmarks: 0.0006 mg/kg.d for intake (of water and fish in the long term) and 1000 µSv/yr for dose

6.3.2 Wollaston Lake

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in Wollaston Lake. Human receptors were not modeled for Wollaston Lake as there is no permanent community in the vicinity of the hypothetical accident.

Table 6.8 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor. As seen from the table, the SI values for short-term water and sediment concentrations as well as semi-aquatic wildlife are above the reference value of 1, these are examined further in the following discussion. 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 terrestrial receptors (grouse, vole, deer, squirrel, and caribou). Radiological dose would not exceed the respective benchmarks for any of these ecological receptors. No additional exceedance is observed under low or high flow conditions.

Water: For the short-term water quality, comparison was also made between the predicted concentration and the results of the SSD. The concentrations of 360-460 µg/L are above the 90^{th} percentile protection level from the SSD but below the 80^{th} percentile level. This indicates that there may be some sensitive zooplankton species that are affected, but wide-spread effects on aquatic biota due to the water concentration change in the short-term is not expected. Long-term uranium concentration is less than the Canadian water quality guidelines for protection of the aquatic life (15 µg/L), thus long-term adverse effects are not expected following clean up.

Sediment: Concentrations in post-remediation conditions (95% cleanup within 15 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.14, spilled UOC would spread over a distance of about 9 m (calcined) and 14 m (un-calcined) in the average flow condition, covering an area of approximately 120-200 m^2 (0.012-0.02 ha). These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations following a spill but the spatial extent would be limited.

Semi-Aquatic Receptors: A UOC spill would result in potential adverse effects to muskrat when considering both the NOAEL and LOAEL TRVs. The assessment of potential effects based on NOAELs is expected to be conservative. The spill could result in potential risks of adverse effects to merganser, scaup, mallard (only un-calcined) and sandpiper. The intakes are largely driven by the incidental ingestion of sediment. Considering the limited spatial extent of the contaminated sediment, population-level effects are unlikely but it is possible for animals directly downgradient of the spill to be affected.

Table 6.8 Consequences on Ecological Receptors for Average Flow in Wollaston Lake

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	**Intake, mg/kg.d**	**Internal Dose**	**External Dose**	**Equivalent Dose*, mSv/d**	**Concentration**	**Intake**	**Dose**
Water-short term	0.36	-	-	-	-	11.	-	-
Water-long term	4.87E-05	-	-	-	-	0.003	-	-
Sediment- dw	11399	-	-	-	-	1.9- 109	-	-
Aquatic Plants-roots	0.008	-	9.56E-07	0.008	0.022	-	-	0.002
Aquatic Plants-leaves	0.008		9.56E-07	7.81E-12	0.014	-		0.001
Benthic Invertebrate	0.004	-	5.17E-07	0.008	0.022	-	-	0.002
Fish-Forage	4.87E-05	-	5.62E-09	0.008	0.022	-	-	0.002
Fish-Predatory	4.87E-05	-	5.62E-09	7.81E-12	0.014	-	-	0.001
Muskrat	0.023	76.8	2.45E-04	0.007	0.007	-	12.6- 24.8	0.003
Merganser	49.4	32.9	0.006	-	0.006	-	2.1	0.007
Scaup	152	215	0.018	-	0.018	-	13.4	0.022
Mallard	6.8	5.7	9.26E-04	-	9.26E-04	-	0.35	0.001
Sandpiper	3.96	107	4.81E-04	0.002	0.003	-	6.7	0.003
Vole	0.020	0.025	1.76E-05	-	1.76E-05	-	<0.001	<0.001
Deer	7.63E-07	0.073	1.88E-06	-	1.88E-06	-	0.006	<0.001
Ptarmigan	4.90E-04	0.022	0.001	-	0.001	-	0.002	0.018
Squirrel	0.015	0.023	1.24E-05	-	1.24E-05	-	<0.001	<0.001
Caribou-B	8.82E-06	0.037	2.17E-05	-	2.17E-05	-	0.003	<0.001
Caribou-W	8.92E-04	0.022	0.002	-	0.002	-	0.002	0.033

Table 6.8 Consequences on Ecological Receptors for Average Flow in Wollaston Lake (Cont'd)

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose*, mSv/d	Concentration	Intake	Dose
Water-short term	0.46	-	-	-	-	13.8	-	-
Water-long term	1.45E-04	-	-	-	-	0.01	-	-
Sediment- dw	33926	-	-	-	-	5.8- 325	-	-
Aquatic Plants-roots	0.025	-	2.85E-06	0.02	0.034	-	-	0.004
Aquatic Plants-leaves	0.025		2.85E-06	2.00E-11	0.014	-	-	0.001
Benthic Invertebrate	0.013	-	1.54E-06	0.02	0.034	-	-	0.004
Fish-Forage	1.45E-04	-	1.67E-08	0.02	0.034	-	-	0.004
Fish-Predatory	1.45E-04	-	1.67E-08	2.00E-11	0.014	-	-	0.001
Muskrat	0.069	229	2.50E-04	0.02	0.02	-	37.5- 73.8	0.008
Merganser	147	97.9	0.017	-	0.017	-	6.1	0.021
Scaup	452	639	0.052	-	0.052	-	40	0.066
Mallard	20.2	16.9	0.002	-	0.002	-	1.1	0.003
Sandpiper	11.8	319	0.001	0.007	0.008	-	19.9	0.01
Vole	0.025	0.031	1.82E-05	-	1.82E-05	-	<0.001	<0.001
Deer	9.57E-07	0.091	1.88E-06	-	1.88E-06	-	0.008	<0.001
Ptarmigan	6.15E-04	0.027	0.001	-	0.001	-	0.002	0.018
Squirrel	0.018	0.029	1.28E-05	-	1.28E-05	-	<0.001	<0.001
Caribou-B	1.11E-05	0.046	2.17E-05	-	2.17E-05	-	0.004	<0.001
Caribou-W	0.001	0.028	0.002	-	0.002	-	0.002	0.033

Benchmarks:
Water, mg/L: 0.033 (short-term); 0.015 (long-term and aquatic plants and fish); 0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th} protection levels)
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 3.1 and 6.1 (muskrat), 16 (merganser, scaup, mallard, sandpiper), 160 (grouse and ptarmigan), 11.4 (vole, deer, squirrel and caribou)
Dose, mSv/d: 9.6 (aquatic receptors); 2.4 (semi-aquatic and terrestrial receptors)
* equivalent dose includes baseline dose, which may be the main contributor to dose for some species.

6.3.3 Lake of the Woods

6.3.3.1 Ecological Receptors

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in Lake of the Woods.

Table 6.9 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor selected for assessment in Lake of the Woods for average flow conditions. As seen from the table, short-term and long-term uranium concentrations are less than the Canadian water quality guidelines (33 µg/L and 15 µg/L). The table does indicate that sediment concentrations as well as semi-aquatic wildlife are above the reference value of 1; these are examined further in the following discussion. 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 terrestrial receptors (grouse, vole or deer). Radiological dose would not exceed the respective benchmarks for any of these ecological receptors. No additional exceedance is observed under low or high flow conditions.

Sediment: Concentrations in post-remediation conditions (95% cleanup within 30 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.18, spilled UOC would spread over a distance of about 300 m (calcined) and 1700 m (un-calcined) for the average flow condition, covering an area of approximately 1.0×10^5 - 8.0×10^5 m^2 (1-8 ha). The bay area of the lake represents about 30 ha. These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations in the bay following a spill.

Semi-Aquatic Receptors: A UOC spill would result in potential adverse effects to muskrat when considering both the NOAEL and LOAEL TRVs. The assessment of potential effects based on NOAELs is expected to be conservative. The spill could result in potential risks of adverse effects to merganser, scaup, mallard (only un-calcined) and sandpiper. The intakes are largely driven by the incidental ingestion of sediment. As the estimated area is much larger than the home range of the receptors population-level effects are possible.

Table 6.9 Consequences on Ecological Receptors for Average Flow in Lake of the Woods

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose*, mSv/d	Concentration	Intake	Dose
Water-short term	7.94E-05	-	-	-	-	0.002	-	-
Water-long term	8.84E-09	-	-	-	-	<0.001	-	-
Sediment- dw	9465	-	-	-	-	1.6- 91	-	-
Aquatic Plants-roots	1.50E-06	-	1.74E-10	0.008	0.022	-	-	0.002
Aquatic Plants-leaves	1.50E-06		1.74E-10	7.81E-12	0.014	-	-	0.001
Benthic Invertebrate	8.13E-07	-	9.39E-11	0.008	0.022	-	-	0.002
Fish-Forage	8.84E-09	-	1.02E-12	0.008	0.022	-	-	0.002
Fish-Predatory	8.84E-09	-	1.02E-12	7.81E-12	0.014	-	-	0.001
Muskrat	0.019	63.8	2.45E-04	0.006	0.006	-	10.5- 20.6	0.002
Merganser	41.	27.3	0.005	-	0.005	-	1.7	0.006
Scaup	126	178	0.015	-	0.015	-	11.1	0.019
Mallard	5.6	4.7	7.90E-04	-	7.90E-04	-	0.29	<0.001
Sandpiper	3.3	88.9	4.03E-04	0.002	0.002	-	5.6	0.003
Grouse	3.17E-06	5.75E-06	1.07E-05	-	1.07E-05	-	<0.001	<0.001
Vole	1.67E-10	1.59E-05	1.88E-06	-	1.88E-06	-	<0.001	<0.001
Deer	1.07E-07	4.76E-06	0.001	-	0.001	-	<0.001	0.018

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mSv/d	Concentration	Intake	Dose
Water-short term	9.96E-05	-	-	-	-	0.003	-	-
Water-long term	3.82E-08	-	-	-	-	<0.001	-	-
Sediment- dw	40875	-	-	-	-	7- 391	-	-
Aquatic Plants-roots	6.49E-06	-	7.49E-10	0.02	0.034	-	-	0.004
Aquatic Plants-leaves	6.49E-06		7.49E-10	2.00E-11	0.014	-		0.001
Benthic Invertebrate	3.51E-06	-	4.06E-10	0.02	0.034	-	-	0.004
Fish-Forage	3.82E-08	-	4.41E-12	0.02	0.034	-	-	0.004
Fish-Predatory	3.82E-08	-	4.41E-12	2.00E-11	0.014	-	-	0.001
Muskrat	0.083	275	2.52E-04	0.024	0.024	-	45- 89	0.01
Merganser	177	118	0.021	-	0.021	-	7.4	0.026
Scaup	545	770	0.063	-	0.063	-	48	0.079
Mallard	24.3	20.3	0.003	-	0.003	-	1.3	0.004
Sandpiper	14.2	384	0.002	0.008	0.01	-	24.	0.012
Grouse	3.98E-06	7.22E-06	1.07E-05	-	1.07E-05	-	<0.001	<0.001
Vole	2.09E-10	1.99E-05	1.88E-06	-	1.88E-06	-	<0.001	<0.001
Deer	1.34E-07	5.97E-06	0.001	-	0.001	-	<0.001	0.018

Benchmarks: Water, mg/L: 0.015 (long-term); 0.033 (short-term and aquatic plants and fish); 0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th} protection levels)
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 3.1 and 6.1 (muskrat), 16 (merganser, scaup, mallard, sandpiper), 160 (grouse), 11.4 (vole, deer)
Dose, mSv/d: 9.6 (aquatic receptors); 2.4 (semi-aquatic and terrestrial receptors)
* equivalent dose includes baseline dose, which may be the main contributor to dose for some species.

6.3.3.2 Human Receptors

Predicted short-term uranium concentrations following a UOC spill in Lake of the Woods (0.1 µg/L) would not exceed the Canadian Drinking Water Quality Guideline (Health Canada 2008) for uranium (20 µg/L). The long-term water uranium concentration (incremental concentration of 0.00002 µg/L) in the lake following a UOC spill would not exceed 20 µg/L. However, fish consumption is also contributing to the daily intake in the long-term exposure scenario. The uranium ingestion from drinking water and fish and hazard quotients (HQ) for long-term exposure were calculated and are shown in Table 6.10. The hazard quotients for adult, child, and toddler receptors were all below 1.

The radiation doses predicted for a child, toddler and adult ingesting water impacted by a UOC spill are summarized in Table 6.10. In all cases, the dose estimates are well below the Canadian Nuclear Safety Commission regulatory incremental dose limit of 1 mSv/yr for members of the public.

Table 6.10 Consequences for Human Receptors for Average Flow in Lake of the Woods

a) Calcined

	Exposure		**HQ**	
Receptor	Intake, mg/kg.d	Equivalent Dose, µSv/d	Intake	Dose
Toddler	6.78E-07	2.27E-07	0.001	<0.001
Child	5.41E-07	2.44E-07	<0.001	<0.001
Adult	4.15E-07	2.35E-07	<0.001	<0.001

b) Un-calcined

	Exposure		**HQ**	
Receptor	Intake, mg/kg.d	Equivalent Dose, µSv/d	Intake	Dose
Toddler	1.74E-06	5.82E-07	0.003	<0.001
Child	1.39E-06	6.25E-07	0.002	<0.001
Adult	1.06E-06	6.03E-07	0.002	<0.001

Note:
Benchmarks: 0.0006 mg/kg.d for intake (of water and fish in the long term) and 1000 µSv/yr for dose

6.3.4 Vancouver Harbour

6.3.4.1 Ecological Receptors

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in Vancouver Harbour.

Table 6.11 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor selected for assessment in Vancouver Harbour for average flow conditions. As seen from the table, short-term and long-term uranium concentrations are less than the Canadian water quality guidelines (33 µg/L and 15 µg/L). The table does indicate that sediment concentrations as well as semi-aquatic wildlife are above the reference value of 1, these are examined further in the following discussion. 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 ptarmigan, grouse, vole or deer. No additional exceedance is observed under low or high flow conditions.

Sediment: Concentrations in post-remediation conditions (95% cleanup within 30 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.20, spilled UOC would spread over a distance of about 1 km (calcined) and 5 km (un-calcined) in the average flow condition, covering an area of approximately 1.0×10^5 - 5.0×10^6 m^2 (1- 50 ha).. These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations following a spill.

Semi-Aquatic Receptors: A UOC spills would result in potential adverse effects to muskrat when considering both the NOAEL and LOAEL TRVs. The assessment of potential effects based on NOAELs is expected to be conservative. The spill could result in potential risks of adverse effects to scaup, merganser (only un-calcined) and sandpiper but not mallard or falcon. The intakes are largely driven by the incidental ingestion of sediment. As the estimated area is much larger than the home range of the receptors population-level effects are possible for muskrat, scaup, merganser and sandpiper.

Table 6.11 Consequences on Ecological Receptors- Average Flow in Vancouver Harbour

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose*, mSv/d	Concentration	Intake	Dose
Water-short term	0.002	-	-	-	-	0.062	-	-
Water-long term	6.78E-08	-	-	-	-	<0.001	-	-
Sediment- dw	2800	-	-	-	-	0.5- 26.8	-	-
Aquatic Plants-roots	1.15E-05	-	1.33E-09	0.008	0.022	-	-	0.002
Aquatic Plants-leaves	1.15E-05		1.33E-09	7.81E-12	0.014	-		0.001
Benthic Invertebrate	6.24E-06	-	7.20E-10	0.008	0.022	-	-	0.002
Fish-Forage	6.78E-08	-	7.83E-12	0.008	0.022	-	-	0.002
Fish-Predatory	6.78E-08	-	7.83E-12	7.81E-12	0.014	-	-	0.001
Muskrat	0.006	18.9	2.43E-04	0.002	0.002	-	3.1- 6.1	<0.001
Merganser	12.1	8.1	0.002	-	0.002	-	0.5	0.002
Scaup	37.3	52.8	0.005	-	0.005	-	3.3	0.006
Mallard	1.7	1.4	3.32E-04	-	3.32E-04	-	0.087	<0.001
Sandpiper	0.97	26.3	1.36E-04	5.48E-04	6.83E-04	-	1.6	<0.001
Falcon	4.23E-09	5.20E-09	1.53E-05	-	1.53E-05	-	<0.001	<0.001
Vole	4.32E-09	4.12E-04	1.88E-06	-	1.88E-06	-	<0.001	<0.001
Deer	2.78E-06	1.24E-04	0.001	-	0.001	-	<0.001	0.018
Ptarmigan	8.24E-05	1.32E-04	1.07E-05	-	1.07E-05	-	<0.001	<0.001

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose*, mSv/d	Concentration	Intake	Dose
Water-short term	0.003	-	-	-	-	0.078	-	-
Water-long term	2.93E-07	-	-	-	-	<0.001	-	-
Sediment- dw	12095	-	-	-	-	2.1- 116	-	-
Aquatic Plants-roots	4.98E-05	-	5.75E-09	0.02	0.034	-	-	0.004
Aquatic Plants-leaves	4.98E-05		5.75E-09	2.00E-11	0.014	-	-	0.001
Benthic Invertebrate	2.70E-05	-	3.11E-09	0.02	0.034	-	-	0.004
Fish-Forage	2.93E-07	-	3.38E-11	0.02	0.034	-	-	0.004
Fish-Predatory	2.93E-07	-	3.38E-11	2.00E-11	0.014	-	-	0.001
Muskrat	0.024	81.5	2.45E-04	0.007	0.007	-	13.4- 26.3	0.003
Merganser	52.4	34.9	0.006	-	0.006	-	2.2	0.008
Scaup	161	228	0.019	-	0.019	-	14.2	0.024
Mallard	7.2	6.	9.70E-04	-	9.70E-04	-	0.37	0.001
Sandpiper	4.2	114	5.08E-04	0.002	0.003	-	7.1	0.004
Falcon	1.83E-08	2.25E-08	1.53E-05	-	1.53E-05	-	<0.001	<0.001
Vole	5.42E-09	5.17E-04	1.88E-06	-	1.88E-06	-	<0.001	<0.001
Deer	3.49E-06	1.55E-04	0.001	-	0.001	-	<0.001	0.018
Ptarmigan	1.03E-04	1.65E-04	1.07E-05	-	1.07E-05	-	<0.001	<0.001

Benchmarks: Water, mg/L: 0.033 (short-term); 0.015 (long-term and aquatic plants and fish);
0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th}
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 3.1 and 6.1 (muskrat), 16 (merganser, scaup, mallard, sandpiper), 160 (falcon, grouse and ptarmigan), 11.4 (vole, deer, squirrel and caribou)
Dose, mSv/d: 9.6 (aquatic receptors); 2.4 (semi-aquatic and terrestrial receptors)
* equivalent dose includes baseline dose, which may be the main contributor to dose for some species.

6.3.4.2 Human Receptors

Predicted short-term uranium concentrations following a UOC spill in Vancouver Harbour (2-3 µg/L) would not exceed the Canadian Drinking Water Quality Guideline (Health Canada 2008) for uranium (20 µg/L). The long-term water uranium concentration (incremental concentration of 0.0001 µg/L) in the lake following a UOC spill would not exceed 20 µg/L. However, fish consumption is also contributing to the daily intake in the long-term exposure scenario. The uranium ingestion from drinking water and fish and hazard quotients (HQ) for long-term exposure were calculated and are shown in Table 6.12. The hazard quotients for adult, child, and toddler receptors were all below 1.

The radiation doses predicted for a child, toddler and adult ingesting water impacted by a UOC spill are summarized in Table 6.12. In all cases, the dose estimates are well below the Canadian Nuclear Safety Commission regulatory incremental dose limit of 1 mSv/yr for members of the public.

