OSISKO DEVELOPMENT

CARIBOO GOLD PROJECT

SECTION 7.5: GROUNDWATER

October 2022

OSISKO DEVELOPMENT

Cariboo Gold Project

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ABBREVIATIONS

Terminology used in this document has been defined where it is first used, while the following list has been presented to assist readers that choose to review only portions of the document.

Abbreviation	Description
°C	degrees Celsius
AE	Associated Engineering
ARD	Acid Rock Drainage
BBA	BBA Engineering Ltd.
BC	British Columbia
BCEAA	*British Columbia Environmental Assessment Act*
BFA	Bulk Fill Area
BGM	Barkerville Gold Mines Ltd.
BMP	Best Management Practice
cm	centimetre
cm/s	centimetre per second
CSR	Contaminated Sites Regulation
DW	drinking water
ECCC	Environment and Climate Change Canada
EA	Environmental Assessment
EAC	Environmental Assessment Certificate
EEM	environmental effects monitoring
El.	elevation
EMA	*Environmental Management Act*
EMLI	Ministry of Energy, Mines and Low Carbon Innovation (BC)
EMP	Environmental Management Plan
ENV	Ministry of Environment and Climate Change Strategy (BC) – formerly Ministry of Environment
ESA	Environmental Site Assessment
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural development (BC)
FSTSF	Filtered Stack Tailings Storage Facility
GCDWQ	Guidelines for Canadian Drinking Water Quality
ha	hectare
Hatfield	Hatfield Consultants
HECMP	Hydrogeology Existing Conditions Monitoring Program
KCB	Klohn Crippen Berger Ltd.
km	kilometre
km^2	square kilometre
L/d	litres per day

Abbreviation	Description
LAA	Local Assessment Area
Ltd.	Limited
LSA	Local Study Area
m	metre
m/s	metres per second
m^3/day	cubic metre per day
m^3/s	cubic metre per second
masl	metres above sea level
MBBR	mix bed bioreactor
mbgs	metres below ground surface
MDMER	Metal and Diamond Mining Effluent Regulations
MEM	Ministry of Energy and Mines (BC)
mg/L	milligrams per litre
ML	Metal Leaching
mm	millimetre
mm/yr	millimetres per year
MZP	Main Zone Pit
N/A	not applicable
NPAG	non-potentially acid generating
NSCP	North Seepage Collection Pond
O&M	operations and maintenance
ODEX	Overburden Drilling Excentric
ODV	Osisko Development Corp.
Project	Cariboo Gold Project (proposed)
PTDL	Pressure transducer datalogger
QR Mill	Quesnel River Mill
QR Mine	Quesnel River Mine
QR TSF	Quesnel River Tailings Storage Facility
RAA	Regional Assessment Area
s	second
SDWQG	Source Drinking Water Quality Guideline
SDWQG-AO	Source Drinking Water Quality Guideline aesthetic objectives
SDWQG-MAC	Source Drinking Water Quality Guideline maximum allowable concentrations
SNC	SNC Lavalin Group Inc.
SSCP	South Seepage Collection Pond
SWRT	Single Well Response Test
SWS	Schlumberger Water Services
TDS	Total dissolved solids
TMF	Tailings Management Facility

Abbreviation	Description
TSF	Tailings storage facility
UCS	Unconfined compressive strength
USGPM	United States gallons per minute
VC	Valued Component
WRSF	waste rock storage facility

7.5 Groundwater

This section presents the effects assessment for the Groundwater Valued Component (VC) for the Cariboo Gold Project (the Project) as proposed by Osisko Development Corp. (ODV). The Groundwater VC has two subcomponents: Groundwater Quality and Groundwater Quantity. The purpose of this assessment is to evaluate the potential changes to Groundwater that may result from the Project.

Rationale for the selection of the Groundwater VC and its subcomponents were:

- Groundwater Quantity: The Project has the potential to alter groundwater levels and groundwater – surface water interaction within and surrounding the Project footprint during Construction, Operations, Closure, and Post-Closure due to excavation, dewatering activities, and mine flooding.
- Groundwater Quality: The Project has the potential to alter groundwater quality through the flooding of the underground and seepage from tailings and waste rock facilities.

The Groundwater VC is linked to (influences) the following VCs or chapters of the assessment: Surface Water (Section 7.4), Land and Resource Use (Section 7.11), and Human Health (Section 7.13).

7.5.1 Relevant Statutes, Policies and Frameworks

The Application Information Requirements or the Project, issued by the British Columbia (BC) Environmental Assessment Office in April 2021, outline the requirements of the Groundwater effects assessment to meet the requirements of the BC *Environmental Assessment Act* (2018).

Provincial and federal acts, regulations, and policies related to the Groundwater VC that are applicable to the Project are listed in Table 7.5-1.

Table 7.5-1 Applicable Provincial and Federal Acts, Regulations, and Policies related to Groundwater

Acts and Regulations	Description
BC Environmental Assessment Act (BCEAA; Government of BC, 2002a)	The BCEAA requires environmental assessments for reviewable projects that need an Environmental Assessment Certificate (EAC).
Environmental Management Act (EMA; Government of BC, 2003)	The EMA prohibits the introduction of waste to the environment unless the introduction of that waste is conducted in accordance with a permit, approval, order, or regulation (EMA Sections 6([2] and 6[3]). The requirement of the EMA is that *"a person must not introduce waste into the environment in such a manner or quantity as to cause pollution"* (EMA Section 6[4]). Pollution is defined in the EMA as *"the presence in the environment of substances or contaminants that substantially alter or impair the usefulness of the environment."*
Water Sustainability Act (Government of BC, 2016)	The right to use water in BC is vested in the provincial government. Use of groundwater in BC requires licensing, for which administrative responsibility lies with the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD), under the *BC Water Users' Communities Act* (Government of BC, 1996b).

Acts and Regulations	Description
Groundwater Protection Regulation (2016)	The Groundwater Protection Regulation ensures that activities related to wells and groundwater are performed in an environmentally safe manner. Under the *Water Sustainability Act* (presented above), the Groundwater Protection Regulation: • Regulates minimum standards for well construction, maintenance, deactivation, and decommissioning, and • Recognizes the types of qualified people certified to drill wells, install well pumps, and perform related services.
Mines Act (Government of BC, 1996c)	A permit under the *Mines Act* and Section 10 of its related Health Safety and Reclamation Code will be the key permit driving planning and approval for development. A mine plan and reclamation program will be submitted to the BC Ministry of Energy, Mines and Low-carbon Innovation (EMLI; for a major mine) or FLNRORD (for a minor mine) regional manager in accordance with the code that outlines the design, construction, operation, and closure parameters of the proposed project, as well as land uses, protection and reclamation plans, and other information that the FLNRORD determines relevant.
Policy for Metal Leaching (ML) and Acid Rock Drainage (ARD) at Mine Sites in British Columbia (Government of BC, 1998)	EMLI and the BC Ministry of Environment and Climate Change Strategy (ENV) are responsible for regulating ML/ARD. The policy for ML/ARD at Mine Sites in BC is a joint policy which allows for protocol agreement and posting of securities under the *Mines Act*.
Fisheries Act (Government of Canada, 1985)	The *Fisheries Act* is a federal Act that protects fish and fish habitat. Section 35 prohibits the harmful alteration, disruption, or destruction of fish habitat, which is defined as water frequented by fish and any other areas on which fish depend directly or indirectly to carry out their life process. Section 36 of the Act prohibits the deposit of a deleterious substance into waters frequented by fish, unless authorized by regulations under the *Fisheries Act* or other federal legislation. Section 36 applies to the point of discharge.
Metal and Diamond Mining Effluent Regulations (MDMER; Government of Canada, 2002)	The MDMER under the *Fisheries Act* permits the deposit of deleterious substances to an aquatic receiving environment provided that the effluent pH is within a defined range, concentrations of the MDMER deleterious substances are within prescribed limits, and the effluent is not acutely lethal to Rainbow Trout or *Daphnia magna*. To assess the adequacy of the effluent regulations, the MDMER requires proponents to conduct environmental effects monitoring (EEM) to evaluate the potential effects of effluent on fish, fish habitat, and use of fisheries resources. Effluent will be monitored for the eight deleterious substances defined in the MDMER. However, it is noted that cyanide and radium-226 are not considered to be parameters of interest at the Mine Site; cyanide is not used as a process reagent and no radiological mineralogy occurs within the deposits in the Project area. Cyanide is included in the model projections and water quality assessment for the Quesnel River Mill.

Acts and Regulations	Description
Drinking Water Protection Act (2001)	The *Drinking Water Protection Act* and Drinking Water Protection Regulation replaces the former Safe Drinking Water Regulation. The *Drinking Water Protection Act* covers all water systems other than single-family dwellings (and systems excluded through the regulation). The Act sets out certain requirements for drinking water operators and suppliers to ensure the provision of safe drinking water to their customers. The requirements specify: • Water system construction proposals must be approved by Public Health Engineers • Water system operators must operate their systems in compliance with the requirements of the Act through operating permits, which may contain specific conditions and are set and approved by the Health Authority Drinking Water Officer • Minimum water treatment and water quality standards are met, and monitoring and testing carried out, as required • Water suppliers must have microbiological samples analyzed by a laboratory which has been approved by the Provincial Health Officer • Operators of water systems serving more than 500 individuals must be certified as operators through the Environmental Operators Certification Program • Public notification must be made in case of water quality problems • Prohibitions against contaminating drinking water or tampering with system • Operating permits and requirements for water supply systems

Notes; BCEAA = *BC Environmental Assessment Act*; BC = British Columbia; EAC = Environmental Assessment Certificate; EMA = *Environmental Management Act*; FLNRORD = BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development; EMLI = BC Ministry of Energy, Mines and Low Carbon Innovation; ENV = BC Ministry of Environment and Climate Change Strategy (ENV); MDMER = Metal and Diamond Mining Effluent Regulations; EEM = environmental effects monitoring

Standard operating procedures were used in the collection of groundwater quantity and quality data according:

- Manual of British Columbia Hydrometric Standards (RISC, 2018);
- Manual of Standard Operation Procedures for Hydrometric Surveys in British Columbia (RISC, 1998);
- Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators (ENV, 2016), and
- BC Field Sampling Manual (ENV, 2013, 2020a).

Regulatory guidance that informed the approaches to assessment were as follows:

- Best Achievable Technology Fact Sheet (ENV, 2015); and
- BC Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Development Activities (ENV, 2012a).

Federal and provincial guidelines were used in the groundwater effects assessment. These science-based guidelines were as follows:

- Source Drinking Water Quality Guidelines (SDWQG; ENV, 2020b);
- Guidelines for Canadian Drinking Water Quality (GCDWQ; Health Canada, 2021);
- BC Contaminated Sites Regulation (B.C Reg 375/96);
- BC Guidance Document for Determining Groundwater at Risk of Containing Pathogens Version 3 September 2017, Health Protection Branch Ministry of health (BC Ministry of Health, 2017);
- Metal and Diamond Mining Effluent Regulations (SOR/2002-222); and
- Policy for Metal Leaching (ML) and Acid Rock Drainage (ARD) at Mine Sites in BC (Government of BC, 1998).

7.5.2 Assessment Boundaries

This section describes the methods used in identifying spatial, temporal, administrative, and technical boundaries for the assessment of the Groundwater VC.

The study areas adopted for the Project define the spatial boundaries within which the environmental effects of the Project are considered. The study areas encompass the physical works and activities of the Project where effects are expected or likely to occur.

The Transportation Routes and Transmission Line were not included in the study areas for Groundwater based on the assumption that construction of the Transmission Line will be appropriately managed such that water quality effects will not occur and that limited interactions are anticipated during operation of these components and groundwater. Further, water-related infrastructure for the Transportation Routes and Transmission Line will be limited to flow-through stream crossings, which will result in negligible changes to streamflow and therefore limited interaction with groundwater.

7.5.2.1 Spatial Boundaries

The spatial boundaries for assessment of the Groundwater VC consist of the Local Assessment Area (LAA) and the Regional Assessment Area (RAA) associated with each of the Project components. The terms “Mine Site” and “Quesnel River Mill (QR Mill)” refer to these portions of the LAA for the Groundwater effects assessment (i.e., these terms are used to refer to the Project components as well as the LAA buffers around them). Table 7.5-2 and Figure 7.5-1, Figure 7.5-2, and Figure 7.5-3 identify the spatial boundaries for Groundwater.

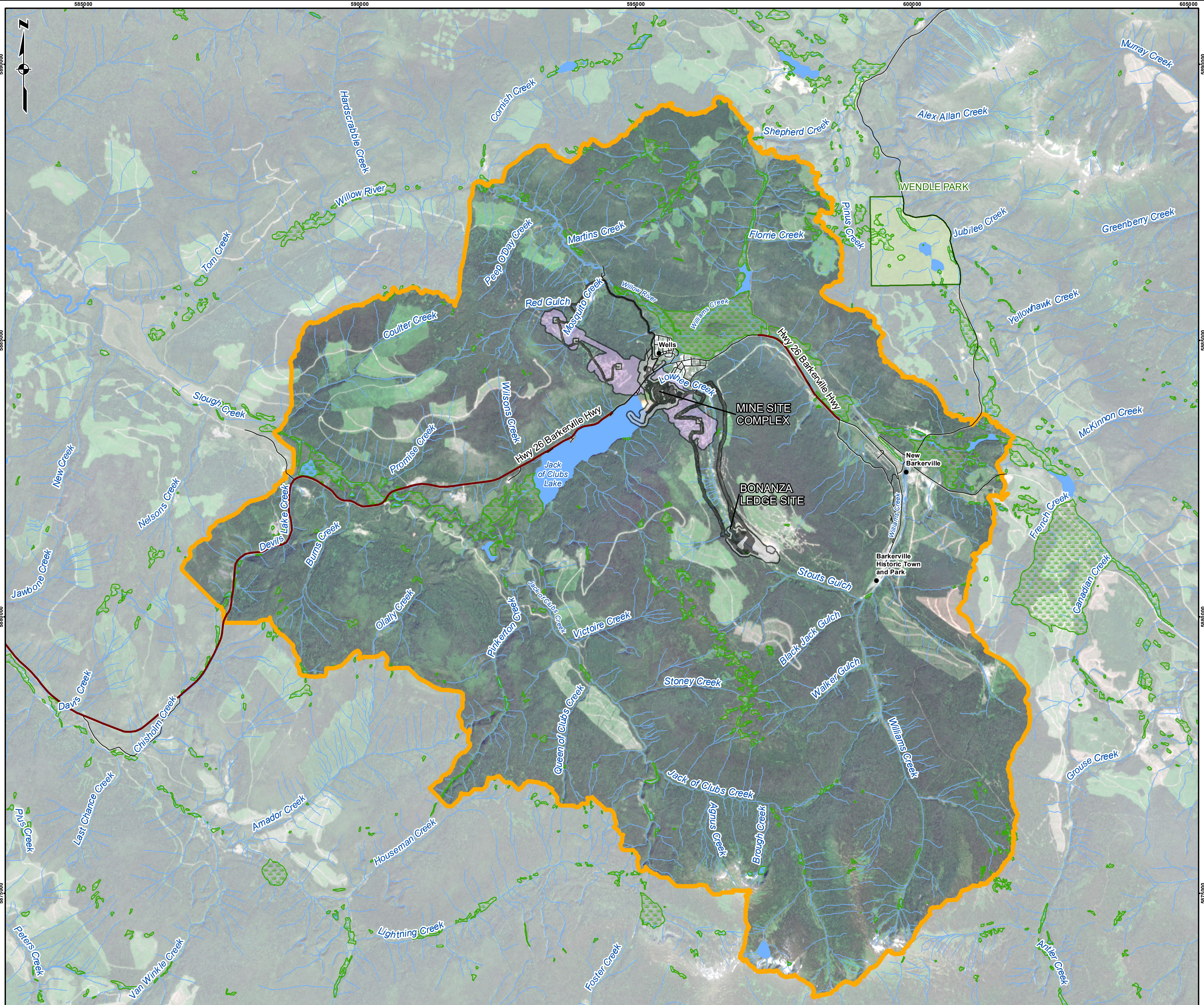
The LAAs were established to encompass the footprints of the physical infrastructure of the Project, and surrounding areas, with the potential to experience direct and indirect effects to Groundwater due to an interaction with a Project component(s) or physical activity.

The RAAs were established to provide a regional context for the assessment of Project effects and have been selected to be consistent with Surface Water RAAs. Generally, each RAA includes the area within which the residual effects of the Project may combine with the effects of other projects and activities, resulting in a cumulative effect.

Table 7.5-2 Spatial Assessment Boundaries – Groundwater

Boundary	Component	Extent
Local Assessment Area	Mine Site	The groundwater LAA in the Mine Site area is coincident with the surface water LAA, given the potential for changes in groundwater flows to affect baseflows and surface water quality. The LAA for the Mine Site includes the watersheds of the Willow River and Slough Creek (142 km^2 or 14,200 ha) associated with the Wells Mine Site.
	QR Mill	The groundwater LAA in the QR Mill area was delineated to be generally coincident with the surface water LAA, given the potential for changes in groundwater flows to affect baseflows and surface water quality and is 9 km^2 (900 ha). However, the West Unnamed Creek watershed is outside of the area of influence for groundwater changes and is not included in the groundwater LAA for the QR Mill.
	Transmission Line	Not applicable
	Transportation Routes	Not applicable
Regional Assessment Area	Mine Site	The groundwater RAA is the same as the surface water RAA. The RAA for the Mine Site is an 875 km^2 (87,500 ha) drainage area of the Willow River at the point immediately upstream of its confluence with Stephanie Creek.
	QR Mill	The groundwater RAA is the same as the surface water RAA. The RAA for the QR Mill consists the drainage area of the Quesnel River, upstream of the confluence with Beaver Creek (459 km^2 or 45,900 ha). The Surface Footprint and the QR Mill LAA are part of the Rudy Creek watershed. The RAA represents the Quesnel River watershed just upstream of the confluence with Rudy Creek to upstream of the confluence with Beaver Creek.
	Transmission Line	Not applicable
	Transportation Routes	Not applicable

Notes: LAA = Local Assessment Area; km^2 = square kilometre; ha = hectare; QR Mill = Quesnel River Mill; RAA = Regional Assessment Area



LEGEND

- HYDROGEOLOGY LOCAL ASSESSMENT AREA
- PROPOSED INFRASTRUCTURE LAYOUT
- PROPOSED UNDERGROUND FOOTPRINT
- HIGHWAY
- ROAD
- WATERCOURSE
- WATERBODY
- WETLAND
- PARK/PROTECTED AREA

REFERENCE(S)
1. WATER FEATURES, ROADS, AND PARK/PROTECTED AREAS OBTAINED FROM THE B.C. MINISTRY OF FORESTS, LAND AND NATURAL RESOURCE OPERATIONS.
2. CONTOUR DATA OBTAINED FROM THE PROVINCE OF BC TRIM DATASET.
3. PROJECT AREA PROVIDED BY BGM.
4. IMAGERY (2020) PROVIDED BY BGM.

NAD83 CSRS
UTM ZONE 10N

1,500 0 1,500
1:70,000 METRES

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CARIBOO GOLD PROJECT

GROUNDWATER - MINE SITE LOCAL ASSESSMENT AREA

REV.	DESCRIPTION	DATE	INITIALS
0	FINAL - APPROVED	2021-07-15	J.L.
0	FINAL - REVIEWED	2021-07-15	D.C.
0	FINAL	2021-07-15	C.C.
A	DRAFT	2022-08-25	J.P.

PROJECT NO.	PHASE	REV.	FIGURE
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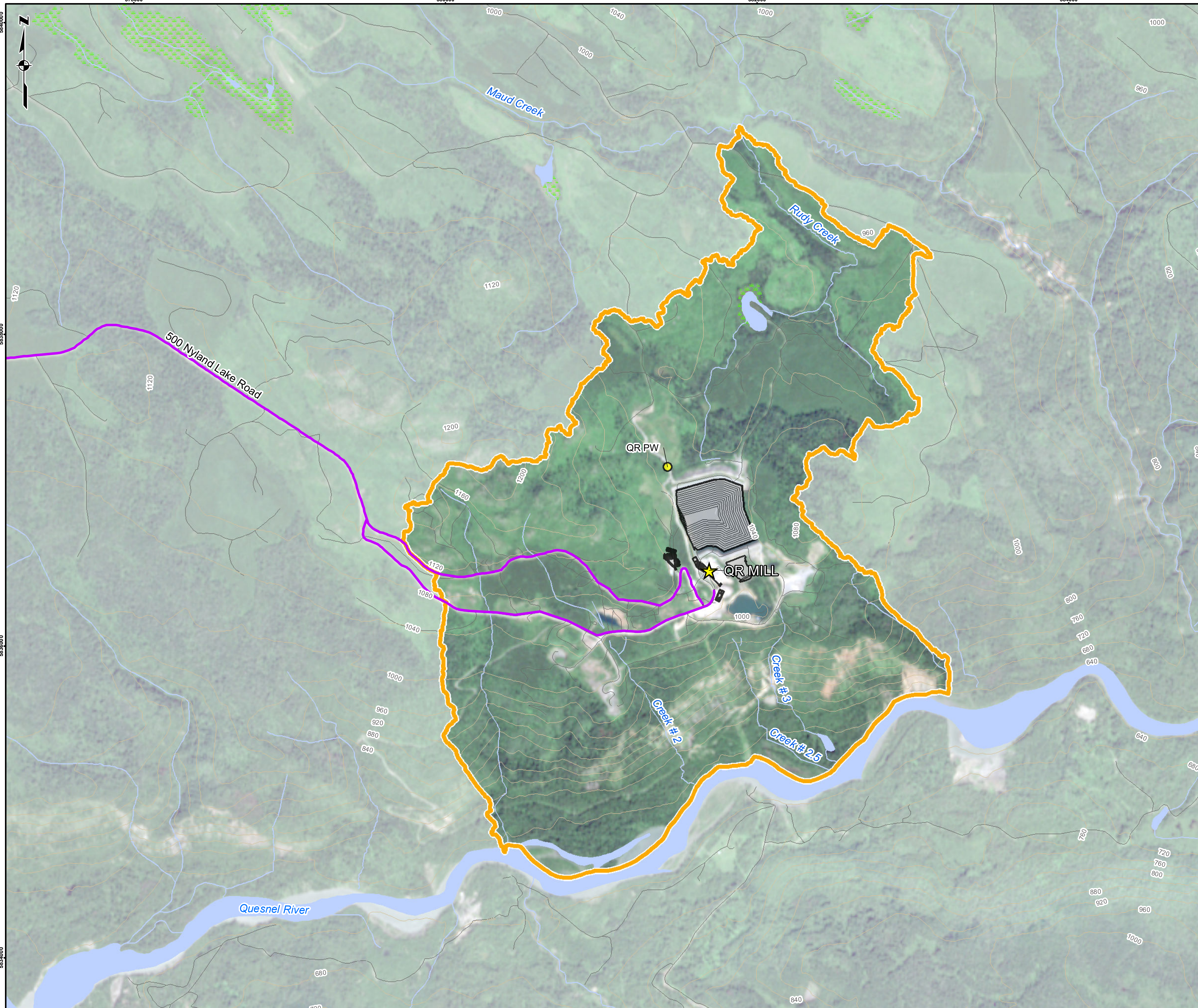

LEGEND

- HYDROGEOLOGY LOCAL ASSESSMENT AREA
- PROPOSED INFRASTRUCTURE LAYOUT
- TRANSPORTATION ROUTES
- ROAD
- CONTOUR (20 m)
- WATERCOURSE
- WETLAND
- WATERBODY
- QR MILL
- POTABLE WATER WELL

REFERENCE(S)

1. WATER FEATURES AND ROADS OBTAINED FROM THE B.C. MINISTRY OF FORESTS, LAND AND NATURAL RESOURCE OPERATIONS.
2. CONTOUR DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
3. PROJECT AREA AND IMAGERY (2020) PROVIDED BY BGM.

NAD83 CSRS
UTM ZONE 10N

500 0 500
1:25,000 METRES

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CARIBOO GOLD PROJECT

GROUNDWATER - QR MILL LOCAL ASSESSMENT AREA

REV.	DESCRIPTION	DATE	INITIALS
0	FINAL - APPROVED	2021-07-15	J.L.
0	FINAL - REVIEWED	2021-07-15	D.C.
0	FINAL	2021-07-15	C.C.
A	DRAFT	2021-07-15	J.P.

PROJECT NO.	PHASE	REV.	FIGURE
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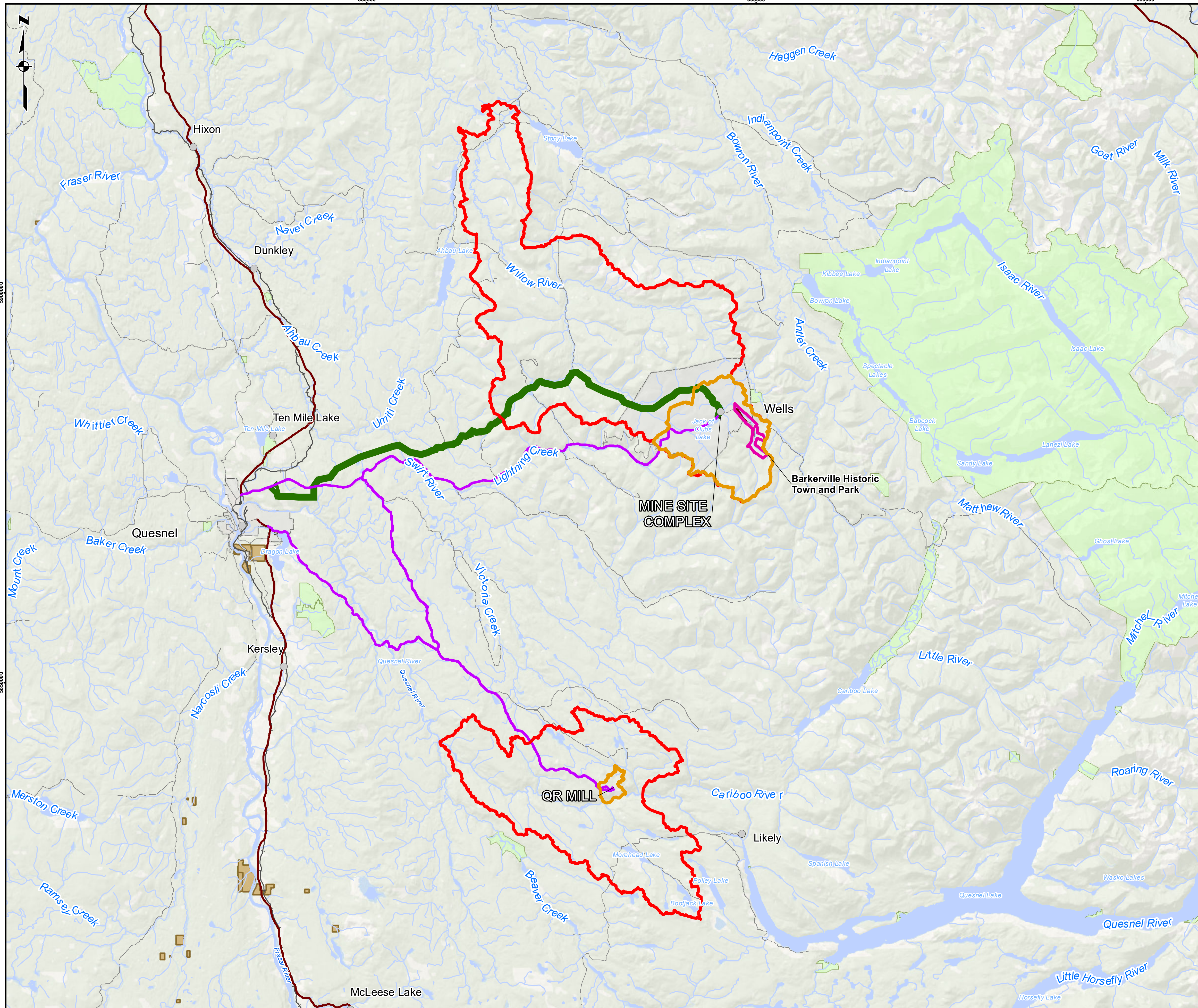

LEGEND

- HYDROGEOLOGY REGIONAL ASSESSMENT AREA
- HYDROGEOLOGY LOCAL ASSESSMENT AREA
- TRANSMISSION LINE ROUTE
- TRANSPORTATION ROUTES
- TOWN
- MUNICIPALITY BOUNDARY
- BARKERVILLE HISTORIC TOWN AND PARK
- INDIAN RESERVE
- PARK/PROTECTED AREA
- WATERBODY
- WATERCOURSE
- HIGHWAY
- ROAD
- RAILWAY

REFERENCE(S)

1. WATER FEATURES, TRANSPORTATION FEATURES OBTAINED FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
2. CITIES/TOWNS, INDIAN RESERVES AND PARK/PROTECTED AREAS OBTAINED FROM THE B.C. MINISTRY OF FORESTS, LANDS, NATURAL RESOURCE OPERATIONS AND RURAL DEVELOPMENT.
3. BASE SOURCE: ESRI, GARMIN, GEBCO, NOAA NGDC, AND OTHER CONTRIBUTORS.

NAD83 CSRS
UTM Zone 10N

0 10 20
1:500,000 KILOMETERS

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CARIBOO GOLD PROJECT

GROUNDWATER - REGIONAL ASSESSMENT AREAS

REV.	DESCRIPTION	DATE	INITIALS
0	FINAL - APPROVED	2021-07-15	J.L.
0	FINAL - REVIEWED	2021-07-15	D.C.
0	FINAL	2021-07-15	C.C.
A	DRAFT	2021-06-11	J.P.

PROJECT NO.	PHASE	REV.	FIGURE
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7.5.2.2 Temporal Boundaries

The temporal boundaries for the Groundwater effects assessment cover the life of the Project through the Construction (1 year), Operations (16 years), Closure (2 years), and Post-Closure Phases (10 years or more; Section 1.5.1, Project Phases). The Construction, Operations, Closure, and Post-Closure (active care) Phases of the Project include components and activities that could interact with and affect Groundwater present within the Mine Site and QR Mill LAAs; however, environmental monitoring of Groundwater will also be required during the Post-Closure (passive care) Phase.

7.5.2.3 Administrative and Technical Boundaries

Administrative boundaries refer to the limitations imposed on an environmental assessment (EA) by political, economic, or social constraints. No administrative boundaries were applied to Groundwater.

Technical boundaries refer to the constraints imposed on an EA by limitations in the ability to predict the potential effects of a project. Predicting the effects of a project and proposed mitigation measures on complex environmental systems is limited by our understanding of how Groundwater responds to various environmental changes. Limitations on prediction confidence include:

- Adequacy of groundwater quality and quantity baseline data due to uncertainty in the extent of existing developments (existing mine workings are flooded, which limits verification of extents);
- Limitations and assumptions surrounding the mine plan, backfilling of the mine workings, and the geochemical information of the backfill materials (paste and cemented rockfill) has implications for predicting groundwater quality at closure;
- Assumptions and limitations of the Analytical Assessment (Sections 7.5.3.1.1 and 7.5.3.1.2); and
- Uncertainty in the extent of the Wells Aquifer and groundwater discharge area within the aquifer from the flooded underground (existing and future).

The characterization of existing conditions for this assessment is described in Section 7.5.3.

7.5.3 Existing Conditions

This section provides an overview of the methodology for collecting baseline data and describes the existing conditions of groundwater within the Project LAAs and RAAs.

7.5.3.1 Information Sources

7.5.3.1.1 Traditional Knowledge

Information gathered during engagement activities, as well as information from the traditional land use studies were incorporated. Lhtako Dené Nation, Williams Lake First Nation, and Xatśūll First Nation provided non-confidential traditional knowledge and land use information for use in the effects assessment. A report prepared by DM Cultural Services Ltd. (2019) provides traditional land use information for the Lhtako Dené Nation and a report prepared by Landmark Resource Management Ltd. (2021) provides traditional land use information for the Xatśūll First Nation and Williams Lake First Nation.

The traditional use studies did not identify current, specific uses in the study areas (DM Cultural Services Ltd., 2019; Landmark Resource Management Ltd., 2021). Lhtako Dené Nation traditionally fished in Jack of Clubs Lake, but reportedly do not do so now because of contamination from historical industrial (i.e., mining) activity. Lhtako Dené Nation, Xatśūll First Nation, and Williams Lake First Nation note that quality and quantity of water is directly related to the health of plants, fish, birds, and other wildlife, and therefore the ability of their communities to hunt, fish, and gather plants.

7.5.3.1.2 Groundwater Quantity and Quality

Government reports, regional monitoring programs, and previous environmental assessments in the LAAs were reviewed to obtain relevant historical data. Specific sources of information related to existing groundwater quantity and quality are summarized in Sections 3.4.1 of the Hydrogeology Existing Conditions Report (Appendix 7.5-1). Information was incorporated from engagement activities, as well as information from the Technical Advisory Committee.

As part of the existing conditions reporting, the following information sources were reviewed:

- An initial site visit to visually assess the Project location and historical mining activities, identify existing groundwater monitoring infrastructure, and compile available data and reports from ODV's archives;
- Available geological maps and reports from public sources (i.e., Geological Survey of Canada, BC Geological Survey, and other provincial ministries);
- The BC provincial aquifer mapping database;
- Water well records from the provincial water well database;
- Monitoring well records from the Provincial Groundwater Observation Well Network;
- Void model and mapping of historical underground mine workings in the region provided by ODV;
- Exploration drillhole database and three-dimensional bedrock geology volumes provided by ODV Geology;
- Groundwater data and hydrogeological information generated in support of the Bonanza Ledge Phase II project, which is within the Mine Site LAA; and
- Groundwater data and hydrogeological information generated in support of QR Mill permit compliance monitoring.

A summary of reports reviewed for their relevance to the existing conditions study is presented in Table 7.5-3 below.

Table 7.5-3 Summary of Reports Reviewed for Hydrogeology Existing Conditions Study

Report Title	Report Authors	Date Published	Data/Information
District of Wells Water Quality Investigation	Associated Engineering (AE)	March 2004	Information on the District of Wells municipal well
Hydrogeologic Testing Data and Groundwater Monitoring Well Installation Report	Schlumberger Water Services (SWS)	November 2009	Borehole logs, monitoring well completion details, and hydraulic testing data for wells at the Bonanza Ledge Site and in the Island Mountain area
Risk Based Detailed Site Investigation, Wells Tailings Deposit, BC	SNC Lavalin Group Inc. (SNC)	March 2011	Borehole logs, monitoring well installation details, groundwater quality, hydraulic testing data, and stratigraphic cross-sections for the Wells Tailings Deposit
Quesnel River Mine (QR Mine) Project 2011 Tailings Dam Seepage Assessment	Klohn Crippen Berger Ltd. (KCB)	January 2012	Borehole logs, monitoring well installation details, and hydraulic testing data near the QR Mill Tailings Dam
QR Mine 2012 TSF Phase II Seepage Assessment	KCB	July 2015	Borehole logs, monitoring well installation details, and hydraulic testing data near the QR Mill Tailings Dam
Quesnel River Mine Hydrogeological Site Investigation Report	KCB	May 2017	Borehole logs, monitoring well installation details, and hydraulic testing data at the QR Mill
Cariboo Gold Project Tailings Management Design – Draft	KCB	September 2020	Tailings and water balance management details at the QR Mill
Gold Quartz Underground Exploration Project – Phase 1 Hydrogeological Assessment Report	Hatfield Consultants (Hatfield)	August 2018	Borehole logs, monitoring well installation details, and hydraulic testing at and above the proposed mine workings level of the Gold Quartz Underground Exploration Project – Phase 1 (precursor to the Cariboo Gold Project)
Consistency of Supplemental Field Investigation Data with Existing Hydrogeological Conceptual Model - Bonanza Ledge Phase II Permit Amendment	Hatfield	October 2018	Borehole logs, monitoring well installation details, hydraulic testing, and groundwater quality at the Bonanza Ledge Site
2018 Geotechnical Site Investigation	BBA Engineering Ltd. (BBA)	December 2018	Borehole logs, monitoring well installations, and hydraulic testing on the Wells Tailings Deposit
Barkerville Gold Mines Hydrogeological Feasibility Study	WSP	September 2019	Borehole logs, monitoring and pumping well installation details, pumping test analysis, and preliminary mine inflow numerical modelling in the Mine Site LAA
QR TMF Investigation	Golder	April 2020	Borehole logs and monitoring well installation details for preliminary FSTSF siting
QR Mill – Climate Existing Conditions Report (Appendix 7.4-5)	Golder	June 2021	Characterization of the baseline climate setting of the QR Mill LAA
Mine Site – Climate Existing Conditions Report (Appendix 7.4-4)	Golder	February 2021	Characterization of the baseline climate setting of the Mine Site LAA

Report Title	Report Authors	Date Published	Data/Information
QR Mill – Hydrology Existing Conditions Report (Appendix 7.4-2)	Golder	June 2021	Characterization of the baseline hydrology of the QR Mill LAA
Valley Zone Hydrogeological Investigation	Golder	November 2020	Borehole logs and monitoring well installation details in the Jack of Clubs Valley
Mine Site – Hydrology Existing Conditions Report (Appendix 7.4-1)	Golder	February 2021	Characterization of the baseline hydrology of the Mine Site LAA
Mine Site – Soil and Terrain Existing Conditions Report (Appendix 7.6-1)	Golder	June 2021	Characterization of the baseline soil conditions of the Mine Site LAA

Notes: BC = British Columbia; QR Mill = Quesnel River Mill; TSF = tailing storage facility; LAA = local study area; TMF = Tailings Management Facility; FSTSF = Filtered Stack Tailings Storage Facility.

7.5.3.2 Regional Overview and Historical Activities

This section summarizes the regional setting and past activities that may affect the Groundwater VC at the Mine Site and QR Mill. The Project is situated within the Quesnel Highlands, east of the Fraser Plateau and West of the Cariboo Mountains (Knight Piésold Ltd., 2000). This location is characterized as mountainous with numerous surface water systems.

The Project resides in the semi-arid to humid slopes of the Cariboo Mountains where there is no distinct wet or dry season. The area has moderate annual precipitation and high annual snow accumulation accompanied by the long cold winters. Although both the Mine Site and QR Mill are located relatively close to each other, climate data was obtained for the two locations to better represent the climate conditions and regional differences. The Environment and Climate Change Canada (ECCC) weather stations used for the Project include Barkerville Station (Climate ID: 1090660) for the Mine Site and Camille Lake Station (Climate ID: 1091235) for the QR Mill (ECCC, 2021a and 2021b).

