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In the matter of

À l'égard de

NexGen Energy Ltd.

NexGen Energy Ltd.

Licence application to prepare a site for and construct its Rook 1 uranium mine and mill project

Demande de permis concernant la préparation de l'emplacement et la construction de son projet de mine et d'usine de concentration d'uranium Rook I

Commission Public Hearing
Part 2

Audience publique de la Commission
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February 9-12, 2026

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Canada

Volume 1: Rook I Project Environmental Impact Statement Technical Support Documents (TSDs)

Part 1

TSD VII, Mine Waste Alternatives Assessment Report
TSD VIII, Accidents and Malfunctions Report
TSD IX, Transportation Risk Assessment Report
TSD X, Vibration Effects Analysis Report
TSD XI, Light Effects Analysis Report
TSD XII, Net-Zero Framework
TSD XIII, Upstream Greenhouse Gas Emissions and Carbon Intensity Discussion
TSD XIV, Groundwater Flow and Solute Transport Modelling Report

Part 2

TSD XV, Tailings Source Term Derivation Report
TSD XVI, Tailings Geochemical Characterization Report
TSD XVII, Waste Rock and Underground Wall Rock Source Term Predictions Report
TSD XVIII, Site-Wide Water Balance and Water Quality Modelling Report
TSD XIX, Conceptual Diffuser Design Report
TSD XX, Downstream Use and Impact Study for Proposed Treated Sewage Discharge Report
TSD XXII, Climate Adaptation Framework

Rook I Project

Environmental Impact Statement

TSD VII: Mine Waste Alternatives Assessment Report

MINE WASTE ALTERNATIVES ASSESSMENT
ROOK I PROJECT, SASKATCHEWAN

Prepared for:

NexGen Energy Ltd.

Prepared by:

WSP Canada Inc.

May 2024

Executive Summary

The Rook I Project (Project) is a proposed new uranium mining and milling operation that is 100% owned by NexGen Energy Ltd. (NexGen). The Project is located in northwestern Saskatchewan, approximately 40 km east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon. The Project resides within Treaty 8 territory and within the Métis Homeland. At a regional scale, the Project is situated within the southern Athabasca Basin adjacent to Patterson Lake, and along the upper Clearwater River system. Access to the Project is from an existing road off Highway 955. The Project will include underground and surface facilities to support the extraction and processing of uranium ore from the Arrow deposit, a land-based, basement-hosted, high-grade uranium deposit.

This report presents a mine waste alternatives assessment prepared for NexGen by Golder Associates Ltd. (Golder), which was acquired by and is now WSP Canada Inc (WSP). The assessment was completed for tailings, gypsum, and waste rock that will be generated by the Project. Alternatives were identified and evaluated using a systematic process to inform the selection of the preferred alternative for each waste type.

Waste types were evaluated separately and in combination to determine the preferred location and technology by completing the following assessments:

- pre-screening for general location;
- screening for specific locations and technologies; and
- multiple accounts analysis (MAA) on alternatives, each including a location and technology.

For the MAAs, alternatives were described during the Construction, Operations, and Closure phases of the Project lifecycle and evaluated using measurable indicators in environmental, technical, economic, and social accounts. These accounts were weighted to reflect perceived importance to Indigenous communities, the local public, and other stakeholders through engagement activities undertaken by NexGen. Each MAA included a sensitivity analysis considering the effect of different weighting schemes on ranking of alternatives. The study follows guidance from Environment and Climate Change Canada (ECCC) and the Canadian Nuclear Safety Commission (CNSC) for mine waste alternatives assessments.

Tailings Alternatives Assessment

A total of 17.7 million tonnes (Mt) of tailings will be generated during the Project, of which 11 Mt will be placed underground to backfill mine workings. The remaining 6.7 Mt must be stored in a tailings management facility (TMF).

Five general locations for tailings storage were pre-screened. General locations that passed pre-screening were located within the conceptual (hereafter referred to as ‘proposed’) Project surface lease boundary and included underground, in-pit, and surface locations. General locations that did not pass pre-screening included storage of tailings off-site, which would increase the area of disturbance beyond the proposed Project surface lease boundary; and storage of tailings in Patterson Lake, which did not meet NexGen’s criterion that no waste be placed in lakes. NexGen has indicated that feedback from local public and Indigenous engagement supported not placing waste in lakes.

Ten specific locations were screened for storage of tailings at the three general locations that passed pre-screening and included four underground, three in-pit, and three surface locations. Locations were described

and screened for relative advantages and disadvantages based on environmental, technical, economic, and social indicators. Four specific locations (one underground, two surface, and one in-pit location) passed screening due to relative advantages compared to the six specific locations that were eliminated.

Four tailings technologies were screened at the four specific locations that passed screening (totalling 16 combinations). Technologies that were screened included co-disposal with waste rock, dewatering by filtering, dewatering by thickening to paste consistency, and deposition as slurry. Technologies were described and screened for relative advantages and disadvantages at the four specific locations that passed screening based on environmental, technical, economic, and social indicators. Four alternatives, each including a location and a technology, passed screening due to relative advantages compared to the 12 eliminated alternatives.

The four alternatives were then developed to a conceptual level, described for Construction, Operations, and Closure stages defined for the assessment, and then evaluated by MAA using quantitative scoring and weighting. Alternatives included storage of cemented paste tailings (CPT) in a purpose-built underground tailings management facility (UGTMF), storage of paste tailings at two surface TMF locations, and subaqueous deposition of slurry tailings in a purpose-built pit. Storage of CPT in a purpose-built UGTMF scored the highest, exceeding scores for in-pit storage, which was the perceived “best practice” in Saskatchewan for storage of uranium tailings at the time of this study. The UGTMF meets a recommendation by the CNSC (2018) to maximize underground storage of tailings and a requirement of the Global Industry Standard on Tailings Management (GTR 2020) to reduce the quantity of tailings and water stored on surface.

A sensitivity analysis was completed to evaluate the effect of bias introduced by account weighting. Results of the sensitivity analysis indicated that the rank of the alternatives and study outcome did not change with account weighting (introduction of bias).

Gypsum Alternatives Assessment

A total of 1.5 Mt gypsum will be generated by the Project, which must be permanently stored.

Five general locations for gypsum storage were pre-screened using the same method as the tailings assessment. General locations that passed pre-screening were located within the proposed Project surface lease boundary and included underground and surface locations. General locations that did not pass pre-screening included storage of gypsum off site, which would increase the area of disturbance; storage of gypsum in Patterson Lake, which did not meet NexGen’s criterion that no waste be placed in lakes; and storage of gypsum in-pit, which would increase surface disturbance and the quantity of overburden and waste rock that would need to be stored on the surface through excavation of a pit.

Four specific locations for storage of gypsum were screened at the two general locations that passed pre-screening. Specific locations that were screened included storage of gypsum with tailings in the UGTMF, in a purpose-built underground facility, with waste rock in a surface waste rock storage area (WRSA), and in a purpose-built surface storage facility. Locations were described and screened for relative advantages and disadvantages based on environmental, technical, economic, and social indicators. Two specific locations, storage of gypsum with tailings in the UGTMF and storage of gypsum with waste rock in a WRSA, passed screening due to relative advantages compared to the two specific locations that were eliminated. Storage of gypsum in separate, purpose-built facilities (gypsum only) did not pass screening due to a greater potential for

environmental effects, greater surface disturbance, increased complexity to design and operate additional facilities, and increased cost relative to storage of gypsum in combination with tailings or waste rock.

The two alternatives for storage of gypsum that passed screening were developed to a conceptual level and described for Construction, Operations, and Closure stages defined for the assessment, and then evaluated by MAA using quantitative scoring and weighting. The placement of gypsum with tailings in the UGTMF scored the highest, with advantages of lower operational complexity and the potential for gypsum to reduce the binder requirement in the CPT. Storage of gypsum with waste rock in the WRSA would require separation and cleaning of the gypsum, and also engineered placement in the WRSA to avoid potential instability related to dissolution of gypsum. Storage of gypsum with the tailings stream was the standard practice for uranium mines in Saskatchewan at the time of this study.

A sensitivity analysis was completed to evaluate the effect of bias introduced by account weighting. Results of the sensitivity analysis indicated that ranking was sensitive to the account weighting scheme. The first-place rank of placement of gypsum with tailings in the UGTMF was consistent for three out of four account weighting scenarios. When using the NexGen account weighting scenario, where a higher weighting is placed on the economic and social accounts, placement of gypsum with waste rock in the WRSA was the preferred alternative.

Waste Rock Alternatives Assessment

A total of 25.4 Mt waste rock will be generated during the Project, of which 10.7 Mt will be potentially acid generating (PAG) waste rock and the remainder will be non-potentially acid generating (NPAG). In addition to mine development, the quantities of waste rock to be managed at the site are tied to the selection of options for tailings and gypsum storage. Storing tailings and gypsum underground requires excavation of underground chambers. Waste rock from excavation of the chambers must be stored. The tailings and gypsum assessments indicated storage of tailings and gypsum underground scored higher than storage on surface. The total waste rock quantity used for the waste rock alternatives assessment therefore included waste rock from the UGTMF (considering tailings and gypsum stored underground), and the mine.

Five general locations for waste rock storage were pre-screened using the same method as the tailings and gypsum assessments. One general location passed pre-screening: storage on surface within the proposed Project surface lease boundary. General locations that did not pass pre-screening included storage of waste rock off site, which would increase the Project footprint and area of disturbance beyond the proposed Project surface lease boundary; storage of waste rock in Patterson Lake, which did not meet NexGen's criterion that no waste be placed in lakes; and storage of waste rock in a pit, which is fatally flawed due to volume incompatibility (i.e., excavating a pit to store waste rock would generate more waste rock than can be backfilled into the pit due to bulking, and does not allow storage of additional waste from the UGTMF or mine). Similar to tailings, NexGen has indicated that feedback from local public and Indigenous engagement supported not placing waste in lakes.

Five specific locations were screened for storage of waste rock at the single general location that passed pre-screening. Waste rock stockpiles at the specific locations were described by three-dimensional models and compared for relative advantages and disadvantages based on environmental, technical, economic, and social indicators. One specific location near the proposed mine terrace passed screening due to relative advantages compared to the four specific locations that were eliminated. The location that passed screening had a shorter haul distance, which reduced the potential for dust generation from haulage, lowered potential operational maintenance requirements and costs for transport, and used the least amount of water for dust suppression

compared to the other locations. The proposed mine terrace location was also consistent with NexGen's overall objective of limiting the spatial extent of the Project by reducing and consolidating the footprint associated with Project infrastructure. NexGen has indicated that feedback from local public and Indigenous engagement supported the idea of minimizing surface footprint.

Six conceptual alternatives for waste rock storage technology at the specific location that passed screening were described for Construction, Operations, and Closure stages defined for the assessment, and then evaluated by MAA using quantitative scoring and weighting. Alternatives were evaluated based on water balances informed by one-dimensional infiltration models, and by quantitative predictions of chemistry of contact water reporting to Patterson Lake based on geochemical source terms and a simplified groundwater mixing model.

The highest scoring alternative included storage of NPAG waste rock in an unlined facility and PAG waste rock in a lined facility with lower-permeability layers within the waste rock (engineered source control). The highest scoring alternative was predicted to have a reduced potential to affect Patterson Lake water quality during Operations and Closure, complied with Saskatchewan Environment and Resource Management (SERM 2000) draft guidelines to use a HDPE (high-density polyethylene) liner for PAG stockpiles, had lower costs for lining compared to fully lined alternatives, had the potential to be progressively closed during operation, and had reduced potential for long-term water treatment. Alternatives without a liner for PAG waste rock did not meet SERM (2000) draft guidelines. Alternatives without engineered source control layers had greater potential to produce water quality that could affect Patterson Lake during Closure and had greater potential to require water treatment post-closure. Alternatives that did not store PAG and NPAG in separate facilities had proportionally more expensive engineering controls than alternatives that segregated waste rock types to focus controls on the PAG waste rock.

The highest scoring alternative (NPAG waste rock in an unlined facility and PAG waste rock in a lined facility with low permeability layers) scored higher than the perceived best practice in Saskatchewan for storage of uranium waste rock at the time of this study, where NPAG waste rock is stored in an unlined facility and PAG waste rock is stored in a lined facility without low permeability layers. A sensitivity analysis was completed to evaluate the effect of bias introduced by account weighting. Results of the sensitivity analysis indicated that ranking is sensitive to the account weighting scheme. The first-place rank was consistent for all weighting scenarios except when the economic account was removed from consideration. When economics were removed from consideration, the highest scoring alternative was a single lined facility (PAG with NPAG) with low permeability layers.

This study is to be read with the Study Limitations section, which precedes the text of the report and forms an integral part of this document.

Study Limitations

WSP Canada Inc. (WSP) has prepared this document in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practicing under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this document. No warranty, express or implied is made.

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The factual data, interpretations, suggestions, recommendations, and opinions expressed in this document pertain to the specific project, site conditions, design objective, development and purpose described to WSP by NexGen and are not applicable to any other project or site location. In order to properly understand the factual data, interpretations, suggestions, recommendations and opinions expressed in this document, reference must be made to the entire document.

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List of Abbreviations

Abbreviation	Definition
1D	one-dimensional
2D	two-dimensional
3D	three-dimensional
CCME	Canadian Council of Ministers of the Environment
CNSC	Canadian Nuclear Safety Commission
CPT	cemented paste tailings
ECCC	Environment and Climate Change Canada
Golder	Golder Associates Ltd.
GTR	Global Tailings Review
LiDAR	light detection and ranging
MAA	multiple accounts analysis
NAD	North American Datum
NexGen	NexGen Energy Ltd.
NLR	neutralized leach residue
NPAG	non-potentially acid generating
PAG	potentially acid generating
Project	Rook I Project
SERM	Saskatchewan Environment and Resource Management
TMF	tailings management facility
UGTMF	underground tailings management facility
UTM	Universal Transverse Mercator
WRSA	waste rock storage area
WSP	WSP Canada Inc.

List of Units

Unit	Definition
%	percent
°	degree
°C	degree Celsius
µg/L	microgram per litre
<	less than
>	more than
g	gravity
H:V	horizontal to vertical
ha	hectare
km	kilometre
lb	pound
m	metre
masl	metres above sea level
mbgs	metre below ground surface
Mm^3	million cubic metres
mm/yr	millimetres per year
t	tonne
Mt	million tonnes
t/m^3	tonnes per cubic metre

1.0 INTRODUCTION

This report presents a mine waste alternatives assessment for tailings, gypsum, and waste rock at the Rook I Project (Project), a proposed uranium mine and milling operation in northern Saskatchewan, Canada. The study was completed for NexGen Energy Ltd. (NexGen) by Golder Associates Ltd. which was acquired by and is now WSP Canada Inc. (WSP).

1.1 Project Description

The Rook I Project is a proposed new uranium mining and milling operation that is 100% owned by NexGen. The Project is located in northwestern Saskatchewan, approximately 40 km east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon (Figure 1). The Project resides within Treaty 8 territory and within the Métis Homeland. At a regional scale, the Project is situated within the southern Athabasca Basin adjacent to Patterson Lake, and along the upper Clearwater River system (Figure 2). Access to the Project is from an existing road off Highway 955.

The Project will include underground and surface facilities to support the extraction and processing of uranium ore from the Arrow deposit, a land-based, basement-hosted, high-grade uranium deposit. The proposed mine life ('Operations' stage) considered for this study was 24 years, with ore milled at an average rate of 1,400 t per day (Golder 2019). The Project will use two underground mining methods to extract the uranium ore: transverse longhole stoping with backfill and longitudinal longhole retreat with backfill (Golder 2019). Waste produced during mining and milling will include tailings, gypsum, and waste rock. More than 50% of the overall tailings produced will be used as backfill for mined-out stopes.

Project lifecycle stages and corresponding stages considered in the mine waste alternatives assessment are presented in Table 1.

Table 1: Project and Mine Waste Alternatives Assessment Project Lifecycle Stages

Project Lifecycle Stage	Mine Waste Alternatives Assessment Lifecycle Stage
Construction	Construction
Operations	Operations
Decommissioning and Reclamation	Closure
Active Closure Stage	
Transitional Monitoring Stage	

1.2 Purpose of Assessment

The purpose of the mine waste alternatives assessment was to evaluate available alternatives for the storage of tailings, gypsum, and waste rock based on environmental, technical, economic, and social indicators for Construction, Operations, and Closure stages. Results of the assessment are intended to inform and rationalize NexGen's selection of preferred alternatives. This report presents the methods and results of the assessment.

1.3 Local Public and Indigenous Engagement

WSP understands NexGen is committed to conducting meaningful engagement with local public and Indigenous communities that would potentially be affected by, or who have expressed interested in, the Project.

Records of local public and Indigenous engagement activities are maintained, including feedback received (NexGen 2019). Feedback received prior to issue of this report indicated general agreement that underground storage of tailings is the preferred approach for the Project, that maximizing the return of waste rock underground should also be a priority, and that surface footprint should be minimized.

2.0 BASIS OF ASSESSMENT

The basis of the mine waste alternatives assessment includes regulations, guidelines, standards, the Project mine waste production schedule, and site characteristics. The basis of assessment is presented in this section.

2.1 Regulations, Guidelines, and Standards

Applicable guidelines and standards considered for the mine waste alternatives assessment included:

- Canadian Nuclear Safety Commission's (CNSC) regulatory document REGDOC-2.11.1, *Waste Management, Volume II: Management of Uranium Mine Waste Rock and Mill Tailings* (CNSC 2018).
  - The CNSC (2018) document states the assessment should include a "…list of all possible candidate mine waste disposal options…" to be screened to "…reduce the number and provide assurance that any of the remaining options could prove to be the preferred option...." The regulation requires scoring and weighting of environmental, technical, economic, and socio-economic characteristics for each alternative.
  - Tailings should be stored underground where possible.
- Environment and Climate Change Canada's (ECCC) *Guidelines for the Assessment of Alternatives for Mine Waste Disposal* (ECCC 2016).
  - The ECCC (2016) guidelines state "…alternatives assessment should objectively and rigorously consider all available options for mine waste disposal…" from "construction through operation, closure, and ultimately long-term monitoring and maintenance" and that the "…assessment will consider the predicted quality and quantity of effluent that would be discharged from each alternative assessed..."
  - Like the CNSC regulation, the ECCC guidelines require consideration and documentation of environmental, technical, and socio-economic elements that will be affected by a new mine waste facility.
- Saskatchewan Environment and Resource Management's (SERM) *Draft Construction Guidelines for Pollution Control Facilities at Uranium Mining and Milling Operations* (SERM 2000).
  - Potentially acid generating (PAG) waste rock piles should be lined with high-density polyethylene (HDPE).
- Global Tailings Review (GTR) *Global Industry Standard on Tailings Management* (GTR 2020).
  - Principle 3: "Use all elements of the knowledge base - social, environmental, local economic and technical - to inform decisions throughout the tailings facility lifecycle, including closure."
  - Requirement 3.2 "For new tailings facilities, the Operator shall use the knowledge base and undertake a multi-criteria alternatives analysis of all feasible sites, technologies and strategies for tailings management. The goal of this analysis shall be to: (i) select an alternative that minimizes risks to people and the environment throughout the tailings facility lifecycle; and (ii) minimize the volume of tailings and water placed in external tailings facilities...".

2.2 Project Mine Waste Production Schedule

The mine processing plant will be capable of producing up to 31 million lbs of triuranium octoxide (U_3O_8) per year over a mine life of 24 years (Golder 2019). Life of mine quantities for tailings, gypsum, and waste rock production used in the mine waste alternatives assessment are summarized in Table 2. For the tailings alternatives assessment, tailings were considered as a combination of neutralized leach residue, effluent treatment plant precipitates, and gypsum. For the gypsum alternatives assessment, quantities used for facility sizing were based on the amount of gypsum generated by the Project. For the waste rock alternatives assessment, waste rock quantities used for facility sizing are based on excavation of both the mine and the underground tailings management facility (UGTMF) chambers and access, assuming gypsum and tailings are placed in the UGTMF.

Table 2: Waste Material Quantities Used for the Mine Waste Alternatives Assessment

Waste Material	Mass (Mt)	Volume (Mm^3)	Dry Density (t/m^3)
Tailings			
Total (including gypsum)	17.7 (calculated)	13.7 (NexGen 2020a)	1.29 (calculated)
Stored in mine stopes	11.0 (calculated)	6.9 (NexGen 2020a)	1.58 (NexGen 2020a)
Stored in underground tailings management facility (UGTMF)	6.7 (calculated)	6.7 (NexGen 2020a)	1.00 (NexGen 2020a)
Gypsum			
Total	1.5 (NexGen 2020a)	1.7 (calculated)	0.87 underground (NexGen 2020b)
Waste Rock			
Total (Mine + UGTMF including gypsum in tailings)	25.4 (NexGen 2020b)	13.8 (calculated)	1.83 (NexGen 2020b)
Potentially acid generating	10.7 (NexGen 2020b)	5.8 (calculated)	
Non-potentially acid generating	14.6 (NexGen 2020b)	8.0 (calculated)	

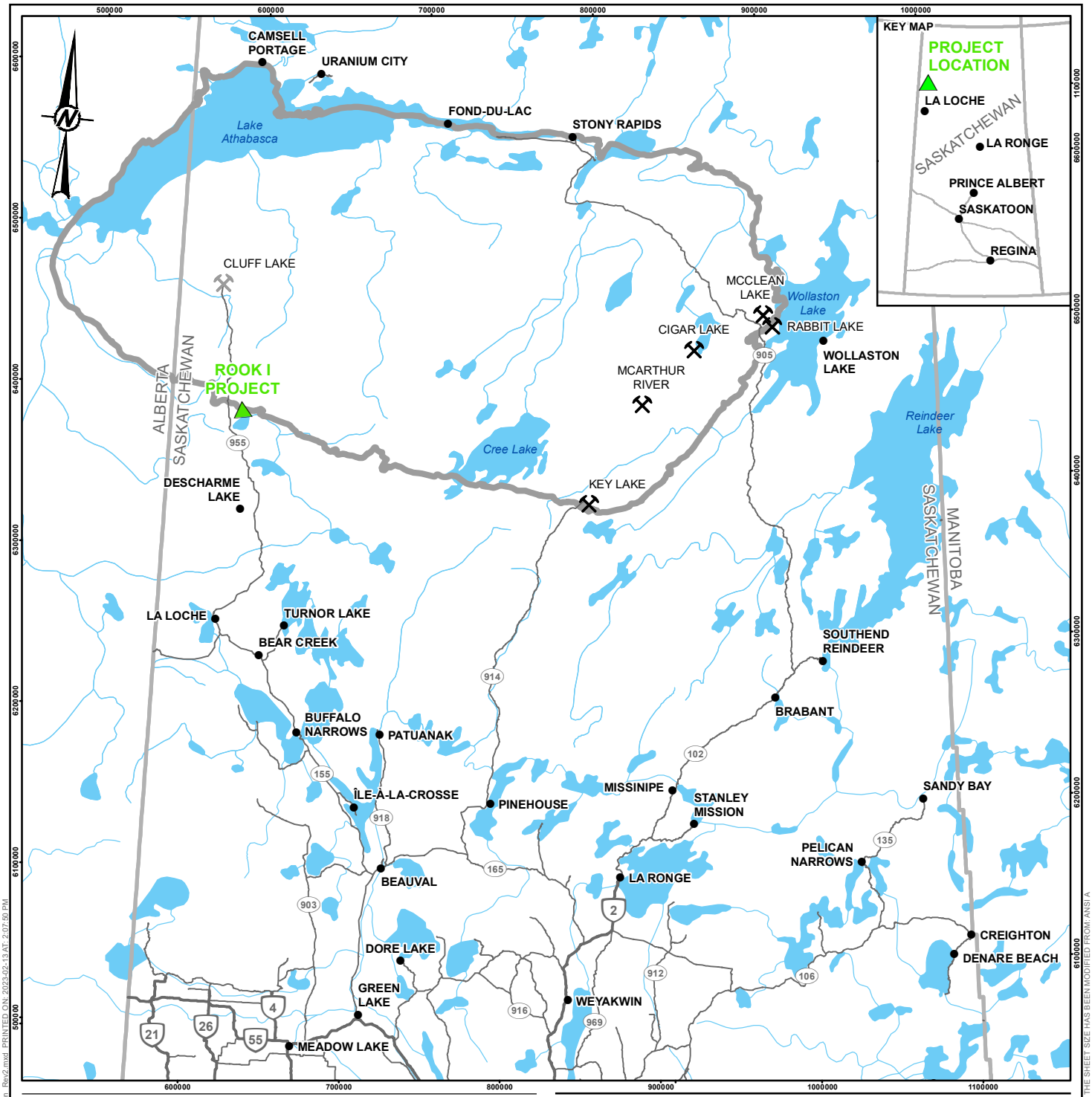
Note: Values may not sum due to rounding.
Mt = million tonnes; Mm^3 = million cubic metres.

2.3 Site Characteristics

Project site characteristics described in this section include location and topography, current land and resource use, planned infrastructure and battery limits, ecology, climate and hydrology, geology and geotechnical conditions, hydrogeology, and seismicity.

2.3.1 Location and Topography

The Project site is located in northern Saskatchewan, approximately 130 km north of the town of La Loche and 640 km northwest of Saskatoon (Figure 1). A conceptual Project surface lease boundary (hereafter referred to as 'the proposed surface lease boundary') on a peninsula within Patterson Lake and near Forrest Lake was assumed for the mine waste alternatives assessment. The site is accessible from an existing road off Highway 955 (Figure 2). Project site topography is dominated by eskers and drumlins with a maximum elevation of 583 metres above sea level (masl) and minimum elevation of 499 masl at Patterson Lake (Golder 2019). The site has been characterized by orthophotography and multispectral light detection and ranging (LiDAR) survey (Axiom 2019). The Project datum is UTM Zone 12N NAD83.



LEGEND

- POPULATED PLACE
- URANIUM MINING FACILITY (ACTIVE)
- URANIUM MINING FACILITY (DECOMMISSIONED)
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- WATERCOURSE
- WATERBODY
- ATHABASCA BASIN BOUNDARY
- PROJECT LOCATION

0 100 200
1:3,500,000 KILOMETRES

REFERENCE(S)

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PROJECTION: UTM ZONE 12 DATUM: NAD 83

CLIENT
NexGen Energy Ltd.

PROJECT
ROOK I PROJECT

TITLE
LOCATION OF THE ROOK I PROJECT, SASKATCHEWAN

CONSULTANT
wsp

YYYY-MM-DD	2023-02-28
DESIGNED	SS
PREPARED	NO/AK
REVIEWED	JMC
APPROVED	MM

PROJECT NO.	PHASE	REV.	FIGURE
20144150		2	1

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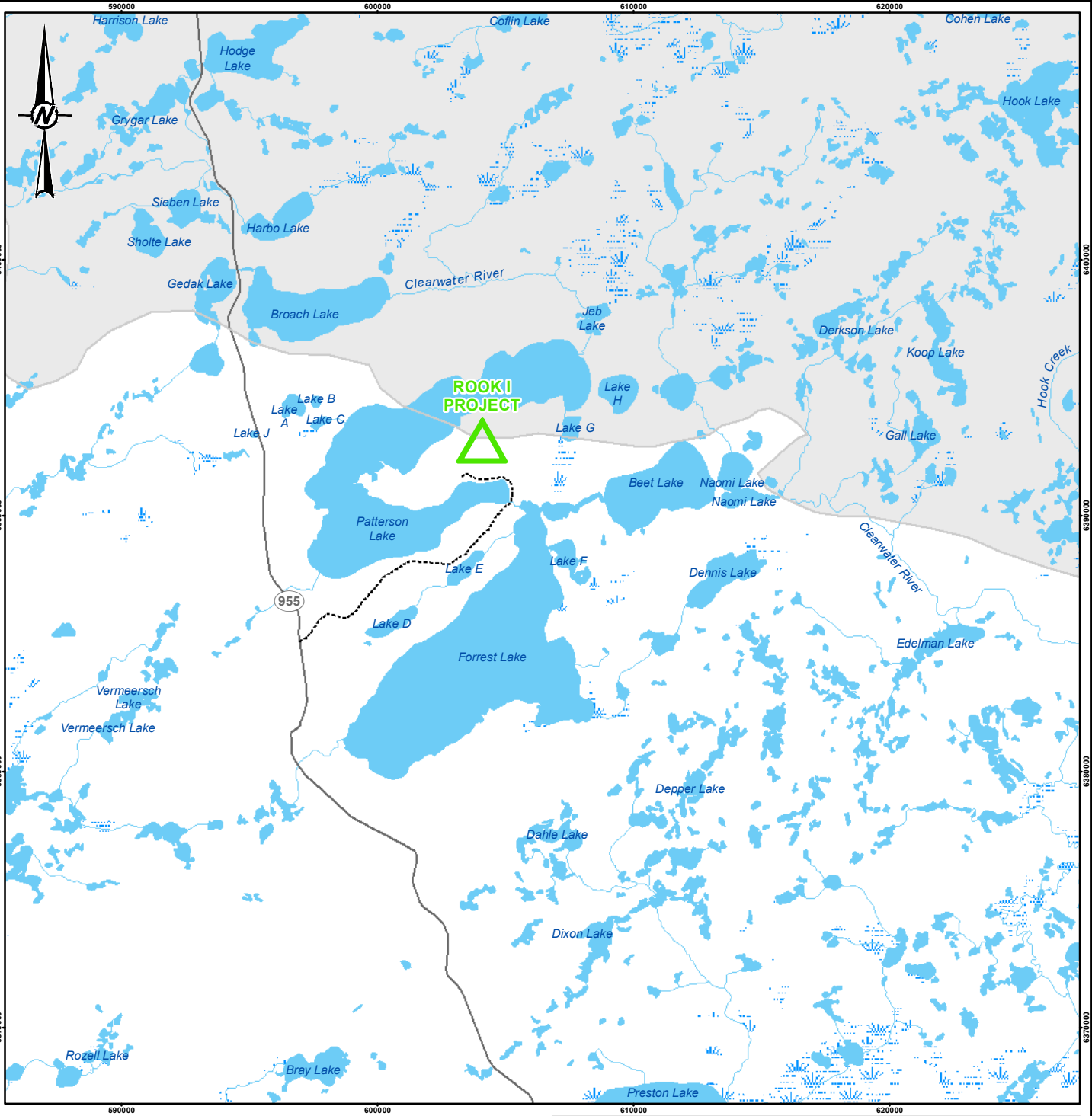

LEGEND

- SECONDARY HIGHWAY
- WATERCOURSE
- WATERBODY
- WETLAND
- ATHABASCA BASIN
- PROJECT LOCATION
- EXISTING ACCESS ROAD

0 5,000 10,000

1:225,000 METRES

REFERENCE(S)

1. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
PROJECTION: UTM ZONE 12 DATUM: NAD 83

CLIENT

NexGen Energy Ltd.

PROJECT

ROOK I PROJECT

TITLE

REGIONAL AREA OF THE ROOK I PROJECT

CONS

wsp

YYYY-MM-DD	2023-02-28
DESIGNED	JMC
PREPARED	NO/AK
REVIEWED	JMC
APPROVED	MM

PROJECT NO.	PHASE	REV.	FIGURE
20144150		2	2

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2.3.2 Current Land and Resource Use

The Project is located within Treaty 8 territory and may overlap with current land and resource use activities by First Nation and Métis peoples (Golder 2019), specifically:

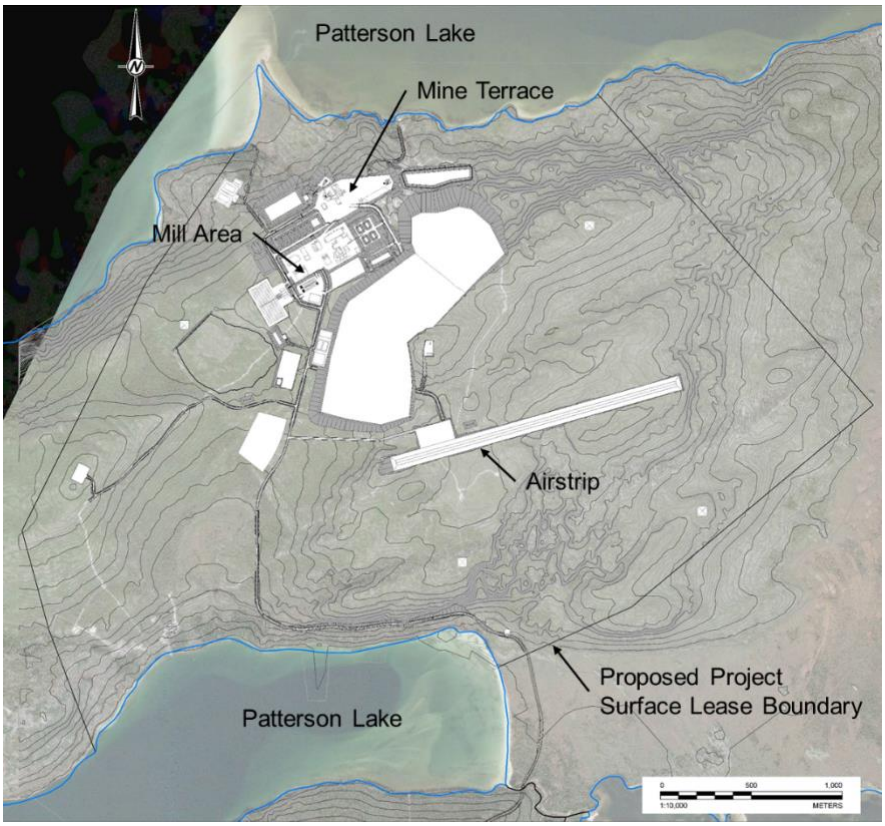
- Clearwater River Dene Nation – Signatory to Treaty 8;
- Birch Narrows Dene Nation – Signatory to Treaty 10;
- Buffalo River Dene Nation – Signatory to Treaty 10;
- and Métis Nation-Saskatchewan.

Hunting, fishing, trapping, and gathering activities may occur in the vicinity the Project. No known cultural heritage sites are located within the proposed Project surface lease boundary (CanNorth 2018). There are no known archaeological sites located in conflict with the Project (HCB 2021).

2.3.3 Planned Infrastructure and Battery Limits

The mine waste alternatives assessment considered an assumed layout for planned infrastructure shown in Figure 3 from NexGen (2020c). The proposed Project surface lease boundary, airstrip, ore deposit, mill area, mine terrace locations, and surrounding lakes were considered fixed for the assessment. Other infrastructure such as the mine camp, access and haul roads, and water management facilities were considered movable for the siting of mine waste alternatives.

Figure 3: Site Infrastructure Constraints and Proposed Project Surface Lease Boundary Used for Mine Waste Alternatives Assessment



2.3.4 Ecology

Wildlife species including moose, deer, black bear, wolf, and woodland caribou are known to be present in the area of the Project (Golder 2019). Some species of conservation concern were identified beyond the proposed Project surface lease boundary and are listed in the *Draft Terrestrial Environment Wildlife Baseline Inventory Report* (Omnia 2020).

2.3.5 Climate and Hydrology

The regional climate is sub-Arctic, typical of mid-latitude continental areas (Golder 2019), and is characterized by the following elements:

Annual precipitation is approximately 0.45 m, where approximately 70% occurs as rain during summer and the remainder occurs as snow during winter.

- Temperatures range from over 30°C in the summer to colder than -40°C in winter. Winter mean temperatures are below 0°C.
- Lake freeze-up typically starts in October and break-up occurs in May.

- The hydrologic setting includes the following key components:
- The Project is located within the Patterson Lake watershed, which is part of the larger Clearwater River watershed.
- The Clearwater River flows south and is part of the Mackenzie River watershed, designated as a Canadian Heritage River.

2.3.6 Geology

Geology in the area of the Project is described in Golder (2019) and summarized here.

- Arrow Deposit
  - Basement-hosted, vein-type uranium deposit.
  - Mineralization is defined by an area comprising several steeply dipping shears.
- Regional
  - The Project is located in southwestern Athabasca Basin, a Paleoproterozoic aged, intracontinental, redbed sedimentary basin covering a large area of northwestern Saskatchewan and a smaller area of northern Alberta.
  - The Athabasca Basin is oval shaped with approximate dimensions of 450 km by 200 km and reaches a maximum thickness of approximately 1,500 m near the centre. The dominant lithology of the basin is sandstone with local conglomeratic beds.
- The southwest portion of the Athabasca Basin is overlain by flat lying Phanerozoic stratigraphy of the Western Canada Sedimentary Basin, including carbonate-rich rocks of the Lower to Middle Devonian Elk Point Group, Lower Cretaceous Manville Group sandstones and mudstones, moderately lithified diamictites, and Quaternary unconsolidated sediments.
  - The Paleoproterozoic basement rocks of the Taltson Domain unconformably underly the Athabasca Basin and the Phanerozoic stratigraphy. The crystalline basement rocks comprise a spectrum of variably altered mafic to ultramafic, intermediate, and local alkaline rock types.
  - The Athabasca Basin and underlying rocks are host to the highest-grade uranium deposits in the world.
- Local
  - Surficial deposits are dominated by Quaternary glacial till of sand with gravels, cobbles, and boulders that ranges from 30 m to 100 m thick over Cretaceous mudstone.
  - The Arrow deposit is overlain by glacial overburden that is approximately 60 m thick as well as the Lower Cretaceous Manville Group and Lower to Middle Devonian Elk Point Group units (Regional Geology).
  - Cretaceous rocks are generally weak and most often geotechnically considered as soil.

2.3.7 Geotechnical Conditions

Geotechnical conditions in bedrock at depth are presented in NRMS (2021) and summarized here.

- Since 2016, four rock mass classification parameters have been collected at site: intact rock strength, rock quality designation, joint spacing, and joint condition data. These parameters are logged for every drill hole, in addition to specifically targeted bedrock geotechnical drill holes.
- Several interpreted basement shears and faults are concordant and acute to mineralization. Shear zones are closely related to controls on rock mass quality. There are eight primary shear zones between the hanging wall and footwall intrusives that are approximately concordant with mineralization. There are five interpreted tertiary shear zones that are approximately 45° to the primary shears.

Geotechnical conditions near surface are presented in BGC (2019) and summarized here.

- **Basal Till (Till 3):** fine sand to sandy till, some interbedded clay, dense to very dense. Deposited over Ablation Till and present only in the northeast corner of the mine development area.
- **Ablation Till:** poorly graded sand, compact to dense, with widespread distribution of cobbles and boulders. Over-thickening and coarse texture are the result of repeated pushing/reworking by glacial thrusting and meltwater. Unit thickness varies from <5 to 25 m.
- **Basal Till (Till 2):** fine sand to sandy till, some interbedded clay, dense to very dense. Deposited during initial glacial thrusting advances. Covered by Ablation Till. Unit thickness varies from 5 to 30 m.
- **Basal Till (Till 1):** sand and silt, dense to very dense. Covered by Ablation Till in uplands located south of the mine development area. Unit thickness varies from <5 to 75 m.
- **Glaciolacustrine Sediments:** interbedding of sands, silts, and clays deposited by proglacial lakes. Buried by Till 2 in some areas of the Project and completely removed by glacial thrusting in some areas, such as the east side of the mine development area. Unit thickness varies from 2 to 15 m.
- **Devonian La Loche Formation:** marine quartzose mudstone and weakly cemented silty and clayey sandstone. Unit thickness has not been confirmed.
- **Athabasca Group:** weakly cemented, poorly graded, fine to medium quartz rich sandstone and conglomerate with lesser dolomite and shale. Not present on the south-southeast side of the Arrow deposit but increases in thickness to the north-northwest.

2.3.8 Hydrogeology

Hydrogeology in the area of the Project is characterized in Golder (2019) by the following elements:

- Groundwater is controlled by low regional topography; regional flow gradients and direction in low-lying areas generally mimic lake elevations for gradient and flow direction, where flow is from higher elevation lakes to lower elevation lakes.
- Shallow groundwater flow is from the topographic high located south of the proposed mine terrace to the north towards Patterson Lake.
- Shallow groundwater flow occurs mainly in unconsolidated glacial tills.

Hydrogeology near surface is also presented in BGC (2019) and summarized here.

- Permeable nature of overburden material results in high infiltration and little surface flow.
- No stream courses are observed in the upper elevations of the terrain.
- Seeps and springs are observed in the lower portions of the slopes.
- Depth to groundwater varies across the mine site from 10 metres below ground surface (mbgs) to 25 mbgs in the mine terrace and 3 to 42 mbgs in the proposed stockpiles area.

2.3.9 Seismicity

The seismic site class and ground motions are characterized by the following elements (from BGC 2019):

- Site classification for seismic response per the National Building Code of Canada is Site Class D, representative of stiff soil.
- Peak ground acceleration = 0.041 g for a 2,475-year return period earthquake.
- The seismic hazard is low.

3.0 ASSESSMENT METHODOLOGY

Three alternatives assessments were completed by waste type in the order of priority for location: tailings storage location was determined first, then gypsum, and then waste rock. The assessment methodology is summarized in this section.

3.1 Method Summary

A common assessment methodology was followed for each mine waste type based on the CNSC (2018) regulation, ECCC (2016) guidelines, and GTR (2020) standard. The methodology is intended to provide a rational basis for assessment of alternatives for tailings, gypsum, and waste rock storage during Construction, Operations, and Closure. The assessment methodology generally included the following stages:

- pre-screening for general location;
- screening for specific locations and technologies; and
- multiple accounts analysis (MAA) on alternatives remaining after screening, where each alternative includes a location and technology.

The level of detail for each stage of the study is summarized in Table 3.

The MAA method included development of conceptual descriptions of each alternative followed by comparison of alternatives using a performance-based scoring system that included indicators in four primary accounts:

- Environmental;
- Technical;
- Economic; and
- Social.

Accounts were divided into sub-accounts that were further categorized by indicators. The indicators were quantitatively (preferred) or qualitatively scored. Indicators were selected that differentiated the alternatives and what were perceived to be important to Indigenous communities, the local public, and other stakeholders. The indicators were selected to be quantifiable, or measurable, where possible. Weighting was applied at the account, sub-account, and indicator levels to purposefully introduce bias reflecting perceived relative importance. Sensitivity analyses were completed by changing account level weightings to eliminate or change bias.

Table 3: Methodology Summary for the Mine Waste Alternatives Assessment

Assessment Stage	Level of Detail by Mine Waste Type		
	Tailings	Gypsum	Waste Rock
Pre-screening for General Location	▪ Descriptive comparison ▪ Relative evaluation for advantages/disadvantages		
Screening for Specific Location	▪ Descriptive comparison ▪ Relative evaluation for advantages/disadvantages		▪ Scoring and weighting by MAA method
Screening for Technology	▪ Descriptive comparison ▪ Relative evaluation for advantages/disadvantages	▪ Not applicable	
Multiple Accounts Analysis	▪ Scoring and weighting by MAA method		
Sensitivity Analysis	▪ Varying account weighting		

MAA = multiple accounts analysis.

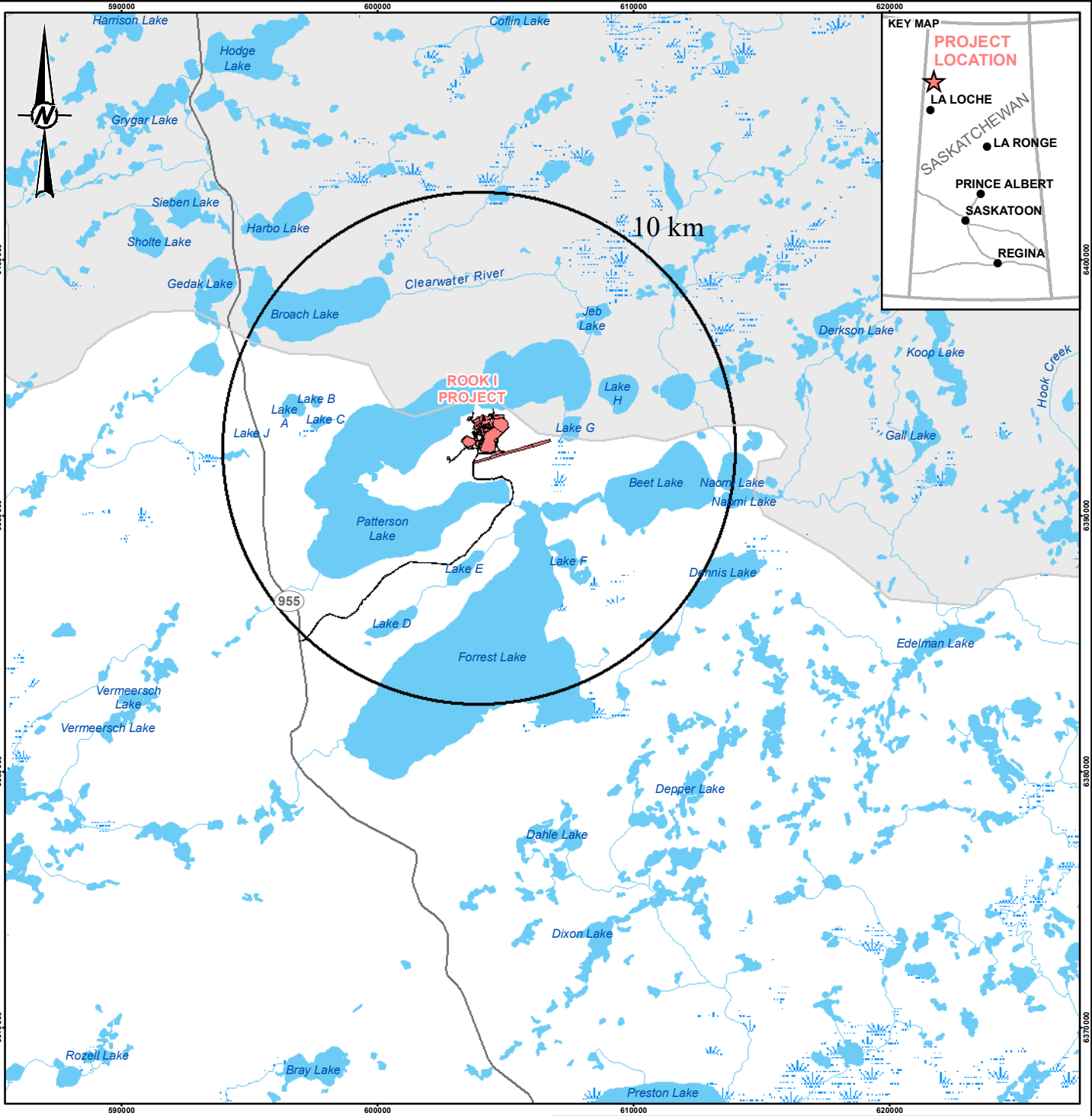
3.2 Pre-screening for General Location

Five general locations were pre-screened for tailings, gypsum, and waste rock storage: underground, in pit, surface, off site, and in lake. For the purpose of pre-screening, the closed Cluff Lake Mine site and sites within a 10 km radius from the Project were considered for off-site mine waste storage locations (Figure 4). Cluff Lake is a closed mine located approximately 80 km north of the Project (Golder 2019).

Relative advantages and disadvantages for each general location were evaluated by pre-screening against the following criteria:

- **Has required storage capacity:** A location was required to have capacity to store the quantity of mine waste to pass pre-screening.
- **No waste in lake (NexGen):** NexGen's criterion that no waste should be placed in lakes was adopted. This was supported by feedback received by NexGen during local public and Indigenous and community engagement.
- **Area of impact:** A location with the least area of impact was preferred.
- **Quantity of waste rock generated:** A location with the least quantity of waste rock generated was preferred.

General locations with relative advantages passed pre-screening, while locations with relative disadvantages or fatal flaws did not pass pre-screening.



LEGEND

- SECONDARY HIGHWAY
- WATERCOURSE
- WATERBODY
- WETLAND
- ATHABASCA BASIN
- PROPOSED PROJECT FOOTPRINT

0 5,000 10,000

1:225,000 METRES

REFERENCE(S)

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PROJECTION: UTM ZONE 12 DATUM: NAD 83

CLIENT

NexGen Energy Ltd.

PROJECT

ROOK I PROJECT

TITLE

PRE-SCREENING FOR GENERAL LOCATION MAP

CONS

wsp

YYYY-MM-DD	2023-02-28
DESIGNED	HL
PREPARED	NO
REVIEWED	BW
APPROVED	BW

PROJECT NO.	PHASE	REV.	FIGURE
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3.3 Screening for Specific Location

Specific locations for tailings and gypsum storage were described for the Construction, Operations, and Closure stages and screened by evaluation of relative advantages and disadvantages for indicators within four accounts: environmental, technical, economic, and social. Indicators were selected that were perceived to be important and that differentiated specific locations. Indicators are presented with the results of each assessment.

Specific locations for waste rock storage were modelled, described for Construction, Operations, and Closure stages, and then screened by MAA methods described in Section 3.5.

3.4 Screening for Technology

Technologies for tailings storage were described for the Construction, Operations, and Closure stages and then screened by evaluation of relative advantages and disadvantages for indicators within four accounts: environmental, technical, economic, and social. Indicators were selected that were perceived to be important and that differentiated the technologies. Indicators are presented with the results of the assessment.

Gypsum was not screened for technology and was considered as a solid form for storage on surface, and as part of the cemented paste tailings (CPT) for storage underground.

Waste rock was not screened for technology. Waste rock technologies were evaluated by MAA.

3.5 Multiple Accounts Analysis

Alternatives were assessed using an MAA approach following ECCC (2016) guidelines. A general methodology is described in this section and includes description of alternatives, sub-account and indicator selection, scoring and weighting, evaluation and ranking, and sensitivity analysis. Any modifications to the methodology are described with the results of each study:

- Description of Alternatives:
  - Alternatives were described for Construction, Operations, and Closure stages.
  - Descriptions were developed to a conceptual level to allow identification and selection of sub-accounts and indicators.
- Sub-account and Indicator Selection:
  - Four accounts (environmental, technical, economic, and social) were divided into sub-accounts that were generally common across assessments. A list of accounts, sub-accounts, and indicators used for the assessments is included as Appendix A, Accounts Ledger, Table A-1.
- Indicators were selected for each sub-account that:
  - Differentiated alternatives.
  - Were perceived to be important to the local public, Indigenous communities, and other stakeholders.
  - Were quantifiable, or measurable, where possible.
- Scoring and Weighting:

- Scoring scales were developed for each indicator with values ranging from 1 to 6 following ECCC (2016) guidelines. When scoring alternatives, a value of 1 was always assigned to indicate the least favourable alternative while a value of 6 was always assigned to indicate the most favourable alternative. The approach has an intended effect of magnifying the differences between alternatives.
- Indicators were scored based on quantitative assessment where possible (preferred method) or by qualitative assessment. Quantitative, measurable indicators were then normalized on a scale of 1 to 6, such that the best alternative scored 6, the lowest scored 1, and the remaining alternatives scores were calculated in proportion to the measured indicator value. Qualitative indicators were also scored on a scale of 1 to 6, such that the best alternative scored 6, the lowest scored 1, and the remaining normalized scores were assigned using scales defined for the specific indicator. Scoring scales and normalized indicator values for each indicator are provided with the results.
- For some quantitative indicators, a higher score indicates a preferred alternative, and for others a lower score indicates a preferred indicator. Normalized scores (of 1 to 6) were scaled such that the preferred option received a higher score.
- Economic indicators were scored based on quantitative indicators, such as volume of material excavated, rather than dollar values. Cost estimates were not developed for the mine waste alternatives assessment.
- Weighting was applied to purposefully introduce bias to each indicator, sub-account, and account to reflect perceived importance to Indigenous communities, the local public, and other stakeholders.
- Indicators were weighted based on perceived importance relative to other indicators within a sub-account; similarly, sub-accounts were weighted based on perceived importance relative to other sub-accounts within an account. Base case account weighting followed ECCC (2016) guidance.
- Steps used in scoring are described at the end of this section.

- Evaluation and Ranking:
  - Alternatives were evaluated by scoring and weighting of indicators and sub-accounts within the four accounts: environmental, technical, economic, and social.
  - Alternatives were then ranked, with the highest overall weighted score ranked 1, the next highest score ranked 2, and so on.
- Sensitivity Analysis:
  - Sensitivity analyses were completed by varying account weighting to evaluate the effect of bias introduced by weighting. Account weighting schemes used in the sensitivity analyses are summarized in Table 4.

Table 4: Account Weighting Schemes Used in Sensitivity Analyses

Account	Account Weighting Scheme							
	ECCC (2016) Base Case		NexGen		Equal		ECCC (2016) Economic = 0	
	Value	Percent	Value	Percent	Value	Percent	Value	Percent
Environmental	6	44.4%	4.1	30%	3.4	25%	6	50%
Technical	3	22.2%	2.0	15%	3.4	25%	3	25%
Economic	1.5	11.1%	3.4	25%	3.4	25%	0	0%
Social	3	22.2%	4.1	30%	3.4	25%	3	25%
Total	**13.5**	**100%**	**13.5**	**100%**	**13.5**	**100%**	**12**	**100%**

Note: Values may not sum due to rounding.

Steps used to calculate the overall weighted score for each alternative follow ECCC (2016) and included:

1) Normalized indicator scores were multiplied by indicator weightings to calculate the indicator merit scores.
2) Indicator merit scores were summed for each sub-account to calculate total indicator merit score.
3) Total indicator merit scores were divided by the sum of indicator weightings to calculate sub-account merit ratings.
4) Sub-account merit ratings were multiplied by sub-account weightings to calculate sub-account merit scores.
5) Sub-account merit scores were summed to calculate total sub-account merit scores.
6) Total sub-account merit scores were divided by the sum of sub-account weightings to calculate account merit ratings.
7) Account merit ratings were multiplied by account weightings to calculate account merit scores.
8) Account merit scores were summed to calculate total account merit scores.
9) Total account merit scores were divided by the sum of account weightings to calculate alternative merit ratings.

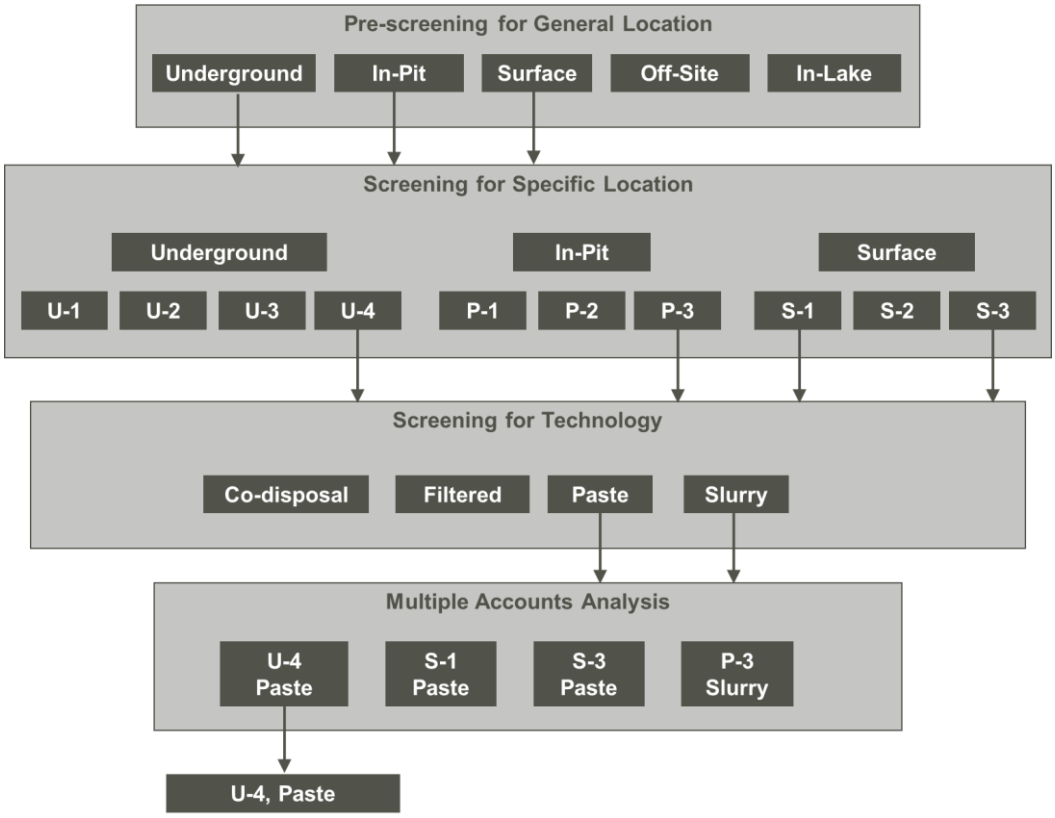
For the waste rock screening for specific location, alternative merit ratings were used to rank locations, where the highest alternative merit rating indicated the best available location and passed screening (i.e., the highest scoring location ranked first and indicated the best location for the storage of waste rock).

For the tailings, gypsum, and waste rock MAA, alternative merit ratings were used to rank alternatives, where the highest alternative merit rating indicated the best available alternatives (i.e., highest score ranked first and indicated best location and technology for the storage of tailings, gypsum, or waste rock).

4.0 TAILINGS ALTERNATIVES ASSESSMENT

An alternatives assessment was completed to identify the best location and technology for storage of tailings. Methods and outcomes for the tailings alternatives assessment are summarized in Figure 5 and described in this section.

Figure 5: Tailings Alternatives Assessment Methods and Outcomes



4.1 Pre-screening for General Location for Tailings Storage

Pre-screening for the general location for tailings storage was completed using the method described in Section 3.2. Five general locations were pre-screened and are described for Construction, Operations, and Closure stages in Table 5.

Table 5: General Locations for Tailings Considered for Pre-screening

Assessment Lifecycle Stage	General Location				
	Underground	In-Pit	Surface	Off-Site	In-Lake
Construction	▪ Excavation of underground chambers (drill, blast, load) ▪ Haulage of excavated rock for placement in WRSA ▪ Construction of tailings distribution and water management systems	▪ Excavation of large pit (drill, blast, load) ▪ Haulage of overburden and rock for placement in WRSA ▪ Construction of tailings distribution and water management systems	▪ Construction of containment structure ▪ Placement of liner ▪ Construction of tailings distribution and water management systems	▪ Construction of transport and haulage infrastructure ▪ Potential construction of containment structure or increase capacity of existing structure ▪ Construction of tailings distribution and water management systems	▪ Construction of tailings distribution system to lake, construct access
Operations	▪ Tailings deposition in underground chambers ▪ Excavation of underground chambers (drill, blast, load) ▪ Haulage of excavated rock for placement in WRSA ▪ Water management	▪ Tailings deposition in pit ▪ Water management	▪ Tailings deposition in containment structure ▪ Raising of containment structure ▪ Water management	▪ Transport tailings to off-site location ▪ Tailings deposition in off-site containment structure ▪ Water management	▪ Tailings deposition in lake
Closure	▪ Progressive decommissioning of filled underground chambers can occur in Operations	▪ Decommissioning of facility and infrastructure (utilities, access) ▪ Draining of pond ▪ Placement of closure cover system	▪ Decommissioning facility and infrastructure (utilities, access) ▪ Draining of pond ▪ Placement of closure cover system	▪ Decommissioning of facility and infrastructure (transport, haulage, utilities, access) ▪ Placement of closure cover system	▪ Decommissioning of facility and infrastructure (utilities, access)

Note: Monitoring is assumed to be common and is not listed.

WRSA = waste rock storage area.

The results from pre-screening for general tailings storage location are presented in Appendix B, Tailings Alternative Assessment, Table B-1 and summarized in this section.

Two general locations did not pass pre-screening:

- **Off-site:** eliminated due to increase in overall surface disturbance area outside of the proposed Project surface lease boundary. There are no nearby facilities that could be used for tailings storage other than Cluff Lake, a closed mine with a decommissioned tailings management facility (TMF) that has no capacity for additional tailings. Transport to and placement of tailings at the closed Cluff Lake facility off site would increase the potential for environmental contamination and liability associated with a closed site that is not owned by NexGen.
- **In-lake:** eliminated based on NexGen's criterion to not place waste in lakes.

Three general locations passed pre-screening and are described in the next section:

- Underground;
- In-pit; and
- Surface.

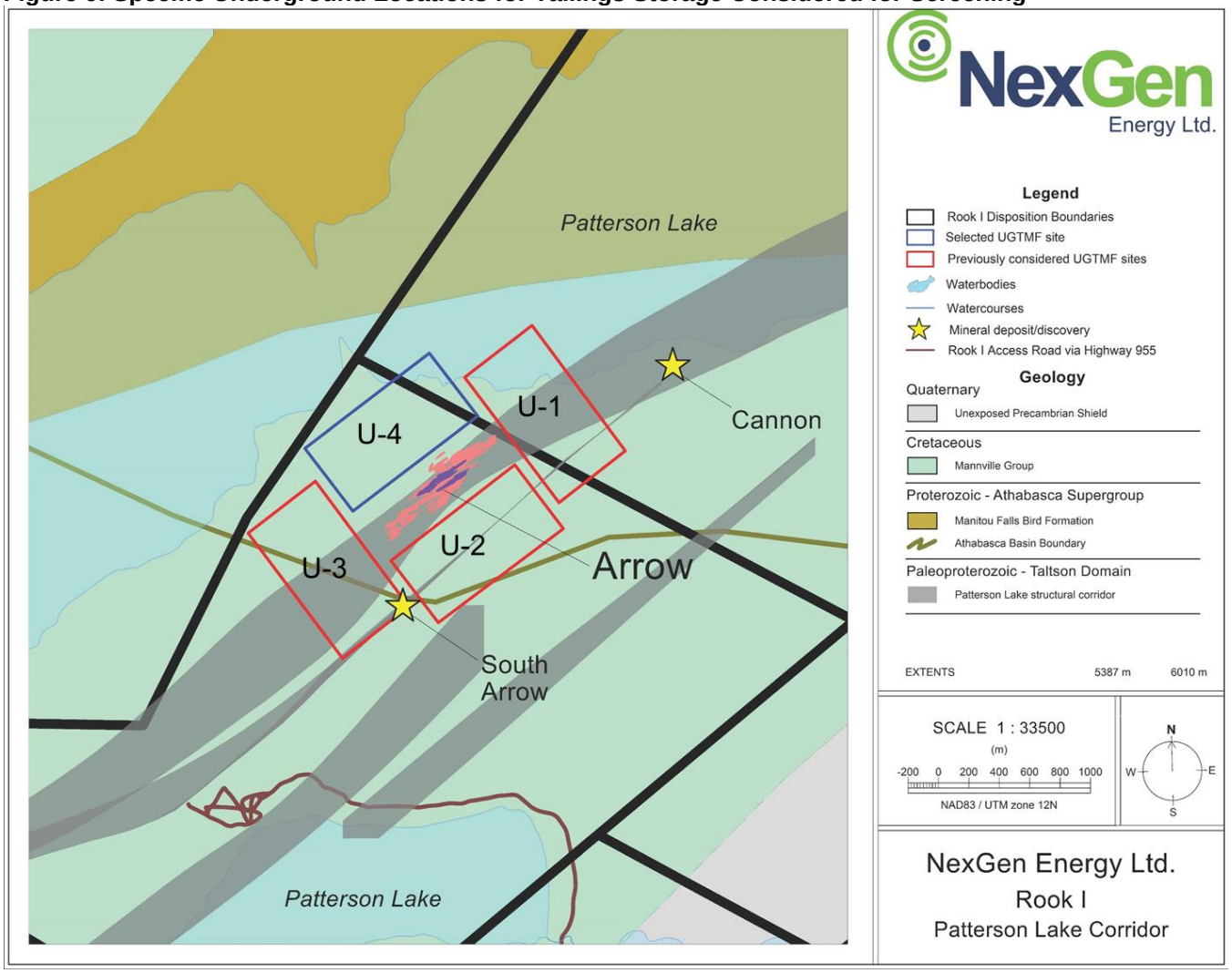
4.2 Surface Screening for Specific Location for Tailings Storage

Screening for a specific location for tailings storage was completed using the method described in Section 3.3. Ten specific locations were screened: four underground, three in pit, and three on surface. Underground locations were provided by NexGen (2020d). In-pit locations and surface locations for tailings were selected considering fixed infrastructure defined in Section 2.3.3.

4.2.1 Underground

The four specific underground locations (U-1, U-2, U-2, and U-4) considered for screening are illustrated in Figure 6 (NexGen 2020d) and described for Construction, Operations, and Closure stages in Table 6.

Figure 6: Specific Underground Locations for Tailings Storage Considered for Screening



Source: NexGen 2020d.

Table 6: Specific Locations for Underground Storage of Tailings Considered for Screening

Assessment Lifecycle Stage	Underground Location			
	U-1	U-2	U-3	U-4
Construction	▪ Incremental excavation of underground chambers (drill, blast) ▪ Incremental removal of excavated rock and haulage to surface, placement at surface			
	▪ Northeast of mine development ▪ Within Patterson Lake structural corridor and adjacent to Cannon mineralization	▪ Southeast of mine development ▪ Adjacent to South Arrow mineralization	▪ Southwest of mine development ▪ Within Patterson Lake structural corridor and adjacent to South Arrow mineralization	▪ Northwest of mine development
Operations	▪ Tailings deposition in underground chambers ▪ Incremental excavation of underground chambers (drill, blast) ▪ Incremental removal of excavated rock and haulage to surface, placement at surface ▪ Water management			
Closure	▪ Progressive decommissioning of filled underground chambers ▪ Final facility and infrastructure decommissioning (utilities, access)			

Note: Monitoring is assumed to be common and is not listed.

The results from screening for specific location for underground tailings storage are presented in Appendix B, Table B-2 and summarized in this section.

Three specific underground locations did not pass screening based on relative disadvantages for indicators within the technical account:

- **U-1:** located adjacent to the Cannon mineral discovery, within the Patterson Lake structural corridor characterized by fault and shear zones and along the Athabasca Basin Boundary (NexGen 2020a) with potential for uranium mineralization.
- **U-2:** located adjacent to the South Arrow mineral discovery (NexGen 2020a) and along the Athabasca Basin Boundary with potential for uranium mineralization.
- **U-3:** located adjacent to the South Arrow mineral discovery and within the Patterson Lake structural corridor characterized by fault and shear zones (NexGen 2020d) with potential for uranium mineralization.

One specific underground location passed screening based on a relative advantage for indicators within the technical account:

- **U-4:** located outside known major geologic structures and potential areas of mineralization.

4.2.2 In-Pit

Three specific locations (P-1, P-2, and P-3) for in-pit storage of tailings were considered for screening and are illustrated in Figure 7 and described in Table 7.

Figure 7: Specific Locations for In-Pit Storage of Tailings Considered for Screening

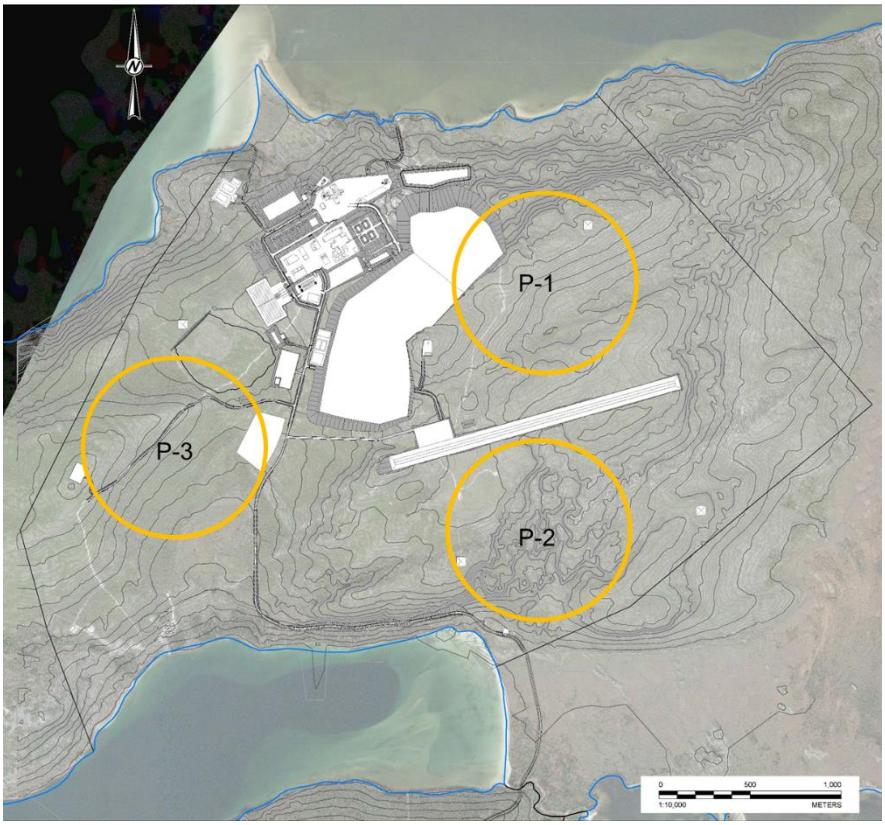


Table 7: Specific Locations for In-Pit Tailings Storage Considered for Screening

Assessment Lifecycle Stage	In-Pit Locations		
	P-1	P-2	P-3
Construction	▪ Excavation of pit (drill, blast) ▪ Removal of excavated overburden and rock, haulage, and placement at surface		
	▪ East of mine development	▪ South of airstrip ▪ Within Patterson Lake structural corridor	▪ Southwest of mine development ▪ Within Patterson Lake structural corridor
Operations	▪ Tailings deposition in pit ▪ Water management		
Closure	▪ Decommissioning of facility and infrastructure (utilities, access) ▪ Placement of closure cover system		

Note: Monitoring is assumed to be common and is not listed.

The results from screening for specific location for in-pit tailings storage are presented in Appendix B, Table B-2 and summarized in this section.

Two specific locations for in-pit storage did not pass screening based on relative disadvantages for indicators within the environmental, technical, economic, and social accounts:

- **P-1:** located within a valley where surface water controls would be required to manage runoff from the surrounding area and where additional excavation into the surrounding area would be required for expansion (higher excavation quantity relative to other locations).
- **P-2:** located within the Patterson Lake structural corridor, nearest to Patterson Lake, and the most visible location due to a natural topographic plateau. This location had the greatest area of impact and cost, and highest risk to worker safety and human health due to longest haul and tailings transport distance from the mine terrace.

One specific location for in-pit storage passed screening based on indicator descriptions and relative evaluation:

- **P-3:** located within a relatively flat topographic area that does not restrict storage capacity or facility expansion. This location has a median haul and transport distance from the mine terrace.

4.2.3 Surface

Three specific locations (S-1, S-2, and S-3) for surface storage of tailings were considered for screening and are illustrated in Figure 8 and described for Construction, Operations, and Closure stages in Table 8.

Figure 8: Specific Locations for Surface Storage of Tailings Considered for Screening

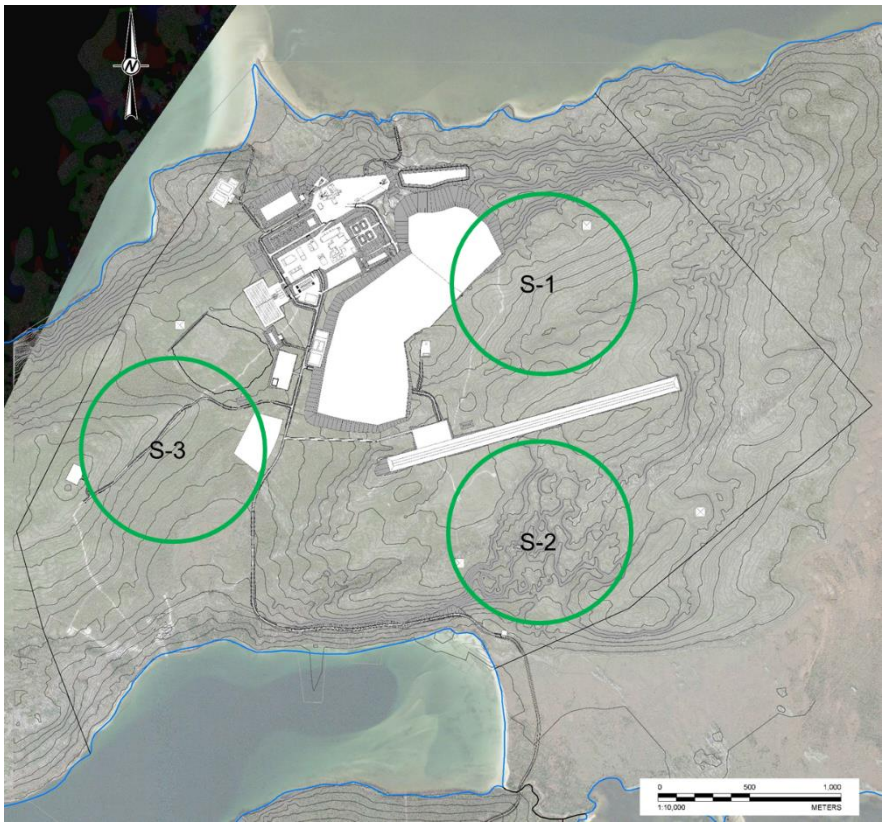


Table 8: Specific Locations for Surface Storage of Tailings Considered for Screening

Assessment Lifecycle Stage	Surface Location		
	S-1	S-2	S-3
Construction	▪ Containment structure and water management works ▪ Placement of liner		
Operations	▪ Tailings deposition in containment structure ▪ Water management		
Closure	▪ Decommissioning of facility and infrastructure decommission (utilities, access) ▪ Placement of closure cover system ▪ Water management		

Note: Monitoring is assumed to be common and is not listed.

The results from screening for specific location for surface storage of tailings are presented in Appendix B, Table B-2 and summarized in this section.

One specific surface location did not pass screening based on indicator descriptions and relative evaluation within the environmental, technical, economic, and social accounts:

- **S-2:** located within the Patterson Lake structural corridor characterized by fault and shear zones that may host uranium (NexGen 2020d), nearest to Patterson Lake, with most visible location and least natural containment due to topographic plateau. Greatest area and cost, and highest risk due to longest haul and tailings transport distance from the mine terrace.

Two specific surface locations passed screening based on indicator descriptions:

- **S-1:** located within a topographic valley with the greatest potential for natural containment. Least area, with concentration of facilities near the mine terrace. Potential cost and operating efficiency due to use of planned access infrastructure with shortest haul and transport from mine terrace.
- **S-3:** located within a relatively flat topographic area that does not restrict storage capacity. Some increase in area, with concentration of facilities near the mill area. Some cost and operating efficiency due to use of planned infrastructure, though farther from the mill area than S-1.

4.3 Screening for Tailings Technology

Screening for technology was completed using the method described in Section 3.4. Four technologies were screened: co-disposal with waste rock (co-disposal), dewatering by filtering (filtered), dewatering in a thickener to paste consistency (paste), and deposition as slurry (slurry). Each technology was considered at each of four locations that passed screening: underground location U-4, in-pit location P-3, and surface locations S-1 and S-3.

4.3.1 Underground

Four technologies were screened at underground location U-4 and are described during the Construction, Operations, and Closure stages in Table 9.

Table 9: Tailings Technologies Considered for Screening at Underground Location U-4

Assessment Lifecycle Stage	Technology			
	Co-disposal	Filtered	Paste	Slurry
Construction	▪ Incremental excavation of underground chambers (drill, blast) ▪ Incremental hauling and storing of excavated rock on surface			
	▪ Paste plant ▪ Mixing plant	▪ Thickener + filter plant	▪ Paste plant	▪ Additional tailings/water management system
Operations	▪ Incremental excavation of underground chambers (drill, blast, load, haul)			
	▪ Tailings thickened to 50%–70% solids ▪ Tailings and waste rock are mixed and placed underground	▪ Tailings thickened and filtered to >70% solids and placed underground ▪ Excavated waste rock hauled to surface for placement in WRSA	▪ Tailings thickened to 50%–70% solids (flowable), binder added and placed underground ▪ Excavated waste rock hauled to surface for placement in WRSA	▪ Tailings dewatered to 30%–50% solids (flowable) and placed underground ▪ Decant of transport water ▪ Excavated waste rock hauled to surface for placement in WRSA
Closure	▪ Progressive decommissioning of filled underground chambers ▪ Final facility and infrastructure decommissioning			

Note: Monitoring is assumed to be common and is not listed.

WRSA = waste rock storage area.

The results from screening for tailings storage underground technology are presented in Appendix B, Table B-3 and summarized in this section.

Three tailings technologies did not pass screening:

- **Co-disposal:** fatally flawed due to volume incompatibility. The excavation of underground chambers to store tailings and waste rock would generate more excavated rock than can be stored underground.
- **Filtered:** fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport, placement, and compaction. Unconsolidated filtered tailings have a higher hydraulic conductivity and can swell once saturated, potentially affecting geochemical stability.
- **Slurry:** there is limited precedent application of placement of slurry tailings underground. Tailings consolidation and consistency are uncontrolled and would require construction of a cap or plug to keep tailings in place after facility decommissioning. There is a higher potential for ecological effect due to the permeability of the tailings and open voids that may form during consolidation.

One tailings technology passed screening based on indicator descriptions and relative evaluation:

- **Paste:** there is a proven precedent for application of paste technology in underground tailings deposition. Cementing the tailings in chambers reduces the potential for effect on the environment.

4.3.2 In-Pit

The four technologies were screened at in-pit location P-3 and are described for Construction, Operations, and Closure stages in Table 10.

Table 10: Tailings Technologies Considered for Screening at In-Pit Location P-3

Assessment Lifecycle Stage	Technology			
	Co-disposal	Filtered	Paste	Slurry
Construction	▪ Excavation of pit on surface (drill, blast) ▪ Removal of excavated overburden and rock			
	▪ Paste plant ▪ Mixing plant	▪ Thickener + filter plant	▪ Paste plant	▪ Additional tailings/water management system
Operations	▪ Tailings thickened to 50%–70% solids (flowable) ▪ Tailings, waste rock, and overburden mixed and placed in pit	▪ Tailings thickened and filtered to >70% solids, placed in pit and compacted ▪ Removal of excavated overburden and rock and haulage for placement at surface	▪ Tailings thickened to 50%–70% solids (flowable) and placed in pit ▪ Removal of excavated overburden and rock and haulage for placement at surface	▪ Tailings dewatered to 30%–50% solids (flowable); subaqueous tailings deposition in pit ▪ Removal of excavated overburden and rock and haulage for placement at surface
Closure	▪ Decommissioning of facility and infrastructure (utilities, access)			

Note: Filters and monitoring are assumed to be common and are not listed.

The results from screening for tailings storage in-pit technology are presented in Appendix B, Table B-4 and summarized in this section.

Three technologies were eliminated based on indicator descriptions and relative evaluation:

- **Co-disposal:** fatally flawed due to volume incompatibility. Excavation of a pit to store tailings and waste rock generates more excavated overburden and rock than can be stored in the pit.
- **Filtered:** fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport, placement, and compaction.
- **Paste:** higher potential for fugitive dust emission and worker exposure to gamma radiation through contact with the tailings and absence of a supernatant pond. Highest cost for construction, operation, and decommissioning of paste plant. Facility closure may be complicated by the presence of ice lenses that may form during tailings deposition.

One technology passed screening based on indicator descriptions and relative evaluation:

- **Slurry:** there is a proven precedent for application of tailings as slurry for storage in pit at other uranium mines. The presence of a supernatant pond reduces the potential for fugitive dust emission and worker exposure to gamma radiation and mitigates the formation of ice lenses within the tailings.

4.3.3 Surface

The four technologies were screened for surface locations S-1 and S-3 and are described for Construction, Operations, and Closure stages in Table 11.

Table 11: Tailings Technologies Considered for Screening at Surface Locations S-1 and S-3

Assessment Lifecycle Stage	Technology			
	Co-disposal	Filtered	Paste	Slurry
Construction	▪ Foundation preparation and placement of liner			
	▪ Paste plant ▪ Mixing plant	▪ Filter plant	▪ Paste plant ▪ Containment structure with progressive raises	▪ Containment structure with progressive raises ▪ Additional tailings/water management system
Operations	▪ Tailings thickened to 50%–70% solids ▪ Tailings and waste rock mixed and placed on surface	▪ Tailings thickened and filtered to >70% solids and placed on surface in stacked facility and compacted	▪ Tailings thickened to 50%–70% solids (flowable) and placed in containment structure ▪ Water management	▪ Tailings dewatered to 30%–50% solids (flowable); subaqueous tailings deposition in containment structure ▪ Tailings transport water management
Closure	▪ Decommissioning of facility and infrastructure (utilities, access) ▪ Placement of closure cover system			

Note: Monitoring is assumed to be common and is not listed.

The results from screening for tailings storage surface technology are presented in Appendix B, Table B-5 and summarized in this section.

Three technologies did not pass screening based on indicator descriptions and relative evaluation:

- **Co-disposal:** fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement.
- **Filtered:** fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport, placement, and compaction.
- **Slurry:** greatest water content and potential for seepage, highest cost for water management. Has a supernatant pond and does not meet GTR (2020) requirement 3.2.(ii) “minimize the volume of tailings and water placed in external tailings facilities”.

One technology passed screening based on indicator descriptions and relative evaluation:

- **Paste:** lower potential for seepage and cost for water management. Complies with GTR (2020) by reducing the volume of water placed in a surface TMF.

4.4 Multiple Accounts Analysis

An MAA for tailings storage alternatives was completed using the method described in Section 3.5. A description of alternatives, the results of the MAA, and the sensitivity analysis are summarized in this section.

4.4.1 Description of Alternatives

Conceptual models were developed for the four TMF alternatives that passed screening to obtain measurable indicators for scoring. The four alternatives are described for Construction, Operations, and Closure stages in Table 12, with key quantities and measurements.

Table 12: Tailings Alternatives Evaluated by Multiple Accounts Analysis

Item	Tailings Alternative			
	Underground Location U-4 Paste Technology	Surface Location S-1 Paste Technology	Surface Location S-3 Paste Technology	In-Pit Location P-3 Slurry Technology
Distance to Patterson Lake (km)[1]	0.2	1.0	0.9	0.9
Distance to mine shaft (km)[1]	0.8	1.5	1.8	1.9
Area of tailings placed on surface (ha)	0.0	92	58	34
Volume earthworks (Mm^3)	11.3	3.2	3.5	12.8
Construction	▪ Excavation of underground chambers (drill, blast) ▪ Haulage of excavated rock for placement at surface	▪ Earthworks for cellular containment structures with progressive raises during Operations, no topographic containment	▪ Single containment structure with progressive raises during Operations, some natural topographic containment	▪ Excavation of pit (drill, blast) ▪ Haulage of excavated overburden and rock and placement at surface
	▪ Paste plant ▪ Tailings transport system	▪ Paste plant ▪ Tailings transport system		▪ Tailings / surface water management systems
Operations	▪ Tailings thickened to 50%–70% solids (flowable), add cement and place in underground chambers ▪ Incremental excavation of underground chambers (drill, blast) ▪ Removal of excavated rock and haulage for placement at surface	▪ Tailings thickened to 50%–70% solids (flowable) and place in surface containment structure		▪ Tailings dewatered to 30%–50% solids (flowable), subaqueous tailings deposition in pit ▪ Operation of tailings/water management systems
Closure	▪ Progressive decommissioning of filled underground chambers during Operations ▪ Decommissioning of final facility and infrastructure (utilities, access)	▪ Decommissioning of facility and infrastructure (utilities, access) ▪ Placement of closure cover complicated by thaw of ice lenses in tailings		▪ Draining of water pond ▪ Placement of cover, considering consolidation ▪ Decommissioning of facility and infrastructure (utilities, access)

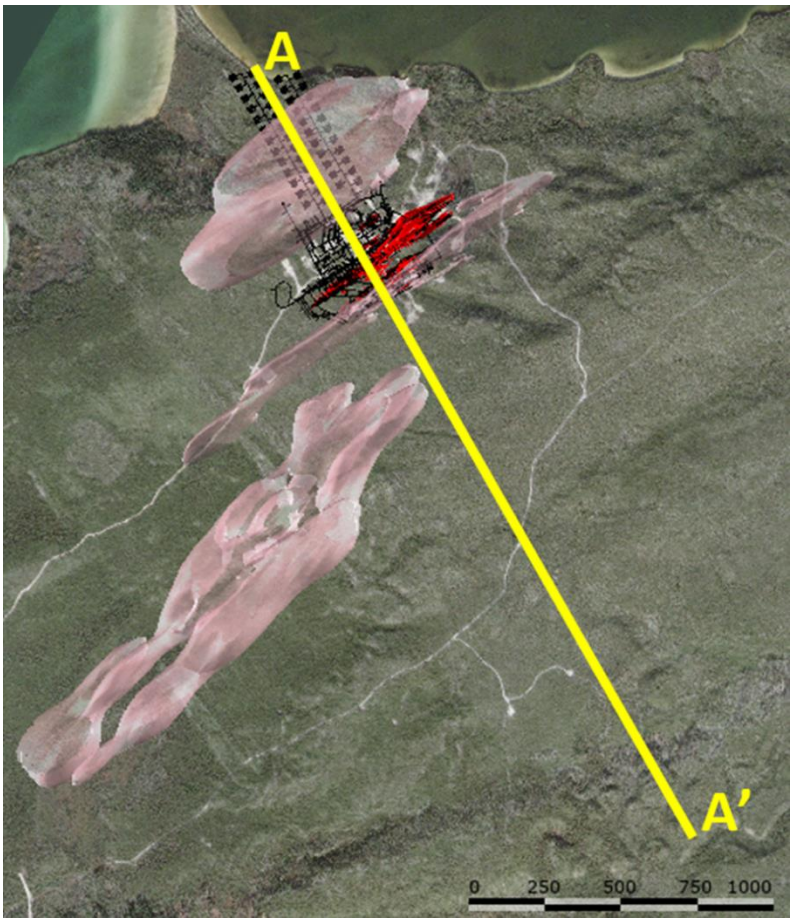
Note: Monitoring is assumed to be common and is not listed.

[1] lateral distance measured from alternative centroid projected to surface.

Mm^3 = million cubic metres

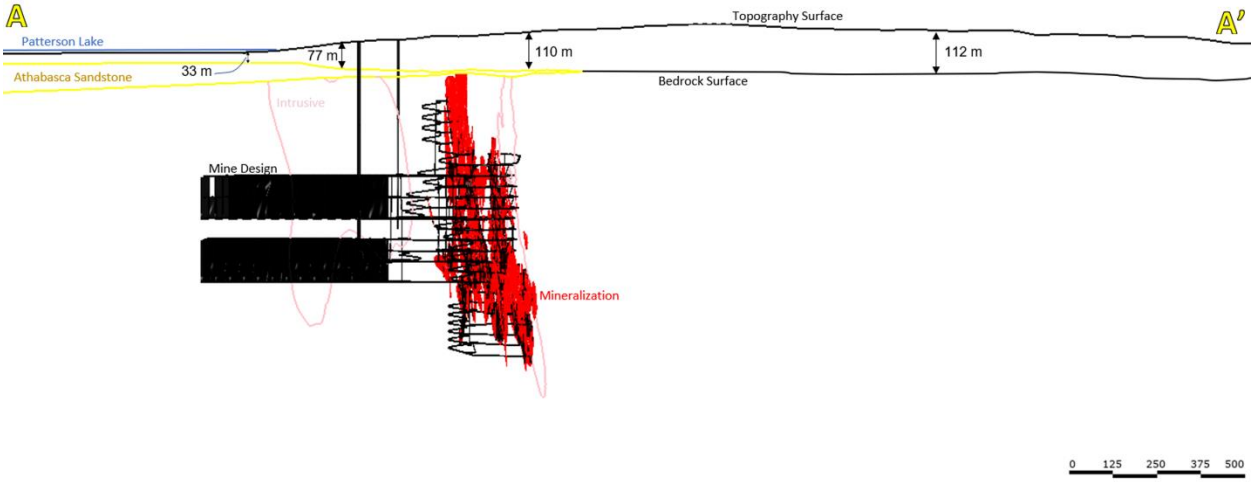
Plan and section illustrations from the conceptual model for the underground alternative are presented in Figure 9 and Figure 10 (NexGen 2020e).

Figure 9: Conceptual Plan Illustration of the Underground (U-4) Paste Technology Alternative



Source: NexGen 2021.

Figure 10: Conceptual Section Illustration of Underground (U-4) Paste Technology Alternative



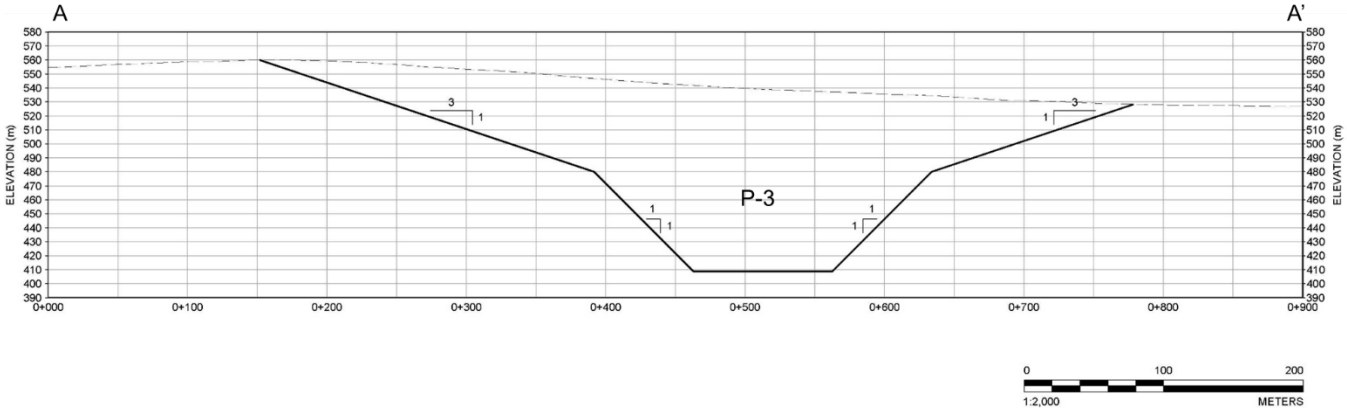
Source: NexGen 2021.

A conceptual model was developed for the in-pit tailings storage alternative using AutoCAD Civil 3D (Autodesk 2019) to obtain measurements and quantities used to score indicators. Plan and section illustrations from the conceptual model for the in-pit alternative are presented in Figure 11 and Figure 12. Assumptions used to develop the conceptual model include:

- maximum excavation slope of 3 horizontal to 1 vertical (3H:1V) in overburden and 1H:1V in bedrock; and
- glacial overburden is approximately 60 m thick (Golder 2019).

Figure 11: Conceptual Plan Illustration of the In-Pit (P-3) Slurry Technology Alternative

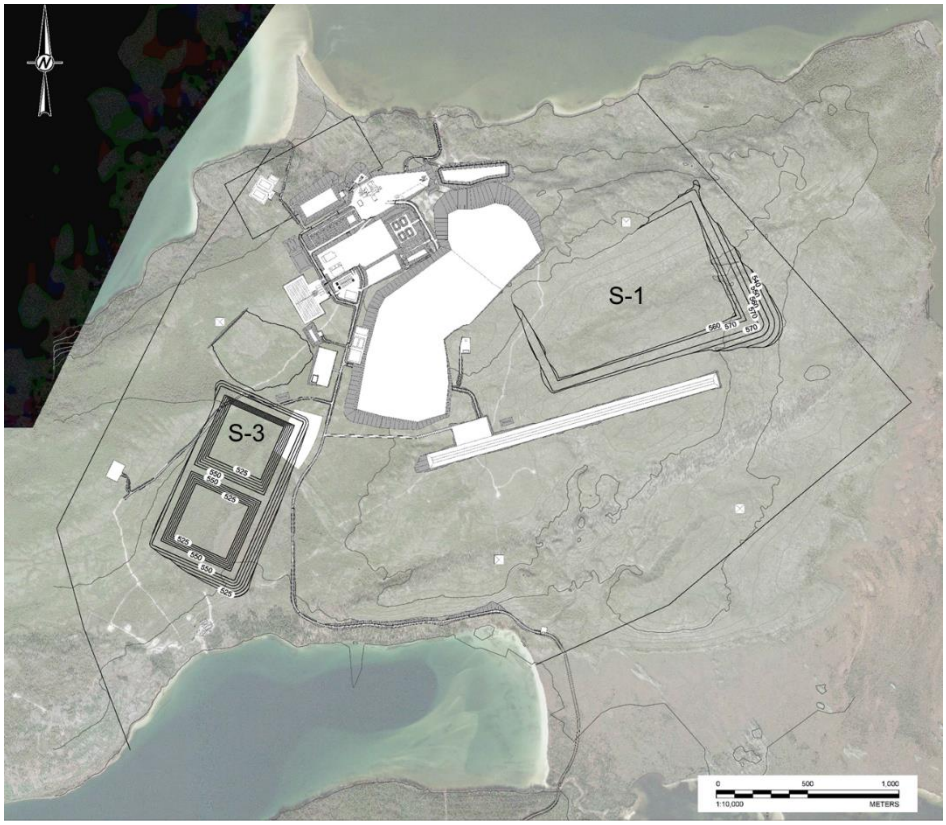
Figure 12: Conceptual Section Illustration of the In-Pit (P-3) Slurry Technology Alternative



Conceptual models were developed for the surface tailings storage alternatives using AutoCAD Civil 3D (Autodesk 2019) to obtain measurements and quantities used to score indicators. Plan illustrations from the conceptual model for surface alternatives at locations S-1 and S-3 are presented in Figure 13. Assumptions used to develop the conceptual models include:

- maximum exterior embankment slope of 3H:1V and interior embankment slope of 2H:1V.

Figure 13: Conceptual Plan Illustration of the Surface Paste Technology Alternatives at Locations S-1 and S-3



4.4.2 Results

A list of indicators, sub-accounts, and weighting is included in Appendix B, Table B-6.

The MAA is presented in Appendix B, Table B-7 and summarized in this section. Alternatives were ranked based on the highest assessment score using ECCC (2016) account weighting:

1) **Underground location U-4 with paste technology** – highest scores in the economic and social accounts:

- **Environmental Account:** lowest score[1] due to shortest distance to Patterson Lake (below the lake), though had lowest surface area, least potential to require surface and contact water management, and least potential for effects on groundwater. Placement underground would result in additional waste rock excavation during construction of the UGTMF and would generate more dust than some other alternatives due to haulage and placement of excavated waste rock on surface.

[1] The distance to Patterson Lake was adopted as an intuitive and easily quantifiable indicator for the ecological integrity sub-account. However, if a more complex indicator was used that also considered gradients and hydraulic conductivities, it is expected that the underground option would score higher in the ecological integrity sub-account and the overall environmental account compared to alternatives that store the tailings on surface.

- **Technical Account:** high score due to intermediate complexity to design, quantity of earthworks, greatest operational flexibility with least risk (modular format is designed for expansion), reduced requirements for surface water management, simplest to close (allows progressive closure during Operations stage) with greatest resistance to post-closure extreme events such as flood or earthquake.
- **Economic Account:** highest score. The evaluation uses total estimated volume of earthworks as a measurable indicator for capital cost, which results in a lower score for the UGTMF in the economic account. The approach does not differentiate types of earthworks and associated unit rates (underground mining excavation versus dam fill placement versus excavation from an open pit) and does not differentiate capital cost versus sustaining capital costs over the life of mine. The UGTMF would be constructed in stages, including an initial starter facility as part of capital expenditure, and then expanded as required over the life of mine. Surface alternatives would be similarly staged. The in-pit alternative would be constructed during the construction phase.
- **Social Account:** highest score due to least potential for visual impact and least health risk to people downstream.

2) **Surface location S-3 with paste technology** – highest score in the technical account:

- **Environmental Account:** lower score due to greater surface disturbance area and potential to affect groundwater and surface water.
- **Technical Account:** highest score due to less complex to design and construct with no additional rock excavated and hauled to surface.
- **Economic Account:** low score due high costs for water treatment, closure, and decommissioning.
- **Social Account:** low score due to the visual disturbance associated with a surface facility.

3) **Surface location S-1 with paste technology** – lowest score in the environmental and social accounts:

- **Environmental Account:** low score due to greatest surface area, and potential to affect surface water, groundwater, plants, fish, and other wildlife.
- **Technical Account:** low score due to requiring an embankment raise should the facility be expanded.
- **Economic Account:** low score due to costs for water treatment, closure, and decommissioning.
- **Social Account:** lowest score due to visual disturbance and potential health risk to people downstream.

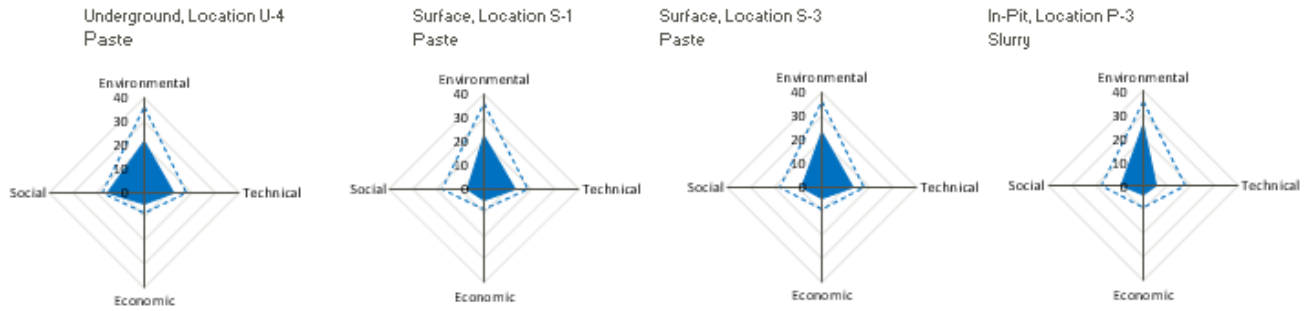
4) **In-Pit location P-3 with slurry technology** – lowest score in the technical and economic accounts:

- **Environmental Account:** highest score due to distance to Patterson Lake, though with a greater surface disturbance area, potential for dust emissions, and potential to affect surface water and groundwater.
- **Technical Account:** lowest score due to complexity to design, construct, and operate, limited potential to expand capacity beyond pit limit, limited potential for progressive closure, and effort required for expansion and design changes.

- **Economic Account:** lowest score due to high capital cost to drill, blast, load, and haul excavated overburden and rock, operational costs for transport of tailings, and water treatment.
- **Social Account:** lower score due to the greater potential for long-term change in land use and the quantity of rock excavated to construct the pit.

Radar charts for the tailings MAA are included as Figure 14 considering ECCC base case weighting to illustrate the distribution of scoring within the environmental, technical, economic, and social accounts for each alternative. The maximum score an alternative can achieve in each account is represented by the dashed line. Placement of tailings underground at location U-4 with paste technology is the preferred alternative based on results of the MAA.

Figure 14: Radar Charts for the Tailings Multiple Accounts Analysis Results



4.4.3 Sensitivity Analysis

A sensitivity analysis was completed using the method described in Section 3.5 to evaluate the effect of bias introduced by weighting, with results presented in Appendix B, Table B-8 and summarized in Table 13. The ranking of alternatives did not change the preferred rank of tailings placed as CPT underground in a UGTMF at location U-4, indicating that weighting of accounts (introduction of bias) does not change the study outcome.

Table 13: Ranking of Tailings Alternatives by Different Account Weighting Schemes

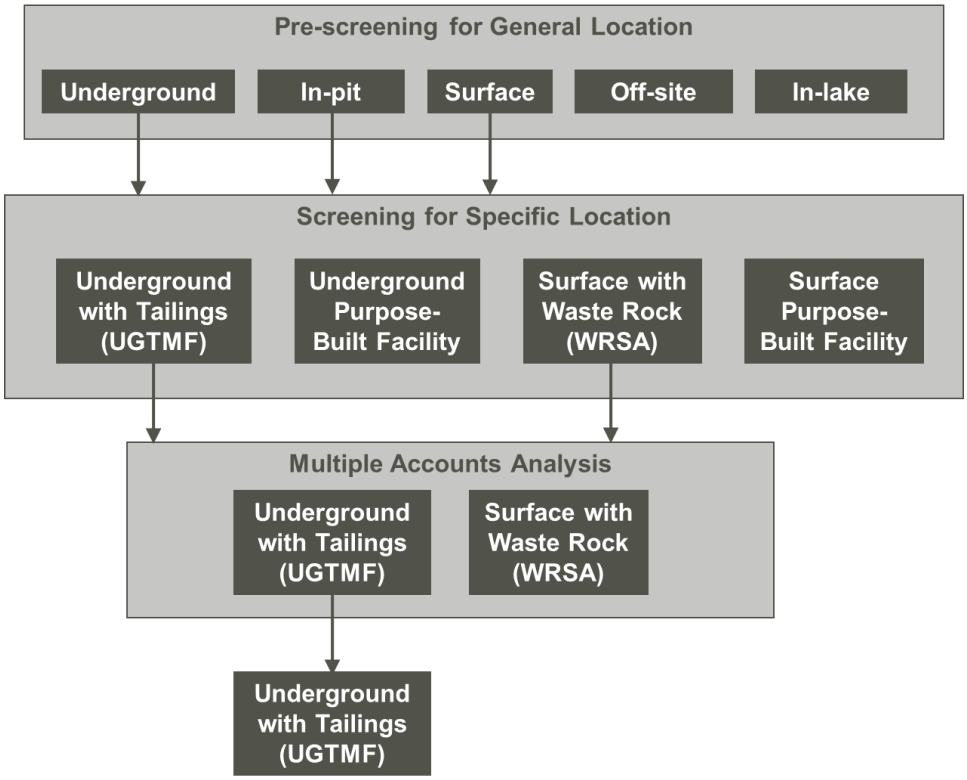
Account Weighting Scheme	Tailings Alternative Rank			
	Underground Location U-4 Paste Technology	Surface Location S-1 Paste Technology	Surface Location S-3 Paste Technology	In-Pit Location P-3 Slurry Technology
ECCC (2016) (Base Case)	1	3	2	4
NexGen	1	3	2	4
Equal	1	3	2	4
ECCC (2016), Economic = 0	1	3	2	4

5.0 GYPSUM ALTERNATIVES ASSESSMENT

An alternatives assessment was completed to identify the best available location and technology for the storage of gypsum. Gypsum is typically disposed as part of the tailings stream at uranium mines in Saskatchewan; however, an assessment was completed to determine if there was a more appropriate alternative for the Rook I Project.

Methods and outcomes for the gypsum alternatives assessment are summarized in Figure 15 and described in this section.

Figure 15: Gypsum Alternatives Assessment Methods and Outcomes



UGTMF = underground tailings management facility; WRSA = waste rock storage area.

5.1 Pre-screening for General Location for Gypsum Storage

Pre-screening for the general location for gypsum storage was completed using the method described in Section 3.2. The five general locations considered during pre-screening are described for Construction, Operations, and Closure stages in Table 14.

The results from pre-screening for general location for gypsum storage are presented in Appendix C, Gypsum Alternatives Assessment, Table C-1 and summarized in this section.

Three general locations did not pass pre-screening:

- **Off-site:** eliminated due to increase in overall surface disturbance area outside of the proposed Project surface lease boundary. There are no nearby facilities that could be used for gypsum storage other than Cluff Lake, a closed mine with a decommissioned TMF that has no capacity for additional gypsum. Transport

to, and placement of gypsum at, the closed Cluff Lake facility off site would increase the potential for environmental contamination and liability associated with a closed site that is not owned or managed by NexGen.

- **In-pit:** eliminated as excavating a pit would generate more overburden and rock excavation than the volume of gypsum to be stored. Would result in additional surface disturbance due to the pit and for storage of excavated overburden and rock.
- **In-lake:** eliminated based on NexGen's criterion to not place waste in lakes.

Two general locations passed pre-screening:

- Underground; and
- Surface.

Table 14: General Locations for Gypsum Considered for Pre-screening

Assessment Lifecycle Stage	General Location				
	Underground	In-Pit	Surface	Off-Site	In-Lake
Construction	▪ Excavation of underground chambers (drill, blast, load) ▪ Haulage of excavated rock for placement in WRSA	▪ Excavation of large pit (drill, blast, load) ▪ Haulage of overburden and rock for placement in WRSA	▪ Construction of containment structure	▪ Construction of transport and haulage infrastructure ▪ Potential construction of containment structure or increase capacity of existing structure	▪ Construction of transport and haulage infrastructure
Operations	▪ Gypsum placement in underground chambers ▪ Excavation of underground chambers (drill, blast, load) ▪ Haulage of excavated rock for placement in WRSA	▪ Gypsum cleaning (if required) ▪ Placement in pit	▪ Gypsum cleaning ▪ Placement in containment structure	▪ Gypsum cleaning ▪ Haulage to off-site location ▪ Placement in off-site containment structure	▪ Gypsum cleaning ▪ Placement in lake

Table 14: General Locations for Gypsum Considered for Pre-screening

Assessment Lifecycle Stage	General Location				
	Underground	In-Pit	Surface	Off-Site	In-Lake
Closure	▪ Progressive decommissioning of filled underground chambers can occur in Operations ▪ Decommissioning of final facility and infrastructure (utilities, access)	▪ Decommissioning of facility and infrastructure (utilities, access) ▪ Placement of closure cover system	▪ Decommissioning of facility and infrastructure (utilities, access) ▪ Placement of closure cover system	▪ Decommissioning of facility and infrastructure (transport, haulage, utilities, access) ▪ Placement of closure cover system	▪ Decommissioning of facility and infrastructure (utilities, access)

Note: Monitoring is assumed to be common and is not listed.

WRSA = waste rock storage area.

5.2 Screening for Specific Location for Gypsum Storage

Screening of specific locations for gypsum storage was completed using the method described in Section 3.3. Four specific locations were screened: two underground and two on surface. Underground locations for gypsum storage included placement with the tailings in a UGTMF and placement in a purpose-built underground facility. Surface locations for gypsum storage included placement with the waste rock in a waste rock storage area (WRSA) and placement in a purpose-built facility.

5.2.1 Underground

The two specific underground locations (UGTMF and purpose-built facility) were screened and are described for Construction, Operations, and Closure stages in Table 15.

Table 15: Specific Locations for Underground Storage of Gypsum Considered for Screening

Assessment Lifecycle Stage	Underground Location	
	UGTMF	Purpose-Built Facility
Construction	▪ Use of planned facility for tailings storage ▪ Incremental excavation of underground chambers (drill, blast) ▪ Incremental removal of excavated rock and haulage to surface, placement at surface	▪ Excavation of purpose-built facility (drill, blast) ▪ Removal of excavated rock and haulage to surface, placement at surface ▪ Separate gypsum delivery system
Operations	▪ Gypsum in tailings stream placed in underground chambers ▪ Incremental excavation of underground chambers (drill, blast) ▪ Incremental removal of excavated rock and haulage to surface, placement at surface ▪ Potential advantage: gypsum may reduce cement binder requirement for CPT	▪ Gypsum placed in purpose-built facility ▪ Incremental removal of excavated rock and haulage to surface, placement at surface ▪ Maintenance and operation of separate gypsum delivery system

Table 15: Specific Locations for Underground Storage of Gypsum Considered for Screening

Assessment Lifecycle Stage	Underground Location	
	UGTMF	Purpose-Built Facility
Closure	▪ Progressive decommissioning of filled underground chambers during Operations ▪ Decommissioning of final facility and infrastructure (utilities, access)	▪ Progressive decommissioning of filled underground chambers during Operations ▪ Decommissioning of final facility and infrastructure (utilities, access) of separate facility

Note: Monitoring is assumed to be common and is not listed.

UGTMF = underground tailings management facility; CPT = cemented paste tailings.

The results from screening for specific location for underground gypsum storage location are presented in Appendix C, Table C-2 and summarized in this section.

- One specific location for underground storage of gypsum did not pass screening based on relative disadvantages on comparison of indicators:
- **Purpose-built:** a separate, purpose-built underground facility would result in the greatest increase in quantity of rock excavated and surface disturbance from haulage and placement of excavated rock, with higher design effort, operational complexity, and lifecycle costs for an additional facility and gypsum delivery system. No potential reduction in cement binder requirement for CPT mine backfill.

One specific underground location passed screening based on relative advantages for indicators:

- **UGTMF:** use of a planned facility and delivery system reduces complexity of operation and cost compared to construction of an additional purpose-built facility, and provides a potential advantage for reducing cement binder requirement for CPT.

5.2.2 Surface

Two specific locations (WRSA, purpose-built facility) for surface storage of gypsum were considered for screening and are described for Construction, Operations, and Closure stages in Table 16.

Table 16: Specific Locations for Surface Storage of Gypsum Considered for Screening

Assessment Lifecycle Stage	Surface Location	
	WRSA	Purpose-Built Facility
Construction	▪ Use of planned facility to store gypsum with waste rock ▪ Incremental placement of excavated rock at WRSA	▪ Purpose-built containment structure ▪ Separate gypsum delivery system
Operations	▪ Gypsum cleaning ▪ Transport to WRSA ▪ Engineered placement with waste rock in WRSA ▪ Incremental placement of excavated rock at WRSA ▪ Potential disadvantage: could result in instability if placed incorrectly	▪ Gypsum cleaning ▪ Transport to and deposition in purpose-built facility ▪ Maintenance and operation of separate gypsum transport and placement system ▪ Requires extra equipment and work front

Table 16: Specific Locations for Surface Storage of Gypsum Considered for Screening

Assessment Lifecycle Stage	Surface Location	
	WRSA	Purpose-Built Facility
Closure	▪ Decommissioning of final facility and infrastructure (utilities, access) for WRSA only (incremental increase on closure)	▪ Decommissioning of final facility and infrastructure (utilities, access) for separate facility in addition to WRSA.

Note: Monitoring is assumed to be common and is not listed.

WRSA = waste rock storage area.

The results from screening of specific locations for surface storage of gypsum are presented in Appendix C, Table C-2 and summarized in this section.

One specific surface location did not pass screening based on indicator descriptions and relative evaluation:

- **Purpose-built:** a separate surface facility would increase surface disturbance with greater potential to affect surface and ground water, greater potential for dust, higher complexity, and higher cost, and would create an additional facility requiring closure.

One specific surface location passed screening based on indicator descriptions and relative evaluation:

- **WRSA:** storage of gypsum in a planned facility and delivery system reduces construction cost and effort, reduces operational complexity, and does not require an additional work front. Placement of gypsum with waste rock may require engineering controls to reduce potential for instability related to dissolution of gypsum.

5.3 Multiple Accounts Analysis

A MAA was completed for gypsum alternatives using the method described in Section 3.5. A description of alternatives, the results of the MAA, and the sensitivity analysis are summarized in this section.

5.3.1 Description of Alternatives

Two alternatives for gypsum, each including a location and technology, were evaluated and are described by Construction, Operations, and Closure stages in Table 17.

Table 17: Gypsum Alternatives Evaluated by Multiple Accounts Analysis

Assessment Lifecycle Stage	Gypsum Alternative	
	UGTMF	WRSA
Construction	▪ Incremental excavation of underground chambers (drill, blast, load) for placement of gypsum ▪ Incremental removal of excavated rock and haulage to surface for placement at WRSA	▪ Incremental increase in size of WRSA due to placement of gypsum
	▪ Construction of planned facility, access, and associated water management systems	
Operations	▪ Gypsum is included in the tailings stream ▪ Tailings are place in underground chambers ▪ Incremental excavation of underground chambers (drill, blast, load) ▪ Incremental removal of excavated rock and haulage to surface for placement at WRSA	▪ Gypsum cleaning ▪ Haulage to WRSA ▪ Engineered placement in WRSA ▪ Incremental increase in size of WRSA due to placement of gypsum

Table 17: Gypsum Alternatives Evaluated by Multiple Accounts Analysis

Assessment Lifecycle Stage	Gypsum Alternative	
	UGTMF	WRSA
	▪ Potential advantage: gypsum may reduce cement binder requirement for CPT	
Closure	▪ Progressive decommissioning of filled underground chambers during Operations ▪ Decommissioning of final facility and infrastructure (utilities, access)	▪ Decommissioning of final facility and infrastructure decommission (utilities, access)

Note: Monitoring is assumed to be common and is not listed.

WRSA = waste rock storage area; CPT = cemented paste tailings.

Quantity assumptions used for the gypsum MAA include:

- For simplification, the waste rock quantity is included in the capital cost for construction, rather than operational cost.

5.3.2 Results

A list of indicators, sub-accounts, and weighting is included as Appendix C, Table C-3.

The MAA is presented in Appendix C, Table C-4 and summarized in this section. Alternatives were ranked based on the score using ECCC (2016) account weighting:

1) **Placement of gypsum with tailings in the UGTMF** – highest score in the environmental and technical accounts, lowest in the economic and social accounts:

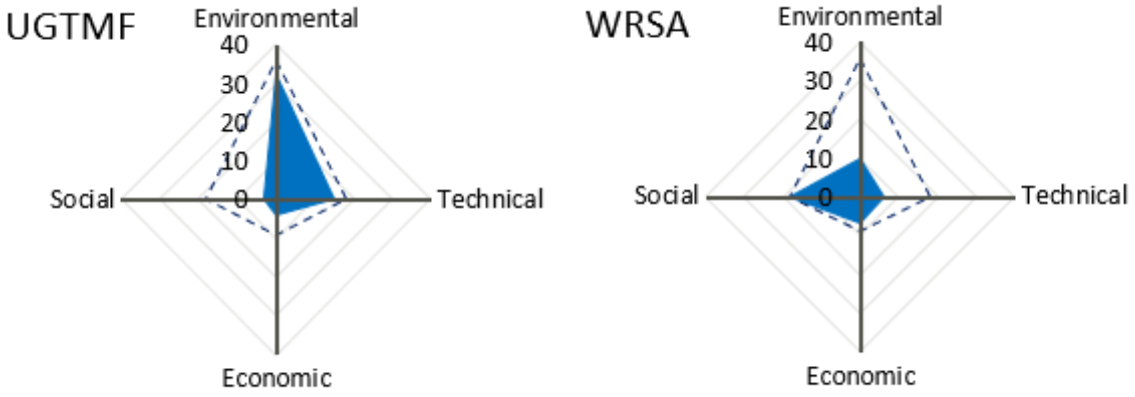
   - **Environmental Account:** highest score due to lowest potential for effects on Patterson Lake and lowest potential for surface contact water management. Storage of gypsum with tailings increases the quantity of waste rock to be excavated in the UGTMF and stored on surface, which has the potential to increase dust emissions from hauling of waste rock relative to storage of gypsum in the WRSA, which could also create dust.
   - **Technical Account:** highest score due to least design effort, proven technology, lower effort required to clean and handle gypsum, with less design effort, and lowest geotechnical risk.
   - **Economic Account:** lowest score due to higher capital cost for facility construction resulting from the increased quantity of waste rock generated from excavation of the UGTMF chambers, otherwise has a lower operating cost for pipeline transport of gypsum with tailings to the UGTMF. Placing gypsum underground has the potential to offset the cost of cement binder added to CPT.
   - **Social Account:** lowest score due to higher quantity of excavation and haulage of rock to surface for UGTMF chamber construction, which would increase potential risks to workers due to additional mining activities.

2) **Placement of gypsum with waste rock in the WRSA** – highest scores in the economic and social accounts, lowest scores in the environmental and technical accounts:

- **Environmental Account:** lowest score because gypsum on surface would increase the potential requirement for management of surface contact water.
- **Technical Account:** lowest score due to requirement for control of placement of gypsum in the WRSA to avoid introducing potential for instability due to dissolution of gypsum, otherwise has higher flexibility during operation for design changes. Requires separation and cleaning of gypsum to be placed on surface.
- **Economic Account:** highest score due to lower capital cost for construction, otherwise has a higher operating cost for haulage and placement of gypsum at the WRSA.
- **Social Account:** highest score due to lower quantity of rock excavation for facility construction.

Radar charts for the gypsum MAA are presented in Figure 16 to illustrate the distribution of scoring within the environmental, technical, economic, and social accounts for each alternative. The maximum score an alternative can achieve in each account is represented by the dashed line. Placement of gypsum underground with CPT in the UGTMF is the preferred alternative based on results of the MAA.

Figure 16: Radar Charts for the Gypsum Multiple Accounts Analysis Results



UGTMF = underground tailings management facility; WRSA = waste rock storage area.

5.3.3 Sensitivity Analysis

A sensitivity analysis was completed using the method described in Section 3.5 to evaluate the effect of bias introduced by weighting, with results presented in Appendix C, Table C-5 and summarized in Table 18. The first-place ranking changes from UGTMF to WRSA when considering the NexGen weighting scheme, where the economic and social accounts have a higher weighting, indicating that account weighting (introduction of bias) does change the study outcome. The change in rank is due, in part, to the limited number of indicators in the social account such that the use of 1 and 6 for indicator scoring changes the overall score.

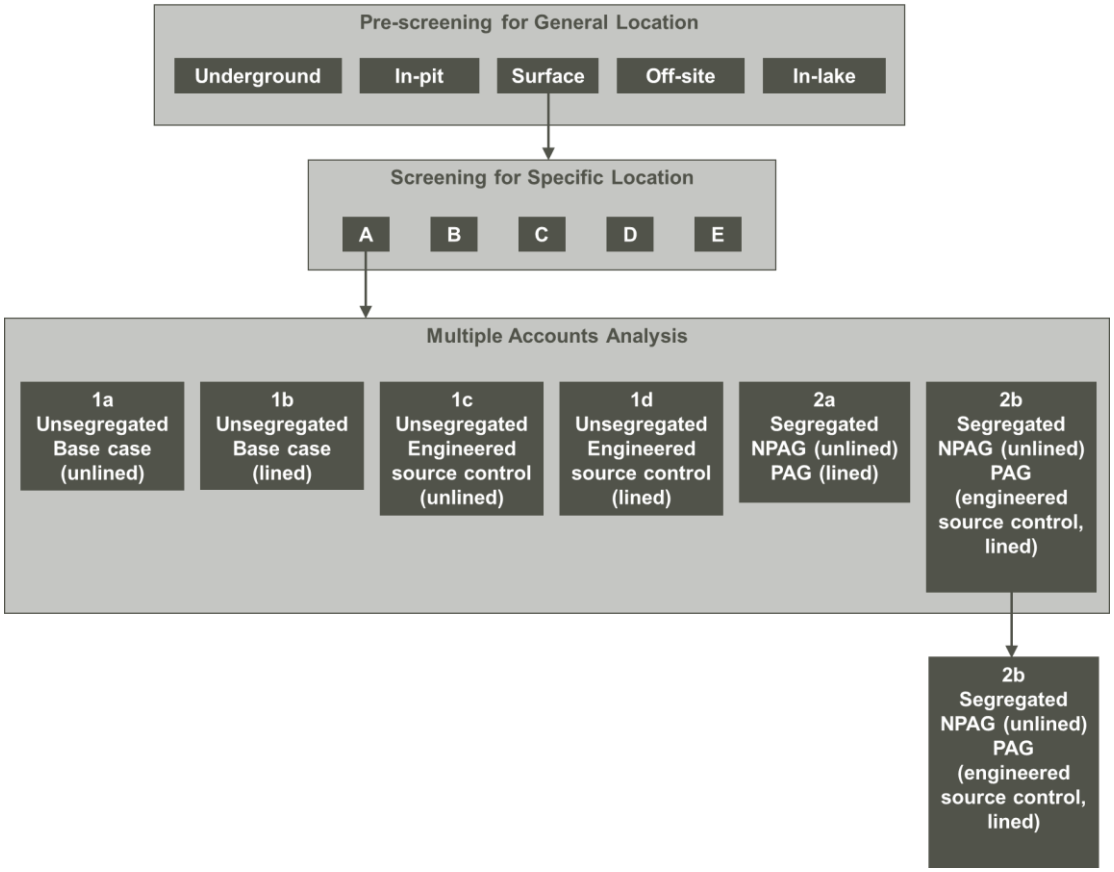
Table 18: Ranking of Gypsum Alternatives by Different Weighting Schemes

Account Weighting Scheme	Gypsum Alternative Rank	
	Underground Tailings Management Facility	Waste Rock Storage Area
ECCC (2016) (Base Case)	1	2
NexGen	2	1
Equal	1	2
ECCC (2016), Economic = 0	1	2

6.0 WASTE ROCK ALTERNATIVES ASSESSMENT

An alternatives assessment was completed to identify the best available location and technology for the storage of waste rock. Methods and outcomes for the waste rock alternatives assessment are summarized in Figure 17 and described in this section.

Figure 17: Waste Rock Alternatives Assessment Methods and Outcomes



NPAG = non-potentially acid generating; PAG = potentially acid generating.

6.1 Pre-screening for General Location for Waste Rock Storage

Pre-screening for the general location for waste rock storage was completed using the method described in Section 3.2. The five general locations were pre-screened and are described for Construction, Operations, and Closure stages in Table 19.

Table 19: General Locations for Waste Rock Considered for Pre-screening

Assessment Lifecycle Stage	General Location				
	Underground	In-Pit	Surface	Off-Site	In-Lake
Construction	▪ Excavation of underground chambers (drill, blast, load) ▪ Incremental removal of excavated rock and place in chambers	▪ Excavation of large pit (drill, blast, load) ▪ Haulage of overburden and rock for placement in pit	▪ Construction of WRSA ▪ Placement of liner (assumed)	▪ Construction of transport and haulage infrastructure ▪ Potential construction of WRSA, including placement of liner, or increase capacity of existing structure	▪ Construction of waste rock haulage system to lake, construct access
Operations	▪ Waste rock deposited in chambers ▪ Incremental excavation of underground chambers (drill, blast) ▪ Incremental removal of excavated rock and placement in chambers	▪ Waste rock placement in pit	▪ Waste rock placement in WRSA	▪ Haulage of waste rock to off-site location ▪ Waste rock placement in off-site WRSA	▪ Waste rock placement in lake
Closure	▪ Progressive decommissioning of filled underground chambers ▪ Decommissioning of final facility and infrastructure (utilities, access)	▪ Decommissioning of facility and infrastructure (utilities, access) ▪ Placement of closure cover system	▪ Decommissioning of facility and infrastructure (utilities, access) ▪ Placement of closure cover system	▪ Decommissioning of facility and infrastructure (transport, haulage, utilities, access) ▪ Placement of closure cover system	▪ Decommissioning of facility and access infrastructure (utilities, access)

Note: Monitoring is assumed to be common and is not listed.

WRSA = waste rock storage area.

The results from pre-screening for general waste rock storage location are presented in Appendix D, Waste Rock Alternatives Assessment, Table D-1 and summarized in this section.

Four general locations were eliminated by pre-screening:

- **Underground:** eliminated due to fatal flaw of volume incompatibility. Excavation of underground chambers would generate more waste rock than can be stored in the same underground chambers; waste rock cannot be stored underground.
- **In-pit:** eliminated due to fatal flaw of volume incompatibility. Excavation of a pit required to store waste rock would generate more excavated overburden and rock than can be stored in the same pit; waste rock from underground mining cannot be stored in a pit without a larger additional waste rock storage facility.
- **Off-site:** eliminated due to increase in overall surface disturbance area outside of the proposed Project surface lease boundary. There are no nearby facilities that could be used for waste rock storage other than Cluff Lake, a closed mine. Transport to, and placement of waste rock at, the closed Cluff Lake facility off site would increase the potential for environmental contamination and liability associated with a closed site that is not owned or managed by NexGen.
- **In-lake:** eliminated based on NexGen's criterion to not place waste in lakes.

One general location for storage of waste rock passed pre-screening:

- Surface.

6.2 Screening for Specific Locations for Waste Rock Storage

Screening for a specific location for waste rock storage was completed using the methods described in Sections 3.3 and 3.5. Five specific locations, all on surface, were considered for the storage of waste rock. Surface locations were selected considering fixed infrastructure defined in Section 2.3.3 and modelled to obtain measurements and quantities used to score indicators for location screening.

6.2.1 Description of Alternatives

Conceptual models were developed for the five specific WRSA surface locations to obtain measurements and quantities used to score indicators. The five specific surface locations are described in Table 20 for Construction, Operations, and Closure stages, with key quantities and measurements.

Conceptual models were developed for the surface waste rock storage alternatives using AutoCAD Civil 3D (Autodesk 2019) to obtain measurements and quantities used to score indicators. Conceptual models for the waste rock alternatives are presented in Figure 18. The concept models were modelled with outer slopes of 4H:1V.

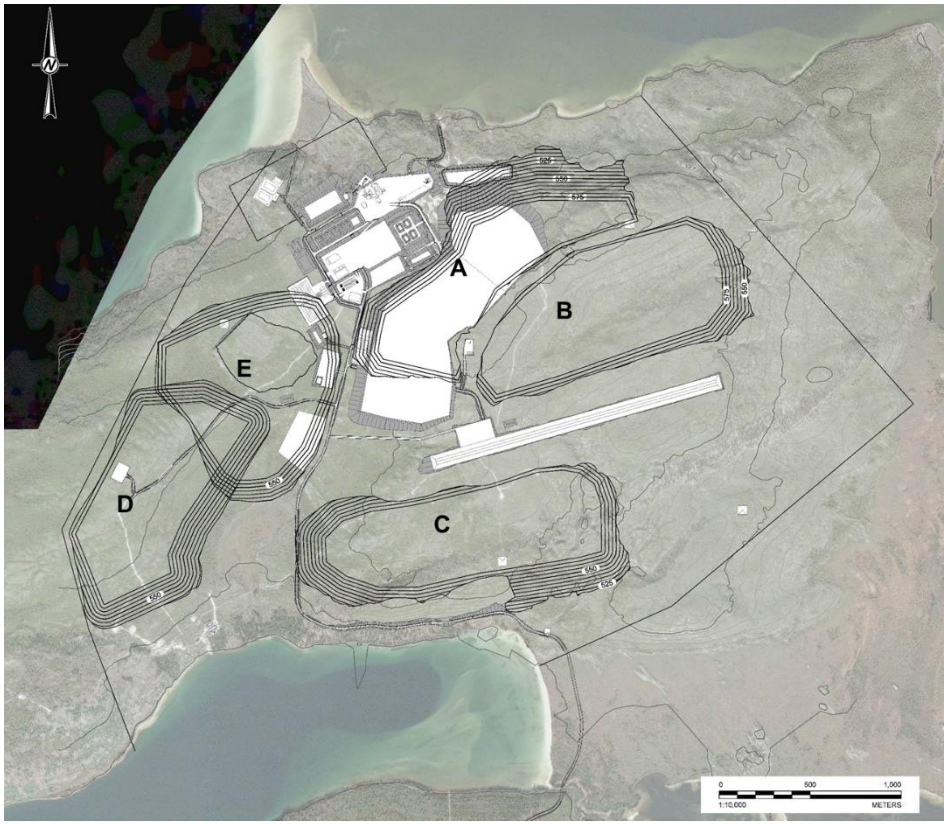
Table 20: Specific Locations for Surface Storage of Waste Rock Evaluated by Multiple Accounts Analysis

Item	Waste Rock Location				
	A	B	C	D	E
Elevation change – measured from mine shaft collar to WRSA crest (m)	49	48	38	37	26
Distance – measured from WRSA toe to Patterson Lake (km)	0.5	0.9	0.5	0.6	0.6
Distance – measured from WRSA centroid to Patterson Lake (km)	1.0	1.2	0.7	1.0	1.0
Distance – measured from WRSA centroid to mine shaft collar (km)	0.9	1.6	2.0	2.2	1.4
Area – measured as 2D footprint area of the WRSA (ha)	87	91	104	91	86
Area – measured as 3D surface area of the WRSA (ha)	88	92	105	92	86
Construction	▪ Foundation preparation for surface WRSA ▪ Placement of liner				
	▪ Southeast and adjacent to the mine and mill terrace	▪ Southeast of the mine and mill terrace, north and adjacent to the airstrip	▪ South of the airstrip	▪ Southwest of the mine and mill terrace	▪ Southwest and adjacent to the mine and mill terrace
Operations	▪ Haulage of waste rock from mine terrace to WRSA				
Closure	▪ Decommissioning of facility and infrastructure (utilities, access) ▪ Placement of closure cover system				

Note: Monitoring is assumed to be common and is not listed.

WRSA = waste rock storage area.

Figure 18: Conceptual Plan of the Specific Locations for Surface Storage of Waste Rock Considered for Screening



6.2.2 Results

A list of indicators, sub-accounts, and weightings used to screen specific waste rock locations is presented in Appendix D, Table D-2.

The results of screening for specific location for waste rock storage by MAA method are presented in Appendix D, Tables D-3 and D-4 and are summarized in this section. Specific locations were ranked based on the highest assessment score using ECCC (2016) account weighting:

1) **Surface location A** – highest scores in the environmental and social accounts:

- **Environmental Account:** highest score due to greater potential for surface and groundwater contact water management. Also had the shortest distance from the mine terrace with the least potential for dust emissions from construction, access, and waste rock haulage.
- **Technical Account:** high score, with highest score for reduced operational risk and complexity due to shorter haul associated with least potential for operational maintenance, though had a shorter distance from Patterson Lake; longer distance is preferred to allow for water management.
- **Economic Account:** high score due to shorter haul and less water use for dust suppression.

- **Social Account:** highest score due to the shortest distance from mine terrace to WRSA (i.e., least worker exposure due to shortest haulage distance and haul duration).

2) **Surface location B** – highest score in the technical account:

- **Environmental Account:** high score due to greatest distance from Patterson Lake, though is close to the proposed Project surface lease boundary, resulting in less area available for contact water management.
- **Technical Account:** highest score due to greatest distance from Patterson Lake, which allows greater area for management of contact water.
- **Economic Account:** intermediate score due to intermediate haul distance and associated cost for transport and operational maintenance, second highest elevation gain from shaft, which increases energy cost, and intermediate surface area with intermediate closure cost score resulting from quantity of cover material required at closure.
- **Social Account:** intermediate score due to intermediate haul distance, greater risk to worker safety and human health resulting from longer transport distance from the shaft to the WRSA.

3) **Surface location E** – highest score in the economic account:

- **Environmental Account:** intermediate score due to shortest setback distance from proposed Project surface lease boundary, infrastructure, wetland, and Patterson Lake, resulting in less available area for contact water management. Also had lowest surface area.
- **Technical Account:** intermediate score due to potential for operation and maintenance resulting from intermediate transport distance from the shaft to WRSA, and intermediate setback distance from Patterson Lake, which is required for management of contact water.
- **Economic Account:** highest score due to least vertical elevation change from shaft to WRSA crest (i.e., least energy use during transport, equipment maintenance) though had an intermediate cost score due to haul distance.
- **Social Account:** intermediate score due to risk to worker safety and human health associated with intermediate transport distance from the shaft to the WRSA.

4) **Surface location D** – lowest score in the social account:

- **Environmental Account:** low score due to intermediate surface area, longest haul and associated highest potential for excessive emissions of fugitive dust and other non-greenhouse gas emissions, and least setback available for surface and groundwater contact water management.
- **Technical Account:** low score due to longest haul distance and associated potential for operational maintenance, and intermediate distance to Patterson Lake for water management.
- **Economic Account:** low score due to higher operating cost resulting from longer transport distance between the shaft and WRSA, and higher closure cost resulting from greater quantity of cover material required at closure.