Table 6.12 Consequences for Human Receptors for Average Flow in Vancouver Harbour

a) Calcined

Receptor	Exposure		HQ	
	Intake, mg/kg.d	Equivalent Dose, µSv/d	Intake	Dose
Toddler	6.78E-07	2.27E-07	0.001	<0.001
Child	5.41E-07	2.44E-07	<0.001	<0.001
Adult	4.15E-07	2.35E-07	<0.001	<0.001

b) Un-calcined

Receptor	Exposure		HQ	
	Intake, mg/kg.d	Equivalent Dose, µSv/d	Intake	Dose
Toddler	1.74E-06	5.82E-07	0.003	<0.001
Child	1.39E-06	6.25E-07	0.002	<0.001
Adult	1.06E-06	6.03E-07	0.002	<0.001

Note:
Benchmarks: 0.0006 mg/kg.d for intake (of water and fish in the long term) and 1000 µSv/yr for dose

6.3.5 Lake Saint-Louis

6.3.5.1 Ecological Receptors

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic, semi-aquatic and terrestrial receptors potentially exposed to a spill in Lake Saint-Louis.

Table 6.13 provides estimated concentration and intake, calculated Screening Index values (SI) for each receptor selected for assessment in Lake Saint-Louis for average flow conditions. As seen from the table, the SI values for short-term water and sediment concentrations as well as semi-aquatic wildlife are above the reference value of 1; these are examined further in the following discussion. 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 grouse, vole or deer. No additional exceedance is observed under low or high flow conditions.

Water: For the short-term water quality, comparison was also made between the predicted concentration and the results of the SSD. The concentration of is above the 95th percentile protection level but below the 90th percentile protection level. This indicates that substantial effects on aquatic biota due to the water concentration change in the short-term are not expected. Long-term uranium concentration is less than the Canadian water quality guidelines (15 µg/L).

Sediment: Concentrations in post-remediation conditions (95% cleanup within 30 m of spill) are expected to exceed both the LEL and SEL. As shown in Figure 5.22, spilled UOC would spread over a distance of about 36 m (calcined) and 56 m (un-calcined) in the average flow condition, covering an area of approximately 750-1200 m^2 (0.075-0.12 ha). These results indicate that a spill of UOC could potentially affect the benthic invertebrate populations following a spill but the spatial extent would be limited.

Semi-Aquatic Receptors: A UOC spill would result in potential adverse effects to muskrat when considering both the NOAEL and LOAEL TRVs. The assessment of potential effects based on NOAELs is expected to be conservative. The spill could result in potential risks of adverse effects to scaup, sandpiper, merganser (only un-calcined) but not mallard. The intakes are largely driven by the incidental ingestion of sediment. Considering the limited spatial extent of the contaminated sediment, population-level effects are unlikely but it is possible for animals directly downgradient of the spill to be affected.

Table 6.13 Consequences on Ecological Receptors for Average Flow in Lake Saint-Louis

a) Calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose*, mSv/d	Concentration	Intake	Dose
Water-short term	0.063	-	-	-	-	1.9	-	-
Water-long term	1.20E-06	-	-	-	-	<0.001	-	-
Sediment- dw	1615	-	-	-	-	0.3- 15.5	-	-
Aquatic Plants-roots	2.04E-04	-	2.35E-08	0.008	0.022	-	-	0.002
Aquatic Plants-leaves	2.04E-04		2.35E-08	7.81E-12	0.014	-		0.001
Benthic Invertebrate	1.10E-04	-	1.27E-08	0.008	0.022	-	-	0.002
Fish-Forage	1.20E-06	-	1.38E-10	0.008	0.022	-	-	0.002
Fish-Predatory	1.20E-06	-	1.38E-10	7.81E-12	0.014	-	-	0.001
Muskrat	0.003	10.9	2.43E-04	9.48E-04	0.001	-	1.8- 3.5	<0.001
Merganser	7.	4.7	9.29E-04	-	9.29E-04	-	0.29	0.001
Scaup	21.5	30.4	0.003	-	0.003	-	1.9	0.003
Mallard	0.97	0.8	2.51E-04	-	2.51E-04	-	0.05	<0.001
Sandpiper	0.56	15.2	8.80E-05	3.16E-04	4.04E-04	-	0.95	<0.001
Grouse	0.003	0.005	1.10E-05	-	1.10E-05	-	<0.001	<0.001
Vole	1.32E-07	0.013	1.88E-06	-	1.88E-06	-	0.001	<0.001
Deer	8.51E-05	0.004	0.001	-	0.001	-	<0.001	0.018

b) Un-calcined

Medium	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose*, mSv/d	Concentration	Intake	Dose
Water-short term	0.079	-	-	-	-	2.4	-	-
Water-long term	5.15E-06	-	-	-	-	<0.001	-	-
Sediment- dw	6945	-	-	-	-	1.2- 66.5	-	-
Aquatic Plants-roots	8.76E-04	-	1.01E-07	0.02	0.034	-	-	0.004
Aquatic Plants-leaves	8.76E-04		1.01E-07	2.00E-11	0.014	-	-	0.001
Benthic Invertebrate	4.74E-04	-	5.47E-08	0.02	0.034	-	-	0.004
Fish-Forage	5.15E-06	-	5.95E-10	0.02	0.034	-	-	0.004
Fish-Predatory	5.15E-06	-	5.95E-10	2.00E-11	0.014	-	-	0.001
Muskrat	0.014	46.8	2.44E-04	0.004	0.004	-	7.7- 15.1	0.002
Merganser	30.1	20.	0.004	-	0.004	-	1.3	0.004
Scaup	92.5	131	0.011	-	0.011	-	8.2	0.014
Mallard	4.1	3.4	6.17E-04	-	6.17E-04	-	0.22	<0.001
Sandpiper	2.4	65.2	3.02E-04	0.001	0.002	-	4.1	0.002
Grouse	0.003	0.006	1.11E-05	-	1.11E-05	-	<0.001	<0.001
Vole	1.66E-07	0.016	1.88E-06	-	1.88E-06	-	0.001	<0.001
Deer	1.07E-04	0.005	0.001	-	0.001	-	<0.001	0.018

Benchmarks: Water, mg/L: 0.015 (long-term); 0.033 (short-term and aquatic plants and fish); 0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th} protection levels)
Sediment, mg/kg dw: 104.4 and 5874 (benthic invertebrates)
Intake, mg/kg.d: 3.1 and 6.1 (muskrat), 16 (merganser, scaup, mallard, sandpiper), 160 (grouse), 11.4 (vole, deer)
Dose, mSv/d: 9.6 (aquatic receptors); 2.4 (semi-aquatic and terrestrial receptors)
* equivalent dose includes baseline dose, which may be the main contributor to dose for some species.

6.3.5.2 Human Receptors

Predicted short-term uranium concentrations following a UOC spill in Lake Saint-Louis (0.15 mg/L) would not exceed the Canadian Drinking Water Quality Guideline (Health Canada 2012) for uranium (0.02 mg/L). The long-term water uranium concentration (incremental concentration of 0.005 µg/L) in the lake following a UOC spill would not exceed 20 µg/L. However, fish consumption is also contributing to the daily intake in the long-term exposure scenario. The uranium ingestion from drinking water and fish and hazard quotients (HQ) for long-term exposure were calculated and are shown in Table 6.14. The hazard quotients for adult, child, and toddler receptors were all below 1.

The radiation doses predicted for a child, toddler and adult ingesting water impacted by a UOC spill are summarized in Table 6.14. In all cases, the dose estimates are well below the Canadian Nuclear Safety Commission regulatory incremental dose limit of 1 mSv/yr for members of the public.

Table 6.14 Consequences for Human Receptors for Average Flow in Lake Saint-Louis

a) Calcined

	Exposure		HQ	
Receptor	Intake, mg/kg.d	Equivalent Dose, µSv/d	Intake	Dose
Toddler	6.78E-07	2.27E-07	0.001	<0.001
Child	5.41E-07	2.44E-07	<0.001	<0.001
Adult	4.15E-07	2.35E-07	<0.001	<0.001

b) Un-calcined

	Exposure		HQ	
Receptor	Intake, mg/kg.d	Equivalent Dose, µSv/d	Intake	Dose
Toddler	7.94E-07	1.61E-08	0.001	<0.001
Child	6.33E-07	1.29E-08	0.001	<0.001
Adult	4.86E-07	9.88E-09	<0.001	<0.001

Note:
Benchmarks: 0.0006 mg/kg.d for intake (of water and fish in the long term) and 1000 µSv/yr for dose

6.4 SUMMARY

Table 6.15 summarizes the results of exposure assessment for all receptors in all accident locations. The detailed calculations showed that there was minimal difference between the results for calcined and un-calcined UOC and thus this table can be taken to represent both types of UOC. These results represent screening index values estimated in the previous sections. Two types are exceedances are identified for ecological receptors, one with population effect, and the less substantial ones with only individual effects. Short-term water quality impacts and sediment impacts in a limited area (generally defined as 0.2 ha in rivers, and 5% of the surface area for lakes) are determined to affect individuals but not populations of biota.

As can be seen, a release of 25% of the content of a shipment of UOC will impact water quality in the short-term but not in the long term.

Sediment concentrations are determined to be impacted with population-level effects in the benthic invertebrate community of the Columbia River as well as Lake of the Woods and Vancouver Harbour.

Intake of water and sediment (as the main cause) would cause most semi-aquatic receptors to have uranium intakes higher than their respective TRVs (between 3 and 16 mg/kg.d). These exceedances are mostly limited to individual animals, except in the Columbia River as well as Lake of the Woods and Vancouver Harbour, which may experience population-level effects.

Drinking the water immediately after the spill (define by short-term water concentrations) would not cause terrestrial receptors (TRVs between 11 and 160 mg/kg.d) any substantial impact. However, concentrations of uranium in such water may exceed the drinking water quality guideline for human consumption in Lac La Ronge and Lake Saint-Louis.

In addition to these results, it was found that the accidental release of UOC to a small lake will result in compromised water and sediment quality of the lake to the extent that the water body loses its value as a habitat and will need remediation. The minimum lake size where the water quality would meet the guideline of 15 µg/L (SENV 2006) following the release of one container of UOC (about 4000 kg of UOC or 3500 kg of uranium) is a 2.3 million m^3 lake. There are many lakes smaller than this threshold along the transportation route. With respect to sediment, assuming that UOC would mix in the top 5 cm of sediment, the minimum size lake for the sediment quality to meet the appropriate guideline is 3.3 ha.

Table 6.15 Summary Results for All Water Crossings (both Calcined and Un-calcined Products)

	RD-1 / RD-3	RI-1	RI-2	RD-1	RD-1	RD-1	RD-1	RI-1	RI-2	RD-1
Parameter	**Assiniboine River**	**Columbia River**	**Kaministiquia River**	**North Saskatchewan River**	**Mississagi River**	**Lac La Ronge**	**Lake of the Woods**	**Vancouver Harbour**	**Lake Saint-Louis**	**Wollaston Lake**
Water-short	×	×	×	×	×	×	☑	☑	×	×
Water-long	□	□	□	□	□	☑	☑	☑	☑	☑
Aquatic										
Benthic Invertebrate	×	☒	×	×	×	×	☒	☒	×	×
Semi-aquatic										
Muskrat	□	□	□	□	□	×	☒	☒	×	×
Merganser	□	□	□	□	□	×	☒	☒	×	×
Mallard	□	□	□	□	□	×	☒	☑	☑	×
Scaup	□	□	□	□	□	×	☒	☒	×	×
Sandpiper	□	□	□	□	□	×	☒	☒	×	×
Falcon	□	□	□	□	□	□	□	☑	□	☑
Terrestrial										
Grouse	☑	☑	☑	☑	☑	☑	☑	□	☑	□
Vole	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Deer	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ptarmigan	□	☑	□	□	□	□	□	☑	□	☑
Squirrel	□	□	□	□	□	□	□	□	□	☑
Caribou-B	□	□	□	□	□	□	□	□	□	☑
Caribou-W	□	□	□	□	□	□	□	□	□	☑
Public										
Short-term Drinking Water	□	□	□	□	□	☒	☑	☑	☒	□
Long-term Drinking water and fish	□	□	□	□	□	☑	☑	☑	☑	□

Note: ☒: exceeds TRV, ×: exceeds TRV with some individuals affected but population-level effects not expected; ☑: does not exceed TRV, □: not applicable

7.0 RISK CALCULATIONS FOR TERRESTRIAL RELEASES

The release of UOC on land along the transportation route could impact human receptors including workers and members of the public. Following such an accident, the areas affected are secured, therefore, access of the wildlife to the accident location is very limited. The following impacts were considered for the assessment of the consequences for release of UOC to land:

- Gamma radiation exposure to workers (truck drivers, handlers, emergency response team members)
- Worker dust inhalation following a release
- Air quality impact for public following an accident (with and without fire)

7.1 WORKER IMPACT FROM THE ACCIDENTS

Following a transportation accident, UOC containers could potentially be breached and their contents could be spilled. Part of the spilled UOC could become airborne due to the impact of the accident. If the accident is followed by a fire, the buoyant effect of fire could contribute to the airborne release of the UOC particles. In case of an accident involving the release of UOC, both workers and members of the public could be exposed to external radiation and as well as inhalation of airborne UOC particles.

7.1.1 Radiological Exposure to Workers

7.1.1.1 Receptors and Exposure Scenarios

Truck driver transporting container(s) with drums

During the transport of UOC, an accident occurs and the drums fall from the container which results in UOC being spilled onto the ground. It is assumed that half of the UOC is spilled onto the ground and the truck driver is exposed to the spilled UOC when the driver exits the truck to assess the extent of the damage caused by the accident.

Shipyard worker near containers

During routine operations, a worker in the shipyard will be exposed to 24 sea-containers. It was assumed that in an accident scenario, 1 sea-container is dropped which results in UOC being spilled onto the ground. It is assumed the half of the UOC is spilled onto the ground and a shipyard worker is exposed to the spilled UOC when the shipyard worker assesses the extent of the damage caused by the accident.

The external dose assessment was performed using MicroShield Version 9.05 (Grove Software 2012). The assumptions used in the MicroShield runs for each scenario are described below.

7.1.1.2 Source Geometry

Spilled UOC

For each scenario, it was assumed that the UOC from half of the drums is spilled onto the ground. Table 7.1 provides a description of the scenarios and the number of drums in which UOC is spilled onto the ground for each scenario.

Table 7.1 Scenario Description

Scenario (Description)	Receptor	Number of Drums in the Container(s) in the Model	Number of Drums in which UOC is Spilled
1 –Truck (To Cameco (Blind River, ON))	Truck Driver	44 [a]	22
2- Truck (To ConverDyn (Metropolis, USA))	Truck Driver	40 [b]	20
3 – Truck (From Northern Sites to Rail Terminal)	Truck Driver	70 [c]	35
4 – Ship (Overseas)	Shipyard Worker	35	18

a) The capacity of the trailer van is 43-45 drums; however, the 44 drums were assumed in the model.
b) The capacity of the trailer van is 40-42 drums; however, the 40 drums were assumed in the model.
c) The capacity of the sea-container is 35 drums; however, there are 2 sea-containers on the trailer.

For the MicroShield calculation, a cylinder volume - side shields was used for the source geometry. The height of the spill was assumed to be 57.2 cm (diameter of the drum) and radius was (i.e., back-calculated from the total volume of the UOC in number of in which UOC is spilled and the height of the spill).

7.1.1.3 Source Material and Density

UOC was conservatively assumed to be 100% U_3O_8. The density of UOC is 2.055 g/cm^3 (Cohen 2005).

The UOC was assumed to have U-238, U-234, and U-235 present at natural abundances. U-238 was assumed to be in equilibrium with its short-lived decay products; Th-234, Pa-234m, Pa-234 (which has a relative concentration of 0.16% of U-238) and U-234. U-235 was assumed to be in secular equilibrium with Th-231.

The activity of each radionuclide for multiple drums in a container was calculated as follows:

$$A_{radionuclide} = SA_{radionuclide} \times (m_{uranium} \times 1000) \times F_{U\ in\ U3O8} \times N_{containers}$$

Where:
$A_{radionuclide}$: activity (Bq)
$SA_{radionuclide}$: specific activity (Bq/g); provided in Table 7.2
$m_{uranium}$: mass of uranium as UOC in one container (kgU)
1000: conversion from kilogram to gram (g/kg)
$F_{u\ in\ U3O8}$: fraction of uranium in U_3O_8 (0.848)
$N_{containers}$: number of containers in scenario.
The activity of the radionuclides for each scenario are shown in Table 7.2.

Table 7.2 Activity of Radionuclides in UOC for Each Scenario

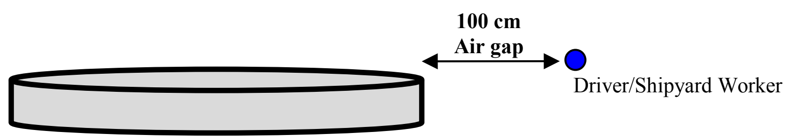
			Activity (Bq)			
Nuclide	**Branching Ratio**	**Specific Activity (Bq/g)**	**Scenario 1 [a]**	**Scenario 2 [b]**	**Scenario 3 [c]**	**Scenario 4 [d]**
U-238	1	1.23E+04	8.54E+10	7.92E+10	1.36E+11	6.99E+10
Th-234	1	1.23E+04	8.54E+10	7.92E+10	1.36E+11	6.99E+10
Pa-234	0.0016	1.98E+01	1.37E+08	1.27E+08	2.17E+08	1.12E+08
Pa-234m	1	1.23E+04	8.54E+10	7.92E+10	1.36E+11	6.99E+10
U-234	1	1.23E+04	8.54E+10	7.92E+10	1.36E+11	6.99E+10
U-235	0.046	5.68E+02	3.93E+09	3.64E+09	6.25E+09	3.21E+09
Th-231	0.046	5.68E+02	3.93E+09	3.64E+09	6.25E+09	3.21E+09

a) 22 drums.
b) 20 drums
c) 35 drums
d) 18 drums

7.1.1.4 Dose Points

The driver and shipyard worker is assumed to be 100 cm from the spilled UOC and 100 cm from the ground. Figure 7.1 shows the location of the receptor in relation to the source. Note that the figure is not to scale and intended to provide a perspective of the dose point with respect to the source.

Figure 7.1 Dose Point



7.1.1.5 Build-up and Integration

The air gap (between the modelled receptors and the source) was selected as the build-up material because this resulted in the highest dose rates in MicroShield for the receptor locations that were modelled.

The calculations for exposure scenarios that cannot be solved analytically are subdivided into smaller steps to increase the precision of the results. The numbers of steps, called integration parameters (in the Radial, Circumferential, and Y Direction (axial)), need to be large enough to allow the calculated dose rates to converge to fixed values, i.e., the rates do not significantly change (less than 1%) when further increasing the number of integrations in the calculations. These values vary depending on the size of the source and receptor location. The integration values for each model were determined by changing the value in each direction until the effective dose equivalent rate converged.

7.1.1.6 Results

Truck driver transporting container(s) with drums

Table 7.3 provides the effective dose rate to the truck driver who is exposed to the spilled UOC when the driver exits the truck to assess the extent of the damage caused by the accident for each scenario. For each scenario, the maximum time spent beside the spill without exceeding the CNSC (2000) radiation dose limit for a member of the public is 1 mSv per year (over natural background levels) is also provided in Table 7.3.

Table 7.3 Effective Dose to Truck Driver

Scenario (Description)	Receptor (s)	Effective Dose Rate (mSv/hr) [a]	Maximum Time Spent Beside the Spill (hr)
1 –Truck (To Cameco (Blind River, ON))	Truck Driver, Forklift Driver	2.6E-03	379
2- Truck (To ConverDyn (Metropolis, USA))	Truck Driver, Forklift Driver	2.6E-03	380
3 – Truck (From Northern Sites to Rail Terminal)	Truck Driver	2.9E-03	340

a) Rotational geometry (with build-up).

<u>Shipyard worker near containers</u>

Table 7.4 provides the effective dose rate to the shipyard worker who is exposed to the spilled UOC when the shipyard worker assesses the extent of the damage caused by the accident. The maximum time spent beside the spill without exceeding the CNSC (2000) radiation dose limit for a member of the public is 1 mSv per year (over natural background levels) is also provided in Table 7.4.