At the Barkerville Station, the mean annual temperature between 1888 to 2017 ranged between a minimum of -3.8°C and a maximum of 7.4°C with a long-term mean of 1.8°C. The highest median temperature is from May through October, peaking in July or August. The mean annual total precipitation was 1,032 millimetres (mm), mean annual rainfall was 529 mm and, the mean annual snowfall was 503 mm. Annual peak monthly mean flows occur in spring, between April and June, during or soon after snowmelt.

At the Camille Lake Station, the mean annual temperature between 1981 to 2010 ranged between a minimum of -8.2°C and a maximum of 14.3°C, with a long-term mean of 3.7°C. The median monthly temperatures were lowest between December and February. The highest median monthly temperatures were recorded from March through October. The mean annual total precipitation was 536 mm, the mean annual rainfall was 369 mm, and the mean annual snowfall was 174 mm. Annual peak monthly mean flows occur in spring, between April and June, during or soon after snowmelt.

Conditions within the LAA have been heavily modified from a long history of mining in the region, with historical underground mine workings and open pits having the potential to act as hydrogeological controls, influencing groundwater levels and flows in the area.

7.5.3.2.1 Mine Site

The Mine Site is located on property owned by ODV and on Crown land. Both the private and Crown parcels have been previously disturbed by historical mining activities, which have resulted in new landscape features such as tailings mounds, waste rock piles, haul roads, and mining infrastructure. The majority of surface Project infrastructure at the Mine Site occurs southwest of the community of Wells on the Wells Historical Tailings Deposit (i.e., camp, Bulk Fill Area [BFA], sediment pond, etc.) and in the Lowhee Creek Valley (Bonanza Ledge Waste Rock Storage Facility [WRSF]). Planned underground infrastructure and mine workings are generally oriented along the strike of the ore deposit, approximately NNW-SSE from Mosquito Creek to Cow Mountain. The Mine Site LAA is presented in Figure 7.5-1.

Many of the valleys in the Mine Site LAA have been subjected to placer mining or hydraulic placer mining during the long history of mining in the area. Many valleys in the area were hydraulically mined, resulting in over steepened valley walls and extensive placer outwash deposits. The sediment composition of the placer outwash deposits varies by location, but most are expected to be predominantly coarse-grained and permeable.

Four historical underground mines, one historical open pit mine, and one active underground mine exist in the Mine Site LAA (Figure 7.5-4). The four historical underground mines, the Cariboo Gold Quartz Mine, Island Mountain Mine, Aurum Mine, and Mosquito Creek Mine, operated intermittently in the 1930s through to the 1980s, leaving over 180 km of mine workings beneath Island Mountain and Cow Mountain. These mine workings are now assumed to be reflooded to the approximate elevation of the valley floor, with the flooded water level elevation controlled by historical mine openings at surface. The Bonanza Ledge Mine, which is currently operated by ODV, is located 4 km southeast of the historic Cariboo Gold Quartz Mine. The small historical open pit mine, which is part of the Bonanza Ledge Mine, operated from 2014 to 2015 before mining proceeded underground. These mine workings are understood from ODV to be presently dewatered. Aurum Mine, located on the north side of Jack of Clubs Lake, across from the Cariboo Gold Quartz Mine, commenced milling in 1934 by Newmont Mining Corporation. Various exploration, development, and mining occurred around the Aurum Mine and Mosquito Creek Mine throughout the 1970s and 1980s.

ODV has identified openings in the underground workings that intersect the ground surface. Based on the voids model obtained from ODV, the historical mine workings beneath Island Mountain are not connected to the historical mine workings beneath Cow Mountain. Individual underground workings are assumed to be hydraulically connected across their extents (ODV is not aware of bulkheads being used to separate areas of the mine developments). This assumption is conservative for the future prediction of groundwater inflow management to the proposed and historical underground developments.

At several locations, groundwater seepage has been observed and sampled from near surface openings of the historical underground mine workings. Some mine openings flow consistently through the year (Mine Seepage 1 and Mine Seepage 2), whereas others flow only during the high flow period (Mine Seepage 3 and Mine Seepage 5). Diffuse groundwater seepage (i.e., not directly associated with mine openings) also emerges from the southern edge of the Jack of Clubs Valley on the Wells Historic Tailings Deposit. Water from this seepage flows west into Jack of Clubs Lake.

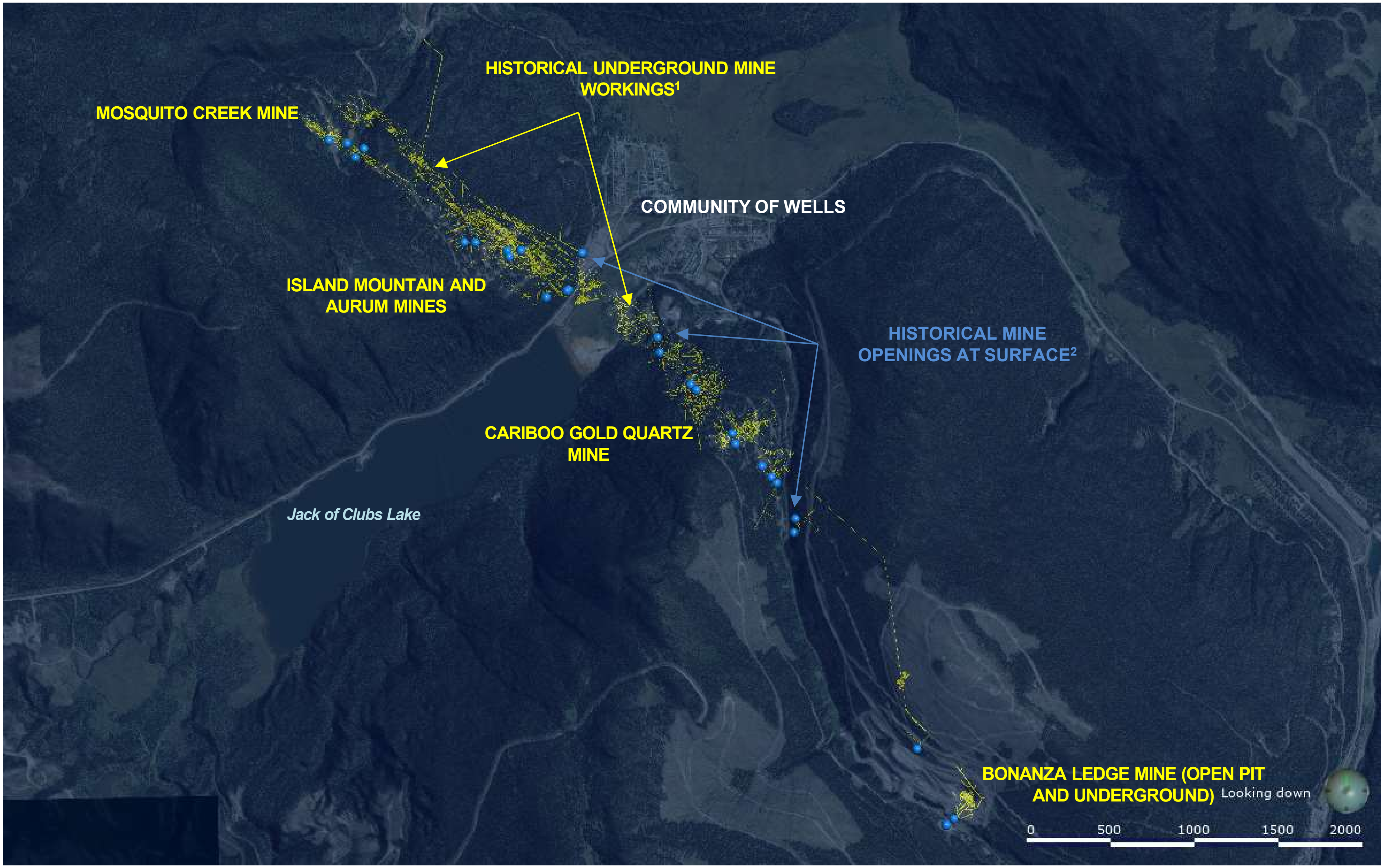
ODV observed and sampled groundwater seepages at the Wells Historical Tailings Deposit. A borehole drilled by ODV exploration in this area encountered artesian conditions on October 20, 2017; ODV collected groundwater samples from this flowing borehole (2017-Artesian-BH). The flow was controlled by October 22, 2017 and a relief well was drilled on October 23, 2017 before it was decommissioned unused. Groundwater seepage was observed approximately 50 metres from the artesian borehole in May 2018. This seepage was bermed, forming two sequential ponds, before discharging directly onto the Wells Historical Tailings Deposit where the water reinfiltrates. ODV sampled the first pond for water quality monitoring (HT Seepage 1) and established an additional sampling location, HT Seepage 2, approximately 100 m downstream of HT Seepage 1, where water flows across the historical tailings surface before either infiltrating or flowing into the wetland area. Groundwater seepage was no longer observed or sampled at the HT Seepage 2 location after July 2018. The groundwater seepage at HT Seepage 1 continues to flow into the two sequential ponds. Further detail on observed groundwater seepage in the Mine Site LAA, as well as a record of the presence or absence of groundwater seepage at these monitoring locations during sampling events, is summarized in Section 4.1.2.1 and Appendix D3 of the Hydrogeology Existing Conditions report (Appendix 7.5-1).

7.5.3.2.1 Quesnel River Mill

The QR Mill is located approximately 115 km from the Mine Site and 58 km southeast of Quesnel. The Project-related infrastructure at the QR Mill is contained within the existing footprint. The mill upgrades and the Filtered Stack Tailings Storage Facility (FSTSF) will be completed within the existing mill area on a brownfield site. The predominant lithology underlying the QR Mill are the basalts of the Nicola Group, with some intrusive rocks noted near the southern slopes of the LAA, north of the Quesnel River. The QR Mill LAA is presented in Figure 7.5-2.

The main existing surface water infrastructure at the QR Mill includes the Quesnel River Mine Tailings Storage Facility (QR TSF), the Main Zone Pit (MZP), the Northwest Zone Pit, and other associated facilities, which are located between 1,000 metres above sea level (masl) and 1,080 masl. Seepage from the north dam is captured at the North Seepage Collection Pond (NSCP) and released through a weir into Rudy Creek when water quality meets existing permit discharge requirements (Appendix 1.0-10; KCB, 2020a). The seepage is stored in the NSCP and pumped to the QR TSF, as needed, when these permit discharge requirements are not met (Appendix 1.0-10; KCB, 2020a). The Cross Dyke is located on the south side of the QR TSF. Seepage from the Cross Dyke is captured at the South Seepage Collection Pond (SSCP) and routed to the MZP (Appendix 1.0-10; KCB, 2020a).

The QR Mill previously operated as the Quesnel River Mine (QR Mine) for a period in the 1990s, operated by Kinross Gold, and again in the 2000s, operated by Cross Lake Minerals Ltd., and finally in the early 2010s by Barkerville Gold Mines Ltd. (BGM). Based on the voids model and site information provided by ODV, historical workings associated with the West Portal and Midwest Portal are flooded and with water levels near ground surface or actively discharging (Figure 7.5-5). The orientation of the historical underground (adit) associated with the North Portal suggests this underground is free draining, with any seepage discharge at the North Portal. Within the QR Mill LAA, there are also four historical open pits (MZP, Northwest Zone Pit, North Lobe Pit, and South Lobe Pit). A portion of the South Lobe Pit has been historically backfilled with non-potentially acid generating (NPAG) rock and soil to create a free draining surface with the North Lobe Pit. The MZP has been partially backfilled with tailings and has a controlled water level elevation of approximately 1,000 masl (KCB, 2020b). The Northwest Zone Pit is flooded but has no active water level control.



[1] – Received 04-16-2020 from BGM [IM_Workings.zip]

[2] – Received 2017 from BGM [AditsShafts.zip]

BARKERVILLE GOLD MINES LTD.

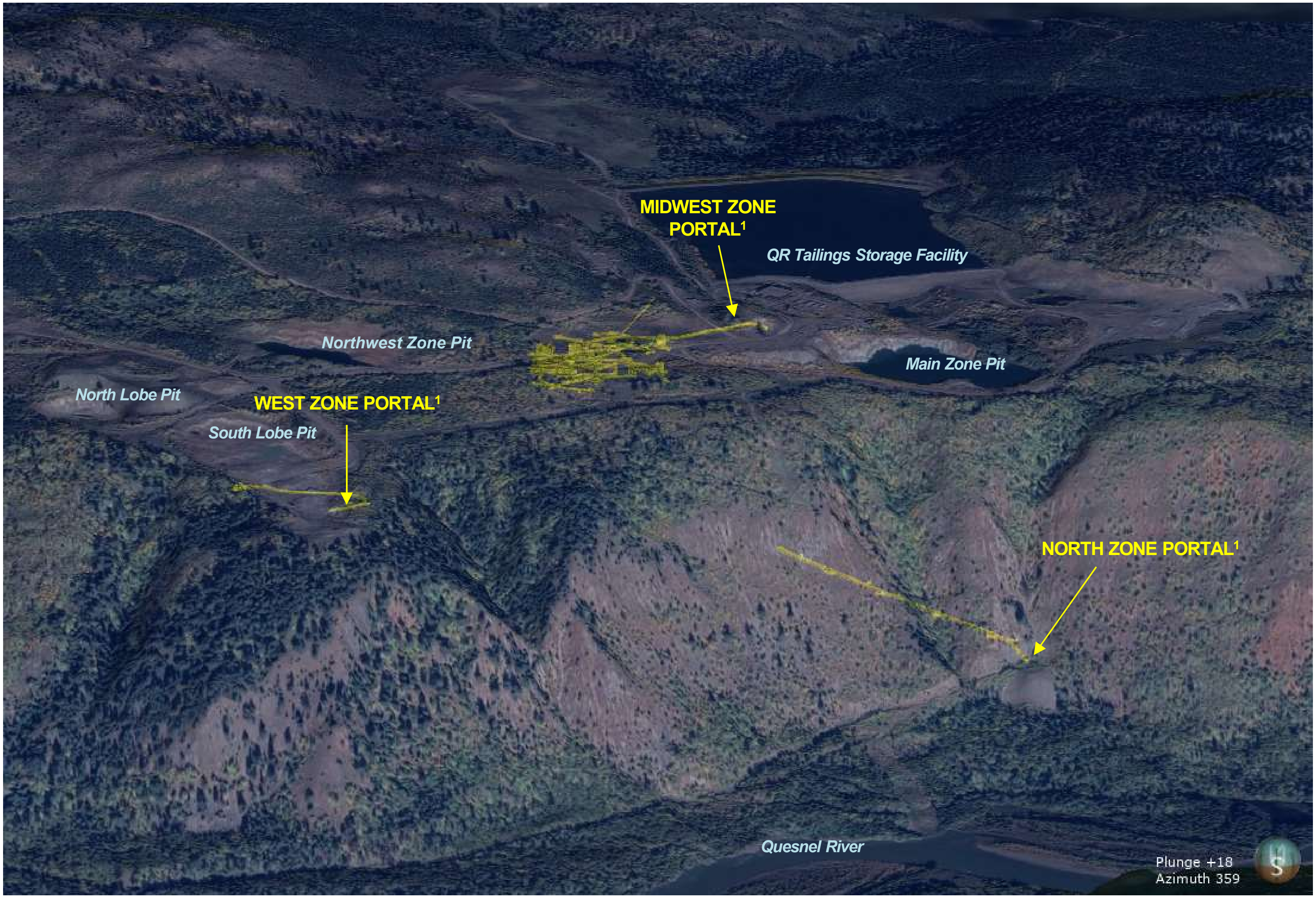
OSISKO DEVELOPMENT

YYYY-MM-DD	2021-06-09
PREPARED	SR
DESIGNED	SR
REVIEWED	NGG
APPROVED	JL

CARIBOO GOLD PROJECT

HISTORICAL UNDERGROUND MINE WORKINGS IN THE MINE SITE LOCAL ASSESSMENT AREA PLAN VIEW

PROJECT NO.	PHASE	REV.	FIGURE
177416001	41500/1514	0	7.5-4



Historical Underground Workings

[1] – Received 04-16-2020 from BGM [VoidsModel.zip]

BARKERVILLE GOLD MINES LTD.

CARIBOO GOLD PROJECT

OSISKO DEVELOPMENT

YYYY-MM-DD	2021-06-09
PREPARED	SR
DESIGNED	SR
REVIEWED	NGG
APPROVED	JL

HISTORICAL UNDERGROUND MINE WORKINGS IN THE QR MILL LOCAL ASSESSMENT AREA ORTHOGONAL VIEW LOOKING NORTH

PROJECT NO.	PHASE	REV.	FIGURE
177416001	41500/1514	0	7.5-5

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

7.5.3.3 Project-Specific Existing Conditions Studies

The baseline characterization of the Groundwater VC is presented in Section 7.5.3.4 and is summarized from detailed information presented in the Groundwater Existing Conditions Report (Appendix 7.5-1). Baseline studies were completed within areas described as a Groundwater Local Study Area (LSA) and a Groundwater Regional Study Area. During Project scoping for the Groundwater effects assessment, assessment areas (LAA and RAA) were refined based on the anticipated extent that potential effects to the Groundwater VC can be reasonably expected (See Section 7.5.2.1). In this section, the results of the baseline studies have been described for the LAA and RAA only.

Appendix 7.5-1 does not make specific reference to Indigenous groundwater users. Indigenous groundwater uses and users were considered in the data review for the existing conditions study; however, consultation and traditional use studies (DM Cultural Services Ltd., 2019; Landmark Resource Management Ltd., 2021) did not identify current specific uses of groundwater in the LAAs.

7.5.3.3.1 Methods Overview

A comprehensive data review of previous hydrogeological work and interpretation was completed to inform and establish the conceptual hydrogeological models for the Mine Site and QR Mill LAAs and RAAs. After the data review, a hydrogeology existing conditions monitoring program (HECMP) was formulated and established, using a combination of previously installed groundwater monitoring infrastructure and targeted new groundwater monitoring locations installed between 2016 and 2019.

Existing hydrogeology conditions were evaluated by the following, as provided in the Cariboo Gold Project Groundwater Existing Conditions Report (Appendix 7.5-1):

- Review of past hydrogeology reports relevant to the LAA and RAA, including the methods used and the referenced data;
- Development of monitoring wells and hydraulic testing at new groundwater wells drilled and incorporated into the HECMP;
- Rehabilitation of monitoring wells, where necessary, and monitoring well development at historical groundwater monitoring wells incorporated into the HECMP;
- Instrumentation of HECMP monitoring wells with pressure transducer dataloggers (PTDLs) to facilitate measurement of high-frequency groundwater levels;
- Identification and incorporation of active groundwater seepage zones into the HECMP; and
- Collection of water levels and groundwater samples through quarterly monitoring events.

Existing conditions are used for reference to identify environmental changes, and for qualitative and quantitative assessments of potential effects on groundwater quality. Existing conditions are also used to provide context to changes to water quality resulting from the Project for future monitoring programs.

Groundwater data collection and analytical methods, and quality assurance/quality control procedures, can be found in Section 3.3.3.3 and Section 3.5, respectively, of the Cariboo Gold Project Hydrogeology Existing Conditions Report (Appendix 7.5-1).

7.5.3.3.2 Groundwater Quantity

Field and desktop surveys completed for or integrated into the hydrogeology existing conditions study to investigate groundwater quantity included hydraulic testing and analysis, manual and high-frequency water level measurements, and a search of the BC Groundwater Wells and Aquifers Database for groundwater users in the LAAs.

7.5.3.3.2.1 Hydraulic Testing

Table 7.5-4 presents a summary of the various known hydraulic testing programs that have taken place in the Mine Site and QR Mill LAAs. The methods and analysis results of the different subsurface hydraulic testing types are described in the Cariboo Gold Hydrogeology Existing Conditions Report (Appendix 7.5-1).

Table 7.5-4 Summary of Subsurface Hydraulic Testing Programs in the Mine Site and Quesnel River Mill Local Assessment Areas

Testing Program and Reference	Hydraulic Testing Type	Number of Boreholes/ Monitoring Wells Tested	Number of Hydraulic Tests Completed
SWS, 2009	Single Well Response Testing	8	9
	Packer Testing	8	17
SNC, 2011	Single Well Response Testing	16	16
KCB, 2012	Single Well Response Testing	4	12
	Packer Testing	4	7
KCB, 2015	Single Well Response Testing	4	7
	Packer Testing	4	7
KCB, 2017	Single Well Response Testing	4	9
Golder, 2016*	Single Well Response Testing	10	24
	Packer Testing	2	5
Golder, 2018*	Single Well Response Testing	13	42
Hatfield, 2018a	Single Well Response Testing	4	8
	Packer Testing	4	17
Hatfield, 2018b	Packer Testing	2	12
BBA, 2018	Single Well Response Testing	3	9
WSP, 2019	Packer Testing	9	29
	Pumping Test	1	1
Golder, 2019*	Single Well Response Testing	10	18
Golder, 2020b	Single Well Response Testing	3	24
Total		**112**	**249**

Note: *This hydraulic testing program was conducted as part of the Hydrogeology Existing Conditions study and reported on as part of the Hydrogeology Existing Conditions Report (Appendix 7.5-1).

7.5.3.3.2.2 Quarterly Hydrogeological Existing Conditions Monitoring Program

Quarterly groundwater monitoring events for the HECMP comprise three main tasks. Manual groundwater level measurements and high-frequency groundwater level monitoring data were collected at monitoring wells, and groundwater quality sampling data was also collected from both monitoring wells and groundwater seepage locations. Manual and high-frequency groundwater level monitoring, including time series plots of hydraulic head, are summarized in Appendix D of the Hydrogeology Existing Conditions Report (Appendix 7.5-1).

7.5.3.3.2.3 Groundwater Use

A search of the BC Groundwater Wells and Aquifers Database yielded 19 registered groundwater wells within the Mine Site LAA (Government of BC, 2021b). Of these 19 wells, 4 have a well status of abandoned and all 19 are registered as unlicensed. Review of this public database, traditional use studies and consultation did not identify Indigenous groundwater uses and users in the LAA (DM Cultural Services Ltd., 2019; Landmark Resource Management Ltd., 2021).

A summary of the registered well record details is presented in Table 7.5-5. Water well records for registered wells within the Mine Site LAA are presented in Appendix K of the Hydrogeology Existing Conditions Report (Appendix 7.5-1). A search of the BC Groundwater Wells and Aquifers Database yielded no registered groundwater wells within the QR Mill LAA.

A groundwater pumping well at the QR Mill supplies the camp with potable water. Although not documented in the Hydrogeology Existing Conditions Report (data was not known at the time), known details of this pumping well and associated water quality sampling is presented in Appendix 7.5-5. The well is shallow at approximately 4 m deep with a water level near ground surface. There is a drainage channel nearby the well, which is suspected to control the water level within the well. The well yield is unknown; however, the ODV Mill Manager indicates the well supplies water for 30 to 40 people at the QR Mill Camp.

Table 7.5-5 Mine Site Local Assessment Area Groundwater Use Summary

Well Tag Number	Intended Water Use	Owner	Year Drilled	Easting	Northing	Well Depth (mbgs)	Estimated Yield (USGPM)
117165	Not Listed	BGM	2018	595212	5884429	106.68	0.75
117166	Not Listed	BGM	2018	595212	5884429	275.54	3.5
71044	Not Listed	BC Ministry of Tourism, Sport and the Arts	1974	599687	5882140	N/A	0
71045	Not Listed	Parks Branch	1974	599690	5882145	19.51	0
28692*	Not Listed	Conklin Gulch	1993	595690	5884500	17.07	Unknown
57317*	Not Listed	Town of Wells	1987	596077	5884509	40.23	Unknown
17076	Water Supply System	Parks Branch	1961	599526	5880992	18.59	0
17086*	Water Supply System	BC Ministry of Tourism, Sport and the Arts	1961	599542	5881075	19.51	N/A

Well Tag Number	Intended Water Use	Owner	Year Drilled	Easting	Northing	Well Depth (mbgs)	Estimated Yield (USGPM)
17089	Water Supply System	BC Ministry of Tourism, Sport and the Arts	1961	599590	5881155	20.42	20
17090	Water Supply System	BC Ministry of Tourism, Sport and the Arts	1961	599469	5881138	21.64	0
20904	Observation Well	ENV	1967	601470	5879461	28.96	20
20906	Observation Well	ENV	1967	601578	5879749	16.46	1
25677*	Not Listed	Parks Branch	1971	599305	5882734	21.34	Unknown
25678	Private Domestic	Parks Branch	1971	598903	5882844	23.16	3
25544	Private Domestic	Forestry Camp at Wells	1971	595980	5884288	10.97	15
57319	Water Supply System	Town of Wells	1987	595854	5884547	46.63	150
58092	Commercial and Industrial	Mosquito Consolidated Gold Mine	1988	595212	5884429	11.89	30
58094	Commercial and Industrial	Mosquito Consolidated Gold Mine	1988	596023	5884383	35.36	100
104540	Water Supply System	Spanish Mountain Gold Ltd.	2011	599263	5883107	16.76	30

Notes: mbgs = metres below ground surface; USGPM = United States gallons per minute; ENV = BC Ministry of Environment and Climate Change Strategy; N/A = not applicable.

According to a Water Quality Investigation completed by AE (AE, 2004), the pumping rate at the time of reporting in 2004 for the District of Wells water supply well (Well Tag Number 57319) was 140 gallons per minute (GPM) and the peak demand was 315,000 litres per day (L/d). The District of Wells supply well sources groundwater from the Wells Aquifer (Aquifer No. 829). There is no data available for other water supply wells in the Mine Site LAA.

7.5.3.3.3 Groundwater Quality

Field and desktop surveys completed for or integrated into the hydrogeology existing conditions study to investigate groundwater quality included borehole drilling and monitoring well installations, as well as the groundwater sampling component of the quarterly groundwater monitoring program.

7.5.3.3.3.1 Borehole Drilling and Monitoring Well Installations

Table 7.5-6 presents a summary of the relevant drilling programs, together with the purpose, drilling method, and number of boreholes/monitoring wells installed. Table 7.5-6 includes historical drilling programs conducted prior to the initiation of the hydrogeology existing conditions study, drilling programs conducted to support the hydrogeology existing conditions study, and recent drilling programs conducted for other purposes in which information and groundwater monitoring infrastructure were incorporated into the hydrogeology existing conditions study.

Table 7.5-6 Summary of Drilling Programs in the Mine Site and Quesnel River Mill Local Assessment Areas

Reference	Area	Purpose	Drilling Method	Number of Boreholes/ Monitoring Wells
KCB, 1995*	QR Mill	Monitoring wells associated with the QR Mine	Air Rotary	6 monitoring wells
Unknown (Est. 1995-1998)	QR Mill	Unknown, but hypothesized to be monitoring wells associated with operation or closure of the QR Mine	Unknown	7 monitoring wells
SWS, 2009	Bonanza Ledge	Prepared for International Wayside Gold Mines Bonanza Ledge Site	NQ Diamond Coring	8 monitoring wells
SNC, 2011	Mine Site	Detailed risk assessment of the Wells Tailings Deposit for the Ministry of Natural Resource Operations - Crown Land Opportunities and Restoration Branch	Auger, sonic, and ODEX Air Rotary Drilling	67 boreholes drilled with 28 completed with monitoring wells
Unknown (Est. 2011)	Mine Site	Unknown, but hypothesized to be associated with hydrogeological investigations for an earlier version of the Project	Unknown	40 monitoring wells
Unknown (Est. 2011)	QR Mill	Unknown, but hypothesized to be monitoring wells associated with QR Mine Closure or QR Mill operation	Unknown	2 monitoring wells
KCB, 2012	QR Mill	To support a BC Ministry of Energy and Mines (MEM) requirement to reduce seepage beneath the north dam of the tailings storage facility prior to placing additional tailings	Sonic Drilling and Diamond Coring	4 monitoring wells
KCB, 2015	QR Mill	To identify seepage migration pathways through and beneath the tailings storage facility	HQ Diamond Coring	4 monitoring wells
Golder, 2016	Wells	Regional monitoring wells in support of the Hydrogeological Existing Conditions Monitoring Program	HQ3 Diamond Coring and ODEX Air Rotary Drilling	11 monitoring wells
KCB, 2017	Wells	Hydrogeological and geotechnical investigation	Air Hammer	4 monitoring wells
Hatfield, 2018a	Mine Site	Hydrogeological investigation in support of the Gold Quartz Underground Exploration Project	Air Rotary	6 monitoring wells
Hatfield, 2018b	Bonanza Ledge	Bonanza Ledge Phase II Permit Amendment application	Unknown	2 monitoring wells and 1 vibrating wire piezometer nest
BBA, 2018	Mine Site	Geotechnical investigation in support of surface infrastructure	Sonic and Pionjar	9 monitoring wells
WSP, 2019	QR Mill	Cariboo Gold Project Preliminary Economic Assessment engineering support	Dual Rotary Air Injection	2 monitoring wells
Golder, 2019	QR Mill	Baseline Hydrogeological Monitoring Program	Sonic Drill Rig	5 monitoring wells

Reference	Area	Purpose	Drilling Method	Number of Boreholes/ Monitoring Wells
Golder, 2020a	QR Mill	Geotechnical investigation of TMF location at QR Mill	Sonic Drill Rig	7 monitoring wells and 4 vibrating wire piezometers
Golder, 2020b	Mine Site	Hydrogeological Existing Conditions Monitoring Program	Sonic Drill Rig	3 monitoring wells
ODV (Ongoing)	Mine Site	Exploration geology boreholes	NQ and HQ Diamond Coring	Over 6,000 boreholes

Notes: QR Mill = Quesnel River Mill; QR Mine = Quesnel River Mine; BC = British Columbia; MEM = Ministry of Energy and Mines; TMF = Tailings Management Facility; ODEX = Overburden Drilling Excentric.

* = No report for this hydraulic testing program was available. Data and results were received as an electronic database.

Methods associated with borehole drilling, monitoring well installation, and monitoring well development for the boreholes drilled in support of the HECMP are described in the Cariboo Gold Hydrogeology Existing Conditions Report (Appendix 7.5-1).

7.5.3.3.3.2 Groundwater Quality Sampling

Field sampling methods for groundwater quality were in general accordance with the procedures described in the BC Field Sampling Manual for Continuous Monitoring and the Collection of Air, Air-Emission, Water, Wastewater, Soil, Sediment, and Biological Samples (ENV, 2013a). The methods for sampling monitoring wells that were part of the HECMP are described in the Hydrogeology Existing Conditions Report (Appendix 7.5-1). Other sources of groundwater quality data were also integrated into the groundwater quality database for the hydrogeology existing conditions study. These include historical groundwater quality data results from previous reports and investigations, and concurrent groundwater sampling conducted by ODV staff for compliance purposes at Bonanza Ledge and QR Mill.

Baseline groundwater quality sampling took place between 2016 and 2020. Additional baseline sampling of groundwater at locations with less than one year of water quality data is ongoing, including the monitoring wells in the Historical Mill Tailings area which were rehabilitated in June 2020. Appendix G of the Cariboo Gold Hydrogeology Existing Conditions Report (Appendix 7.5-1) summarizes historical groundwater quality data prior to the HECMP sampling. The overall period of groundwater quality monitoring ranged from October 2009 to December 2020.

The Mine Site LAA was characterized by a total of 48 monitoring wells or temporary sampling points and the QR Mill LAA was characterized by a total of 22 monitoring wells. Table 7.5-7 summarizes sampling locations in the Mine Site LAA and a summary of the sampling locations in the QR LAA is presented in Table 7.5-8. The hydrostratigraphic groupings are described in Section 7.5.3.4.1.

Table 7.5-7 Mine Site Local Assessment Area Groundwater Quality Monitoring Locations

Section	Area	Aquifer Type	Number of Samples	Monitoring Range
Overburden Monitoring Wells				
BLMW2S	Bonanza Ledge	Overburden	4	2016-05-07 to 2017-09-11
MW16-10S	Bonanza Ledge	Overburden	20	2016-05-08 to 2020-12-13
MW09-007B	Mine Site	Glaciolacustrine	6	2009-10-07 to 2020-11-16

Section	Area	Aquifer Type	Number of Samples	Monitoring Range
MW09-007C	Mine Site	Glaciolacustrine	6	2009-10-07 to 2020-11-24
MW09-029B	Mine Site	Glaciolacustrine	6	2009-10-09 to 2020-11-23
MW09-063B	Mine Site	Glaciolacustrine	5	2009-10-08 to 2020-09-25
MW09-091B	Mine Site	Glaciolacustrine	5	2009-10-07 to 2020-11-23
MW09-091C	Mine Site	Glaciolacustrine	5	2009-10-07 to 2020-11-23
MW18-02A	Mine Site	Glaciolacustrine	6	2019-03-01 to 2020-09-27
MW09-063A	Mine Site	Placer Outwash/ Alluvial Fan	5	2009-10-08 to 2020-11-17
MW09-091A	Mine Site	Placer Outwash/ Alluvial Fan	5	2009-10-07 to 2020-09-27
MW-19-08S	Mine Site	Placer Outwash/ Alluvial Fan	4	2020-05-08 to 2020-11-24
District of Wells MW	Mine Site	Wells Aquifer	13	2017-09-08 to 2020-11-19
MW-19-07	Mine Site	Wells Aquifer	2	2020-05-08 to 2020-08-17
MW-19-08D	Mine Site	Wells Aquifer	4	2020-05-08 to 2020-11-24
34586 - 2011 NEST	Mine Site	Regional Overburden	7	2017-09-07 to 2020-08-18
MW18-01A	Mine Site	Regional Overburden	2	2019-05-28 to 2020-12-11
MW-LL-16-01B	Mine Site	Regional Overburden	13	2017-09-06 to 2020-12-13
MW-LL-16-02B	Mine Site	Regional Overburden	12	2017-09-09 to 2020-12-11
MW-LL-16-03A	Mine Site	Regional Overburden	15	2017-09-06 to 2020-12-09
MW-LL-16-03B	Mine Site	Regional Overburden	13	2017-09-06 to 2020-12-09
MW-LL-16-04A	Mine Site	Regional Overburden	9	2017-09-07 to 2020-12-09
Bedrock Monitoring Wells				
MW18-01B	Mine Site	Deep Bedrock/ Mining Level	4	2019-03-06 to 2019-12-11
MW18-02B	Mine Site	Deep Bedrock/ Mining Level	7	2018-12-06 to 2020-09-27
MW18-03B	Mine Site	Deep Bedrock/ Mining Level	4	2018-12-13 to 2019-12-11
34582 - 2011 NEST	Mine Site	Regional Bedrock	7	2017-09-07 to 2019-09-18
34583 - 2011 NEST	Mine Site	Regional Bedrock	13	2017-09-07 to 2020-12-10
MW-HL-16-01	Mine Site	Regional Bedrock	1	2017-12-13 to 2017-12-13
MW-HL-16-02	Mine Site	Regional Bedrock	14	2017-09-08 to 2020-12-10
MW-HL-16-03	Mine Site	Regional Bedrock	13	2017-09-08 to 2020-12-10
MW-LL-16-01A	Mine Site	Regional Bedrock	13	2017-09-07 to 2020-12-13

Section	Area	Aquifer Type	Number of Samples	Monitoring Range
MW-LL-16-02A	Mine Site	Regional Bedrock	14	2017-09-09 to 2020-12-11
MW-LL-16-04B	Mine Site	Regional Bedrock	11	2017-09-10 to 2020-12-09
BLMW2D	Mine Site (Bonanza Ledge)	Shallow Bedrock	19	2016-05-07 to 2020-12-12
MW16-10D	Mine Site (Bonanza Ledge)	Shallow Bedrock	17	2016-07-26 to 2020-12-13
Historical Mining and Anthropogenic Deposit Monitoring Wells				
ARTESIAN	Mine Site	Historical Tailings Seepage	1	2020-09-26 to 2020-09-26
HT SEEPAGE 1	Mine Site	Historical Tailings Seepage	31	2018-05-25 to 2019-08-28
HT SEEPAGE 2	Mine Site	Historical Tailings Seepage	12	2018-05-27 to 2018-07-24
MINE SEEPAGE 1	Mine Site	Surface Mine Seepage	12	2017-09-09 to 2020-11-15
MINE SEEPAGE 2	Mine Site	Surface Mine Seepage	9	2017-09-09 to 2020-11-15
MINE SEEPAGE 3	Mine Site	Surface Mine Seepage	1	2019-05-23 to 2019-05-23
MINE SEEPAGE 5	Mine Site	Surface Mine Seepage	6	2018-06-04 to 2020-11-16
2017-ARTESIAN-BH	Mine Site	Deep Historical Workings	4	2017-10-20 to 2017-10-22
CM-20-050	Mine Site	Deep Historical Workings	2	2020-07-29 to 2020-07-30
MW09-007A	Mine Site	Historical Mill Tailings	6	2009-10-07 to 2020-11-16
MW09-026	Mine Site	Historical Mill Tailings	7	2009-10-07 to 2020-11-17
MW09-029A	Mine Site	Historical Mill Tailings	6	2009-10-09 to 2020-11-23
MW09-052	Mine Site	Historical Mill Tailings	4	2009-10-09 to 2020-11-23

Table 7.5-8 Quesnel River Mill Local Assessment Area Groundwater Quality Monitoring Locations

Station	Area	Aquifer Type	Number of Samples	Monitoring Range
Overburden Monitoring Wells				
MW16-01S	QR Mill	Overburden	12	2016-05-29 to 2020-10-16
MW16-02S	QR Mill	Overburden	28	2016-05-29 to 2020-10-15
MW1A	QR Mill	Overburden	16	2015-10-14 to 2020-12-16

Station	Area	Aquifer Type	Number of Samples	Monitoring Range
MW1B	QR Mill	Overburden	13	2015-10-14 to 2020-12-16
MW2A	QR Mill	Overburden	15	2015-10-16 to 2020-10-15
MW2B	QR Mill	Overburden	14	2015-10-14 to 2020-10-15
QR-19-08B	QR Mill	Overburden	5	2019-09-22 to 2020-10-17
Bedrock Monitoring Wells				
MW11-02-QR	QR Mill	Shallow Bedrock	8	2015-10-16 to 2020-08-25
MW16-01D	QR Mill	Shallow Bedrock	13	2016-05-09 to 2020-10-16
MW16-02D	QR Mill	Shallow Bedrock	28	2016-05-29 to 2020-10-15
MW-19-01	QR Mill	Shallow Bedrock	4	2019-09-23 to 2020-10-15
MW-19-02	QR Mill	Shallow Bedrock	4	2019-09-23 to 2020-10-15
MW-19-03	QR Mill	Shallow Bedrock	4	2019-09-23 to 2020-10-16
MW-19-04	QR Mill	Shallow Bedrock	4	2019-09-23 to 2020-10-16
MW-19-06	QR Mill	Shallow Bedrock	4	2019-09-23 to 2020-10-16
QR-19-08A	QR Mill	Shallow Bedrock	5	2019-09-22 to 2020-10-17
QR-19-10A	QR Mill	Shallow Bedrock	5	2019-09-23 to 2020-10-22
MW10	QR Mill	Deep Bedrock	12	2015-10-16 to 2020-12-18
MW11-01-QR	QR Mill	Deep Bedrock	11	2015-10-16 to 2020-10-14
MW13	QR Mill	Deep Bedrock	30	2015-10-14 to 2020-12-17
MW6-QR	QR Mill	Deep Bedrock	13	2016-11-28 to 2020-12-15
MW8	QR Mill	Deep Bedrock	13	2016-10-28 to 2020-12-18

Notes: QR Mill = Quesnel River Mill

7.5.3.4 Existing Conditions Characterization

7.5.3.4.1 Hydrostratigraphy

7.5.3.4.1.1 Mine Site

The overburden hydrostratigraphy for the Mine Site LAA is characterized in greatest detail in the Jack of Clubs Valley, Willow River Valley, and downstream Williams Creek Valley due to the proximity of existing and proposed Project infrastructure and resultant greater availability of data.