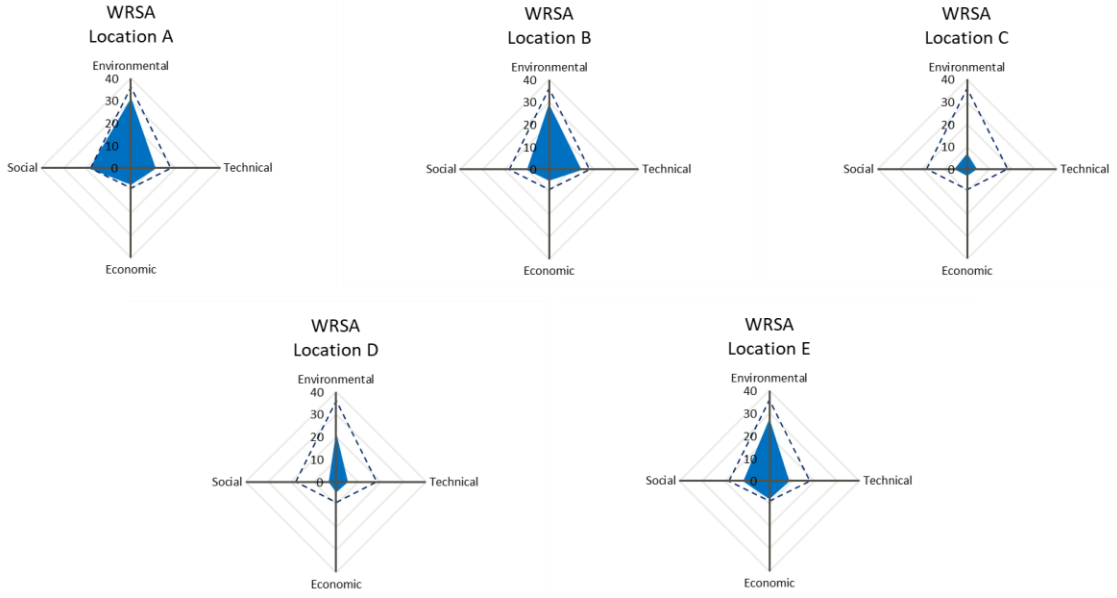
- **Social Account:** lowest score due to greatest distance from mine shaft to WRSA (i.e., longest haul distance results in greatest potential for worker exposure).

5) **Surface location C** – lowest score in the environmental, technical, and economic accounts:

- **Environmental Account:** lowest score due to proximity to Patterson Lake and the airstrip, a steep gradient toward the lake that would limit ability to manage water, and greatest surface area.
- **Technical Account:** lowest score due to short distance and steep gradient to Patterson Lake that would limit ability to effectively manage water.
- **Economic Account:** lowest score due to long haul, greatest WRSA area for closure cover placement. Longer haul results in higher cost for dust suppression water use, and waste rock transport and placement.
- **Social Account:** low due score to long haul and associated risk to worker safety and human health.

Radar charts for the waste rock storage location screening by MAA method are presented in Figure 19 to illustrate the distribution of scoring within the environmental, technical, economic, and social accounts. The maximum score an alternative can achieve in each account is represented by the dashed line. Location A passed screening for specific location was carried forward to the MAA.

Figure 19: Radar Charts for the Waste Rock Storage Location Screening Results



WRSA = waste rock storage area.

6.3 Multiple Accounts Analysis

An MAA for waste rock storage alternatives was completed using the method described in Section 3.5. A description of alternatives, the results of the MAA, and the sensitivity analysis are summarized in this section.

6.3.1 Description of Alternatives

Six alternatives, each including the selected screening location and a technology, were evaluated for Construction, Operations, and Closure stages. These alternatives, along with key quantities and measurements used in the analysis, are summarized in Table 21.

Simplified water balances were developed to estimate the rate of infiltration, and one-dimensional infiltration model scenarios were developed to predict inflows and outflows on an annual basis (Okane 2020; BGC 2020). Geochemical source terms were developed by SRK Consulting (Canada) Inc. for each waste rock alternative as a mass flux. A simplified groundwater mixing model was then used to predict average and peak concentrations of constituents in seepage reaching Patterson Lake for operational and closure periods. Alternatives were evaluated for the Operations and Closure stages based on potential seepage water quality predictions. Indicators included predicted concentrations of the constituents that exceeded Canadian Council of Ministers of the Environment (CCME) guidelines as shown in Table 21.

Table 21: Waste Rock Alternatives Evaluated by Multiple Accounts Analysis

Item	Waste Rock Alternative					
	1a Unsegregated Base Case Unlined	1b Unsegregated Base Case Lined	1c Unsegregated Engineered Source Control Unlined	1d Unsegregated Engineered Source Control Lined	2a Segregated NPAG (Unlined) PAG (Lined)	2b Segregated NPAG (Unlined) PAG (Engineered Source Control, Lined)
Liner area – measured as 2D area of the WRSA to be lined, ha	0	87	0	87	37	37
Mass – borrow for engineered layers, t	0.0	0.0	2.5	2.5	0	1.1
Concentration – copper allowable (Operations), µg/L	2.0					
Concentration – copper exceedance (Operations), µg/L	4.0	0.0	4.0	0.0	0.0	0.0
Concentration – cobalt allowable (Closure), µg/L	1.0					
Concentration – cobalt exceedance (Closure), µg/L	3.8	3.8	0.0	0.0	3.8	0.0
Construction	▪ Surface WRSA with water control measures, access and haul roads					
	▪ One facility	▪ One facility ▪ Placement of liner for whole facility	▪ One facility	▪ One facility ▪ Placement of liner for whole facility	▪ Two facilities ▪ Placement of liner for one facility	▪ Two facilities ▪ Placement of liner for one facility

Table 21: Waste Rock Alternatives Evaluated by Multiple Accounts Analysis

Item	Waste Rock Alternative					
	1a Unsegregated Base Case Unlined	1b Unsegregated Base Case Lined	1c Unsegregated Engineered Source Control Unlined	1d Unsegregated Engineered Source Control Lined	2a Segregated NPAG (Unlined) PAG (Lined)	2b Segregated NPAG (Unlined) PAG (Engineered Source Control, Lined)
Operations	▪ Haulage of waste rock from mine shaft to WRSA					
	▪ End-dumping waste rock	▪ End-dumping waste rock	▪ Placement of waste rock in layers ▪ Excavation and placement of engineered source control in layers	▪ Placement of waste rock in layers ▪ Excavation and placement of engineered source control in layers	▪ End-dumping waste rock	▪ End-dumping NPAG waste rock ▪ Placement of PAG waste rock in layers ▪ Excavation and placement of engineered source control in layers
Closure	▪ Decommissioning of facility and infrastructure (utilities, access)					
	▪ Placement of cover system	▪ Placement of cover system	▪ Placement of cover system ▪ Closure of borrow source	▪ Placement of cover system ▪ Closure of borrow source	▪ Placement of cover system	▪ Placement of cover system ▪ Closure of borrow source

Note: Monitoring is assumed to be common and is not listed.

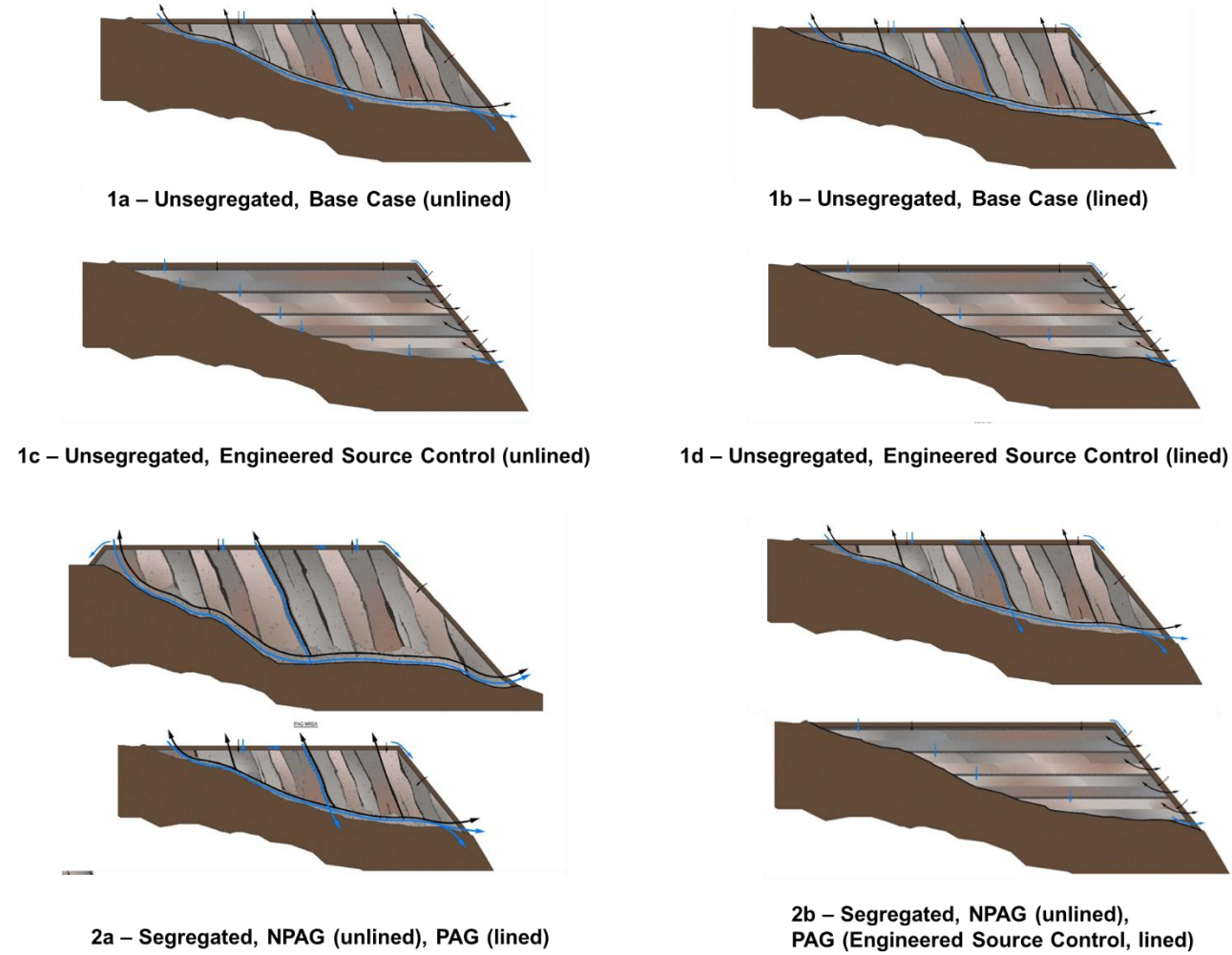
PAG = potentially acid generating; NPAG = non-potentially acid generating; WRSA = waste rock storage area.

Additional assumptions used to develop the conceptual models were:

- In unsegregated facilities, NPAG and PAG waste rock are not separated and are placed together in a single facility.
- In segregated facilities, NPAG and PAG waste rock are separated and placed in two separate facilities.
- The concept of engineered source control is where a 0.5 m lift of fine-grained material is placed between 5 m lifts of waste rock (Okane 2020). In concept, the fine-grained layer acts to control flow of water and oxygen, which provides a control on chemistry.

Section illustrations from the conceptual model for WRSA alternatives were provided by NexGen (2020e) and are presented in Figure 20.

Figure 20: Conceptual Plan Illustrations of the Waste Rock Technologies



Source: NexGen 2020e.

6.3.2 Results

A list of indicators, sub-accounts, and weights for the waste rock alternatives assessment MAA is included in Appendix D, Table D-5.

The MAA is presented in Appendix D, Table D-6 and summarized in this section. Results of ranking by assessment score using ECCC (2016) account weighting are:

1) **Alternative 2b:** Segregated, NPAG (unlined) and PAG (engineered source control, lined) – highest score in the environmental account (tied with Alternative 1d), lowest score in the technical account:

   - **Environmental Account:** highest score, tied with Alternative 1d, due to no predicted exceedance of CCME constituent concentrations in seepage during Operations or Closure. For the PAG pile, placement of materials in layers reduces dust generation relative to end-dump waste rock placement.
   - **Technical Account**: lowest score due to the complexity and design effort, number of water management systems required, higher operational complexity due to number of activities, effort required for expansion, optimization or design changes, and number of facilities to close. Would require more maintenance and water management controls for separate facilities. Complies with SERM (2000) draft guideline to place PAG waste on a liner.
   - **Economic Account:** intermediate score, with intermediate capital, operating, and closure cost scores due to requirement of intermediate amounts of liner, engineered layers, and treatment of water captured on liner from PAG facility.
   - **Social Account:** intermediate score due to potential intermediate increase in employment opportunities with two facilities to construct, operate, and close. Intermediate score based on quantity of local materials used. Intermediate score for health risk to people downstream due to intermediate level of engineering controls for water management. Intermediate score for risk to workers due to intermediate levels of noise, dust, and equipment exposure.

2) **Alternative 1d:** Unsegregated, Engineered Source Control (lined) – highest scores in the environmental (tied with Alternative 2b) and social accounts, lowest score in the economic account:

   - **Environmental Account:** highest score, tied with Alternative 2b, due to no predicted exceedance of CCME constituent concentrations in seepage during Operations or Closure. Construction of the entire pile in layers would reduce dust generation relative to end-dumped waste rock placement.
   - **Technical Account:** intermediate score due to additional mass required for engineered layers, highest lined area, and effort required to expand a lined facility. Complies with SERM (2000) draft guideline to place PAG waste on a liner.
   - **Economic Account:** lowest score due liner and finer layers, as well as requirement to treat water captured on the liner during Operations.
   - **Social Account:** highest score due to least noise, dust and equipment exposure, and largest change in local employment opportunities resulting from specialized labour requirements for liner installation and placement of finer layers.

3) **Alternative 1c:** Unsegregated, Engineered Source Control (unlined) – intermediate scores in all accounts:

- **Environmental Account:** intermediate score with predicted copper concentration exceedance from CCME guidelines during Operations (no liner) and greater surface area of impact resulting from the quantity of borrow material required for engineered source control layers.
- **Technical Account:** intermediate score. Does not comply with SERM (2000) draft guideline to place PAG waste on a liner.
- **Economic Account:** intermediate score as no liner is required, only one facility to close, and lower cost score for water treatment post-closure due to use of engineered source control.
- **Social Account:** intermediate score due to potential health risk to people downstream (no liner) and high local resource consumption for fine-grained layers.

4) **Alternative 1b:** Unsegregated, Base Case (lined) – scored highest in the technical account:

- **Environmental Account:** low score due to predicted exceedance of CCME limits for cobalt concentration during Closure.
- **Technical Account:** highest score due to ease of design and construction of single (unsegregated) lined facility. Complies with SERM (2000) draft guidelines for liner below PAG waste rock.
- **Economic Account:** low score due to requirement for liner and for treatment of water captured on liner during Operations and Closure – no engineered layers.
- **Social Account:** intermediate score due to lack of use of local resources for engineered layers (none), and due to worker safety due to potential exposure to noise, dust, and equipment.

5) **Alternative 2a:** Segregated, NPAG (unlined), PAG (lined) – intermediate scores in all accounts:

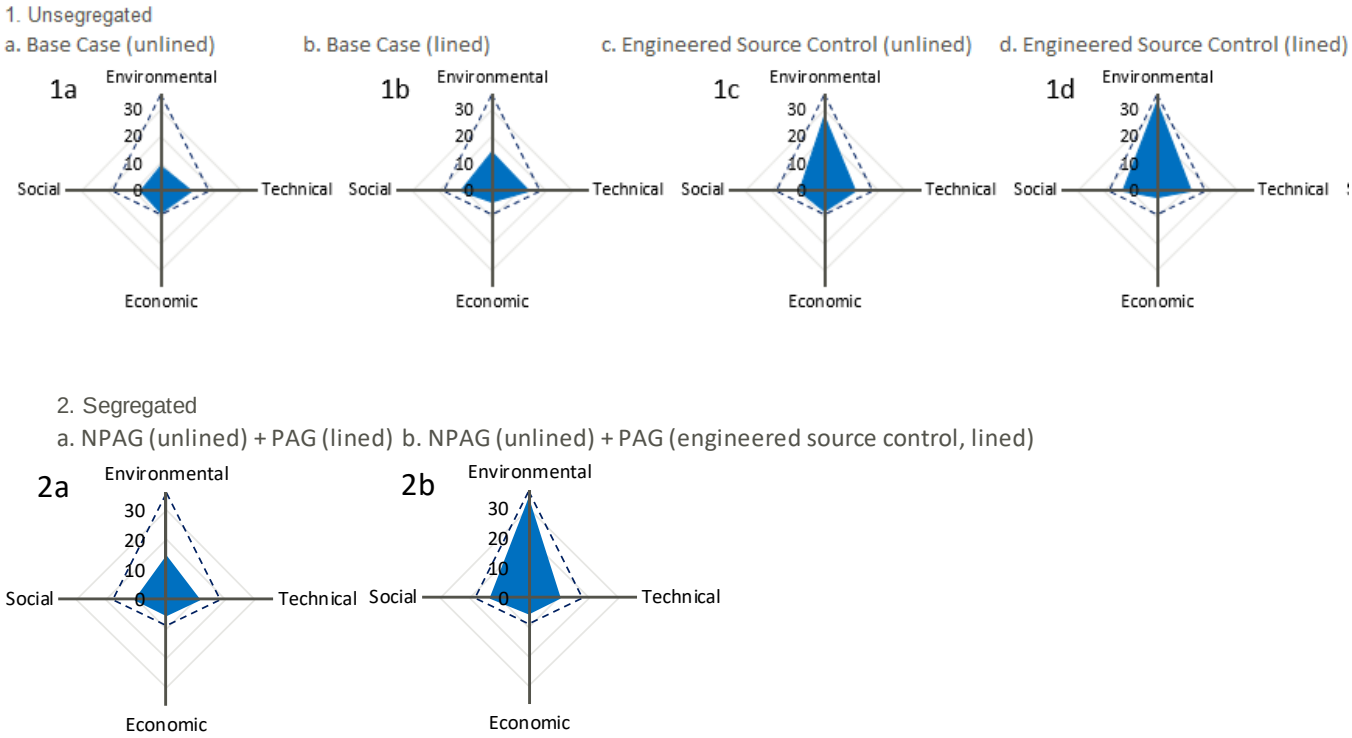
- **Environmental Account:** intermediate score with predicted exceedance of CCME limits for cobalt concentration during Closure – no engineered layers.
- **Technical Account:** intermediate score due to the complexity and design effort, number of water management systems required, higher operational complexity due to number of activities, effort required for expansion, optimization or design changes, and number of facilities to close. Requires more maintenance and water management controls for separate facilities. Complies with SERM (2000) draft guideline to place PAG waste on a liner.
- **Economic Account:** intermediate score due to lined area for PAG facility and requirement to close two separate facilities.
- **Social Account:** intermediate score due to greater risk to worker safety and human health by exposure to noise, dust, and equipment with the construction of two separate facilities.

6) **Alternative 1a:** Unsegregated, Base Case (unlined) – highest score in the economic account, lowest score in the environmental and social accounts:

- **Environmental Account:** lowest score due to predicted exceedance of CCME limits for copper concentration during Operations and cobalt during Closure – no liner and no engineered layers.
- **Technical Account:** intermediate score, though does not comply with SERM (2000) draft guideline to place PAG waste rock on a liner.
- **Economic Account:** highest score, with the simplest design and least construction effort – no liner, no engineered layers.
- **Social Account:** lowest score due to least change in employment opportunities resulting from least specialized labour requirement for liner and engineered layer placement, greater risk to worker safety and human health by exposure to noise, dust, and equipment, highest health risk to people downstream due to lack of engineering controls for water management.

Radar charts for the waste rock MAA are included as Figure 21 to illustrate the distribution of scoring within the environmental, technical, economic, and social accounts for each alternative. The maximum score an alternative can achieve in each account is represented by the dashed line. Placement of waste rock on the surface at location A in segregated NPAG (unlined) and PAG (engineered source control, lined) WRSA facilities scored highest based on results of the MAA.

Figure 21: Radar Charts for the Waste Rock Multiple Accounts Analysis Results



NPAG = non-potentially acid generating; PAG = potentially acid generating.

6.3.3 Sensitivity Analysis

A sensitivity analysis was completed using the method described in Section 3.5 to evaluate the effect of bias introduced by weighting, with results presented in Appendix D, Table D-7 and summarized in Table 22. The results of sensitivity analysis indicate that account weighting (introduction of bias) does change the study outcome.

Table 22: Ranking of Waste Rock Alternatives by Different Weighting Schemes

Account Weighting Scheme	Waste Rock Alternative Rank					
	1a	1b	1c	1d	2a	2b
ECCC (2016) (Base Case)	6	4	3	2	5	1
NexGen	6	4	2	3	5	1
Equal	5	4	2	3	6	1
ECCC (2016), Economic = 0	6	4	3	1	5	2

The first ranked alternative was Alternative 2b (segregated, NPAG [unlined] and PAG [lined with engineered source control]) considering account weighting from ECCC (2016), NexGen, and equal weighting. Under ECCC weighting with the economic account weight set to zero, the highest ranked alternative was Alternative 1d (unsegregated, engineered source control, and lined).

The second ranked alternative was Alternative 1d under ECCC weighting, Alternative 1c under NexGen and equal weighting, and Alternative 2b under ECCC weighting with economic weight set to zero.

The third ranked alternative was Alternative 1c under ECCC weighting and ECCC weighting with economic weight set to zero, and Alternative 1d under NexGen and equal weighting.

The fourth ranked alternative was Alternative 1b under all weighting schemes.

The fifth ranked alternative was Alternative 2a under ECCC weighting, NexGen weighting, and ECCC weighting with economic weight set to zero, and Alternative 1a for equal weighting.

The sixth ranked alternative was Alternative 1a under ECCC weighting, NexGen weighting, and ECCC weighting with economic weight set to zero, and Alternative 2a for equal weighting.

7.0 SUMMARY AND DISCUSSION

This section presents a summary of the mine waste alternatives assessment outcomes, followed by discussion of the influence of study approach, weighting, scoring, and indicator selection, and comparison of study outcomes to practice for mine waste management for uranium mines in Saskatchewan at the time of this study.

Tailings

The tailings alternatives assessment included pre-screening for five general locations followed by screening for ten specific locations, screening for four technologies at four locations (sixteen combinations), and an evaluation of four alternatives (location and technology) by multiple accounts analysis (MAA).

The placement of tailings as cemented paste backfill (CPT) in an underground tailings management facility (UGTMF) was the highest scoring alternative for tailings management. The underground location is outside of known geologic structures and mineralized deposits. The technology has precedent for the controlled deposition of CPT, and placement of the tailings underground complies with the Canadian Nuclear Safety Commission (CNSC 2018) and Global Tailings Review (GTR 2020).

Gypsum

The gypsum alternatives assessment included pre-screening for five general locations, followed by screening for four specific locations, and an evaluation of two alternatives (location and technology) by MAA.

The placement of gypsum with tailings in an UGTMF was the highest scoring alternative. There is a potential for gypsum to reduce requirement for cement in the CPT.

Waste Rock

The waste rock alternatives assessment included pre-screening for five general locations followed by screening for five specific locations by MAA, and an evaluation of six alternatives (location and technology) by MAA.

The highest scoring alternative was the segregation of NPAG and PAG waste rock into two facilities, with NPAG waste rock stored in an unlined facility and PAG waste rock stored in a lined facility with additional engineered source control, where waste rock is alternated with low-permeability, fine-grained layers to control water quality.

The location of the WRSA near the mine shaft reduces haul distance and associated dust, cost, and risk to workers. Segregating the NPAG and PAG rock types allows reduction of the liner area and complies with the Saskatchewan Environment and Resource Management (SERM 2000) draft guideline to use of a HDPE liner for PAG stockpiles.

The method used in the waste rock alternatives assessment included description of alternatives by preliminary prediction of water balance and chemistry of seepage that may report to Patterson Lake to allow quantitative evaluation of differences. Prediction of water balance and chemistry is not typically completed for mine waste alternatives assessments; most alternatives assessments describe options at a conceptual level only.

Influence of Study Approach

The study is intended to be comprehensive, to demonstrate that all practical mine waste storage alternatives have been considered and evaluated. Locations were evaluated first because the masses of tailings, gypsum, and waste rock that will be generated by the Rook I Project (Project) must be stored somewhere. The study pre-screened general locations first, then screened by specific locations and technologies, and finally evaluated the resulting alternatives by MAA.

Generally, the results of location pre-screening indicated that storing mine waste within the proposed Project surface lease boundary will limit the area of Project impact. Storing wastes off site would increase the area of Project impact. In-lake storage is fatally flawed due to NexGen’s criterion that no waste should be placed in lakes, which was supported by feedback received during Indigenous and local public engagement.

The evaluation of location first, then technology, is a choice and could be approached differently; however, re-ordering the study such that technologies are considered first or in parallel to location is not expected to change the outcome.

Three alternatives assessments were completed in the order of priority, where tailings location was selected first, followed by gypsum, and lastly by waste rock. Alternatives that represent a combination of the three types of mine waste at multiple locations, such as co-disposal of waste rock and tailings and storage of gypsum with waste rock or tailings, were also considered. Re-ordering of the study, such that waste rock or gypsum are considered first or in parallel to tailings, is not expected to change the outcome.

Influence of Weighting, Scoring, and Indicator Selection

The MAA methodology included weighting to purposefully introduce bias based on perceived importance to Indigenous communities, the local public, and other stakeholders. Indicator-level weighting changes the influence of indicators relative to other indicators in the same sub-account but does not change the influence of the account or sub-account on the overall score. Similarly, sub-account weighting changes the influence of sub-accounts relative to the other sub-accounts in the same account but does not change the influence of the account on the overall score. The account weights have the largest effect on the study outcome and were varied in sensitivity analyses to evaluate the effect of weighting induced bias. The study has used a consistent approach to weighting (bias) for each mine waste assessment, with similar influence of indicators, sub-accounts, and accounts.

Indicators were selected that were perceived to be both important to Indigenous communities, the local public, and other stakeholders, and that differentiate the alternatives. Where possible, indicators were selected that were quantifiable, or measurable, rather than qualitative, requiring interpretation. Where indicators are qualitative, the scoring scale is provided. For both quantitative and qualitative indicators, the alternatives were scored on a scale of 1 to 6, with the end values of 1 and 6 always assigned. The effect of always assigning the end values of 1 and 6 is to increase or magnify the differentiation between alternatives. In some cases (e.g., social account for gypsum alternatives assessment), the relative difference between alternatives is not high, and the scoring scheme increases the apparent difference. The effect was recognized, and was mitigated by indicator, sub-account, and account weighting.

Comparison of Study Outcomes to Current Practices

The industry standard practices for management of uranium mine waste in Saskatchewan at the time this study are compared to the study outcomes in this section.

Uranium tailings management practices in Saskatchewan have changed with time, evolving from surface storage to subaqueous storage in pits, with corresponding reduction in geotechnical and geochemical risk. The highest scoring alternative in the study was storage of tailings in a purpose-built underground facility, with reduced potential to impact the environment and people compared to the recent industry practice of subaqueous storage in pits.

The standard practice for management of gypsum at uranium mines in Saskatchewan was to store the gypsum with the tailings stream. Gypsum alternatives were not typically evaluated separately from tailings. This study evaluated alternatives for storage of gypsum for the Rook I Project including with the tailings, with waste rock, and in purpose-built surface and underground facilities. The highest scoring alternative for storage of gypsum was with the tailings, which was consistent with industry standard or practice. However, the highest alternative also considered storing gypsum underground, which was not typical.

The standard practice for management of waste rock at uranium mines in Saskatchewan was to store PAG and NPAG types separately, with PAG waste on a liner. The highest scoring alternative follows the same method, and also introduces layers of fine-grained material as an additional control on seepage water quality. The alternative with additional controls scored higher than a facility constructed following industry standard practice.

8.0 DOCUMENT CLOSURE

The reader is referred to the Study Limitations section, which precedes the text and forms an integral part of this report.

We trust that this report meets your present requirements. If you have any questions, please do not hesitate to contact the undersigned.

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APPENDIX A

Account Ledger

Table A-1: Composite Account Ledger for the Mine Waste Alternatives Assessment

Account	Sub-account	Sub-account Weighting			Indicator	Indicators						
		Tailings	Gypsum	Waste Rock		Tailings			Gypsum		Waste Rock	
		Multiple Accounts Analysis	Multiple Accounts Analysis	Multiple Accounts Analysis		Screening for Specific Location	Screening for Technology	Multiple Accounts Analysis	Screening for Specific Location	Multiple Accounts Analysis	Screening for Specific Location	Multiple Accounts Analysis
Environmental	Ecological Integrity	6	6	6	Surface area of impact.	x	x	x	x		x	
					Surface area of impact, borrow for engineered layers.							x
					Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	x	x	x			x	
					Potential for impact to Patterson Lake during operation.					x		x
					Potential for impact to Patterson Lake during closure.							x
	Hydrologic Regime	1	1	1	Surface water - potential for contact water management.	x	x	x		x	x	
					Surface water - potential for non-contact water management.			x				
					Surface water - potential for impact.				x			
					Groundwater - potential for contact water management.		x				x	
					Groundwater - potential for impact.			x	x			
	Air Quality	1	1	1	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	x	x	x	x	x	x	x
Technical	Design and Reliability	6	3	6	Facility design effort.		x	x	x	x		x
					Proven precedent for technology and configuration.		x		x	x		x
					Compliance with SERM (2000) draft guidelines.							x
					Difference in mass (engineered layers)							x
					Available storage capacity.	x						
	Construction Risk and Complexity	2	1	2	Liner area.							x
					Water management infrastructure (number of systems to be constructed).							x
					Geotechnical stability considering major geologic structures.	x						
					Geotechnical stability considering foundation conditions and waste placement			x	x	x		
	Operational Risk and Complexity	3		3	Operation and maintenance for transport and disposal system.	x	x	x	x		x	x
					Water balance and management during seasonal changes.	x	x	x			x	x
					Potential for progressive facility closure during operation.		x	x	x			x
					Potential for radon mitigation.			x				
					GTR (2020) 3.2 ii requirement of new TSFs to minimise the volume of tailings and water placed in external tailings facilities.		x	x				
	Closure Risk and Complexity	1		1	Ease of decommissioning. Number of facilities.							x
					Ease of decommissioning.		x	x	x			
					Resistance to extreme events (flood and earthquake) and climate change.			x				
	Flexibility	2	1	2	Effort required for expansion, optimization, and design changes.	x		x		x		x
Economic	Capital Cost	4	2	4	Liner procurement and installation.							x
					Facility construction and centralization.	x	x	x	x	x		
					Water treatment plant for surface runoff.			x				
					Paste plant.		x	x				
	Operating Cost	2	1	2	Transport and placement.						x	
					Energy use for transport – diesel (haul).						x	
					Transport and placement of gypsum, including energy, diesel, labor.				x	x		
					Transport and placement of tailings, including energy, diesel, labor.	x	x	x				
					Water use.						x	
					Water treatment.			x				
					Water treatment (capture by lined alternatives).							x
					Engineered layers.							x
					Requirement for tailings binder, flocculant, or other additives.		x	x	x	x		
					Paste plant.		x					
					Excavating and hauling additional waste rock.		x		x			
	Closure Cost	1		1	Facility closure.	x		x	x		x	x
					Water treatment.		x	x				x
Social	Community Impact	1		1	Change in local employment opportunities.		x	x				x
					Visual disturbance for an observer.	x		x	x			
	Change in Land Use	1		1	Local resource consumption as borrow source(s) for construction.	x			x			x
					Potential for loss of access and current land use.			x				
	Population at Risk	1	1	1	Worker safety and human health during construction, operation, and closure.	x	x	x	x	x	x	x
					Health risk to people downstream.							x
					Physical risk to people downstream		x	x				

APPENDIX B

Tailings Alternatives Assessment

Table B-1: Tailings Alternatives Assessment, Pre-screening for General Location

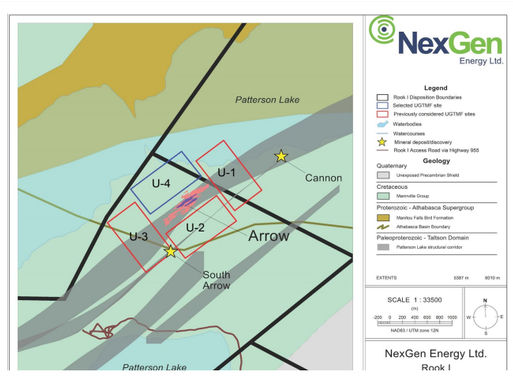
Pre-screening Criteria	General Locations				
	Underground	In-Pit	Surface	Off-Site	In-Lake
Has required storage capacity	Yes	Yes	Yes	Yes	Yes
No waste in lake (NexGen)	Aligned	Aligned	Aligned	Aligned	Fatally flawed
Area of impact.	Minimal surface disturbance area	Additional surface disturbance area	Additional surface disturbance area	Increase overall surface disturbance area outside proposed Project surface lease boundary	Minimal surface disturbance area
Quantity of waste rock generated	Increase in rock quantity from tailings chambers + access	Greatest increase in rock + overburden quantities	No change	No change	No change
Result	**Pass**	**Pass**	**Pass**	**Eliminated**	**Eliminated**

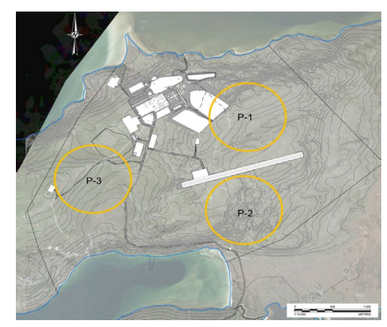
Note: red text indicates a relative disadvantage

Table B-2: Tailings Alternatives Assessment, Screening for Specific Location

Account	Sub-account	Indicator	Underground Location U-1 vs. U-2 vs. U-3 vs. U-4				In Pit Location P-1 vs. P-2 vs. P-3			Surface Location S-1 vs. S-2 vs. S-3		
			U-1	U-2	U-3	U-4	P-1	P-2	P-3	S-1	S-2	S-3
Environmental	Ecological Integrity	Surface area of impact.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Least area of impact for haulage and infrastructure, shortest transport.	Greatest area of impact for haulage and infrastructure, longest transport.	Some area of impact for haulage and infrastructure, moderate transport.	Least area of impact for haulage and infrastructure, shortest transport.	Greatest area of impact for haulage and infrastructure, longest transport.	Some area of impact for haulage and infrastructure, moderate transport.
		Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Some potential due to distance from Patterson Lake.	Greatest potential due to proximity to Patterson Lake.	Some potential due to distance from Patterson Lake.	Low potential due to distance from Patterson Lake.	Greater potential due to distance to Patterson Lake.	Low potential due to distance from Patterson Lake.
	Hydrologic Regime	Surface water - potential for contact water management.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Some potential due to distance to proposed Project surface lease boundary and infrastructure constraint for runoff management.	Greatest potential due to proximity to Patterson Lake and steep topography.	Some potential due to distance to proposed Project surface lease boundary and infrastructure constraint for runoff management.	Some potential due to distance to proposed Project surface lease boundary and infrastructure constraint for runoff management.	Greatest potential due to proximity to Patterson Lake and steep topography.	Some potential due to distance to proposed Project surface lease boundary and infrastructure constraint for runoff management.
	Air Quality	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Least potential to impact air quality due to shortest transport distance.	Greatest potential to impact air quality due to longest transport distance.	Some potential to impact air quality due to transport distance.	Least potential to impact air quality due to shortest transport distance.	Greatest potential to impact air quality due to longest transport distance.	Some potential to impact air quality due to transport distance.
Account	**Sub-account**	**Indicator**	**Underground** U-1 vs. U-2				**In Pit** P-1 vs. P-2 vs. P-3			**Surface** S-1 vs. S-2 vs. S-3		
			U-1	U-2	U-3	U-4	P-1	P-2	P-3	S-1	S-2	S-3
Technical	Design and Reliability	Available storage capacity.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Topographic valley restricts storage capacity expansion.	Topographic plateau with small drainages may restrict storage capacity expansion.	Topographic flat area does not restrict storage capacity expansion.	Topographic valley area offers greatest storage capacity advantage.	Topographic plateau with small drainages reduces storage capacity.	Topographic low and flat area with some advantage to storage capacity.
	Construction Risk and Complexity	Geotechnical stability considering major geologic structures.	Located within Patterson Lake structural corridor and along the Athabasca Basin Boundary.	Located along the Athabasca Basin Boundary.	Located within Patterson Lake structural corridor.	No known major geologic structures.	No known major geologic structures.	Located within Patterson Lake structural corridor.	Located within Patterson Lake structural corridor and along the Athabasca Basin Boundary.	No known major geologic structures.	Located within Patterson Lake structural corridor.	Located within Patterson Lake structural corridor and along the Athabasca Basin Boundary.
	Operational Risk and Complexity	Operation and maintenance for transport and disposal system.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Shortest transport distance to operate and maintain.	Longest transport distance to operate and maintain.	Medium transport distance to operate and maintain.	Shortest transport distance to operate and maintain.	Longest transport distance to operate and maintain.	Medium transport distance to operate and maintain.
		Water balance and management during seasonal changes.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Requires management of runoff from surrounding area.	No additional facility runoff management required.	Requires management of runoff from surrounding area.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.
	Flexibility	Effort required for expansion, optimization, and design changes.	Located between Arrow and Cannon deposit/discovery, potential impact to future expansion.	Located adjacent to South Arrow deposit/discovery, potential impact to future expansion.	Located adjacent to South Arrow deposit/discovery, potential impact to future expansion.	No impact to future expansion.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Greatest effort due to constraints of proposed Project surface lease boundary (east), airstrip (south), mine (west).	Some effort due to constraints of airstrip (north), Lake Patterson (south), proposed Project surface lease boundary (east).	Some effort due to constraints of mine (north) and access (east).
Account	**Sub-account**	**Indicator**	**Underground** U-1 vs. U-2				**In Pit** P-1 vs. P-2 vs. P-3			**Surface** S-1 vs. S-2 vs. S-3		
			U-1	U-2	U-3	U-4	P-1	P-2	P-3	S-1	S-2	S-3
Economic	Capital Cost	Facility construction and centralization.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Lowest cost due to centralized infrastructure (e.g., haulage, access, utility corridor).	Highest cost due to least centralized infrastructure (e.g., haulage, access, utility corridor).	Intermediate cost due to some centralized infrastructure (e.g., haulage, access, utility corridor).	Lowest cost due to centralized infrastructure (e.g., haulage, access, utility corridor).	Highest cost due to least centralized infrastructure (e.g., haulage, access, utility corridor).	Intermediate cost due to some centralized infrastructure (e.g., haulage, access, utility corridor).
	Operating Cost	Transport and placement of tailings, including energy, diesel, labor.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Lowest cost due to shortest transport distance with increase in elevation.	Highest cost due to longest transport distance.	Intermediate cost due to transport distance with limited elevation change.	Lowest cost due to shortest transport distance with increase in elevation.	Highest cost due to longest transport distance.	Intermediate cost due to transport distance with limited elevation change.
	Closure Cost	Facility closure.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Lowest cost due to most compact footprint area (e.g., haulage, access, utility corridor).	Highest cost due to least compact footprint area for infrastructure (e.g., haulage, access, utility corridor).	Intermediate cost due to footprint area (e.g., haulage, access, utility corridor).	Lowest cost due to most compact footprint area (e.g., haulage, access, utility corridor).	Highest cost due to least compact footprint area for infrastructure (e.g., haulage, access, utility corridor).	Intermediate cost due to footprint area (e.g., haulage, access, utility corridor).
Account	**Sub-account**	**Indicator**	**Underground** U-1 vs. U-2				**In Pit** P-1 vs. P-2 vs. P-3			**Surface** S-1 vs. S-2 vs. S-3		
			U-1	U-2	U-3	U-4	P-1	P-2	P-3	S-1	S-2	S-3
Social	Community Impact	Visual disturbance for an observer.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Least disturbance due to topographic low area with greatest natural containment.	Greatest visibility due to topographic plateau.	Some disturbance due to relatively flat area with some natural containment.	Least disturbance due to topographic low area with greatest natural containment.	Greatest visibility due to topographic plateau.	Some disturbance due to relatively flat area with some natural containment.
	Change in Land Use	Local resource consumption as borrow source(s) for construction.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Least consumption due to greatest natural topographic containment.	Greatest consumption due to topographic plateau, lack of natural containment.	Some consumption due to natural topographic containment.
	Population at Risk	Worker safety and human health during construction, operation, and closure.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Indicator not differentiating.	Lowest risk due to shortest transport and haul distance.	Highest risk due to longest transport and haul distance.	Intermediate.	Lowest risk due to shortest transport and haul distance.	Highest risk due to longest transport and haul distance.	Intermediate.
		Result	**Eliminated**	**Eliminated**	**Eliminated**	**Pass**	**Eliminated**	**Eliminated**	**Pass**	**Pass**	**Eliminated**	**Pass**

Note: red text indicates a relative disadvantage.





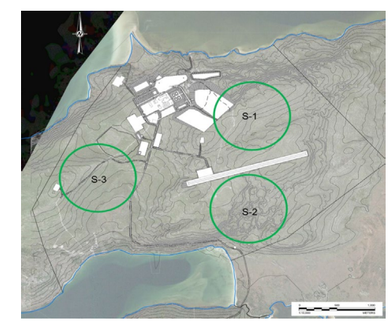


Table B-3: Tailings Alternatives Assessment, Screening for Technology at Underground Location U-4

Account	Sub-account	Indicator	Underground Location U-4			
			Co-disposal	Filtered	Paste	Slurry
Environmental	Ecological Integrity	Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	Fatally flawed due to volume incompatibility; excavation of underground chambers required to store tailings and waste rock generates more excavated rock to store underground.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement; unconsolidated filtered tailings may have a higher hydraulic conductivity and can swell on saturation, potentially impacting the geochemical stability of the TMF.	Least potential due to controlled deposition.	Greatest potential due to water management requirements, hydraulic conductivity of tailings and potential for opening of voids due to consolidation.

Account	Sub-account	Indicator	Underground Location U-4			
			Co-disposal	Filtered	Paste	Slurry
Technical	Design and Reliability	Proven precedent for technology and configuration.	Fatally flawed due to volume incompatibility; excavation of underground chambers required to store tailings and waste rock generates more excavated rock to store underground.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement.	Proven precedent.	Limited application. Tailings consolidation and consistency are uncontrolled. Requires cemented cap or plug to keep tailings in place after decommissioning.

Account	Sub-account	Indicator	Underground Location U-4			
			Co-disposal	Filtered	Paste	Slurry
Economic	Capital Cost	Facility construction and centralization.	Fatally flawed due to volume incompatibility; excavation of underground chambers required to store tailings and waste rock generates more excavated rock to store underground.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement.	Lower cost, excavation for tailings + binder.	Higher cost, excavation for tailings + water and water management.
		Paste plant.			Highest cost.	Not required.
	Operating Cost	Transport and placement of tailings, including energy, diesel, labor.			Cost of pump transport.	Cost of water return system.
		Requirement for tailings binder, flocculant, or other additives.			Highest cost.	Not required.
		Excavating and hauling additional waste rock.			Cost to haul waste rock to surface, excavation for tailings + binder.	Cost to haul waste rock to surface, excavation for tailings + water.

Account	Sub-account	Indicator	Underground Location U-4			
			Co-disposal	Filtered	Paste	Slurry
Social	Population at Risk	Worker safety and human health during construction, operation, and closure.	Fatally flawed due to volume incompatibility; excavation of underground chambers required to store tailings and waste rock generates more excavated rock to store underground.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement.	Lower risk for paste plant operation, requiring less excavation and water management.	Higher risk due to requirements for water management system construction and operation, and greater quantity of waste rock to transport.
		Result	**Eliminated**	**Eliminated**	**Pass**	**Eliminated**

Note: red text indicates a relative disadvantage.

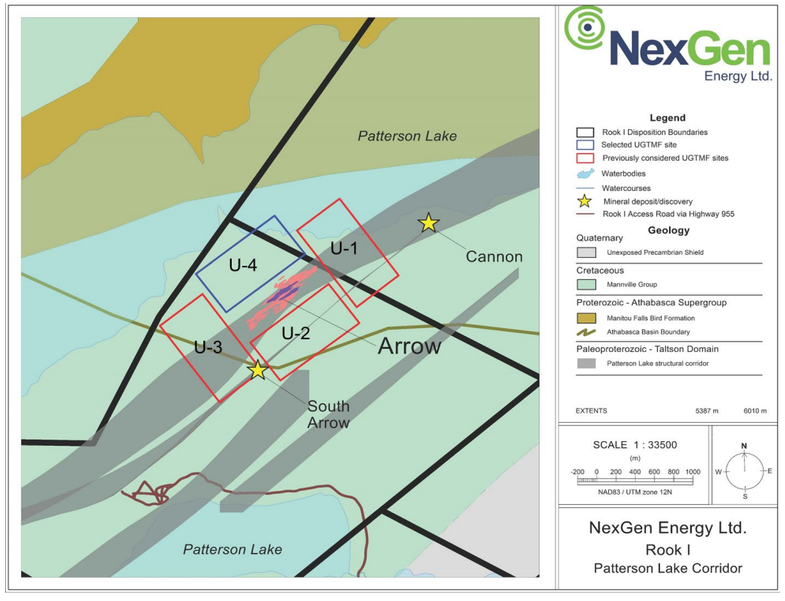


Table B-4: Tailings Alternatives Assessment, Screening for Technology at In Pit Location P-3

Account	Sub-account	Indicator	In Pit Location P-3			
			Co-disposal	Filtered	Paste	Slurry
Environmental	Ecological Integrity	Surface area of impact.	Fatally flawed due to volume incompatibility - excavation of a pit generates more excavated overburden and rock to store in-pit.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement; unconsolidated filtered tailings have a higher hydraulic conductivity and can swell once saturated, potentially impacting the geochemical stability of the TMF.	Least area of impact.	Greatest area of impact due to increased overburden and waste rock excavation.
	Hydrologic Regime	Surface water – potential for contact water management.			Least potential due to less quantity of excavation.	Greatest potential due to increased overburden and waste rock excavation to store lower tailings density and pond.
		Groundwater – potential for contact water management.			Least potential due to lack of pond.	Greater potential due to pond.
	Air Quality	Potential for excessive emissions of fugitive dust (e.g., particulates, heavy metals) and other non-GHG emissions during construction and operation.			Greater potential due to quantity of overburden and waste rock excavation (tailings + binder) and absence of supernatant pond.	Some potential due to quantity of overburden and waste rock excavation (tailings + water).

Account	Sub-account	Indicator	In Pit Location P-3			
			Co-disposal	Filtered	Paste	Slurry
Technical	Design and Reliability	Facility design effort.	Fatally flawed due to volume incompatibility - excavation of a pit generates more excavated overburden and rock to store in-pit.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement; unconsolidated filtered tailings have a higher hydraulic conductivity and can swell once saturated, potentially impacting the geochemical stability of the TMF.	Some effort (pit + tailings dewatering and transport + delivery).	Some effort (pit + tailings transport + greater capacity water reclaim system).
		Proven precedent for technology and configuration.			No.	Yes; technology applied at other uranium mines.
	Operation Risk and Complexity	Operation and maintenance for transport and disposal system.			Less maintenance (paste plant, pump + pipe, access road, least overburden and waste rock quantity).	More maintenance (pump + pipe, access road, water reclaim, greatest overburden and waste rock quantity).
		Water balance and management during seasonal changes.			Lower management effort	Greater management effort for subaqueous disposal pond management.
	Closure Risk and Complexity	Ease of decommissioning.			Complicated by ice lenses.	Complicated due to time required for consolidation.

Account	Sub-account	Indicator	In Pit Location P-3			
			Co-disposal	Filtered	Paste	Slurry
Economic	Capital Cost	Facility construction.	Fatally flawed due to volume incompatibility - excavation of a pit generates more excavated overburden and rock to store in-pit.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement; unconsolidated filtered tailings have a higher hydraulic conductivity and can swell once saturated, potentially impacting the geochemical stability of the TMF.	Lowest cost due to smaller excavation.	Highest cost due to larger excavation, water reclaim system.
		Paste plant.			Highest cost.	Not required.
	Operating Cost	Transport and placement of tailings, waste rock, including energy, diesel, labor.			Costs for pump + pipe, access road systems.	Cost for pump + pipe, access road, water reclaim systems.
		Paste plant.			Highest cost.	Not required.

Account	Sub-account	Indicator	In Pit Location P-3			
			Co-disposal	Filtered	Paste	Slurry
Social	Community Impact	Change in local employment opportunities.	Fatally flawed due to volume incompatibility - excavation of a pit generates more excavated overburden and rock to store in-pit.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement; unconsolidated filtered tailings have a higher hydraulic conductivity and can swell once saturated, potentially impacting the geochemical stability of the TMF.	Some jobs for pipeline transport, paste plant (specialized).	Least jobs for pipeline transport, water reclaim system.
	Population at Risk	Worker safety and human health during construction, operation, and closure.			Higher risk because of lack of gamma shielding by supernatant pond (no pond), dust exposure.	Lower risk because subaqueous deposition provides shielding from gamma radiation, dust exposure.
		Result	**Eliminated**	**Eliminated**	**Eliminated**	**Pass**

Note: red text indicates a relative disadvantage.

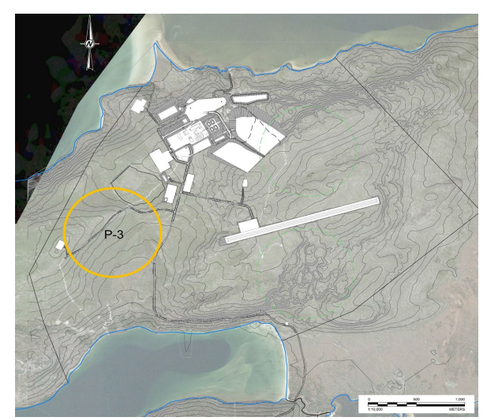


Table B-6: Tailings Alternatives Assessment, Multiple Accounts Analysis Sub-account and Indicator Weighting Summary

Account	Sub-account	Sub-account Weight (Ws)	Indicator	Indicator Weight (Wi)
Environmental	Ecological Integrity	6	Surface area of impact.	1
			Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	1
	Hydrologic Regime	1	Surface water - potential for contact water management.	3
			Surface water - potential for non-contact water management.	1
			Groundwater - potential for impact.	1
	Air Quality	1	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	1
Technical	Design and Reliability	6	Facility design effort.	1
	Construction Risk and Complexity	2	Geotechnical stability considering foundation conditions and waste placement.	1
	Operational Risk and Complexity	3	Operation and maintenance for transport and disposal system.	3
			Water balance and management during seasonal changes.	1
			Potential for progressive facility closure during operation.	1
			Potential for radon mitigation.	1
			GTR (2020) 3.2 ii requirement of new tailings facilities to minimise the volume of tailings and water placed in external tailings facilities.	6
	Closure Risk and Complexity	1	Ease of decommissioning.	1
			Resistance to extreme natural events (flood, earthquake) and climate change.	1
	Flexibility	2	Effort required for expansion, optimization, and design changes.	1
Economic	Capital Cost	4	Facility construction and centralization.	1
			Water treatment plant for surface runoff.	1
			Paste plant.	1
	Operating Cost	2	Transport and placement of tailings, including energy, diesel, labor.	1
			Requirement for tailings binder, flocculant, or other additives.	1
			Water treatment.	1
	Closure Cost	1	Facility closure.	1
			Water treatment.	3
Social	Community Impact	1	Visual disturbance for an observer.	1
			Change in local employment opportunities.	1
	Change in Land Use	1	Potential for loss of access and current land use.	1
	Population at Risk	1	Physical risk to people downstream.	1
			Worker safety and human health during construction, operation, and closure.	1

Table B-5: Tailings Alternatives Assessment, Screening for Technology at Surface Location S-1 or S-3

Account	Sub-account	Indicator	Surface Location S-1 or S-3			
			Co-disposal	Filtered	Paste	Slurry
Environmental	Hydrologic Regime	Surface water – potential for contact water management.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement.		Some potential.	Greatest potential due to pond on surface.
		Groundwater – potential for contact water management.			Some potential.	Greatest potential for seepage.

Account	Sub-account	Indicator	Surface Location S-1 or S-3			
			Co-disposal	Filtered	Paste	Slurry
Technical	Design and Reliability	Facility design effort.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement.		Some effort (embankment(s) + tailings + paste plant + delivery).	Some effort (embankment(s) + tailings + dewatering + greater water reclaim + delivery.
	Operational Risk and Complexity	Operation and maintenance for transport and disposal system.			Least maintenance (pump + pipe, access road).	Greatest maintenance (pump + pipe, access road, greater water reclaim).
		Water balance and management during seasonal changes.			Some water management due to high water content with potential formation of ice lenses; freeze/thaw.	Greatest requirement for water management (pond); freeze/thaw.
		Potential for progressive facility closure during operation.			Low potential for progressive facility closure.	Least potential for progressive facility closure.
		GTR (2020) 3.2 ii requirement of new TSFs to minimize the volume of tailings and water placed in external tailings facilities.			Some reduction in water stored on surface, operated with no large pond.	Greatest volume of water on surface (pond); geohazard.
	Closure Risk and Complexity	Ease of decommissioning.			Complicated by ice lenses.	Complicated due to draindown and consolidation.

Account	Sub-account	Indicator	Surface Location S-1 or S-3			
			Co-disposal	Filtered	Paste	Slurry
Economic	Capital Cost	Facility construction and centralization.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement.		Lowest cost.	Highest cost due to increase in excavation size, water management.
		Paste plant.			Highest cost.	Not required.
	Operating Cost	Transport and placement of tailings, including energy, diesel, labor.			Cost of pump transport.	Cost of water return system.
		Paste plant.			Highest cost.	Not required.
	Closure Cost	Water treatment.			Lowest cost.	Highest cost due to water management, time for drainage and consolidation of tailings.

Account	Sub-account	Indicator	Surface Location S-1 or S-3			
			Co-disposal	Filtered	Paste	Slurry
Social	Community Impact	Change in local employment opportunities.	Fatally flawed due to potential worker exposure to gamma radiation through contact with the tailings and dust ingestion during transport and placement.		Some jobs for embankment construction, pipeline transport, paste plant (specialized).	Least jobs for embankment construction, pipeline transport, water reclaim system.
	Population at Risk	Physical risk to people downstream.			Lowest risk due to lack of water retained on tailings surface.	Highest risk due to water maintained on tailings surface (pond); geohazard.
		Worker safety and human health during construction, operation, and closure.			Higher risk because of lack of gamma shielding by supernatant pond (no pond), dust exposure.	Lower risk because subaqueous deposition provides shielding from gamma radiation, dust exposure.
		Result	**Eliminated**	**Eliminated**	**Pass**	**Eliminated**

Note: red text indicates a relative disadvantage.

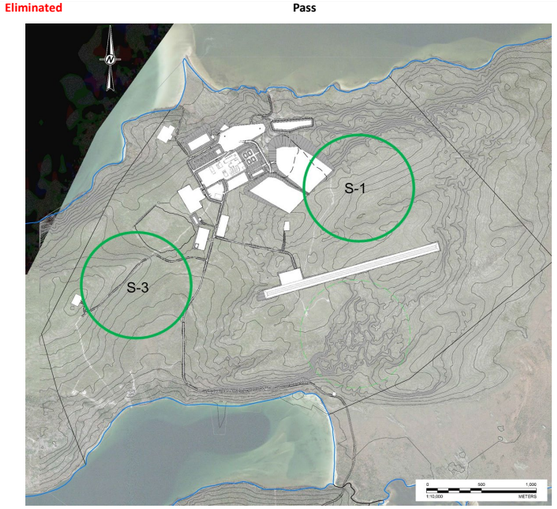


Table B-7: Tailings Alternatives Assessment, Multiple Accounts Analysis

Account	Sub-account	Indicator	Description	Indicator Measurement	Unit	Indicator Quantity				Indicator Value (S)				Indicator Weight (Wi)	Indicator Merit Score (S*Wi)				Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)				
						Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	
Environmental	Ecological Integrity	Surface area of impact.	Measured as the 2D surface area of the tailings facility (not including waste rock or stripping), with the lowest surface area preferred for lowest potential impact.	Area	ha	0.0	92.2	58.2	33.7	6.0	1.0	2.8	4.2	1	6.0	1.0	2.8	4.2	6	21.0	21.0	23.9	28.8	
		Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	Measured as distance from tailings facility centroid to Patterson Lake, with the longest distance preferred for lowest potential impact.	Distance	km	0.2	1.0	0.9	0.9	1.0	6.0	5.1	5.4	1	1.0	6.0	5.1	5.4						
														Total indicator merit score (Σ{S × Wi})	7.0	7.0	8.0	9.6						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	3.5	3.5	4.0	4.8						
	Hydrologic Regime	Surface water - potential for contact water management.	*see below	Value	#	-	-	-	-	6.0	3.0	1.0	5.0	3	18.0	9.0	3.0	15.0	1	6.0	2.2	1.4	4.6	
		Surface water - potential for non-contact water management.	Measured as the 2D surface area of the TMF, with the lowest surface area preferred for diverting non-contact water.	Area	ha	0.0	92.2	58.2	33.7	6.0	1.0	2.8	4.2	1	6.0	1.0	2.8	4.2						
		Groundwater - potential for impact	*see below	Value	#	-	-	-	-	6.0	1.0	1.0	4.0	1	6.0	1.0	1.0	4.0						
														Total indicator merit score (Σ{S × Wi})	30.0	11.0	6.8	23.2						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	6.0	2.2	1.4	4.6						
	Air Quality	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	Measured as the highest amount of material hauled to surface.	Volume	M m³	11.3	3.2	3.5	12.8	1.8	6.0	5.8	1.0	1	1.8	6.0	5.8	1.0	1	1.8	6.0	5.8	1.0	
														Total indicator merit score (Σ{S × Wi})	1.8	6.0	5.8	1.0		**28.8**	**29.2**	**31.1**	**34.5**	**Total sub-account merit score (Σ{Rs × Ws})**
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	1.8	6.0	5.8	1.0		**3.6**	**3.7**	**3.9**	**4.3**	**Account merit rating (Ra = Σ{Rs×Ws}/ ΣWs)**

Indicator	Value	Descriptor
Surface water - potential for contact water management.	6 (Best)	Underground - no potential surface contact water management for tailings; excavated waste rock to be placed in WRSA and use existing controls
	5	In Pit - limited potential due to greatest toe setback from proposed Project surface lease boundary, infrastructure, wetland, and Patterson Lake, and shallow gradient beyond toe.
	4	
	3	Surface, S-1 is farther from Patterson Lake, allows more area for water management than S-3
	2	
	1 (Worst)	Tailings on surface, greatest potential due to proximity to proposed Project surface lease boundary, infrastructure, wetland and Patterson Lake, and steep gradient beyond toe.
Groundwater - potential for impact.	6 (Best)	Underground - least potential for seepage to impact groundwater (cemented).
	5	
	4	
	3	
	2	
	1 (Worst)	Surface - greatest potential for seepage to impact groundwater.

Account	Sub-account	Indicator	Description	Indicator Measurement	Unit	Indicator Quantity				Indicator Value (S)				Indicator Weight (Wi)	Indicator Merit Score (S*Wi)				Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)				
						Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	
Technical	Design and Reliability	Facility design effort	*see below	Value	#	-	-	-	-	3.0	6.0	6.0	1.0	1	3.0	6.0	6.0	1.0	6	18.0	36.0	36.0	6.0	
														Total indicator merit score (Σ{S × Wi})	3.0	6.0	6.0	1.0						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	3.0	6.0	6.0	1.0						
	Construction Risk and Complexity	Geotechnical stability considering foundation conditions and waste placement.	Measured as the quantity of earthworks, with the lowest quantity preferred.	Volume	M m³	11.3	3.2	3.5	12.8	1.8	6.0	5.8	1.0	1	1.8	6.0	5.8	1.0	2	3.6	12.0	11.6	2.0	
														Total indicator merit score (Σ{S × Wi})	1.8	6.0	5.8	1.0						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	1.8	6.0	5.8	1.0						
	Operational Risk and Complexity	Operation and maintenance for transport and disposal system.	Measured as distance from shaft to tailings facility centroid, with the shortest distance preferred.	Distance	km	0.8	1.5	1.8	1.9	6.0	2.9	1.2	1.0	3	18.0	8.8	3.7	3.0	3	17.5	5.2	4.4	11.0	
		Water balance and management during seasonal changes.	Measured as the area of the tailings facility on surface, with the lowest surface area preferred (generates less tailings contact water from precipitation).	Area	ha	0	92.2	58.2	33.7	6.0	1.0	2.8	4.2	1	6.0	1.0	2.8	4.2						
		Potential for progressive facility closure during operation	*see below	Value	#	-	-	-	-	6.0	4.0	4.0	1.0	1	6.0	4.0	4.0	1.0						
		Potential for radon mitigation	*see below	Value	#	-	-	-	-	4.0	1.0	1.0	6.0	1	4.0	1.0	1.0	6.0						
		GTR (2020) 3.2 ii requirement of new tailings facilities to minimise the volume of tailings and water placed in external tailings facilities	*see below	Value	#	-	-	-	-	6.0	1.0	1.0	5.0	6	36.0	6.0	6.0	30.0						
														Total indicator merit score (Σ{S × Wi})	70.0	20.8	17.6	44.2						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	5.8	1.7	1.5	3.7						
	Closure Risk and Complexity	Ease of decommissioning	*see below	Value	#	-	-	-	-	6.0	1.0	1.0	3.0	1	6.0	1.0	1.0	3.0	1	6	1	1	3	
		Resistance to extreme natural events (flood, earthquake) and climate change	*see below	Value	#	-	-	-	-	6.0	1.0	1.0	3.0	1	6.0	1.0	1.0	3.0						
														Total indicator merit score (Σ{S × Wi})	6.0	1.0	1.0	3.0						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	6.0	1.0	1.0	3.0						
	Flexibility	Effort required for expansion, optimization, and design changes	*see below	Value	#	-	-	-		6.0	3.0	4.0	1.0	1	6.0	3.0	4.0	1.0	2	12	6	8	2	
														Total indicator merit score (Σ{S × Wi})	6.0	3.0	4.0	1.0		**57.1**	**60.2**	**61.0**	**24.0**	**Total sub-account merit score (Σ{Rs × Ws})**
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	6.0	3.0	4.0	1.0		**4.1**	**4.3**	**4.4**	**1.7**	**Account merit rating (Ra = Σ{Rs×Ws}/ ΣWs)**

Indicator	Value	Descriptor
Facility design effort.	6 (Best)	Surface - least design effort; dam design, paste plant, tailings transport, water management
	5	
	4	
	3	Underground - blasting and waste rock excavation + haul, paste plant, water return
	2	
	1 (Worst)	In Pit - greatest effort; blasting, pit wall stability, filters, tailings transport, water management
Potential for progressive facility closure during operation.	6 (Best)	Underground - greatest potential for progressive closure
	5	
	4	Surface - some potential for progressive closure
	3	
	2	
	1 (Worst)	In Pit - least potential for progressive closure
Potential for radon mitigation.	6 (Best)	In Pit - least potential due to water cover over tailings
	5	
	4	Underground - high potential to mitigation using mine ventilation system
	3	
	2	
	1 (Worst)	Surface - highest potential with no pond on surface paste alternative
GTR (2020) 3.2 ii requirement of new tailings facilities to minimise the volume of tailings and water placed in external tailings facilities.	6 (Best)	Underground - no tailings or water stored on surface
	5	In Pit - low potential for tailings or pond release
	4	
	3	
	2	
	1 (Worst)	Surface - tailings stored on surface
Ease of decommissioning.	6 (Best)	Underground - simplest to decommission
	5	
	4	
	3	In Pit - must consider dewatering pond, tailings consolidation, cover placement
	2	
	1 (Worst)	Surface - decommissioning complicated by ice lenses, tailings consolidation, cover placement
Resistance to extreme natural events (flood, earthquake) and climate change.	6 (Best)	Underground - resistant to extreme events and climate change
	5	
	4	
	3	In Pit - some resistance to extreme events and climate change
	2	
	1 (Worst)	Surface - least resistant to extreme events and climate change
Effort required for expansion, optimization, and design changes.	6 (Best)	Underground - least effort due modular design expanded by additional chamber excavation
	5	
	4	Surface, S-3 - requires only additional cell or raise
	3	Surface, S-1 - additional raise
	2	
	1 (Worst)	In Pit - most effort to expand, excavation required

Account	Sub-account	Indicator	Description	Indicator Measurement	Unit	Indicator Quantity				Indicator Value (S)				Indicator Weight (Wi)	Indicator Merit Score (S*Wi)				Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)				
						Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	
Economic	Capital Cost	Facility construction and centralization.	Earthworks (not considering staging).	Volume	M m³	11.3	3.2	3.5	12.8	1.8	6.0	5.8	1.0	4	7.3	24.0	23.3	4.0	4	9.5	17.3	16.9	7.3	
		Water treatment plant for surface runoff.	Water treatment plant required for surface tailings contact water.	Count	No.	0.0	1.0	1.0	1.0	6.0	1.0	1.0	1.0	1	6.0	1.0	1.0	1.0						
		Paste plant	Paste plant required	Count	No.	1.0	1.0	1.0	0.0	1.0	1.0	1.0	6.0	1	1.0	1.0	1.0	6.0						
														Total indicator merit score (Σ{S × Wi})	14.3	26.0	25.3	11.0						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	2.4	4.3	4.2	1.8						
	Operating Cost	Transport and placement of tailings, including energy, diesel, labor.	Measured as distance from shaft to TMF centroid, with the shortest distance preferred for lowest cost.	Distance	km	0.8	1.5	1.8	1.9	6.0	2.9	1.2	1.0	1	6.0	2.9	1.2	1.0	2	8.7	5.3	4.2	5.3	
		Requirement for tailings binder, flocculant, or other additives	*see below	Value	#					1.0	4.0	4.0	6.0	1	1.0	4.0	4.0	6.0						
		Water treatment.	Water treatment plant required for surface tailings contact water.	Count	No.	0.0	1.0	1.0	1.0	6.0	1.0	1.0	1.0	1	6.0	1.0	1.0	1.0						
														Total indicator merit score (Σ{S × Wi})	13.0	7.9	6.2	8.0						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	4.3	2.6	2.1	2.7						
	Closure Cost	Facility closure	*see below	Value	#	-	-	-	-	6.0	1.0	1.0	4.0	1	6.0	1.0	1.0	4.0	1	6.0	1.0	1.0	4.0	
		Water treatment	*see below	Value	#	-	-	-	-	6.0	1.0	1.0	4.0	3	18.0	3.0	3.0	12.0						
														Total indicator merit score (Σ{S × Wi})	24.0	4.0	4.0	16.0		**24.2**	**23.6**	**22.0**	**16.7**	**Total sub-account merit score (Σ{Rs × Ws})**
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	6.0	1.0	1.0	4.0		**3.5**	**3.4**	**3.1**	**2.4**	**Account merit rating (Ra = Σ{Rs×Ws}/ ΣWs)**

Indicator	Value	Descriptor
Requirement for tailings binder, flocculant, or other additives.	6 (Best)	In Pit - no cement or flocculant required
	5	
	4	Surface - flocculant required for paste
	3	
	2	
	1 (Worst)	Underground - cement and flocculant required
Facility closure.	6 (Best)	Underground - lowest cost to decommission
	5	
	4	In Pit - must consider dewatering pond, tailings consolidation, cover placement
	3	
	2	
	1 (Worst)	Surface - highest cost due to consideration of thaw of ice lenses, tailings consolidation, cover placement
Water treatment.	6 (Best)	Underground - lowest cost because tailings contact water limited to groundwater flow through cemented mass
	5	
	4	In Pit - some water treatment required
	3	
	2	
	1 (Worst)	Surface - highest cost due to water treatment

Account	Sub-account	Indicator	Description	Indicator Measurement	Unit	Indicator Quantity				Indicator Value (S)				Indicator Weight (Wi)	Indicator Merit Score (S*Wi)				Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)				
						Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	
Social	Community Impact	Visual disturbance for an observer.	Measured as the 2D surface area of the TMF, with the lowest surface area preferred for lowest visual impact.	Area	ha	0.0	92.2	58.2	33.7	6.0	1.0	2.8	4.2	1	6.0	1.0	2.8	4.2	1	5.0	1.0	1.9	5.1	
		Change in local employment opportunities	*see below	Value	#	-	-	-	-	4.0	1.0	1.0	6.0	1	4.0	1.0	1.0	6.0						
														Total indicator merit score (Σ{S × Wi})	10.0	2.0	3.8	10.2						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	5.0	1.0	1.9	5.1						
	Change in Land Use	Potential for loss of access and current land use	*see below	Value	#	-	-	-	-	6.0	3.0	3.0	1.0	1	6.0	3.0	3.0	1.0	1	6.0	3.0	3.0	1.0	
														Total indicator merit score (Σ{S × Wi})	6.0	3.0	3.0	1.0						
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	6.0	3.0	3.0	1.0						
	Population at Risk	Physical risk to people downstream	*see below	Value	#	-	-	-	-	6.0	1.0	2.0	6.0	1	6.0	1.0	2.0	6.0	1	4.6	3.5	3.9	3.5	
		Worker safety and human health during construction, operation, and closure.	Measured as the quantity of earthworks, with the lowest quantity preferred.	Volume	M m3	8.4	3.2	3.5	12.8	3.3	6.0	5.8	1.0	1	3.3	6.0	5.8	1.0						
														Total indicator merit score (Σ{S × Wi})	9.3	7.0	7.8	7.0		**15.6**	**7.5**	**8.8**	**9.6**	**Total sub-account merit score (Σ{Rs × Ws})**
														Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	4.6	3.5	3.9	3.5		**5.2**	**2.5**	**2.9**	**3.2**	**Account merit rating (Ra = Σ{Rs×Ws}/ ΣWs)**

Indicator	Value	Descriptor
Change in local employment opportunities.	6 (Best)	In Pit - greatest increase in employment opportunities due to pit excavation during construction period, water management
	5	
	4	Underground - chamber excavation during mine life, paste plant operation
	3	
	2	
	1 (Worst)	Surface paste - least change in employment opportunities - required for dam construction (may be staged) and paste plant operation
Potential for loss of access and current land use.	6 (Best)	Underground - least potential for surface disruption
	5	
	4	
	3	Surface - moderate potential for long-term disruption of current land use
	2	
	1 (Worst)	In-Pit - greatest potential for long-term disruption of current land use
Physical risk to people downstream.	6 (Best)	Lowest risk for underground and in-pit
	5	
	4	
	3	
	2	Some risk for Surface, S-3 due to potential consequence of failure and runout
	1 (Worst)	Highest risk for Surface, S-1 due to potential consequence of failure and runout

ECCC Weighting

Account	Account Weight (W_a)	Account Merit Rating (R_a)				Account Merit Score (R_a*W_1)				
		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	
Environmental	6	3.6	3.7	3.9	4.3	21.6	21.9	23.3	25.8	
Technical	3	4.1	4.3	4.4	1.7	12.2	12.9	13.1	5.2	
Economic	1.5	3.5	3.4	3.1	2.4	5.2	5.1	4.7	3.6	
Social	3	5.2	2.5	2.9	3.2	15.6	7.5	8.8	9.6	
	13.5					**54.7**	**47.4**	**50.0**	**44.2**	**Total account merit score (Σ{Ra × Wa})**
						4.1	**3.5**	**3.7**	**3.3**	**Alternative merit rating (A = Σ{Ra×Wa}/ ΣWa)**
						1	**3**	**2**	**4**	**Rank**

Table B-8: Tailings Alternatives Assessment, Multiple Accounts Analysis Sensitivity

ECCC Weighting

Account	Weight	Account Merit Weighting				Account Merit Score			
		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry
Environmental	6	3.6	3.7	3.9	4.3	21.6	21.9	23.3	25.8
Technical	3	4.1	4.3	4.4	1.7	12.2	12.9	13.1	5.2
Economic	1.5	3.5	3.4	3.1	2.4	5.2	5.1	4.7	3.6
Social	3	5.2	2.5	2.9	3.2	15.6	7.5	8.8	9.6
	13.5				Total Account Merit Score	54.7	47.4	50.0	44.2
					Account Merit Rating	4.1	3.5	3.7	3.3
					Rank	**1**	**3**	**2**	**4**

NexGen Weighting

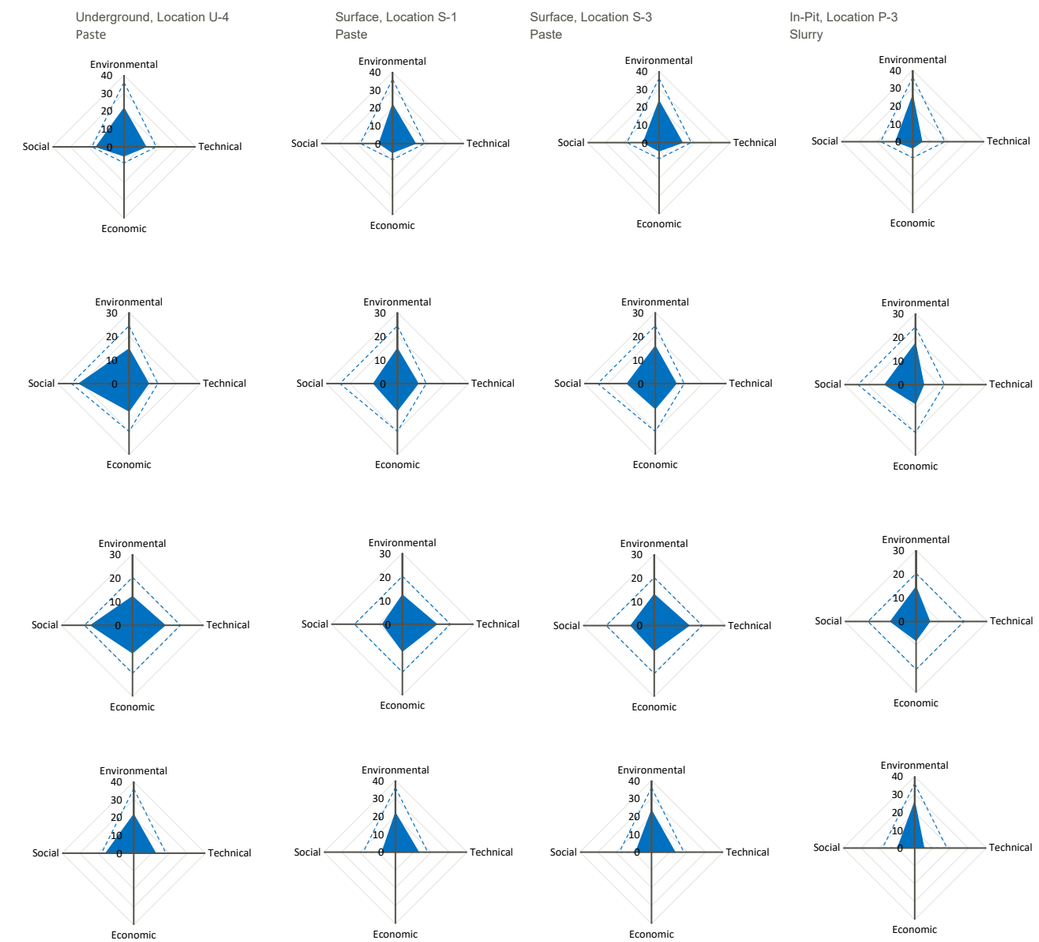
Account	Weight	Account Merit Rating				Account Merit Score			
		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry
Environmental	4.1	3.6	3.7	3.9	4.3	14.6	14.8	15.7	17.4
Technical	2.0	4.1	4.3	4.4	1.7	8.3	8.7	8.8	3.5
Economic	3.4	3.5	3.4	3.1	2.4	11.7	11.4	10.6	8.0
Social	4.1	5.2	2.5	2.9	3.2	21.1	10.1	11.9	12.9
	13.5				Total Account Merit Score	55.6	45.0	47.1	41.9
					Account Merit Rating	4.1	3.3	3.5	3.1
					Rank	**1**	**3**	**2**	**4**

Equal Weighting

Account	Weight	Account Merit Rating				Account Merit Score			
		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry
Environmental	3.4	3.6	3.7	3.9	4.3	12.2	12.3	13.1	14.5
Technical	3.4	4.1	4.3	4.4	1.7	13.8	14.5	14.7	5.8
Economic	3.4	3.5	3.4	3.1	2.4	11.7	11.4	10.6	8.0
Social	3.4	5.2	2.5	2.9	3.2	17.6	8.4	9.9	10.8
	13.5				Total Account Merit Score	55.2	46.7	48.4	39.2
					Account Merit Rating	4.1	3.5	3.6	2.9
					Rank	**1**	**3**	**2**	**4**

ECCC Weighting with Economic = 0

Account	Weight	Account Merit Rating				Account Merit Score			
		Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry	Underground Location U-4 Paste	Surface Location S-1 Paste	Surface Location S-3 Paste	In Pit Location P-3 Slurry
Environmental	6	3.6	3.7	3.9	4.3	21.6	21.9	23.3	25.8
Technical	3	4.1	4.3	4.4	1.7	12.2	12.9	13.1	5.2
Economic	0	3.5	3.4	3.1	2.4	0.0	0.0	0.0	0.0
Social	3	5.2	2.5	2.9	3.2	15.6	7.5	8.8	9.6
	12				Total Account Merit Score	49.5	42.3	45.2	40.6
					Account Merit Rating	4.1	3.5	3.8	3.4
					Rank	**1**	**3**	**2**	**4**



APPENDIX C

Gypsum Alternatives Assessment

Table C-1: Gypsum Alternatives Assessment, Pre-screening for General Location

Pre-screening Criteria	General Locations				
	Underground	In-Pit	Surface	Off-site	In-Lake
Has required storage capacity	Yes	Yes	Yes	Yes	Yes
No waste in lake (NexGen).	Aligned	Aligned	Aligned	Aligned	Fatally flawed
Area of impact.	None	Additional surface disturbance area within proposed Project surface lease boundary	Additional surface disturbance area within proposed Project surface lease boundary	Increase in overall surface disturbance area outside proposed Project surface lease boundary	Disturbance of lake outside proposed Project surface lease boundary
Quantity of waste rock generated.	Volume of gypsum stored + volume for underground access	Overburden + waste rock from pit development greater than volume of gypsum stored	No change	No change	No change
Result	**Pass**	**Eliminated**	**Pass**	**Eliminated**	**Eliminated**

Note: red text indicate a relative disadvantage.

Table C-2: Gypsum Alternatives Assessment, Screening for Specific Location

Account	Sub-account	Indicator	Underground UGTMF vs. Purpose Built		Surface WRSA vs. Purpose Built	
			UGTMF (underground, gypsum with tailings)	**Purpose Built** (underground, gypsum only)	**WRSA** (surface, gypsum with waste rock)	**Purpose Built** (surface, gypsum only)
Environmental	Ecological Integrity	Surface area of impact.	Least increase in surface disturbance due to size of the UGTMF and quantity of excavated material stored on surface.	Greatest increase in surface disturbance due to additional volume of underground excavation .	Least area of impact due to size of WRSA.	Greatest area of disturbance for additional facility, access roads, and water management infrastructure.
	Hydrologic Regime	Surface water - potential for impact.	Least potential for impact due to increase in additional excavated material stored on surface.	Greatest potential for impact due to increase in additional excavated material stored on surface.	Least potential - mitigated by planned controls for WRSA.	Greatest potential - requires additional controls to mitigate impact.
		Groundwater - potential for impact.	Least potential change in seepage quality and quantity, mitigated by planned controls for the UGTMF.	Greatest potential for impact due to larger volume containing waste underground, additional controls may be required.	Least potential - mitigated by planned controls for WRSA.	Greatest potential due to additional surface facility area, requires additional controls and instrumentation for water management and monitoring.
	Air Quality	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	Incremental increase/non differentiating.	Incremental increase/non differentiating.	Least potential - mitigated by planned controls for WRSA.	Greatest potential due to additional surface facility area.

Account	Sub-account	Indicator	Underground UGTMF vs. Purpose Built		Surface WRSA vs. Purpose Built	
			UGTMF (underground, gypsum with tailings)	**Purpose Built** (underground, gypsum only)	**WRSA** (surface, gypsum with waste rock)	**Purpose Built** (surface, gypsum only)
Technical	Design and Reliability	Facility design effort.	Least effort due to single facility to design.	Greatest due to additional facility to design.	Least effort due to single facility to design.	Greatest due to additional facility to design.
		Proven precedent for technology and configuration.	Proven, potential advantage to use gypsum as binder for tailings.	Proven.	Less precedent - some geotechnical uncertainty in placement of large or concentrated volumes of gypsum in waste rock that can be mitigated by placement methods.	Proven.
	Construction Risk and Complexity	Geotechnical stability considering foundation conditions and waste placement.	Indicator not applicable.	Indicator not applicable.	Relies on WRSA foundation - no additional facility.	Requires consideration of foundation conditions for additional facility.
	Operational Risk and Complexity	Operation and maintenance for transport and disposal system.	Least complexity due to use of UGTMF systems.	Greatest complexity due to requirement for separate systems.	Potential use of planned WRSA fleet.	Requires more equipment to operate.
		Potential for progressive facility closure during operation.	Indicator not applicable.	Indicator not applicable.	Indicator not applicable.	Indicator not applicable.
	Closure Risk and Complexity	Ease of decommissioning.	Simplest - single facility to close.	Most complex due to additional facility to close.	Simplest - single facility to close.	More complex - additional surface facility to close.

Account	Sub-account	Indicator	Underground UGTMF vs. Purpose Built		Surface WRSA vs. Purpose Built	
			UGTMF (underground, gypsum with tailings)	**Purpose Built** (underground, gypsum only)	**WRSA** (surface, gypsum with waste rock)	**Purpose Built** (surface, gypsum only)
Economic	Capital Cost	Facility construction and centralization.	Lowest cost due to size of UGTMF (e.g., number of chambers).	Highest cost due to construction of separate facility and access to construct.	Lowest cost due to incremental increase in size of WRSA.	Highest cost due to increase in surface disturbance for additional facility, access, equipment, and infrastructure.
	Operating Cost	Transport and placement of gypsum, including energy, diesel, labor.	Lowest cost due to use of transport system for the UGTMF.	Highest cost due to operation of separate transport system.	Lowest cost due to use of WRSA fleet.	Highest cost due to additional equipment.
		Requirement for tailings binder, flocculant, or other additives.	Lowest cost due to potential for gypsum to decrease tailings binder requirement.	Highest cost for tailings binder (no potential advantage).	Indicator not differentiating.	Indicator not differentiating.
		Excavating and hauling additional waste rock.	Lowest cost - incremental increase in waste rock excavation.	Highest cost due to increase in waste rock excavation.	Indicator not differentiating.	Indicator not differentiating.
	Closure Cost	Facility closure.	Lowest cost due to single facility to close.	Highest cost due to additional facility to close.	Lowest cost due to single facility to close.	Highest cost due to additional facility to close.

Account	Sub-account	Indicator	Underground UGTMF vs. Purpose Built		Surface WRSA vs. Purpose Built	
			UGTMF (underground, gypsum with tailings)	**Purpose Built** (underground, gypsum only)	**WRSA** (surface, gypsum with waste rock)	**Purpose Built** (surface, gypsum only)
Social	Community Impact	Visual disturbance for an observer.	Indicator non-differentiating.	Indicator non-differentiating.	Least due to incremental increase in size of WRSA.	Greatest due to additional facility.
	Change in Land Use	Local resource consumption as borrow source(s) for construction.	Indicator non-differentiating.	Indicator non-differentiating.	Least due to incremental increase in size of WRSA.	Greatest due to additional facility.
	Population at Risk	Worker safety and human health during construction, operation, and closure.	Lowest risk - single facility to construct, operate, and close.	Highest risk due to additional facility to construct, operate, and close.	Lowest risk - single facility to construct, operate, and close.	Highest risk due to additional facility to construct, operate, and close.
		Result	**Pass**	**Eliminated**	**Pass**	**Eliminated**

Note: red text indicate a relative disadvantage.

Table C-3: Gypsum Alternatives Assessment Sub-account and Indicator Weighting Summary

Account	Sub-account	Sub-account Weight (Ws)	Indicator	Indicator Weight (Wi)
Environmental	Ecological Integrity	6	Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	1
	Hydrologic Regime	1	Surface water - potential for contact water management.	1
	Air Quality	1	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	1
Technical	Design and Reliability	3	Facility design effort.	1
			Proven precedent for technology and configuration.	6
	Construction Risk and Complexity.	1	Geotechnical stability considering foundation conditions and waste placement.	1
	Flexibility	1	Effort required for expansion, optimization, and design changes.	1
Economic	Capital Cost	2	Facility construction and centralization.	1
	Operating Cost	1	Transport and placement of gypsum, including energy, diesel, labor.	1
			Requirement for tailings binder, flocculant, or other additives.	1
Social	Population at Risk	1	Worker safety and human health during construction, operation, and closure.	1

Table C-4: Gypsum Alternatives Assessment, Multiple Accounts Analysis

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity		Indicator Value (S)		Indicator Weight (Wi)	Indicator Merit Score (S*Wi)		Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)		
						UGTMF	WRSA	UGTMF	WRSA		UGTMF	WRSA		UGTMF	WRSA	
Environmental	Ecological Integrity	Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	*see below	Value	#	-	-	6	1	1	6	1	6	36	6	
								Total indicator merit score (Σ(S × Wi))			6.0	1.0				
								Subaccount merit rating (Rs = Σ(S×Wi)/ ΣWi)			6.0	1.0				
	Hydrologic Regime	Surface water - potential for contact water management.	*see below	Value	#	-	-	6	1	1	6	1	1	6	1	
								Total indicator merit score (Σ(S × Wi))			6.0	1.0				
								Subaccount merit rating (Rs = Σ(S×Wi)/ ΣWi)			6.0	1.0				
	Air Quality	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	Material to surface	Tonnage	Mt	4.4	0.0	1	6	1	1	6	1	1	6	
								Total indicator merit score (Σ(S × Wi))			1.0	6.0		**43.0**	**13.0**	**Total sub-account merit score (Σ(Rs × Ws))**
								Subaccount merit rating (Rs = Σ(S×Wi)/ ΣWi)			1.0	6.0		**5.4**	**1.6**	**Account merit rating (Ra = Σ(Rs×Ws)/ ΣWs)**

Indicator	Value	Descriptor
Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	6 (Best)	UGTMF - during operations and closure, the flow gradient is from Patterson Lake to the UGTMF. In post-closure all options have potential to impact Patterson Lake.
	5	
	4	
	3	
	2	
	1 (Worst)	WRSA - in operations and closure the flow gradient is towards Patterson Lake. In post-closure all options have potential to impact Patterson Lake.
Surface water - potential for contact water management.	6 (Best)	UGTMF - Least potential for contact water management, incremental increase in excavated material to surface
	5	
	4	
	3	
	2	
	1 (Worst)	WRSA - Greatest potential for contact water management

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity		Indicator Value (S)		Indicator Weight (Wi)	Indicator Merit Score (S*Ws)		Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)		
						UGTMF	WRSA	UGTMF	WRSA		UGTMF	WRSA		UGTMF	WRSA	
Technical	Design and Reliability	Facility design effort.	*see below	Value	#	-	-	6	1	1	6	1	3	18	3	
		Proven precedent for technology and configuration.	*see below	Value	#	-	-	6	1	6	36	6				
								Total indicator merit score (Σ(S × Wi))			42.0	7.0				
								Subaccount merit rating (Rs = Σ(S×Wi)/ ΣWi)			6.0	1.0				
	Construction Risk and Complexity.	Geotechnical stability considering foundation conditions and waste placement.	*see below	Value	#	-	-	6	1	1	6	1	1	6	1	
								Total indicator merit score (Σ(S × Wi))			6.0	1.0				
								Subaccount merit rating (Rs = Σ(S×Wi)/ ΣWi)			6.0	1.0				
	Flexibility	Effort required for expansion, optimization, and design changes.	*see below	Value	#	-	-	1	6	1	1	6	1	1	6	
								Total indicator merit score (Σ(S × Wi))			1.0	6.0		**25.0**	**10.0**	**Total sub-account merit score (Σ(Rs × Ws))**
								Subaccount merit rating (Rs = Σ(S×Wi)/ ΣWi)			1.0	6.0		**5.0**	**2.0**	**Account merit rating (Ra = Σ(Rs×Ws)/ ΣWs)**

Indicator	Value	Descriptor
Facility design effort.	6 (Best)	UGTMF - least design effort - incremental increase in chambers in UGTMF and use of UGTMF transport system
	5	
	4	
	3	
	2	
	1 (Worst)	WRSA - greatest design effort for gypsum removal from tailings stream, haul from plant to WRSA, manage placement to avoid segregation
Proven precedent for technology and configuration.	6 (Best)	UGTMF - proven precedent for placement of gypsum with tailings
	5	
	4	
	3	
	2	
	1 (Worst)	WRSA - not common, requires management of placement of gypsum with waste rock to avoid segregation
Geotechnical stability considering foundation conditions and waste placement.	6 (Best)	UGTMF - no change expected to stability of WRSA with additional waste rock
	5	
	4	
	3	
	2	
	1 (Worst)	WRSA - potential impact to stability related to dissolution of gypsum
Effort required for expansion, optimization, and design changes.	6 (Best)	WRSA - requires less effort to expand WRSA
	5	
	4	
	3	
	2	
	1 (Worst)	UGTMF - requires more effort to expand both UGTMF and WRSA

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity		Indicator Value (S)		Indicator Weight (Wi)	Indicator Merit Score (S*Wi)		Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)		
						UGTMF	WRSA	UGTMF	WRSA		UGTMF	WRSA		UGTMF	WRSA	
Economic	Capital Cost	Facility construction and centralization.	Waste rock to surface	Tonnage	Mt	4.4	0	1	6	1	1	6	2	2.0	12.0	
								Total indicator merit score (Σ(S × Wi))			1.0	6.0				
								Subaccount merit rating (Rs = Σ(S×Wi)/ ΣWi)			1.0	6.0				
	Operating Cost	Transport and placement of gypsum, including energy, diesel, labor.	*see below	Value	#	-	-	6	1	1	6	1	1	6.0	1.0	
		Requirement for tailings binder, flocculant, or other additives.	Gypsum available	Tonnage	Mt	1.5	0	6	1	1	6	1				
								Total indicator merit score (Σ(S × Wi))			12.0	2.0		**8.0**	**13.0**	**Total sub-account merit score (Σ(Rs × Ws))**
								Subaccount merit rating (Rs = Σ(S×Wi)/ ΣWi)			6.0	1.0		**2.7**	**4.3**	**Account merit rating (Ra = Σ(Rs×Ws)/ ΣWs)**

Indicator	Value	Descriptor
Transport and placement of gypsum, including energy, diesel, labor.	6 (Best)	UGTMF - lower cost due to potential use of planned tailings transport system
	5	
	4	
	3	
	2	
	1 (Worst)	WRSA - higher cost due to requirement to separate gypsum from tailings, clean gypsum, load, haul, place

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity		Indicator Value (S)		Indicator Weight (Wi)	Indicator Merit Score (S*Wi)		Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)		
						UGTMF	WRSA	UGTMF	WRSA		UGTMF	WRSA		UGTMF	WRSA	
Social	Population at Risk	Worker safety and human health during construction, operation, and closure.	Material to surface	Tonnage	Mt	4.4	0.0	1.0	6.0	1	1	6	1	1.0	6.0	
								Total indicator merit score (Σ(S × Wi))			1.0	6.0		**1.0**	**6.0**	**Total sub-account merit score (Σ(Rs × Ws))**
								Subaccount merit rating (Rs = Σ(S×Wi)/ ΣWi)			1.0	6.0		**1.0**	**6.0**	**Account merit rating (Ra = Σ(Rs×Ws)/ ΣWs)**

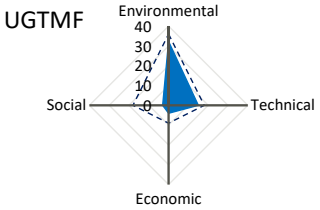
ECCC Weighting

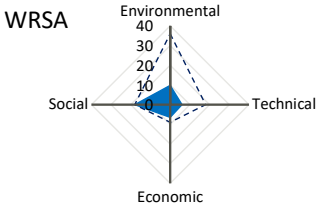
Account	Account Weight (W_a)	Account Merit Rating (R_a)		Account Merit Score (R_a*W_a)		
		UGTMF	WRSA	UGTMF	WRSA	
Environmental	6	5.4	1.6	32.3	9.8	
Technical	3	5.0	2.0	15.0	6.0	
Economic	1.5	2.7	4.3	4.0	6.5	
Social	3	1.0	6.0	3.0	18.0	
	13.5			**54.3**	**40.3**	**Total account merit score (Σ(Ra × Wa))**
				4.0	**3.0**	**Alternative merit rating (A = Σ(Ra×Wa)/ ΣWa)**
				1	**2**	**Rank**

Table C-5: Gypsum Alternatives Assessment, Multiple Accounts Analysis Sensitivity

ECCC Weighting

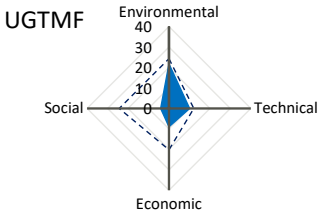
Account	Weight	Account Merit Weighting		Account Merit Score		
		UGTMF	WRSA	UGTMF	WRSA	
Environmental	6	5.4	1.6	32.3	9.8	
Technical	3	5.0	2.0	15.0	6.0	
Economic	1.5	2.7	4.3	4.0	6.5	
Social	3	1.0	6.0	3.0	18.0	
	13.5			54.3	40.3	Total Account Merit Score
				4.0	3.0	Account Merit Rating
				1	**2**	**Rank**

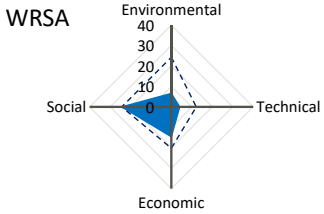




NexGen Weighting

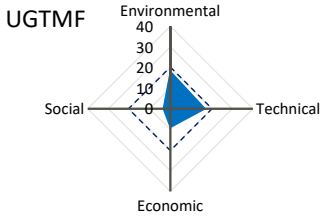
Account	Weight	Account Merit		Account Merit Score		
		UGTMF	WRSA	UGTMF	WRSA	
Environmental	4.1	5.4	1.6	21.8	6.6	
Technical	2.0	5.0	2.0	10.1	4.1	
Economic	3.4	2.7	4.3	9.0	14.6	
Social	4.1	1.0	6.0	4.1	24.3	
	13.5			44.9	49.6	Total Account Merit Score
				3.3	3.7	Account Merit Rating
				2	**1**	**Rank**

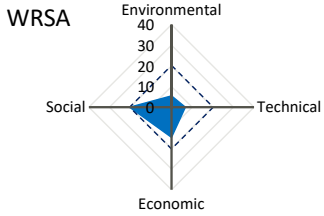




Equal Weighting

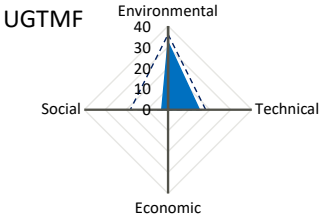
Account	Weight	Account Merit		Account Merit Score		
		UGTMF	WRSA	UGTMF	WRSA	
Environmental	3.4	5.4	1.6	18.1	5.5	
Technical	3.4	5.0	2.0	16.9	6.8	
Economic	3.4	2.7	4.3	9.0	14.6	
Social	3.4	1.0	6.0	3.4	20.3	
	13.5			47.4	47.1	Total Account Merit Score
				3.5	3.5	Account Merit Rating
				1	**2**	**Rank**

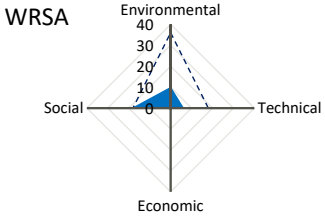




ECCC Weighting with Economic = 0

Account	Weight	Account Merit		Account Merit Score		
		UGTMF	WRSA	UGTMF	WRSA	
Environmental	6	5.4	1.6	32.3	9.8	
Technical	3	5.0	2.0	15.0	6.0	
Economic	0	2.7	4.3	0.0	0.0	
Social	3	1.0	6.0	3.0	18.0	
	12			50.3	33.8	Total Account Merit Score
				4.2	2.8	Account Merit Rating
				1	**2**	**Rank**





APPENDIX D

Waste Rock Alternatives Assessment

Table D-1: Waste Rock Alternatives Assessment, Pre-screening for General Location

Pre-screening Criteria	General Locations				
	Underground	In-Pit	Surface	Off-site	In-Lake
Has required storage capacity	Fatally flawed - volume incompatibility (i.e. excavation generates more waste rock than can be stored)	Fatally flawed - volume incompatibility (i.e. excavation generates more waste rock than can be stored)	Yes	Yes	Yes
No waste in lake (NexGen).	Aligned	Aligned	Aligned	Aligned	Fatally flawed
Area of impact.	None	Additional surface disturbance area	Additional surface disturbance area	Increase in overall surface disturbance area outside proposed Project surface lease boundary	Minimal surface disturbance area
Quantity of waste rock generated.	Not applicable	Not applicable	No change	No change	No change
Result	**Eliminated**	**Eliminated**	**Pass**	**Eliminated**	**Eliminated**

Note: red text indicates a relative disadvantage.

Table D-2: Waste Rock Alternatives Assessment, Sub-account and Indicator Weighting Summary for Specific Location Screening

Account	Sub-account	Sub-account Weight (Ws)	Indicator	Indicator Weight (Wi)
Environmental	Ecological Integrity	6	Surface area of impact.	1
			Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	1
	Hydrologic Regime	1	Surface water - potential for contact water management.	3
			Groundwater - potential for contact water management.	1
	Air Quality	1	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	1
Technical	Operational Risk and Complexity	1	Operation and maintenance for transport and disposal system.	1
			Water balance and management during seasonal changes.	1
Economic	Operating Cost	2	Transport and placement.	1
			Energy use for transport – diesel (haul).	1
			Water use.	1
	Closure Cost	1	Facility closure.	1
Social	Population at Risk	1	Worker safety and human health during construction, operation, and closure.	1

Table D-3: Waste Rock Alternatives Assessment, Screening for Specific Location

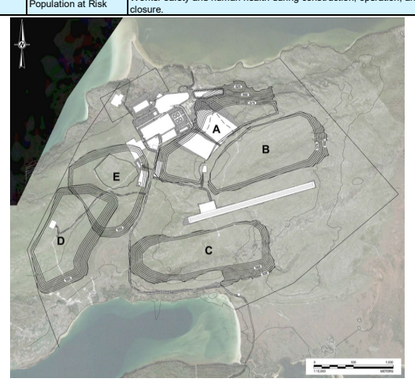
Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity					Indicator Value (S)					Indicator Weight (Wi)	Indicator Merit Score (S*Wi)					Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)					
						A	B	C	D	E	A	B	C	D	E		A	B	C	D	E		A	B	C	D	E	
Environmental	Ecological Integrity	**Surface area of impact.**	**Measured as the 2D surface area of the WRSA, with the lowest surface area preferred for least potential impact.**	**Area**	**ha**	87	91	104	91	86	5.7	4.5	1.0	4.5	6.0	1	5.7	4.5	1.0	4.5	6.0	6	28.8	31.6	6.0	25.4	30.7	
		Potential for impact to plant, fish, and other wildlife population and habitat during construction, operation, and closure.	Measured as distance from WRSA centroid to Patterson Lake, with the longest distance preferred for least potential impact.	Distance	km	1.0	1.2	0.7	1.0	1.0	3.9	6.0	1.0	3.9	4.2	1	3.9	6.0	1.0	3.9	4.2							
																Total indicator merit score (Σ{S × Wi})	**9.6**	**10.5**	**2.0**	**8.5**	**10.2**							
																Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	**4.8**	**5.3**	**1.0**	**4.2**	**5.1**							
	Hydrologic Regime	Surface water - potential for contact water management.	*see below	Value	#	-	-	-	-	-	6.0	3.0	1.0	1.0	1.0	3	18.0	9.0	3.0	3.0	3.0	1	6.0	3.0	1.0	1.0	1.0	
		Groundwater - potential for contact water management.	*see below	Value	#	-	-	-	-	-	6.0	3.0	1.0	1.0	1.0	1	6.0	3.0	1.0	1.0	1.0							
																Total indicator merit score (Σ{S × Wi})	**24.0**	**12.0**	**4.0**	**4.0**	**4.0**							
																Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	**6.0**	**3.0**	**1.0**	**1.0**	**1.0**							
	Air Quality	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	Measured as distance from shaft to WRSA centroid, with the shortest distance preferred for least potential emissions.	Distance	km	0.9	1.6	2.0	2.2	1.4	6.0	3.2	1.7	1.0	3.8	1	6.0	3.2	1.7	1.0	3.8	1	6.0	3.2	1.7	1.0	3.8	
																Total indicator merit score (Σ{S × Wi})	**6.0**	**3.2**	**1.7**	**1.0**	**3.8**		**40.8**	**37.9**	**8.7**	**27.4**	**35.5**	**Total sub-account merit score (Σ{Rs × Ws})**
																Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	**6.0**	**3.2**	**1.7**	**1.0**	**3.8**		**5.1**	**4.7**	**1.1**	**3.4**	**4.4**	**Account merit rating (Ra = Σ{Rs×Ws}/ ΣWs)**

Indicator	Value	Descriptor
Surface water - potential for contact water management.	6 (Best)	Greatest setback from proposed Project surface lease boundary, infrastructure, wetland, and Patterson Lake, and shallow gradient beyond toe.
	5	
	4	
	3	
	2	
	1 (Worst)	Least setback from proposed Project surface lease boundary, infrastructure, wetland and Patterson Lake, and steep gradient beyond toe.
Groundwater - potential for contact water management.	6 (Best)	Greatest setback from proposed Project surface lease boundary, infrastructure, wetland, and Patterson Lake, and shallow gradient beyond toe.
	5	
	4	
	3	
	2	
	1 (Worst)	Least setback from proposed Project surface lease boundary, infrastructure, wetland and Patterson Lake, and steep gradient beyond toe.

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity					Indicator Value (S)					Indicator Weight (Wi)	Indicator Merit Score (S*Wi)					Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)					
						A	B	C	D	E	A	B	C	D	E		A	B	C	D	E		A	B	C	D	E	
Technical	Operational Risk and Complexity	Operation and maintenance for transport and disposal system.	Measured as distance from shaft to WRSA centroid, with the shortest distance preferred for least operation and maintenance potential.	Distance	km	0.9	1.6	2.0	2.2	1.4	6.0	3.2	1.7	1.0	3.8	1	6.0	3.2	1.7	1.0	3.8	1	3.6	4.6	1.4	1.7	2.9	
		Water balance and management during seasonal changes.	Measured as distance from WRSA toe to Patterson Lake, with the longest distance preferred for greater seasonal change management.	Distance	km	0.5	0.9	0.5	0.6	0.6	1.1	6.0	1.0	2.3	1.9	1	1.1	6.0	1.0	2.3	1.9							
																Total indicator merit score (Σ{S × Wi})	**7.1**	**9.2**	**2.7**	**3.3**	**5.7**		**3.6**	**4.6**	**1.4**	**1.7**	**2.9**	**Total sub-account merit score (Σ{Rs × Ws})**
																Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	**3.6**	**4.6**	**1.4**	**1.7**	**2.9**		**3.6**	**4.6**	**1.4**	**1.7**	**2.9**	**Account merit rating (Ra = Σ{Rs×Ws}/ ΣWs)**

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity					Indicator Value (S)					Indicator Weight (Wi)	Indicator Merit Score (S*Wi)					Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)					
						A	B	C	D	E	A	B	C	D	E		A	B	C	D	E		A	B	C	D	E	
Economic	Operating Cost	Transport and placement.	Measured as distance from shaft to WRSA centroid, with the shortest distance preferred for least transport and placement cost.	Distance	km	0.9	1.6	2.0	2.2	1.4	6.0	3.2	1.7	1.0	3.8	1	6.0	3.2	1.7	1.0	3.8	2	8.7	5.0	4.5	3.7	9.1	
		Energy use for transport – diesel (haul).	Measured as vertical elevation change from shaft to WRSA crest, with the least elevation change preferred for least energy use during transport and subsequent equipment maintenance.	Elevation Change	m	48.5	48	38	37	26	1.0	1.1	3.3	3.6	6.0	1	1.0	1.1	3.3	3.6	6.0							
		Water use.	Measured as distance from shaft to WRSA centroid, with the shortest distance preferred for less dust suppression water use required.	Distance	km	0.9	1.6	2.0	2.2	1.4	6.0	3.2	1.7	1.0	3.8	1	6.0	3.2	1.7	1.0	3.8							
																Total indicator merit score (Σ{S × Wi})	**13.0**	**7.6**	**6.8**	**5.6**	**13.6**							
																Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	**4.3**	**2.5**	**2.3**	**1.9**	**4.5**							
	Closure Cost	Facility closure.	Measured as 3D cover placement area, with the lowest surface area preferred for less cover system placement.	Area	ha	88	92	105	92	86	5.6	4.6	1.0	4.5	6.0	1	5.6	4.6	1.0	4.5	6.0	1	5.6	4.6	1.0	4.5	6.0	
																Total indicator merit score (Σ{S × Wi})	**5.6**	**4.6**	**1.0**	**4.5**	**6.0**		**14.2**	**9.6**	**5.5**	**8.2**	**15.1**	**Total sub-account merit score (Σ{Rs × Ws})**
																Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	**5.6**	**4.6**	**1.0**	**4.5**	**6.0**		**4.7**	**3.2**	**1.8**	**2.7**	**5.0**	**Account merit rating (Ra = Σ{Rs×Ws}/ ΣWs)**

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity					Indicator Value (S)					Indicator Weight (Wi)	Indicator Merit Score (S*Wi)					Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)					
						A	B	C	D	E	A	B	C	D	E		A	B	C	D	E		A	B	C	D	E	
Social	Population at Risk	Worker safety and human health during construction, operation, and closure.	Measured as distance from shaft to WRSA centroid, with the least distance preferred to reduce number of workers exposed.	Distance	km	0.9	1.6	2.0	2.2	1.4	6.0	3.2	1.7	1.0	3.8	1	6.0	3.2	1.7	1.0	3.8	1	6.0	3.2	1.7	1.0	3.8	
																Total indicator merit score (Σ{S × Wi})	**6.0**	**3.2**	**1.7**	**1.0**	**3.8**		**6.0**	**3.2**	**1.7**	**1.0**	**3.8**	**Total sub-account merit score (Σ{Rs × Ws})**
																Subaccount merit rating (Rs = Σ{S×Wi}/ ΣWi)	**6.0**	**3.2**	**1.7**	**1.0**	**3.8**		**6.0**	**3.2**	**1.7**	**1.0**	**3.8**	**Account merit rating (Ra = Σ{Rs×Ws}/ ΣWs)**



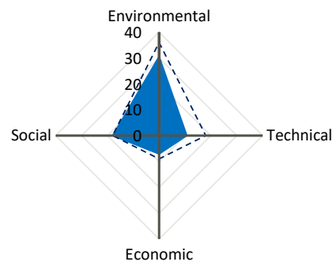
ECCC Weighting	Account	Account Weight (Wa)	Account Merit Rating (Ra)					Account Merit Score (Rs*Wa)					
			A	B	C	D	E	A	B	C	D	E	
44%	Environmental	6	5.1	4.7	1.1	3.4	4.4	30.6	28.4	6.5	20.6	26.6	
22%	Technical	3	3.6	4.6	1.4	1.7	2.9	10.7	13.8	4.1	5.0	8.6	
11%	Economic	1.5	4.7	3.2	1.8	2.7	5.0	7.1	4.8	2.8	4.1	7.5	
22%	Social	3	6.0	3.2	1.7	1.0	3.8	18.0	9.7	5.1	3.0	11.4	
100%	Total	13.5						**66**	**57**	**18**	**33**	**54**	**Total account merit score (Σ{Ra × Wa})**
								4.9	**4.2**	**1.4**	**2.4**	**4.0**	**Alternative merit rating (A = Σ{Ra×Wa}/ ΣWa)**
								1	**2**	**5**	**4**	**3**	**Rank**

Table D-4: Waste Rock Alternatives Assessment, Specific Location Screening Result Summary

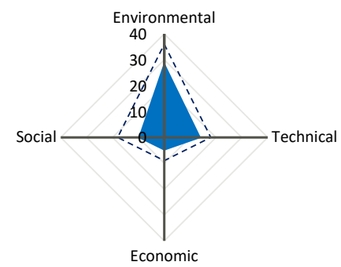
ECCC Weighting

Account	Account Weight	Account Merit Weighting					Account Merit Score				
		A	B	C	D	E	A	B	C	D	E
Environmental	6	5.1	4.7	1.1	3.4	4.4	31	28	7	21	27
Technical	3	3.6	4.6	1.4	1.7	2.9	11	14	4	5	9
Economic	1.5	4.7	3.2	1.8	2.7	5.0	7	5	3	4	8
Social	3	6.0	3.2	1.7	1.0	3.8	18	10	5	3	11
						Total Account Merit Score	**66**	**57**	**18**	**33**	**54**
						Alternative Merit Rating	**4.9**	**4.2**	**1.4**	**2.4**	**4.0**
						Rank	**1**	**2**	**5**	**4**	**3**

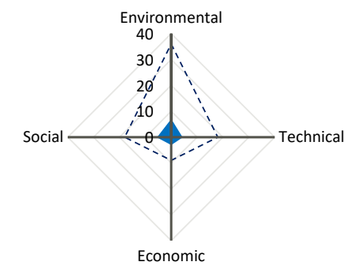
WRSA
Location A



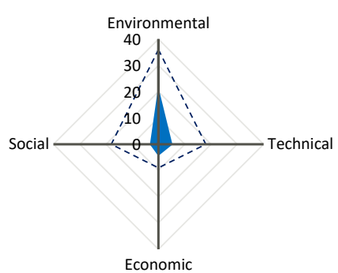
WRSA
Location B



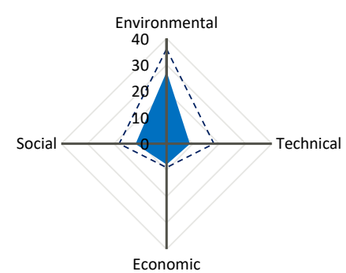
WRSA
Location C



WRSA
Location D



WRSA
Location E



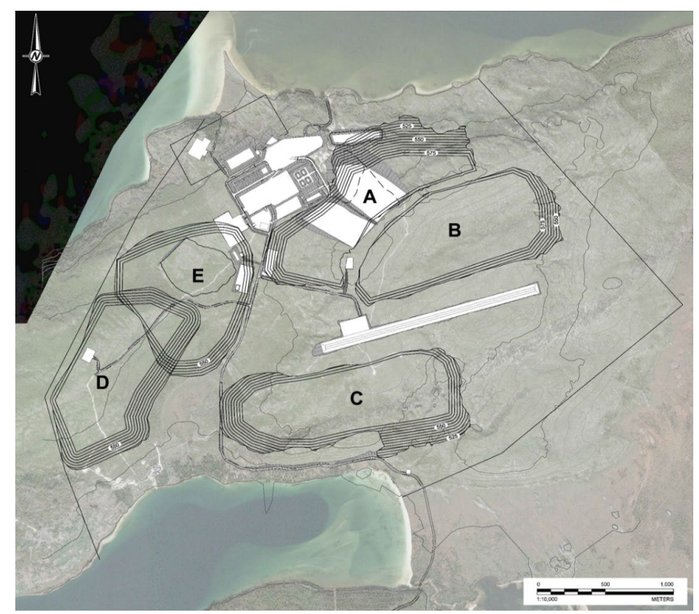


Table D-5: Waste Rock Alternatives Assessment, Sub-account and Indicator Weighting Summary for Multiple Accounts Analysis

Account	Sub-account	Sub-account Weight (Ws)	Indicator	Indicator Weight (Wi)
Environmental	Ecological Integrity	6	Surface area of impact, borrow for engineered layers.	1
			Potential for impact to Patterson Lake during operation.	2
			Potential for impact to Patterson Lake during closure.	6
	Air Quality	1	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	1
Technical	Design and Reliability	6	Facility design effort.	1
			Proven precedent for technology and configuration.	6
			Compliance with SERM (2000) draft guidelines.	4
			Difference in mass (engineered layers).	1
	Construction Risk and Complexity	2	Liner area.	1
			Water management infrastructure (number of systems to be constructed).	1
	Operational Risk and Complexity	3	Operation and maintenance for transport and disposal system.	1
			Water balance and management during seasonal changes.	1
			Potential for progressive facility closure during operation.	1
	Closure Risk and Complexity	1	Ease of decommissioning. Number of facilities.	1
	Flexibility	2	Effort required for expansion, optimization, and design changes.	1
Economic	Capital Cost	4	Liner procurement and installation.	1
	Operating Cost	2	Water treatment (capture by lined alternatives).	1
			Engineered layers.	2
	Closure Cost	1	Facility closure.	1
			Water treatment.	1
Social	Community Impact	1	Change in local employment opportunities.	1
	Change in Land Use	1	Local resource consumption as borrow source(s) for construction.	1
	Population at Risk	1	Health risk to people downstream.	1
			Worker safety and human health during construction, operation, and closure.	1

Table D-6: Waste Rock Alternatives Assessment, Multiple Accounts Analysis

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity						Indicator Value (S)						Indicator Weight (Wi)	Indicator Merit Score (S*Wi)						Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)					
						1a	1b	1c	1d	2a	2b	1a	1b	1c	1d	2a	2b		1a	1b	1c	1d	2a	2b		1a	1b	1c	1d	2a	2b
Environmental	Ecological Integrity	Surface area of impact, borrow for engineered layers.	Borrow for engineered layers	Mass	Mt	0.0	0.0	2.5	2.5	0.0	1.1	6	6	1	1	6	4	1	6.0	6.0	1.0	1.0	6.0	3.9	6	9.3	16.0	26.0	32.7	16.0	34.6
		Potential for impact to Patterson Lake during operation.	Peak concentration of copper during operation reporting to Patterson Lake	Concentration Copper	ug/L	4.0	0.0	4.0	0.0	0.0	0.0	1	6	1	6	6	6	2	2.0	12.0	2.0	12.0	12.0	12.0							
		Potential for impact to Patterson Lake during closure.	Concentration of cobalt (highest exceedance of CCME concentration limits)	Concentration Cobalt	ug/L	3.8	3.8	0.0	0.0	3.8	0.0	1	1	6	6	1	6	6	6.0	6.0	36.0	36.0	6.0	36.0							
																		Total indicator merit score (Σ(Si * Wi))	14.0	24.0	39.0	49.0	24.0	51.9							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	1.6	2.7	4.3	5.4	2.7	5.8							
	Air Quality	Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	*see below	Value	#	-	-	-	-	-	-	1	1	6	6	1	4	1	1.0	1.0	6.0	6.0	1.0	4.0	1	1.0	1.0	6.0	6.0	1.0	4.0
																		Total indicator merit score (Σ(Si * Wi))	1.0	1.0	6.0	6.0	1.0	4.0							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	1.0	1.0	6.0	6.0	1.0	4.0							

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Sub-account Merit Score (Rs*Ws)						
						1a	1b	1c	1d	2a	2b	
Environmental	Ecological Integrity	Surface area of impact, borrow for engineered layers.	Borrow for engineered layers	Mass	Mt	10.3	17.0	32.0	38.7	17.0	38.6	Total sub-account merit score (Σ(Rs * Ws))
						1.5	2.4	4.6	5.5	2.4	5.5	Account merit rating (Ra = Σ(Rs*Ws)/ ΣWs)

Indicator	Value	Descriptor
Potential for excessive emissions of fugitive dust (e.g. particulates, heavy metals) and other non-GHG emissions during construction and operation.	6 (Best)	Bottom-up construction method
	5	
	4	
	3	
	2	
	1 (Worst)	End dumped construction method

1. Unsegregated
   a. Base Case (unlined)
   b. Base Case (lined)
   c. Engineered Source Control (unlined)
   d. Engineered Source Control (lined)
2. Segregated
   a. NPAG (unlined) + PAG (lined)
   b. NPAG (unlined) + PAG (engineered source control, lined)

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity						Indicator Value (S)						Indicator Weight (Wi)	Indicator Merit Score (S*Wi)						Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)					
						1a	1b	1c	1d	2a	2b	1a	1b	1c	1d	2a	2b		1a	1b	1c	1d	2a	2b		1a	1b	1c	1d	2a	2b
Technical	Design and Reliability	Facility design effort.	*see below	Value	#	-	-	-	-	-	-	6	5	4	3	2	1	1	6.0	5.0	4.0	3.0	2.0	1.0	6	11.0	32.5	13.5	29.0	31.0	32.4
		Proven precedent for technology and configuration.	*see below	Value	#	-	-	-	-	-	-	1	5	3	5	5	6	6	6.0	30.0	18.0	30.0	30.0	36.0							
		Compliance with SERM (2000) draft guidelines.	*see below	Value	#	-	-	-	-	-	-	1	6	1	6	6	6	4	4.0	24.0	4.0	24.0	24.0	24.0							
		Difference in mass (engineered layers).	Mass engineered layers	Tonnage	Mt	0.0	0.0	2.5	2.5	0.0	1.1	6	6	1	1	6	4	1	6.0	6.0	1.0	1.0	6.0	3.9							
																		Total indicator merit score (Σ(Si * Wi))	22.0	65.0	27.0	58.0	62.0	64.9							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	1.8	5.4	2.3	4.8	5.2	5.4							
	Construction Risk and Complexity	Liner area.	Liner Area	Liner Area	ha	0	87	0	87	37	37	6	1	6	1	4	4	1	6.0	1.0	6.0	1.0	3.9	3.9	2	12.0	7.0	12.0	7.0	4.9	4.9
		Water management infrastructure (number of systems to be constructed).	Number of Facilities	Number of Facilities	Count	1	1	1	1	2	2	6	6	6	6	1	1	1	6.0	6.0	6.0	6.0	1.0	1.0							
																		Total indicator merit score (Σ(Si * Wi))	12.0	7.0	12.0	7.0	4.9	4.9							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	6.0	3.5	6.0	3.5	2.5	2.5							
	Operational Risk and Complexity	Operation and maintenance for transport and disposal system.	*see below	Value	#	-	-	-	-	-	-	6	5	4	3	2	1	1	6.0	5.0	4.0	3.0	2.0	1.0	3	13.0	12.0	14.0	12.0	8.0	8.0
		Water management.	Number of Facilities	Number of Facilities	Count	1	1	1	1	2	2	6	6	6	6	1	1	1	6.0	6.0	6.0	6.0	1.0	1.0							
		Potential for progressive facility closure during operation.	*see below	Value	#	-	-	-	-	-	-	1	1	4	3	5	6	1	1.0	1.0	4.0	3.0	5.0	6.0							
																		Total indicator merit score (Σ(Si * Wi))	13.0	12.0	14.0	12.0	8.0	8.0							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	4.3	4.0	4.7	4.0	2.7	2.7							
	Closure Risk and Complexity	Ease of decommissioning. Number of facilities.	*see below	Number of Facilities	Count	1	1	1	1	2	2	6	6	6	6	1	1	1	6.0	6.0	6.0	6.0	1.0	1.0	1	6.0	6.0	6.0	6.0	1.0	1.0
																		Total indicator merit score (Σ(Si * Wi))	6.0	6.0	6.0	6.0	1.0	1.0							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	6.0	6.0	6.0	6.0	1.0	1.0							
	Flexibility	Effort required for expansion, optimization, and design changes.	*see below	Value	#	-	-	-	-	-	-	6	3	4	2	3	1	1	6.0	3.0	4.0	2.0	3.0	1.0	2	12.0	6.0	8.0	4.0	6.0	2.0
																		Total indicator merit score (Σ(Si * Wi))	6.0	3.0	4.0	2.0	3.0	1.0							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	6.0	3.0	4.0	2.0	3.0	1.0							

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Sub-account Merit Score (Rs*Ws)						
						1a	1b	1c	1d	2a	2b	
Technical	Design and Reliability	Facility design effort.	*see below	Value	#	54.0	63.5		53.5	58.0	50.9	48.3 Total sub-account merit score (Σ(Rs * Ws))
						3.9	4.5		3.8	4.1	3.6	3.5 Account merit rating (Ra = Σ(Rs*Ws)/ ΣWs)

Indicator	Value	Descriptor
Facility design effort.	6 (Best)	1a Least design effort, unsegregated + unlined
	5	1b unsegregated + lined
	4	1c unsegregated + engineered source control
	3	1d unsegregated + lined + engineered source control
	2	2a Segregated + lined
	1 (Worst)	2b Greatest design effort, segregated + lined + engineered source control
Proven precedent for technology and configuration.	6 (Best)	Proven precedent + potential unproven benefit
	5	Proven precedent
	4	
	3	Unproven but potential benefit
	2	
	1 (Worst)	Proven not to work
Compliance with SERM (2000) draft guidelines.	6 (Best)	Complies
	5	
	4	
	3	
	2	
	1 (Worst)	Does not comply
Operation and maintenance for transport and disposal system.	6 (Best)	1a load, haul, dump, push
	5	1b load, haul, dump, push over liner
	4	1c load, haul, dump, spread waste rock, plus load, haul, dump, spread engineered layers
	3	1d load, haul, dump, spread waste rock, plus load, haul, dump, spread engineered layers, place liner
	2	2a load, haul, dump, with 2 work fronts requiring spreading, over liner
	1 (Worst)	2b load, haul, dump, spread waste rock (PAG), push waste rock (NAG), plus load, haul, dump, spread engineered layers, over liner
Potential for progressive facility closure during operation.	6 (Best)	Greatest potential for progressive closure
	5	
	4	
	3	
	2	
	1 (Worst)	Least potential for progressive closure
Effort required for expansion, optimization, and design changes.	6 (Best)	Least effort to expand - no liner or engineered source control, one pile
	5	
	4	
	3	
	2	
	1 (Worst)	Greatest effort to expand - liner, 2 facility, engineered source control

Alternatives:
1. Unsegregated
   a. Base Case (unlined)
   b. Base Case (lined)
   c. Engineered Source Control (unlined)
   d. Engineered Source Control (lined)
2. Segregated
   a. NPAG (unlined) + PAG (lined)
   b. NPAG (unlined) + PAG (engineered source control, lined)

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity						Indicator Value (S)						Indicator Weight (Wi)	Indicator Merit Score (S*Wi)						Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)					
						1a	1b	1c	1d	2a	2b	1a	1b	1c	1d	2a	2b		1a	1b	1c	1d	2a	2b		1a	1b	1c	1d	2a	2b
Economic	Capital Cost	Liner procurement and installation.	Liner Area	Area	ha	0	87	0	87	37	37	6.0	1.0	6.0	1.0	3.9	3.9	1	6.0	1.0	6.0	1.0	3.9	3.9	4	24.0	4.0	24.0	4.0	15.5	15.5
																		Total indicator merit score (Σ(Si * Wi))	6.0	1.0	6.0	1.0	3.9	3.9							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	6.0	1.0	6.0	1.0	3.9	3.9							
	Operating Cost	Water treatment (capture by lined alternatives).	Volume	Treated per year	$M m^3/year$	0.0	0.1	0.0	0.9	0.6	0.4	6.0	5.1	6.0	1.0	2.3	3.9	1	6.0	5.1	6.0	1.0	2.3	3.9	2	12.0	11.4	5.3	2.0	9.6	7.8
		Engineered layers.	Fine Material	Mass	Mt	0.0	0.0	2.5	2.5	0.0	1.1	6.0	6.0	1.0	1.0	6.0	3.9	2	12.0	12.0	2.0	2.0	12.0	7.8							
																		Total indicator merit score (Σ(Si * Wi))	18.0	17.1	8.0	3.0	14.3	11.6							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	6.0	5.7	2.7	1.0	4.8	3.9							
	Closure Cost	Facility closure.	Number of Facilities	Number of Facilities	Count	1.0	1.0	1.0	1.0	2.0	2.0	6.0	6.0	6.0	6.0	1.0	1.0	1	6.0	6.0	6.0	6.0	1.0	1.0	1	3.5	3.5	6.0	6.0	1.0	3.5
		Water treatment.	*see below	Value	#	-	-	-	-	-	-	1.0	1.0	6.0	6.0	1.0	6.0	1	1.0	1.0	6.0	6.0	1.0	6.0							
																		Total indicator merit score (Σ(Si * Wi))	7.0	7.0	12.0	12.0	2.0	7.0							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	3.5	3.5	6.0	6.0	1.0	3.5							

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Sub-account Merit Score (Rs*Ws)						
						1a	1b	1c	1d	2a	2b	
Economic	Capital Cost	Liner procurement and installation.	Liner Area	Area	ha	39.5	18.9		35.3	12.0	25.1	26.8 Total sub-account merit score (Σ(Rs * Ws))
						5.6	2.7		5.0	1.7	3.7	3.8 Account merit rating (Ra = Σ(Rs*Ws)/ ΣWs)

Indicator	Value	Descriptor
Water treatment.	6 (Best)	Lowest cost for water treatment (engineered source control)
	5	
	4	
	3	
	2	
	1 (Worst)	Highest cost for water treatment (no engineered source control)

Alternatives:
1. Unsegregated
   a. Base Case (unlined)
   b. Base Case (lined)
   c. Engineered Source Control (unlined)
   d. Engineered Source Control (lined)
2. Segregated
   a. NPAG (unlined) + PAG (lined)
   b. NPAG (unlined) + PAG (engineered source control, lined)

Account	Sub-account	Indicator	Description	Indicator Parameter	Unit	Indicator Quantity						Indicator Value (S)						Indicator Weight (Wi)	Indicator Merit Score (S*Wi)						Sub-account Weight (Ws)	Sub-account Merit Score (Rs*Ws)					
						1a	1b	1c	1d	2a	2b	1a	1b	1c	1d	2a	2b		1a	1b	1c	1d	2a	2b		1a	1b	1c	1d	2a	2b
Social	Community Impact	Change in local employment opportunities.	*see below	Value	#	-	-	-	-	-	-	1.0	3.0	4.0	6.0	2.0	5.0	1	1.0	3.0	4.0	6.0	2.0	5.0	1	1.0	3.0	4.0	6.0	2.0	5.0
																		Total indicator merit score (Σ(Si * Wi))	1.0	3.0	4.0	6.0	2.0	5.0							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	1.0	3.0	4.0	6.0	2.0	5.0							
	Change in Land Use	Local resource consumption as borrow source(s) for construction.	Fine Material for Engineered Layers	Tonnage	Mt	0.0	0.0	2.5	2.5	0.0	1.1	6.0	6.0	1.0	1.0	6.0	3.9	1	6.0	6.0	1.0	1.0	6.0	3.9	1	6.0	6.0	1.0	1.0	6.0	3.9
																		Total indicator merit score (Σ(Si * Wi))	6.0	6.0	1.0	1.0	6.0	3.9							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	6.0	6.0	1.0	1.0	6.0	3.9							
	Population at Risk	Health risk to people downstream.	*see below	Value	#	-	-	-	-	-	-	1.0	5.0	3.0	6.0	4.0	5.0	1	1.0	5.0	3.0	6.0	4.0	5.0	1	1.0	3.0	4.5	6.0	2.5	4.0
		Worker safety and human health during construction, operation, and closure.	*see below	Value	#	-	-	-	-	-	-	1.0	1.0	6.0	6.0	1.0	3.0	1	1.0	1.0	6.0	6.0	1.0	3.0							
																		Total indicator merit score (Σ(Si * Wi))	2.0	6.0	9.0	12.0	5.0	8.0							
																		Subaccount merit rating (Rs = Σ(Si*Wi)/ ΣWi)	1.0	3.0	4.5	6.0	2.5	4.0							

Sub-account	Sub-account Merit Score (Rs*Ws)						
	1a	1b	1c	1d	2a	2b	
Community Impact	8.0	12.0		9.5	13.0	10.5	12.9 Total sub-account merit score (Σ(Rs * Ws))
	2.7	4.0		3.2	4.3	3.5	4.3 Account merit rating (Ra = Σ(Rs*Ws)/ ΣWs)

Indicator	Value	Descriptor
Change in local employment opportunities.	6 (Best)	Specialized labor for liner installation, + placement of engineered layers
	5	Some (partial) liner placement + some engineered layer placement
	4	Unlined + engineered layer placement
	3	Lined
	2	Some (partial) liner
	1 (Worst)	No liner or engineered layers
Health risk to people downstream.	6 (Best)	Least risk due to most engineering controls for water management
	5	Fully lined
	4	Partially Lined
	3	Engineered source control
	2	
	1 (Worst)	Highest risk due to fewest engineering controls for water management
Worker safety and human health during construction, operation, and closure.	6 (Best)	Least noise, dust, and equipment exposure
	5	
	4	
	3	
	2	
	1 (Worst)	Greatest noise, dust and equipment exposure

Alternatives:
1. Unsegregated
   a. Base Case (unlined)
   b. Base Case (lined)
   c. Engineered Source Control (unlined)
   d. Engineered Source Control (lined)
2. Segregated
   a. NPAG (unlined) + PAG (lined)
   b. NPAG (unlined) + PAG (engineered source control, lined)

ECCC Weighting

Account	Account Weight (W_a)	Account Merit Rating (R_a)						Account Merit Score (R_a*W_a)								
		1a	1b	1c	1d	2a	2b	1a	1b	1c	1d	2a	2b			
Environmental	6	1.5	2.4	4.6	5.5	2.4	5.5	8.9	14.6	27.4	33.1	14.6	33.1	33.1	8.9	
Technical	3	3.9	4.5	3.8	4.1	3.6	3.5	11.6	13.6	11.5	12.4	10.9	10.4	13.6	10.4	
Economic	1.5	5.6	2.7	5.0	1.7	3.7	3.8	8.5	4.1	7.6	2.6	5.6	5.7	8.5	2.6	
Social	3	2.7	4.0	3.2	4.3	3.5	4.3	8.0	12.0	9.5	13.0	10.5	12.9	13.0	8.0	
	13.5							56.9	44.2	56.0	61.1	41.6	62.1	Total account merit score (Σ(Ra * Wa))		
								2.7	3.3	4.1	4.5	3.1	4.6	Alternative merit rating (A = Σ(Ra*Wa)/ ΣWa)		
								6	4	3	2	5	1	Rank		

Table D-7: Waste Rock Alternatives Assessment, Multiple Accounts Analysis, Sensitivity

ECCC Weighting

Account	Weight	Account Merit Weighting						Account Merit Score					
		1a	1b	1c	1d	2a	2b	1a	1b	1c	1d	2a	2b
Environmental	6	1.5	2.4	4.6	5.5	2.4	5.5	8.9	14.6	27.4	33.1	14.6	33.1
Technical	3	3.9	4.5	3.8	4.1	3.6	3.5	11.6	13.6	11.5	12.4	10.9	10.4
Economic	1.5	5.6	2.7	5.0	1.7	3.7	3.8	8.5	4.1	7.6	2.6	5.6	5.7
Social	3	2.7	4.0	3.2	4.3	3.5	4.3	8.0	12.0	9.5	13.0	10.5	12.9
	13.5						Total Account Merit Score	36.9	44.2	56.0	61.1	41.6	62.1
							Account Merit Rating	2.7	3.3	4.1	4.5	3.1	4.6
							Rank	**6**	**4**	**3**	**2**	**5**	**1**

NexGen Weighting

Account	Weight	Account Merit Rating						Account Merit Score					
		1a	1b	1c	1d	2a	2b	1a	1b	1c	1d	2a	2b
Environmental	4.1	1.5	2.4	4.6	5.5	2.4	5.5	6.0	9.8	18.5	22.4	9.8	22.3
Technical	2.0	3.9	4.5	3.8	4.1	3.6	3.5	7.8	9.2	7.7	8.4	7.4	7.0
Economic	3.4	5.6	2.7	5.0	1.7	3.7	3.8	19.0	9.1	17.0	5.8	12.6	12.9
Social	4.1	2.7	4.0	3.2	4.3	3.5	4.3	10.8	16.2	12.8	17.6	14.2	17.4
	13.5						Total Account Merit Score	43.6	44.3	56.1	54.1	44.0	59.6
							Account Merit Rating	3.2	3.3	4.2	4.0	3.3	4.4
							Rank	**6**	**4**	**2**	**3**	**5**	**1**

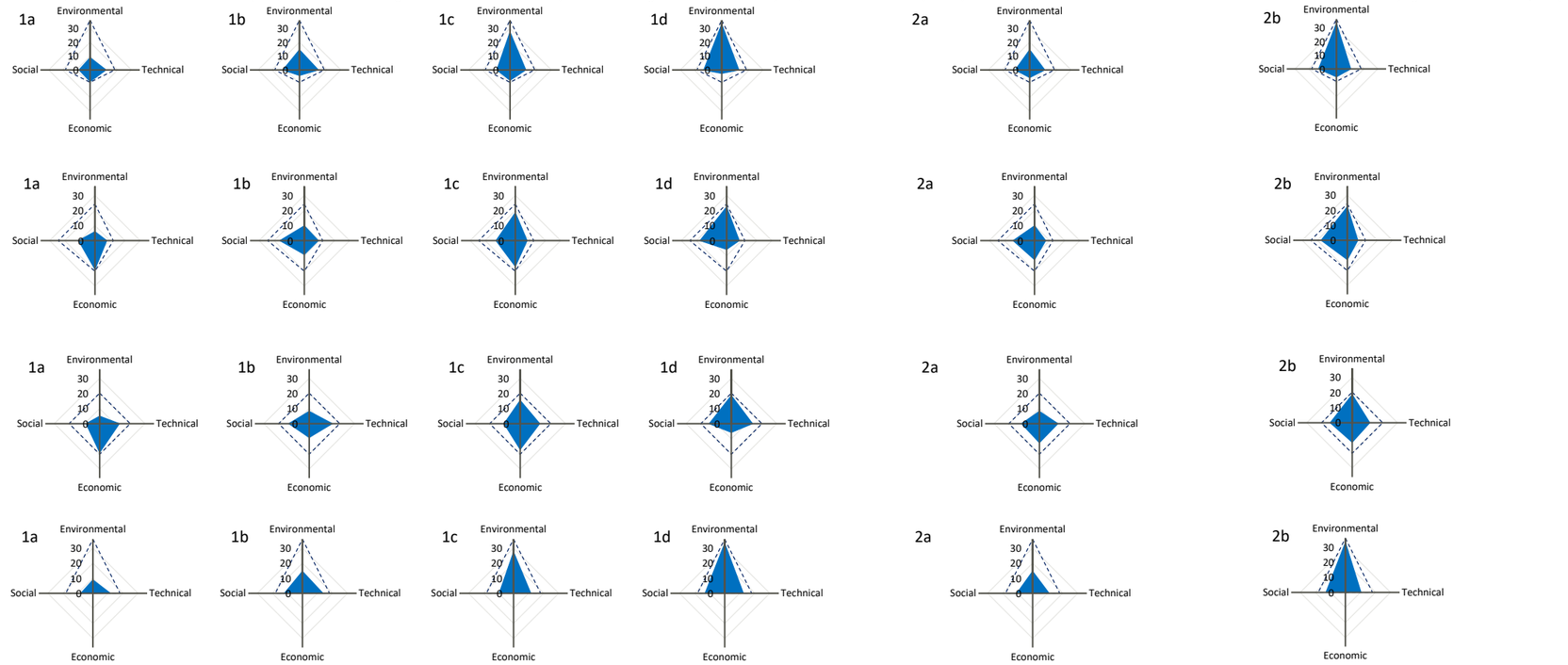
Equal Weighting

Account	Weight	Account Merit Rating						Account Merit Score					
		1a	1b	1c	1d	2a	2b	1a	1b	1c	1d	2a	2b
Environmental	3.4	1.5	2.4	4.6	5.5	2.4	5.5	5.0	8.2	15.4	18.6	8.2	18.6
Technical	3.4	3.9	4.5	3.8	4.1	3.6	3.5	13.0	15.3	12.9	14.0	12.3	11.7
Economic	3.4	5.6	2.7	5.0	1.7	3.7	3.8	19.0	9.1	17.0	5.8	12.6	12.9
Social	3.4	2.7	4.0	3.2	4.3	3.5	4.3	9.0	13.5	10.7	14.6	11.8	14.5
	13.5						Total Account Merit Score	46.0	46.1	56.0	53.0	44.9	57.7
	3.375						Account Merit Rating	3.4	3.4	4.2	3.9	3.3	4.3
							Rank	**5**	**4**	**2**	**3**	**6**	**1**

ECCC Weighting with Economic = 0

Account	Weight	Account Merit Rating						Account Merit Score					
		1a	1b	1c	1d	2a	2b	1a	1b	1c	1d	2a	2b
Environmental	6	1.5	2.4	4.6	5.5	2.4	5.5	8.9	14.6	27.4	33.1	14.6	33.1
Technical	3	3.9	4.5	3.8	4.1	3.6	3.5	11.6	13.6	11.5	12.4	10.9	10.4
Economic	0	5.6	2.7	5.0	1.7	3.7	3.8	0.0	0.0	0.0	0.0	0.0	0.0
Social	3	2.7	4.0	3.2	4.3	3.5	4.3	8.0	12.0	9.5	13.0	10.5	12.9
	12						Total Account Merit Score	28.4	40.2	48.4	58.6	36.0	56.3
							Account Merit Rating	2.4	3.3	4.0	4.9	3.0	4.7
							Rank	**6**	**4**	**3**	**1**	**5**	**2**

1. Unsegregated
a. Base Case (unlined)
b. Base Case (lined)
c. Engineered Source Control (unlined)
d. Engineered Source Control (lined)
2. Segregated
a. NPAG (unlined) + PAG (lined)
b. NPAG (unlined) + PAG (engineered source control, lined)



Alternatives:
1. Unsegregated
a. Base Case (unlined)
b. Base Case (lined)
c. Engineered Source Control (unlined)
d. Engineered Source Control (lined)
2. Segregated
a. NPAG (unlined) + PAG (lined)
b. NPAG (unlined) + PAG (engineered source control, lined)

Rook I Project

Environmental Impact Statement

TSD VIII: Accidents and Malfunctions Report

ACCIDENTS AND MALFUNCTIONS FOR THE ROOK I PROJECT - TECHNICAL SUPPORT DOCUMENT

REPORT PREPARED FOR:

NexGen Energy Ltd.
www.nexgenenergy.ca
Saskatoon, SK

REPORT PREPARED BY:

Ecometrix Incorporated
www.ecometrix.ca
Mississauga, ON

Ref. 19-2574
13 November 2024

Ecometrix | Environmental INTELLIGENCE

ACCIDENTS AND MALFUNCTIONS FOR THE ROOK I PROJECT - TECHNICAL SUPPORT DOCUMENT

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Project Principal and Reviewer

EXECUTIVE SUMMARY

Ecometrix Incorporated (Ecometrix) was retained by NexGen Energy Ltd. (NexGen) to complete the accidents and malfunctions assessment for the NexGen Rook I Project (Project), a proposed uranium mining and milling operation in northwestern Saskatchewan. For reference, the assessment of accidents and malfunctions is intended to provide a clear identification of the potential Project-associated hazards that fall outside the range of "typical" day-to-day events.