Table 7.4 Effective Dose to Shipyard Worker

Scenario (Description)	Receptor (s)	Effective Dose Rate (mSv/hr) [a]	Maximum Time Spent Beside the Spill (hr)
4 – Ship (Overseas)	Shipyard Worker	2.5E-03	399

a) Rotational geometry (with build-up).

7.1.1.7 Radon Exposure

During the milling operations, radium is effectively removed from uranium oxides and disposed along with the mine tailings. The residual radium activity concentration in UOC is too small to support significant radon emanation from the released UOC. Therefore, the dose due to radon inhalation was not calculated in this assessment.

7.1.1.8 Dust Inhalation

The exposure of the workers to dust following an accident scenario is very short (less than one minute). Therefore, application of ERPG level 2 criteria which is defined for one hour exposure may not be appropriate. For such a short-term exposure, we will use kidney burden of 3 µg uranium per g of kidney as the benchmark for the assessment of this scenario.

In order to calculate the air concentration following a spill, the methodology proposed by U. S. DOE (1994) to estimate the source terms is used. In this methodology, the airborne source term is estimated by the following five-component linear equation:

$$\text{Source Term} = \text{MAR x DR x ARF x RF x LPF}$$

where:

MAR = Material-at-Risk
DR = Damage Ratio
ARF = Airborne Release Fraction
RF = Respirable Fraction
LPF = Leakpath Factor

- MAR: Uranium content of two sea container: 2*12,975=25,950 kg.
- DR: It was assumed that half of the UOC is affected.
- ARF: The U.S. DOE (1994) recommends the value of 0.001 for impact disturbances of powder in metal containers.
- RF: was considered at 0.1, based on the DOE (1994) recommended value for impact disturbances of powder in metal containers.
- LPF: During this scenario, it is expected that the impacted material be partially contained by the container. The LPF was assumed to be 0.1.

The sources term is calculated as follows:

$$\text{Source Term} = \text{MAR x DR x ARF x RF x LPF}$$
$$\text{Source Term} = 25{,}950 \text{ kg x } 0.5 \text{ x } 0.001 \text{ x } 0.1\text{x } 0.1 = 0.13 \text{ kg U}$$

If the released UOC is dispersed in a hemisphere with a radius of 10 m (volume of 2,100 m), the immediate uranium concentration in air near the accident area would be 32 mg/m^3:

$$0.13 \text{ kg} * 1{,}000{,}000 \text{ mg/kg} / 2{,}100 \text{ m}^3 = 62 \text{ mg/m}^3$$

Generally accepted nephrotoxic threshold level of 3 µg uranium per g of kidney (ATSDR 1999) was used to derive the air concentration benchmark for concentration of uranium in air. The kidney retention from uranium inhaled was calculated using ICRP (1994b) Publication 66 biokinetic model. The parameters used in the calculation are:

- Exposure time for the driver = 30 s
- Breathing rate for heavy activity = 1.6 m^3/h (IAEA 1999)
- Kidney weight = 300 g

Total kidney burden = 300 g of kidney x 3 µg uranium per g of kidney = 0.9 mg uranium

The fractional kidney retention for type F uranium compound (conservative assumption for chemical toxicity of uranium) is calculated at 0.034.

Total inhaled uranium for 3 µg uranium per g of kidney = 0.9 mg uranium / 0.034 = 26.47 mg
Total air volume inhaled = 1.6 m^3/h x 30 s /3600 s/h = 0.0133 m^3 air inhaled
Benchmark uranium concentration in air = 26.47 mg uranium inhaled / 0.0133 m^3 air inhaled = 1990 mg/m^3

Based on the above calculations, exposure of workers to the air with uranium concentration of 1990 mg/m^3 for 30 s will result in kidney burden of 3 µg uranium per g of kidney. Therefore, 1990 mg/m^3 was select as the chemical toxicity benchmark for this study.

With respect to the chemical toxicity, the calculated average uranium concentration in the air during 30 s of exposure (32 mg/m^3) is much less than the calculated benchmark of 1990 mg/m^3. Based on the kidney toxicity value of 3 µg uranium per g of kidney used to drive the benchmark, no statistically or biologically significant increases in frequency or severity of an effect on the exposed driver is expected.

The regulatory limits to NEW are 100 mSv per five-year dosimetry period (i.e., annual average of 20 mSv/y) with a maximum of 50 mSv per one-year dosimetry period (CNSC 2000b).

In the UOC production process, uranium is selectively extracted, therefore any other radioactive isotopes were not considered in the radiological exposure assessment. The dose coefficients for various solubility classes for uranium isotopes are shown in Table 7.5.

Table 7.5 Inhalation Dose Coefficients

Radionuclide	Inhalation (mSv/Bq)[a b]		
	F[c]	M[c]	S[c]
U-238	4.9E-04	2.6E-03	7.3E-03
U-234	5.5E-04	3.1E-03	8.5E-03
U-235	5.1E-04	2.8E-03	7.7E-03

Notes:

a) U-238 includes dose coefficients (DC) from U-238, Th-234 and Pa-234. U-235 includes DCs from U-235 and Th-231 and U-234 includes only U-234 DC also

b) 1 µm Activity Median Aerodynamic Diameter (AMAD), ICRP 72

c) Solubility class or absorption rate F (fast absorption, high solubility), M (moderate absorption, moderate solubility), S (slow absorption, low solubility)

The concentrations and activity concentrations of the species considered are as follows:

U-238 concentration = 32 mg/m^3
U-238 activity concentration = 62 mg/m^3 *12.35Bq/mg (specific activity) = 763 Bq/m^3
U-234 activity concentration = 763 Bq/m^3
U-235 activity concentration = 763 * 0.046 (ratio of U-235 at equilibrium) = 35.1 Bq/m^3
Exposure time for workers = 30 s
Breathing rate for heavy activity = 1.6 m^3/h (IAEA 1999)

Table 7.6 shows the calculated inhalation dose for the worker near the accident site.

Table 7.6 Calculated Inhalation Effective Dose for the Worker Near the Accident Site

Radionuclide	Activity Concentration (Bq/m^3)	Intake (Bq)	Dose Coefficient (mSv/Bq)	Effective Dose (mSv)
U-238	763	10.18	7.30E-03	0.073
U-234	763	10.18	8.50E-03	0.087
U-235	135.1	0.468	7.70E-03	0.0037
Total				0.164

If the driver is exposed to the emitted dust within a year, the calculated total inhalation dose of 0.164 mSv is much less than the regulatory dose limit. Therefore, it was concluded that overall no adverse health effects are expected for the driver exposed to the dust following an accident for 30 s.

7.1.1.9 Summary

The calculation of the total effective doses to the truck driver and first responders (unprotected) attending the accidents shows that the total effective doses are well below all regulatory limits. In addition, the dust inhalation following an accident by the driver or first responders showed that both chemical and radiological doses were much below their respective benchmarks.

7.2 PUBLIC IMPACT FROM THE ACCIDENTS

Airborne release of UOC particles following an accident (both with and without fire) could adversely affect the air quality of the areas surrounding the accident location. Air dispersion modeling was conducted to calculate the concentration of uranium in air at various distances for the accident location. Case studies completed for cities of Vancouver, Regina, and Montreal included:

- Truck accident with fire (SC1)
- Truck accident without fire (SC2)
- Train accident with fire (SC3)
- Train accident without fire (SC4)

7.2.1 Source Term Estimation

The assessment of the consequences of the airborne release of UOC release requires the definition of the source terms. To characterize the source term, we follow the widely accepted methodology proposed by U. S. Department of Energy (DOE 1994) to estimate the source terms.

Definition of the source term involves a number of considerations, among them the quantity of material released, the physical and chemical form(s) of the released materials, the time dependence of the release and other factors that may affect the initial characteristics of the released material (e.g., meteorological conditions at the time of the release and building wake effects).

The airborne source term is typically 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 actually impacted by the initiating event(s) (fire, extreme winds, accident-generated conditions for example). The DR is estimated based upon 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 a 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 (AED) 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 = Leakpath 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).

7.2.1.1 Truck accident without fire (SC2)

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

- MAR: Content of a trailer van (16,305 kg U).
- DR: It was assumed that half of the drums are breached (0.5).

- ARF: The U.S. DOE provides the ARF for impact disturbances (Table 7.7). The ARF was selected as 0.001 based on the DOE recommended value in the second row of Table 7.7.

Table 7.7 Airborne Release Fraction
Source: US DOE (1994)

Compound	State	Disturbance	Bounding ARF	Bounding RF
Powder	Loose, resting (no container)	Impact	1.E-02	0.2
Powder	Contained (metal container, e.g. can)	Impact	1.E-03	0.1
Powder	Loose, resting (no container)	Blowing wind	0.0134w* + 0.00543	1

* w = wind speed (m/s)

- RF: was assumed to be 0. 1 based on the DOE recommended value in the second row of Table 7.7.

- LPF: was assumed to be 1.

The sources term is calculated as follows:

Source Term = MAR x DR x ARF x RF x LPF
Source Term = 16,305 kg x 0.5 x 0.001 x 0.1 x 1 = 0.82 kg
For one hour average concentration, the release rate will be 0.82 kg/hr or 0.23 g/s.

7.2.1.2 Truck accident with fire (SC1)

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

- MAR: Content of a trailer van (16,305 kg U).

- DR: It was assumed that half of the drums are breached (0.5).

- ARF: was assumed at 0.025 for release fraction of powder materials during fire or low velocity air movement (Table A33 of DOE 1994)

- RF: similar to SC1, it was assumed to be 0.1.

- LPF: was conservatively assumed to be 1.

The sources term is calculated as follows:

Source Term = MAR x DR x ARF x RF x LPF
Source Term = 16,305 kg x 0.5 x 0.025 x 0.1 x 1 = 20.38 kg.

For one hour average concentration, the release rate will be 20.38 kg/hr or 5.66 g/s.

7.2.1.3 Train accident without fire (SC4)

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

- MAR: Content of a 6 ISO containers (6x12,975=77,850 kg U).
- DR: It was assumed that half of the drums are breached (0.5).
- ARF: The U.S. DOE provides the ARF for impact disturbances (Table 7.7). The ARF was selected as 0.001 based on the DOE recommended value in the second row of Table 7.7.
- RF: was assumed to be 0. 1 based on the DOE recommended value in the second row of Table 7.7.
- LPF: was assumed to be 1.

The sources term is calculated as follows:

Source Term = MAR x DR x ARF x RF x LPF
Source Term = 77,850 kg x 0.5 x 0.001 x 0.1 x 1 = 3.89 kg

For one hour average concentration, the release rate will be 3.89 kg/hr or 1.1 g/s.

7.2.1.4 Train accident with fire (SC3)

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

- MAR: Content of a 6 ISO containers (6x12,975=77,850 kg U).
- DR: It was assumed that half of the drums are breached (0.5).
- ARF: was assumed at 0.025 for release fraction of powder materials during fire or low velocity air movement (Table A33 of DOE 1994)

- RF: similar to SC1, it was assumed to be 0.1.

- LPF: was conservatively assumed to be 1.

The sources term is calculated as follows:

Source Term = MAR x DR x ARF x RF x LPF
Source Term = 77,850 kg x 0.5 x 0.025 x 0.1 x 1 = 97.31kg.

For one hour average concentration, the release rate will be 97.31kg/hr or 27.03 g/s.

7.2.2 Sites Description

In this assessment three sites are studied: Montreal Port, Vancouver Port, and Regina Station. Table 7.8 lists the locations of the three different sites.

Table 7.8 Site Locations

Site Name	**Geographic Coordinates**		**UTM Coordinates**		
	Latitude	**Longitude**	**Easting (km)**	**Northing (km)**	**UTM Zone**
Montreal Port	45.5531	-73.5257	615.074	5045.453	18
Vancouver Port	49.2880	-123.1110	491.928	5459.478	10
Regina Station	50.4530	-104.6110	527.615	5589.072	13

7.2.3 CALPUFF Atmospheric Dispersion Modelling System

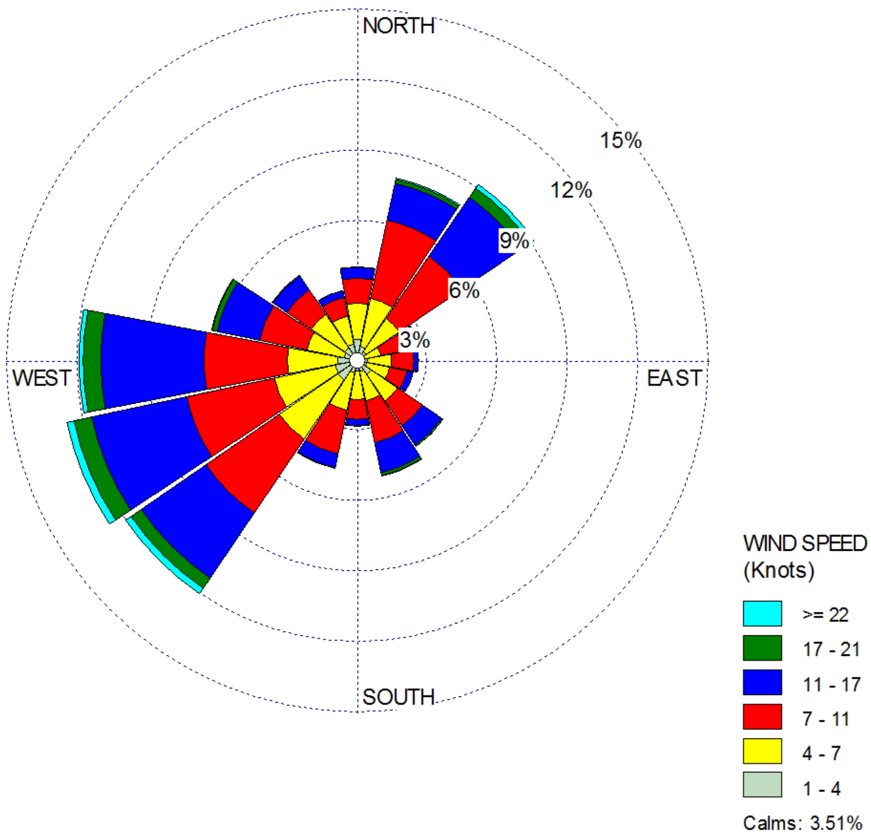
The CALMET/CALPUFF modelling system is a regulatory model in Newfoundland and Labrador for short-range applications and it is the regulatory US EPA model for long-range application. For this study, the modelling was undertaken using the Version 6.334 (level 110421) in so-called screening level approach. CALPUFF is a non-steady state puff dispersion model that utilizes the CALMET wind fields and accounts for spatial changes in meteorology, variable surface conditions, and plume interactions with terrain. CALPUFF can handle both simple and complex terrain. In this application, single point meteorology was used, which is equivalent to the meteorology used for models such as AERMOD. With this approach, CALPUFF provides concentration estimates that are reasonably conservative when compared to a CALPUFF modelling effort employing a fully-developed wind field. CALPUFF also has the capability to handle buoyant area sources, which was used in the analysis.

7.2.4 Meteorological Data

Meteorological data used in these studies were hourly surface observations from the nearby airports for three sites listed in Table 7.8. Meteorological data were obtained for the 2009-2013 period. The hourly surface data used were wind speed and direction, ceiling, ambient temperature, pressure and opaque sky cover (or total sky cover in the absence of opaque sky cover). For the upper air observations, three stations were used – Quillayute WA (Vancouver), Glasgow MT (Regina), Maniwaki QC (Montreal) - (source: NOAA's National Weather Centre) for the five years period 2009-2013. The upper air soundings were 12 GMT data of height, pressure, temperature and wind at several pressure levels up to 5 km.

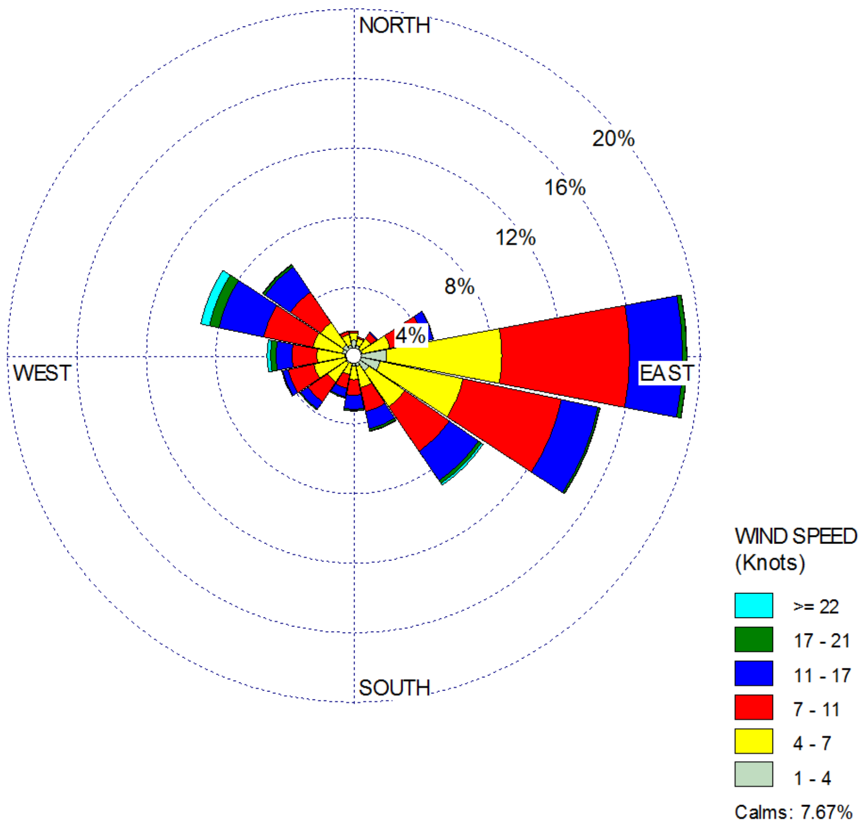
The datasets were prepared by SENES using the AERMET meteorological pre-processor to derive the input for the CALPUFF model. Urban land use surface parameters were determined for each site (AERMET Manual). Wind roses for the three sites are presented in Figure 7.2, Figure 7.3, Figure 7.4, and Figure 7.5. Land use was classified as urban in AERMET.

Figure 7.2 Wind Rose for Montreal Pierre Elliot Trudeau Airport 2009-2013 (winds from)



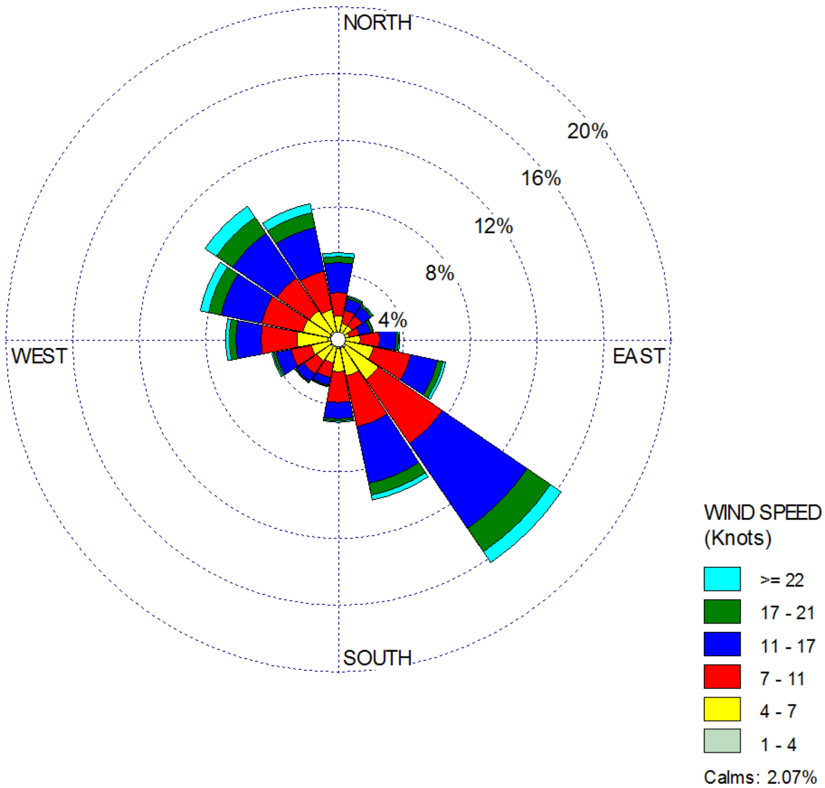
Based on this wind rose it is clear that for the five year period, the predominant wind direction is WSW. The average wind speed is 4.3 m/s with 3.51% calms.