Table 7.5-9 lists the overburden hydrostratigraphic units for the Mine Site LAA. Figures showing the location and lateral extents of the Mine Site LAA hydrostratigraphic units are presented in Appendix E on Figures E1 to E6 of the Hydrogeology Existing Conditions Report (Appendix 7.5-1). Interpretative cross-sections of the hydrostratigraphy are presented in Appendix E on Figures E7 to E10 of the Hydrogeology Existing Conditions Report (Appendix 7.5-1).

Table 7.5-9 Summary of Mine Site Local Assessment Area Hydrostratigraphic Units - Overburden

Hydrostratigraphic Unit	Typical Observed Unit Thickness [m]	Typical Elevation Range [m El.]	Hydrogeological Classification
Fill	Variable	Variable	Local Aquifer
Till/Lowlands	Variable	1200 - 1800	Regional Aquitard/Local Aquifer
Placer Outwash	5 – 20	1190 - 1240	Local Aquifers
Historical Mill Tailings	2 – 12	1190 - 1199	Local Aquitard
Glaciolacustrine	10 – 35	1140 - 1190	Regional Aquitard
Alluvium/Alluvial Fans	Variable	1160 - 1230	Local Aquifers
Wells Aquifer	2 – 20	1150 - 1165	Regional Aquifer

Notes: m = metres; El. = elevation; N/A = not applicable.

Based on the hydrostratigraphic interpretation and hydraulic test results, Table 7.5-10 below presents a summary of hydraulic conductivity estimates for each hydrostratigraphic unit.

Table 7.5-10 Summary of Hydraulic Conductivity for Overburden Hydrostratigraphic Units in Mine Site Local Assessment Area

Hydrostratigraphic Units	Test Types	Number of Tests	Hydraulic Conductivity [m/s]			Data Sources
			Maximum	Minimum	Geomean	
Fill/Waste Rock	SWRT	1	2E-04	2E-04	N/A	SNC, 2011
Till/Lowlands	SWRT	16	4E-04	4E-09	2E-05	BBA, 2019; Golder (Appendix 7.5-1); Hatfield, 2018a
Placer Outwash	SWRT	11	8E-03	4E-05	4E-04	SNC, 2011; BBA, 2019
Historical Mill Tailings	SWRT	7	9E-05	6E-07	1E-05	SNC, 2011
Glaciolacustrine	SWRT	2	7E-07	2E-07	4E-07	SNC, 2011
Alluvium/Alluvial Fans	SWRT	16	1E-02	6E-07	1E-04	SNC, 2011; Golder (Appendix 7.5-1)
Wells Aquifer	SWRT	6	2E-03	1E-04	7E-04	Golder (2020b and Appendix 7.5-1)

Notes: m/s = metres per second; SWRT = Single Well Response Test.

Table 7.5-11 presents a summary of bedrock hydrostratigraphy and associated hydraulic conductivity results for the Mine Site LAA. The bedrock hydrostratigraphy of the Mine Site LAA was informed by the geology from the boreholes, geological interpretation by ODV, and hydraulic testing results (SWRTs, packer tests, and a pumping test). Previous hydrostratigraphic interpretation of bedrock hydraulic conductivities in the Mine Site LAA by WSP (WSP, 2019) did not identify any strong correlation between lithology and hydraulic conductivity, or between depth and hydraulic conductivity, and the bedrock was considered a single hydrostratigraphic unit. A pumping test conducted by WSP (2019) to test the hydraulic conductivity of the Jack of Clubs fault zone indicated that the hydraulic conductivity was low (less than 1E-10 m/s), suggesting that the Jack of Clubs Fault is not a zone of enhanced permeability, but could be a potential barrier (hydraulic conductivity test results were on the low end of other bedrock test results). Other fault structures, both local and regional, intersect the proposed underground workings and the historical underground workings, but these fault structures have not been tested. The location and lateral extent of the Mine Site LAA bedrock hydrostratigraphic units are presented in Appendix E on Figure E11 of the Hydrogeology Existing Conditions Report (Appendix 7.5-1). Table 7.5--11 presents a summary of hydraulic conductivity results for the bedrock hydrostratigraphic units in the Mine Site LAA.

Table 7.5-11 Summary of Hydraulic Conductivity for Bedrock Hydrostratigraphic Units in Mine Site Local Assessment Area

Bedrock Unit	Hydraulic Conductivity (m/s)			Count
	Maximum	Minimum	Geomean	
Regional Bedrock and Jack of Club Fault	8E-06	6E-12	2E-08	46
Other Mine Area Bedrock	8E-07	4E-10	2E-08	34
Siltstone	4E-08	2E-10	1E-09	13

Note: m/s = metres per second.

7.5.3.4.1.2 Quesnel River Mill

The hydrostratigraphic units for the QR Mill LAA are summarized in Table 7.5-12, and the hydraulic properties of the hydrostratigraphic units are presented in Table 7.5-13. Interpretative cross-sections of the hydrostratigraphy in the QR Mill LAA are presented in Appendix F on Figures F1 to F3 of the Hydrogeology Existing Conditions Report (Appendix 7.5-1).

The QR Mill LAA was heavily glaciated, and much of the overburden was eroded, leaving only a thin (<3 m) layer of overburden materials, mostly glacial till overlying bedrock. The bedrock in the QR Mill LAA is comprised predominantly of the basalts of the Nicola Group, with no other major lithologies present in the area. Hydraulic conductivity results for the bedrock reveal a depth-dependency, where bedrock from approximately 0 – 35 metres below ground surface (mbgs) exhibits a higher hydraulic conductivity than bedrock below 35 mbgs. On this basis, the bedrock is subdivided into a Shallow Bedrock hydrostratigraphic unit comprising bedrock above 35 mbgs and a Deep Bedrock hydrostratigraphic unit comprising bedrock below 35 mbgs. Wally's Fault, a subvertical fault structure that runs north-south along the west of the existing QR TSF, has been identified as being a potential zone of enhanced permeability by previous investigations and was the subject of a trial bedrock grouting project (KCB, 2012; 2015). The location of Wally's Fault is potentially associated with a bedrock low along the west side of the north dam of the QR TSF, and it is inferred to be 2-4 m wide. The hydraulic properties of Wally's Fault have not been established.

Table 7.5-12 Summary of Quesnel River Mill Local Assessment Area Hydrostratigraphic Units

Hydrostratigraphic Unit	Typical Observed Unit Thickness [m]	Hydrogeological Classification
Overburden	0.5 – 13	Regional Aquitard/Local Aquifer
Shallow Bedrock	10 – 35	Regional Aquifer
Deep Bedrock	Basement Rock	Regional Aquitard
Wally's Fault	2 – 4, subvertical	Potential Structural Flow

Table 7.5-13 Summary of Hydraulic Conductivity Data for Hydrostratigraphic Units in the Quesnel River Mill Local Assessment Area

Hydrostratigraphic Unit	Test Types	Number of Tests	Hydraulic Conductivity [m/s]			Data Sources
			Maximum	Minimum	Geomean	
Overburden	SWRT	7	1E-04	3E-08	1E-05	Golder, 2019*; KCB, 2017
Shallow Bedrock (< 35 mbgs)	SWRT, Packer Testing	19	9E-06	2E-08	7E-07	Golder, 2019; KCB, 2015
Deep Bedrock (> 35 mbgs)	SWRT, Packer Testing	22	8E-07	1E-09	2E-08	KCB, 2012; KCB, 2015; KCB, 2017
Wally's Fault	N/A	N/A	N/A	N/A	N/A	KCB, 2012; KCB, 2015

Notes: m/s = metres per second; SWRT = Single Well Response Test; mbgs = metres below ground surface; N/A = not applicable.
*This hydraulic testing program was conducted as part of the Hydrogeology Existing Conditions study and reported on as part of the Hydrogeology Existing Conditions Report (Appendix 7.5-1).

7.5.3.4.2 Groundwater Recharge

Regional groundwater recharge from precipitation will occur from direct rainfall and snow melt into the surficial geological units, and, within the valleys, this recharge may be enhanced by runoff/recharge from the upland areas. Recharge from precipitation will be supplemented near mine facilities by seepage from nearby surface water features (creeks, ponds, and lakes) from potential groundwater-surface interactions. Recharge would be expected to be lowest in the winter when precipitation is predominantly observed as snow and temperatures drop below zero. The recharge will ramp up during freshet, with snow melt, and then fluctuate with variations in precipitation and evaporation throughout the summer and fall. This pattern is consistent with seasonal fluctuations in hydraulic head data observed in monitoring wells in the LAAs. Hydraulic heads are generally lowest during the late fall and winter, and highest hydraulic heads are observed in the spring and are associated with freshet.

As part of surface water balance modelling completed for the Mine Site (Appendix 1.0-1), infiltration from precipitation into the natural ground was estimated to be approximately 19% of the total annual precipitation (Table 7.5-14), which corresponds to approximately 196 millimetres per year (mm/yr) for the Mine Site LAA and 127 mm/yr for the QR Mill LAA.

Table 7.5-14 Estimated Monthly Recharge from Precipitation for the Mine Site and Quesnel River Mill

Area	Infiltration to Subsurface as % of Annual Precipitation												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Natural Ground	0	0	0.4	2.1	2.2	2.1	2.2	2.2	2.1	2.2	2.1	1.7	19

Note: % = percent

As part of earlier hydrogeological assessments for the Mine Site, WSP (2019) defined three distinct recharge zones with different recharge rates to determine variable recharge over the assessment area. The recharge varied as a function of topography and included:

- Mountain tops: high rates of recharge due to increased rainfall with elevation, reduced run off, and increased weathering of bedrock (164 mm/yr);
- Mountain flanks: low rates of recharge due to steep topography leading to high run-off (18 mm/yr); and
- Valley floor: high rates of recharge due to subdued topography and permeable soil, and enhanced infiltration from upland runoff (75 mm/yr).

Orographic control on precipitation is common and higher precipitation with elevation is supported by mean annual precipitation (MAP) isohyets reviewed on the provincial MAP raster-dataset for BC published online by the University of British Columbia. In consideration of this, this zonation was maintained in a numerical model assessment for the Mine Site completed prior to the Application by Golder (2020b) and resulted in final calibrated annual recharge values for the Mine Site for the mountain tops, mountain flanks, and valley floor in the Mine Site LAA of 197 mm/yr, 20 mm/yr, and 90 mm/yr, respectively. These calibrated recharge rates provided a reasonable match of modelled predicted stream baseflow to low flow data collected at hydrometric stations within the LAAs. Low flow measurements in streams are useful as an estimate of groundwater baseflow in streams, as low flow periods correspond to when contributions of surface water runoff will be at a minimum. Because the model was calibrated to observed low flow conditions, slightly higher recharge rates may be more appropriate for representation of annual average conditions, and for wet season flows, and were considered during the numerical modelling as part of this assessment.

Values adopted in the Mine Site Groundwater Model (Appendix 7.5-3 of the Application) are similar to the 2020 Golder Assessment (Golder, 2020b) and resulted in final calibrated annual recharge values for the mountain tops, mountain flanks, and valley floor of 275 mm/yr, 130 mm/yr, and 152 mm/yr, respectively. These values are somewhat higher than values adopted for WSP (2019) and Golder (2020) but are within reasonable limits considering available data on infiltration and stream base flow. The 2019 WSP and 2020 Golder model was calibrated to observed low flow conditions, and it was considered that slightly higher recharge rates may be more appropriate for representation of annual average conditions. WSP (2019) also provided estimates of recharge using the Thornthwaite method that ranged between 61mm/yr and 673 mm/yr depending on the assumed run-off coefficient and the range of precipitation observed at the BC Government Barkerville meteorological station since 2003. Recharge was verified in the model by its ability to represent baseflow estimates in Black Jack Gulch, Mosquito Creek, Slough Creek, Jack of Clubs Creek, and the Willow River. Recharge is also considered reasonable in consideration of estimates of infiltration from precipitation into the subsurface as part of the water balance modelling for the Project, which indicated an average infiltration of 19%, or 196 mm/yr, for the Mine Site. Calibrated recharge rates were higher than 196 mm/yr in the mountain tops where precipitation would be highest (300 mm/yr) and lower towards the valley (152 mm/yr) and valley flanks (130 mm/yr). The applied recharge resulted in a good match to baseflow estimates, which is a check on the applied recharge rates (Appendix 7.5-3). For the QR Model, a similar approach was adopted (Appendix 7.5-2). Calibrated rates were estimated to be 130 mm/yr at higher elevations and 100 mm/yr in the valley and slopes. These recharge rates resulted in a good match to baseflow estimates for streams within the model area. The QR Model values are lower than the Mine Site values because overall precipitation within the QR Mill LSA is lower than the Mine Site LSA.

7.5.3.4.3 Hydraulic Head Monitoring

A summary table presenting the monitoring locations, LAA area, type of monitoring (manual measurements, high frequency, or both), and period of record is provided in Appendix D1 of the Hydrogeology Existing Conditions Report (Appendix 7.5-1). Groundwater hydrographs for the Mine Site LAA and QR Mill LAA can be found in Appendices D2 and D3, respectively. Maps showing hydraulic head contours, inferred groundwater flow directions, and vertical hydraulic gradients in 2020 are presented in Appendix D4 of the Hydrogeology Existing Conditions Report (Appendix 7.5-1).

7.5.3.4.3.1 Mine Site

Measured hydraulic heads are generally close to surface across the Mine Site LAA, both in the valleys of the study area and in the highlands. Most of the groundwater hydrographs are relatively stable on a year-to-year basis, with hydraulic heads exhibiting some minor year-to-year variation on the order of a few meters depending on the amount of infiltration during/following the freshet. The exception to this are the hydraulic heads observed at the MW2S/D monitoring well nest in Stouts Gulch Valley, just east of the Bonanza Ledge Site, and hydraulic heads in MW18-03B, a deep bedrock well installed near the proposed mining horizon on Cow Mountain (Figure 7.5-6). At MW2S/D, hydraulic heads quickly responded to underground mine dewatering at the Bonanza Ledge Site, dropping below the level of the PTDLs and remaining below the high-frequency measurement point over the duration of the monitoring period. The PTDLs were left installed near the bottoms of the monitoring wells at these locations in order to measure a potential rise in hydraulic heads associated with seasonal recharge, but none was observed. At MW18-03B, a minor year-over-year rise in water levels is observed between 2019 and 2020. This deep well, located near the proposed mining horizon and the historic underground workings, may be responding to changes in the conditions in the historic workings or seasonal changes in precipitation.

Seasonally, hydraulic heads in most of the Mine Site LAA monitoring wells are generally lowest during the late fall and winter, when freezing conditions persist and recharge is at a minimum. Highest hydraulic heads are observed in the spring and are associated with the freshet when the snow melts and soils promote groundwater recharge. In the Mine Site LAA, the rise in hydraulic head typically begins in late April, rising to a peak in late May and June, when the freshet is at its maximum. Monitoring wells at higher elevations, such as MW-HL-16-02 and MW-HL-16-03, often exhibit a slightly delayed rise in groundwater levels, likely owing to the delayed thaw and release of the snowpack at higher elevations.

Different types of short-term fluctuations (i.e., days to weeks) are observed in the high-frequency data of the groundwater hydrographs, including:

- Groundwater rise in response to recharge from precipitation events;
- Slow recovery of water levels in response to well purging for groundwater sampling (in wells installed in lower hydraulic conductivity materials);
- Minor drawdown in DOW MW (30 - 40 cm) in response to groundwater extraction at the District of Wells community well; and

- Water level rises associated with infiltration into flushmount wells (MW-LL-16-04A/B) or with pressurization and release of pressure at a monitoring well that is under flowing artesian conditions (MW18-02B).

Shallow monitoring wells, particularly on the Wells Historic Tailings Deposit, tend to be more responsive to precipitation events, with faster, larger responses observed in the shallowest monitoring wells of a well nest (i.e., MW09-007A and MW09-029A) (Figure 7.5-7). The 30-40 cm wide ”band” of water level variations observed in the DOW MW is representative of a frequent pumping signature from the nearby community well showing up in the hourly measurements.

In the area around the Wells Historic Tailings Deposit, as presented in Figure D4-5 through D4-7 of the Hydrogeology Existing Conditions Report (Appendix 7.5-1), groundwater is close to surface across the majority of the area and the general groundwater flow mimics the topographic relief, with groundwater generally flowing from areas of high elevation to areas of low elevation. Surface water drainage plays an important role for groundwater movement across the area, as locally higher groundwater elevations are observed in proximity to the permeable alluvial deposits and placer outwash associated with Lowhee Creek. Similarly, Jack of Clubs Lake and the Willow River are the eventual discharge zones/sinks for groundwater in the valley overburden. Historical mine openings on the valley walls are observed to be free draining or dry and an important control on the flooded water level elevation in the historical workings. Within the valley on the Wells Historical Tailings Deposit, the groundwater seepage area, which emerged from the tailings beginning in 2018, provides localized and continuous recharge to the shallow groundwater flow system in this area. Vertical hydraulic gradients in the area are influenced by the permeable deposits, notably the alluvial deposits and placer outwash, which may act to preferentially route groundwater flow from the higher elevations to the valley. In the areas near Lowhee Creek, wells installed in these alluvial or placer outwash deposits (i.e., MW09-091A/B, MW19-08S, MW09-063A/B) show that these deposits often drive vertical hydraulic gradients to the overlying or underlying soil, both during high and low water periods. Further west, near Jack of Clubs Lake and the Willow River, nested monitoring wells typically exhibit downward or neutral hydraulic gradients throughout the year, representative of their location as a groundwater discharge zone. MW18-02, which is a nested monitoring well location with one well in the bedrock and one well in the overburden, consistently displays an upward vertical hydraulic gradient, highlighting Jack of Clubs Valley as a regional groundwater discharge zone.

7.5.3.4.3.2 QR Mill

Hydraulic head elevations are close to ground surface across the QR Mill LAA, with most measured hydraulic heads across the area within 5 m of the ground surface, except for the deeper monitoring wells closer to the south slopes, which are locally depressed due to topographic influences. Figures D3-1 through D3-8 in Appendix D3 of the Hydrogeology Existing Conditions Report (Appendix 7.5-1) present the groundwater hydrographs for the HECMP wells in the QR Mill LAA. Interpreted influences on local groundwater levels in the QR Mill LAA include:

- The existing QR TSF pond, situated in a small bedrock saddle, which is interpreted to cause increased hydraulic heads to the north and south of the QR TSF, including flowing artesian conditions observed in monitoring wells along the western side of the north and south dams.

- The MZP, a former open pit mine, which acts as a local groundwater sink, with a controlled water level at approximately 1,000 masl. This pit will be the location of tailings deposition for the proposed expansion of the Bonanza Ledge Mine, which will be finished prior to any activities in the area in support of the Project.
- The Northwest Zone Pit, a smaller former open pit mine, which acts as a possible local groundwater sink/discharge zone and which is not regulated.
- Two small networks of flooded underground mine workings, one located near MW10 in the southwest of the LAA (associated with the West Portal) and one near the MZP (associated with the Midwest Portal).
- A large (>300 m), steep topographic decline at the south end of the LAA leading down to the Quesnel River.
- An exploration audit (North Portal) advanced into the bedrock located near the base of the south slopes that is free draining based on the provided orientation of the adit.

Figure 7.5-5 shows the locations of historical underground workings and open pits in the QR Mill LAA. High-frequency hydraulic head monitoring was initiated in the QR Mill LAA in late 2019, after the integration of the QR Mill into the Project, and is ongoing.

Minimal year-to-year changes in groundwater elevations are apparent in the groundwater hydrographs. In the existing data record, seasonal high hydraulic heads in shallow monitoring wells are observed two times throughout the year, once in late fall to early winter, likely associated with periods of increased rainfall prior to soils freezing and/or reduced evapotranspiration, and again in mid-April to July, corresponding with the spring melt and freshet. Low hydraulic head periods are observed during the drier summer months, from July to October, and again during the winter when the ground is frozen and groundwater recharge is at its minimum. The groundwater elevation changes observed in the shallow overburden and bedrock wells are in the range of a couple of metres. In deeper monitoring wells in the bedrock, seasonal variations in hydraulic head are generally less pronounced. The biannual groundwater highs observed in shallow wells are not explicitly observed in deeper wells; however, some wells do show a degree of responsivity to the snowmelt/freshet period.

Different types of short-term fluctuations are observed in the high-frequency data of the groundwater hydrographs. Most often, these fluctuations are associated with water level responses to sampling events in lower hydraulic conductivity monitoring wells (i.e., MW6-QR and MW13). Large 2 m increases in groundwater levels were observed at both MW1A and MW1B in late April 2020 and July/August 2020. It is unclear what is responsible for these increases, though they may be associated with releases of water from the QR TSF pond.

As presented in Figures D4-8 through D4-11 of the Hydrogeology Existing Conditions report (Appendix 7.5-1), a local topographic low generally bisects the LAA north-south. The QR TSF straddles the drainage divide in this low with surface water drainage, driven by the higher hydraulic head elevations of the QR TSF pond. Seepage is collected in ponds to the north and south of the QR TSF, with further drainage to the north towards Rudy Creek and to the south towards the MZP. The MZP acts as a local sink for shallow groundwater flow, with the MZP water level maintained at an elevation of approximately 1,000 masl. The two mine openings (Midwest Zone Portal and West Zone Portal, as shown on Figure 7.5-5) on the QR Mill plateau connected to flooded historical workings often actively discharge water to surface and do not exert a significant hydrogeological control on the groundwater flow patterns. The North Portal opening, located at closer elevation to the Quesnel River and associated with the exploration drift advanced into the cliff, also actively flows and discharges water to surface. This exploration drift is understood not to be vertically developed and is expected to locally depressurize the surrounding bedrock. The exploration drift is located over 150 m vertical distance away from the upper plateau of the QR Mill LAA and the effects (if any) that this local depressurization would have on groundwater elevations in the existing wells is not discernable from the local depression of hydraulic heads associated with the topographic decline of the south slopes.

Across the study area, downward vertical gradients are observed throughout the year in the south (QR-19-08A/B and MW11-01-QR/MW11-02-QR) as a result of the influence of the topography of the south slopes and, locally, from groundwater drawdown associated with the MZP. Near the QR TSF, upward hydraulic gradients and flowing artesian conditions are consistently observed on the western side of both the north and south dams (MW2A/B and MW16-01S/D, respectively), whereas downward hydraulic gradients are consistently observed on the east side of the north dam (MW1A/B). The western side of the north and south dams is built overtop of a bedrock low that may be associated with a fault structure (Wally's Fault) and increased hydraulic connection to the higher water levels in the QR TSF. The downward hydraulic gradients observed at the eastern side of the north dam likely reflect the influence of the seepage collection pond downstream of the North Dam of the QR TSF. In the southeast portion of the QR Mill LAA, upward hydraulic gradients are consistently observed at QR-19-10A/B, likely as a result of proximity to higher elevation areas to the east. The shallow well at this location, QR-19-10B, is consistently dry, but the deeper nested well has a hydraulic head higher than the bottom of the overlying well, suggesting that the shallower well is either installed in a lower permeability material or is above a confining layer of some type. This observation is consistent with drilling observations for the shallow groundwater table wells (MW-19-01 through MW-19-06), which did not observe groundwater in the overburden material but, when groundwater was located in the underlying bedrock, the hydraulic head in the bedrock well rose to the elevation of the overburden after well installation. Vertical hydraulic gradients at the MW16-02S/D monitoring well pair to the north were variable throughout the course of a year. Upward vertical hydraulic gradients were observed during low groundwater conditions (i.e., from August to November), whereas downward hydraulic gradients were observed during periods of relatively high groundwater elevations during the rest of the year.

7.5.3.4.4 Groundwater-Surface Water Interaction

Regional and local hydrometric data for the Project is described in the Hydrology Existing Conditions Reports for the Mine Site and QR Mill (Golder, 2021e; 2021f; Appendix 7.4-1 and Appendix 7.4-2) and has been used to estimate baseflow. Baseflow is defined as the flow that enters a surface water stream through the subsurface. Baseflow was defined as a percentage of the total flow. The recorded discharge hydrographs at each monitoring station were analyzed to visually estimate the baseflow portion of the hydrograph. This portion was then compared to the total surface water flow and a percent baseflow was calculated for each month to express that.

There are five local hydrometric stations within the Mine Site LAA and five within the QR Mill LAA. The location of the hydrometric stations and associated watershed are presented in the Hydrology Existing Conditions Reports and included in Appendix L of the Hydrogeology Existing Conditions Report (Appendix 7.5-1). Table 7.5-15 presents the estimated range of baseflow for local stations within the

Mine Site LAA. Table 7.5-16 presents the estimated range of baseflow for local stations within the QR Mill LAA.

7.5.3.4.5 Groundwater Quality

The groundwater quality results are presented below for the Mine Site LAA and QR Mill LAA hydrostratigraphic units. The results are discussed based on general parameters (i.e., pH, turbidity, total dissolved solids [TDS]) and parameters with concentrations above the SDWQG in the Water Quality Guideline Series as part of the BC Ambient Water Quality Guidelines, Drinking Water, and Fresh Water Aquatic Standards in BC Contaminated Sites Regulation (CSR) Schedule 3.2 (B.C. Reg. 375/96). Hydrostratigraphic units and individual monitoring wells are additionally examined in terms of major ion chemistry using Piper Plots (Appendix I) and in terms of temporal trends using time-series graphs (Appendix H) in the Hydrogeology Existing Conditions Report (Appendix 7.5-1).

7.5.3.4.5.1 Mine Site

Table 7.5-7 summarizes monitoring locations, sampling period of record, and screened hydrostratigraphic unit for each of the monitoring wells/temporary sampling points discussed below. This section discusses the general characteristics of the four main hydrostratigraphic units in the LAA, including bedrock, overburden, Historical Mill Tailings, and historical mine workings. Detailed Mine Site water quality data are presented in Appendix G of the Hydrogeology Existing Conditions Report (Appendix 7.5-1).

Bedrock water quality is mostly consistent across the LAA. Four monitoring wells (MW-HL-16-02, MW18-01B, MW18-02B, and MW18-03B) had historically high pH measurements (>9). These high pH measurements are likely a result of grout infiltration within the sand pack, which has an observed effect on groundwater water quality at these locations as indicated by the parameters identified above CSR standards. The remainder of the bedrock monitoring wells had circumneutral pH values, which are considered more indicative of bedrock water quality at the Mine Site LAA. Water quality trends at the monitoring wells with circumneutral pH were relatively consistent and stable across the Mine Site LAA.

In the overburden aquifers, there are distinct differences in water quality throughout the LAA. Regional overburden aquifers are, for the most part, defined by lower water quality concentrations than the other hydrostratigraphic units. One exception is arsenic concentrations at MW-LL-16-03B, which have been consistently above the CSR Drinking Water Standards and are not representative of the entire regional aquifer.

Table 7.5-15 Estimated Baseflow for the Local Stations Within the Mine Site Local Assessment Area

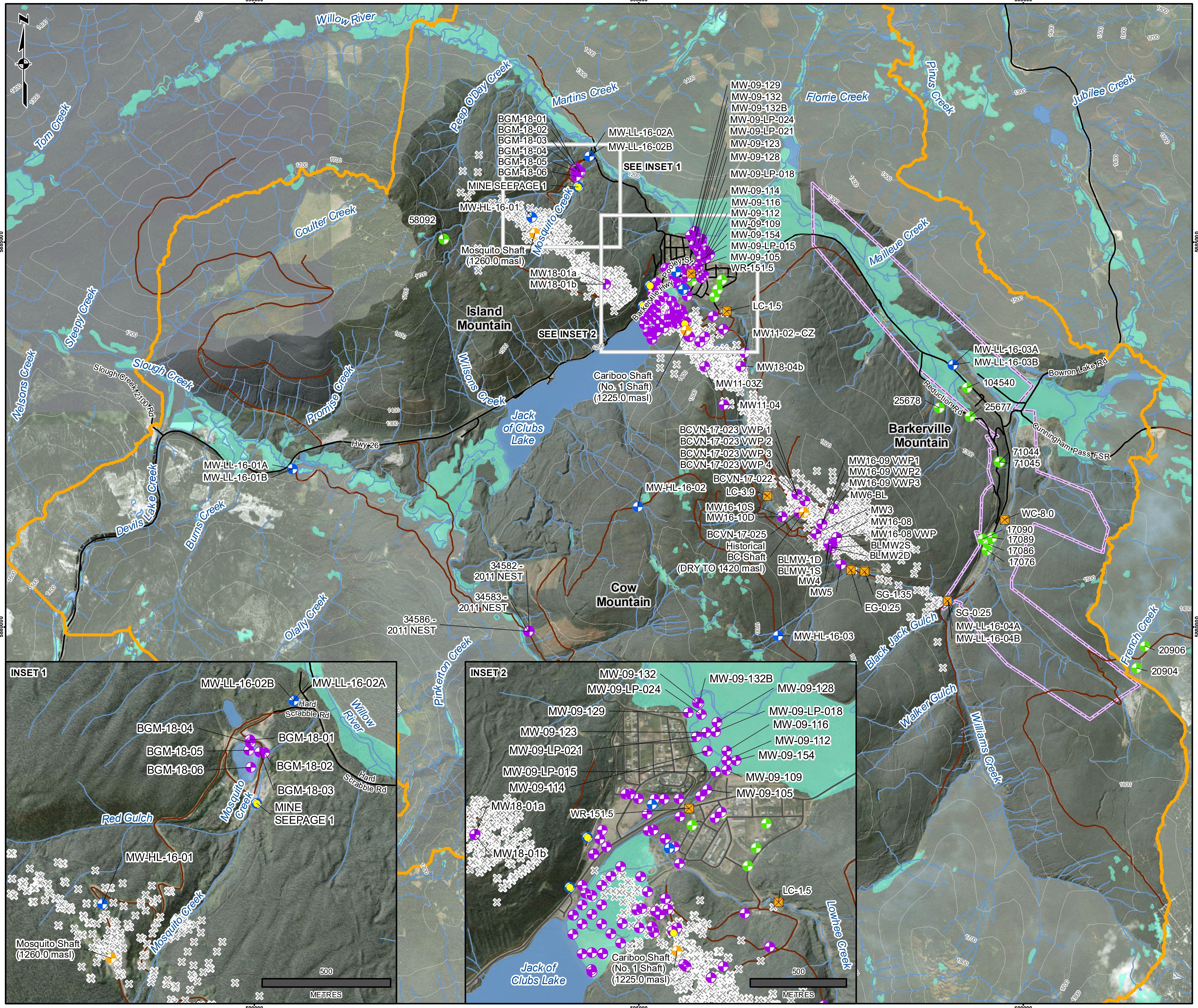
Station	Drainage Area (km^2)	Estimated Mean Baseflows (m^3/s)												
		Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseflow %			91%	92%	82%	62%	67%	89%	79%	76%	72%	75%	84%	83%
H12-Black Jack Gulch upstream of Barkerville	1.5	0.011	0.004	0.002	0.003	0.009	0.034	0.040	0.014	0.005	0.005	0.007	0.007	0.004
H25-Mosquito Creek close to the confluence with the Willow River	2.7	0.029	0.009	0.006	0.007	0.024	0.087	0.107	0.037	0.014	0.014	0.019	0.019	0.010
H24-Slough Creek downstream of the confluence with Coulter Creek	24.2	0.339	0.110	0.071	0.080	0.268	1.009	1.248	0.421	0.161	0.165	0.210	0.217	0.117
H21-Jack of Clubs Creek upstream of Jack of Clubs Lake	31.5	0.513	0.164	0.110	0.123	0.405	1.547	1.872	0.627	0.237	0.251	0.322	0.326	0.175
H16-Willow River downstream of the confluence with Mosquito Creek	110.4	1.367	0.448	0.293	0.328	1.122	4.102	4.903	1.667	0.612	0.645	0.898	0.919	0.466

Notes: m^3/s = cubic metre per second; km^2 = square kilometres; % = percent.

Table 7.5-16 Estimated Baseflow for the Local Stations Within the Quesnel River Mill Local Assessment Area

Station	Estimated Mean Baseflows (m^3/s)												
	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseflow %		89%	83%	50%	49%	82%	84%	71%	79%	81%	74%	72%	84%
SW2 – upstream of Sandy Lake	0.008	0.005	0.003	0.004	0.035	0.025	0.008	0.006	0.003	0.003	0.002	0.003	0.002
SW3 – downstream of Sandy Lake	0.012	0.007	0.004	0.006	0.049	0.035	0.012	0.008	0.005	0.004	0.003	0.004	0.003
Creek #2	0.003	0.002	0.001	0.002	0.014	0.01	0.003	0.002	0.001	0.001	0.001	0.001	0.001
Creek #2.5	0.001	0.0004	0.0002	0.0003	0.0027	0.0019	0.0006	0.0004	0.0003	0.0002	0.0002	0.0002	0.0002
Creek #3	0.002	0.001	0.001	0.001	0.008	0.006	0.002	0.001	0.001	0.001	0.001	0.001	0.001

Notes: m^3/s = cubic metre per second; % = percent.



LEGEND

- GOLDER WELLS
- NON-GOLDER BOREHOLES AND WELLS
- WATER WELL RECORDS
- GROUNDWATER SEEPAGE LOCATIONS
- ODV HYDROMETRIC MONITORING STATION
- HISTORIC MINE WORKINGS
- ODV GEOLOGY DATABASE BEDROCK CONTACTS
- LOCAL ASSESSMENT AREA
- BARKERVILLE HISTORIC TOWN AND PARK
- HIGHWAY/ROAD
- RESOURCE ROAD
- CONTOUR (100 m)
- WATERCOURSE
- WETLAND
- WATERBODY

REFERENCE(S)

1. TRAILS, WATER FEATURES, ROADS, BARKERVILLE HISTORIC TOWN/PARK, CITIES (INSET), PROVINCIAL BORDERS (INSET) OBTAINED FROM THE B.C. MINISTRY OF FORESTS, LAND AND NATURAL RESOURCE OPERATIONS.
2. HILLSHADE DERIVED FROM LIDAR DATA FLOWN BY MCELHANEY CONSULTANTS LTD. JUNE 27, 2016.
3. BASE DATA SOURCE: ESRI, GEOBASE, NRCAN, AND THE GIS USER COMMUNITY.
4. INSET TOPOGRAPHIC MAP © ESRI AND ITS LICENSORS. USED UNDER LICENSE, ALL RIGHTS RESERVED.
5. SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY
SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY.

NAD83 CSRS
UTM ZONE 10N

1,000 0 1,000
1:50,000 METRES

CARIBOO GOLD PROJECT

GROUNDWATER - SUBSURFACE DATA LOCATIONS
MINE SITE LOCAL STUDY AREA

OSISKO DEVELOPMENT

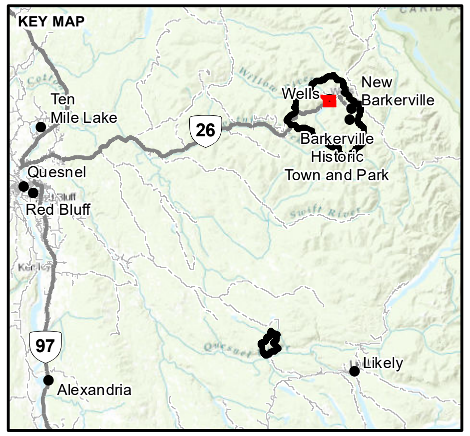
REV.	DESCRIPTION	DATE	INITIALS
0	FINAL - APPROVED	2021-07-15	J.L.
0	FINAL - REVIEWED	2021-07-15	D.C.
0	FINAL	2021-07-15	C.C.
A	DRAFT	2021-06-11	J.P.

PROJECT NO.	PHASE	REV.	FIGURE
1774160	41500/1506	0	7.5-6

25mm IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

LEGEND

- GOLDER WELLS
- NON-GOLDER BOREHOLES AND WELLS
- WATER WELL RECORDS
- GROUNDWATER SEEPAGE LOCATIONS
- ODV HYDROMETRIC MONITORING STATION
- HISTORIC MINE WORKINGS
- ODV GEOLOGY DATABASE BEDROCK CONTACTS
- HIGHWAY/ROAD
- RESOURCE ROAD



REFERENCE(S)

1. TRAILS, WATER FEATURES, ROADS, OBTAINED FROM THE B.C. MINISTRY OF FORESTS, LAND AND NATURAL RESOURCE OPERATIONS.
2. IMAGERY (2017 AND 2019) PROVIDED BY ODV.
3. BASE DATA SOURCE: ESRI, GEOBASE, NRCAN, AND THE GIS USER COMMUNITY.
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NAD83 CSRS
UTM ZONE 10N

100 0 100
1:5,000 METRES

OSISKO DEVELOPMENT

CARIBOO GOLD PROJECT

GROUNDWATER - SUBSURFACE DATA LOCATIONS
WELLS HISTORIC TAILINGS DEPOSIT

REV.	DESCRIPTION	DATE	INITIALS
0	FINAL - APPROVED	2021-07-15	J.L.
0	FINAL - REVIEWED	2021-07-15	D.C.
0	FINAL	2021-07-15	C.C.
A	DRAFT	2021-06-11	J.P.