This technical support document (TSD) provides the details of that assessment, which is included in the Environmental Impact Statement (EIS) Section 21, Accidents and Malfunctions.

Proposed Project

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

Scope and Objective

The scope of this assessment includes all potential Project-related accidents and malfunctions that may occur during any phase of the Project and transportation-related accidents along the Project access road to Highway 955.

The objective of this assessment was to evaluate the potential effects on the human health and biophysical environment resulting from radiological and conventional accidents and malfunctions with consideration of proposed preventive and mitigative measures.

Assessment Methods

This assessment provides a framework for quantifying the risks associated with these hazards. The five basic steps in the process of risk assessment for the accidents and malfunctions assessment were as follows:

1. **Hazard identification**: the identification of physical situations with the potential for harming human health or the biophysical environment. Hazard scenarios were identified using a systematic approach with consideration of the existence of sources of hazards and initiating events for each project component and activity. Scenarios were identified for several potential events, such as releases of chemical and radiological constituents, fires, and explosions.

2. **Bounding scenarios**: the identified hazard scenarios were then screened qualitatively for the perceived effects and probability of occurrence as well as the potential risk using a risk matrix approach. Project information, experience from similar projects, particularly those located in Northern Saskatchewan, and professional judgment were used for this initial screening. Among the high or moderate-risk scenarios, bounding scenarios were selected. The bounding scenarios encompass the effects of other scenarios screened for each Project component and activity. The subsequent analysis focussed on these bounding scenarios.

3. **Probability analysis**: the estimation of the probability of occurrence of the selected bounding scenario occurring within a specific time period, or in specified circumstances.

4. **Effects analysis**: quantitative evaluation of the potential effects of a selected bounding scenario to the human health or biophysical environment.

5. **Risk estimation and ranking**: the estimation of the effect of a scenario and the probability with which it is likely to occur; that is, risk is the product of effect and probability (risk = consequence × probability of occurrence).

Hazard Identification and Screening

A total of 93 hazard scenarios were identified and screened. From these, six bounding scenarios were identified for further, quantitative analysis. These included three scenarios deemed to be high risk and three scenarios deemed to be moderate risk, based on the initial risk screening process. The six hazard scenarios that were selected as bounding scenarios for more detailed risk analysis are presented in Table ES-1.

Table ES-1: Bounding Scenarios Identified for Further Assessment by the Hazard Identification Process

No.	Accident or Malfunction Scenario	Location	Effect Pathway	Interactions with the Environment
1	Traffic accident (uranium concentrate)	Access road at bridge crossing	Aquatic release of uranium concentrate	Affects the water quality, sediment quality, terrestrial and aquatic biota, and members of the public
2	Traffic accident (chemical)	Access road at bridge crossing	Aquatic release of fuel, hazardous chemicals	Affects the water quality, sediment quality, terrestrial and aquatic biota, and members of the public
3	Solvent extraction fire or explosion	Solvent extraction building	Atmospheric release of uranium concentrate (chemical toxicity)	Affects the air quality, and members of the public
4	Tailings transfer pipe or pump failure	Tailings release to surface within secondary containment	Terrestrial release of radioactivity	Affects the soil and potentially groundwater, and terrestrial biota
5	Untreated effluent transfer pipe failure	Effluent treatment system	Terrestrial release of radioactivity	Affects the soil, groundwater, and terrestrial biota
6	Acid plant tail gas scrubber failure	Acid plant	Atmospheric release of sulphur dioxide	Affects air quality, and members of the public

Assessment of the Overall Risk Associated with the Bounding Scenarios

Detailed quantitative assessment of the six bounding scenarios was completed to reconsider the risks to the biophysical environment. The analysis considered both probability and potential effects to determine the overall level of risk. The results of the assessment are summarized below.

The detailed assessment (Table ES-2) found that the risks of the selected bounding scenarios are low to moderate, and they represent a tolerable level of risk in consideration of proposed safeguards and design features that reduce the risk level to as low as reasonably practical (ALARP).

Table ES-2: Summary of Assessment Results for Bounding Scenarios

No.	Accident or Malfunction Scenario	Location	Probability	Estimated Effects Consequence	Overall Risk Rating
1	Traffic accident (uranium concentrate)	Access road at bridge crossing	Highly unlikely	Moderate	Low risk
2	Traffic accident (chemical)	Access road at bridge crossing	Highly unlikely	Moderate	Low risk
3	Solvent extraction fire or explosion	Solvent extraction building	Unlikely	Minor to moderate	Low risk
4	Tailings transfer pipe or pump failure	Tailings release to surface within secondary containment	Likely	Minor	Low risk
5	Untreated effluent transfer pipe failure	Effluent treatment system	Likely	Minor	Low risk
6	Acid plant tail gas scrubber failure	Acid plant	Likely	Minor to moderate	Low to moderate risk

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Abbreviations

Acronym	Definition
AEGL	Acute Exposure Guideline Level
ALARP	as low as reasonably practicable
ALOHA	areal locations of hazardous atmospheres
ARF	airborne release fraction
ATSDR	Agency for Toxic Substances and Disease Registry
CNSC	Canadian Nuclear Safety Commission
DR	damage ratio
EIS	Environmental Impact Statement
ERPG	Emergency Response Planning Guideline
ETP	effluent treatment plant
HDPE	high density polyethylene
LPF	leak path factor
MAR	material at risk
NexGen	NexGen Energy Ltd.
NPAG WRSA	non-potentially acid generating waste rock storage area
PAG WRSA	potentially acid generating waste rock storage area
pH	potential of hydrogen
Project	Rook I Project
RBE	relative biological effectiveness
RF	respirable fraction
TSD	technical support document
U_3O_8	triuranium octoxide
UGTMF	underground tailings management facility
USDOE	United States Department of Energy
W1	worst-case weather conditions
W2	typical weather conditions

Units of Measure

Units	Definition
%	percent
µg/L	micrograms per litre
µL/L	microlitres per litre
µm	micron
Bq/g	becquerels per gram
Bq/L	becquerels per litre
cm	centimetre
cm/s	centimetres per second
g/cm^3	grams per cubic centimetre
g/m^3	grams per cubic metre
g/s	grams per second
gal	imperial gallon
GBq	giga-becquerels
GBq/h	giga-becquerels per hour
kg	kilogram
kg/d	kilograms per tonne
kg/m^3	kilograms per cubic metre
kg/t	kilograms per tonne
h	hour
km	kilometre
km^2	square kilometres
km/h	kilometres per hour
L	litre
$L/m^2/s$	litres per square metre per second
L/s	litres per second
m	metre
m/s	metres per second
m^2	square metres
m^3	cubic metres
m^3/d	cubic metres per day
m^3/h	cubic metres per hour
m^3/s	cubic metres per second
m^3/yr	cubic metres per year
masl	metres above sea level
mg/L	milligrams per litre
mg/m^3	milligrams per cubic metre

Units	Definition
mGy/d	milligrays per day
MBq	mega-becquerels
MBq/h	mega-becquerels per hour
min	minute
mm	millimetre
mm/°C/d	millimetres per degrees Celsius day
mm/yr	millimetres per year
mph	miles per hour
ppm	parts per million
t	tonne
t/d	tonnes per day
t/h	tonnes per hour

1.0 INTRODUCTION

Ecometrix Incorporated (Ecometrix) was retained by NexGen Energy Ltd. (NexGen) to complete the accidents and malfunctions assessment for the NexGen Rook I Project (Project), a proposed uranium mining and milling operation in northwestern Saskatchewan. This technical support document (TSD) provides the details of that assessment, which is included in the EIS Section 21, Accidents and Malfunctions.

1.1 Overall Scope and Objective of the Assessment

The scope of this assessment includes all potential Project-related accidents and malfunctions that may occur during any phase of the Project and transportation-related accidents along the Project access road to Highway 955. The assessment of accidents and malfunctions is intended to provide a clear identification of the potential Project-associated hazards that fall outside the range of "typical" day-to-day events.

The objective of this assessment was to evaluate the potential effects on the human health and biophysical environment resulting from radiological and conventional accidents and malfunctions with consideration of proposed preventive and mitigative measures.

The effects on the occupational health and safety are not within the scope of this assessment. Consistent with CSA N288.6-22 (CSA Group 2022), nuclear energy workers would be classified and monitored in accordance with the requirements of NexGen's Radiation Protection Program and therefore did not require assessment. Non-nuclear energy workers at the Project site would be subject to occupational exposure and workplace monitoring outlined in NexGen's Health and Safety Program; therefore, these workers were also excluded.

1.2 Background Information

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

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

1.3 Regulatory Context

For the purpose of this assessment, accidents and malfunctions refer to events or conditions that are not part of any activity or normal operation of the Project (i.e., typical day-to-day events) as proposed by NexGen. Despite rigorous planning and the implementation of best practices and preventative measures, the potential exists for accidents and malfunctions to occur during any

Project phase. If such unplanned events or conditions occur, adverse environmental effects could result if not addressed or responded to in an appropriate manner.

Federal guidance for the assessment of accidents and malfunctions is provided in Canadian Nuclear Safety Commission (CNSC) REGDOC-2.9.1: Environmental Protection: Environmental Principles, Assessments and Protection Measures (CNSC 2020). Specific considerations regarding the scope of such assessments are described in REGDOC-2.9.1, which indicates that the EIS should provide an assessment of potential health and environmental effects resulting from postulated radiological and conventional malfunctions and/or accidents. The EIS should also include any mitigation measures such as monitoring, contingency, clean up, or restoration work in the surrounding environment that would be required during or immediately following the postulated malfunction and accident scenarios (CNSC 2020).

Section 5.4 of the Transportation of Dangerous Goods Regulations (Government of Canada 2021a) sets out the requirements for the loading and securing of dangerous goods to prevent damage to the container or to the means of transport that could lead to an accidental release. Section 8 of the Transportation of Dangerous Goods Regulations is relevant to accidental release and accidental release reporting requirements.

The provincial (i.e., Saskatchewan) mandate is less prescriptive than that provided within CNSC REGDOC-2.9.1. Both the technical proposal guidelines (Government of Saskatchewan 2014a) and the guidelines for the preparation of the terms of reference (Government of Saskatchewan 2014b) that have been prepared by the Environmental Assessment Branch of the Ministry of Environment under *The Environmental Assessment Act* (Government of Saskatchewan 1980) make reference to addressing effects associated with accidents and malfunctions that may occur during all Project phases within the EIS submission.

1.4 Report Format

Following this introductory subsection, the remainder of this TSD is organized follows:

- Section 2.0: provides Project-related information.
- Section 3.0: describes the methods for the accidents and malfunctions assessment.
- Section 4.0: presents general considerations and context for the accident and malfunctions assessment.
- Section 5.0: presents the environmental quality guidelines and toxicity benchmarks for the released contaminants.
- Section 6.0 through Section 11.0: present for each of the accident and malfunction bounding scenarios that have been identified: a description and characterization of the scenario, an assessment of probability of the scenario, and the potential effects associated with the scenario.
- Section 12.0: combines the results of probabilities and potential effects and presents the assessment of the risk of the bounding scenarios.

- Section 13.0: provides a list of references cited in this report.

The detailed hazard identification assessment completed in support of this assessment is provided Appendix A, Hazard Identification for the Accidents and Malfunctions Assessment.

2.0 PROJECT INFORMATION

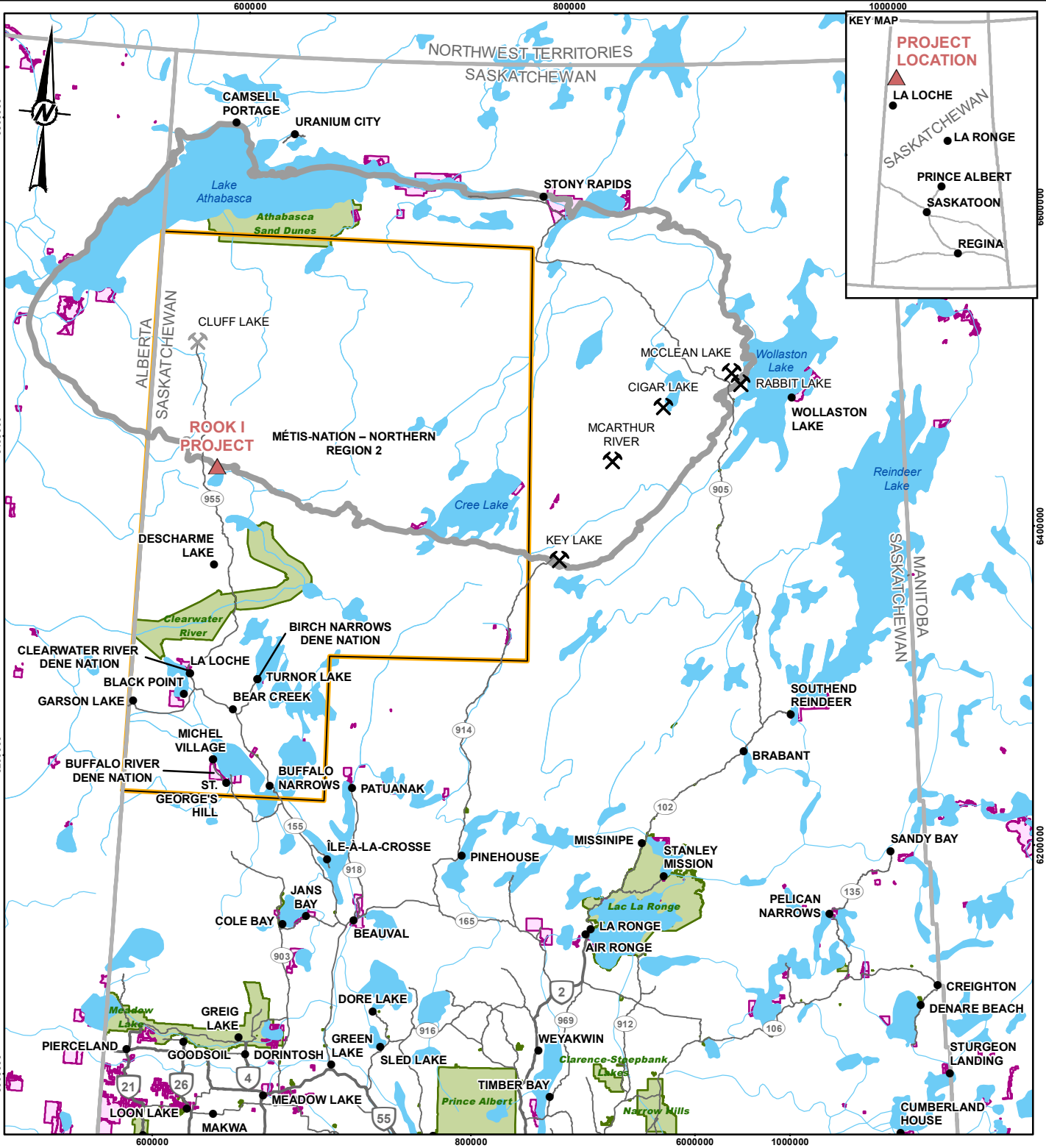
2.1 Project Location

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

The Project would include the following key facilities to support the extraction and processing of uranium from the Arrow deposit for transportation off site (Figure 2-3):

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

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



LEGEND

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

0 100 200
1:3,500,000 KILOMETRES

REFERENCE(S)

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

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LOCATION OF THE ROOK I PROJECT

CONSULTANT

wsp

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

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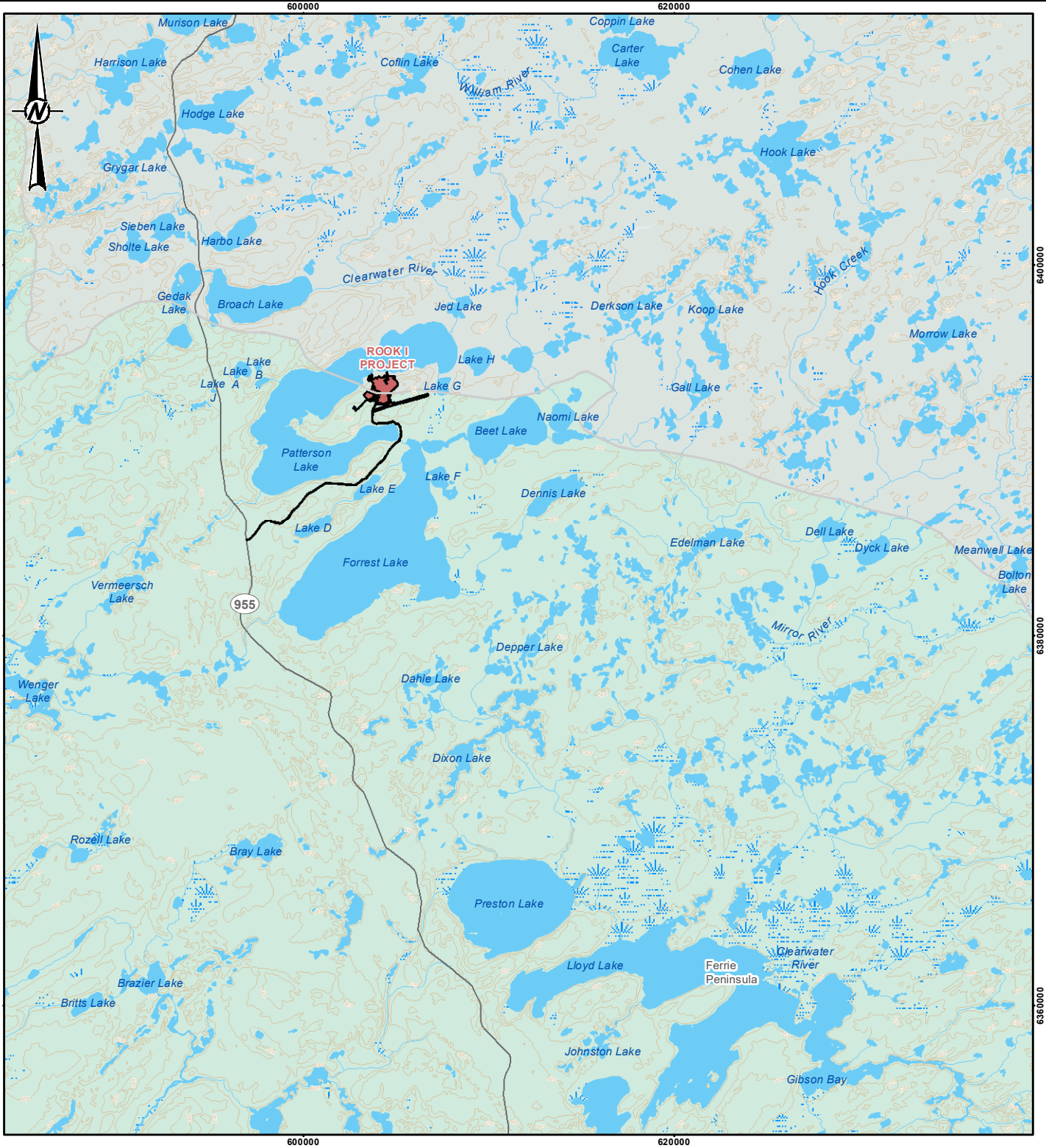

LEGEND

- ELEVATION CONTOUR (20 m INTERVAL)
- SECONDARY HIGHWAY
- WATERCOURSE
- ATHABASCA BASIN
- WATERBODY
- WETLAND
- WOODED AREA
- PROPOSED PROJECT FOOTPRINT

0 5 10
1:300,000 KILOMETRES

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

PROJECT
NexGen Energy Ltd.
ROOK I PROJECT

TITLE
REGIONAL AREA OF THE ROOK I PROJECT

CONSULTANT
wsp

PROJECT		20144150	PHASE	3314 - 6
DESIGN	JMC	2023-10-25	SCALE AS SHOWN	REV. 0
GIS	NO	2023-10-25	**FIGURE 2-2**	
CHECK	JMC	2023-10-25		
REVIEW	MM	2023-10-25		

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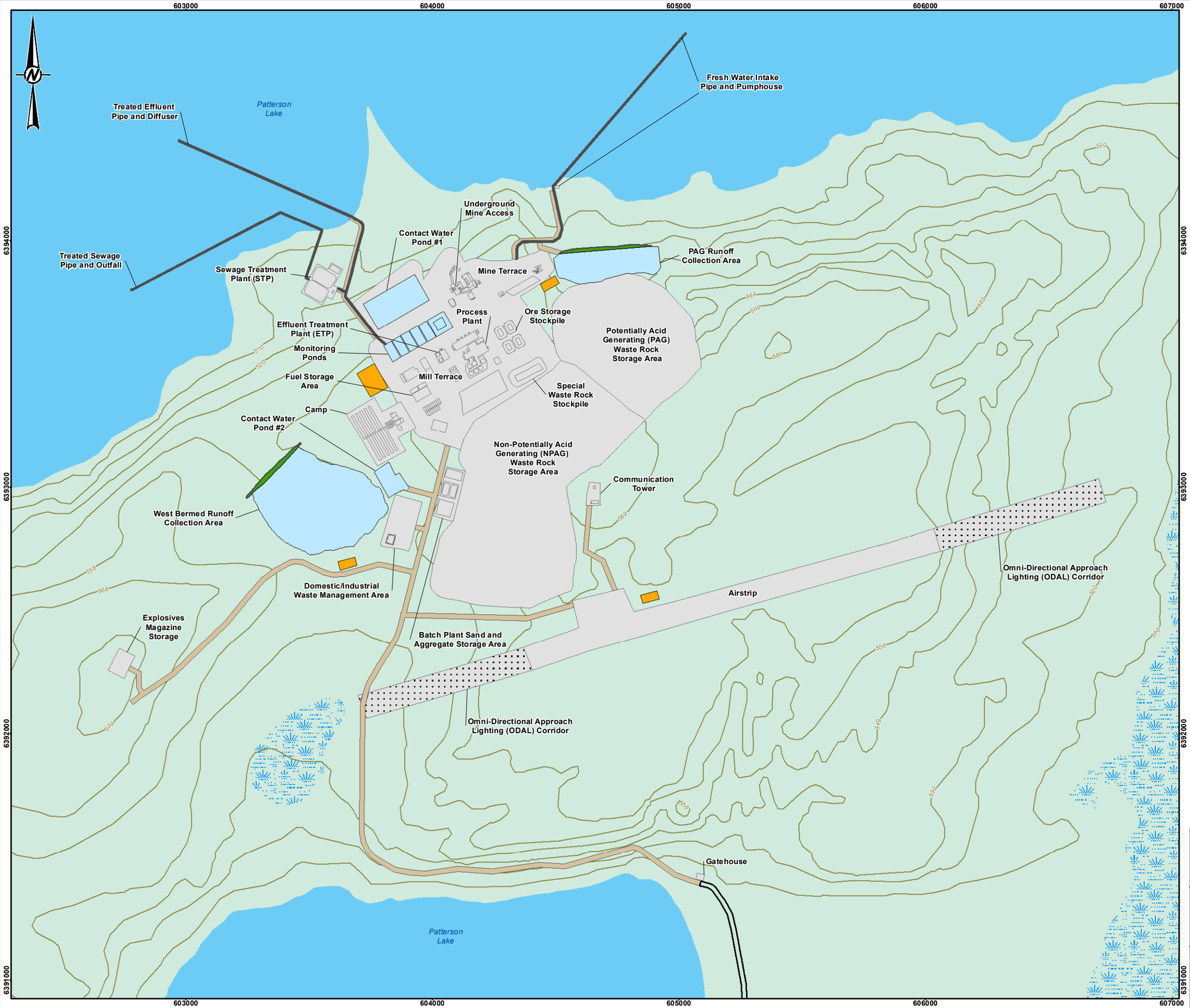

LEGEND

- ELEVATION CONTOUR (10 m INTERVAL)
- WATERBODY
- WETLAND
- WOODED AREA
- INTAKE OR DISCHARGE PIPE
- ACCESS ROAD
- CONTACT WATER CONTAINMENT BERM
- OMNI-DIRECTIONAL APPROACH LIGHTING (ODAL) CORRIDOR
- PROJECT INFRASTRUCTURE
- SITE ROAD
- TOPSOIL STORAGE AREA
- WATER MANAGEMENT POND

0 0.5 1
1:15,500 KILOMETRES

REFERENCE(S)

1. PROJECT FEATURES OBTAINED FROM NEXGEN, APRIL 6, 2021 AND UPDATED JUNE 8, 2021 .
2. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LAYOUT OF INFRASTRUCTURE AND FACILITIES FOR THE ROOK I PROJECT

CONSULTANT

wsp

PROJECT		20144150	PHASE	3314 - 6
DESIGN	JV	2020-03-13	SCALE AS SHOWN	REV. 0
GIS	NO	2023-10-25		
CHECK	JMC	2023-10-25	**FIGURE 2-3**	
REVIEW	MM	2023-10-25		

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2.2 Project Details and Components

The Project would include the Construction, Operations, Decommissioning and Reclamation (i.e., Closure) of a uranium mine and process plant buildings, including associated infrastructure to support the extraction and processing of uranium ore. Key Project details are summarized in Table 2-1.

Table 2-1: Key Rook I Project Details

Terms	Details
Scope of the Project	• NexGen is proposing a new uranium mining and milling operation located adjacent to Patterson Lake in the southwestern Athabasca Basin in northern Saskatchewan • The proposed Project would include underground and surface facilities to support the mining and milling of uranium ore from the Arrow deposit • The Project would include an underground mine, a process plant, and additional infrastructure including a camp for personnel, an airstrip, an ETP, and supporting waste and water management facilities
Rook I Project	• The proposed Rook I Project is a new uranium mining and milling operation located on the Patterson Lake peninsula in the southwestern Athabasca Basin in northern Saskatchewan • The Rook I Project is 100% owned and managed by NexGen • The mineral resource basis for the proposed Project is the Arrow deposit, a land-based, 100% basement-hosted, high-grade uranium deposit
Arrow deposit	• A land-based, basement-hosted, high-grade uranium deposit that is 100% owned by NexGen
Underground mine development	• The Project would use long hole stoping mining methods to extract the ore, including primarily transverse stope mining and longitudinal retreat stope mining • The underground mine development would include a number of key activities, including shaft sinking, lateral development, vertical development, installation of mine services, and development of the UGTMF
Uranium concentrate	• The Project term for triuranium octoxide (U_3O_8) once the material has been processed and is ready for shipment
Process plant	• Process plant throughput is designed for 1,300 tonnes of ore per day • Total net uranium recovery from the milling process is estimated to be 97.6% based on the results of the metallurgical test programs completed in 2018 and 2019 • The process plant consists of the technologies and infrastructure used to transform uranium ore into uranium concentrate
UGTMF	• Purpose-built, underground facility with chambers dedicated to the storage and progressive decommissioning for tailings and other waste streams generated through mining and processing • Three UGTMF cavities are planned for initial development during Construction to provide adequate storage capacity to support the start of mining and milling operations
Mine rock	• Includes all material sourced from underground, including ore (equal or greater than 0.26% U_3O_8 and waste rock (less than 0.26% U_3O_8)

Terms	Details
Waste rock	• Includes non-potential acid generating mine rock, potentially acid generating mine rock, and special waste
NPAG	• The NPAG waste rock is clean mine rock with less than 0.03% U_3O_8 and less than 0.1% sulphur. All NPAG mine rock would either be stockpiled for use as construction material at site or become NPAG waste rock that is stored in the NPAG WRSA
PAG	• The PAG waste rock is mine rock with less than 0.03% U_3O_8 and greater than or equal to 0.1% sulphur. All PAG mine rock would become PAG waste rock that is stored in the PAG WRSA
Special waste	• Special waste is mine rock with insufficient grade to be considered ore (i.e., greater than 0.03% of U_3O_8 and less than 0.26% U_3O_8). All special waste would be temporarily stored in the special waste rock stockpile
NPAG WRSA	• The NPAG WRSA would permanently store clean mine rock at surface and would not be lined
PAG WRSA	• The PAG WRSA would permanently store PAG mine rock at surface and would be fully lined with HDPE and have self-contained water collection
Special waste rock stockpile	• The separate stockpile where special waste would be temporarily stored at surface and would be fully lined with HDPE and have self-contained water collection • Special waste would be processed throughout Operations and then transferred to the UGTMF for permanent storage
Ore storage stockpile	• The separate stockpile on surface where ore would be temporarily stored until transferred to the process plant. This stockpile includes four piles with differing grades and would be fully lined with HDPE and have self-contained water collection
ETP	• The Project facility that would treat contact water from the Project. The treated effluent would be pumped to the monitoring ponds, tested, and then discharged to the environment, after meeting discharge criteria
Sewage treatment plant	• The Project facility that would treat sewage from the Project. The treated sewage discharge would be released to the environment after meeting discharge criteria
Mine water	• Water that flows into the underground workings
Contact water	• Water that may have been physically or chemically altered by Project activities. This water may be diverted and require management (e.g., treatment) before release to the environment. This includes dewatering of mine water from underground mining activities as well as all runoff on surfaces disturbed by the Project
Non-contact water	• Water that has not been physically or chemically altered by Project activities. This water is typically diverted when practical and allowed to discharge directly to the receiving environment
Fresh water	• Water sourced from Patterson Lake for use by the Project
Release water	• Contact water that has been treated in the ETP and is discharged to the environment, after meeting discharge criteria
Waste water (or treated sewage discharge)	• Water that has been treated in the sewage treatment plant and is ready for discharge to the environment, after meeting discharge criteria

Terms	Details
Sewage	• Waste water from toilets, sinks, showers, laundry, kitchen, and other domestic sources and facilities at the Project, including but not limited to sanitary liquid waste of human origin
Supporting infrastructure	• Includes all Project surface facilities including but not limited to waste management infrastructure, water management and treatment infrastructure, administration and camp facilities, utilities, airstrip, and site roads

UGTMF = underground tailings management facility; PAG WRSA= potentially acid generating waste rock storage area; NPAG WRSA = non-potentially acid generating waste rock storage area; U_3O_8 = triuranium octoxide; ETP = effluent treatment plant; HDPE = high density polyethylene.

Based on the review of Project-related information, the following key Project components and activities were identified and form the basis of consideration of potential accident and malfunction scenarios:

- site preparation;
- shaft sinking;
- access road and land transportation;
- airstrip;
- mining;
- hoisting;
- mine dewatering system;
- processing plant;
- solvent extraction building;
- UGTMF and mining stopes;
- NPAG waste rock stockpile;
- ore, special, and PAG waste rock stockpiles;
- effluent treatment system;
- ponds and retention berms;
- gypsum precipitation, washing, and storage;
- acid plant;
- electrical system and power plant;
- fire protection system;
- low-level radioactive waste management system and incinerator;
- liquified natural gas power plant; and
- mine ventilation system.

2.3 Project Timeline

The timeline over which potential accident and malfunction scenarios has been considered includes the Project lifespan. The Project lifespan includes the period of time from the initiation

of Construction to the completion of Closure (i.e., up to the subsequent transfer of the property to Institutional Control). The lifespan of the Project is anticipated to be 43 years, as summarized in Table 2-2.

Table 2-2: Rook I Project Timeline

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

CNSC = Canadian Nuclear Safety Commission.

3.0 ASSESSMENT METHODS

The methods by which the accident and malfunction assessment was carried out are described below.

For reference, the temporal and spatial extents of the assessment are as follows:

- The temporal extent of the evaluation includes all phases associated with the Project lifespan, including Construction, Operations, and Decommissioning and Reclamation (i.e., Closure).
- The spatial extent of the evaluation includes the Project site and the Project access road to its junction with Highway 955.

3.1 Overview

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

The five basic steps in the process of risk assessment for the accidents and malfunctions assessment were as follows:

1. **Hazard identification**: the identification of physical situations with the potential for harming human health or the biophysical environment. Hazard scenarios were identified using a systematic approach with consideration of the existence of sources of hazards and initiating events for each project component and activity. Scenarios were identified for several potential events, such as releases of chemical and radiological constituents, fires, and explosions. The detailed methods and the complete list of identified scenarios are provided in the hazard identification report that is provided in Appendix A.

2. **Bounding scenarios:** the identified hazard scenarios were then screened qualitatively for the perceived effects and probability of occurrence as well as the potential risk using a risk matrix approach (Section 3.2.2). Project information, experience from similar projects, particularly those located in Northern Saskatchewan, and professional judgment were used for this initial screening. Among the high or moderate-risk scenarios, bounding scenarios were selected. The bounding scenarios encompass the effects of other scenarios screened for each Project component and activity. The subsequent analysis focussed on these bounding scenarios.

3. **Probability analysis**: the estimation of the probability of occurrence of the selected bounding scenario occurring within a specific time period, or in specified circumstances.

4. **Effects analysis:** quantitative evaluation of the potential effects of a selected bounding scenario to the human health or biophysical environment.

5. **Risk estimation and ranking**: the estimation of the effect of a scenario and the probability with which it is likely to occur; that is, risk is the product of effect and probability (risk = consequence × probability of occurrence). The risk was evaluated using the risk matrix presented in risk matrix approach (Section 3.2).

3.2 Hazard Identification

The hazard identification process is a systematic approach to identify possible hazards associated with all components (physical system) and activities in a work process. A hazard can be defined as a physical event or condition that has the potential for causing damage to people, property, or the environment (e.g., fire, explosion, release of chemicals, or radioactivity).

The full hazard identification report is provided in Appendix A. The hazard identification evaluation was used to identify a comprehensive list of potential Project-related accident and malfunction scenarios, screen these scenarios as to potential risks and, based on the initial screening results, select a number of high or moderate-risk scenarios as bounding scenarios. These bounding scenarios were carried forward for more detailed risk assessment. The hazard identification evaluation focussed on risks to the human health and biophysical environment.

The hazard identification involved the consideration of the following three elements that, in combination, present a risk to the human health and biophysical environment:

a) the sources of hazard (e.g., presence of hazardous materials);

b) hazardous situations (e.g., presence of ignition source); and

c) initiating events (e.g., natural causes, technical failure, or human error).

A screening evaluation was applied to all accident and malfunction scenarios by qualitatively evaluating the likelihood and consequence to determine a risk level.

The likelihood index is derived from the qualitative estimation of the probability of the scenarios. While there are standards and regulatory documents (e.g., REGDOC-2.4.2, Safety Analysis, Probabilistic Safety Assessment [PSA] for Reactor Facilities [CNSC 2014]) that govern the assessment of the probability of the hazard scenarios for nuclear reactors, no such documents exist for non-reactor facilities. The focus of these documents is design-basis and beyond design-basis accidents that affect the integrity of the reactor core. The annual probability of releases from these accidents can be $1x10^{-6}$ and lower, while the consequence of these accidents could be very severe (i.e., catastrophic). In contrast, the probability of accidents and malfunctions at non-reactor facilities such as mines and process plants can be higher, as derived from the operating experience of similar installations. The International Atomic Energy Agency's TECDOC-1267 (IAEA 2002) states that while a plant-specific qualitative risk analysis should be conducted for a nuclear reactor facility, for non-nuclear facilities hazard identification and screening, evaluation of selected accident scenarios, and a combination of qualitative and quantitative analysis should be conducted. This document does not prescribe what probabilities should be considered.

Based on the operating experience of similar facilities considered in this assessment, a range of probabilities were considered. On a scale of increasing likelihood, scenarios were categorized as highly unlikely, unlikely, likely, very likely, and almost certain as shown in Table 3-1.

Table 3-1: Likelihood Index

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

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

On a scale of increasing consequence, scenarios were categorized as negligible, minor, moderate, major, and catastrophic as shown in Table 3-2.

Table 3-2: Consequence Index

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

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

For the purpose of the assessment, risks were identified as being low (i.e., coloured green in the matrix) where the screening evaluation considered the risk as generally being acceptable, as the likelihood of these scenarios can be effectively managed through application of planned controls and/or the consequence of the effect would be low (i.e., negligible to moderate). Low-risk scenarios have a consequence of negligible to moderate, with the likelihood ranging from highly unlikely to almost certain.

Risks are identified as being moderate (i.e., coloured yellow in the matrix) where the screening evaluation considers the risk as generally being tolerable. In some cases, a moderate-risk scenario can encompass the risk of several screened scenarios for each effect category (e.g., toxic release, fire). In these cases, a moderate-risk scenario can be carried forward as a bounding scenario for

more detailed analysis. Moderate-risk scenarios have a consequence of minor to catastrophic, with a likelihood ranging from highly unlikely to almost certain. In many cases, risk-reduction activities would reduce the risk associated with these scenarios to as low as reasonably practicable (ALARP). Under this condition, the risk may be characterized as tolerable.

Risks were identified as being high (i.e., coloured red in the matrix) where the screening evaluation considered the risk as generally being unacceptable. High-risk scenarios have a consequence of major to catastrophic, with a likelihood ranging from unlikely to almost certain. As the evaluation of the risk at this hazard identification stage was qualitative and subject to some uncertainty, hazard scenarios identified as high risk that were not associated with the NexGen health and safety program best practices (i.e., risk is reduced to ALARP) were advanced for further detailed assessment so that a more detailed evaluation of risk and potential management activities could be considered.

Figure 3-1: Hazard Analysis Risk Matrix

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

3.2.1 Evaluation of Project Components and Activities

Sources of hazards, hazardous situations, and initiating events associated with Project components and activities were evaluated as described in the hazard identification report (Appendix A). A total of 93 hazard scenarios were identified and evaluated.

Following the screening evaluation outlined in Section 3.2, a total of nine of the hazard scenarios were characterized as high risk. Three of the high-risk scenarios were identified as requiring further detailed assessment for more accurate characterization of risk. Each of these three scenarios is associated with a release of contaminants to the environment where the potential effects may be more far-reaching than can be adequately assessed by the screening assessment. Therefore, additional, more quantitative evaluation is appropriate. The remaining six high-risk scenarios that were not recommended for further detailed assessment are associated with major injuries and/or occupational fatalities. These scenarios were not advanced in the accidents and malfunctions assessment as they are outside the scope of this assessment.

Thirty-three of the scenarios evaluated were characterized as moderate-risk scenarios. Generally, the moderate-risk scenarios were deemed to represent a tolerable level of risk in consideration of proposed safeguards and design features that reduce the risk level to ALARP. A total of nine moderate-risk scenarios were recommended for further detailed assessment - four for release of uranium from the mill building, three for release of sulphur dioxide from the acid plant, one for release of untreated effluent, and one for a surface release of tailings. The effects of four moderate-risk uranium release scenarios are expected to be much less than the loaded solvent fire scenario, which is a high-risk scenario due to the amount of uranium involved. Thus, the four moderate-risk uranium release scenarios are bounded by the uranium loaded fire scenario. The effects of two sulphur dioxide release scenarios are bounded by tail-gas scrubber failure scenario due to the amount of gas available for release upstream of the scrubber. Therefore, three moderate-risk scenarios were selected as bounding scenarios for further assessment.

The remaining 51 scenarios evaluated were characterized as low-risk scenarios based on their likelihood of occurrence and/or effect in consideration of the planned or existing safeguards and design features. Low-risk scenarios were not carried forward for more detailed analysis as they are adequately characterized by the screening process.

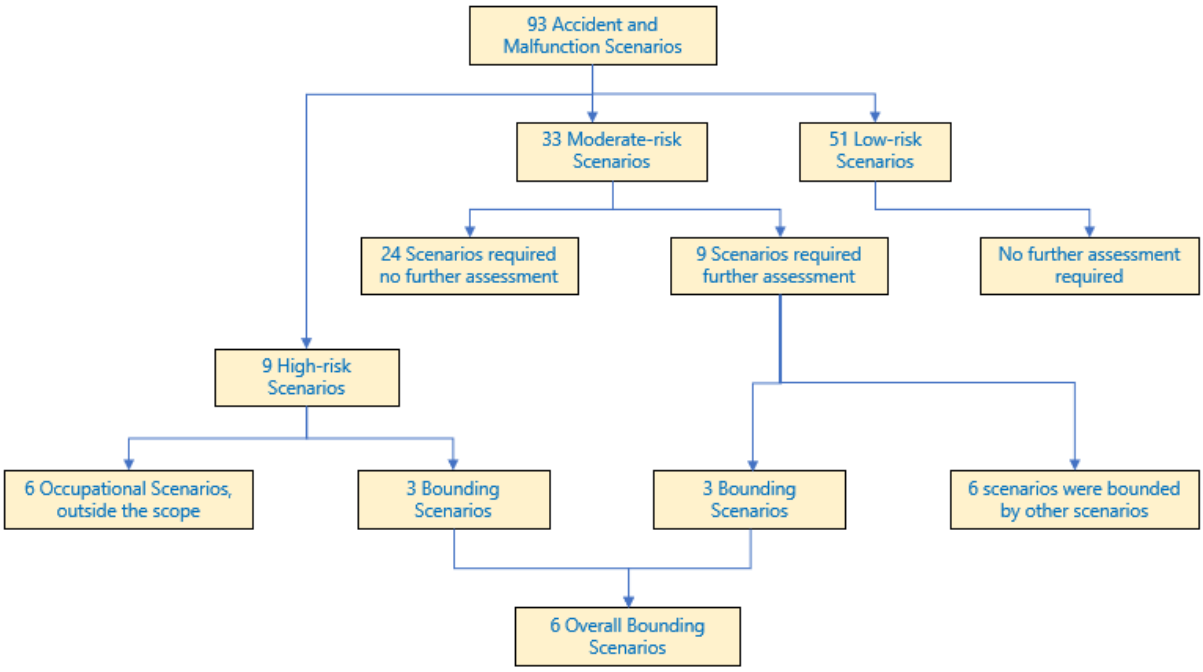
Figure 3-2 shows the process by which the bounding scenarios were selected.

The storage and transportation of explosives and detonators was not included in the list of Project components and activities used for this evaluation. The transport, storage, and use of explosives and detonators are heavily regulated to minimize risks. Use and handling of explosives for the Project would be managed as per the *Explosives Act*, as well as the following standards:

- CAN/BNQ 2910-500/2015 Explosives – Magazines for Industrial Explosives (SCC 2015a); and
- CAN/BNQ 2910-510/2015 Explosives – Quantity Distances (SCC 2015b).

Additionally, in accordance with The Mines Regulations, 2018, the location of the explosive or detonator facility would be a minimum of 60 m from any work area, fire hazard, or other vulnerable area, and would not be located on any main travel way (e.g., access ramp). Risks for transport, storage, and use of explosives would always be considered ALARP given the regulatory framework and the controls required (e.g., explosives management planning); therefore, these risks were not evaluated in the hazard assessment. For this reason, further assessment of potential effects to the environment, human health, and worker safety is not required.

Figure 3-2: Selection of Bounding Scenarios



3.2.2 Bounding Scenarios

From the initial screening process detailed in the hazard identification report (Appendix A), six hazard scenarios (i.e., three high risk and three moderate risk) were selected as bounding scenarios for more detailed risk analysis (Table 3-3). Herein, a bounding scenario is used to represent an event in which its potential effects are considered to represent those associated with other accident and malfunction scenarios; or, alternatively, the potential effects of scenarios that are bounded by another are expected to fit within the envelope of those associated with the bounding scenario. Utilizing the bounding scenario approach avoids duplication in the evaluation process while confirming the evaluation is completed in a conservative manner.

For six identified bounding scenarios, a general description of the hypothetical event, the release characterization (e.g., contaminants, quantities), the probabilities of the events, and their potential effects on the human health and biophysical environment are provided in Section 6.0 to Section 11.0.

Table 3-3: Bounding Scenarios Identified for Further Assessment by the Hazard Identification Process

No.	Accident or Malfunction Scenario	Location	Effect Pathway	Interactions with the Environment
1	Traffic accident (uranium concentrate)	Access road at bridge crossing	Aquatic release of uranium concentrate	Affects the water quality, sediment quality, terrestrial and aquatic biota, and members of the public
2	Traffic accident, (chemical)	Access road at bridge crossing	Aquatic release of fuel, hazardous chemicals	Affects the water quality, sediment quality, terrestrial and aquatic biota, and members of the public
3	Solvent extraction fire or explosion	Solvent extraction building	Atmospheric release of uranium concentrate (chemical toxicity)	Affects the air quality, and members of the public
4	Tailings transfer pipe or pump failure	Tailings release to surface within secondary containment	Terrestrial release of radioactivity	Affects the soil and potentially groundwater, and terrestrial biota
5	Untreated effluent transfer pipe failure	Effluent treatment system	Terrestrial release of radioactivity	Affects the soil and potentially groundwater, and terrestrial biota
6	Acid plant tail gas scrubber failure	Acid plant	Atmospheric release of sulphur dioxide	Affects air quality, and members of the public

high risk; moderate risk
Note: Effect Pathway describes nature of the event and exposure media, and therefore the nature of the assessment of effects.

3.3 Probability Analysis

The detailed assessment of the bounding scenarios requires the quantification of the probability of the effects of the bounding scenarios. The estimation of the probability requires the identification of the probability of the initiating events leading to the hazard scenario and the conditional probability of any of the associated events within the casual event chain.

Commonly, the probability estimation relies on the statistics collected by various government and non-government agencies for similar processes. These include:

- Transportation-related scenario probabilities estimated based on the transportation accident statistics available by various government agencies.
- Equipment and structural failures and incidents based on the industry experience and failure rates available from various organizations.

In some cases, there is not enough historical information to support a statistically meaningful evaluation of the probability. In these cases, the probabilities are reported as less than a specific value. For example, the probability of the mechanical failure of a structure is reported as less than 0.01 if the life span of the structure is 100 years and no historical information is available for mechanical failure of similar structures. In many cases, assessor's experience and professional judgment are used in the probability evaluation.

The quantification of probabilities considered the prevention measures that would be implemented through NexGen's health, safety, environmental, and quality policies, practices, and procedures (Section 4.0).

3.4 Effects Analysis

The detailed assessment included the quantification of the potential effects of each of the bounding scenarios on the human health and biophysical environment. The quantification of the effects included the assessment of the fate and transport of a chemical or radiological release and associated exposures related to the scenario. It also included the characterization of the source terms when there is potential for the release of radioactivity and hazardous materials to the environment.

The fate and transport of the released materials and the exposure to the receptors were evaluated to quantify the effects of the scenario. Technical Support Document XXI, Environmental Risk Assessment, provides an understanding of how people interact with the environment within the vicinity of the Project and assesses the potential for human and ecological receptors to be exposed to Project-related media during one or more Project phases. Detailed rationale for human and ecological receptor selection is provided in the Environmental Risk Assessment.

The quantification of potential effects considered the risk prevention and mitigative measures that would be implemented through NexGen's health, safety, environmental, and quality policies, practices, and procedures (Section 4.0). This approach provided a more in-depth, quantitative and representative characterization of the risk of these scenarios, as the estimation of the risk in the hazard identification report (Appendix A) was preliminary, and completed at the screening level using primarily qualitative methods.

3.5 Risk Estimation and Ranking

The risk estimation for the bounding scenarios was performed through mapping the results of the quantification of the likelihood and consequence on the risk matrix presented in Section 3.2, Figure 3-1.

4.0 CONSIDERATIONS FOR THE ACCIDENT AND MALFUNCTIONS ASSESSMENT

Over the past four decades of global commercial nuclear facility operation, the frequency and severity of accidents has been markedly lower than those in related industrial operations (OECD 2010). This can be attributed to the rigorous regulatory framework and well-developed plans and procedures for safe operation of nuclear facilities, including uranium mining and milling operations, particularly in Northern Saskatchewan. The experience gained from the accidents that have occurred has resulted in improved engineered safety features and operating procedures. Therefore, assessing the probability that similar accidents might occur in the future based on historical data is conservative.

It is the intention of NexGen to develop and operate the Project in a manner that mitigates potential adverse effects on the human health and biophysical environment to the extent possible. NexGen would verify that all work to be completed during the Project would meet, or exceed, the regulatory requirements stipulated by the province of Saskatchewan, the CNSC, and other regulatory authorities. Through complying with all regulations and standards, engagement with Indigenous Groups, local communities, workers, and other stakeholders, and by embracing the application of technology and best practices, NexGen is focused on achieving high standards in all facets of the business and across the Project lifespan, which would serve to mitigate potential Project-related effects, including those that may be associated with postulated accident and malfunction scenarios. As part of this commitment, NexGen adopts a hierarchy of controls (i.e., elimination, substitution, engineering, administrative, personal protective equipment) as part of the Integrated Management System to prevent, eliminate, and reduce hazards and mitigate the risks associated with activities throughout the Project lifespan. In practice, these controls would be implemented and their effectiveness monitored via management system processes defined in topic-specific programs which include, but may not be limited to the following:

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

- Asset Management Program.

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

- process and operational controls;
- mine development and control;
- workplace inspections;
- training;
- radiation exposure monitoring and protection;
- spill response;
- security;
- environmental monitoring;
- emergency response; and
- transportation emergency response.

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

5.0 CHEMICAL, OCCUPATIONAL, AND RADIOLOGICAL BENCHMARKS

The following subsections define relevant benchmarks used to assess the potential effects of the postulated accident and malfunction scenarios. The benchmarks presented are specific to the bounding scenarios that have been considered, and are provided for atmospheric and aquatic environments. The benchmarks were specifically selected with consideration of the interactions of the bounding scenarios with the environment presented in Table 3-1 for the following:

- uranium (scenarios 1 and 3):
  - atmospheric environment; and
  - aquatic and terrestrial environment;
- radioactivity (scenarios 1, 4, and 5):
  - aquatic and terrestrial environment;
- sulphur dioxide (scenario 6):
  - atmospheric environment.

5.1 Uranium

Atmospheric Environment

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

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

Exposure limits for emergency scenarios are defined by a hierarchy of threshold concentrations for one-hour exposure. These include the Acute Exposure Guideline Level (AEGL), the Emergency Response Planning Guideline (ERPG), and the Temporary Emergency Exposure Limit

(USDOE 2016). Temporary Emergency Exposure Limits are intended for use until AEGLs and ERPGs are adopted for chemicals and have similar definitions as the corresponding ERPG levels. The AEGL and ERPG are defined for three levels as follows (USDOE 2016):

AEGL-1 The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible on cessation of exposure.

AEGL-2 The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

AEGL-3 The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

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

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

ERPG-1 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing effects other than mild transient adverse health effects, or perceiving a clearly defined, objectionable odour.

ERPG-2 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

ERPG-3 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects.

The most commonly used benchmarks for emergency release scenarios are ERPG-2 and AEGL-2. Emergency Response Planning Guideline values developed by the American Industrial Hygiene Association are provided in Table 5-1. These values were taken from the Protective Action Criteria tables (USDOE 2016).

Table 5-1: Emergency Response Planning Guidelines for Uranium Oxide and Uranium Concentrate

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

Source: USDOE 2016.
ERPG = Emergency Response Planning Guideline.

Aquatic Environment

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

Canadian Water Quality Guidelines for uranium (total recoverable, unfiltered) for the protection of aquatic life are 15 µg/L and 33 µg/L for long-term exposure and short-term exposure, respectively (CCME 2011).

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

5.2 Radioactivity

Radiation Protection Regulations, SOR/2000-203, governs the annual effective dose equivalent limits for individual members of the public exposed to the radioactivity resulting from industrial activities such as uranium mining and process plant buildings. The effective dose limit for the general public is 1 mSv per calendar year (Government of Canada 2021b).

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

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

The Canadian Standard N288.6, which addresses Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills (CSA Group 2022), recommends an RBE of 10 to be applied to the component of internal dose from alpha emitters. This assessment follows this recommendation. The standard also recommends that radiation dose benchmarks for quantitative effects assessment should follow UNSCEAR (2008); i.e., 100 µGy/h for terrestrial biota and 400 µGy/h 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.

5.3 Sulphur Dioxide

The AEGL values for sulphur dioxide are provided in Table 5-2 (USDOE 2016).

Table 5-2: Acute Exposure Guideline Levels for Sulphur Dioxide

Chemical	AEGL-2	AEGL-3
Sulphur dioxide	0.75 ppm	9.6 ppm

Source: USDOE 2016.
AEGL = Acute Exposure Guideline Level; ppm = parts per million.

6.0 BOUNDING SCENARIO 1: TRAFFIC ACCIDENT (URANIUM CONCENTRATE AND RADIOACTIVITY)

This bounding scenario consists of the release of uranium concentrate into the Clearwater River under the bridge along the Project access road. A general description of the hypothetical event, hypothetical contaminants release characterization (e.g., contaminants, quantities), the probability of the scenario, and its potential effects on the human health and biophysical environment is provided below.

6.1 Scenario Description

Vehicular access to the Project site would be via an existing road accessed from Provincial Highway 955 that leads to the current exploration camp. The access road would be used to transport equipment and supplies to and from the Project, as well as the trucking of the uranium concentrate product from site. Personnel would be flown to and from the site. The access road is roughly 13.7 km long and partially circumnavigates Patterson Lake until it reaches the Project site. The gravel access road has a posted speed limit of 40 km/h.

Figure 6-1 shows the mine footprint and the access road. There is one bridge across the Clearwater River with a posted weight limit of 50 t and speed limit of 10 km/h. The bridge is approximately 20 m long, 5.7 m wide, and has no guardrails. Small metal guards approximately 0.15 m high guide the driver across the bridge deck (NexGen 2019).

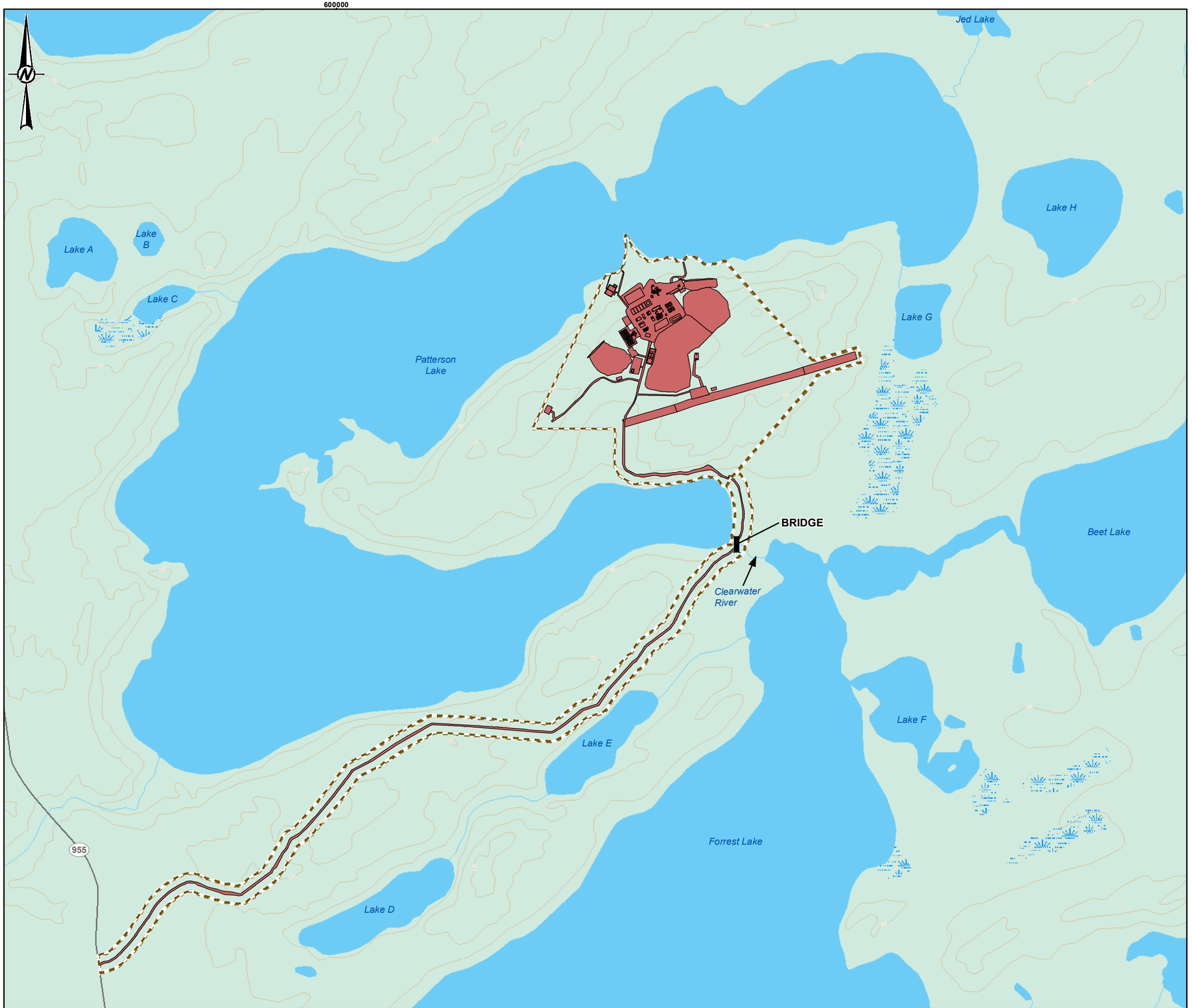
A traffic accident, collision, rollover, or run off near the Clearwater River crossing or on the bridge could potentially result in a release of uranium concentrate into the surface water under the bridge. The flow direction of the Clearwater River at the bridge is east towards Forrest, Beet, and Naomi lakes.

The flow rates for the waterbodies upstream and downstream of the postulated accident location are provided in the table below (Table 6-1).

Table 6-1: Flow Rates for Waterbodies Upstream and Downstream of the Site Access Road Bridge Crossing

Waterbody	Annual Average Outflow (m^3/s)
Patterson Lake South	1.3
Forrest Lake North	2.2
Beet Lake	2.4

The calcined (i.e., heated strongly to remove impurities) uranium concentrate would be packaged into standard 205 L (45 gal) steel drums for shipping. The gross weight of each drum is between 430 kg and 450 kg. It is projected that there would be 90 to 100 drums packaged per process plant operating day, requiring an average number of two trips per day, for 330 days per year.



LEGEND

- BRIDGE
- ELEVATION CONTOUR (20 m INTERVAL)
- SECONDARY HIGHWAY
- WATERCOURSE
- WATERBODY
- WETLAND
- WOODED AREA
- PROPOSED PROJECT FOOTPRINT
- MAXIMUM DISTURBANCE AREA

0 1.5 3
1:50,000 KILOMETRES

REFERENCE(S)
1. PROJECT FEATURES OBTAINED FROM NEXGEN, APRIL 6, 2021.
2. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. ECOZONES OBTAINED FROM AGRICULTURE AND AGRI-FOOD CANADA (AAFC).

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT
NexGen Energy Ltd.
ROOK I PROJECT

TITLE
LOCATION OF THE BRIDGE ACROSS THE CLEARWATER RIVER

CONSULTANT
wsp

PROJECT		20144150	PHASE	3314 - 6
DESIGN	LJ	2020-03-13	SCALE AS SHOWN	REV. 0
GIS	NO	2023-02-28	**FIGURE 6-1**	
CHECK	JMC	2023-02-28		
REVIEW	LJ	2023-02-28		

PATH: I:\CLIENTS\NexGen\20144150\Mapping\Products\TrailLandUse\HumanHeath_EIS\Accidents_Malfunctions\20144150_Fig6-1_Bridge-Location-Across-ClearwaterRiver_Rev0.mxd PRINTED ON: 2023-02-28 AT: 11:29:05 AM

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In uranium concentrate, the short-lived decay products of uranium-238 (i.e., thorium-234; protactinium-234m; protactinium-234, which has a relative concentration of 0.16% of uranium-238; and uranium-234), and uranium-235 (i.e., thorium-231) are assumed to be in equilibrium with their respective parents as the analysis considers both uranium and its decay products. Radioactive equilibrium exists when a radionuclide decays at the same rate at which it is being produced by its parent decay. The activity concentration of these radionuclides in uranium concentrate can be derived using the uranium-238 concentration and branching ratios shown in Table 6-2. The branching ratio for decay is the percentage of particles that decay by an individual decay mode with respect to the total number of particles that decay.

Table 6-2: Radionuclides in Uranium Concentrate

Radionuclide	Half-Life	Branch Percentage
Uranium-238	$4.47 \times 10^{+09}$ years	n/a
Thorium-234	24.1 days	100% uranium-238
Protactinium-234m	1.16 minutes	100% uranium-238
Protactinium-234	6.7 hours	0.16% uranium-238
Uranium-234	$2.45 \times 10^{+05}$ years	100% uranium-238
Uranium-235 (4.6% of uranium-238)	$7.04 \times 10^{+08}$ years	n/a
Thorium-231	1.063 days	100% uranium-235

From other studies conducted for McClean Lake uranium mills in northern Saskatchewan, the particle size distribution for three calcined uranium concentrate samples were measured using a Beckman Coulter LS Particle Size Analyzer[2]. Table 6-3 provides a summary of particle size distribution for these studies.

Table 6-3: Uranium Concentrate Particle Size Distribution

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

Source: Obtained from Cameco Corporation during the assessment of accidents and malfunctions for Millennium Mine Project.
< = less than.

[2] This information was obtained from Cameco Corporation during the assessment of accidents and malfunctions for Millennium Mine Project.

The solubility of calcined samples from the McClean Lake Operation located in northern Saskatchewan were analyzed over 24, 48, and 72 hours. The Organisation for Economic Cooperation and Development (OECD) Guideline for Testing of Chemicals; Water Solubility (adopted 27.07.95; OECD 1995), flask method, was followed for these tests. The results are shown in Table 6-4. For these tests, bulk and particle densities of uranium concentrate were 2.1 g/cm^3 and 9.6 g/cm^3, respectively. Based on the solubility data from the McClean Lake Operation samples, on average, a solution of about 0.125 g of uranium concentrate in 250 mL of water in 24 hours would lead to a uranium concentration of 4,800 µg/L. This value was assumed to apply to the release of uranium concentrate into the surface water under the scenario being assessed.

Table 6-4: Solubility of Calcined Uranium Concentrate

Sample Source	Sample No.	Estimated Solubility (g/L) by Test Duration		
		24 h	48 h	72 h
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)	n/a	n/a

n/a – values not determined for these tests.
Source: Obtained from Cameco Corporation during the assessment accidents and malfunctions for Millennium Mine project.

6.2 Release Characterization

The performance of drums similar to those proposed to be used for uranium concentrate shipment during transportation accident scenarios was determined by McSweeney et al. (2004). The authors concluded that, based on drum deformations performed in a previous analysis, if a drum experienced a crush force of 100,000 lbs, then the deformation of the drum would cause the lid to detach from the drum. Using this drum failure mechanism, and assuming the drums weigh 450 kg and are arranged in the truck four rows across in a single layer with no stacking, at a speed of 48 km/h, the front 25% of the drums would fail, at 60 km/h to 97 km/h, 55% would fail, at 145 km/h, 75% would fail, and at ≥193 km/h, all would fail.

Given that the speed of the truck would be less than 40 km/h, it was concluded that less than 25% of the drums would fail upon a traffic accident scenario. Assuming 100 drums in two shipments per day, each shipment would have 22,500 kg (49,560 lb) of uranium concentrate based on the following calculation:

- 100 drums in two shipments / 2 = 50 drums per shipment.
- 50 drums x 450 kg/drum = 22,500 kg uranium concentrate = 49,560 lb.

If 25% of this amount is released, the total release weight would be approximately 5,625 kg of uranium concentrate. It is also assumed that 95% of the released uranium concentrate can be recovered from the released location after the accident. This assumption is based on the

expectation that most of the uranium concentrate released would remain in relatively close proximity to the release location, given the high particle density of uranium concentrate (8.3 g/cm^3) that results in a high settling velocity (USDOE 2001) and the low water velocity and depth at the release location (Table 6-1).

The short-term dissolved release rate was estimated using solubility data. Solubility of calcined uranium ore concentrate was considered at an average value of 4,800 µg/L (or 4.8 g/m^3) over the first 72 hours, which is the average solubility of McClean Lake uranium ore concentrate samples. It was assumed that such concentrations applied to a cross section of water defined by the lateral footprint of the spill (i.e., the total 6 m of the Clearwater River crossing) and a water column depth of 10 cm. The water velocity was assumed to be 1 m/s. At an average depth of 0.3 m, the total flow rate is 1.8 m^3/s:

- 6 m × 0.3 m × 1 m/s = 1.8 m^3/s.

The dissolution rate is calculated as 2.9 g/s.

- 6 m × 0.1 m × 1 m/s × 4.8 g/m^3 = 2.9 g/s.

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. It was assumed that such concentrations applied to a cross section of water defined by the lateral footprint of the spill and a water column depth of 10 cm.

6.3 Assessment of Probability

Traffic risk mitigation measures include:

- traffic control measures, such as the speed limit at the bridge of 10 km/h;
- a travel management plan;
- a spill and emergency response plan; and
- driver training.

Despite the risk control measures, there is always a residual probability of accidents occurring. The probability of occurrence of a transportation accident and sequence of events resulting in a release of hazardous materials is the key factor for quantifying the transportation risk. Statistical data for transportation accidents are available for general transportation, as well as the transportation of hazardous materials. General transportation accident statistics are commonly presented as the number of accidents per million kilometres or million miles of transport vehicle travelled, and specific hazardous materials transportation accident statistics are commonly presented as the number of accidents per million tonne-miles or million tonne-kilometres of materials transported.

Using hazardous material transportation accident statistics would be more relevant for risk assessment studies; however, the statistical datasets for hazardous material transportation are less available and were therefore not used for this assessment. The data regarding the total volume and mass transported by various modes of transportation are maintained by shipping companies, and in most cases, are only available to regulatory agencies such as Transport Canada. The publicly available information is reported on a lump sum basis (i.e., the information does not include the breakdown for specific chemical or transportation route). In addition, the statistical breakdown for transportation routes is not readily available and the route data, particularly for road transportation, are maintained by road transport companies and are not publicly available. Therefore, in many cases, general transportation accidents statistics for trucks, trains, and marine vessels are used to conduct the risk assessment.

In Canada, the statistics related to the transportation and road accidents are primarily collected and maintained by federal and provincial government agencies including Transport Canada (2019) and its branches (such as the Canada Transportation Safety Board), the Saskatchewan Ministry of Highways and Infrastructure, and Saskatchewan Government Insurance (SGI 2019). The statistics indicate that average accident rates for Canada and Saskatchewan were 1.2 and 0.89 per one million kilometres travelled, respectively. The local statistics indicate that these rates were 2.68 and 0.8 per one million kilometres travelled for Highway 915 and Highway 955, respectively. These highways are part of the transportation route and are the closest to the proposed Project site.

It was also assumed that a traffic accident on the bridge or within 40 m from either side of the bridge would have the potential to release uranium concentrate to the Clearwater River. Using the transportation route lengths and the transportation accident rates estimated above, and assuming two trips per day for 330 days per year, the frequency of traffic accidents involving uranium concentrate in the vicinity of the Clearwater River crossing (i.e., considering a 40 m buffer at each side of the bridge) are estimated as follows:

for release to water: 5.3×10^{-05} to 1.7×10^{-04} per year.

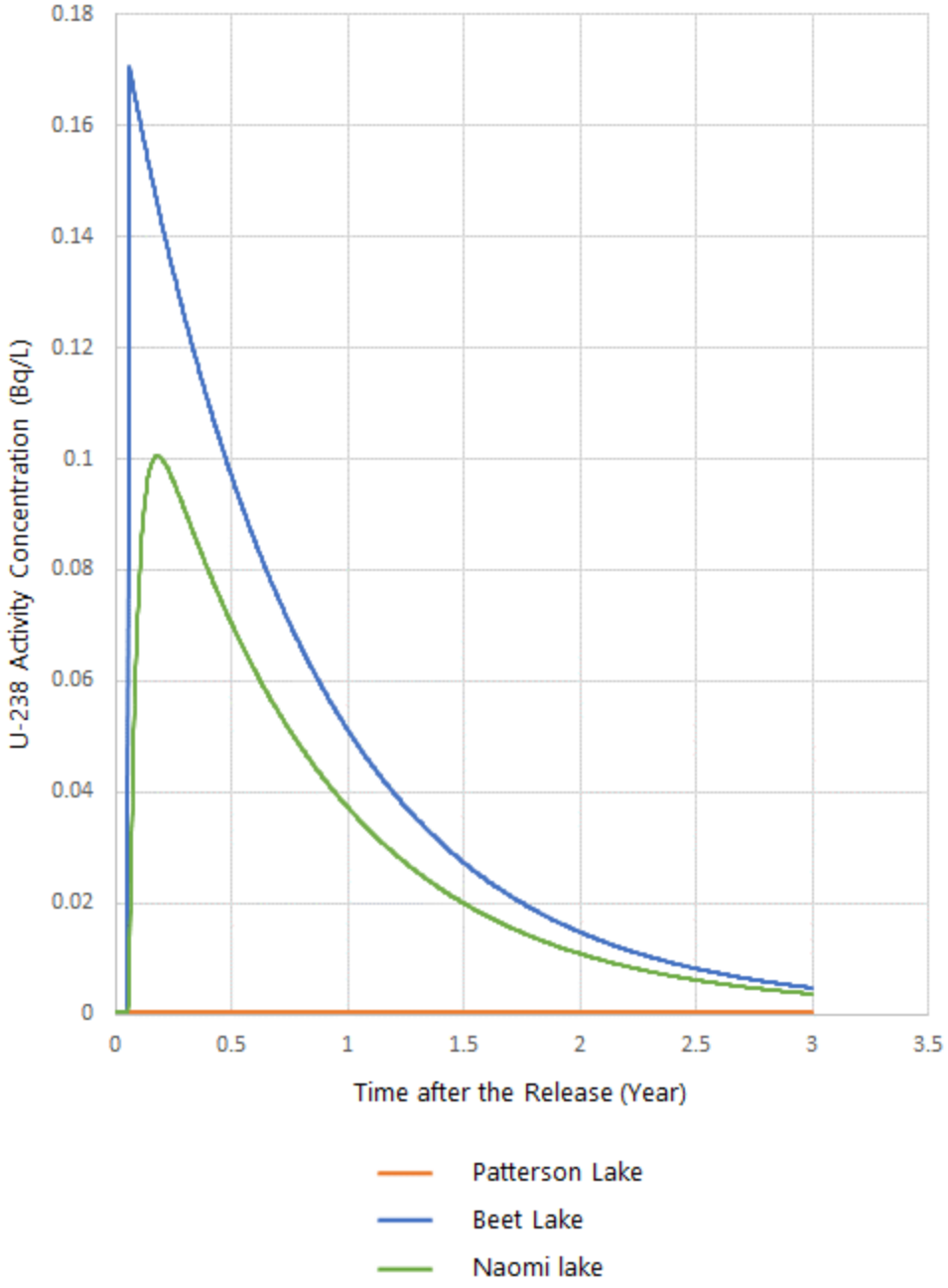
The above probabilities were calculated as a range using both Transport Canada and Saskatchewan Government Insurance statistics.

According to the probability ratings described in Section 3.2, Table 3-1, the probability that this accident and malfunction scenario would occur is highly unlikely.

6.4 Assessment of Potential Effects

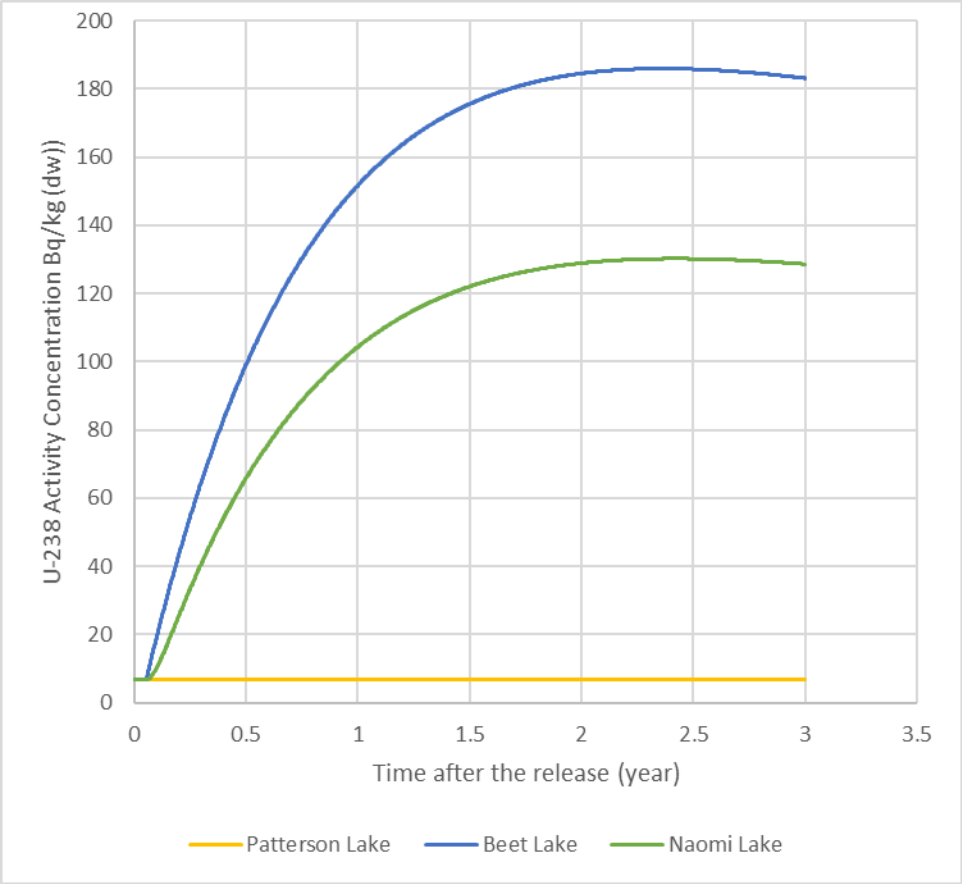
Using the release rate of uranium concentrate calculated in Section 6.2, the long-term surface water and sediment activity concentrations of uranium were calculated. Figure 6-2 and Figure 6-3 show the concentrations in Patterson Lake, Beet Lake, and Naomi Lake. The surface water and sediment concentrations would be much higher in a small area immediately downstream of the release location.

Figure 6-2: Long-Term Surface Water Activity Concentrations of Uranium Following an Aquatic Release of Uranium Concentrate



U-238 = uranium-238; Bq/L = becquerels per litre.

Figure 6-3: Long-Term Sediment Activity Concentrations of Uranium Following an Aquatic Release of Uranium Concentrate



U-238 = uranium-238; Bq/kg (dw) = becquerels per kilogram, dry weight.

The maximum calculated surface water concentration in Beet Lake is 0.17 Bq/L or 13.7 µg/L (based on uranium-238 specific activity of 12,445 Bq/g). This concentration is less than both the 20 µg/L guideline for total natural uranium in drinking water and the 15 µg/L guideline for the protection of aquatic life for long-term exposure. In the immediate vicinity of the release (Forrest Lake North), the maximum uranium concentration is calculated to be 29.2 Bq/L or 2,345 µg/L, which constitutes an exceedance of the water quality objectives presented above. However, this maximum concentration would occur for a short period of time (i.e., less than an hour) in a localized area, and would quickly dissipate to concentrations below both the guidelines for drinking water and protection of aquatic life.

The calculated surface water and sediment concentrations were used to estimate the radioactive dose to a number of human, terrestrial, riparian, and aquatic receptors. For reference, receptors identified are the same as those used in the Project Environmental Risk Assessment (TSD XXI).

The closest receptor considered is the subsistence harvester at Beet Lake. The maximum total doses due to all exposure pathways to human receptors present in the area are shown in Table 6-5. Although the short-term exposure to a human receptor following a release in close

proximity to the release area could be high, this exposure is unlikely because emergency response would isolate this area and prevent direct access to it. The calculated long-term doses to all human receptors are lower than the CNSC effective dose limits for the public of 1 mSv in one year.

Table 6-5: Estimated Maximum Total Radiation Dose to Human Receptors Following an Aquatic Release of Uranium Concentrate (Reference Location Representative of Baseline Exposure)

Receptor	Receptor Location	Total Dose[(a)] (mSv/yr)
Subsistence harvester	Reference location	2.66×10^{-03}
Subsistence harvester one-year-old	Reference location	3.17×10^{-03}
Subsistence harvester	Beet Lake	3.05×10^{-03}
Subsistence harvester one-year-old	Beet Lake	3.39×10^{-03}

a) The Subsistence Harvester in this scenario is conservatively assumed to consume the entirety of their Traditional Food from the Beet Lake location.
mSv/yr = millisieverts per year.

The maximum total dose rates due to all exposure pathways to terrestrial and riparian ecological receptors are shown in Table 6-6. Although the short-term exposure of these receptors following a release at the close vicinity of the release area could be high, this exposure is short-term (within a few hours because of the dilution of dissolved portion of the released uranium concentrate) and limited to a small geographic area (less than few hundred metres from the release location). The calculated maximum dose rates at Beet Lake to all terrestrial and riparian receptors are lower than the benchmark of 2.4 mGy/d.

Table 6-6: Estimated Maximum Total Radiation Dose to Terrestrial and Semi-Aquatic Receptors at Beet Lake Following an Aquatic Release of Uranium Concentrate

Receptor	Total Dose (mGy/d)
Beaver *(Castor canadensis)*	2.50×10^{-05}
Black bear *(Ursus americanus)*	1.74×10^{-05}
Canada goose *(Branta canadensis)*	7.05×10^{-05}
Grey wolf *(Canis lupus)*	1.42×10^{-06}
Grouse *(Falcipennis canadensis)*	5.01×10^{-04}
Little brown myotis *(Myotis lucifugus)*	7.33×10^{-06}
Common loon *(Gavia immer)*	4.79×10^{-05}
Mallard *(Anas platyrhynchos)*	7.32×10^{-04}
Mink *(Neovison vison)*	4.11×10^{-06}
Moose *(Alces americanus)*	2.08×10^{-05}
Muskrat *(Ondatra zibethicus)*	2.90×10^{-05}
Red fox *(Vulpes vulpes)*	1.30×10^{-06}
Rusty blackbird *(Euphagus carolinus)*	8.45×10^{-04}
Snowshoe hare *(Lepus americanus)*	2.11×10^{-05}
Southern red-backed vole *(Myodes gapperi)*	7.67×10^{-06}
Woodland caribou *(Rangifer tarandus caribou)*	1.60×10^{-05}

mGy/d = milligrays per day.

The maximum total dose rates due to all exposure pathways to aquatic receptors are shown in Table 6-7 and Table 6-8 in Patterson Lake (reference location upstream of the release, provided for comparison) and Beet Lake, respectively. Although the short-term exposure of these receptors following a release at the close vicinity of the release area could be high, this exposure is short-term (within a few hours because of the dilution of dissolved portion of the released uranium concentrate) and limited to a small geographic area (less than few hundred metres from the release location). The calculated maximum dose rates at Beet Lake to all aquatic receptors are lower than the benchmark of 9.6 mGy/d.

Table 6-7: Estimated Maximum Total Radiation Dose to Aquatic Receptors in Patterson Lake Upstream of the Release of Uranium Concentrate

Receptor	Total Dose (mGy/d)
Benthic invertebrate	1.09×10^{-08}
Zooplankton	4.44×10^{-05}
Northern pike *(Esox lucius)*	8.83×10^{-06}
Whitefish *(Coregonus clupeaformis)*	1.67×10^{-06}
Macrophytes	2.22×10^{-05}
Phytoplankton	2.22×10^{-05}

mGy/d = milligrays per day.

Table 6-8: Estimated Long-Term Total Radiation Dose to Aquatic Receptors in Beet Lake Following an Aquatic Release of Uranium Concentrate

Receptor	Total Dose (mGy/d)
Benthic invertebrate	2.92×10^{-07}
Zooplankton	5.98×10^{-04}
Northern pike	1.19×10^{-04}
Whitefish	2.24×10^{-05}
Macrophytes	2.99×10^{-04}
Phytoplankton	2.99×10^{-04}

mGy/d = milligrays per day.

Based on the potential for short-term and localized exposure, and calculated long-term exposure and dose to ecological receptors as well as the calculated long-term dose to human receptors, and in consideration of the effect scale described in Section 3.2, Table 3-2, the consequence of this bounding scenario is judged to be moderate.

7.0 BOUNDING SCENARIO 2: TRAFFIC ACCIDENT (CHEMICAL)

This bounding scenario consists of the release of fuel and hazardous chemicals into the Clearwater River under the bridge along the Project access road. A general description of the hypothetical event, hypothetical contaminants release characterization (e.g., contaminants, quantities), the probability of the scenario and its potential effects on the human health and biophysical environment is provided below.

7.1 Scenario Description

This scenario is similar to Bounding Scenario 1, except that it potentially results in the release of chemicals or fuel such as diesel, gasoline, or liquified natural gas at the site access bridge over the Clearwater River. The information related to the fuel and chemicals transported to the site is summarized in Table 7-1.

Table 7-1: Chemicals Transported to the Project Site

Chemical	Variable	Value
Diesel and gasoline	Fuel tanker truck capacity	30 m^3
	Fuel tanker truck trips per day	10 each for diesel and gasoline
Organic solvents	Daily volume of organic solvent consumption	Negligible. The solvent consumption is minimum due to regeneration
	Organic solvent tanker truck capacity	40 t
	Organic solvent tanker truck trips per month	1 (assumed). The solvent consumption is minimum due to regeneration)
Liquified natural gas	Liquified natural gas tanker truck capacity	48 m^3
	Liquified natural gas tanker truck trips per day	3
Hydrogen peroxide	Daily volume of hydrogen peroxide consumption	18,289 L
	Hydrogen peroxide tanker truck capacity	11,350 L to 18,900 L
	Hydrogen peroxide tanker truck trips per day	0.97 to 1.61
Molten sulphur	Daily volume of molten sulphur consumption	50,280 L
	Molten sulphur tanker truck capacity	25 t
	Molten sulphur tanker truck trips per day	3.5

Source: NexGen 2021.

7.2 Release Characterization

It was conservatively assumed that the entire cargo would be released during an event. Based on information provided by NexGen (2021), the following is assumed:

- Diesel fuel (30 cubic metre [m^3] release): The released diesel forms a sheen on top of water with a thickness of approximately 1 µm. While as much as 15% of the diesel would dissolve in the water column (NOAA 2023), up to 30% would evaporate from the surface of water

(Silver and Mackay 1984). The rest of the fuel, which is predominantly heavier components, would stay afloat or be adsorbed into the soil or shallow sediments along the river and downstream lake banks.

- Gasoline (30 m^3 release): The released gasoline forms a sheen on top of water with a thickness of approximately 1 µm. While as much as 25% of the gasoline would dissolve in the water column, up to 70% would evaporate from the surface of water (Silver and Mackay 1984). The rest of the fuel, which is predominantly heavier components, would stay afloat or be adsorbed into the soil or shallow sediments along the river and downstream lake banks.
- Organic solvents (40 t release): The released solvent behaves similarly to diesel fuel, as discussed above.
- Liquified natural gas (30 m^3 release): The release would most likely undergo a phenomenon called cold explosion. The released liquified natural gas would evaporate quickly and be released to the atmosphere (Melhem and Ozog 2006).
- Hydrogen peroxide (approximately18 m^3 release): Hydrogen peroxide and water are miscible liquids. Thus, upon release, the entire volume of hydrogen peroxide would mix with water. Hydrogen peroxide is a reactive oxygen species and decomposes slowly when exposed to light in natural environment, and rapidly in the presence of organic compounds. Decomposition releases hydroxyl radicals that react rapidly with organic compounds in the environment. The typical products of hydrogen peroxide decomposition (i.e., water and oxygen) do not harm organisms in fresh water. Organisms in small, confined waterbodies could be affected by hydrogen peroxide itself, or by reactive hydroxyl radicals formed when it reacts with metal catalysts in the water such as iron (II) sulphate (Schmidt et al., 2006). This would need to occur before hydrogen peroxide decomposes or dilutes to background levels in the environment. In a study conducted by Rach et al. (1997), fish were exposed to hydrogen peroxide concentrations ranging from 100 µL/L to 5,000 µL/L parts per million (ppm) for 15-min or 45-min treatments every other day for four consecutive treatments to determine the sensitivity of various species and life stages of fish. It was found that most species of fish tolerated hydrogen peroxide of greater than 1,000 ppm with no adverse effects. The concertation of 1,000 ppm requires a dilution of less than 1 to 1,000. It means 18 m^3 should be diluted to 18,000 m^3. This would occur in a stretch of less than 200 m of Clearwater River before it reaches the Forest Lake. Therefore, acute effects on a large fish population are not expected. The effects are expected to be transient, and chronic effects are not expected.
- Molten sulphur (25 t release): When molten sulphur is released into cold surface water, brownish amorphous or plastic sulphur is produced by the rapid cooling process. The amorphous form has long coiled polymeric molecules that make it elastic. The solubility of this substance is extremely low and can be considered to not be released into the water column through the dissolution process.

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

7.3 Assessment of Probability

Traffic risk mitigation measures for this scenario are the same as those presented for Bounding Scenario 1. The frequency of traffic accidents involving fuel or chemicals in the vicinity of the Clearwater River crossing (i.e., considering 40 m buffer at each side of the bridge), assuming 12 trips per day for 330 days per year, are estimated as:

for release to water: 3.1×10^{-04} to 1.0×10^{-03} per year.

The above probabilities were calculated as a range using both Transport Canada and Saskatchewan Government Insurance statistics.

According to the probability ratings described in Section 3.2, Table 3-1, the probability that this accident and malfunction scenario would occur is highly unlikely.

7.4 Assessment of Potential Effects

Among the chemicals considered for this scenario, the effects of the release of gasoline and solvents are bounded by the effects associated with the release of diesel fuel. Both gasoline and solvents are lighter with higher vapour pressure; therefore, they have a shorter residence time in the aquatic environment and have a lesser tendency for adsorption to sediments and suspended solids in the water column. To that end, the assessment of effects from a potential spill of fuel and hazardous materials due to a traffic accident at the access road bridge crossing of the Clearwater River focused on the release of diesel. The release of diesel into the Clearwater River was deemed by the preliminary hazard assessment to have the greatest likelihood and consequence in terms of potential adverse effects on aquatic and semi-aquatic biota among the fuel and chemical types that would be transported to or from the Project site. This assumption is based on the expected behaviour of diesel fuel in water and its potential for toxicity.

Diesel fuel is considered a non-persistent oil. It will lose 45% of its volume due to evaporation and dissolution within 48 hours of an accidental release, even in cold weather. Small diesel spills (i.e., 2 m^3 to 20 m^3) will usually evaporate and disperse within a day or less in the aquatic environment; thus, seldom is there any oil on the surface for responders to recover (NOAA 2023). With a specific gravity between 0.82 and 0.88, diesel fuel is lighter than water, so it is not possible for diesel to sink and accumulate on the sediment bed as pooled or free oil unless adsorption occurs with sediment. Diesel dispersed in the water column can adhere to fine-grained suspended sediments that can then settle out and deposit at the bottom. This process is more likely to occur where there is a presence of fine-grained sediment, which is not the case in the Clearwater River as it is fed by large lakes that effectively remove sediment from the water column. This process is not likely to result in measurable sediment contamination for small spills (NOAA 2023). The residual diesel would likely be completely degraded within one to two months; therefore, a complete surface water cleanup for small-scale diesel spills is not feasible.

Nevertheless, the unplanned release of diesel still poses a threat to aquatic organisms and particularly aquatic birds if they are exposed. Fish, aquatic invertebrates, and aquatic vegetation

that come in direct contact with a diesel spill may be killed. However, small spills in open water are so rapidly diluted that fish kills are unlikely, unless the spill is in confined, shallow water.

The theoretical maximum size of 1 µm thick diesel fuel sheen that can be created by a 30 m^3 spill is $3 \times 10^{+07}$ square metres (m^2); however, due to evaporation and dissolution of 45% of the spilled diesel, the size the slick is much smaller, particularly in a slow-moving surface waterbody. This is the case at the Project site, where the elevations of Patterson Lake (498.59 metres above sea level [masl]), Forrest Lake (498.34 masl), and Beet Lake (498.29 masl) are similar. The water flow rate in the Clearwater River between Forrest Lake and Beet Lake is approximately 2.3 m^3/s, and when considering the width of the connecting channel between the two lakes (i.e., 100 m to 400 m) and the depth of less than 2 m, the average water velocity is less than 1 cm/s. At this velocity, a spill would travel less than 1 km in a day. Considering the lifetime of diesel fuel, the diesel sheen would likely not travel beyond 2 km from the bridge on the access road. Thus, the affected areas would be limited to the northern end of Forrest Lake and Beet Lake Channel.

Emissions associated with evaporated diesel fuel would be transient in nature, localized, and likely dispersed rapidly by prevailing winds. Given this, wildlife and avian risks related to exposure to diesel components emitted to the atmosphere through volatilization are expected to be highly unlikely, with avoidance being the most likely outcome, though toxicity through the inhalation pathway is still possible (King et al. 2021). Exposure of workers and crews dispatched to respond to the accidental release could also be at risk of exposure via inhalation. Such risks would be mitigated through the use of risk management measures, such as personal protective equipment and adherence to appropriate safety protocols. These risk management measures would be described in the risk management processes and applicable documentation within NexGen's Integrated Management System, including spill response planning and procedures. These measures would be developed and implemented prior to the initiation of licensed Project activities.

Overall, the effects of a diesel spill under this scenario are transient, and some adverse effects to aquatic biota and potentially birds may occur within the affected area. Due to short-term exposure, irreversible population-level residual effects are not expected. Additionally, risks to accident responders are assumed to be mitigated through the use of risk management measures that would be described in emergency response planning documentation.

Based on the above, and in consideration of the effect scale described in Section 3.2, Table 3-2 the consequence of this accident and malfunction scenario is judged to be moderate, per the matrix shown in Figure 3-1.

8.0 BOUNDING SCENARIO 3: SOLVENT EXTRACTION FIRE OR EXPLOSION

This bounding scenario involves damage to equipment or vessels containing uranium-bearing solutions resulting in fire and release of uranium concentrate to the environment. A general description of the hypothetical event, hypothetical contaminants release characterization (e.g., contaminants, quantities), the probability of the scenario, and its potential effects on the human health and biophysical environment is provided below.

8.1 Scenario Description

This bounding scenario involves damage to the equipment or vessels containing uranium-bearing solutions due to human error or equipment failure, resulting in release to the environment, fire, and exposure of workers or members of the public to airborne uranium.

The Olympic Dam Mill (BHP Billiton) in Australia had three fires in the solvent extraction circuit in 1999, 2001, and 2002. These fires indicated flaws in design and operation of solvent extraction facilities erected prior to 2002 in relation to fire prevention and protection. For plants designed since 2002, fire safety issues have been closely examined and incorporated into appropriate low-risk designs. In light of the lessons learned from these fires, fire prevention and fire protection measures have been implemented in the new designs of the solvent extraction circuits. The BHP Billiton's 2003 Environment, Health and Safety Annual Report states:

> The hazard of an internal fire was not identified at any time during the design, construction and operation prior to the fire incidents. In rebuilding the solvent extraction plants, we incorporated new standards for fire prevention and fire protection as identified in the investigation of the 2001 fire. (BHP Billiton 2003)

Despite major improvements in the design and operation of the solvent extraction circuits, the history of fire indicates that a fire in the solvent extraction area is possible and is a plausible scenario. NexGen's design and operational procedures for the solvent extraction area at the Project site would include provisions for fire safety, specifically those related to the release of flammable materials, static electricity, and other sources of ignition as well as fire-fighting capabilities.

A fire that originates in the solvent extraction process area and involves loaded solvent could potentially release a large amount of uranium to the atmosphere. The fire that would follow a spill and exposure of spilled solvent to an ignition source could spread to other process plant areas if not extinguished rapidly. The accumulated organic vapour could also form an explosive vapour cloud.

The selected fire scenario was assessed through two separate scenarios:

1. Indoor fire in the solvent extraction building; and
2. Unconfined fire.

8.2 Release Characterization

The quantification of release followed the widely accepted methods proposed by the United States Department of Energy (USDOE) to estimate source terms (USDOE 1994). According to the USDOE, the airborne source term is typically estimated by the following five-component linear equation:

source term (kg/lb or kg/lb/s) = MAR (kg/lb or kg/lb/s) × DR × ARF × RF × LPF

where:

MAR = Material at risk is the amount of chemical or radionuclide available to be acted on by a given physical stress. For facilities, processes, and activities, the MAR is a value representing some maximum quantity of chemical present or reasonably anticipated for the process or structure being analyzed.

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

ARF = Airborne release fraction, or airborne release rate for continuous release, is the coefficient used to estimate the amount of a chemical released or suspended in air as an aerosol or gas and thus available for transport due to physical stresses from a specific accident.

RF = Respirable fraction is the fraction of airborne chemical particles that can be transported through air and inhaled into the human respiratory system. The RF is commonly assumed to include particles of 10 µm aerodynamic equivalent diameter or less. Other definitions of "respirable particles" have been presented by various groups at different times, but for the present purposes, 10 µm and smaller particles were considered respirable. For gaseous chemicals, the RF is 1.

LPF = Leak path factor is the fraction of the chemical or radionuclide transported through some confinement deposition or filtration mechanism. There can be many LPFs for some accident conditions (e.g., the fraction transported from the package, such as a shipping container, to the enclosure; 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).

Background information on source term parameters for the solvent fire scenario is summarized in Table 8-1, and estimates for each parameter are developed below, as well as the estimated airborne source term value.

MAR:

The total volume of the uranium-rich solvent is 100 m^3, which will burn during a fire. The fire is assumed to be unmitigated (not extinguished). The US Nuclear Regulatory Commission (USNRC 2004) Fire Dynamics Tools were used to calculate the Fire Duration, T_{FD}, for a liquid pool fire:

$$T_{FD} = 4V/\pi D^2 v$$

where:

V = volume of solvent available for burning: 100,000 L

D = solvent spill or exposure area diameter; in the worst-case scenario, the entire ground floor area could be involved in a fire (i.e., 20 m by 20 m)

v = regression rate (i.e., liquid pool burning rate) based on solvent properties (USNRC 2004) of 0.05 $L/m^2/s$ for the solvent

The theoretical burning rate will be 400 × 0.05 = 20 L/s and the fire duration was calculated as 83 min. The maximum uranium concentration in the loaded solvent is 8 g/L (8 kg/m^3) and the density of this solution is approximately 1,500 kg/m^3. Therefore, MAR will be calculated as:

MAR = 20 L x 8 g/L = 160 g/L = 0.16 kg/s

DR:

A constant burn rate was assumed with no credit for initial fire build-up time. In practice, the fire duration may be less because the fire would be extinguished as part of the fire response. If it is assumed that the fire would last one hour, the DR would be 0.45. Conservatively, the fire duration limit of one hour was not considered and the DR was assumed to be 1. Also, the effects of oxygen availability on the burning rate were not considered, which is a conservative assumption because oxygen limitation is often a factor that governs compartment fire behaviour. If oxygen starvation becomes a limiting factor in burning rate (e.g., fire in enclosed or congested areas), the burning rate could be less.

ARF:

From the information presented in Table 8-1, the ARF is assumed to be 0.1 based on the ARF data published by USDOE (USDOE 1994).

RF:

It was assumed that all the aerosols produced in the fire are respirable; therefore, the RF = 1 (Table 8-1).

LPF for confined fire in the building:

During a fire, natural or mechanical ventilation would be enhanced by the chimney effect of the fire. The building ventilation rate during a fire can be estimated based on the volume of air drawn into the building to support the fire. The volume of air needed to support a burning rate of 20 L/s kerosene is approximately 220 m^3/s. Assuming 14 air changes per hour (typical of a closed building during fire), maximum air flow through the building is about 27 m^3/s. This volume of air can only support a burning rate of 2.5 L/s of solvent. The limiting factor in the rate of fire is the availability of oxygen. Thus, the LPF would be 2.5/20 = 0.125.

The airborne source term is calculated as:

> 0.16 kg/s × 1 × 0.1 × 1 × 0.125 = 0.002 kg/s uranium = 0.0024 kg/s (0.005 lb/s) U_3O_8 (uranium concentrate)

LPF for unconfined fire:

If the building envelope is breached, then the calculations for the previous scenario are still valid; however, the LPF would be 1. Therefore, the source term for this scenario would be 0.016 kg/s uranium or 0.0189 kg/s U_3O_8 (uranium concentrate).

Since the atmospheric benchmarks (Protective Action Criteria) are defined for 1-hour exposure and the fire can potentially burn for more than an hour, it was conservatively assumed for the source term that the above amount is released in one hour.

Table 8-1: Airborne Release Fraction and Respirable Fraction Values for Various Fire Scenarios

Liquid Fire Parameter Values – Summary Values									
Type of Stress	***Material***	**Conditions**			**Median ARF**	**Bounding ARF**	**Median RF**	**Bounding RF**	**Comments**
Fire	Organic combustible liquids	Quiescent burning	Small surface area or Small solvent layer over large pool that burns to self-extinguishment	n/a	6×10^{-03}	1×10^{-02}	1	1	n/a
Fire	Organic combustible liquids	Vigorous boil-off	Large surface area or pool or Solvent layer burning over limited aqueous layer with sufficient turbulence to disrupt the bulk of the aqueous layer	Does not burn to complete dryness	n/a	3×10^{-02}	n/a	1	Does not involve burning to complete dryness
Fire	Organic combustible liquids	Vigorous boil-off	Large surface area	Burns to complete dryness or burning solvent over aqueous phase burning to complete dryness for both phases	1×10^{-02}	1×10^{-01}	1	1	Typically an external outside heat source
Fire	Organic combustible liquids	Aqueous solution or air-dried salts	Porous absorbing surface (e.g., cracks, pits, soil, sand)	n/a	n/a	5×10^{-03}	n/a	0.4	Based on gasoline fire
Fire	Organic combustible liquids	Aqueous Solution or air-dried salts	Heat conducting surface (e.g., metal)	n/a	n/a	2×10^{-01}	n/a	0.3	Based on gasoline fire

Source: USDOE 1994.
Note: Quiescent burning = relatively undisturbed liquid surface (opposite of vigorous boil-off), while vigorous boil-off = strongly disturbed liquid surface (opposite of quiescent burning).
ARF = airborne release fraction; RF = respirable fraction.
n/a = data not provided in original source material.

8.3 Assessment of Probability

The following mitigating measures would be in place to reduce the probability of a release and potential for fire:

- concrete mixer-settler to facilitate visual leak inspection;
- emergency organic dump tanks and fast-acting valves to transfer solvent extraction mixer-settlers in case of fire;
- fire detection systems;
- fire safety plan and firefighting systems;
- regular and preventive inspections, testing, and maintenance programs;
- emergency response plan;
- full containment of process plant building or mixer-settler area; and
- ambient air monitoring.

Uranium bearing solution would be stored or processed in mixer-settler or storage tanks and transported through piping systems. A spill of these solutions could occur as a result of the following events:

- overflow of storage or process vessels;
- leaks or rupture in storage tanks and process vessels;
- failure of valves or other piping system components;
- failure of the pumps; and
- failure of other process components such as screens and filters.

Average probabilities of failures for different components in the solvent extraction building were based on the information provided by the Center for Chemical Process Safety of the American Institute of Chemical Engineers (AIChE-CCPS 1989) and are shown in Table 8-2.

Table 8-2: Average Failure Probability for Solvent Extraction Process Equipment

Equipment with Potential for a Major Spill or Fire	Failure Rate (All Modes; Per Year)
Vessels (i.e., atmospheric and metallic; assuming 2 major vessels containing uranium reach solvents)	10^{-3}
Piping (i.e., metal; straight section and connection; assuming 100 sections)	10^{-4} per item
Pumps (e.g., motor driver and pressure-centrifugal; assuming 5 pumps)	10^{-2}

Source: Center for Chemical Process Safety (AIChE-CCPS 1989).

If it is assumed that the plant is in service 350 days per year for eight hours per day (i.e., 2,800 hours per year), this would result in a failure frequency of 6×10^{-02} per year under this scenario.

$$10^{-3} \times 2 + 10^{-4} \times 100 + 10^{-2} \times 5 = 6 \times 10^{-02} \text{ per year}$$

Less than 10% of the releases would result in a fire (AIChE-CCPS1989); therefore, the probability of fire would be $6 \times 10^{-02} \times 0.1 = 6 \times 10^{-03}$ per year.

The US Nuclear Regulatory Commission reported that the frequency of a major solvent extraction fire occurring at a uranium process plant was in the range of 4×10^{-04} to 1×10^{-02} per year (USNRC 1980). The above calculated value is within the range provided by the USNRC.

According to the probability ratings described in Section 3.2, Table 3-1, the probability that this accident and malfunction scenario would occur is unlikely.

8.4 Assessment of Potential Effects

To estimate the consequence of the potential effects associated with Bounding Scenario 3, the Areal Locations of Hazardous Atmospheres (ALOHA) model was used. ALOHA is a standalone software application developed and supported by the Emergency Response Division, a division within the National Oceanic and Atmospheric Administration (NOAA) in collaboration with the Office of Emergency Management of the Environmental Protection Agency. The primary purpose of ALOHA is to provide estimates of the spatial extent of some common hazards associated with chemical spills or releases to emergency response personnel (NOAA 2013).

As mentioned in Section 8.2, Release Characterization, a fire that originates in the solvent extraction building and involves loaded solvent could release uranium to the atmosphere. This fire event was assessed through two separate scenarios:

1. a contained, indoor fire in the solvent extraction building; and
2. an unconfined fire.

As noted in Section 5.1, although uranium is a radioactive substance, for natural and depleted uranium, the risks from intake of uranium are related to its chemical toxicity, and the potential for such effects is the basis of the assessment for this scenario.

8.4.1 Confined Indoor Fire

This scenario assumes that the fire is confined inside the building and that the building envelope remains intact. The fire could involve the loaded solvent directly, such as a fire in the loaded solvent vessels or from spilled loaded solvent.

The design of the process and the operational procedures minimize the probability of ignition leading to a fire. For example, all switches and motor controls would be explosion proof and

designed not to create a source of ignition, and welding would not be permitted in the area except under extremely controlled conditions, including the use of a fire watch during and after the job in accordance with the required work permit. To the extent that the building envelope remains intact after the unlikely initiating event, it may act as containment for the release scenario.

The source term calculated in Section 8.2 was 2.0 g/s uranium or 2.4 g/s uranium concentrate. The air concentration versus distance was calculated and compared with the benchmarks provided in Section 5.0, Chemical, Occupational, and Radiological Benchmarks, for the following two weather conditions:

- W1: worst-case weather conditions: 95th percentile wind speed and Pasquill stability class F. Stability class F is a stable atmospheric condition that occurs during nighttime, overcast conditions, with a wind speed of less than 2 m/s, typically 1.5 m/s. Thus, wind speed of 1.5 m/s and stability class F were selected as the worst-case condition for dispersion of released materials (NOAA 2019).
- W2: typical weather conditions: average wind speed and Pasquill stability class D. Stability class D is a neutral atmospheric condition that occurs during slight to moderate daytime solar intensity and thin nighttime overcast conditions, with a wind speed of around 5.0 m/s or slightly higher. This represents the average condition for dispersion of released materials (NOAA 2019). The wind rose in the area of the Project indicates that the most frequent wind speed is approximately 5 m/s. Thus, 5 m/s was selected as the typical wind speed.

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

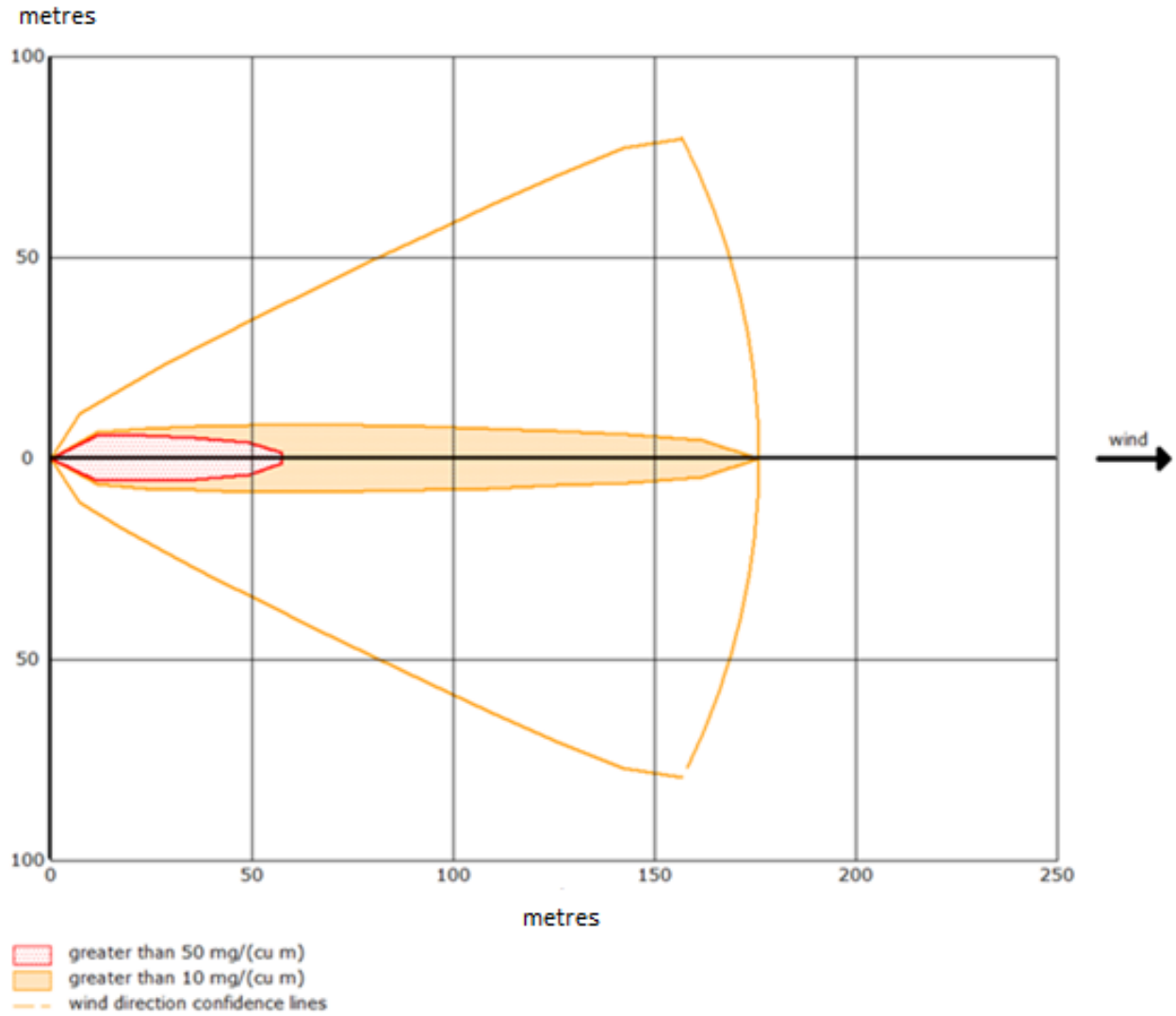
The results of the modelling of uranium concentration in air down-wind or the fire are summarized in Table 8-3. Figure 8-1 shows the results for W1 weather condition, and Figure 8-2 shows the results for W2 weather condition.

Table 8-3: Results of Uranium Fire Release Modelling for the Contained, Indoor Fire

Weather Condition	Distance to ERPG-3 (m)	Distance to ERPG-2 (m)
W1	58	176
W2	30	68

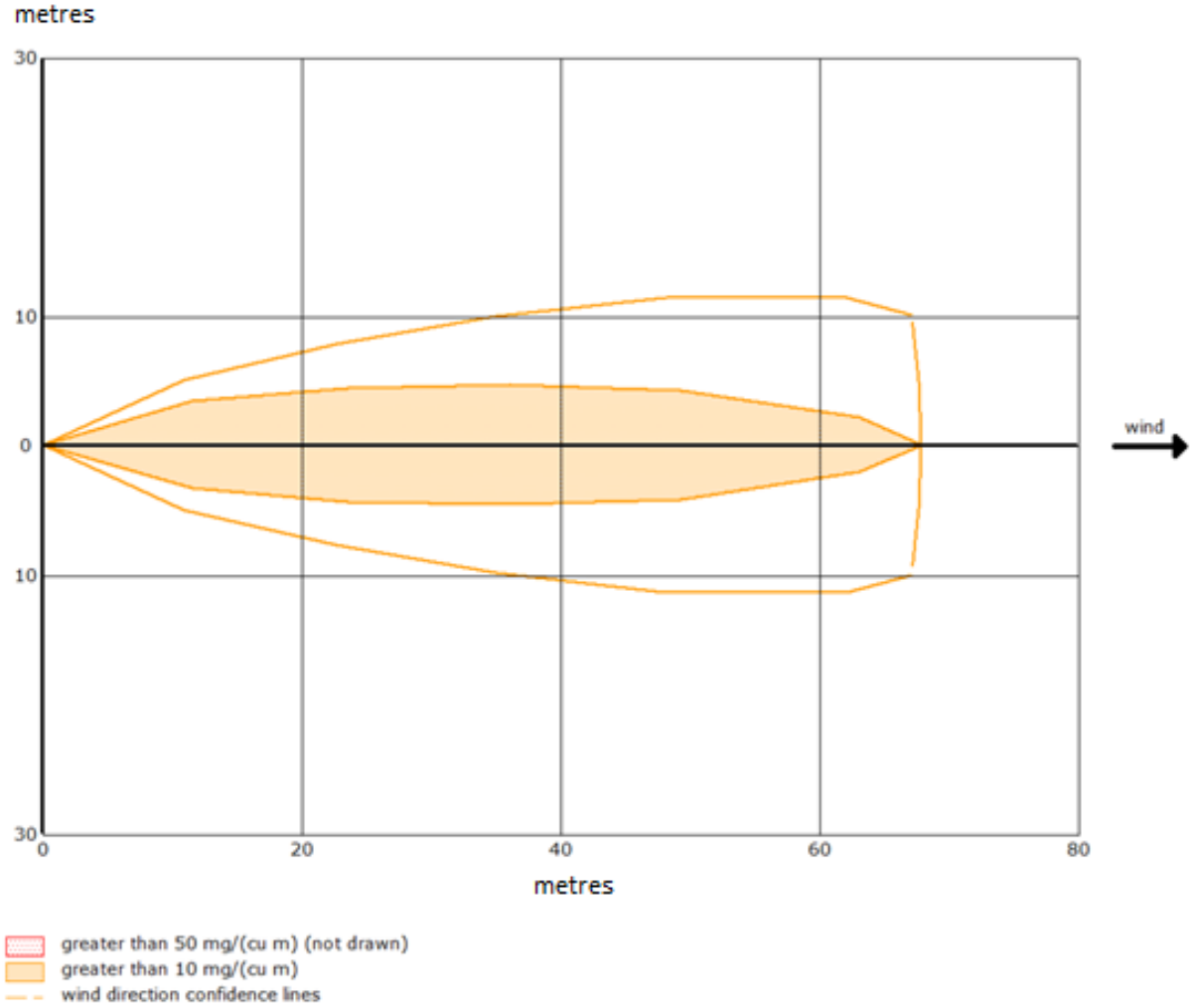
ERPG = Emergency Response Planning Guideline; W1 = worst-case weather conditions; W2 = typical weather conditions.

Figure 8-1: Concentration of Uranium in Air for a Confined Indoor Fire for Worst-Case Weather Conditions



Note: The ERPG-2 for uranium concentrate is 10 mg/m^3; ERPG-3 for uranium concentrate is 50 mg/m^3.
cu m = cubic metre; ERPG = Emergency Response Planning Guideline.

Figure 8-2: Concentration of Uranium in Air for a Confined Indoor Fire for Typical Weather Conditions



Note: The ERPG-2 for uranium concentrate is 10 mg/m^3; ERPG-3 for uranium concentrate is 50 mg/m^3.
Cu m = cubic metre; ERPG = Emergency Response Planning Guideline.

As highlighted in Section 5.0, the most frequently used benchmark for emergency release scenarios is ERPG-2. The results indicate that the ERPG-2 benchmark of 10 mg/m^3 would be reached (i.e., the uranium levels would be below the threshold beyond this distance) at 176 m from the assumed source of the release (i.e., the solvent extraction building) for weather condition W1, and at 68 m for weather condition W2 representing the more likely weather condition.

It should be noted that the release during a fire is short-term (i.e., less than a few hours in duration); therefore, surface accumulation, and extended exposure to vegetation and wildlife, is not expected.

Based on the above, and in consideration of the consequence scale described in Section 3.2, Table 3-2, the consequence of the potential effects of this scenario are rated minor to moderate within a relatively short distance from the release.

8.4.2 Unconfined Fire

For an unconfined fire, where it is assumed the building envelope has been breached, the calculations described for the contained, indoor file remain valid; however, the LPF would be 1 and the release rate, as calculated in Section 8.2, would be 16 g/s uranium or 18.9 g/s uranium concentrate. The air concentrations versus distance were modelled using these release rates for the W1 and W2 weather conditions and compared with the benchmarks provided.

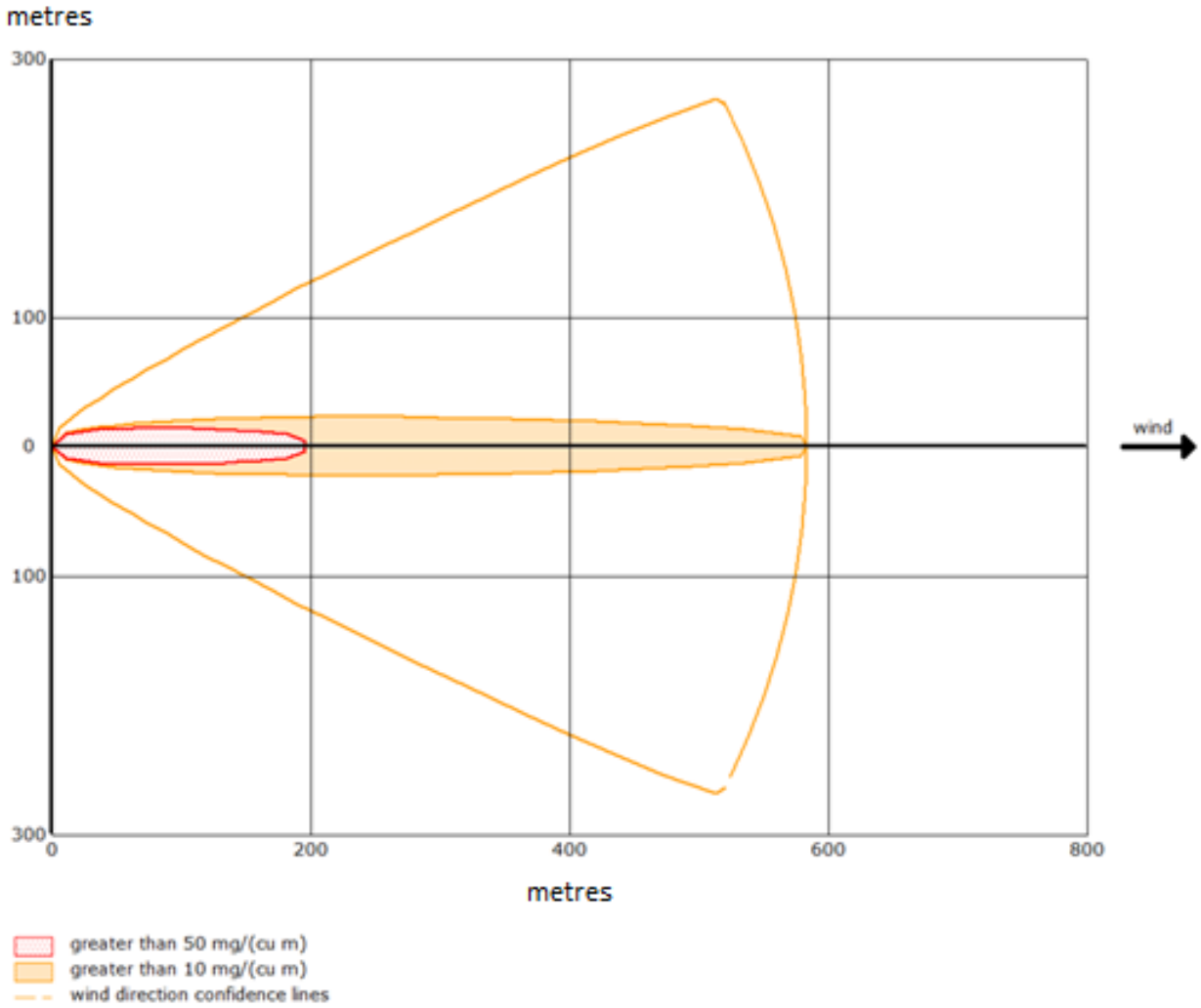
The results of the modelling of uranium concentration in air down-wind of the fire are summarized in Table 8-4. Figure 8-3 shows the results for W1 weather condition, and Figure 8-4 shows the results for W2 weather condition.

Table 8-4: Results of Uranium Fire Release Modelling for Unconfined Fire

Weather Condition	Distance to ERPG-3 (m)	Distance to ERPG-2 (m)
W1	196	584
W2	91	214

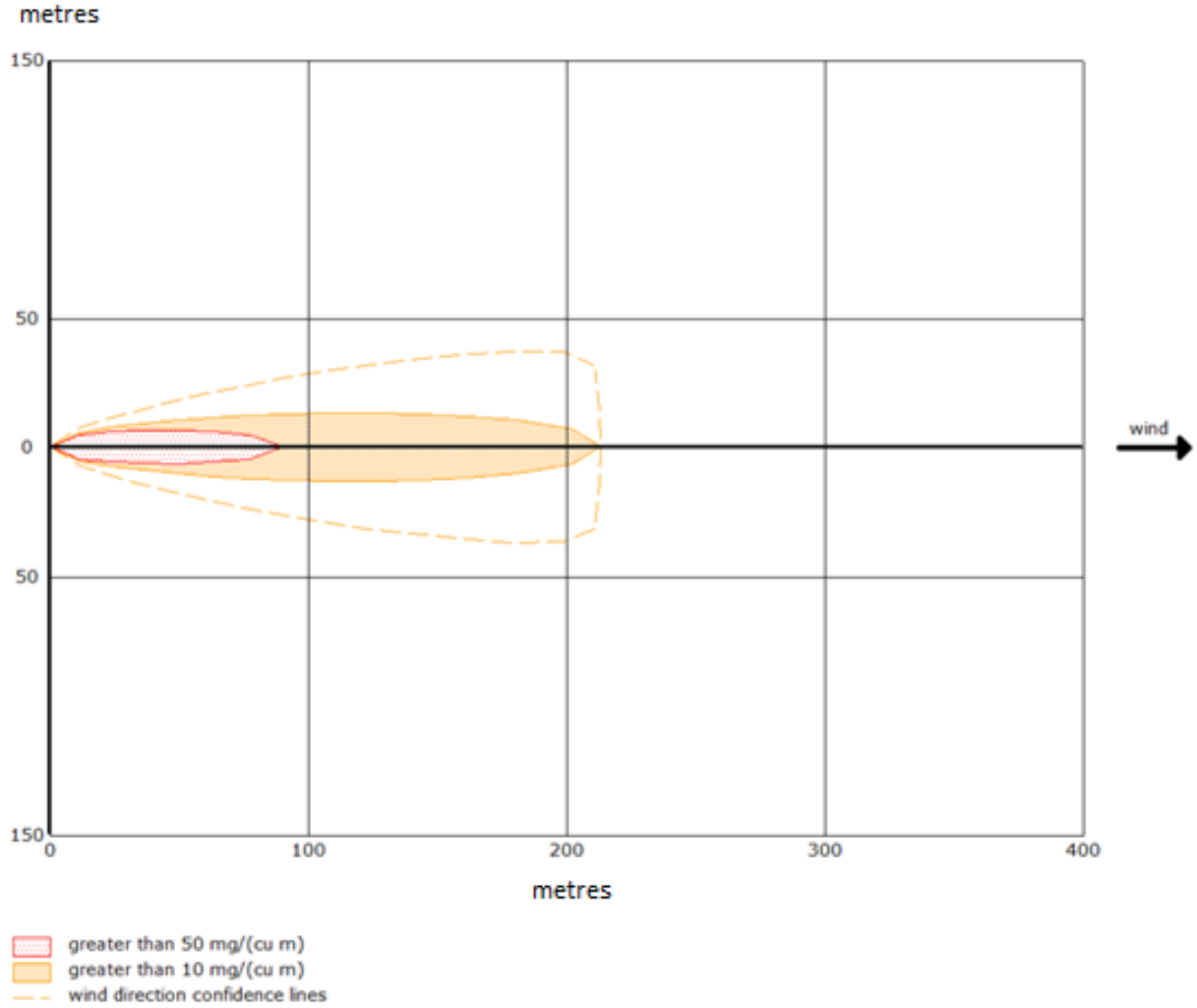
ERPG = Emergency Response Planning Guideline; W1 = worst-case weather conditions; W2 = typical weather conditions.

Figure 8-3: Concentration of Uranium in Air for Unconfined Fire for Worst-Case Weather Conditions



Note: The ERPG-2 for uranium concentrate is 10 mg/m^3; ERPG-3 for uranium concentrate is 50 Mg/m^3.
cu m = cubic metre; ERPG = Emergency Response Planning Guideline.

Figure 8-4: Concentration of Uranium in Air for Unconfined Fire for Typical Weather Conditions



Note: The ERPG-2 for uranium concentrate is 10 mg/m^3; ERPG-3 for uranium concentrate is 50 Mg/m^3.
cu m = cubic metre; ERPG = Emergency Response Planning Guideline.

As per Section 5.1, the most frequently used benchmark for emergency release scenarios is ERPG-2. The results indicate that the ERPG-2 benchmark would be reached (i.e., the uranium levels would be below the threshold beyond this distance) at 584 m from the source of the release (i.e., the solvent extraction building) for weather condition W1, and at 214 m for weather condition W2 representing the more likely weather condition.

Based on the above, and in consideration of the effect scale described in Section 3.2, Table 3-2, the consequence of the potential effects of this scenario is rated minor to moderate within a relatively short distance from the release.

9.0 BOUNDING SCENARIO 4: TAILINGS TRANSFER PIPE OR PUMP FAILURE

This bounding scenario involves the release of tailings from pump and pipes at the surface. A general description of the hypothetical event, hypothetical contaminants release characterization (e.g., contaminants, quantities), the probability of the scenario, and its potential effects on the human health and biophysical environment is provided below.

9.1 Scenario Description

In the process plant, ore would be leached with sulphuric acid and hydrogen peroxide through series of leach tanks in the leaching circuit. The leached slurry would be transferred to the counter current decantation circuit where the uranium bearing solution is separated from the leached residue. Uranium is concentrated in solution as it flows through the series of thickener tanks in the opposite direction of the solids residue. The tailings slurry from the counter current decantation circuit that contains the solids residue would be transferred to the tailings neutralization area where it would be neutralized using lime followed by a dewatering step using a belt filter. The dewatered tailings would be transported to the paste plant and blended with a binder. This product would primarily used for making cemented paste backfill for placement in mined stopes. Another portion of the neutralized tailings, along with gypsum and effluent precipitates, would be pumped to and mixed in the paste backfill plant. This combined paste product would then be transferred underground through a piping system and placed into the UGTMF.

A breach in the piping down the mine shaft and underground workings would result in the release of paste tailings in the mine. This may result in occupational exposure; however, environmental exposures, including those via the groundwater pathways, are highly unlikely. Thus, only the release of tailings from pump and pipes near the paste plant is considered in this assessment. The catastrophic failure of the tailings transfer pipe near the paste plant presents the bounding effect for this scenario. If the tailings are released outside the paste plant, the release may cause soil and groundwater contamination. There is a potential for surface water contamination if the released materials reach the lake.