Figure 7.3 Wind Rose for Vancouver International Airport 2009-2013 (winds from)



For Vancouver, the predominant wind direction is winds from the east with a five year average wind speed of 3.7 m/s and 7.67% calms

Figure 7.4 Wind Rose for Regina International Airport 2009-2013 (winds from)



The wind rose for Regina illustrates that the predominant wind direction is from the SE, with an average wind speed of 5.1 m/s and 2.07% calms.

7.2.5 Model grid

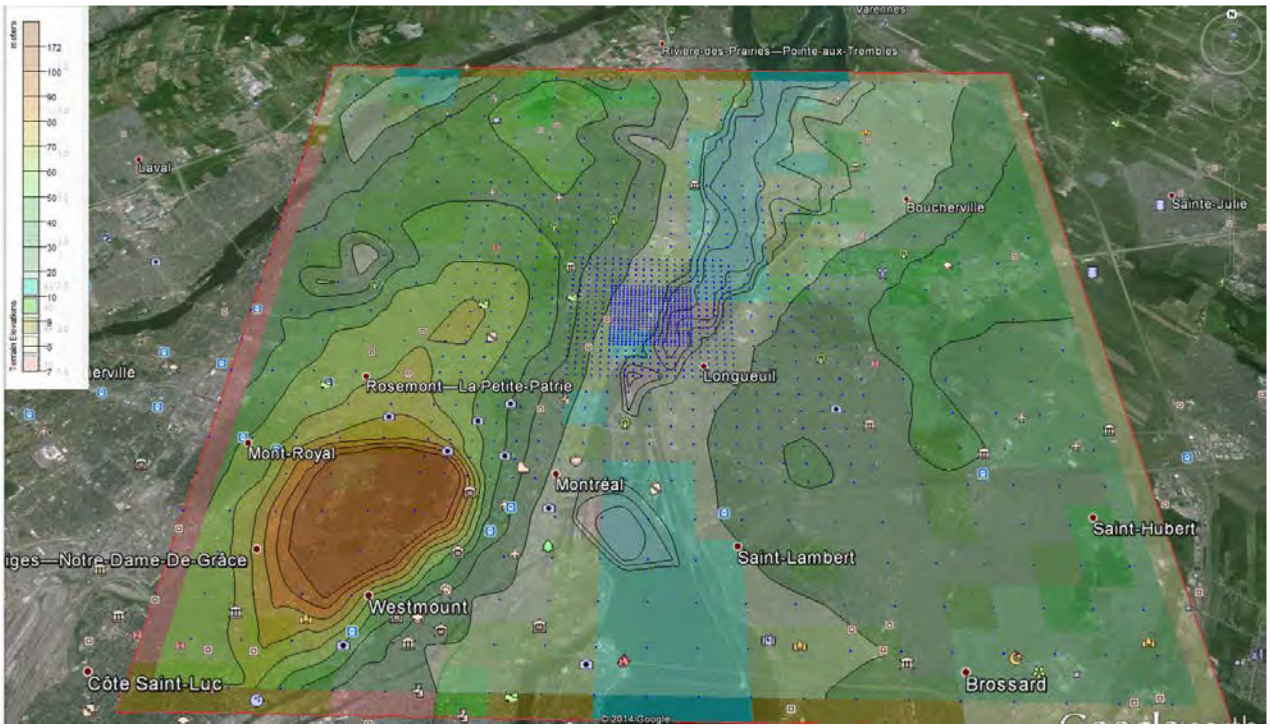
The model grids used for all four locations were centered at the UTM coordinates listed in Table 7.8. The SW corner of the area source was placed at the coordinates listed in Table 7.8. A variable spaced grid was used within the 10 km by 10 km model domain.

There are three nested grids with the following horizontal spacing:

- 100 m x 100 m up to 1 km distance in both X and Y direction from the source;
- 200 m x 200 m up to 2 km
- 500 m x 500 m up to 5 km
- 1000 m x 1000 m up to 10 km in both directions from the source point.

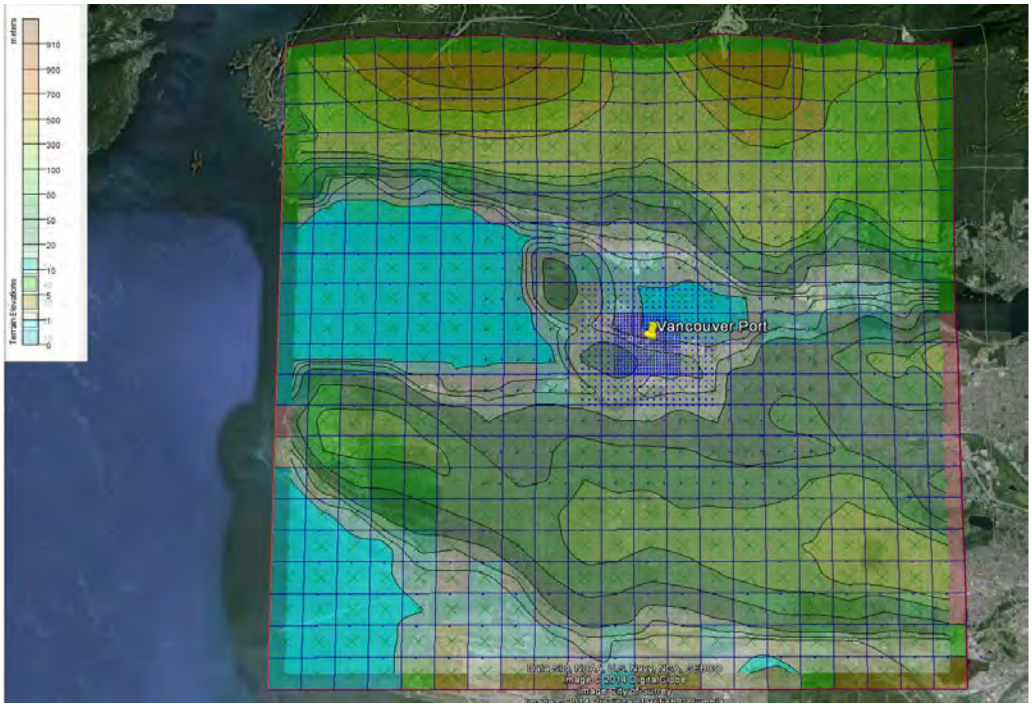
Gridded terrain elevations for the modelling domain were derived from 30 arc-second Digital Elevation Models (DEM) produced by the United States Geological Survey (USGS). Figure 7.5, Figure 7.6, and Figure 7.7 present the modelling domains with elevation contours and the receptor grids used for each location.

Figure 7.5 Montreal Model Domain and Grid Points



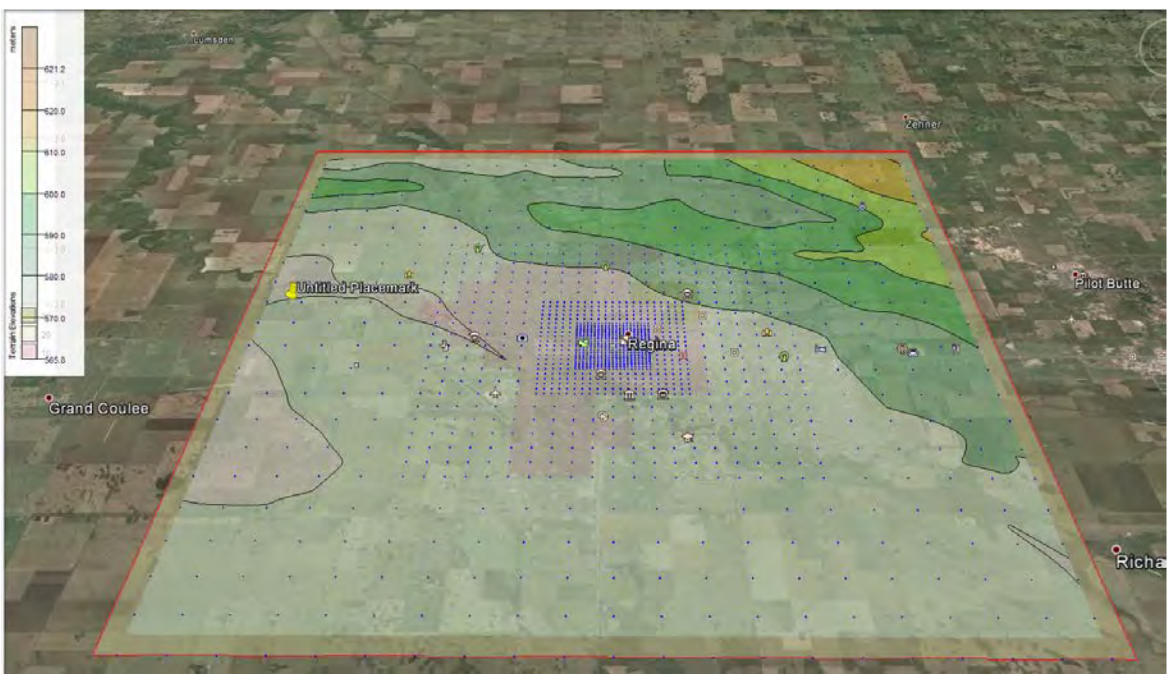
Note: WGS-84 projection

Figure 7.6 Vancouver Model Domain and Grid Points



Note: WGS-84 projection

Figure 7.7 Regina Model Domain and Grid Points



Note: WGS-84 projection

7.2.6 Air Dispersion Model Set Up

Four (4) different scenarios were modelled for each of the facilities noted above. Air emissions of UOC resulting from the accident scenarios were modelled using the buoyant area source algorithm in the CALPUFF model. Table 7.9 summarizes the assumptions and model input parameters used in the air dispersion modelling.

Table 7.9 CALPUFF Model Input parameters

Parameter	Model Inputs			
	SC1	SC2	SC3	SC4
Source Area (m^2)	75	75	108	108
Effective Release Height (m)	12	12	36	36
Terrain Elevation (m)				
Montreal	7	7	7	7
Regina	578	578	578	578
Vancouver	0	0	0	0
Gas exit Temperature (K)	733	283	933	283
Effective Vertical Velocity (m/s)	3.0	0.1	5.0	0.1
Initial Vertical Spread (m)	9.3	9.3	9.3	9.3
Emission Rate (g/s)	5.66	0.23	27.03	1.08

For each of the scenarios, time series for five years are generated to develop maximum, second highest, 9^{th} and 440^{th} predicted concentrations.

7.2.7 Air Dispersion Model Results Summary

Model results are presented in Table 7.10 as maximum and 99th percentile predicted hourly air concentrations of U3O8.

Table 7.10 Predicted Hourly Air Concentrations of UOC (µg/m³)

City	Accident Scenario	Maximum Concentration of U_3O_8				99th Percentile Concentration of U_3O_8			
		UTM Easting (m)	UTM Northing (m)	Predicted Concentration (µg/m³)	% of ERPG-2	UTM Easting (m)	UTM Northing (m)	Predicted Concentration (µg/m³)	% of ERPG-2
Montreal, QC	SC1	614674	5045453	18.7	0.19%	615374	5045653	10.0	0.10%
	SC2	615174	5045453	106.0	1.06%	615174	5045453	39.1	0.39%
	SC3	614674	5045453	11.2	0.11%	615374	5045653	6.2	0.06%
	SC4	615174	5045453	87.5	0.87%	615174	5045453	31.9	0.32%
Regina, SK	SC1	527715	5589072	15.0	0.15%	527715	5589072	7.5	0.07%
	SC2	527715	5589072	89.6	0.90%	527715	5589072	25.7	0.26%
	SC3	527715	5589072	10.0	0.10%	527715	5589072	5.0	0.05%
	SC4	527715	5589072	71.0	0.71%	527715	5589072	20.6	0.21%
Vancouver, BC	SC1	491528	5459278	21.2	0.21%	491528	5459479	13.7	0.14%
	SC2	492028	5459479	146.2	1.46%	492028	5459479	59.7	0.60%
	SC3	491528	5459278	13.7	0.14%	491528	5459479	8.7	0.09%
	SC4	492028	5459479	117.3	1.17%	492028	5459479	49.4	0.49%
ERPG-2 Criteria Level (µg/m³)				**10,000**				**10,000**	

7.2.8 Summary

The results of the air dispersion models for airborne emission of UOC following a traffic accident indicated that the maximum uranium concentration in air is a small fraction of ERPG level 2 benchmark for both fire and no-fire scenarios (0.05-0.2% and 0.2-1.2%, respectively). Therefore no impact to members of the public is expected.

8.0 SUMMARY AND CONCLUSSIONS

A risk assessment was conducted to assess the probability and consequence of ground transportation accident scenarios that would result in the release of UOC. The assessment considered a number of potential accident scenarios that would result in a release to surface water and a number of scenarios involving release to land. Both groups of scenarios included releases from truck and train accidents.

The probability assessment was conducted using the statistical data for general transportation as well as the data from the transportation of dangerous goods from various jurisdictions at national and provincial levels. This information was used with the UOC transportation routes (both truck and train) from northern Saskatchewan to North American refineries and to shipping ports for delivery abroad. The results of the assessment showed that:

- The probability of accidents involving transportation of dangerous goods is smaller than the probability of general transportation accidents.
- The accident rate for trains is slightly less than the accident rate for truck transport when compared on a per million tonne-km basis.
- The probability of release of UOC to surface water ranged from $1x10^{-5}$ to $1.5x10^{-5}$ during one year for the identified truck transportation routes.
- The probability of release of UOC to surface water ranged from $1x10^{-5}$ to $3x10^{-5}$ during one year for the identified train transportation routes. Greater probability of train accidents compared with truck accidents is attributed to the longer train routs and greater exposure to the surface water.
- The probability of release of UOC to land at the vicinity of population centres ranged from $4x10^{-5}$ to $1x10^{-4}$ during one year for the identified truck transportation routes.
- The probability of release of UOC to land at the vicinity of population centres ranged from $8x10^{-6}$ to $2x10^{-4}$ during one year for the identified train transportation routes.

Overall the probability of an accident that could result in the release of UOC to the environment during transportation was calculated to be very unlikely.

For surface water scenarios, the releases to large rivers, large lakes and harbours and small lakes were assessed. The following five rivers and five lakes were selected as case studies:

- Columbia River (British Columbia)
- North Saskatchewan River (Saskatchewan)
- Assiniboine River (Manitoba)
- Kaministiquia River (Ontario)

- Mississagi River (Ontario)
- Vancouver Harbour (British Columbia)
- Wollaston Lake (Saskatchewan)
- Lac La Ronge (Saskatchewan)
- Lake of the Woods (Ontario)
- Lake St. Louis (Quebec)

The consequence assessment for surface water releases assumed loss of containment of 25% of the shipment following a ground transportation accident. It was assumed that the UOC that settles close to the spill site will be removed through a post-accident clean-up program; however, it is likely that some residual UOC will be present in sediment subsequent to remediation and this was accounted for in the assessment. The solubility tests conducted on the UOC shows approximately 1% solubility. The results indicated that:

- The water quality of both lakes and rivers are impacted adversely in short term, but the effects on both systems are reversible and the systems will recover in the long term. Calculations also showed that the short-term effects persist for approximately 1 to 2 weeks depending on the characteristics of the river or lake system under study.

- In the short term, with respect to aquatic biota (e.g. zooplankton), effects can be expected for some sensitive species but population level impacts were not identified for the scenarios examined

- Sediment concentrations are determined to be adversely impacted, this would result in effects on benthic invertebrates that reside in sediment. Generally the spatial extent of the impact would be limited; however, in some of the scenarios considered, there is the potential for population-level effects in the benthic invertebrate communities of the Columbia River as well as Lake of the Woods and Vancouver Harbour, among the systems studied.

- Intake of uranium by semi-aquatic receptors may exceed their respective TRVs. The estimated intake is driven by the residual UOC in sediment. These exceedances are expected to be mostly limited to individual animals directly downstream; however, in the Columbia River as well as Lake of the Woods and Vancouver Harbour, the extent of contaminated sediment may result in population-level effects.

- Drinking the water immediately following the spill (defined by short-term water concentrations) would not result in impacts to terrestrial receptors.

- The concentration of uranium in water following a release may exceed the drinking water quality guideline for human consumption in Lac La Ronge and Lake Saint-Louis in the short-term.

- The release of uranium to small lakes (smaller than 3.6 million m^3 volume) may cause adverse effects which may persist for longer terms and would not be confined to one water body.

Overall, the consequence assessment for release to surface water indicates that the effects for release to large lakes and rivers are minor (except for a few lakes where the effects could be moderate to major). The effects to small lake systems could be major to severe (according to the definitions provided in Table 1.2). However, the probability of an accident that would result in a release is extremely small, resulting in low to moderate risk. A moderate risk is considered to be As Low As Reasonably Practicable (ALARP) given all regulatory oversight, the preventive and mitigative measures for transportation of dangerous goods, particularly class 7 material.

The consequence assessment for release to land included consideration of the following impacts:

- Workers dust inhalation following a release
- Air quality impact for public following an accident (with and without fire)

The calculation of the total effective doses to the truck driver and first responders (un protected) attending the accidents shows that the total effective doses are well below all regulatory limits. In addition, the dust inhalation following an accident by the driver or first responders showed that both chemical and radiological doses were far below their respective benchmarks.

The results of the air dispersion models for airborne emission of UOC following a traffic accident indicated that the maximum uranium concentration in air is a small fraction of ERPG level 2 benchmark for both fire and no-fire scenarios (0.05-0.2% and 0.2-1.2%, respectively). Therefore no impact to members of the public is expected.

Overall, it was concluded that the impact of transportation accidents that would result in the release of UOC to land, on the workers is minor. Given the low probability of such accidents, the risk from such accidents is deemed to be low.

The results of the risk assessment for the accidental release during UOC transport to both surface water and land are summarized in Table 8.1.

Table 8.1 Summary of the Risk Assessment for both Surface Water and Land Release Scenarios

Scenario Description	Probability Rating [a]	Consequence Rating [b]	Risk [c]
Spill of UOC into major rivers	Highly Unlikely	Moderate	Negligible Risk
Spill of UOC into a generic small lake	Highly Unlikely	Severe	Moderate Risk
Spill of UOC into larger lakes	Highly Unlikely	Major [d]	Moderate Risk
Spill of UOC on land from truck accident	Highly Unlikely	Moderate	Negligible Risk
Spill of UOC on land from train accident	Highly Unlikely	Moderate	Negligible Risk
Spill of UOC on land followed by airborne release (truck accidents)	Highly Unlikely	Minor	Negligible Risk
Spill of UOC on land followed by airborne release (train accidents)	Highly Unlikely	Minor	Negligible Risk
Spill of UOC on land followed by fire and airborne release (truck accidents)	Highly Unlikely	Minor	Negligible Risk
Spill of UOC on land followed by fire and airborne release (train accidents)	Highly Unlikely	Minor	Negligible Risk

Notes:
a Probability ratings are based on Table 1.1
b Consequence ratings are based on Table 1.2
c Risk is estimated based on Table 1.3
d For the majority of large lakes the consequence of releases are moderate, for other lakes the risk is negligible.