PROJECT NO.	PHASE	REV.	FIGURE
1774160	41500/1506	0	7.5-7

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25mm

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The glaciolacustrine aquifer is located below the Historical Mill Tailings deposits and placer outwash/alluvial fan (MW09-007B, MW09-007C, MW09-29B, MW09-063B, MW09-091B, and MW09-091C). In areas where the aquifer underlies Historical Mill Tailings (e.g., MW09-007B, MW09-007C, and MW09-029B), there is no evidence of downward migration of porewater from the tailings based on similar concentrations of parameters between previous sampling (2009-2010) and the most recent sampling results.

The Wells Aquifer has some varying water quality between the three monitoring wells (MW-19-07, MW-19-08D, and District of Wells MW). The District of Wells MW had higher concentrations of TDS, calcium, sulphate, and arsenic than MW-19-07 and MW-19-08D, which were bicarbonate dominant with lower metal concentrations. All samples from the District of Wells MW had arsenic concentrations above the CSR drinking water standard.

Groundwater quality in the Wells Historical Tailings Deposit is defined by more parameters above CSR standards and SDWQG compared to other hydrostratigraphic units. This trend is most evident at MW09-007A, which is installed within the historical tailings near Jack of Clubs Lake. Recent water quality results at MW09-007A are consistent, and in some instances, decreasing (e.g., cobalt, iron, and nickel), compared to previous results (2009/2010) and suggest ongoing weathering of the sulphide bearing Historical Mill Tailings in this area. In other areas of the Historical Mill Tailings (e.g., MW09-26, MW09-29A, and MW09-52), concentrations of most parameters (e.g., sulphate, arsenic, cobalt, iron, nickel, and zinc) are relatively stable over time and lower when compared to MW09-007A. However, it is noted that MW09-026 has higher concentrations of some parameters (e.g., calcium, magnesium, and sulphate) in recent water quality samples compared to the previous sampling.

Seepage from the Wells Historical Tailings Deposit and historical mine workings show distinct differences in composition between locations. Seepage monitored at historical mine workings (e.g., Mine Seepage 1, 2, 3, and 5) typically has low concentrations of most parameters, with the exception of cobalt at Mine Seepage 5 and zinc at Mine Seepage 1, although sampling is sporadic due to flow from these locations only occurring during wet (high precipitation) times of the year. The water quality at these seepage locations contrasts with the water quality from deeper historical mine workings, which is characterized by the results from 2017-Artesian-BH and CM-20-050 and had higher concentrations of several key parameters (e.g., sulphate and arsenic). The water quality and intermittent flow suggest that these mine seepage locations may be more a result of groundwater infiltration through the overlying rock mass as opposed to flooded mine workings discharge. The other seepage locations (HT Seepage 1, HT Seepage 2, and Artesian) are located on the historical tailings area and the source of seepage is currently undefined. HT Seepage 2 is downgradient of HT Seepage 1 and Artesian, which are both directly at the observed seepage location. As expected, concentrations typically decrease along the seepage flow pathway. Some attenuation of metal loadings may occur at HT Seepage 1, as calcium and sulphate concentrations suggest gypsum saturation and iron staining is noted along the flow pathway, suggesting oxidation of iron. In comparison, water quality at these locations differs from other seepage locations and is characterized by higher concentrations of many parameters (e.g., sulphate, arsenic, cobalt, iron, and manganese), which are more like the deeper historical mine workings water quality (2017-Artesian-BH and CM-20-050). Although the seepage expresses at surface, some flow within the historical tailings may also be occurring. Increasing trends in major ions are noted at MW09-026 (directly downgradient of the seepage location) in the 2020 sampling compared to the 2009/2010 results. Metal concentrations remain lower at MW09-026 and further monitoring would be required to understand if subsurface flow is occurring from the seepage location.

7.5.3.4.5.2 QR Mill

Table 7.5-8 summarizes monitoring locations, sampling period of record, and screened hydrostratigraphic unit for the QR Mill LAA monitoring wells. The main hydrostratigraphic units in the LAA include deep bedrock (>50 m), shallow bedrock (<50 m), and overburden. Detailed QR Mill groundwater quality data are presented in Appendix G of the Hydrogeology Existing Conditions Report (Appendix 7.5-1).

Deep bedrock groundwater has higher arsenic concentrations at two locations (MW8 and MW10), with an increasing trend at MW10; both wells are installed in the proximity of known historical underground workings (Figure 7.5-8). Zinc concentrations also show an increasing trend at two locations (MW13 and MW11-01-QR); both monitoring wells are also installed downgradient of mining areas.

Concentrations of most parameters were relatively stable in shallow bedrock monitoring wells (e.g., sulphate, total ammonia, chromium, copper, and nickel). Arsenic concentration trends are consistent with groundwater migration within the shallow bedrock from the tailings facility area southward. Arsenic concentrations decreased at MW16-01D and increased in 2020 at QR19-08A. The cause of a large increase in iron, manganese, and zinc concentrations at MW11-02-QR in 2020 is currently undefined, but believed to be related to sampling error, although mining-related influences cannot be ruled out given the observed trends in MW11-01-QR (deeper bedrock) installed at the same location.

In the overburden, groundwater quality trends are predominantly driven by potential seepage from the existing tailings facility. This is evidenced by the high TDS, sulphate, ammonia, and cyanide concentrations in the monitoring wells in the vicinity of the tailings facility (both to the north and south). To the north, groundwater quality trends have been relatively stable throughout monitoring. The exceptions are increasing trends in some parameters near the tailings facility (e.g., arsenic, iron, and zinc). Downgradient to the north of the QR TSF (e.g., MW16-02S), concentrations show no trends in sulphate or dissolved metals, which is considered representative of regional overburden groundwater quality. Similar trends are noted to the south of the QR TSF, with monitoring wells close to the QR TSF displaying higher concentrations of some parameters, indicative of seepage, while monitoring wells further to the south (QR19-08B) show lower concentrations.

7.5.3.4.6 Conceptual Hydrogeological Model

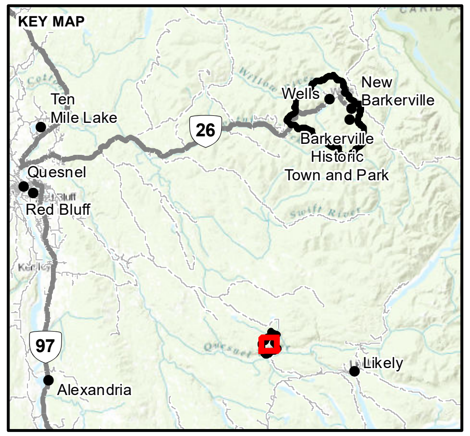
A conceptual hydrogeological model is a simplified descriptive and pictorial representation of the hydrogeological system that organizes and simplifies the hydrogeology so that it can be readily modelled in a numerical model. The conceptual hydrogeological model defines the major groundwater processes (i.e., inflows, outflows, groundwater flow direction) in general terms to facilitate understanding of the major concepts in site-wide groundwater distribution and movement.

7.5.3.4.6.1 Mine Site

The conceptual hydrogeological model for the Mine Site LAA can be described as a mountain-valley hydrogeological system that has been altered by historical and current mining processes. The conceptual flow system for the Mine Site LAA is shown on Figure 7.5-9, and the conceptual flow system for the Historical Tailings Deposit Area is shown on Figure 7.5-10. Cross-sections of the conceptual flow system are shown on Figures 7.5-11 to 7.5-12. A summary of the conceptual model is provided below.

LEGEND

- GOLDER WELLS
- NON-GOLDER BOREHOLES AND WELLS
- ODV HYDROMETRIC MONITORING STATION
- LOCAL ASSESSMENT AREA
- CONTOUR (10 m)
- WATERCOURSE



REFERENCE(S)

1. WATER FEATURES, CITIES (INSET), PROVINCIAL BORDERS (INSET) OBTAINED FROM THE B.C. MINISTRY OF FORESTS, LAND AND NATURAL RESOURCE OPERATIONS.
2. SERVICE LAYER CREDITS: SOURCE: ESRI, MAXAR, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY ESRI, GARMIN, GEBCO, NOAA NGDC, AND OTHER CONTRIBUTORS.
3. BASE DATA SOURCE: ESRI, GEOBASE, NRCAN, AND THE GIS USER COMMUNITY.
4. INSET TOPOGRAPHIC MAP © ESRI AND ITS LICENSORS. USED UNDER LICENSE, ALL RIGHTS RESERVED.

NAD83 CSRS
UTM ZONE 10N

200 0 200
1:10,000 METRES

OSISKO DEVELOPMENT

CARIBOO GOLD PROJECT

GROUNDWATER - SUBSURFACE DATA LOCATIONS
QR MILL LOCAL STUDY AREA

REV.	DESCRIPTION	DATE	INITIALS
0	FINAL - APPROVED	2021-07-15	J.L.
0	FINAL - REVIEWED	2021-07-15	D.C.
0	FINAL	2021-07-15	C.C.
A	DRAFT	2021-06-11	J.P.

PROJECT NO.	PHASE	REV.	FIGURE
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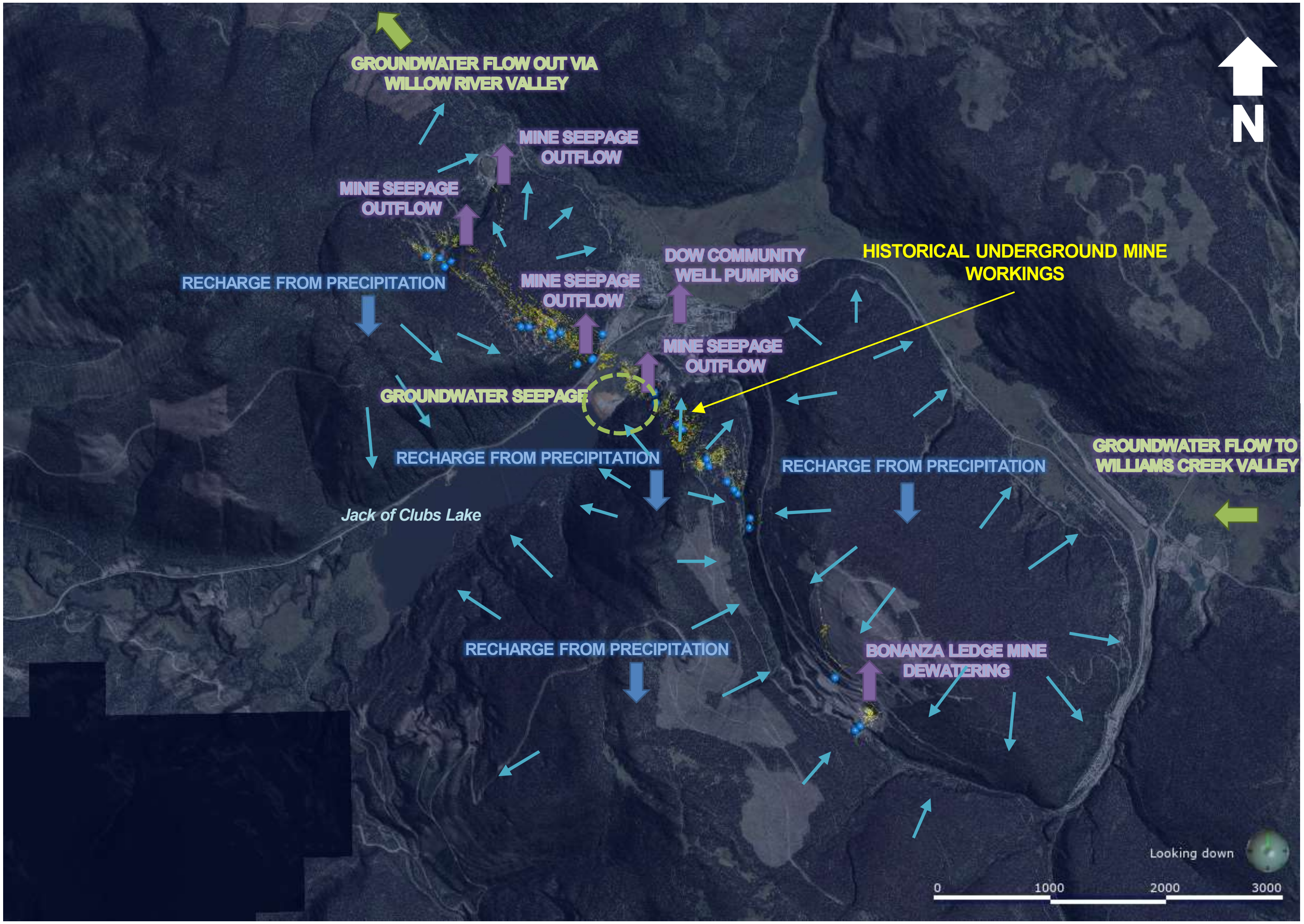


GROUNDWATER INPUTS
GROUNDWATER OUTPUTS
GROUNDWATER TRANSFERS
GROUNDWATER FLOW DIRECTION
HISTORICAL MINE OPENINGS

BARKERVILLE GOLD MINES LTD.

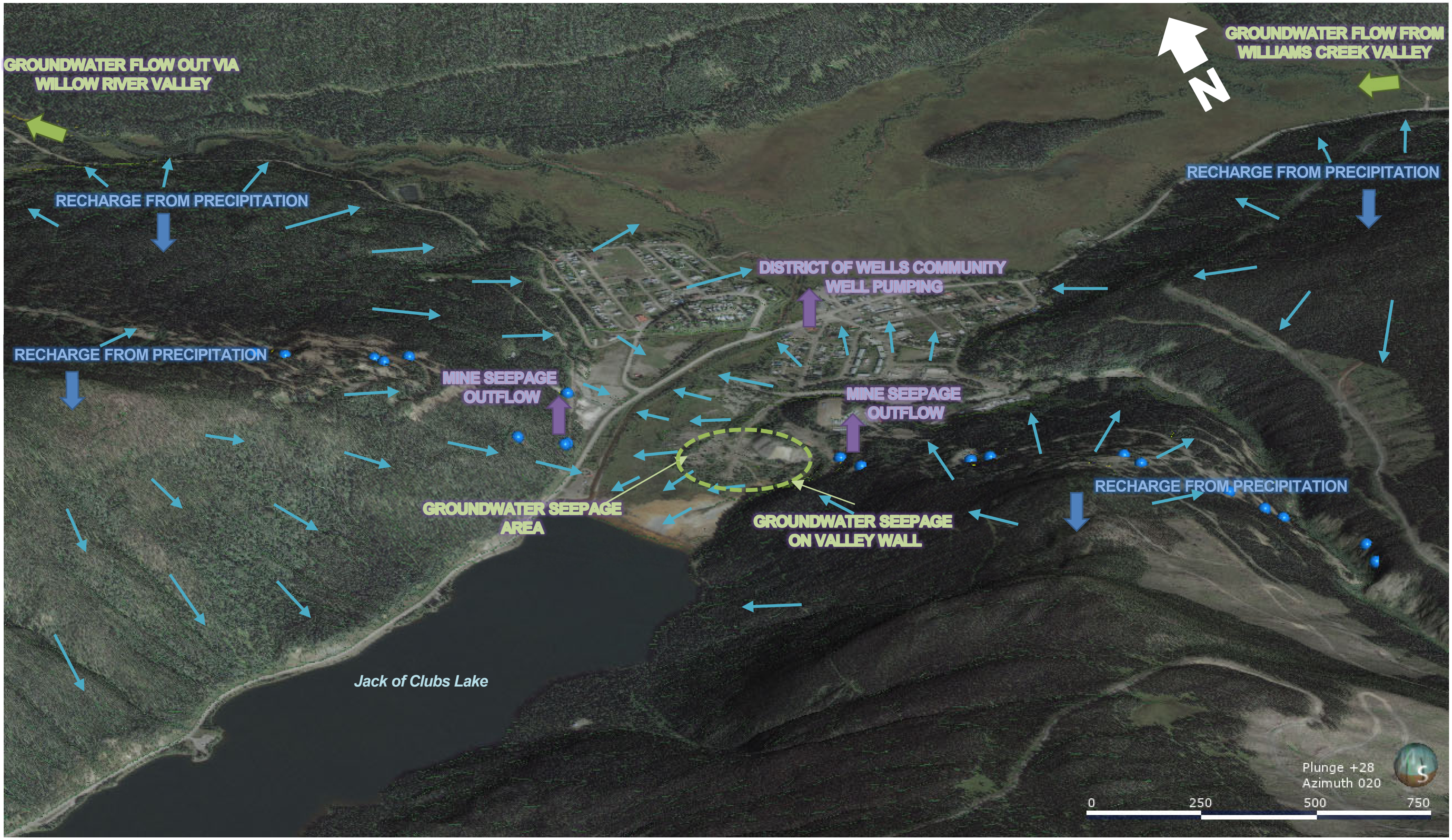
CARIBOO GOLD PROJECT

OSISKO DEVELOPMENT

YYYY-MM-DD	2021-06-09
PREPARED	SR
DESIGNED	SR
REVIEWED	NGG
APPROVED	JL

MINE SITE LOCAL ASSESSMENT AREA
CONCEPTUAL GROUNDWATER FLOW MODEL

PROJECT NO.	PHASE	REV.	FIGURE
177416001	41500/1514	0	7.5-9



GROUNDWATER INPUTS

GROUNDWATER OUTPUTS

GROUNDWATER TRANSFERS

GROUNDWATER FLOW DIRECTION

BARKERVILLE GOLD MINES LTD.

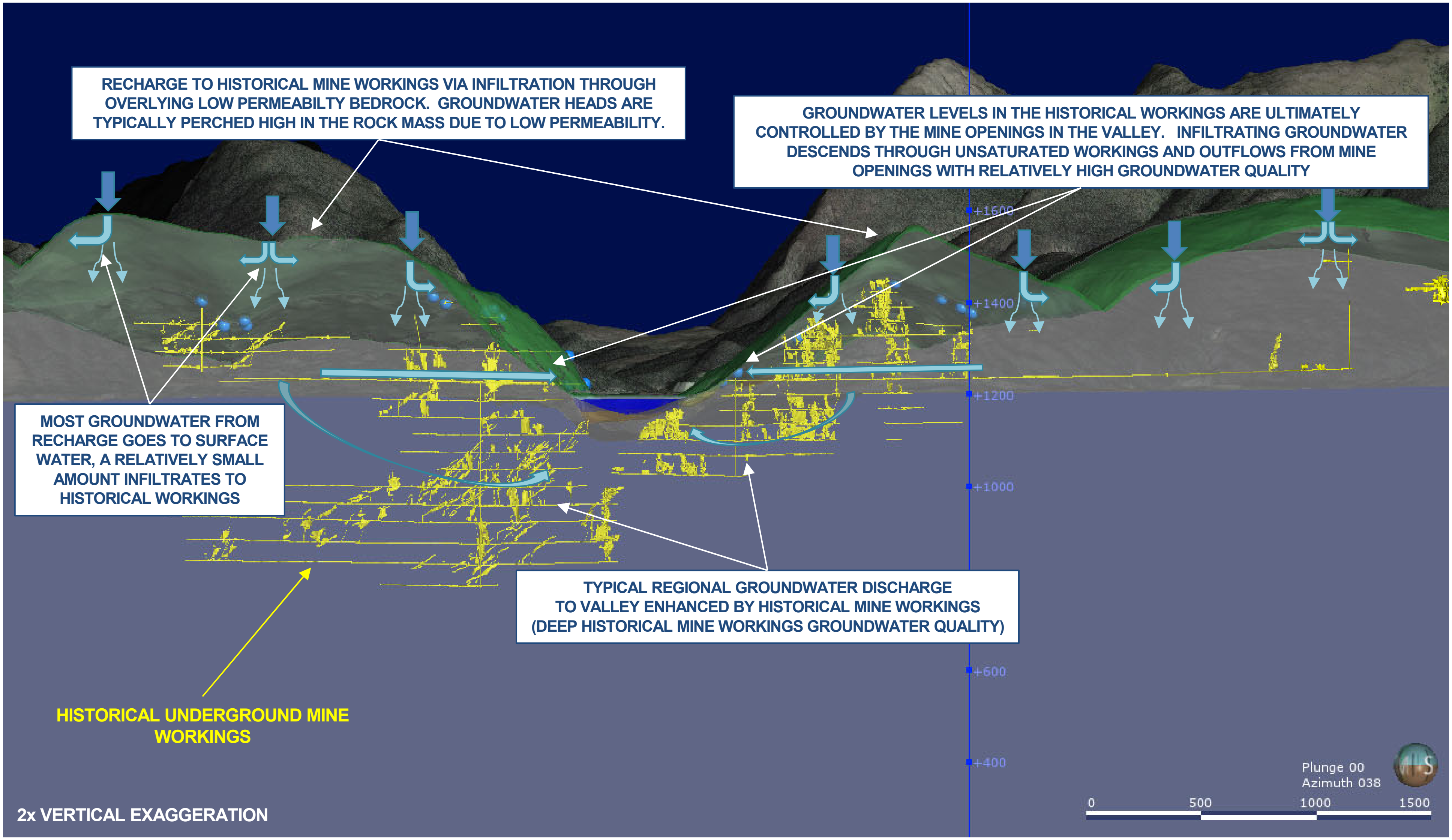
OSISKO DEVELOPMENT

YYYY-MM-DD	2021-06-09
PREPARED	SR
DESIGNED	SR
REVIEWED	NGG
APPROVED	JL

CARIBOO GOLD PROJECT

MINE SITE LOCAL ASSESSMENT AREA
CONCEPTUAL GROUNDWATER FLOW MODEL
IN WELLS HISTORICAL TAILINGS DEPOSIT AREA

PROJECT NO.	PHASE	REV.	FIGURE
177416001	41500/1514	0	7.5-10



GROUNDWATER FLOW

HISTORICAL MINE OPENINGS

PRECIPITATION

BARKERVILLE GOLD MINES LTD.

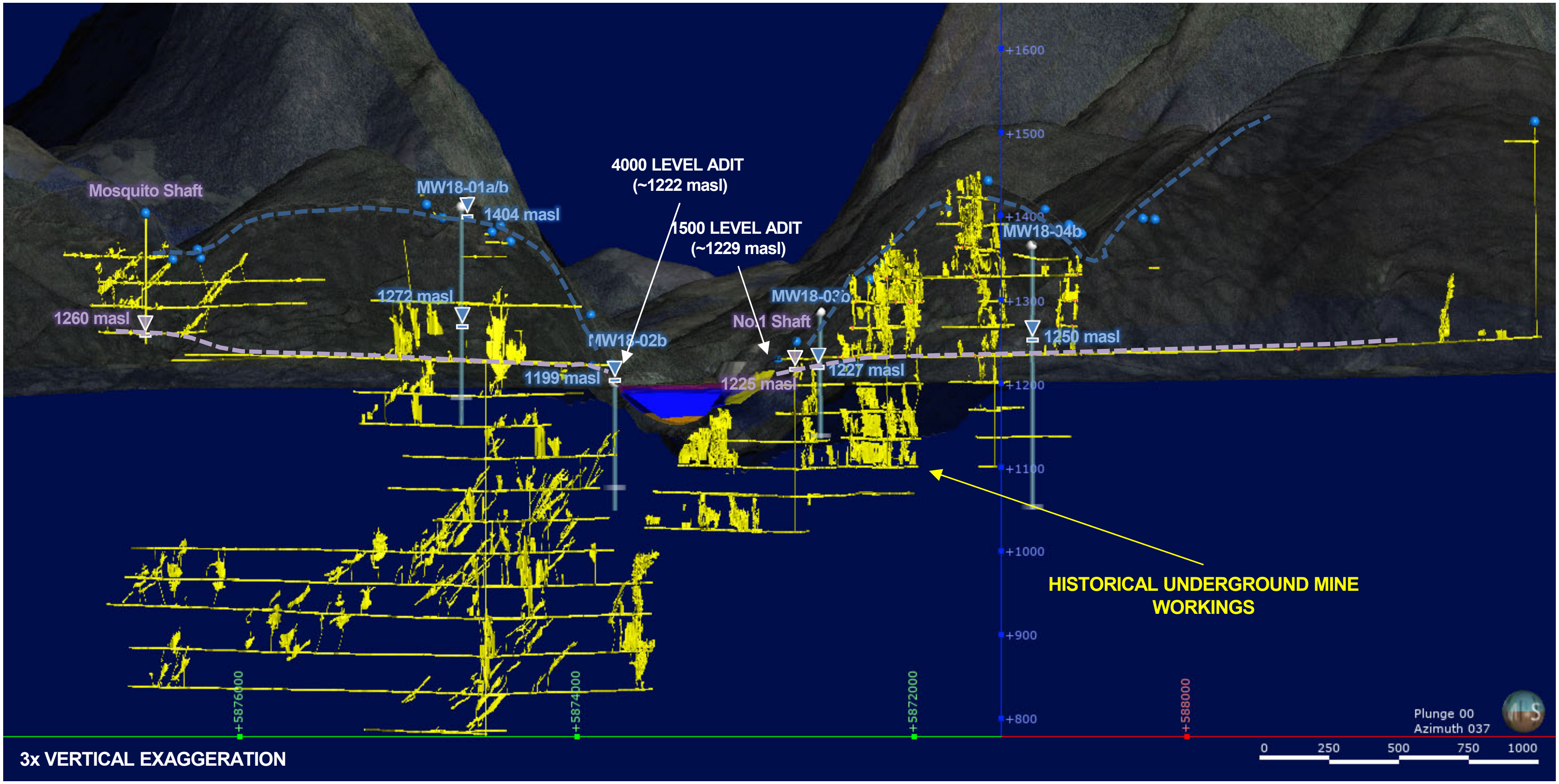
CARIBOO GOLD PROJECT

OSISKO DEVELOPMENT

YYYY-MM-DD	2021-06-09
PREPARED	SR
DESIGNED	SR
REVIEWED	NGG
APPROVED	JL

MINE SITE LOCAL ASSESSMENT AREA
CONCEPTUAL CROSS-SECTION GROUNDWATER FLOW MODEL
REGIONAL GROUNDWATER FLOW / HISTORICAL MINE WORKINGS

PROJECT NO.	PHASE	REV.	FIGURE
177416001	41500/1514	0	7.5-11



WATER LEVEL IN HISTORICAL MINE WORKINGS

GROUNDWATER LEVEL

INFERRED WATER LEVEL IN HISTORICAL MINE WORKINGS

INFERRED GROUNDWATER TABLE

HISTORICAL MINE OPENINGS

BARKERVILLE GOLD MINES LTD.

CARIBOO GOLD PROJECT

OSISKO DEVELOPMENT

YYYY-MM-DD	2021-06-09
PREPARED	SR
DESIGNED	SR
REVIEWED	NGG
APPROVED	JL

MINE SITE LOCAL ASSESSMENT AREA
CONCEPTUAL CROSS-SECTION AND GROUNDWATER LEVELS NEAR HISTORICAL MINE WORKINGS

PROJECT NO.	PHASE	REV.	FIGURE
177416001	41500/1514	0	7.5-12

The overburden of the Jack of Clubs Valley is a sequence of interlayered aquifers and aquitards deposited during previous glaciations. Overall, the Mine Site hydrostratigraphy has been sub-divided into 10 hydrostratigraphic units, consisting of:

- Four local or regional overburden aquifers (Fill, Placer Outwash, Alluvium/Alluvial Fans, and Wells Aquifer),
- Three local or regional overburden aquitards (Till/Lowlands, Historical Mill Tailings, Glaciolacustrine), and
- Four bedrock units (Siltstone, Mine Area Bedrock, Regional Bedrock, and the Jack of Clubs Fault Zone).

In a broad sense, groundwater flow in the overburden near Jack of Clubs Valley can be classified into two systems: a deep groundwater system (i.e., Wells Aquifer hydrostratigraphic unit) and a shallow groundwater system (i.e., Alluvium/Alluvial Fans and Placer Outwash hydrostratigraphic units), which are separated by a thick package of low permeability clays and silts (Glaciolacustrine hydrostratigraphic unit). The Wells Aquifer is the principal groundwater source for municipal water supply for the District of Wells.

Groundwater elevations can generally be considered a subdued reflection of topography, with higher groundwater elevations in the upland areas and lower groundwater elevations in the lowland areas. Similarly, regional groundwater flow directions are generally from areas of high elevation to areas of low elevation. Both groundwater elevations and flow directions are locally influenced by underground mine workings.

Within the Mine Site LAA, there are over 180 km of historical underground mine workings that strike perpendicularly beneath the mountains that straddle the main Jack of Clubs Valley. These historical underground mine workings act as hydrogeological controls (local sinks), influencing the groundwater flow in the LAA and contributing to a downward hydraulic gradient near the underground workings. The historical underground mine workings are partially flooded, with the flooded water level controlled predominantly by adits in the valley walls located approximately 5 – 20 metres above the surface of the valley floor. These adits connecting with the valley walls are free draining and discharge groundwater seepage locally to the margins of the valley. Historical mine workings above the adit elevations daylighting in the valley walls are assumed to be predominantly dry and contributing to localized depressurization of the surrounding bedrock. The extent of depressurization is interpreted to be small based on hydraulic head data that shows saturated bedrock at higher elevations, and in consideration of the low bedrock hydraulic conductivity.

Groundwater seepage from the mine openings is observed and is greater in spring and early summer during the high-water freshet period, and declining or ceasing during the drier summer and in the winter. The flooded workings are not known to have bulkheads and, therefore, will influence hydraulic heads by equalizing the hydraulic head across the flooded interconnected workings. This process is likely responsible for the groundwater seepage observed on the south Jack of Clubs Valley wall near the Historical Mine Tailings hydrostratigraphic unit.

From a groundwater quality perspective, seepage from the mine openings tends to have lower TDS and trace metal concentrations compared to the water quality observed in the deeper flooded workings and within the bedrock and overburden. The lower TDS and trace metals concentrations in the seepage is attributed to the source of seepage likely being infiltration of recharge, with a lower residence time of this water in comparison to the regional flow system. Groundwater quality in the flooded portions of the historical underground mine workings tends to have higher TDS and trace metal concentrations in comparison to the adits that discharge to the valley walls.

Groundwater quality in the shallow valley overburden varies, with the highest concentrations of trace metals observed in the Historical Mill Tailings hydrostratigraphic unit in the Wells Historical Tailings Deposit area, in particular along the southern margin of the valley where there is exposed tailings and oxidation of the tailings appears to be ongoing. Groundwater quality in the Glaciolacustrine hydrostratigraphic unit beneath the Historical Mill Tailings has lower concentrations compared to the overlying tailings, which may indicate downward flow is low. Groundwater quality in the deeper Wells Aquifer is typically within CSR standards; however, the groundwater quality shows elevated concentrations of some parameters (e.g., TDS and arsenic) compared to overlying and underlying aquifers.

Two notable groundwater seepage areas exist in the Wells Historic Tailings Deposit area. The first, a diffuse groundwater seepage area along the southern Jack of Clubs Valley wall, flows relatively continuously and is assumed to be associated with the enhanced regional groundwater flow to the Jack of Clubs Valley. The second is a groundwater seepage area that emerged within the Wells Historical Tailings Deposit in 2018. Subsequent to the emergence of this groundwater seepage area, the location was bermed off into two ponds in sequence to contain the groundwater before outletting onto the tailings surface. The water quality of this second groundwater seepage area is similar to groundwater quality in the deep historical mine workings, although no pathway for this has been definitively established. The local increase in water levels associated with the groundwater seepage, and the construction of the ponds, has the potential to influence the groundwater flow system in this area, with steeper local gradients and higher groundwater velocities in the vicinity of the ponds. Groundwater quality in a downgradient nearby monitoring location appears to show a response to this groundwater seepage (e.g., increasing concentrations of calcium, magnesium, and sulphate).

7.5.3.4.6.2 QR Mill

The QR Mill LAA is located on a relatively exposed bedrock plateau, with a steep (greater than 300 m elevation) topographic decline along the southern side, down to the Quesnel River. The plateau, being exposed during the period of the last glaciation, had much of its overburden eroded and removed by the glaciers, resulting in a relatively thin overburden layer, comprised predominantly of glacial till overlying bedrock. The thickest overburden is located in a small, north-south oriented depression located to the east of the QR Mill. Historical and current mining activities have altered the area, with three small networks of historical underground mine workings, several small open pit mines, and the QR TSF, which sits in the saddle of the north-south oriented depression between areas of higher elevation to the east and west.

The hydrostratigraphy of the QR Mill LAA has been separated into four hydrostratigraphic units:

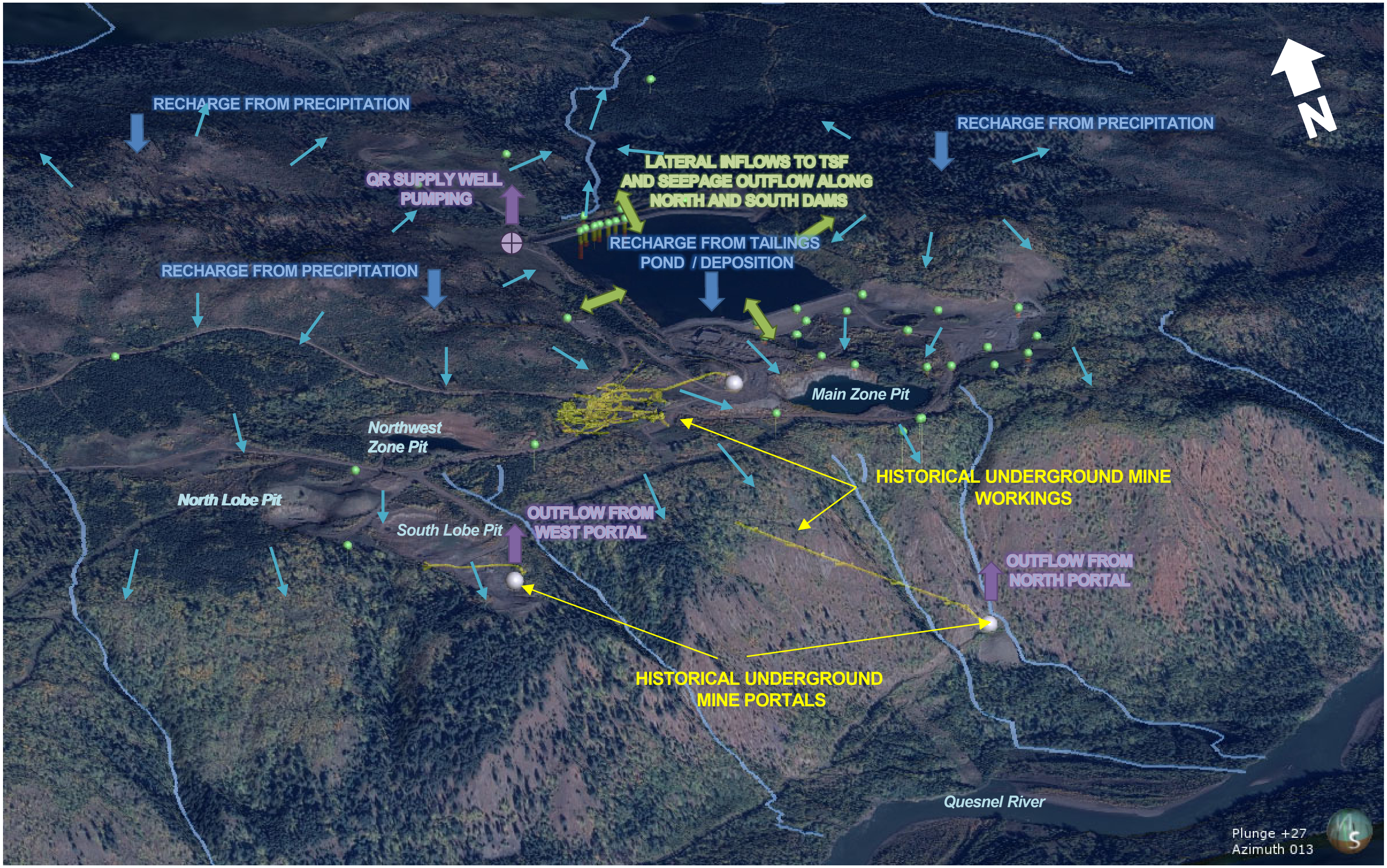
- Thin overburden (glacial till);

- Shallow weathered bedrock (upper 35 m of bedrock);
- Deep Bedrock; and
- Wally's Fault located under the western portion of the QR TSF, with an approximately north-south orientation.

The groundwater levels across the LAA are a subdued reflection of topography and are consistently close to the ground surface, with inferred preferential flow through the shallow weathered bedrock. The hydraulic properties of Wally's Fault are untested, but it is possible the fault acts as a preferential flow zone. Groundwater recharge occurs primarily in upland areas of higher elevation and groundwater discharge occurs in areas of lower elevation. Shallow groundwater levels across the LAA vary seasonally and experience two groundwater peaks during the year: one during the snowmelt/freshet period and one in the fall.

The pond levels of the QR TSF, which sits above the saddle of the north-south oriented topographic depression, provide a driver for groundwater flow. Seepage from the QR TSF is collected in ponds to the north and south of the dams, with further seepage to the north to the Rudy Creek Valley and to the south via water management infrastructure and ultimately to Creek #3. The MZP acts as a local sink for groundwater and outflows to Creek #3 as part of the local water management. The Northwest pit is also flooded and may locally affect groundwater flow, though they have no defined outflow. Shallow groundwater quality downgradient of the QR TSF shows less influence of mine activities compared to shallow groundwater quality in closer vicinity to the QR TSF.

Three historical underground workings are present in the QR LAA, with portals connected to surface (Midwest Portal, West Portal, and North Portal). Groundwater levels in the West Portal and Midwest Portal are either near ground surface or there is observed seepage discharging to ground surface. The orientation of the underground connected to the North Portal suggests this underground is free draining, with discharge at the portal. Given the underground connected to the North Portal is free draining, the underground is assumed to locally depressurize the surrounding bedrock, but its influence on groundwater levels in monitoring wells on the plateau is difficult to discern from the influence of the natural gradient developed behind the steep topographic slope. A groundwater well, QR-PW, provides the potable water supply for the mill facilities and will act as a local groundwater sink. Figure 7.5-13 presents the conceptual groundwater flow model for the QR Mill LAA.



GROUNDWATER INPUTS

GROUNDWATER OUTPUTS

GROUNDWATER TRANSFERS

GROUNDWATER FLOW DIRECTION

PUMPING WELL

BARKERVILLE GOLD MINES LTD.