The tailings pipe transport information is summarized in Table 9-1.

Table 9-1: Tailings Transport Information

Parameter	Value
Transfer rate of tailings	To mine stopes: 59.7 m^3/h (max) To UGTMF: 73.5 m^3/h (max)
Tailings density	To mine stopes: 1,690 kg/m^3 (max) To UGTMF: 1,537 kg/m^3 (max)
Tailings transfer pipe length	Surface borehole casing = 1,444 m Inter-level borehole casing = 478 m Level piping - high pressure = 850 m Level piping - mid pressure = 6,840 m Level piping - low pressure = 5,288 m Stope piping = 9,059 m
Activity concentration of the main radionuclide (e.g., radium-226) in tailings	Radium-226 (s) = 390 Bq/g in backfill stopes Radium-226 (s) = 185 Bq/g in UGTMF tailings

Source: NexGen 2021.
UGTMF = underground tailings management facility; s = soluble; Bq/g = becquerels per gram.

The area in the vicinity of the solvent extraction and process plant buildings is considered the most probable location for surface release of tailings under this scenario. In the worst-case situation, the released tailings would flow north, away from the developed footprint of the site. For the assessment, it was conservatively assumed that the surface water management system would not collect any portion of the released tailings, and therefore, the volume of mixed tailings solids and untreated tailings supernatant would flow unmitigated to the north. The distance between the edge of the facility and Patterson Lake shoreline is more than 300 m with a slope ranging between 2% and 5%.

9.2 Release Characterization

The transport of radioactivity (radium-226) within the pipes is calculated as follows:

To mine stopes: 59.7 m^3/h x 1,690 kg/m3 × 390,000 Bq/kg = 39.3 GBq/h; and

To UGTMF: 73.5 m^3/h × 1,537 kg/m^3 × 185,000 Bq/kg = 20.9 GBq/h.

The larger value of 39.3 GBq/h was considered for this assessment.

A major release from the piping system would result in the sudden drop in flow and pressure within the pipe that would be detected by the automated control system. The process control allows for the isolation of the failed portion of the piping system. With this in mind, it is expected that the contents of the isolated section of piping would be released within a few minutes and therefore a 15-minute release scenario is reasonable and conservative. Assuming a 15-minute release period, the amount of release would be 15/60 h × 59.7 m^3/h = 14.93 m^3, which would contain 9.83 GBq of radium-226. Based on the residual uranium content, the amount of uranium concentrate released under this scenario would be 3.8 kg. The potential exposure to alpha radiation from radon progeny and long-lived radioactive dust is limited to workers, which is

outside the scope of this assessment. The dust release associated with contaminated soil is only a concern when the soil is dry. In this condition, the entrained soil particles can be mobilized due to wind erosion resulting in dust, and possibly exposure. Public exposure due to contaminated dust is only possible if the material remains in place after it has dried. Emergency response to a tailings release would be swift, so such conditions would not likely prevail, and therefore public exposure is highly unlikely and was not addressed in this assessment.

9.3 Assessment of Probability

The piping system would be designed and constructed in compliance with process piping code ASME B31.3. The entire system would be regularly inspected and tested for defects. A maintenance program would be in place to confirm the mechanical integrity of the process components.

According to the Center for Chemical Process Safety of the American Institute of Chemical Engineers (AIChE CCPS 1989), the probability of a failure of a piping system similar to that of the Project is approximately 2×10^{-02} per year.

According to the probability ratings described in Section 3.2, Table 3-1, the probability that this accident and malfunction scenario would occur is likely.

9.4 Assessment of Potential Effects

The transport of the liquid materials released to the surface is affected by several factors including:

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

Landforms such as drumlins, lakes, wetlands, rivers, and muskegs are common in the area of the proposed Project. Elevations in the region range from 583 masl at the crest of major drumlins to 480 masl (i.e., surface elevation) for some of the lowland lakes. The surface elevation of Patterson Lake is approximately 499 masl.

The proposed Project location is dominated by sandstone; bedrock outcroppings are rare but are known to exist in areas to the eastern half of the exploration lease. The organic topsoil layer at the surface is very thin. The sandy surficial material hydraulic conductivity ranges from 1×10^{-06} m/s to 7×10^{-05} m/s (NexGen 2021). For similar soil characteristics, Simmons and Keller (2005) conducted a series of experiments contracted by the USDOE and showed that the penetration rate of spilled liquid into soil depends on slope, soil permeability, soil wettability, surface roughness, and initial moisture content of soil. In this study, experimental results were fitted into the Green-Ampt equation (Simmons and Keller, 2005). This equation relates the vertical infiltration rate with soil permeability, pressure head, and capillary suction. The results show that the penetration rates ranged from 0.07 cm/s to 0.1 cm/s for silt loam and sandy soils (i.e., with air porosity of 30% to 45%) with slopes of 2.4% and 4.8%. This experimental condition is similar to

the surface conditions around the Project site. In most experiments, the final moisture content of 60% was reached after the front head of the spills disappeared.

Assuming the water content of the soil increases from 20% to 60% for a maximum tailings release of 14.93 m^3 in this scenario (i.e., 9.83 GBq of radium-226), approximately 37.3 m^3 of the soil could be contaminated, as calculated below:

0.6 - 0.2 = 0.4 (40% of additional water)

14.93/0.4 = 37.3 m^3 of soil

If the soil was completely saturated following the spill, the maximum slurry release of 14.93 m^3 would result in 18.7 m^3 of contaminated–soil:

1 - 0.2 = 0.8 (80% of additional water)

14.93/0.8 = 18.7 m^3 of soil

If the penetration lasted 15 min, the maximum depth of contamination would be 90 cm, assuming a penetration rate of 0.1 cm/s:

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

For a penetration rate of 0.07 cm/s, the depth of contamination would be 63 cm:

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

The surface area potentially affected by the spill based on the different saturation conditions and penetration rates is estimated to range from 20.8 m^2 to 59.2 m^2, as calculated below:

area = 37.3/0.9 = 41.4 m^2 (i.e., 60% saturation and depth of 0.9 m)

area = 18.7/0.63 = 29.7 m^2 (i.e., 100% saturation and depth of 0.63 m)

area = 37.3/0.63 = 59.2 m^2 (i.e., 60% saturation and depth of 0.63 m)

area = 18.7/0.9 = 20.8 m^2 (i.e., 100% saturation and depth of 0.9 m)

For any of these combinations, a relatively small area would be expected to be affected in comparison to the distance to the Patterson Lake. Thus, the possibility of the release reaching Patterson Lake is improbable, and therefore, no effects on the lake from the accidental release of tailings to surface water would be expected. The maximum area of 59.2 m^2 is equivalent to an oval (since the release is on a slope) with a major axis of 12.2 m and minor axis of 6.1 m. For context, the distance from the hypothetical accident location to Patterson Lake is on the order of 300 m. Although enhanced runoff that may be associated with wet weather events could influence this evaluation, any potential effects on Patterson Lake are likely to be minimal, given the small size of the affected area.

Shallow groundwater flow is generally affected by local-scale topography, which is representative of conditions at the site. Shallow groundwater flow movement is from the topographic high located south of the proposed mine and process plant development in a northerly direction towards Patterson Lake. There is potential for groundwater contamination within the predicted area of soil contamination under this scenario, and therefore, there is the potential for groundwater-associated transport to Patterson Lake.

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

$$V = K \times I/n$$

where:

V = groundwater velocity

K = horizontal hydraulic conductivity

I = horizontal hydraulic gradient

n = effective porosity

As described above, $k = 1 \times 10^{-06}$ m/s, and the hydraulic gradient was assumed to be the maximum of the surface slope = 0.058. The effective porosity was assumed at 0.45.

In this case:

$$V = 1 \times 10^{-06} \text{ m/s} \times 0.058/(0.45) = 1.1 \times 10^{-07} \text{ m/s}.$$

Assuming the above velocity, it is estimated that it would take the groundwater approximately 85 years to reach Patterson Lake. Implementation of the spill response plan and associated cleanup would be expected to occur over a time period of days, or at maximum weeks, following the incident and therefore no material migration of contaminated groundwater outside the immediately affected area would be expected. Thus, the contamination of soil and shallow groundwater is expected to be contained within a small area near the release location, and no contamination would be expected to reach Patterson Lake along the groundwater pathway, because the contaminated soil would be removed during spill clean-up.

During the winter months, when the soil is frozen, no penetration of spilled tailings supernatant into the soil is expected. Therefore, no soil or groundwater contamination is expected; however, it is conceivable that the materials could spread over a larger surface area, and therefore from a practical perspective, the cleanup may be more extensive and take longer.

Based on the above, and in consideration of the effect scale described in Section 3.2, Table 3-2, the consequence of the potential effects of this scenario is rated minor.

10.0 BOUNDING SCENARIO 5: UNTREATED EFFLUENT TRANSFER PIPE FAILURE

This bounding scenario involves the release of untreated effluent from the piping system connecting the first stage reactor tanks, first stage clarifier, second stage reactor tanks, and the effluent treatment system. The distance between the piping and the Patterson Lake shoreline is variable, but is on the order of a few hundred meters with a slope between 1% and 5%. A general description of the hypothetical event, hypothetical contaminants release characterization (e.g., contaminants, quantities), the probability of the scenario, and its potential effects on the human health and biophysical environment are provided in the following subsections.

10.1 Scenario Description

Site contact water (e.g., process plant waste water, mine water, mineralized site runoff) would be treated and tested as required prior to release to the environment. As part of this process, contact water requiring treatment would be collected and stored in a settling pond prior to treatment. The settling pond would be double-lined with 80 mm high density polyethylene (HDPE) liner for primary and secondary containment.

The current design for the ETP includes a two-stage chemical (lime neutralization) treatment process to remove metals followed by a pH adjustment process prior to pumping to the treated effluent water tank. The treatment process would consist of first and second stages of treatments, with all stages containing two reactor tanks and a clarifier and a pH adjustment tank. Further details of the treatment technology are provided in EIS Section 4.0, Project Alternatives. As noted in that subsection, the ETP design is subject to further refinement as part of licensing for the Project.

Treated effluent from the effluent water tank would report to one of four monitoring ponds which would allow composite sample to be collected while the pond is filled. When the pond is full, the composite sample would be analyzed, and assay results would be examined based on effluent release limits. Once the quality of the water is within specification of the limits, it can be released to Patterson Lake. Any off-specification treated effluent water would return to settling for re-processing.

Table 10-1 summarizes the characteristic of the ETP and includes treatment capacity, piping size to and from the plant, estimated radium loading entering the plant, and fluid density assumption.

A breach in the untreated effluent piping at the surface is considered in this scenario. The catastrophic failure of the transfer pipe at the surface represents the bounding effect for this scenario. Failure of the piping between the process plant and the ETP would result in a release inside the mill building or outside the mill building within the mill terrace. The specific scenario considers a release of untreated effluent to surface outside the mill building.

Table 10-1: Untreated Effluent Transfer Information

Item	Value
Effluent treatment capacity (feed)	275 m^3/h to 600 m^3/h
Effluent pipe size (diameter) to and from the ETP	12" from settling pond to ETP
Maximum activity concentration of the main radionuclide (e.g., radium-226) in untreated effluent	Radium-226 (aq) = 600 Bq/L based on the untreated effluent pumped to ETP
Assumed density of effluent	1,000 kg/m^3

Source: NexGen 2021.
aq = aqueous; Bq/L = becquerels per litre; ETP = effluent treatment plant.

10.2 Release Characterization

The transport of radioactivity (radium-226) within the pipe is calculated as follows:

$$600\ m^3/h \times 1{,}000\ kg/m^3 \times 600\ Bq/L = 360 \text{ mega-becquerels per hour (MBq/h)}$$

As discussed in Section 9.2, it is expected the content of the isolated section releases within a few minutes and therefore a 15-minute release scenario is reasonable and conservative. Assuming a 15-minute release, the amount of release would be 15/60 h × 600 m^3/h = 150 m^3, which would contain 90 MBq of radium-226. Based on the residual uranium content, the amount of uranium concentrate released would be 7.6 kg.

10.3 Assessment of Probability

The piping systems would be designed and constructed in compliance with process piping code ASME B31.3. The entire system would be regularly inspected and tested for defects. A maintenance program would be in place to confirm the mechanical integrity of the process components.

According to the Center for Chemical Process Safety (AIChE-CCPS 1989), the failure of a piping system similar to that of the Project is approximately 2×10^{-02} per year.

According to the probability ratings described in Section 3.2, Table 3-1, the probability that this accident and malfunction scenario would occur is likely.

10.4 Assessment of Potential Effects

The assessment of this scenario is similar to that of Bounding Scenario 4.

Assuming the water content of the soil increases from 20% to 60% in the affected area during this event, for the maximum untreated effluent release of 150 m^3, approximately 375 m^3 of soil would be contaminated along the release pathway under this scenario, as calculated below:

0.6 - 0.2 = 0.4 (40% of additional water added to the soil)

150 m^3/0.4 = 375 m^3 of soil

It is conservatively assumed that no untreated effluent would be contained within the site surface water management system in this event.

If the soil is completely saturated following the spill, for the maximum untreated effluent release of 150 m^3, 187.5 m^3 of soil would potentially be contaminated along the release pathway, as calculated below:

1 – 0.2 = 0.8 (80% of additional water added to the soil)

150 m^3/0.8 = 187.5 m^3 of soil

If the penetration lasts 15 minutes, the maximum depth of contamination would be 90 cm, assuming a penetration rate of 0.1 cm/s:

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

For a penetration rate of 0.07 cm/s, the depth of contamination would be 63 cm:

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

The surface area affected by the spill based on the different saturation conditions and penetration rates is estimated to range from 208 m^2 to 595 m^2, as calculated below:

area = 375 m^3/0.9 m = 417 m^2 (i.e., 60% saturation and penetration depth of 0.9 m)

area = 187.5 m^3/0.63 m = 298 m^2 (i.e., 100% saturation and penetration depth of 0.63 m)

area = 375 m^3/0.63 m = 595 m^2 (i.e., 60% saturation and penetration depth of 0.63 m)

area = 187.5 m^3/0.9 m = 208 m^2 (i.e., 100% saturation and depth of 0.9 m)

For any of these combinations, a relatively small area is expected to be affected in comparison to the distance to the Patterson Lake. Thus, the possibility of the accidental release reaching Patterson Lake is improbable; and therefore, no effects on the lake from the surface water pathways would be expected.

There is potential for groundwater contamination within the area of soil contamination. Shallow groundwater flow is generally affected by local-scale topography, which is representative of conditions at the Project site. Shallow groundwater flow movement is from the topographic high located south of the proposed mine and process plant development in a northerly direction towards Patterson Lake. There is potential for groundwater contamination within the area of soil contamination and therefore there is a potential for groundwater-associated transport to Patterson Lake.

As discussed in Section 9.0, Bounding Scenario 4: Tailings Transfer Pipe or Pump Failure and Release of Radioactivity, implementation of the spill response plan and associated cleanup would be expected to occur over a time period of days (or at maximum, weeks) following the incident, whereas groundwater transport would be measured in years. No meaningful migration of contaminated groundwater outside the immediately-affected area would be expected. Thus, the contamination of soil and shallow groundwater is expected to be contained within a small area near the release location, and no contamination would be expected to reach Patterson Lake along the groundwater pathway.

Based on the above, and in consideration of the effect scale described in Section 3.2, Table 3-2, the consequence of the potential effects of this scenario are rated as minor.

11.0 BOUNDING SCENARIO 6: ACID PLANT TAIL GAS SCRUBBER FAILURE

This bounding scenario involves an uncontrolled release of sulphur dioxide from the tail gas scrubbers. A general description of the hypothetical event, hypothetical contaminants release characterization (e.g., contaminants, quantities), the probability of the scenario and its potential effects on the human health and biophysical environment is provided below.

11.1 Scenario Description

Molten sulphur would be fed to the acid plant where it would be burned in the presence of dry air to produce a sulphur dioxide gas stream. The sulphur dioxide gas stream would be cooled and then fed to a converter system where it would be converted into sulphur trioxide gas via a catalytic oxidation process. The sulphur trioxide gas would be scrubbed with water to produce sulphuric acid at a production grade between 94% and 98% for use in the milling process. The tail gas from the process would be scrubbed in a wet scrubber system to remove the sulphur dioxide before releasing residual gases into the atmosphere.

The acid plant would be in a standalone building separate from the process plant. The plant is designed to produce 300 t/d of sulphuric acid, requiring 90 t/d of sulphur feed.

Any process upset, or failure of equipment, instrumentation, or piping in the burner and converter, absorber, or tail gas scrubbers could potentially result in the release of sulphur dioxide. If the vessels, exchangers, and/or piping system handling sulphur dioxide fail, then a release of sulphur dioxide into the atmosphere could result.

The catastrophic failure of the piping system in the acid plant is highly unlikely. A more likely event is the failure of the tail gas scrubber. This event would result in the release of tail gas containing sulphur dioxide to the atmosphere before scrubbing.

11.2 Release Characterization

The throughput of sulphur dioxide in the acid plant is 180 t/d, or 7.5 t/h or 2,880 m^3/h. The total volume of the pipes and vessels containing sulphur dioxide upstream of the tail pipe scrubber is estimated at about 200 m^3 or 0.5 t.

The sulphur dioxide content of the tail gas in a typical acid plant is approximately 15 kg/t of acid produced. This would be 15 kg/t × 300 t = 4,500 kg/d. Under this scenario, the total amount released during a 15-minute event would be 47 kg, or approximately 0.05 t. This released amount is 10% of the entire capacity upstream of the tail gas scrubber.

11.3 Assessment of Probability

The following mitigating measures would be in place to reduce the probability of a release and potential for tailings release:

- sulphur dioxide monitoring;
- routine and preventive inspection, testing, and maintenance program; and
- ambient air monitoring.

A release of sulphur dioxide could occur as a result of the following events:

- failure of the sulphur furnace, heat exchanger, economizer, waste heat boilers, absorption tower; and tail gas scrubber.
- failure of valves or other piping system components.

As described above, the failure of the tail gas scrubber is the most likely cause of the sulphur dioxide release. According to the Center for Chemical Process Safety (AIChE-CCPS 1989), the probability of a failure of a wet scrubber is less than 3×10^{-02} per year.

According to the probability ratings described in Section 3.2, Table 3-1, the probability that this accident and malfunction scenario would occur is likely.

11.4 Assessment of Potential Effects

The source term calculated in Section 11.2 for the release of sulphur dioxide from the acid plant was 47 kg of sulphur dioxide based on a 15-minute response time, or 52 g/s of sulphur dioxide. The air concentration versus distance was calculated using the ALOHA model and compared with the benchmarks provided in Section 5.3 for the W1 and W2 weather conditions (AEGL-2). As indicated previously, the probability of the W1 weather condition is less than 5% of the probability of weather condition W2.

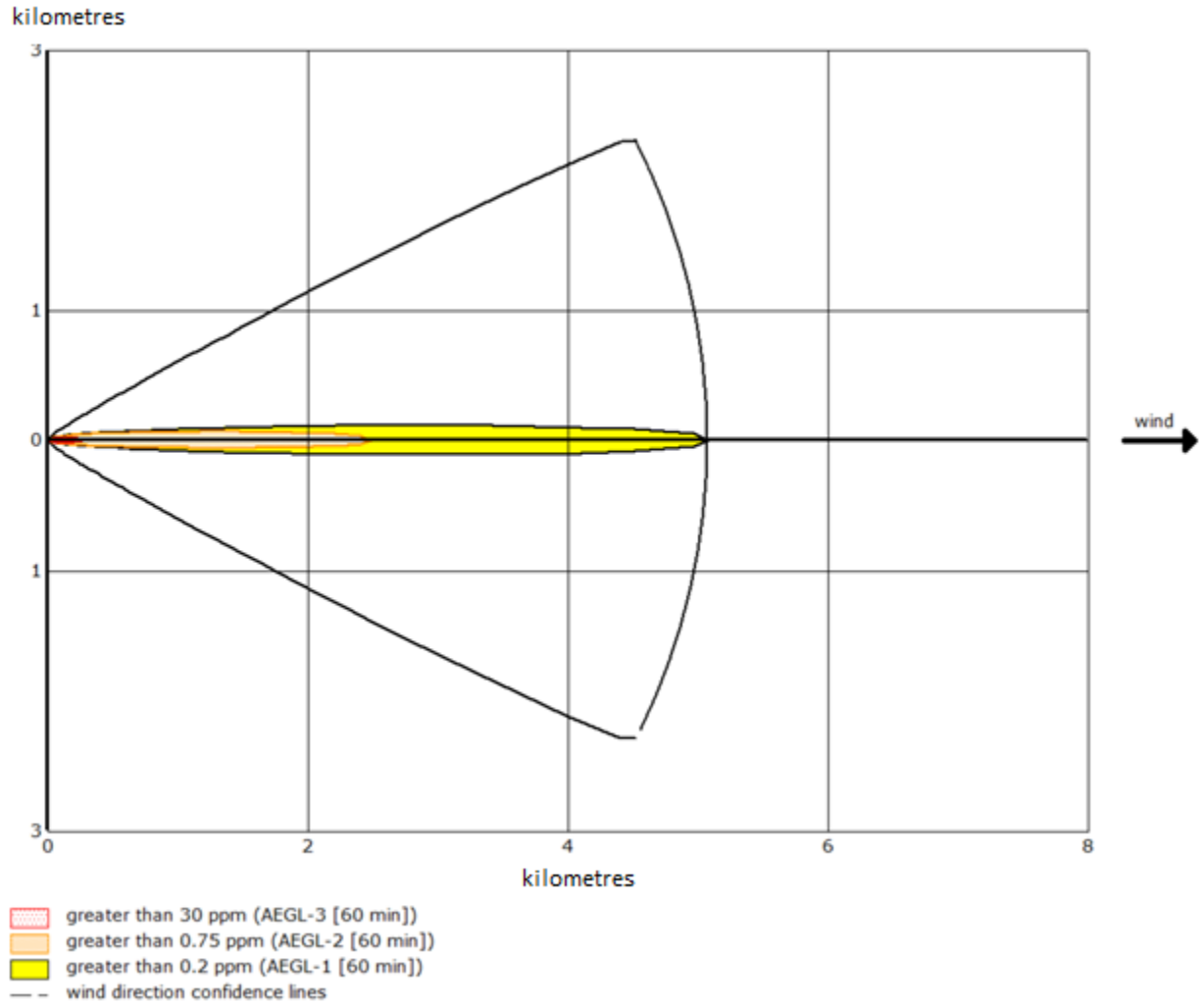
The results of the modelling are summarized in Table 11-1. Figure 11-1 shows the results for the W1 weather condition and Figure 11-2 shows the results for the W2 weather condition.

Table 11-1: Results of Sulphur Dioxide Release Modelling

Weather Condition	Distance to AEGL-3 (m)	Distance to AEGL-2 (m)	Distance to AEGL-1 (m)
W1	261	2,500	5,100
W2	122	849	1,700

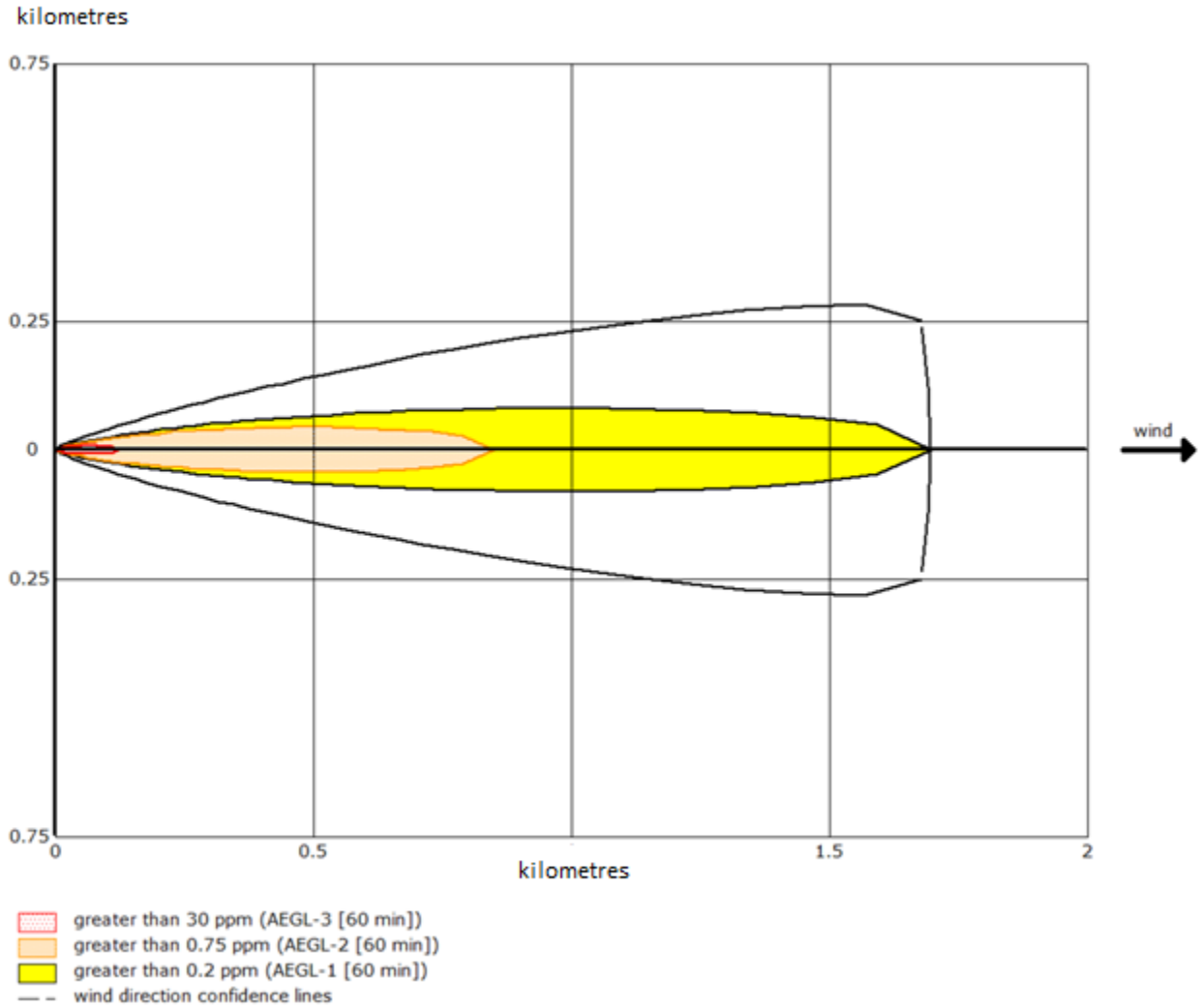
AEGL = Acute Exposure Guideline Level; W1 = worst-case weather conditions; W2 = typical weather conditions.

Figure 11-1: Sulphur Dioxide Dispersion for Worst-Case Weather Conditions



Note: Concentration of sulphur dioxide in air is shown.
AEGL = Acute Exposure Guideline Level; ppm = parts per million.

Figure 11-2: Sulphur Dioxide Dispersion for Typical Weather Conditions



Note: Concentration of sulphur dioxide in air is shown.
AEGL = Acute Exposure Guideline Level; ppm = parts per million.

As highlighted in Section 5.2, the most frequently used benchmark for emergency scenarios is AEGL-2. The results indicate that the AEGL-2 benchmark would be reached (i.e., sulphur dioxide levels would be below the threshold beyond this distance) at 2,500 m from the source of the release (i.e., the acid plant) for weather condition W1, and at 849 m for weather condition W2 representing the more likely weather condition.

As mentioned in Section 11.3, this weather scenario occurs with a probability of 3×10^{-02} per year (i.e., approximately once in 33 years) with a duration of about one hour. The conditional probability of a rain event occurring at the same time makes surface deposition less probable. In addition, due to short duration of this event, surface accumulation of any deposition was considered to be negligible and the effects on the wildlife or vegetation were therefore judged to be minor.

Based on the above, and in consideration of the effect scale described in Section 3.2, Table 3-2, the consequence of the potential effects of this scenario was rated minor to moderate within a short distance from the release.

12.0 ASSESSMENT OF RISK OF BOUNDING SCENARIOS

The results of the risk assessment of the bounding accident scenarios are summarized in Table 12-1.

The results combine the analysis of both likelihood and consequence of effect for each bounding scenario (Section 6.0 through Section 11.0) to identify and overall risk rating according to the risk ranking framework presented in Section 3.0. The difference between the risk ranking presented below and the original risk screening process (Section 3.0) is that the risk ratings below were assigned based on the quantitative assessment of these accident and malfunction scenarios.

The overall risk ratings indicate that the traffic accident scenarios releasing uranium concentrate (Scenario 1) and chemicals (Scenario 2), failure of pipes and pumps for tailings (Scenario 3), effluent transfer pipe failure (Scenario 4), and the untreated effluent transfer pipe failure (Scenario 5) have a low risk. The overall risk associated with tail gas scrubber failure (Scenario 6) has been determined to be low to moderate. Low to moderate risk scenarios were deemed to represent a tolerable level of risk in consideration of proposed safeguards and design features that reduce the risk level to ALARP.

Table 12-1: Summary of Assessment Results for Bounding Scenarios

No.	Accident or Malfunction Scenario	Location	Likelihood	Estimated Effects Consequence	Overall Risk Rating[(a)]
1	Traffic accident (uranium concentrate)	Access road at bridge crossing	Highly unlikely	Moderate	Low risk
2	Traffic accident (chemical)	Access road at bridge crossing	Highly unlikely	Moderate	Low risk
3	Solvent extraction fire or explosion	Solvent extraction building	Unlikely	Minor to moderate	Low risk
4	Tailings transfer pipe or pump failure	Tailings release to surface within secondary containment	Likely	Minor	Low risk
5	Untreated effluent transfer pipe failure	Effluent treatment system	Likely	Minor	Low risk
6	Acid plant tail gas scrubber failure	Acid plant	Likely	Minor to moderate	Low to moderate risk

a) Based on Figure 3-1.

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Appendix A HAZARD IDENTIFICATION FOR THE ACCIDENTS AND MALFUNCTIONS ASSESSMENT - NEXGEN ROOK I PROJECT

HAZARD IDENTIFICATION FOR THE ACCIDENTS AND MALFUNCTIONS ASSESSMENT – APPENDIX A - NEXGEN ROOK I PROJECT

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HAZARD IDENTIFICATION FOR THE ACCIDENTS AND MALFUNCTIONS ASSESSMENT – APPENDIX A - NEXGEN ROOK I PROJECT

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EXECUTIVE SUMMARY

Ecometrix Incorporated (Ecometrix) was retained by NexGen Energy Ltd. (NexGen) to complete the accidents and malfunctions assessment for the NexGen Rook I Project (Project), a proposed uranium mining and milling operation in northwestern Saskatchewan. For reference, the assessment of accidents and malfunctions is intended to provide a clear identification of the potential Project-associated hazards that fall outside the range of "typical" day-to-day events. This report details the Hazard Identification (HI) that has been completed to support the Environmental Assessment in the EIS. The HI is used to identify potential hazard scenarios, screen these scenarios as to potential environmental risks and, based on this screening, recommend scenarios that would be carried forward for more detailed consideration in the completion of the Accidents and Malfunctions Assessment.

Scope and Applicability

The scope of the HI included consideration across the following Project phases: Construction, Operations, and Decommissioning and Reclamation (i.e., Closure).

The spatial extent of the evaluation included the Project site and associated access road to its junction with Highway 955.

The evaluation focused on potential environmental risks associated with identified hazard scenarios. Although some hazards related to worker safety were identified, worker safety (risks and consequences) is out of the scope of this assessment.

Methods

The hazard identification process is a systematic approach to identify possible hazards associated with all components (physical system) and activities in a work process. A hazard can be defined as a physical event or condition that has the potential for causing damage to people, property, or the environment (e.g., fire, explosion, release of chemicals, or radioactivity). The components and activities for hazard identification were selected through the review of Project-related components. The hazard scenarios were identified by investigating the components and activities individually. The evaluation considered the sources of the hazard (e.g., presence of hazardous materials), hazardous situations (e.g., height or extreme heat), and initiating events (e.g., natural causes, technical failure, human error), that in combination, present a risk to the biophysical environment. A screening evaluation was applied to each scenario by qualitatively evaluating consequence and likelihood to determine a risk level (low, moderate, or high).

The following nodes were considered in the HI:

- site preparation;
- shaft sinking;

- access road / land transportation;
- airstrip;
- mining;
- hoisting;
- mine dewatering system;
- processing plant;
- solvent extraction building;
- tailings transfer pipe and underground tailings management facility (UGTMF) and mining stopes;
- non-potentially acid generating (NPAG) waste rock stockpile;
- ore, special waste, and potentially acid generating (PAG) waste rock stockpiles;
- effluent treatment system;
- ponds and retention berms;
- gypsum precipitation, washing, and storage;
- acid plant;
- electrical system and power plant;
- fire protection system;
- low-level radioactive waste management system / incinerator;
- liquified natural gas (LNG) power plant; and
- mine ventilation system.

Recommended Scenarios for Further Consideration

Based on the HI process, the hazard scenarios that were selected for more detailed risk analysis are listed below.

Node	Accident or Malfunction Scenario	Location	Effect pathway
3.1	Traffic accident (uranium concentrate)	Access road at bridge crossing	Aquatic release of uranium concentrate
3.3	Traffic accident (chemical)	Access road at bridge crossing	Aquatic release of fuel, hazardous chemicals
9.3	Solvent extraction fire or explosion	Solvent extraction building	Atmospheric release of uranium concentrate (chemical toxicity)
10.2	Tailings transfer pipe or pump failure	Tailings release to surface within secondary containment	Terrestrial release of radioactivity
13.3	Untreated effluent transfer pipe failure	Effluent treatment system	Terrestrial release of radioactivity
16.3	Acid plant tail gas scrubber failure	Acid plant	Atmospheric release of sulphur dioxide

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ABBREVIATIONS AND UNITS OF MEASURE

Abbreviations

Acronym	Definition
ALARP	As Low as Reasonably Practicable
EIS	Environmental Impact Statement
HI	Hazard Identification
ID	identification
LNG	liquified natural gas
NexGen	NexGen Energy Ltd.
NPAG	non-potentially acid generating
PAG	potentially acid generating
Project	Rook I Project
UGTMF	underground tailings management facility

Units of Measure

Units	Definition
%	percent
>	greater than
km	kilometres
t	tonne

1.0 INTRODUCTION

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

Ecometrix Incorporated (Ecometrix) was retained by NexGen to complete the accidents and malfunctions assessment for the Project, a proposed uranium mining and milling operation in northwestern Saskatchewan. For reference, the assessment of accidents and malfunctions is intended to provide a clear identification of the potential Project-associated hazards that fall outside the range of "typical" day-to-day events. This report details the Hazard Identification (HI) that has been completed to support the Environmental Assessment in the EIS. The HI is used to identify potential hazard scenarios, screen these scenarios as to potential environmental risks and, based on this screening, recommend scenarios that would be carried forward for more detailed consideration in the completion of the Accidents and Malfunctions Assessment.

1.1 Project Information

The Project includes the Construction, Operations, Decommissioning and Reclamation (i.e., Closure) of a uranium mine and processing plant, including associated infrastructure to support the extraction and processing of uranium ore. Key Project details are summarized in Table 1-1. The timeline for the Project from the initiation of Construction to the completion of Closure (and subsequent transfer of the property to Institutional Control) is anticipated to be 43 years.

Table 1-1: Key Rook I Project Details

Terms	Details
Scope of the Project	• NexGen is proposing a new uranium mining and milling operation located adjacent to Patterson Lake in the southwestern Athabasca Basin in northern Saskatchewan • The proposed Project would include underground and surface facilities to support the mining and milling of uranium ore from the Arrow deposit • The Project would include an underground mine, a process plant, and additional infrastructure including a camp for personnel, an airstrip, an ETP, and supporting waste and water management facilities
Rook I Project	• The Rook I Project is a new uranium mining and milling operation located on the Patterson Lake peninsula in the southwestern Athabasca Basin in northern Saskatchewan • The Rook I Project is 100% owned and managed by NexGen • The mineral resource basis for the proposed Project is the Arrow deposit, a land-based, 100% basement-hosted, high-grade uranium deposit
Arrow deposit	• A land-based, basement-hosted, high-grade uranium deposit that is 100% owned by NexGen

Table 1-1: Key Rook I Project Details

Terms	Details
Underground mine development	• The Project would use long hole stoping mining methods to extract the ore, including primarily transverse stope mining and longitudinal retreat stope mining • The underground mine development would include a number of key activities, including shaft sinking, lateral development, vertical development, installation of mine services, and development of the UGTMF
Uranium concentrate	• The Project term for triuranium octoxide (U_3O_8) once the material has been processed and is ready for shipment
Process plant	• Process plant throughput is designed for 1,300 tonnes of ore per day • Total net uranium recovery from the milling process is estimated to be 97.6% based on the results of the metallurgical test programs completed in 2018 and 2019 • The process plant consists of the technologies and infrastructure used to transform uranium ore into uranium concentrate
UGTMF	• Purpose-built, underground facility with chambers dedicated to the storage and progressive decommissioning for tailings and other waste streams generated through mining and processing • Three UGTMF cavities are planned for initial development during Construction to provide adequate storage capacity to support the start of mining and milling operations
Mine rock	• Includes all material sourced from underground, including ore (equal or greater than 0.26% U_3O_8 and waste rock (less than 0.26% U_3O_8)
Waste rock	• Includes non-potential acid generating mine rock, potentially acid generating mine rock, and special waste
NPAG	• The NPAG waste rock is clean mine rock with less than 0.03% U_3O_8 and less than 0.1% sulphur. All NPAG mine rock would either be stockpiled for use as construction material at site or become NPAG waste rock that is stored in the NPAG WRSA
PAG	• The PAG waste rock is mine rock with less than 0.03% U_3O_8 and greater than or equal to 0.1% sulphur. All PAG mine rock would become PAG waste rock that is stored in the PAG WRSA
Special waste	• Special waste is mine rock with insufficient grade to be considered ore (i.e., greater than 0.03% of U_3O_8 and less than 0.26% U_3O_8). All special waste would be temporarily stored in the special waste rock stockpile
NPAG WRSA	• The NPAG WRSA permanently stores clean mine rock at surface and would not be lined
PAG WRSA	• The PAG WRSA permanently stores PAG mine rock at surface and would be fully lined with HDPE and have self-contained water collection
Special waste rock stockpile	• The separate stockpile where special waste would be temporarily stored at surface and would be fully lined with HDPE and have self-contained water collection • Special waste would be processed throughout Operations and then transferred to the UGTMF for permanent storage
Ore storage stockpile	• The separate stockpile on surface where ore would be temporarily stored until transferred to the process plant. This stockpile includes four piles with differing grades and would be fully lined with HDPE and have self-contained water collection
ETP	• The Project facility that treats contact water from the Project. The treated effluent is pumped to the monitoring ponds, tested, and then discharged to the environment, after meeting discharge criteria

Table 1-1: Key Rook I Project Details

Terms	Details
Sewage treatment plant	• The Project facility that treats sewage from the Project. The treated sewage discharge is released to the environment, after meeting discharge criteria
Mine water	• Water that flows into the underground workings
Contact water	• Water that may have been physically or chemically altered by Project activities. This water may be diverted and require management (e.g., treatment) before release to the environment. This includes dewatering of mine water from underground mining activities as well as all runoff on surfaces disturbed by the Project
Non-contact water	• Water that has not been physically or chemically altered by Project activities. This water is typically diverted when practical and allowed to discharge directly to the receiving environment
Fresh water	• Water sourced from Patterson Lake for use by the Project
Release water	• Contact water that has been treated in the ETP and is discharged to the environment, after meeting discharge criteria
Waste water (or treated sewage discharge)	• Water that has been treated in the sewage treatment plant and is ready for discharge to the environment, after meeting discharge criteria
Sewage	• Waste water from toilets, sinks, showers, laundry, kitchen, and other domestic sources and facilities at the Project, including but not limited to sanitary liquid waste of human origin
Supporting infrastructure	• Includes all Project surface facilities including but not limited to waste management infrastructure, water management and treatment infrastructure, administration and camp facilities, utilities, airstrip, and site roads

UGTMF = underground tailings management facility; PAG WRSA= potentially acid generating waste rock storage area; NPAG WRSA= non-potentially acid generating waste rock storage area; U_3O_8 = triuranium octoxide; ETP = effluent treatment plant; HDPE = high density polyethylene.

1.2 Scope and Applicability of the Hazard Identification Process

The regulations governing the EIS requires that the effects of Accidents and Malfunctions related to the Project components be assessed. As a step towards the Accidents and Malfunctions assessment, an HI evaluation needs to be completed. The objective of HI is to identify all scenarios that have a potential to present a risk to the biophysical environment. The HI includes a screening assessment of the scenarios to identify those that require more detailed assessment of the probabilities and the severity of their consequences. The screening evaluation is applied to a given scenario by qualitatively evaluating consequence and likelihood to determine an overall risk ranking (Section 2.0, Hazard Identification Methodology). The evaluations of the probabilities and severity of the consequences, as well as the characterization of the risk of the selected scenarios, are included in the Accidents and Malfunctions assessment.

The scope of the HI included consideration of the following Project phases: Construction, Operations, and Decommissioning and Closure. The spatial extent of the evaluation included the Project site and associated access road to its junction with Highway 955.

The evaluation focused on potential environmental risks associated with identified hazard scenarios. Although some hazards related to worker safety were identified, worker safety (risks and consequences) is out of the scope of this assessment.

1.3 Information Sources

Information used to complete this evaluation has been provided by NexGen. Key information has been drawn from the Project's Feasibility Report, as well as reports that have been generated by NexGen's risk review and management process. The list of information sources is provided in the reference section of this report.

2.0 HAZARD IDENTIFICATION METHODOLOGY

The HI evaluation was performed to identify hazard scenarios associated with the Project that may result in consequences to the biophysical environment. The hazard scenarios were subsequently assessed at a screening level as to potential risks to the biophysical environment, and to identify scenarios that should be carried forward for more detailed evaluation.

2.1 Process Hazards Analysis

The hazard identification process is a systematic approach to identify possible hazards associated with all components (physical system) and activities in a work process. A hazard can be defined as a physical event or condition that has the potential for causing damage to people, property, or the environment (e.g., fire, explosion, release of chemicals, or radioactivity).

The hazard identification evaluation was used to identify a comprehensive list of potential Project-related accident and malfunction scenarios, screen these scenarios as to potential risks, and, based on the initial screening results, select a number of high or moderate-risk scenarios as bounding scenarios. These bounding scenarios were carried forward for more detailed risk assessment. The hazard identification evaluation focussed on risks to the human health and biophysical environment.

The hazard identification involved the consideration of the following three elements that, in combination, present a risk to the human health and biophysical environment:

a) the sources of hazard (e.g., presence of hazardous materials);

b) hazardous situations (e.g., presence of ignition source); and

c) initiating events (e.g., natural causes, technical failure, or human error).

A screening evaluation was applied to all accident and malfunction scenarios by qualitatively evaluating the likelihood and consequence to determine a risk level.

The likelihood index is derived from the qualitative estimation of the probability of the scenarios. While there are standards and regulatory documents (e.g., REGDOC-2.4.2, Safety Analysis, Probabilistic Safety Assessment [PSA] for Reactor Facilities (CNSC n.d.[1]) that govern the assessment of the probability of the hazard scenarios for nuclear reactors, no such documents exist for non-reactor facilities. The focus of these documents is design-basis and beyond design-basis accidents that affect the integrity of the reactor core. The annual probability of releases from these accidents can be $1x10^{-6}$ and lower, while the consequence of these accidents

[1] CNSC (Canadian Nuclear regulatory Commission). n.d. REGDOC-2.4.2, Safety Analysis Probabilistic Safety Assessment (PSA) for Reactor Facilities, Version 2. Available at **https://www.nuclearsafety.gc.ca/eng/pdfs/regulatory-documents/regdoc2-4-2/REGDOC-2_4_2_Probabilistic_Safety_Assessment_(PSA)_for_Reactor_Facilities_Version_2.pdf.**

could be very severe (i.e., catastrophic). In contrast, the probability of accidents and malfunctions at non-reactor facilities such as mines and process plants can be higher, as derived from the operating experience of similar installations. The International Atomic Energy Agency's TECDOC-1267 (IAEA 2002[2]) states that while a plant-specific qualitative risk analysis should be conducted for a nuclear reactor facility, for non-nuclear facilities hazard identification and screening, evaluation of selected accident scenarios, and a combination of qualitative and quantitative analysis should be conducted. This document does not prescribe what probabilities should be considered.

Based on the operating experience of similar facilities considered in this assessment, a range of probabilities were considered. On a scale of increasing likelihood, scenarios were categorized as highly unlikely, unlikely, likely, very likely, and almost certain as shown in Table 2-1.

Table 2-1: Likelihood Index

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

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

On a scale of increasing consequence, scenarios were categorized as negligible, minor, moderate, major, and catastrophic as shown in Table 2-2.

Table 2-2: Consequence Index

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

[2] IAEA (International Atomic Energy Agency). 2002. Procedures for conducting probabilistic safety assessment for non-reactor nuclear facilities, IAEA-TECDOC-1267, January 2002, ISSN 1011–4289. Available at **https://www-pub.iaea.org/MTCD/Publications/PDF/te_1267_prn.pdf.**

The resulting risk levels are defined according to the hazard analysis risk matrix shown in Figure 2-1.

For the purpose of the assessment, risks were identified as being low (i.e., coloured green in the matrix) where the screening evaluation considered the risk as generally being acceptable, as the likelihood of these scenarios can be effectively managed through application of planned controls and/or the consequence of the effect would be low (i.e., negligible to moderate). Low-risk scenarios have a consequence of negligible to moderate, with the likelihood ranging from highly unlikely to almost certain.

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

Risks were identified as being high (i.e., coloured red in the matrix) where the screening evaluation considered the risk as generally being unacceptable. High-risk scenarios have a consequence of major to catastrophic, with the likelihood ranging from unlikely to almost certain. As the evaluation of the risk at this hazard identification stage was qualitative and subject to some uncertainty, the hazard scenarios identified as high risk were advanced for further detailed assessment so that a more detailed evaluation of risk and potential management activities could be considered.

Figure 2-1: Hazard Analysis Risk Matrix

Likelihood		**Consequence**				
		1	**2**	**3**	**4**	**5**
		Negligible	**Minor**	**Moderate**	**Major**	**Catastrophic**
5	**Almost Certain**	Low	Moderate	Moderate	High	High
4	**Very Likely**	Low	Low	Moderate	High	High
3	**Likely**	Low	Low	Moderate	Moderate	High
2	**Unlikely**	Low	Low	Low	Moderate	High
1	**Highly Unlikely**	Low	Low	Low	Moderate	Moderate

2.2 Definition of Project Components and Activities

Based on the review of key Project components and activities, the following nodes were considered in the HI evaluation:

- site preparation;
- shaft sinking;
- access road / land transportation;
- airstrip;
- mining;
- hoisting;
- mine dewatering system;
- process plant;
- solvent extraction building;
- tailings transfer pipe and underground tailings management facility (UGTMF);
- non-potentially acid generating (NPAG) waste rock stockpile;
- ore, special waste, and potentially acid generating (PAG) waste rock stockpiles;
- effluent treatment system;
- ponds and retention berms;
- gypsum precipitation, washing, and storage;
- acid plant;
- electrical system and power plant;
- fire protection system;
- low-level radioactive waste management system / incinerator;
- liquified natural gas (LNG) power plant; and
- mine ventilation system.

3.0 EVALUATION OF NODES

For each of the nodes, HI evaluations are shown in Table 3-1 through Table 3-21. In each case, the evaluation considers consequence(s), existing safeguards and design features, and the qualitative evaluation of likelihood and severity of consequences.

The following notations are provided in support of the HI tables:

- "CO" is Construction;
- "OP" is Operations;
- "ADR" is Active Decommissioning and Reclamation Stage;
- "TM" is Transitional Monitoring Stage;
- "L" is likelihood;
- "S" is severity of the consequences; and
- "RR" is risk ranking.

With consideration of sources of hazard and initiating events, a total of 93 hazard scenarios were identified and evaluated.

Six of the hazard scenarios characterized as high-risk (3) or ALARP-moderate (3) scenarios require further detailed assessment for more accurate characterization of the risk.

Six high-risk scenarios that were not recommended for further detailed assessment are associated with major injuries and/or occupational fatalities. These scenarios have not been advanced since it is assumed that the NexGen health and safety program will be best practice and therefore in these cases the risk is ALARP.

Thirty-three of the scenarios evaluated were characterized as moderate-risk scenarios. Generally, the moderate-risk scenarios were deemed to represent a tolerable level of risk in consideration of proposed safeguards and design features that reduce the risk level to ALARP. As noted above, three moderate-risk scenarios are recommended for further detailed assessment. Each of these is associated with a contaminant release to the environment. A further six moderate-risk scenarios were also considered for further detailed assessment; however, they were deemed to be bounded by other scenarios and therefore no further analyses were completed.

The balance of the scenarios evaluated (51) were characterized as low-risk scenarios, based on low likelihood of occurrence and/or consequence in consideration of planned existing safeguards and design features.

Site preparation: For site preparation, nine hazard scenarios were identified, and each have the potential to occur during all phases and stages of the Project. All hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-1: Hazard Identification Evaluation – Site Preparation

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
1.1	Fall/slip	CO / OP / ADR / TM	Occupational major injuries	Occupational health and safety program Personnel training and orientation Personal protection equipment	5	4	ALARP, High	Best practice in worker health and safety program resulting in ALARP, no further assessment
1.2	Fall/slip	CO / OP / ADR / TM	Occupational fatalities	Occupational health and safety program Personnel training and orientation Personal protection equipment	2	5	ALARP, High	Best practice in worker health and safety program resulting in high but ALARP, no further assessment
1.3	Vehicle and construction equipment accident	CO / OP / ADR / TM	Occupational major injuries	Occupational health and safety program Personnel training and orientation Preventive and routine maintenance	4	4	ALARP, High	Best practice in worker health and safety program resulting in ALARP, no further assessment
1.4	Vehicle and construction equipment accident	CO / OP / ADR / TM	Occupational fatalities	Occupational health and safety program Personnel training and orientation Preventive and routine maintenance	2	5	ALARP, High	Best practice in worker health and safety program resulting in high but ALARP, no further assessment
1.5	Vehicle accident	CO / OP / ADR / TM	Hazardous materials spill	Site traffic control, speed limit, signage Personnel training and orientation Spill and emergency response plan	4	2	Low	Risk level is low, minor consequences, no further assessment
1.6	Fuel storage failure	CO / OP / ADR / TM	Hydrocarbon release	Storage inspection, maintenance Double-walled fuel storage and or secondary containment Spill and emergency response plan	1	3	Low	Risk level is low, highly unlikely event, no further assessment
1.7	Refuelling accident	CO / OP / ADR / TM	Hydrocarbon release	Personnel training Containment Spill and emergency response plan	4	2	Low	Risk level is low, minor consequence event, no further assessment
1.8	Fuel storage and transfer fire and explosion	CO / OP / ADR / TM	Occupational major injuries	Fire safety plan and firefighting system Personal protection equipment Personnel training and orientation	2	4	ALARP, Moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment
1.9	Fuel storage and transfer fire and explosion	CO / OP / ADR / TM	Occupational fatalities	Fire safety plan and firefighting system Buried pipes Personal protection equipment Personnel training and orientation	1	5	ALARP, Moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; TM = Transitional Monitoring; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Shaft sinking: For shaft sinking, four hazard scenarios were identified, which have the potential to occur during the Construction of the Project. All hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-2: Hazard Identification Evaluation – Shaft Sinking

ID#	Accident/Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
2.1	Shaft wall failure	CO	Occupational major injuries	Occupational health and safety program Personnel training and orientation Personal protection equipment	5	4	ALARP, High	Best practice in worker health and safety program resulting in ALARP, no further assessment
2.2	Shaft wall failure	CO	Occupational fatalities	Occupational health and safety program Personnel training and orientation Personal protection equipment	1	5	ALARP, Moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment
2.3	Groundwater ingress	CO	Underground flooding and potential for groundwater contamination	Temporary ground freeze Mine construction procedure based on geotechnical analysis Engineered shaft liner design where required Emergency response procedure Groundwater monitoring	3	2	Low	Risk level is low, minor consequence event, no further assessment
2.4	Surface flood	CO	Underground flooding and potential for groundwater contamination	Surface water and flood management, shaft opening protection and structure Emergency response procedure Groundwater monitoring	2	2	Low	Risk level is low, minor consequence event, no further assessment

CO = Construction; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Access road / land transportation: For access road / land transportation, eight hazard scenarios were identified, which have the potential to occur during the Construction, Operations, and Closure of the Project. The screening assessment shows that two hazard scenarios may be high risk and further assessment is required to characterize the risk in more detail. Other hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-3: Hazard Identification Evaluation – Access Road / Land Transportation

ID#	Accident/Malfunction	Phase or Stage	Consequences	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
3.1	Traffic accident at bridge crossing (uranium concentrate)	CO / OP / ADR	Aquatic release of radioactivity	Traffic control measures Travel management plan Spill and emergency response plan Personnel training	3	5	High	Further assessment recommended
3.2	Vehicle accident including rollover, collision, run off road	CO / OP / ADR	Terrestrial release of radioactivity	Traffic control measures Travel management plan Spill and emergency response plan Personnel training	3	4	ALARP, Moderate	Best practice in terrestrial spill containment and cleanup resulting in ALARP, no further assessment
3.3	Traffic accident at bridge crossing (chemical)	CO / OP / ADR	Aquatic release of fuel, hazardous, chemicals and reagents	Traffic control measures Travel management plan Spill and emergency response plan Personnel training	3	5	High	Further assessment recommended
3.4	Vehicle accident including rollover, collision, run off road	CO / OP / ADR	Terrestrial release of fuel, hazardous, chemicals and reagents	Traffic control measures Travel management plan Spill and emergency response plan Personnel training	3	4	ALARP, Moderate	Best practice in terrestrial spill containment and cleanup resulting in ALARP, no further assessment
3.5	Vehicle fire	CO / OP / ADR	Release of hydrocarbons and fuel	Travel management plan Spill and emergency response plan Fire safety plan and firefighting systems Personnel training	1	4	ALARP, Moderate	Best practice in terrestrial spill containment and cleanup resulting in ALARP, no further assessment
3.6	Vehicle fire	CO / OP / ADR	Atmospheric release of particulate and combustion by-products	Travel management plan Spill and emergency response plan Fire safety plan and firefighting systems Personnel training Ambient air monitoring	1	3	Low	Low risk, highly unlikely event. Reversible and transient effect. No further assessment
3.7	Vehicle fire	CO / OP / ADR	Uncontrolled explosion of explosives	Explosives management plan Fire safety plan and firefighting systems Personnel training	1	5	ALARP, Moderate	Best practice in explosive management resulting in ALARP, no further assessment
3.8	Vehicle – wildlife collision	CO / OP / ADR	Wildlife injury/fatality	Traffic control measures Travel management plan	4	2	Low	Individual level effect, reversible and nonsignificant effect, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Airstrip: For the airstrip, four hazard scenarios were identified, which have the potential to occur during the Construction, Operations, and Closure of the Project. The hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-4: Hazard Identification Evaluation – Airstrip

ID#	Accident/Malfunction	Phase of Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
4.1	Fuel storage failure	CO / OP / ADR	Hydrocarbon release	Storage inspection and maintenance Secondary containment Spill and emergency response plan	1	3	Low	Risk level is low, highly unlikely event, no further assessment
4.2	Refuelling accident	CO / OP / ADR	Hydrocarbon release	Personnel training Containment Spill and emergency response plan	4	2	Low	Risk level is low, minor consequence event, no further assessment
4.3	Airplane crash	CO / OP / ADR	Occupational major injuries / fatality Atmospheric release of particulate and combustion by-products Release of hydrocarbons and fuel Damage to mine infrastructure structure	Travel management plan Spill and emergency response plan Fire safety plan and firefighting systems Personnel training	1	5	ALARP, Moderate	Highly unlikely event, ALARP, no further assessment
4.4	Plane de-icing chemical release	CO / OP / ADR	Terrestrial release of reagent; possible aquatic release of reagent	Personnel training Containment Spill and emergency response plan	3	2	Low	Risk level is low, minor consequence event, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Mining: For mining, ten hazard scenarios were identified, which have the potential to occur during the Operations of the Project. The screening assessment shows that one hazard scenario requires further assessment to characterize the risk in more detail. All other hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-5: Hazard Identification Evaluation – Mining

ID#	Accident/Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
5.1	Mine back or wall failure	OP	Release of hazardous materials (corrosive, toxic, and flammable materials including chemicals and reagents) and potential for groundwater contamination	Mine water management and containment Monitoring Spill and emergency response plan	1	3	Low	Low risk, highly unlikely event, no further assessment
5.2	Mine back or wall failure	OP	Occupational major injuries	Occupational health and safety program Personnel training and orientation Refuge stations	1	4	ALARP, Moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment
5.3	Mine back or wall failure	OP	Occupational fatalities	Occupational health and safety program Personnel training and orientation Mining procedure Geotechnical investigation and analysis Refuge stations	1	5	ALARP, Moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment

ID#	Accident/Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
5.4	Personnel falls into open ore/waste pass	OP	Occupational major injuries/fatality	Adequate lighting and signage and indicator lights Wheel stop barriers Vent plug on empty passes Occupational health and safety program Personnel training and orientation Mining procedures	1	5	ALARP, Moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment
5.5	Uncontrolled explosion	OP	Damage to mine structure due to blast over pressure and potential for release of hazardous materials Occupational injuries/fatality	Best practice in mine development Explosives management Engineered blast designs	1	5	ALARP, Moderate	Best practice in mine development and highly unlikely event resulting in ALARP, no further assessment
5.6	Vehicle accident	OP	Release of fuel and groundwater contamination	Mine water management and containment Monitoring Spill and emergency response plan	2	2	Low	Low risk, minor consequence event, no further assessment
5.7	Mine fire by any cause	OP	Atmospheric release of radioactive materials Occupational injuries/fatalities	Emergency response plan Fire safety plan and firefighting systems Fire fighting system Self rescuer units carried by personnel Ambient air monitoring Air monitoring in underground mine Remote ventilation control Underground refuge stations	2	5	ALARP, High	Best practice in worker health and safety program, the environmental consequences are limited, no further assessment
5.8	Fuel storage failure	OP	Hydrocarbon release underground and potential groundwater contamination	Storage inspection and maintenance Secondary containment Spill and emergency response plan	1	3	Low	Risk level is low, highly unlikely event, no further assessment
5.9	Refuelling accident	OP	Hydrocarbon release underground and potential groundwater contamination	Personnel training Containment Spill and emergency response plan	4	2	Low	Risk level is low, minor consequence event, no further assessment
5.10	Failure of pipes and pumps for tailings transfer	OP	Release of radioactivity to the environment	Mine water management Groundwater monitoring Routine inspection and maintenance Emergency response plan	2	4	ALARP, Moderate	Best practice in tailings management and moderate consequence event resulting in ALARP; however, due to unknown consequence at the screening level this scenario is recommended for further assessment and is considered in Scenario 10.2

OP = Operations; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Hoisting: For hoisting, one hazard scenario was identified, which has the potential to occur during the Construction, Operations, and Closure of the Project. The hazard scenario has appropriate safeguards and design features to minimize the risk such that no further assessment is required for this hazard.

Table 3-6: Hazard Identification Evaluation – Hoisting

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
6.1	Hoist failure	CO / OP / ADR	Release of hazardous materials (chemicals and reagents) and potential for groundwater contamination	Hoist Safety Systems Mine water management and containment Monitoring Spill and emergency response plan	1	3	Low	Low risk, highly unlikely event, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking.

Mine dewatering system: For the mine dewatering system, two hazard scenarios were identified, which have the potential to occur during the Construction, Operations, and Closure of the Project. The hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-7: Hazard Identification Evaluation – Mine Dewatering System

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
7.1	Main Underground Dewatering System failure	CO / OP / ADR	Mine flooding and potential for groundwater contamination	Redundancy Preventive and routine maintenance System monitoring Mine water management Emergency response plan	3	2	Low	Risk level is low, minor consequence event, no further assessment
7.2	High flow – groundwater ingress, surface flooding	CO / OP / ADR	Mine flooding and potential for groundwater contamination	Appropriate design and pump capacity Mine water management Emergency response plan	2	2	Low	Risk level is low, minor consequence event, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking.

Processing plant: For the processing plant (excluding the solvent extraction circuit), eleven hazard scenarios were identified, which have the potential to occur in the Operations of the Project. The screening assessment shows that three hazard scenarios involving release of uranium are moderate risk. All these scenarios were bounded by a large solvent fire scenario. All other hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-8: Hazard Identification Evaluation – Process Plant

ID#	Accident/Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
8.1	Ore spill	OP	Release of radioactivity	Ambient monitoring Spill and emergency response plan	2	2	Low	Low risk, minor consequence event, no further assessment
8.2	Process vessel and piping system failure	OP	Release of sulphuric acid	Ambient monitoring Secondary containment Process sumps Mill building is contained Redundant temperature/reagent controls on leach tanks to protect liners from high temperature Spill and emergency response plan	3	2	Low	Low risk, minor consequence event, no further assessment
8.3	Process vessel and piping system failure, clarifier overflow	OP	Release of pregnant aqueous solution	Ambient monitoring Secondary containment Process sumps Mill building is contained Redundant temperature/reagent controls on leach tanks to protect liners from high temperature Spill and emergency response plan	3	2	Low	Low risk, minor consequence event, no further assessment
8.4	Process vessel and piping system failure	OP	Release of acidic fume and radon in leaching building	Ambient monitoring Building ventilation Redundant temperature/reagent controls on leach tanks to protect liners from high temperature	3	2	Low	Low risk, minor consequence event, no further assessment

ID#	Accident/Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
				Spill and emergency response plan				
8.5	Belt filter air exhaust to atmosphere	OP	Not expecting particulate in this exhaust stream. Could be radon, sulphuric acid	Filter bed exhaust to be scrubbed before atmospheric release	3	2	Low	Low risk, minor consequence event, no further assessment
8.6	Hydrogen peroxide spill	OP	Potential for fire	Separate and contained hydrogen peroxide system (separation from organics) Spill and emergency response plan	2	3	Low	Low risk, moderate consequence event, no further assessment
8.7	Facility fire	OP	Release of uranium concentrate powder to atmosphere	Ambient air monitoring Fire safety plan and firefighting systems Emergency response plan	2	4	ALARP, Moderate	The consequence is bounded by Scenario 9.3
8.8	Process containment and gas cleaning and filtration system failure	OP	Release of uranium concentrate powder to atmosphere	Regular and preventive inspection, testing, and maintenance program Ambient air monitoring	3	4	ALARP, Moderate	The consequence is bounded by Scenario 9.3
8.9	Calciner wet scrubber failure	OP	Release of uranium dust and residual fluorine gas to atmosphere	Regular and preventive inspection, testing, and maintenance program Ambient air monitoring The release is short-term as the operation will stop upon failure of the scrubber	3	3	ALARP, Moderate	The consequence is bounded by Scenario 9.3
8.10	Hydrogen buildup in the in the leach tanks	OP	Hydrogen evolution may result in formation of explosive atmosphere in the leach tanks. It may explode upon presence of ignition source	The results of hydrogen evolution quantification tests performed on samples with different grades showed no hydrogen gas was detected during the leaching of a different grade ore; as a precaution, the installation of hydrogen detectors may be investigated	2	3	Low	The energy content of hydrogen gas mixture (within explosive limits) inside the tanks are low. The explosion energy is therefore low and may result in localized damage. Low risk, moderate consequence event, no further assessment
8.11	Paste plant mixing error	OP	Low moisture content paste may set prematurely inside the underground pipe causing the blockage of the piping system	Operator training Quality control Operating procedures Maintenance program for the control systems	3	2	Low	Low risk, minor consequence event, no further assessment

OP = Operations; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Solvent extraction building: For the solvent extraction circuit, four hazard scenarios were identified, which have the potential to occur in the Operations of the Project. The screening assessment shows that one hazard scenario, involving a solvent extraction fire and/or explosion (Scenario 9.3), may require further assessment to characterize the risk in more detail. A second scenario involving a solvent extraction fire and/or explosion, Scenario 9.2, is bounded by this former scenario. The additional two scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-9: Hazard Identification Evaluation – Solvent Extraction Building

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
9.1	Process vessel and piping system failure	OP	Release of organic solvent	Concrete mixer-settler to facilitate visual leak inspection Regular and preventive inspection, testing, and maintenance program Secondary containment Mill building is contained Ambient monitoring Spill and emergency response plans	3	2	Low	Low risk, minor consequence event, no further assessment
9.2	Solvent fire and/or explosion	OP	Atmospheric release of radioactivity	Dump tanks and fast-acting valves to transfer SX mixer/settlers in case of fire. Fire detection Regular and preventive inspection, testing, and maintenance program Fire safety plan and firefighting systems Ambient air monitoring Emergency response plan	2	4	ALARP, Moderate	The consequence is bounded by Scenario 9.3
9.3	Solvent extraction fire and/or explosion	OP	Domino effect and process plant fire resulting in release of radioactivity	Dump tanks and fast-acting valves to transfer SX mixer/settlers in case of fire. Fire detection Regular and preventive inspection, testing, and maintenance program Fire safety plan and firefighting systems Ambient air monitoring Emergency response plan	1	5	High	Further assessment recommended
9.4	Dump tank leak	OP	Leakage from the dump tank following a fire scenario and groundwater contamination	The dump tank is a concrete underground tank that is normally empty; the tank will be inspected regularly for any visual sign of structural defects	2	3	Low	Low risk, moderate consequence event, no further assessment

OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Tailings transfer pipe and UGTMF: For the UGTMF, as well as the mining stopes, two hazard scenarios were identified, which have the potential to occur during the Operations and Closure of the Project. The screening assessment shows that one hazard scenario requires further assessment to characterize the risk in more detail. For the second hazard scenario, appropriate safeguards and design features would be in place to minimize the risk such that no further assessment is required.

Table 3-10: Hazard Identification Evaluation – Tailings Transfer Pipe and UGTMF

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
10.1	Failure of tailings cell containment	OP / ADR	Potential for groundwater contamination	Engineered Design Groundwater monitoring	1	5	ALARP, Moderate	Best practice in tailings management and highly unlikely event resulting in ALARP, Inherent Safety, no further assessment
10.2	Tailings transfer pipe or pump failure	OP / ADR	Potential for soil / groundwater contamination	The pipe is in a secondary containment Groundwater monitoring Routine inspection and maintenance Emergency response plan	3	3	ALARP, Moderate	Further assessment recommended

OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

NPAG waste rock stockpile: For the NPAG Waste Rock Stockpile, four hazard scenarios were identified, which have the potential to occur during the Construction, Operations, and Closure of the Project. All hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-11: Hazard Identification Evaluation – Non-Potentially Acid Generating Waste Rock Stockpile

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
11.1	Stockpile slope failure	CO / OP / ADR	Release of material into surrounding environment	Regular inspection	2	2	Low	Low risk, unlikely event, no further assessment
11.2	Stockpile erosion	CO / OP / ADR	Blockage or diversion of ditches or surface water and discharge of materials into the environment	Containment being designed to accommodate a 24-hour, 1 in 100 year event Regular inspection	1	3	Low	Low risk, unlikely event, no further assessment
11.3	Uncontrolled leachate / seepage release through runoff	CO / OP / ADR	Discharge of materials into the environment	NPAG stockpile containment being designed to accommodate a 24-hour, 1 in 100 year event Regular inspection Ambient monitoring Surface water management Spill response plan	1	2	Low	Low risk, unlikely event, no further assessment
11.4	Uncontrolled leachate / seepage release	CO / OP / ADR	Discharge of materials into the environment	NPAG stockpile containment being designed to accommodate a 24-hour, 1 in 100 year event Regular inspection and maintenance of facility Groundwater monitoring Spill response plan	2	3	Low	Low risk, unlikely event, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; NPAG = non-potentially acid generating.

Ore, special waste, and PAG waste rock stockpiles: For ore, special waste, and PAG waste rock stockpiles, four hazard scenarios were identified, which have the potential to occur during the Construction, Operations, and Closure of the Project. All hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-12: Hazard Identification Evaluation – Ore, Special, and Potentially Acid Generating Waste Rock Stockpiles

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
12.1	Stockpile slope failure	CO / OP / ADR	Release of contaminants into surrounding environment	Containment being designed to accommodate a 24-hour, 1 in 100 year event Single-lined pad with leak detection system Regular inspection The slope of the stockpile is designed to provide stability	1	4	ALARP, Moderate	Best management practice results in ALARP, highly unlikely event, no further assessment
12.2	Stockpile erosion	CO / OP / ADR	Blockage or diversion of ditches or surface water and discharge of materials into the environment	Containment being designed to accommodate a 24-hour probable maximum precipitation event Single-lined pad with leak detection system Regular inspection	1	3	Low	Low risk, unlikely event, no further assessment
12.3	Uncontrolled leachate / seepage release through runoff	CO / OP / ADR	Discharge of contaminants into the environment	Regular inspection Ambient monitoring Surface water management Spill response plan	1	3	Low	Low risk, unlikely event, no further assessment
12.4	Uncontrolled leachate / seepage release through lining failure	CO / OP / ADR	Discharge of contaminants into the environment	Regular inspection and maintenance of lining Groundwater monitoring Spill response plan	1	4	ALARP, Moderate	Best management practice results in ALARP, highly unlikely event, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Effluent treatment system: For the effluent treatment system, three hazard scenarios were identified, which have the potential to occur during the Operations and Closure of the Project. The screening assessment shows that one hazard scenario requires further assessment to characterize the risk in more detail. Other hazard scenario would have appropriate safeguards and design features in place to minimize the risk such that no further assessment is required.

Table 3-13: Hazard Identification Evaluation – Effluent Treatment System

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
13.1	Equipment/piping failure	OP / ADR	Contaminant and radioactivity release	Routine and preventive testing, inspection, and maintenance program Piping design pressure higher than pumps shutoff pressure Process monitoring Secondary containment for clarifier Spill response plan	2	3	Low	Low Risk, no further assessment
13.2	Effluent clarifier overflow	OP / ADR	Contaminant and radioactivity release	Secondary containment Spill response plan	2	3	Low	Low Risk, no further assessment
13.3	Untreated effluent transfer pipe failure	OP / ADR	Release of reagents, occupational exposure, and environmental contamination	Routine and preventive testing, inspection, and maintenance program Process monitoring Controls to maintain barium chloride below its maximum solubility Spill response plan	3	3	ALARP, Moderate	Further assessment recommended

OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Ponds and retention berms: For ponds and retention berms, four hazard scenarios were identified, which have the potential to occur during the Operations and Closure of the Project. All hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-14: Hazard Identification Evaluation – Ponds and Retention Berms

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
14.1	Pond overtopping	OP / ADR	Contaminant and radioactivity release	Ponds to have capacity for a 24-hour probable maximum precipitation or 1 in 100 year event Process control Surface water management Ambient monitoring Spill and emergency response plan	2	3	Low	Low risk, unlikely event, no further assessment
14.2	Pond containment or embankment failure	OP / ADR	Contaminant and radioactivity release	Regular inspection and maintenance program Surface water management Ambient monitoring Spill and emergency response plan	1	5	ALARP, Moderate	Best engineering practice in maintenance and inspection of the containment systems and berms, no further assessment
14.3	Pond lining failure and leakage	OP / ADR	Contaminant and radioactivity release	Groundwater monitoring Hydraulic containment with a separate well	3	4	ALARP, Moderate	Best engineering practice in maintenance, no further assessment
14.4	Surface flooding	OP / ADR	Contaminant and radioactivity release	Ponds to have capacity for a 24-hour probable maximum precipitation event Process control Surface water management Ambient monitoring Spill and emergency response plan	1	3	Low	Low risk, highly unlikely event, no further assessment

OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Gypsum precipitation, washing, and storage: For gypsum precipitation, washing, and storage, two hazard scenarios were identified, which have the potential to occur in the Operations of the Project. These hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-15: Hazard Identification Evaluation – Gypsum Precipitation, Washing, and Storage

ID#	Accident/Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
15.1	Loaded strip piping leakage	OP	Contaminant release	Secondary containment for piping between buildings	2	2	Low	Low risk, minor consequence event, no further assessment
15.2	Gypsum reactor failure	OP	Contaminant release	Secondary containment Spill and emergency response plan	2	3	Low	Low risk, unlikely event, no further assessment

OP = Operation; L = likelihood; S = severity; RR = risk ranking.

Acid plant: For the acid plant, five hazard scenarios were identified that have the potential to occur in the Operations of the Project. The screening assessment shows that one hazard scenario requires further assessment to characterize the risk in more detail. Two of the scenarios were bounded by an acid plant tail gas scrubber failure scenario. Two other hazard scenarios would have appropriate safeguards and design features in place to minimize the risk such that no further assessment is required.

Table 3-16: Hazard Identification Evaluation – Acid Plant

ID#	Accident/Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
16.1	Truck, tanks, reactor, and storage vessels failure, sulphur spill during offloading (this is very common)	OP	Release of sulphur and acid	Housekeeping procedure Secondary containment Routine and preventive inspection, testing, and maintenance program Acid plant building is contained Spill and emergency response plans	3	2	Low	Low risk, minor consequence event, no further assessment
16.2	Piping and piping component failure	OP	Release of acid	Acid resistant lined secondary containment with leak detection Sumps Routine and preventive inspection, testing, and maintenance program Acid plant building is contained Spill and emergency response plans	2	2	Low	Low risk, minor consequence event, no further assessment
16.3	Acid plant tail gas scrubber failure	OP	Release of acid gas to the atmosphere, worker exposure, environmental damage	Sulphur dioxide and hydrogen sulphide monitors Routine and preventive inspection, testing, and maintenance program Ambient air monitoring	2	4	ALARP, Moderate	Further assessment recommended
16.4	Scrubber, absorber failure	OP	Release of acid gas to the atmosphere, worker exposure, environmental damage	Sulphur dioxide and hydrogen sulphide monitors Routine and preventive inspection, testing, and maintenance program Ambient air monitoring	2	4	ALARP, Moderate	This scenario is bounded by Scenario 16.3
16.5	Sulphur dioxide gas emission during plant start-up that spreads to other process plant area	OP	Release of acid gas to the atmosphere Worker inhalation of sulphur dioxide fume causing respiratory acid burn, Environmental damage	Sulphur dioxide and hydrogen sulphide monitors Routine and preventive inspection, testing, and maintenance program Ambient air monitoring	2	4	ALARP, Moderate	Unlikely event. Scenario is bounded from a biophysical environment perspective by Scenario 16.3

OP = Operation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Electrical system and power plant: For the electrical system and power plant, three hazard scenarios were identified, which have the potential to occur during Construction, Operations, and Closure of the Project. All hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-17: Hazard Identification Evaluation – Electrical System and Power Plant

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
17.1	Substation transformer leak	CO / OP / ADR	Release of mineral oil and potential for groundwater contamination	Spill and emergency response plan Secondary containment and gravel pit	3	2	Low	Low risk, minor consequence event, no further assessment
17.2	Transformer, turbine, generator fire/explosion	CO / OP / ADR	Occupational major injuries	Fire safety plan and firefighting systems Occupational health and safety program Personnel training and orientation Personal protection equipment Fire detection and alarm Emergency response plan	2	4	ALARP, Moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment
17.3	Transformer, turbine, generator fire/explosion	CO / OP / ADR	Occupational fatalities	Fire safety plan and firefighting systems Occupational health and safety program Personnel training and orientation Personal protection equipment Emergency response plan	1	5	ALARP, Moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

Fire protection system: For the fire protection system, two hazard scenarios were identified, which have the potential to occur during Construction, Operations, and Closure of the Project. These hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-18: Hazard Identification Evaluation – Fire Protection System

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
18.1	Failure of fire pump or foam system	CO / OP / ADR	Loss of firefighting capacity	Redundancy Regular and preventive testing, maintenance, and inspection Fire safety plan and firefighting systems Emergency response plan	1	3	Low	Low risk, highly unlikely event, no further assessment
18.2	Loss or lack of fire water	CO / OP / ADR	Loss of firefighting capacity	Fire safety plan and firefighting systems	1	3	Low	Low risk, highly unlikely event, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking.

Low-level radioactive waste management system / incinerator: For the low-level radioactive waste management system / incinerator, two hazard scenarios were identified, which have the potential to occur during Construction, Operations, and Closure of the Project. These hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-19: Hazard Identification Evaluation – Low-Level Radioactive Waste Management System / Incinerator

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
19.1	Hazardous waste spill	CO / OP / ADR	Potential for surface water and soil contamination	Waste management plan On-site monitoring Emergency response plan	3	2	Low	Low risk, minor consequence event, no further assessment
19.2	Incinerator fire	CO / OP / ADR	Uncontrolled release of hazardous material	Fire safety plan and firefighting systems Operate incinerator within design parameters Ambient air monitoring Radiation Protection personal protective equipment, such as powered air purifying respirator or self-contained breathing apparatus Emergency response plan	2	3	Low	Low risk, moderate consequence event, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking.

LNG power plant: For the LNG power plant, six hazard scenarios were identified that have the potential to occur during Construction, Operations, and Closure of the Project. All hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-20: Hazard Identification Evaluation – Liquified Natural Gas Power Plant

ID#	Accident/Malfunction	Phase or Stage	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
20.1	LNG transportation accident	CO / OP / ADR	Fire or explosion resulting major injuries	Regular truck inspection and maintenance Travel management plan Fire safety plan and firefighting systems Emergency response plan	3	4	ALARP, Moderate	Regular truck inspection and maintenance resulting in ALARP, no further assessment
20.2	LNG transportation accident	CO / OP / ADR	Fire or explosion resulting fatalities	Regular truck inspection and maintenance Travel management plan Fire safety plan and firefighting systems Emergency response plan	1	5	ALARP, Moderate	Regular truck inspection and maintenance resulting in ALARP, no further assessment
20.3	LNG storage failure and release of gas	CO / OP / ADR	Fire or explosion	Regular storage facility inspection and maintenance Fire safety plan and firefighting systems Emergency response plan	1	5	ALARP, Moderate	Regular storage facility inspection and maintenance resulting in ALARP, no further assessment
20.4	Piping and piping component failure and release for gas	CO / OP / ADR	Fire or explosion	Regular storage facility inspection and maintenance Fire safety plan and firefighting systems Emergency response plan	3	2	Low	Low risk, minor consequence event, no further assessment
20.5	Vaporization unit failure and release of gas	CO / OP / ADR	Fire or explosion	Regular piping inspection and maintenance Fire safety plan and firefighting systems Emergency response plan	3	2	Low	Low risk, minor consequence event, no further assessment
20.6	Pump failure and release of gas	CO / OP / ADR	Fire or explosion	Regular pumps inspection and maintenance Fire safety plan and firefighting systems Emergency response plan	3	2	Low	Low risk, minor consequence event, no further assessment

CO = Construction; OP = Operation; ADR = Active Decommissioning and Reclamation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable; LNG = liquified natural gas.

Mine ventilation system: For the mine ventilation system, three hazard scenarios were identified, which have the potential to occur during Construction and Operations of the Project. All hazard scenarios have appropriate safeguards and design features to minimize the risk such that no further assessment is required for any of these hazards.

Table 3-21: Hazard Identification Evaluation – Mine Ventilation System

ID#	Accident/Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
21.1	Power outage	CO / OP	Loss of ventilation and accumulation of radon, toxic fumes	Radiation protection plan Occupational health and safety program Refuge stations Equipment monitoring and alarms Second egress from Exhaust Shaft Emergency response plan	2	3	Low	Risk level is low, highly unlikely event, no further assessment
21.2	Ventilation fans failure	CO / OP	Loss of ventilation and accumulation of radon, toxic fumes	Radiation protection plan Occupational health and safety program Equipment monitoring and alarms Refuge stations Emergency response plan	2	3	Low	Risk level is low, highly unlikely event, no further assessment
21.3	Mine air heater fire	CO / OP	Smoke release into the mine	Preventive maintenance of the heating equipment Fire safety plan and firefighting systems and firefighting systems Equipment monitoring and alarms Engineered safety systems Air monitoring in underground mine Refuge stations Emergency response plan	3	4	ALARP, Moderate	Regular and preventive inspection and maintenance resulting in ALARP, no further assessment

CO = Construction; OP = Operation; L = likelihood; S = severity; RR = risk ranking; ALARP = As Low as Reasonably Practicable.

4.0 SELECTION OF ACCIDENT SCENARIOS FOR FURTHER ASSESSMENT

Based on the HI process presented in the previous section, six hazard scenarios have been selected for more detailed risk analysis (Table 4-1). This further assessment will include the calculation of the likelihood and consequences of each of these selected scenarios. This will result in more in-depth and representative characterization of the risk of these scenarios, as the estimation of the risk in this current report was preliminary and at the screening level.

Table 4-1: Hazard Scenarios Identified for Further Assessment by the Hazard Identification Process

Node	Accident or Malfunction Scenario	Location	Effect Pathway
3.1	Traffic accident (uranium concentrate)	Access road at bridge crossing	Aquatic release of uranium concentrate
3.3	Traffic accident (chemical)	Access road at bridge crossing	Aquatic release of fuel, hazardous chemicals
9.3	Solvent extraction fire or explosion	Solvent extraction building	Atmospheric release of uranium concentrate (chemical toxicity)
10.2	Tailings transfer pipe or pump failure	Tailings release to surface within secondary containment	Terrestrial release of radioactivity
13.3	Untreated effluent transfer pipe failure	Effluent treatment system	Terrestrial release of radioactivity
16.3	Acid Plant tail gas scrubber failure	Acid plant	Atmospheric release of sulphur dioxide

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Rook I Project

Environmental Impact Statement

TSD IX: Transportation Risk Assessment Report

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

REPORT PREPARED FOR:

NexGen Energy Ltd.
www.nexgenenergy.ca
Saskatoon, SK

REPORT PREPARED BY:

Ecometrix Incorporated
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Mississauga, ON

Ref. 19-2574
1 November 2024

Ecometrix | Environmental INTELLIGENCE

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

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EXECUTIVE SUMMARY

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

Proposed Project

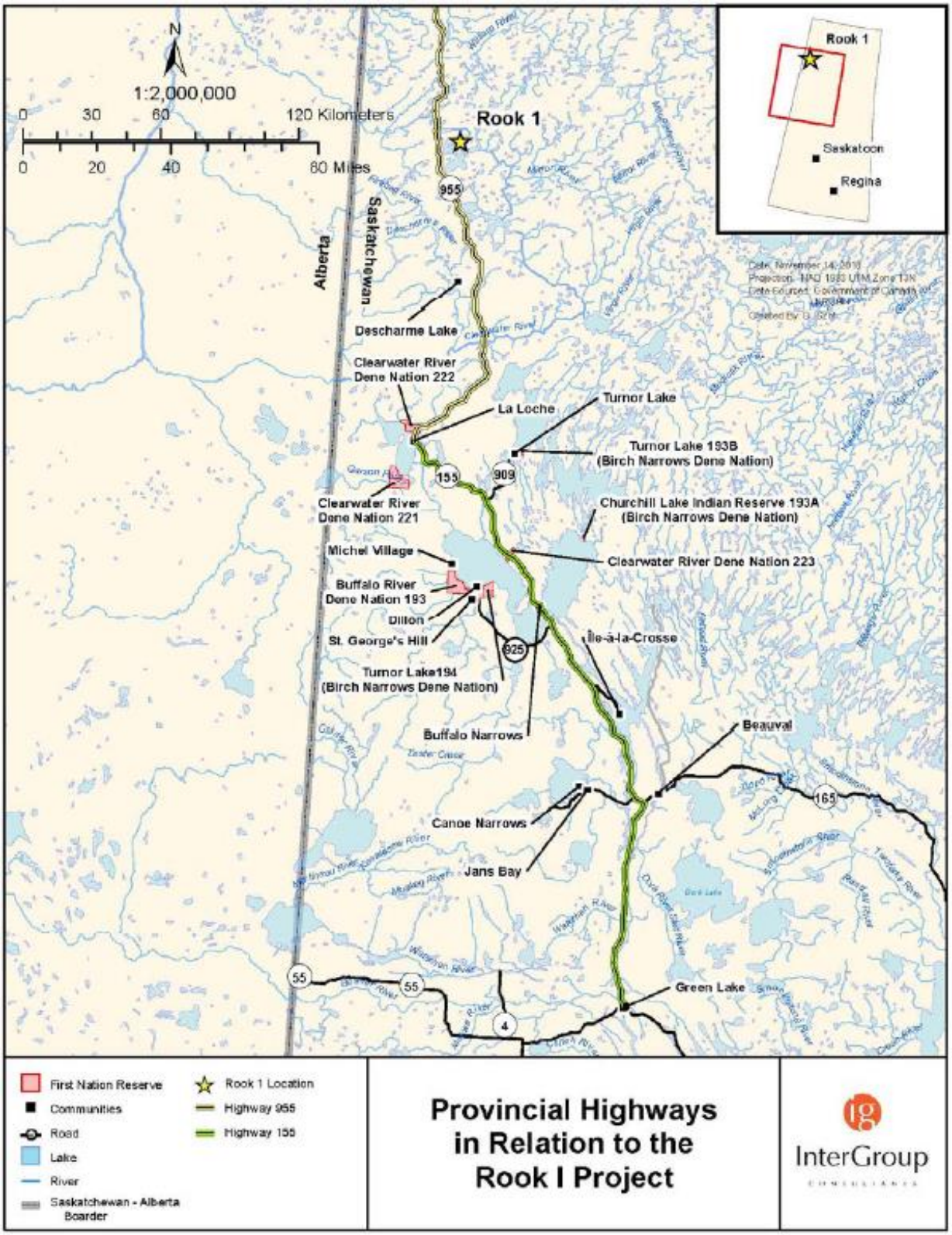
The Project is a proposed new uranium mining and milling operation that is 100 percent (%) owned by NexGen. The Project would be located in northwestern Saskatchewan, approximately 40 kilometres (km) east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of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

Objective and Scope of the Assessment

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

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

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



Assessment Methodology

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

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

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

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

Table ES-1: Likelihood Ratings

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

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

Table ES-2: Consequence Index

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

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

Figure ES-2: Hazard Analysis Risk Matrix

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

Transportation Accident Scenarios

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

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

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

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

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

Hazardous Materials Selected

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

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

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

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

Transportation Setting

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

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

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

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

Conclusions

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

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

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

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

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ABBREVIATIONS AND UNITS OF MEASURE

Abbreviations

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

Units of Measure

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

1.0 INTRODUCTION

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

1.1 Background Information

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

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

1.2 Regulatory Context

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

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

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

1.3 Overall Scope and Objective of the Assessment

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

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

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

1.4 Report Format

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

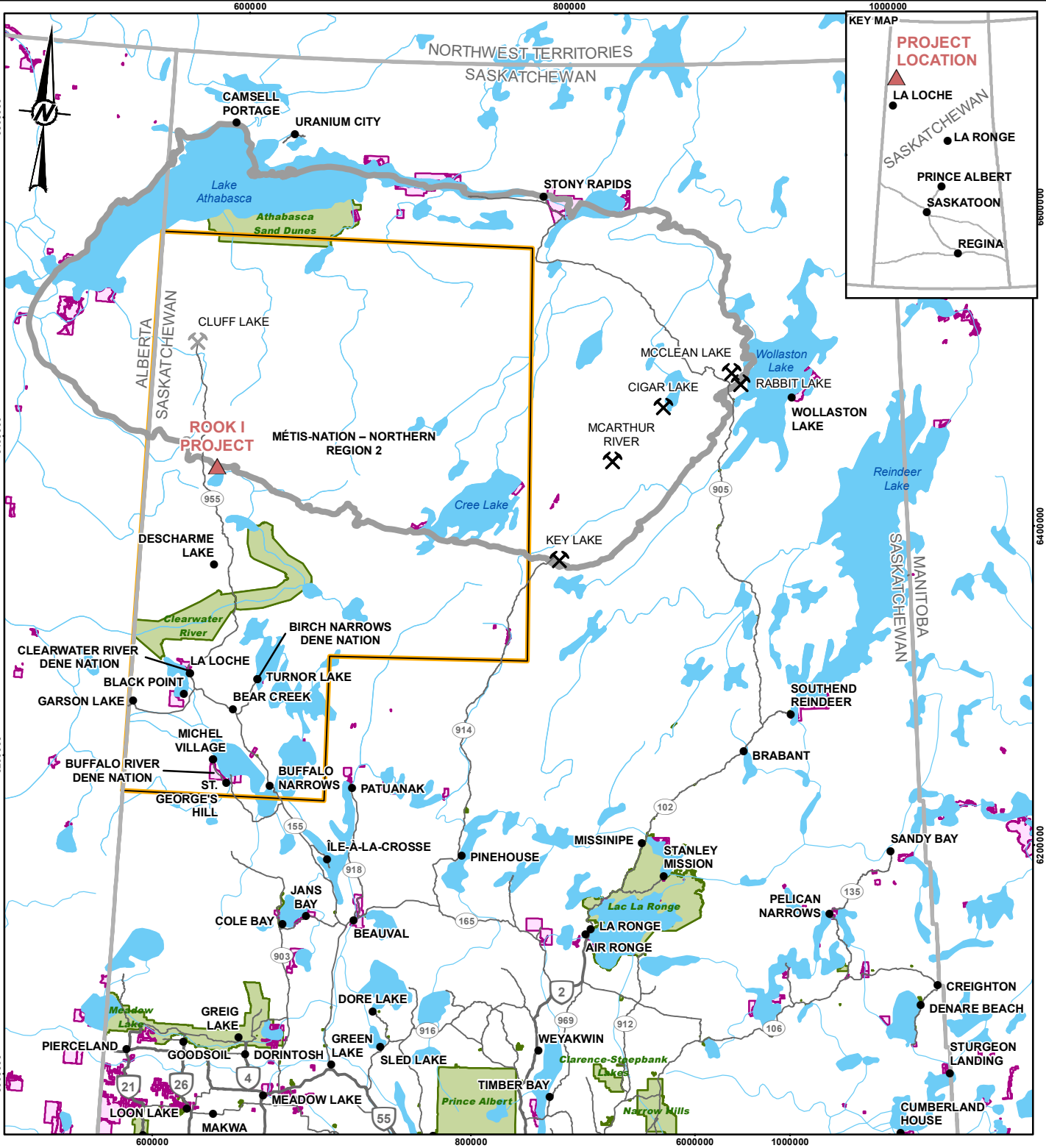
- Section 2.0: provides Project-related information;
- Section 3.0: provides the assessment methodology;
- Section 4.0: describes risk controls related to NexGen management programs considered for the assessment;
- Section 5.0: describes the hazardous materials considered in the assessment as well as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

2.0 PROJECT INFORMATION

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

2.1 Rook I Project Location

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



LEGEND

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

REFERENCE(S)

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

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LOCATION OF THE ROOK I PROJECT

CONSULTANT

wsp

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

PATH: I:\CLIENTS\NexGen\20144150\Mapping\Products\General\EIS_FIGURES_SECTION1\20144150_004_Fig2-1_Location-of-the-Rook-I-Project_Rev9.mxd PRINTED ON: 2022-02-28 AT: 12:01:58 PM

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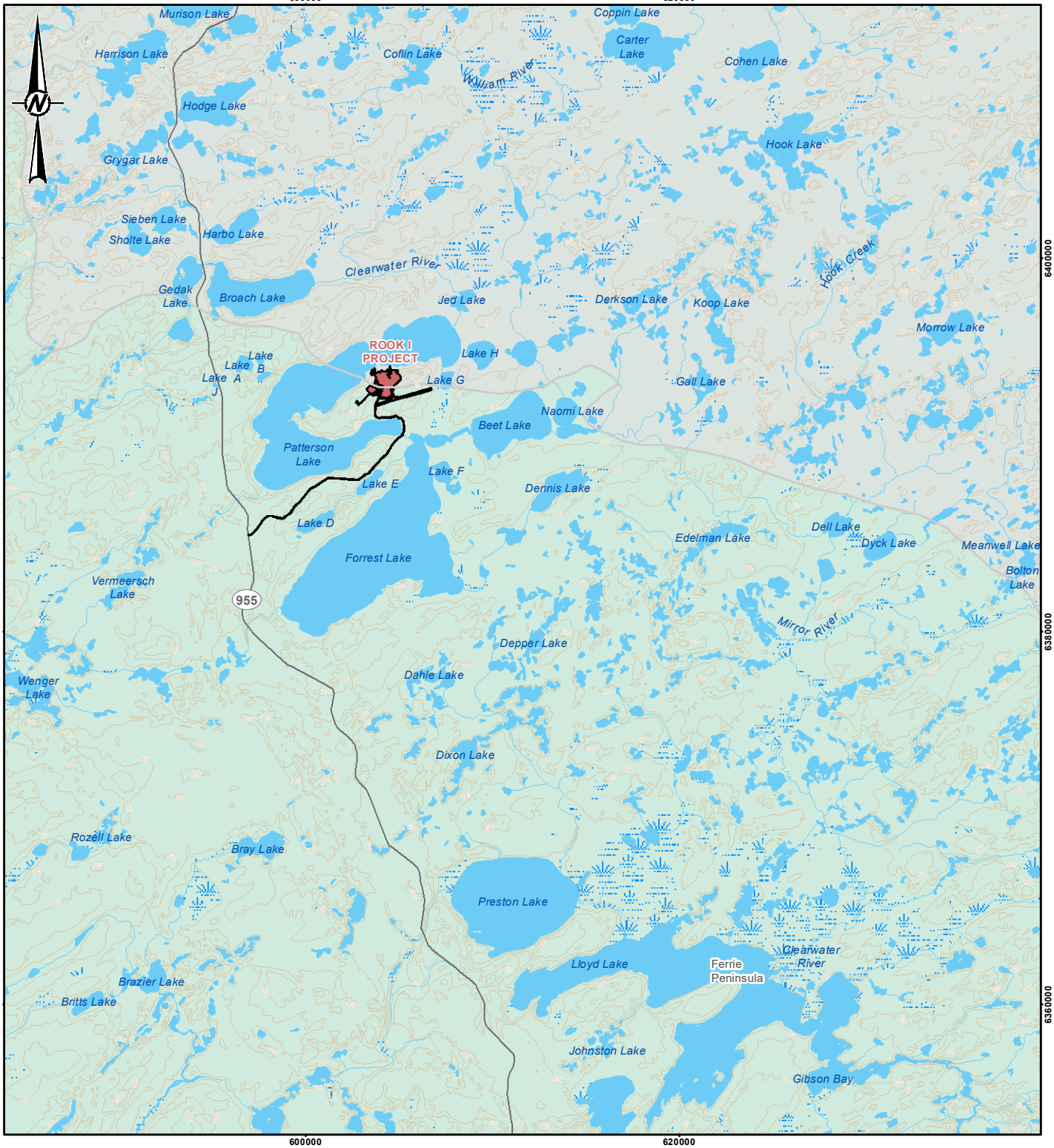

LEGEND

- ELEVATION CONTOUR (20 m INTERVAL)
- SECONDARY HIGHWAY
- WATERCOURSE
- ATHABASCA BASIN
- WATERBODY
- WETLAND
- WOODED AREA
- PROPOSED PROJECT FOOTPRINT

0 5 10
1:300,000 KILOMETRES

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

PROJECT
NexGen Energy Ltd.
ROOK I PROJECT

TITLE
REGIONAL AREA OF THE ROOK I PROJECT

CONSULTANT
wsp

PROJECT		20144150	PHASE	3314 - 6
DESIGN	JMC	2023-10-25	SCALE AS SHOWN	REV. 0
GIS	NO	2023-10-25	**FIGURE 2-2**	
CHECK	JMC	2023-10-25		
REVIEW	MM	2023-10-25		

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2.2 Rook I Project Timeline

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

Table 2-1: Rook I Project Phases

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

CNSC = Canadian Nuclear Safety Commission.

2.3 Key Support Facilities

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

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

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

3.0 ASSESSMENT METHODOLOGY

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

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

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

3.1 Scenario Identification

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

3.2 Probability Analysis

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

Table 3-1: Likelihood Ratings

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

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

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

3.3 Effects Analysis

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

Table 3-2: Consequence Index

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

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

3.4 Risk Estimation and Ranking

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

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

Figure 3-1: Hazard Analysis Risk Matrix

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

For the purpose of the assessment, risks were identified as being low where the screening evaluation considered the risk as generally being acceptable, as the risk of these scenarios can be effectively managed through application of planned controls. Low-risk scenarios have a

consequence of negligible to moderate with the likelihood ranging from highly unlikely to almost certain.

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

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

4.0 CONSIDERATIONS FOR THE TRANSPORTATION ACCIDENT ASSESSMENT

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

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

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

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

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

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

5.0 TRANSPORTATION OF HAZARDOUS MATERIALS

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

5.1 Hazardous Materials

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

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

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

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

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

5.1.1 Uranium Concentrate

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

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

Table 5-1: Radionuclides Present in Uranium Concentrate

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

n/a = not applicable.

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

Table 5-2: Uranium Ore Concentrate Particle Size Distribution

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

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

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

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

Table 5-3: Solubility of Calcined Uranium Concentrate

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

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

5.1.2 Fuel and Chemicals

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

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

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

Source: NexGen 2021.
LNG = liquified natural gas.

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

5.2 Transportation Quantities

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

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

Table 5-5: Traffic Generation for Construction

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

Table 5-6: Traffic Generation for Operations

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

Table 5-7: Traffic Generation for Closure

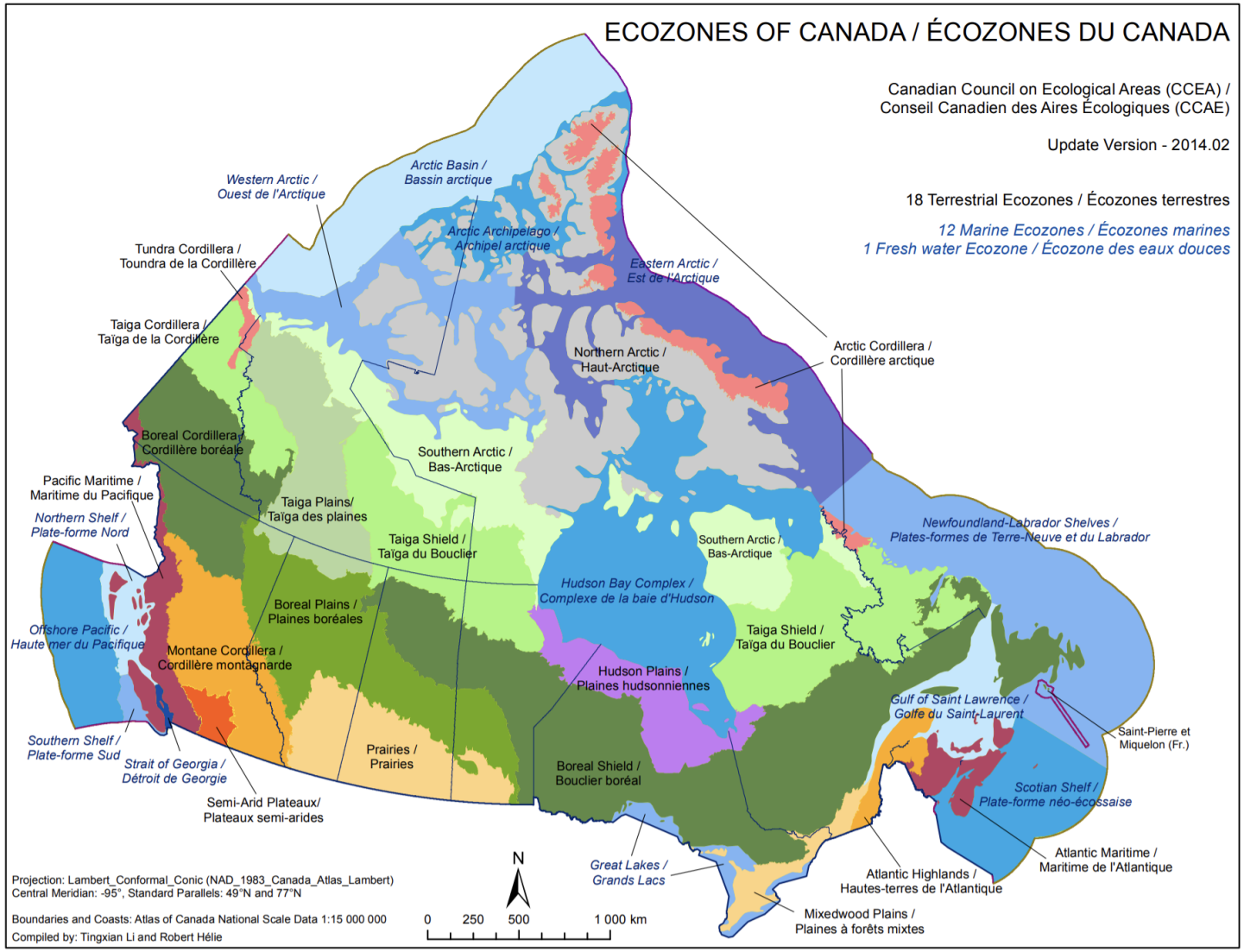
Category	Generation		
	Trips/Day	Trips/Week	One-Time Trips
Expendables	24	11	0
Labour	0	0	0
One-time equipment deliveries	0	0	1,970
Total	**24**	**11**	**1,970**

5.3 Transportation Setting

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

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

Figure 5-1: Ecozones of Canada



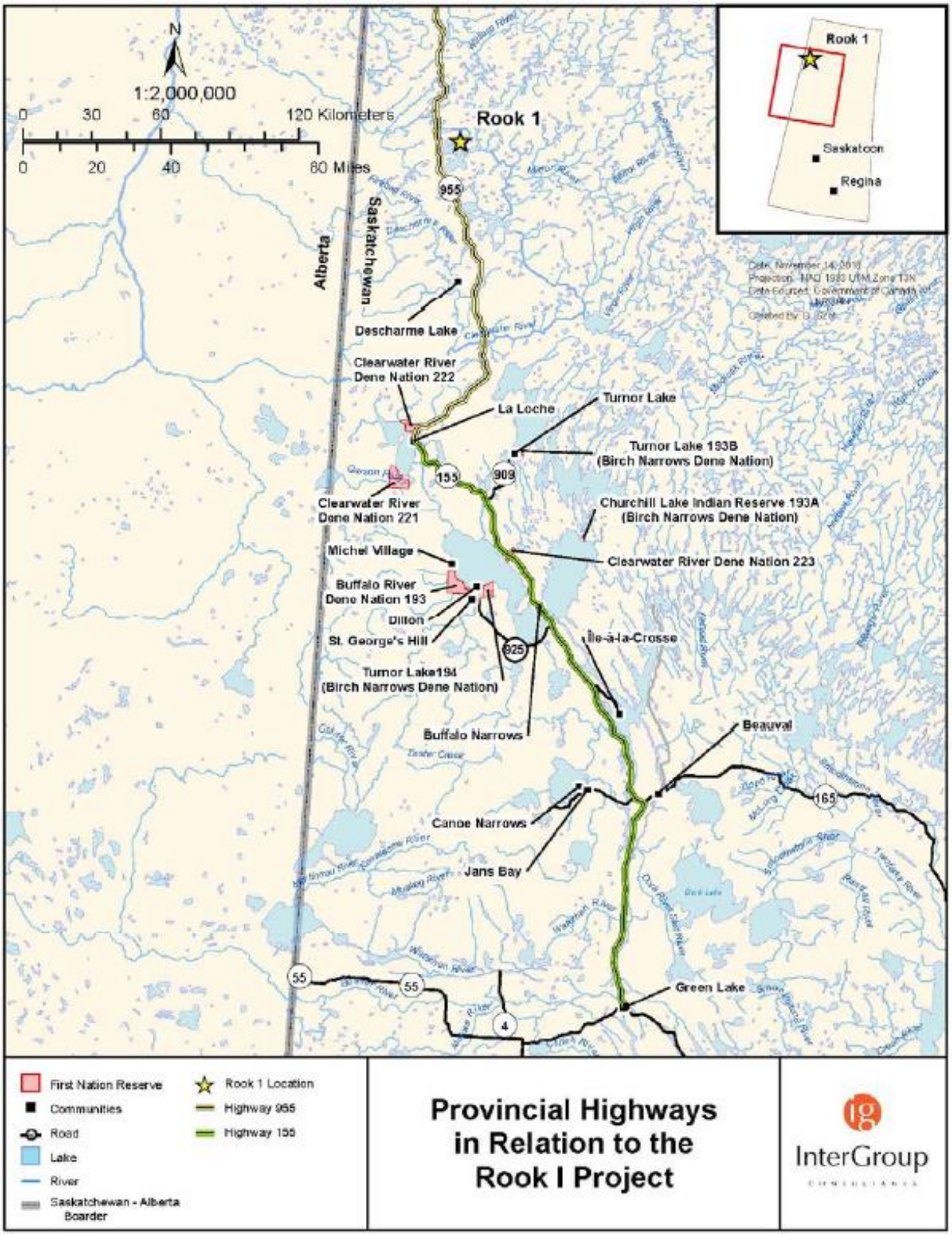
5.4 Transportation Route

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

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

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

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



5.4.1 Water Crossings, Communities, and Intersections

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

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

Table 5-8: Transportation Route Water Features

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

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

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

Table 5-9: Communities Along the Transportation Route

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

Table 5-10: Major Intersections and Road Features

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

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

6.0 TRANSPORTATION ACCIDENT SCENARIOS

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

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

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

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

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

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

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

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

6.1 Aquatic Release Scenario

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

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

6.2 Terrestrial Release Scenario

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

6.3 Atmospheric Release Scenario

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

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

6.4 Vehicle-Human Accident Scenario

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

6.5 Vehicle-Wildlife Accident Scenario

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

7.0 RECEPTORS AND TOXICITY BENCHMARKS

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

7.1 Selected Ecological and Human Receptors

7.1.1 Ecological Receptors

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

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

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

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

7.1.2 Human Receptors

The human receptors considered for this assessment include the following:

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

7.2 Toxicity Benchmarks

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

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

7.2.1 Uranium

7.2.1.1 Atmospheric Environment

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

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

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

The three levels of the AEGLs are defined as follows:

AEGL-1 The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible on cessation of exposure.

AEGL-2 The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

AEGL-3 The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

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

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

The three levels of the ERPGs are defined as follows:

ERPG-1 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing effects other than mild transient adverse health effects, or perceiving a clearly defined, objectionable odour.

ERPG-2 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

ERPG-3 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects.

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

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

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

ERPG = Emergency Response Planning Guidelines.

7.2.1.2 Aquatic Environment

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

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

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

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

7.2.1.3 Terrestrial Environment

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

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

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

7.2.2 Radioactivity

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

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

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

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

7.2.3 Smoke and its Toxic Components

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

emergency response planning purposes. The AEGLs and PACs for carbon monoxide and PAHs are provided in Table 7-3.

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

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

n/a = not available; AEGL = Acute Exposure Guideline Level; PAC = Protective Action Criteria; ppm = parts per million; PAH = polycyclic aromatic hydrocarbon.
a) PAC-2 = Irreversible or other serious health effects that could impair the ability to take protective action; PAC-3 = Life-threatening health effects.

8.0 PROBABILITY ASSESSMENT

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

8.1 Transportation Volume and Accident Statistics

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

8.1.1 Provincial Data

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

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

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

Source: SGI 2018.

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

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

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

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

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

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

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

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

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

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

8.1.2 Regional Statistics

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

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

8.2 Accident Frequency Calculation

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

Accident frequency (per year) = Number of trips per year × Travel distance (km) / 1,000,000 × Accident rate (per MVkm)

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

Table 8-4: Summary of Annual Accident Frequencies

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

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

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

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

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

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

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

Table 8-5: Summary of Annual Accident Probabilities

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

a) Assumed 24 years of operations.

9.0 FATE AND TRANSPORT ASSESSMENT

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

9.1 Aquatic Release Scenario

9.1.1 Fate and Transport Assessment Methods

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

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

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

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

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

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

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

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

9.1.2 Uranium Concentrate Release Characterization

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

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

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

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

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

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

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

9.1.3 Non-Radiological Release Characterization

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

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

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

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

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

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

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

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

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

9.1.4 Release to the Clearwater River

9.1.4.1 River Flow Data

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

The crossing where the hypothetical truck accident occurs is located 91 km south of the access road junction on Highway 955 (Figure 9-1). The river width at the crossing is about 80 m. The closest hydrometric gauging station is station 06AF005 (near Waterhen River). The variation in flow of the Clearwater River at this station over 15 years is shown in Figure 9-2. Minimum, average,

and maximum flows considered for this assessment are 5% of the flow variation (13.3 m^3/s), average flow (21.9 m^3/s), and 95% of the flow variation (35.5 m^3/s), respectively. Corresponding river depths are 0.6 m, 1.1 m, and 2.1 m, respectively.

Figure 9-1: The Clearwater River Crossing Location

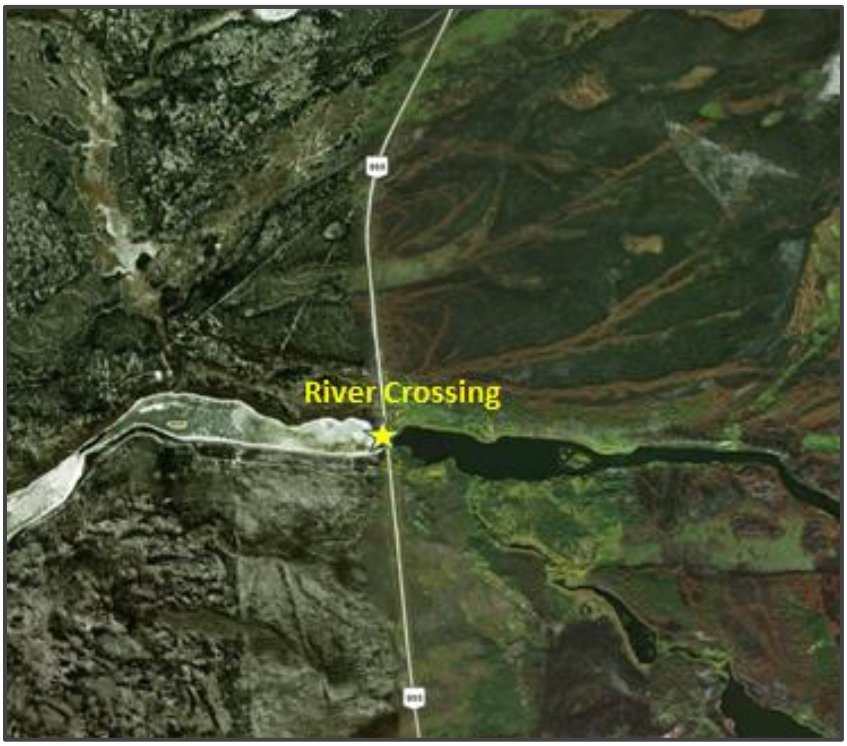
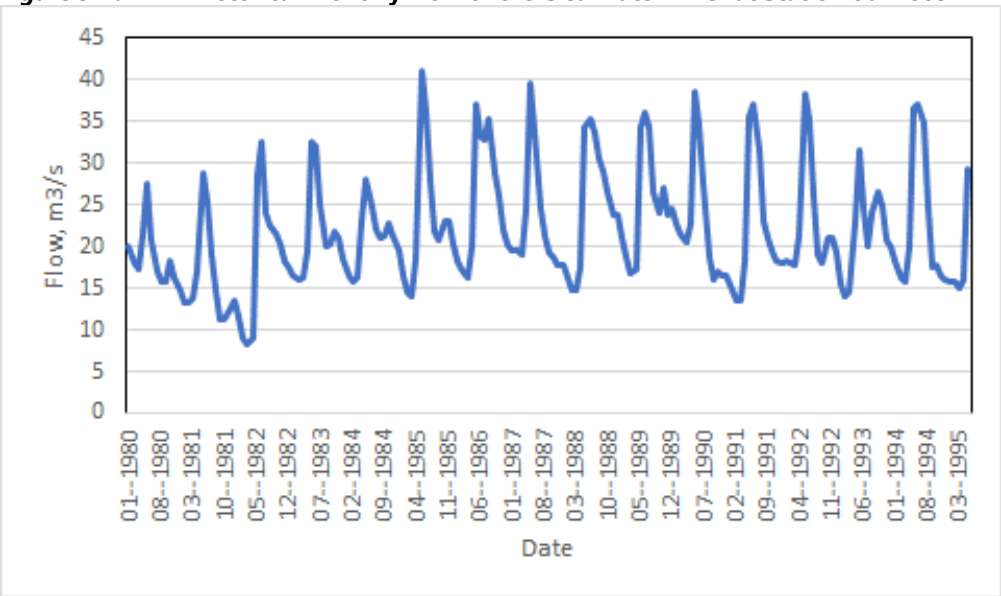


Figure 9-2: Historical Monthly Flow of the Clearwater River at Station 06AF005



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

9.1.4.2 Uranium Concentrate Fate and Transport Results

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

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

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

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

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

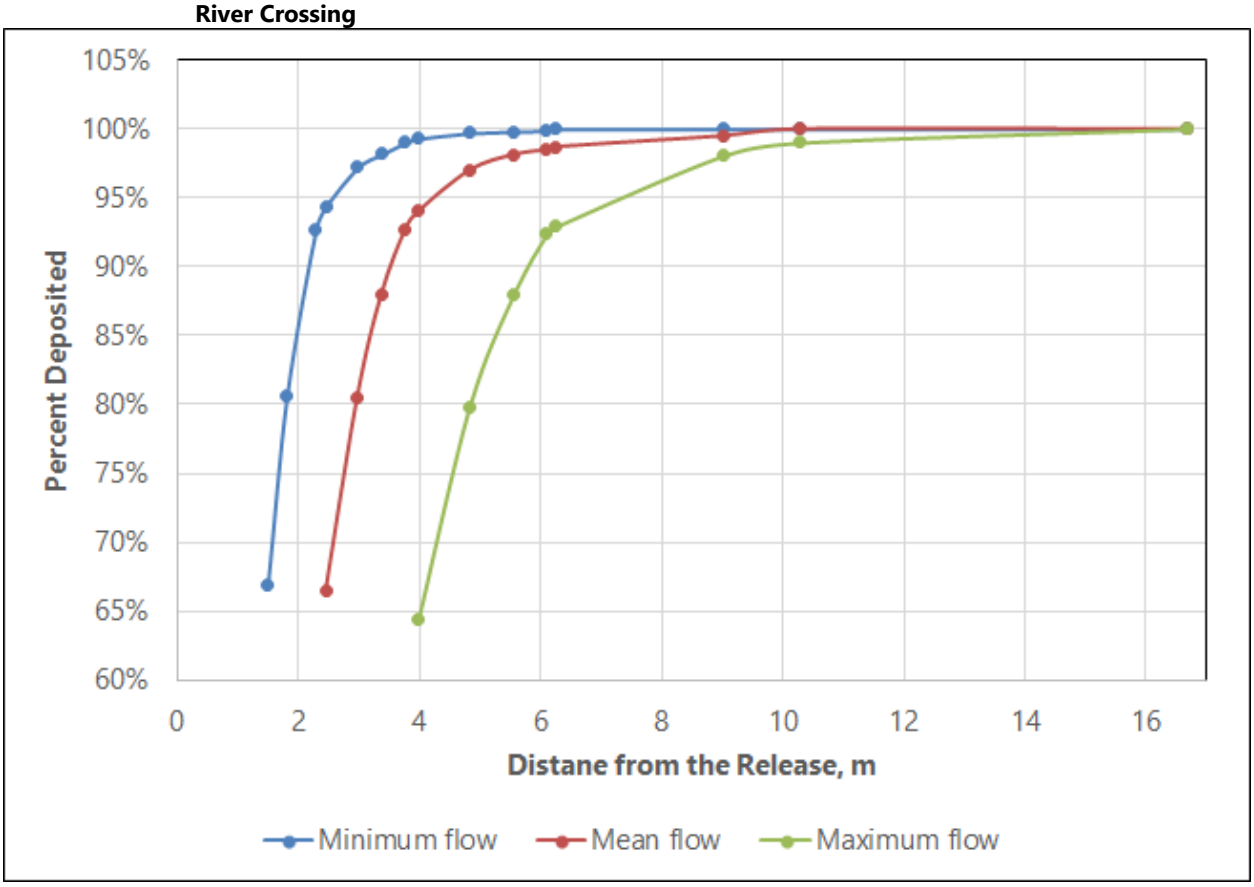


Table 9-1: Estimated Post-Remediation Concentrations of Uranium Concentrate in Sediment and Porewater Downstream of the Clearwater River Crossing

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

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

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

remediation. Therefore, the assumption of seven days for short-term concentration is conservative.

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

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

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

9.1.4.3 Hydrocarbon Fate and Transport Results

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

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

The theoretical maximum size of a 1 µm thick diesel fuel sheen that can be created by a 30 m^3 spill is 3×10^7 m^2. However, due to evaporation and dissolution of the majority of the spilled diesel, the size of the sheen is typically much smaller, particularly in slow-moving surface waterbodies. The average water velocity in the Clearwater River is 0.24 m/s. At this velocity, the spill would travel about 20 km in a day. Considering the lifetime of diesel fuel, the diesel sheen could travel as much as 40 km from the bridge over the Clearwater River. The effects would be transient (within a day or two); however, some damage to aquatic biota, and potentially birds,

would occur within this area. Due to short-term exposure, irreversible population-level damage is not expected.

9.1.5 Release to the Canoe River

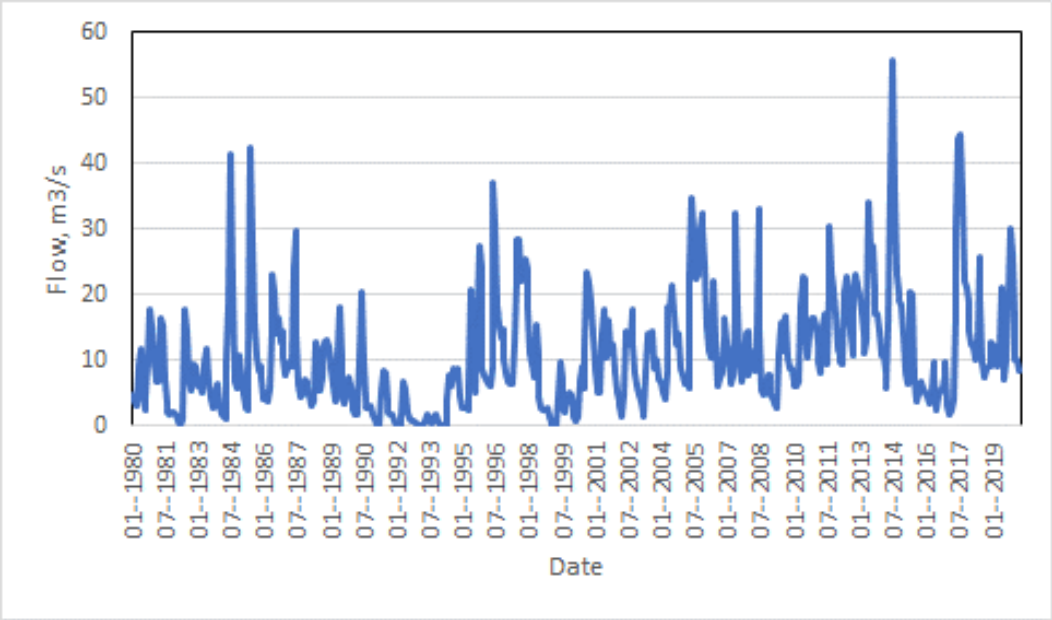
9.1.5.1 River Flow Data

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

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

Figure 9-4: The Canoe River Crossing Location

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



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

9.1.5.2 Uranium Concentrate Fate and Transport Results

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

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

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

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

the affected volume is smaller, resulting in a higher concentration. Higher flow conditions result in a greater footprint and hence lower concentration.

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

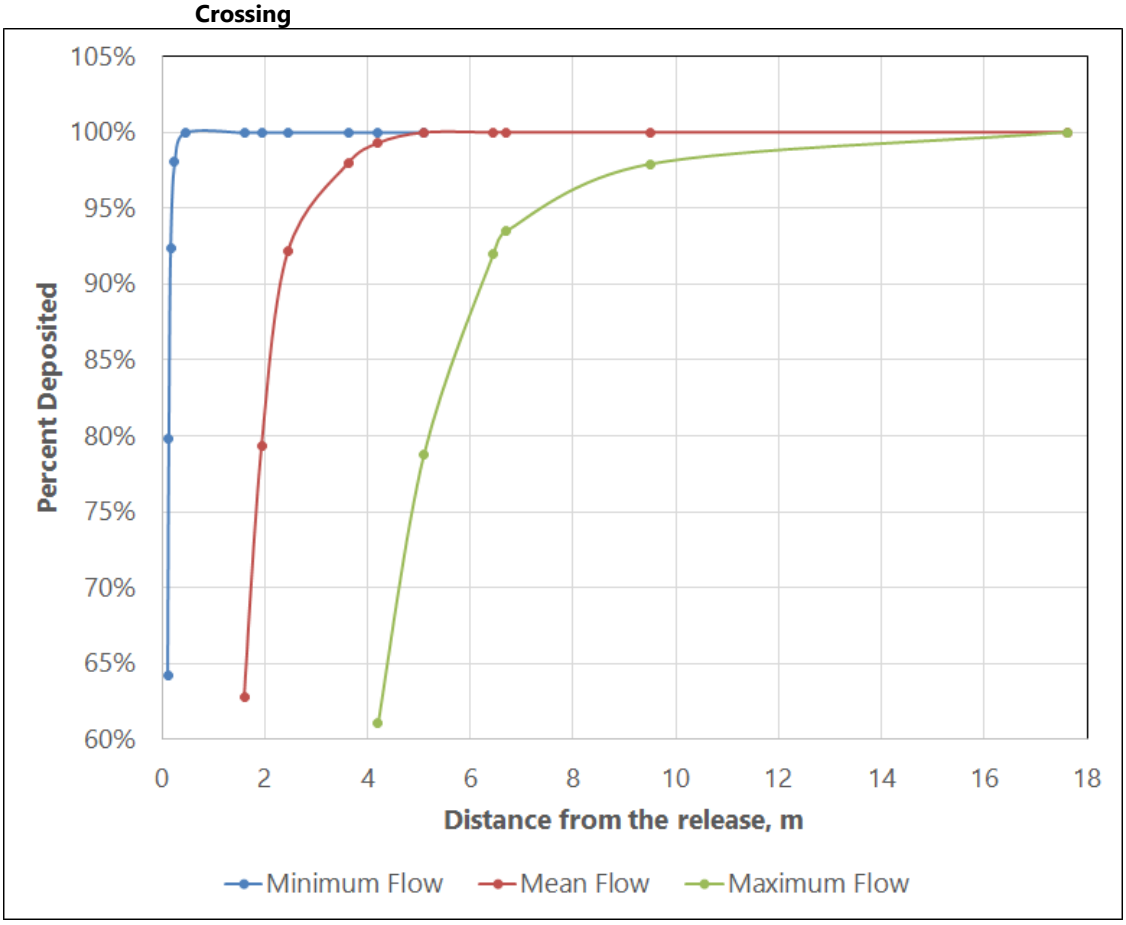


Table 9-3: Estimated Post-Remediation Concentrations of Uranium Concentrate in Sediment and Porewater Downstream of the Canoe River Crossing

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

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

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

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

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

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

9.1.5.3 Hydrocarbon Fate and Transport Results

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

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

9.1.6 Release to the Beaver River

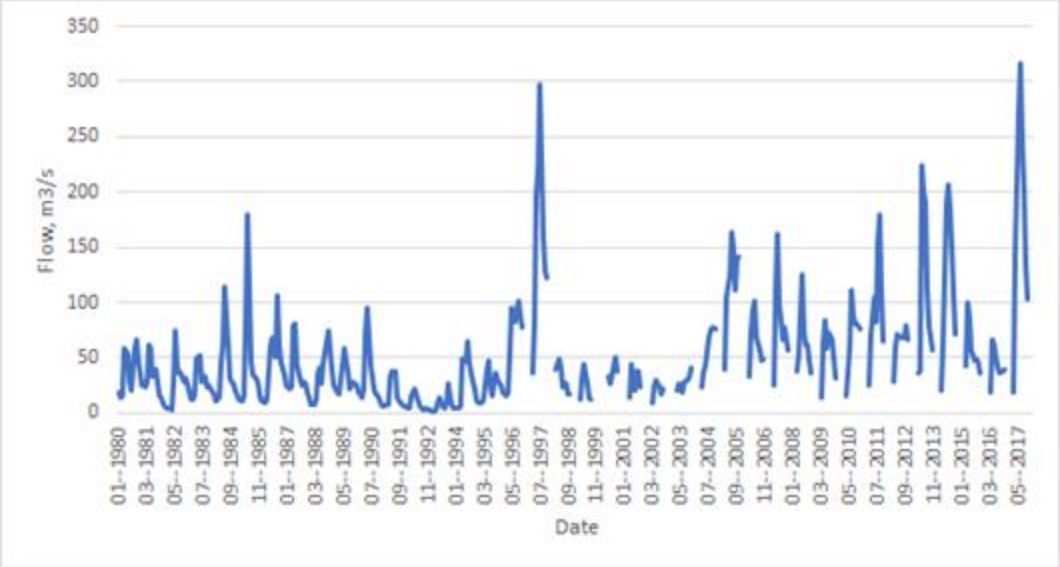
9.1.6.1 River Flow Data

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

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

Figure 9-8: The Beaver River Crossing Location

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



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

9.1.6.2 Uranium Concentrate Fate and Transport Results

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

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

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

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

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

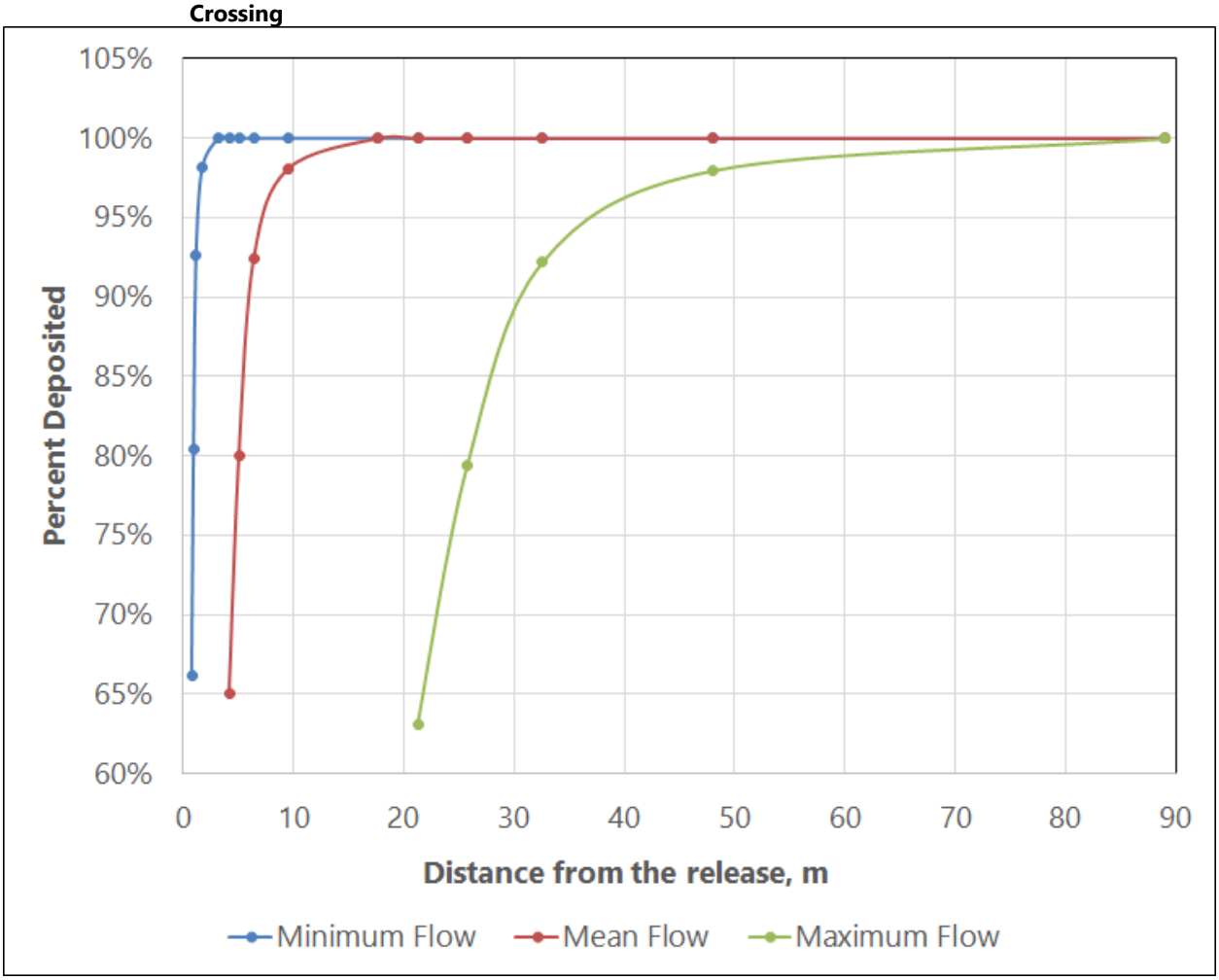


Table 9-5: Estimated Post-Remediation Sediment and Porewater Quality Downstream of the Beaver River Crossing

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

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

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

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

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

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

9.1.6.3 Hydrocarbon Fate and Transport Results

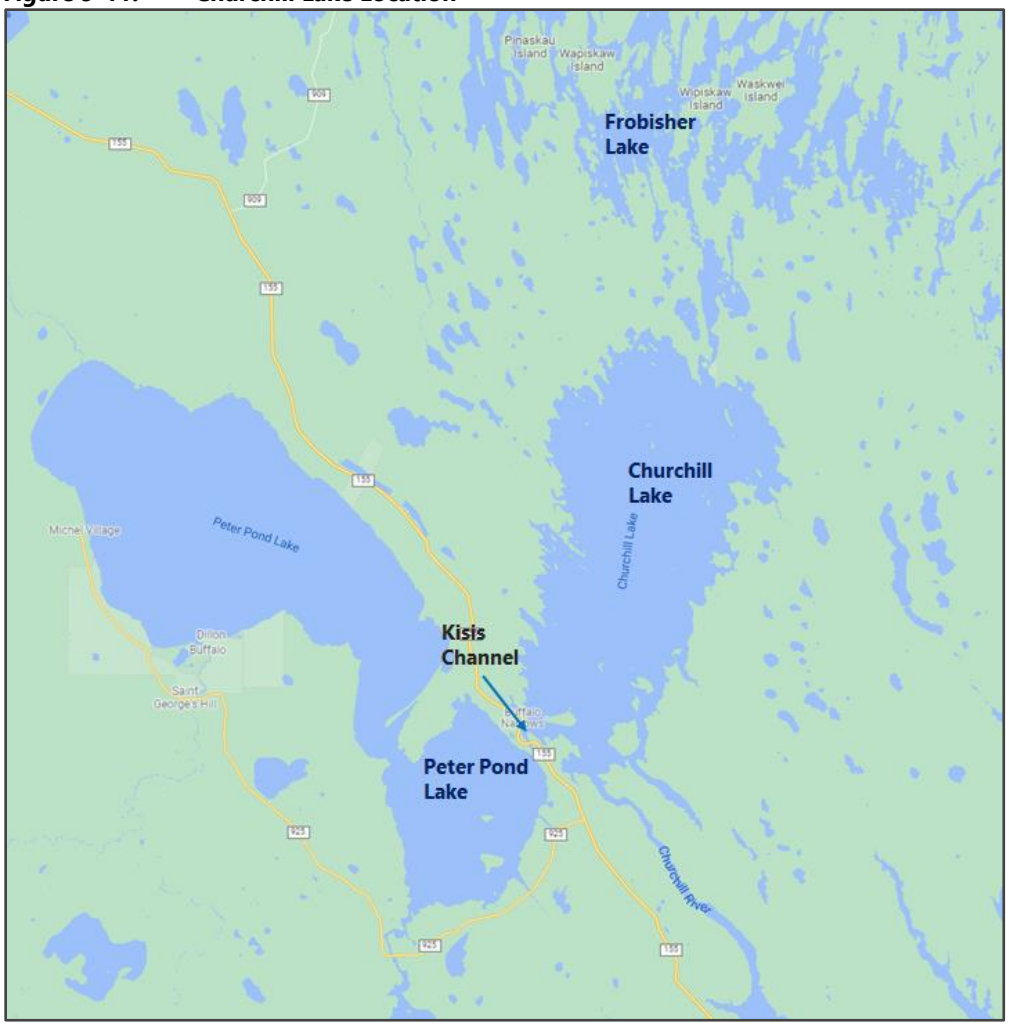
The theoretical maximum size of a 1 µm diesel fuel sheen that can be created by a 30 m^3 spill is 3×10^7 m^2. However, due to evaporation and dissolution of the majority of the spilled diesel, the size of the sheen would be much smaller, particularly in slow-moving surface waterbodies. The average water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

9.1.7 Release to Churchill Lake

9.1.7.1 Lake Bathymetry

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

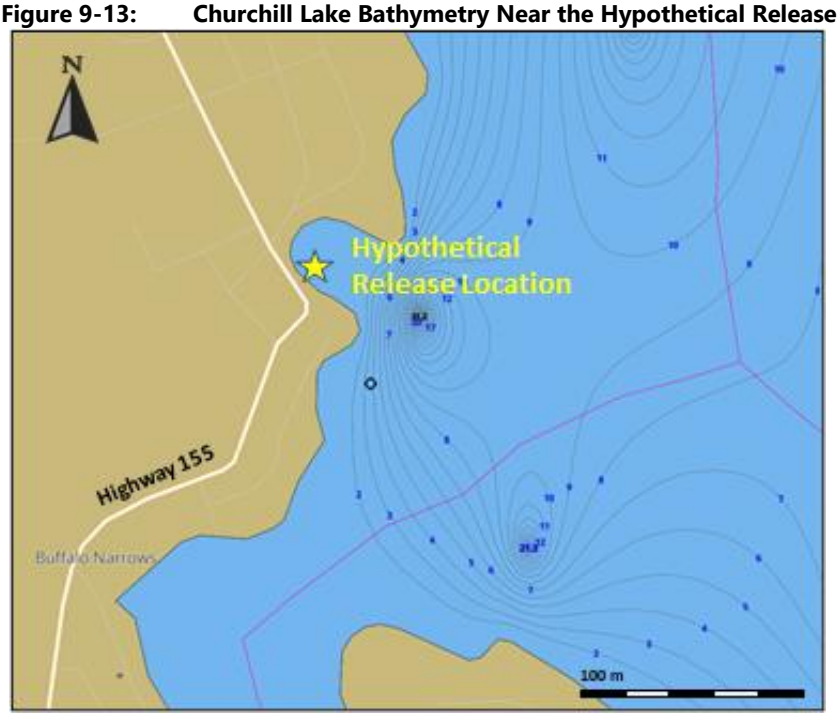
Figure 9-11: Churchill Lake Location



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

Figure 9-12: Churchill Lake at Highway 155

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



9.1.7.2 Uranium Concentrate Fate and Transport Results

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

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

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

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

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

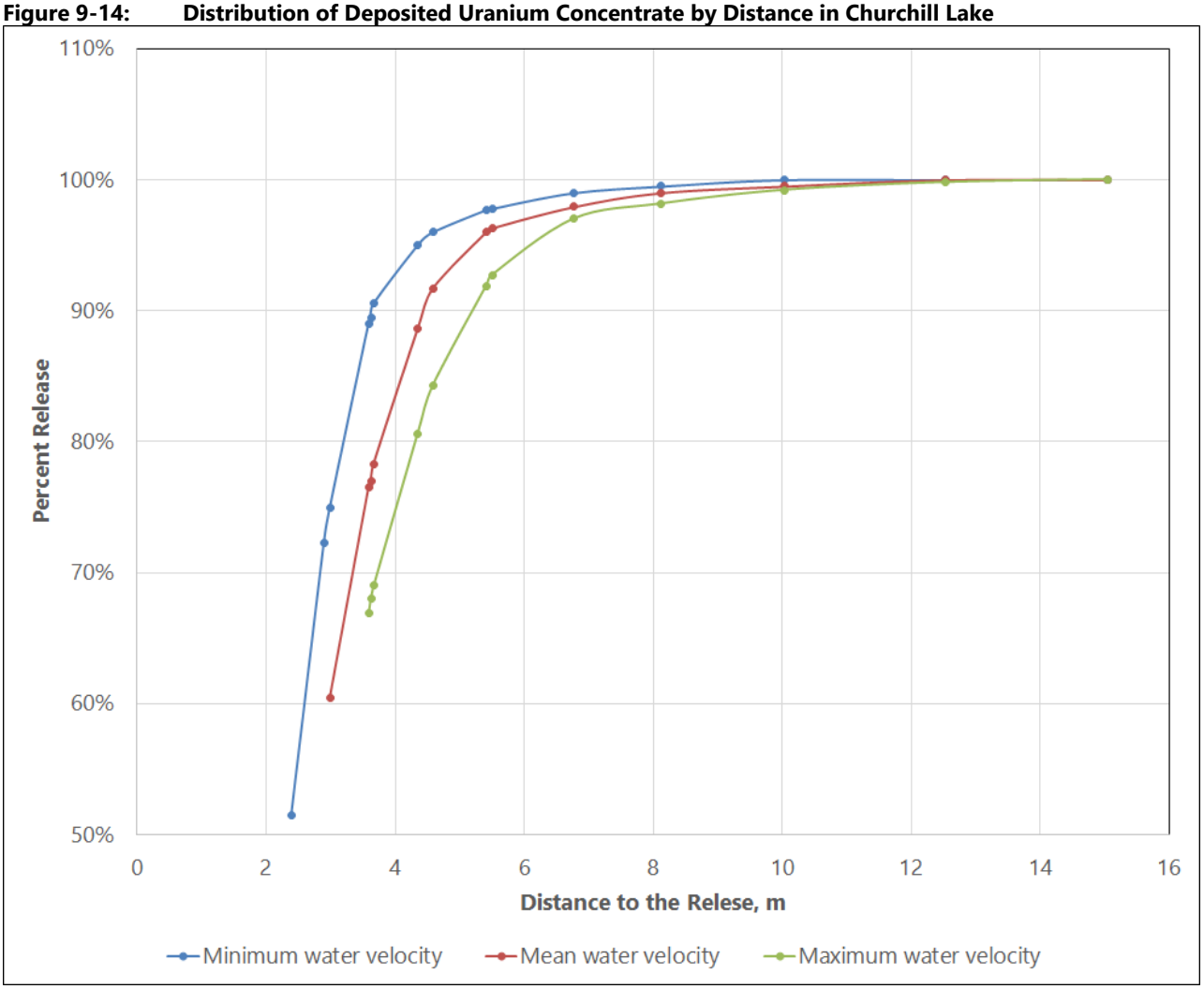


Table 9-7: Estimated Post-Remediation Sediment and Porewater Quality in Churchill Lake

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

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

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

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

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

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

9.1.7.3 Hydrocarbon Fate and Transport Results

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

9.2 Terrestrial Release Scenarios

9.2.1 Uranium Concentrate Fate and Transport Results

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

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

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

9.2.2 Hydrocarbon Fate and Transport Results

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

- the slope of the ground;

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

9.3 Atmospheric Release Scenarios

9.3.1 Assessment Methods

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

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

Two atmospheric release scenarios were assessed:

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

9.3.2 Release Characterization

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

Source term = MAR × DR × ARF × RF × LPF

Where:

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

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

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

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

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

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

9.3.2.1 Truck Accident with Fire

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

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

The source term is calculated as follows:

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

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

9.3.2.2 Truck Accident without Fire

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

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

Table 9-9: Airborne Release Fractions

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

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

The source term is calculated as follows:

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

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

9.3.2.3 Smoke

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

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

9.3.3 Fate and Transport of Atmospheric Releases

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

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

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

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

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

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

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

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

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

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

10.0 RISK CHARACTERIZATION

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

10.1 Aquatic Release Scenarios

10.1.1 Risk Characterization for Aquatic Receptors

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

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

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

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

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

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

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

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

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

10.1.2 Release of Uranium Concentrate

10.1.2.1 Release to the Clearwater River

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

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

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

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

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

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

10.1.2.2 Release to the Canoe River

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

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

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

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

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

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

10.1.2.3 Release to the Beaver River

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

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

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

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

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

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

10.1.2.4 Release to Churchill Lake

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

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

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

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

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

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

10.1.2.5 Overall Risk of the Aquatic Release of Uranium Concentrate

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

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

10.1.3 Release of Hydrocarbons

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

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

10.2 Terrestrial Release Scenarios

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

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

10.3 Atmospheric Release Scenarios

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

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

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

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

10.4 Vehicle-Human Interactions

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

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

10.5 Vehicle-Wildlife Interactions

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

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

11.0 SUMMARY OF KEY RESULTS

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

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

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

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

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

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

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STUDY LIMITATIONS

This report has been prepared by Ecometrix Incorporated (Ecometrix) and includes environmental conclusions and recommendations. In preparing the report, Ecometrix relied in good faith on data, information collected, and modelling results by others and made available to Ecometrix. Ecometrix did not independently confirm such information, unless specifically stated, and does not accept responsibility for any deficiencies, inaccuracies or misstatements in the work of others as provided, nor for conditions or issues outside of the scope of work.