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APPENDIX A

ROUTES EXPOSURE CHARACTERISTICS

APPENDIX A: ROUTES EXPOSURE CHARACTERISTICS

Table A.1 Summary of Route Rd-1 Exposure Characteristics

Population Centre	Length (m)	Sensitive Environment	Length (m)	River Crossings	Length (m)	Near Water Body	Length (m)
Brabant/Brabant Lake	765	Lac La Ronge Pro. Park	4685	No Name	110	No Name	22
Missinipe	1088	Grand Valley Pro. Park	807	No Name	110	No Name	20
Wadin Bay	1509	Whiteshell Pro. Park	20448	No Name	110	No Name	13
No Name	662	Kakabeka Falle Pro. Park	2065	No Name	110	No Name	38
La Ronge Airport	600	Obatanga Pro. Park	6275	No Name	110	No Name	12
La Ronge	5013	Michipicoten Post Pro. Park	1059	No Name	110	No Name	15.2
Air Ronge	1853	Lake Superior Pro. Park	90156	No Name	110	No Name	14
Weyakwin	1759	Montreal River Pro. Park	954	No Name	110	No Name	16.7
Christopher Lake	1979	Lake Superior Pro. Park Addition	9143	No Name	110	No Name	14
Northside	654	Lake Superior Pro. Park Addition	3801	No Name	110	Wollaston Lake	19
Spruce Home	621			No Name	110	Wollaston Lake	33.6
Prince Albert	8048			No Name	110	Huggins Lake	46.4
Saint Louis	689			No Name	110	Jamieson Lake	45
Hoey	1907			No Name	130	Hills Lake	25
Wakaw	1873			No Name	110	Courtenay Lake	170
Cudworth	1138			No Name	110	Findlay Lake	140
Meacham	1460			No Name	110	Bothwell Lake	13
Young	1418			No Name	125	Bothwell Lake	17
Watrous	2085			No Name	115	Bothwell Lake	50
Simpson	915			No Name	125	Atwater Lake	65
Imperial	795			Purdey Lake	120	Schaffer Lake	33.5

Population Centre	Length (m)	Sensitive Environment	Length (m)	River Crossings	Length (m)	Near Water Body	Length (m)
Liberty	462			No Name	110	Gocki Lake	30
Bethune	1134			Smith Falls	125	Gocki Lake	36
Lumsden	1147			No Name	110	Purdey Lake	90
Regina	12691			Otter Rapids	170	McLennan Lakes	22.7
Emerald Park, White City	4797			No Name	110	Brigadier-General Ross Lake	43.5
Balgonie	1399			Otter Rapids-Sauger Whitefish, Pike	200	Burnt Lake	20
McLean	926			No Name	110	Burnt Lake	80
Indian Head	1712			No Name	110	Kismen Lake	101.6
Sintaluta	1006			Montreal River	120	Lindsay Lake	140
Wolseley	1880			No Name	110	Wierzycki Lake	280
Grenfell	1280			No Name	200	No Name	83.1
Broadview	1114			No Name	110	Jaysmith Lake	50
Whitewood	1702			No Name	150	Cratty Lake	480
Wapella	541			No Name	377	McLennan Lakes	140
Moosomin	2302			South Saskatchewan River	410	Hailstone Lake	11
Fleming	854			No Name	520	Dickens Lake	28.7
Elkhorn	1151			No Name	110	Devil Lake	70.5
Virden	1962			No Name	130	Walker Bay/Otter Lake	220
Oar Lake	1645			Wascana Lake	138	Bielby Lake	90
Griswold	996			Wascana Lake	130	Hine Lake, Althouse Lake	130
Alexander	510			No Name	145	Mullock Lake	56.5
Brandon	1823			Assiniboine River	190	Kuskawao Lake	50
Sidney	918			No Name	120	Poulton Lake	30
Austin	1860			No Name	110	Naniskak Lakes	25
MacGregor	2218			No Name	120	Lynx Lake	20
Portage La Prairie	3212			Assiniboine River	200	Lac La Ronge	450

Population Centre	Length (m)	Sensitive Environment	Length (m)	River Crossings	Length (m)	Near Water Body	Length (m)
Fortier	495			Red River	281	Potato Lake	11
Bernard	951			Red River Floodway	140	No Name	38.6
Elie	1307			No Name	110	No Name	56
Dacotah	857			No Name	110	No Name	14
Saint-Francois Xavier	2072			No Name	110	No Name	76.4
Headingley	1844			Keewatin Bay	279	No Name	36
Winnipeg	22475			Cameron Bay	142	No Name	950
Richer	1683			Norman Bay	180	No Name	760
Falcon Lake	653			No Name	120	No Name	24
Clearwater Bay	486			Richard Lake	232	No Name	60.5
Keewatin	1699			Edison Lake	110	No Name	1090
Kenora	6025			river into Sportsman's Bay	110	No Name	300
Longbow Lake	1063			Eagle River	170	No Name	740
Willard Lake	283			No Name	120	No Name	3010
Vermilion Bay	1827			Wabigoon River	150	No Name	47.6
Oxdrift	762			No Name	122	No Name	47.6
Two Mile Corner	2352			No Name	110	No Name	860
Dryden	5765			No Name	110	No Name	30.7
Wabigoon	862			No Name	110	No Name	120
Dinorwic	987			No Name	110	No Name	660
Borups Corners	354			No Name	110	Barren Lake, Falcon Lake	35
Ignace	2741			No Name	193	Lyons Lake	21.1
Sistonen's Corners	580			No Name	110	Moth Lake	43.7
Mokomon	912			No Name	110	Engineers Lake	43.7
Kakabeka Falls	1891			No Name	150	Caribou Lake	55
Carter's Corners	1369			No Name	140	Granite Lake	50
Thunder Bay	8849			Umber Lake	145	Paddy Creek	14
Loon	457			No Name	121	Portage Bay	120
Dorion	991			No Name	120	Norman Bay	33.9
Nipigon	2383			No Name	125	Laurensons Lake	41.2
Gurney	723			Kaministiquia River	201	Hilly Lake	17.5
Cavers	442			No Name	120	Longbow Lake	30

Population Centre	Length (m)	Sensitive Environment	Length (m)	River Crossings	Length (m)	Near Water Body	Length (m)
Rossport	543			No Name	110	Dogtooth Lake	13
Selim	480			Wolf River	125	Joyce Lake	36.5
Schreiber	1700			No Name	146	Percy Lake	35
Terrace Bay	2366			No Name	157	Percy Lake	75.5
Marathon	1930			No Name	130	No Name	41
No Name	2690			No Name	120	North Narrow Lake	54.4
White River	1949			No Name	110	Foot Lake	31.5
Wawa	1136			Gravel River	130	Willard Lake	60
Michipicoten	770			No Name	155	Island Lake	24.5
Agawa Bay	500			No Name	110	Richard Lake	110
Montreal River	1069			No Name	150	Earngey Lake	96.8
Harmony Beach	1205			river into Santoy Bay/Lake Superior	120	Little Joe Lake	60
Havilland	547			Prairie River	124	Bee Lake	60
Heyden	1308			No Name	150	Peterson Lake	36.3
Glenview Cottages	536			Pic River	163	George Lake	53.1
Odena	395			No Name	149	Triangle Lake	84.6
Sault Ste. Marie	11927			No Name	110	Ely Lake, Nixon Lake	86.6
Echo River	811			No Name	120	Rutters Bay/Thunder Lake	26.8
Echo Bay	774			No Name	110	Thunder Lake	71.8
Laird	1898			Dunc Lake	300	Jaskfish Lake	170
Desbarats	489			Kichidabadik Inlet	190	No Name	64.7
Bruce Mines	1253			White Lake	122	Shell Lake	30
Nestorville	453			No Name	140	Agimake Lake	20
Thessalon	740			North Crocker's Lake	120	Lodge Lake	74.7
Livingstone Creek	445			Little Lake	120	No Name	50
Sowerby	496			No Name	110	No Name	60
Iron Bridge	1339			No Name	127	Inwood Lake	33
Blind River	531			Saniga Lake	120	Pearl Lake	54
				No Name	120	Lake Superior	140

Population Centre	Length (m)	Sensitive Environment	Length (m)	River Crossings	Length (m)	Near Water Body	Length (m)
				Fungus Lake	120	Bear Trap Lake	38.9
				Kabenung Lake	140	Lake Superior	520
				No Name	110	Billy Lake	25
				No Name	170	Lily Bay	20
				Michipicoten River	204	Rongie Lake	105
				Salter Lake	184	Walker Lake	101.9
				South Old Woman River	130	Jackfish Lake	260
				No Name	110	No Name	39
				No Name	150	Black Fox Lake	56.7
				Agawa River	167	Ripple Lake	60
				No Name	110	Dam Lake	36.4
				No Name	120	Wolf Camp Lake	43
				No Name	125	Rouse Lake	110
				Batchawana River	188	Moose Lake	44.3
				Chippewa Falls	125	Dunc Lake	160
				No Name	110	Kichidabadik Inlet	180
				No Name	150	Nursey Lake	24
				No Name	115	Green Lakes	57.8
				The Rapids	143	Crocker's Lake	76.8
				Echo River	136	Marion Lake	54
				Bar River	120	Hammer Lake	440
				No Name	130	Dennison Lake	30
				No Name	125	Burnfield, Cotton, Bogle Lake	88.7
				No Name	110	Fungus Lake	71
				No Name	130	Desolation Lake	35.6
				Livinstone Creek	110	Catfish Lake	230
				No Name	125	Crozier Lake	82
				Mississagi River	197	Blackington Lake	14

Population Centre	Length (m)	Sensitive Environment	Length (m)	River Crossings	Length (m)	Near Water Body	Length (m)
						Antoine Lake	46.3
						Line Lake	20
						Fenton Lake	130
						Moose Lake	22.4
						Hnery Lake	37.8
						Old Woman Bay/Lake Superior	36
						Red Rock, Colette, Murphy Lake	107
						Dad, Baby, Mom Lake	60
						Doc Greig Lake	60
						Lake Superior	90
						Katherine Cove/Lake Superior	57.4
						Kenny Lake	30
						Lake Superior	150
						Beta Lake	46
						Gamma Lake	13
						Alona Bay/Lake Superior	90
						Mica Bay/Lake Superior	370
						Mamainse Harbour, Flour Bay	620
						Beardens Lake, Deadman's Cove	30
						Coppermine Rock	14
						Cottrell Cove, Sawpit Bay	170
						Lake Superior	160
						Lake	81

Population Centre	Length (m)	Sensitive Environment	Length (m)	River Crossings	Length (m)	Near Water Body	Length (m)
						Superior	
						Lake Superior	44
						Lake Superior	99.3
						Old Mil Bay/Lake Superior	260
						Lake Superior	200
						Lake Huron	20
						Clear Lake	46.5
						Warnock Lake	38.7
						Mississagi River	1570
Total	**204493**		**139393**		**19193**		**22516**

Table A.2 Summary of Route Rd-2 Exposure Characteristics

Population Centre	Length (m)	River Crossings	Length (m)	Near Water Body	Length (m)
Saskatoon	18548	South Saskatchewan River	246	Blackstrap Reservoir	105
Dundurn	628	No Name	110	No Name	696
Hanley	543	No Name	125	No Name	54
Kenaston	457	Condie Reservoir	122	No Name	681
Bladworth	542	No Name	120	No Name	50
Davidson	2591	No Name	110	No Name	79
No Name	982	No Name	110	No Name	201
Craik	376	No Name	110	No Name	28
Aylesbury	799	No Name	120	No Name	1918
Chamberlain	862	No Name	120	Wascana Lake	30
Findlater	427			No Name	74
Bethune	489			No Name	36
Lumsden	502				
Regina	14382				
Corinne	465				
Ceylon	1163				
Minton	377				
Total	**44133**		**1293**		**3952**

Table A.3 Summary of Route Rd-3 Exposure Characteristics

Population Centre	Length (m)	Sensitive Environment	Length (m)	River Crossings	Length (m)	Near Water Body	Length (m)
Saskatoon	18548	Grand Valley Pro. Park	807	South Saskatchewan River	246	Blackstrap Reservoir	105
Dundurn	628			No Name	110	No Name	696
Hanley	543			No Name	125	No Name	54
Kenaston	457			Condie Reservoir	122	No Name	681
Bladworth	542			No Name	120	No Name	50
Davidson	2591			Little Saskatchewan River	157	No Name	79
No Name	982			No Name	110	No Name	201
Craik	376			No Name	110	No Name	28
Aylesbury	799			Assiniboine River	178	No Name	1918
Chamberlain	862			No Name	110	No Name	437
Findlater	427			No Name	110	No Name	126
Bethune	489			Assiniboine River	186	No Name	33
Lumsden	502			Kronsgart Drain	130	No Name	46
Regina	14382			No Name	50	No Name	474
Emerald Park, White	2972			No Name	40	No Name	1712
Balgonie	1399					No Name	782
Saint Joseph's	583					No Name	220
Mclean	911					No Name	1532
Indian Head	1712						
Sintaluta	1006						
Wolseley	1880						
Summerberry	292						
Grenfell	1280						
Broadview	1280						
Percival	696						
Whitewood	1702						
Burrows	527						
Wapella	541						
Mossomin	2302						
Fleming	854						
Elkhorn	1151						
Virden	1962						
Oar Lake	1645						

Population Centre	**Length (m)**	**Sensitive Environment**	**Length (m)**	**River Crossings**	**Length (m)**	**Near Water Body**	**Length (m)**
Griswold	996						
Alexander	610						
Kemnay	317						
Brandon	1823						
Douglas	431						
Sidney	918						
Austin	1860						
MacGregor	2218						
Portage La Prairie	3212						
Fortier	495						
Bernard	951						
Elie	1307						
Dacotah	857						
Saint Francois Xavier	2072						
Headingley	1844						
Winnipeg	22475						
Howden	400						
Ste. Agath	2419						
Morris	2065						
Saint Jean Baptiste	1252						
Letellier	936						
West Lynee	388						
Total	**116669**		**807**		**1904**		**9173**

Table A.4 Summary of Route Rl-1 Exposure Characteristics

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Regina	5080	Crownsnest Pro. Park	930	No Name	215	No Name	99
Grand Coulee	1182	Elk Valley Pro. Park	1419	No Name	210	No Name	209
Pense	818	Morrissey Pro. Park	558	No Name	372	No Name	322
Belle Plaine	652	Wasa Lake Pro. Park	533	No Name	238	No Name	30
Pasqua	1018	Thunder Hill Pro. Park	666	No Name	220	No Name	45
Moose Jaw	5340	Fairmont Hot Springs	812	No Name	210	No Name	171
Bohram	439	Windermere Lake Pro. Park	2014	Reed	1120	No Name	662
Caron	657	James Chabot Pro. Park	569	No Name	220	No Name	45
Mortlach	1096	Radium Hot Springs	1001	No Name	220	No Name	38
Parkbeg	522	Burges and James Gadsden Pro. Park	2777	No Name	210	No Name	33
Valjean	525	Marl Creek Pro. Park	955	No Name	220	No Name	37
Chaplin	1051	Glacier Nat. Park	42750	No Name	210	No Name	119
Uren	676	Canyon Hot Springs	1036	No Name	210	No Name	101
Ernfold	659	Mt. Revelstoke Nat. Park	12514	No Name	210	No Name	777
Morse	790	Victor Lake Nat. Park	493	No Name	210	Reed Lake	78
Herbert	1371	Banana Island Pro. Park	1042	No Name	220	Reed Lake	78
Rush Lake	715	Pritchard Pro. Park	2646	No Name	210	No Name	55
No Name	491	Monte Creek/Pro. Park	462	No Name	210	No Name	50
Waldeck	1226	Steelhead Pro. Park	976	No Name	210	No Name	198
Swift Current	7606	Walhachin Oxbows Pro. Park	1000	No Name	210	No Name	96

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Beverley	726	Juniper Beach Pro. Park	895	No Name	220	Gander Lake	38
Webb	752	Epsom Pro. Park	1345	No Name	307	No Name	63
Gull Lake	1756	Spences Bridge	477	No Name	215	No Name	113
Carmichael	719	Goldpan Pro. Park	724	No Name	210	No Name	45
Tompkins	1088	Skihist Pro. Park	3017	No Name	215	Hay Lake	56
Piapot	827	Alexandra Bridge Pro. Park	1186	No Name	210	No Name	181
Maple Creek	1680	Yale-Garry Oak Eco. Reserve	681	No Name	220	No Name	71
Hatton	468	Emory Creek Pro. Park	1308	No Name	220	No Name	142
Walsh	613	Kilby Pro. Park	254	No Name	210	No Name	86
Irvine	995			Old Man River	320	No Name	47
Dunmore	1715			No Name	210	Old Man River	57
Medicine Hat	877			No Name	220	No Name	50
Roytal	471			Old Man River	310	No Name	49
Bullshead	532			No Name	210	No Name	47
Fitzgerald	597			No Name	215	No Name	78
Seven Persons	1247			Pincher Creek	255	No Name	225
Whitla	494			Old Man River	322	No Name	631
Winnifred	444			Lundbreck Falls	230	Crownsnest Lake	354
Bow Island	1349			No Name	230	Island Lake	107
Burdett	793			Elk River	220	Summit Lake	142
Grassy Lake	1102			No Name	220	No Name	1791
Purple Springs	564			No Name	230	Elk River	904
Taber	3633			No Name	230	Elk River	813
Barnwell	1216			No Name	220	Elk River	167
Cranford	567			No Name	215	Elk River	458
Chin	623			Kootenay River	356	Elk River	1122
Tempest	504			Kootenay River	375	Kootenay River	757
Coaldale	3000			Shookumchuk	230	Kootenay River	57

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
				River			
Lethbridge	5100			No Name	232	Kootenay River	91
Heritage Heights	1439			No Name	215	Kootenay River	126
Coalhurst	1762			Columbia River	230	Kootenay River	108
Kipp	647			Columbia River	230	Kootenay River	353
Monarch	923			Columbia River	293	Kootenay River	252
Pearce	675			No Name	240	Kootenay River	201
Fort Macleod	1880			Columbia River	292	Kootenay River	337
Stowe	536			No Name	225	Kootenay River	101
Brocket	1873			No Name	220	No Name	38
Pincher Station	851			No Name	215	No Name	121
Cowley	1067			Columbia River	471	Schookumchuk River	172
Lundbreck	822			Eagle River	250	Kootenay River	99
Bellevue	2360			Eagle River	245	Kootenay River	465
Blairmore	3572			Eagle River	269	Kootenay River	99
Crownsnest	2569			Shuswap Lake	329	Kootenay River	550
Hazell	347			No Name	215	Kootenay River	219
Sparwood	5472			Nicola River	245	Columbia Lake	1498
Hosmer	1307			Fraser River	297	No Name	68
Fernie	2994			Fraser River	238	Windermere Lake	1334
Cokato	1063			No Name	281	Dorothy Lake	34
Elko	435			Mountain Slough	220	Windermere Lake	87
Caithness	562			Harrison River	460	Columbia River	205
Galloway	1663			No Name	230	Columbia River	879
Jaffray	989			Hatzic Lake	541	Columbia River, many small	818
Bull River	569			Fraser River	338	Columbia River, many small	272
Fort Steele	966			Kanaka Creek	227	No Name	155
Wasa	828			Katzie Slough	210	Columbia River, many small	750