OSISKO DEVELOPMENT

YYYY-MM-DD	2021-06-09
PREPARED	SR
DESIGNED	SR
REVIEWED	NGG
APPROVED	JL

CARIBOO GOLD PROJECT

QR MILL LOCAL ASSESSMENT AREA
CONCEPTUAL GROUNDWATER FLOW MODEL (PLAN VIEW)

PROJECT NO.	PHASE	REV.	FIGURE
177416001	41500/1514	0	7.5-13

7.5.4 Potential Effects

The assessment methodology used to assess the potential effects of the Project has been outlined in Section 6.0, Valued Component Assessment Methods. A summary of this assessment methodology as it relates to Groundwater is provided below in Section 7.5.3.1.

7.5.4.1 Methods

Construction, operations, and closure of the Project have the potential to change Groundwater. Potential interactions between Project components and activities during these phases on Groundwater have been identified in Section 7.5.3.3, using an interaction matrix and the approach described in Section 6.4.1.

Groundwater numerical modelling studies and water quality (geochemical) modelling studies were conducted as part of the groundwater effects assessment. These studies were also used to inform the identification of potential effects to Groundwater and the characterization of residual effects related to the Project. Therefore, for simplicity, model settings and assumptions are described in the following Sections 7.5.3.1 and 7.5.3.2. Results of model predictions are summarized in Sections 7.5.3.4.1 through 7.5.3.4.3.

Indigenous groundwater uses and users were considered in the groundwater modelling studies and groundwater effects assessment; however, review of public databases (Section 7.5.3.3.4.3), consultation, and traditional use studies (DM Cultural Services Ltd., 2019; Landmark Resource Management Ltd., 2021) did not identify current specific uses of groundwater in the LAAs.

7.5.4.1.1 Numerical Model Assessment Techniques (Quantity and Quality)

The Groundwater effects assessment for the Project uses two groundwater numerical models (one for the Mine Site and one for QR Mill) to quantify changes in groundwater quantity within the LAAs considered for Groundwater. The approach adopted for these models was designed to be consistent with the BC guidelines for groundwater modelling (ENV, 2012a).

The numerical groundwater models for the Mine Site and QR Mill were constructed using FEFLOW (Version 7.2). This numerical code was selected because it is capable of simulating variably saturated groundwater flow and solute transport in three dimensions and in heterogeneous porous media under a variety of hydrogeological boundary conditions and hydraulic stresses. The available types of boundary conditions were a key factor in the selection of FEFLOW as a wide variety is needed to simulate the evolution of mining at the Mine Site.

The groundwater models were developed based on the conceptual groundwater model presented in Section 7.5.3.4.6, and as summarized in the Hydrogeology Existing Conditions Report (Appendix 7.5-1). Development of the model and calibration, sensitivity analysis, prediction results, and limitations of the model are described in Appendix 7.5-2 for the QR Mill and Appendix 7.5-3 for the Mine Site. Overall, as documented in these appendices, the following tasks were completed to identify and quantify potential effects to Groundwater Quantity:

- Assessment points were defined for predicting changes in water quantity that linked with assessment locations for surface water quantity and quality. These assessment points included surface water features and seepage collection points associated with mine facilities.

- Numerical groundwater models were built to reflect the conceptual groundwater model for the QR Mill LAA and the Mine Site LAA.
- The developed models were calibrated to site-specific measurements of hydraulic head, estimated groundwater baseflow contributions, and measured seepage rates from existing facilities for observed conditions in 2019.
- Sensitivity analysis was completed to assess the sensitivity of the model to uncertainty in hydraulic properties of the hydrostratigraphic units.
- The calibrated model was used as the initial conditions for simulating the changes in groundwater conditions and groundwater fluxes expected to develop during operations and closure.
- A combination of steady-state and transient simulations was used to predict conditions during operations and closure according to the mine plan provided by ODV.

7.5.4.1.1.1 Mine Site Numerical Groundwater Model

Assessment Approach

The calibrated model was used to predict groundwater flow conditions for three periods: existing conditions (calibration model), operations, and post-closure. For each time period, the Mine Site Model was adjusted to represent the changes in the Mine Site that affect groundwater and run as a steady-state simulation. For operations, transient simulations were also completed to evaluate the annual change in underground dewatering rates.

Changes in groundwater flow conditions were evaluated using the following metrics:

- Changes in hydraulic head in the Mine Site LAA;
- Changes in groundwater baseflow contribution to surface water; and
- Changes in the proportion of the groundwater from the flooded underground in groundwater discharge to surface water.

Changes in the proportion of the groundwater base flow contribution originating from the flooded underground was evaluated using simplified transport analysis. Model nodes representative of the flooded underground were assigned a concentration of 100 milligrams per litre (mg/L). The resulting predicted concentration at the receptor, through advective flow only, indicates the percent contribution of flow originating from the simulated source (i.e., a predicted concentration of 20 mg/L indicates 20% of the flow originates from the simulated source). Results of the simplified transport were compared to particle tracking as a secondary check of seepage migration pathlines.

Following completion of base case predictions using the calibrated model parameters, a series of sensitivity analysis were completed in which hydraulic properties were varied by a factor of 2 to 5 from calibrated values. Model calibration results were reviewed for each of the sensitivity runs. Alternative sensitivity runs were conducted if a given sensitivity resulted in a poor calibration or reproduction of existing conditions. Only sensitivity runs that resulted in a reasonable calibration to observed data were considered in the uncertainty analysis.

Model Assumptions

The calibrated model was used to predict changes between existing conditions, operations, and closure (post-closure). The following section outlines the changes in conditions at the Mine Site that could affect groundwater flow and that were simulated in the model. Details on the model set-up and boundary conditions are presented in Appendix 7.5-3.

Existing Conditions

- The Wells Community Well is assumed to pump at 315 cubic metre per day (m^3/day). This rate corresponds to the peak day demand of 315,000 L/d stated in the AE Water Quality Investigation report (AE, 2004).
- Underground dewatering at Bonanza Ledge is in progress, with 2019 as-built conditions as provided by ODV.
- Other historical underground workings (Cariboo Gold Quartz Mine, Island Mountain Mine, Aurum Mine, and Mosquito Creek Mine) are present and assumed to be reflooded, with flooded water level elevations controlled by historic openings at surface. Individual underground workings are assumed to be hydraulically connected across their extents (ODV is not aware of bulkheads being used to separate areas of the mine developments). This assumption is conservative for the future prediction of groundwater inflow management to the proposed and historical underground developments.

Constructions and Operations

- A new potable water well will be installed to supply water to the camp. The location of this well has not been selected, but it has been assumed to be in the Wells Aquifer, such that the effect of this well on the existing Wells water supply well can be assessed. The water demand from the new potable well has been assumed to be 242 m^3/day during construction and operations. The pumping rate at the Wells Community Well is assumed to be unchanged.
- The Project underground was evaluated on an average annual basis according to the mine plan provided by ODV. It was assumed that historical underground workings would be dewatered in advance of the Project development to a depth of 50 meters below the Project workings in any given year.
- Historical and Project underground workings will be progressively backfilled with cemented and/or paste backfill. A tight seal is typically not achieved in the underground workings with this backfill; therefore, the hydraulic connection is assumed to be unimpeded by this backfill during mining. This assumption is conservative with respect to the prediction of effects associated with dewatering.
- The Bonanza Ledge Phase II Project is assumed to be complete, with all active underground mining finished. For conservative predictions of dewatering rates, the Bonanza Ledge workings are assumed to be fully flooded at the start of operations.

Conceptually, the above changes to the Mine Site are expected to lower groundwater levels near the historical and Project workings as a result of dewatering and operation of a new potable water supply well. The underground workings will act as a hydraulic sink, potentially reducing base flow to surface water and reducing mine-influenced groundwater from flowing to the Wells Aquifer.

End of Closure (Post-Closure)

Changes to the Mine Site at the end of closure relative to existing conditions and the end of operations that could affect groundwater include:

- The underground workings will be allowed to flood. Historical and Project underground workings will be progressively backfilled with cemented/paste backfill. A tight seal is typically not achieved in the underground workings with this backfill; therefore, the hydraulic connection is assumed to be unimpeded by this backfill during mining.
- Underground mine openings including portals and ventilation raises will be sealed with engineer designed plugs preventing ingress by people and animals and permitting the underground workings to be flooded to minimize further ML/ARD. It is assumed that these portals will not restrict the discharge of water if water levels in the workings rise above the mine opening.
- It is assumed that the new potable water well for the Project camp facility will be shut down in closure.

Conceptually, the above changes to the Mine Site would be expected to allow groundwater levels to recover to levels near to existing conditions. Some alteration is expected from existing conditions due to the expansion of the underground workings in width, which may result in additional underdrainage of the highlands above the underground workings.

Model Limitations

- A simplified three-dimensional geology model was constructed to support hydrogeological numerical modelling. As such, geology was simplified into major aquifers and aquitards, and may omit units of geotechnical/structural significance. This approach is considered reasonable for the objective of the regional model, which is to support the understanding of changes in seepage migration pathways and groundwater discharge quantities, but it may not represent precise pathways on a local scale.
- In general, consistent hydraulic properties were assigned to each hydrostratigraphic unit, though, in reality, local variation will occur spatially within each unit. While local modifications may have improved calibration, it is not practical to collect sufficient data to make these modifications. During calibration, assigned parameters were selected to be within the range of available field measured values and to represent groundwater conditions in the LAA and observed gradients over a larger scale.
- The Mine Site has historical underground workings, and it is assumed the extents are as provided by ODV. The historical workings are assumed to be free draining and it is assumed that no bulkheads have been installed to restrict hydraulic connection within the underground workings. The extent of underground workings provided by ODV suggest there may be gaps in the mapped coverage of existing underground workings and that other regions of the highlands may be under drained by historical workings. If this is true, residual changes in base flow may be less than predicted if the lateral extent of the existing workings is underrepresented.

- The final location of the new water supply well is not available. For this assessment, the well has been assumed to be in the Wells Aquifer such that the effect of the well on the Wells Community Well, if any, can be assessed. Site-specific testing will be required as part of final selection of the well location for evaluation of expected water quality and influence of the well on the Wells Aquifer.
- Uncertainty exists in the understanding of where flooded underground groundwater model discharges to the Jack of Clubs Valley, though discharge is expected given the upward hydraulic gradients and existing observed discharge at the surface of the historic mill tailings. Given the valley is an overall discharge zone, contributions of groundwater migration from the flooded undergrounds to surface can be reasonably assessed, as the precise location of the discharge is less sensitive to the assessment. For water that may or may not be intercepted by the water supply wells; however, the uncertainty is considered high given the sensitivity of the discharge zone area to the well capture zone. Prediction results suggest the Wells Community Well presently intercepts some mine influenced water and that this influence could increase in the future. The precise contribution cannot be fully assessed and may be both over or underestimated by the numerical model, in consideration of the uncertainty of the Wells Aquifer extent and location of existing workings under the valley. The effects assessment should therefore consider that the Wells Community Well may intercept mine influenced groundwater and evaluate the need for mitigation under this assumption.

7.5.4.1.1.2 Quesnel River Mill Numerical Groundwater Model

Assessment Approach

The calibrated model was used to predict groundwater flow conditions for three time periods: existing conditions (calibration model), end of operations, and post-closure. For each time period, the QR Mill Model was adjusted to represent the changes in the QR Mill that affect groundwater and run as a steady-state simulation.

Changes in groundwater flow conditions were evaluated using the following metrics:

- Changes in hydraulic heads in the QR Mill LAA.
- Changes in groundwater baseflow contribution to five surface water areas:
  - Rudy Creek SW2;
  - Rudy Creek SW3;
  - Creek #3;
  - Creek #2; and
  - Creek #2.5.
- Changes in the proportion of the groundwater base flow contribution originating from the TSF, MZP, NSCP, and SSCP.

Following completion of base case predictions using the calibrated model parameters, a series of sensitivity analyses were completed in which hydraulic properties were varied by a factor of 3 to 5 from calibrated values. Model calibration results were reviewed for each of the sensitivity runs. Alternative sensitivity runs were made if a given sensitivity run resulted in a poor calibration or reproduction of existing conditions. Only sensitivity runs that resulted in a reasonable calibration to observed data were considered in the uncertainty analysis.

Changes in the proportion of the groundwater base flow contribution originating from the FSTSF and MZP were evaluated using simplified transport analysis. Model nodes representative of the FSTSF, MZP, NSCP, and SSCP were assigned a concentration of 100 mg/L. The resulting predicted concentration at the receptor, through advective flow only, indicates the percent contribution of flow originating from the simulated source (i.e., a predicted concentration of 20 mg/L indicates 20% of the flow originates from the simulated source). Results of the simplified transport were compared to particle tracking as a secondary check of seepage migration path lines.

Model Assumptions

Table 7.5-17 provides a summary of key operating conditions for each prediction period (existing conditions, operations, and post-closure). Water levels assumed for the ponds and pit lakes are from key assumptions for each phase presented in the Water Balance and Water Quality Model study (KCB, 2021).

Existing Conditions:

- The QR Mill is presently in care and maintenance with the QR TSF pond maintained at an elevation of 1,028 masl.
- The water level in the MZP is maintained presently controlled at an elevation of approximately 1,000 masl.
- Seepage collection occurs in the North Tailings Dam, in the South Cross Dyke, and in the NSCP and SSCP.
- A water supply well exists to the north of the QR TSF, but extractions from the well are assumed to be negligible. This assumption is considered conservative for the prediction of Project effects when extraction occurs during operations to meet the needs of the QR Mill.

End of Operations:

- The pond in the existing QR TSF is drained and a geomembrane liner is present over the existing tailings surface to form the base of the FSTSF, with Project tailings placed over top of the liner (full-build out). Leakage through the liner was assumed to range from 0 to 0.01 L/s, based on the liner having up to 10% liner defects, as quantified and reported in the tailings design report (Appendix 1.0-10; KCB, 2021a). There will be drains above the liner that will drain to a sump or contact water collection ditch at the South Cross Dyke.
- The tailings level in the MZP would be raised from its existing elevation of approximately 976 masl to 994 masl as part of the Bonanza Ledge Phase II Project. The pond in the MZP would be lowered from 1,000 masl to approximately 995 masl (one metre above the top of tailings). Surface water levels are based on estimates in the Water Balance and Water Quality Model study (KCB, 2021) and are summarized on Table 7.4-11.
- The surface water levels in the SSCP would be slightly higher than existing conditions and have an expanded footprint. Surface water levels are based on estimates in the Water Balance and Water Quality Model study (KCB, 2021) and are summarized in Table 7.4-11.

- The potable water well to the north of the FSTSF would be operated at a maximum rate of 36 m^3/day. This pumping rate was estimated by ODV to meet the needs of the QR Mill camp, as described in Section 1.5 of Chapter 1.

Conceptually, the above changes to the QR Mill area would be expected to lower groundwater levels surrounding the FSTSF and MZP as a result of reduced infiltration of seepage through tailings (via removal of the pond and placement of the liner) and the lowering of the operation pond level in the MZP.

End of Closure (Post-Closure):

Changes to the QR Mill at the end of closure relative to existing conditions and the end of operations that could affect groundwater include:

- A cover will be placed over the filtered stack tailings that will further reduce seepage loss to the groundwater flow system. Considering both the cover and liner, infiltration to the top of the existing tailings was assumed to range between 0 to 0.001 L/s, based on the liner and cover having up to 10% liner defects, as quantified and reported in the tailings design report (Appendix 1.0-10; KCB, 2021a).
- The tailings level in the MZP would be unchanged from end of operations and the completion of the Bonanza Ledge Phase II Project.
- The pond in the MZP is assumed to be at spillway elevation, which would be approximately 2 m higher than existing conditions and 1 metre higher than the current spillway elevation.
- The SSCP would be breached and is assumed to be a free drainage discharge zone, with runoff inferred to go to the MZP.
- The potable water well to the north of the FSTSF is assumed to shut down (pumping rate of zero).

Conceptually, the above changes to the QR Mill area would be expected to further lower groundwater levels surrounding the FSTSF as a result of reduced infiltration of seepage through tailings (via removal of the pond and placement of the liner and cover placement). Slight changes in water levels are possible near the MZP due to the change in spillway height, but these are expected to be minor since it is only raised by 1 m.

Table 7.5-17 Quesnel River Mill Model – Key Model Settings for Boundary Conditions

Assumption	Stage		
	Existing Conditions	End of Operations	Post-Closure
Simulated Infiltration through the liner	N/A – No Liner Pond at 1,028 masl	0 mm/y to 1.6 mm/y (0 L/s to 0.01 L/s)	0 mm/y to 0.16 mm/y (0 L/s to 0.001 L/s)
Potable well	-	36 m^3/day	-
Top of Tailings Stored in MZP (masl)	976	994	994
Water level in MZP (masl)	1,000	995	1,002
SSCP (masl)	1,015	1,018	N/A – Pond breached
Water level in the NSCP (masl)	1,002	1,002	1,002

Notes: mm/yr = millimetres per year; L/s = litres per second; masl = metres above sea level; MZP = Main Zone Pit; N/A = not applicable; m^3/day = cubic metres per day; NSCP = North Seepage Collection Pond; SSCP = South Seepage Collection Pond.

Model Limitations

- A simplified three-dimensional geology model was constructed to support hydrogeological numerical modelling. As such, geology was simplified into major aquifers and aquitards, and may omit units of geotechnical significance. This approach is considered reasonable for the objective of the model, which is to support the understanding of changes in seepage migration pathways and groundwater discharge quantities, but it may not represent precise pathways on a local scale.
- In general, consistent hydraulic properties were assigned to each hydrostratigraphic unit, though, in reality, local variation will occur spatially within each unit. While local modifications may have improved calibration, it is not practical to collect sufficient data to make these modifications. During calibration, assigned parameters were selected to be within the range of available field measured values and to represent groundwater conditions in the LAA and observed gradients over a larger scale.
- The QR Mill has historical underground workings, and it is assumed the extents are as provided by ODV. The historical workings are assumed to be free draining and it is assumed no bulkheads have been installed to restrict hydraulic connection within the underground workings. As Project-related changes relevant to groundwater are limited to the FSTSF, assumptions related to the historical workings are thought to have negligible effect on model predictions.
- Construction details for the existing water supply well are not available. The well was assumed to be installed in the overburden and shallow bedrock; however, completion details and the ability of the well to sustain the target pumping rate for operations will need to be assessed. A new well may be required to achieve the target extraction rate if the existing well is found to be too shallow or in poor condition. However, as the model simulations consider the target rate, Project effects if a new well is installed in the same general area would be like that presented in this assessment.

7.5.4.1.2 Mine Site Water Quality Source Terms

Assessment Approach

The results of the water quality assessment are discussed in detail in Appendix 7.5-4. A water quality prediction (i.e., source-term) was developed for the underground mine workings at closure, including the period of initial flooding and stable conditions after the flooding of the mine. The underground mine backfill (comprising cemented and/or paste backfill) and exposed rock in the walls of the underground mine workings will contribute soluble load to groundwater during mine water recharge. The underground mine source terms were evaluated in the context of applicable water quality guidelines, monitored groundwater quality from historical underground workings (represented by sample CM-20-050 [2020-07-30]), and the composition of the District of Wells community water supply (represented by results from monitoring well District of Wells MW).

The underground mine water quality source term was developed using a mass loading approach. Mass loading rates were calculated for the exposed wall rock (represented by ore sorter waste) using geochemical test results, including humidity cell test data. The total mass of contributed by each material type was estimated based on the volume of material exposed in the walls of the underground mine workings. The total mass load was subsequently converted to a concentration-based water quality (mg/L) using the predicted average groundwater flow rate in the underground mine, discussed in Appendix 7.5-3.

Mass loading rates representative of the predicted initial groundwater quality were developed using the first six weeks of humidity cell test data, which represents the soluble load that will be released from rock during the flooding of mine workings. Mass loads were calculated for base case and upper-case conditions using the average and 95th percentile data from the existing conditions geochemical dataset over the described time periods. The mass loads for each of these scenarios were then converted to a water quality using average groundwater inflow rates.

Groundwater from the flooded historical mine workings currently discharges to the Wells Aquifer. The Wells Aquifer supplies potable water to the District of Wells via a pumping well and is currently interpreted to intercept groundwater from the flooded historical mine workings (Appendix 7.5-3). A potential exists for the District of Wells community water supply pumping well to capture increased mine influence water in the post-closure period, following re-flooding of the historical and future mine workings. Based on the results of the hydrogeological model (assuming mitigation), it is predicted that the District of Wells community water supply well conservatively could comprise up to 10% mine water at closure.

Assumptions

The water quality predictions relied on the following assumptions:

- It is assumed that the mine will be completely flooded at closure and 100% of the surface area in the underground workings will interact with groundwater during initial flooding.
- It is assumed that the stored load in the exposed rock wall of the historical underground workings is still available for interaction with groundwater and will contribute mass loads in addition to the planned workings.
- The mass loads associated with the wall rock exposed in the underground mine workings were conservatively assumed to be equal to mass loads associated with ore sorter waste material.

Model Limitations

The water quality predictions results are inherently bounded by the same limitations that effect the mine site numerical groundwater model. The model assumes a static water quality, when, in reality, underground mine water quality may vary over time as the mine fills, and soluble load is flushed from the mine walls.

7.5.4.2 Valued Components, Assessment Endpoints, and Measurement Indicators

Primary Measurement Indicators and Assessment Endpoints provide a means of determining an incremental Project-related change to VCs. These are summarized in Table 7.5-18. The Groundwater VC is linked to (influences) the following VCs or chapters of the assessment: Surface Water (Chapter 7.4), Vegetation (Chapter 7.7), Human Health (Chapter 7.13), Culture (Chapter 7.15), Lhtako Dené Nation (Chapter 11), Williams Lake First Nation (Chapter 12), Xatśūll First Nation (Chapter 13), and Summary of Biophysical Factors that Support Ecosystem Function (Chapter 16).

Table 7.5-18 Assessment Endpoints and Measurement Indicators for Groundwater

Sub-component	Primary Measurement Indicators	Assessment Endpoints
Groundwater Quantity	Magnitude and temporal variation of groundwater contribution to streamflow. Magnitude and temporal variation of groundwater water levels/gradients in the LAA due to groundwater removal (underground workings and construction of FSTSF).	Maintenance of the quantity of groundwater flows to local watercourses and aquifers for municipal and domestic use.
Groundwater Quality	Groundwater quality of drinking water resources and downgradient watercourse receptors. Groundwater quality parameters in monitoring wells compared to baseline and provincial or federal guidelines for drinking water (District of Wells) and for freshwater aquatic life (local watercourses)	Discharge groundwater quality from flooded underground workings. Groundwater quality in baseflow contributions to downstream watercourses. Potable water supply wells.

Notes: LAA = local assessment area; FSTSF = Filtered Stack Tailings Storage Facility.

7.5.4.3 Project Interactions

Project components and activities have the potential to interact with and lead to effects on Groundwater. Interactions and potential effects are identified in Table 7.5-19.

Table 7.5-19 Potential Project Interactions – Groundwater

Project Phase and Activity	Groundwater		Potential Effect
	GW Quality	GW Quantity	
Construction (1 Year)			
Land clearing, transformation, and compaction	X	X	Surface Water Runoff and Reduced Groundwater Infiltration
Site grading, excavations, including blasting, and fill to support infrastructure	X	X	
Stripping of topsoil and overburden stockpiling	X	X	
Land clearing and site preparation for the Transmission Line	X	X	
Construction/installation of the Transmission Line and ancillary structures, including access roads	X	X	
Construction and use of sewage and septic handling system at the Mine Site Complex	X	X	Alteration in groundwater quality and quantity from discharge from Sewage and Septic Handling System at Mine Site Complex
Equipment maintenance/machinery and vehicle refueling	X	-	Alteration in groundwater quality from Structures, Equipment, and Material Handling
Construction of new water well, storage and associated potable	X	X	

Project Phase and Activity	Groundwater		Potential Effect
	GW Quality	GW Quantity	
water supply line at the Mine Site Complex			Alteration in groundwater flow and water level elevation from Underground Dewatering and operation of a Water Supply Well (Mine Site)
Development of Island Mountain Portal, ventilation raises, and emergency egresses	-	X	
Development of Valley Portal (main service access) and ventilation shafts and raises	-	X	
Development of underground mine main ramp, stopes, and facilities for mining, crushing, and rail-veying ore and storage silos	X	X	
Underground water management for new and historical underground mine areas	X	X	
Construction of the surface water management system (two sedimentation ponds: one at Mine Site Complex and upgrade of the one at Bonanza Ledge) and water diversion for contact and non-contact water	X	X	Alteration in groundwater quality and quantity from Mine Waste Stockpiles and Surface Water Management Systems
Drawdown of existing tailings storage facility at QR Mill, treatment, and discharge to Rudy Creek	X	X	Alteration to groundwater flow quantity and quality from alteration of seepage from QR TSF/FSTSF
Progressive reclamation as opportunity arises	X	X	Reduced Groundwater Infiltration from Reclamation of Disturbed Areas
Operations (16 years)			
Solid, hazardous, and sanitary wastes generation and management	X		Alteration in groundwater quality from Structures, Equipment, and Material Handling
Operation of sewage and septic handling system at the Mine Site	X	X	Alteration in groundwater quality and quantity from discharge from Sewage and Septic Handling System at Mine Site Complex
Operation of the fuel and diesel storage reservoir at the Mine Site	X	-	Alteration in groundwater quality from Structures, Equipment, and Material Handling
Equipment maintenance/machine and vehicle refueling	X	X	
Ongoing development and operation of WRSF at Bonanza Ledge Site (starting the end of Year 1)	X	X	Alteration in groundwater quality from seepage from Mine Waste Stockpiles
Chemical and hazardous material storage, management, and handling, including explosives	X	-	Alteration in groundwater quality from Structures, Equipment, and Material Handling

Project Phase and Activity	Groundwater		Potential Effect
	GW Quality	GW Quantity	
Operation of Water Management System (sedimentation ponds at Mine Site Complex and Bonanza Ledge Site) and water diversion system	X	X	
Operation of the Camp at the Mine Site Complex	-	X	Alteration in groundwater flow and water level elevation from Underground Dewatering and operation of a Water Supply Well (Mine Site)
Operation of Island Mountain Portal (underground access Year 1 and 2, to be used as emergency egress Year 3 to 16), Valley Portal, ventilation raises, and other emergency egress	X	X	
Ongoing development of underground workings and ore passes	X	X	
Underground operations (drilling, blasting, crushing, vertical conveying, ore storage in silos, backfill operations)	X	-	
Underground water management	-	X	
Progressive decommission of underground infrastructures	X	X	
Progressive backfilling of stopes and tunnels	X	X	
Operation of water management system at QR Mill	X	X	Alteration to groundwater flow quantity and quality from alteration of seepage from QR TSF/FSTSF
Deposition and compaction of tailings at the FSTSF at QR Mill	X	X	
Progressive reclamation as opportunity arises	X	X	Reduced Groundwater Infiltration from Reclamation of Disturbed Areas
Closure (2 years)			
Removal of mining equipment and materials	X	X	Alteration of Groundwater Flow Quantity and Quality from Underground Flooding
Construction of bulkheads to seal access to the underground mine	X	X	
Flood underground	X	X	
Disposal of hazardous materials	X	X	Alteration in groundwater quality from Structures, Equipment, and Material Handling
FSTSF decommissioning (recontouring, cover completion, and revegetation)	X	X	Alteration to groundwater flow quantity and quality from alteration of seepage from QR TSF/FSTSF
Decommissioning of Bonanza Ledge WRSF	X	X	Alteration in groundwater quality and quantity from seepage from Mine Waste Stockpiles and Surface Water Management Systems

Project Phase and Activity	Groundwater		Potential Effect
	GW Quality	GW Quantity	
Post-Closure (10+ years)			
Post-Closure monitoring (active and passive care periods)	X	X	Alteration of Groundwater Flow Quantity and Quality from Underground Flooding Alteration to groundwater flow quantity and quality from alteration of seepage from QR TSF/FSTSF

Notes: QR Mill = Quesnel River Mill; QR TSF = Quesnel River Tailings Storage Facility; FSTSF = Filtered Stack Tailings Storage Facility; WRSF = Waste Rock Storage Facility.

7.5.4.4 Discussion of Potential Effects

7.5.4.4.1 Predicted Changes to Groundwater Quantity and Quality

Groundwater numerical modelling studies and geochemical modelling studies were conducted as part of the groundwater effects assessment. These studies were also used to inform the identification of potential effects to Groundwater and the characterization of residual effects related to the Project. Therefore, for simplicity, model settings and assumptions are described in Sections 7.5.3.1 and 7.5.3.2. Results of model predictions are summarized in the following Sections 7.5.3.4.1.1 through 7.5.3.4.1.3. The predicted changes to groundwater quality at the QR Mill are discussed qualitatively in Section 7.5.3.4.1.4.

7.5.4.4.1.1 Mine Site – Predicted Changes to Groundwater Quantity Relative to Existing Conditions

Table 7.5-20 and Table 7.5-21 present a summary of the predictions results for the Mine Site LAA for existing conditions, end of operations, and closure and post-closure. These simulations were completed using steady-state model simulations that incorporated the Project features described in Section 7.5.3.1.1 for each phase. These results are further discussed in the assessment of positive effects (Section 7.5.5) and assessment of negative residual effects (Section 7.5.6). Section 7.5.6 also provides transient inflow predictions for the mining period on an average annual basis.

7.5.4.4.1.2 QR Mill – Predicted Changes to Groundwater Quantity Relative to Existing Conditions

Table 7.5-22, Table 7.5-23, Table 7.5-24A, and Table 7.5-24B present a summary of the predictions results for the QR Mill LAA for existing conditions, end of operations, and closure and post-closure. These simulations were completed using steady-state model simulations that incorporated the Project features described in Section 7.5.3.1.1.2 for each phase.

These results are discussed further in the assessment of positive effects (Section 7.5.5) and assessment of negative residual effects (Section 7.5.6).

Table 7.5-20 Mine Site Model – Predicted Change in Baseflow

Assessment Node		Base Case					Alternative Scenario 1 Bedrock Factor of Two Higher					Alternative Scenario 2 Inclusion of Permeable Jack of Club Fault and BC Vein				
		Existing (m^3/day)	Operations (m^3/day)	% Change From Existing	Closure (m^3/day)	% Change From Existing	Existing (m^3/day)	Operations (m^3/day)	% Change From Existing	Closure	% Change From Existing	Existing (m^3/day)	Operations (m^3/day)	% Change From Existing	Closure (m^3/day)	% Change From Existing
Mine Seepage 1		375	-	-100%	475	27%	425	-	-100%	550	29%	375	-	-100%	475	27%
Mine Seepage 2		550	-	-100%	1,175	114%	625	-	-100%	1,450	132%	525	-	-100%	1,250	138%
Mine Seepage 5		500	-	-100%	-	-100%	875	-	-100%	-	-100%	650	-	-100%	-	-100%
H16	Willow River Downstream Confluence with Mosquito Creek	46,550	39,025	-16%	46,450	0%	45,525	35,500	-22%	45,600	0%	46,175	38,875	-16%	46,075	0%
H16'	Willow River Upstream Confluence with Mosquito Creek	45,625	38,425	-16%	45,575	0%	44,900	35,275	-21%	45,000	0%	45,250	38,300	-15%	45,200	0%
H24	Slough Creek at the Highway 26 Crossing	10,200	10,350	1%	10,200	0%	10,400	10,300	-1%	10,425	0%	10,425	10,350	-1%	10,375	0%
H21	Jack of Clubs Upstream of Jack of Clubs Lake	13,025	13,025	0%	12,975	0%	12,950	12,950	0%	12,975	0%	13,000	13,075	1%	13,025	0%
H12	Black Jack Gulch Upstream of Barkerville	525	525	0%	525	0%	325	325	0%	325	0%	525	525	0%	525	0%
H25	Upper Mosquito Creek Close to Confluence with Willow River	350	300	-14%	350	0%	50	25	-50%	50	0%	350	300	-14%	325	-7%
SG-0.25	Stouts Gulch Upstream of the Culvert at Barkerville	1,800	1,725	-4%	1,875	4%	1,525	1,350	-11%	1,525	0%	1,775	1,625	-8%	1,775	0%
SG-1.35	Stouts Creek Upstream of Confluence with Williams Creek	1,200	1,150	-4%	1,250	4%	900	750	-17%	875	-3%	1,200	1,050	-13%	1,175	-2%
EG-0.25	Emory Gulch Upstream of the Confluence with Stouts Gulch	200	125	-38%	200	0%	125	50	-60%	125	0%	150	60	-60%	150	0%
LC-1.5	Lowhee Creek Upstream of the Confluence with Willow River	1,050	675	-36%	975	-7%	625	300	-52%	575	-8%	975	575	41%	900	-8%
LC-3.9	Lowhee Creek (near the toe of the WRSF)	425	400	-6%	425	0%	225	200	-11%	225	0%	400	400	0%	400	0%
LC	Lowhee Creek Upstream Planned Diversion to Willow River	1,050	675	-36%	975	-7%	625	300	-52%	575	-8%	975	575	-41%	900	-8%
WG	Watson's Gulch Upstream Confluence with Lowhee Creek	100	<50	>50%	100	0%	<50	<50	-	<50	-	<50	<50	-	<50	-
WC-8.0	Williams Creek at Barkerville	12,025	11,850	-1%	12,125	1%	11,550	11,125	-4%	11,550	0%	11,975	11,750	-2%	11,925	0%
WLM-02	William's Creek Upstream of Walker Gulch	4,975	4,950	-1%	5,025	1%	4,975	5,000	1%	5,000	1%	4,975	4,950	-1%	4,950	-1%
CG	Conklin Gulch Upstream Confluence with William's Creek	2,225	2,225	0%	2,200	-1%	2,200	1,950	-11%	2,200	0%	2,225	2,225	0%	2,225	0%
WC	William's Creek at the Confluence with Willow River	23,550	22,975	-2%	23,600	0%	23,200	22,050	-5%	23,175	0%	23,525	22,875	-3%	23,450	0%
JC	Outlet at Jack of Clubs Lake to Willow River (includes Lowhee Creek catchment)	19,425	17,800	-8%	19,325	-1%	18,775	16,725	-11%	18,700	0%	19,200	17,675	-8%	19,125	0%
WR-5	Willow River Reach 5	21,050	15,875	-25%	21,000	0%	20,525	13,975	-32%	20,650	1%	20,750	15,775	-24%	20,775	0%

Notes: m^3/day = cubic metre per day; % = percent; > = greater than; WRSF = waste rock storage facility

Table 7.5-21 Mine Site Model – Summary of the Proportion of Underground Mine Water in Baseflow

Assessment Node		Base Case		Alternative Scenario 1: Bedrock Factor of Two Higher		Alternative Scenario 2: Inclusion of Permeable Jack of Club Fault and BC Vein	
		Proportion of Underground Water in Baseflow (%)		Proportion of Underground Water in Baseflow (%)		Proportion of Underground Water in Baseflow (%)	
		Existing	Closure	Existing	Closure	Existing	Closure
Mine Seepage 1		100	100	100	100	100	100
Mine Seepage 2		100	100	100	100	100	100
Mine Seepage 5		100	0	100	0	100	0
H16	Willow River Downstream Confluence with Mosquito Creek	0.8	1.2	1.2	1.9	0.8	1.2
H16'	Willow River Upstream Confluence with Mosquito Creek	0.8	1.2	1.2	1.9	0.8	1.3
H24	Slough Creek at the Highway 26 Crossing	0	0	0	0	0	0
H21	Jack of Clubs Upstream of Jack of Clubs Lake	0	0	0	0	0	0
H12	Black Jack Gulch Upstream of Barkerville	0	0	0	0	0	0
H25	Upper Mosquito Creek Close to Confluence with Willow River	0	0	0	0	0	0
SG-0.25	Stouts Gulch Upstream of the Culvert at Barkerville	0	0	0	0	0	0
SG-1.35	Stouts Creek Upstream of Confluence with Williams Creek	0	0	0	0	0	0
EG-0.25	Emory Gulch Upstream of the Confluence with Stouts Gulch	0	0	0	0	0	0
LC-1.5	Lowhee Creek Upstream of the Confluence with Willow River	0	0	0	0	0	0
LC-3.9	Lowhee Creek (near the toe of the WRSF)	0	0	0	0	0	0
LC	Lowhee Creek Upstream Planned Diversion to Willow River	0	0	0	0	0	0
WG	Watson's Gulch Upstream Confluence with Lowhee Creek	0	0	0	0	0	0
WC-8.0	Williams Creek at Barkerville	0	0	0	0	0	0
WLM-02	William's Creek Upstream of Walker Gulch	0	0	0	0	0	0
CG	Conklin Gulch Upstream Confluence with William's Creek	0	0	0	0	0	0
WC	William's Creek at the Confluence with Willow River	0	0	0	0	0	0
JC	Outlet at Jack of Clubs Lake to Willow River (includes Lowhee Creek catchment)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
WR-5	Willow River Reach 5	2.2	3.3	3.2	5.1	2.2	3.4

Notes: % = percent; < = less than; WRSF = waste rock storage facility

Table 7.5-22 Quesnel River Mill Model – Predicted Changes in Seepage at North Dam and South Dam relative to Existing Conditions

Project Phase	Liner/Cover Assumption	FSTSF Collection System					
		North Tailings Dam			South Cross Dyke		
		Seepage Collection (m^3/day)	% Change from Existing Conditions	% Contribution in Inflow from FSTSF	Inflow (m^3/day)	% Change from Existing Conditions	% Contribution in Inflow from FSTSF
Base Case							
Existing Conditions	N/A	567	NA	91	102	NA	70
End of Operations	10% Liner Defect	86	-85%	59	26	-75%	39
	No Liner Defects	84	-85%	59	25	-75%	39
Post-Closure	10% Liner and Cover Defects	90	-84%	56	33	-68%	47
	No Liner and Cover Defects	90	-84%	56	33	-68%	46
Alternative Scenario 1 - Bedrock and Walley's Fault Hydraulic Conductivity Increased by a Factor of 2							
Existing Conditions	-	573	NA	91	99	NA	76
End of Operations	10% Liner Defect	84	-85%	60	11	-89%	23
	No Liner Defect	83	-86%	60	10	-90%	20
Post-Closure	10% Liner Defect	88	-85%	56	18	-82%	43
	No Liner Defect	88	-85%	56	18	-82%	42
Alternative Scenario 2 - Overburden Hydraulic Conductivity Increased by a Factor of 3							
Existing Conditions	-	676	NA	89	116	NA	72
End of Operations	10% Liner Defect	65	-90%	33	12	-90%	5
	No Liner Defect	64	-91%	32	12	-90%	5
Post-Closure	10% Liner Defect	66	-90%	27	15	-87%	22
	No Liner Defect	66	-90%	27	15	-87%	22
Alternative Scenario 3 - Weathered Bedrock Hydraulic Conductivity Increased by a Factor of 3							
Existing Conditions	-	581	NA	91	106	NA	76
End of Operations	10% Liner Defect	89	-85%	63	14	-87%	31
	No Liner Defect	88	-85%	63	13	-88%	29
Post-Closure	10% Liner Defect	93	-84%	59	22	-79%	46
	No Liner Defect	93	-84%	58	22	-79%	46

Notes: m^3/day = metres cubed per day; % = percent; N/A = not applicable; FSTSF = Filtered Stack Tailings Storage Facility.