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Appendix A Water Features

Water Feature No 1 – Unnamed Creek

Water Feature No 2 – Unnamed Creek

Water Feature No 3 – Unnamed Creek

Water Feature No 4 – Unnamed Creek

Water Feature No 5 – Unnamed Creek

Water Feature No 6 – Unnamed Creek

Water Feature No 7 – Unnamed Creek

Water Feature No 8 – Unnamed Creek

Water Feature No 9 – Clearwater River

Water Feature No 10 – Unnamed Creek

Water Feature No 11 – Unnamed Creek

Water Feature No 12 – Unnamed Creek

Water Feature No 13 – Unnamed Creek

Water Feature No 14 – Unnamed Creek

Water Feature No 15 – Bear Creek

Water Feature No 16 – Unnamed Creek

Water Feature No 17 – Unnamed Creek

Water Feature No 18 – Churchill Lake

Water Feature No 19 – Kisis Channel & Bridge

Water Feature No 20 – Unnamed Creek

Water Feature No 21 – Unnamed Creek

Water Feature No 22 – Unnamed Creek

Water Feature No 23 – Unnamed Creek

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

Water Feature No 25 – Unnamed Creek

Water Feature No 26 – Canoe River

Water Feature No 27 – Unnamed Creek

Water Feature No 28 – Unnamed Creek

Water Feature No 29 – Unnamed Creek

Water Feature No 30 – Waterhen River

Water Feature No 31 – Beaver River

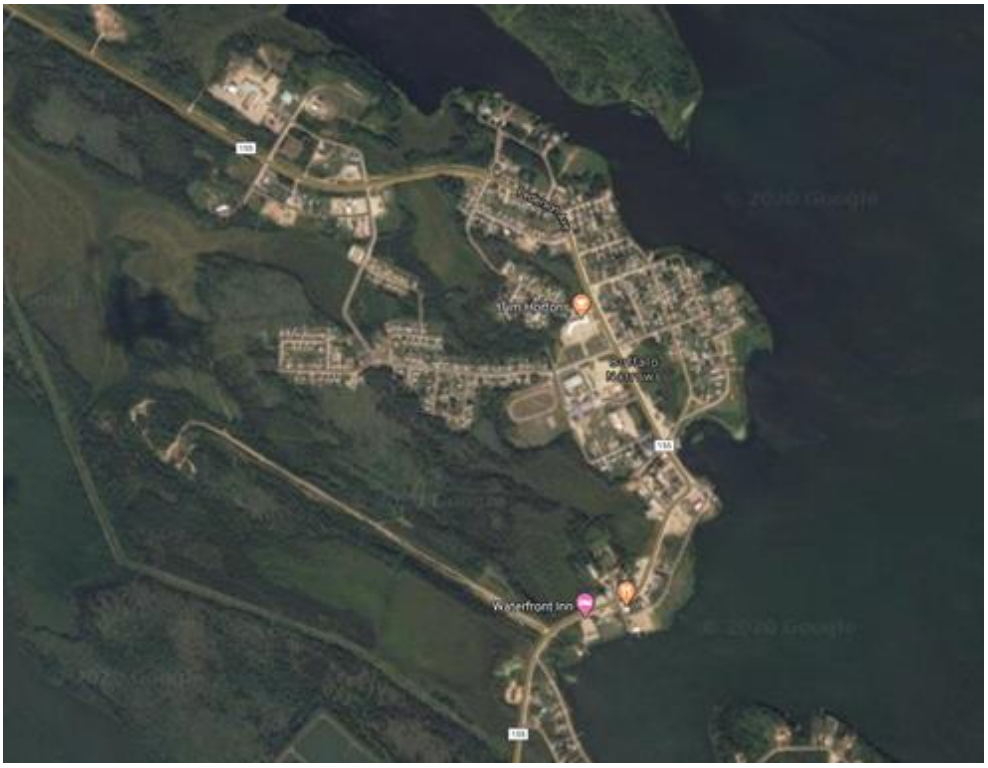
Water Feature No 32 – Cowan River

Water Feature No 33 – Unnamed Creek

Appendix B Communities

Population Centre No 1 – La Loche

Population Centre No 2 – Bear Creek



Population Centre No 3 – Buffalo Narrows

Population Centre No 4 – Beauval, English River

Population Centre No 5 – Green Lake

Appendix C Intersections

Intersection No 1 – Access road - Highway 955 Intersection

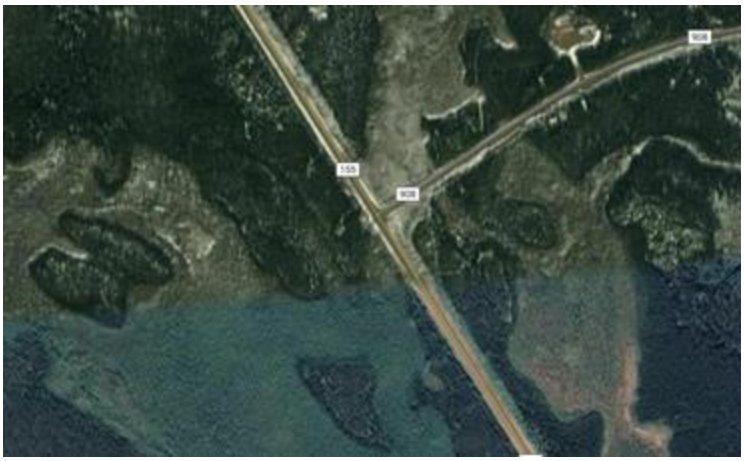
Intersection No 2 – Highway 955 - 155 Intersection

Intersection No 3 – Highway 909 - 155 Intersection

Intersection No 4 – Highway 155 Sharp Turn

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

Intersection No 6 – Highway 925 - 155 Intersection



Intersection No 7 – Highway 908 - 155 Intersection

Intersection No 8 – Highway 965 - 155 Intersection

Intersection No 9 – Highway 165 - 155 Intersection

Intersection No 10 – Highway 55 - 155 Intersection

Appendix D Descriptions of Methods and Sample Calculations

Sample Fate and Transport Calculations:

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

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

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

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

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

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

icle Sizes and Settling Velocities (m/s)

For a laminar flow

Stoke's law

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

Calcined

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

For a turbulent flow

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

Calcined

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

Clearwater River

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

Distance from spill before settling, m:

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

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

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

Distance from spill before settling, m:

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

Area Impacted:

Lateral Dispersion Coefficient m2/s

$$E_v = \phi d u^* \qquad u_* = \sqrt{gdS}$$

d	= Depth (hydraulic radius), [m]		
u^*	= Shear Velocity, [m/sec]		
ϕ	= 0.23 (long, wide lab flume)		Elder, 1959
	= 0.17 (straight lab flume)		Sayre (1973), Sayre and Chang (1968)
	= 0.22 – 0.65, most 0.3		Yotsukura and Cobb(1972), Yotsukura and Sayre (1976)
	3.5		MIT for strong meanders
		2	somewhat strong
s	slope	0.001	assumed

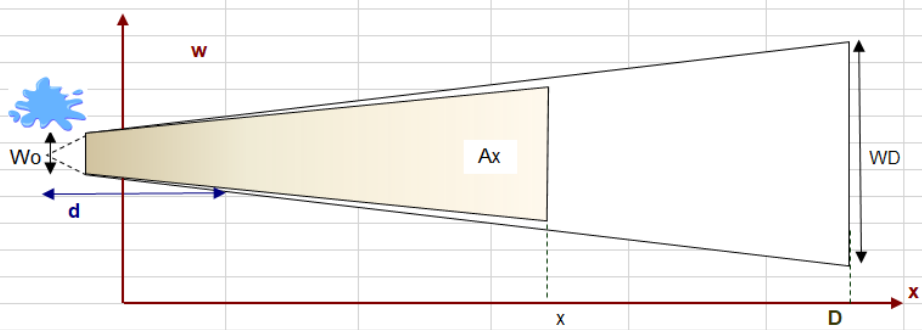
	Minimum Q	Mean Q	Maximum Q
u*	0.076	0.102	0.140
Ev	0.090	0.219	0.558

Lateral mixing time

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

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

L,m	34		
Tmix, s	12847	5271	2072
Distance before reaching shores, m	3560	1312	438



Wo	12.0	m							
D=	3560	1312	438	m					
WD	80	m							
WD/ Wo = (D+d) /d									
d= Wo * D/ (WD-Wo)									
WD/ Wx= (D+d)/(x+d)									
Wx=WD*(x+d)/ (D+d)									
Wx= x / D * (WD-Wo) + Wo									
Ax = (Wx +Wo) * x /2									
Assumptions for calculation of concentrations:									
Depth that yellowcake will mix in:			0.05	m	assumed				
Mass of yellowcake:			5625	kg					
Volume of yellowcake:			2.744	m3					
Density of yellowcake			2,050,000	g/m3					
Fraction of yellowcake released:			1						
Amount of yellowcake released:			5625	kg					
			5625000	g					
Assumed clean-up efficiency:									
		distance, m	E	1-E					
		15	0.95	0.05					
		15.1	0	1					
Concentration of each element in sediment after the spill:									
Csp = Fyel * Cyel + Fsed * Cbg									
Cbg: background concentration									
Cyel: concentration in yellowcake									
Fyel= Vyel * Fs * (1-E) / Vt * (1-p)									
Fs = particle fraction settling in the area									
E= removal efficiency									
Vt = At * depth									
At: impacted area									
p: porosity of sediment			0.70						
density of sediment		g/m3	1,300,000	particles assumed clay (ro = 2000 kg/m3)					
Fsed= 1- Fyel									
∴									
Cf = Yellow cake quantity / (Sediment + yelllowcake)									
Cf = [(Vyel* Fs * (1-E) * ρyel * Cyel)/ (Vt *ρsed* (1-p) +Vyel* Fs * (1-E) *ρyel)] + (1-(Vyel* Fs * (1-E)/ (At * depth * (1-p)))) * Cbg									
Concentrations									
Media		U	U-238	Th-234	Pa-234	Pa-234m	U-234	U-235	Th-231
Background (Bq or µg /g)		0	0	0	0	0	0	0	0
Yellowcake (Bq or µg /g)		8.48E+05	10473	10473	168	10473	10473	482	482
Load in yellowcake (Bq or µg)		4.8E+12	5.9E+10	5.9E+10	9.4E+08	5.9E+10	5.9E+10	2.7E+09	2.7E+09

Distribution of yellowcake over sediment

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

Particle size (area)-distance Matrix

Minimum flow

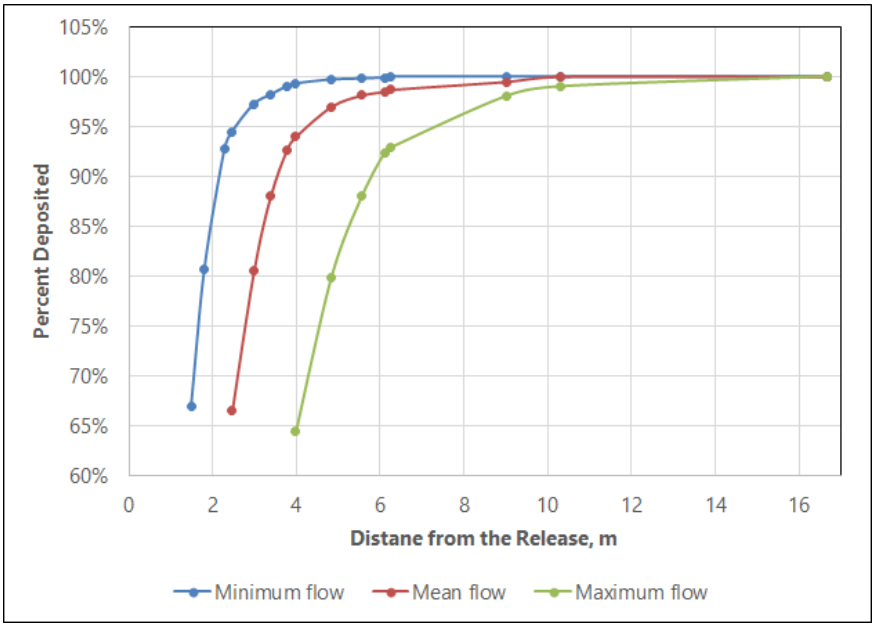
Particle size	*35-55*	*25-35*	*15-25*	*5-15*	*<5*			
Distance/Area	*17.9*	*21.8*	*27.5*	*40.7*	*75.6*			
1.5	1	0.82	0.65	0.44	0.24			
1.8	0	0.18	0.14	0.09	0.05			
2.3	0	0	0.21	0.14	0.08			
3.4	0	0	0	0.32	0.17			
6.3	0	0	0	0	0.46			
Yellowcake quantity								
						Total		
1.5	139.16	1521.16	1687.56	363.67	53.14	3764.70	67%	66.93%
1.8	0.00	324.50	360.00	77.58	11.34	773.41	14%	80.68%
2.3	0.00	0.00	543.67	117.16	17.12	677.95	12%	92.73%
3.4	0.00	0.00	0.00	266.54	38.95	305.49	5%	98.16%
6.3	0.00	0.00	0.00	0.00	103.45	103.45	2%	100.00%
						5625.00		
						5625.		

Mean flow

	35-55	*25-35*	*15-25*	*5-15*	*<5*			
Distance/Area	*29.6*	*36.1*	*45.8*	*68.*	*127.7*			
2.5	1	0.82	0.65	0.44	0.23			
3.0	0	0.18	0.14	0.10	0.05			
3.8	0	0	0.21	0.14	0.08			
5.6	0	0	0	0.33	0.17			
10.3	0	0	0	0	0.47			
Yellowcake quantity								
						Total		
2.5	139.16	1513.66	1675.63	359.57	51.99	3740.01	66%	66.49%
3.0	0.00	332.00	367.52	78.87	11.40	789.79	14%	80.53%
3.8	0.00	0.00	548.08	117.61	17.01	682.70	12%	92.67%
5.6	0.00	0.00	0.00	268.90	38.88	307.78	5%	98.14%
10.3	0.00	0.00	0.00	0.00	104.72	104.72	2%	100.00%
						5625.00		
						5625.		

Max flow

	35-55	*25-35*	*15-25*	*5-15*	*<5*			
Distance/Area	*49.*	*61.2*	*78.4*	*118.6*	*233.5*			
4.0	1	0.80	0.63	0.41	0.21			
4.8	0	0.20	0.16	0.10	0.05			
6.1	0	0	0.22	0.15	0.07			
9.0	0	0	0	0.34	0.17			
16.7	0	0	0	0	0.49			
Yellowcake quantity								
						Total		
4.0	139.16	1478.32	1620.05	340.94	47.05	3625.52	64%	64.45%
4.8	0.00	367.33	402.55	84.72	11.69	866.28	15%	79.85%
6.1	0.00	0.00	568.64	119.67	16.51	704.82	13%	92.38%
9.0	0.00	0.00	0.00	279.62	38.58	318.21	6%	98.04%
16.7	0.00	0.00	0.00	0.00	110.17	110.17	2%	100.00%
						5625.00		



Estimated Sediment Quality

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

Predicted Sediment Quality
Weighted-average

Flow	C, µg/g	
Minimum	11765	*10498*
Average	8259	*8364*
Maximum	5700	*6242*

since clean-up extends to only 15 m, most of yellowcake in high flow (beyond 15 m) is not cleaned-up.

Porewater Quality- Long-term

Weighted- Average Porewater Concentrations

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

Sediment-water partition coefficient

3.5	m3/kg	SENES 2010 (Cigar Lake)

Water Quality

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

Water concentration

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

Exposure and Risk Characterization
Clearwater River

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

Dose Conversion Coefficients							
Dose Conversion Coefficients - Aquatic Receptors							
Unit: mGy/d per Bq/g							
U-238+	Internal	U-238 + Th-234+ 0.046 Th-231 + Pa-234m+ 0.0016 Pa-234 + U-234 + 0.046 U-235					
	External	U-238 + Th-234 + Pa-234m+ U-234 + 0.045 U-235 (beta + gamma only)					
Ra-226+	Internal	Ra-226 + 0.3* (Rn-222 + ...Po-214)					
	External	Ra-226 + 1.0* (Rn-222 + ...Po-214) (beta + gamma only)					
Pb-210+ = Pb-210 + Bi-210 (internal or external)							
Note: U-238+ (Bq) = 12.3 * U (mg) \ (mGy/d)/ (Bq/g) = (mGy/d)/ (mg/kg) / 12.3/1000							
Constituent	Internal -Fish	External -Fish	Internal-Aquatic Plant	External-Aquatic Plant	Internal-Benthos	External-Benthos	
U-238+	0.14	0.006	0.14	0.006	0.14	0.006	(mGy/d)/ (Bq/g)
Uranium	0.00001	4.64E-07	1.15E-05	4.64E-07	1.15E-05	4.64E-07	(mGy/d)/ (mg/kg)
Th-230	0.066	1.95E-05	0.066	1.95E-05	0.066	1.95E-05	(mGy/d)/ (Bq/g)
Ra-226+	0.16	0.024	0.16	0.024	0.16	0.024	(mGy/d)/ (Bq/g)
Pb-210+	0.006	0.002	0.006	0.002	0.006	0.002	(mGy/d)/ (Bq/g)
Po-210	0.075	9.42E-08	0.075	9.42E-08	0.075	9.42E-08	(mGy/d)/ (Bq/g)

Internal Dose Conversion Coefficients- Terrestrial Receptors										
Unit: mGy/d per Bq/g										
Constituent										
U-238+	0.14					Uranium	Th-230	Ra-226+	Pb-210+	Po-210
Uranium	0.000012	converted to mGy/d per mg/kg				0.000012	0.066	0.16	0.006	0.075
Th-230	0.066									
Ra-226+	0.16									
Pb-210+	0.006									
Po-210	0.075									
Ref: Amiro 1997										
Dose Conversion Coefficients- Human Receptors										
Unit: µSv/Bq										
Note: U-238+ (Bq) = 12.3 * U (mg) ∴ µSv/Bq = µSv/mg / 12.3										
	Toddler		Child		Adult					
Constituent	Inhalation	Ingestion	Inhalation	Ingestion	Inhalation	Ingestion				
U-238+	52.5	0.25	35.8	0.185	17.8	0.0995				
Uranium	4.27	.02	2.91	.02	1.45	.01	converted to µSv/mg			
Th-230	35.	0.41	24.	0.31	14.	0.21				
Ra-226+	29.	0.96	19.	0.62	9.5	0.28				
Pb-210+	18.3	3.6	11.	2.2	5.6	0.69				
Po-210	14.	8.8	8.6	4.4	4.3	1.2				

Exposure

Concentration in Ecological Receptors

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

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

Second and Third Trophic Levels:

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

Intake of Metals

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

Absorbed Doses

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

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

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

Equivalent Doses

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

No RBE applied to Pb-210+

Gamma dose rate= 2.88 x 10^-4 x Eγ x nγ x φ xCs x 0.5 µGy/hr

Eγ	photon energy (MeV)
nγ	gamma disintegration proportion
φ	absorbed fraction of energy
Cs	Uranium concentration in sediment (Bq/kg ww)
0.5	to account for the unequal distribution of radionuclides in thesediment

Screening Index

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

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

Intake through Ingestion by Human Receptors

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

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

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

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

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

Rook I Project

Environmental Impact Statement

TSD X: Vibration Effects Analysis Report

VIBRATION EFFECT ANALYSIS TECHNICAL SUPPORT DOCUMENT FOR THE ROOK I PROJECT

Prepared for:

NexGen Energy Ltd.

Prepared by:

WSP Canada Inc.

December 2023

Executive Summary

A vibration analysis was undertaken for the Rook I Project (Project). The analysis evaluated potential vibration effects resulting from explosive blasting anticipated for the proposed Project and explosive blasting anticipated for the Fission Patterson Lake South Property, proposed by Fission Uranium Corp. and located approximately 5.2 km west of the proposed Project footprint.

Vibration was analyzed using two measurement indicators:

- peak particle velocity, which characterizes ground vibration; and
- peak pressure level, which characterizes overpressure in air or water.

Peak particle velocity and peak pressure level were predicted using empirical formulae from engineering handbooks and from regulatory guidance documents.

Vibration levels were predicted at sensitive receptors located within the study area that extends 10 km from the maximum disturbance area for the Project. Sensitive receptors were identified through engagement conducted by NexGen Energy Ltd. (NexGen) with local First Nations and Métis Groups (collectively referred to as Indigenous Groups) and local communities. These receptors correspond to the closest known human presence within the vibration study area and were used to predict the effects of vibration from blasting on fish habitat and people.

The vibration analysis also predicted effects from blasting at a conceptual receptor corresponding to the point within Patterson Lake nearest the anticipated location of Project blasting. This conceptual receptor was included to capture maximum vibration levels for comparison with Fisheries and Oceans Canada (DFO) thresholds.

Vibration effects were analyzed using thresholds from:

- Environment and Climate Change Canada (ECCC), which are primarily intended to protect against minor cosmetic damage to structures.
- Fisheries and Oceans Canada, which are intended to protect general fish habitat and fish spawning habitat.
- Australian and New Zealand Environment Council (ANZEC), which are intended to protect against human annoyance.

The vibration analysis concluded:

- Vibration from blasting activities would not result in human annoyance or cosmetic damage to structures at any of the sensitive receptors identified through NexGen's engagement with Indigenous Groups and local communities.
- Vibration from blasting activities would not result in adverse effects to general fish habitat or fish spawning habitat.

Abbreviations and Units of Measure

Abbreviation	Definition
ANZEC	Australian and New Zealand Environment Council
DFO	Fisheries and Oceans Canada
ECCC	Environment and Climate Change Canada
LSA	local study area
NexGen	NexGen Energy Ltd.
PPL	peak pressure level
PPV	peak particle velocity
Project	Rook I Project
RFD	reasonably foreseeable development
RSA	regional study area
UGTMF	underground tailings management facility

Unit	Definition
cm/s	centimetres per second
dBA	A-weighted decibel
dBL	linear decibel
kg	kilogram
km	kilometre
kPa	kilopascal
mm/s	millimetres per second

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1.0 INTRODUCTION

NexGen Energy Ltd. (NexGen) is proposing to develop a new uranium mining and milling operation in northwestern Saskatchewan, called the Rook I Project (Project). The Project would be located approximately 40 km east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon (Figure 1-1). The Project would reside within Treaty 8 territory and the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake, along the upper Clearwater River system. Access to the Project would be from an existing road off Highway 955 (Figure 1-2), with on-site worker accommodation serviced by fly-in/fly-out access.

The Project would include the following key facilities to support the extraction and processing of uranium from the Arrow deposit for transportation off site (Figure 1-3):

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

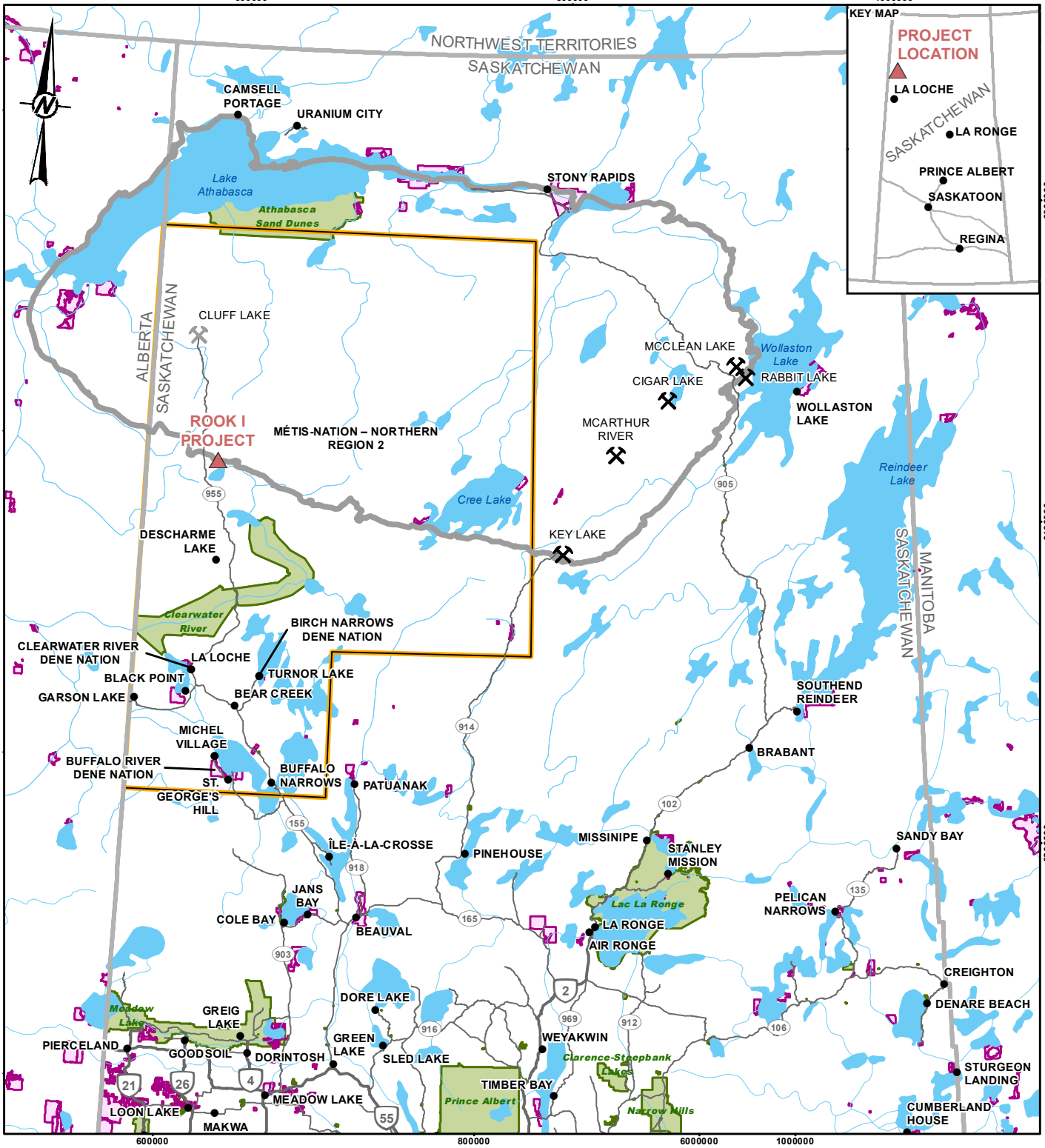
This technical support document to the Environmental Impact Statement (EIS) analyzes potential vibration effects from the proposed Project. Vibration from the Project could influence aquatic and terrestrial ecosystems, as well as the people that use natural resources or ecosystem services (e.g., surface water, fish, plants, wildlife). For the proposed Project, the only potential source of vibration that could create adverse effects to the social and biophysical environment would be explosive blasting. Explosive blasting would be required during Construction and Operations. Accordingly, this technical support document to the EIS analyzes potential vibration effects from Project blasting. Vibration from Project blasting could influence aquatic and terrestrial ecosystems, as well as the people that use natural resources or ecosystem services (e.g., surface water, fish, plants, and wildlife). The

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

vibration analysis provides information that is used to support the assessments of biophysical, cultural, and socio-economic valued components.

Vibration specifically supports the effects assessments for the following components:

- fish and fish habitat (EIS Section 11);
- wildlife and wildlife habitat (EIS Section 14);
- cultural and heritage resources and Indigenous land and resource use (EIS Section 16); and
- other land and resource use (EIS Section 17).



LEGEND

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

REFERENCE(S)

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

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LOCATION OF THE ROOK I PROJECT

CONSULTANT

wsp

PROJECT		20144150	PHASE	3314 - 6
DESIGN	JMC	2023-10-25	SCALE AS SHOWN	REV. 0
GIS	NO	2023-10-25	**FIGURE 1-1**	
CHECK	JMC	2023-10-25		
REVIEW	MM	2023-10-25		

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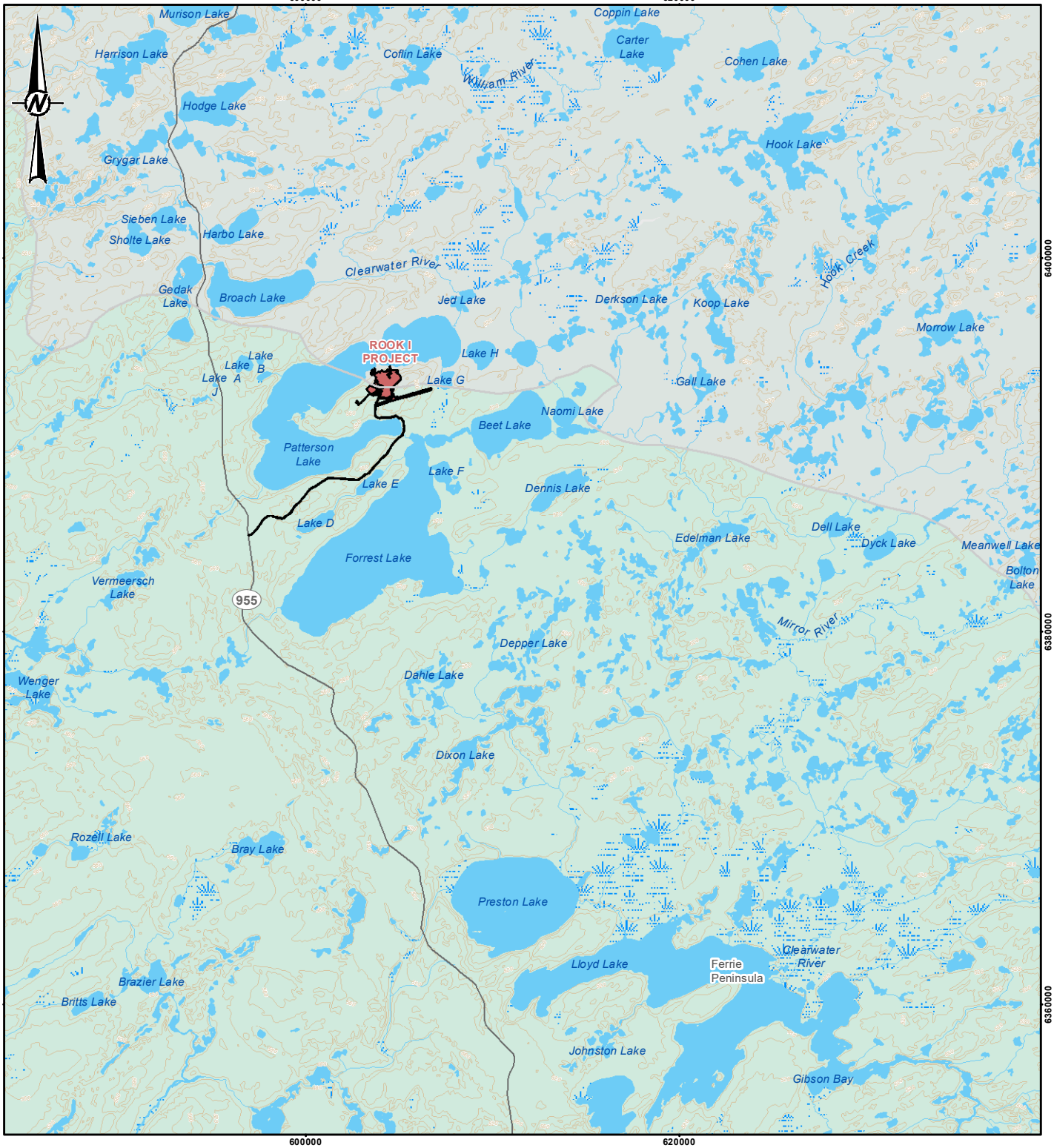

LEGEND

- ELEVATION CONTOUR (20 m INTERVAL)
- SECONDARY HIGHWAY
- WATERCOURSE
- ATHABASCA BASIN
- WATERBODY
- WETLAND
- WOODED AREA
- PROPOSED PROJECT FOOTPRINT

0 5 10
1:300,000 KILOMETRES

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

PROJECT
NexGen Energy Ltd.
ROOK I PROJECT

TITLE
REGIONAL AREA OF THE ROOK I PROJECT

CONSULTANT
wsp

PROJECT		20144150	PHASE	3314 - 6
DESIGN	JMC	2023-10-25	SCALE AS SHOWN	REV. 0
GIS	NO	2023-10-25	**FIGURE 1-2**	
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REVIEW	MM	2023-10-25		

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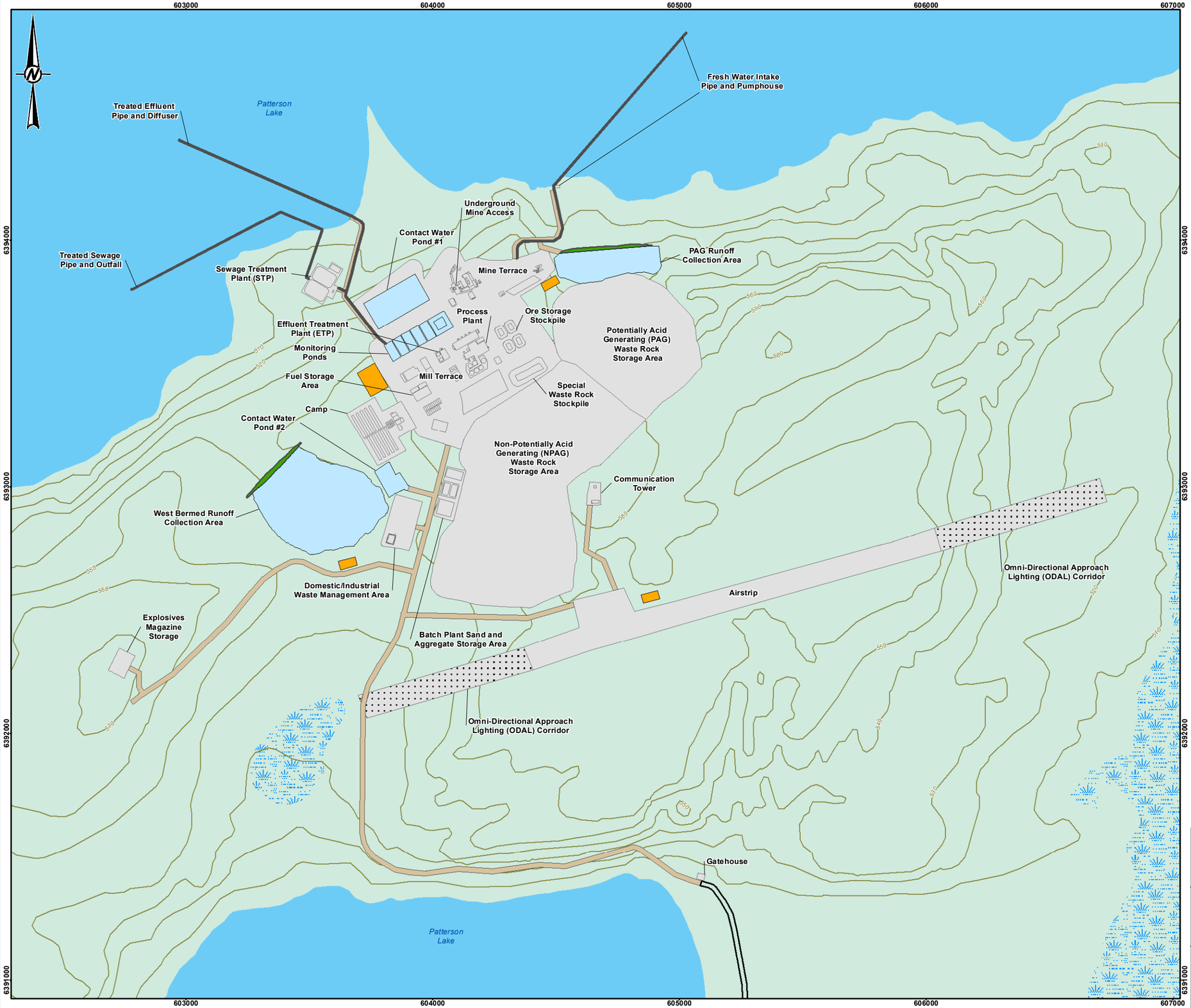

LEGEND

- ELEVATION CONTOUR (10 m INTERVAL)
- WATERBODY
- WETLAND
- WOODED AREA
- INTAKE OR DISCHARGE PIPE
- ACCESS ROAD
- CONTACT WATER CONTAINMENT BERM
- OMNI-DIRECTIONAL APPROACH LIGHTING (ODAL) CORRIDOR
- PROJECT INFRASTRUCTURE
- SITE ROAD
- TOPSOIL STORAGE AREA
- WATER MANAGEMENT POND

0 0.5 1
1:15,500 KILOMETRES

REFERENCE(S)

1. PROJECT FEATURES OBTAINED FROM NEXGEN, APRIL 6, 2021 AND UPDATED JUNE 8, 2021 .
2. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LAYOUT OF INFRASTRUCTURE AND FACILITIES FOR THE ROOK I PROJECT

CONSULTANT

wsp

PROJECT		20144150	PHASE	3314 - 6
DESIGN	JV	2020-03-13	SCALE AS SHOWN	REV. 0
GIS	NO	2023-10-25		
CHECK	JMC	2023-10-25	**FIGURE 1-3**	
REVIEW	MM	2023-10-25		

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25mm

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2.0 METHODS

This subsection of the technical support document describes the methods used to analyze potential vibration effects from Project blasting. It describes the measurement indicators used to characterize vibration levels, the regulatory thresholds used to characterize vibration effects, the study area and receptors used in the analysis, and the methods used to predict vibration levels from blasting activities.

2.1 Measurement Indicators

Vibration from explosive blasting was analyzed using two measurement indicators:

- **Peak particle velocity (PPV):** characterizes ground vibration (i.e., the physical shaking of the ground as a result of an explosive detonation) and is expressed in millimetres per second (mm/s).
- **Peak pressure level (PPL):** characterizes overpressure (i.e., the movement of air or water as a result of an explosive detonation) and is expressed in linear decibels (dBL) in air or kilopascals (kPa) in water.

People experience overpressure differently than audible sound because most of the energy associated with explosive overpressure occurs at frequencies too low to be perceived by the human ear or auditory system. Therefore, it is not appropriate to compare audible noise levels, expressed in A-weighted decibels (dBA), to PPL values, expressed in linear decibels. For example, an audible noise level of 115 dBA is extremely loud, while a PPL of 115 dBL is barely perceptible and inaudible.

Vibration from explosives can cause disturbance to the people that use natural resources or ecosystem services. Vibration from explosives can also cause disturbance, injury, or death to fish. Wildlife can perceive ground vibration; therefore, vibration can affect wildlife habitat use around the Project.

2.1.1 Regulatory Guidance and Thresholds

Vibration from Project blasting was analyzed using thresholds from:

- Environment and Climate Change Canada (ECCC) *Environmental Code of Practice for Metal Mines* (Environment Canada 2009);
- Fisheries and Oceans Canada (DFO) *Guidelines for the Use of Explosives in or near Canadian Fisheries Waters* (Wright and Hopky 1998) and associated recommendations (Cott and Hanna 2005); and
- Australian and New Zealand Environment Council (ANZEC) *Technical Basis for Guidelines to Minimise Annoyance Due to Blasting Overpressure and Ground Vibration* (ANZEC 1990).

The PPV and PPL vibration thresholds from ECCC, DFO, and ANZEC are presented in Table 2-1.

Table 2-1: Vibration Thresholds

Measurement Endpoint	ECCC Cosmetic Damage Threshold	DFO Fish Protection Threshold	ANZEC Human Annoyance Threshold
ground vibration; PPV	12.5 mm/s	13 mm/s	5 mm/s
overpressure; PPL	128 dBL	50 kPa	115 dBL

ECCC = Environment and Climate Change Canada; DFO = Fisheries and Oceans Canada; ANZEC = Australian and New Zealand Environment Council; PPV = peak particle velocity; PPL = peak pressure level; dBL = linear decibel; kPa = kilopascal.

Vibration thresholds from Environment Canada (2009) are primarily intended to protect against minor cosmetic damage to structures and are applicable at receptors located “beyond the boundaries of the mine property”. Vibration thresholds from DFO are intended to protect general fish habitat and fish spawning habitat. The DFO PPV threshold applies “in a spawning bed during the period of egg incubation” (Wright and Hopky 1998), and the DFO PPL threshold applies to general fish habitat. Vibration thresholds from ANZEC are intended to protect against human annoyance and are applicable at “sensitive sites” such as “residences” (ANZEC 1990). There are no regulatory standards or accepted thresholds for analyzing vibration effects on terrestrial wildlife.

2.2 Study Area

A maximum disturbance area of 981 ha was used for the assessment of terrain and soils, vegetation, and wildlife and wildlife habitat to address uncertainty in the final design of the Project. The maximum disturbance area represents the smallest scale of assessment and an area where the potential direct effects of the anticipated Project on soils, vegetation, and wildlife can be assessed accurately and precisely. The spatial boundary of the maximum disturbance area was delineated by applying buffers to the outer edges of the anticipated Project infrastructure. The spatial boundary was also constrained to the shoreline of Patterson Lake (Figure 2-1).

The study area for the vibration analysis was defined as a 10 km buffer surrounding the maximum disturbance area for the Project (Figure 2-1). This study area is large enough to characterize any vibration effects from the Project, as well as any potential cumulative effects from the Patterson Lake South Property, which is a reasonably foreseeable development (RFD) proposed by Fission Uranium Corp. (Fission 2019, 2021).

Receptors within the vibration study area were primarily identified through NexGen’s engagement with local First Nations and Métis Groups (collectively referred to as Indigenous Groups) and local communities. A review was completed of the comments provided on the Rook I Project Description by the Clearwater River Dene Nation (CRDN 2019), Métis Nation – Saskatchewan (MN-S 2019), and Ya’thi Néné Land and Resources (YNLRO 2019). Indigenous Knowledge and Traditional Land Use Studies completed by the Clearwater River Dene Nation (Technical Support Document [TSD] V.1: CRDN; TSD V.2: CRDN), Métis Nation – Saskatchewan (TSD IV: MN-S), Birch Narrows Dene Nation (TSD II: BNDN), Buffalo River Dene Nation (TSD III: BRDN), and Ya’thi Néné Land and Resources (TSD VI: YNLR) were also reviewed. Receptors identified through this process are shown in Figure 2-1. These receptors correspond to the closest known human presence within the vibration study area. These same receptors were used in the assessment of potential noise effects (EIS Section 7.3, Noise) and in the analysis of potential light effects (TSD XI, Light Effects Analysis Report).

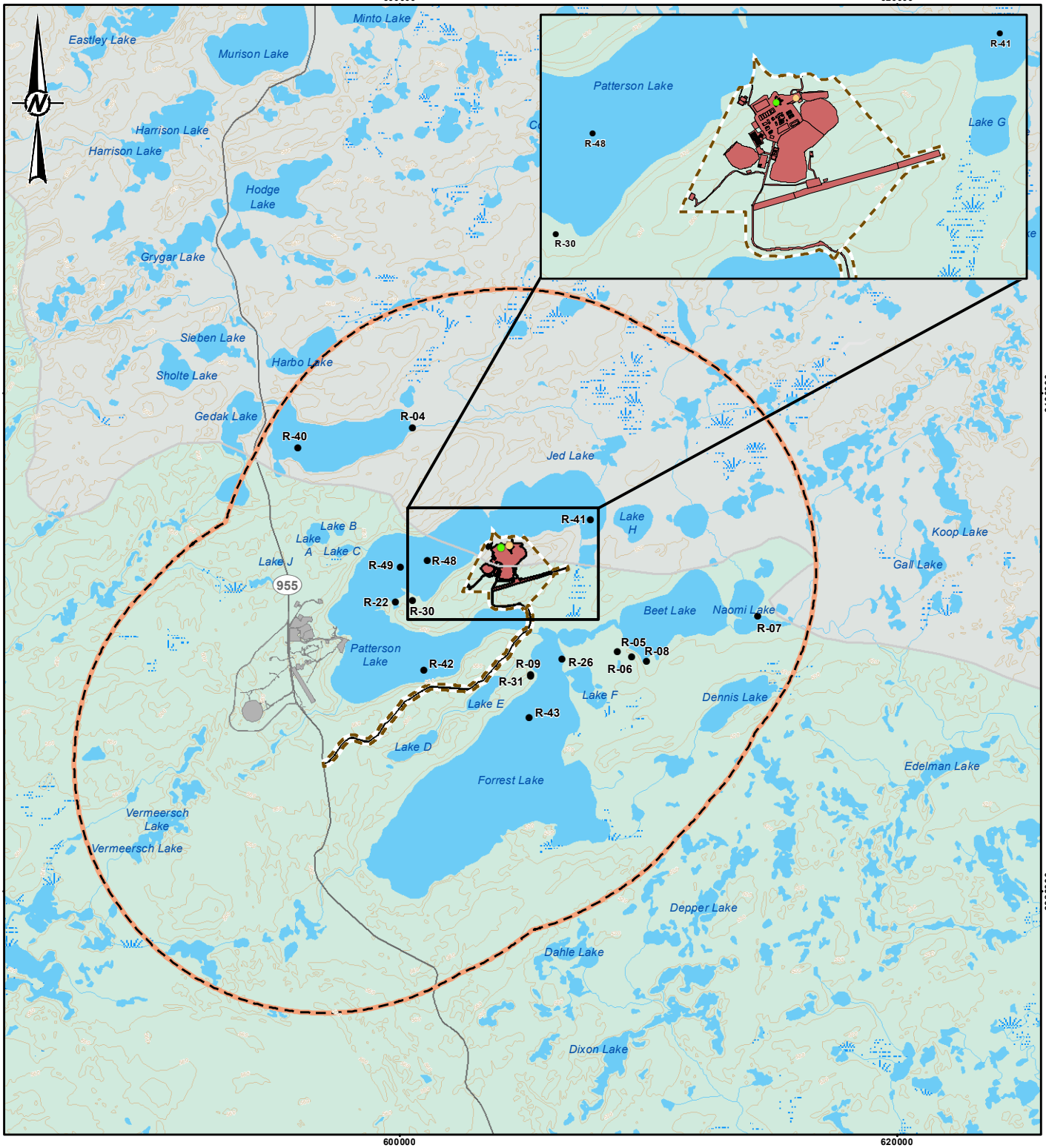
One conceptual receptor was also considered in the vibration analysis. The conceptual receptor corresponds to the point within Patterson Lake nearest the anticipated location of Project blasting (R-Fish). This conceptual receptor was included in the analysis to capture maximum vibration levels for comparison with DFO thresholds.

The vibration thresholds relevant to different terrestrial and aquatic receptors are outlined in the list below and are presented in Table 2-2 along with the receptors considered in the vibration analysis.

- **Terrestrial receptors:** Vibration was analyzed using PPV and PPL thresholds from the ECCC and ANZEC documents. Thresholds from DFO are not applicable for terrestrial receptors.
- **Human receptors at angling locations:** Vibration was analyzed using PPL thresholds from ECCC and ANZEC documents to characterize effects on human users over water. Vibration was also analyzed using

PPV and PPL thresholds from DFO to characterize effects on fish under water. The PPV thresholds from the ECCC and ANZEC are intended to characterize ground vibration and, therefore, are not relevant at these aquatic receptors.

- **Aquatic receptor corresponding to the shortest distance between Patterson Lake and the anticipated location of Project blasting:** Vibration was analyzed using PPV and PPL thresholds from DFO. Because this receptor is assumed to be under water, thresholds from ECCC and ANZEC are not relevant at this receptor.



LEGEND

- ELEVATION CONTOUR (20 m INTERVAL)
- SECONDARY HIGHWAY
- WATERCOURSE
- ATHABASCA BASIN
- WATERBODY
- WETLAND
- WOODED AREA
- PROPOSED PROJECT FOOTPRINT
- MAXIMUM DISTURBANCE AREA
- FISSION PATTERSON LAKE SOUTH PROPERTY FOOTPRINT
- PROJECT EXHAUST SHAFT
- PROJECT PRODUCTION SHAFT
- VIBRATION RECEPTORS
- VIBRATION STUDY AREA

0 5 10
1:225,000 KILOMETRES

REFERENCE(S)

1. PROJECT FEATURES OBTAINED FROM NEXGEN, APRIL 6, 2021
2. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
3. FISSION (FISSION URANIUM CORP.) OBTAINED FROM 2019 TECHNICAL REPORT ON THE PRE-FEASIBILITY STUDY OF THE PATTERSON LAKE SOUTH PROPERTY USING UNDERGROUND MINING METHODS.

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

VIBRATION STUDY AREA AND RECEPTORS

CON

wsp

PROJECT		20144150	PHASE	3102 - 3
DESIGN	VY	2023-10-25	SCALE AS SHOWN	REV. 0
GIS	NO	2023-10-25	**FIGURE 2-1**	
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REVIEW	AF	2023-10-25		

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25mm

Table 2-2: Vibration Receptors and Relevant Thresholds

Receptor Identification Code[a]	Universal Transverse Mercator Coordinates (Zone 12)		Receptor Description	Relevant Thresholds
	Easting (m)	Northing (m)		
R-04	600523	6398606	Cabin[b]	Terrestrial receptor: PPV and PPL thresholds from ECCC and ANZEC.
R-05	608757	6389632	Lodge[b]	Terrestrial receptor: PPV and PPL thresholds from ECCC and ANZEC.
R-06	609329	6389420	Cabin (old cabin)[b]	Terrestrial receptor: PPV and PPL thresholds from ECCC and ANZEC.
R-07	614387	6391050	Cabin[b]	Terrestrial receptor: PPV and PPL thresholds from ECCC and ANZEC.
R-08	609942	6389235	Camp (tourist camp)[b]	Terrestrial receptor: PPV and PPL thresholds from ECCC and ANZEC.
R-09	605286	6388706	Camp (tourist camp)[b]	Terrestrial receptor: PPV and PPL thresholds from ECCC and ANZEC.
R-22	599851	6391630	Fishing (nets)[b]	Human receptor at angling location: PPL thresholds from ECCC and AZEC; PPV and PPL thresholds from DFO.
R-26	606543	6389350	Plane crash[b]	Terrestrial receptor: PPV and PPL thresholds from ECCC and ANZEC.
R-30	600546	6391678	Historical camp[b]	Terrestrial receptor: PPV and PPL thresholds from ECCC and ANZEC.
R-31	605282	6388662	Camp (rough camp)[b]	Terrestrial receptor: PPV and PPL thresholds from ECCC and ANZEC.
R-40	595924	6397789	Fishing[b]	Human receptor at angling location: PPL thresholds from ECCC and ANZEC; PPV and PPL thresholds from DFO.
R-41	607681	6394910	Fishing[b]	Human receptor at angling location: PPL thresholds from ECCC and ANZEC; PPV and PPL thresholds from DFO.
R-42	600992	6388870	Fishing[b]	Human receptor at angling location: PPL thresholds from ECCC and ANZEC; PPV and PPL thresholds from DFO.
R-43	605233	6386971	Fishing[b]	Human receptor at angling location: PPL thresholds from ECCC and ANZEC; PPV and PPL thresholds from DFO.
R-48	601140	6393297	Fishing[b]	Human receptor at angling location: PPL thresholds from ECCC and ANZEC; PPV and PPL thresholds from DFO.
R-49	600042	6393020	Fishing[b]	Human receptor at angling location: PPL thresholds from ECCC and ANZEC; PPV and PPL thresholds from DFO.
R-Fish	n/a[c]	n/a[c]	Point within Patterson Lake nearest the anticipated location of Project blasting; minimum separation distance 345 m.	Aquatic receptor without human presence: PPV and PPL thresholds from DFO.

a) This table lists all the receptors within the vibration study area that were identified during community engagement activities. Receptor numbering is non-continuous because some of the locations identified during community engagement activities were beyond the vibration study area.

b) Receptor description provided during community engagement activities.

c) This is a conceptual receptor that represents the minimum separation between Patterson Lake and anticipated Project blasting (i.e., 345 m).

PPL = peak pressure level; PPV = peak particle velocity; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council; DFO = Fisheries and Oceans Canada.

2.3 Temporal Boundaries

The temporal scope of the vibration analysis focuses on the 43-year period from initial Construction to the end of Decommissioning and Reclamation (i.e., Closure) as defined by the following Project phases (EIS Section 6.4.2, Temporal Boundaries):

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

The temporal boundaries applied to cumulative effects include the period during which explosive blasting at the Patterson Lake South Property may overlap Project blasting.

Explosive blasting is anticipated during Construction and Operations of the Project, but not during Closure. As such, quantitative vibration modelling focused on Construction and Operations to capture maximum predicted PPV and PPL from Project-related activities.

2.4 Prediction Methods

Empirical formulae from a blast vibration reference handbook (Richards and Moore 1995) were used to predict vibration levels that may cause cosmetic damage to buildings and/or human annoyance. The empirical formula used to predict PPV (expressed in mm/s) is presented in Equation 1, where D is the distance between the blast location and the receptor (expressed in metres), Q is the instantaneous charge mass (expressed in kilograms), k is a unitless "site constant", and e is a unitless "site exponent". The site constant (k) is used to represent general site conditions and the site exponent (e) is used to represent the blasting substrate. Assumed values of constants are described in the following subsection. The empirical formula used to predict PPL (expressed in dBL) is presented in Equation 2.

$$PPV = k\left(\frac{D}{\sqrt{Q}}\right)^{-e} \quad \textbf{(Equation 1)}$$

$$PPL = 20\log_{10}\left(3300 \times \left(\frac{D}{\sqrt[3]{Q}}\right)^{-1.2} / (20 \times 10^{-6})\right) \quad \textbf{(Equation 2)}$$

Empirical formulae presented in the DFO guideline document (Wright and Hopky 1998) were used to predict vibration levels for fish habitat. The empirical formula used to predict PPV (expressed in mm/s) is presented in Equation 3. The empirical formula used to predict PPL (expressed in kPa) is presented in Equation 4, where PPV is obtained from Equation 3, d_W is the density of water (expressed in g/cm^3), d_R is the density of the blasting substrate (expressed in g/cm^3), c_W is the speed of sound in water (expressed in cm/s), and c_R is the speed of sound in the blasting substrate (expressed in cm/s).

$$PPV = 1000 \times 10^{\left(-1.6 \times \log_{10}\left(D/\sqrt{Q}\right)\right)} \quad \textbf{(Equation 3)}$$

$$PPL = \frac{PPV \times d_W c_W d_R c_R}{10^5 \times (d_R c_R + d_W d_R)} \quad \textbf{(Equation 4)}$$

2.4.1 Inputs and Assumptions

For active facilities, site-specific values for the site constant (k), site exponent (e), substrate density (d_R), and substrate sound speed (c_R) can be determined based on a statistical analysis of multiple blasts. Because Project blasting has not yet occurred, the vibration analysis for the Project used conservative estimates for the input constants (i.e., values that would tend to overestimate vibration effects from Project blasting). In particular, the vibration analysis assumed:

- site constant (k) of 5,000, which is representative of heavily confined charges (Richards and Moore 1995);
- site exponent (e) of 2.1, which is representative of blasting in granite (Richards and Moore 1995);
- substrate density (d_R) of 2.64 g/cm^3, which is representative of blasting in rock (Wright and Hopky 1998); and
- a substrate sound speed (c_R) of 457,200 cm/s, which is representative of blasting in rock (Wright and Hopky 1998).

Because Project blasting requirements would evolve throughout Construction and Operations, the vibration analysis focused on the maximum instantaneous charge masses for three different types of stope blasting:

- transverse production stopes, in which long hole stopes are extracted perpendicular to the strike of the ore body;
- longitudinal production stopes, in which long hole stopes are extracted parallel to the strike of the ore body; and
- development of the UGTMF chambers.

Focusing on the maximum instantaneous charge masses anticipated for the Project is a conservative approach to analyzing vibration effects (i.e., effects are likely overestimated).

Vibration levels were also predicted for blasting associated with the Patterson Lake South Property (Fission 2019). Blasting data for the Patterson Lake South Property were not publicly available at the time this vibration analysis was completed; therefore, blasting at the Patterson Lake South Property was assumed to be similar to anticipated blasting associated with the Project. In particular, the vibration analysis assumed blasting at the Patterson Lake South Property would use the same instantaneous charge masses anticipated for the Project and applied the same conservative estimates for site-specific constants (i.e., k, e, d_R, and c_R) in the empirical formulae.

Publicly available information about the Fission Patterson Lake South Property indicates that tailings would be stored above ground and there would be no underground tailings management facility associated with this development (Fission 2019). However, the Patterson Lake South Property would require underground blasting below Patterson Lake; vibration levels from this underground blasting activity were predicted using the same instantaneous charge mass as UGTMF blasting for the Project.

Table 2-3 presents the instantaneous charge masses used to predict vibration levels for Project blasting and for blasting at the Patterson Lake South Property.

Table 2-3: Charge Masses for Vibration Analysis

Project Blasting		Blasting at Patterson Lake South Property	
Type of Blasting	Maximum Instantaneous Charge Mass (kg)	Type of Blasting	Maximum Instantaneous Charge Mass[c] (kg)
Transverse	282.7[a]	Transverse	282.7
Longitudinal	282.7[a]	Longitudinal	282.7
UGTMF	519.0[b]	Underground	519.0

a) Espenberg 2021.
b) Halliday 2021.
c) Blasting at the Patterson Lake South Property was assumed to be similar to anticipated blasting associated with the Project.
UGTMF = underground tailings management facility.

For each receptor identified in Table 2-2, PPV and PPL vibration levels from the Project and from the Patterson Lake South Property were predicted for transverse, longitudinal, and UGTMF/underground blasting using instantaneous charge masses from Table 2-3. Vibration levels were predicted for Project blasting at the

production shaft and the exhaust shaft. Vibration levels were also predicted for Project blasting at the nearest anticipated location to Patterson Lake.

2.5 Analysis Cases

Analysis cases were applied to the vibration study area to estimate the incremental and cumulative effects from the Project and the Patterson Lake South Property. The approach incorporated temporal boundaries for analyzing the potential effects from previous, existing, and approved projects and RFDs before, during, and after the anticipated lifespan of the Project. Analysis cases included a Base Case, Application Case, and RFD Case.

Base Case is represented by existing conditions. The Base Case describes the existing environment in the vibration study area before application of the Project to provide an understanding of the current conditions that may be influenced by the Project.

Application Case represents predictions of the combined effects of the previous and existing projects/activities and natural factors in the Base Case plus the potential effects from the proposed Project. This case was also used to identify and assess incremental, Project-specific changes that are predicted to occur.

Reasonably Foreseeable Development (RFD) Case includes the Base Case, Application Case, and the Patterson Lake South Property.

3.0 RESULTS

3.1 Base Case

There are no sources of explosive blasting currently active within the vibration study area. Therefore, PPV and PPL for the Base Case are effectively zero for all receptors.

3.2 Application Case

Table 3-1 presents predicted vibration levels for blasting at the Project production shaft. Table 3-2 presents predicted vibration levels for blasting at the Project exhaust shaft. Table 3-3 presents predicted vibration levels for blasting at the nearest anticipated location to Patterson Lake.

Table 3-1: Predicted Vibration Levels for Blasting at the Project Production Shaft

Receptor Identification Code	Transverse Blasting				Longitudinal Blasting				UGTMF Blasting			
	Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis	
	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)
R-04	0.0	93.3	n/a[(a)]	n/a[(a)]	0.0	93.3	n/a[(a)]	n/a[(a)]	0.0	95.4	n/a[(a)]	n/a[(a)]
R-05	0.0	92.8	n/a[(a)]	n/a[(a)]	0.0	92.8	n/a[(a)]	n/a[(a)]	0.0	94.9	n/a[(a)]	n/a[(a)]
R-06	0.0	91.9	n/a[(a)]	n/a[(a)]	0.0	91.9	n/a[(a)]	n/a[(a)]	0.0	94.0	n/a[(a)]	n/a[(a)]
R-07	0.0	87.3	n/a[(a)]	n/a[(a)]	0.0	87.3	n/a[(a)]	n/a[(a)]	0.0	89.4	n/a[(a)]	n/a[(a)]
R-08	0.0	91.1	n/a[(a)]	n/a[(a)]	0.0	91.1	n/a[(a)]	n/a[(a)]	0.0	93.2	n/a[(a)]	n/a[(a)]

Table 3-1: Predicted Vibration Levels for Blasting at the Project Production Shaft

Receptor Identification Code	Transverse Blasting				Longitudinal Blasting				UGTMF Blasting			
	Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis	
	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)
R-09	0.0	94.7	n/a[a]	n/a[a]	0.0	94.7	n/a[a]	n/a[a]	0.1	96.8	n/a[a]	n/a[a]
R-22	n/a[b]	95.7	0.1	0	n/a[b]	95.7	0.1	0	n/a[b]	97.8	0.2	0
R-26	0.0	95.0	n/a[a]	n/a[a]	0.0	95.0	n/a[a]	n/a[a]	0.1	97.1	n/a[a]	n/a[a]
R-30	0.0	97.2	n/a[a]	n/a[a]	0.0	97.2	n/a[a]	n/a[a]	0.1	99.3	n/a[a]	n/a[a]
R-31	0.0	94.6	n/a[a]	n/a[a]	0.0	94.6	n/a[a]	n/a[a]	0.1	96.7	n/a[a]	n/a[a]
R-40	n/a[b]	89.0	0.0	0	n/a[b]	89.0	0.0	0	n/a[b]	91.1	0.1	0
R-41	n/a[b]	98.2	0.2	0	n/a[b]	98.2	0.2	0	n/a[b]	100.3	0.3	0
R-42	n/a[b]	93.6	0.1	0	n/a[b]	93.6	0.1	0	n/a[b]	95.7	0.1	0
R-43	n/a[b]	91.8	0.1	0	n/a[b]	91.8	0.1	0	n/a[b]	93.9	0.1	0
R-48	n/a[b]	100.5	0.3	0	n/a[b]	100.5	0.3	0	n/a[b]	102.7	0.4	1
R-49	n/a[b]	97.2	0.2	0	n/a[b]	97.2	0.2	0	n/a[b]	99.3	0.2	0

a) DFO vibration analysis is not required for terrestrial receptors.

b) ECCC and ANZEC analysis of PPV is not required for human receptors at angling locations.

UGTMF = underground tailings management facility; PPL = peak pressure level; PPV = peak particle velocity; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council; DFO = Fisheries and Oceans Canada; kPa = kilopascal; dBL = linear decibel.

Table 3-2: Predicted Vibration Levels for Blasting at the Project Exhaust Shaft

Receptor Identification Code	Transverse Blasting				Longitudinal Blasting				UGTMF Blasting			
	Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis	
	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)
R-04	0.0	93.1	n/a[a]	n/a[a]	0.0	93.1	n/a[a]	n/a[a]	0.0	95.2	n/a[a]	n/a[a]
R-05	0.0	93.2	n/a[a]	n/a[a]	0.0	93.2	n/a[a]	n/a[a]	0.0	95.3	n/a[a]	n/a[a]
R-06	0.0	92.2	n/a[a]	n/a[a]	0.0	92.2	n/a[a]	n/a[a]	0.0	94.3	n/a[a]	n/a[a]
R-07	0.0	87.6	n/a[a]	n/a[a]	0.0	87.6	n/a[a]	n/a[a]	0.0	89.7	n/a[a]	n/a[a]
R-08	0.0	91.3	n/a[a]	n/a[a]	0.0	91.3	n/a[a]	n/a[a]	0.0	93.5	n/a[a]	n/a[a]
R-09	0.0	94.7	n/a[a]	n/a[a]	0.0	94.7	n/a[a]	n/a[a]	0.1	96.8	n/a[a]	n/a[a]
R-22	n/a[b]	95.0	0.1	0	n/a[b]	95.0	0.1	0	n/a[b]	97.1	0.2	0
R-26	0.0	95.2	n/a[a]	n/a[a]	0.0	95.2	n/a[a]	n/a[a]	0.1	97.3	n/a[a]	n/a[a]
R-30	0.0	96.4	n/a[a]	n/a[a]	0.0	96.4	n/a[a]	n/a[a]	0.1	98.5	n/a[a]	n/a[a]
R-31	0.0	94.6	n/a[a]	n/a[a]	0.0	94.6	n/a[a]	n/a[a]	0.1	96.7	n/a[a]	n/a[a]

Table 3-2: Predicted Vibration Levels for Blasting at the Project Exhaust Shaft

Receptor Identification Code	Transverse Blasting				Longitudinal Blasting				UGTMF Blasting			
	Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis	
	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)
R-40	n/a[b]	88.7	0.0	0	n/a[b]	88.7	0.0	0	n/a[b]	90.8	0.1	0
R-41	n/a[b]	99.1	0.2	0	n/a[b]	99.1	0.2	0	n/a[b]	101.2	0.3	0
R-42	n/a[b]	93.2	0.1	0	n/a[b]	93.2	0.1	0	n/a[b]	95.3	0.1	0
R-43	n/a[b]	91.7	0.1	0	n/a[b]	91.7	0.1	0	n/a[b]	93.9	0.1	0
R-48	n/a[b]	99.5	0.2	0	n/a[b]	99.5	0.2	0	n/a[b]	101.6	0.3	0
R-49	n/a[b]	96.4	0.1	0	n/a[b]	96.4	0.1	0	n/a[b]	98.5	0.2	0

a) DFO vibration analysis is not required for terrestrial receptors.

b) ECCC and ANZEC analysis of PPV is not required for human receptors at angling locations.

UGTMF = underground tailings management facility; PPL = peak pressure level; PPV = peak particle velocity; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council; DFO = Fisheries and Oceans Canada; kPa = kilopascal; dBL = linear decibel.

Table 3-3: Predicted Vibration Levels for Project Blasting at the Nearest Anticipated Location to Patterson Lake

Receptor Identification Code	Transverse Blasting				Longitudinal Blasting				UGTMF Blasting			
	Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis	
	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)
R-Fish[a]	n/a[b]	n/a[b]	8.0	10	n/a[b]	n/a[b]	8.0	10	n/a[b]	n/a[b]	12.9	17

a) Conceptual receptor located 345 m from the blast site.

b) ECCC and ANZEC vibration analysis is not required for aquatic receptors without human presence.

UGTMF = underground tailings management facility; PPL = peak pressure level; PPV = peak particle velocity; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council; DFO = Fisheries and Oceans Canada; kPa = kilopascal; dBL = linear decibel.

Table 3-4 compares maximum predicted PPV values from Project blasting to ECCC and ANZEC thresholds for each terrestrial receptor. Table 3-5 compares maximum predicted PPL values from Project blasting to ECCC and ANZEC thresholds for each terrestrial receptor and each human receptor at an angling location.

Table 3-6 compares maximum predicted PPV values from Project blasting to the DFO threshold for each aquatic receptor. Table 3-7 compares maximum predicted PPL values from Project to the DFO threshold for each aquatic receptor. By focusing on the maximum predicted PPV or PPL value at each receptor, the results presented in Table 3-4, Table 3-5, Table 3-6, and Table 3-7 represent a precautionary analysis of vibration effects from the Project.

Table 3-4: Comparison of Peak Particle Velocity from Project Blasting to Environment and Climate Change Canada and Australian and New Zealand Environment Council Thresholds

Receptor Identification Code	PPV Thresholds (mm/s)		Blasting Scenario with Maximum PPV	Maximum PPV (mm/s)	Result
	ECCC[(a)]	ANZEC[(b)]			
R-04	12.5	5.0	UGTMF blasting at Project production shaft	0.0	Maximum PPV is less than ECCC and ANZEC thresholds
R-05	12.5	5.0	UGTMF blasting at Project exhaust shaft	0.0	
R-06	12.5	5.0	UGTMF blasting at Project exhaust shaft	0.0	
R-07	12.5	5.0	UGTMF blasting at Project exhaust shaft	0.0	
R-08	12.5	5.0	UGTMF blasting at Project exhaust shaft	0.0	
R-09	12.5	5.0	UGTMF blasting at Project exhaust shaft	0.1	
R-26	12.5	5.0	UGTMF blasting at Project exhaust shaft	0.1	
R-30	12.5	5.0	UGTMF blasting at Project production shaft	0.1	
R-31	12.5	5.0	UGTMF blasting at Project exhaust shaft	0.1	

a) PPV threshold from ECCC document (Environment Canada 2009).

b) PPV threshold from ANZEC document (ANZEC 1990).

UGTMF = underground tailings management facility; PPV = peak particle velocity; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council.

Table 3-5: Comparison of Peak Pressure Level from Project Blasting to Environment and Climate Change Canada and Australian and New Zealand Environment Council Thresholds

Receptor Identification Code	PPL Thresholds (dBL)		Blasting Scenario with Maximum PPL	Maximum PPL (dBL)	Result
	ECCC[(a)]	ANZEC[(b)]			
R-04	128.0	115.0	UGTMF blasting at Project production shaft	95.4	Maximum PPL is less than ECCC and ANZEC thresholds
R-05	128.0	115.0	UGTMF blasting at Project exhaust shaft	95.3	
R-06	128.0	115.0	UGTMF blasting at Project exhaust shaft	94.3	
R-07	128.0	115.0	UGTMF blasting at Project exhaust shaft	89.7	
R-08	128.0	115.0	UGTMF blasting at Project exhaust shaft	93.5	
R-09	128.0	115.0	UGTMF blasting at Project exhaust shaft	96.8	
R-22	128.0	115.0	UGTMF blasting at Project production shaft	97.8	
R-26	128.0	115.0	UGTMF blasting at Project exhaust shaft	97.3	
R-30	128.0	115.0	UGTMF blasting at Project production shaft	99.3	
R-31	128.0	115.0	UGTMF blasting at Project production shaft	96.7	
R-40	128.0	115.0	UGTMF blasting at Project production shaft	91.1	
R-41	128.0	115.0	UGTMF blasting at Project exhaust shaft	101.2	
R-42	128.0	115.0	UGTMF blasting at Project production shaft	95.7	
R-43	128.0	115.0	UGTMF blasting at Project exhaust shaft	93.9	
R-48	128.0	115.0	UGTMF blasting at Project production shaft	102.7	
R-49	128.0	115.0	UGTMF blasting at Project production shaft	99.3	

a) PPL threshold from ECCC document (Environment Canada 2009).

b) PPL threshold from ANZEC document (ANZEC 1990).

UGTMF = underground tailings management facility; PPL = peak particle level; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council; dBL = linear decibel.

Table 3-6: Comparison of Peak Particle Velocity from Project Blasting to Fisheries and Oceans Canada Thresholds

Receptor Identification Code	DFO PPV Threshold[(a)] (mm/s)	Blasting Scenario with Maximum PPV	Maximum PPV (mm/s)	Result
R-22	13.0	UGTMF blasting at Project production shaft	0.2	Maximum PPV is less than DFO threshold
R-40	13.0	UGTMF blasting at Project exhaust shaft	0.1	
R-41	13.0	UGTMF blasting at Project exhaust shaft	0.3	
R-42	13.0	UGTMF blasting at Project production shaft	0.1	
R-43	13.0	UGTMF blasting at Project exhaust shaft	0.1	
R-48	13.0	UGTMF blasting at Project production shaft	0.4	
R-49	13.0	UGTMF blasting at Project production shaft	0.2	
R-Fish	13.0	UGTMF blasting 345 m from Patterson Lake	12.9	

a) PPV threshold from DFO guidance document (Wright and Hopky 1998).
UGTMF = underground tailings management facility; PPV = peak particle velocity; DFO = Fisheries and Oceans Canada.

Table 3-7: Comparison of Peak Pressure Level from Project Blasting to Fisheries and Oceans Canada Thresholds

Receptor Identification Code	DFO PPL Threshold (kPa)[(a)]	Blasting Scenario with Maximum PPL	Maximum PPL (kPa)	Result
R-22	50	UGTMF blasting at Project production shaft	0	Maximum PPL is less than DFO threshold
R-40	50	UGTMF blasting at Project exhaust shaft	0	
R-41	50	UGTMF blasting at Project exhaust shaft	0	
R-42	50	UGTMF blasting at Project production shaft	0	
R-43	50	UGTMF blasting at Project exhaust shaft	0	
R-48	50	UGTMF blasting at Project production shaft	1	
R-49	50	UGTMF blasting at Project production shaft	0	
R-Fish	50	UGTMF blasting 345 m from Patterson Lake	17	

a) PPL threshold from DFO guidance document (Wright and Hopky 1998).
UGTMF = underground tailings management facility; PPL = peak pressure level; DFO = Fisheries and Oceans Canada; kPa = kilopascal.

3.3 Reasonably Foreseeable Development Case

Table 3-8 presents predicted vibration levels for blasting at the Fission Patterson Lake South Property. Because the duration of blasting events is very short (on the order of milliseconds), it is unlikely that Project vibration effects would occur at the same time as vibration effects from the Patterson Lake South Property. Notwithstanding, as a precautionary analysis, Table 3-9 presents predicted cumulative vibration levels during simultaneous blasting at the Project and the Patterson Lake South Property. Cumulative values in Table 3-9 were obtained by summing predicted vibration levels from blasting at the Patterson Lake South Property (Table 3-8) with maximum predicted vibration levels from Project blasting (Table 3-1, Table 3-2, Table 3-3).

Table 3-8: Predicted Vibration Levels for Blasting at the Patterson Lake South Project

Receptor Identification Code	Transverse Blasting				Longitudinal Blasting				Underground Blasting			
	Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis	
	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV/ (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)
R-04	0.0	89.1	n/a[a]	n/a[a]	0.0	89.1	n/a[a]	n/a[a]	0.0	91.2	n/a[a]	n/a[a]
R-05	0.0	86.9	n/a[a]	n/a[a]	0.0	86.9	n/a[a]	n/a[a]	0.0	89.0	n/a[a]	n/a[a]
R-06	0.0	86.3	n/a[a]	n/a[a]	0.0	86.3	n/a[a]	n/a[a]	0.0	88.4	n/a[a]	n/a[a]
R-07	0.0	82.6	n/a[a]	n/a[a]	0.0	82.6	n/a[a]	n/a[a]	0.0	84.7	n/a[a]	n/a[a]
R-08	0.0	85.8	n/a[a]	n/a[a]	0.0	85.8	n/a[a]	n/a[a]	0.0	87.9	n/a[a]	n/a[a]
R-09	0.0	90.6	n/a[a]	n/a[a]	0.0	90.6	n/a[a]	n/a[a]	0.0	92.7	n/a[a]	n/a[a]
R-22	n/a[b]	101.8	0.3	0	n/a[b]	101.8	0.3	0	n/a[b]	103.9	0.5	1
R-26	0.0	89.1	n/a[a]	n/a[a]	0.0	89.1	n/a[a]	n/a[a]	0.0	91.2	n/a[a]	n/a[a]
R-30	0.1	99.6	n/a[a]	n/a[a]	0.1	99.6	n/a[a]	n/a[a]	0.1	101.7	n/a[a]	n/a[a]
R-31	0.0	90.6	n/a[a]	n/a[a]	0.0	90.6	n/a[a]	n/a[a]	0.0	92.7	n/a[a]	n/a[a]
R-40	n/a[b]	90.5	0.1	0	n/a[b]	90.5	0.1	0	n/a[b]	92.6	0.1	0
R-41	n/a[b]	86.9	0.0	0	n/a[b]	86.9	0.0	0	n/a[b]	89.0	0.1	0
R-42	n/a[b]	98.7	0.2	0	n/a[b]	98.7	0.2	0	n/a[b]	100.8	0.3	0
R-43	n/a[b]	90.0	0.0	0	n/a[b]	90.0	0.0	0	n/a[b]	92.1	0.1	0
R-48	n/a[b]	95.8	0.1	0	n/a[b]	95.8	0.1	0	n/a[b]	97.9	0.2	0
R-49	n/a[b]	98.2	0.2	0	n/a[b]	98.2	0.2	0	n/a[b]	100.3	0.3	0
R-Fish	n/a[c]	n/a[c]	0.1	0	n/a[c]	n/a[c]	0.1	0	n/a[c]	n/a[c]	0.1	0

a) DFO vibration analysis is not required for terrestrial receptors.

b) ECCC and ANZEC analysis of PPV is not required for human receptors at angling locations.

c) ECCC and ANZEC analysis is not required for aquatic receptors.

PPL = peak pressure level; PPV = peak particle velocity; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council; DFO = Fisheries and Oceans Canada; kPa = kilopascal; dBL = linear decibel.

Table 3-9: Predicted Cumulative Vibration Levels for Simultaneous Blasting at the Project and the Patterson Lake South Property

Receptor Identification Code	Transverse Blasting				Longitudinal Blasting				UGTMF/Underground Blasting			
	Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis		Vibration Predictions for ECCC and ANZEC Analysis		Vibration Predictions for DFO Analysis	
	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)	PPV (mm/s)	PPL (dBL)	PPV (mm/s)	PPL (kPa)
R-04	0.0	94.7	n/a[a]	n/a[a]	0.0	94.7	n/a[a]	n/a[a]	0.0	96.8	n/a[a]	n/a[a]
R-05	0.0	94.1	n/a[a]	n/a[a]	0.0	94.1	n/a[a]	n/a[a]	0.0	96.2	n/a[a]	n/a[a]
R-06	0.0	93.2	n/a[a]	n/a[a]	0.0	93.2	n/a[a]	n/a[a]	0.0	95.3	n/a[a]	n/a[a]
R-07	0.0	88.8	n/a[a]	n/a[a]	0.0	88.8	n/a[a]	n/a[a]	0.0	90.9	n/a[a]	n/a[a]
R-08	0.0	92.4	n/a[a]	n/a[a]	0.0	92.4	n/a[a]	n/a[a]	0.0	94.6	n/a[a]	n/a[a]
R-09	0.0	96.1	n/a[a]	n/a[a]	0.0	96.1	n/a[a]	n/a[a]	0.1	98.2	n/a[a]	n/a[a]
R-22	n/a[b]	102.8	0.4	0	n/a[b]	102.8	0.4	0	n/a[b]	104.9	0.7	1
R-26	0.0	96.2	n/a[a]	n/a[a]	0.0	96.2	n/a[a]	n/a[a]	0.1	98.3	n/a[a]	n/a[a]
R-30	0.1	101.6	n/a[a]	n/a[a]	0.1	101.6	n/a[a]	n/a[a]	0.2	103.7	n/a[a]	n/a[a]
R-31	0.0	96.1	n/a[a]	n/a[a]	0.0	96.1	n/a[a]	n/a[a]	0.1	98.2	n/a[a]	n/a[a]
R-40	n/a[b]	92.8	0.1	0	n/a[b]	92.8	0.1	0	n/a[b]	94.9	0.2	0
R-41	n/a[b]	99.4	0.2	0	n/a[b]	99.4	0.2	0	n/a[b]	101.5	0.4	0
R-42	n/a[b]	99.9	0.3	0	n/a[b]	99.9	0.3	0	n/a[b]	102.0	0.4	0
R-43	n/a[b]	94.0	0.1	0	n/a[b]	94.0	0.1	0	n/a[b]	96.1	0.2	0
R-48	n/a[b]	101.8	0.4	0	n/a[b]	101.8	0.4	0	n/a[b]	103.9	0.6	1
R-49	n/a[b]	100.7	0.4	0	n/a[b]	100.7	0.4	0	n/a[b]	102.8	0.5	0
R-Fish	n/a[c]	n/a[c]	8.1	10	n/a[c]	n/a[c]	8.1	10	n/a[c]	n/a[c]	13.0	17

a) DFO vibration analysis is not required for terrestrial receptors.

b) ECCC and ANZEC analysis of PPV is not required for human receptors at angling locations.

c) ECCC and ANZEC analysis is not required for aquatic receptors.

UGTMF = underground tailings management facility; PPL = peak pressure level; PPV = peak particle velocity; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council; DFO = Fisheries and Oceans Canada; kPa = kilopascal; dBL = linear decibel.

Table 3-10 compares maximum predicted cumulative PPV values to ECCC and ANZEC thresholds for each terrestrial receptor. Table 3-11 compares maximum predicted cumulative PPL values to ECCC and ANZEC thresholds for each terrestrial receptor and each human receptor at an angling location. Table 3-12 compares maximum predicted cumulative PPV values to the DFO threshold for each aquatic receptor. Table 3-13 compares maximum predicted cumulative PPL values to the DFO threshold for each aquatic receptor. By focusing on the maximum predicted cumulative PPV or PPL value at each receptor, the results presented in Table 3-10, Table 3-11, Table 3-12, and Table 3-13 represent a precautionary analysis of vibration effects from the Project and the Patterson Lake South Property.

Table 3-10: Comparison of Cumulative Peak Particle Velocity to Environment and Climate Change Canada and Australian and New Zealand Environment Council Thresholds

Receptor Identification Code	PPV Thresholds (mm/s)		Cumulative Blasting Scenario with Maximum PPV	Maximum PPV (mm/s)	Result
	ECCC[(a)]	ANZEC[(b)]			
R-04	12.5	5.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.0	Maximum PPV is less than ECCC and ANZEC thresholds
R-05	12.5	5.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.0	
R-06	12.5	5.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.0	
R-07	12.5	5.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.0	
R-08	12.5	5.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.0	
R-09	12.5	5.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.1	
R-26	12.5	5.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.1	
R-30	12.5	5.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.2	
R-31	12.5	5.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.1	

a) PPV threshold from ECCC document (Environment Canada 2009).

b) PPV threshold from ANZEC document (ANZEC 1990).

UGTMF = underground tailings management facility; PPV = peak particle velocity; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council.

Table 3-11: Comparison of Cumulative Peak Pressure Level Based to Environment and Climate Change Canada and Australian and New Zealand Environment Council Thresholds

Receptor Identification Code	PPL Thresholds (dBL)		Cumulative Blasting Scenario with Maximum PPL	Maximum PPV (dBL)	Result
	ECCC[(a)]	ANZEC[(b)]			
R-04	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	96.8	Maximum PPL is less than ECCC and ANZEC thresholds
R-05	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	96.2	
R-06	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	95.3	
R-07	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	90.9	
R-08	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	94.6	
R-09	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	98.2	
R-22	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	104.9	
R-26	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	98.3	
R-30	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	103.7	
R-31	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	98.2	
R-40	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	94.9	
R-41	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	101.5	
R-42	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	102.0	
R-43	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	96.1	
R-48	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	103.9	
R-49	128.0	115.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	102.8	

a) PPL threshold from ECCC document (Environment Canada 2009).

b) PPL threshold from ANZEC document (ANZEC 1990).

UGTMF = underground tailings management facility; PPL = peak pressure level; PPV = peak particle velocity; ECCC = Environment and Climate Change Canada; ANZEC = Australian and New Zealand Environment Council; dBL = linear decibel.

Table 3-12: Comparison of Cumulative Peak Particle Velocity to Fisheries and Oceans Canada Thresholds

Receptor Identification Code	DFO PPV Threshold[a] (mm/s)	Cumulative Blasting Scenario with Maximum PPV	Maximum PPV (mm/s)	Result
R-22	13.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.7	Maximum PPV is less than DFO threshold
R-40	13.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.2	
R-41	13.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.4	
R-42	13.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.4	
R-43	13.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.2	
R-48	13.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.6	
R-49	13.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0.5	
R-Fish	13.0	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	13.0	Maximum PPV is equal to DFO threshold

a) PPV threshold from DFO guidance document (Wright and Hopky 1998).

UGTMF = underground tailings management facility; PPV = peak particle velocity; DFO = Fisheries and Oceans Canada.

Table 3-13: Comparison of Cumulative Peak Pressure Level to Fisheries and Oceans Canada Thresholds

Receptor Identification Code	DFO PPL Threshold (kPa)[a]	Blasting Scenario with Maximum PPL	Maximum PPL (kPa)	Result
R-22	50	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	1	Maximum PPL is less than DFO threshold
R-40	50	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0	
R-41	50	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0	
R-42	50	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0	
R-43	50	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0	
R-48	50	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	1	
R-49	50	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	0	
R-Fish	50	Simultaneous UGTMF blasting at the Project and underground blasting at the Patterson Lake South Property	17	

a) PPL threshold from DFO guidance document (Wright and Hopky 1998; Cott and Hanna 2005).

UGTMF = underground tailings management facility; PPL = peak pressure level; DFO = Fisheries and Oceans Canada; kPa = kilopascal.

4.0 CONCLUSION

Through NexGen's community engagement program, Indigenous Groups and local communities selected the location of 16 terrestrial receptors and human receptors at angling locations. These receptors correspond to the closest known human presence within the vibration study area and were used to predict the effects of vibration from Project blasting on fish habitat and people.

The vibration analysis also predicted effects from Project blasting at a conceptual receptor. The conceptual receptor corresponds to the point within Patterson Lake nearest the anticipated location of Project blasting. This conceptual receptor was included to capture maximum vibration levels for comparison with DFO thresholds.

The vibration analysis considered vibration from Project blasting (Application Case) and vibration from simultaneous blasting at the Project and the Patterson Lake South Property (RFD Case). The Patterson Lake South Property is a proposed future development (RFD) in the vibration study area. Because the duration of blasting events is very short (on the order of milliseconds), it is unlikely that Project vibration effects would occur at the same time as vibration effects from the Patterson Lake South Property. Notwithstanding, by considering cumulative vibration levels, the results presented in the vibration analysis represent a precautionary analysis of vibration effects from the Project and the Patterson Lake South Property.

Results from the analyses predict that ground vibration (PPV) and overpressure (movement of air or water; PPL) from Project blasting and from blasting anticipated at the Patterson Lake South Property would be less than vibration thresholds from the ECCC guidance document (Environment Canada 2009) and the ANZEC guidance document (ANZEC 1990) at each of the 16 receptors identified by Indigenous Groups and local communities. These results indicate that vibration from blasting activities would not result in human annoyance or cosmetic damage to structures at any sensitive receptors in the vibration study area.

Similarly, results from the analyses predict that ground vibration and overpressure from Project blasting and from blasting anticipated at the Patterson Lake South Property would not exceed vibration thresholds from the DFO guidance documents (Wright and Hopky 1998; Cott and Hanna 2005). These results indicate that vibration from blasting activities would not result in adverse effects on general fish habitat or fish spawning habitat in the vibration study area.

Signature Page

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STUDY LIMITATIONS

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The passage of time affects the information and assessment provided in this report. WSP's opinions are based upon information that existed at the time of the production of the report. The Services provided allowed WSP to form no more than an opinion of the actual conditions of the site at the time the site was visited and cannot be used to assess the effect of any subsequent changes in the quality of the site, or its surroundings, or any laws or regulations.

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Rook I Project

Environmental Impact Statement

TSD XI: Light Effects Analysis Report

GOLDER
MEMBER OF WSP

LIGHT EFFECTS ANALYSIS TECHNICAL SUPPORT DOCUMENT FOR THE ROOK I PROJECT

Prepared for:

NexGen Energy Ltd.

Prepared by:

Golder Associates Ltd.

March 2022

Executive Summary

A light analysis was undertaken for the Rook I Project (Project). The analysis evaluated potential effects resulting from artificial lighting anticipated for the Project, and included artificial lighting anticipated for the Patterson Lake South Property, planned by Fission Uranium Corp. (Fission 2019, 2021), which is located approximately 5.2 km west of the proposed Project footprint.

Light was analyzed using two measurement indicators:

- light trespass, which is light or illuminance that strays from its intended purpose onto nearby areas where lighting may be undesirable; and
- sky glow, which is stray light that is scattered in the atmosphere, brightening the natural sky and reducing star visibility.

Light trespass levels were predicted using a commercial computer program called AGi32. Sky glow levels were predicted using a purpose-built computer program developed based on a model from the light assessment literature.

Light trespass and sky glow levels were predicted at 16 sensitive receptors located within the light study area. Sensitive receptors were identified through NexGen Energy Ltd. (NexGen) engagement with local First Nations and Métis Groups (collectively referred to as Indigenous Groups) and northern communities.

There are no federal or provincial regulations or guidelines for the analysis of potential light effects. Therefore, light trespass effects were analyzed using thresholds from the International Commission on Illumination (CIE), and sky glow effects were analyzed using thresholds from the Institution of Lighting Professionals (ILP).

The light analysis concluded:

- Light trespass from the Project and from the Fission Patterson Lake South Property are predicted to be less than applicable light trespass thresholds.
- Light trespass levels at the 16 receptors are predicted to be unchanged as a result of the Project and the proposed Fission Patterson Lake South Property.
- For some receptors and environmental conditions, sky glow from the Project is predicted to be brighter than the threshold applicable to environmental lighting zone E1 – “relatively uninhabited rural area”.
- For all receptors, cumulative sky glow from the Project in combination with the Fission Patterson Lake South Property is predicted to be brighter than the E1 threshold.
- Cumulative sky glow from the Project in combination with the Fission Patterson Lake South Property is predicted to be less bright than the threshold applicable to environmental lighting zone E2 – “sparsely inhabited rural area”.

The significance of potential light effects is assessed in the following sections of the Environmental Impact Statement (EIS):

- fish and fish habitat (EIS Section 11);
- wildlife and wildlife habitat (EIS Section 14);
- cultural and heritage resources and Indigenous land and resource use (EIS Section 16); and
- other land and resource use (EIS Section 17).

The light effects analysis achieved the objective of characterizing potential light effects from the Project and the Fission Patterson Lake South Property. Specifically, light trespass and sky glow levels were predicted using computer models and analyzed in the context of thresholds from the CIE and the ILP.

Abbreviations and Units of Measure

Abbreviation	Definition
CIE	International Commission on Illumination
EIS	Environmental Impact Statement
ILP	Institution of Lighting Professionals
NexGen	NexGen Energy Ltd.
Project	Rook I Project
RFD	reasonably foreseeable development
SSALR	simplified short approach lighting with runway alignment indicator lights
TSD	technical support document

Unit	Definition
%	percent
km	kilometre
lux	1 lumen per square metre
m	metre
mag/arcsec^2	magnitude per square second of arc
mlux	millilux; 0.001 lumens per square metre

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1 INTRODUCTION

NexGen Energy Ltd. (NexGen) is proposing to develop a new uranium mining and milling operation in northwestern Saskatchewan, called the Rook I Project (Project). The Project would be located approximately 40 km east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon (Figure 1-1). The Project would reside within Treaty 8 territory and the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake, along the upper Clearwater River system. Access to the Project would be from an existing road off Highway 955 (Figure 1-2), with on-site worker accommodation serviced by fly-in/fly-out access.

The Project would include the following key facilities to support the extraction and processing of uranium from the Arrow deposit for transportation off site (Figure 1-3):

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

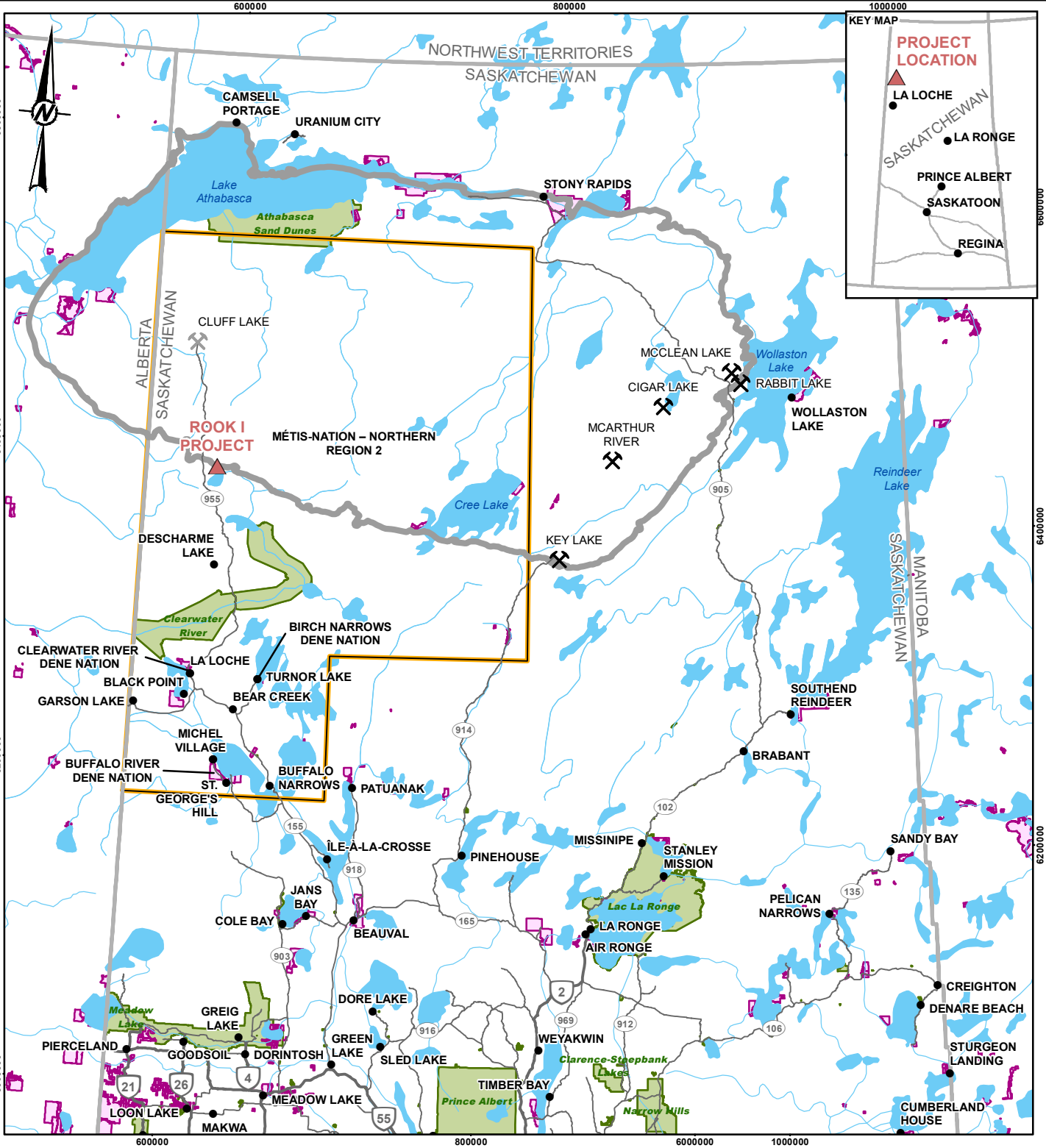
This technical support document (TSD) to the Environmental Impact Statement (EIS) analyzes potential light effects from the proposed Project. Artificial light sources (luminaires) would be installed outdoors to illuminate work areas and roadways, to alert aircraft to the presence of elevated infrastructure, and to guide aircraft using the on-site airstrip. These outdoor luminaires could create adverse effects on the social and biophysical environment. Outdoor luminaires would be required during both Construction and Operations of the Project. Accordingly, this TSD to the EIS analyzes potential light effects during Construction and Operations of the Project. Light from Project luminaires could influence aquatic and terrestrial ecosystems, as well as the people that use natural resources or ecosystem services (e.g., surface water, fish, plants, and wildlife). The light

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

analysis provides information that is used to support the assessments of biophysical, cultural, and socio-economic valued components.

Light specifically supports the effects assessments for the following components:

- fish and fish habitat (EIS Section 11);
- wildlife and wildlife habitat (EIS Section 14);
- cultural and heritage resources and Indigenous land and resource use (EIS Section 16); and
- other land and resource use (EIS Section 17).



LEGEND

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

0 100 200
1:3,500,000 KILOMETRES

REFERENCE(S)

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

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LOCATION OF THE ROOK I PROJECT

CONSULTANT

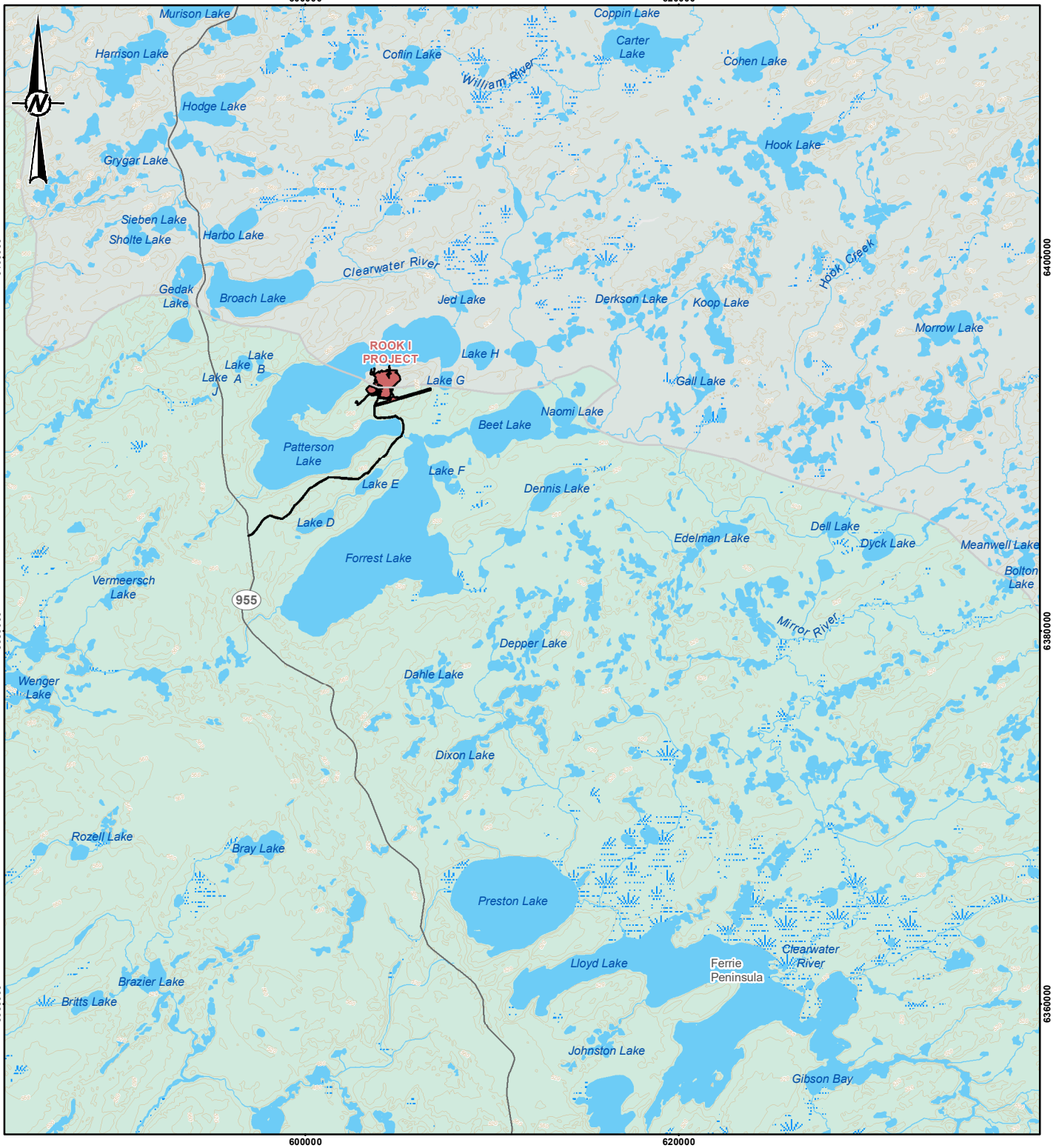
GOLDER MEMBER OF WSP

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

PATH: I:\CLIENTS\NexGen\20144150\Mapping\Products\General\EIS_FIGURES_SECTION1\20144150_003_Fig1-1_Location-of-the-Rook-I-Project_Rev9.mxd PRINTED ON: 2022-02-28 AT: 11:59:15 AM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

25mm



LEGEND

- ELEVATION CONTOUR (20 m INTERVAL)
- SECONDARY HIGHWAY
- WATERCOURSE
- ATHABASCA BASIN
- WATERBODY
- WETLAND
- WOODED AREA
- PROPOSED PROJECT FOOTPRINT

0 5 10
1:300,000 KILOMETRES

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

PROJECT
NexGen Energy Ltd.
ROOK I PROJECT

TITLE
REGIONAL AREA OF THE ROOK I PROJECT

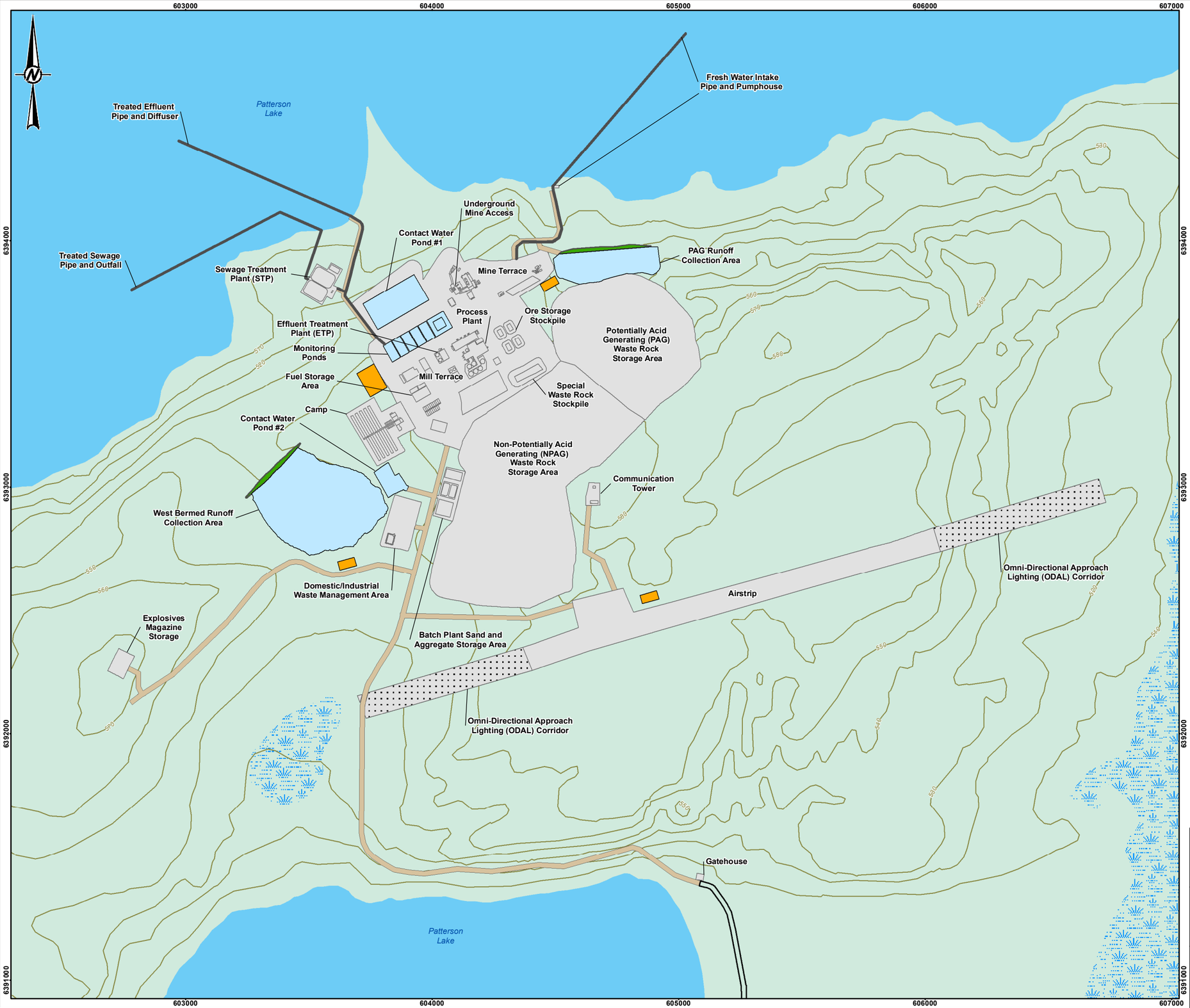
CONSULTANT
GOLDER MEMBER OF WSP

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

PATH: I:\CLIENTS\NexGen\20144150\Mapping\Products\General\EIS_FIGURES_SECTION1\20144150_007_Fig1-2_Regional-Area_Rook_I_Project_Rev0.mxd PRINTED ON: 2022-02-28 AT 12:08:07 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

25mm



LEGEND

- ELEVATION CONTOUR (10 m INTERVAL)
- WATERBODY
- WETLAND
- WOODED AREA
- INTAKE OR DISCHARGE PIPE
- ACCESS ROAD
- CONTACT WATER CONTAINMENT BERM
- OMNI-DIRECTIONAL APPROACH LIGHTING (ODAL) CORRIDOR
- PROJECT INFRASTRUCTURE
- SITE ROAD
- TOPSOIL STORAGE AREA
- WATER MANAGEMENT POND

0 0.5 1

1:15,500 KILOMETRES

REFERENCE(S)

1. PROJECT FEATURES OBTAINED FROM NEXGEN, APRIL 6, 2021 AND UPDATED JUNE 8, 2021 .
2. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LAYOUT OF INFRASTRUCTURE AND FACILITIES FOR THE ROOK I PROJECT

CONSULTANT

GOLDER MEMBER OF WSP

PROJECT		20144150	PHASE	3314 - 6
DESIGN	JV	2020-03-13	SCALE AS SHOWN	REV. 0
GIS	NO	2022-03-18		
CHECK	JMC	2022-03-18	**FIGURE 1-3**	
REVIEW	MM	2022-03-18		

PATH: I:\CLIENTS\NexGen\20144150\Mapping\Products\General\EIS_FIGURES_SECTION12\20144150_011_Fig1-3_Layout-of-Infrastructure-and-Facilities_Rook_I_Project_Rev0.mxd PRINTED ON: 2022-03-18 AT: 10:46:38 AM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25mm

2 METHODS

This section of the TSD describes the methods used to analyze potential effects from Project lighting. It describes the measurement indicators used to characterize light levels, the analysis thresholds used to analyze light effects, the study area and receptors used in the analysis, and the methods used to predict light levels from the Project.

2.1 Measurement Indicators

Potential light effects are analyzed using two measurement indicators:

- Light trespass is light or illuminance that strays from its intended purpose onto nearby areas where lighting may be undesirable. Light trespass is measured in units of lux (1 lumen per square metre) or millilux (mlux; 0.001 lumen per square metre).
- Sky glow is stray light that is scattered in the atmosphere, brightening the natural sky and reducing star visibility. Sky glow is measured in units of magnitude per square second of arc (mag/arcsec^2); these units reflect “sky quality” relative to a theoretical condition in which there is zero sky glow. Larger values represent better “sky quality” and less sky glow.

Representative illumination values for several common situations and environments are provided in Table 2-1; this information can be used to provide context to the light trespass predictions that appear elsewhere in the TSD. Representative sky glow values for several common situations and environments are provided in Table 2-2; this information can be used to provide context to the sky glow predictions that appear elsewhere in the TSD.

Table 2-1: Illumination for Common Situations and Environments

Sample Situation/Environment	Illumination Level (lux)
Moonless overcast night[(a)]	0.0001
Moonless clear night[(a)]	0.002
Full moon on a clear night[(a)]	0.27
Family living room[(b)]	50
Hallway[(c)]	80
Overcast day[(a)]	1,000
Full daylight (not direct sun) [(a)]	10,000 to 25,000

a) Schlyter 2021.
b) AGO 1998.
c) AGO 2005.
lux = 1 lumen per square metre.

Table 2-2: Sky Glow for Common Situations and Environments

Sample Situation/Environment	Sky Glow (mag/arcsec^2)
Standard natural background (zero sky glow)	21.6
Limit for astronomical site of international standing	21.5
Limit for dark sky site for most astronomers	21.2
Full moon night sky	18
Night sky in densely populated area	17
Clear sky 30 minutes after sunset	15
Heavily overcast daytime sky	8
Clear daytime sky	3

Source: Narisada and Schreuder 2004.
mag/arcsec^2 = magnitude per square second of arc.

2.1.1 Analysis Thresholds

There are no federal or provincial regulatory thresholds for the analysis of potential light effects from the Project. In the absence of federal or provincial regulatory guidance, light effects from the Project were analyzed using thresholds from:

- International Commission on Illumination (CIE) *Technical Report: Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Installations* (CIE 2017); and
- Institution of Lighting Professionals (ILP) *Guidance Note for the Reduction of Obtrusive Light* (ILP 2020).

The CIE is a technical, scientific, and cultural non-profit organization whose objectives are:

- To provide an international forum for the discussion of all matters relating to the science, technology, and art in the fields of light and lighting and for the interchange of information in these fields between countries.
- To develop basic standards and procedures of metrology in the fields of light and lighting.
- To prepare and publish standards, reports and other publications concerned with all matters relating to science, technology, and art in the fields of light and lighting.
- To maintain liaison and technical interaction with other international organizations concerned with matters related to the science, technology, standardization, and art in the fields of light and lighting (CIE 2021).

The ILP is professional body based in the United Kingdom (UK) that establishes standards for good practice in the development of interior and exterior lighting (ILP 2021). The ILP is consulted by the UK government on a wide range of issues, including legislation and regulations that affect the built environment (ILP 2021).

The CIE has established five environmental lighting zones (CIE 2017) in recognition that some areas are more sensitive to light effects than others. For example, the CIE acknowledges that lighting considered acceptable and appropriate in a busy urban centre may not be acceptable in a remote national park. The CIE environmental lighting zones are described in Table 2-3.

The CIE guidance recommends light trespass thresholds for each environmental lighting zone (CIE 2017). Corresponding sky glow thresholds are provided in the ILP guidance (ILP 2020). Light trespass and sky glow

thresholds for each environmental lighting zone are presented in Table 2-3. The light trespass thresholds are generally applicable to all environmental conditions, while the sky glow thresholds are only applicable under summertime conditions when the sky is clear.

Because there are no federal or provincial regulatory thresholds for the analysis of potential light effects, Project compliance with the CIE and ILP thresholds is not mandatory. Instead, the CIE and ILP thresholds provide a helpful framework for analyzing potential light effects. Exceedance of the light trespass and/or sky glow thresholds from Table 2-3 may annoy or disturb human and wildlife receptors, but exceedance of these thresholds is not a risk to health or safety.

Table 2-3: Environmental Lighting Zones and Analysis Thresholds

Zone[(a)]	Lighting Environment[(a)]	Examples[(a)]	Light Trespass Threshold[(b)] (lux)	Sky Glow Threshold[(c)] (mag/arcsec^2)
E0	Intrinsically dark	UNESCO Starlight Reserves, IDA Dark Sky Parks, major optical observatories	0	20.5
E1	Dark	Relatively uninhabited rural areas	0.1	20
E2	Low district brightness	Sparsely inhabited rural area	1	15
E3	Medium district brightness	Well inhabited rural and urban settlements	2	n/a[(d)]
E4	High district brightness	Town and city centres and other commercial areas	5	n/a[(d)]

a) CIE 2017.
b) Light trespass thresholds taken from CIE 2017.
c) Sky glow thresholds taken from ILP 2020. These thresholds are applicable under summertime conditions with clear skies.
d) There is no sky glow threshold applicable to this environmental lighting zone (ILP 2020).
UNESCO = United Nations Educational, Scientific, and Cultural Organization; IDA = International Dark-Sky Association; lux = 1 lumen per square metre; mag/arcsec^2 = magnitude per square second of arc; n/a = not applicable.

2.2 Study Area

A maximum disturbance area of 981 ha was used for the assessment of terrain and soils, vegetation, and wildlife and wildlife habitat to address uncertainty in the final design of the Project. The maximum disturbance area represents the smallest scale of assessment and an area where the potential direct effects of the anticipated Project on soils, vegetation, and wildlife can be assessed accurately and precisely. The spatial boundary of the maximum disturbance area was delineated by applying buffers to the outer edges of the anticipated Project infrastructure. The spatial boundary was also constrained to the shoreline of Patterson Lake (Figure 2-1).

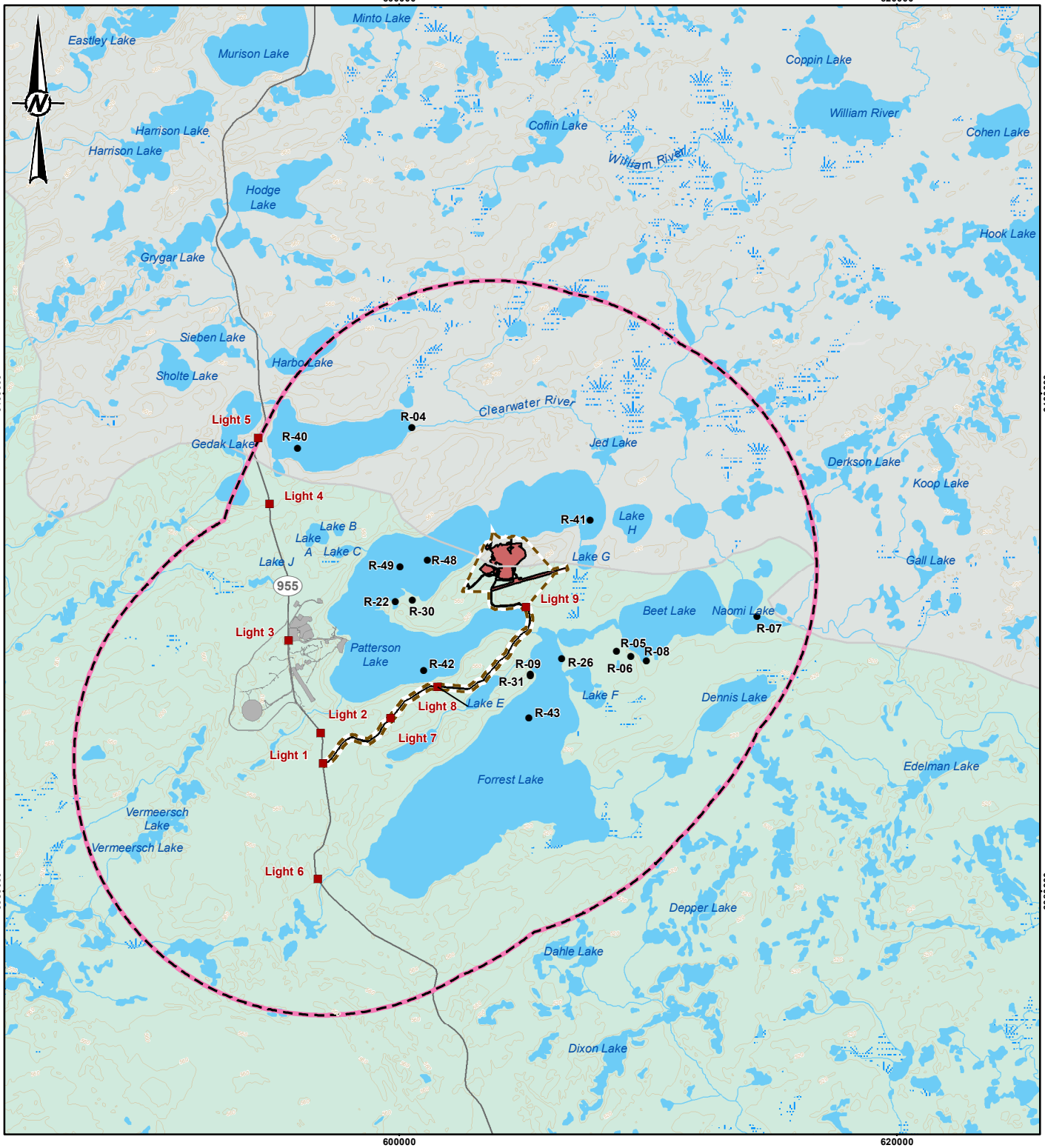
The study area for the light analysis was defined as a 10 km buffer surrounding the maximum disturbance area for the Project (Figure 2-1). This study area is large enough to characterize any vibration effects from the Project, as well as any potential cumulative effects from the Patterson Lake South Property, which is a reasonably foreseeable development (RFD) proposed by Fission Uranium Corp. (Fission 2019, 2021).

Receptors within the light study area were primarily identified through NexGen's engagement with Indigenous Groups and local communities. A review was completed of the comments provided on the Rook I Project Description by the Clearwater River Dene Nation (CRDN 2019), Métis Nation – Saskatchewan (MN-S 2019), and Ya'thi Néné Land and Resources (YNLRO 2019). Indigenous Knowledge and Traditional Land Use Studies completed by the Clearwater River Dene Nation (TSD V.1: CRDN), Métis Nation – Saskatchewan (TSD IV: MN-S), Birch Narrows Dene Nation (TSD II: BNDN), Buffalo River Dene Nation (TSD III: BRDN), and Ya'thi Néné

Land and Resources (TSD VI: YNLRO) were also reviewed. Receptors identified through this process are shown in Figure 2-1, along with light measurement stations used in the noise and light baseline study for the Project (Annex II, Noise and Light Baseline Report). These receptors correspond to the closest known human presence within the light study area. These same receptors were used in the assessment of potential noise effects (EIS Section 7.3, Noise) and in the analysis of potential vibration effects (TSD X, Vibration Effects Analysis Report).

Table 2-4 presents a list of receptors considered in the light analysis and identifies the environmental lighting zone and analysis thresholds that are applicable at each receptor. The light study area is relatively uninhabited under existing conditions and is not located within designated parks or reserves; therefore, all receptors are classified as environmental lighting zone E1. If development of the Project proceeds, the light study area would become sparsely inhabited with mine workers and support staff, in which case environmental lighting zone E2 may become a more appropriate classification.

Table 2-4 also identifies the baseline measurement station that is most representative of existing conditions at each receptor. During the baseline field program, light trespass and sky glow levels were measured at nine stations (Light 1 through Light 9) under summertime cloudy skies, summertime clear skies, wintertime cloudy skies, and wintertime clear skies. Existing light trespass and sky glow levels observed at the nine baseline measurement stations were assigned to the 16 receptors considered in the light analysis based on physical proximity. For example, measurements collected at Light 5 were assigned to receptor R-04 because Light 5 is the closest measurement station to R-04. Similarly, measurements collected at Light 9 were assigned to receptor R-05 because Light 9 is the closest measurement station to R-05. Given the general lack of human activity and artificial light sources throughout the light study area, it was not necessary to measure existing conditions at each receptor; using representative data from the closest measurement station accurately characterizes existing conditions at the receptors.



LEGEND

- ELEVATION CONTOUR (20 m INTERVAL)
- SECONDARY HIGHWAY
- WATERCOURSE
- ATHABASCA BASIN
- WATERBODY
- WETLAND
- WOODED AREA
- MAXIMUM DISTURBANCE AREA
- PROPOSED PROJECT FOOTPRINT
- FISSION PATTERSON LAKE SOUTH PROPERTY FOOTPRINT
- LIGHT MEASUREMENT STATIONS
- LIGHT RECEPTORS
- LIGHT STUDY AREA

0 5 10
1:225,000 KILOMETRES

REFERENCE(S)

1. PROJECT FEATURES OBTAINED FROM NEXGEN, APRIL 6, 2021.
2. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
3. FISSION (FISSION URANIUM CORP.) OBTAINED FROM 2019 TECHNICAL REPORT ON THE PRE-FEASIBILITY STUDY OF THE PATTERSON LAKE SOUTH PROPERTY USING UNDERGROUND MINING METHODS.

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LIGHT STUDY AREA AND RECEPTORS

CONSULTANT

GOLDER MEMBER OF WSP

PROJECT		20144150	PHASE	3102 - 3
DESIGN	VY	2022-03-02	SCALE AS SHOWN	REV. 0
GIS	NO	2022-03-02	**FIGURE 2-1**	
CHECK	VY	2022-03-02		
REVIEW	AF	2022-03-02		

PATH: I:\CLIENTS\NexGen\20144150\Mapping\Products\Noise\Light\A ssessment\Technical\Support\Document Figures\20144150_Fig2-1_Rook I_Light_Study_Area_Receptors_Rev0.mxd PRINTED ON: 2022-03-02 AT: 3:09:36 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

25mm

Table 2-4: Light Receptors and Relevant Thresholds

Receptor Identification Code[a]	Universal Transverse Mercator Coordinates (Zone 12)		Receptor Description[b]	Representative Baseline Measurement Station	Environmental Lighting Zone[c]	Analysis Threshold	
	Easting (m)	Northing (m)				Light Trespass (lux)	Sky Glow[d] (mag/arcsec^2)
R-04	600523	6398606	Cabin	Light 5	E1	0.1	20
R-05	608757	6389632	Lodge	Light 9	E1	0.1	20
R-06	609329	6389420	Cabin (old cabin)	Light 9	E1	0.1	20
R-07	614387	6391050	Cabin	Light 9	E1	0.1	20
R-08	609942	6389235	Camp (tourist camp)	Light 9	E1	0.1	20
R-09	605286	6388706	Camp (tourist camp)	Light 9	E1	0.1	20
R-22	599851	6391630	Fishing (nets)	Light 8	E1	0.1	20
R-26	606543	6389350	Plane crash	Light 9	E1	0.1	20
R-30	600546	6391678	Historical camp	Light 8	E1	0.1	20
R-31	605282	6388662	Camp (rough camp)	Light 9	E1	0.1	20
R-40	595924	6397789	Fishing	Light 5	E1	0.1	20
R-41	607681	6394910	Fishing	Light 9	E1	0.1	20
R-42	600992	6388870	Fishing	Light 8	E1	0.1	20
R-43	605233	6386971	Fishing	Light 8	E1	0.1	20
R-48	601140	6393297	Fishing	Light 9	E1	0.1	20
R-49	600042	6393020	Fishing	Light 8	E1	0.1	20

a) This table lists all receptors within the light study area that were identified during community engagement activities. Receptor numbering is non-continuous because some of the locations identified during community engagement activities are beyond the light study area (i.e., some of the locations identified during community engagement activities are more than 10 km from the maximum disturbance area for the Project). Because light trespass and sky glow levels would attenuate with distance, potential light effects would be greater at receptors within the study area than at receptors beyond the study area.

b) Receptor description provided during community engagement activities.

c) Environmental lighting zone E1 reflects the present status of the light study area. If development of the Project proceeds, the light study area would become sparsely inhabited with mine workers and support staff, in which case environmental lighting zone E2 may become a more appropriate classification.

d) Sky glow thresholds are applicable under summertime conditions with clear skies.

lux = 1 lumen per square metre; mag/arcsec^2 = magnitude per square second of arc.