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Shookumchuk	344			Pitt River	655	Columbia River, many small	1663
Canal Flats	667			Coquitlam River	210	many small various	1226
No Name	949					Columbia River, many small	2171
No Name	1371					Columbia River, many small	709
Invermere	3233					Columbia River	91
Edgewater	671					Columbia River	548
Brisco	578					Columbia River	893
Spillimacheen	413					Columbia River	127
Harrogate	998					Columbia River	1515
Castledale	460					Kinbasket Lake	1013
Parson	831					No Name	1944
McMurdo	537					No Name	2559
Nicholson	2179					No Name	1924
Golden	3150					No Name	901
Blaeberry	477					Wetask Lake	45
Forde	398					No Name	117
Donald	1037					Victor Lake	80
Rogers	404					Three Valley Lake	294
Revelstoke	5191					Griffin Lake	135
Big Eddy	2010					Eagle River	1623
Malakwa	1094					Eagle River	971
Solsqua	421					Eagle River	1731
Sicamous	1002					Shuswap Lake	1891
Annis	861					Shuswap Lake	964
Canoe	1280					McGuire Lake	28
Salmon Arm	3115					Shuswap Lake	43
Tappen	595					Shuswap Lake	3917
Carlin	450					Shuswap Lake	359
Notch Hill	611					Little Shuswap Lake	679
Chase	2913					Little Shuswap Lake	531

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Juniper Ridge	2982					Kamloops Lake	307
Kamloops	4382					Kamloops Lake	112
Mission Flats	496					Thomspon River	2630
Savona	1835					Thompson River	2982
Walhacin	903					Thompson River	422
Ashcroft	1262					Thompson River	1701
Lytton	1124					Thompson River	5567
Kanaka Bar	554					Thompson River	3373
Canyon Alpine	529					Fraser River	9480
North Bend	603					Klahater Lake	63
Boston Bar	1892					Fraser River	632
Yale	476					Devil Lake	40
Dogwood Valley	809					Fraser River	1851
Choate	444					Fraser River	820
Hope	715					Harrison River	301
Ruby Creek	822					Lake Errock	34
Kent	2215					Lake Errock	39
Harrison Mills	308					No Name	479
Lake Errock	1969					river into Fraser River	131
Deroche	726					river into Fraser River	127
Dewdney	654					Fraser River	376
Hatzic	1690					Fraser River	126
Mission	4028					Fraser River	434
Whonnock	875					Burrard Inlet	213
Albion	2401						
Maple Ridge	9867						
Coquitlam	11757						
Vancouver	12260						
Total	**211355**		**85040**		**20523**		**84250**

Table A.5 Summary of Route Rl-2 Exposure Characteristics

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Regina	5826	Beaudry Pro. Park	2744	No Name	210	No Name	1060
Pilot Butte	2245	Whiteshell Pro. Park	2445	No Name	210	No Name	1210
Balgonie	1173	Whiteshell Pro. Park	28600	No Name	326	No Name	1086
Saint Joseph's	418	Winnange Lake Pro. Park	2624	No Name	210	No Name	965
Maclean	739	Winnange Lake Pro. Park	4907	No Name	250	No Name	881
Qu'Appelle	1209	Aaron Pro. Park	1486	No Name	210	No Name	1297
Indian Head	1842	Ruby Lake Pro. Park	11893	No Name	258	No Name	8550
Sintaluta	877	Gravel River Nature Res.	3005	Assiniboine River	264	No Name	938
Wolseley	1588	Rainbow Falls Pro. Park	1515	No Name	210	No Name	857
Summerberry	340	Prairie River Mouth Nature Res.	1461	Red River	401	No Name	1074
Grenfell	1389	Neys Pro. Park	9658	Siene River	226	No Name	743
Oakshela	426	Red Sucker Point Nature Res.	2423	Red River Floodway	210	No Name	1140
Broadview	1298	Craig's Pit Nature Res.	1348	Cooks Creek	210	No Name	960
Percival	874	Woman River Forest Pro. Park	8349	No Name	210	No Name	660
Whitewood	1956	Biscotasi Lake Pro. Park	1271	No Name	210	No Name	394
Burrows	923	Biscotasi Lake Pro. Park	1253	Whitemouth River	268	No Name	679
Wapella	974	Biscotasi Lake Pro. Park	873	No Name	215	No Name	165
Moosomin	2152	Spanish River Pro. Park	36322	Hansons Creek Dam	210	No Name	236
Fleming	700	Windy Lake Pro. Park	2153	Norman Bay	275	No Name	41
Kirkella	518	Amable du Fond River Pro. Park	2059	Kenora Bay	243	No Name	45

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Elkhorn	1187	Samuel de Champlain Pro. Park	1891	Lester Lake	259	No Name	91
Hargrave	589	Driftwood Pro. Park	2319	Trout Lake	210	No Name	137
Virden	2296	Morris Island Conservation Area	2425	Trout Lake	430	Red River	471
Oak Lake	1559			Viaduct Lake	419	Whitemouth River	118
Griswold	953			Feist Lake	382	Skull Pond	47
Alexander	1187			No Name	210	Telford Pond	51
Kemnay	910			Eagle River	220	Hansons Creek	605
Brandon	6730			No Name	215	South Cross Lake, Caddy Lake	131
Charter	739			No Name	210	Macara Lake	32
Douglas	1044			No Name	210	Longpine Lake	160
Camp Hughes	627			Wabigoon River	210	Harvey Lake	53
Carberry	1512			Kelpyn Bay	945	Whitefish Lake	114
Melbourne	560			No Name	210	Kennedy Lake	60
Sidney	1060			No Name	210	No Name	67
Austin	1355			No Name	210	Kalmar Lake	102
MacGregor	1835			No Name	210	No Name	92
Bagot	713			No Name	210	Monument Lake	118
Portage La Prairie	4216			No Name	220	Sherwood Lake	125
Newton	583			No Name	226	Greenwater Lake	33
Oakville	1039			No Name	238	Bunny Lake	85
Bernard	961			No Name	242	Deception Lake	94
Elie	1500			No Name	210	Helen Lake	131
Dacotah	924			No Name	210	Jennie Lake	91
White Plains	620			No Name	220	Lake Lulu	63
Calrin	488			No Name	210	Lake Lulu, Louise Lake	315
West Perimeter South	2162			No Name	210	War Eagle Lake	29
Ridgewood South	5352			No Name	220	Paddy Creek	57
Winnipeg	21745			No Name	210	Darlington, Mink, Portage, Keewatin Bay	550
Oakbank	2645			No Name	210	Cameron Bay	30
Hazelridge	626			Bittern Lake	210	Norman Bay	73

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Molson	449			Wolf River	215	Round Lake	34
Whitemouth	1703			No Name	240	Breakneck Lake	34
Rennie	811			No Name	210	Island Lake	75
Ingolf	557			Nipigon River	279	Lester Lake	84
Keewatin	2340			No Name	220	McDonald Lake	208
Kenora	3444			No Name	215	Railway Lake	67
Vermilion Bay	1658			No Name	215	Beaver Lake	56
Waldhof	770			Gravel River	215	Scovil Lake	53
Eagle River	596			Gravel River	215	Little Scovil Lake	54
Dryden	2964			No Name	241	Trout Lake	167
Wabigoon	806			No Name	232	Trout Lake	161
Dinorwic	724			No Name	220	North Narrow Lake	443
Dyment	495			No Name	279	No Name	35
Ignace	876			No Name	290	No Name	35
Upsala	374			No Name	250	Hawk Lake	41
No Name	577			No Name	220	No Name	27
Murillo	1257			Little Cedar Lake	215	Clare Lake	158
Thunder Bay	17879			No Name	240	Lilium Lake	204
Wild Goose	2110			No Name	220	Rail Lake	254
Loon	1079			Tarpon Lake	484	Feist Lake	201
No Name	481			No Name	220	No Name	73
Ouimet	450			No Name	215	No Name	107
Dorion	2908			No Name	210	No Name	239
Hurkett	772			West Tripoli Lake	250	Upper Stewart Lake	46
Nipigon	2942			No Name	210	Crabclaw Lake	168
Gurney	506			Little Triston Lake	489	Strawberry Lake	157
Cavers	700			No Name	300	Edison Lake	276
Pays Plat	655			No Name	220	The Gilbert Stretch	76
Rossport	1130			Sixty One Bay	397	Sportsman's Bay	324
Selim	946			Dog Lake Narrows	433	Nixon Lake	66
Schreiber	959			Hay Bay	422	Eagle Lake	389
Terrace Bay	1395			Hand Lake	373	No Name	140
Jackfish	614			No Name	210	Milanese's Lakes	48
Marathon	3101			Reflection Lakes	487	Canard Lake	37
Heron Bay	570			No Name	210	Wabigon Lake	100

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Mobert	1004			Poulin Lake	332	No Name	190
White River	1634			Nemegos Lake	220	No Name	219
Lochalsh	409			Kinogama Lake	210	Barrit Bay	226
Missanabie	1031			Woman Lake	215	Kennabutch Lake	127
Dalton	1033			No Name	215	Pinafore Lake	126
Esher	495			Ramsey Lake	289	No Name	49
Chapleau	2129			Ramsey Lake	443	No Name	321
Devon	664			No Name	210	Shell Lake	43
Sultan	621			Spanish River	686	Three Mile Lake	30
Ramsey	517			Houghton Lake	305	Agimake Lake	50
Biscotasing	697			Hogsback Channel	373	Potter's Pond	37
Stralak	440			Houghton Lake	337	One Mile Lake	27
Benny	393			No Name	215	Grim Lake, South Lake	100
Cartier	1308			Bannerman Lake	267	Bonheur, Iron Lake	152
Windy Lake	347			Geneva Lake	322	Raven Lake	101
Phelans	468			No Name	210	Sandal Lake	50
Chelmsford	1650			Crab Lake	382	Grass Lake	62
Belanger	768			No Name	251	Lodge Lake	57
Azilda	2619			No Name	227	Hawk Lake	250
Sudbury	8204			No Name	210	No Name	87
Romford	1133			No Name	253	Tea Lake	37
Nickel Centre	1759			Lake Nipissing	210	Hay Lake	400
Wahnapitae	1450			No Name	210	Mainey, Inwood, Upsala Lake	217
Markstay	829			No Name	210	No Name	1709
Markstay-Warren	916			Sturgeon River	229	Kaministiquia River	472
Markstay-Warren	1177			No Name	232	Lake Superior	442
Verner	2131			No Name	210	No Name	686
Cache Bay	898			No Name	255	No Name	175
West	3200			Amable du	228	Loon Lake	293

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Nipissing				Fond River			
No Name	595			Amable du Fond River	220	No Name	91
North Bay	6467			No Name	210	Lake Superior/Nipigon River	381
Nipissing Junction	1409			Ottawa River	572	Ivan Lake	74
Corbeil	831			No Name	258	Lake Superior	126
Nosbonsing	416			No Name	258	Lake Superior/Nipigon Bay	469
Bonfield	950			Ottawa River	609	Lake Superior	148
Rutherglen	650			Ottawa River	688	Lake Superior/Cypress Bay	237
Eau Claire Station	546			Eagle Creek	247	Lake Superior	754
Mattawa	3159			Rideau River	296	Lake Superior/Gravel Bay	3873
Bissett Creek	672			No Name	349	East Pond	37
Stonecliffe	671			Riviere Delisle	215	Lake Superior	1007
Wylie	632			Riviere Delisle	220	Lake Superior	325
Chalk River	1253			McDonald-Robertson Drain	210	Little Steel Lake	247
Petawawa	10796			No Name	215	Ripple Lake	108
Pembroke	4668			St. Lawrence River	629	Lake Superior/McKellar Harbour	72
Government Road	627			St. Lawrence River	590	Lake Superior	292
Beachburg	932					Lake Superior	55
Ledgerwoods Corner	1009					Neys Lake	44
Bristol	458					Echo Lake	90
Norway Bay	2117					Lake Superior/Peninsula Bay	397
Pontiac	488					Red Sucker Lake	67

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
Station							
Vydon Acres	1214					Peninsula Harbour	98
Fitzroy	534					Lake Superior	167
Dunrobin	747					Heron Bay	134
Malwood	468					Rouse Lake	67
Harwood Plains	1419					Cache Lake	203
Shirley's Brook	2916					Cigar Lake	122
Bells Corners	2325					No Name	168
Ottawa	18431					Bradley Lake	81
Carlsbad Springs	605					Rust Lake	89
Vars	942					Trudeau Lake	78
Limoges	2178					Giles Bay, Babitabonanik Bay	720
Casselman	3255					White River/Elora Lake	1035
Moose Creek	988					No Name	87
Maxville	1227					No Name	298
Greenfield	617					Tarpon Lake	71
Alexandria	2115					No Name	550
Glen Robertson	1507					No Name	474
Sainte-Justine-Station	626					Negwazu Lake	713
De Baujeu	419					Newcombe Lake	52
Saint-Polycarpe	1579					Friendly Lake	41
Coteau-Station	1267					Summit Lake	127
Coteau-Du-Lac	1005					Tripoli Lake	29
Vaudreuil-Dorion	3585					No Name	161
Terrasse-Vaudreuil	1784					No Name	126
Lile-Perrot	1756					No Name	54
Sainte-Anne-De-Bellevue	1223					No Name	386
Montreal	33309					Eighty Four Lake	129
						Leg Lake	31
						Hobon Lake	97
						No Name	39

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
						Otter Lake	55
						No Name	111
						No Name	68
						Wabatongushi Lake	83
						Lochalsh Bay	801
						Dog Lake	124
						Dog Lake Narrows	93
						Dog Lake	93
						Argo Lake	43
						No Name	164
						Pickle Lake	50
						Carry Lake	142
						No Name	197
						Porcupine Lake	88
						Buckhorn Lake	160
						No Name	239
						No Name	457
						Reflection Lakes	182
						Wayland Bay	40
						Henna Lake	135
						Windermere Lake	714
						Healey Bay	199
						Healey Bay	97
						No Name	81
						No Name	119
						Adagio Lake	147
						Brusaw Lake	73
						Wangoon Lake	167
						No Name	243
						Colin Lake	314
						No Name	46
						No Name	704
						Poulin Lake	105
						No Name	73
						No Name	49
						No Name	589
						Nemegos Lake	50
						No Name	160
						No Name	411
						No Name	49
						No Name	515
						Valois Lake	74
						No Name	249

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
						Cavell Lake	142
						No Name	235
						No Name	45
						Leblanc Lake	48
						Sheldon Lake	54
						Joffre Lake	33
						View Lake	156
						Kane Lake	51
						Norton Arm	113
						Spanish River	55
						Houghton Lake	110
						Hogsback Channel	160
						Houghton Lake	88
						Drefal Lake	101
						No Name	98
						Salisbury Lake	55
						Eureka Lake	22
						St. John Lake	43
						Low Lake	137
						Larkin Lake	268
						No Name	196
						Lebell Lake	532
						No Name	1118
						Straight Lake	225
						Present Lake	58
						No Name	82
						No Name	141
						No Name	124
						Bannerman Lake	118
						Geneva Lake	52
						Geneva Lake	79
						Geneva Lake	62
						Crab Lake	76
						Crab Lake	132
						No Name	180
						Windy Lake	192
						Ramsey Lake	366
						Frenchman's Bay/Ramsey Lake	78
						Lake Nipissing	1980
						Lake Nipissing	1432
						Lake Nipissing	2315
						No Name	494
						Lake Nosbonsing	5808

Population Centre	Length (m)	Sensitive Environments	Length (m)	River Crossing	Length (m)	Near Water Body	Length (m)
						No Name	106
						Upper Johnston Lake	65
						Smith Lake	91
						Crooked Chute Lake	90
						Amable du Fond River	68
						Taggart Lake	97
						Earl's Lake	86
						Ottawa River	3504
						No Name	200
						Adelard Lake	160
						Ottawa River	899
						Way Lake	31
						Roney Lake	123
						Moor Lake	87
						Heart Lake	98
						Sidetrack Lake	103
						Spur Lake	30
						Iota Lake	23
						No Name	299
						Black Duck Lake	91
						Corry Lake	181
						No Name	112
						Lac des Chats	99
						Baie du Camp	63
						Ottawa River	102
						No Name	228
Total	**322093**		**133024**		**35935**		**87227**

APPENDIX B

TOXICITY REFERENCE VALUES

APPENDIX B: TOXICITY REFERENCE VALUES

B.1 INTRODUCTION

This write up summarizes the methodology to develop species sensitivity distribution (SSD) for uranium acute aquatic toxicity.

The Water Quality Task Group of the Canadian Council of the Ministers of the Environment (CCME) has a protocol to develop the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME 2007). The goals of the protocol include: (i) accounting for the unique properties of contaminants which influence their toxicity; and (ii) incorporating the SSD method, which uses all available toxicity data (provided these data pass quality control criteria) in the development of the guideline. The SSD approach has been adopted for the development of the site-specific water quality objectives and is therefore supported by the CCME protocol (CCME 2007).

B.2 PROCEDURE

The first step in the development of SSDs for uranium was the compilation of relevant aquatic toxicity data. Toxicity data were summarized and screened to meet the following criteria:

- Freshwater tests;
- Acute; and
- LCx, ECx, ICx, MATC/NOEC/LOEC endpoints (where x >=10); and,
- Inorganic chemical form.

Toxicity tests completed in a saltwater environment were excluded from the dataset.

Acute tests were considered to be less than or equal to 4 days (96 hours), with the exception of the algae *Pseudokirchneriella subcapitata* and the aquatic sowbug *Asselus aquaticus*. A 72 hour test duration is recommended for conducting chronic toxicity tests for *Pseudokirchneriella subcapitata* (Environment Canada 2007) while 96 hour test durations are acceptable for the *Asellus aquaticus*. Therefore, only data points for these species with test durations of less than 3 days (for *Pseudokirchneriella subcapitata*) and less than 4 days (for *Asellus aquaticus*) were included in the dataset.

Data points were also removed if the concentrations were reported as "less than", since an accurate number could not be determined. Result concentrations reported as "greater than" were conservatively assumed to be equal to the concentration. When multiple endpoints were reported for a specific species, following the CCME protocol for the derivation of water quality guidelines (CCME 2007), LC50 or equivalent endpoints were selected.

After the compilation of the dataset, toxicity data were grouped by species. If only 1 toxicity value was available for a species then that value was used as the toxicity value for the species; however, when multiple toxicity values were available for a species then the geometric mean of the toxicity values was calculated and assumed to represent the toxicity value for that species.

The geometric mean was selected instead of the arithmetic mean in order to minimize the bias towards high test results. Species mean values were then ranked from lowest to highest and the percent of species affected was calculated using equation (1):

$$\%\ \mathit{Affected} = \frac{\text{Rank - 0.5}}{\text{Number of Species}} \times 100 \qquad (1)$$

After manipulation of the dataset and ranking, the US EPA SSD generator (2010) and the SSD Master V3 (CCME 2013) were used to develop the curves for the SSDs. The U.S. EPA SSD generator applies a log-probit distribution to the dataset to develop the SSD curve, while the SSD Master V3 develops curves for normal, logistic, extreme value, and Gumbel models. The curves were compared and one was selected for the SSD based on the best fit of the data in the lower end of the curve, using visual assessment of the curves, as well as the statistical fit parameters. Model parameters in SSD Master V3 are estimated using ordinary least squares (OLS) and there are concerns with this method compared with the maximum likelihood estimate (MLE) approach; however, Zajdlik & Associates (2014) found that the SSD Master V3 estimates using OLS are generally biased downwards compared with the MLE approach. Therefore, while this approach might not be favoured, it does remain conservative.

The following sections present the data and SSD curves developed for each constituent of interest.