Table 7.5-23 QR Model - Predicted Changes in Baseflow from Existing Conditions at Rudy Creek relative to Existing Conditions

Project Phase	Scenario	Rudy Creek SW2						Rudy Creek SW3*					
		Inflow (m^3/day)	Outflow (m^3/day)	Net Flow (m^3/day)	% Change from Existing Conditions	% Contribution in Inflow from FSTSF	% Contribution in Inflow from NSCP	Inflow (m^3/day)	Outflow (m^3/day)	Net Flow (m^3/day)	% Change from Existing Conditions	% Contribution in Inflow from FSTSF	% Contribution in Inflow from NSCP
Base Case													
Existing Conditions	-	421	87	334	NA	3	2	588	94	494	NA	2	1
End of Operations	10% Liner Defect	400	94	306	-8%	1	2	565	102	463	-6%	1	1
End of Operations	No Liner Defects	400	94	306	-8%	1	2	565	102	463	-6%	1	1
Post-Closure	10% Liner and Cover Defects	410	90	320	-4%	1	2	576	98	478	-3%	1	1
Post-Closure	No Liner and Cover Defects	410	90	320	-4%	1	2	576	98	478	-3%	1	1
Alternative Scenario 1 - Bedrock Hydraulic Conductivity Increased by a Factor of 2													
Existing Conditions	-	420	87	333	NA	4	2	587	94	493	NA	3	2
End of Operations	10% Liner Defect	400	97	303	-9%	2	2	565	105	460	-7%	1	2
End of Operations	No Liner Defects	400	97	303	-9%	2	2	565	105	460	-7%	1	2
Post-Closure	10% Liner and Cover Defects	406	92	314	-6%	2	2	572	100	472	-4%	1	2
Post-Closure	No Liner and Cover Defects	406	92	314	-6%	2	2	572	100	472	-4%	1	2
Alternative Scenario 2 - Overburden Hydraulic Conductivity Increased by a Factor of 3													
Existing Conditions	-	741	388	353	NA	8	5	959	469	490	NA	6	4
End of Operations	10% Liner Defect	723	417	306	-13%	3	6	939	499	440	-10%	3	4
End of Operations	No Liner Defects	723	418	305	-14%	3	6	939	499	440	-10%	3	4
Post-Closure	10% Liner and Cover Defects	729	408	321	-9%	3	6	945	490	455	-7%	3	4
Post-Closure	No Liner and Cover Defects	729	408	321	-9%	3	6	945	490	455	-7%	3	4
Alternative Scenario 3 - Weathered Bedrock Hydraulic Conductivity Increased by a Factor of 3													
Existing Conditions	-	427	88	339	NA	4	2	593	96	497	NA	3	2
End of Operations	10% Liner Defect	408	100	308	-9%	2	2	571	108	463	-6%	2	2
End of Operations	No Liner Defects	408	100	308	-9%	2	2	571	108	463	-6%	2	2
Post-Closure	10% Liner and Cover Defects	414	94	320	-6%	2	2	578	102	476	-4%	2	2
Post-Closure	No Liner and Cover Defects	414	94	320	-6%	2	2	578	102	476	-4%	2	2

Notes: Inflow = Groundwater Discharge to Surface Water; Outflow = Surface Water Discharge to Groundwater; Rudy Creek SW3 includes the upstream Rudy Creek SW2.
m3/day = metres cubed per day; % = percent; NSCP = North Seepage Collection Pond; FSTSF = Filtered Stack Tailings Storage Facility

Table 7.5-24A QR Model - Predicted Changes in Baseflow from Existing Conditions at Creek #2, Creek #2.5, and Creek #3 relative to Existing Conditions

Project Phase	Scenario	Creek #2					Creek #2.5					Creek #3					Quesnel River	
		Inflow (m^3/day)	Change from Existing Conditions	% Contribution in Inflow from FSTSF	% Contribution in Inflow from MZP	% Contribution in Inflow from SSCP	Inflow (m^3/day)	Change from Existing Conditions	% Contribution in Inflow from FSTSF	% Contribution in Inflow from MZP	% Contribution in Inflow from SSCP	Inflow (m^3/day)	Change from Existing Conditions	% Contribution in Inflow from FSTSF	% Contribution in Inflow from MZP	% Contribution in Inflow from SSCP	Inflow (m^3/day)	Change from Existing Conditions
Base Case																		
Existing Conditions	-	57	N/A	0	0	0	22	N/A	0	0	0	71	N/A	<0.5	<0.5	0	80	N/A
End of Operations	10% Liner Defect	56	-2%	0	0	0	21	-5%	0	0	0	69	-3%	<0.5	<0.5	0	80	0%
End of Operations	No Liner Defects	56	-2%	0	0	0	21	-5%	0	0	0	69	-3%	0	<0.5	0	80	0%
Post-Closure	10% Liner and Cover Defects	57	0%	0	0	0	22	0%	<0.5	0	0	73	3%	0	<0.5	0	80	0%
Post-Closure	No Liner and Cover Defects	57	0%	0	0	0	22	0%	<0.5	0	0	73	3%	0	<0.5	0	80	0%
Alternative Scenario 1 - Bedrock Hydraulic Conductivity Increased by a Factor of 2																		
Existing Conditions	-	47	N/A	0	0	0	18	N/A	0	6	0	65	N/A	1	1	0	112	N/A
End of Operations	10% Liner Defect	46	-2%	0	0	0	15	-17%	0	3	0	62	-5%	1	<0.5	<0.5	112	0%
End of Operations	No Liner Defects	46	-2%	0	0	0	15	-17%	0	3	0	62	-5%	<0.5	<0.5	<0.5	112	0%
Post-Closure	10% Liner and Cover Defects	46	-2%	0	0	0	19	6%	1	1	0	65	0%	<0.5	<0.5	0	112	0%
Post-Closure	No Liner and Cover Defects	46	-2%	0	0	0	19	6%	1	2	0	65	0%	<0.5	<0.5	0	112	0%
Alternative Scenario 2 - Overburden Hydraulic Conductivity Increased by a Factor of 3																		
Existing Conditions	-	95	N/A	0	0	0	23	N/A	0	0	0	71	N/A	0	<0.5	0	80	N/A
End of Operations	10% Liner Defect	95	0%	0	0	0	22	-4%	0	0	0	70	-1%	0	0	0	80	0%
End of Operations	No Liner Defects	95	0%	0	0	0	22	-4%	0	0	0	70	-1%	0	0	0	80	0%
Post-Closure	10% Liner and Cover Defects	95	0%	0	0	0	23	0%	1	0	0	77	8%	0	<0.5	0	80	0%
Post-Closure	No Liner and Cover Defects	95	0%	0	0	0	23	0%	1	0	0	77	8%	0	<0.5	0	80	0%
Alternative Scenario 3 - Weathered Bedrock Hydraulic Conductivity Increased by a Factor of 3																		
Existing Conditions	-	54	N/A	0	0	0	29	N/A	0	19	0	61	N/A	0	5	0	110	N/A
End of Operations	10% Liner Defect	54	0%	0	0	0	25	-14%	0	13	0	56	-8%	0	1	0	110	0%
End of Operations	No Liner Defects	54	0%	0	0	0	25	-14%	0	13	0	56	-8%	0	1	0	110	0%
Post-Closure	10% Liner and Cover Defects	54	0%	0	0	0	30	3%	<0.5	6	0	62	2%	0	3	0	110	0%
Post-Closure	No Liner and Cover Defects	54	0%	0	0	0	30	3%	<0.5	7	0	62	2%	0	3	0	110	0%

Notes: m^3/day = metres cubed per day; % = percent; FSTSF = Filtered Stack Tailings Storage Facility; MZP = Main Zone Pit; SSCP = South Seepage Collection Pond; < = less than; N/A = not applicable.

Table 7.5-24B QR Model - Predicted Changes in Baseflow from Existing Conditions at Creek #2.5, Creek #3, and Downstream Seepage Faces

Project Phase	Scenario	Creek #2.5 and Downstream Seepage Faces					Creek #3 and Downstream Seepage Faces				
		Inflow (m^3/day)	% Change from Existing Conditions	% Contribution from FSTSF	% Contribution in Inflow from MZP	% Contribution in Inflow from SSCP	Inflow (m^3/day)	Change from Existing Conditions	% Contribution in Inflow from FSTSF	% Contribution in Inflow from MZP	% Contribution in Inflow from SSCP
Base Case											
Existing Conditions	-	100	NA	2	1	<0.5	117	NA	<0.5	<0.5	0
End of Operations	10% Liner Defect	89	-11%	<0.5	<0.5	1	108	-8%	0	0	0
End of Operations	No Liner Defects	89	-11%	<0.5	<0.5	1	108	-8%	0	0	0
Post-Closure	10% Liner and Cover Defects	90	-10%	<0.5	1	0	112	-4%	0	<0.5	0
Post-Closure	No Liner and Cover Defects	90	-10%	<0.5	1	0	112	-4%	0	<0.5	0
Alternative Scenario 1 - Bedrock Hydraulic Conductivity Increased by a Factor of 2											
Existing Conditions	-	138	NA	6	6	1	131	NA	1	<0.5	0
End of Operations	10% Liner Defect	119	-14%	2	4	5	119	-9%	<0.5	<0.5	<0.5
End of Operations	No Liner Defects	119	-14%	2	4	5	119	-9%	<0.5	<0.5	<0.5
Post-Closure	10% Liner and Cover Defects	123	-11%	1	8	0	121	-8%	<0.5	<0.5	0
Post-Closure	No Liner and Cover Defects	123	-11%	1	8	0	121	-8%	<0.5	<0.5	0
Alternative Scenario 2 - Overburden Hydraulic Conductivity Increased by a Factor of 3											
Existing Conditions	-	101	NA	4	0	1	117	NA	<0.5	<0.5	0
End of Operations	10% Liner Defect	89	-12%	1	0	3	109	-7%	0	0	0
End of Operations	No Liner Defects	89	-12%	1	0	3	109	-7%	0	0	0
Post-Closure	10% Liner and Cover Defects	90	-11%	1	1	0	116	1%	0	<0.5	0
Post-Closure	No Liner and Cover Defects	90	-11%	1	1	0	116	1%	0	<0.5	0
Alternative Scenario 3 - Weathered Bedrock Hydraulic Conductivity Increased by a Factor of 3											
Existing Conditions	-	156	NA	2	11	0	131	NA	<0.5	2	0
End of Operations	10% Liner Defect	135	-13%	1	10	2	115	-12%	0	1	0
End of Operations	No Liner Defects	135	-13%	1	9	1	115	-12%	0	1	0
Post-Closure	10% Liner and Cover Defects	140	-10%	<0.5	14	0	121	-8%	0	3	0
Post-Closure	No Liner and Cover Defects	140	-10%	<0.5	14	0	121	-8%	0	3	0

Notes: m^3/day = metres cubed per day; % = percent; FSTSF = Filtered Stack Tailings Storage Facility; MZP = Main Zone Pit; SSCP = South Seepage Collection Pond; < = less than

7.5.4.4.1.3 Mine Site – Predicted Changes to Groundwater Quality Relative to Existing Conditions

Table 7.5-25 presents underground mine water quality predictions. The table also includes water quality data from the District of Wells monitoring well ('District of Wells MW') and monitoring data that represents the composition of groundwater quality in the historical workings ('CM-20-050').

Predicted water quality is compared to the following standards to identify constituents of potential concern:

- Drinking water standards in BC CSR Schedule 3.2 (B.C Reg. 375/96);
- Freshwater aquatic standards in BC CSR Schedule 3.2 (B.C Reg. 375/96);
- Source drinking water quality guideline maximum allowable concentrations (SDWQG-MAC) as part of the BC Ambient Water Quality Guidelines (ENV, 2020); and
- Source drinking water quality guideline aesthetic objectives (SDWQG-AO) as part of the BC Ambient Water Quality Guidelines (ENV, 2020).

Table 7.5-25 Predicted Post-Closure Underground Mine Water Quality

Parameter	Units	Water Quality Objectives				Monitoring Wells		Predicted Water Quality for Underground Workings	
		CSR Aquatic Life-Freshwater	CSR Drinking Water	SDWQG-MAC	SDWQG-AO	CM-20-050 2020-07-30	District of Wells 2020-08-31	Base Case	Upper Case
Ammonia	mg/L as N	1.3	-	-	-	1.0	0.0092	0.49	0.49
Nitrate	mg/L as N	400	10	10	-	<0.1	<0.025	0.62	0.62
Aluminum	mg/L	-	9.5	9.5	-	0.48	0.025	0.41	0.96
Antimony	mg/L	0.090	0.0060	0.0060	-	<0.0002	<0.0001	**0.018**	**0.033**
Arsenic	mg/L	0.050	0.010	0.010	-	0.15	0.011	**0.086**	**0.19**
Barium	mg/L	10	1.0	-	-	0.12	0.068	0.026	0.050
Beryllium	mg/L	0.0015	0.0080	-	-	<0.0002	<0.0001	0.000050	0.000036
Bismuth	mg/L	-	-	-	-	<0.0001	<0.00005	0.000036	0.000036
Boron	mg/L	12	5.0	5.0	-	<0.02	<0.01	0.071	0.12
Cadmium	mg/L	0.00050	0.0050	0.0050	-	<0.00001	<0.000005	0.00023	0.00035
Calcium	mg/L	-	-	-	-	518	131	79	117
Chloride	mg/L	1500	250	-	250	<10	<2.5	52	**298**
Chromium	mg/L	0.010	0.050	0.050	-	0.00059	<0.0001	0.00044	0.00085
Cobalt	mg/L	0.040	0.0010	0.0010	-	0.00038	0.00016	**0.0070**	**0.0086**
Copper	mg/L	0.020	1.5	2.0	1.0	0.0016	<0.0002	0.0071	0.014
Iron	mg/L	-	6.5	-	0.30	21	0.66	0.45	0.052
Lead	mg/L	0.040	0.010	0.0050	-	0.00070	0.000073	0.00031	0.00081
Lithium	mg/L	-	0.0080	-	-	0.0054	0.0013	0.0078	**0.021**
Magnesium	mg/L	-	-	-	-	207	51	33	58
Manganese	mg/L	-	1.5	0.12	0.020	1.1	1.2	0.59	1.1
Molybdenum	mg/L	10	0.25	0.088	-	0.00099	0.00088	0.0106	0.020
Nickel	mg/L	0.25	0.080	0.080	-	0.0013	<0.0005	0.053	**0.095**
Phosphorus	mg/L	-	-	-	0.010	0.083	<0.05	0.041	0.083
Potassium	mg/L	-	-	-	-	10	0.40	23	59
Selenium	mg/L	0.020	0.010	0.010	-	<0.0001	<0.00005	0.0013	0.0033
Silicon	mg/L	-	-	-	-	9.0	4.1	5.7	9.5
Silver	mg/L	0.00050	0.020	-	-	0.00027	<0.00001	0.000037	0.000036
Sodium	mg/L	-	200	-	-	17	2.7	38	**203**
Strontium	mg/L	-	2.5	7.0	-	2.3	0.53	0.33	0.67
Sulphate	mg/L	1280	500	-	500	1870	289	201	**510**
Sulphur	mg/L	-	-	-	-	654	97	84	187
Tellurium	mg/L	-	-	-	-	<0.0004	<0.0002	0.00018	0.00018
Thallium	mg/L	0.0030	-	-	-	<0.00002	<0.00001	0.000063	0.00015
Thorium	mg/L	-	-	-	-	0.00027	<0.0001	0.000036	0.000036
Tin	mg/L	-	2.5	-	-	0.00023	<0.0001	0.00019	0.00031
Titanium	mg/L	1.0	-	-	-	0.0049	0.00040	0.00071	0.00073
Uranium	mg/L	0.085	0.020	0.020	-	0.031	0.0015	0.013	**0.029**
Vanadium	mg/L	-	0.020	-	-	<0.001	<0.0005	0.00081	0.00073
Zinc	mg/L	0.075	3.0	3.0	5.0	0.0049	0.0037	0.032	0.029
Zirconium	mg/L	-	-	-	-	0.00054	<0.0002	0.00018	0.00029

Notes: Shaded cells represent values greater than the CSR aquatic life guideline
Bolded cells represent values greater than the CSR drinking water guidelines
Red font represents values greater than the SDWQG-MAC
Double underlined cells represent values greater than the SDWQG-AO
CSR = Contaminated Sites Regulation; SDWQG-MAC = Source drinking water quality guideline maximum allowable concentrations; SDWQG-AO = Source drinking water quality guideline aesthetic objectives; mg/L = milligrams per litre

In general, the composition of predicted underground mine water quality is of order-of-magnitude similarity to that measured in existing mine water (CM-20-050). Predicted sulphate concentrations are lower than those currently measured in existing mine water; it is likely that sulphate concentrations will equilibrate at concentrations similar to those measured at CM-20-050 over time. The water quality predictions do not account for geochemically credible mineral solubility controls that could limit concentrations of some parameters.

The predicted concentrations do not account for the input of alkalinity from cement that will be present in paste and cemented rockfill. Based on experience at other underground mines that use similar backfill methods, it is possible that pH values up to 10 could be reached if the mine floods prior to complete curing of the cemented backfill. If the cement cures completely prior to re-flooding, the pH will more likely return to that currently measured in underground mine water (approximately pH 7 at CM-20-050).

Based on the results of the hydrogeological model (assuming mitigation), it is predicted that underground mine water could mix with water in the Wells Aquifer under existing conditions and at closure. According to the flow model predictions, water pumped from the District of Wells community water supply well could contain up to 10% underground mine water post-closure. Table 7.5-26 presents the predicted composition of the District of Wells community water supply well, which could continue to report elevated concentrations of As, Mn, and P relative to water quality standards. Arsenic concentrations would increase relative to currently measured concentrations.

Table 7.5-26 Predicted Post-Closure Water Quality at District of Wells Community Water Supply Well

Parameter	Units	CSR Aquatic Life-Freshwater	CSR Drinking Water	SDWQG-MAC	SDWQG-AO	District of Wells Monitoring Well	Mixed Mine Water and District of Wells Monitoring Well - 10% Predicted Mine Water	
							Base Case	*Upper Case*
Ammonia	mg/L as N	1.3	-	-	-	0.009	0.057	0.057
Nitrate	mg/L as N	400	10	10	-	0.013	0.073	0.073
Aluminum	mg/L	-	9.5	9.5	-	0.025	0.059	0.11
Antimony	mg/L	0.090	0.0060	0.0060	-	0.0001	0.0017	0.0030
Arsenic	mg/L	0.050	0.010	0.010	-	**0.011**	**0.018**	**0.027**
Barium	mg/L	10	1.0	-	-	0.068	0.063	0.066
Beryllium	mg/L	0.0015	0.0080	-	-	0.000050	0.000050	0.000048
Bismuth	mg/L	-	-	-	-	0.000025	0.000026	0.000026
Boron	mg/L	12	5.0	5.0	-	0.005	0.011	0.015
Cadmium	mg/L	0.00050	0.0050	0.0050	-	0.000003	0.000023	0.000034
Calcium	mg/L	-	-	-	-	131	125	129
Chloride	mg/L	1500	250	-	250	1	5.8	28
Chromium	mg/L	0.010	0.050	0.050	-	0.00005	0.000085	0.00012
Cobalt	mg/L	0.040	0.0010	0.0010	-	0.0002	0.00078	0.00092
Copper	mg/L	0.020	1.5	2.0	1.0	0.0001	0.00073	0.0014
Iron	mg/L	-	6.5	-	0.30	0.66	0.63	0.60
Lead	mg/L	0.040	0.010	0.0050	-	0.00007	0.000094	0.00014
Lithium	mg/L	-	0.0080	-	-	0.0013	0.0019	0.0031
Magnesium	mg/L	-	-	-	-	51	49	51
Manganese	mg/L	-	1.5	0.12	0.020	1.2	1.1	1.2
Molybdenum	mg/L	10	0.25	0.088	-	0.0009	0.0018	0.0026
Nickel	mg/L	0.25	0.080	0.080	-	0.0003	0.0051	0.0088
Phosphorus	mg/L	-	-	-	0.010	0.025	0.026	0.030
Potassium	mg/L	-	-	-	-	0.4	2.5	5.7

Parameter	Units	CSR Aquatic Life-Freshwater	CSR Drinking Water	SDWQG-MAC	SDWQG-AO	District of Wells Monitoring Well	Mixed Mine Water and District of Wells Monitoring Well - 10% Predicted Mine Water	
							Base Case	*Upper Case*
Selenium	mg/L	0.020	0.010	0.010	-	0.00003	0.00014	0.00032
Silicon	mg/L	-	-	-	-	4.1	4.2	4.5
Silver	mg/L	0.00050	0.020	-	-	0.000005	0.0000078	0.0000078
Sodium	mg/L	-	200	-	-	2.7	5.9	21
Strontium	mg/L	-	2.5	7.0	-	0.53	0.51	0.54
Sulphate	mg/L	1280	500	-	500	289	278	306
Sulphur	mg/L	-	-	-	-	97	95	105
Tellurium	mg/L	-	-	-	-	0.00010	0.00011	0.00011
Thallium	mg/L	0.0030	-	-	-	0.000005	0.000010	0.000018
Thorium	mg/L	-	-	-	-	0.000050	0.000048	0.000048
Tin	mg/L	-	2.5	-	-	0.000050	0.000063	0.000073
Titanium	mg/L	1.0	-	-	-	0.00040	0.00042	0.00043
Uranium	mg/L	0.085	0.020	0.020	-	0.0015	0.0025	0.0040
Vanadium	mg/L	-	0.020	-	-	0.00025	0.00030	0.00029
Zinc	mg/L	0.075	3.0	3.0	5.0	0.0037	0.0062	0.0059
Zirconium	mg/L	-	-	-	-	0.00010	0.00011	0.00012

Notes: CSR = Contaminated Sites Regulation; SDWQG-MAC = Source drinking water quality guideline maximum allowable concentrations; SDWQG-AO = Source drinking water quality guideline aesthetic objectives; mg/L = milligrams per litre; % = percent
Shaded cells represent values greater than the CSR aquatic life guideline
Bolded cells represent values greater than the CSR drinking water guidelines
Red font represents values greater than the SDWQG-MAC
Double underlined cells represent values greater than the SDWQG-AO

7.5.4.4.1.4 Quesnel River Mill – Predicted Changes to Water Quality Relative to Existing Conditions

The predicted base case composition of seepage from the NSCP, SSCP, and MZP in Appendix 7.4-9 was compared to groundwater quality standards to identify constitutes of potential concern in groundwater seepage from these sources. Seepage concentrations were also reviewed in the context of existing water quality in nearby groundwater monitoring wells to qualitatively evaluate the potential effect on groundwater quality resulting from seepage. The results of this comparison indicate the following:

NSCP: Seepage from the NSCP will report to Rudy Creek upstream of the SW2 assessment node. Monitoring wells MW1A/B and MW2A/B are in the groundwater flow pathway between the NSCP and Rudy Creek. The predicted composition of seepage from the NSCP in pre-mining and/or operations contains concentrations of cobalt, sulphate, antimony, and selenium above drinking water standards and concentrations of selenium above aquatic life standards. Drinking water exceedances (cobalt and sulphate) have been measured in groundwater samples collected from wells downstream of the NSCP. No predicted parameter concentrations in the NSCP exceeded groundwater standards in post-closure.

SSCP and MZP Seepage: Seepage from the SSCP will predominantly report to the MZP and will therefore have limited potential to affect groundwater quality downstream of the MZP pit towards Creek #2.5 and Creek #3. Seepage from the MZP will discharge to Creek #2.5 and Creek #3, and associated seepage faces downstream of the assessment nodes. Monitoring wells MW11-01, MW11-02, and MW-8 are in the groundwater flow pathway between the MZP and these creeks. The predicted composition of seepage from the MZP pit in pre-mining and/or operations contains concentrations of sulphate, antimony, arsenic, cobalt, manganese, nickel, and selenium above the drinking water standards and concentrations of ammonia, total cyanide, copper, nitrite, and selenium above aquatic life standards. Of these parameters, concentrations of sulphate, arsenic and cobalt have been measured in down-stream monitoring wells at concentrations above drinking water standards. No predicted parameter concentrations exceeded groundwater standards in post-closure except selenium. Selenium in the early years of closure is above aquatic life and drinking water standards, but transitions between years 2045 and 2050 to below applicable standards.

7.5.4.4.2 Increased Surface Water Runoff, Reduced Groundwater Infiltration

Project activities resulting in erosion and mobilization of sediment have the potential to result in effects to groundwater quantity and quality. Specifically, Project activities associated with vegetation/land clearing, soil excavation, and road construction/upgrades have the potential to result in increased surface run-off and reduced infiltration and evapotranspiration due to the removal of vegetation and organic soils, and exposure of loose, disturbed soils.

The Project has been designed to avoid or minimize disturbance and impacts on the environment and stakeholders, where possible. Project infrastructure at the Mine Site will be mainly located on brownfield sites that have been previously disturbed by historical mining operations, which should limit alteration of groundwater recharge and infiltration quality. Infrastructure outside of the historical mine footprint will be located on previously disturbed areas or follow existing alignments, where possible. The Project will utilize the existing QR Mill without increasing the existing footprint.

7.5.4.4.3 Alteration of Groundwater Quantity and Quality from Discharge from Sewage and Septic Handing System at the Mine Site Complex

A sewage and septic handling system will be located near the new worker accommodation at the Mine Site Complex. Sewage and septic waste from the new worker accommodation will pass through the treatment system and ultimately discharge to two drainage fields.

7.5.4.4.3.1 Groundwater Quantity

Drainage galleries have been designed according to the Municipal Wastewater Regulation for a percolation rate of 15 minutes/25 mm (Chapter 1). Local elevation of groundwater levels near the drainage galleries will be minimized by appropriate design, and by the high permeability of the alluvial and placer outwash inferred to be present near the drainage galleries. The application of appropriate infiltration gallery design will reduce or eliminate this pathway for potential effects on groundwater quantity.

7.5.4.4.3.2 Groundwater Quality

Sewage and septic waste from the new worker accommodation will be piped to the treatment system prior to being discharged to the drainage galleries. The treatment system will be located east of the accommodation pad and will consist of three large fibre-reinforced polymer tanks – a trash tank, an equalization chamber, and a mix bed bioreactor (MBBR). Wastewater from the kitchen/dining/recreation facility will pass through a grease trap prior to entering the trash tank. Effluent will be treated by the MBBR system. The application of treatment and appropriate infiltration gallery design will reduce or eliminate this pathway for potential effects to groundwater quality.

7.5.4.4.4 Alteration to Groundwater Flow and Water Level Elevation from Underground Dewatering and Operation of a Water Supply Well (Mine Site)

Groundwater will be removed to facilitate development of the underground mine at the Mine Site and to meet other Project water demands. In addition to dewatering historical and future underground workings, a new potable water supply well will be installed for the Project. The final location of the new potable well is still under assessment, but two locations are being carried forward to detailed design:

- Valley Zone Softball Diamond Area. This well would be located within the Wells Aquifer, which is also utilized by the Community of Wells.
- ODV Office Location. This well would be located near the ODV office within shallow unconfined placer deposits and/or near surface bedrock.

7.5.4.4.4.1 Groundwater Quantity

The removal of groundwater from dewatering of the underground workings and operation of a new water supply well can result in a change to the direction and rate of groundwater flow and to the elevation of the groundwater table. Removal of water from groundwater systems will tend to result in a localized depression in the groundwater level and a drawdown in the surrounding groundwater system. This change has the potential to reduce baseflow discharge to surface water receivers.

7.5.4.4.4.2 Groundwater Quality

The act of groundwater removal has limited potential to alter groundwater quality. Groundwater extraction from underground dewatering will result in the underground being a hydraulic sink and the capture of surface infiltration. Groundwater removed to meet Project demands, such as development of the underground mine, will be treated prior to discharge to the receiving environment.

The water supply well would operate during operations. Water quality would be verified as part of well testing and design, and verified for suitability for drinking water and suitability for treatment if water quality is found to be unacceptable for consumption. Construction and operations associated with the Project would not be expected to affect water quality in either proposed well location as the underground development will be dewatered and act as a hydraulic sink.

7.5.4.4.5 Alteration to Groundwater Flow Quantity and Quality from Alteration of Seepage from the QR Tailings Storage Facility/Filtered Stack Tailings Storage Facility and Operation of a Water Supply Well

Prior to construction of the FSTSF, the existing QR TSF pond will be drawn down to facilitate placement of the Project tailings. A 60 mm high-density polyethylene geomembrane will be installed over the existing tailings and side slopes of the existing QR TSF impoundment to form the base of the FSTSF. There will be drains above the liner, which will be installed after the first stage of tailings placement and drain to a sump or contact water collection ditch at the South Cross Dyke (i.e., the drains will not be in direct contact with the liner). A low permeability cover, consisting of a geomembrane overlain by glacial till, will be put in place at closure. Test holes are also being advanced at QR Mill to have interception wells in place between the NSCP and Rudy Creek to mitigate seepage migration between the FSTSF and Rudy Creek if unacceptable surface water quality is observed in Rudy Creek.

An existing water supply well to the north of the QR TSF will be used to supply water during construction, operations, and closure.

7.5.4.4.5.1 Groundwater Quantity

Draining of the existing QR TSF and placement of the liner, and the use of the potable well located northwest of the FSTSF during constructions and operations, may lower the surrounding water levels near the FSTSF. These changes have the potential to reduce baseflow discharge to surface water. Water level changes to the south of the FSTSF will be mitigated by the expansion of the SSCP during operations; however, in closure, the SSCP will be breached and allowed to drain through surface water management to the MZP (assuming water quality objectives are reached).

In operations, the water level in the MZP is assumed to be maintained at a lower level than existing conditions. The lowering of the water level in the MZP in operations could potentially reduce baseflow in some of the creeks located immediately south of the pit lake along the slope; however, it will reduce the seepage of water out of the pit which could affect groundwater quality. This effect is limited to the Operations Phase when the water level in the MZP will be reduced relative to existing conditions.

During operations, increased pumping from the water supply well to the north of the FSTSF may reduce baseflow to Rudy Creek and locally depress water levels. This effect is not present in closure (no residual effect) as the well will be decommissioned.

7.5.4.4.5.2 Groundwater Quality

The act of groundwater removal has limited potential to alter groundwater quality. Construction of the FSTSF includes a liner and a cover, which will reduce the seepage loss to the groundwater flow system. Lateral inflow to the existing tailings below the liner is expected to continue and will ultimately discharge to the seepage collection infrastructure and surface-water receptors, as it does under existing conditions:

- Seepage from the NSCP towards Rudy Creek occurs under existing conditions and will continue during each phase of the Project.
- Seepage from the SSCP occurs under existing phases and will continue into closure until the SSCP pond is breached and allow to drain as surface flow to the MZP.
- Seepage from the MZP to Creek #2.5 and Creek #3 occurs under existing conditions and will continue during each phase of the Project.

A comparison of existing water quality to predicted water quality indicates that some parameters may be higher in seepage from the facilities during operations. Seepage from the NSCP and MZP are expected to be below CSR aquatic life standards, however, in long term post-closure.

7.5.4.4.6 Alteration in Groundwater Quality and Quantity from Seepage from Mine Waste Stockpiles and Surface Water Management Systems

During the life of the Project, there is the potential for seepage from the FSTSF, BFA, and overburden/WRSF to enter downstream waterbodies either directly or through groundwater to surface water connections. The historical waste material will be covered by a NPAG liner to separate it from the BFA that will be constructed on top of the covered historical material. The BFA is expected to reach capacity early in Project development, at which point it will be progressively reclaimed with an engineered cover.

Runoff and shallow seepage from the FSTSF/waste rock/overburden facilities will not be released directly to the environment during construction or operations. During the Construction and Operation Phases, surface water runoff and shallow seepage from the FSTSF/waste rock/overburden facilities or that has been in contact with mine waste materials will be captured through a series of perimeter collection ditches and sumps.

7.5.4.4.6.1 Groundwater Quantity

The potential for seepage discharge to affect groundwater and streamflow in the downstream environment during operations is limited because the major site facilities will be lined, and seepage will be collected and managed within the Project water management system. During post-closure, after active water treatment and management activities have ceased (passive care period), shallow seepage from stockpiles will be collected by perimeter ditching and passively conveyed to the receiving environment through the closure drainage systems. The mine waste stockpiles will be covered at closure with low permeability materials, which is anticipated to reduce the infiltration flow into the stockpiles, such that residual seepage will be of limited magnitude.

7.5.4.4.6.2 Groundwater Quality

During the Construction and Operations Phases, the potential for seepage to affect groundwater quality is limited because the major site facilities will be lined. Seepage will be collected and treated prior to discharge to the receiving environment. However, during post-closure, it is possible that seepage will be released to groundwater without treatment as a result of degradation of the liners over time, which will have the potential to result in changes in the physical or chemical composition of groundwater.

7.5.4.4.7 Alteration in Groundwater Quality from Structures, Equipment, and Material Handling

During construction, operations, and closure, material and equipment may be handled that, if not contained and appropriately handled and decommissioned, could result in release to the environment and alteration of groundwater quality if the release infiltrates into the groundwater flow system. No effect on groundwater quantity is expected as groundwater flow will not be reduced or increased.

7.5.4.4.8 Alteration of Groundwater Flow Quantity and Quality from Underground Flooding

During operations, underground developments (historical and future) at the Mine Site will be progressively backfilled with cemented paste/tailings and rockfill. Groundwater will continue to flow through exposed rock surfaces from the underground excavation and existing fractured rock in geological structures like faults; existing underground mine workings and the groundwater flow regime are currently subject to this process. At closure, underground workings will be allowed to passively flood to minimize the ML/ARD potential of rock exposed in mine openings.

7.5.4.4.8.1 Groundwater Quantity

Depressed water levels near the dewatered underground workings will recover as the underground workings flood. Groundwater gradients and inflows to the backfilled mine workings will diminish over time as groundwater hydraulic heads re-equilibrate. Final equilibrium underground levels may be altered from existing conditions as a result of the expanded network of hydraulicly connected underground workings, and discharges from the existing portals/adits at ground surface may be altered from existing conditions (both higher and lower).

7.5.4.4.8.2 Groundwater Quality

Flooded underground water from existing historical workings will discharge to the Wells Aquifer, which is the current aquifer that supplies potable water to the District of Wells through the operation of a pumping well. Following reflooding, discharge of groundwater from the flooded historical workings will continue, along with discharge from the Project workings. This discharge has the potential to affect groundwater quality.

7.5.4.4.9 Reduced Groundwater Infiltration from Reclamation of Disturbed Areas

Reclamation of disturbed areas includes contouring and revegetation. Revegetation slows surface runoff, increasing the potential for infiltration. It is expected that progressive reclamation will occur throughout the Project life as opportunities arise. Revegetation of disturbed areas may result in a small enhancement of groundwater infiltration; therefore, it not expected to have a negative residual effect on groundwater quantity and quality.

7.5.5 Effects Management

Mitigation measures that are expected to reduce or eliminate an adverse effect, or enhance a positive effect, are described below. Mitigation measures include those integrated into Project design and specific mitigation identified for Groundwater. Management Plans will be developed prior to construction to provide details on Groundwater mitigation measures, implementation methods, and schedule. Developing these management plans prior to construction and operations is standard practice for projects.

Selection of mitigation measures for Groundwater was informed by factors described in Section 6.5.1.

Indigenous groundwater uses and users were considered in the effects management; however, review of public databases (Section 7.5.3.3.4.3), consultation, and traditional use studies (DM Cultural Services Ltd., 2019; Landmark Resource Management Ltd., 2021) did not identify current specific uses of groundwater in the LAAs.

7.5.5.1 Mitigation Approach

Mitigation measures for the Project are based on the review and consideration of pre-existing best management practices (BMPs), regulatory and guidance documents, and mitigation measures successfully employed for similar projects. The selection of mitigation options appropriate to the Project was assisted through consideration of the "Procedures for Mitigating Impacts on Environmental Values (Environmental Mitigation Procedures)" (ENV, 2014a). Measures were selected following methods as described in Section 6.5.1.1.

As described in the following sections, key mitigations to Groundwater include:

- As part of the underground water management plan, mitigations to Groundwater will include procedures for grouting/sealing historical boreholes intersected by the mine workings, where a hydraulic connection could be formed between the underground and ground surface, resulting in artesian flow at ground surface post-closure following flooding of the underground. This would include investigation of the area where artesian discharge is currently observed in the area of the Historical Mill Tailings following dewatering of the historic underground. Grouting is also an adaptive management strategy that can be implemented if intersected structures are of enhanced permeability, resulting in higher than expected underground inflows.
- At closure, under the Reclamation and Closure Plan, underground mine openings, including portals and ventilation raises, will be sealed with engineer designed plugs preventing ingress by people and animals and permitting the underground workings to be flooded to minimize further ML/ARD. The portal entrances will be closed either with a small pond at the entrance to enable monitoring of water quality and seepage from the closed portal or the portal will be backfilled with NPAG material, which will enable seepage monitoring and discharge once approved. The plugs will have monitoring instrumentation installed and the designs will be updated with considerations that may arise out of agency review.
- With the applied mitigations described above and in the following sections, groundwater quality would either be similar to existing conditions and/or below applicable drinking water guidelines.

7.5.5.1.1 Project Design Mitigation

The Project has been designed to avoid or minimize disturbance and impacts on the environment and land/water user, where possible. Project infrastructure at the Mine Site will mainly be located on brownfield sites that have been previously disturbed by historical mining operations. Infrastructure outside of the historical mine footprint will be located on previously disturbed areas or follow existing alignments, where possible. The Project will also utilize the existing QR Mill without increasing the existing footprint.

Where ODV has received feedback on potential Project alternatives, ODV has incorporated this feedback into various aspects of Project design and management. Section 1.7 summarizes the key components of the Project for which alternatives and options were reviewed.