2.3 Temporal Boundaries

The temporal scope of the light analysis focuses on the 43-year period from initial Construction to the end of Decommissioning and Reclamation (i.e., Closure) as defined by the following Project phases (EIS Section 6.5.2, Temporal Boundaries):

- **Construction Phase (Construction):** includes site preparation; mine, process plant, and additional infrastructure development; transportation of people and materials to and from the Project; and all activities associated with commissioning the Project up until Operations commences. The duration of Construction is expected to be four years.

- **Operations Phase (Operations):** includes all activities associated with mining and processing ore; tailings management; management of waste rock, domestic waste, and hazardous materials; water management; release of treated effluent; site maintenance; progressive reclamation; and transportation of staff and materials to and from the Project up until Decommissioning and Reclamation commences. The duration of Operations is expected to be 24 years.
- **Decommissioning and Reclamation Phase (Closure):** includes two stages expected to occur over 15 years:
  - **Active Closure Stage:** active decommissioning and reclamation activities occur post-Operations, such as backfilling mine workings, removal of physical infrastructure, recontouring and revegetating disturbed areas, and any other activities deemed necessary to achieve decommissioning objectives and return the site to a safe and stable condition prior to post-Closure activities. The duration of the Active Closure Stage is expected to be five years.
  - **Transitional Monitoring Stage:** includes monitoring and reporting activities that occur post Active Closure that would continue until monitoring and reporting verifies that the performance criteria have been met. Once performance criteria have been fully demonstrated, an application to be released from the Canadian Nuclear Safety Commission licence would be submitted to the Canadian Nuclear Safety Commission for approval. Once that is achieved, and upon Provincial approval, the land would be transferred under Provincial management through the Institutional Control Program. The duration of the Transitional Monitoring Stage is nominally 10 years; however, NexGen acknowledges this duration would be dependent on the achievement of performance criteria.

The presence of luminaires is anticipated during Construction and Operations , and during the Active Closure Stage of Closure. Because lighting during the Active Closure Stage is expected to be less intense than during either Construction or Operations, quantitative light modelling focused on Construction and Operations to capture maximum predicted light trespass and sky glow from Project-related activities. This represents a conservative analysis of potential light effects from the Project (i.e., an approach that tends to overestimate potential effects).

The temporal boundaries applied to cumulative effects include the period during which the presence of luminaires at the Fission Patterson Lake South Property may overlap the presence of Project luminaires. Information presented in the Fission Patterson Lake South Property prefeasibility study was not sufficient to characterize separately potential light effects from construction and operation of that project (Fission 2019). Therefore, the light analysis characterized potential effects once the Fission Patterson Lake South Property becomes fully operational as surrogate information for the construction and decommissioning phases. To be clear, the light analysis of potential cumulative effects considered one snapshot in which Project Construction temporally overlaps the fully operational Fission Patterson Lake South Property and another snapshot in which Project Operations temporally overlaps the fully operational Fission Patterson Lake South Property. Lighting required for operations is anticipated to be greater than for the other project phases, and so this approach to analyzing the Fission Patterson Lake South Property is considered conservative.

2.4 Baseline Measurement Methods

A baseline study was conducted to characterize existing light trespass and sky glow levels in the light study area (Annex II, Noise and Light Baseline Report). The light baseline study was conducted overnight on:

- 13 September 2018 and 14 September 2018;
- 14 September 2018 and 15 September 2018;
- 18 March 2020 and 19 March 2020;
- 22 March 2020 and 23 March 2020; and
- 23 March 2020 and 24 March 2020.

Measurements were collected at nine stations (Light 1 through Light 9; Figure 2-1). All measurement data were collected during periods when the night sky was dark (i.e., both sun and moon below the horizon). Measurement data were collected over multiple nighttime periods to capture a variety of environmental conditions: summertime cloudy skies, summertime clear skies, wintertime cloudy skies, and wintertime clear skies.

Measurement data were collected in general accordance with guidance from the Illuminating Engineering Society of North America (IESNA 2000) and the CIE (CIE 1997, 2017). Existing light trespass levels were measured using a Solar Light PMA2010 photometer, outfitted with a PMA2131 scotopic detector. Existing sky glow levels were measured using a Unihedron sky quality meter.

2.5 Prediction Methods

Light trespass from the Project and from the Fission Patterson Lake South Property was predicted using a commercial computer program called AGi32, developed by Lighting Analysts Inc. Inputs to the AGi32 computer models included location, orientation, and emissions from luminaires, location and dimensions of buildings and other objects, and location of light receptors (Table 2-4).

In the absence of commercial sky glow models, sky glow from the Project and from the Fission Patterson Lake South Property was predicted using a computer program developed by Golder based on a model from Garstang (1986) that predicts sky brightness caused by a city or large industrial facility at receptor locations outside the city/facility. The Garstang sky glow model accounts for molecular scattering, aerosol scattering, reflectivity of the ground, facility-receptor distance, and luminous intensity of the city/facility. Inputs to the Garstang sky glow model include location and emissions from luminaires, ground reflectivity (i.e., the amount of light reflected by the ground), and location of light receptors (Table 2-4).

2.5.1 Inputs and Assumptions

Project illumination requirements for outdoor work areas are presented in Table 2-5 (Poole 2019a).

Table 2-5: Illumination Requirements for Outdoor Work Areas

Outdoor Work Area	Illumination Requirement (lux)
Parking lots	30
Roads around buildings	30
General (e.g., areas adjacent to buildings and outdoor equipment)	10

Source: Poole (2019a).
lux = 1 lumen per square metre.

Roadway lighting for the Project would consist of 15 m vertical poles with 2.4 m upsweeps (Poole 2019b). These lights would be spaced at 80 m horizontal intervals along the segment of the access road between the gatehouse and the Project site, and along other roads within the Project footprint (Poole 2019b). There would be no artificial lighting along the segment of the access road between the Project gatehouse and Highway 955.

Lighting for the Project airstrip would be designed based on the "simplified short approach lighting with runway alignment indicator lights" (SSALR) system from *TP 312 – Aerodrome Standards and Recommend Practices* (Transport Canada 2015; Halliday 2021). The SSALR system consists of a series of flashing lights that guide pilots along the approach path to the airstrip and mark the landing threshold and runway apron. Elevated Project structures (i.e., headframe and communication tower) would be marked with aircraft warning lights, in accordance with *Standard 621 – Obstruction Marking and Lighting* (Transport Canada 2019; Poole 2019a).

Because information about lighting at the Fission Patterson Lake South Property was not publicly available at the time this lighting analysis was completed, it was assumed the Fission Patterson Lake South Property would have the same general illumination requirements as the Project (Table 2-5), and would make use of the same roadway lighting design and the same SSALR system at the on-site airstrip. This approach was taken because the Fission Patterson Lake South Property is a similar type of development to the proposed Project and is anticipated to have similar lighting requirements. Publicly available information suggests there are no headframes associated with the Fission Patterson Lake South Property; instead, ore would be hauled to the surface using trucks (Fission 2019). As such, aircraft warning lights were not modelled at the Fission Patterson Lake South Property.

Specific vendors and luminaires for the Project are yet to be confirmed. Therefore, the light analysis identified representative luminaires from the database provided within the AGi32 computer program. The AGi32 luminaire database is updated regularly and contains detailed information about thousands of luminaires from dozens of manufacturers. Representative luminaires considered in the light analysis are summarized in Table 2-6. These luminaires are from large, well-established manufacturers and are likely similar to those that would ultimately be installed on site. In any case, the light trespass and sky glow modelling is not sensitive to the particular make/model of luminaires; the relevant quantity for the light analysis is the light emissions (lumens) of the luminaires.

Table 2-6: Representative Luminaires Considered in the Light Analysis

Luminaire Identification Code	Make/Model	Description	Light Emissions (lumens)
Site Bright	GE Lighting Solutions / EASC Z5NX30	400-watt LED; pole-mounted; used to light general work areas	54,200
Site Medium	GE Lighting Solutions / EALP01 KAAA730	274-watt LED; pole-mounted; used to light general work areas	32,700
Parking Area	GE Lighting Solutions / ECBB C5F530	110-watt LED; pole-mounted; used to light parking areas	13,410
Wall Mount	GE Lighting Solutions / EWNB F3730	125-watt LED; wall-mounted; used to light areas outside of buildings	13,900
Streetlight	GE Lighting Solutions / ERHM01 30E1730	253-watt LED; pole-mounted; used to light roadways	28,800
Airstrip Bright	ATX Appleton Group / 95003	150-watt quartz halogen; various mounting configurations; used for airstrip lighting and SSALR system	1,593
Airstrip Medium	Simes / S1050.14	50-watt quartz halogen; various mounting configurations; used for airstrip lighting and SSALR system	211
Aircraft Warning	Performance in Lighting / Quasar 10 4WB	4-watt LED; aircraft warning light mounted on elevated structures	402

LED = light emitting diode; SSALR = simplified short approach lighting with runway alignment indicator lights.

Within the AGi32 light trespass model and the Garstang sky glow model, luminaires from Table 2-6 were allocated to Project buildings and work areas until light levels were predicted to reach the illumination requirements from Table 2-5. Luminaires were allocated to roadways based on the Project design specifications (Poole 2009b). Luminaires were allocated to the Project airstrip in accordance with the Transport Canada SSALR requirements (Transport Canada 2015), and aircraft warning lights were allocated to the Project headframe and communication tower in accordance with the applicable Transport Canada standard (Transport Canada 2019). Luminaires were allocated to the Fission Patterson Lake South Property in a similar manner.

The luminaire allocation used to model light trespass and sky glow from Construction and Operations is presented in Table 2-7. The luminaire allocation used to model light trespass and sky glow from the Fission Patterson Lake South Property is also presented in Table 2-7.

Table 2-7: Luminaire Allocation

Luminaire Identification Code	Quantity of Luminaires		
	Project Construction	Project Operations	Fission Patterson Lake South Property
Site Bright	120	120	669
Site Medium	96	96	0[a]
Parking Area	93	93	0[a]
Wall Mount	170	241	0[a]
Streetlight	121	121	166
Airstrip Bright	236	236	236
Airstrip Medium	18	18	18
Aircraft Warning	18	18	0[b]

a) In the absence of a detailed footprint or building information for the Fission Patterson Lake South Property, illumination requirements for general work areas were achieved using the Site Bright luminaires. Site Medium, Parking Area, and Wall Mount luminaires were not considered in the light models developed for the Fission Patterson Lake South Property because illumination requirements were achieved using the Site Bright luminaires.

b) There are no headframes associated with the Fission Patterson Lake South Property; as such, aircraft warning lights were not modelled at the Fission Patterson Lake South Property.

Because light trespass results from light shining directly on a receptor, predictions from the AGi32 light trespass model are not sensitive to ground cover (i.e., light reflected from the ground is not accounted for in the AGi32 algorithm). In contrast, light reflecting from the ground is a key component of sky glow modelling using the Garstang (1986) model. To characterize potential differences in sky glow during the summertime and wintertime periods, the Project and Patterson Lake South were modelled based on bare ground (i.e., summertime conditions) and snow-covered ground (i.e., wintertime conditions). Bare ground was assumed to reflect 25% of incident light and snow-covered ground was assumed to reflect 85% of incident light (Engineering Toolbox 2021). Because of the greater reflectivity from snow-covered ground, sky glow levels tend to be elevated during the wintertime period.

2.6 Analysis Cases

Analysis cases were applied to the light study area to estimate the incremental and cumulative effects from the proposed Project and the Fission Patterson Lake South Property. The approach incorporated temporal boundaries for analyzing the potential effects from previous, existing, and approved projects and RFDs before, during, and after the anticipated lifespan of the Project. Analysis cases included a Base Case, Application Case, and RFD Case.

Base Case is represented by existing conditions. The Base Case describes the existing environment in the light study area before application of the proposed Project to provide an understanding of the current conditions that may be influenced by the Project.

Application Case represents predictions of the combined effects of the previous and existing projects/activities and natural factors in the Base Case plus the potential effects from the proposed Project. This case was also used to identify and assess incremental, Project-specific changes that are predicted to occur.

Reasonably Foreseeable Development (RFD) Case includes the Base Case, Application Case, and the Fission Patterson Lake South Property.

3 RESULTS

This section summarizes existing conditions in the light study area (Base Case), then presents results from the light trespass and sky glow modelling for the Project (Application Case). Project-specific light trespass and sky glow predictions are presented for Construction and Operations. Cumulative light trespass and sky glow levels, which include the contribution from the proposed Fission Patterson Lake South Property (RFD Case), are subsequently presented. Predicted light trespass and sky glow levels are analyzed using thresholds taken from guidance documents published by the CIE (2017) and the ILP (2020).

3.1 Base Case

Existing light trespass and sky glow levels in the light study area were established by means of a baseline field program (Annex II). Table 3-1 presents existing light trespass levels at each of the 16 receptors considered in the light analysis and compares existing levels to the light trespass threshold applicable to environmental lighting zone E1 (CIE 2017). The results presented in Table 3-1 indicate that existing light trespass levels at all receptors are below the applicable light trespass threshold.

Table 3-1: Existing Light Trespass Levels

Receptor Identification Code	Representative Baseline Measurement Station	Existing Light Trespass Level[a] (mlux)				Light Trespass Threshold[b] (mlux)	Comment
		Summertime Cloudy Skies	Summertime Clear Skies	Wintertime Cloudy Skies	Wintertime Clear Skies		
R-04	Light 5	6	3	1	3	100	Existing conditions are below threshold
R-05	Light 9	3	4	22	4	100	Existing conditions are below threshold
R-06	Light 9	3	4	22	4	100	Existing conditions are below threshold
R-07	Light 9	3	4	22	4	100	Existing conditions are below threshold
R-08	Light 9	3	4	22	4	100	Existing conditions are below threshold
R-09	Light 9	3	4	22	4	100	Existing conditions are below threshold
R-22	Light 8	0	0	1	3	100	Existing conditions are below threshold
R-26	Light 9	3	4	22	4	100	Existing conditions are below threshold
R-30	Light 8	0	0	1	3	100	Existing conditions are below threshold
R-31	Light 9	3	4	22	4	100	Existing conditions are below threshold
R-40	Light 5	6	3	1	3	100	Existing conditions are below threshold
R-41	Light 9	3	4	22	4	100	Existing conditions are below threshold
R-42	Light 8	0	0	1	3	100	Existing conditions are below threshold
R-43	Light 8	0	0	1	3	100	Existing conditions are below threshold
R-48	Light 9	3	4	22	4	100	Existing conditions are below threshold
R-49	Light 8	0	0	1	3	100	Existing conditions are below threshold

a) Existing light trespass levels were measured during a baseline field program (Annex II).
b) Light trespass threshold applicable to environmental lighting zone E1 (CIE 2017).
mlux = millilux (0.001 lumen per square metre).

Table 3-2 presents existing sky glow levels at each of the 16 receptors considered in the light analysis and compares existing levels under summertime clear skies to the sky glow threshold applicable to environmental lighting zone E1 (ILP 2020). As discussed in Section 2.1.1, Analysis Thresholds, the ILP sky glow threshold only applies to summertime clear skies; there are no sky glow thresholds applicable to other environmental conditions.

The units used to quantify sky glow (mag/arcsec^2) reflect “sky quality” relative to a theoretical condition in which there is zero sky glow. Larger values represent better “sky quality” and less sky glow; in particular, an existing sky glow value greater than 20 mag/arsec^2 indicates existing conditions are darker than the 20 mag/arcsec^2 threshold, and an existing sky glow value less than 20 mag/arcsec^2 indicates conditions are brighter than the 20 mag/arcsec^2 threshold.

The results presented in Table 3-2 indicate that existing conditions in the light study area are generally darker than the applicable sky glow threshold. However, existing conditions at receptors R-22, R-30, R-42, R-43, and R-49 (5 of the 16 receptors) are brighter than the applicable E1 sky glow threshold. As discussed in the in the noise and light baseline study (Annex II), elevated sky glow levels in the light study area likely result from the combined influence of aurora activity during the field study and the presence of Fort McMurray approximately 180 km southwest of the light study area.

At the five receptors (R-22, R-30, R-42, R-43, and R-49) with elevated sky glow, the difference between the measured sky glow and the E1 threshold is 0.1 mag/arcsec^2 (i.e., 19.9 mag/arcsec^2 measurement vs. 20 mag/arcsec^2 threshold). This is less than the magnitude of the difference in sky glow observed under different environmental conditions at these same receptors. For example, the difference between the brightest and darkest skies at R-22/Light 8 was observed to be 1.7 mag/arcsec^2 (i.e., 19.9 mag/arcsec^2 for summertime clear vs. 21.6 mag/arcsec^2 for wintertime cloudy). This suggests the magnitude of elevated sky glow at receptors R-22, R-30, R-42, R-43, and R-49 can be considered small within the context of variability in the existing environment.

Table 3-2: Existing Sky Glow Levels

Receptor Identification Code	Representative Baseline Measurement Station	Summertime Clear Skies			Existing Sky Glow[a] (mag/arcsec^2)		
		Existing Sky Glow[a] (mag/arcsec^2)	Sky Glow Threshold[b] (mag/arcsec^2)	Comment	Summertime Cloudy Skies	Wintertime Cloudy Skies	Wintertime Clear Skies
R-04	Light 5	20.5	20	Existing conditions are darker than threshold	19.8	20.8	20.1
R-05	Light 9	20.1	20	Existing conditions are darker than threshold	20.7	20.8	20.7
R-06	Light 9	20.1	20	Existing conditions are darker than threshold	20.7	20.8	20.7
R-07	Light 9	20.1	20	Existing conditions are darker than threshold	20.7	20.8	20.7
R-08	Light 9	20.1	20	Existing conditions are darker than threshold	20.7	20.8	20.7
R-09	Light 9	20.1	20	Existing conditions are darker than threshold	20.7	20.8	20.7
R-22	Light 8	19.9	20	Existing conditions are brighter than threshold	20.6	21.6	20.3
R-26	Light 9	20.1	20	Existing conditions are darker than threshold	20.7	20.8	20.7
R-30	Light 8	19.9	20	Existing conditions are brighter than threshold	20.6	21.6	20.3
R-31	Light 9	20.1	20	Existing conditions are darker than threshold	20.7	20.8	20.7
R-40	Light 5	20.5	20	Existing conditions are darker than threshold	19.8	20.8	20.1
R-41	Light 9	20.1	20	Existing conditions are darker than threshold	20.7	20.8	20.7
R-42	Light 8	19.9	20	Existing conditions are brighter than threshold	20.6	21.6	20.3
R-43	Light 8	19.9	20	Existing conditions are brighter than threshold	20.6	21.6	20.3
R-48	Light 9	20.1	20	Existing conditions are darker than threshold	20.7	20.8	20.7
R-49	Light 8	19.9	20	Existing conditions are brighter than threshold	20.6	21.6	20.3

a) Existing light trespass levels were measured during a baseline field program (Annex II).

b) Sky glow threshold applicable to environmental lighting zone E1 (ILP 2020). These thresholds are applicable under summertime conditions with clear skies; there are no sky glow thresholds applicable to other environmental conditions.

mag/arcsec^2 = magnitude per square second of arc.

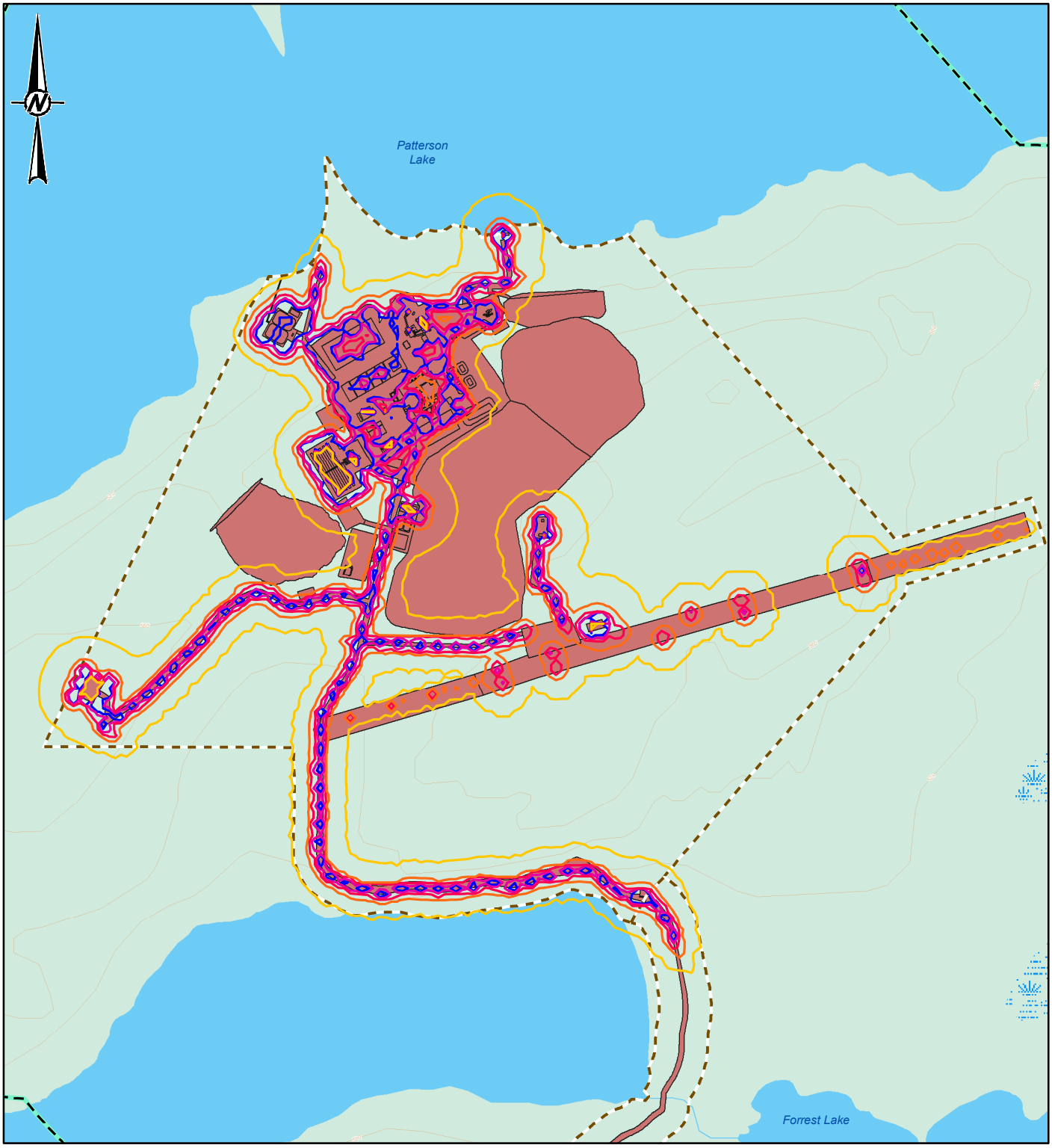
3.2 Application Case

3.2.1 Construction

Figure 3-1 presents a light trespass contour map showing predicted light trespass levels for the Project during Construction. As shown in Figure 3-1 light trespass from Construction is predicted to be primarily confined to the maximum disturbance area. However, there are several places where light trespass is predicted to extend beyond the maximum to the area by up to 200 m (e.g., adjacent the surface explosives magazine, intake water facility, and gatehouse).

For each of the 16 receptors considered in the light analysis, Table 3-3 presents predicted Application Case cumulative light trespass levels during Construction. Application Case cumulative light trespass levels were calculated by summing predictions from the AGi32 light trespass model of Construction with existing light trespass levels (Table 3-2).

Table 3-3 also compares Application Case cumulative light trespass levels during Construction to the light trespass threshold applicable to environmental light zone E1 (CIE 2017). Table 3-3 shows that Application Case cumulative light trespass levels during Project Construction are predicted to comply with the applicable light trespass threshold. Moreover, Table 3-3 shows that Application Case cumulative light trespass levels during Construction would be effectively identical to existing light trespass levels; in other words, Construction would result in no change to existing light trespass levels at receptors in the light study area. This result does not mean that artificial light associated with Construction would not be visible in the light study area. Project lights would be visible from any location where there is direct line of sight. However, artificial light associated with Construction would not result in increased illumination at receptors in the light study area.



LEGEND

- ELEVATION CONTOUR (20 m INTERVAL)
- WATERCOURSE
- WATERBODY
- WETLAND
- WOODED AREA
- MAXIMUM DISTURBANCE AREA
- PROPOSED PROJECT FOOTPRINT
- LIGHT LOCAL STUDY AREA

PREDICTED LIGHT TRESPASS LEVEL [LUX]

- 0.001 LUX
- 0.1 LUX
- 1 LUX
- 5 LUX
- 10 LUX

0 0.6 1.2
1:24,000 KILOMETRES

REFERENCE(S)
1. PROJECT FEATURES OBTAINED FROM NEXGEN, APRIL 6, 2021
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PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT
NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LIGHT TRESPASS - PROJECT CONSTRUCTION

CONSULTANT
GOLDER MEMBER OF WSP

PROJECT		20144150	PHASE	3102 - 3
DESIGN	VY	2022-03-02	SCALE AS SHOWN	REV. 0
GIS	NO	2022-03-02	**FIGURE 3-1**	
CHECK	VY	2022-03-02		
REVIEW	AF	2022-03-02		

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Table 3-3: Application Case Cumulative Light Trespass Levels during Construction

Receptor Identification Code	Existing Light Trespass Level (mlux)				Predicted Light Trespass from Project Construction (mlux)	Cumulative Light Trespass Level (mlux)				Light Trespass Threshold[(a)] (mlux)
	Summertime Cloudy Skies	Summertime Clear Skies	Wintertime Cloudy Skies	Wintertime Clear Skies		Summertime Cloudy Skies	Summertime Clear Skies	Wintertime Cloudy Skies	Wintertime Clear Skies	
R-04	6	3	1	3	0	6	3	1	3	100
R-05	3	4	22	4	0	3	4	22	4	100
R-06	3	4	22	4	0	3	4	22	4	100
R-07	3	4	22	4	0	3	4	22	4	100
R-08	3	4	22	4	0	3	4	22	4	100
R-09	3	4	22	4	0	3	4	22	4	100
R-22	0	0	1	3	0	0	0	1	3	100
R-26	3	4	22	4	0	3	4	22	4	100
R-30	0	0	1	3	0	0	0	1	3	100
R-31	3	4	22	4	0	3	4	22	4	100
R-40	6	3	1	3	0	6	3	1	3	100
R-41	3	4	22	4	0	3	4	22	4	100
R-42	0	0	1	3	0	0	0	1	3	100
R-43	0	0	1	3	0	0	0	1	3	100
R-48	3	4	22	4	0	3	4	22	4	100
R-49	0	0	1	3	0	0	0	1	3	100

a) Light trespass threshold applicable to environmental lighting zone E1 (CIE 2017).
mlux = millilux (0.001 lumen per square metre).

For each of the 16 receptors considered in the light analysis, Table 3-4 presents predicted Application Case cumulative sky glow levels during Construction. Application Case cumulative sky glow levels were calculated by summing predictions from the Garstang (1986) sky glow model of Construction with existing sky glow levels (Table 3-2). Note that sky glow levels are expressed in units (mag/arcsec^2) that do not sum in the conventional manner. For example, 20.5 mag/arcsec^2 + 20.6 mag/arcsec^2 = 19.8 mag/arcsec^2 (not 41.1 mag/arcsec^2).

As discussed in Section 2.5.1, Inputs and Assumptions, sky glow levels were predicted for summertime clear skies and wintertime clear skies. The Garstang model cannot predict sky glow during cloudy periods, so these conditions were not considered in the analysis. As discussed in Section 2.1.1, the ILP sky glow threshold only applies to summertime clear skies, so the inability to predict sky glow under cloudy skies does not limit the validity of the light analysis.

For the summertime clear skies modelling scenario, Table 3-4 compares Application Case cumulative sky glow levels during Construction to the sky glow threshold applicable to environmental lighting zone E1 (ILP 2020). Results presented in Table 3-4 suggest Application Case cumulative sky glow levels during Construction would result in skies brighter than the E1 threshold for 15 of the 16 receptors considered in the light analysis. For context, note that existing sky glow levels at five receptors (R-22, R-30, R-42, R-43, and R-49) already exceed the E1 threshold (Table 3-2). Also, note that the maximum difference between the predicted sky glow level in Table 3-4 and the E1 threshold is 1.4 mag/arcsec^2 (receptor R-48), which is less than the 1.7 mag/arcsec^2 difference between existing sky glow levels under summertime clear skies and wintertime cloudy skies (Table 3-2). This suggests the magnitude of the elevated sky glow predicted for the Application Case can be considered small within the context of variability in the existing environment. Moreover, none of the Application Case cumulative sky glow predicted for Construction is brighter than the 15 mag/arcsec^2 threshold that applies to environmental lighting zone E2. In other words, the ILP would consider sky glow associated with Construction to be reasonable and acceptable for a sparsely inhabited rural area (ILP 2020).

Table 3-4: Application Case Cumulative Sky Glow Levels during Construction

Receptor Identification Code	Summertime Clear Skies					Wintertime Clear Skies		
	Existing Sky Glow (mag/arcsec^2)	Predicted Sky Glow from the Construction (mag/arcsec^2)	Cumulative Sky Glow (mag/arcsec^2)	Sky Glow Threshold[(a)] (mag/arcsec^2)	Comment	Existing Sky Glow (mag/arcsec^2)	Predicted Sky Glow from Construction (mag/arcsec^2)	Cumulative Sky Glow (mag/arcsec^2)
R-04	20.5	20.6	19.8	20	Brighter than threshold	20.1	19.4	18.9
R-05	20.1	20.4	19.5	20	Brighter than threshold	20.7	19.3	19.0
R-06	20.1	20.6	19.6	20	Brighter than threshold	20.7	19.5	19.2
R-07	20.1	21.9	19.9	20	Brighter than threshold	20.7	20.8	20.0
R-08	20.1	20.8	19.6	20	Brighter than threshold	20.7	19.7	19.3
R-09	20.1	19.9	19.2	20	Brighter than threshold	20.7	18.7	18.5
R-22	19.9	19.8	19.1	20	Brighter than threshold	20.3	18.6	18.4
R-26	20.1	19.9	19.2	20	Brighter than threshold	20.7	18.7	18.5
R-30	19.9	19.5	18.9	20	Brighter than threshold	20.3	18.3	18.1
R-31	20.1	19.9	19.2	20	Brighter than threshold	20.7	18.7	18.5
R-40	20.5	21.5	20.1	20	Darker than threshold	20.1	20.4	19.5
R-41	20.1	19.6	19.1	20	Brighter than threshold	20.7	18.4	18.3
R-42	19.9	20.1	19.2	20	Brighter than threshold	20.3	19.0	18.7
R-43	19.9	20.6	19.4	20	Brighter than threshold	20.3	19.4	19.0
R-48	20.1	18.9	18.6	20	Brighter than threshold	20.7	17.7	17.6
R-49	19.9	19.6	19.0	20	Brighter than threshold	20.3	18.4	18.2

a) Sky glow threshold applicable to environmental lighting zone E1 (ILP 2020). These thresholds are applicable under summertime conditions with clear skies.

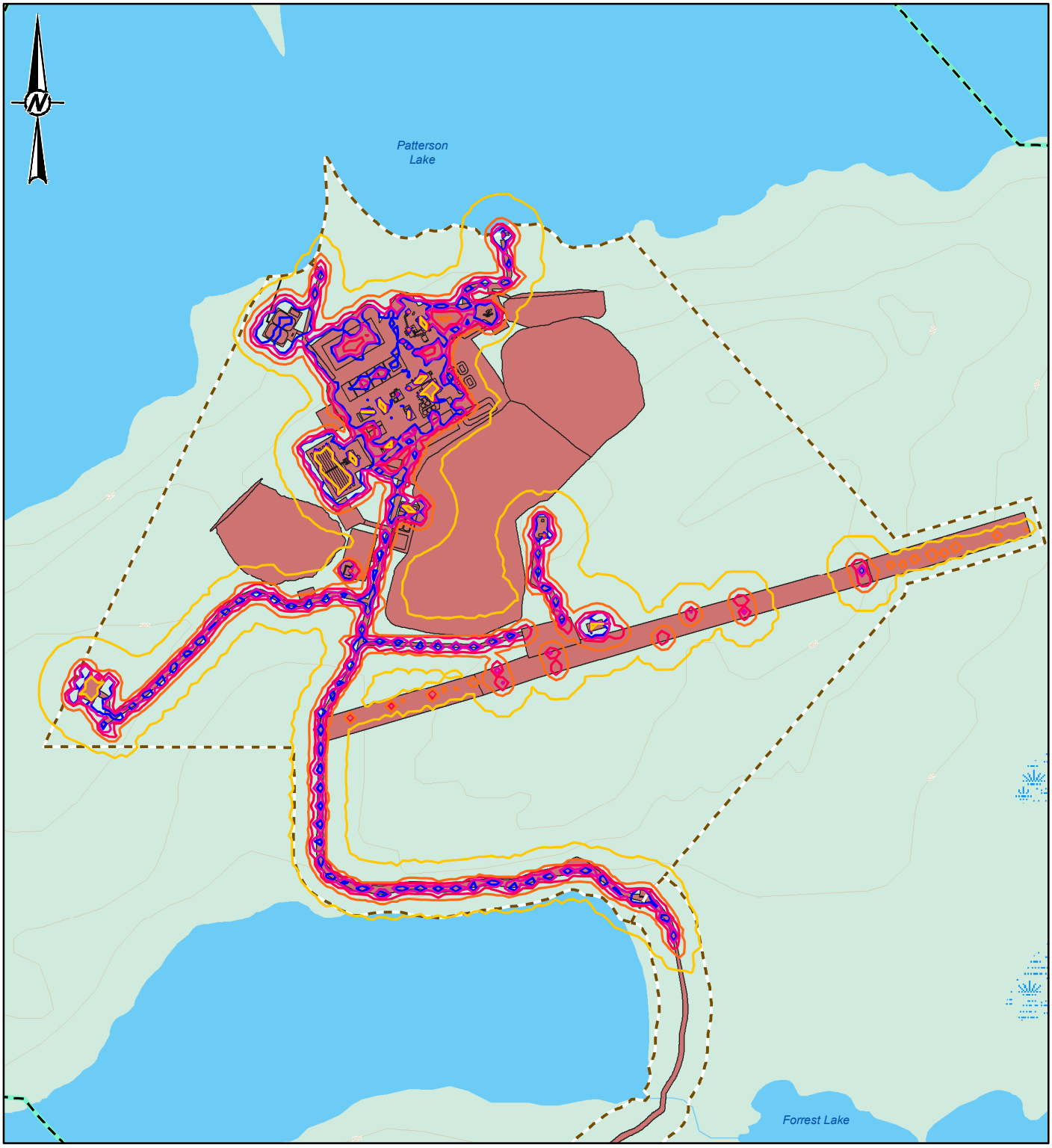
mag/arcsec^2 = magnitude per square second of arc.

3.2.2 Operations

Figure 3-2 presents a light trespass contour map showing predicted light trespass levels for the Project during Operations. As shown in Figure 3-2, light trespass from Operations is predicted to be primarily confined to the maximum disturbance area. However, there are several places where light trespass is predicted to extend beyond the maximum disturbance area by up to 200 m (e.g., adjacent the surface explosives magazine, intake water facility, and gatehouse).

For each of the 16 receptors considered in the light analysis, Table 3-5 presents predicted Application Case cumulative light trespass levels during Operations. Application Case cumulative light trespass levels were calculated by summing predictions from the AGi32 light trespass model of Operations with existing light trespass levels (Table 3-2).

Table 3-5 also compares Application Case cumulative light trespass levels during Operations to the light trespass threshold applicable to environmental light zone E1 (CIE 2017). Table 3-5 shows that Application Case cumulative light trespass levels during Operations are predicted to comply with the applicable light trespass threshold. Moreover, Table 3-5 shows that Application Case cumulative light trespass levels during Operations would be effectively identical to existing light trespass levels; in other words, Operations would result in no change to existing light trespass levels at receptors in the light study area. This result does not mean that artificial light associated with Operations would not be visible in the light study area. Project lights would be visible from any location where there is direct line of sight. However, artificial light associated with Operations would not result in increased illumination at receptors in the light study area.



LEGEND

- ELEVATION CONTOUR (20 m INTERVAL)
- WATERCOURSE
- WATERBODY
- WETLAND
- WOODED AREA
- MAXIMUM DISTURBANCE AREA
- PROPOSED PROJECT FOOTPRINT
- LIGHT LOCAL STUDY AREA

PREDICTED LIGHT TRESPASS LEVEL [LUX]

- 0.001 LUX
- 0.1 LUX
- 1 LUX
- 5 LUX
- 10 LUX

0 0.6 1.2
1:24,000 KILOMETRES

REFERENCE(S)
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PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT
NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LIGHT TRESPASS - OPERATIONS

CONSULTANT
GOLDER MEMBER OF WSP

PROJECT		20144150	PHASE	3102 - 3
DESIGN	VY	2022-03-02	SCALE AS SHOWN	REV. 0
GIS	NO	2022-03-02	**FIGURE 3-2**	
CHECK	VY	2022-03-02		
REVIEW	AF	2022-03-02		

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Table 3-5: Application Case Cumulative Light Trespass Levels during Operations

Receptor Identification Code	Existing Light Trespass Level (mlux)				Predicted Light Trespass from Operations (mlux)	Cumulative Light Trespass Level (mlux)				Light Trespass Threshold[a] (mlux)
	Summertime Cloudy Skies	Summertime Clear Skies	Wintertime Cloudy Skies	Wintertime Clear Skies		Summertime Cloudy Skies	Summertime Clear Skies	Wintertime Cloudy Skies	Wintertime Clear Skies	
R-04	6	3	1	3	0	6	3	1	3	100
R-05	3	4	22	4	0	3	4	22	4	100
R-06	3	4	22	4	0	3	4	22	4	100
R-07	3	4	22	4	0	3	4	22	4	100
R-08	3	4	22	4	0	3	4	22	4	100
R-09	3	4	22	4	0	3	4	22	4	100
R-22	0	0	1	3	0	0	0	1	3	100
R-26	3	4	22	4	0	3	4	22	4	100
R-30	0	0	1	3	0	0	0	1	3	100
R-31	3	4	22	4	0	3	4	22	4	100
R-40	6	3	1	3	0	6	3	1	3	100
R-41	3	4	22	4	0	3	4	22	4	100
R-42	0	0	1	3	0	0	0	1	3	100
R-43	0	0	1	3	0	0	0	1	3	100
R-48	3	4	22	4	0	3	4	22	4	100
R-49	0	0	1	3	0	0	0	1	3	100

a) Light trespass threshold applicable to environmental lighting zone E1 (CIE 2017).
mlux = millilux (0.001 lumen per square metre).

For each of the 16 receptors considered in the light analysis, Table 3-6 presents predicted Application Case cumulative sky glow levels during Operations. Application Case cumulative sky glow levels were calculated by summing predictions from the Garstang (1986) sky glow model of Operations with existing sky glow levels (Table 3-2). Note that sky glow levels are expressed in units (mag/arcsec^2) that do not sum in the conventional manner. For example, 20.5 mag/arcsec^2 + 20.5 mag/arcsec^2 = 19.7 mag/arcsec^2 (not 41.0 mag/arcsec^2).

As discussed in Section 2.5.1, sky glow levels were predicted for summertime clear skies and wintertime clear skies. The Garstang model cannot predict sky glow during cloudy periods, so these conditions were not considered in the analysis. As discussed in Section 2.1.1, the ILP sky glow threshold only applies to summertime clear skies, so the inability to predict sky glow under cloudy skies does not limit the validity of the light analysis.

For the summertime clear skies modelling scenario, Table 3-6 compares Application Case cumulative sky glow levels during Operations to the sky glow threshold applicable to environmental lighting zone E1 (ILP 2020). Results presented in Table 3-6 suggest Application Case cumulative sky glow levels during Operations would result in skies brighter than the E1 threshold for 15 of the 16 receptors considered in the light analysis. For context, note that existing sky glow levels at five receptors (R-22, R-30, R-42, R-43, and R-49) already exceed the E1 threshold (Table 3-2). Also, note that the maximum difference between the predicted sky glow level in Table 3-6 and the E1 threshold is 1.4 mag/arcsec^2 (receptor R-48), which is less than the 1.7 mag/arcsec^2 difference between existing sky glow levels under summertime clear skies and wintertime cloudy skies (Table 3-2). This suggests the magnitude of the elevated sky glow predicted for the Application Case can be considered small within the context of variability in the existing environment. Moreover, none of the Application Case cumulative sky glow predicted for Operations is brighter than the 15 mag/arcsec^2 threshold that applies to environmental lighting zone E2. In other words, the ILP would consider sky glow associated with Operations to be reasonable and acceptable for a sparsely inhabited rural area (ILP 2020).

Table 3-6: Application Case Cumulative Sky Glow Levels during Operations

Receptor Identification Code	Summertime Clear Skies					Wintertime Clear Skies		
	Existing Sky Glow (mag/arcsec^2)	Predicted Sky Glow from Operations (mag/arcsec^2)	Cumulative Sky Glow (mag/arcsec^2)	Sky Glow Threshold[(a)] (mag/arcsec^2)	Comment	Existing Sky Glow (mag/arcsec^2)	Predicted Sky Glow from Operations (mag/arcsec^2)	Cumulative Sky Glow (mag/arcsec^2)
R-04	20.5	20.5	19.7	20	Brighter than threshold	20.1	19.4	18.9
R-05	20.1	20.4	19.5	20	Brighter than threshold	20.7	19.2	19.0
R-06	20.1	20.6	19.6	20	Brighter than threshold	20.7	19.4	19.1
R-07	20.1	21.8	19.9	20	Brighter than threshold	20.7	20.7	19.9
R-08	20.1	20.8	19.6	20	Brighter than threshold	20.7	19.6	19.3
R-09	20.1	19.8	19.2	20	Brighter than threshold	20.7	18.7	18.5
R-22	19.9	19.7	19.0	20	Brighter than threshold	20.3	18.6	18.4
R-26	20.1	19.8	19.2	20	Brighter than threshold	20.7	18.6	18.5
R-30	19.9	19.4	18.9	20	Brighter than threshold	20.3	18.2	18.1
R-31	20.1	19.9	19.2	20	Brighter than threshold	20.7	18.7	18.5
R-40	20.5	21.5	20.1	20	Darker than threshold	20.1	20.3	19.4
R-41	20.1	19.5	19.0	20	Brighter than threshold	20.7	18.3	18.2
R-42	19.9	20.1	19.2	20	Brighter than threshold	20.3	18.9	18.6
R-43	19.9	20.5	19.4	20	Brighter than threshold	20.3	19.4	19.0
R-48	20.1	18.9	18.6	20	Brighter than threshold	20.7	17.7	17.6
R-49	19.9	19.5	18.9	20	Brighter than threshold	20.3	18.3	18.1

a) Sky glow threshold applicable to environmental lighting zone E1 (ILP 2020). These thresholds are applicable under summertime conditions with clear skies.
mag/arcsec^2 = magnitude per square second of arc.

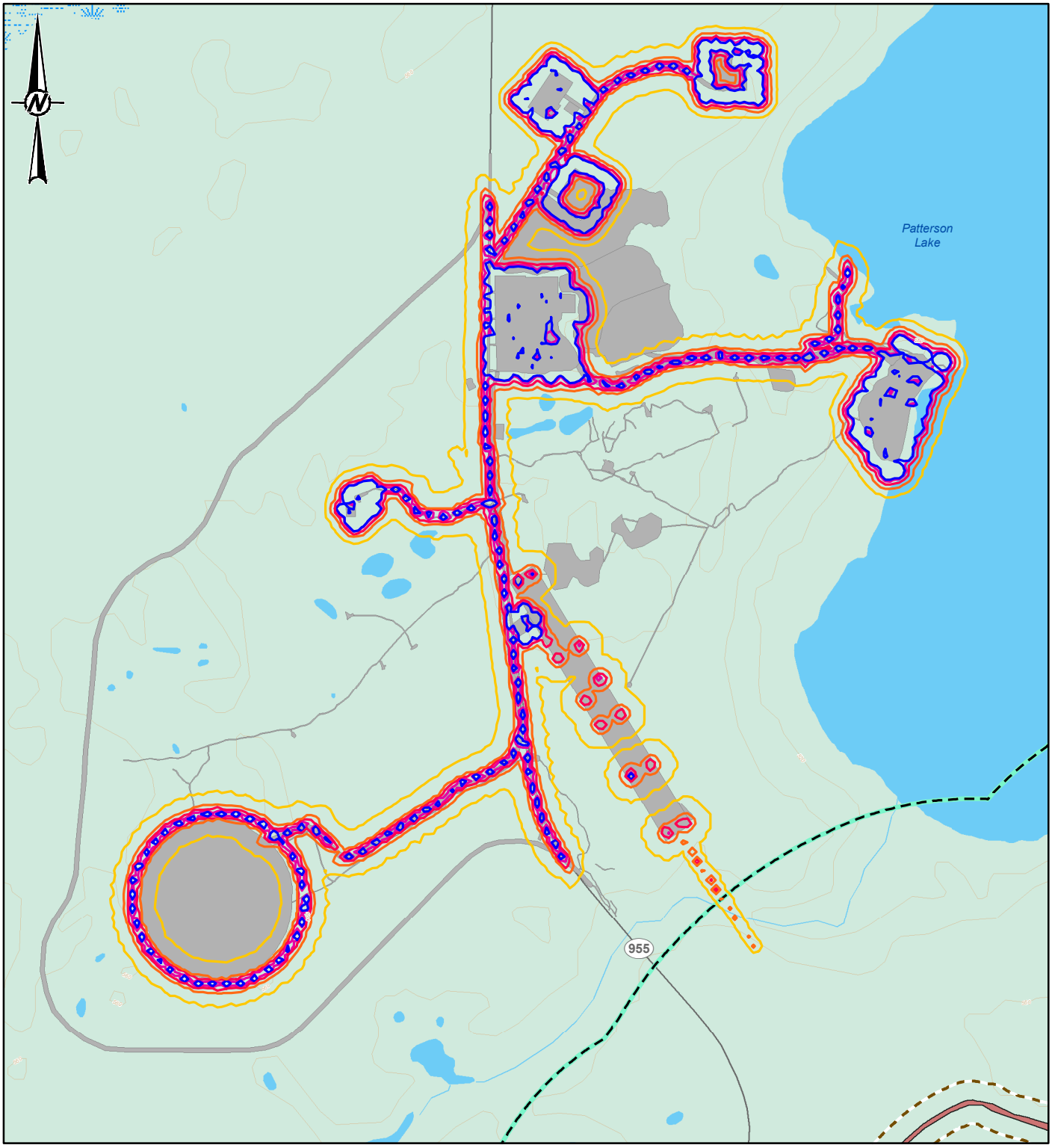
3.3 Reasonably Foreseeable Development Case

Figure 3-3 presents a light trespass contour map showing predicted light trespass levels associated with the Fission Patterson Lake South Property. As shown in Figure 3-3, light trespass from the Fission Patterson Lake South Property is predicted to be confined to an area with approximately 200 m of the Fission Patterson Lake South Property footprint.

For each of the 16 receptors considered in the light analysis, Table 3-7 presents predicted RFD Case cumulative light trespass levels during Construction. These RFD Case cumulative light trespass levels were calculated by summing predictions from the AGi32 light trespass models of Construction and the Fission Patterson Lake South Property with existing light trespass levels (Table 3-2).

For each of the 16 receptors considered in the light analysis, Table 3-7 presents predicted RFD Case cumulative light trespass levels during Operations. These RFD Case cumulative light trespass levels were calculated by summing predictions from the AGi32 light trespass models of Operations and the Fission Patterson Lake South Property with existing light trespass levels (Table 3-2).

Table 3-7 and Table 3-8 also compare RFD Case cumulative light trespass levels to the light trespass threshold applicable to environmental light zone E1 (CIE 2017). Table 3-7 and Table 3-8 show that RFD Case cumulative light trespass levels are predicted to comply with the applicable light trespass threshold. Moreover, Table 3-7 and Table 3-8 show that RFD Case cumulative light trespass levels are effectively identical to existing light trespass levels; in other words, the Project and the Fission Patterson Lake South Property would result in no change to existing light trespass levels at receptors in the light study area. This result does not mean that artificial light associated with the Project or Fission Patterson Lake South Property would not be visible in the light study area. Artificial lights would be visible from any location where there is direct line of sight. However, artificial light associated with the Project and the Fission Patterson Lake South Property would not result in increased illumination at receptors in the light study area.



LEGEND

- ELEVATION CONTOUR (20 m INTERVAL)
- SECONDARY HIGHWAY
- WATERCOURSE
- WATERBODY
- WETLAND
- WOODED AREA
- MAXIMUM DISTURBANCE AREA
- PROPOSED PROJECT FOOTPRINT
- FISSION PATTERSON LAKE SOUTH PROPERTY FOOTPRINT
- LIGHT LOCAL STUDY AREA

PREDICTED LIGHT TRESPASS LEVEL [LUX]

- 0.001 LUX
- 0.1 LUX
- 1 LUX
- 5 LUX
- 10 LUX

0 0.8 1.6
1:30,000 KILOMETRES

REFERENCE(S)

1. PROJECT FEATURES OBTAINED FROM NEXGEN, APRIL 6, 2021
2. BASE DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
3. FISSION (FISSION URANIUM CORP.) OBTAINED FROM 2019 TECHNICAL REPORT ON THE PRE-FEASIBILITY STUDY OF THE PATTERSON LAKE SOUTH PROPERTY USING UNDERGROUND MINING METHODS.

PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

NexGen Energy Ltd.

ROOK I PROJECT

TITLE

LIGHT TRESPASS - FISSION PATTERSON LAKE SOUTH PROPERTY

CONSULTANT

GOLDER MEMBER OF WSP

PROJECT		20144150	PHASE	3102 - 3
DESIGN	VY	2022-03-02	SCALE AS SHOWN	REV. 0
GIS	NO	2022-03-02	**FIGURE 3-3**	
CHECK	VY	2022-03-02		
REVIEW	AF	2022-03-02		

PATH: I:\CLIENTS\NexGen\20144150\Mapping\Products\Noise\Light\HAssessment\Technical\SupportDocument\Figures\20144150_Fig3-3_Rook_I_Light_Trespass_Project_Patterson Lake South Property_Rev0.mxd PRINTED ON: 2022-03-02 AT: 3:11:41 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

25mm

Table 3-7: Reasonably Foreseeable Development Case Cumulative Light Trespass Levels during Construction

Receptor Identification Code	Existing Light Trespass Level (mlux)				Predicted Light Trespass from Construction (mlux)	Predicted Light Trespass from Fission Patterson Lake South Property (mlux)	Cumulative Light Trespass Level (mlux)				Light Trespass Threshold[a] (mlux)
	Summertime Cloudy Skies	Summertime Clear Skies	Wintertime Cloudy Skies	Wintertime Clear Skies			Summertime Cloudy Skies	Summertime Clear Skies	Wintertime Cloudy Skies	Wintertime Clear Skies	
R-04	6	3	1	3	0	0	6	3	1	3	100
R-05	3	4	22	4	0	0	3	4	22	4	100
R-06	3	4	22	4	0	0	3	4	22	4	100
R-07	3	4	22	4	0	0	3	4	22	4	100
R-08	3	4	22	4	0	0	3	4	22	4	100
R-09	3	4	22	4	0	0	3	4	22	4	100
R-22	0	0	1	3	0	0	0	0	1	3	100
R-26	3	4	22	4	0	0	3	4	22	4	100
R-30	0	0	1	3	0	0	0	0	1	3	100
R-31	3	4	22	4	0	0	3	4	22	4	100
R-40	6	3	1	3	0	0	6	3	1	3	100
R-41	3	4	22	4	0	0	3	4	22	4	100
R-42	0	0	1	3	0	0	0	0	1	3	100
R-43	0	0	1	3	0	0	0	0	1	3	100
R-48	3	4	22	4	0	0	3	4	22	4	100
R-49	0	0	1	3	0	0	0	0	1	3	100

a) Light trespass threshold applicable to environmental lighting zone E1 (CIE 2017).
mlux = millilux (0.001 lumen per square metre).

Table 3-8: Reasonably Foreseeable Development Case Cumulative Light Trespass Levels during Operations

Receptor Identification Code	Existing Light Trespass Level (mlux)				Predicted Light Trespass from Operations (mlux)	Predicted Light Trespass from Fission Patterson Lake South Property (mlux)	Cumulative Light Trespass Level (mlux)				Light Trespass Threshold[a] (mlux)
	Summertime Cloudy Skies	Summertime Clear Skies	Wintertime Cloudy Skies	Wintertime Clear Skies			Summertime Cloudy Skies	Summertime Clear Skies	Wintertime Cloudy Skies	Wintertime Clear Skies	
R-04	6	3	1	3	0	0	6	3	1	3	100
R-05	3	4	22	4	0	0	3	4	22	4	100
R-06	3	4	22	4	0	0	3	4	22	4	100
R-07	3	4	22	4	0	0	3	4	22	4	100
R-08	3	4	22	4	0	0	3	4	22	4	100
R-09	3	4	22	4	0	0	3	4	22	4	100
R-22	0	0	1	3	0	0	0	0	1	3	100
R-26	3	4	22	4	0	0	3	4	22	4	100
R-30	0	0	1	3	0	0	0	0	1	3	100
R-31	3	4	22	4	0	0	3	4	22	4	100
R-40	6	3	1	3	0	0	6	3	1	3	100
R-41	3	4	22	4	0	0	3	4	22	4	100
R-42	0	0	1	3	0	0	0	0	1	3	100
R-43	0	0	1	3	0	0	0	0	1	3	100
R-48	3	4	22	4	0	0	3	4	22	4	100
R-49	0	0	1	3	0	0	0	0	1	3	100

a) Light trespass threshold applicable to environmental lighting zone E1 (CIE 2017).
mlux = millilux (0.001 lumen per square metre).

For each of the 16 receptors considered in the light analysis, Table 3-9 presents predicted RFD Case cumulative sky glow levels during Construction. These RFD Case cumulative sky glow levels were calculated by summing predictions from the Garstang (1986) sky glow models of Construction and the Fission Patterson Lake South Property with existing sky glow levels (Table 3-2).

For each of the 16 receptors considered in the light analysis, Table 3-10 presents predicted RFD Case cumulative sky glow levels during Operations. These RFD Case cumulative sky glow levels were calculated by summing predictions from the Garstang (1986) sky glow models of Operations and the Fission Patterson Lake South Property with existing sky glow levels (Table 3-2).

As discussed in Section 2.5.1, sky glow levels were predicted for summertime clear skies and wintertime clear skies. The Garstang model cannot predict sky glow during cloudy periods, so these conditions were not considered in the analysis. As discussed in Section 2.1.1, the ILP sky glow threshold only applies to summertime clear skies, so the inability to predict sky glow under cloudy skies does not limit the validity of the light analysis.

For the summertime clear skies modelling scenario, Table 3-9 and Table 3-10 compare RFD Case cumulative sky glow levels to the sky glow threshold applicable to environmental lighting zone E1 (ILP 2020). Results presented in Table 3-9 and Table 3-10 suggest RFD Case cumulative sky glow levels would result in skies brighter than the E1 threshold for all 16 receptors considered in the light analysis. For context, note that existing sky glow levels at five receptors (R-22, R-30, R-42, R-43, and R-49) already exceed the E1 threshold (Table 3-2). Also, note that the maximum difference between the predicted sky glow level in Table 3-9 or Table 3-10 and the E1 threshold is 1.9 mag/arcsec^2 (receptor R-22), which is very close to the 1.7 mag/arcsec^2 difference between existing sky glow levels under summertime clear skies and wintertime cloudy skies (Table 3-2). This suggests the magnitude of the elevated sky glow predicted for the RFD Case can be considered small within the context of variability in the existing environment. Moreover, none of the RFD Case cumulative sky glow is predicted to be brighter than the 15 mag/arcsec^2 threshold that applies to environmental lighting zone E2. In other words, the ILP would consider cumulative sky glow associated with the Project and the Fission Patterson Lake South Property to be reasonable and acceptable for a sparsely inhabited rural area (ILP 2020).

Table 3-9: Reasonably Foreseeable Development Case Cumulative Sky Glow Levels during Construction

Receptor Identification Code	Summertime Clear Skies						Wintertime Clear Skies			
	Existing Sky Glow (mag/arcsec^2)	Predicted Sky Glow from Construction (mag/arcsec^2)	Predicted Sky Glow from the Fission Patterson Lake South Property (mag/arcsec^2)	Cumulative Sky Glow (mag/arcsec^2)	Sky Glow Threshold[(a)] (mag/arcsec^2)	Comment	Existing Sky Glow (mag/arcsec^2)	Predicted Sky Glow from Construction (mag/arcsec^2)	Predicted Sky Glow from the Fission Patterson Lake South Property (mag/arcsec^2)	Cumulative Sky Glow (mag/arcsec^2)
R-04	20.5	20.6	20.7	19.4	20	Brighter than threshold	20.1	19.4	19.5	18.4
R-05	20.1	20.4	21.6	19.3	20	Brighter than threshold	20.7	19.3	20.4	18.8
R-06	20.1	20.6	21.7	19.4	20	Brighter than threshold	20.7	19.5	20.5	18.9
R-07	20.1	21.9	22.9	19.8	20	Brighter than threshold	20.7	20.8	21.7	19.8
R-08	20.1	20.8	21.9	19.5	20	Brighter than threshold	20.7	19.7	20.7	19.1
R-09	20.1	19.9	20.7	19.0	20	Brighter than threshold	20.7	18.7	19.4	18.1
R-22	19.9	19.8	18.7	18.1	20	Brighter than threshold	20.3	18.6	17.4	17.0
R-26	20.1	19.9	21.0	19.0	20	Brighter than threshold	20.7	18.7	19.8	18.2
R-30	19.9	19.5	19.0	18.2	20	Brighter than threshold	20.3	18.3	17.7	17.1
R-31	20.1	19.9	20.7	19.0	20	Brighter than threshold	20.7	18.7	19.5	18.2
R-40	20.5	21.5	20.1	19.4	20	Brighter than threshold	20.1	20.4	18.9	18.4
R-41	20.1	19.6	21.5	19.0	20	Brighter than threshold	20.7	18.4	20.3	18.1
R-42	19.9	20.1	19.2	18.5	20	Brighter than threshold	20.3	19.0	17.9	17.5
R-43	19.9	20.6	20.8	19.2	20	Brighter than threshold	20.3	19.4	19.6	18.5
R-48	20.1	18.9	19.5	18.2	20	Brighter than threshold	20.7	17.7	18.3	17.2
R-49	19.9	19.6	19.0	18.2	20	Brighter than threshold	20.3	18.4	17.8	17.2

a) Sky glow threshold applicable to environmental lighting zone E1 (ILP 2020). These thresholds are applicable under summertime conditions with clear skies.
mag/arcsec^2 = magnitude per square second of arc.

Table 3-10: Reasonably Foreseeable Development Case Cumulative Sky Glow Levels during Operations

Receptor Identification Code	Summertime Clear Skies						Wintertime Clear Skies			
	Existing Sky Glow (mag/arcsec^2)	Predicted Sky Glow from Operations (mag/arcsec^2)	Predicted Sky Glow from the Fission Patterson Lake South Property (mag/arcsec^2)	Cumulative Sky Glow (mag/arcsec^2)	Sky Glow Threshold[(a)] (mag/arcsec^2)	Comment	Existing Sky Glow (mag/arcsec^2)	Predicted Sky Glow from Operations (mag/arcsec^2)	Predicted Sky Glow from the Fission Patterson Lake South Property (mag/arcsec^2)	Cumulative Sky Glow (mag/arcsec^2)
R-04	20.5	20.5	20.7	19.4	20	Brighter than threshold	20.1	19.4	19.5	18.4
R-05	20.1	20.4	21.6	19.3	20	Brighter than threshold	20.7	19.2	20.4	18.7
R-06	20.1	20.6	21.7	19.4	20	Brighter than threshold	20.7	19.4	20.5	18.8
R-07	20.1	21.8	22.9	19.8	20	Brighter than threshold	20.7	20.7	21.7	19.8
R-08	20.1	20.8	21.9	19.5	20	Brighter than threshold	20.7	19.6	20.7	19.0
R-09	20.1	19.8	20.7	18.9	20	Brighter than threshold	20.7	18.7	19.4	18.1
R-22	19.9	19.7	18.7	18.1	20	Brighter than threshold	20.3	18.6	17.4	17.0
R-26	20.1	19.8	21.0	19.0	20	Brighter than threshold	20.7	18.6	19.8	18.2
R-30	19.9	19.4	19.0	18.2	20	Brighter than threshold	20.3	18.2	17.7	17.1
R-31	20.1	19.9	20.7	19.0	20	Brighter than threshold	20.7	18.7	19.5	18.2
R-40	20.5	21.5	20.1	19.4	20	Brighter than threshold	20.1	20.3	18.9	18.4
R-41	20.1	19.5	21.5	18.9	20	Brighter than threshold	20.7	18.3	20.3	18.0
R-42	19.9	20.1	19.2	18.5	20	Brighter than threshold	20.3	18.9	17.9	17.5
R-43	19.9	20.5	20.8	19.1	20	Brighter than threshold	20.3	19.4	19.6	18.5
R-48	20.1	18.9	19.5	18.2	20	Brighter than threshold	20.7	17.7	18.3	17.2
R-49	19.9	19.5	19.0	18.2	20	Brighter than threshold	20.3	18.3	17.8	17.2

a) Sky glow threshold applicable to environmental lighting zone E1 (ILP 2020). These thresholds are applicable under summertime conditions with clear skies.
mag/arcsec^2 = magnitude per square second of arc.

4 KEY FINDINGS

Results from the analyses predict that light trespass from the Project and from the Fission Patterson Lake South Property would be less than light trespass thresholds from the CIE guidance document (CIE 2017). Moreover, light trespass levels at the 16 receptors are predicted to be unchanged as a result of the Project and the proposed Fission Patterson Lake South Property. In other words, cumulative light trespass levels would be equal to existing light trespass levels for all 16 receptors. This result does not mean that artificial light associated with the Project or Fission Patterson Lake South Property would not be visible in the light study area. Artificial lights would be visible from any location where there is direct line of sight. However, artificial light associated with the Project and the Fission Patterson Lake South Property would not result in increased illumination at receptors in the light study area.

Results from the analyses predict that, for some receptors and environmental conditions, sky glow from the Project would be brighter than the ILP threshold applicable to environmental lighting zone E1 – “relatively uninhabited rural area” (ILP 2020). For all receptors, cumulative sky glow from the Project in combination with the Fission Patterson Lake South Property is predicted to be brighter than the E1 threshold.

For context, note that existing sky glow levels at five receptors already exceed the E1 threshold. Also, note that the difference between the predicted sky glow levels and the E1 threshold can be considered small within the context of variability in the existing environment. Moreover, cumulative sky glow from the Project in combination with the Fission Patterson Lake South Property is predicted to be less bright than the ILP threshold applicable to environmental lighting zone E2 – “sparsely inhabited rural area” (ILP 2020). In other words, the ILP would consider cumulative sky glow associated with the Project and the proposed Fission Patterson Lake South Property to be reasonable and acceptable for a sparsely inhabited rural area (ILP 2020).

The significance of potential light effects on VCs is assessed in the following sections of the EIS:

- fish and fish habitat (EIS Section 11);
- wildlife and wildlife habitat (EIS Section 14);
- cultural and heritage resources and Indigenous land and resource use (EIS Section 16); and
- other land and resource use (EIS Section 17).

The light effects analysis achieved the objective of characterizing potential light effects from the Project and the Fission Patterson Lake South Property. Specifically, light trespass and sky glow levels were predicted using computer models and analyzed in the context of thresholds from CIE (2017) and ILP (2020).

CLOSING

Golder is pleased to submit this report to NexGen in support of the environmental assessment for the Rook I Project. For details on the limitations and use of information presented in this report, please refer to the Study Limitations section following this page. If you have any questions or require additional details related to this study, please contact the undersigned.

Golder Associates Ltd.

Victor Young (M.Sc)
Acoustic Scientist

Andrew Faszer (B.Sc., INCE)
Senior Consultant

VY/AF/MM

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Rook I Project

Environmental Impact Statement

TSD XII: Net-Zero Framework

GOLDER
MEMBER OF WSP

NET-ZERO FRAMEWORK TECHNICAL SUPPORT DOCUMENT FOR THE ROOK I PROJECT

Prepared for:

NexGen Energy Ltd.

Prepared by:

Golder Associates Ltd.

April 2022

Abbreviations and Units of Measure

Abbreviation	Definition
GHG	greenhouse gas
IMS	Integrated Management System
NB	New Brunswick
NexGen	NexGen Energy Ltd.
Project	Rook I Project
SACC	Strategic Assessment of Climate Change
SMR	small modular reactor

Unit	Definition
%	percent
km	kilometre
MW	megawatt

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1 INTRODUCTION 1

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1 INTRODUCTION

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

NexGen has a vision to help deliver the clean energy fuel needs of current and future generations. The proposed Project would provide a source of uranium that could be used in small modular reactor technology. If used in Saskatchewan, this technology could reduce carbon emissions in electricity production, and therefore contribute to the Government of Government of Canada's ability to meet its environmental obligations and commitments with respect to climate change by displacing higher greenhouse gas (GHG) intensity, fossil fuel (e.g., coal) electrical generation. With the proposed Project, NexGen is advancing the world's largest uranium project under development, with a commitment to protecting and promoting the health, safety, and well-being of people and the environment. As part of its vision and values, NexGen is committed to protecting and preserving the environment through the lifespan of the Project and to responsibly managing energy use and GHG emissions as outlined in the Integrated Management System (IMS) Policy.

Notwithstanding its potential for net GHG reductions, the Project has the potential to affect climate change through the emissions of GHGs associated with different Project activities during the Construction, Operations, and Decommissioning and Reclamation (i.e., Closure) phases. As part of the Environmental Impact Statement (EIS), a detailed assessment of the potential effects of the Project on climate change was undertaken (EIS Section 7.4, Climate Change). This included preparation of a GHG emissions inventory and identification of the main sources of GHG emissions for the proposed Project. With a 4-year Construction duration and 24-year Operations duration, the operational lifespan of the Project is planned to extend until the early 2050s.

This net-zero framework has been developed based on the guidance provided in the *Draft Technical Guide Related to the Strategic Assessment of Climate Change* (SACC; SACC Technical Guide; Government of Canada 2021). Considering the early stage of Project development, the net-zero framework provides a preliminary assessment of potential alternative technologies and practices that could be used to reduce Project GHG emissions during the lifespan of the Project. Considerations for future decision making on the implementation of alternative technologies and practices have been identified, and it is expected that the framework would evolve as the Project design advances.

Finally, the framework outlines key barriers to implementing the technologies and discusses required support from Government to facilitate the implementation.

2 CONTEXT

The Project falls under the *Canadian Environmental Assessment Act,* 2012 (CEAA 2012). Under the CEAA 2012, there is no requirement to develop a net-zero plan or demonstrate how the Project plans to reduce emissions over the course of the Project lifespan. However, there is new guidance called the *Strategic Assessment of Climate Change (SACC) 2020* (Government of Canada 2020a) and the accompanying SACC Technical Guide that applies to Projects falling under the *Impact Assessment Act,* 2019 (IAA 2019). Although the Project is not required to develop a net-zero plan, NexGen has commenced the process of planning for

future reduction in GHG emissions at the proposed Project. To that end, this net-zero framework would be used as a roadmap for fulfilling NexGen's commitment to protecting and preserving the environment through the Project lifespan and to responsibly managing energy use and GHG emissions, as outlined in the IMS Policy. Further discussion of the IMS is found in the Technical Support Document XIII, Upstream Greenhouse Gas Emissions and Carbon Intensity Discussion.

The SACC (Government of Canada 2021) and accompanying draft SACC Technical Guide outline the approach to developing a net-zero plan and requires that both direct emissions (Scope 1) and acquired energy GHG emissions such as grid electricity (Scope 2) are considered. There are no Scope 2 emissions for the Project, so the net-zero framework focusses on Scope 1 emissions. The development of a net-zero plan is guided by the best available technologies / best environmental practices determination process, which includes identification of GHG mitigation measures. The net-zero plan process as outlined in the SACC is summarized in a series of steps shown in Table 1. This process would be used as a guide for developing the net-zero framework for the Project.

Table 1: Strategic Assessment of Climate Change Steps of the Best Available Technologies / Best Environmental Practices Determination Process to Support a Net-Zero Plan

Step	Description
Step 1: Listing of technologies and practices	Projects identify all available technologies and practices based on the identified main sources of emissions for each project phase.
Step 2: Technical feasibility assessment	Projects identify whether the identified technologies and practices are feasible for implementation under specific circumstances of the project.
Step 3: GHG reduction potential assessment	Projects identify the GHG effects of each identified technology/practice on the main sources of emissions for the project.
Step 4A: Economic feasibility assessment	Projects eliminate technologies and practices that may not be economically feasible for implementation during the project lifespan.
Step 4B: Additional considerations	Projects identify the social, health, and environmental effects of the alternative technologies and practices, through stakeholder engagement.
Step 5: Selection of best available technologies / best environmental practices	Projects combine technologies and practices and develop scenarios at the project level by considering emission sources and potential interactions between the mitigation measures.
Step 6: Review by the Government of Canada	This step includes review which is undertaken by the Impact Assessment Agency of Canada or life cycle regulators, with the support of expert federal authorities.

GHG = greenhouse gas.

3 PROJECT GREENHOUSE GAS EMISSIONS PROFILE

Based on the GHG inventory described in Section 7.4 of the Environmental Impact Statement, the Project's main sources of Scope 1 GHG emissions are summarized in Table 2. This emission profile is the average annual emissions over the Project's lifespan by source. On-site electricity generation, on-site mobile equipment, and mine and building heating have the highest emissions compared to others, and hence they have been considered for the net-zero framework. Emissions associated with land use change, stationary combustion, waste incineration, industrial processes, and explosives have a relatively small combined contribution of 12.6% of annual emissions, and therefore have not been evaluated in the net-zero framework at this early stage.

Table 2: Project Main Greenhouse Gas Emission Sources

GHG Emission Source	Total % of Average Annual GHG Emissions	Description
On-site electricity generation	59.3%	Emissions from natural gas and diesel combustion from the generators used to produce electricity.
On-site mobile equipment	14.7%	Emissions from diesel combustion of surface and underground mobile equipment that would be used for construction, mine operations, road maintenance, material management, and personnel movement.
Mine and building heating	13.4%	Emissions from natural gas combustion within the mine and building heaters used for underground and surface operations.
Land use change, stationary combustion, waste incineration, industrial processes, and explosives	12.6%	Emissions from land use change includes emissions from the lost carbon sink annually due to removed vegetation and the one-time total carbon losses in biomass due to disturbances. Emissions from stationary combustion includes emissions from the natural gas and diesel combustion from the burner that would heat the calciner to remove impurities from the processed ore and fossil fuel use in the incinerator. Emissions from waste incineration includes the emissions released through the incineration of domestic and low-level radiological waste. Emissions from industrial processes includes the emissions from the sulphuric acid production plant and the acidification of ore material. Emissions from explosives includes emissions associated with blasting.

GHG = greenhouse gas.

4 NET-ZERO FRAMEWORK

The net-zero framework provides early identification of potential technologies and practices that could be used to reduce future GHG emissions from the Project.

Considering that the Project is still in an early phase, this document provides the net-zero framework that was guided by steps 1 through 3 of the best available technologies / best environmental practices determination process from the SACC (Table 1).

Project-specific considerations at each step are described in the following:

Step 1: Listing of technologies and practices

- A preliminary list of available and emerging technologies and practices for the main sources of Project GHG emissions was developed.
- A brief description was developed for each technology/practice that outlines how the technology could be applied to the Project, and any Project-specific studies undertaken to date to evaluate the feasibility of the technology/practice option.

Step 2: Technical feasibility assessment

For each identified technology/practice from Step 1, the current status of the technology/practice was identified using the categories summarized in Table 3.

Table 3: Technology/Practice Status Categories

Category	Description
Established	Commercially available and wide adoption in the mining sector
Available	Commercially available and limited adoption in the mining sector
Emerging	Not in wide commercial use, pilot project level
Research and development	Theoretical and planned pilot

Step 3: GHG reduction potential assessment

For each technology/practice from Step 1, the GHG reduction potential was identified using the categories summarized in Table 4.

Table 4: Greenhouse Gas Emissions Reduction Potential Categories

Category	Description
Low	<10% reduction potential in site-wide absolute emissions
Moderate	10%-50% reduction potential in site-wide absolute emissions
High	>50% reduction potential in site-wide absolute emissions

< = less than; > = more than.

5 ALTERNATIVE TECHNOLOGIES AND PRACTICES ASSESSMENT

Based on the approach provided in Section 4 of this document, a preliminary alternative technologies and practices assessment was conducted for the Project, which is summarized in Table 5. The assessment focussed on the activities that are the largest GHG emission sources, including on-site electricity generation, on-site mobile equipment, and mine building and heating. For on-site electricity generation, feasibility studies have been undertaken on alternative energy sources such as solar, wind and grid connection (Stantec 2019 and SLR 2021). Solar energy was eliminated from project design as it was identified that it is not technically feasible to implement solar panels compared to wind energy, as summarized in Table 5. Connection to the grid was also eliminated as a feasible option because of the high costs associated with installing a powerline. If the emissions intensity of Saskatchewan grid is reduced, the costs associated with grid connection could be revisited and re-evaluated against the costs associated with other alternative technologies for onsite electricity generation.

Based on the Project's development timelines, the EIS has been based on power generation using natural gas from Liquified Natural Gas (LNG). As the Project design progresses, and in consideration that on-site electricity generation is the largest Project GHG emission source, future work is expected to further assess and refine power generation options.

The alternative technologies and practices have been grouped by opportunity category by which the emissions could be reduced (e.g., fuel switching, electrification). For the identified technologies and practices, the current technology status and the GHG emissions reduction potential were identified based on the categories summarized in Table 3 and Table 4, respectively. The preliminary list of technologies and practices represents the available options at the time of this report. The available technology and practices would likely evolve and need to be re-evaluated, as discussed in Section 6, Decision Making.

Table 5: Alternative Technology and Practices Assessment

Opportunity Category	Technology Option	Technology Description	Current Technology Status	Preliminary GHG Reduction Potential
On-Site Electricity Generation				
On-site electricity generation	Hybrid System	A hybrid system is a combination of two or more methods of electricity generation to supply power. It is commonly used to integrate renewable energy sources such as solar photovoltaic (PV) or wind turbines so that they become a portion of the overall power supply. A hybrid system could be used for on-site electricity generation, which includes incorporating an on-site power plant combined with renewable energy alternatives (e.g., solar PV arrays, wind turbines) and batteries. A renewable energy scoping study was conducted for the Project to investigate the technical and commercial potential of including renewable energy generation at the Project (SLR 2021). Results of the scoping study indicated that a hybrid system including combination of natural gas generators and wind turbines along with a battery energy storage system are a feasible proposition for the Project, and recommended the proposition could be included in future design phases, as they are advanced. To produce approximately 50% of electricity through wind turbines, 12 wind turbines with a rated power of 3.465 MW plus 13 MWh battery energy storage was considered in the study (SLR 2021). Generating electricity utilizing solar PV technology was not found to be feasible for the Project due to the variance in solar radiation available between the summer and winter months (SLR 2021).	**Established:** This technology is commercially available and widely adopted in the mining sector. Some examples where this technology has been implemented at mine sites that are located in Northern Canada include: ▪ Diavik Mine (Diavik Diamond Mines Inc.) in the Northwest Territories have installed four 2.3 MW E70 Enercon turbines, that have been operational since 2012. ▪ Raglan Mine (Glencore) in Northern Quebec have installed two 3 MW E82 Enercon turbines (2014 & 2018). Glencore has committed to installing two more turbines as of 2021. The wind turbine generation is integrated into the mine diesel grid, supported by energy storage, as part of their micro grid pilot project. ▪ Meliadine Mine (Agnico Eagle) in Nunavut is pursuing a wind farm project at their operations.	**Low to Moderate:** Reduction potential would depend on the percentage of power source coming from natural gas versus wind. With 50% of power from renewables, this would result in a moderate classification Having 50% of power come from renewables would lead to an approximate 30% reduction potential in site-wide emissions, as on-site electricity generation is responsible for 59.3% of total Project emissions.
On-site electricity generation	SMR	An SMR is a nuclear reactor facility that is smaller than a traditional nuclear power plant, and it may employ novel technologies such as passive/inherent safety features, and extensive use of factory-built modules (CNSC 2020). For remote mine sites with electricity demands between 10 and 20 MV, SMRs could potentially reduce energy costs	**Research and development:** Currently, this technology is in the research and development phase and not available commercially. In 2021, four power companies (Ontario Power Generation, Bruce Power, Energie NB Power, and SaskPower) published a report that provided a feasibility assessment of SMR development and deployment and provided the power companies' business case	**High:** The Project has a nominal electricity demand of 24.1 MW, based on the power requirements from the mine feasibility study, which was nine 3.329 MW natural-gas fired generation units to meet nominal demand of 24.1 MW (SLR 2021). Deployment of two, 10-MW unit SMRs could help meet 20 MW (83%) of this

Table 5: Alternative Technology and Practices Assessment

Opportunity Category	Technology Option	Technology Description	Current Technology Status	Preliminary GHG Reduction Potential
		(Ontario Power Generation et al. 2021). Currently, four utilities (SaskPower, Ontario Power Generation, Bruce Power, and NB Power) are working on developing three streams of SMRs. One of those streams (i.e., Stream 3) includes bringing affordable, clean energy to remote mine sites (Ontario Power Generation et al. 2021).	for implementation of SMRs in the provinces of Saskatchewan, New Brunswick, and Ontario (Ontario Power Generation et al. 2021). Stream 3 of this study proposed a new class of micro-SMRs that would be suitable for mine sites. To advance the technology, a 5 MW gas-cooled reactor project is underway at the Chalk River site in Ontario. The project is being undertaken by the Ultra Safe Nuclear Corporation (USNC) and is expected to be operational by 2026 (Ontario Power Generation et al. 2021).	electricity demand, which would lead to an approximate 50% reduction in site-wide absolute emissions, as on-site electricity generation is responsible for 59.3% of total Project emissions.
On-Site Mobile Equipment				
Fuel switching	Diesel to biodiesel	Biodiesel is a diesel fuel substitute that is used in diesel engines and is made from renewable materials such as plant oils, waste cooking oils, and animal fats (Government of Canada 2020b). Biodiesel is blended with petroleum diesel and blends of 20% biodiesel (B20) are commonly approved for use in equipment. The higher biodiesel blends can gel in colder conditions, so it is best suited for underground work or seasonal use in the warmer months.	**Available:** Biodiesel is available for implementation; however, blends are generally a low percentage and limited to warmer months for surface equipment. Barriers to wider adoption of higher blends relate to varying performance feedback. While some operations have been able to operate at higher blends, such as Hutchinson Salt Company in Kansas having used 100% biodiesel in their underground equipment since 2003 (Biodiesel Sustainability Now, 2020), other mines have reported operational issues relating to additional maintenance requirements and lower equipment performance, with blends closer to B20 (Carmeuse, 2019).	**Low:** The GHG emissions reduction would depend on the biodiesel blend used. Assuming all diesel use in the mobile fleet is replaced with a B20 blend, it would lead to an approximate 20% reduction of GHGs from mobile equipment (14.7% of Project emissions), and would reduce total Project emissions by almost 3%.
	Diesel to renewable diesel	Renewable diesel is produced through various processes such as hydrotreating, gasification, pyrolysis, and other biochemical and thermochemical technologies. It is chemically the same as diesel and can be used directly as a diesel substitute year-round (US Department of Energy 2021).	**Emerging:** This technology is not in wide commercial use in the mining sector in Canada. There is currently a limited supply of renewable diesel, although this is expected to change in the future as more production is planned. For example, the Strathcona refinery in Alberta could produce about 3 million litres of renewable diesel per day in 2024 (Imperial Oil 2022).	**Moderate:** Assuming all diesel use in the mobile fleet is replaced, it would lead to 100% reduction of GHGs from mobile equipment, and would reduce total Project emissions by 14.7%.
	Diesel to Hydrogen (Hydrogen Fuel Cell Equipment)	Hydrogen fuel cells convert hydrogen and oxygen into electricity onboard, while producing no tailpipe emissions. This electricity can be utilized to	**Emerging:** This technology is expected to be piloted in 2022 at the Mogalakwena (Anglo American) platinum mine in South Africa,	**Moderate:** Assuming all diesel use in the mobile fleet is replaced, it would lead to 100% reduction of GHGs from mobile equipment, and

Table 5: Alternative Technology and Practices Assessment

Opportunity Category	Technology Option	Technology Description	Current Technology Status	Preliminary GHG Reduction Potential
		power an electric drivetrain of any piece of equipment. The total lifecycle GHG emissions depend on the carbon intensity of the hydrogen production.	powering a Komatsu 930E (291-ton capacity) haul truck. A 3.5 MW electrolyser will be constructed on site for the hydrogen fuel production (Anglo, n.d.). Development of an underground fuel cell loader was carried out almost 20 years ago; however, due to the smaller market, as well as safety concerns with storing and operating hydrogen underground, commercialisation for surface equipment has made further advances (Vehicle Projects Inc., 2009).	would reduce total Project emissions by 14.7%.
Electrification	Battery-powered haul truck	Battery electric haul trucks are powered by energy stored in batteries, and do not have a conventional gasoline or diesel engine.	**Available:** This technology is being planned/implemented at Canadian underground mines including: ▪ Brucejack Mine (Pretivm) have undertaken a successful trial and have purchased 50-tonne haul trucks (Sandvik Z50s) to replace their existing diesel haul trucks (Sandvik 2021). ▪ Borden Mine (Goldcorp) is planned to be all electric mine fleet. ▪ Glencore's Onaping Depth Project (in construction) will be an all-electric fleet deep mine operation (Mining News North 2021).	**Low:** Assuming all diesel use in the mobile fleet is replaced with electric, and assuming the on-site electricity generation is the hybrid system described above with 50% of power from renewables, this would lead to an approximate 7% reduction potential of total Project emissions, as mobile fleet emissions are responsible for 14.7% of total Project emissions. The reductions due to electrification of haul trucks only would be less than 7% of total Project emissions, because haul truck are only a portion of the mobile fleet.

Table 5: Alternative Technology and Practices Assessment

Opportunity Category	Technology Option	Technology Description	Current Technology Status	Preliminary GHG Reduction Potential
	Battery-powered loaders and utility/light vehicle trucks	Battery electric vehicles and loaders are powered by energy stored in batteries, and do not have a conventional gasoline or diesel engine.	**Available:** This technology is being planned/implemented at Canadian Mine sites including: ▪ The Onaping Depth Project (Glencore) have two battery electric flat decks, with one serving as the water truck for ramp maintenance to support the mine construction. In addition, two electric utility vehicles are used for personnel movement throughout the mine (Glencore 2020).	**Low:** Assuming all diesel use in the mobile fleet is replaced with electric, and assuming the on-site electricity generation is the hybrid system described above with 50% of power from renewables, this would lead to an approximate 7% reduction potential in total Project emissions, as mobile fleet emissions are responsible for 14.7% of total Project emissions. The reductions due to electrification of battery powered loaders and utility/light vehicle trucks would be less than 7% because they are only a portion of the mobile fleet.
	Conveyors	A conveyor system can be used as a transportation system to move ore instead of hauling with a mobile fleet. The most common conveyor system is a belt system.	**Established:** This technology is available and has been implemented by various mining operations. This technology is being planned/implemented at mine sites including: ▪ Goldex Mine (Agnico Eagle) has a 3 km underground railveyor system with electric motors which are powered by hydroelectric power source (Railveyor, n.d.).	**Low:** Conveyors would only replace a portion of the mobile fleet used on the site. Mobile fleet emissions comprise 14.7% of total Project emissions, and use of conveyors would only reduce part of these emissions. Hence, use of conveyors would help in reduction of less than 10% of total Project emissions.
	Tethered electric mining equipment	Tethered electric mining equipment have a hybrid diesel/electric powertrain. The diesel power allows the equipment to move around the mine. When in operation, the equipment tether to an electrical source.	**Established:** This technology is available for equipment such as loaders, shovels and drills. This technology is being planned/implemented at mine sites including: ▪ The Zielitz Potash mine is testing a tethered electric LHD (Load Haul Dump) with onboard battery capability for mobility for it's underground mine (International Mining 2021). ▪ The Borden Gold Mine (Goldcorp) located in Sudbury, Ontario will be using tethered equipment (such as tethered scoops) for underground mining operations. The mine plans to use tethered scoops until quick-charge battery is viable (Goldcorp 2016, Pollon 2016)	**Low:** Assuming all diesel use in mobile fleet is replaced with electric, and assuming the on-site electricity generation is the hybrid system described above with 50% of power from renewables, this would lead to an approximate 7% reduction potential in total Project emissions, as mobile fleet emissions are responsible for 14.7% of total Project emissions. The reductions due to tethered electric mining equipment only would be less than 7% of total Project emissions because the tethered equipment are only a portion of the mobile fleet.

Table 5: Alternative Technology and Practices Assessment

Opportunity Category	Technology Option	Technology Description	Current Technology Status	Preliminary GHG Reduction Potential
Fleet management and autonomous haul trucks	Fleet management and tracking tools	Fleet management systems and tracking tools include computer-based dispatching tools, which optimize haulage and vehicle routes and reduce truck idling time. Properly maintaining equipment prevents failures and lowers overall operational costs (Mining Technology 2018).	**Established:** This technology is available for near-term implementation with a range of vendors providing services for fleet management. More traditionally seen in open pit operations, fleet management is being adopted underground with communication system improvements. Myra Falls (Nystar) in British Columbia adopted an underground fleet management system in 2020, increasing production by about 15% on average (Outliers Mining Solutions, n.d.).	**Low:** Increasing equipment utilization, while eliminating unnecessary idling time is estimated to reduce mobile fleet emissions by about 3% (Teck, 2014), which would result in the total Project emission reduction of less than 1%.
	Autonomous haul trucks	Autonomous haul trucks use technology to drive the vehicle instead of an operator. Operation of the truck can be optimized reducing fuel consumption and maintenance.	**Emerging:** Though this technology is available for implementation for open pit mines, it is in a development stage for underground mines: ▪ The Brucutu iron ore open pit mine (Vale) in Brazil has become the first mine with 100% autonomous haulage (Jamasmie 2021). ▪ Volvo Group is developing autonomous trucks for underground mines which were tested at the Kristineberg mine in Sweden (1,300 m underground) (Mining Technology 2021). ▪ Sandvik has launched AutoMine for Trucks in March 2020 for autonomous truck haulage for underground mines (Mining Technology 2021).	**Low:** GHG reduction would be a result of reduced fuel consumption and increased operational efficiency. Based on various studies, autonomous vehicles are estimated to reduce GHG emissions by about 10% (Engholm et al., 2020), which would reduce the total Project emissions by 1.5%.

Table 5: Alternative Technology and Practices Assessment

Opportunity Category	Technology Option	Technology Description	Current Technology Status	Preliminary GHG Reduction Potential
Mine and Building Heating				
Efficient technologies	Heat recovery / heat exchangers	Heat recovery captures waste heat from process water, process plant exhaust, ventilation exhaust and/or compressors via a preheater / heat exchanger.	**Available:** This technology is available and has been implemented in the global mining sector: ▪ Zinkgruvan mine (Lundin) installed a plate heat exchanger for their mine ventilation heating system, using the heat in the return air to preheat incoming air (Holmund, 2015). ▪ Line Creek Coal mine (Teck) installed a heat exchanger unit between the exhaust and intake air to recover waste heat (Government of BC, n.d.).	**Low:** Potential energy reduction depends on the technology application and varies based on the amount of heat energy recovered. The largest heating load is expected to be heating ventilation air, and according to Holmund (2015), the fuel consumption for heating can be reduced by up to 90%. Assuming ventilation accounts for about half of the mine and building heating emissions (13.4%), it may reduce total Project emissions by up to 6%.
Energy supply	Air to air heat pumps	Heat transfer from ambient air via heat exchanger, which is then brought up to design temperature through a heat pump. These systems are typically integrated into heating, ventilation, and air conditioning (HVAC) systems for building heating.	**Available:** This technology is widely available and has been successfully installed in various HVAC applications for residential, commercial or industrial buildings. Though specific case studies to the mining sector were not available, this technology is being implemented by the Vancouver City Hall: ▪ Vancouver City Hall is implementing Air Source Heat Recovery unit which is more efficient and can meet the requirements of cooling, heating, and domestic hot water (City of Vancouver, n.d.).	**Low:** In terms of site-wide absolute emission reduction, the GHG reduction potential is low (<5%), as space heating loads are generally small at mine sites.

GHG = greenhouse gas; HVAC = heating, ventilation, and air conditioning; MW = megawatt; MWh = megawatt hour; NB = New Brunswick; SMR = small modular reactor.

6 DECISION MAKING

The technologies and practices identified in Section 5, Alternative Technologies and Practices, provide alternatives that could help the Project reduce GHG emissions from on-site electricity generation, on-site mobile equipment, and mine and building heating in the future. However, for future decision making on selection of which GHG reduction technologies and practices to implement, a range of factors have been identified that need to be considered including: Indigenous, public, and regulatory engagement; technologies and practices interdependencies; and economic feasibility assessment. More detailed decision making would consider barriers to the implementation and solutions required to overcome those barriers, which could include Government support. Future decision making would revisit and build upon the alternatives technologies and practices identified, as a part of NexGen's continual improvement process. This approach of re-assessing technologies and practices aligns with NexGen's commitment to manage energy use and reduce GHG emissions.

Indigenous and Stakeholder Engagement:

Indigenous, public, and regulatory engagement is a key consideration in making decisions on which future technologies and practices could be implemented. The Project could consider undertaking engagement as a part of the continual improvement process to identify whether:

- a technology or practice could have social or health effects that could affect local Indigenous Groups and communities, including their quality of life, employment, demographics, and Indigenous rights; and
- a technology or practice could have adverse effects such as release of air pollutants or affect carbon sinks.

Technologies and Practices Interdependencies:

The technologies and practices listed in Section 5 could be interdependent, and it is necessary to identify those interdependencies as a part of decision making. For example, the alternatives technologies and practices assessment identified that SMRs have the highest emission reduction potential. Integration of an SMR has the potential to provide a clean source of electricity, which would change the profile of GHG emissions at the Project. Under this scenario, the GHG emission reduction potential of other technologies would have to be reviewed again, as an SMR would likely facilitate electrification of other sources such as mobile fleet and increase the emissions reduction potential as compared to the base case assumption of LNG as the primary fuel source for on-site electricity generation.

Economic Feasibility Assessment:

Economic feasibility is a key consideration in identifying whether a technology or practice could be implemented. The Project could consider the following for an economic feasibility assessment:

- if the technology or practice is feasible based on implementation costs, profits, and price of carbon;
- if the costs and uncertainty are high for a technology or practice that has not been used or tested on mine sites, under similar conditions; and
- if there are any other economic risks associated with the technology or practice.

For example, a feasibility study was conducted for the Project to assess the economic viability of alternative energy options (SLR 2021). In that study, economically viable combinations of numbers and sizes of generators, wind turbines, solar cells, and batteries were identified, and evaluated in terms of net present cost. Results of the study indicated that a hybrid system would be more economically attractive than connecting to the existing power grid (SLR 2021).

7 REQUIRED GOVERNMENT SUPPORT TO OVERCOME BARRIERS TO SMALL MODULAR REACTORS

The alternative technologies and practices assessment (Section 5) identified a range of measures that could be implemented by the Project to reduce GHG emissions. Of the technologies and practices considered, SMRs have the highest emission reduction potentials. However, implementation of SMRs currently has a range of barriers including:

- working prototypes for the industry, as they are not commercially available at this time;
- regulatory, licensing, and permitting uncertainty, both at provincial and federal levels;
- large capital investments; and
- potential Indigenous and public perception and acceptance of the technology.

Federal and provincial government support would be required to overcome the barriers associated with implementation of SMRs, specifically the following:

- increasing public awareness and acceptance for implementation of SMRs;
- increasing the investment and innovation in the SMR technology and infrastructure;
- defining regulatory requirements (e.g., permitting and licensing) and ensuring the regulatory processes are efficient for implementation of the technology;
- conducting a detailed, sector-wide study that could help define the strategies and/or incentives for implementation of SMRs on the provincial scale; and
- aligning with the emission reduction potentials outlined in the Made-in-Saskatchewan Climate Change Strategy (Government of Saskatchewan 2017), by implementation of SMRs on remote mine sites.

Currently, the Project design includes on-site power generation through natural gas. Providing Project-level support for implementation of SMRs aligns with the *Saskatchewan Growth Plan* (Government of Saskatchewan 2015) that aims to reduce GHG emissions from electricity generation by 40% by 2030 from 2005 levels. In its Made-in-Saskatchewan Climate Change Strategy (Government of Saskatchewan 2017), the Government of Saskatchewan has identified that SaskPower has committed to increase renewable power generation to 40% of it's total generating capacity by 2030. SaskPower also anticipates that there could be an increase in the demand for zero emissions electricity to support the electrification of transportation and other sectors and there could be more stringent regulations to reduce carbon dioxide emissions from power generation post-2030. Hence, SaskPower is evaluating potential alternatives to reduce their GHG emissions, including implementation of SMRs (Ontario Power Generation et al. 2021). The Government of Saskatchewan is also evaluating options to fuel the provincial SMRs with provincially mined uranium (Ontario Power Generation et al. 2021).

An economic and technical feasibility study is being conducted by SaskPower for deployment of a 300 megawatt (MW) nuclear power plant by 2032. SaskPower is also evaluating potential deployment of an additional 900 MW of power generating capacity from SMRs between 2035 and 2042. The Government of Saskatchewan aims to investigate the possibility of creating commercial contracts in the heavy industry and mining industry for implementation of SMRs (Ontario Power Generation et al. 2021). Hence, the remote mine sites in Saskatchewan have an opportunity to collaborate with the provincial government to implement SMRs and reduce their GHG

emissions. By providing support to the Project for implementation of SMRs fuelled by provincial uranium, the Project would be able to reduce its GHG emissions considerably and contribute towards the ongoing emission reduction targets set by the Government of Saskatchewan. Implementation of SMRs also supports achieving Federal Government targets of phasing out coal by 2030 and achieving net-zero GHG emissions by 2050.To support the implementation of SMRs, the Federal Government would need to define efficient regulatory processes, including permitting and licensing of SMRs and management of waste.

8 SUMMARY

Based on the requirements stated in the *Canadian Environmental Assessment Act*, 2012, and the SACC, a net-zero plan is not required for the proposed Project. However, the Project has a potential to affect climate change through the emission of GHG. As a part of its vision and values, NexGen is committed to protecting and preserving the environment through the lifespan of the Project and to responsibly managing energy use and GHG emissions. In alignment with NexGen's vision and values, a net-zero framework has been developed for the Project which has considered guidance provided in the SACC Technical Guide.

The net-zero framework identifies a range of alternative technologies and practices that could be implemented by the Project to reduce GHG emissions. Considering the early stage of Project development, the framework is guided on the first three steps of the draft SACC Technical Guide, which includes listing of technologies and practices, a technical feasibility assessment, and a GHG reduction potential assessment.

Following that, the proposed net-zero framework identifies that, for future decision making on implementation of GHG reduction technologies and practices, a range of factors need to be considered including: Indigenous, public, and regulatory engagement; technologies and practices interdependencies; and economic feasibility assessment. The framework is expected to evolve to incorporate these decision-making considerations as the Project design advances.

Given the interdependency of potential GHG reduction opportunities, if any technology or practices are selected for implementation, it could modify the feasibility of implementation of other technologies and practices. Hence, as a part of the continual improvement process, the alternative technologies or practices would need to be re-assessed based on implementation of any new technologies and practices as part of the continual improvement process described in the IMS Manual and Environmental Protection Program.

CLOSING

Golder is pleased to submit this report to NexGen in support of the environmental assessment for the Rook I Project. For details on the limitations and use of information presented in this report, please refer to the Study Limitations section following this page. If you have any questions or require additional details related to this study, please contact the undersigned.

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The passage of time affects the information and assessment provided in this report. Golder's opinions are based upon information that existed at the time of the production of the report. The Services provided allowed Golder

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Rook I Project

Environmental Impact Statement

TSD XIII: Upstream Greenhouse Gas Emissions and Carbon Intensity Discussion

GOLDER
MEMBER OF WSP

UPSTREAM GREENHOUSE GAS EMISSIONS AND CARBON INTENSITY DISCUSSION TECHNICAL SUPPORT DOCUMENT FOR THE ROOK I PROJECT

Prepared for:

NexGen Energy Ltd.

Prepared by:

Golder Associates Ltd.

March 2022

Abbreviations and Units of Measure

Abbreviation	Definition
CEAA 2012	*Canadian Environmental Assessment Act, 2012*
CNSC	Canadian Nuclear Safety Commission
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
EIS	Environmental Impact Statement
GHG	greenhouse gas
Project	Rook I Project
Proposed CNSC Path	Proposed CNSC Path Forward for Assessing Total GHG Production from Nuclear Facilities
SACC	Strategic Assessment of Climate Change

Unit	Definition
%	percent
°C	degrees Celsius
g	gram
km	kilometre
kt	kilotonne
CO_2e/kWh	carbon dioxide equivalent per kilowatt hour
CO_2e/yr	carbon dioxide equivalent per year

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1 INTRODUCTION

NexGen Energy Ltd. (NexGen) is proposing to develop a new uranium mining and milling operation in northwestern Saskatchewan, called the Rook I Project (Project). The Project would be located approximately 40 km east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon. The Project would reside within Treaty 8 territory and the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake, along the upper Clearwater River system. Access to the Project would be from an existing road off Highway 955, with on-site worker accommodation serviced by fly-in/fly-out access.

The purpose of this technical support document is to provide a discussion of the relevance and requirement to conduct an upstream assessment of greenhouse gas (GHG) emissions for the Project. Upstream GHG emissions are domestic and non-domestic emissions from all stages of production, from the point of resource extraction or utilization to the project under review (Government of Canada 2020). The discussion is separated into two portions:

- A review of applicable legislation and policy to provide context for when an assessment of upstream GHG emissions is required as part of an Environmental Assessment.
- An overview of how the uranium concentrate produced from the Project can contribute to the nuclear energy sector and how nuclear energy is expected to contribute to the Government of Canada's ability to meet its environmental obligations and its commitments in respect of climate change and other international jurisdiction's GHG reduction plans. Specifically, how nuclear energy can improve the carbon intensity of electric grids.

This document was developed to inform and support the assessment of the climate change valued component in the Environmental Impact Statement (EIS) Section 7.4, Climate Change, but is not included in the assessment of significance. The discussion relies on both professional experience and published information.

2 REVIEW OF APPLICABLE LEGISLATION AND POLICY

This subsection summarizes applicable legislation and policies considered to identify whether an upstream GHG assessment is required for the Project. The applicable legislation and policies are the *Canadian Environmental Assessment Act, 2012* (CEAA 2012), the *Strategic Assessment of Climate Change 2020* (SACC; Government of Canada 2020), and *The Proposed CNSC Path Forward for Assessing Total GHG Production from Nuclear Facilities* (Proposed CNSC Path; CNSC 2017).

The nuclear fuel life cycle consists of various industrial processes that describe uranium throughout its life cycle, from mining to electricity generation to waste disposal (World Nuclear Association 2021). The *Life Cycle Analysis of Greenhouse Gas Emissions from the Mining and Milling of Uranium in Saskatchewan* (Parker 2014) and the Proposed CNSC Path (CNSC 2017) have identified the core elements within the nuclear generational life cycle, which starts with mining, milling and fabrication, and are followed by the construction, operation, and decommission of nuclear plants along with waste management (World Nuclear Association 2021).

According to the Canadian Nuclear Safety Commission (CNSC) 2017 guidance, the core elements of a nuclear fuel life cycle include:

- mining-milling (construction, operation, decommission);
- refining/conversion (construction, operation, decommission);
- fuel fabrication;
- nuclear power plant (construction, operation, decommission); and
- waste disposal (low, intermediate, and high-level radioactive waste disposal).

The proposed Project activities are associated with the mining and milling of uranium. As outlined in EIS Section 7.4.2.4, Temporal Boundaries, the Project timelines and phases include Construction (4-year duration), Operations (24-year duration), and Closure (15-year duration).

Based on the CNSC guidance, the mining-milling activities associated with the Project are the most upstream activities of the nuclear fuel life cycle. The CNSC 2017 definition of upstream assessment is consistent with the CEAA 2012 and SACC 2020 guidance, as described below.

2.1 Canadian Environmental Assessment Act, 2012

The Project is being assessed under CEAA 2012, and therefore, the Environmental Assessment needs to meet the requirements of CEAA 2012 (EIS Section 1.3, Regulatory Context). Under CEAA 2012, there is no requirement for an upstream assessment; rather, the GHG assessment under CEAA 2012 focuses on the direct and indirect emissions (Scopes 1 and 2)[1] from the project itself.

Subsequent to the release of CEAA 2012, Environment and Climate Change Canada clarified on 19 March 2016 through a posting in the Canada Gazette that an assessment of upstream GHG emissions will be required for certain oil and gas projects (Government of Canada 2016). As defined by Environment and Climate Change Canada in the methodology proposed in the Gazette announcement, upstream GHG emissions include all industrial activities from the point of resource extraction to the project under review. The specific processes included as upstream activities will vary by resource and project type, but in general, they include extraction, processing, handling, and transportation. The assessment of the upstream emissions is separated into two parts, consistent with the Environment and Climate Change Canada methodology. Part A is a quantitative estimate of the range of GHG emissions released upstream of the project (Government of Canada 2016). Part B discusses the conditions under which the Canadian GHG upstream emissions estimated in Part A could be expected to occur even if the project were not built (Government of Canada 2016).

Based on the requirements of CEAA 2012, the Project does not require an upstream GHG assessment to be conducted.

[1] Scope 1 emissions are ones occurring from sources that are owned or controlled by the proponent (e.g., emissions from fuel combustion in owned or controlled boilers). Scope 2 emissions are the ones occurring at sources that are not owned or controlled by the proponent but are accounted in the proponent's GHG inventory as they are a result of organization's energy use (e.g., carbon emissions from the generation of purchased electricity, or heat).

2.2 Strategic Assessment of Climate Change

Under the SACC 2020 (Government of Canada 2020), an upstream assessment is required for all projects (not just oil and gas) that are likely to exceed the upstream GHG thresholds based on different timelines; the current threshold is 500 kilotonnes (kt) of carbon dioxide equivalent (CO_2e) annually. The SACC 2020 retains the Part A and B approaches as outlined in the Canada Gazette (Government of Canada 2016). The definition of upstream assessment in SACC 2020 is consistent with the definition from CEAA 2012.

For a project proceeding under the *Impact Assessment Act*, the Tailored Impact Statement Guidelines (IAAC 2020) will confirm if an upstream GHG assessment is required in the impact statement (i.e., the Environmental Assessment) based on preliminary calculations conducted by the Impact Assessment Agency of Canada along with expert federal authorities. The SACC does allow proponents to discuss how a project can contribute to Canada's ability to meet its GHG reduction targets and how a project may help displace emissions internationally and result in global emission reductions (Government of Canada 2020).

Based on calculations in Section 7.4 of the EIS, the Project upstream emissions are expected to be below the threshold provided by the SACC (Government of Canada 2020), and therefore, an upstream assessment would not be required for the Project — even if it were conducted under Impact Assessment Agency of Canada 2020.

2.3 Proposed Canadian Nuclear Safety Commission Path Forward for Assessing Total Greenhouse Gas Production from Nuclear Facilities

The Proposed CNSC Path (CNSC 2017) guidance proposes a path for assessing total GHG production from nuclear facilities, including the upstream assessment (CNSC 2017). The assessment outlined in Section 7.4 of the EIS follows this guidance. The guideline outlines that GHG emissions for nuclear facilities start with the mining and milling of uranium. The guideline suggests following a cradle-to-gate analysis to include emissions from upstream processes of a nuclear power plant (i.e., mining, milling, refining/conversion, and fuel fabrication). For example, a project for a refinery will include GHG emissions assessment associated with both the mining and milling activities. A project for fuel fabrication will include GHG emissions assessment associated with the mining, milling, and refining of the uranium.

For the Project, the proposed activities included are on-site mining and milling of uranium, which are the most upstream activities of a nuclear fuel lifecycle according to the guidance. Considering that the Project is the most upstream of the nuclear fuel lifecycle, an upstream GHG emissions assessment is not required to be conducted for the Project based on the cradle-to-gate framework (CNSC 2017). The CNSC 2017 suggestion for upstream assessment is consistent with the suggestion for upstream assessment from CEAA 2012 and SACC 2020.

2.4 Summary

Based on CEAA 2012, the SACC (Government of Canada 2020), and Proposed CNSC Path (CNSC 2017), an upstream assessment would not be required for the Project. The requirements for an upstream assessment based on relevant acts and regulations and how these requirements may relate to the Project are summarized in Table 2.4-1.

Rather than focus on upstream GHG emissions, Section 3, Nuclear Energy and Carbon Intensity, discusses how the Project can help displace emissions internationally and result in global emission reductions by providing mined material to the nuclear energy sector.

Table 2.4-1: Upstream Assessment Requirements in Relation to the Project

Act/ Regulation	Requirement	Project Upstream Assessment Description
CEAA 2012	Not a requirement within CEAA; however, was a 2016 Gazette requirement for oil and gas projects.	Considering the requirement is only for oil and gas projects, upstream assessment is not required for the Project.
SACC	An upstream assessment is required for projects that are likely to exceed the upstream GHG thresholds. The current threshold is 500 kt of CO_2e annually.	Upstream GHG emissions are expected to be well below the threshold provided by SACC (Government of Canada 2020). Hence, an upstream assessment is not required.
Proposed CNSC Path	Upstream assessment should follow a cradle-to-gate analysis with nuclear fuel cycle starting with mining and milling.	The guidance states that nuclear fuel cycle starts with mining and milling, which are the most upstream activities. The Project activities include mining and milling activities. Emissions associated with mining and milling have been analyzed in EIS Section 7.4, Climate Change. Hence, an upstream GHG assessment would not be required as the emissions that have been analyzed are the most upstream.

CEAA 2012= *Canadian Environmental Assessment Act, 2012*; SACC = Strategic Assessment of Climate Change; CNSC = Canadian Nuclear Safety Commission; Proposed CNSC Path = Proposed CNSC Path Forward for Assessing Total GHG Production from Nuclear Facilities; GHG = greenhouse gas; EIS = Environmental Impact Statement; CO_2e = carbon dioxide equivalent; kt = kilotonne.

3 NUCLEAR ENERGY AND CARBON INTENSITY

According to Section 2.2, Strategic Assessment of Climate Change, upstream emissions associated with the Project are negligible compared to the threshold listed in the SACC. The results also discuss how the uranium concentrate produced from the Project can contribute to the nuclear energy sector and how nuclear energy is part of Canada's and other international jurisdiction's low carbon plans.

3.1 Emissions Associated with the Project

The proposed activities associated with the Project only include mining and milling operations, in relation to the nuclear fuel lifecycle. Based on the nuclear fuel lifecycle, mining-milling activities associated with the Project are at the front-end and are the most upstream activities of the nuclear fuel lifecycle. There are limited upstream activities to the Project; these could include emissions embodied in resources required for the construction materials, and emissions associated with transportation of personnel, materials, and equipment. Even though construction activities can be energy and resource intensive, the emissions associated with Scope 1, Scope 2, and Scope 3[2] upstream activities are approximately 4.8% of the emissions from a nuclear fuel life cycle (Parker et al. 2016). The Scope 1, Scope 2, and Scope 3 emissions associated with the mining and milling stage attribute to approximately 30% of the emissions of the nuclear fuel life cycle (Parker et al. 2016). The Scope 1 emissions for the Project have been reported in EIS Section 7.4. There are no Scope 2 emissions associated with the Project. As per EIS Section 7.4, Table 7.4-12, the Project's maximum annual GHG emissions are estimated to be 171 kt CO_2e/yr (carbon dioxide equivalent per year) during Construction, 82 kt CO_2e/yr during Operations, and 69 kt CO_2e/yr during Closure. These emissions are well below the upstream emissions threshold specified in the SACC (i.e., 500 kt CO_2e annually). Therefore, based on the above percentages of the stages of the nuclear fuel life cycle, it is anticipated that the upstream Scope 3 emissions associated with the resources need for the Project would be even less than this limit.

[2] Scope 3 emissions are the ones that are a consequence of the proponent's activities but occur from sources not financially or operationally controlled by the proponent (e.g., emissions from waste)

3.2 Demand for Nuclear Energy

Under the 2015 Paris Agreement (UNFCC 2015), Canada has committed to reduce its GHG emissions by 40% to 45% below 2005 levels by 2030 (Prime Minister of Canada 2021). To meet these requirements, the Government of Canada aims to reduce its carbon dioxide (CO_2) emissions by 219 million metric tonnes by 2030 (Canadian Nuclear Society, n.d.).

Currently, 80% of Canada's electricity generation is from non-emitting sources and Canada aims to increase that to 90% by 2030. To meet the GHG emission reduction targets and growing electricity demands, considerable new electrical capacity will have to be installed in Canada along with efforts in decarbonization (Canadian Nuclear Association 2017). To achieve the decarbonization at the lowest possible cost in Canadian provinces, there would be a need to install a diverse set of low carbon technologies, including nuclear (Canadian Nuclear Association 2017). In Canada, various climate scenarios for low GHG economy modelling analyses indicate the importance of nuclear energy installation before mid-century to meet the Paris Agreement Targets. Studies indicate that provinces such as Saskatchewan, Alberta, Ontario, and New Brunswick would have to identify how nuclear energy can support their GHG emission reduction targets along with meeting higher electricity demands at lower costs (Canadian Nuclear Association 2017). For example, in Saskatchewan, there is a high potential to transition towards nuclear energy considering the availability of high-quality uranium reserves that will provide an opportunity to move away from oil and coal and reduce GHG emissions.

In Canada, nuclear power is the second largest source of low carbon economy, behind hydroelectricity (Canadian Nuclear Association 2021). Even though hydroelectric power is a zero-emission option in Canada, there is a limited number of locations remaining across the country that are suitable for hydroelectric power generation. For installing hydroelectricity, the geography of a location needs to be appropriate, and Canada is already near 90% of its hydro capacity (Canadian Nuclear Association 2021). Nuclear power is readily expandable in Canada as there is abundant supply of uranium. Nuclear requires a fraction of the land footprint when compared to hydroelectric, solar, and wind (Canadian Nuclear Association 2021) on a per-energy unit basis. In Canada, nuclear energy displaces approximately 50 million metric tonnes of CO_2 emissions per year compared to the same amount of electricity produced from natural gas (Canadian Nuclear Society, n.d.). Nuclear power plants, in comparison to renewable energy, could also help stabilize the electrical grids as they can limit the effects from seasonal fluctuations. In addition to increasing low carbon electricity, nuclear energy can also help stabilize electricity prices, lower levelized cost of electricity, provide reliable baseload capacities, create jobs, boost local economy, and reduce air pollution from electricity generation (ECCC 2020; Canadian Nuclear Society, n.d).

The importance of nuclear energy is also recognized at a global scale, where nuclear power is the second largest source of low carbon electricity. To achieve the international Paris Agreement targets, there would have to be an 80% increase in global nuclear power production by 2040 compared to the current levels, along with investments in renewable energy sources (International Energy Agency 2019). Based on the GHG emission policies at a global scale, nuclear generating capacity is projected to increase by 2040 in Canada and globally. In the long term, there would be a need for significant uranium resources nationally and internationally to support the use and growth of nuclear capacity to transition to low-carbon electricity generation (Nuclear Energy Agency and the International Atomic Energy Agency 2020).

Currently, Canada is the second largest producer and exporter of uranium. In 2016, 23% of the world's uranium was produced in Canada. Globally, the use of Canadian mined and milled uranium in nuclear power plants avoids approximately 300 million tonnes to 500 million tonnes of CO_2 emissions worldwide. All of the uranium

that is supplied globally from Canada is mined in Saskatchewan (International Atomic Energy Agency Ministerial Conference 2017). Given the GHG emission reduction targets of countries, there is a projected expansion in the demand for nuclear power as a part of overall energy supply. To meet the increasing demand for nuclear power, the demand for uranium for fuel fabrication is projected to increase with increasing electricity demand and a need to reduce GHG emissions from electricity generation.

Based on the projected increasing demands of nuclear energy and uranium supply, the Project can help meet the demands for low-emissions power generation through supplying uranium for fuelling the nuclear reactors. Therefore, based on the projected demand for uranium, if the Project is not approved, uranium would still be mined and milled at other locations to meet the increasing demand of uranium and the national and international scale. Considering Saskatchewan has a major source of uranium, the Project would play a key role in helping to meet the demands of uranium required for the nuclear power plants.

3.3 Nuclear Energy and Reduction of Carbon Intensity of Electric Grids (Displacement of National and International Greenhouse Gas Emissions)

Carbon intensity is a measure of the amount of CO_2 produced per unit of electrical energy generated. Carbon intensity of electricity depends on the fuel used in generation of electricity along with efficiency of power generation and transportation (Carbon Tracer n.d.). The current world average carbon intensity of the power sector is approximately 500 g CO_2e/kWh (carbon dioxide equivalent per kilowatt hour; Buongiorno et al. 2019). Based on the climate change stabilization scenarios developed by the International Energy Agency in 2017, to limit the global mean temperature warming to 2.0°C, the power sector's carbon intensity must be reduced to 10 g to 25 g CO_2e/kWh by 2050 and less than 2 g CO_2e/kWh by 2060 (Buongiorno et al. 2019). The New Nuclear Watch Institute study on *The Failings of Levelized Cost and the Importance of System-Level Analysis* has identified that, on a per megawatt of installed capacity basis, nuclear power is associated with 34% greater reduction in carbon intensity of a power system compared to that of renewable energy (NNWI 2020).

In many advanced economies, nuclear has been the largest source of low carbon economy. Globally, 55 gigatonnes of CO_2 emissions have been avoided over the last 50 years due to the use of nuclear power, which is equal to two years of global energy related CO_2 emissions (International Energy Agency 2019). Renewables and nuclear energy are both important resources for a low carbon economy. However, currently, renewables require back-up capacity due to seasonal fluctuations, which in most cases is supplied by carbon-emitting, natural gas-fired power plants. Because nuclear power plants do not require conventional power backup generation capacity, nuclear power is expected to have a greater affect on a system level carbon intensity compared to renewable energy (NNWI 2020).

Adding to that, nuclear power in itself, along with hydro and wind power, emits the lowest quantity of GHGs per unit of electricity throughout its life cycle. For example, a study for the Organisation for Economic Co-operation and Development countries estimates that nuclear power has one of the lowest carbon intensities, generating approximately 25 g CO_2e/kWh as compared to fossil fuel chains having carbon intensity of 450 g to 1,250 g CO_2e/kWh. Findings indicate that in Organisation for Economic Co-operation and Development countries, nuclear power has accounted for lowering the carbon intensity of energy economies in the last 25 years (Nuclear Energy Agency n.d.). In Canada in 2005, the nuclear industry produced 85 terawatt hours of electricity, which was approximately 11% of Canada's total energy use. This energy generation led to emission of 468,000 and 594,000 tonnes of CO_2 per year, which was 0.07% of Canada's total emissions for the year. Compared to that,

a 500 megawatt coal-fired power plant produces approximately 0.4% of Canada's total electricity and 0.4% of Canada's total GHG emissions (Ilnyckyj 2009). In Canada, without nuclear power, GHG emissions from electricity generation would be 50% higher during the 1971 to 2018 periods (IEA 2019). In Ontario, between 2005 and 2015, nuclear energy has helped the province phase out coal by providing a clean energy option that is affordable and reliable. Ontario's nuclear stations help avoid approximately 60 million tonnes of GHG emissions, which is equivalent to taking about 12 million combustion engine vehicles off the road (Canadian Nuclear Association 2017).

Based on the SACC (Government of Canada 2020), the Project could contribute to the Government of Canada's ability to meet its environmental obligations and its commitments in respect of climate change by enabling the displacement of high GHG intensity fossil fuel electrical generation and helping the production of renewable energy.

Further, the Project could help displace emissions internationally, as the Project could likely result in reduction of global emission reductions by supplying uranium to meet the increasing demands for nuclear projects.

4 KEY FINDINGS

Based on the requirements stated in CEAA 2012, the SACC (Government of Canada 2020), and the Proposed CNSC Path (CNSC 2017), this technical support document shows that an upstream assessment is not required. Instead, the discussion focuses on how the proposed Project can help displace GHG emissions internationally, resulting in global emission reductions, by providing uranium concentrate to the nuclear energy sector.

There is a growing demand for uranium at a national and an international scale. If the proposed Project is not approved, uranium would be mined and milled at other locations to meet this demand.

The Project could assist Canada's ability to meet its GHG reduction targets. The uranium concentrate from the Project could contribute to the nuclear energy sector and influence how nuclear energy is considered low carbon plans for Canada and international jurisdictions. Nuclear energy has a low carbon intensity and helps displace tonnes of GHG emissions per year from fossil fuel electricity generation at a national and international scale.

CLOSING

Golder is pleased to submit this report to NexGen in support of the environmental assessment for the Rook I Project. For details on the limitations and use of information presented in this report, please refer to the Study Limitations section following this page. If you have any questions or require additional details related to this study, please contact the undersigned.

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Rook I Project

Environmental Impact Statement

TSD XIV: Groundwater Flow and Solute Transport Modelling Report

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELLING REPORT
TECHNICAL SUPPORT DOCUMENT FOR THE ROOK I PROJECT

Prepared for:

NexGen Energy Ltd.

Prepared by:

WSP Canada Inc.

November 2024

Executive Summary

NexGen Energy Ltd. (NexGen) is proposing to develop a new uranium mining and milling operation in northwestern Saskatchewan, called the Rook I Project (Project). The Project would be located approximately 40 kilometres (km) east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon. The Project would reside within Treaty 8 territory and the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake, along the upper Clearwater River system. Patterson Lake is at the interface of the Boreal Shield and Boreal Plain ecozones. Access to the Project would be from an existing road off Highway 955, with on-site worker accommodation serviced by fly-in/fly-out access. The Project would include underground and surface facilities to support the extraction and processing of triuranium octoxide (U_3O_8) from the Arrow deposit, a land-based, basement-hosted, high-grade uranium deposit.

WSP Canada Inc. (WSP) was retained by NexGen to provide estimates of short-term (i.e., Operations) and long-term (i.e., post-closure) solute mass loadings from the waste products associated with the Project (i.e., tailings and waste rock source areas) to downgradient receptors, such that these loadings could be incorporated into an environmental impact statement and risk assessment for the proposed Project. Another objective of this work was to evaluate the potential groundwater management requirements (i.e., groundwater inflow rates) during Construction, Operations, and Decommissioning and Reclamation (i.e., Closure).

To achieve these objectives, a groundwater flow model was developed and calibrated to current (i.e., predevelopment) conditions. Details of the data and conceptual model used to develop the groundwater flow model development and calibration are provided under separate cover (Annex III, Hydrogeology Baseline Report). The groundwater flow model was configured to represent the Operations conditions, and a transient simulation was completed to evaluate the rates of groundwater inflow to the mine through time under various scenarios. It was also adapted to represent post-closure conditions through inclusion of tailings in the underground tailings management facility (UGTMF), backfill in the stopes, and the underground workings that would remain open at Closure. The groundwater flow model was then used to identify groundwater flow pathways from source areas (i.e., UGTMF tailings, stope backfill, and above-grade waste rock) through the geological environment to the downgradient receptors during post-closure.

The results of the groundwater flow and solute transport simulations were reviewed, and the following key findings were identified:

Predictive simulations of Construction and Operations resulted in groundwater inflows that ranged from a total of approximately 1,200 cubic metres per day (m^3/d) to 2,000 m^3/d during the period from 2022 (Year -4) to 2035 (Year 10) of the simulation. The greatest portion of inflow occurring in underground openings was associated with the open workings and not with the UGTMF or stope excavations. At 2035 (Year 10), the total groundwater inflows increased to approximately 3,900 m^3/d, corresponding to the opening of additional stopes. After 2041 (Year 16), the groundwater inflows were relatively stable at approximately 3,500 m^3/d total inflow.

The simulated groundwater inflows were found to be relatively sensitive to the input values applied to the model for hydraulic conductivity of the fault zone and bedrock. Simulated groundwater inflows were found to be up to approximately double the base case values when the fault zone hydraulic conductivity was increased by a factor of 5 and when the hydraulic conductivity of the bedrock was increased by a factor of 2.

It was assumed that all groundwater inflows associated with mine dewatering would contribute to a reduction in baseflows to the Patterson Lake watershed. The peak simulated groundwater inflow rates reflect a reduction in baseflow of approximately 6 percent (%).

At the end of Operations, the simulated drawdown extends approximately 2 km to the north, 4 km to the south, and 3.5 km in both the east and west directions, based on the 5 metres (m) drawdown contour. Vertically, the extent of depressurization is generally limited to the basement rock, as the overlying sandstone aquifer is increasingly more transmissive.

The primary groundwater flow pathway from the waste rock storage areas (WRSAs) was simulated to travel through the overburden (unconsolidated glacial till) via two pathways (i.e., one to the north and one to the south), which both discharge within Patterson Lake. Hydraulic conditions along this pathway are anticipated to be similar for both Operations and Closure. During Operations, a portion of the seepage from the potentially acid generating (PAG) WRSA would be intercepted via the liner.

Upon completion of mining and placement of underground waste, the mine would be flooded and groundwater pressures would re-establish to natural hydrostatic conditions, which are anticipated to be similar to those observed in the predevelopment period. The primary transport pathway from the underground waste would be vertically upwards through the fault zone to the interface with the sandstone, then laterally (i.e., northwest) through the sandstone, with the ultimate groundwater discharge location in Patterson Lake.

The approximate advective groundwater travel time from the upper horizon of the mine to the discharge location at Patterson Lake is estimated to be approximately 4,300 years. For the overburden pathways, the approximate advective groundwater travel time from the waste rock piles to Patterson Lake is estimated at 43 years to the north and 77 years to the south.

Peak mass loadings are driven primarily by waste rock and reflooded mine workings for most solutes (based on a review of mass loadings by source area). For a minority of solutes (e.g., arsenic), the proportions of solute mass from underground backfill and waste rock sources are similar.

The solute loadings were most sensitive to the source terms for backfill and the UGTMF tailings for solutes where the upper bound source was much greater than the base case (e.g., lead, where the upper bound source was much greater than the base case for the UGTMF). Because the surface waste rock loadings represent a large portion of the overall mass loadings, the results were also sensitive to the upper bound waste rock source term.

In general, model results were not sensitive (i.e., resulting in less than 5% difference) in simulations in which adjustments were made to the hydraulic conductivities of the backfill materials or a reduction was made in the area of the bedrock flow pathway.

Abbreviations and Units of Measure

Abbreviation	Definition
3-D	three-dimensional
CPB	cemented paste backfill
CPT	cemented paste tailings
NexGen	NexGen Energy Ltd.
NPAG	non-potentially acid generating
PAG	potentially acid generating
Project	Rook I Project
RSA	regional study area
SR	sensitivity run
UGTMF	underground tailings management facility
WRSA	waste rock storage area
WSP	WSP Canada Inc.

Unit	Definition
%	percent
°	degree
kg/m^3	kilograms per cubic metre
km	kilometre
$L/s/km^2$	litres per second per square kilometre
m	metre
m/day	metres per day
m/s	metres per second
m^2	square metre
m^3/d	cubic metres per day
masl	metres above sea level
mm	millimetre
mm/yr	millimetres per year

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Solute Transport Modelling Figures

1.0 INTRODUCTION

1.1 Background

NexGen Energy Ltd. (NexGen) is proposing to develop a new uranium mining and milling operation in northwestern Saskatchewan, called the Rook I Project (Project). The Project would be located approximately 40 kilometres (km) east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon (Figure A-1). The Project would reside within Treaty 8 territory and the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake, along the upper Clearwater River system. Patterson Lake is at the interface of the Boreal Shield and Boreal Plain ecozones. Access to the Project would be from an existing road off Highway 955, with on-site worker accommodation serviced by fly-in/fly-out access. The Project would include underground and surface facilities to support the extraction and processing of triuranium octoxide (U_3O_8) from the Arrow deposit, a land-based, basement-hosted, high-grade uranium deposit.

1.2 Objectives

The work described in this document was completed as a part of the technical support for NexGen's current Environmental Assessment of the Project. WSP Canada Inc. (WSP) was retained by NexGen to provide estimates of short-term (i.e., Operations and Closure) and long-term (i.e., post-closure) solute mass loadings from the waste products associated with the Project (i.e., tailings and waste rock source areas) to downgradient receptors. These loadings were incorporated into the Environmental Impact Statement (EIS) and risk assessment for the proposed Project. Note that the EIS risk assessment model used was completed by Ecometrix and is documented in the EIS.

Another objective of this work was to estimate groundwater inflow rates during Construction, Operations, and Decommissioning and Reclamation (i.e., Closure).

1.3 Scope of Work

To meet the work objectives the following tasks were completed:

- **Estimate groundwater inflows and extent of depressurization**: A three-dimensional (3-D) numerical groundwater flow model was developed to reflect the conceptual hydrogeological model and calibrated based on target groundwater elevations and baseflow information. The model was first established to represent current (i.e., predevelopment) conditions and subsequently modified to represent various stages of the mine Operations and Closure. This model was reconfigured to represent Operations conditions to estimate groundwater inflows to the underground development and receptors during Operations of the mine and the resulting depressurization in the bedrock.
- **Delineate groundwater flow pathways:** The groundwater flow model was configured to represent long-term post-closure conditions to delineate the groundwater flow pathways from the tailings and waste rock management facilities and groundwater flow rates during post-closure.

- **Estimate solute mass loadings to receptors:** An analytical solute transport model was developed using GoldSim (GTG 2021) based on the delineation of groundwater flow pathways and rates of flow through the backfill mine waste materials, underground tailings management facility (UGTMF) tailings, reflooded mine workings, and waste rock remaining at grade following Closure. The model was used to estimate the solute mass release from the source areas to the surrounding environment and to calculate the rate of transport of this mass to downgradient receptors (i.e., Patterson Lake). The model accounts for seepage from the waste rock storage areas (WRSAs) during Operations and Closure, and seepage from the underground solute source areas during Closure.
- **Evaluate model sensitivity:** To address the uncertainty associated with key model input parameters and assumptions, a sensitivity analysis was completed where the model was run using alternative configurations, and the results were compared to the base case simulation results.

1.4 Report Organization

Section 2.0, Groundwater Flow Model Development, of this report provides an overview of the conceptual hydrogeological model and details the development and calibration of the groundwater flow model. Section 3.0, Impact Assessment, describes the impact assessment approach for Operations and post-closure and Section 4.0, Results, provides the results of the impact assessment. The sensitivity analysis is described in Section 5.0.

2.0 GROUNDWATER FLOW MODEL DEVELOPMENT

2.1 Conceptual Model

The area of the Project has been the subject of previous investigations completed in support of resource exploration, the pre-feasibility study, and the Environmental Assessment. The analysis and interpretation of data collected as a part of these earlier studies have allowed for the development of a conceptual hydrogeological model for the Project. Data used in the development of the conceptual hydrogeological model (e.g., topography and drainage, geology, hydrogeology) are provided in the baseline hydrogeology report (Annex III, Hydrogeology Baseline Report). Key aspects of the conceptual hydrogeological model that pertain to the development of the numerical groundwater flow model are summarized below.

The topography and drainage in the regional study area (RSA) are illustrated in Figure A-2. The Project would be located along the southwestern rim of the Athabasca Basin, a large Paleoproterozoic-aged, flat-lying sedimentary basin that covers much of northern Saskatchewan and part of northern Alberta (RPA 2017). The topography of the Project site is dominated by glacial features including eskers and drumlins locally modified by wind action following retreat of the Laurentide Ice Sheet (Norris et al. 2017). Surface drainage in the RSA occurs as a part of the Clearwater River system, which is defined by the topographic divide of the Broach Lake catchment (i.e., the headwaters of the system) and includes, sequentially downstream in the Clearwater River system, the catchments of Patterson Lake, Forrest Lake, Beet Lake, and Naomi Lake and their associated tributaries.

The primary geological units include crystalline basement rock, paleo-weathered basement rock, Athabasca sandstone bedrock, Devonian sandstone/siltstone/mudstone bedrock, Cretaceous sandstone/siltstone/mudstone bedrock, and glacial drift (i.e., overburden).

These are illustrated as geological cross-sections in Figure A-3a and Figure A-3b. Within the crystalline basement rock and paleo-weathered basement rock there are sub-vertical fracture zones and fault zones. Section 5.1.3 of Annex III, Hydrogeology Baseline Report, provides additional details.

Results of hydraulic response testing for the geological units are provided in Figure A-4. Based on these results, hydrostratigraphic units were defined that correspond to the geological units. Competent basement rock is considered to have low hydraulic conductivity (i.e., on the order of 10^{-10} metres per second [m/s]). Within the crystalline bedrock, the higher permeability fault zones and shear zones are considered to be the primary hydraulic pathways. The sandstone unit is considered to be the primary bedrock aquifer in the area of the Project, with data from laboratory permeability testing indicating hydraulic conductivity values on the order of 10^{-05} m/s. The glacial drift is also considered to be an aquifer, with interpreted hydraulic conductivity values from hydraulic response testing ranging from 10^{-04} m/s to 10^{-06} m/s. Section 5.2.2 of Annex III provides additional details.

Within the bedrock, measured hydraulic gradients indicate that under existing conditions the primary groundwater flow direction is upwards and to the north-northwest (i.e., towards Patterson Lake). This is illustrated as a cross-section in Figure A-5 and in plan view in Figure A-6a, Figure A-6b, and Figure A-6c. In the glacial drift deposits, the groundwater flow direction is downwards and to the north-northwest (i.e., towards Patterson Lake). Section 5.2.1 of Annex III provides additional details.

In areas within the RSA where groundwater elevation monitoring data are not available, it is anticipated that localized discharge of groundwater occurs at surface water features. Groundwater recharge in the RSA occurs within the glacial drift.