B.3 URANIUM SSD FOR ACUTE AQUATIC TOXICITY

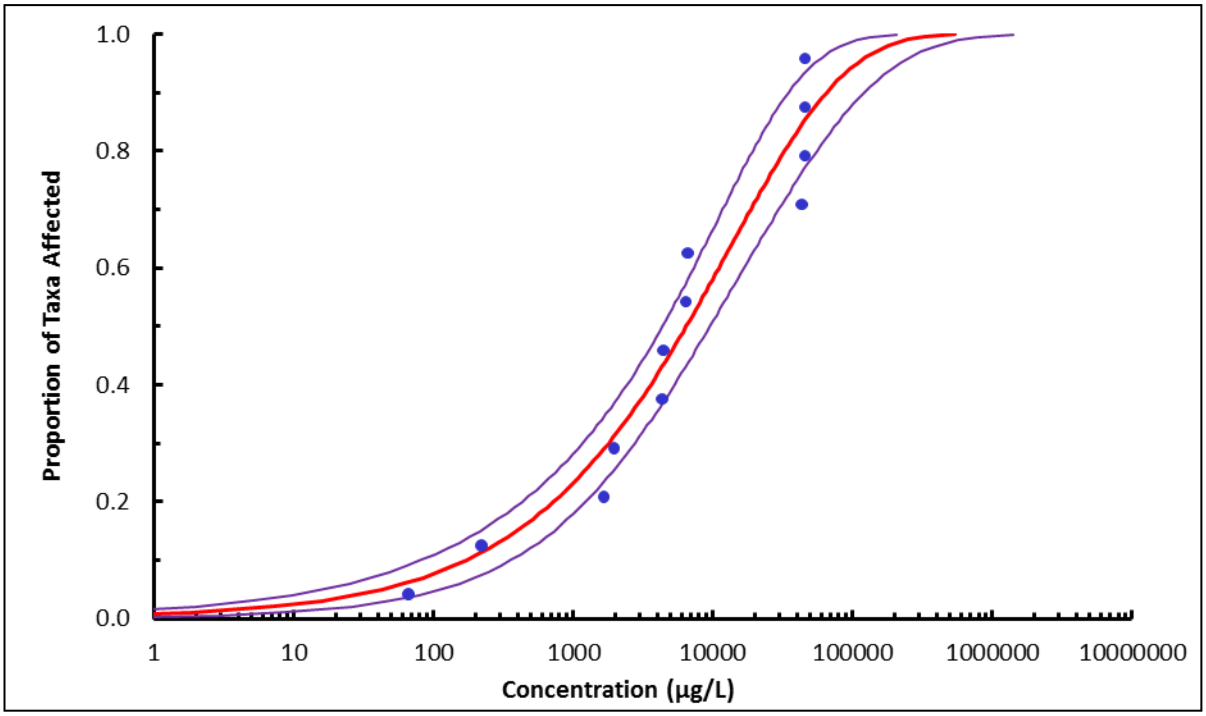
Data presented for acute toxicity in CCME (2011, Table 11) were used as the basis of the dataset, with additional data from U.S. EPA AQUIRE/ECOTOX. The additional data screen resulted in the addition of two additional LC_{50} data points for the water flea *Ceriodaphnia dubia* and two LC50 data points for the zebra fish *Danio rerio*. While an LC_{50} endpoint was available for the Asiatic clam *Corbicula manilensis*, this species was not added to the dataset as the endpoint concentration was substantially higher than any endpoints included for other species and the focus of the SSD curve development is on lower concentrations.

The aquatic toxicity data for uranium were grouped by species (Table B.1) and the 12 species were ranked. The SSD curve presented in Figure B.1 was developed using the SSD Master V3 (CCME 2013). The extreme value model was selected as it resulted in the best fit in the lower portion of the curve and resulted in the lowest Anderson-Darling test statistic (A^2 = 0.462). Additional parameters describing the curve can be found in Table B.2.

Table B.1 Summary of Data for Development of SSD for Uranium Acute Aquatic Toxicity

Test Species	Common Name	End Point	Concentration (µg/L)	Species Mean Concentration (µg/L)	Rank	% Affected
Ceriodaphnia dubia	Water Flea	LC50	50	66		4%
		LC50	71			
		LC50	60			
		LC50	89			
Daphnia pulex	Water Flea	LC50	220	220		13%
Lepomis macrochirus	Bluegill	LC50	1,670	1,670		21%
Pimephales promelas	Fathead Minnow	LC50	2,000	1,972		29%
		LC50	2,000			
		LC50	2,100			
		LC50	1,800			
Oncorhynchus mykiss	Rainbow Trout	LC50	6,200	4,342		38%
		LC50	4,200			
		LC50	3,900			
		LC50	4,000			
		LC50	3,800			
Danio rerio	Zebra Danio	LC50	3,050	4,418		46%
		LC50	6,400			
Daphnia magna	Water Flea	LC50	6,530	6,424		54%
		LC50	6,320			
Salvelinus fontinalis	Brook Trout	LC50	8,000	6,633		63%
		LC50	5,500			
Catostomus latipinnis	Flannelmouth sucker	LC50	43,500	43,500		71%
		LC50	43,500			
		LC50	43,500			
		LC50	43,500			
Xyrauchen texanus	Razorback Sucker	LC50	46,000	46,000		79%
Ptychocheilus lucius	Colorado Squawfish	LC50	46,000	46,000		79%
Gila elegans	Bonytail	LC50	46,000	46,000		79%

Figure B.1 Species Sensitive Distribution for the Protection of Aquatic Life – Uranium (Acute)



Extreme Value Model: $$F(x) = 1 - e^{-e^{\frac{x-\mu}{s}}}$$

Table B.2 Uranium Acute SSD Curve Parameters

PARAMETERS	
μ	4.12
s	0.836
A^2	0.462
Critical A^2	1.93
MSE	0.00618

Table B.3 summarizes the concentrations that are protective of 80%, 90%, and 95% of the species, based on the central tendency and upper and lower prediction intervals of the SSD curve. The specific species from the SSD potentially affected at each protection level for the central tendency are also summarized.

Table B.3 Protection Levels Based on Uranium Species Sensitive Distribution

Protection Level	Concentration (µg/L)			Species Affected at Central Tendency
	Central Tendency	Upper Prediction Interval	Lower Prediction Interval	
95%	43	114	16	
90%	172	360	82	*Ceriodaphnia dubia*
80%	729	1234	431	*Ceriodaphnia dubia, Daphnia pulex*

B.4 REFERENCES

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APPENDIX C

METHODOLOGY FOR TRANSPORT AND FATE ANALYSIS

APPENDIX C: METHODOLOGY FOR TRANSPORT AND FATE ANALYSIS

C.1 SEDIMENT QUALITY

Impact on sediment quality as a result of a yellowcake spill into a river was assessed through estimation of the area on which particles settle onto existing sediments. This requires the estimation of settling velocity (for different particle sizes) and travel distance before settling (in longitudinal and lateral dimensions; for different flow rates).

Settling Velocity

In the absence of experimental data for settling velocity of each particle size, Newton's equation was used:

$$V_s = \sqrt{\frac{4\, g\, (\rho_s - \rho) d_p}{3\, C_d\, \rho}}$$

where,

V_s = *terminal settling velocity (m/s)*
g = *gravitational constant (m/s²)*
ρ_s = *density of the particle (kg/m³)*
ρ = *density of the fluid (kg/m³)*
d_p = *particle diameter (m)*
C_d = *Drag Coefficient (dimensionless)*

Drag coefficient depends on the relative importance of flow inertia and fluid friction (viscosity). The ratio of inertial to viscous forces is the Reynolds number:

$$Re = \frac{\rho\, v\, L}{\mu}$$

where,

ρ = *Density of the fluid (kg/m³)*
v = *Mean velocity of fluid (m/s)*
L = *Characteristic dimension; hydraulic radius for canals (m)*
μ = *Dynamic viscosity of fluid (kg/(m.s))*

For laminar flows (Re<1), C_D = 24/Re and Newton's equation can be written as:

$$V_s = \frac{g\, {d_p}^2 (\rho_s - \rho)}{18\, \mu}$$

For transient flows (1<Re<10000),

$$C_D = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34$$

For turbulent flows, C_D = 0.4, and

$$V_s = \sqrt{\frac{10\ g\ (\rho_s - \rho) d_p}{3\ \rho}}$$

Settling velocities for the laminar and turbulent flows are shown in Table C.1 for calcined and uncalcined yellowcake.

Table C.1 Particles Settling Velocity Estimated for Laminar and Turbulent Flows

a) Calcined yellowcake

Particle Size Category (µm)	Average Particle Size (µm)	Weight % in Screen Fraction	V_s (m/s), Laminar	V_s (m/s), Turbulent
35-55	44	2.5	0.007	0.111
25-35	30	32.8	0.003	0.092
15-25	19	46.1	0.001	0.073
5-15	8.6	14.7	0.0003	0.049
<5	2.5	4.0	0.00002	0.027

a) Uncalcined yellowcake

Particle Size Category (µm)	Average Particle Size (µm)	Weight % in Screen Fraction	V_s (m/s), Laminar	V_s (m/s), Turbulent
200- 400	266	2.8	0.242	0.273
50- 200	110	7.8	0.041	0.175
15- 50	29	56.8	0.003	0.090
5- 15	9	18.1	0.0003	0.050
<5	1	14.2	0.000004	0.017

Settling Distance

The time required for the particles to fully settle out, combined with the downstream flow velocity, dictate the distance downstream from the input source the particles will travel. The distance downstream is therefore a function of the stream velocity. The amount of time required for a particle to settle out of the column is a function of settling velocity and river depth.

$$D = t_s \times V_f \quad and \quad t_s = \frac{H}{V_s}$$

where:

D = Settling distance (m)
t_s *= Settling time (s)*
V_f *= Stream velocity (m/s)*
H= River depth (m)

Example calculation for Assiniboine River: Settling velocity for size category of 200-400 µm of un-calcined product: 0.273 m/s (Table C-1); depth: 1.8 m; settling time: 1.8/0.273= 6.5 s; stream velocity: 0.147 m/s, and distance travelled: 6.5 x 0.147 = 0.95 m

It was assumed that all particles with a settling velocity equal to or greater than the critical settling velocity, v_s, will settle out at or prior to time t_s.

It was assumed that stream flow is uniform down the length of the river and that channel morphometry remains relatively consistent in terms of hydraulic properties. In order to determine stream velocity, the stream discharge and cross-sectional area need to be known. Stream velocity is calculated as:

$$V_f = \frac{Q}{A}$$

where:

Q = River discharge rate (m^3/s)
A = Cross-sectional area (m^2)

The lateral distance travelled from the point of spill was estimated using a lateral dispersion coefficient as follows:

$$E_v = \emptyset\, L\, u^* \qquad and \qquad u^* = \sqrt{gLs}$$

where,

L = *hydraulic radius (m)*
*u** = *Shear velocity (m/sec)*
φ = *0.23 (long, wide lab flume), 0.17 (straight lab flume), 0.65 (gentle meanders); 3.5 (strong meanders)*
s = *slope*

The lateral mixing time is then related to the distance travelled laterally as follows:

$$t_{mix} \approx \frac{L^2}{E_v}$$

Sediment Volume Impacted

The potential impacts on sediment quality due to the release of yellowcake were modelled assuming that all of the spilled yellowcake entered the river. The potential impacted area was determined by taking the travel distance of the particles and an estimated width of the impact area. The width of the river that may be impacted by settling solids was estimated to be 12 metre at the site of release (about twice the width of a container), which could gradually spread out to the entire river width downstream from the spill. If the lateral mixing width is less than the width of the river, then the plume will travel parallel to the river banks after it reaches the lateral mixing width. In each case the impacted area was calculated for a trapezoid as follows:

$$A = (Wd_1 + Wd_2) \times (d_2 - d_1) / 2$$

and

$$W_d = d / d_{max} \times (Wd_{max} - Wd_0) + Wd_0$$

where,

A = *area of impacted sediment between each two points (d_1 and d_2) (m^2)*
W_d = *width of impacted sediment at selected distance d (m)*
d = *distance from the location of spill (d_0)*
d_{max} = *maximum distance traveled (m)*
Wd_{max} = *maximum mixing width (m)*

Example calculation for Assiniboine River:
Lateral dispersion coefficient= 2 x (80x1.78/(80+2x1.78)) x √(9.8 x(80x1.78/(80+2x1.78)) x 0.001) = 0.44 m^2/s
Time for mixing with the entire width of the river = ((80-12)/2)^2 / 0.44 = 2631 s
Distance before reaching the shore (dmax)= 2631 s x 0.147 m/s = 385 m
Width at a distance of 0.95 m (for particles 200-400 µm) = 0.95/387 x (80-12) +2 = 12.2 m
Area at a distance of 0.95 m = (12+12.2)/2 x 0.95 = 11.5 m^2

As the solids are expected to settle on top of the existing sediment with some mixing, a mixing depth of 5 cm was assumed for assessment purposes as the biologically active zone. It is also expected that mixing would occur during remediation activities. Therefore, the volume of the sediment impacted by each particle size category (corresponding to a travelled distance) can be calculated as follows:

$$V_{sed} = A * D$$

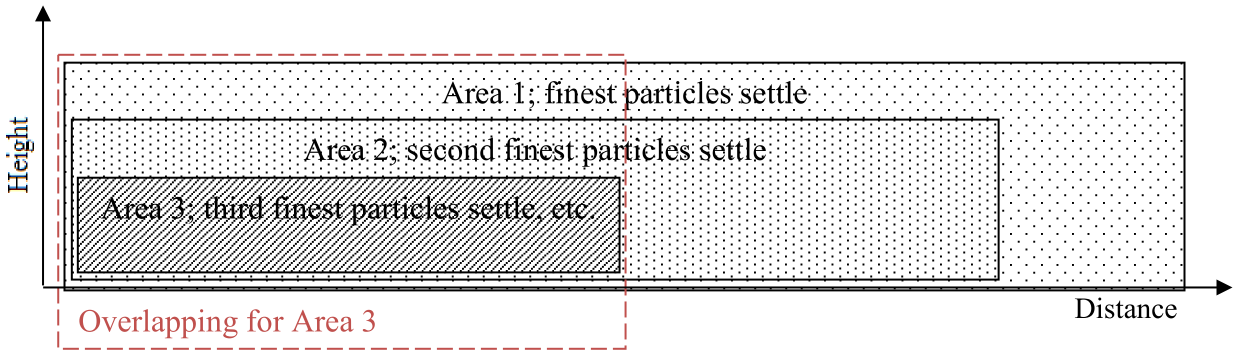
where,

V_{sed} = *volume of impacted sediment (m^3)*
D = *depth that solids will mix*

Yellowcake masses for each particle size were then re-distributed to the defined areas so that the areas where coarser particles settle also receive finer particles (see Figure C.1 for an illustration).

Example calculation for Assiniboine River: Volume of impacted sediment = 11.5 m^2 x 0.05 m = 0.58 m^3 Volume of yellowcake for the particle sizes 200-400 µm= 2 m^3 * 2.9% = 0.06 m^3

Figure C.2 Illustration of Particle Settling Areas



Sediment Quality

Concentrations in the sediment were estimated using the results of the particle dispersion analysis. In this assessment, it was assumed that the yellowcake that settles close to the spill site will be removed through a post-accident clean-up program. The removal efficiency is assumed to be 95% within the first 15 m with no removal in the further field.

Estimates of sediment quality were performed for three scenarios: minimum, mean and maximum flows. As the location where the deposition occurs for different particle sizes and the distance the particles may travel is dependent on the stream flow, the different flow scenarios provide a range in predicted sediment concentrations.

The quality of the yellowcake and the fraction of particles of each size were used in the predictions of incremental sediment concentrations (assuming no background levels). Concentration of each COPC in each particle size category (corresponding to a weight percent, removal efficiency, and impacted sediment) for each flow scenario was calculated as follows:

$$C_{sp} = F_{yel} \times C_{yel} \quad and \quad F_{yel} = \frac{V_{yel} \times \rho_{yel} \times F_s \times (1 - E_c)}{V_{sed} \times \rho_{sed} + V_{yel} \times \rho_{yel} \times F_s \times (1 - E_c)}$$

Where:

C_{sp}	*= concentration in sediment after the spill (Bq/g or µg/g)*
F_{yel}	*= fraction of impacted sediment which is yellowcake*
C_{yel}	*= concentration in yellowcake (Bq/g or µg/g)*
V_{yel}	*= volume of spilled yellowcake (m^3)*
ρ_{yel}	*= yellowcake bulk density (kg/m^3)*
F_s	*= fraction of yellowcake deposited in each calculated area*
E_C	*= cleanup efficiency*
V_{sed}	*= volume of impacted sediment (m^3)*
ρ_{sed}	*= sediment bulk density (kg/m^3); wet weight*

Example calculation for Assiniboine River:
Mass of sediment= 0.58 m3 x 1300 kg/m3= 748 kg
Mass of yellowcake = 0.06 m3 x 2050 kg/m3 = 1226 kg
Uranium concentration of the coarsest particles = 1226 x 0.854 / (748 +1226) x (1-0.95) = 26331 µg/g; same calculation for other particle size categories
Weighted average for all particle sizes as Σ (concentration x weight percent)/ Σ (concentrations)

C.2 POREWATER QUALITY

Porewater quality for the impacted area was estimated using a sediment-to-water partition coefficient, which is about 3.5 m^3/kg for uranium based on experience at other locations (SENES 2010) as well as literature.

Example calculation for Assiniboine River:
11802 µg/g x 3.5 m^3/kg /1000 = 41 µg/L

C.3 WATER QUALITY

The potential impact on water quality due to the release of yellowcake was modelled assuming that 25% of the yellowcake in all drums on a truck of ISO container was released at the time of the incident. Long-term concentrations were also estimated to account for transfer of the settled uranium from sediment to water.

It was assumed that the spilled material would initially mix with only a small fraction of the river flow (5%, which is likely a very conservative estimate). Mixing throughout the complete width of rivers will not occur until further downstream.

Water quality modelling was performed for minimum, average and maximum flow conditions to cover different dilution potentials. The low flow condition was determined by taking the average minimum month over the flow record's period, that is the low flow month of each year was determined (independent of the time of year the low month may occur in a given year), and an average was taken for the period. The same procedure was used to determine the average high flow month.

Incremental water concentrations sustained as a result of a spill were estimated using dissolved release rates assigned to the short-term as well as the long-term conditions. The short-term release rate was estimated using solubility data (an average value of 5 g/m^3 for calcined and 6.6 g/m^3 for un-calcined products), while the long-term release rate used the concentration estimated for pore-water quality in each scenario. It was assumed that at the site and time of release, the water column concentration is 5 (or 6.6) g/m^3 up to a height of one meter. In the long-term, the first 5 centimeters of water adjacent to the sediment was assumed to be at the pore-water concentration. A release rate was estimated and used in the calculation of water concentration throughout the water column, as follows:

$$C_{wat} = \frac{C_S \times V_{wat} \times X_S}{Q_{wat} \times P}$$

where,

C_{wat} = concentration of uranium in water column after the spill (mg/L)
C_S = concentration of uranium in the source (g/m^3); solubility or porewater
V_{Wat} = water velocity (m/s)
X_S = cross section of the source (m^2)
Q_{Wat} = river discharge rate (m^3/s)
P = percent of river flow impacted

Example calculation for Assiniboine River: Short term concentration: [6.6 g/m^3 (yellowcake solubility in water) x 8.48 x 10^5 (µg/g U) x 0.25 m/s x (12 x 1) m^2] / [47 (m^3/s river flow) x 1000 x 25% (impacted water)] ≈ 1,200 (µg/L U in river). Short-term duration: [1% (solubility) x 4076 kg x 0.848 (g/g U)] / [15 µg/L (U water quality guideline) x 12 m^2 (water column cross section) / 1000000)] / 0.25 m/s (average water velocity) = 9 days Long term: [25/1000 g/m^3 (porewater concentration) x 8.48 x 10^5 (µg/g U) x 0.25 m/s x (12 x 0.05) m^2] / [47 (m^3/s river flow) x 1000 x 25% (impacted water)] = 0.27 (µg/L U in river).

APPENDIX D

METHODOLOGY FOR EXPOSURE ANALYSIS

APPENDIX D: METHODOLOGY FOR EXPOSURE ANALYSIS

D.1 INPUT PARAMETERS FOR ECOLOGICAL RECEPTORS

Input parameters used in the exposure estimation are as follows:

- Dietary characteristics
- Transfer factors
- Dose coefficients
- Bioaccessibility factors for soil and sediment.