7.5.5.1.1.1 Water Management Plans

Water management plans have been or will be developed to limit the potential for Project-related effects on Groundwater. Relevant plans that will mitigate Project effects on Groundwater for the Mine Site and QR Mill are summarized in this section.

Mine Site

Treated domestic sewage effluent will be released by a septic drain field to be located on the southeastern side of the camp location. Drainage galleries have been designed per the Municipal Wastewater Regulation for a percolation rate of 15 minutes/25 mm. The septic drain field will be constructed without major change to the existing topography and the treated domestic sewage effluent is expected to percolate away from the drain field into the groundwater system.

During the Construction and Operations Phases, the potential for seepage from Mine Waste Stockpiles to affect Groundwater is limited because the major site facilities will be lined. Seepage will be collected and treated prior to discharge to the receiving environment. An underdrain will also be constructed beneath the Bonanza Ledge WRSF to help control water levels within the WRSF and to direct water from the Bonanza Ledge South Sump to the Bonanza Ledge Sediment Pond and ultimately to the water treatment plant.

During post-closure, it is possible that seepage will be released to groundwater without treatment as a result of degradation of the liners and underdrains over time, and this has the potential to result in changes in the physical or chemical composition of groundwater. WRSF areas will be rehabilitated, including revegetation, application of a low-permeability cover, and land forming, if necessary and practicable. Runoff water may infiltrate the groundwater flow system or flow directly to downstream surface water receptors. This runoff has been accounted in the Surface Water VC as direct runoff to surface water and, therefore, it has not carried forward in the Groundwater VC assessment as a seepage path to surface water.

QR Mill

Prior to construction of the FSTSF, the existing QR TSF pond will be dewatered, and a geomembrane liner will be installed over the existing tailings. Drains will be present above the liner to further reduce potential infiltration of tailings seepage to the groundwater flow system and diversion of this water to seepage collection systems. Water removed by filtering will be reused by the mill. Contact runoff will be retained within the site water management system and routed towards the former MZP. The MZP will collect excess process water and collected contact water runoff prior to treatment by the water treatment plant.

Interception wells were installed in 2022 between the NSCP and Rudy Creek to capture groundwater seepage from the FSTSF and NSCP in the event surface water quality in Rudy Creek increases above surface water quality guidelines due to the Project.

During operations, seepage collection systems will be operational to capture and re-use seepage from the FSTSF. At Closure, the FSTSF will have a low-permeability cover to further reduce infiltration and reduce seepage losses from the FSTSF to the groundwater environment. The exiting contact water ditches will be reclaimed and runoff will be directed to the receiving environment when it conforms with relevant water quality requirements at closure (Chapter 7.4).

7.5.5.1.2 Best Management Practices

BMPs that are applicable to this Project for Groundwater include:

- At closure, salvageable equipment/materials will be removed, and infrastructure will be decommissioned. ODV will remove chemicals, reagents, explosives, and hazardous materials and return them to suppliers or dispose of them in a designated facility. Until removal, chemicals will be stored in existing storage containers during operations in accordance with the Hazardous Waste Regulation (Government of BC, 1988).
- Inventories of reagents and other chemicals will be managed through operations to reduce quantities remaining at closure. Transportation, storage, use, and disposal of explosives for the Project will be conducted in accordance with BMPs and applicable regulations.
- Inert, non-salvageable materials that pose no risk of soil contamination or risk to surrounding waterways will be used as underground backfill on-site or removed off-site.
- An inspection program will be developed and implemented during operations to determine whether soil has been affected by contamination through hydrocarbon spills or other mine waste materials, including areas around fuel tanks.
- ODV will follow established guidelines for site assessment and remediation strategies used in mitigating and/or remediating contamination. Phase 1 and Phase 2 Environmental Site Assessments (ESAs) have been conducted for the Mine Site and QR Mill (Golder, 2021i, j, k, l). The Phase 1 ESAs consisted of a visual inspection and desktop review of available information (Golder, 2021i, j). The Phase 2 ESAs assessed soil quality at the Areas of Potential Environmental Concern identified in the Phase I ESAs (Golder, 2021k, l). At closure, an ESA will be conducted by a professional approved by the Contaminated Sites Approved Professionals Society of BC. After remediation, site conditions will be compared to the BC CSR standards that are most appropriate to the target end land use.

7.5.5.1.3 Environmental Management and Monitoring Plans

Environmental Management Plans (EMPs) have been developed for ODV operations and will be updated to limit the potential for Project-related effects on the surrounding surface water and groundwater environments.

Environmental management plans for the Project, which will incorporate mitigation measures that will manage impacts to Groundwater, are expected to include the following:

- Surface Erosion Prevention and Sediment Control Plan;
- Soil Management Plan;
- Metal Leaching/Acid Rock Drainage Management Plan;
- Fuel Management and Spill Contingency Plan;
- Waste (Refuse and Emissions) Management Plan;
- Mine Emergency Response Plan;
- Chemicals and Materials Storage and Handling Plan;
- Reclamation and Closure Plan;
- Water Management Plans (Mine Site and QR Mill); and
- Reclamation and Closure Plan.

In addition, a plan for groundwater monitoring will form part of an Environmental Monitoring Plan for the Project. This is discussed further in Section 7.5.9.

7.5.5.2 Alternative Water Supply Development

The Wells Aquifer is presently affected by historical mine influenced water that is predicted to be captured by the water supply well for the Community of Wells (Appendix 7.5-3). Due to the larger width of the underground workings below the Wells Aquifer, potential exists for the additional mine influenced water to be captured in post-closure due to the reflooding the underground workings. However, it should be noted that, due to current concerns regarding the quality of the community water supply, ODV is actively working with the District of Wells to: 1) establish a new well location (sourcing water from suitable surface water or groundwater options other than the Wells Aquifer or an area of non-mine influenced water); and 2) upgrade the current water supply pipeline infrastructure to resolve current problems with potable water supply for the community. In addition, the following steps will be taken by ODV to protect the appropriate future use of groundwater in the Wells Aquifer within the area of Project influence on groundwater quality:

- Sharing of information with the municipality, regulatory agencies, and community members on the groundwater quality.
- Supporting the municipality to explore opportunities (e.g., putting in place certain zoning, covenants, or liens on properties) such that future development triggers connection to the municipal drinking water system.
- Supporting the municipality in the development of a program such that future development located above the potentially impacted zones will be connected to the municipal drinking water system; and
- Implementation of a new community water source, or the outlined engineered mitigation of hydraulic containment described in Chapter 7.5, if a new community water source is not located.

Groundwater modelling for the Project indicates that other mitigation measures could be implemented prior to the start of closure in the event an alternative water supply is not identified. Simulated mitigation measures include a pumping well in the Wells Aquifer to hydraulically contain the area of upwelling from the flooded underground workings, on its own or in combination with a lower permeability cut-off wall to isolate the portion of the Wells Aquifer influenced by mine water. These mitigation measures have been successfully implemented at other sites, but it is not the preferred mitigation since the community water supply well is predicted to already be capturing mine influenced water from the flooded historical underground.

Table 7.5-27 presents a summary of mitigation options being considered with respect to effects on the water supply well for the community of Wells, along with potential treatment technologies that could be implemented if required. With the applied mitigations, groundwater quality to the community well was predicted to be similar to existing conditions (Appendix 7.5-4), with no residual effect.

Table 7.5-27 Summary of Mitigation Options for Managing Effects on the Community of Wells Water Supply Well

Consideration		Cut-off Wall and Pumping	Groundwater Treatment	New Well	New Surface Water Supply
Technical Feasibility		There are various types of techniques to install cut-off walls. Based on the currently available information, it appears that a Trench Cutter (Hydro-Mill) would be the most suitable technique for the site conditions and technical requirements. This equipment has installed low permeability elements to depths of 100 m and deeper through bedrock with unconfined compressive strength (UCS) of over 100 megapascals (MPa) in the past.	Based on water quality projections, removal of As, Fe and Mn may be required. In addition, the TDS concentration of the well water may be higher than it currently is and may exceed the Health Canada aesthetic objective limit for potable water of 500 mg/L. pH adjustment (to 6 or 7) may be required depending on the raw well water pH. The stated pH range would also be expected to allow arsenic removal by adsorption onto iron precipitates. A rule of thumb states that arsenic can be adequately removed by this process if the iron concentration is between 20 and 50 times the arsenic concentration by weight. Although iron is projected to be present in the well water, the iron concentration would likely be insufficient to achieve the required arsenic removal and additional iron precipitates would have to be added. Typically, ferric chloride is used for this process. Iron precipitates and manganese could be removed by the filtration/adsorption process that is currently being used for well water treatment. TDS removal could be accomplished by nanofiltration or reverse osmosis treatment. Both processes would require aluminium, iron, and manganese removal as pre-treatment as these constituents can cause fouling of the membranes used for the processes. Additional pre-treatment such as feeding of an antiscalant and filtration to protect the membrane modules from small particles would also be required. In addition, post treatment (raising the pH of the treated water) to make the treated water less corrosive may be required. Regular chemical cleaning of the membranes used for treatment is typically required. Treatability testing is required to determine the process design parameters.	A new well outside of the Wells Aquifer, and area of flooded underground discharge, would eliminate the capture of flooded mine water in the community water supply (both for existing conditions and at post closure). A well outside the Wells Aquifer could potentially require minimal treatment. It is anticipated that the water of a new well developed in the District of Wells area, either in the Wells Aquifer or elsewhere, would exhibit elevated concentrations of iron, manganese, and, potentially arsenic associated with the regional geology and unrelated to the historical and project workings. In addition, it is likely that the water would be hard. Water treatment methods for the removal of iron, manganese, and arsenic are available, if required. The treatment process of the existing water plant is capable of removing these parameters and it is anticipated that the process could be used to treat the water from a new well if it displayed a similar quality. Water softening is currently not conducted. Therefore, it is anticipated that it would not be required for water from a new well.	A new Surface Water Supply could consider surface licenses for Willow River, or alternative locations further away with the construction of a pipeline. Treatment was evaluated for Willow River, given its proximity, however, with construction of a pipeline, further surface water sources could be considered, including potentially sources requiring minimal treatment. Based on water quality data provided for Station WR-151.5 on the Willow River for the years 2015 to 2021 and a total of 98 samples, surface water treatment would require removal of iron and manganese, filtration, disinfection, and, potentially, removal of organic carbon. Removal of organic carbon may be required to remove colour and to lower the potential for the formation of disinfection by-products upon chlorination. A potential treatment process that could be used and that would meet BC surface water treatment requirements is as follows: ozonation to oxidize iron and manganese and to reduce the size of organic carbon molecules, removal of oxidized iron and manganese and other particles in a roughing filter containing a layer of activated carbon for removal of excess ozone, filtration in a slow sand filter, and disinfection of the filtered water with UV light and chlorine. Slow sand filtration is a simple physical, chemical, biological process that is capable of high removal efficiencies for pathogens. The biological aspect of the process can remove organic carbon, especially following pre-ozonation.
Effectiveness		Many case studies exist where barrier walls of permeability 1x10-6 cm/s or lower have been successfully used to reduce or eliminate flow of impacted waters.	The treatment processes identified can be used to produce water that meets the requirements of the BC Drinking Water Regulation and Health Canada guidelines.	Analytical data for treated water samples collected at the existing water treatment plant meets Health Canada guidelines with respect to arsenic, iron, and manganese, and demonstrates the effectiveness of the described process.	The described treatment process is well established and can be expected to produce water that meets the requirements of the BC Drinking Water Regulation and Health Canada guidelines.
Timeline for Construction and Implementation		9 to 15 months including the following phases – design, preparation of contract documents, tendering, selection of a contractor, procurement, construction, and commissioning.		9-12 months required for implementing water treatment, regardless of the option. This allows time for design, preparation of contract documents, tendering, selection of a contractor, procurement, construction, and commissioning. Does not include permitting of water well or surface water source.	
Potential Effects	Community	Disruption to the community (noise, dust) during installation. Large work platforms required along cut-off wall alignment for the large construction equipment (large cranes, bentonite tanks, desanders, large footprint of equipment).	Disruption to the community (noise, dust) during expansion of the existing water treatment building or construction of a new building. The described treatment processes likely would require a class 4 operator (highest level) as the chief operator. Additional operators would be required for backup.	Disruption to the community (noise, dust) during development of a new well, construction of new infrastructure such as construction of a new water main, building of an access road, extension of the electrical power grid, and construction of a new treatment building, if required.	Disruption to the community (noise, dust) during construction of a new treatment building. Much larger filtration area required in comparison to the filter used in the existing water treatment plant, but the wastewater generation rate would be considerably smaller. A plant using the described treatment process likely would be classified as a level 2 plant and, given the number of people served, could be operated by an operator with a small water systems operator classification (to be confirmed).
	Environment	Stream would have to be temporarily diverted and a bypass installed during construction. Carbon emissions will be associated with transport of equipment, operation of equipment, and supply of cement & bentonite.	The wastewater generated by the metal removal process would either have to be discharged to sewer, and thus would end up in the sewage treatment lagoon, or could be further treated to remove solids. The solid fraction would have to be landfilled because of the high metals content. A relatively large portion of the water delivered to a nanofiltration or reverse osmosis plant is turned into a concentrate stream that contains the removed constituents. The concentrate could only be disposed of in the sewage lagoon if sufficient excess capacity is available. If all waste streams from the treatment plant are discharged to the sewage lagoon, and all homes are connected to the lagoon, the concentrations of the constituents identified above in the wastewater can be expected to be similar to the concentrations in the well water. Constituents removed during water treatment may accumulate in the sludge of the lagoon. Depending on their concentration and leachability, disposal of the sludge as a hazardous waste may be required.	Following development of a new well, and construction of new infrastructure and a new water treatment plant (if required), potential effects would be similar to the existing well water treatment process.	Temporary impact on the surface water during construction of a water intake (screen and intake pipe).
Cost		High capital cost for wall and treatment plant; moderate Operations and Maintenance (O&M) costs for treatment.	Moderate capital costs and high O&M costs.	Low capital costs for well and infrastructure, assuming reasonable distance from the new well to existing infrastructure; low capital costs for treatment plant; and low O&M costs for treatment.	Low capital cost for surface water infrastructure; moderate capital costs for treatment plant; and low O&M costs for treatment.

Notes: MPa = megapascals; TDS = total dissolved solids; mg/L = milligram per litre; UV = ultraviolet; cm/s = centimetre per second; O&M = operations and maintenance

7.5.5.3 Effectiveness and Uncertainty of Mitigation

Most of the proposed mitigation presented above and summarized in Table 7.5-28 includes standard measures that are known to be effective (based on relevant/applicable experience with other mining projects); therefore, the uncertainty associated with their use is low. Any uncertainty associated with the effectiveness of the proposed mitigation measures will be addressed through Water Management Plans that will be implemented prior to the start of construction. If monitoring indicates that effectiveness of mitigation measures is lower than predicted, further mitigation may be required through adaptive management strategies.

7.5.5.4 Mitigation Summary

Table 7.5-28 summarizes the proposed Groundwater mitigation measures and their effectiveness at each Project phase. This table also identifies the residual effects that will be carried forward for residual effects characterization.

Table 7.5-28 Proposed Mitigation Measures and Their Effectiveness – Groundwater

Project Phase	Valued Component/ Subcomponent	Project Effects	Mitigation	Effectiveness	Uncertainty	Residual Effect
All phases	All Groundwater subcomponents	Increased Surface Water Runoff, Reduced Groundwater Infiltration	• Vegetation clearing, soil stripping, grubbing, and grading for construction, temporary workspace, or storage areas, will occur only within the approved Project boundaries. • Brownfield sites that have been previously disturbed by historical mining operations will be used for the placement of Project infrastructure. • Sediment and erosion control measures (e.g., silt curtains) will be implemented.	High	Low	No
Construction, Operations, Closure	All Groundwater subcomponents	Alteration of Groundwater Quantity and Quality from Discharge from Sewage and Septic Handing System at the Mine Site Complex	• Sewage and septic waste will be piped to a treatment system prior to being discharged to the drainage galleries. Effluent will be treated by the MBBR system. • Drainage galleries have been designed according to the Municipal Wastewater Regulation	High	Low	No
Construction, Operations	All Groundwater subcomponents	Alteration to Groundwater Flow and Water Level Elevation from Underground Dewatering and Operation of a Water Supply Well	• Groundwater removed to facilitate development of the underground mine will be treated to meet permit requirements prior to discharge to the receiving environment.	Low	Low	Yes
All phases	All Groundwater subcomponents	Alteration to Groundwater Flow Quantity and Quality from Alteration of Seepage from QR TSF/FSTSF and Operation of a Water Supply Well	• Interception wells will be operated in the event seepage from the FSTSF results in the migration of poor-quality groundwater and results in surface water concentrations above applicable guidelines/criteria. • A liner will be placed over existing tailings and a cover will be placed over the final Filtered Stack tailings surface.	High	Low	Yes
Construction, Operations, Closure	All Groundwater subcomponents	Alteration in Groundwater Quality and Quantity from Seepage from Mine Waste Stockpiles and Surface Water Management Systems	• The historical waste material will be covered by a NPAG liner to separate it from the BFA that will be constructed on top of the covered historical material. It will be progressively reclaimed with an engineered cover. • Major site facilities will be lined, and seepage will be collected and managed, within the Project water management system. • A cover will be placed over the mine waste stockpiles at closure.	High	Low	No (pathway assessed in Chapter 7.4 for Surface Water)
Post-Closure	All Groundwater subcomponents	Alteration in Groundwater Quality and Quantity from Seepage from Mine Waste Stockpiles and Surface Water Management Systems	• During post-closure, after active water treatment and management activities have ceased (passive care period), shallow seepage from stockpiles will be collected by perimeter ditching and passively conveyed to the receiving environment through the closure drainage systems.	High	Low	No (pathway assessed in Chapter 7.4 for Surface Water)
All phases	Groundwater Quality	Alteration in Groundwater Quality from Structures, Equipment, and Material Handling	• At closure, salvageable equipment/materials will be removed and infrastructure will be decommissioned. ODV will remove chemicals, reagents, explosives, and hazardous materials, and return them to suppliers or dispose of them in a designated facility. Until removal, chemicals will be stored in existing storage containers during operations in accordance with the Hazardous Waste Regulation (Government of BC, 1988). • Inventories of reagents and other chemicals will be managed through operations to quantities required for current and planned usage. Transportation, storage, use, and disposal of explosives for the Project will be conducted in accordance with BMP and applicable regulations. • Inert, non-salvageable materials that pose no risk of soil contamination or risk to surrounding waterways will be used as underground backfill on-site or removed off-site. • An inspection program will be developed and implemented during operations to determine whether soil has been affected by contamination through hydrocarbon spills or other mine waste materials, including areas around fuel tanks. • ODV will follow established guidelines for site assessment and remediation strategies used in mitigating and/or remediating contamination.	High	Low	No

Project Phase	Valued Component/ Subcomponent	Project Effects	Mitigation	Effectiveness	Uncertainty	Residual Effect
Closure, Post Closure	All Groundwater subcomponents	Alteration of Groundwater Flow Quantity and Quality from Underground Flooding	• No unconsolidated backfill (rockfill and/or tailings) will be placed in underground workings. All underground backfill will be cemented (comprising a mixture of cemented and/or paste rockfill and tailings) to reduce chemical loading from the rockfill. • An alternative water supply from groundwater or surface water will be sourced for the Community of Wells. • Hydraulic containment of groundwater from underground mine workings through pumping in potential combination with a low permeability cut-off will be a back-up mitigation.	High	Low	Yes
All phases	Groundwater Quantity	Reduced Groundwater Infiltration from Reclamation of Disturbed Areas	• Vegetation clearing, soil stripping, grubbing, and grading for construction, temporary workspace, or storage areas, will occur only within the approved Project boundaries. • Brownfield sites that have been previously disturbed by historical mining operations will be used for the placement of Project infrastructure. • Reclamation of disturbed areas will occur progressively throughout Project life (including contouring and revegetation), incorporating strategies to manage potential for runoff and erosion and to increase the potential for groundwater infiltration.	High	Low	No

7.5.6 Assessing Positive Effects

Positive effects on groundwater quantity and quality are generally not expected because of the Project. At the QR Mill, seepage from the existing QR TSF will be reduced; however, the overall percent contribution of seepage water in the groundwater baseflow to surface water will be relatively unchanged, indicating the groundwater quality and quantity of the groundwater baseflow will be similar to baseline conditions.

7.5.7 Assessing Negative Residual Effects

7.5.7.1 Summary of Residual Effects

The residual effects for Groundwater after application of mitigation measures are:

- Alternation to groundwater flow and water level elevation from underground dewatering and operation of a water supply well (Mine Site);
- Alteration to groundwater flow quantity and quality from alteration of seepage from the QR TSF/FSTSF and operation of a water supply well; and
- Alteration of groundwater flow quantity and quality from underground flooding;
- These residual effects were assessed by subcomponent and location according to the following statements:
    - Changes to groundwater quantity at the Mine Site during construction and operations due to dewatering of underground workings and operation of a potable water supply well;
    - Changes to groundwater quantity at the Mine Site post-closure due to the flooding of the underground developments;
    - Changes to groundwater quantity post-closure due to the flooding of the underground developments;
    - Changes to groundwater quality at the Mine Site due to migration and discharge of groundwater from flooded underground workings during closure and post-closure;
    - Changes to groundwater quantity at the QR Mill during construction, operations, closure, and post-closure due to the construction of the FSTSF; and
    - Changes to groundwater quality at the QR Mill due to construction of the FSTSF.

Indigenous groundwater uses and users were considered in the residual affects assessment; however, review of public databases (Section 7.5.3.3.4.3), consultation, and traditional use studies (DM Cultural Services Ltd., 2019; Landmark Resource Management Ltd., 2021) did not identify current specific uses of groundwater in the LAAs.

7.5.7.2 Methods

The characterization of potential residual effects was based on several criteria, including context, magnitude, extent, duration, reversibility, and frequency, as well as risk and uncertainty (likelihood and consequence). These criteria are defined for Groundwater in Table 7.5-29.

Table 7.5-29 Residual Effects Criteria – Groundwater

Criteria	Description
Context	**Low**—the groundwater flow system has a low resilience to imposed stresses, which means it will not easily adapt to the potential residual effect **Neutral**—the groundwater flow system has a neutral resilience to imposed stresses and may be able to respond and adapt to the potential residual effect **High**—the groundwater flow system has a high natural resilience to imposed stresses and thus can adapt to the potential residual effect
Magnitude	**Groundwater Quantity:** **Negligible:** predicted percent change in total groundwater quantity is less than 1% **Low:** predicted percent change in total groundwater quantity is between 1% and 20% **Moderate:** predicted percent change in total groundwater quantity is between 20% and 40% **High:** Predicted percent change in total groundwater quantity is greater than 40% **Groundwater Quality:** **Low:** releases do not cause exceedance of guidelines or cause exceedances that are less than background exceedances **Moderate:** releases contribute slightly to existing background exceedances **High:** releases cause exceedance of guidelines (where guidelines were not previously exceeded)
Extent	**Local:** effect restricted to the LAA **Regional:** effect extends beyond the LSA into the RAA **Beyond Regional:** effect extends beyond the RAA
Duration	Regarding Groundwater Quantity and Quality, the duration of a potential residual effect is assessed according to the following three levels **Short-term:** the anticipated potential residual effect occurs temporarily during the Construction Phase or will last less than two years in operations **Medium-term:** the anticipated potential residual effect will be felt for a limited period greater than two years, generally corresponding to the Operations and Closure Phases **Long-term:** the anticipated potential residual effect will be felt beyond closure
Reversibility	Regarding Groundwater Quantity and Quality, a potential residual effect may be: **Fully reversible:** effect can be reversed **Partially reversible:** effect can be reversed partially **Irreversible:** effect is permanent
Frequency	Regarding Groundwater Quality, the frequency of a potential residual effect may be described as: **Once:** a potential residual effect is confined to one discrete event **Regular:** a potential residual effect occurs at consistent intervals **Irregular:** a potential residual effect occurs at sporadic intervals **Continuous:** a potential residual effect occurs constantly
Affected Populations	**Even**: the potential effect is experienced by any and all sub-populations **Disproportionate**: the potential effect is experienced only by certain sub-populations or experienced more acutely by certain sub-populations

Notes: % = percent; LAA = local assessment area; RAA = regional assessment area.

7.5.7.2.1 Assessment Techniques

The characterization of the residual effects on Groundwater relies on the analytical and numerical groundwater modelling assessment summarized in Section 7.5.3.1.1 and in the Groundwater Analytical and Numerical Modelling Assessment Reports (Appendix 7.5-2, Appendix 7.5-3, and Appendix 7.5-4). The groundwater modelling assessment was carried out in accordance with BC Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Development Activities with provincial recommendations (ENV, 2012a). The methods used to develop the relies on the analytical and numerical groundwater modelling assessment that form the basis of the residual effects evaluation are described in detail in Section 7.5.3.1.1.

7.5.7.2.2 Risk and Uncertainty

For the purposes of this EA, the likelihood and consequences of a potential residual effect occurring will be described as risk.

Likelihood is the probability of an event occurring and can be influenced by many factors. For the purposes of the EA, likelihood is defined as the following:

- Low: <40% chance of effect occurring;
- Medium: 40 to 80% chance of effect occurring; and
- High: >80% chance of effect occurring.

Consequence is defined as the outcome of an event affecting Groundwater. Consequence can be assessed as minor, moderate, or major (Table 6.7-1) based on the combination of magnitude and geographical extent of the residual effect.

Based on the results of the likelihood and consequence ratings for each residual effect, as described above, risk to Groundwater can be determined based on a risk matrix for the Project provided in Figure 6.7-2. Risk levels can be assessed as low, moderate, and high. Additional risk analysis may be required if there is high uncertainty in the effectiveness of mitigation measures (Section 6.5.1.2) or if the risk rating is high. If additional risk analysis is required, a range of likely, plausible, and possible outcomes with respect to likelihood and consequence will be considered and additional studies, mitigation, or management plans may be required.

Many types of uncertainty are relevant to assessing whether an effect will occur and the implications of the effect. The assessment includes a characterization of uncertainty and level of confidence in the predicted potential residual effects. Confidence is a measure of how well potential residual effects are understood and the quality of the input data. It considers the level of uncertainty associated with the residual effects assessment. Where appropriate, uncertainty may also be addressed by additional mitigation, as required, or through monitoring programs designed to verify the effects predictions and/or the effectiveness of mitigation.

In summary, the following are considered in the determination of confidence in the residual effects assessment for the Groundwater VC:

- Reliability of data inputs and analytical methods used to predict Project effects;
- Confidence regarding the effectiveness of mitigation measures; and

- Certainty of the predicted outcome.

Confidence will be characterized as follows:

- Low: Cause-effect relationships between the Project and Groundwater are poorly understood. There may be several unknown external variables and/or data for the Project area that are incomplete. The effectiveness of the mitigation measures may not yet be proven. Modelling results may vary considerably, given the data inputs. There is a high degree of uncertainty in the conclusions of the assessment.
- Moderate: The cause-effect relationships between the Project and Groundwater are not fully understood (e.g., there are several unknown external variables or data for the Project area that are incomplete). The effectiveness of mitigation measures may be moderate or high. Modelling predictions are relatively confident. Based on the above, there is a moderate confidence in the assessment conclusions.
- High: There is a good understanding of the cause-effect relationship between the Project and Groundwater, and sufficient data is available to support the assessment. The effectiveness of the selected mitigation measures is moderate to high. There is a low degree of uncertainty associated with data inputs and/or modelling techniques, and variation from the predicted effect is expected to be low. Given the above, there is high confidence in the conclusions of the assessment.

The definition of importance of a residual effect is presented in Section 6.7.2.

7.5.7.3 Potential Residual Effects

7.5.7.3.1 Changes to Groundwater Quantity at the Mine Site during Construction and Operations Due to Dewatering of Underground Workings and Operation of a Potable Water Supply Well

Residual Effect Analysis

Construction and operations at the Mine Site will alter groundwater quantity in the Mine Site relative to existing conditions through the following mechanisms:

- Depression of water levels in the Mine Site LAA from dewatering of the historical and Project undergrounds. Interception of groundwater by dewatering has potential to reduce surface water baseflows, reduce discharges where historical mine workings intersect ground surface, and lower water levels in the Wells aquifer, a drinking water aquifer utilized by the community of Wells.
- Underground workings will be progressively backfilled with cemented and/or paste backfill; however, backfilling of the underground workings is unlikely to result in a full hydraulic seal, and equilibration of hydraulic head across the workings is expected. No impedance of flow through the workings is assumed for the operations predictions, which is conservative for the prediction of groundwater discharge rates and Project effects on Groundwater.
- Depression of water levels from the commissioning and operation of a water supply well from the Project. Operation of the water supply well has the potential to alter stream baseflow through the interception of groundwater by the well, and to interfere with the operation of the Wells community well through the lowering of water levels in the aquifer.

Model predictions results are presented in Table 7.5-20 and Table 7.5-21 of Section 7.5.3.4.1.1, and outlined below:

- During operations, discharges to Mine Seepage #1, #2, and #5 are predicted to cease due to the dewatering of the historical and Project undergrounds.
- Baseflow changes are predicted to occur because of dewatering of the underground and range from a reduction of <1% up to 60%. High changes in base flow (greater than 40%) are observed in portions of Emory Gulch, Lowhee Creek, Watson's Gulch, and Upper Mosquito Creek. Baseflow changes are conservatively high, particularly in the Bonanza Ledge area for Emory Gulch, Lowhee Creek, and Watson Gulch, due to the use of discrete feature elements to represent the historical underground workings. Discrete feature elements can cause artificially high negative pressures along their length when dewatered, which induces more flow towards the underground workings than would occur (discussed in Section 5.0, Model Limitations). The predicted changes in baseflow are therefore considered to be conservatively high and actual changes in baseflow would be expected to be lower. This is supported by the observation that Bonanza Ledge workings are presently depressurized for active mining so that reductions to baseflow have already occurred near these workings and additional reductions in baseflow should be minimal.
- At the end of operations, the most significant area of depressurization is the Island Mountain/Shaft area, where over 400 m of drawdown is predicted. This area coincides with the deepest mine workings at -740 m and -710 m elevation. In the Jack of Clubs Valley and Wells Aquifer, drawdown is less than 5 m and no desaturation of the Wells Aquifer is predicted. This is because of the low permeability of bedrock in comparison to the overburden sediments, and the presence of Jack of Clubs Lake and the Willow River, which together will serve to limit the drawdown effects in the overburden. It also indicates that the quantity of water that the water supply well for the Community of Wells withdraws will not be affected by the Project during construction and operations.
- Based on the results of the Base Case and sensitivity analysis, the drawdown cone at the end of operations associated with the dewatering of the underground workings and operation of a potable supply well was predicted to extend to some of the numerical model boundaries. This may indicate that, at some locations, the groundwater divides could potentially shift, capturing additional recharge from the areas outside of the model domain (i.e., from the RAA). The influence of this additional recharge, if it were to occur, was further assessed by sensitivity simulations by applying specified head boundaries at the model perimeter that allow for the inflow of water from these adjacent watersheds. Results showed that additional flow from outside of the model domain is negligible compared to predicted mine inflow and estimated baseflow in the watercourses within the LAA. On this basis, the selection of model boundaries is assumed to result in negligible effects on model predictions and in a negligible effect in baseflow to creeks outside of the LAA.

Characterization of Residual Effect

The residual effect to groundwater from changes to groundwater quantity at the Mine Site during construction and operations due to underground dewatering and operation of potable water supply wells is characterized in Table 7.5-30.

Table 7.5-30 Residual Effect Characterization for Changes to Groundwater Quantity at the Mine Site during Construction and Operations Due to Dewatering of Underground Workings and Operation of a Potable Water Supply Well

Criteria	Characterization	Rationale
Context	Neutral	Groundwater flow system has a neutral resilience to imposed stresses and may be able to respond and adapt to the potential residual effect.
Magnitude	Low to High	Predicted changes in groundwater discharge to surface water relative to existing conditions range between 0% to 60%. Water level reduction in the Wells Aquifer will not impede use of the Community of Wells water supply well. High ranking applies to Lowhee Creek, Watson’s Gulch, Emory Gulch, and Upper Mosquito Creek baseflow changes.
Extent	Local	Limited to the LAA (verified with sensitivity analysis).
Duration	Medium Term	Effects are predicted to last through operations and part of closure as the underground floods.
Reversibility	Partially to Fully Reversible	Reflooding of the underground will cause hydraulic heads and stream baseflows to recover.
Frequency	Continuous	Hydraulic heads will be lowered throughout operations due to dewatering of the underground.
Affected Populations	Even	The potential effect is experienced by any and all sub-populations.

Notes: % = percent; LAA = Local Assessment Area

Risk and Uncertainty

The risk and uncertainty associated with changes to groundwater quantity at the mine site during construction and operations due to underground dewatering and operation of a potable water supply wells is characterized in Table 7.5-31.

Table 7.5-31 Risk and Uncertainty Characterization for Changes to Groundwater Quantity at the Mine Site during Construction and Operations Due to Dewatering of Underground Workings and Operation of a Potable Water Supply Well

Criteria	Characterization	Rationale
Likelihood	High	Changes to groundwater flow are expected to occur, but at values less than predicted for streams with a high rating due to the use of discrete feature elements.
Consequence	Moderate	Magnitude is low to high, and extent is local, which results in a moderate rating. Streams with high magnitude rating are considered conservative because of the modelling method, which will overestimate streamflow losses.
Risk	Moderate	Consequence is Low to Moderate, depending on the stream, and likelihood is moderate for the predictive effects, which results in a high-risk rating per the risk matrix in Chapter 6, Table 6.7-2.
Uncertainty	Low	The cause-effect relationship is well understood, and sufficient data is available to support the assessment. There is a low degree of uncertainty associated with data inputs and/or modelling techniques, though the method results in a potential bias in baseflow reductions to be high.

Although a moderate ranking is identified in this section for risk to select streams, changes in stream baseflow is not the endpoint for the Surface Water VC and the effect is further evaluated in Chapter 7.4.

Importance

The importance is considered high. Groundwater-surface water interactions and groundwater resources have been identified as a top interest by Indigenous nations, community members, the public, local governments, and/or provincial and federal government agencies.

7.5.7.3.2 Changes to Groundwater Quantity at the Mine Site at Post-Closure due to Flooding of the Underground Developments

Residual Effect Analysis

Closure of the Mine Site will alter groundwater quantity in the Mine Site relative to existing conditions through the following mechanisms:

- At closure, the underground dewatering activities will stop, and groundwater levels will progressively rise near to the current level. The excavation of the proposed underground will result in a larger network of underground workings that have potential to underdrain the highlands above the workings, resulting in changes to stream base flow.
- Underground workings will be filled with cemented backfill; however, backfilling of the underground workings is unlikely to result in a full hydraulic seal and equilibration of hydraulic head across the workings is expected to be possible.

Model predictions are presented in Table 7.5-20 and Table 7.5-21 of Section 7.5.3.4.1.1 and outlined below as they relate to this residual effect:

- At post-closure, flow to Mine Seepage #1 and #2 is predicted to increase, whereas discharge at Mine Seepage #5 is not predicted to occur. Water from Mine Seepage #1 is inferred to flow overland to Mosquito Creek and/or reinfiltrate into the ground where it may then flow to Mosquito Creek or further downstream to the Willow River. Water from Mine Seepage #2 is inferred to flow overland to the Willow River and/or reinfiltrate into the ground and then flow into the Willow River. Water from Mine Seepage #5, if it does discharge, is inferred to flow overland towards the Placer Outwash deposits, where it would then be expected to reinfiltrate into the groundwater flow system.
- At closure, predicted base flows are within 10% of existing conditions, with some streams seeing a potential increase in flow due to the change in the extent of the flooded underground workings.
- At closure, a drawdown greater than one metre is predicted to extend approximately 1 km to 1.5 km from the Project underground workings. In the area of the Wells Aquifer, predicted hydraulic heads are generally within 1 metre of existing conditions, indicating a low residual change in water levels within the Wells Aquifer.

Climate change effects were not directly simulated in the model due to the complexity of trying to reproduce the relationship of the infiltration and interflow that would be present in the mountainous terrain, and instead they are qualitatively discussed here. Variations in annual distribution of recharge may cause larger variations in hydraulic head throughout the year, but overall evaluation of future climate conditions indicates recharge may increase by 2% to 19% on an annual basis, which may reduce changes in baseflow predicted for the Project in post-closure relative to existing conditions.

Freshet interflows could be reduced due to lower snowpack depths, which could reduce peak baseflow contributions in the Spring and peak flows through mine seepage locations.

Characterization of Residual Effect

The residual effect to Groundwater from post-closure groundwater quantity changes at the Mine Site due to flooding of underground developments is characterized in Table 7.5-32.

Table 7.5-32 Residual Effect Characterization for Changes to Groundwater Quantity at the Mine Site at Post-Closure due to Flooding of the Underground Developments

Criteria	Characterization	Rationale
Context	Neutral	Groundwater flow system has a neutral resilience to imposed stresses and may be able to respond and adapt to the potential residual effect.
Magnitude	Low	Predicted changes in groundwater discharge to surface water relative to existing conditions range between 0% and 10%. Water level reduction in Wells Aquifer less than 1 m change from existing conditions.
Extent	Local	Limited to the LAA.
Duration	Long-term	Effects are predicted to persist in post-closure.
Reversibility	Irreversible	Effects are permanent.
Frequency	Continuous	Hydraulic heads will be maintained in an altered state due to the excavation and flooding the undergrounds.
Affected Populations	Even	The potential effect is experienced by any and all sub-populations.

Notes: % = percent; m = metre; LAA = Local Assessment Area

Risk and Uncertainty

The risk and uncertainty associated with post-closure groundwater quantity changes at the Mine Site due to flooding of underground developments is characterized in Table 7.5-33.

Table 7.5-33 Risk and Uncertainty Characterization for Changes to Groundwater Quantity at the Mine Site at Post-Closure due to Flooding of the Underground Developments

Criteria	Characterization	Rationale
Likelihood	High	Changes to groundwater flow are expected to occur.
Consequence	Minor	Magnitude is low and extent is local, which results in a Minor rating per the consequence matrix in Chapter 6, Table 6.7-1.
Risk	Low	Consequence is low and likelihood is high, which results in a low rating per the risk matrix in Chapter 6, Table 6.7-2.
Uncertainty	Low	The cause-effect relationship is well understood, and sufficient data is available to support the assessment. There is a low to moderate degree of uncertainty associated with data inputs and/or modelling techniques.