Details on the implementation of the hydrogeological conceptual model within the numerical groundwater flow model are described in the following subsections.

2.2 Numerical Model Approach

As noted above, the objectives of groundwater flow modelling were to develop and calibrate a groundwater flow model representing the current (i.e., predevelopment) conditions for the site and use that model to estimate groundwater inflows, estimate the extent and magnitude of groundwater depressurization, and delineate groundwater flow pathways from mine waste source areas to receptors.

To achieve these objectives, a 3-D numerical groundwater model was constructed and calibrated to represent the “best estimate” of groundwater flow conditions based on the conceptual model. The general assumptions and limitations of the numerical model are summarized below:

- Groundwater flow is laminar (i.e., fluid moving along smooth paths), steady, and governed by Darcy’s Law.
- Groundwater flow in the model, regardless of the presence of bedrock fractures, is represented by an equivalent porous media approach.
- Hydraulic heads are vertically averaged within a given model layer.
- Material properties applied in the model are based on the units defined in the 3-D geological (Leapfrog) model developed by NexGen. Geological contacts were extrapolated within the areas of the groundwater flow model domain that were not covered by the geological model.

- Recharge estimates reflect deeper recharge and discharge characteristics of the groundwater flow system and do not account for shallow infiltration and discharge to intermittent streams (i.e., interflow).
- A regionalized approach to model calibration was employed such that parameter values were established for the hydrostratigraphic units on a regional scale.
- The most recent available calibration data were used in the calibration process (i.e., typically corresponding to December 2019), which were assumed to be representative of steady-state predevelopment conditions.

A finite element modelling package developed by the DHI-WASY Institute in Germany (FEFLOW; Diersch 2009), was used as the numerical simulation tool for the assessment. FEFLOW is capable of simulating saturated and unsaturated groundwater flow and solute and heat transport in three dimensions. FEFLOW was selected for this work given its capabilities to efficiently discretize local features around each of the main mine features (e.g., mine tunnels, mine workings, UGTMF) yet maintain a relatively regional overall footprint to estimate changes in more regional groundwater elevations and water balances. FEFLOW v7.2 was used to complete the simulations presented in this report.

2.3 Regional Study Area Flow Model

2.3.1 Model Mesh and Extents

The model extents are illustrated in Figure A-1 and define the RSA boundary. As shown in the figure, the model was constructed based on a rectangular mesh of approximately 26.5 km by 18.5 km that is oriented based on the general regional surface drainage for the area, with the northwest portion of the model domain situated along a topographic high and the southeast portion of the model situated along a topographic low (i.e., with drainage to the Clearwater River). It is thought that the regional deep groundwater flow system does not necessarily reflect the shallow local drainage patterns at surface water features.

The model mesh was configured with an element size of approximately 600 metres (m) along the model periphery, transitioning to approximately 6 m in the central portion of the model in the vicinity of the Project. Vertically, the model was discretized into 38 numerical layers, ranging in thickness from 0.25 m to 20 m. The total number of grid cells was 1,411,038. Section 2.3.3, Material Properties, provides details on the model layering with reference to the hydrostratigraphic units.

2.3.2 Boundaries

Figure A-7 illustrates the groundwater flow model boundaries. Lakes and watercourses (e.g., streams and creeks) within the model domain were represented using fixed head boundaries applied at the elevation of the water feature on model slice 1. Fixed head boundary nodes were also specified along the downstream (i.e., southeast) lateral model boundary on slices (i.e., surfaces that define model layers) 6 to 39 to allow regional outflow of groundwater through the bedrock. In the absence of groundwater elevation data in this area, these nodes were assigned an elevation of 485 metres above sea level (masl), corresponding to the approximate low point in topography along the periphery of the model.

The model recharge distribution was determined by applying a uniform infiltration rate equivalent to one-third of the mean annual precipitation (an infiltration rate of 140 millimetres per year [mm/yr] calculated based on a mean annual precipitation of 419 millimetres [mm]) and allowing the model to remove excess infiltration where groundwater elevations in the upper model layer rose above the ground surface. This value was assigned as an

initial estimate of the infiltration rate and corresponds to an equivalent basin yield of 4.4 litres per second per square kilometre (L/s/km^2). The recharge rate is a function of the infiltration capability of the soil based on surface elevation, glacial drift thickness, glacial drift hydraulic conductivity, and proximity to surface water features. The calculated infiltration rate applied in the model using this approach corresponded to a regional average of 93 mm/yr (i.e., approximately 3 L/s/km^2), or approximately 22 percent (%) of the mean annual precipitation.

2.3.3 Material Properties

The generalized hydrostratigraphy for the Project site is described in Section 2.1, Conceptual Model, and illustrated schematically in Figure A-3a and Figure A-3b. To represent this hydrostratigraphy in the groundwater flow model, a total of 38 numerical layers were used and divided as follows:

- Twelve evenly spaced, laterally variable layers were specified between the ground surface, which ranged from 601 masl to 487 masl, and a horizontal slice at elevation 360 masl. This spacing resulted in a thickness of each layer that ranged from approximately 10 m to 20 m and model slice elevations that generally aligned with hydrostratigraphic unit contact elevations in the vicinity of the Project. These layers encompass the upper and lower glacial drift units, Cretaceous bedrock, Devonian bedrock, and the upper portions of the sandstone and paleo-weathered rock units.
- Layers of constant thickness were specified below elevation 360 masl, with a 30 m thickness for layers 13 to 18 (i.e., to elevation 180 masl), then 20 m thickness for layers 19 to 33 (i.e., to elevation -120 masl), and 106 m thickness for layers 34 to 38 (i.e., to elevation -650 masl at the base of the model). These layers encompass the lower portions of the sandstone and paleo-weathered basement rock units and the entirety of the basement rock unit.

Elements within the 3-D model mesh were assigned material properties based on their proximity to the geological units in the 3-D geology model using Leapfrog. In some cases, the interpolation routine resulted in spatial gaps; therefore, manual adjustments were made to improve connectivity of the unit across the mesh. This was particularly relevant for the fault zone and shear zone units, which are relatively thin compared to the mesh spacing. The resulting material distribution applied in the model is illustrated in the cross-sections in Figure A-8, which shows regional northwest-southeast material zones, Figure A-9, which shows regional southwest-northeast material zones, and Figure A-10, which shows local material zones.

The horizontal and vertical hydraulic conductivity values applied to the main hydrostratigraphic units are summarized in the tables embedded in Figure A-8, Figure A-9, and Figure A-10. A summary of the assignment of material properties is as follows:

- In general, the hydraulic conductivity values applied in the model agree with the measured data. For the basement rock, paleo-weathered basement rock, shear zone, and upper glacial drift units, the model value was at or slightly below the geometric mean value from the measured data. For the fault zone, the model value was slightly above the geometric mean value.
- For the sandstone unit, the hydraulic conductivity was approximately two orders of magnitude above the geometric mean value. The assignment of these values is detailed further as a part of the discussion on model calibration in Section 2.4, Model Calibration.

- The hydraulic conductivity anisotropy ratios were derived through the model calibration process (detailed in the subsection below). The values assigned to the overburden, Cretaceous, and Devonian units reflect the strong vertical (downwards) gradient through the overburden to the underlying rock. These are considered reasonable given the interbedded nature of these units.
- Within the vicinity of the Project (i.e., the local study area), the fault zone and shear zone units were mapped individually in the 3-D geological model and as such have been incorporated in the groundwater flow model as independent material property zones. Therefore, the basement rock in the local area was assigned a lower hydraulic conductivity (i.e., 1.0×10^{-09} m/s, reflective of competent rock) in the local area as compared to the fault zones (i.e., 2.0×10^{-07} m/s) and shear zones (i.e., 8.3×10^{-09} m/s). Based on the geological model, these features extend to the top of the paleo-weathered unit.
- It is understood that the fault zone and shear zone features extend outside of the local area where they are presently mapped. Based on geophysical survey data (i.e., Z-tipper axis electromagnetic and airborne magnetic data) provided by NexGen, these features extend approximately 4 km to the southwest and approximately 700 m to the northeast (i.e., beneath Patterson Lake). To account for the presence of these features, the bedrock in this area was assigned a horizontal hydraulic conductivity of 1.3×10^{-07} m/s with an orientation of 43° from north (i.e., approximating the trend of the fault and shear zones) and 1.0×10^{-08} m/s in the perpendicular (i.e., northwest-southeast) direction.
- Outside of the area where the fault zone and shear zones are assumed to be present, the bedrock was assigned a hydraulic conductivity value of 1.0×10^{-08} m/s, as determined through the model calibration process.
- A zone of high hydraulic conductivity was used to represent Patterson Lake, where necessary, to account for the lake bathymetry.
- Based on the interpreted geological surfaces, Patterson Lake is in direct hydraulic connection with the sandstone unit. For the purposes of the hydrogeological assessment, the delineation of groundwater flow pathways did not consider the presence of lake bottom sediments (a conservative assumption).
- In the absence of measured data, the porosity values assigned to the units were based on typical values for similar geological units in the Athabasca Basin (COGEMA 1997, 2004). The assigned porosity values range from 0.01 for the basement rock to 0.2 for the till.

2.4 Model Calibration

The groundwater flow model was calibrated using PEST optimization software, which iteratively adjusts model parameters (e.g., hydraulic conductivity and recharge) within user-defined constraints until the model error, as calculated based on target data (e.g., groundwater elevations), is minimized. In this instance, PEST was implemented directly through the FEFLOW user interface. Additional details on PEST can be found in the software user's manual (Watermark Numerical Computing 2021).

Following the completion of the optimization routine, the model results were checked for a reasonable match between the simulated and observed groundwater elevations (i.e., calibration statistics and spatial distribution of residuals), and groundwater flow patterns (i.e., discharge areas and depths to groundwater). If a reasonable match was not achieved, the input parameters and/or constraints on the optimization routine were adjusted and

the optimization routine was re-run. Specific calibration targets included the most recent available groundwater elevations measured from 34 monitoring wells and 27 vibrating wire piezometers located in the local study area. Section 5.2 of Annex III provides a summary of the monitoring locations.

A regionalized approach to parameterization was adopted wherein the calibration process parameter values were associated with regional hydrostratigraphic units and adjusted globally during the calibration process to best match the observed data. Small-scale variations, as may be required to match observed data at the scale of individual wells, were not employed.

Low flow periods from streamflow measurements at monitored watercourses within the model domain were also used to check model calibration.

The results of the model calibration are illustrated in Figure A-11, which shows a statistical summary of the calibration process, and in Figure A-12 through Figure A-15, which show simulated groundwater elevations and flow directions for various hydrostratigraphic horizons. A comparison of the simulated and measured groundwater elevations is provided in Table 1. A review of the results presented in these tables and figures led to the following observations:

- The calibrated model achieved a normalized root mean squared error of 8.1% with a root mean square error of 3.7 m and a residual mean error of -0.3 m (Figure A-11), which are considered reasonable. A strong spatial bias was not observed in the simulated groundwater elevations, as shown on the residual error distribution map in Figure A-11.
- The groundwater flow patterns simulated by the model appear reasonable given the conceptual understanding of groundwater flow in the area of the Project. As shown in Figure A-6a, Figure A-6b, and Figure A-6c, groundwater flow is generally simulated to occur from south to north (i.e., towards Patterson Lake).

Baseflow (the portion of surface water flows originating as groundwater seepage) estimates for the surface water catchments (Annex IV.1, Regional Meteorological and Hydrological Characterization Report) were approximately 3.5 L/s/km^2. Using the catchment areas for Patterson Lake, this baseflow corresponds to an equivalent recharge rate of approximately 110 mm/yr (i.e., 3.5 L/s/km^2). The model average recharge rate of 93 mm/yr (i.e., 2.9 L/s/km^2) is similar to this estimate and is therefore considered to be reasonable.

Table 1: Comparison of Simulated and Observed Groundwater Elevations

Monitoring Location	Groundwater Elevation (masl)		Difference (m)	Monitoring Location	Groundwater Elevation (masl)		Difference (m)
	Observed Value	Calculated Value			Observed Value	Calculated Value	
2018_MW-002A	520.04	517.78	-2.26	GAR-19-019-VWP1-146	497.74	501.22	3.47
2018_MW-002B	519.93	515.05	-4.88	GAR-19-019-VWP2-248	505.67	502.75	-2.91
2018_MW-003A	512.65	513.60	0.95	GAR-19-019-VWP3-353	504.45	503.85	-0.61
2018_MW-004A	514.06	522.68	8.62	GAR-19-019-VWP4-545	503.86	505.10	1.24
2018_MW-004B	513.82	517.62	3.80	GAR-19-021-VWP1-86	498.95	500.70	1.75
2018_MW-005B	543.78	538.61	-5.17	GAR-19-022-VWP1-131	498.55	500.71	2.17
2018_MW-006A	528.99	534.85	5.86	GAR-19-022-VWP2-287	499.90	503.08	3.18
2018_MW-006B	528.65	532.01	3.36	GAR-19-022-VWP3-482	504.69	504.80	0.11
2018_MW-007A	528.39	526.49	-1.90	GAR-19-022-VWP4-575	508.26	505.32	-2.95
2018_MW-007B	528.40	522.43	-5.97	GAR-19-023-VWP1-116	502.06	507.38	5.32
2018_MW-008A	528.81	521.74	-7.07	GAR-19-024-VWP1-234	508.73	505.65	-3.09
2018_MW-008B	527.67	517.49	-10.2	GAR-19-024-VWP2-301	508.73	505.46	-3.27
2018_MW-009A	523.97	522.83	-1.14	GAR-19-024-VWP3-594	513.01	505.20	-7.82
2018_MW-009B	523.59	522.30	-1.29	GAR-19-024-VWP4-655	508.08	505.33	-2.74
2018_MW-010A	511.93	511.27	-0.66	GAR-18-013_Z1	506.51	505.39	-1.12
2018_MW-010B	498.86	500.56	1.70	GAR-18-013_Z2	506.30	505.38	-0.92
DH-BGC17-01	530.19	525.22	-4.97	GAR-18-013_Z3	505.77	505.26	-0.51
DH-BGC17-02	526.15	523.45	-2.70	GAR-18-013_Z4	505.40	504.99	-0.42
DH-BGC17-03	518.16	529.36	11.2	GAR-18-013_Z5	505.11	504.84	-0.26
DH-BGC17-04	533.48	535.81	2.33	GAR-18-013_Z6	504.51	504.53	0.02
DH-BGC17-05	519.57	519.30	-0.27	GAR-18-013_Z7	504.26	504.13	-0.13
GAR-17-001-VWP1-303	506.37	503.48	-2.89	GAR-18-013_Z8	503.43	503.83	0.40
GAR-17-002-VWP1-654	502.73	505.56	2.83	GAR-18-013_Z9	503.08	503.39	0.32
GAR-17-003-VWP1-276	503.09	503.35	0.27	GAR-18-013_Z10	503.00	502.64	-0.36
GAR-17-004-VWP1-99	498.59	500.19	1.60	GAR-18-013_Z11	502.24	501.82	-0.42
GAR-17-004-VWP2-106	499.16	500.24	1.08	GAR-18-013_Z12	501.70	500.93	-0.77
GAR-19-018-VWP1-159	499.55	500.80	1.25	GAR-18-013_Z13	500.48	503.71	3.23
GAR-19-018-VWP2-235	500.00	502.17	2.17				
GAR-19-018-VWP3-363	504.23	503.73	-0.51				
GAR-19-018-VWP4-544	510.41	505.04	-5.37				

Note: GAR-18-013 refers to the Westbay installation.
masl = metres above sea level.

2.5 Baseline Flow Regime

The simulated groundwater conditions under current (i.e., predevelopment) conditions are illustrated in Figure A-12 through Figure A-15. Based on the results of the simulation, the groundwater flow regime in the vicinity of the proposed mine and surrounding area is characterized as follows:

- Groundwater flow directions in the glacial drift are predominantly towards the local surface water and drainage features throughout the model domain (Figure A-12). In the area of the surface infrastructure of the mine, the groundwater flow direction in the glacial drift is towards Patterson Lake. Because the mine would be situated on a peninsula within Patterson Lake, a groundwater flow divide in the glacial drift exists to the south of the mine trending parallel to the axis of the peninsula. Groundwater flow to the north of the divide flows to the north and groundwater flow to the south of the divide flows towards the south, ultimately discharging in Patterson Lake in both directions.
- The lateral groundwater flow direction in the shallow bedrock (Figure A-13) is predominantly from west to east over most of the model domain, with a component of the flow towards major water features (e.g., Patterson Lake and Forrest Lake) in localized areas. In the northern portion of the groundwater flow model, flow is towards the south. This flow pattern generally follows the topographic setting of the Clearwater River catchment. Local to the mine area, the groundwater flow in the shallow bedrock is similar to the glacial drift. A groundwater flow divide was simulated to the south of the proposed mine, with flow directed to the northern and southern portions of Patterson Lake on the respective sides of the divide.
- Groundwater flow directions in the deep bedrock is predominantly from west to east, with the highest hydraulic gradient occurring west of Patterson Lake (Figure A-14). Local to the proposed mine, the lateral groundwater flow direction is to Patterson Lake to the north. The groundwater flow divide noted above in the shallow bedrock was also simulated to occur in the deep bedrock, although less pronounced.
- The vertical groundwater flow direction is downwards in the area of the topographic high located to the south of the mine, transitioning to upwards in the area of the underground mine and UGTMF (Figure A-15). The influence of the structures (i.e., fault zones and shear zones) is evident in the simulated groundwater elevations, as indicated by localized reduction in groundwater pressures near these features. The structures are considered more conductive than the adjacent basement rock and represent the primary groundwater flow path between the mine horizon and groundwater discharge locations in Patterson Lake.

3.0 IMPACT ASSESSMENT

3.1 Assessment Approach

As stated in Section 1.0, Introduction, a primary objective of the groundwater flow and solute transport modelling is to provide estimates of solute mass loadings resulting from the proposed Project to downstream receptors. To achieve this objective, the approach involved development of a groundwater flow model and calibration of this model to existing (i.e., predevelopment) conditions. The construction and calibration of the groundwater flow model is detailed in Section 2.0 of this document.

The model was subsequently reconfigured to represent conditions during Operations and over the long term during post-closure. Groundwater flow simulations were completed with the Operations conditions model to estimate the rate of groundwater inflow to the mine, extent of depressurization (i.e., drawdown) in the bedrock,

and to delineate the groundwater flow pathways from the surface facilities (i.e., WRSAs) to the discharge location under Operations conditions.

The post-closure groundwater flow model was used to delineate the flow components through the source areas. A particle tracking analysis was completed to delineate the post-closure groundwater flow pathways from the source areas through the geological pathway to the ultimate groundwater discharge location (Section 3.3, Post-Closure).

Results of the groundwater flow model were used as input to an analytical solute transport (GoldSim) model, which was used to estimate solute mass flux from the source areas in the underground mine and surface facilities, through the downstream geological pathways to the ultimate receiving environment.

GoldSim is a commercially available, highly graphical, flexible, object-oriented computer program that is designed to provide the user with an understanding of the factors that control the performance of an engineered or natural system, as defined by a user specified mathematical model, and to predict the future behaviour (i.e., performance) of the defined system. A detailed description of the GoldSim software, including example applications and manuals, is documented in the Main Users Guide (GTG 2018a) and the Contaminant Transport Module Users Guide (GTG 2018b). Version 12.1 was used for the predictive calculations completed in this report.

The solute transport simulation completed using the best-estimate parameter set (i.e., the calibrated model with expected source concentrations) is referred to as the Base Case scenario. This is identical to the scenario referred to as the Application Case in the EIS (EIS Section 8.2.5, Assessment Cases). Details on the groundwater flow and solute transport modelling are provided in the following sections.

3.2 Operations

During Operations, groundwater reporting to the underground mine would be pumped to surface and treated and/or managed as needed. As such, the underground mine would be under hydraulic containment and release of mining-affected groundwater from potential underground sources to the surrounding environment would not occur.

3.2.1 Seepage from Surface Facilities

It is understood that the special waste pile and ore storage stockpile would be designed to include double liner systems and as such no seepage is anticipated from these facilities to the receiving environment. For the purposes of this assessment, the WRSAs were conservatively assumed to be in place during Construction and Operations (i.e., 28 years) and remain in place following Closure, and as such, were included in the solute transport model for Construction and Operations.

The placement method evaluated as a part of this assessment included segregation of potentially acid generating (PAG) and non-potentially acid generating (NPAG) waste rock. In addition, the PAG would be placed using engineered controls with design of horizontal layering to limit oxygen ingress into the waste rock (Technical Support Document [TSD] XVII, Waste Rock and Underground Wall Rock Source Term Predictions Report).

3.2.2 Groundwater Inflows and Drawdown under Long-Term Operations

As the mine development progresses, groundwater would continue to seep into the mine, resulting in depressurization of the bedrock. To estimate the rate of groundwater inflow to the mine and the extent of depressurization, the groundwater flow model was configured to represent the progressive mine development as

a transient simulation. For this simulation, model boundaries (i.e., seepage nodes) representing the mine workings were “switched on” in annual increments according to the mine development plan.

The mine plan used for this assessment is detailed in RPA (2020). The model boundary configuration for the forecast Operations simulation is shown in Figure A-16.

For the purposes of this assessment, it was assumed that backfilled stopes and UGTMF chambers would continue to be free draining throughout Operations. As such, the seepage boundaries implemented in the model remain active after backfilling has occurred. Further, it was assumed that liners would be installed within the mine shafts throughout the more permeable sandstone unit. As such, these were assumed to be no-flow boundaries in the model.

Two additional simulations were completed using the model to evaluate the potential range in groundwater inflow rates, and to test the sensitivity of key model input values. Because the fault zone is the primary pathway for groundwater flow at the underground mine horizon, the first additional simulation involved a five-fold increase in the hydraulic conductivity of this unit (i.e., from 2×10^{-07} m/s to 1×10^{-06} m/s). Similarly, the second additional simulation involved doubling the hydraulic conductivity of the basement rock adjacent to the mine workings (i.e., from 1×10^{-09} m/s to 2×10^{-09} m/s). The hydraulic conductivity values applied in both additional simulations were within the ranges available from testing (Section 2.1). For both additional simulations, the groundwater flow rates reporting to the model boundaries representing the mine workings were tracked with time as per the Base Case simulation.

3.2.3 Influence of Mine Dewatering on Surface Water Features

Groundwater depressurization associated with mine dewatering would propagate from the underground development outward (i.e., laterally and vertically), potentially affecting the groundwater discharge rates to surface water features. To quantify the potential effect on groundwater discharge rates to surface water features, the simulated flux (i.e., discharge) to model boundaries representing surface water features was compared for the predevelopment and forecast simulations. The simulated change in groundwater flux was calculated independently for each major watershed located within the model domain.

3.3 Post-Closure

Figure A-17 provides a schematic illustration of the GoldSim solute transport model, identifying the source, pathways, and downstream receptor. Advective fluxes presented in Figure A-17 for the underground (i.e., UGTMF, primary backfill, secondary backfill, and reflooded mine workings) are predicted flow rates from the groundwater model following reflooding of the mine workings. As summarized on Figure A-17, the predictive flux through the UGTMF, primary backfill, secondary backfill, and reflooded mine workings are 0.55 m^3/day, 0.32 m^3/day, 0.15 m^3/day, and 2.7 m^3/day, respectively. Pathways and travel length were derived from the groundwater model through particle tracking analysis detailed in Section 3.3.2, Groundwater Flow Pathways, and Section 4.4, Pathways Delineation and Travel Times. In summary, mass released from the source area migrates through the subsurface pathways, ultimately discharging to downgradient surface water receptor (i.e., Patterson Lake). A summary of the source areas, pathways, and solute transport model properties is provided below.

3.3.1 Description of Source Areas

As a part of the mine planning process, tailings would be placed in the underground mine workings, including primary and secondary stopes, and a purposely built UGTMF. Tailings material would be converted to cemented paste tailings (CPT) or a cemented paste backfill (CPB) before disposal. The binder content and inclusion of process waste with the CPT and CPB varies depending on where it would be disposed, with higher binder content CPB allocated for primary and secondary stopes and lower binder content CPT allocated for disposal in the UGTMF (Annex III).

A description of the physical and chemical characteristics of each of the source areas is provided below.

Given the relative volumes of waste material and the generally low seepage rates in the geological pathways, it was assumed for the solute transport modelling that the sources were infinite. The one exception to this is the reflooded mine workings, as detailed below.

For the tailings and stope backfill sources, the advective and diffusive components of mass flux were calculated within GoldSim separately. Advective flux was calculated as

$$J_A = Q_T C_0 \qquad \text{(Equation 1)}$$

where:

- J_A = Advective mass flux (M/T)
- Q_T = flow out of the source mass (L^3/T); and
- C_0 = source concentration (M/L^3).

Diffusive flux out of the source mass and into the groundwater flow zone was calculated by applying Fick's First Law:

$$\text{Diffusive flux (J)} = -D^* \frac{\partial C}{\partial x} \qquad \text{(Equation 2)}$$

where:

- J = diffusive flux (M/T per unit area [L^2]);
- D = effective diffusion coefficient (L^2/T), which accounts for the molecular diffusivity (L^2/T) of the fluid and porosity (-) and tortuosity of the medium;
- C = solute concentration (M/L^3);
- x = position (L);
- M = mass;
- L = length; and
- t = time.

This is illustrated conceptually on Figure A-17. The source concentrations were considered to remain constant over time (i.e., no decay of the source at the tailings/host rock interface).

The concentration profiles adjacent the tailings mass were calculated by dividing the zones into arrays of “mixing” cells within GoldSim for a 5 m wide active flow zone within the host rock. A total of 20 mixing cells were specified over this distance, with variable widths ranging from 0.03 m to 0.8 m. Diffusive mass flux was calculated between each of the cells, and groundwater flow within the host rock, normal to the direction of diffusion, was imposed across each cell based on predictions obtained from the 3-D flow model.

Underground Tailings Storage Facility Tailings

The CPT that would be disposed of in the UGTMF were geochemically and hydraulically characterized, as detailed in TSD XV, Tailings Source Term Derivation Report. A summary of the source term for these materials, based on the geochemical characterization, is provided in Table 2, and hydraulic conductivity values, based on the hydraulic characterization, are provided in Figure A-16. The source concentrations values were applied as an infinite source to represent the UGTMF in the solute transport model.

Stope-Backfill

The CPB that would be disposed of in the stopes were geochemically and hydraulically characterized in TSD XV. These materials were characterized according to their placement destination (i.e., within primary or secondary stopes). A summary of the source term and hydraulic properties for these materials is provided in Table 2. These values were applied to represent the stope backfill sources in the solute transport model.

Flooded Mine Workings

As the mine would be flooded during Closure, the oxidized material remaining in open workings would contact flood water and potentially dissolve into it. This process was accounted for in the solute transport model by the inclusion of an additional source applied as a time-variable mass loading rate over a five-year period (i.e., during reflooding). It was assumed that after the mine workings are reflooded, oxygen availability would be limited and the additional mass loadings from the exposed mine surfaces would be negligible. Source terms for the reflooded mine workings were developed and provided by TSD XVII and are provided in Table 2.

As indicated in Table 2, values for certain solutes (e.g., phosphorus, ammonia, radium-228) were not included in the source data. To account for potential mass of these solutes in the reflooded mine workings, a mass loading rate was estimated based on the product of the ratio of the chloride mass loading rate in the reflooded mine workings source to chloride concentration in the UGTMF tailings and the CPT concentration for the undefined solute.

Waste Rock

A portion of the precipitation that falls on the WRSAs would infiltrate through the waste rock and report as seepage to groundwater in the underlying overburden. Source terms for the waste rock were developed and provided in TSD XVII. To reflect the distribution of material types included in the WRSAs (i.e., the PAG WRSA and NPAG WRSA), this source was divided into two components: PAG and NPAG sources. The mass loading rates applied to represent the WRSAs in this assessment included Source Term 4 (segregated NPAG) and Source Term 5 (Segregated PAG) in TSD XVII.

To account for changes in the condition of the WRSAs during Operations, Closure, and in post-closure, a time-variable source term was applied in the solute transport model to represent the Operations and post-closure conditions, as summarized in Table 2. The Operations source term was applied as a constant value over the first 30 years of the simulation (i.e., approximating Construction and Operations), and the post-closure source was applied over the remainder of the simulation duration to reflect the cover-in-place WRSAs conditions (e.g., reduced infiltration). As such, the mass loading rates from the WRSAs were assumed to continue indefinitely (i.e., the source was assumed to have infinite mass).

As indicated in Table 2, values for certain solutes (e.g., phosphorus, ammonia, radium-228) were not included in the source data. To account for potential mass of these solutes in the waste rock sources, a mass loading rate was estimated based on the product of the ratio of the chloride mass loading rate in the waste rock source to chloride concentration in the UGTMF tailings and the UGTMF (CPB and CPT) tailings concentration for the undefined solute.

Table 2: Source Terms

Solute	Source Concentration (mg/L)						Mass Loading Rate (kg/yr)													
	Primary Stope		Secondary Stope		UGTMF		Reflooded Mine Workings						Waste Rock (NPAG Component, Base Case)		Waste Rock (PAG Component, Base Case)		Waste Rock (NPAG Component, Upper Case)		Waste Rock (PAG Component, Upper Case)	
	Base Case	Upper Case	Base Case	Upper Case	Base Case	Upper Case	2050	2051	2052	2053	2054	2055	Operations	Post-Closure	Operations	Post-Closure	Operations	Post-Closure	Operations	Post-Closure
Aluminum	3.6	26.8	3.3	24.2	1.4	5.3	1,600	2,100	340	990	1,700	99	0.47	0.15	0.039	810	0.48	0.16	0.039	1200
Ammonia[a]	3.3	3.5	3.2	3.4	2.6	2.6	684	252	90	153	288	49	153	87	13	21	234	135	18	30
Arsenic	0.49	0.74	0.64	1.14	1.7	4.11	76	23	10	13	23	5	3.7	2	0.17	0.16	5.5	3.1	0.26	0.24
Boron	0.44	0.5	0.45	0.54	0.55	0.8	760	130	110	120	240	52	19	11	2.8	5.9	28	16	4.1	8.8
Cadmium	0.0029	0.0045	0.0027	0.0045	0.0013	0.0046	8.6	1.4	1.3	1.1	1.9	0.53	0.017	0.0097	0.029	0.078	0.026	0.014	0.044	0.12
Calcium	2,139	2,490	2,251	2,566	3,085	3,138	32,000	17,000	4,100	8,500	16,000	2,000	4,200	2,300	420	720	6,300	3,500	630	1,100
Chloride	716	754	666	699	287	293	76,000	28,000	10,000	17,000	32,000	5,400	17,000	9,700	1,400	2,300	26,000	15,000	2,000	3,300
Chromium	0.042	0.14	0.04	0.228	0.025	0.884	6.8	2.3	1.3	1.9	4.7	0.49	0.55	0.31	0.12	0.13	0.83	0.46	0.18	0.2
Cobalt	0.0061	0.0125	0.006	0.0174	0.005	0.0544	94	42	11	22	55	5.1	0.37	0.2	16	32	0.55	0.31	24	49
Copper	0.13	0.19	0.14	0.21	0.23	0.39	95	100	10	41	67	4.9	1.3	0.74	33	52	2	1.1	49	78
Fluoride[a]	5.8	6.5	5.5	6.2	3.7	3.8	967	356	127	216	407	69	216	123	18	29	331	191	25	42
Iron	0.111	1.613	0.108	1.558	0.089	1.144	5,200	1,100	990	1,400	3,700	420	230	130	160	470	340	190	240	710
Lead	0.11	0.77	0.10	1.36	0.04	5.82	3.7	2.3	0.72	1.4	2.8	0.26	0.013	0.0031	0.0015	0.56	0.011	0.0027	0.0013	0.63
Lead-210	6.7×10^{-09}	2.7×10^{-08}	6.1×10^{-09}	2.6×10^{-08}	1.6×10^{-09}	1.7×10^{-08}	1.0×10^{-07}	1.0×10^{-07}	1.0×10^{-07}	1.0×10^{-07}	1.0×10^{-07}	1.0×10^{-07}	8.8×10^{-09}	2.8×10^{-09}	7.0×10^{-10}	2.4×10^{-09}	8.8×10^{-09}	2.8×10^{-09}	7.0×10^{-10}	2.4×10^{-09}
Magnesium	1.6	1.8	1.8	2.0	3.1	3.2	8,800	6,400	1,400	3,200	5,500	660	470	260	420	2,100	700	390	630	3,100
Manganese	0.025	0.025	0.024	0.053	0.02	0.264	110	110	14	44	60	6.6	5.8	3.2	7.7	45	8.7	4.8	12	68
Mercury	0.0000038	0.000012	0.0000063	0.000016	0.000026	0.000045	0.56	0.26	0.07	0.13	0.24	0.039	0.055	0.031	0.0073	0.0073	0.082	0.046	0.011	0.011
Molybdenum	230	598	218	558	133	263	23,000	3,300	3,300	2,700	4,600	1,400	3.4	1.9	0.36	0.23	5.1	2.8	0.54	0.24
Nickel	0.005	0.035	0.007	0.068	0.02	0.311	64	49	8.5	22	39	3.7	0.76	0.42	6.9	28	1.1	0.64	10	43
Nitrate[a]	0.020	0.020	0.021	0.021	0.023	0.023	6.1	2.2	0.80	1.4	2.6	0.43	1.4	0.8	0.11	0.18	2.1	1.2	0.16	0.26
NO_2 as N[a]	0.025	0.026	0.025	0.025	0.024	0.024	6.3	2.3	0.83	1.4	2.7	0.45	1.4	0.8	0.12	0.19	2.2	1.2	0.17	0.27
Phosphorus[a]	0.027	0.028	0.027	0.028	0.026	0.026	7.0	2.6	0.91	1.6	2.9	0.49	1.6	0.9	0.13	0.21	2.4	1.4	0.18	0.30
Polonium-210	2.0×10^{-11}	2.4×10^{-11}	1.9×10^{-11}	2.3×10^{-11}	1.2×10^{-11}	1.3×10^{-11}	1.9×10^{-09}	1.9×10^{-09}	1.9×10^{-09}	1.9×10^{-09}	1.9×10^{-09}	1.9×10^{-09}	6.6×10^{-11}	2.2×10^{-11}	5.4×10^{-12}	1.9×10^{-11}	6.6×10^{-11}	2.2×10^{-11}	5.4×10^{-12}	1.9×10^{-11}
Radium-226	7.5×10^{-06}	7.8×10^{-06}	7.0×10^{-06}	7.2×10^{-06}	3.1×10^{-06}	3.2×10^{-06}	1.4×10^{-03}	1.4×10^{-03}	1.4×10^{-03}	1.4×10^{-03}	1.4×10^{-03}	1.4×10^{-03}	1.6×10^{-06}	1.2×10^{-06}	3.0×10^{-07}	1.6×10^{-06}	1.6×10^{-06}	1.2×10^{-06}	3.0×10^{-07}	1.6×10^{-06}
Radium-228[a]	6.6×10^{-10}	1.9×10^{-09}	7.1×10^{-10}	1.8×10^{-09}	1.1×10^{-09}	1.8×10^{-09}	5.0×10^{-07}	5.0×10^{-07}	5.0×10^{-07}	5.0×10^{-07}	5.0×10^{-07}	5.0×10^{-07}	$0.0 \times 10^{+00}$	4.3×10^{-10}	$0.0 \times 10^{+00}$	5.9×10^{-10}	$0.0 \times 10^{+00}$	4.3×10^{-10}	$0.0 \times 10^{+00}$	5.9×10^{-10}
Selenium	1.1	1.6	1.0	1.5	0.5	0.6	27	4.4	4.1	4.1	9.7	1.7	0.36	0.2	0.42	1.8	0.54	0.3	0.63	2.6
Silver	0.0096	0.0195	0.0089	0.0184	0.0031	0.01	3	1.3	0.39	0.71	1.3	0.21	0.29	0.16	0.038	0.039	0.43	0.24	0.057	0.058
Sodium	3,048	3,267	2,893	3,205	1,728	2,745	4,000	1,300	780	1,000	2,300	270	230	130	34	22	340	190	51	34
Strontium	0	0	0	0	0	0	420	110	67	89	200	32	22	12	4.6	13	33	19	6.9	20
Sulphate	12,091	13,837	11,764	13,336	9,315	9,577	130,000	88,000	17,000	40,000	67,000	9,000	12,000	6,400	4,700	18,000	17,000	9,700	7,000	27,000
Thorium-228	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thorium-230	0	0	0	0	0	0	2.7×10^{-03}	2.7×10^{-03}	2.7×10^{-03}	2.7×10^{-03}	2.7×10^{-03}	2.7×10^{-03}	5.0×10^{-05}	1.6×10^{-05}	3.9×10^{-06}	1.3×10^{-05}	5.0×10^{-05}	1.6×10^{-05}	3.9×10^{-06}	1.3×10^{-05}
Uranium-234	8.9×10^{-07}	6.6×10^{-06}	9.4×10^{-07}	6.7×10^{-06}	1.3×10^{-06}	6.8×10^{-06}	0.18	0.18	0.18	0.18	0.18	0.18	0.00389	0.00124	0.00031	0.00286	0.00389	0.00124	0.00031	0.00286
Uranium-238	0.017	0.123	0.017	0.123	0.024	0.126	3,411	3,411	3,411	3,411	3,411	3,411	72	23	5.7	53	72	23	5.7	53
Vanadium	0.037	0.05	0.057	0.069	0.21	0.214	53	10	7.8	7.8	15	3.4	1.1	0.61	0.1	0.019	1.7	0.92	0.15	0.029
Zinc	0.034	0.053	0.04	0.114	0.089	0.573	130	83	17	39	66	8.9	12	6.5	4.8	16	18	9.8	7.2	24

Source: TSD XVII, Waste Rock and Underground Wall Rock Source Term Predictions Report.

Notes: Waste rock loadings applied in the solute transport model include the sum of PAG and NPAG components. The Operations source applies in the first 30 years of the simulation, and the Closure source applies for the remainder of the simulation. Reflooded mine workings reflect by-year loadings following reflooding.

a) The mass loading for this solute was not provided in data (including waste rock and reflooded mine workings). Source concentrations were approximated based on the ratio of chloride in UGTMF tailings to chloride in the waste rock or reflooded mine workings components, except for Radium-228, which was based on the ratio of Radium-226.

PAG = potentially acid generating; NPAG = non-potentially acid generating; UGTMF = underground tailings management facility.

3.3.2 Groundwater Flow Pathways

As mining progresses, the stopes and UGTMF chambers would be backfilled with CPB and CPT, as outlined above. Upon completion of mining and placement of underground waste, the mine would be flooded, and groundwater pressures would re-establish to natural hydrostatic conditions, which are anticipated to be similar to those observed in the predevelopment period. Upon saturation of the mine backfill and open workings, groundwater would migrate from these source areas, through the geological pathways, discharging to the receiving environment. Similarly, seepage from the waste rock remaining at grade would continue at a reduced rate, as compared to Operations, following cover system placement.

The groundwater flow model was used to estimate the rates of flow through the underground waste materials and within the flow pathways. This was achieved using the current conditions (i.e., calibrated) model as a starting point and adding hydraulic conductivity zones to represent the CPT in the UGTMF, CPB in the mined stopes, and open workings, as illustrated in Figure A-16. A steady state simulation was completed using this model and results of the simulation were analyzed to estimate rates of flow through the waste zones. This model is distinct from that used to estimate groundwater inflows to the underground workings and as such does not include any boundaries to represent dewatering.

Delineation of the groundwater flow pathways and travel times was completed by releasing particles at the mine waste storage areas (e.g., UGTMF, backfilled stopes, WRSAs) and forward-tracking their position through the simulated groundwater flow field to the ultimate groundwater discharge location. Groundwater travel time through the pathways is estimated in the model as a function of the simulated hydraulic gradients, applied hydraulic conductivity values, and effective porosity values.

The governing equation for 1-D transport of a solute can be written as:

$$R\frac{\partial c}{\partial t} = D_x\frac{\partial^2 c}{\partial x^2} - u\frac{\partial c}{\partial x} - \lambda R c \qquad \text{(Equation 3)}$$

$$u = \frac{V_D}{n_e} \qquad \text{(Equation 4)}$$

$$R = 1 + \frac{K_D \rho}{n_e} \qquad \text{(Equation 5)}$$

where:

- R = retardation factor;
- c = solute concentration (M/L^3);
- t = time (T);
- D_x = dispersion coefficient in the direction of flow (L^2/T);
- x = position in the direction of flow (L);
- λ = first-order decay rate (T^{-1}).
- u = pore water velocity (L/T);

V_D = Darcy velocity (L/T);

K_D = distribution coefficient (L^3/M).

ρ_D = bulk dry density (M/L^3); and

n_e = effective porosity (-).

To simulate transport of solutes involved in sequential first-order decay reactions, Equation 3 is applied to the first species in the decay chain and coupled with the following, which represents transport of the remaining species:

$$R_i \frac{\partial c_i}{\partial t} = D_x \frac{\partial^2 c_i}{\partial x^2} - u \frac{\partial c_i}{\partial x} - \lambda_i R_i c_i + \lambda_{i+1} R_{i+1} c_{i+1} \qquad \text{(Equation 6)}$$

For: i = 1…n

3.4 Solute Transport Properties

Table 3 includes details on the properties applied to the solute transport model. The data used to support these values are summarized as follows:

- Adsorption to the materials within the seepage pathways was considered. Solute partitioning coefficients were applied to the bedrock pathways (i.e., within the fault zone and sandstone) as specified in Table 3. The values selected for this assessment were derived from site analogue values, where available, or literature values as indicated in the table.
- Effective porosity and density values were assigned based on site analogue data (Golder 2006). Porosities were 1.5% for the fault zone, 9.8% for the sandstone, and 30% for the overburden, and density was 2,610 kilograms per cubic metre (kg/m^3) for the fault zone, 2,390 kg/m^3 for the sandstone, and 1,800 kg/m^3 for the overburden.
- The surface areas of the UGTMF CPT and primary and secondary stope CPB were determined based on 3-D mine plan files for the underground workings provided by NexGen (provided 19 November 2020).
- Groundwater flow pathway dimensions were delineated through a particle tracking analysis, as detailed in Section 3.3.
- The specific discharge through the host rock adjacent the tailings and backfill applied to the solute transport calculation was conservatively selected as the greatest value (i.e., 1×10^{-05} m/day) predicted by the flow model.
- Dispersivity was assumed to be 10% of the pathway length (Thompson 2006).
- In the absence of data, the diffusivity source for boron and nickel were assumed to be the same as bicarbonate (HCO_3; Li and Gregory 1974) and ammonium (Li and Gregory 1974), respectively.

Table 3: Solute Transport Properties

Solute	Adsorption-Partition Coefficient				Diffusivity	
	Fault		Sandstone			
	(m^3/kg)	Source	(m^3/kg)	Source	1×10^{-05} cm^2/s	Source
Aluminum	0	2	0	2	0.346	7
Ammonia	0	1	0	1	1.96	8
Arsenic	0.0011	3	0.0015	5	0.31	3
Boron	0.00019	1	0.00019	1	1.18	Assumed same as bicarbonate (HCO_3) in 8
Cadmium	0.017	4	0	6	0.72	7
Calcium	0	2	0	2	0.673	7
Chlorine	0	2	0	2	2.03	7
Chromium	0.001	1	0.001	1	0.6	7
Cobalt	0.019	1	0	2	0.34	7
Copper	0.04	4	0.017	6	0.71	7
Fluoride	0	1	0	1	2.03	Assumed same as Chloride
Iron	0.0015	1	0.0015	1	0.719	7
Lead	0.053	3	0.023	5	0.95	7
Magnesium	0	2	0	2	0.594	8
Manganese	0	2	0	2	0.575	7
Mercury	0.03	1	0.03	1	0.03	7
Molybdenum	0.000455	4	0.0015	5	0.31	8
Nickel	0.0055	4	0.0063	5	0.66	Assumed the same as ammonium (NH_4) in 7
Nitrate	0	2	0	2	1.9	7
Nitrogen dioxide	0	2	0	2	1.91	8
Phosphorus	0	2	0	2	0.824	8
Polonium	0.029	3	0.013	5	0.45	7
Radium	0.081	4	0.043	5	0.89	7
Selenium	0.0011	4	0.0015	5	0.31	7
Silver	0.0004	1	0.0004	1	1.648	7
Sodium	0	2	0	2	1.13	Assumed same as Molybdenum
Strontium	0	2	0	2	0.794	8
Sulphate	0	4	0	5	0.54	7
Thorium	0.1	4	0.28	6	0.15	8
Uranium	0.0071	3	0.003	5	0.43	8
Vanadium	0	2	0	2	1	Assumed value
Zinc	0.04	3	0.017	5	0.34	8

Sources:
1. Stenge and Peterson 1989, Table 4.1. The value was selected based on less than 10% clay and a pH of 5-9.
2. Assumed zero.
3. Value used from Golder 2006 for Regolith / Fault and diffusivity.
4. Value used from Golder 2013 for Regolith.
5. Value used from Golder 2006 for Sandstone.
6. Value used from Golder 2013 for Sandstone.
7. CRC 2004, Section 5.
8. Li and Gregory 1974, Table 1.

Note: Solute partitioning coefficients were not applied to the overburden pathway.

Parameter	Value
UGTMF Surface Area	1,565,500 m^2
Primary Backfill Surface Area	531,700 m^2
Secondary Backfill Surface Area	1,013,100 m^2
Specific Discharge in Host Rock (q)	1×10^{-05} m/day
Fault zone effective porosity (n_e)	1.5%
Sandstone effective porosity (n_e)	9.8%
Overburden effective porosity (n_e)	30%
Fault zone density	2,610 kg/m^3
Sandstone density	2,390 kg/m^3
Overburden density	1,800 kg/m^3
Overburden pathway 1 gradient	0.046 m/m
Overburden pathway 2 gradient	0.035 m/m
Overburden pathway 1 cross-sectional area	17,000 m^2
Overburden pathway 2 cross-sectional area	10,000 m^2
Overburden pathway 1 length	900 m
Overburden pathway 2 length	1,200 m
Fault pathway cross-sectional area	34,000 m^2
Fault pathway length	260 m

4.0 RESULTS

The main objectives of the predictive modelling were to estimate the groundwater inflows to the underground development and extent of depressurization during Operations, and the solute mass loading rates from groundwater pathways to downgradient environmental receptors.

4.1 Groundwater Inflows

Figure A-18 provides the simulated groundwater inflow rates to the underground development during Operations. For the base case simulation, during the period from 2022 (Year -4) to 2035 (Year 10), the groundwater inflows ranged from a total of approximately 1,200 cubic metres per day (m^3/d) to 2,000 m^3/d, with the greatest portion of inflow occurring at the “other workings” (i.e., any underground opening not associated with the UGTMF or stope excavations). At 2035 (Year 10), the total groundwater inflows increased to approximately 3,900 m^3/d, corresponding to the opening of additional stopes in the upper levels of the mine (at 360 masl). After 2041 (Year 16), the groundwater inflows are relatively stable at approximately 3,500 m^3/d total inflow, with approximately 60% of inflows derived from stopes and 20% derived from each of the UGTMF and additional workings areas.

When the hydraulic conductivity of the fault zone was increased by a factor of 5, the simulated groundwater inflows to the underground mine increased by a factor of approximately 2 for the first 11 years of the simulation, then gradually declined to a factor of 1.2 above the base case for the remainder of the simulation. This indicates that the simulated groundwater inflow rates are relatively sensitive to the input value assigned to the hydraulic conductivity of the fault zone.

For the simulation where hydraulic conductivity of the basement rock was increased by a factor of 2, the groundwater inflows to the underground mine increased by a factor of approximately 1.6 in the first 11 years of the simulation, then gradually declined to a factor of 1.1 above the base case for the remainder of the simulation. For Years 2 and 3, the simulated groundwater inflow rates were greater than the base case by a factor of 1.8. This indicates that the simulated groundwater inflow rates are approximately proportional to the hydraulic conductivity value for the basement rock for the early period of mine development.

4.2 Drawdown

The extent of the simulated groundwater drawdown in bedrock (i.e., at approximately the upper horizon of the mine) at the end of Operations is illustrated in Figure A-19, represented as metres of water depressurization of the bedrock. The simulated drawdown extends approximately 2 km to the north, 4 km to the south, and 3.5 km in both the east and west directions, based on the 5 m depressurization contour. Vertically, the extent of depressurization is generally limited to the basement rock, as the overlying sandstone aquifer is more transmissive by over four orders of magnitude.

4.3 Baseflow

The results of the groundwater flow model were reviewed to evaluate the changes in groundwater discharge to surface water features within the model domain. Based on this review, it was determined that a conservative approach would be taken to apply a reduction in groundwater discharge to the Patterson Lake watershed that is equivalent to the calculated groundwater inflow to the underground mine workings. Under predevelopment conditions, the estimated groundwater discharge to the watershed is approximately 68,300 m^3/d.

As noted above, peak groundwater inflows to the mine are approximately 3,900 m^3/d, representing a total baseflow reduction of approximately 6%.

4.4 Pathways Delineation and Travel Times

The groundwater flow pathways for the long-term post-closure condition are illustrated in Figure A-20a for underground sources and Figure A-20b for at-grade sources. Based on the particle tracking analysis, groundwater originating at the UGTMF, and stope backfill source areas migrated vertically upward primarily through the fault and shear zones, then laterally through the sandstone, before discharging within Patterson Lake. The total vertical length of the flow pathway for the underground sources is approximately 260 m, as measured from the top of the mine (i.e., 180 masl) to the top of the paleo weathered rock unit (i.e., 440 masl). The cross-sectional area through the fault zones was estimated to be 34,400 m^2 based on the number of fault zones intersected by the mine workings (i.e., 10), the average length of faults intersected by the source areas (i.e., 344 m), and an assumed width of 10 m per fault zone. The total horizontal length through the sandstone is approximately 1,000 m, with a flow pathway width of 350 m and height of 20 m estimated based on the particle pathway dimensions.

Based on the hydraulic gradients, hydraulic conductivities, pathway dimensions, and effective porosity values applied to the pathways (i.e., 0.015 for the fault zone and 0.098 for the sandstone), the approximate advective groundwater travel time from the upper horizon of the mine to the discharge location at Patterson Lake is estimated to be approximately 1,000 years.

Groundwater originating beneath the WRSAs travels through the overburden bidirectionally to the north and south, ultimately discharging in Patterson Lake for both pathways. The flow component to the south originates primarily from the NPAG WRSA and the component directed to the north originates from both the NPAG and PAG WRSAs. The approximate advective groundwater travel time from the WRSAs to Patterson Lake was estimated at 43 years to the north and 77 years to the south.

4.5 Mass Loadings to Receptors

The simulated peak solute mass loading rates are provided in Table 4, along with sensitivity scenarios described in Section 4.0, Results, and plotted for selected solutes in Figure A-21a and Figure A-21b. Peak mass loadings are driven primarily by waste rock and reflooded mine workings, based on a review of mass loadings by source area. This is evident in the Figure A-21 plots for copper, uranium, and radium, for example, where solute mass arrives at the receptor early (i.e., approximately 100 years), and the loading rate is maintained throughout the simulation duration due to the infinite source assumption. For some solutes, the arrival of mass loading from the reflooded mine workings is visible in the loading curves (e.g., for uranium this occurs at around 10,000 years). For a minority of solutes, the relative portions of mass from underground backfill and waste rock sources are more balanced (i.e., for sulphate, calcium, and strontium). Solutes where the peak mass loading rates are driven by underground sources include molybdenum, sodium, and (to a lesser extent) vanadium.

Table 4: Results Summary

	Solute																	
	Ag	Al	As	B	Ca	Cd	Cl	Co	Cr	Cu	F	Fe	Hg	Mg	Mn	Mo	Na	NH3
Base Case Peak Mass Loading Rate (g/yr)	210.6	812669	2918	20756	5376000	89.78	13030000	32209	472	52879	163880	604519	38.93	2362000	48220	175901	2463000	115559
Percent Change Relative to Base Case																		
SR1 - Bedrock K	0.9%	0.0%	3.0%	2.8%	1.1%	0.1%	-1.5%	0.0%	0.2%	0.0%	-1.5%	0.2%	0.0%	0.0%	0.0%	2.8%	2.6%	-1.5%
SR2 - Fault Zone K	2.2%	0.1%	6.2%	8.4%	7.1%	0.6%	-1.4%	0.0%	1.7%	0.1%	-1.8%	0.4%	0.0%	0.0%	0.0%	25.3%	23.9%	-1.9%
SR3 - UGTMF Tailings K	0.1%	0.0%	11.2%	0.3%	10.1%	0.3%	0.4%	0.0%	1.0%	0.1%	0.4%	0.0%	0.0%	0.0%	0.0%	14.6%	13.5%	0.4%
SR4 - Backfill K	0.8%	0.1%	7.1%	0.5%	12.9%	1.0%	1.5%	0.0%	2.9%	0.1%	1.0%	0.0%	0.0%	0.0%	0.0%	42.6%	40.3%	0.8%
SR5 - Fracture Zone Area	3.1%	0.0%	0.0%	11.3%	-2.9%	0.0%	-2.8%	0.0%	0.3%	0.0%	-2.9%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	-3.0%
SR6 - Upperbound UGTMF Source	0.3%	0.1%	17.1%	0.1%	0.2%	0.8%	0.0%	0.0%	37.9%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	15.3%	8.7%	0.0%
SR7 - Upperbound Backfill Source	1.6%	1.7%	10.4%	0.1%	3.7%	1.3%	0.2%	0.0%	24.2%	0.1%	0.3%	0.1%	0.0%	0.0%	0.0%	130%	8.0%	0.1%
SR8 - Upperbound Waste Rock Source	47.0%	48.0%	40.4%	38.1%	27.2%	51.6%	46.4%	53.1%	46.6%	49.8%	46.9%	49.6%	48.9%	47.8%	51.0%	0.5%	2.9%	47.1%
SR9 - All Upperbound Sources	52.3%	51.0%	107.1%	39.1%	57.4%	56.3%	48.7%	53.2%	160%	50.3%	48.7%	49.8%	48.9%	47.9%	51.3%	284%	85.2%	48.4%

	Solute																	
	Ni	NO2	NO3	P	Pb	Pb210	Po210	Ra226	Ra228	Se	SO4	Sr	Th228	Th230	U234	U238	V	Zn
Base Case Peak Mass Loading Rate (g/yr)	28441	1066	1023	1171	638.8	0.00003081	5.243E-07	0.002796	2.377E-09	2779	34200000	28880	1.184E-09	0.03176	4.191	77582	3082	22544
Percent Change Relative to Base Case																		
SR1 - Bedrock K	0.0%	-1.5%	-1.5%	-1.5%	0.2%	0.0%	0.0%	0.0%	0.0%	0.6%	1.1%	3.8%	0.0%	0.0%	0.5%	0.5%	4.0%	0.0%
SR2 - Fault Zone K	0.0%	-2.1%	-2.1%	-2.0%	3.1%	0.1%	0.1%	0.0%	0.0%	7.2%	7.3%	6.5%	0.0%	0.0%	1.1%	1.1%	6.8%	0.0%
SR3 - UGTMF Tailings K	0.0%	0.4%	0.4%	0.3%	1.2%	0.0%	0.0%	0.0%	0.0%	3.5%	5.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.6%	0.1%
SR4 - Backfill K	0.0%	0.6%	0.5%	0.6%	5.4%	0.0%	0.0%	0.0%	0.0%	12.5%	11.8%	0.2%	0.0%	0.0%	0.0%	0.0%	0.5%	0.1%
SR5 - Fracture Zone Area	0.0%	-3.0%	-3.0%	-3.1%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	8.7%	0.0%	0.0%	1.9%	1.9%	8.8%	0.0%
SR6 - Upperbound UGTMF Source	0.2%	0.0%	0.0%	0.0%	185.4%	0.0%	0.1%	0.0%	0.0%	0.8%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
SR7 - Upperbound Backfill Source	0.1%	0.0%	0.0%	0.0%	119.6%	0.2%	0.2%	0.1%	0.0%	12.0%	3.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%
SR8 - Upperbound Waste Rock Source	53.5%	47.2%	47.3%	47.1%	10.9%	0.0%	0.0%	0.0%	0.0%	32.4%	36.0%	35.0%	0.0%	0.0%	0.0%	0.0%	0.0%	50.1%
SR9 - All Upperbound Sources	54.1%	48.3%	48.3%	48.2%	556%	0.4%	0.5%	0.3%	0.0%	67.8%	58.0%	35.0%	0.0%	0.0%	0.1%	0.1%	1.3%	51.4%

SR = sensitivity run; UGTMF = underground tailings management facility.
Shading indicates range in values:

minimum (-3.1%) — 0% — maximum (556%)

5.0 SENSITIVITY ANALYSIS

To address the uncertainty associated with model input parameters and assumptions, a sensitivity analysis was completed. This involved completing additional simulations with varied inputs and comparing their output (i.e., in terms of peak mass loading rates to receptors) with the base case results. The additional simulations consisted of the following:

- **Sensitivity Run 1 (SR1):** increase hydraulic conductivity of bedrock by a factor of 5.
- **Sensitivity Run 2 (SR2):** increase hydraulic conductivity of fault zone by a factor of 5.
- **Sensitivity Run 3 (SR3):** increase hydraulic conductivity of the UGTMF tailings to the maximum value from testing (i.e., factor of 4).
- **Sensitivity Run 4 (SR4):** increase hydraulic conductivity of the backfill to the maximum value from testing (i.e., factor of 5).
- **Sensitivity Run 5 (SR5):** reduce fault zone contact area (i.e., the cross-sectional area of the flow path) by a factor of 2.
- **Sensitivity Run 6 (SR6):** upper bound UGTMF source.
- **Sensitivity Run 7 (SR7):** upper bound primary + secondary backfill source.
- **Sensitivity Run 8 (SR8):** upper bound waste rock source.
- **Sensitivity Run 9 (SR9):** all upper bound sources combined.

Results of the sensitivity analysis in terms of the peak mass loading rates are provided in Table 4. Results of the sensitivity analysis in terms of the relative change in peak mass loading as compared to the base case are provided in Figure A-24; the time-history plots for select solutes are provided in Figure A-21. Figure A-22 presents the same information as Figure A-21 as well as simulated mass loading rates for the first 42 years of the Project lifespan shown on a separate y-axis. Data series representing the initial 42 years are plotted against the primary y-axis, whereas data series representing the full simulation period are plotted against the secondary y-axis. To provide further resolution of mass loading rates, Figure A-23 presents the same information as Figure A-21, but presents only the first 42 years of the Project. A review of the results led to the following observations:

- Because the surface waste rock loadings represent a large portion of the overall mass loadings, the results were generally most sensitive to the upper bound waste rock source term.
- The overall highest peak mass loading rates occurred when all upper bound sources were combined (SR9).
- The solute loadings were also sensitive to the source terms for backfill and the UGTMF tailings for solutes where the upper bound source was much greater than the base case (e.g., lead, where the upper bound source was much greater than the base case for the UGTMF).
- In general, model results were not sensitive (i.e., less than 5% difference) for simulations in which adjustments were made to the hydraulic conductivities of the materials (SR1 to SR4) and the cross-sectional area of the fracture zone (SR5).

6.0 KEY FINDINGS

The potential residual effects of the Project on hydrogeology, or groundwater quantity and quality, which represents an intermediate component for the EA, were characterized through an evaluation of baseline data and a hydrogeological modelling approach. The Project has the potential to cause adverse effects on hydrogeology during Operations through the inflow of groundwater into the underground mine. Also, seepage from the WRSAs have the potential to affect groundwater quality in the shallow overburden aquifer. Following Closure of the mine, groundwater elevations would re-establish to current conditions (i.e., static) and groundwater would be in contact with the backfilled materials. Therefore, the Project has the potential to cause adverse effects on groundwater quality in the bedrock aquifer, and along the groundwater flow pathway to its ultimate discharge location. A summary of the key findings from this assessment is provided as follows:

- During Operations, seepage to the mine would result in a depressurization of the surrounding bedrock, which would be observed as a reduction in groundwater elevation at monitoring locations (i.e., groundwater drawdown). The extent of the simulated groundwater drawdown in bedrock resulting from the mine dewatering at the end of Operations is extended approximately 2 km to the north, 4 km to the south, and 3.5 km in both the east and west directions, based on the 5 m drawdown contour. Vertically, the extent of depressurization is generally limited to the basement rock, as the overlying sandstone aquifer is considerably more transmissive. The maximum simulated drawdown within the sandstone was estimated to be less than 5 m in the immediate area of the mine workings.
- For the Base Case simulation, during the period from 2022 to 2035, the groundwater inflows to the underground development were predicted to range from a total of approximately 1,200 m^3/d to 2,000 m^3/d, with the greatest portion of inflow occurring at the underground openings not associated with the UGTMF or stope excavations. At 2035, the total groundwater inflows increased to approximately 3,900 m^3/d, corresponding to the opening of additional stopes. After 2041, the groundwater inflows are relatively stable at approximately 3,500 m^3/d total inflow, with approximately 60% of inflows derived from stopes and 20% derived from each of the UGTMF and additional workings areas.
- During Operations, the groundwater seepage collected from the underground mine would be treated and discharged to Patterson Lake. Assuming that all groundwater seepage collected at the underground mine originates as surface infiltration from the Patterson Lake catchment, the resulting long-term net change to the overall water balance of the surface water system is negligible.
- Based on the particle tracking analysis, groundwater originating at the UGTMF and stope backfill source areas is predicted to migrate vertically upward primarily through the fault and shear zones, then laterally through the sandstone, before discharging within Patterson Lake (the “receptor”). The total vertical length of the flow pathway for the underground sources is approximately 260 m, as measured from the top of the mine (i.e., 180 masl) to the top of the paleoweathered rock unit (i.e., 440 masl). The approximate advective groundwater travel time from the upper horizon of the mine to the discharge location at Patterson Lake is estimated to be approximately 1,000 years.
- Seepage from beneath the WRSAs was predicted to infiltrate vertically downward to the water table then laterally towards Patterson Lake in both the northerly and southerly directions. For the overburden pathways, the approximate advective groundwater travel time from the piles to Patterson Lake was 43 years to the north and 77 years to the south.

- Based on a review of the solute transport model output, including a comparison of mass loading rates from individual source areas, it was determined that peak mass loadings are driven primarily by waste rock and reflooded mine workings for most solutes. For a minority of solutes, the relative portions of mass from underground backfill and waste rock sources is more balanced (i.e., for sulphate, calcium, and strontium). Solutes where the peak mass loading rates are driven by underground sources include molybdenum, sodium, and, to a lesser extent, vanadium.
- The model sensitivity analysis indicated that because the surface waste rock loadings represent a large portion of the overall mass loadings, the results were generally most sensitive to the upper bound waste rock source term. The loadings to Patterson Lake were also sensitive to the source terms for backfill and the UGTMF tailings for solutes where the upper bound source was much greater than the Base Case (e.g., lead, where the upper bound source was much greater than the Base Case for the UGTMF).
- In general, model results were not sensitive (i.e., less than 5% difference) for simulations in which adjustments were made to the hydraulic conductivities of the groundwater flow pathways and backfill materials and the cross-sectional area of the fracture zone area.

Results from the hydrogeological modelling and assessment were provided to the hydrology (EIS Section 9, Hydrology) and surface water quality (EIS Section 10, Surface Water Quality and Sediment Quality) disciplines for the assessment of how changes to groundwater may affect the receiving environment.

7.0 MODEL LIMITATIONS

Hydrogeological investigations and groundwater modelling are dynamic and inexact sciences. They are dynamic in the sense that the state of any hydrological system is changing with time and in the sense that the science is continually developing new techniques to evaluate these systems. They are inexact in the sense that groundwater systems are complicated beyond human capability to evaluate them comprehensively in detail, and we invariably do not have sufficient data to do so. A groundwater model uses the laws of science and mathematics to draw together the available data into a mathematical or computer-based representation of the essential features of an existing hydrogeological system. While the model itself obviously lacks the detailed reality of the existing hydrogeological system, the behaviour of a valid groundwater model reasonably approximates that of the real system. The validity and accuracy of the model depends on the amount of data available relative to the degree of complexity of the geologic formations, the site geochemistry, the fate and transport of the dissolved compounds, and on the quality and degree of accuracy of the data entered. Model predictions are expected to differ from measured data collected in the future due to the inherent uncertainty of hydrogeological systems. Therefore, every groundwater model is a simplification of a reality and the model described in this report is not an exception.

This model provides a predictive scientific tool to evaluate the effects on a real groundwater system of specified hydrological stresses and/or to compare various scenarios in a decision-making process; however, despite the professional care taken during the construction of the model and in conducting the simulations, its accuracy is bound to the normal uncertainty associated to groundwater modelling and no warranty, expressed or implied, is made.

8.0 CLOSING

WSP is pleased to submit this report to NexGen in support of the environmental assessment for the Rook I Project. For details on the limitations and use of information presented in this report, please refer to the Study Limitations section following this page. If you have any questions or require additional details related to this study, please contact the undersigned.

WSP Canada Inc.

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MEMBER 9446
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Association of Professional Engineers & Geoscientists of Saskatchewan
CERTIFICATE OF AUTHORIZATION
WSP Canada Inc.
Number **C0868**
Permission to Consult held by:

Discipline	Sk. Reg. No.	Signature
Hydrogeology	9446	

STUDY LIMITATIONS

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The scope and the period of WSP's services are as described in WSP's proposal, and are subject to restrictions and limitations. WSP did not perform a complete assessment of all possible conditions or circumstances that may exist at the site referenced in the report. If a service is not expressly indicated, do not assume it has been provided. If a matter is not addressed, do not assume that any determination has been made by WSP in regard to it. Any assessments, designs and advice made in this report are based on the conditions indicated from published sources and the investigation described. No warranty is included, either express or implied, that the actual conditions will conform exactly to the assessments contained in this report. Where data supplied by the Client or other external sources (including without limitation, other consultants, laboratories, public databases), including previous site investigation data, have been used, it has been assumed that the information is correct unless otherwise stated. No responsibility is accepted by WSP for incomplete or inaccurate data supplied by others.

The passage of time affects the information and assessment provided in this report. WSP's opinions are based upon information that existed at the time of the production of the report. The Services provided allowed WSP to form no more than an opinion of the actual conditions of the site at the time the site was visited and cannot be used to assess the effect of any subsequent changes in the quality of the site, or its surroundings, or any laws or regulations.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to WSP by the Client, communications between WSP and the Client, and to any other reports prepared by WSP for the Client relative to the specific site described in the report. In order to properly understand the suggestions,

recommendations and opinions expressed in this report, reference must be to the foregoing and to the entirety of the report. WSP cannot be responsible for use of portions of the report without reference to the entire report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client and were prepared for the specific purpose set out herein. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, is the responsibility of such third parties. WSP accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

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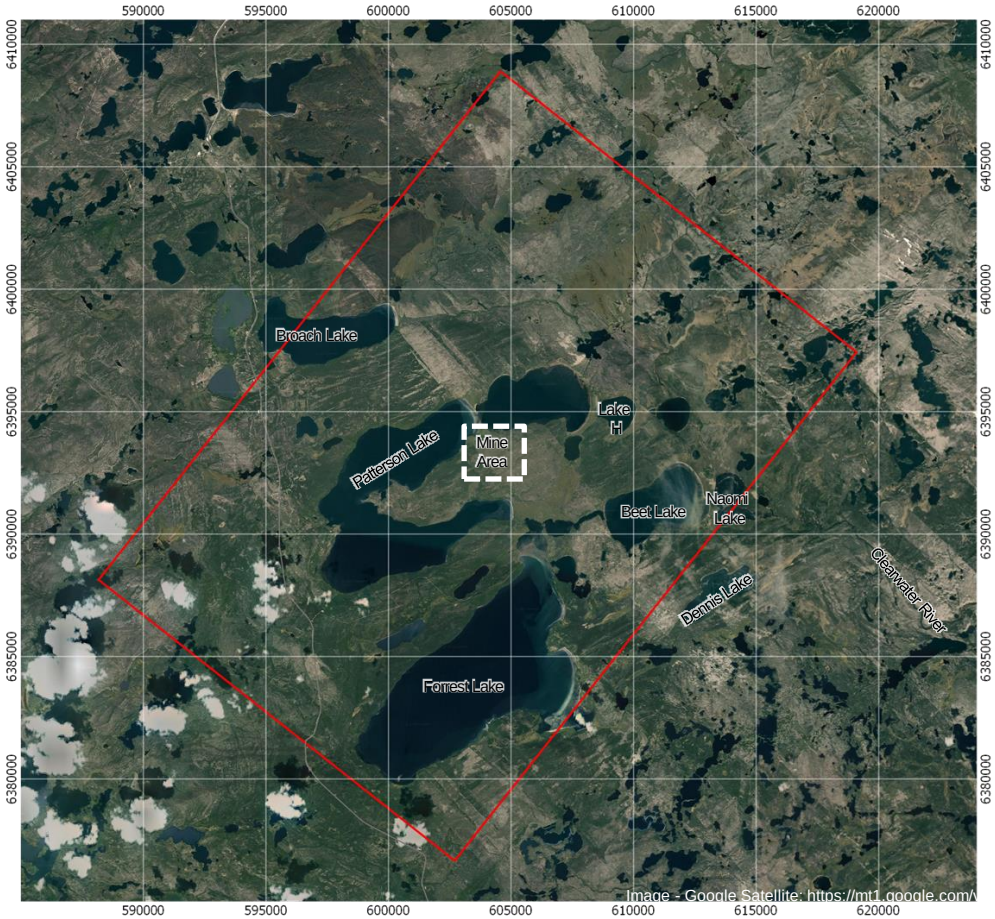
APPENDIX A

Solute Transport Modelling Figures



LEGEND

- Surface Facilities
- Underground Development
- Waste Rock Stockpiles
- Extent of Groundwater Flow Model

CLIENT

NexGen Energy Ltd.

CONSULTANT

wsp

YYYY-MM-DD	2021-06-28
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

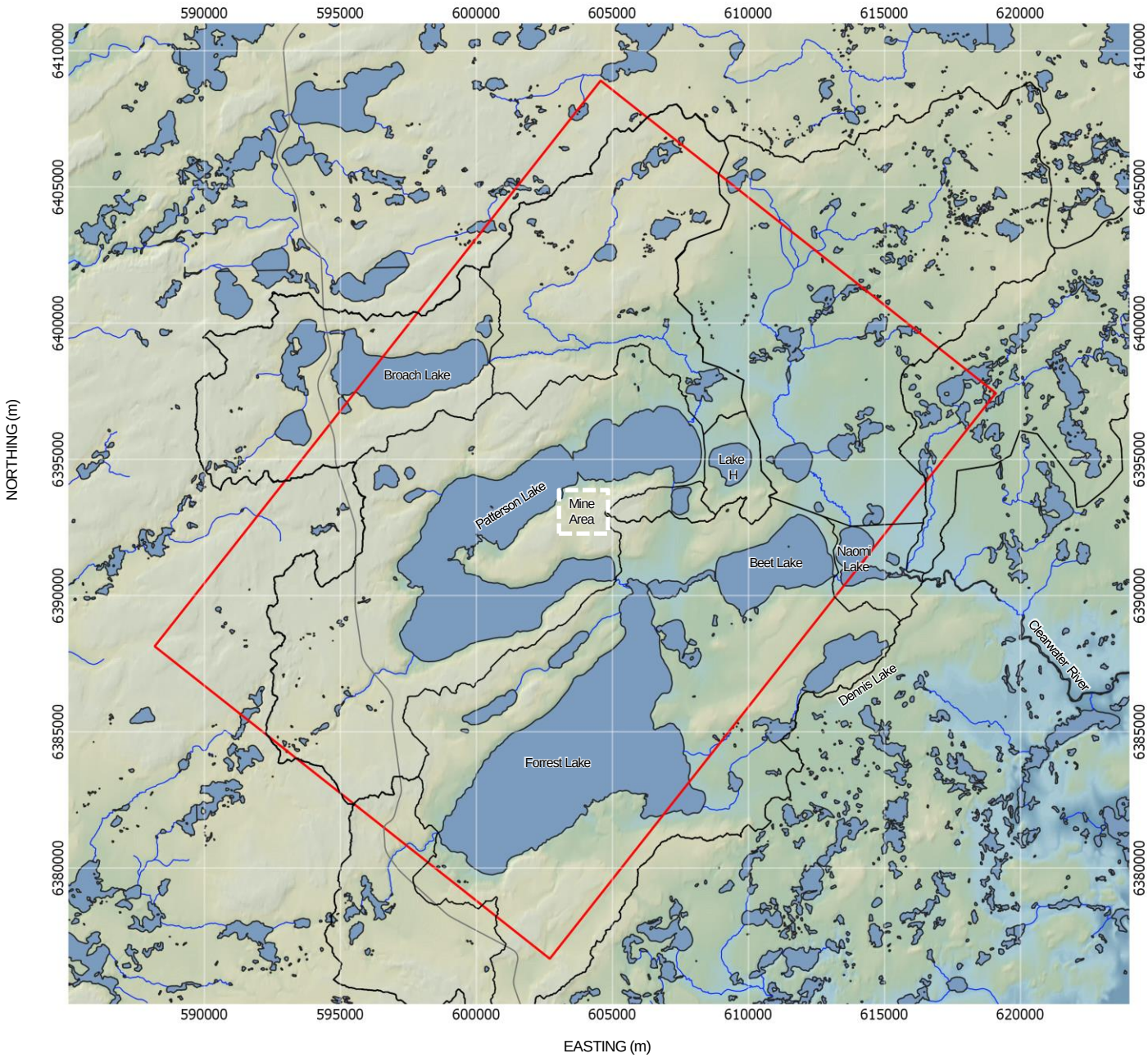
PROJECT

NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE

SITE LAYOUT AND MODEL DOMAIN

PROJECT No.	PHASE	Rev.	Figure
20144150	3104	0	A-1



LEGEND

- Underground Development
- Extent of Groundwater Flow Model
- Surface Drainage Catchments
- Watercourse
- Waterbody

Ground Surface Elevation (masl)

540 — 490

Note:

1) Surface water features shown for Clearwater River catchment only

CLIENT

NexGen Energy Ltd.

CONSULTANT

wsp

YYYY-MM-DD	2021-06-28
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

PROJECT

NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE

TOPOGRAPHY AND DRAINAGE

PROJECT No.	PHASE	Rev.	FIGURE
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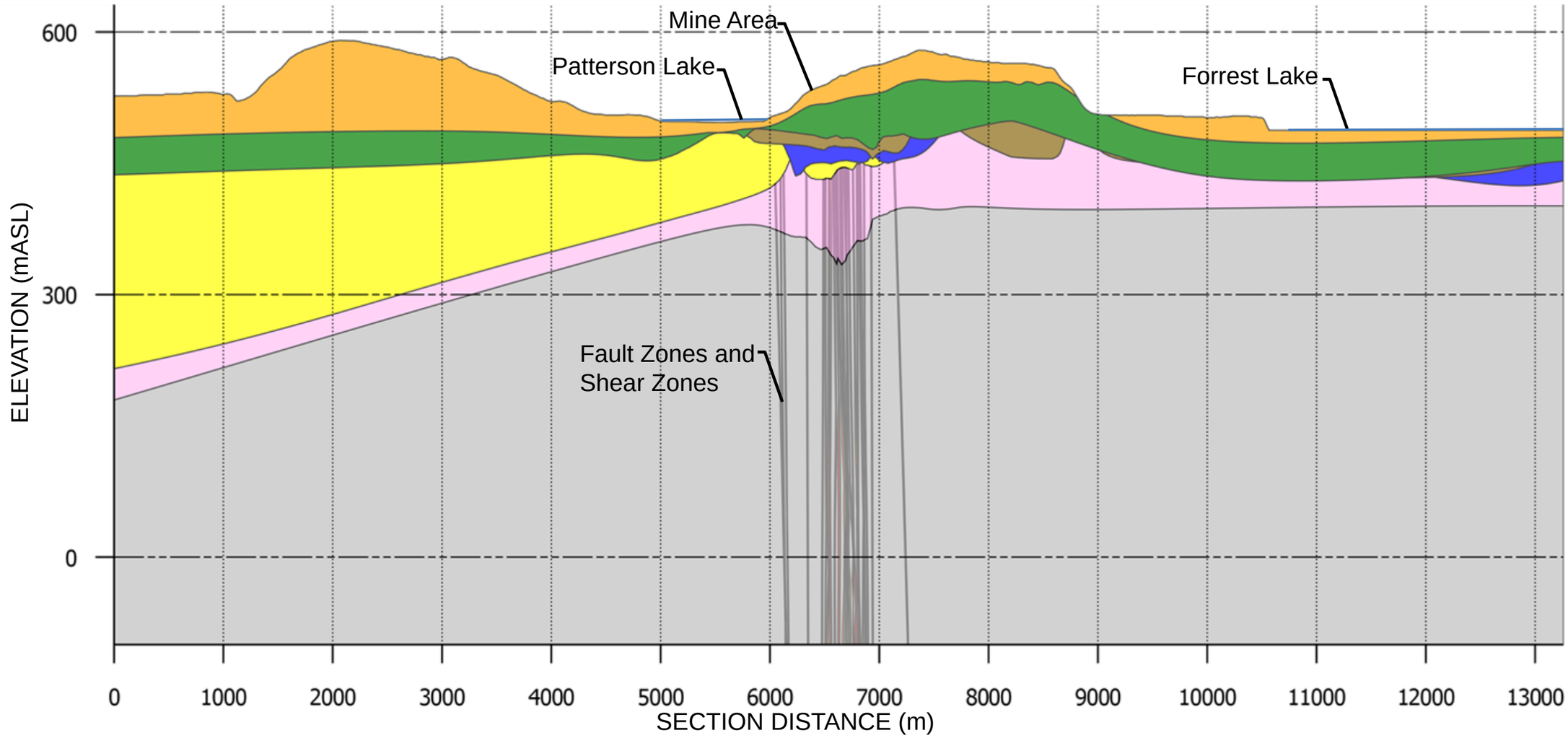

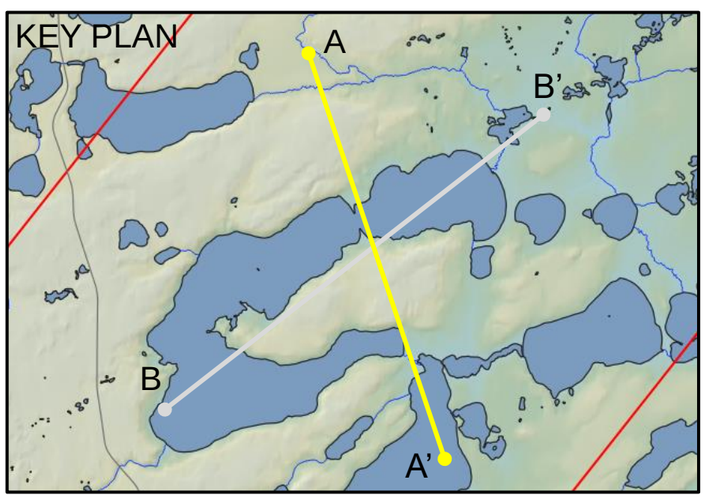

LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK

Notes:
Vertical exaggeration: 8x

CLIENT
NexGen Energy Ltd.

CONSULTANT
wsp

YYYY-MM-DD	2021-06-28
PREPARED	CT
DESIGN	CT
REVIEW	NB
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
CONCEPTUAL HYDROGEOLOGICAL MODEL
REGIONAL CROSS-SECTION A-A'
(NORTHWEST-SOUTHEAST)

PROJECT No.	PHASE	Rev.	FIGURE
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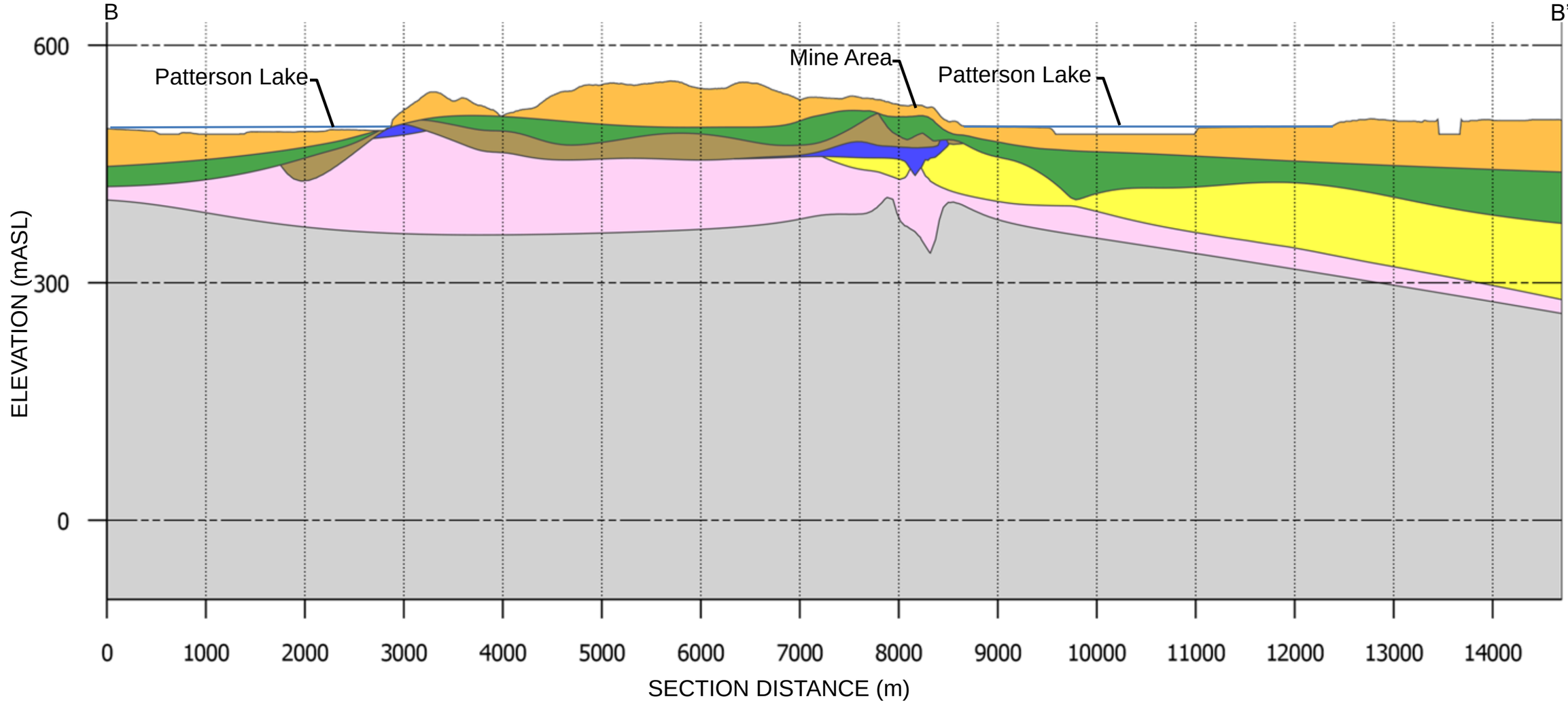
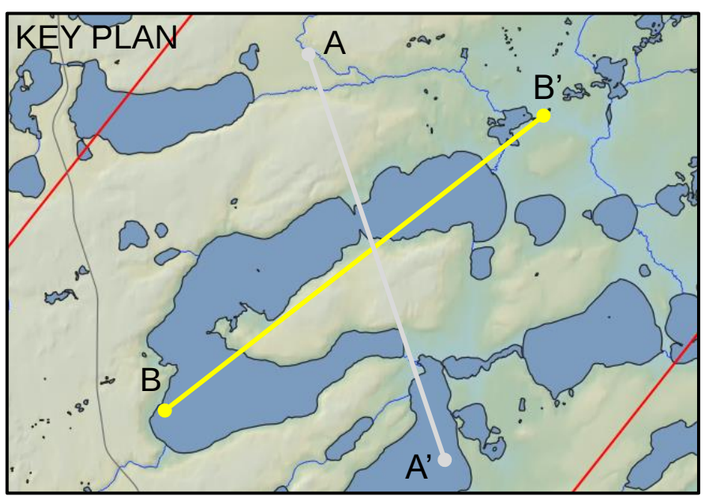




LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK

Notes:
Vertical exaggeration: 8x

CLIENT
NexGen Energy Ltd.

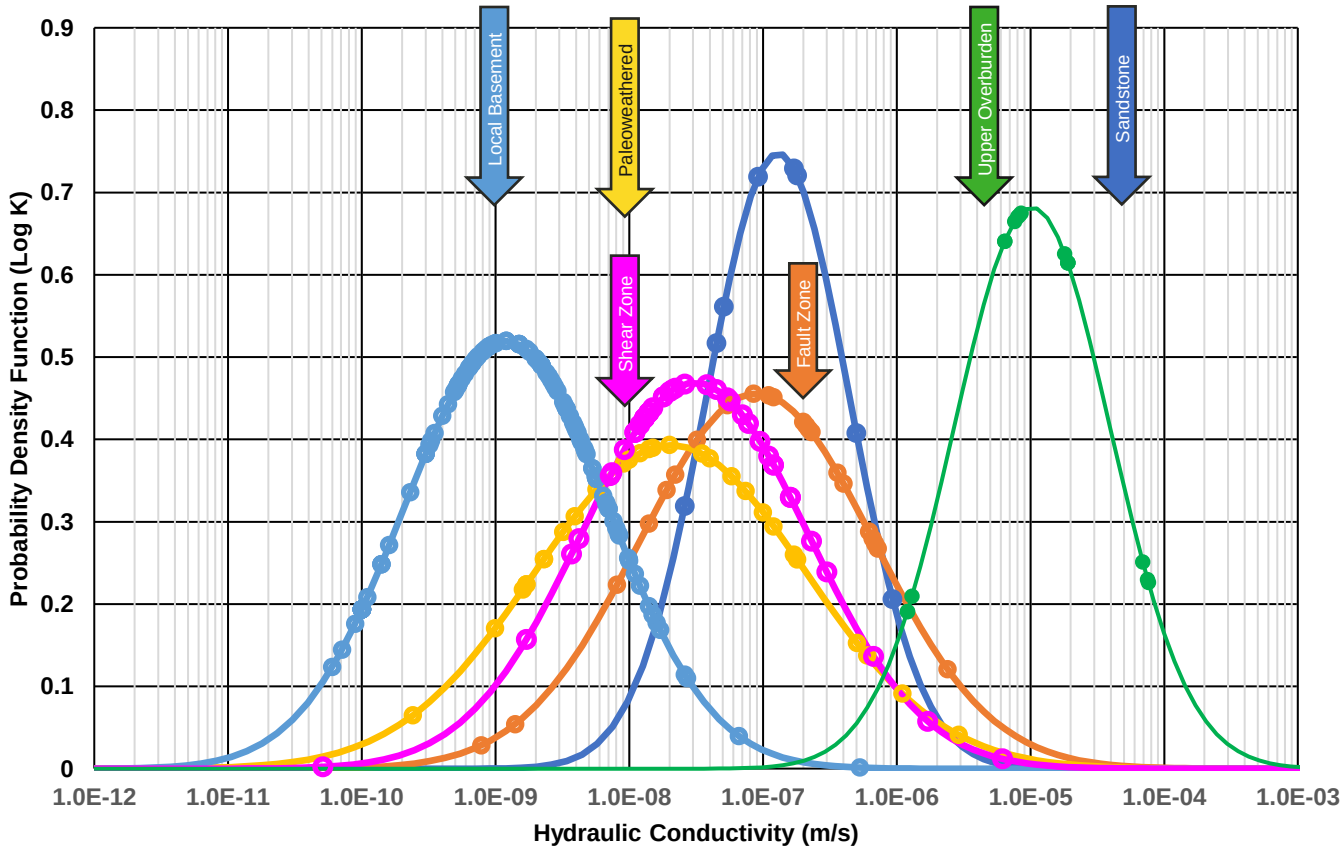
CONSULTANT
wsp

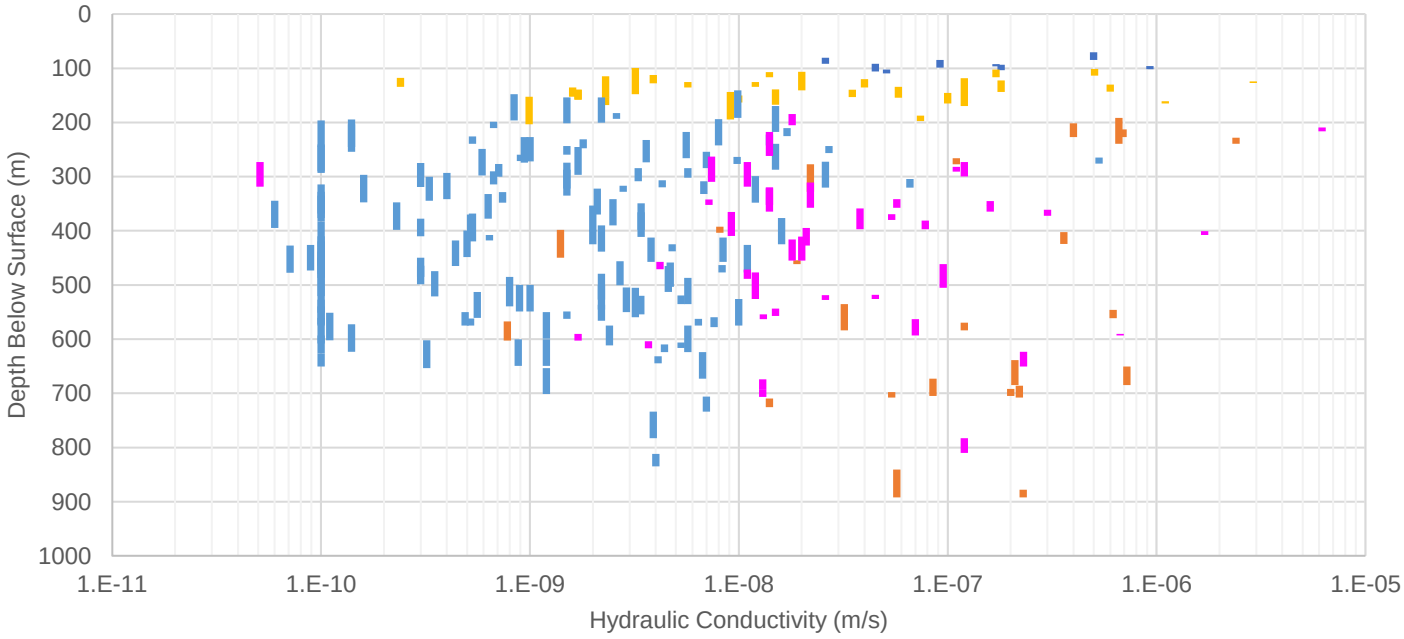
YYYY-MM-DD	2020-06-28
PREPARED	CT
DESIGN	CT
REVIEW	
APPROVED	

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
CONCEPTUAL HYDROGEOLOGICAL MODEL
REGIONAL CROSS-SECTION B-B'
(SOUTHWEST-NORTHEAST)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-3b





Note:

1) Not shown are the lower till, Cretaceous and Devonian units, for which specific testing data was unavailable.

Legend:

AthabascaSS
Fault Zone
Paleoweathered
SPG
Shear Zone
Overburden

Arrow Indicates Value Applied in the Groundwater Flow Model

Fault Zone

CLIENT

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YYYY-MM-DD	2021-06-28
PREPARED	SK
DESIGN	SK
REVIEW	NB
APPROVED	MT

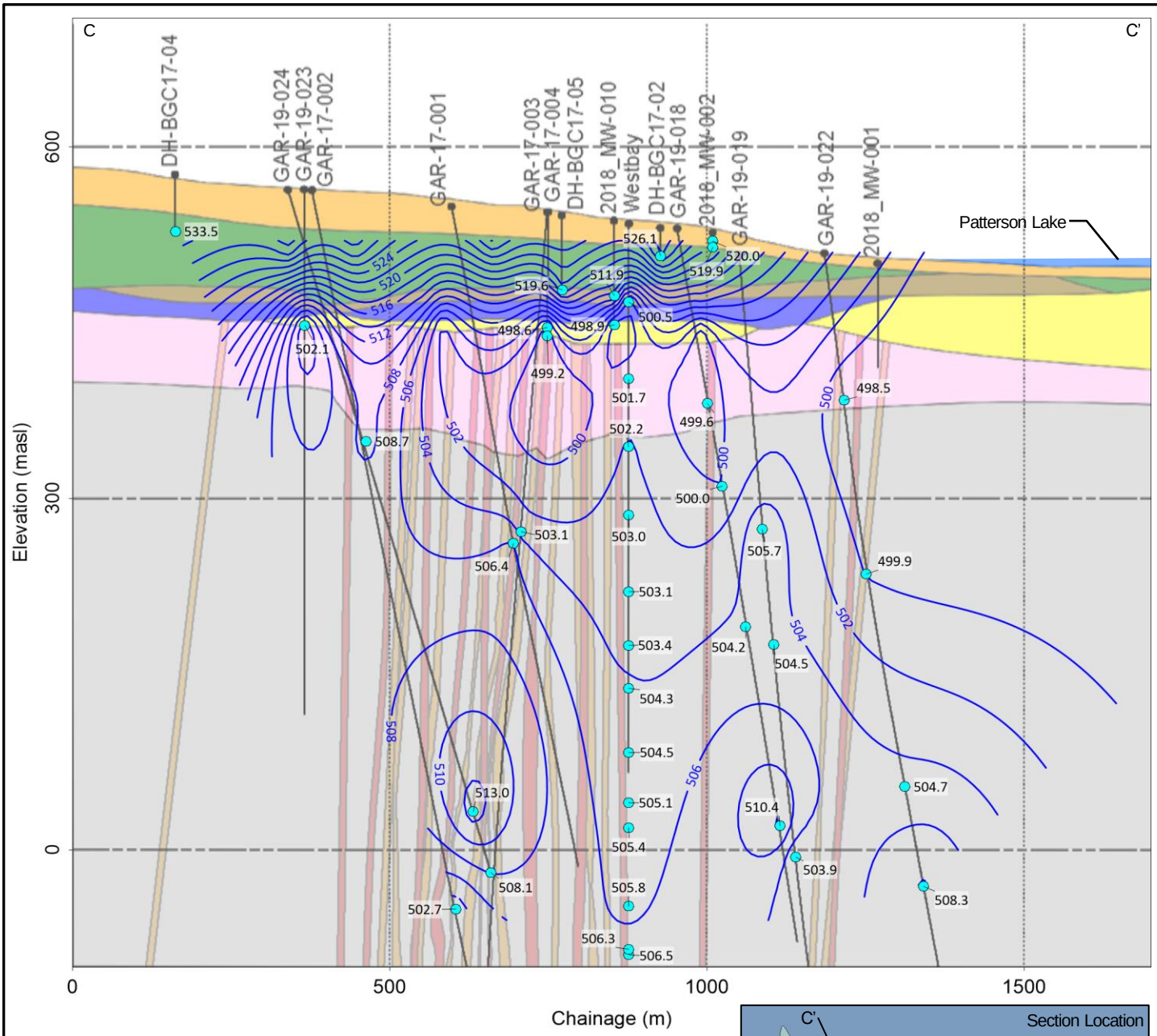
PROJECT

NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE

HYDRAULIC CONDUCTIVITY BY UNIT AND DEPTH

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-4

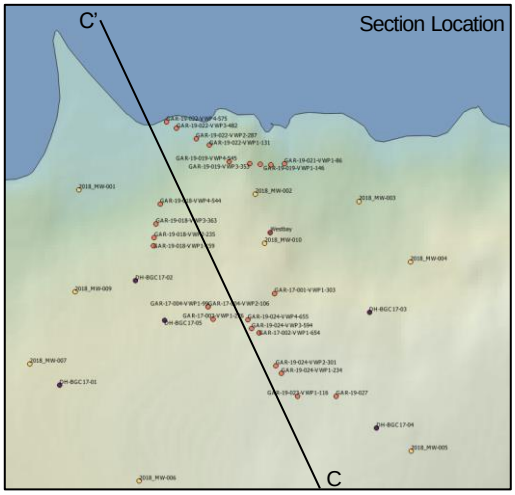


LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK
- SHEAR ZONE
- FAULT ZONE
- INTERPRETED GROUNDWATER ELEVATION CONTOUR (mASL)

Note:

1) Groundwater contours based on the most recent available measurement as of July 2019.



CLIENT

NexGen Energy Ltd.

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YYYY-MM-DD	2021-06-28
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

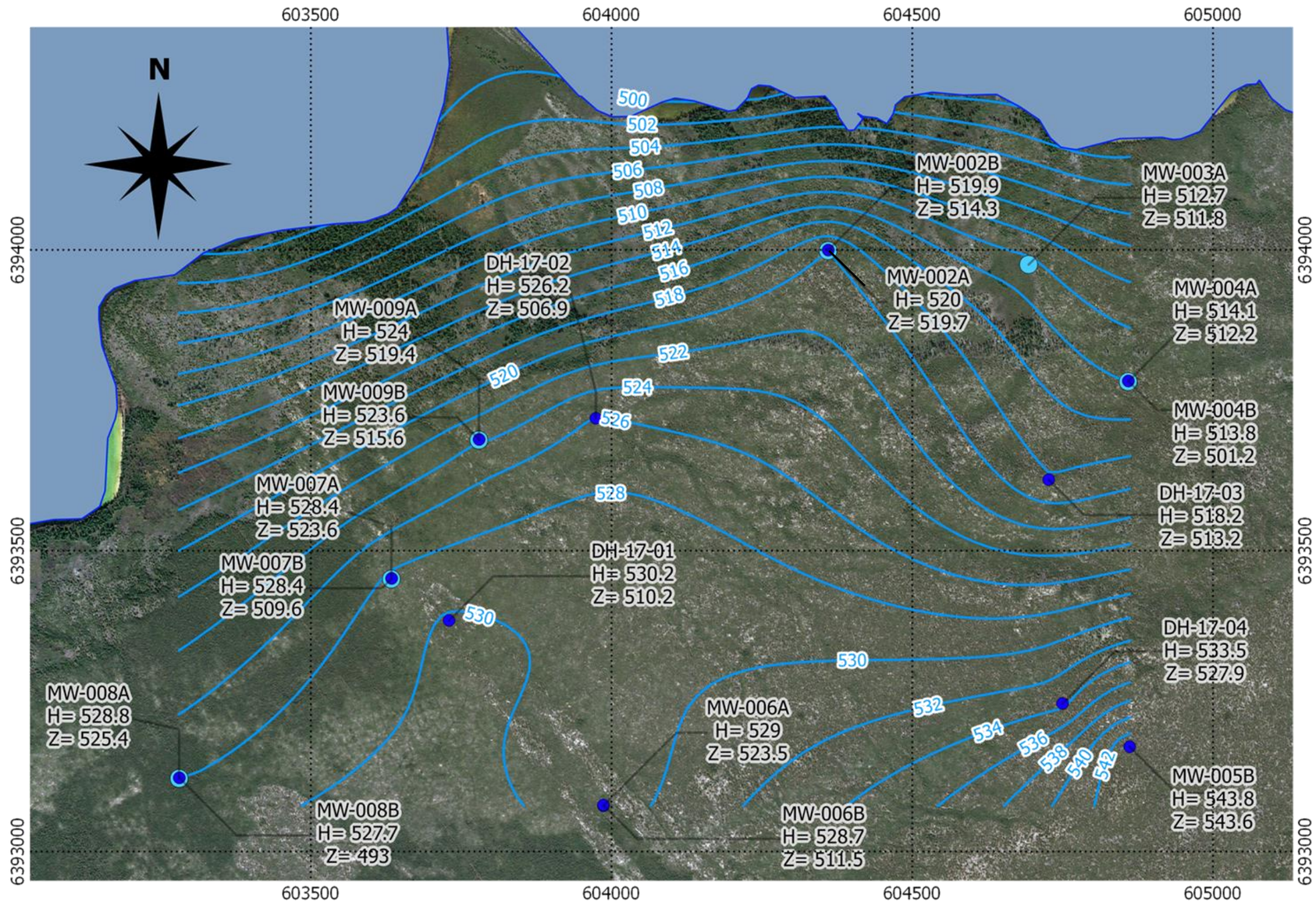
PROJECT

NEXGEN ENERGY LTD.
ROOK I PROJECT

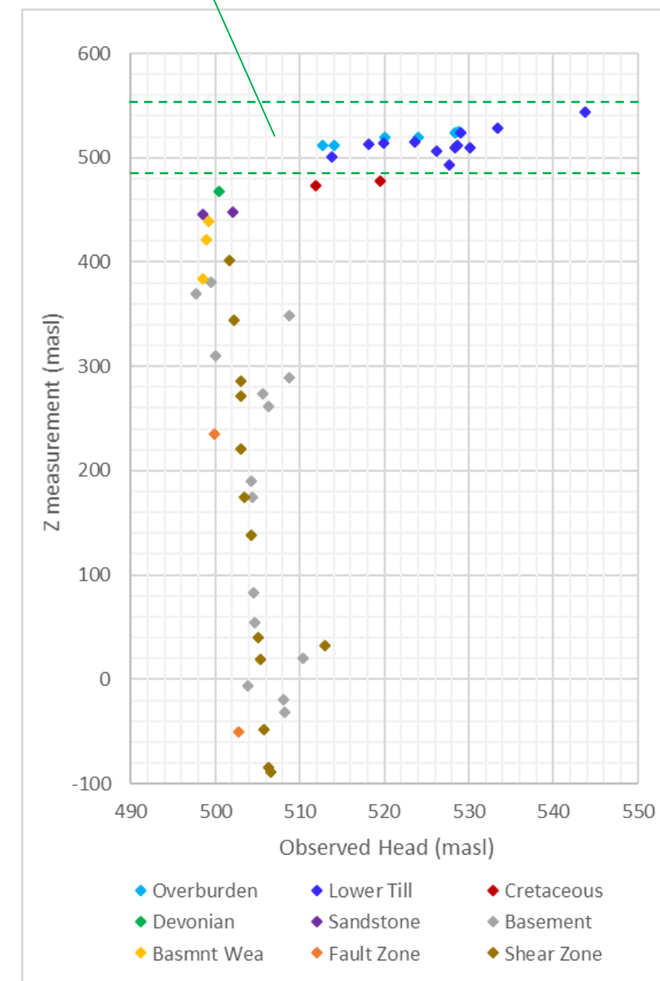
TITLE

CONCEPTUAL HYDROGEOLOGICAL MODEL LOCAL CROSS-SECTION C-C' (NORTHWEST-SOUTHEAST)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-5



Observations considered on contour estimation



LEYEND

WATER BODY

GROUNDWATER CONTOUR

OBSERVATION POINT

- Name
- H= GW Elv
- Z= Meas Elv

OBSERVATION POINT BY UNIT

- Overburden
- Lower till

NOTAS

1. Groundwater observation point labels shows name of the borehole, groundwater elevation (GW Elv) and measurement point elevation (Meas Elv) which considers the screen mid-point for screened boreholes, or the exact elevation for vibrating wires.
2. Groundwater contour level shown on top of the line.

CLIENT

NexGen Energy Ltd.

CONSULTANT

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YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

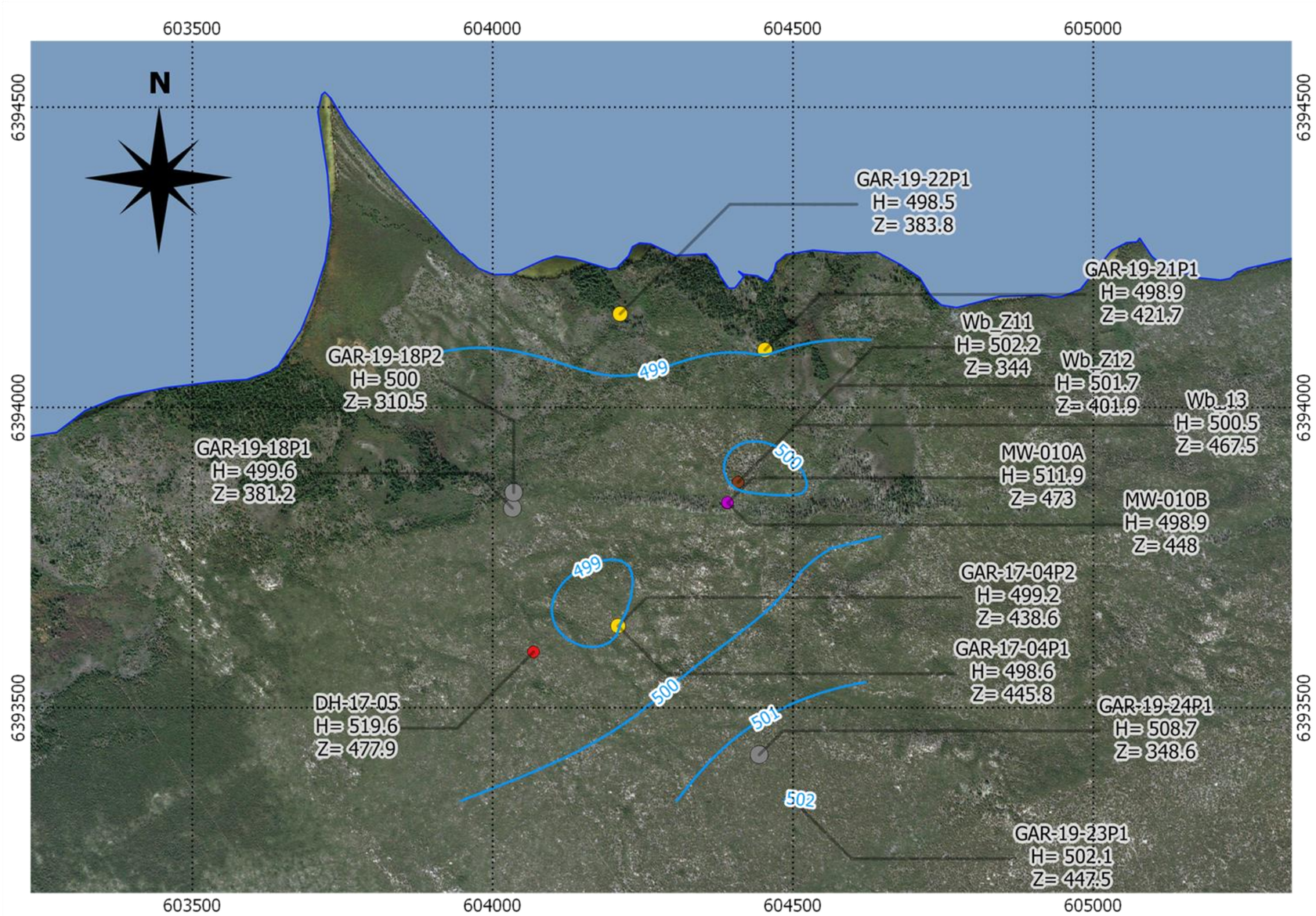
PROJECT

NEXGEN ENERGY LTD.
ROOK I PROJECT

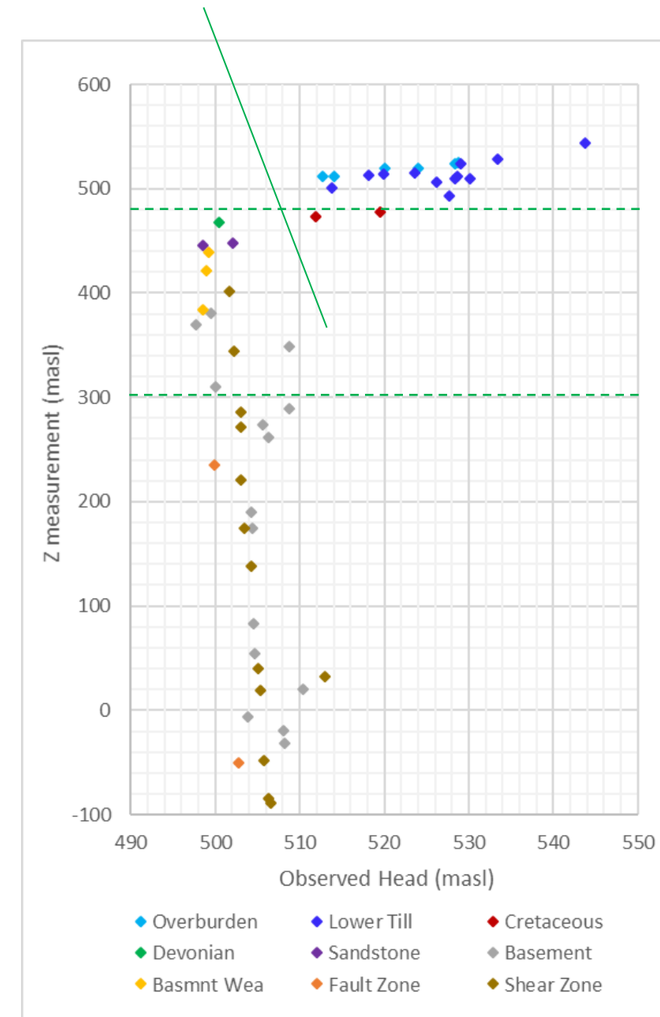
TITLE

CONCEPTUAL HYDROGEOLOGICAL MODEL
GROUNDWATER CONTOUR MAPS (GLACIAL DRIFT)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-6a



Observations considered on contour estimation



LEYEND

WATER BODY

GROUNDWATER CONTOUR

OBSERVATION POINT

Name
H= GW Elv
Z= Meas Elv

OBSERVATION POINT BY UNIT

- Basement
- Basement (w)
- Sandstone
- Cretaceous
- Devonian
- Shear Zone

NOTAS

1. Groundwater observation point labels shows name of the borehole, groundwater elevation (GW Elv) and measurement point elevation (Meas Elv) which considers the screen mid-point for screened boreholes, or the exact elevation for vibrating wires.
2. Groundwater contour level shown on top of the line.
3. Cretaceous and GAR-19-24P1 observations ignored for contour definition. Cretaceous water levels observed shows a behavior similar to shallow boreholes, while GAR-19-24P1 measuring location is deeper than surrounding observations.

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YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

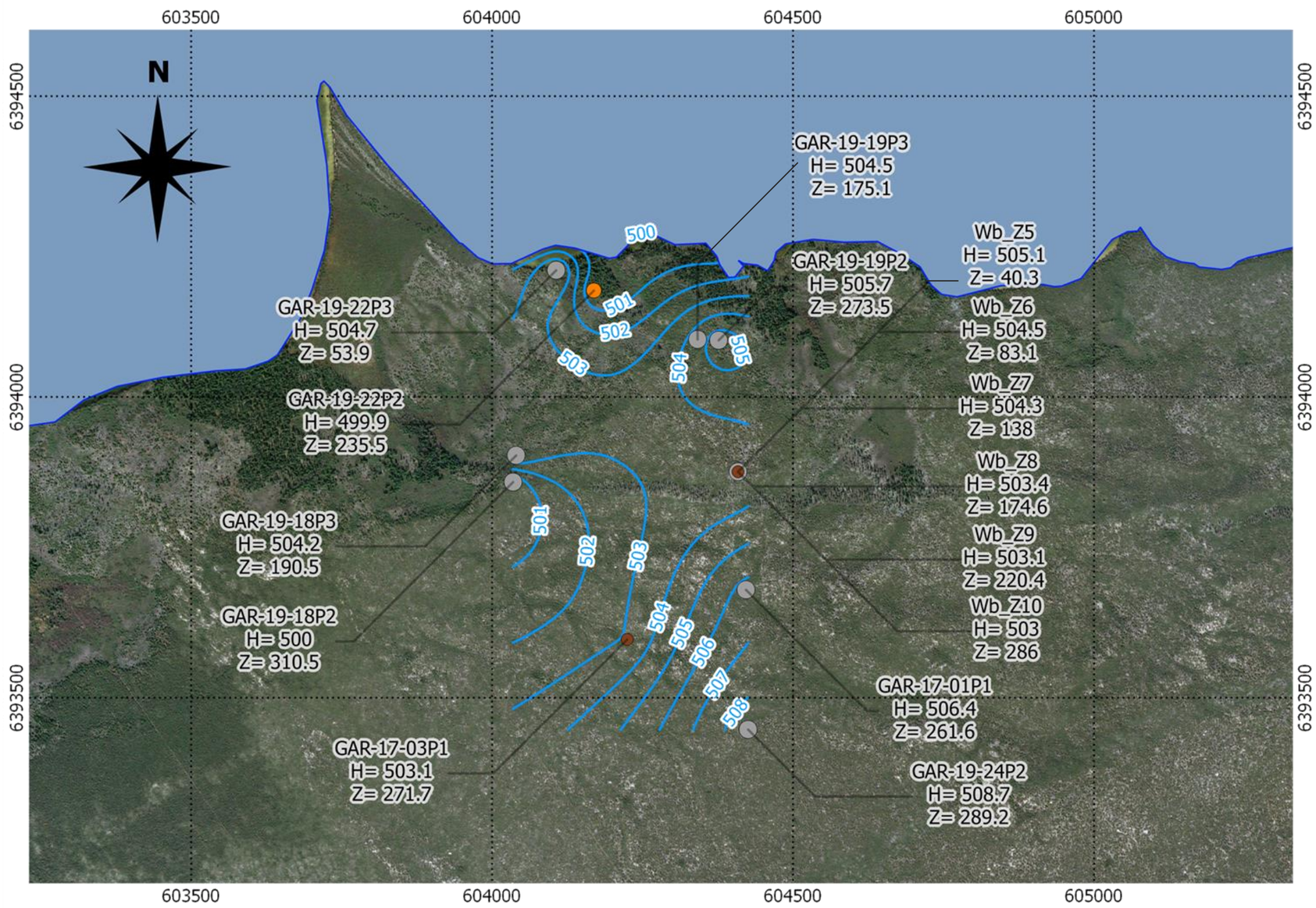
PROJECT

NEXGEN ENERGY LTD.
ROOK I PROJECT

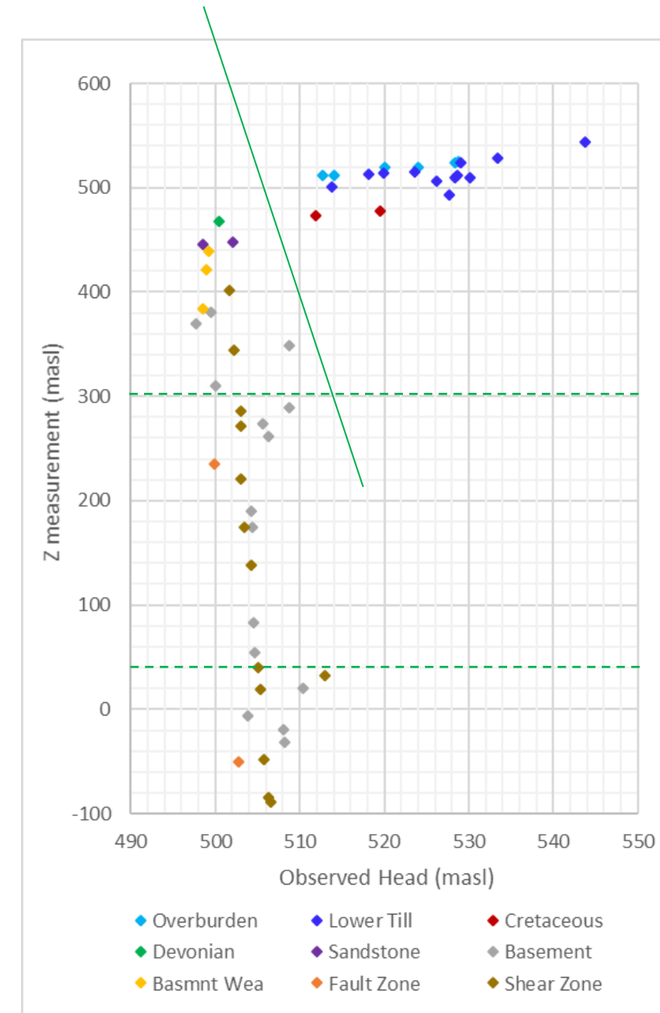
TITLE

CONCEPTUAL HYDROGEOLOGICAL MODEL
GROUNDWATER CONTOUR MAPS (MID-MINE LEVEL)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-6b



Observations considered on contour estimation



LEYEND

WATER BODY

GROUNDWATER CONTOUR

OBSERVATION POINT

Name
H= GW Elv
Z= Meas Elv

OBSERVATION POINT BY UNIT

Basement
Fault Zone
Shear Zone

NOTAS

1. Groundwater observation point labels shows name of the borehole, groundwater elevation (GW Elv) and measurement point elevation (Meas Elv) which considers the screen mid-point for screened boreholes, or the exact elevation for vibrating wires.
2. Groundwater contour level shown on top of the line.

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YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

PROJECT

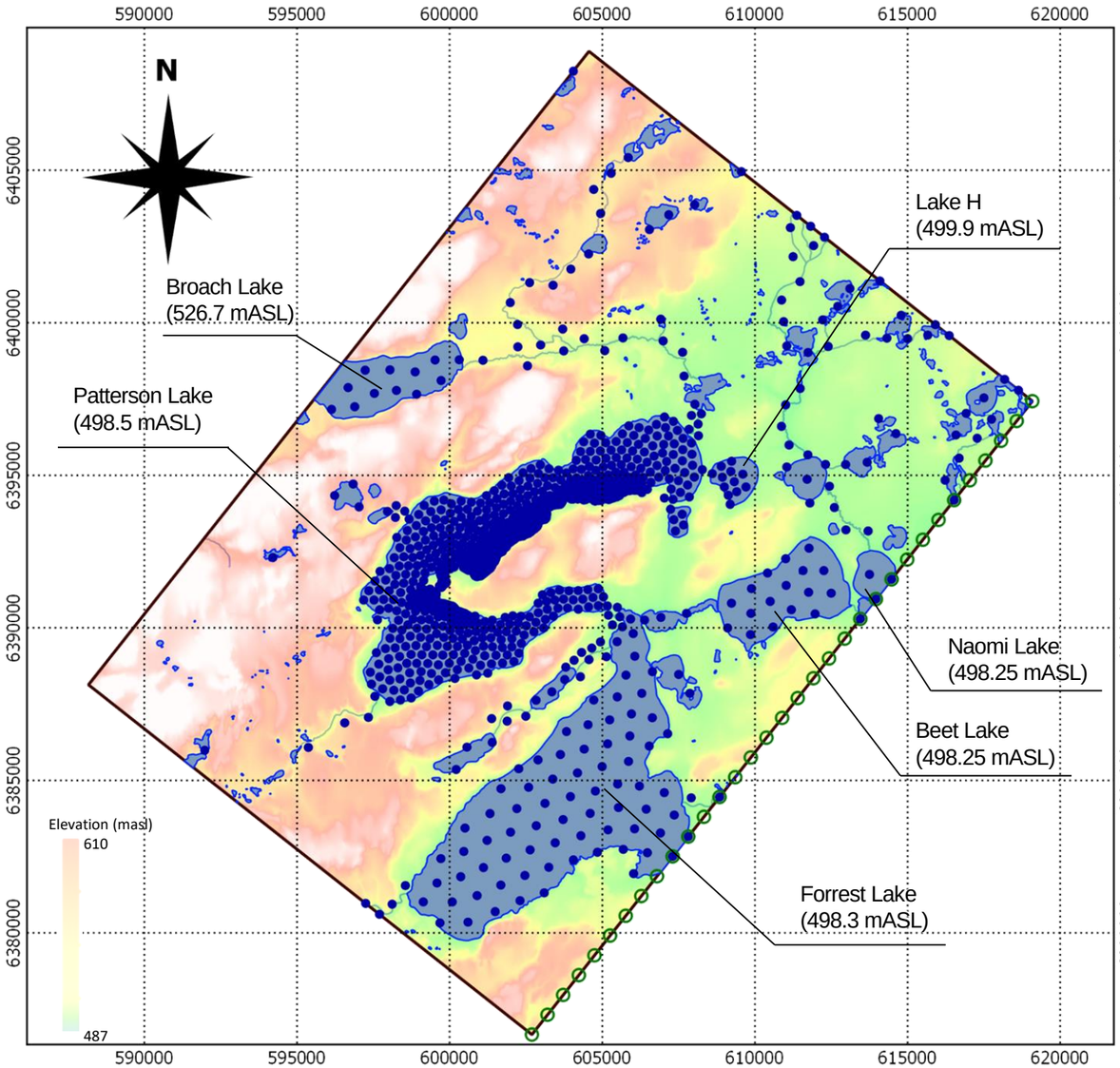
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE

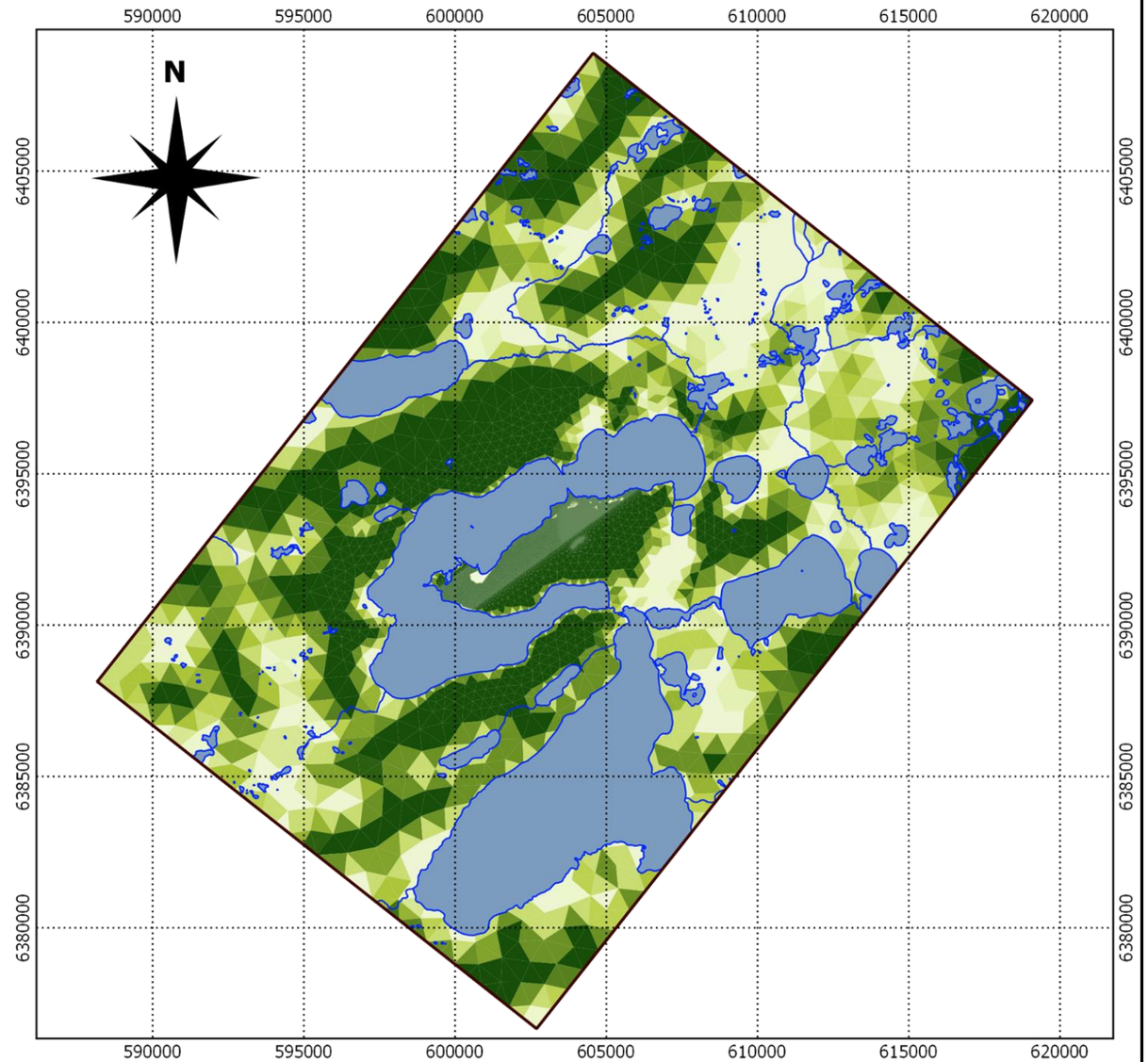
CONCEPTUAL HYDROGEOLOGICAL MODEL
GROUNDWATER CONTOUR MAPS (DEEP MINE LEVEL)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-6c

GROUNDWATER FLOW BOUNDARIES



SURFICIAL RECHARGE DISTRIBUTION



0 2 4 6 8 km

LEGEND

- Watercourse
- Waterbody
- Domain
- Lakes and streams
- Constant head Slice 6 to 39

Net Recharge (mm/yr)

0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
100 - 110
110 - 120
120 - 130
130 - 140
140

NOTES

1. Lake and stream constant head boundaries are placed on model slice 1. Specified elevations correspond to ground surface for streams, and fixed head for lakes.
2. The model recharge distribution was determined by applying a uniform infiltration rate of 140 mm/yr, and allowing the model to remove excess infiltration in the event that groundwater elevations rise above ground surface. Refer to Section 3.3 of the report for additional details.

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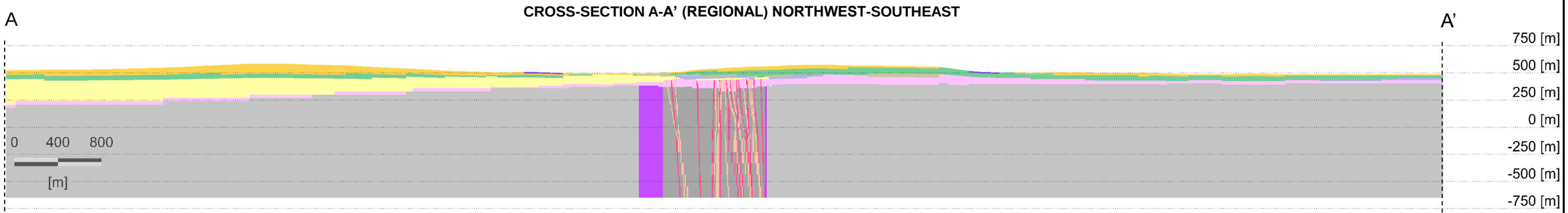
YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

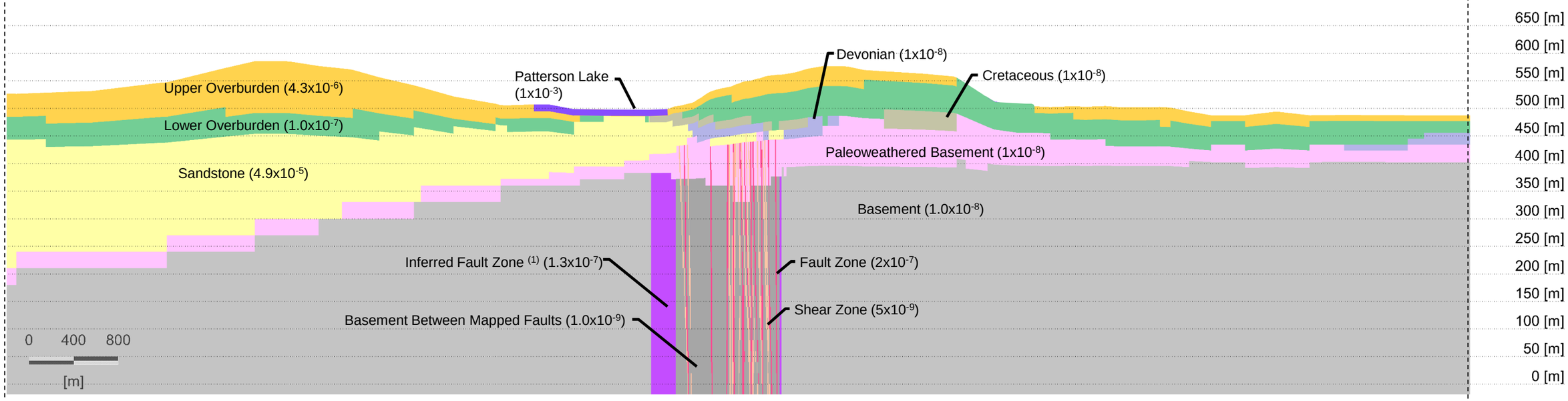
TITLE
MODEL BOUNDARY CONDITIONS AND RECHARGE RATES (CURRENT CONDITIONS)

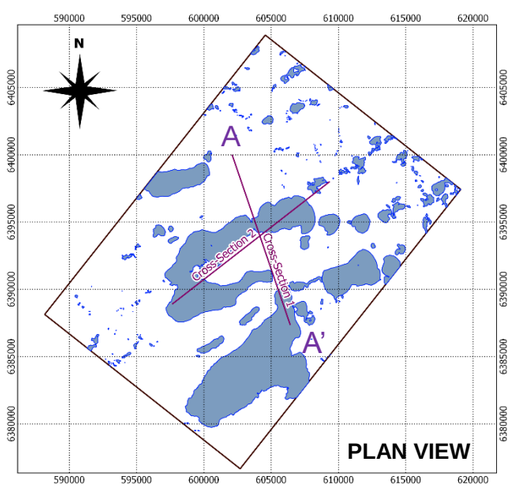
PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-7

CROSS-SECTION A-A' (REGIONAL) NORTHWEST-SOUTHEAST



CROSS-SECTION A-A' (REGIONAL) NORTHWEST-SOUTHEAST (DETAIL ABOVE 0 MASL, VERTICAL EXAGGERATION 5:1)





Unit	Horizontal Hydraulic Conductivity (Kh, m/s)	Vertical Hydraulic Conductivity (Kv, m/s)	Kh:Kv	Porosity (-)
Lake	1.0E-3	1.0E-3	1	1
Upper Overburden	4.3E-06	5.0E-08	87	0.2
Lower Overburden (Till)	1.0E-07	1.4E-09	74	0.2
Cretaceous Bedrock	1.0E-08	5.0E-11	200	0.1
Devonian Bedrock	1.5E-07	5.0E-11	2943	0.1
Sandstone Bedrock	4.9E-05	5.0E-06	9.8	0.1
Paleoweathered Bedrock	1.0E-08	9.5E-10	11	0.05
Basement Bedrock	1.0E-08	8.3E-10	12	0.01
Fault Zone	2.0E-07	1.0E-08	20	0.05
Shear Zones	8.3E-09	1.0E-08	0.8	0.05
Inferred Fault Zone (1)	1.3E-07	1.9E-09	70	0.05
Inner Basement	1.0E-09	1.0E-10	10	0.01

Note:
1) Inferred fault zone refers to the area interpreted to encompass the fault zones and shear zones present in the local 3D geological model. This zone extends approximately 4 km to the southwest from the mine area, and approximately 700 m to the northeast. Preferential horizontal hydraulic conductivity is applied at an angle of 43 degrees from north. Refer to section 4.5.2.4 of the text.

LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK
- SHEAR ZONE
- FAULT ZONE
- INFERED FAULT ZONE
- BASEMENT BETWEEN MAPPED FAULTS
- LAKE

CLIENT
NexGen Energy Ltd.