Dietary characteristics of ecological receptors are provided in Section 4.

Transfer factors are empirical values that provide a measure of the partitioning behaviour of a COPC between two environmental media. Transfer factors can describe partitioning between many different media, including water-to-fish, water-to-benthic invertebrates, food-to-animal flesh and other media. TFs from the abiotic environment (water, soil) to biota directly relate the concentration in one medium to another. Table D.1 summarizes the TF values used to calculate concentrations of uranium and radionuclides in environmental media from the abiotic components. Transfer factors for aquatic species are based on available information from the McClean Lake Operation. Transfer factors for semi-aquatic and terrestrial species are based on literature data for reference bird and mammal (SENES 2008).

Table D.2 shows the selected Dose Coefficients (DCs) for the estimation of dose. The DCs were obtained from Amiro (1997) and Blaylock et al. (1993). DCs for internal and external exposure are provided.

Bioaccessibility factors take into account the fact that only a portion of the constituents present in soil or sediment can be potentially absorbed into the body of animals or people. Bioaccessibility factors were conservatively considered to be 100% for all species and pathways, with the exception of bioaccessibility of uranium in yellowcake ingested through contaminated soil by terrestrial receptors. This was assumed to be 1% based on the 0.2% fraction recommended for slow processes involving uranium by the ICRP (1994a) and the low solubility of yellowcake in water (<1%).

Table D.1 Transfer Factors used in the Assessment

a) Water to Aquatic Species

Constituent	Unit	Aquatic Plant	Benthos	Fish
Uranium	mg/kg (ww)/mg/L	170	92	1
Th-230	Bq/kg (ww)/Bq/L	460	90	36
Ra-226	Bq/kg (ww)/Bq/L	1400	1400	27
Pb-210	Bq/kg (ww)/Bq/L	880	330	25
Po-210	Bq/kg (ww)/Bq/L	1500	2300	310

b) Food to Semi-aquatic and terrestrial species

Constituent	Unit	Birds	Mammals
Uranium	d/kg	1.0	3.00E-04
Th-230	d/kg	0.1	2.00E-04
Ra-226	d/kg	0.3	1.00E-04
Pb-210	d/kg	0.2	4.00E-04
Po-210	d/kg	2.5	0.005

Table D.2 Dose Coefficients Used for Ecological Receptors

a) Aquatic Receptors (in mGy/d per Bq/g)

Constituent	Internal	External	Radionuclides Included
U-238+	0.14	0.006	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)
Th-230	0.002	7.02E-05	Th-230
Ra-226+	0.066	1.95E-05	+ Internal:Ra-226 + 0.3* (Rn-222 + ...Po-214) External: Ra-226 + 1.0* (Rn-222 + ...Po-214) (beta + gamma only)
Pb-210+	0.16	0.024	Pb-210 + Bi-210 (internal or external)
Po-210	0.006	0.002	Po-210

b) Terrestrial Receptors (in mGy/d per Bq/g)

Constituent	Internal	Radionuclides Included
U-238+	0.14	U-238 + Th-234 + Pa-234m+ U-234 + 0.045* U-235
Th-230	0.066	Th-230
Ra-226+	0.16	Ra-226 + 0.3* (Rn-222 + ...Po-214)
Pb-210+	0.006	Pb-210 + Bi-210
Po-210	0.075	Po-210

D.2 IMPACT ON ECOLOGICAL RECEPTORS

The results of water and sediment quality predictions were used to assess exposures of ecological species to uranium. The assessment of effects to ecological receptors is made by comparing exposure estimates to TRVs. For example, intake (or dose) estimates are compared to non-radiological TRVs and to dose rate guidelines for radionuclides to assess the risks of adverse health effects for each of the ecological receptors.

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/d or Bq/d) and then use a transfer factor or TF (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 being important for estimating internal radiological dose while intakes are used for assessment of non-radiological contaminants.

The concentration of uranium in species in the first trophic level (aquatic plants, benthic invertebrates and fish) was estimated based on water concentration as follows:

$$C_{species} = C_{water} \times TF$$

Example calculation for Lac La Ronge: Concentration in aquatic plants: 1.68E-05 mg/L × 170 L/kg = 0.003 mg/kg

The concentration of uranium in species in the second trophic level (birds, caribou and arctic ground squirrel) was estimated based on water and food concentrations and quantities as follows:

$$C_{species} = (\,(C_{water} \times Q_{water}) + (\sum (C_{food} \times F_{food}) \times Q_{food})) \times F_{local} \times TF$$

Example calculation for Lac La Ronge: Concentration in muskrat: {0.087 mg/L × 0.1 L/d + [(16399 × (1-0.7) mg/kg ww × 0.064 (sediment fraction) + 0.003 mg/L × 170 L/kg × 0.749 (aquatic plant fraction) + 0.002 mg/L × 92 L/kg × 0.14 (benthic fraction) + 1.68E-05mg/L × 1 L/kg × 0.047 (fish fraction)] × 0.35 kg/d } × 0.0003 d/kg ww = 0.033 mg/kg Concentration in grouse: 0.087 mg/L × 0.04 L/d × 1 d/kg ww = 0.003 mg/kg

Intake of uranium by each species was estimated as follows:

$$I_{species} = \frac{C_{species}}{TF \times BW_{species}}$$

Example calculation for Lac La Ronge: Intake by muskrat: 0.033 mg/kg / 1 kg (body weight)/ 0.0003 d/kg ww = 111 mg/kg.d

Radiation dose for aquatic species was estimated as follows:

$$D_{equivalent} = D_{internal} \times RBE + D_{external}$$
$$D_{internal} = C_{species} \times DCF_{internal}$$
$$D_{external} = C_{water\ or\ sediment} \times DCF_{external}$$

Radiation dose for semi-aquatic and terrestrial species was estimated as follows:

$$D_{equivalent} = C_{species} \times DCF_{internal} \times RBE$$

where,

C: concentration
Q: quantity
F food: fraction of total food that consists of the specific food item
F_{local}: fraction of total food that is local
TF: transfer factor
I: intake
BW: body weight
D: radiation dose
DCF: dose conversion factor
RBE: relative biological effectiveness

Example calculation for Lac La Ronge:
Equivalent dose in aquatic plants:
internal: 0.003 mg/kg / (12.3x1000 Bq/kg) x 0.14 (mGy/d)/ (Bq/g) × 10 (RBE) +
external: 16399 mg/kg / (12.3x1000 Bq/kg) × 0.006 (mGy/d)/ (Bq/g)] +
baseline dose- calculated similarly for baseline concentrations: 0.014 mSv/d
= 0.022 µSv/d
Equivalent dose in muskrat:
internal: 0.033 mg/kg / (12.3x1000 Bq/kg) × 0.14 (mGy/d) / (Bq/g) × 10 (RBE) +
external: 0.01 (integrated coefficient for gamma rates from radionuclides) x 2.88 E-04 (shape factor) x 0.5 (to account for unequal distribution of radionuclides) x 4920 mg/kg ww / 12.3 mg/Bq x 24 hr/d x 1 (time fraction) + baseline dose: 2.4 E-04 mSv/d = 0.01 µSv/d

D.3 INPUT PARAMETERS FOR HUMAN RECEPTORS (MEMBERS OF PUBLIC)

The body weight and daily intakes of water and fish by adult, child, and toddler are shown in Table D.3.

Table D.3 The Body Weight (kg) and Daily Intakes of Water and Fish (kg/day)

Food Item	Adult	Child	Toddler
Water	1.6	0.86	0.6
Fish	0.0636	0.0512	0.0373
Body Weight	70.7	32.9	16.5

Source: CanNorth (2000), HC (2010)

The water-to fish transfer factor for uranium was assumed to be 1 L/kg fw. The dose coefficients used in the assessment are those recommended by the ICRP. Ingestion DCFs depend on the chemical form of the radionuclide and the consequent gut-to-blood transfer factor (f1). The values selected reflect the ICRP Publication 72 (1996) recommended f1 values and DCs for members of the public. These values are provided in Table D.4.

Table D.4 Ingestion Dose Conversion Factors for Human Receptors (µSv/Bq)

Constituent	Toddler	Child	Adult
U-238+	0.25	0.185	0.0995
Th-230	0.41	0.31	0.21
Ra-226+	0.96	0.62	0.28
Pb-210+	3.6	2.2	0.69
Po-210	8.8	4.4	1.2

D.4 IMPACT ON HUMAN RECEPTORS (MEMBERS OF PUBLIC)

The results of the water quality predictions were used to assess exposures of a resident to chemical uranium as well as radionuclides.

For short-term assessment, the estimated uranium concentration in water was compared to the water quality guideline (20 µg/L).

For long-term assessment, the estimated uranium concentration in water and fish was used to calculate the intake of contaminants. Estimated daily intake of uranium was compared with the human oral TRV of 0.0006 mg/kg-day. Estimated radiological dose was compared to the human reference dose.

Radiological dose from ingestion of water (or fish) was estimated as follows:

$$D_{ingestion} = C_{water} \times Q_{water} \times F_{time} \times DCF_{ingestion}$$

where,

C: concentration
Q: quantity
F time: fraction of time in the area
DCF: dose conversion factor

Example calculation for Lac La Ronge: Fish intake by a toddler: (1.68E-05 mg/L × 0.6 L/d + 1.68E-05 mg /kg x 0.037 (fish fraction) × 1.75 kg/d) × 1 / 16.5 kg = 6.78E-07 mg/kg.d Equivalent Dose: .78E-07 mg/kg.d ×16.5 kg × 0.25 µSv/Bq / 12.3 (Bq/ mg) = 2.27E-07 µSv/d

D.5 SCREENING INDEX

The comparison of intake (or dose) estimates to TRVs or dose rate guidelines is usually undertaken by the calculation of screening index values. The SI values provide an integrated description of the potential hazard, the exposure (or dose) response relationship and the exposure evaluation (U.S. EPA 1992; AIHC 1992).

For aquatic receptors, the screening index is simply a ratio of the predicted or estimated COPC concentration in water (or sediment) to the TRV for the given aquatic species. For example the estimated concentration for uranium in water divided by the TRV for predatory fish provides the screening index for predatory fish exposed to uranium, as follows:

$$Screening\ Index = \frac{Estimated\ Concentration}{TRV}$$

The acute exposure to all aquatic species, with the exception of benthic invertebrates was assessed. Since an acute TRV is not available for benthic invertebrates and they are exposed to both sediments and water, benthic invertebrate exposure was considered to be chronic. In addition to being exposed to water, benthic invertebrates reside in sediment, which represents another pathway of exposure to uranium.

For terrestrial receptors exposed to non-radionuclides, the screening index is calculated by dividing the predicted intake (based on food intake and composition) by the receptor of interest by the selected toxicity reference value for that receptor, as shown below:

$$Screening\ Index = \frac{Estimated\ Intake}{TRV}$$

For radionuclides, the total dose rate received by an ecological receptor is divided by the reference dose rate to calculate a screening index value, as shown in the following equation:

$$Screening\ Index = \frac{Dose\ Rate}{Reference\ Dose\ Rate}$$

The screening index values derived from these calculations are not estimates of the probability of ecological impact. Rather, the index values are positively correlated with the potential of an effect (i.e., higher index values imply greater potential of an effect). Different magnitudes of the screening index have been used in other studies to screen for the potential ecological effects. A screening index value of 1.0 has been used in most ecological risk assessments (e.g., Suter 1991). Cardwell et al. (1993) suggested an index value of 0.3, based upon a conservative approach designed to account for potential chronic toxicity and chemical synergism. In this study, an index value of 1.0 was used to examine the potential adverse effects of COPC on aquatic and terrestrial.

APPENDIX E

MICROSHEILD INPUT/OUTPUT FILES

APPENDIX E: MICROSHEILD INPUT/OUTPUT FILES

MicroShield 9.05 SENES Consultants (9.05-0000)

Date	By	Checked

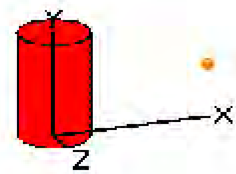
Filename	Run Date	Run Time	Duration
Forklift (1).msd	August 12, 2014	11:22:35 AM	00:00:05

Project Info	
Case Title	Forklift
Description	1 Container
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	85.1 cm (2 ft 9.5 in)
Radius	28.6 cm (11.3 in)

Dose Points			
A	X	Y	Z
#1	128.72 cm (4 ft 2.7 in)	42.55 cm (1 ft 4.8 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	2.19e+05 cm³	Yellowcake	2.055
Transition		Air	0.00122
Air Gap		Air	0.00122
Wall Clad	.12 cm	Iron	7.86
Top Clad	.12 cm	Iron	7.86



Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: ICRP-107

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Pa-234	2.0349e-004	7.5292e+006	9.3054e-004	3.4430e+001
Pa-234m	1.2719e-001	4.7060e+009	5.8162e-001	2.1520e+004
Th-231	5.8500e-003	2.1645e+008	2.6751e-002	9.8980e+002
Th-234	1.2719e-001	4.7060e+009	5.8162e-001	2.1520e+004
U-234	1.2719e-001	4.7060e+009	5.8162e-001	2.1520e+004
U-235	5.8500e-003	2.1645e+008	2.6751e-002	9.8980e+002
U-238	1.2719e-001	4.7060e+009	5.8162e-001	2.1520e+004

Buildup: The material reference is Air Gap Integration Parameters	
Radial	40
Circumferential	40
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With	Exposure Rate mR/hr No	Exposure Rate mR/hr With	Absorbed Dose Rate mrad/hr No	Absorbed Dose Rate mrad/hr With	Absorbed Dose Rate mGy/hr No	Absorbed Dose Rate mGy/hr With

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Case Summary of ISO Containers (24) Page 1 of 2

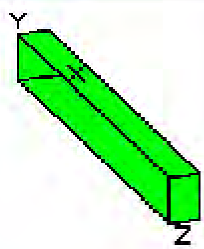
MicroShield 9.05 SENES Consultants (9.05-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
ISO Container (24).msd	August 11, 2014	5:37:25 PM	00:00:04

Project Info	
Case Title	ISO Containers (24)
Description	35 drums in the Container x 24 Containers
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	228.8 cm (7 ft 6.1 in)
Width	3.1e+3 cm (101 ft 4.1 in)
Height	340.4 cm (11 ft 2.0 in)



Dose Points			
A	X	Y	Z
#1	329.22 cm (10 ft 9.6 in)	100.0 cm (3 ft 3.4 in)	1.5e+3 cm (50 ft 8.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	2.41e+08 cm³	Yellowcake	1.57
Shield 1	.12 cm	Iron	7.86
Shield 2	.3 cm	Iron	7.86
Air Gap		Air	0.00122

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: ICRP-107

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Pa-234	1.4100e-001	5.2170e+009	5.8612e-004	2.1686e+001
Pa-234m	8.8108e+001	3.2600e+012	3.6625e-001	1.3551e+004
Th-231	4.0541e+000	1.5000e+011	1.6852e-002	6.2353e+002
Th-234	8.8108e+001	3.2600e+012	3.6625e-001	1.3551e+004
U-234	8.8108e+001	3.2600e+012	3.6625e-001	1.3551e+004
U-235	4.0541e+000	1.5000e+011	1.6852e-002	6.2353e+002
U-238	8.8108e+001	3.2600e+012	3.6625e-001	1.3551e+004

Buildup: The material reference is Air Gap
Integration Parameters

X Direction	70
Y Direction	20
Z Direction	30

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With	Exposure Rate mR/hr No	Exposure Rate mR/hr With	Absorbed Dose Rate mrad/hr No	Absorbed Dose Rate mrad/hr With	Absorbed Dose Rate mGy/hr No	Absorbed Dose Rate mGy/hr With

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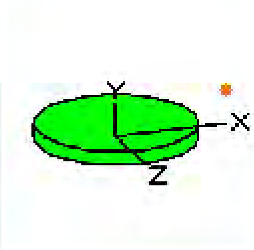
MicroShield 9.05 SENES Consultants (9.05-0000)		
Date	**By**	**Checked**

Filename	Run Date	Run Time	Duration
Spill - BR.msd	August 12, 2014	3:05:05 PM	00:00:14

Project Info	
Case Title	Spill - BR
Description	22 drums (half of a container)
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	42.55 cm (1 ft 4.8 in)
Radius	237.77 cm (7 ft 9.6 in)



Dose Points			
A	**X**	**Y**	**Z**
#1	337.77 cm (11 ft 1.0 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields			
Shield N	**Dimension**	**Material**	**Density**
Source	7.56e+06 cm³	Yellowcake	2.055
Transition		Air	0.00122
Air Gap		Air	0.00122
Immersion		Air	0.00122

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: ICRP-107

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Pa-234	3.6919e-003	1.3660e+008	4.8852e-004	1.8075e+001
Pa-234m	2.3070e+000	8.5360e+010	3.0527e-001	1.1295e+004
Th-231	1.0614e-001	3.9270e+009	1.4044e-002	5.1963e+002
Th-234	2.3070e+000	8.5360e+010	3.0527e-001	1.1295e+004
U-234	2.3070e+000	8.5360e+010	3.0527e-001	1.1295e+004
U-235	1.0614e-001	3.9270e+009	1.4044e-002	5.1963e+002
U-238	2.3070e+000	8.5360e+010	3.0527e-001	1.1295e+004

Buildup: The material reference is Air Gap
Integration Parameters

Radial	50
Circumferential	50
Y Direction (axial)	60

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup	Absorbed Dose Rate mrad/hr No Buildup	Absorbed Dose Rate mrad/hr With Buildup	Absorbed Dose Rate mGy/hr No Buildup	Absorbed Dose Rate mGy/hr With Buildup

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Case Summary of Truck Driver - BR

MicroShield 9.05 SENES Consultants (9.05-0000)

Date	By	Checked

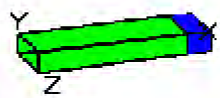
Filename	Run Date	Run Time	Duration
Truck Driver - BR.msd	August 11, 2014	4:20:57 PM	00:00:02

Project Info	
Case Title	Truck Driver - BR
Description	44 drums in the Sea Container
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	629.2 cm (20 ft 7.7 in)
Width	228.8 cm (7 ft 6.1 in)
Height	85.1 cm (2 ft 9.5 in)

Dose Points			
A	X	Y	Z
#1	739.77 cm (24 ft 3.2 in)	42.55 cm (1 ft 4.8 in)	114.4 cm (3 ft 9.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	1.23e+07 cm³	Yellowcake	1.61
Shield 1	.12 cm	Iron	7.86
Shield 2	.3 cm	Iron	7.86
Shield 3	100.0 cm	Air	0.00122
Shield 4	.15 cm	Iron	7.86
Air Gap		Air	0.00122



Source Input: Grouping Method - Standard Indices Number of Groups: 25 Lower Energy Cutoff: 0.015 Photons < 0.015: Included Library: ICRP-107				
Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Pa-234	7.3811e-003	2.7310e+008	6.0248e-004	2.2292e+001
Pa-234m	4.6135e+000	1.7070e+011	3.7658e-001	1.3933e+004
Th-231	2.1224e-001	7.8530e+009	1.7324e-002	6.4100e+002
Th-234	4.6135e+000	1.7070e+011	3.7658e-001	1.3933e+004
U-234	4.6135e+000	1.7070e+011	3.7658e-001	1.3933e+004
U-235	2.1224e-001	7.8530e+009	1.7324e-002	6.4100e+002
U-238	4.6135e+000	1.7070e+011	3.7658e-001	1.3933e+004

Buildup: The material reference is Air Gap Integration Parameters	
X Direction	70
Y Direction	20
Z Direction	20

Results									
Energy	Activity	Fluence Rate	Fluence Rate	Exposure Rate	Exposure Rate	Absorbed Dose Rate	Absorbed Dose Rate	Absorbed Dose Rate	Absorbed Dose Rate

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