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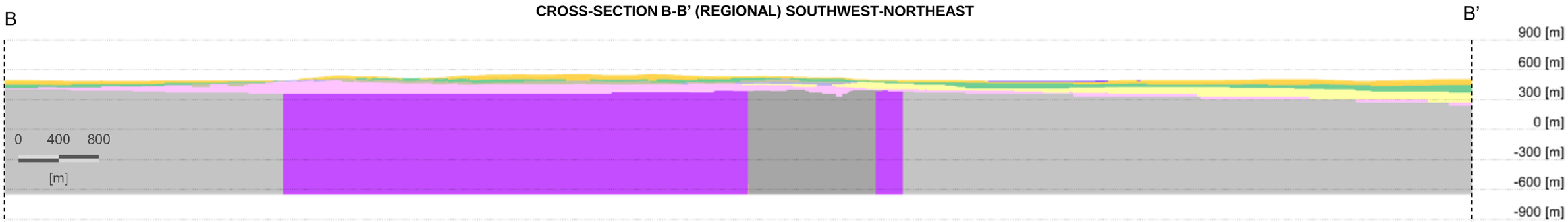
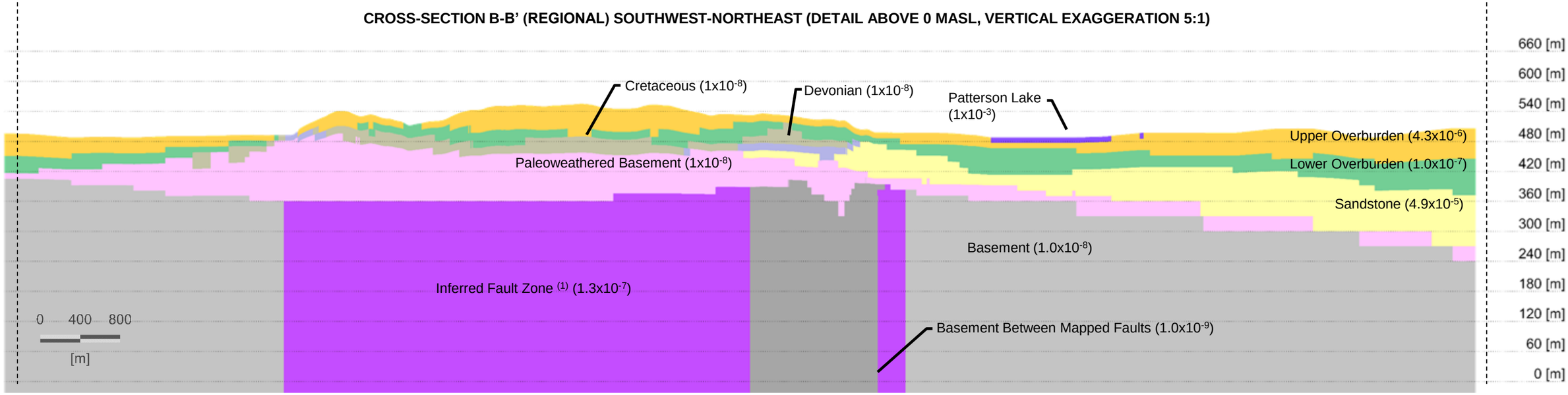
YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

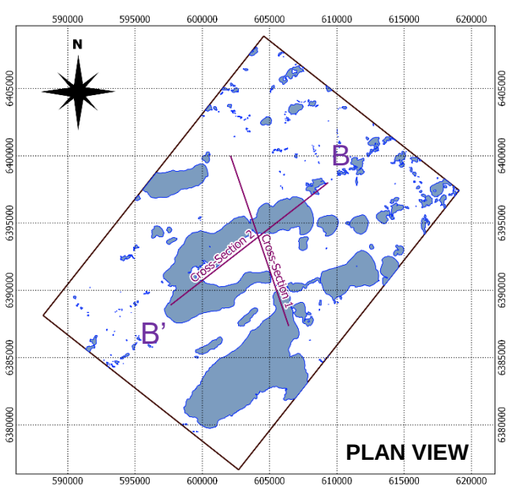
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
CALIBRATED MODEL HYDRAULIC CONDUCTIVITY DISTRIBUTION
CROSS-SECTION A-A' (REGIONAL) NORTHWEST-SOUTHEAST

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-8







Unit	Horizontal Hydraulic Conductivity (Kh, m/s)	Vertical Hydraulic Conductivity (Kv, m/s)	Kh:Kv	Porosity (-)
Lake	1.0E-3	1.0E-3	1	1
Upper Overburden	4.3E-06	5.0E-08	87	0.2
Lower Overburden (Till)	1.0E-07	1.4E-09	74	0.2
Cretaceous Bedrock	1.0E-08	5.0E-11	200	0.1
Devonian Bedrock	1.5E-07	5.0E-11	2943	0.1
Sandstone Bedrock	4.9E-05	5.0E-06	9.8	0.1
Paleoweathered Bedrock	1.0E-08	9.5E-10	11	0.05
Basement Bedrock	1.0E-08	8.3E-10	12	0.01
Fault Zone	2.0E-07	1.0E-08	20	0.05
Shear Zones	8.3E-09	1.0E-08	0.8	0.05
Inferred Fault Zone (1)	1.3E-07	1.9E-09	70	0.05
Inner Basement	1.0E-09	1.0E-10	10	0.01

Note:
1) Inferred fault zone refers to the area interpreted to encompass the fault zones and shear zones present in the local 3D geological model. This zone extends approximately 4 km to the southwest from the mine area, and approximately 700 m to the northeast. Preferential horizontal hydraulic conductivity is applied at an angle of 43 degrees from north. Refer to section 4.5.2.4 of the text.

LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK
- SHEAR ZONE
- FAULT ZONE
- INFERED FAULT ZONE
- BASEMENT BETWEEN MAPPED FAULTS
- LAKE

CLIENT: NexGen Energy Ltd.

CONSULTANT: wsp

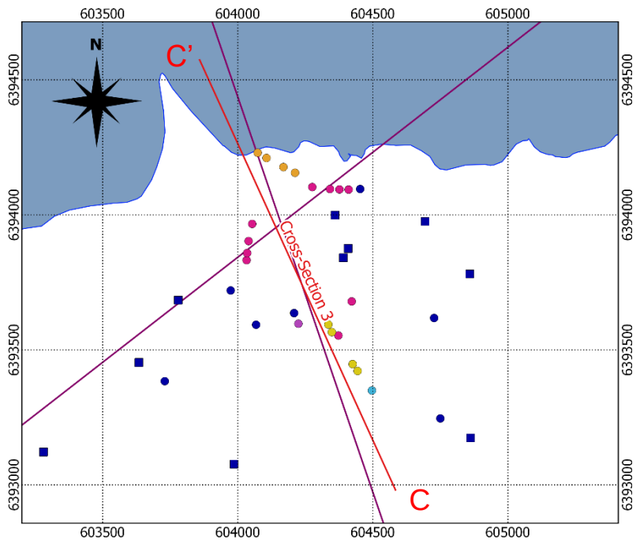
YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

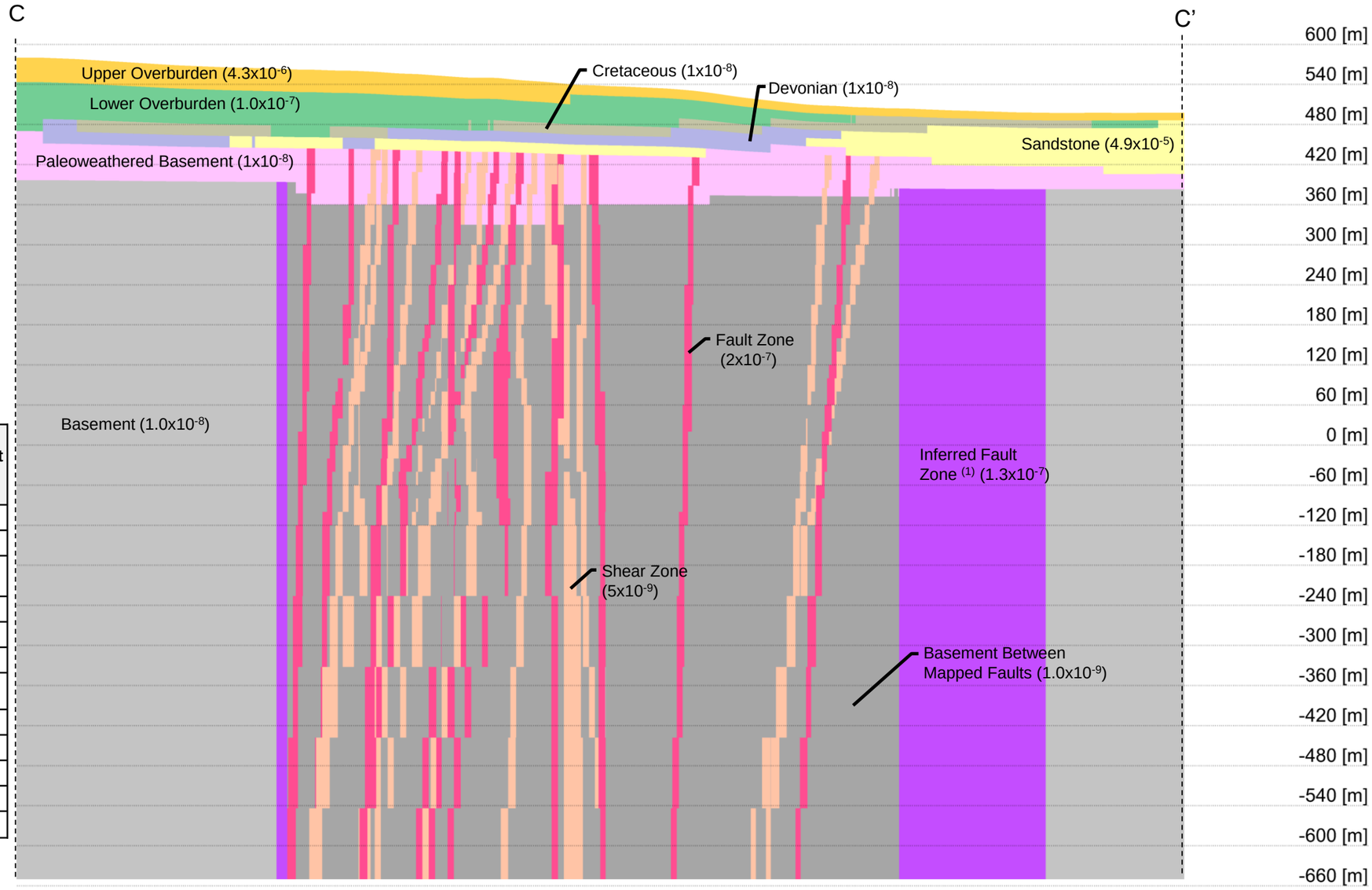
TITLE
CALIBRATED MODEL HYDRAULIC CONDUCTIVITY DISTRIBUTION
CROSS-SECTION B-B' (REGIONAL) SOUTHWEST-NORTHEAST

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-9

PLAN VIEW



CROSS-SECTION C-C' (LOCAL) MINE AREA TO PATTERSON LAKE



Unit	Horizontal Hydraulic Conductivity (Kh, m/s)	Vertical Hydraulic Conductivity (Kv, m/s)	Kh:Kv	Porosity (-)
Lake	1.0E-3	1.0E-3	1	1
Upper Overburden	4.3E-06	5.0E-08	87	0.2
Lower Overburden (Till)	1.0E-07	1.4E-09	74	0.2
Cretaceous Bedrock	1.0E-08	5.0E-11	200	0.1
Devonian Bedrock	1.5E-07	5.0E-11	2943	0.1
Sandstone Bedrock	4.9E-05	5.0E-06	9.8	0.1
Paleoweathered Bedrock	1.0E-08	9.5E-10	11	0.05
Basement Bedrock	1.0E-08	8.3E-10	12	0.01
Fault Zone	2.0E-07	1.0E-08	20	0.05
Shear Zones	8.3E-09	1.0E-08	0.8	0.05
Inferred Fault Zone (1)	1.3E-07	1.9E-09	70	0.05
Inner Basement	1.0E-09	1.0E-10	10	0.01

Note:
1) Inferred fault zone refers to the area interpreted to encompass the fault zones and shear zones present in the local 3D geological model. This zone extends approximately 4 km to the southwest from the mine area, and approximately 700 m to the northeast. Preferential horizontal hydraulic conductivity is applied at an angle of 43 degrees from north. Refer to section 3.4 of the text.

LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK
- SHEAR ZONE
- FAULT ZONE
- INFERED FAULT ZONE
- BASEMENT BETWEEN MAPPED FAULTS
- LAKE

NOTES

1. Plan view maps shows boreholes for reference. Refer to Figure 5 to check the corresponding name.

CLIENT
NexGen Energy Ltd.

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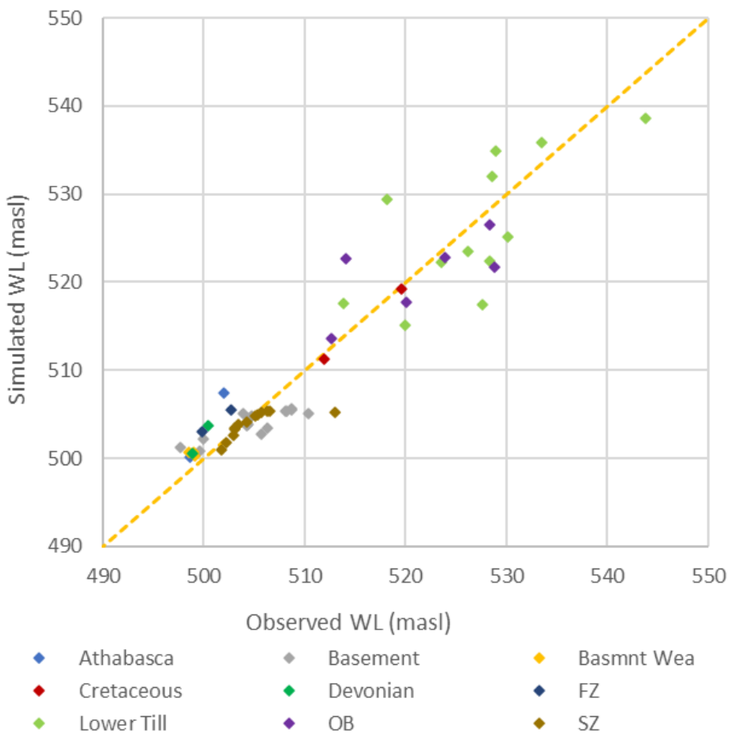
YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
CALIBRATED MODEL HYDRAULIC CONDUCTIVITY DISTRIBUTION CROSS-SECTION C-C' (LOCAL) MINE AREA TO PATTERSON LAKE

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-10



Calibration statistics

# Observation points	57
Mean error (m)	-0.3
Root mean squared error (m)	3.7
Normalizaed RMSE (%)	8.1%

LEGEND

RESIDUAL ERROR – (SIMULATED MINUS OBSERVED GROUNDWATER ELEVATION (m)

- <-5
- -5 to -2
- -2 to 2
- 2 to 5
- >5

NOTAS

1. Simulated against observed heads graph shows observations based on measured hydrogeological unit.
2. Residual error distribution graph uses brackets to show elevation at nested piezometers
3. Marker size shows the magnitude of the difference between observation and simulated head

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YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

PROJECT

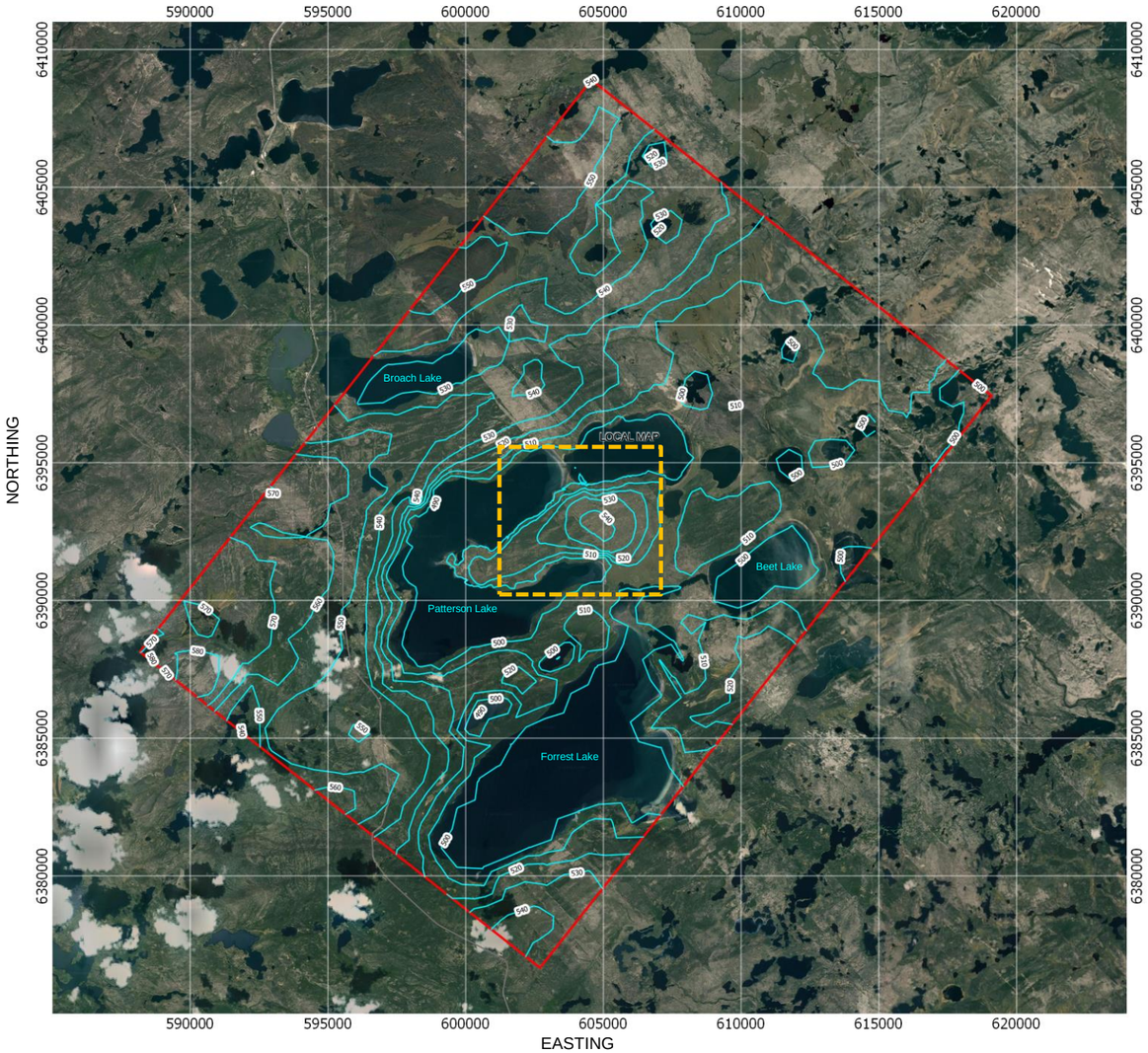
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE

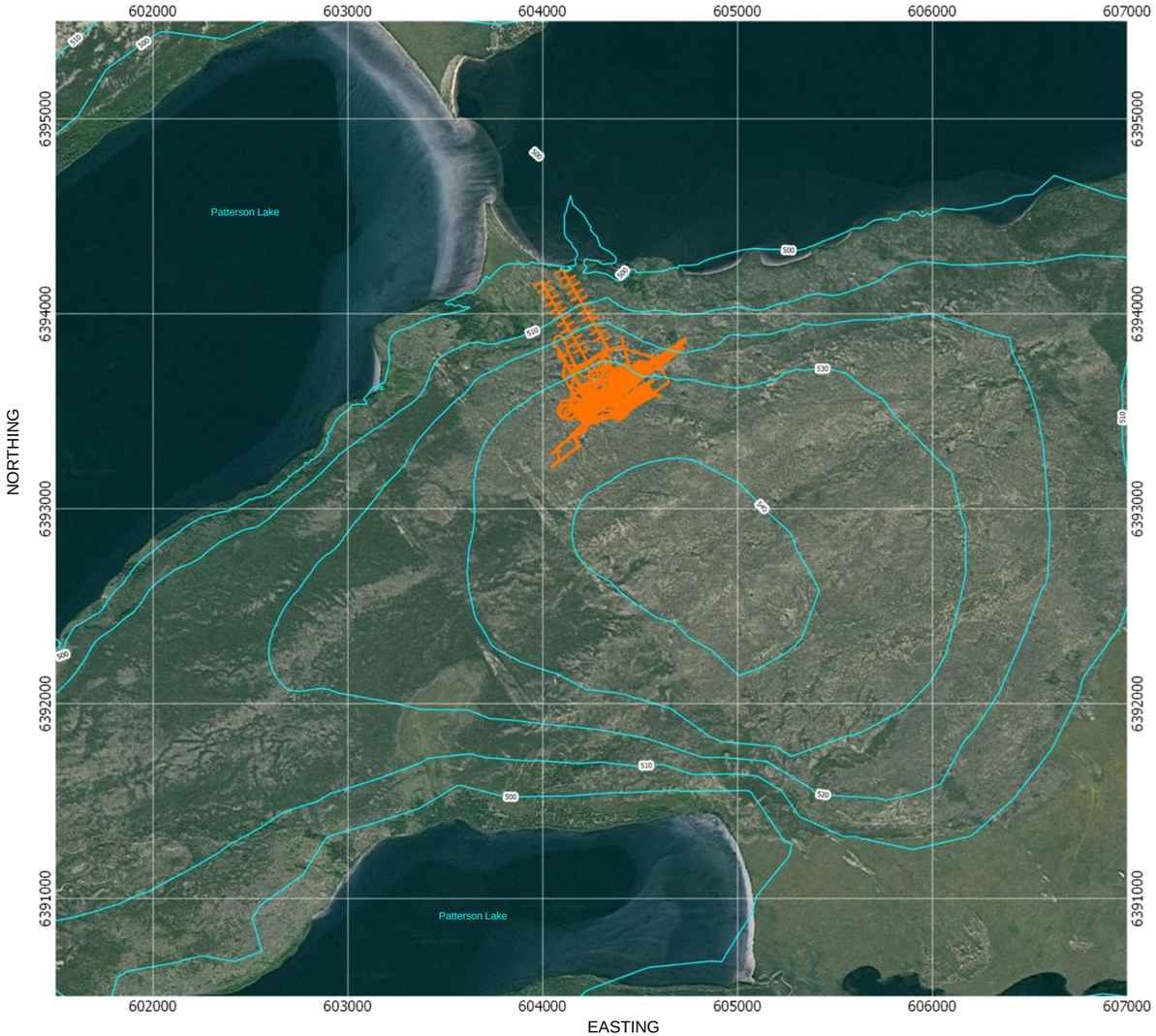
MODEL CALIBRATION

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-11

REGIONAL SCALE - FULL MODEL DOMAIN



LOCAL SCALE – MINE AREA



LEGEND

- MODEL DOMAIN
- SIMULATED GROUNDWATER ELEVATION (mASL)
- UNDERGROUND DEVELOPMENT

Notes:
1) Simulated overburden groundwater elevations correspond to model slice 2 (approx. elevation 520 mASL in the mine area).

2) 3-D mine plan files for the underground workings provided by NexGen (November 19, 2020).

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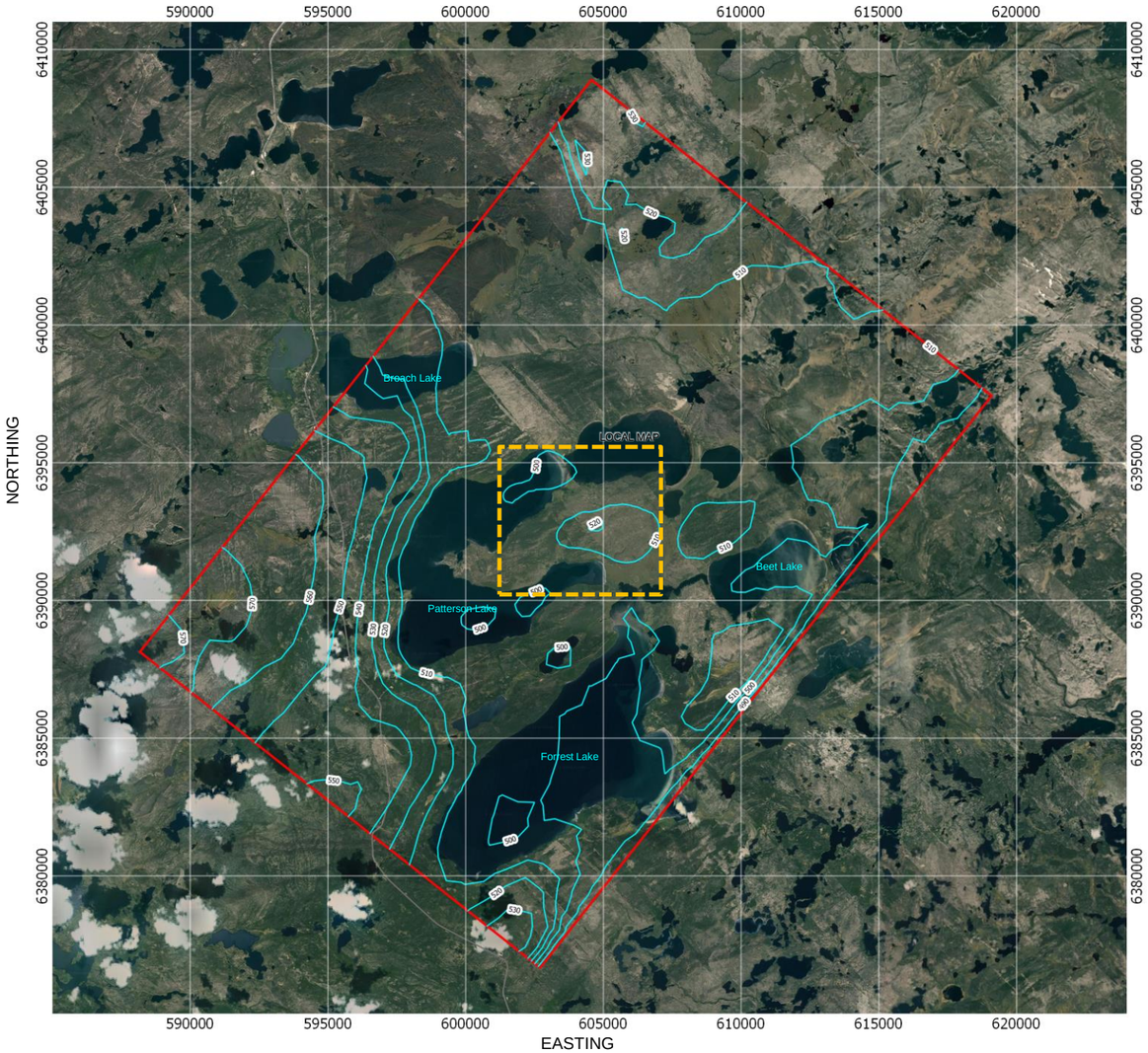
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

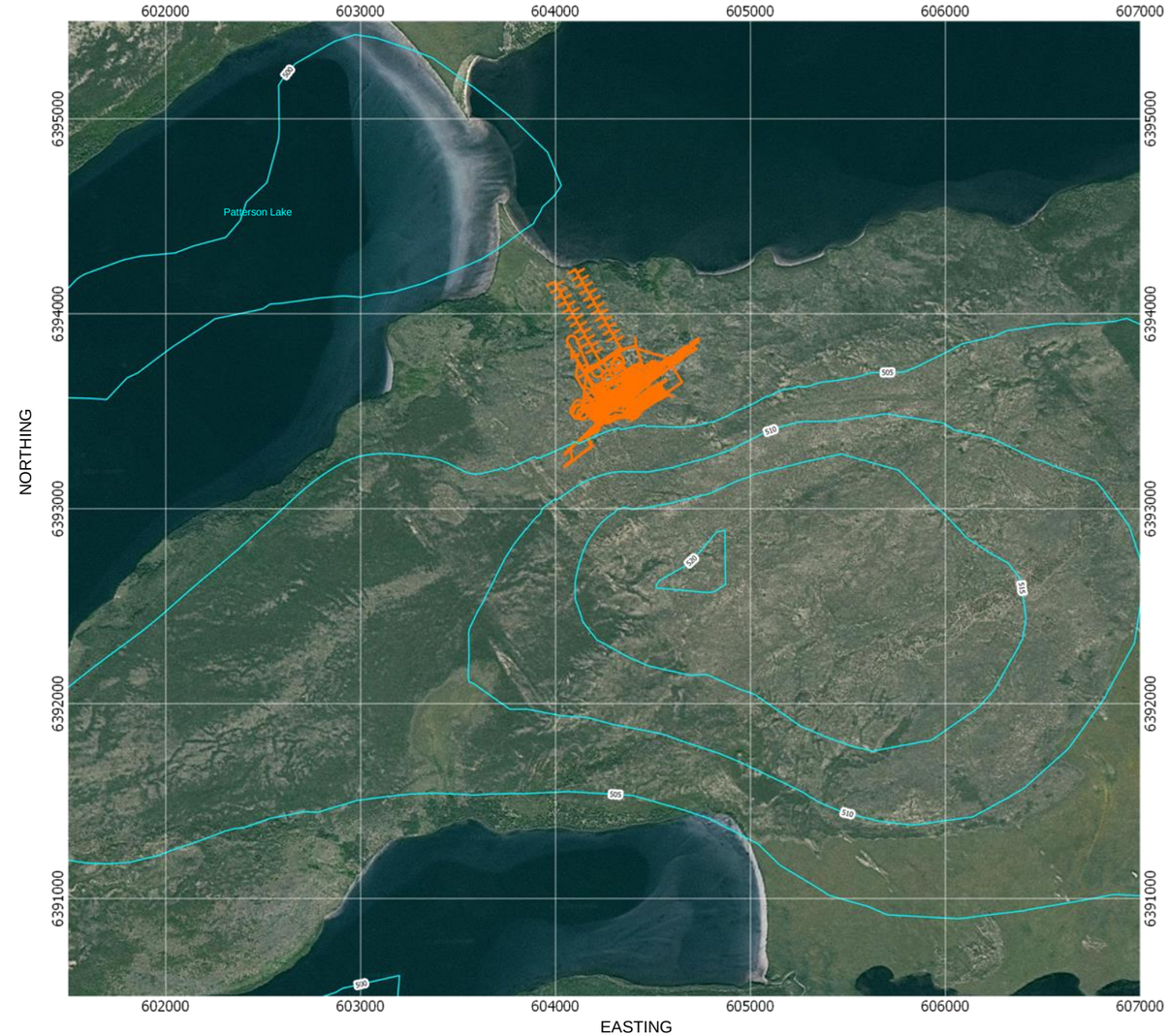
TITLE
SIMULATED GROUNDWATER FLOW ELEVATIONS FOR CURRENT (PREDEVELOPMENT) CONDITIONS – GLACIAL DRIFT

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-12

REGIONAL SCALE - FULL MODEL DOMAIN



LOCAL SCALE – MINE AREA



LEGEND

- MODEL DOMAIN
- SIMULATED GROUNDWATER ELEVATION (mASL)
- UNDERGROUND DEVELOPMENT

Notes:

1) Simulated shallow bedrock groundwater elevations correspond to model slice 10 (approx. elevation 405 mASL in the mine area)

2) 3-D mine plan files for the underground workings provided by NexGen (November 19, 2020).

CLIENT
NexGen Energy Ltd.

CONSULTANT
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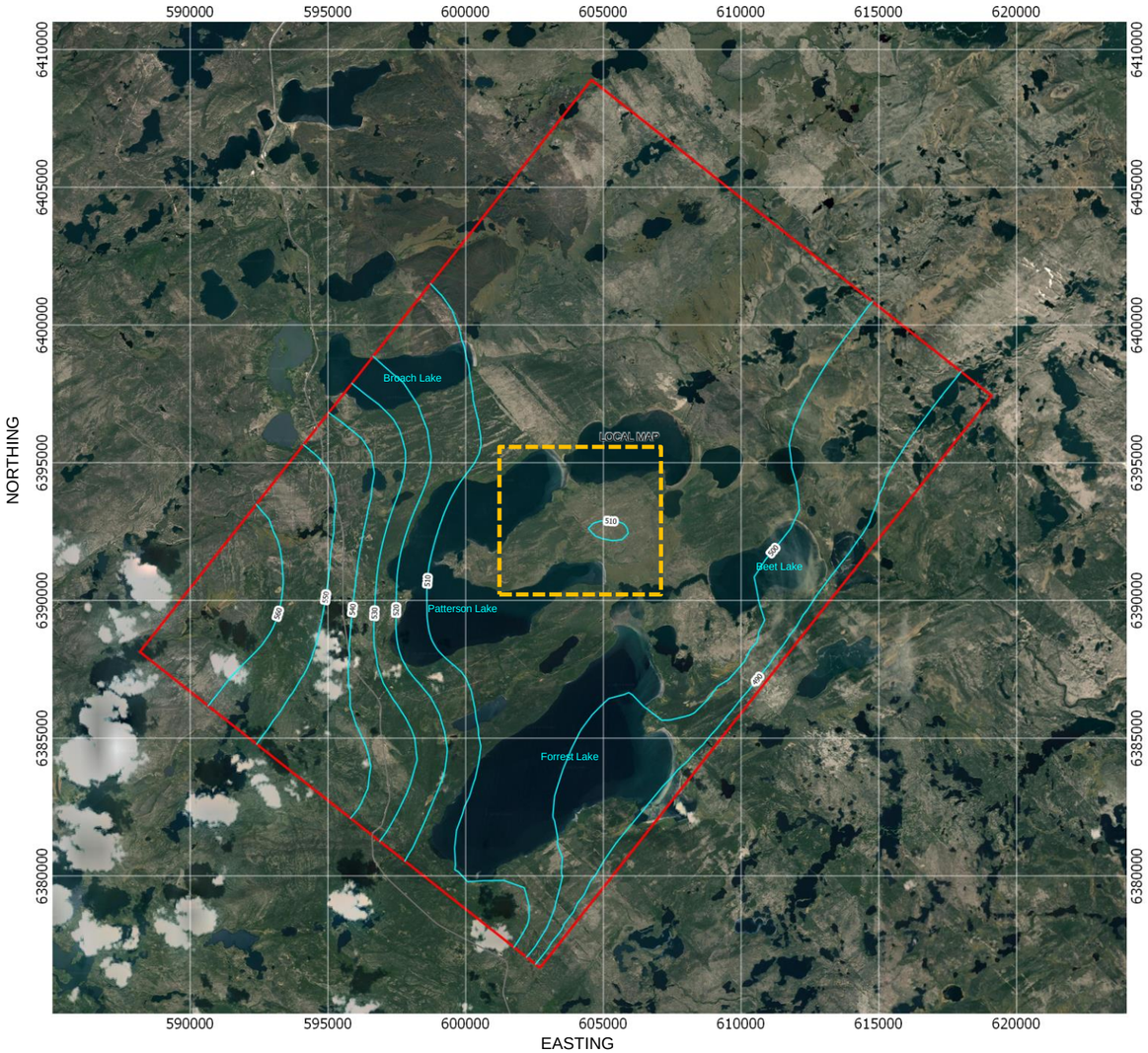
YYYY-MM-DD	2021-06-28
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

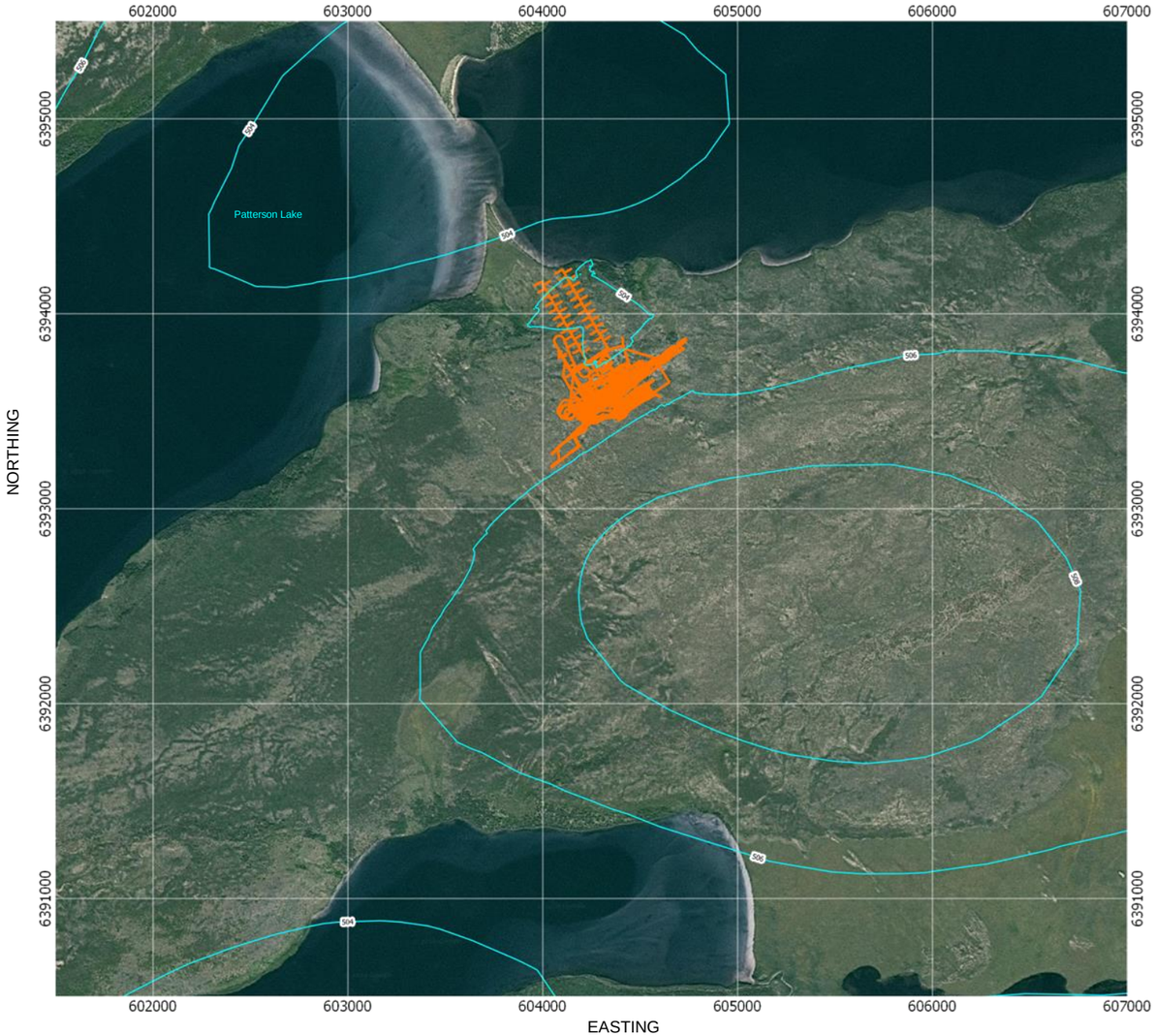
TITLE
SIMULATED GROUNDWATER FLOW ELEVATION FOR CURRENT (PREDEVELOPMENT) CONDITIONS – SHALLOW BEDROCK

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-13

REGIONAL SCALE - FULL MODEL DOMAIN



LOCAL SCALE – MINE AREA



LEGEND

- MODEL DOMAIN
- SIMULATED GROUNDWATER ELEVATION (mASL)
- UNDERGROUND DEVELOPMENT

Notes:

1) Simulated deep bedrock groundwater elevations correspond to model slice 20 (elevation 160 mASL).

2) 3-D mine plan files for the underground workings provided by NexGen (November 19, 2020).

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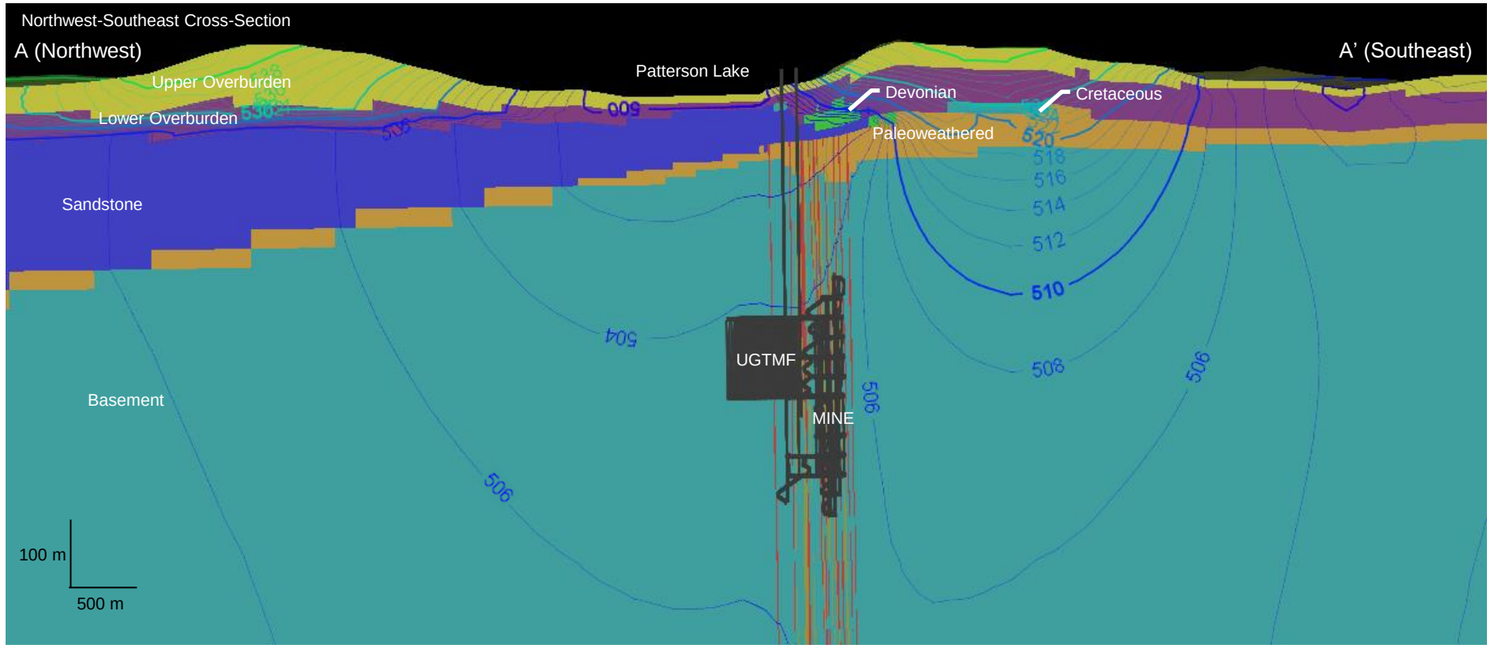
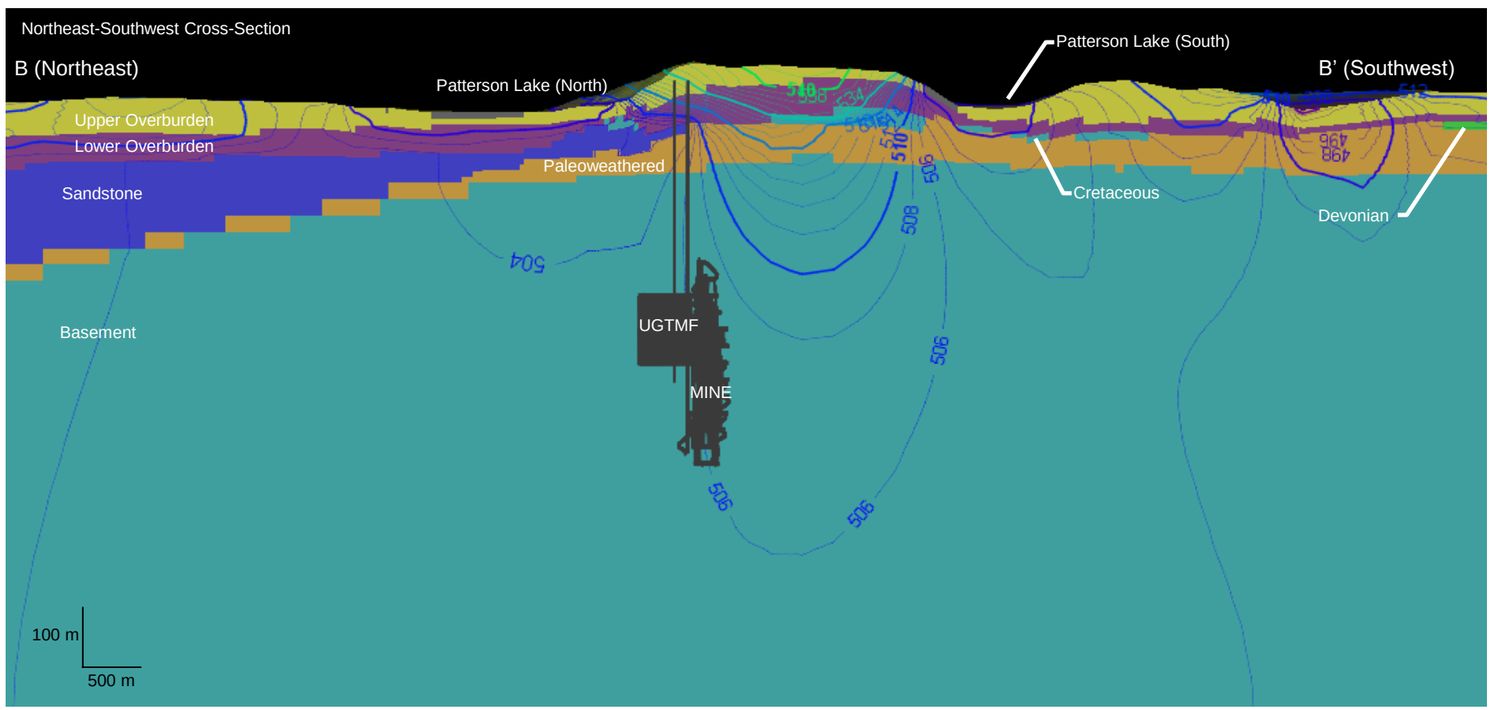
YYYY-MM-DD	2021-06-28
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

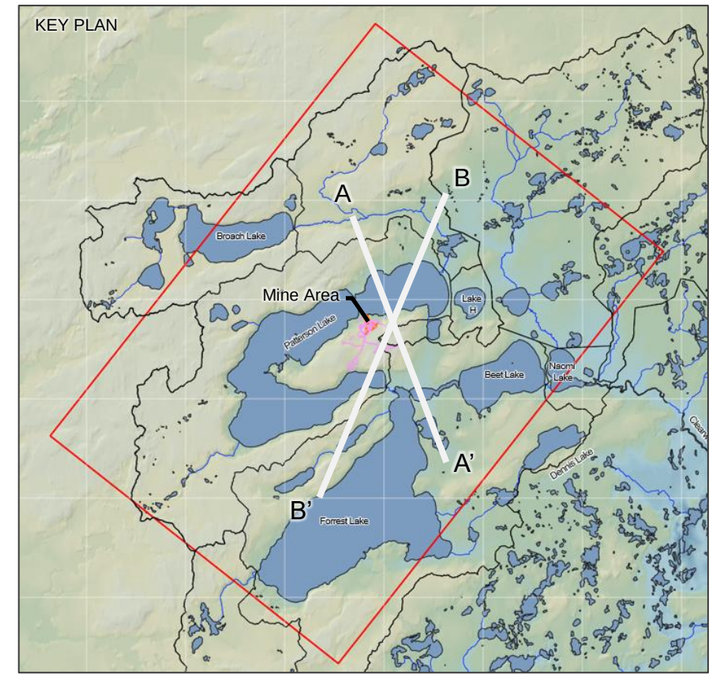
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SIMULATED GROUNDWATER FLOW ELEVATIONS FOR CURRENT (PREDEVELOPMENT) CONDITIONS – DEEP BEDROCK

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-14







LEGEND

- MODEL DOMAIN
- SIMULATED GROUNDWATER ELEVATION (mASL)
- UNDERGROUND DEVELOPMENT

Note:
1) 3-D mine plan files for the underground workings provided by NexGen (November 19, 2020).

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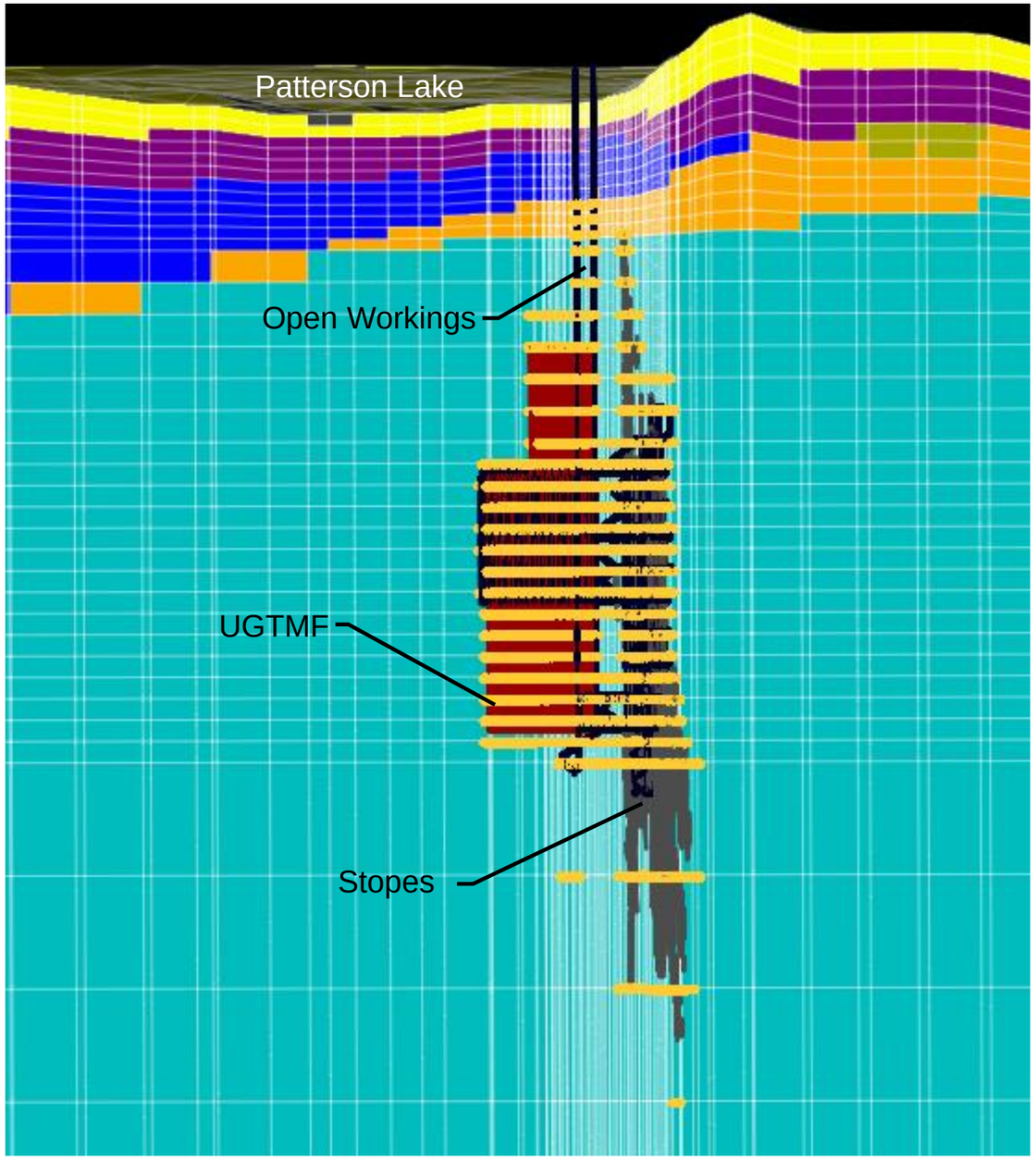
YYYY-MM-DD	2021-06-28
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

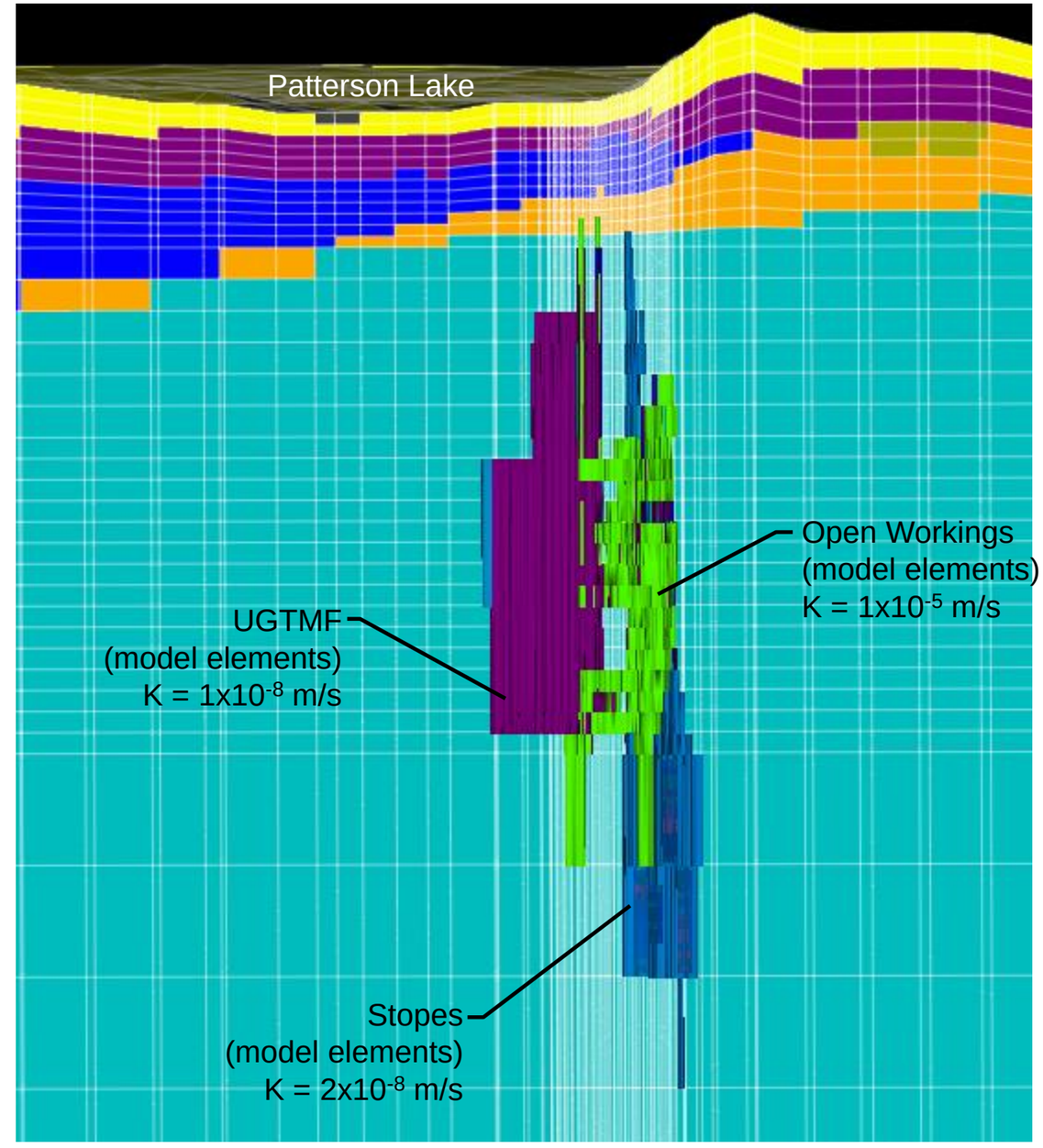
TITLE
SIMULATED GROUNDWATER FLOW ELEVATIONS FOR CURRENT (PREDEVELOPMENT) CONDITIONS – CROSS SECTIONS

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	0	A-15

Operations Configuration



Post-Closure Configuration



LEGEND

- MODEL SEEPAGE NODE BOUNDARY
- BASEMENT ROCK
- PALEOWEATHERED BASEMENT ROCK
- SANDSTONE
- DEVONIAN ROCK
- LOWER OVERBURDEN (TILL)
- UPPER OVERBURDEN

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CONSULTANT
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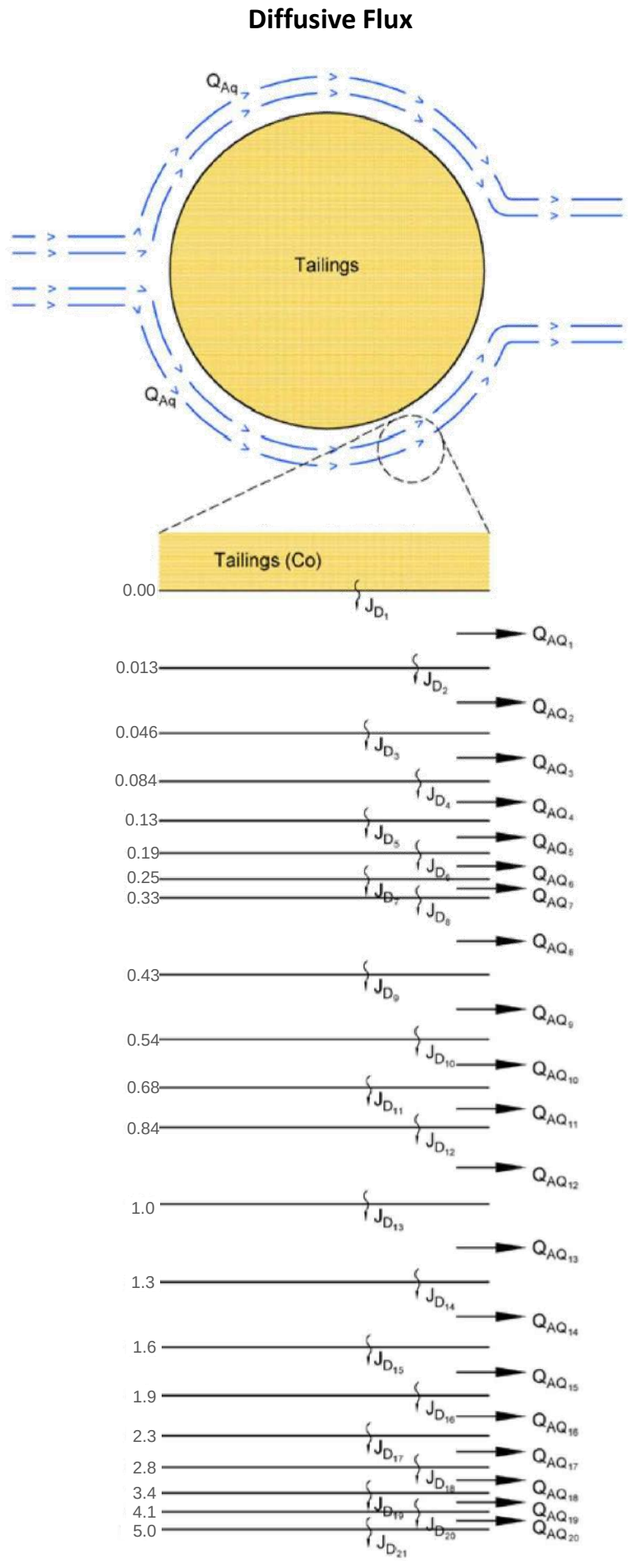
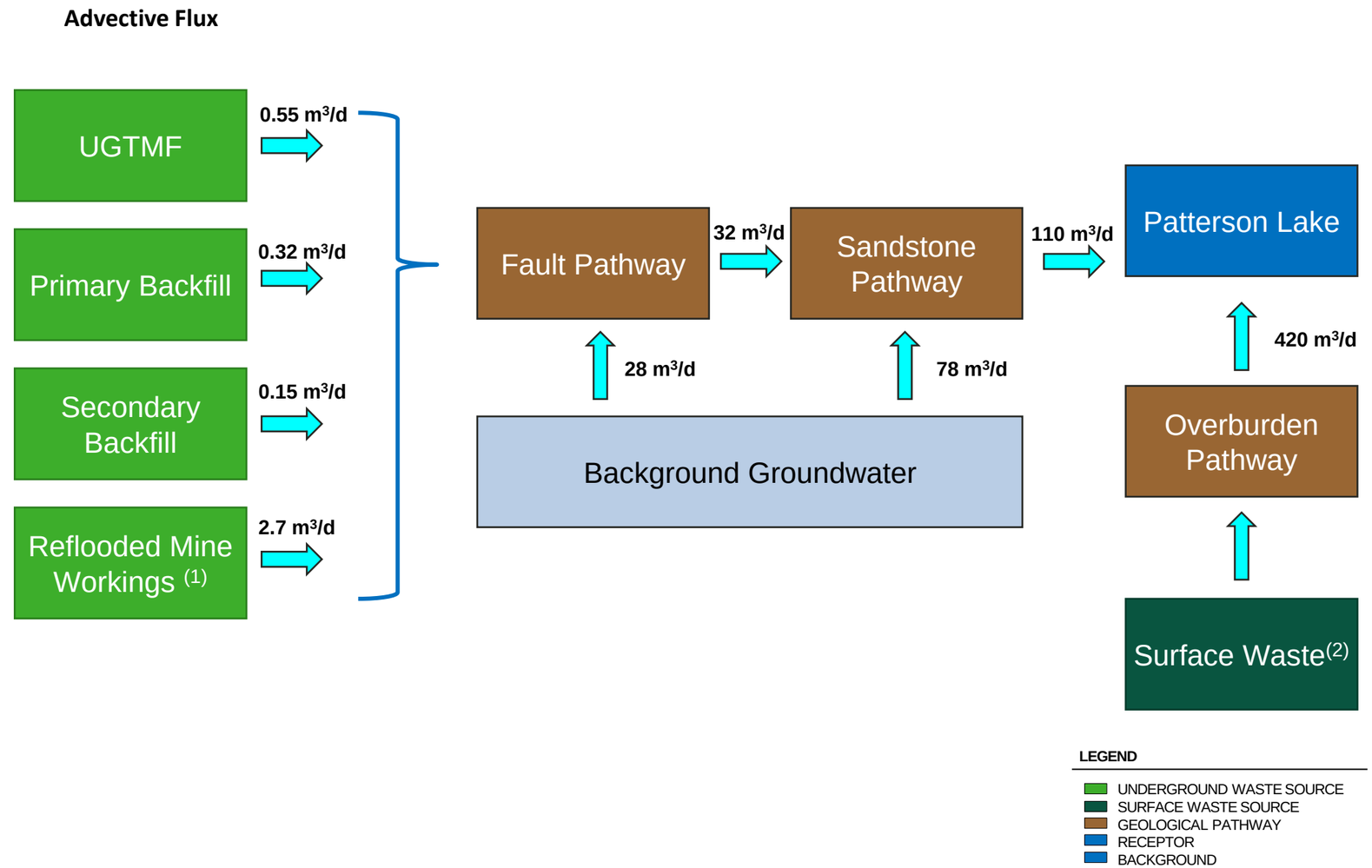
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
IMPLEMENTATION OF UNDERGROUND DEVELOPMENT IN THE PREDICTIVE MODEL

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	0	A-16

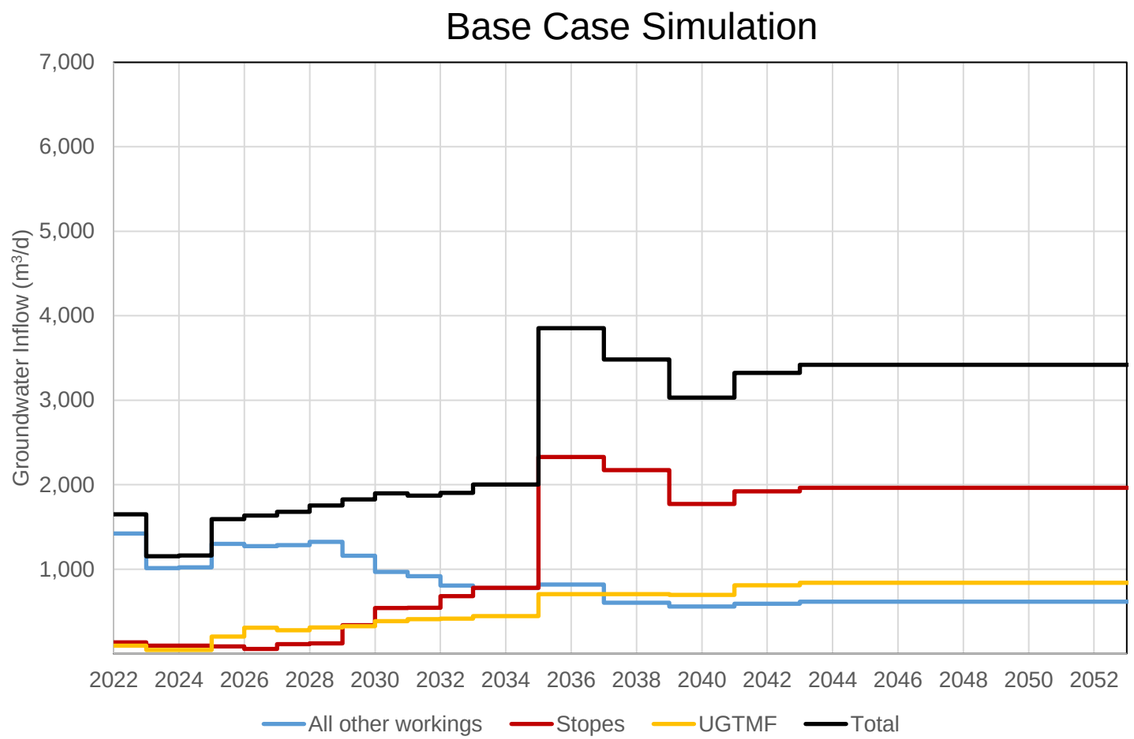


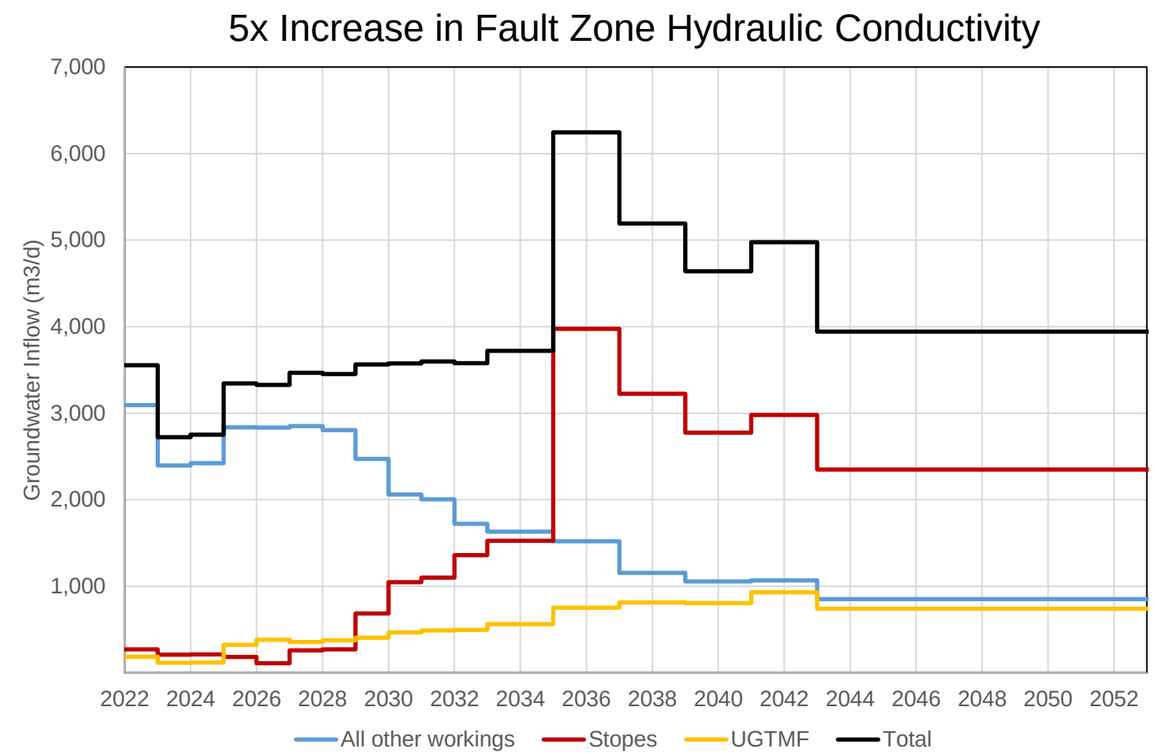


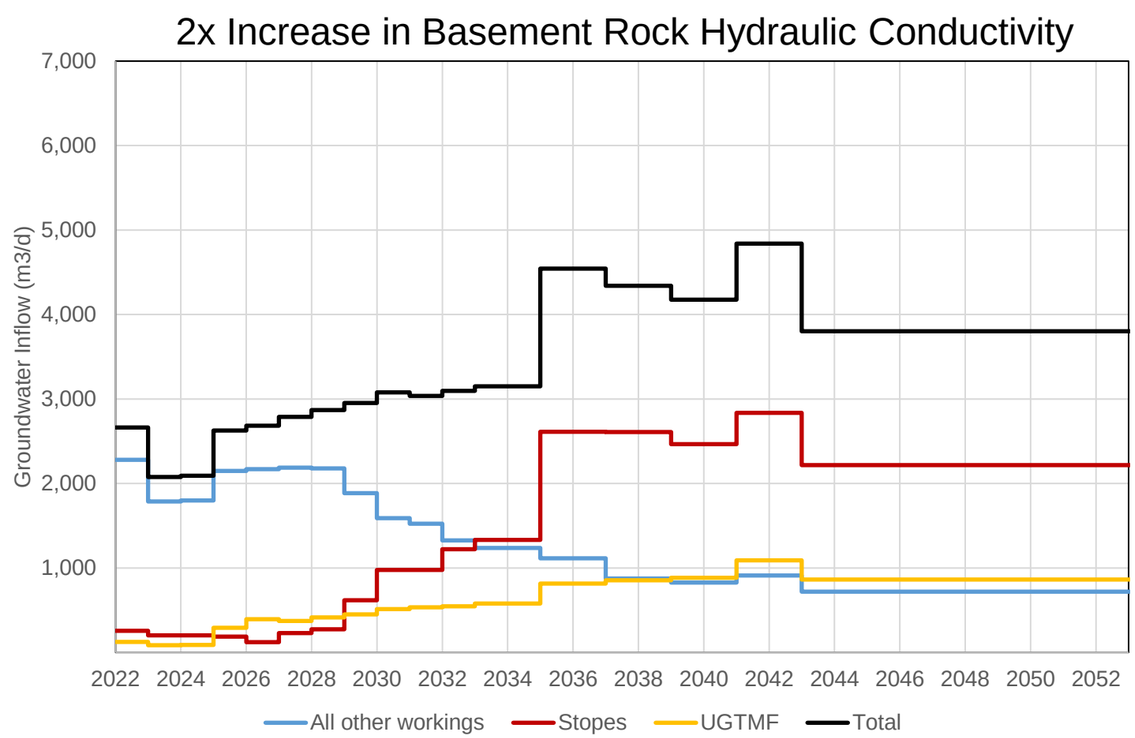
Notes:

1) Mass loading rates from reflooded mine workings provided by SRK (November 30, 2020).
2) Mass loading rates from surface waste provided by SRK (November 26, 2020). The model is configured using the "Option 2 Engineered" scenario. No flow rate associated with this source (i.e., mass loading rates only)
3) Q_{AQ} refers to flow component through the bedrock adjacent to the tailings; Co refers to concentration at the tailings; J_D refers to diffusive mass flux

CLIENT	NexGen Energy Ltd.
CONSULTANT	wsp
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT
PROJECT	NEXGEN ENERGY LTD. ROOK I PROJECT
TITLE	SOLUTE TRANSPORT MODEL SCHEMATIC
PROJECT No.	20144150
PHASE	XXXX
Rev.	0
FIGURE	A-17







Year	Annual Average (m^3/d)		
	Base Case	5x Increase in Fault Zone K	2x Increase in Basement K
2022	1651	3554	2664
2023	1153	2724	2078
2024	1162	2752	2091
2025	1594	3344	2628
2026	1636	3327	2683
2027	1679	3466	2788
2028	1755	3452	2869
2029	1826	3563	2954
2030	1897	3575	3079
2031	1870	3597	3036
2032	1903	3579	3096
2033	2001	3720	3150
2035	3852	6246	4544
2037	3483	5193	4341
2039	3031	4641	4177
2041	3325	4977	4839
2043	3420	3943	3802

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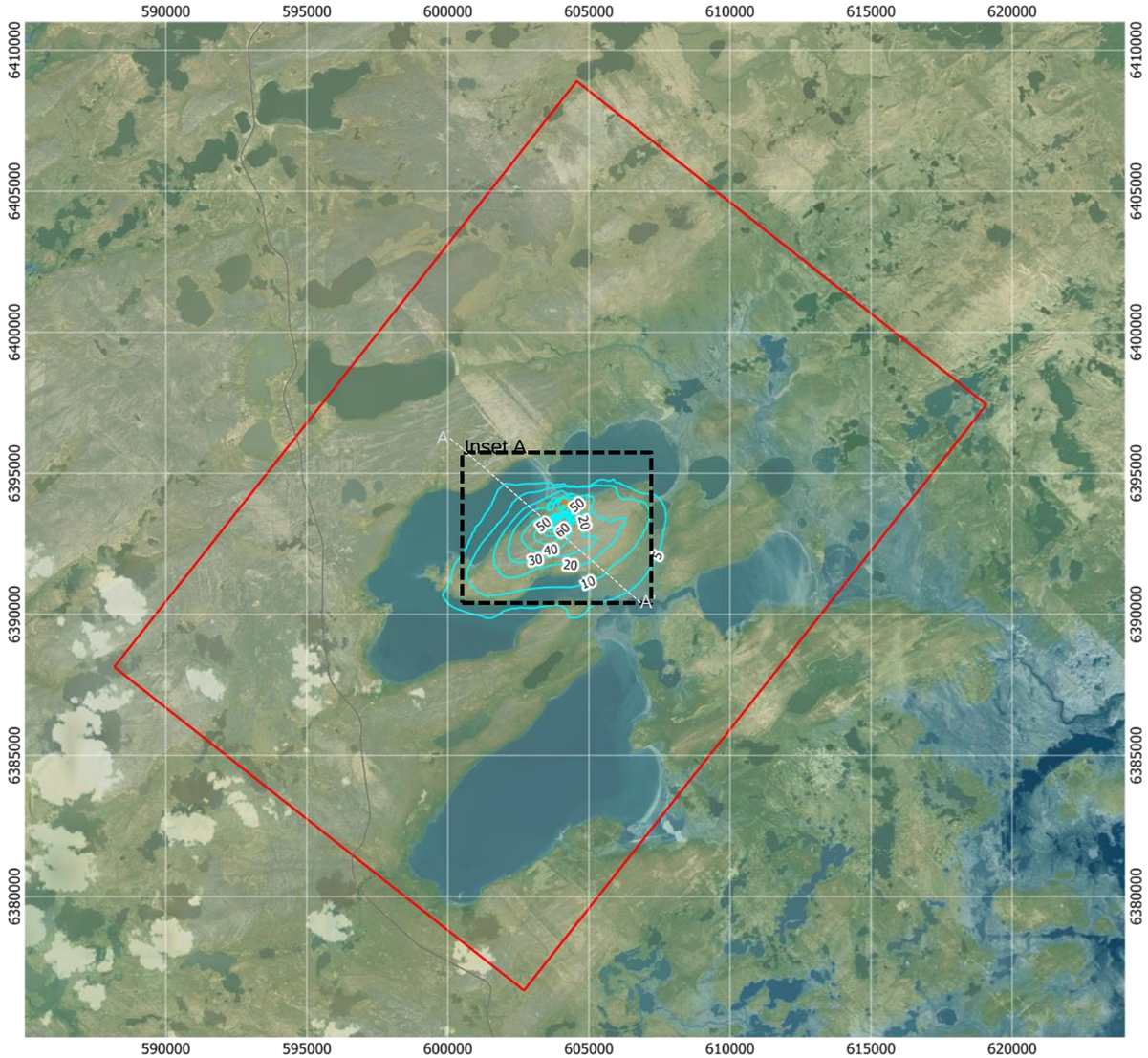
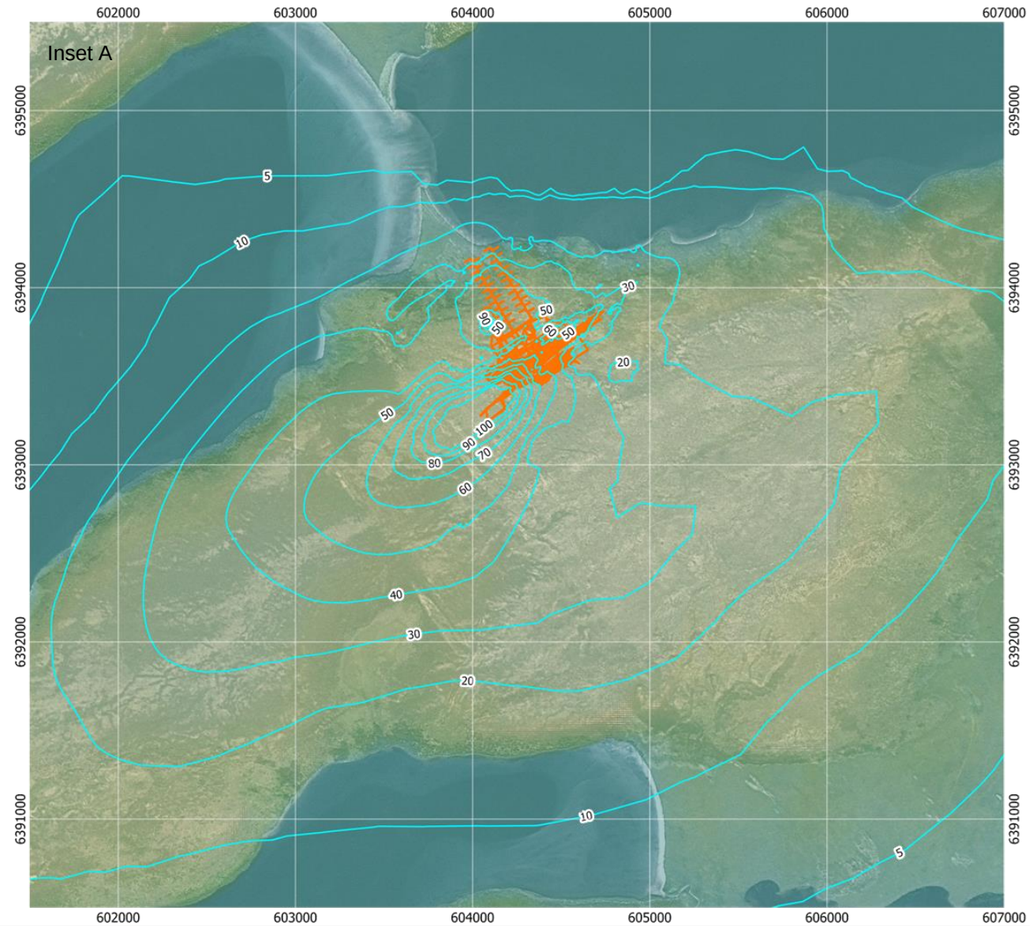
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

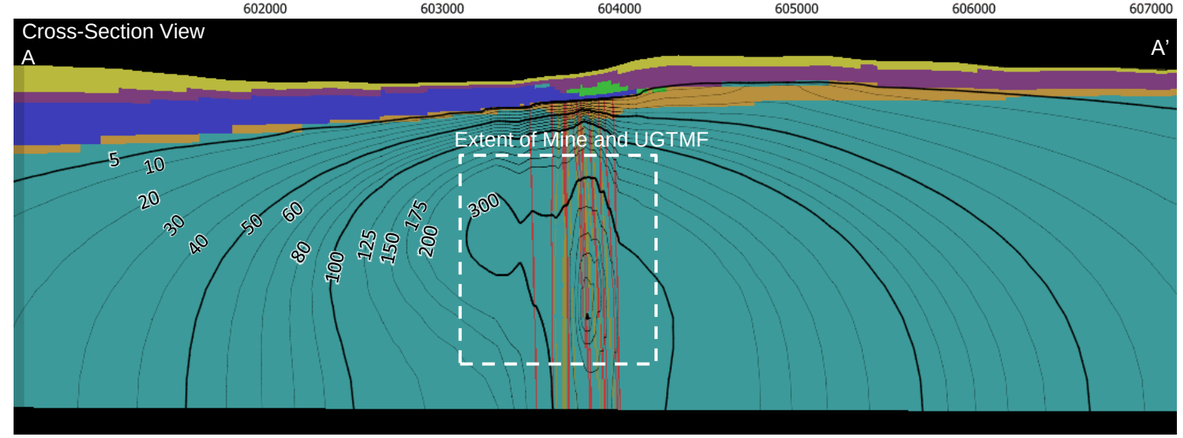
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SIMULATED GROUNDWATER INFLOWS TO THE MINE

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	0	A-18







LEGEND

- MODEL DOMAIN
- UNDERGROUND WORKINGS
- SIMULATED GROUNDWATER DRAWDOWN CONTOUR (m)

Notes:

1) Groundwater drawdown shown for basement rock at elevation 330 mASL, approximately 200 m below ground surface.

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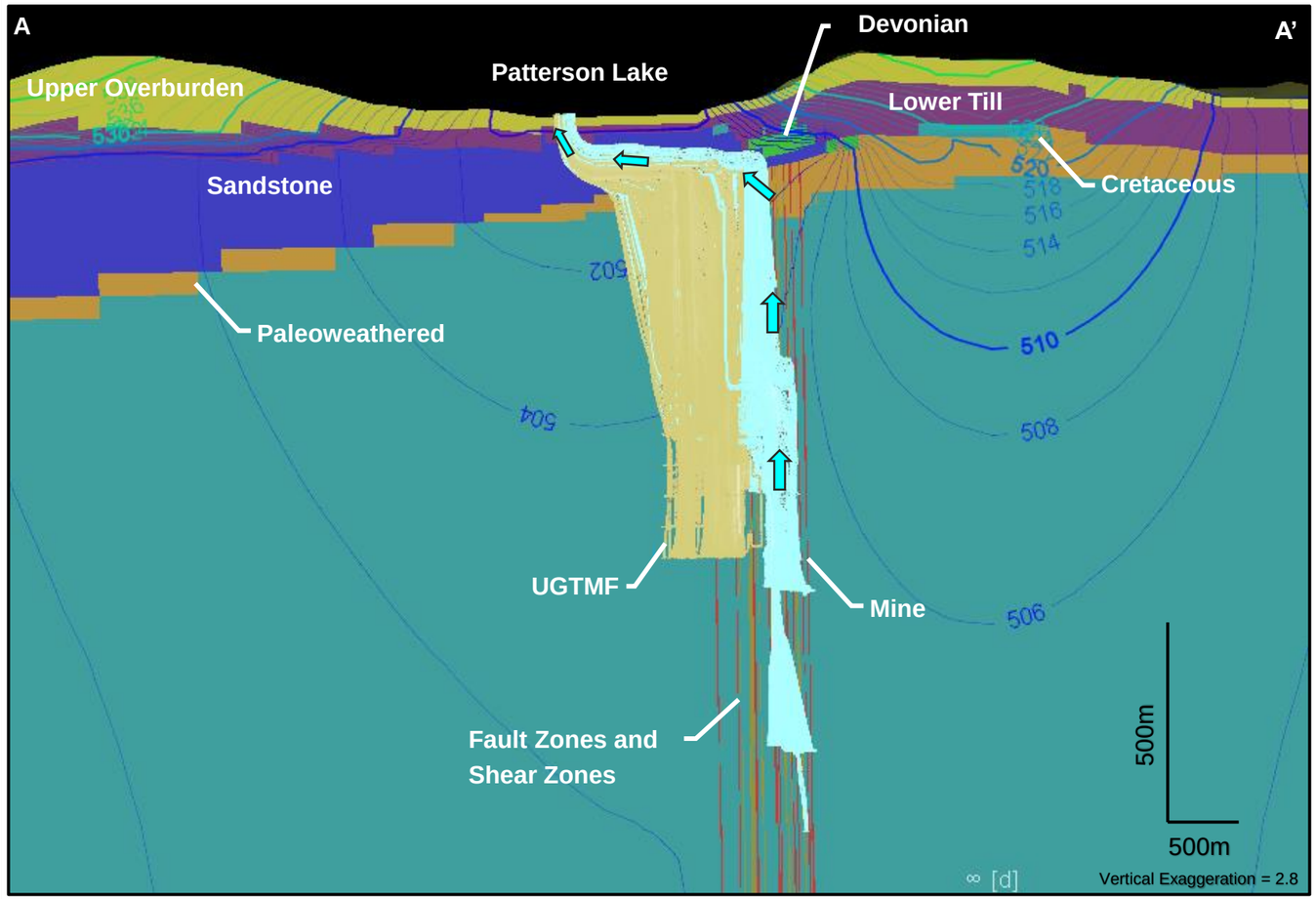
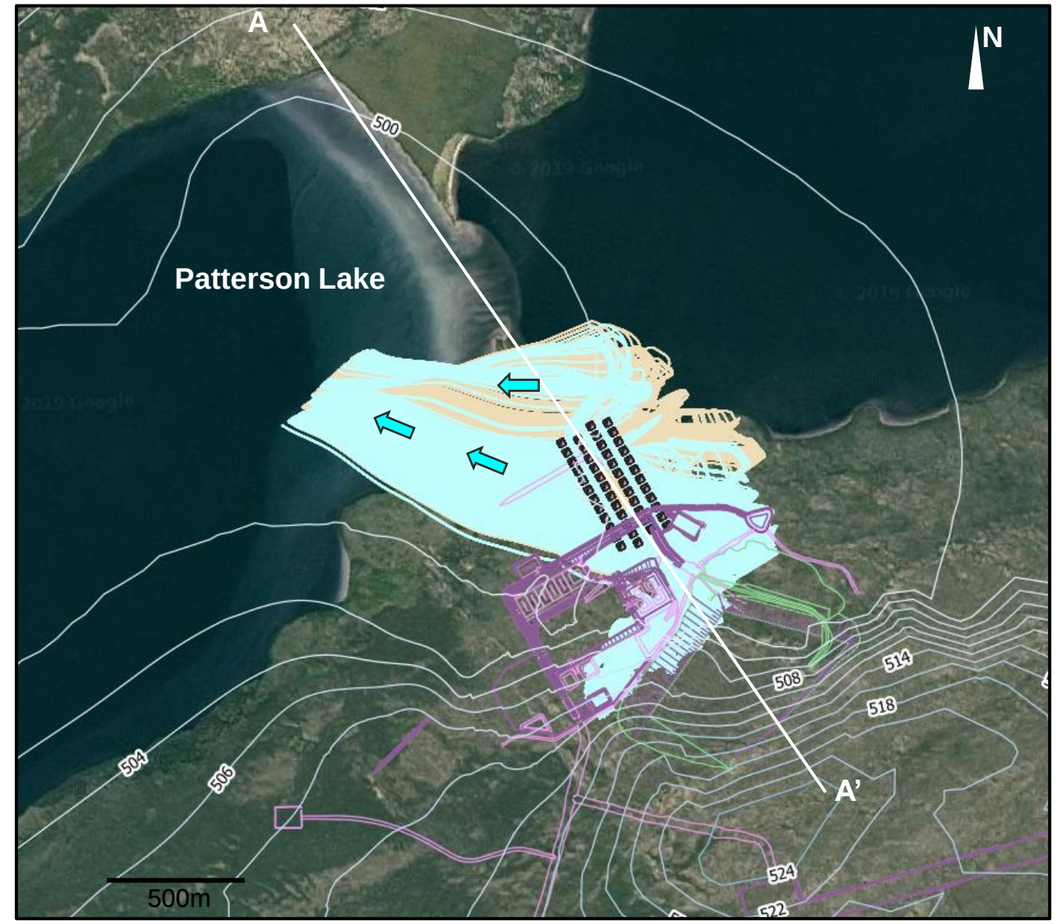
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SIMULATED GROUNDWATER DRAWDOWN AT THE END OF OPERATIONS

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	0	A-19





LEGEND

- SIMULATED GROUNDWATER HEAD CONTOUR – SECTION VIEW (m)
- SIMULATED GROUNDWATER HEAD CONTOUR – PLAN VIEW (m)
- SIMULATED GROUNDWATER FLOW PATHWAY (UGTMF)
- SIMULATED GROUNDWATER FLOW PATHWAY (BACKFILL)
- BASEMENT ROCK
- PALEOWEATHERED BASEMENT ROCK
- SANDSTONE
- DEVONIAN ROCK
- CRETACEOUS ROCK
- LOWER OVERBURDEN (TILL)
- UPPER OVERBURDEN

Notes:

1) Arrows indicate direction of groundwater flow pathway
2) Simulated groundwater head contours reflect long-term post-closure conditions.

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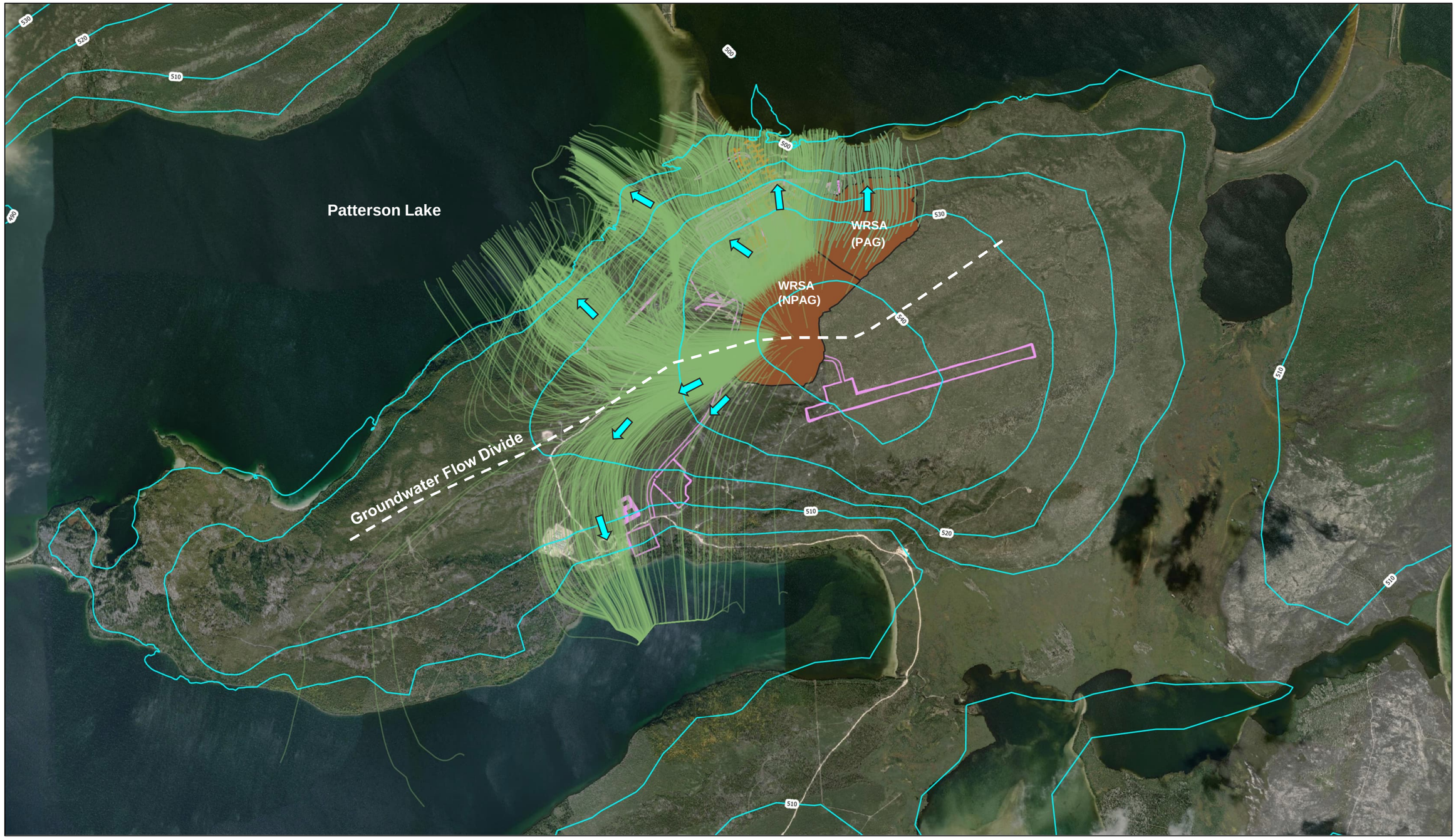
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
PARTICLE TRACKING ANALYSIS – GROUNDWATER FLOW PATHWAYS FOR UNDERGROUND SOURCES

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	0	A-20a



LEGEND

- SIMULATED GROUNDWATER FLOW CONTOUR – PLAN VIEW (m)
- SIMULATED GROUNDWATER FLOW PATHWAY
- SURFACE WASTE FACILITIES (SOURCE AREA)
- SURFACE MINE INFRASTRUCTURE

Notes:

1) Arrows indicate direction of groundwater flow pathway
2) Simulated groundwater head contours reflect long-term post-closure conditions.

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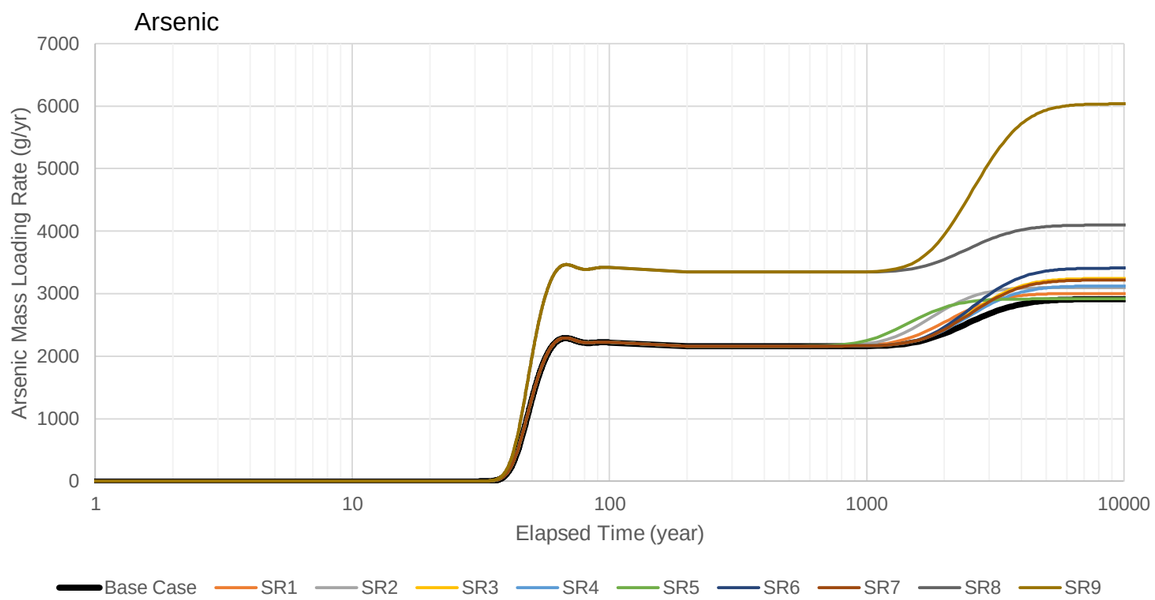
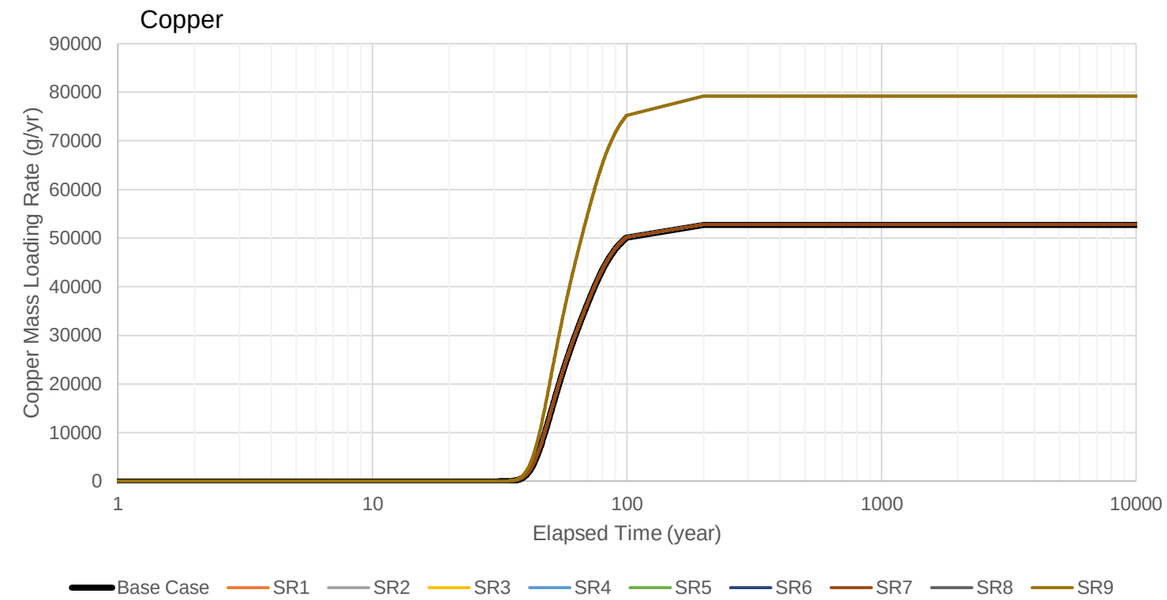
YYYY-MM-DD	2024-11-07
PREPARED	AC
DESIGN	NB
REVIEW	JL
APPROVED	JL

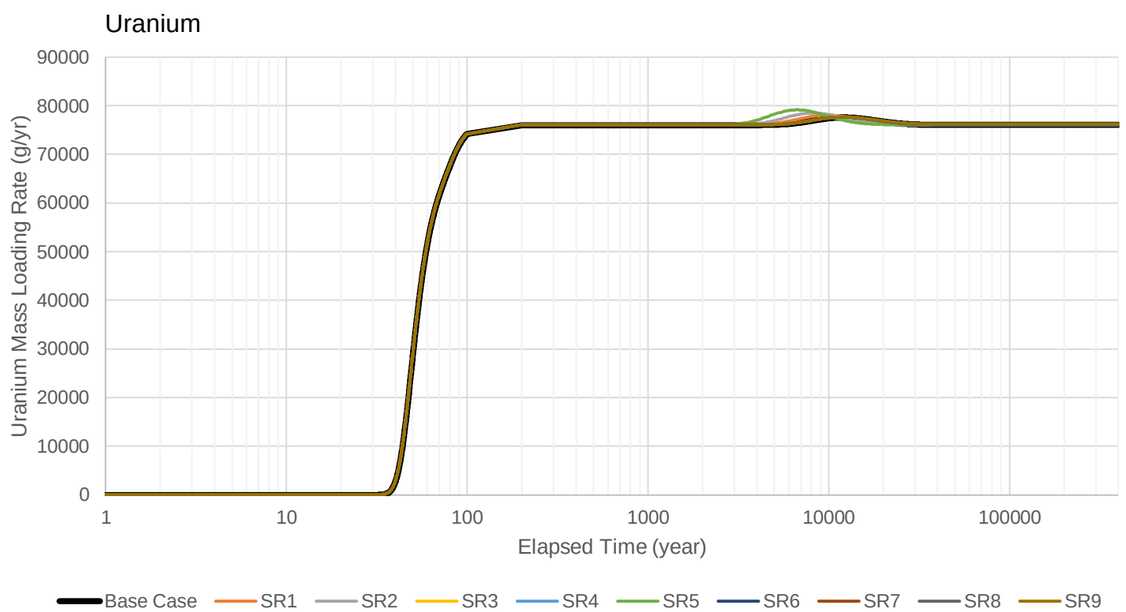
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

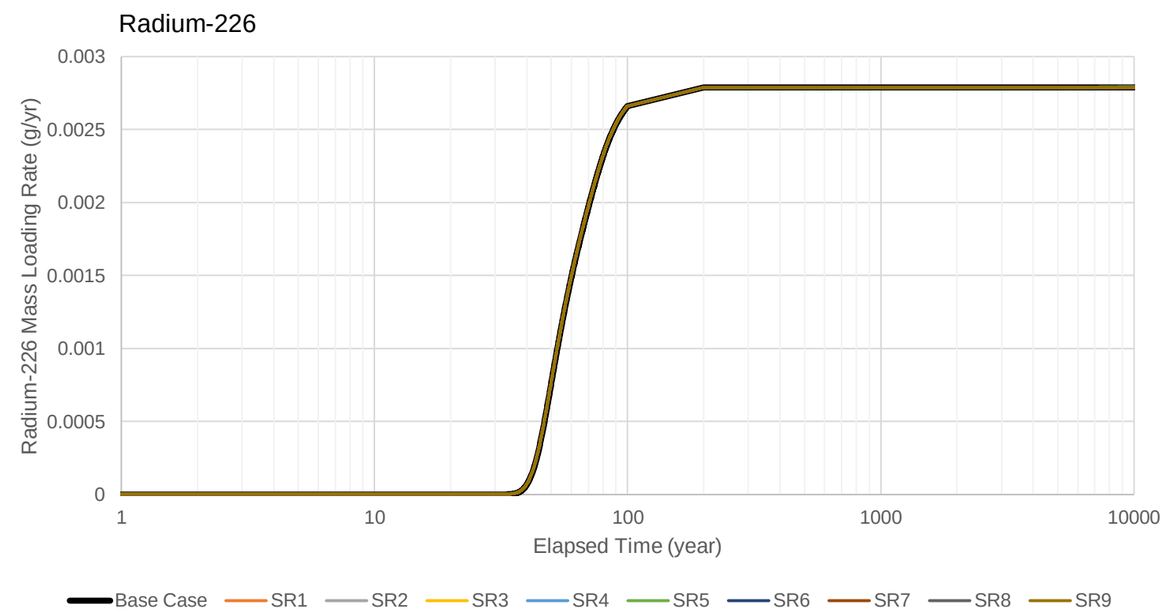
TITLE
PARTICLE TRACKING ANALYSIS – GROUNDWATER FLOW PATHWAYS FOR ABOVE GROUND SOURCES

PROJECT No.	PHASE	Rev.	FIGURE
CA00226400.3030		0	A-20b









CLIENT
NexGen Energy Ltd.

CONSULTANT
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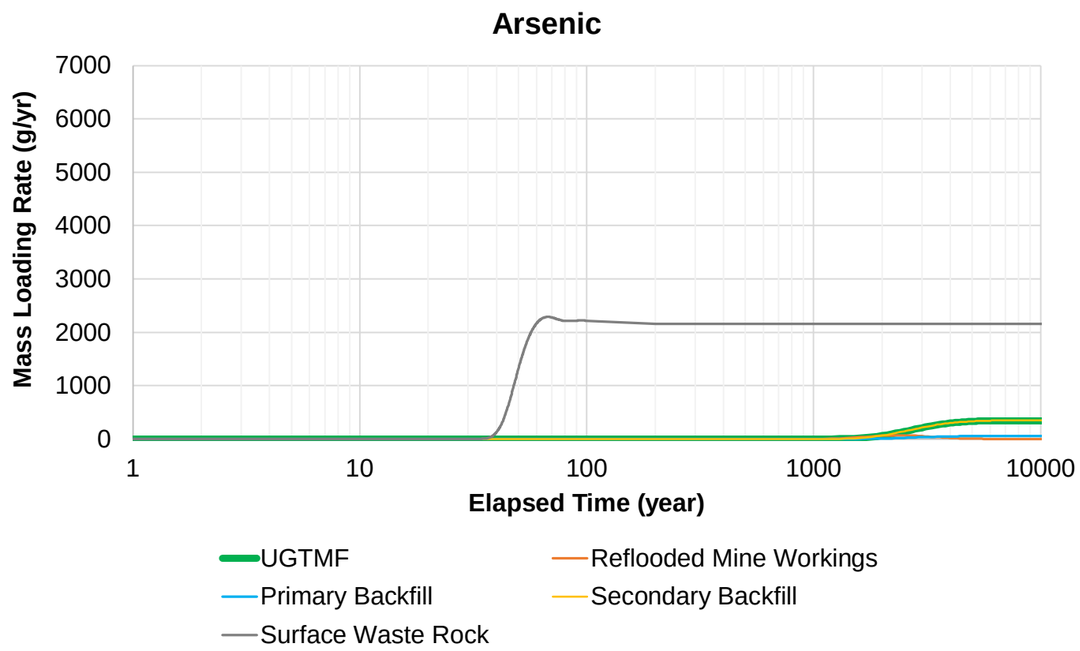
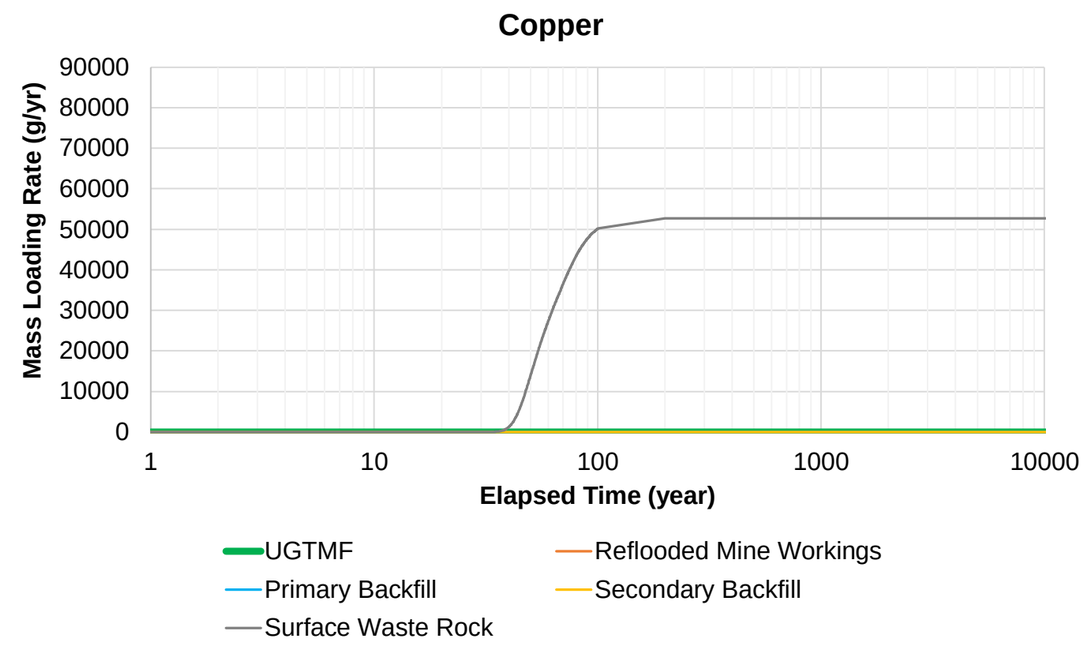
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

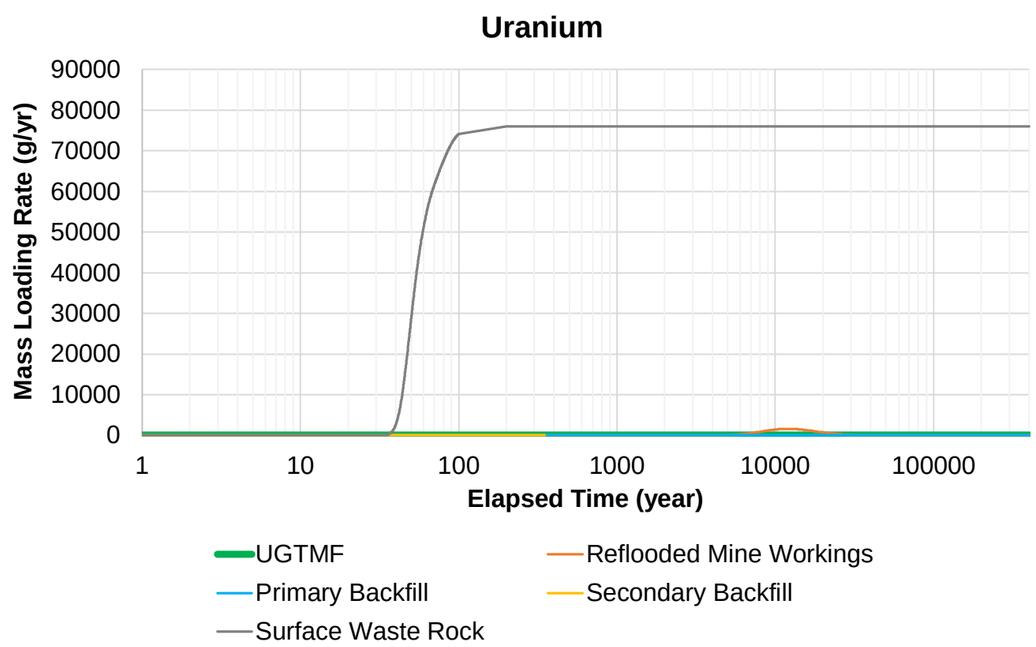
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

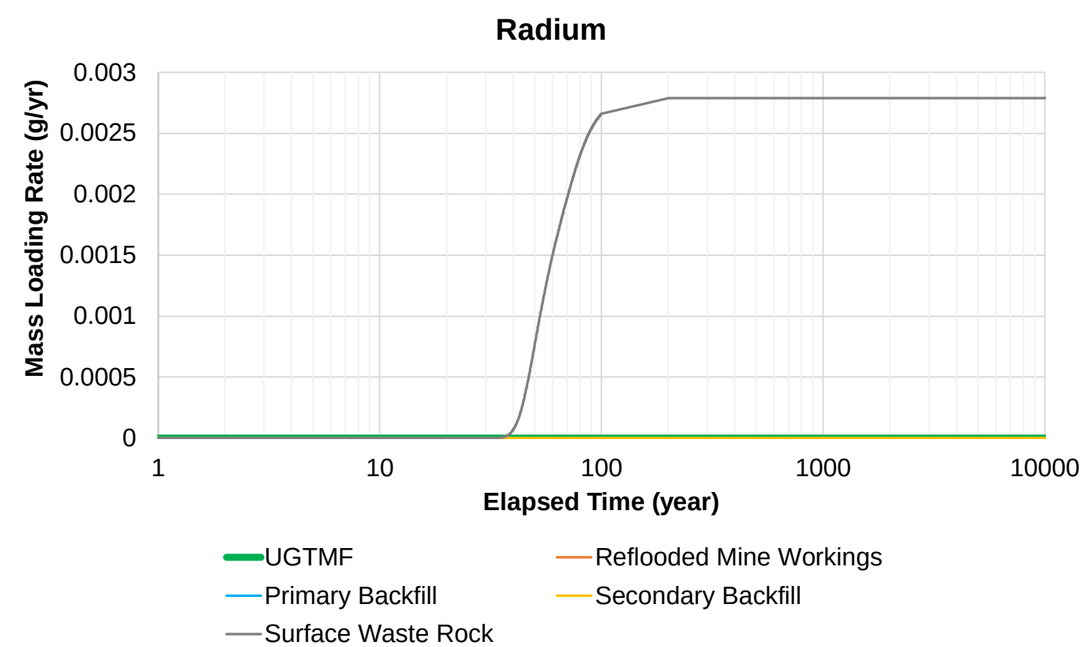
TITLE
SIMULATED MASS LOADING RATES TO PATTERSON LAKE – PLOTS FOR SELECT SOLUTES

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3100.3130	0	A-21a









CLIENT
NexGen Energy Ltd.

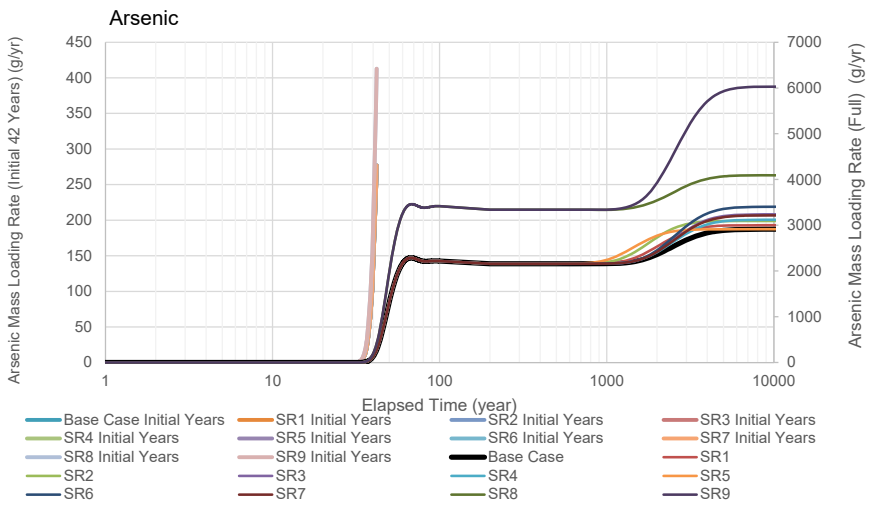
CONSULTANT
wsp

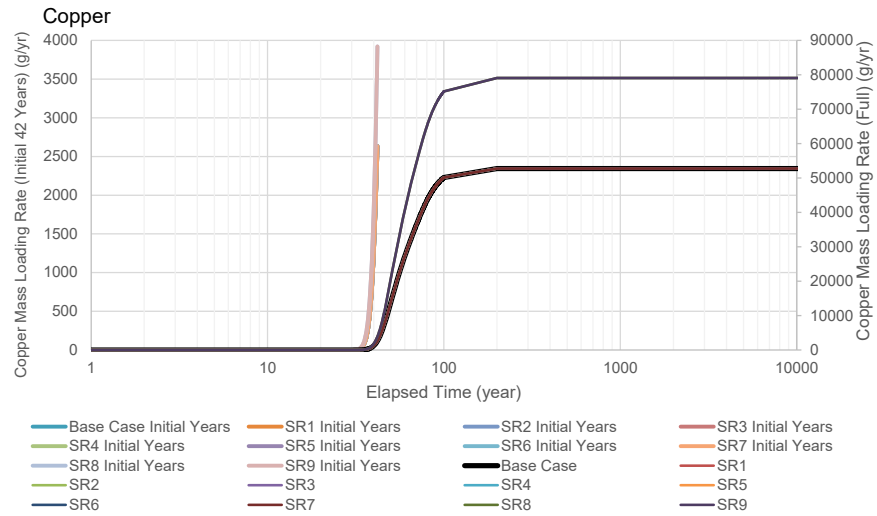
YYYY-MM-DD	2024-04-16
PREPARED	RS
DESIGN	RS
REVIEW	JL
APPROVED	JL

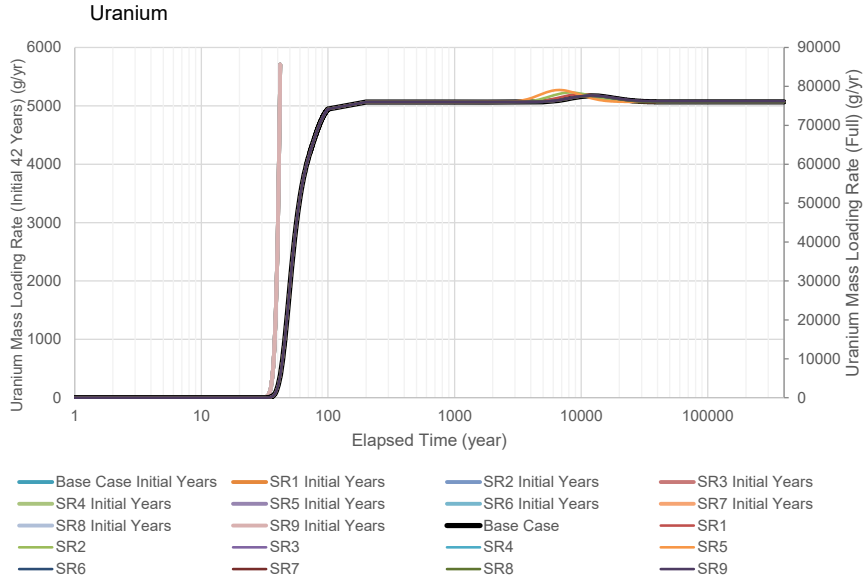
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

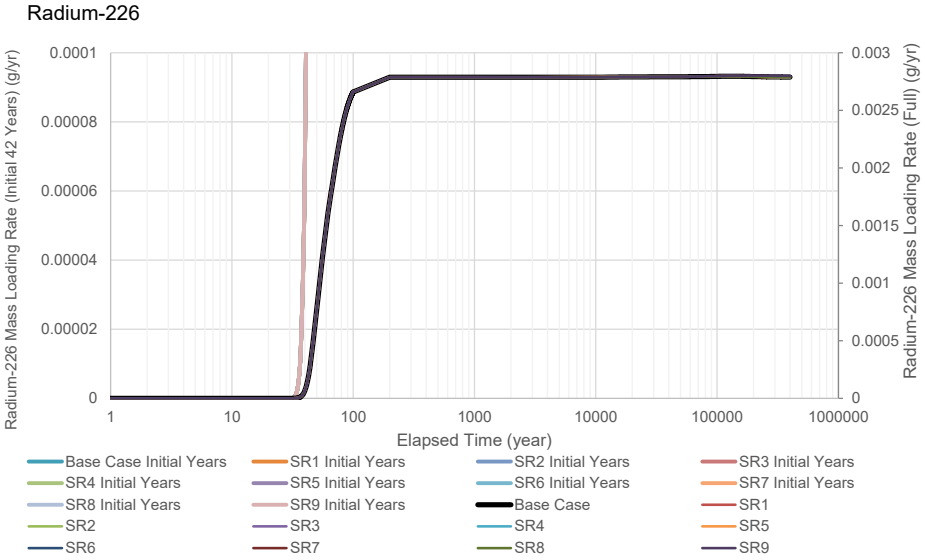
TITLE
SIMULATED MASS LOADING RATES BY SOURCE TO PATTERSON LAKE – PLOTS FOR SELECT SOLUTES BY SOURCE (BASE CASE)

PROJECT No.	PHASE	Rev.	FIGURE
22522691	3100.3130	0	A-21b









Note: Initial Years Correspond to Years 0 to 42.

CLIENT
NexGen Energy Ltd.

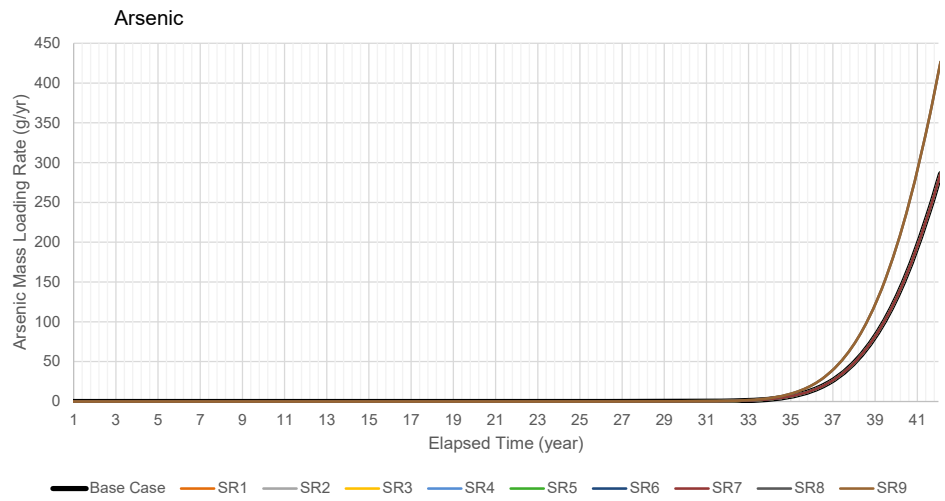
CONSULTANT
wsp

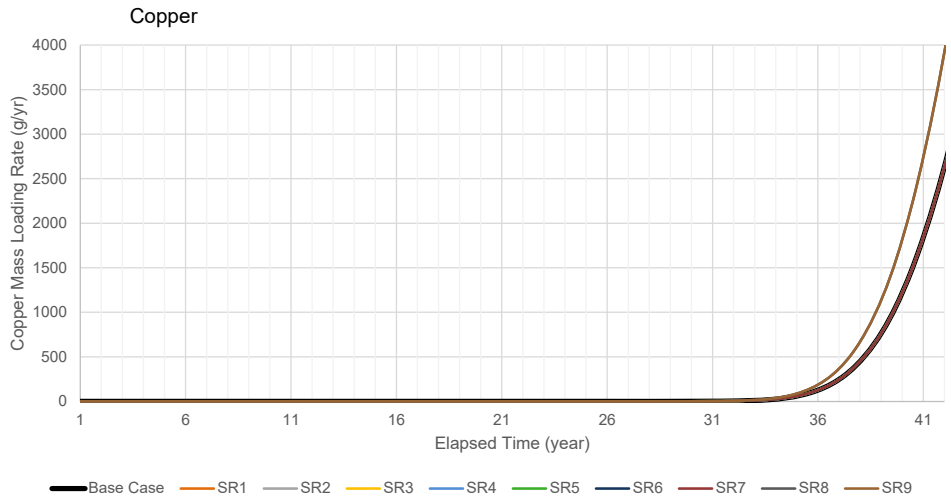
YYYY-MM-DD	2023-05-03
PREPARED	NB
DESIGN	NB
REVIEW	JL
APPROVED	MT

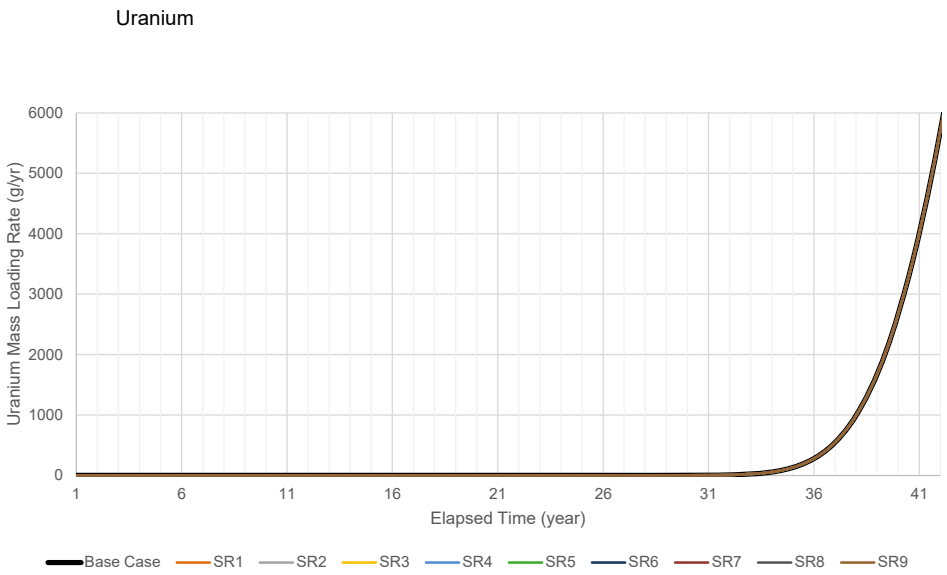
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

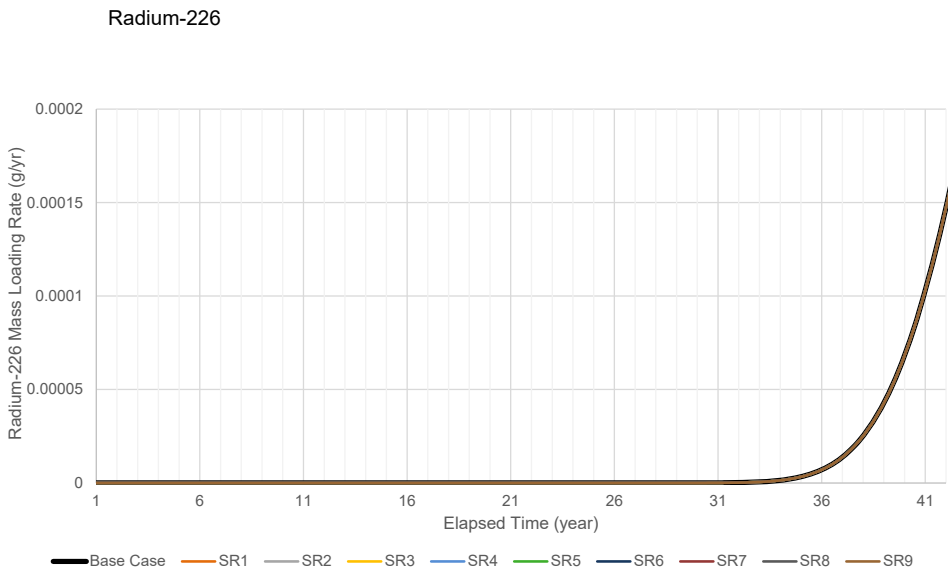
TITLE
SIMULATED MASS LOADING RATES TO PATTERSON LAKE – PLOTS FOR SELECT SOLUTES – FULL SIMULATION PERIOD AND INITIAL 42 YEARS

PROJECT No.	PHASE	Rev.	FIGURE
20144150		0	A-22









CLIENT
NexGen Energy Ltd.

CONSULTANT
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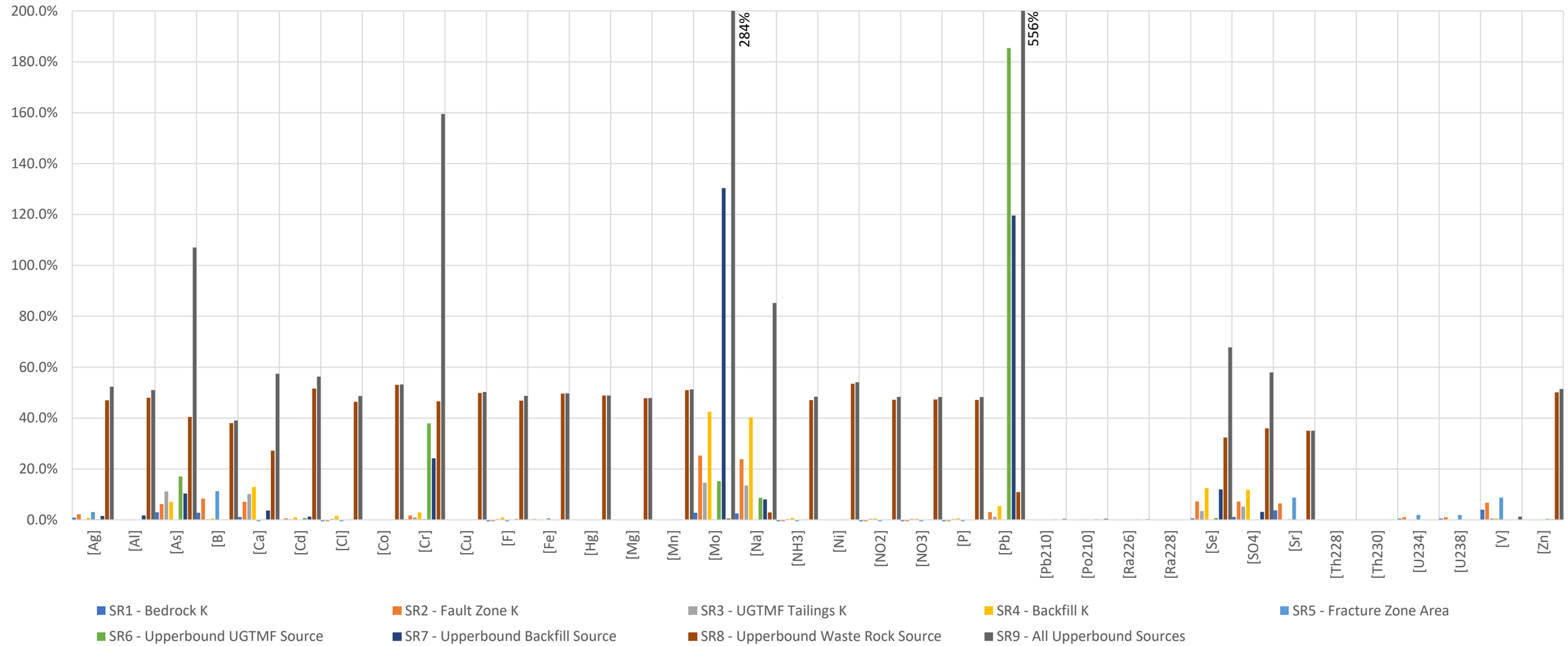
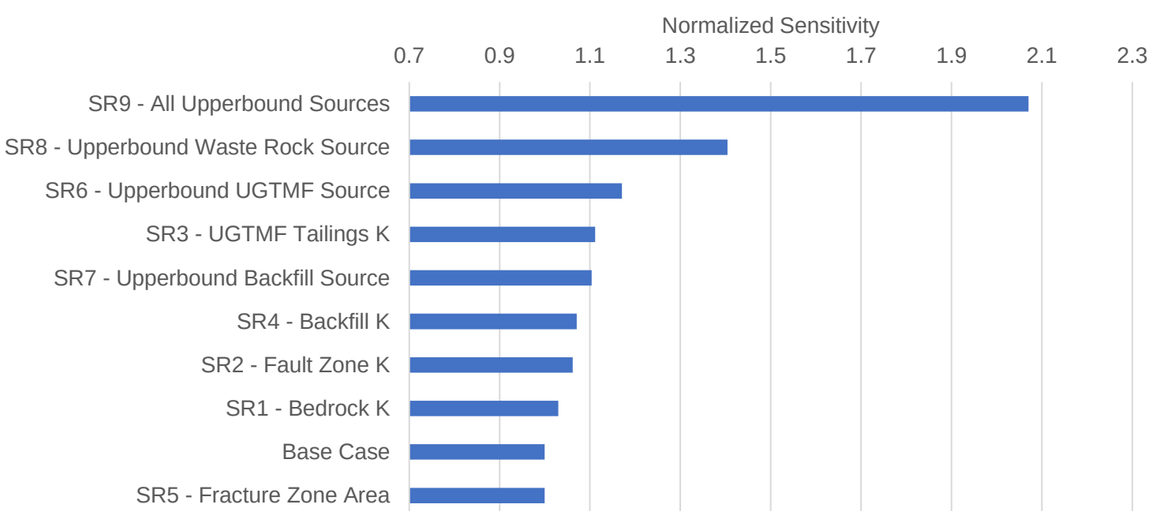
YYYY-MM-DD	2023-05-03
PREPARED	NB
DESIGN	NB
REVIEW	JL
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SIMULATED MASS LOADING RATES TO PATTERSON LAKE – PLOTS FOR SELECT SOLUTES FOR INITIAL 42 YEARS

PROJECT No.	PHASE	Rev.	FIGURE
20144150		0	A-23





CLIENT
NexGen Energy Ltd.

CONSULTANT
wsp

YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SOLUTE TRANSPORT MODEL – RESULTS OF SENSITIVITY SIMULATIONS

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	0	A-24