Importance

The importance is considered high. Groundwater-surface water interactions and groundwater resources has been identified as a top interest by Indigenous nations, community members, the public, local governments, and/or provincial and federal government agencies.

7.5.7.3.3 Changes to Groundwater Quality at the Mine Site at Post-Closure due to Flooding of the Underground Developments

Residual Effect Analysis

Operation of the underground mine will alter groundwater quality in the underground developments relative to existing conditions through the following mechanisms:

- Rock exposed in historic and new mine openings will be exposed to oxygen, which could result in the onset of sulphide mineral oxidation.
- The mineral weathering products resulting from sulphide mineral oxidation will build up in exposed rock. This process will occur during all phases of the mine when rock is exposed to oxygen in underground workings, and could result in the onset of incipient processes of ARD/ML.
- Mine workings above the water table will continue to produce loading from mineral weathering products. Mine workings below the water table will not be subject to mineral weathering following the flooding of the mine workings, when oxygen is limited.
- The weathering products that build up in the mine workings will be released to groundwater during mine flooding. This is a process that will only occur during mine flooding.
- Mineral weathering products in exposed mine workings above the water table will be continually released to contact water during periods of groundwater recharge (if any).

Model predictions are summarized in Section 7.5.3.4.1.1 and outlined below as they relate to this residual effect:

- Closure and post-closure underground mine water is predicted to have elevated concentrations of Sb, As, Cl, Co, Fe, Li, Mn, Ni, P, Na, SO_4, and U relative to water quality guidelines.
- Predicted concentrations of Sb, Cl, Co, Li, and Cl are elevated relative to existing underground mine water quality. Predicted concentrations of all other parameters (As, Fe, Mn, Ni, Na, and SO_4) are similar to those currently occurring in the underground workings.

Characterization of Residual Effect

The residual effect to Groundwater from changes to post-closure groundwater quality due to flooding of underground mine workings is characterized in Table 7.5-34.

Table 7.5-34 Residual Effect Characterization for Changes to Groundwater Quality Post-Closure due to Flooding of the Underground Developments

Criteria	Characterization	Rationale
Context	Low	The groundwater flow system has a low resilience to imposed stresses, which means it will not easily adapt to the potential residual effect.
Magnitude	Moderate	Predicted underground mine water quality will exceed guidelines for key parameters of potential concern. Concentrations of arsenic and sulphate exceed relevant guidelines in existing underground mine water (CM-20-050 [2020-07-30]).
Extent	Local	Limited to the LAA
Duration	Long-Term	Effects are predicted to persist in post-closure.
Reversibility	Irreversible	Effect is predicted to be permanent, following closure.
Frequency	Continuous	Effects are predicted to persist in post-closure.
Affected Populations	Even	The potential effect is experienced by any and all sub-populations.

Notes: LAA = Local Assessment Area

Risk and Uncertainty

Table 7.5-35 presents the risk and uncertainty characterization for changes to Groundwater quality post-closure due to flooding of the underground developments.

Table 7.5-35 Risk and Uncertainty Characterization for Changes to Groundwater Quality Post-Closure due to Flooding of the Underground Developments

Criteria	Characterization	Rationale
Likelihood	High	Changes to groundwater quality are expected to occur.
Consequence	Moderate	Magnitude is moderate and extent is local, which results in a moderate rating per the consequence matrix in Chapter 6, Table 6.7-1.
Risk	Moderate	Consequence is moderate and likelihood is high, which results in a moderate rating per the risk matrix in Chapter 6, Table 6.7-2.
Uncertainty	Moderate	The cause-effect relationship is understood and sufficient data is available to support the assessment. There is a low to moderate degree of uncertainty associated with data inputs and/or modelling techniques.

Importance

The importance is considered high. Groundwater-surface water interactions and groundwater resources has been identified as a top interest by Indigenous nations, community members, the public, local governments, and/or provincial and federal government agencies.

7.5.7.3.4 Changes to Groundwater Quality at the Mine Site due to Migration and Discharge of Groundwater from Flooded Underground Workings during Closure and Post-Closure

Residual Effect Analysis

As discussed in Appendix 7.5-3, groundwater from the flooded historical mine workings is currently captured by the Wells Aquifer. At closure, groundwater from the flooded mine workings will continue to discharge to the Wells Aquifer. Closure of the Mine Site will alter groundwater quality in the Mine Site relative to existing conditions as follows:

- The existing, flooded historical underground mine workings have elevated concentrations of As, Fe, Mn, SO_4, and U relative to water quality guidelines.
- Additional chemical load will be generated from the re-flooding of historical mine workings and flooding of new mine workings. The predicted future composition of underground mine water has elevated concentrations of several parameters relative to water quality guidelines, including: Sb, As, Cl, Co, Fe, Li, Mn, Ni, P, Na, SO_4, and U.
- The underground mine groundwater could contribute additional loading of the parameters listed above to the Wells Aquifer during the closure and post-closure period.

The Wells Aquifer supplies potable water to the District of Wells via a pumping well. A potential exists for the water supply well for the District of Wells to capture increased mine influenced water in the post-closure period, following the re-flooding of the historical and future mine workings. Based on the results of the hydrogeological model (assuming mitigation), it is predicted that the District of Wells community water supply well could comprise up to 10% mine water at closure. With this composition of water, predicted water quality would be expected to be similar to existing conditions at the well (Appendix 7.5-4), with no residual effect.

However, it should be noted that, due to current concerns regarding the quality of the community water supply, ODV is actively working with the District of Wells to: 1) establish a new well location (sourcing water from suitable surface water or groundwater options other than the Wells Aquifer or reducing the influence of mining from a water quality perspective); and 2) upgrade the current water supply pipeline infrastructure to resolve current problems with the potable water supply for the community.

Characterization of Residual Effect

The residual effect to Groundwater from changes to Mine Site groundwater quality due to closure and post-closure migration and discharge of groundwater from flooded underground workings is characterized in Table 7.5-36.

Table 7.5-36 Residual Effect Characterization for Changes to Groundwater Quality at the Mine Site due to Migration and Discharge of Groundwater from Flooded Underground Workings during Closure and Post-Closure

Criteria	Characterization	Rationale
Context	Low	The groundwater flow system has a low resilience to imposed stresses, which means it will not easily adapt to the potential residual effect.
Magnitude	Moderate	Predicted underground mine water quality will exceed guidelines for key parameters of potential concern. Concentrations of arsenic and sulphate exceed relevant guidelines in existing underground mine water (CM-20-050 [2020-07-30]). This moderate rating applies to the Wells Aquifer and groundwater down-gradient of the mine workings, it does not apply to the Community of Wells water supply well, which is considered mitigated per measures in Section 7.5.4.2.
Extent	Local	Limited to the LAA
Duration	Long Term	Effects are predicted to persist in post-closure.
Reversibility	Irreversible	Effect is predicted to be permanent following mine closure.
Frequency	Continuous	Effects are predicted to persist in post-closure.
Affected Populations	Even	The potential effect is experienced by any and all sub-populations.

Notes: LAA = Local Assessment Area

Risk and Uncertainty

The risk and uncertainty associated with changes to Mine Site groundwater quality due to closure and post-closure migration and discharge of groundwater from flooded underground workings is characterized in Table 7.5-37.

Table 7.5-37 Risk and Uncertainty Characterization for Changes to Groundwater Quality at the Mine Site due to Migration and Discharge of Groundwater from Flooded Underground Workings during Closure and Post-Closure

Criteria	Characterization	Rationale
Likelihood	High	Changes to groundwater quality in the Wells Aquifer are expected to occur.
Consequence	Moderate	Magnitude is moderate and extent is local, which results in a moderate rating per the consequence matrix in Chapter 6, Table 6.7-1.
Risk	Moderate	Consequence is moderate and likelihood is high, which results in a moderate rating per the risk matrix in Chapter 6, Table 6.7-2.
Uncertainty	Moderate	The cause-effect relationship is well understood, and sufficient data is available to support the assessment. There is a low to moderate degree of uncertainty associated with data inputs and/or modelling techniques.

Importance

The importance is considered high. Groundwater-surface water interactions and groundwater resources has been identified as a top interest by Indigenous nations, community members, the public, local governments, and/or provincial and federal government agencies.

7.5.7.3.5 Changes to Groundwater Quantity at the Quesnel River Mill during Construction and Operations of the Filtered Stack Tailings Storage Facility

Residual Effect Analysis

Construction and operation of the FSTSF will alter groundwater in the QR Mill LAA relative to existing conditions through the following mechanisms:

- Reduction of seepage loss from the FSTSF that results in the lowering of hydraulic heads near and surrounding the FSTSF and potential reduction in stream baseflow. Seepage is reduced by the drainage of the pond and placement of the liner overtop of the existing tailings prior to placement of the dry filtered stack tailings. Seepage collection is also altered/reduced by the placement of drains in the tailings above the liner.
- Depression of the water table from operation of the water supply well, with potential reduction in stream baseflow.
- Lowering of the MZP water level from existing conditions from about 1,000 masl to about 995 masl, which will locally lower hydraulic heads near the MZP and potentially reduce stream baseflow in Creek#2, Creek#2.5, and Creek#3.
- Expansion of the SSCP footprint, which will locally alter hydraulic heads according to the maintained water level.

Model predictions are summarized in Table 7.5-22, Table 7.5-23, Table 7.5-24A, and Table 7.5-24B of Section 7.5.3.4.1.2. Base case predictions using the calibrated model indicate construction and operations of the FSTSF and water supply well could reduce baseflow in Rudy Creek SW2 by 8% relative to existing conditions. Baseflow at Rudy Creek SW3, which includes the upstream Rudy Creek SW2, could be reduced by approximately 6%. Considering the uncertainty in model predictions due to the uncertainty in model hydraulic properties, baseflows in Rudy Creek were most sensitive to the overburden hydraulic properties. The predicted change in groundwater discharge to surface water was expected to be up to 14% less than existing conditions at the end of operations for Rudy Creek SW2 and 10% less for Rudy Creek SW3, assuming the overburden hydraulic conductivity is a factor of three times higher than the calibrated properties.

Considering the Base Case and uncertainty scenarios, predicted changes at Creek #2, Creek #2.5, and Creek #3 ranged up to 8% reduction at Creek #3, 17% reduction at Creek #2.5, and 2% reduction at Creek #2. Changes in baseflow at Creek #3 and Creek #2.5 are affected by the hydraulic connection to the MZP. The lower operational water level in the MZP results in the diversion of groundwater away from the creeks towards the MZP. Creek #2 is located cross-gradient to the FSTSF and MZP; therefore, changes in groundwater baseflow contributions in this creek are predicted to be negligible.

Based on the results of the Base Case and sensitivity analysis, the drawdown cone at the end of operations associated with construction and operation of the FSTSF was predicted to extend to some of the numerical model boundaries. This may indicate that, at some locations, the groundwater divides could potentially shift, capturing additional recharge from the areas outside of the model domain (i.e., from the RAA). The influence of this additional recharge, if it were to occur, was further assessed by sensitivity simulations by applying specified head boundaries at the model perimeter that allows for the inflow of water from these adjacent watersheds. Results showed that additional flow from outside of the model domain that may flow to surface water receptors in the model domain ranged between 3 m^3/day (Base Case) and 7 m^3/day (Uncertainty Scenarios). These flow rates are considered low relative to existing stream base flow and within the range of measured stream flow variation. On this basis, the selection of model boundaries is assumed to result in negligible effects on model predictions and in a negligible effect in baseflow to creeks outside of the LAA.

Characterization of Residual Effect

The residual effect on Groundwater quantity at the QR Mill during construction and operations of the FSTSF is characterized in Table 7.5-38.

Table 7.5-38 Residual Effect Characterization for Groundwater Quantity at the Quesnel River Mill during Construction and Operations of the Filtered Stack Tailings Storage Facility

Criteria	Characterization	Description
Context	Neutral	Groundwater flow system has a neutral resilience to imposed stresses and may be able to respond and adapt to the potential residual effect.
Magnitude	Low	Predicted changes in groundwater discharge to surface water within 0% to -17%.
Extent	Local	Limited to the LAA (verified with sensitivity analysis).
Duration	Long-Term	Effects are predicted to remain after closure.

Criteria	Characterization	Description
Reversibility	Partially Reversible	Reduction in pumping rate from the water supply well in closure and increase in closure MZP pond level will result in partial recovery of water levels and groundwater baseflow contributions.
Frequency	Continuous	Hydraulic heads around the FSTSF will be permanently lowered following the drainage of the pond, placement of the liner, and the deposition of filtered stack tailings.
Affected Populations	Even	The potential effect is experienced by any and all sub-populations

Notes: % = percent; LAA = local study area; MZP = Main Zone Pit; FSTSF = Filtered Stack Tailings Storage Facility.

Risk and Uncertainty

The risk and uncertainty associated with changes to groundwater quantity at the QR Mill during construction and operations of the FSTSF is characterized in Table 7.5-39.

Table 7.5-39 Risk and Uncertainty Characterization for Groundwater Quantity at the Quesnel River Mill during Constructions and Operations of the Filtered Stack Tailings Storage Facility

Criteria	Characterization	Rationale
Likelihood	High	Changes to groundwater flow are expected to occur.
Consequence	Minor	Magnitude is low and extent is local, which results in a Minor rating per the consequence matrix in Chapter 6, Table 6.7-1.
Risk	Low	Consequence is low and likelihood is high, which results in a low rating per the risk matrix in Chapter 6, Table 6.7-2.
Uncertainty	Low	The cause-effect relationship is well understood, and sufficient data is available to support the assessment. There is a low to moderate degree of uncertainty associated with data inputs and/or modelling techniques.

Importance

The importance is considered high. Groundwater-surface water interactions and groundwater resources has been identified as a top interest by Indigenous nations, community members, the public, local governments, and/or provincial and federal government agencies.

7.5.7.3.6 Changes to Groundwater Quantity at the Quesnel River Mill during Closure and Post-Closure of the Filtered Stack Tailings Storage Facility

Residual Effect Analysis

Closure of the FSTSF will alter groundwater in the QR Mill LAA relative to existing conditions through the following mechanisms:

- Reduction of seepage loss from the FSTSF that results in the lowering of hydraulic heads near and surrounding the FSTSF and potential reduction in stream baseflow. Seepage is reduced by the drainage of the pond and placement of liner on top of the existing tailings in pre-mining/operations, and placement of a cover over the Project tailings in closure.

- Presence of additional tailings from the Bonanza Ledge Phase II Project, from a height of 976 masl to 994 masl in the MZP. Placement of additional tailings may introduce hydraulic resistance to the discharge of groundwater to the MZP.
- Adjustment in maximum pond level in the MZP through the 1 m increase in spillway elevation.
- Decommissioning of the SSCP once water quality objectives are reached by breaching the dam and allowing discharge to the former pond footprint and drainage to the MZP.

Model predictions are summarized in Table 7.5-22, Table 7.5-23, Table 7.5-24A, and Table 7.5-24B of Section 7.5.3.4.1.2.

In post-closure, baseflow to Rudy Creek increases relative to the end of operations due the cessation of pumping at the potable water well. Relative to existing conditions; however, the baseflow to Rudy Creek SW2 is predicted to be between 4% and 9% lower than existing conditions, and the baseflow to Rudy Creek SW3 is predicted to be between 3% and 7% lower than existing conditions. The reduction in baseflow at the end of closure relative to existing conditions is associated with the placement of the liner and cover in the FSTSF, which reduces seepage loss from the FSTSF.

At the end of closure, base flow at Creek #2, Creek #2.5, and Creek #3 is predicted to be similar or slightly higher than existing conditions. The largest change was predicted at Creek #3 for the scenario where the hydraulic conductivity of the overburden was assumed to be a factor of 3 higher than the Base Case; for this scenario the base flow was predicted to be approximately 8% higher than existing conditions. In consideration of these creeks and seepage faces that may be present downstream of the surface water assessment nodes, small net reductions in baseflow may be observed (between 4 to 11%). Reductions Baseflow at the Quesnel River is not predicted to change during closure and post-closure relative to existing conditions.

Climate change effects were not directly simulated in the model and are instead qualitatively assessed here. Variations in annual distribution of recharge may cause larger variations in hydraulic head throughout the year, but overall evaluation of future climate conditions indicates recharge may increase by 2 % to 19% on an annual basis, which may reduce changes in baseflow predicted for the Project in post-closure relative to existing conditions. Freshet interflows could be reduced due to lower snowpack depths, which could reduce peak baseflow contributions in the spring.

Characterization of Residual Effect

The residual effect to Groundwater quantity at the QR Mill during closure and post-closure of the FSTSF is characterized in Table 7.5-40.

Table 7.5-40 Residual Effect Characterization for Groundwater Quantity at the Quesnel River Mill during Closure and Post-Closure of the Filtered Stack Tailings Storage Facility

Criteria	Characterization	Description
Context	Neutral	Groundwater flow system has a neutral resilience to imposed stresses and may be able to respond and adapt to the potential residual effect.
Magnitude	Low	Predicted changes in baseflow within -11% (reduction) to 8% (increase) of existing conditions.
Extent	Local	Limited to the LAA (verified with sensitivity analysis).
Duration	Long-Term	Effects are predicted to remain in post-closure.

Criteria	Characterization	Description
Reversibility	Irreversible	Effect is predicted to be permanent following the closure of the FSTSF.
Frequency	Continuous	Hydraulic heads around the FSTSF will be permanently lowered following closure of the FSTSF.
Affected Populations	Even	The potential effect is experienced by any and all sub-populations.

Notes: % = percent; LAA = local study area; FSTSF = Filtered Stack Tailings Storage Facility

Risk and Uncertainty

The risk and uncertainty associated with changes to groundwater quantity at the QR Mill during closure and post-closure of the FSTSF is characterized in Table 7.5-41.

Table 7.5-41 Risk and Uncertainty Characterization for Groundwater Quantity at the Quesnel River Mill during Closure and Post-Closure of the Filtered Stack Tailings Storage Facility

Criteria	Characterization	Rationale
Likelihood	High	Changes to groundwater flows are expected to occur.
Consequence	Minor	Magnitude is low and extent is local, which results in a minor rating per the consequence matrix in Chapter 6, Table 6.7-1.
Risk	Low	Consequence is minor and likelihood is high, which results in a low rating per the risk matrix in Chapter 6, Table 6.7-2.
Uncertainty	Moderate	The cause-effect relationship is well understood, and sufficient data is available to support the assessment. There is a low to moderate degree of uncertainty associated with data inputs and/or modelling techniques.

Importance

The importance is considered high. Groundwater-surface water interactions and groundwater resources has been identified as a top interest by Indigenous nations, community members, the public, local governments, and/or provincial and federal government agencies.

7.5.7.3.7 Changes to Groundwater Quality at the Quesnel River Mill during Operations of the Filtered Stack Tailings Storage Facility

Residual Effect Analysis

The effect of changes to seepage quality from the QR Mill during operations was evaluated by considering the relative change in the proportion of baseflow that originates from FSTSF seepage water, as well as a comparison of the predicted future composition of seepage water to current seepage water quality. Changes to baseflow are addressed by model predictions summarized in Table 7.5-22, Table 7.5-23, Table 7.5-24A, and Table 7.5-24 of Section 7.5.3.4.1.2. QR Mill water quality predictions are discussed in Appendix 7.4-9.

The composition of seepage from the FSTSF in the Base Case and uncertainty scenarios is estimated to be predominantly seepage from the existing tailings under the liner resulting from lateral groundwater inflow into the existing tailings. Seepage from the Project tailings is restricted by the liner during operations and predicted to be approximately 3% of the total seepage from the FSTSF, assuming 10% liner defects. Seepage from the Project tailings will primarily discharge to the NSCP and effects of the Project tailings on downgradient groundwater quality is expected to be minor.

Seepage from the SSCP will predominantly report to the MZP and will therefore have limited potential to affect groundwater quality downstream of the MZP pit towards Creek #2.5 and Creek #3. The extension and increase in water level in the SSCP during operations results in only a small increase in the contribution of SSCP seepage water to the creek baseflow from groundwater during operations. The increase in contributions from the SSCP to groundwater baseflow ranges from 0 to 4% for Creek #2.5 and from 0 to 0.5% for Creek #3.

Seepage from the MZP will discharge to Creek #2.5 and Creek #3, and associated seepage faces downstream of the surface water assessment nodes. The predicted composition of seepage from the MZP pit in pre-mining and/or operations contains concentrations of sulphate, antimony, arsenic, cobalt, nickel, manganese, and selenium above the drinking water standards and concentrations of ammonia, total cyanide, copper, nitrite, and selenium above aquatic life standards. Of the predicted parameter concentrations, most are at concentrations similar to or lower than existing conditions. Exceptions are total cyanide, arsenic, manganese, and selenium. Total cyanide is below applicable CSR standards over most of pre-mining and operations period except for a short spike in approximately 2033 when concentrations are predicted to exceed the CSR aquatic life standard in the MZP. In consideration of its short duration, the brief increase in total cyanide is unlikely to have significant influence on down-gradient groundwater quality (surface water quality affects are assessed in Chapter 7.4). Manganese, arsenic, and selenium in the MZP are predicted to increase somewhat in operations to concentrations above drinking water standards, prior to decreasing to below drinking water standards in closure. Drinking water exceedances (arsenic) are present down-gradient of the MZP under existing conditions. Selenium concentrations are predicted to increase in the MZP in operations to concentrations above the CSR aquatic life standards. In terms of seepage proportions, total seepage loss from the MZP to groundwater is predicted to decrease by between 28 and 80% relative to existing conditions because of a reduction in the pit water level during operations. As a result of this reduction, the contribution of MZP seepage water in Creek #2.5 and Creek #3 base flow also reduces. The percent reduction in contributions from the MZP to groundwater baseflow is up to 17%. The effects of groundwater quality changes on surface water quality are evaluated in Chapter 7.4.

Characterization of Residual Effect

The residual effect on Groundwater quality at the QR Mill during operations of the FSTSF is characterized in Table 7.5-42.

Table 7.5-42 Residual Effect Characterization for Groundwater Quality at the Quesnel River Mill during Operations of the Filtered Stack Tailings Storage Facility

Criteria	Characterization	Description
Context	Neutral	Groundwater flow system has a neutral resilience to imposed stresses and may be able to respond and adapt to the potential residual effect.

Criteria	Characterization	Description
Magnitude	Moderate	A moderate rating is applied only due to the potential for selenium to increase in the MZP to above aquatic life standards. A low ranking is considered applicable to other parameters. Groundwater quality is not the end point for the aquatic life assessment and the surface water effects assessment is presented in Chapter 7.4.
Extent	Local	Limited to the LAA (verified with sensitivity analysis).
Duration	Medium-term	Predicted concentrations reduce in closure/post-closure to below CSR groundwater standards.
Reversibility	Partially Reversible	Reduction in pumping rate from the water supply well in closure and the increase in closure MZP pond level will result in some recovery of base flow contributions back to existing conditions. Predicted concentrations reduce in closure/post-closure to below CSR groundwater standards.
Frequency	Continuous	Hydraulic heads around the FSTSF will be permanently lowered following the drainage of the pond, and the deposition of filtered stack tailings, resulting in continuous alteration of contributions of seepage water to groundwater baseflow to surface water.
Affected Populations	Even	The potential effect is experienced by any and all sub-populations.

Notes: % = percent; FSTSF = Filtered Stack Tailings Storage Facility; MZP = Main Zone Pit; LAA = local assessment area.

Risk and Uncertainty

The risk and uncertainty at the QR Mill from groundwater quality at the QR Mill during operations of the FSTSF is characterized in Table 7.5-43.

Table 7.5-43 Risk and Uncertainty Characterization for Groundwater Quality at the Quesnel River Mill during Operations of the Filtered Stack Tailings Storage Facility

Criteria	Characterization	Rationale
Likelihood	High	Changes to groundwater flows are expected to occur.
Consequence	Moderate	Magnitude is moderate and extent is local, which results in a moderate rating per the consequence matrix in Chapter 6, Table 6.7-1. A moderate rating is applied only due to the potential for selenium to increase in the MZP to above aquatic life standards. A low ranking is considered applicable to other parameters.
Risk	Moderate	Consequence is moderate and likelihood is high, which results in a moderate rating per the risk matrix in Chapter 6, Table 6.7-2.
Uncertainty	Moderate	The cause-effect relationship is well understood, and sufficient data is available to support the assessment. There is a low to moderate degree of uncertainty associated with data inputs and/or modelling techniques.

Importance

The importance is considered high. Groundwater-surface water interactions and groundwater resources has been identified as a top interest by Indigenous nations, community members, the public, local governments, and/or provincial and federal government agencies.

7.5.7.3.8 Changes to Groundwater Quality at the Quesnel River Mill during Closure and Post-Closure of the Filtered Stack Tailings Storage Facility

Residual Effect Analysis

The effect of changes to seepage quality from the QR Mill during closure and post-closure of the FSTSF was evaluated by considering the relative change the proportion of baseflow that originates from seepage water, as well as a comparison of the predicted future composition of seepage water to current seepage water quality. Changes to baseflow are addressed by model predictions summarized in Table 7.5-22, Table 7.5-23, Table 7.5-24A, and Table 7.5-24B of Section 7.5.3.4.1.2. QR Mill water quality predictions are discussed in Appendix 7.4-9.

The composition of seepage from the FSTSF in the base case and uncertainty scenarios is estimated to be predominantly seepage from the existing tailings, resulting from lateral groundwater inflow into the existing tailings. Seepage from the Project tailings is restricted by the liner and cover during operations and is predicted to be approximately 0.3% of the total seepage from the FSTSF, assuming 10% liner and cover defects. Therefore, the effect of Project tailings on downgradient groundwater quality is expected to be minor.

Predicted concentrations of parameters in the NSCP are below applicable standards during post-closure, and at similar or lower concentrations than existing concentrations. Interception wells have been installed between the NSCP and Rudy Creek to capture groundwater seepage from the FSTSF and NSCP in the event surface water quality in Rudy Creek increases above surface water quality guidelines due to the Project. The highest predicted increase in contribution of NSCP seepage water in creek base flow from existing conditions was 1%. Therefore, the effect of seepage from the NSCP on groundwater quality in post-closure is predicted to be minor.

Predicted concentrations of parameters in the MZP transition from operations to below applicable standards and to concentrations similar to or lower than existing concentrations. The slowest transition in parameter concentrations above applicable standards in operations is selenium, which in the early years of closure is above aquatic life and drinking water standards, but between 2045 and 2050 transitions to below applicable groundwater standards. The highest increase in contribution of MZP seepage water in creek base flow was 3%. Therefore, the effect of seepage from the MZP on groundwater quality in post-closure is expected to be minor.

Characterization of Residual Effect

The residual effect to Groundwater from groundwater quality at the QR Mill during closure and post-closure of the FSTSF is characterized in Table 7.5-44.

Table 7.5-44 Residual Effect Characterization for Groundwater Quality at the Quesnel River Mill during Closure and Post-Closure of the Filtered Stack Tailings Storage Facility

Criteria	Characterization	Description
Context	Neutral	Groundwater flow system has a neutral resilience to imposed stresses and may be able to respond and adapt to the potential residual effect.
Magnitude	Low	Seepage from the NSCP and MZP is predicted to be below groundwater standards in post-closure and at similar or lower concentrations to existing conditions. The highest predicted increase in the % contribution of seepage from the NSCP and MZP to downstream surface water was 3%. This has a minor effect on groundwater quality.
Extent	Local	Limited to LAA (verified with sensitivity analysis).
Duration	Long Term	Effects are predicted to occur after closure.
Reversibility	Irreversible	Effect is predicted to be permanent following the closure of the FSTSF.
Frequency	Once	The increase in % contribution of seepage water from the MZP lake occurs when the water level raises to spillway elevation. The effect on groundwater quality will be minor.
Affected Populations	Even	The potential effect is experienced by any and all sub-populations.

Notes: % = percent; LAA = local assessment area; FSTSF = Filtered Stack Tailings Storage Facility; NSCP = North Seepage Collection Pond; MZP = Main Zone Pit.

Risk and Uncertainty

The risk and uncertainty at the QR Mill from groundwater quality at the QR Mill during closure and post-closure of the FSTSF is characterized in Table 7.5-45.

Table 7.5-45 Risk and Uncertainty Characterization for Groundwater Quality at the Quesnel River Mill during Closure and Post-Closure of the Filtered Stack Tailings Storage Facility

Criteria	Characterization	Rationale
Likelihood	High	Changes to groundwater and surface water quality are expected to occur.
Consequence	Minor	Magnitude is low and Extent is local, which results in a minor rating per the consequence matrix in Chapter 6, Table 6.7-1.
Risk	Low	Consequence is minor and likelihood is high, which results in a low rating per the risk matrix in Chapter 6, Table 6.7-2.
Uncertainty	Moderate	The cause-effect relationship is well understood, and sufficient data is available to support the assessment. There is a low to moderate degree of uncertainty associated with data inputs and/or modelling techniques.

Importance

The importance is considered high. Groundwater-surface water interactions and groundwater resources has been identified as a top interest by Indigenous nations, community members, the public, local governments, and/or provincial and federal government agencies.

7.5.8 Characterization of Negative Residual Effects

Negative residual effects for Groundwater are summarized in Table 7.5-46.

Indigenous groundwater uses and users were considered in the residual effects assessment; however, review of public databases (Section 7.5.3.3.4.3), consultation, and traditional use studies (DM Cultural Services Ltd., 2019; Landmark Resource Management Ltd., 2021) did not identify current specific uses of groundwater in the LAAs.

Table 7.5-46 Summary of Residual Effects for Groundwater

Residual Effect	Context	Magnitude	Extent	Duration	Reversibility	Frequency	Affected Populations	Risk	Confidence
Changes to Groundwater Quantity at the Mine Site during Construction and Operations Due to Dewatering of Underground Workings and Operation of a Potable Water Supply Well	Neutral	Low to High	Local	Medium-Term	Partially Reversible	Continuous	Even	Moderate	High
Changes to Groundwater Quantity at the Mine Site at Post-Closure due to Flooding of the Underground Developments	Neutral	Low	Local	Long-Term	Irreversible	Continuous	Even	Low	High
Changes to Groundwater Quality at the Mine Site at Post-Closure due to Flooding of the Underground Developments	Low	Moderate	Local	Long-Term	Irreversible	Continuous	Even	Moderate	Moderate
Changes to Groundwater Quality at the Mine Site due to Migration and Discharge of groundwater from Flooded Underground Workings during Closure and Post-Closure	Low	Moderate	Local	Long-Term	Irreversible	Continuous	Even	Moderate	Moderate
Changes to Groundwater Quantity at the QR Mill during Operations of the Filtered Stack Tailings Storage Facility	Neutral	Low	Local	Long-Term	Partially Reversible	Continuous	Even	Low	High
Changes to Groundwater Quantity at the QR Mill during Closure and Post-Closure due to construction of the Filtered Stack Tailings Storage Facility	Neutral	Low	Local	Long-Term	Irreversible	Continuous	Even	Low	High
Changes to Groundwater Quality at the QR Mill during Operations due to construction of the Filtered Stack Tailings Storage Facility	Neutral	Moderate	Local	Medium-Term	Partially Reversible	Continuous	Even	Low	High
Changes to Groundwater Quality at the QR Mill during Closure and Post-Closure of the Filtered Stack Tailings Storage Facility	Neutral	Low	Local	Long-Term	Irreversible	Continuous	Even	Low	High

Notes: QR Mill = Quesnel River Mill

7.5.9 Cumulative Effects

7.5.9.1 Identified Residual Effects

The potential residual effects for Groundwater after application of mitigation measures are:

- Changes to groundwater quantity at the Mine Site during construction and operations due to dewatering of underground workings;
- Changes to groundwater quantity at the Mine Site during construction, operations, and closure due to the operation of a potable water supply well;
- Changes to groundwater quality at the Mine Site during closure and post-closure due to the flooding of the underground developments;
- Changes to groundwater quality at the Mine Site due to groundwater seepages from waste rock piles and underground workings post-closure;
- Changes to groundwater quantity at the QR Mill during construction, operations, closure, and post-closure due to the construction of the FSTSF; and
- Changes to groundwater quality at the QR Mill due to construction of the FSTSF.

7.5.9.2 Cumulative Effects Assessment Boundaries

The cumulative effects assessment boundaries are defined as the maximum spatial and temporal scales over which there is a potential for residual Project effects for Groundwater to interact with the potential residual effects of other past, present, and reasonably foreseeable future projects and activities.

Spatial Boundaries

The spatial boundaries for Groundwater for the cumulative effects assessment is the LAA, as presented in Table 7.5-1 and Figures 7.5-1 and 7.5-2. Developments outside of the LAA, but within the RAA, may influence the groundwater flow system, but will not directly overlap with effects of the Project (Figure 7.5-3).

Temporal Boundaries

Temporal boundaries considered for the cumulative effects assessment of the Project include:

- **Present and Ongoing**: initiated prior to 2021, but anticipated to carry on beyond the construction start date of the Project.
- **Planned/Reasonably Foreseeable Future**: planned to start during mine life (construction – post-closure). Generally, the proposed end date for inclusion in the effects assessment is 2046, which represents the end of the Post-closure (active care) Phase.

For Groundwater, temporal boundaries for the cumulative effects assessment include the Construction, Operations, Closure, and Post-Closure Phases of the Project.

7.5.9.3 Interactions with Past, Present, or Reasonably Foreseeable Projects and Activities

Past, present, and reasonably foreseeable future projects and activities have been identified for inclusion in the cumulative effects assessment from a variety of sources including municipal, regional, provincial, and federal government agencies and company websites, and are detailed in Table 6.9-1. Projects and activities that have the potential to interact with Groundwater are presented in Table 7.5-47. Past and current projects have been addressed in the existing conditions and modelling and are therefore not further considered in this assessment.

Table 7.5-47 List of Projects and Activities with potential to interact within the Groundwater Residual Effects

Project/Activity	Temporal	Project Life	Location	Proponent
Bonanza Ledge Phase II Reclamation (outside Project Footprint)	Reasonably Foreseeable Future	Proposed	4 km south of Wells	ODV
Mosquito Creek Reclamation	Reasonably Foreseeable Future	Proposed	6 km northwest of Wells	ODV

Interactions with effects of past, present, and reasonably foreseeable future projects and activities that directly interact with Groundwater residual effects are presented in Table 7.5-48.

Table 7.5-48 Interactions with Effects of Past, Present, and Reasonably Foreseeable Projects and Activities for Groundwater Residual Effects

Potential Residual Effect	Bonanza Ledge Phase II Reclamation (outside Cariboo Gold Footprint)	Mosquito Creek Reclamation
Changes to groundwater quantity at the Mine Site during construction and operations due to dewatering of underground workings.	Y	Y
Changes to groundwater quantity at the Mine Site during construction, operations, and closure due to the operation of a potable water supply well.	Y	Y
Changes to groundwater quality at the Mine Site during closure and post-closure due to the flooding of the underground developments.	Y	Y
Changes to groundwater quality at the Mine Site due to groundwater seepages from waste rock piles and underground workings post-closure.	Y	N
Changes to groundwater quantity at the QR Mill during construction, operations, closure, and post-closure due to the construction of the FSTSF.	Y	N
Changes to groundwater quality at the QR Mill due to construction of the FSTSF	Y	N

Notes: Y = Yes, interaction exists between the residual effect of the Project and the other past, current, or future project/activity.
N = No, interaction does not exist between the residual effect of the Project and the other past, current, or future project/activity.
FSTSF = Filtered Stack Tailings Storage Facility.
QR Mill = Quesnel River Mill.

7.5.9.4 Existing Conditions

An updated description of existing conditions is not required as the Cumulative Effects Assessment Area is the same as the VC assessment LAA already discussed.

7.5.9.5 Potential Cumulative Effects

Bonanza Ledge Phase II is an underground mining development proposed by ODV, which will be complete by the start of the Project. Reclamation activities for Bonanza Ledge Phase II outside of the Project will be ongoing during the Project. Active closure reclamation activities are planned for 2024 to 2025.

Mosquito Creek is a previous mining development owned by ODV. The Mosquito Creek Mine is currently in Care and Maintenance, and reclamation and closure activities are ongoing.

Indigenous groundwater uses and users were considered in the residual effects assessment, however, review of public databases (Section 7.5.3.3.4.3), consultation, and traditional use studies (DM Cultural Services Ltd., 2019; Landmark Resource Management Ltd., 2021) did not identify current specific uses of groundwater in the LAAs.

7.5.9.5.1 Changes to Groundwater Quantity at the Mine Site and Quesnel River Mill during Construction, Operations, Closure, and Post-Closure

Dewatering and flooding of the underground for Bonanza Ledge Phase II Reclamation, and other historical workings at Mosquito Creek and elsewhere, has been considered in the groundwater predictions for the Mine Site during the Construction, Operations, and Post-Closure Phases. Therefore, cumulative effects related to Bonanza Ledge Phase II Reclamation and Mosquito Creek Reclamation have already been considered.

7.5.9.5.2 Changes to Groundwater Quality at the Mine Site and Quesnel River Mill during Construction, Operations, Closure, and Post-Closure

Flooding of the underground for Bonanza Ledge Phase II Reclamation, and other historical workings at Mosquito Creek, has been considered in the groundwater predictions for the Mine Site during closure/post-closure. Therefore, cumulative effects related to Bonanza Ledge Phase II Reclamation and Mosquito Creek Reclamation have already been considered.

7.5.9.6 Mitigation Measures

Potential adverse cumulative effects were not identified. Additional mitigation is not required.

7.5.9.7 Residual Cumulative Effects Characterization

Potential adverse cumulative effects were not identified. Characterization of residual cumulative effects is not required.

7.5.10 Follow-up Strategy

To verify the results of the effects assessment, a groundwater monitoring plan will be implemented according to EMPs developed for the Project. Environmental monitoring plans will be developed by qualified environmental professionals to achieve compliance with EAC Commitments and Assurances and with terms and conditions of regulatory permits and approvals, and to monitor the effectiveness of mitigation measures.

Monitoring is designed to verify the effects predictions, reduce uncertainty, determine the effectiveness of Project design features and mitigation, and provide appropriate feedback to operations for modifying or adopting new mitigation designs, policies, and practices. A monitoring program will be established to monitor potential changes to Groundwater quantity and quality during all phases of the Project to verify the effects predictions on Groundwater. Monitoring results will be assessed according to pre-determined decision criteria that may trigger management actions within a decision framework. These results will also feed into the overall adaptive management approach to be adopted by the Project.

For groundwater quantity and quality, the purpose of the monitoring plan is to provide information on the groundwater flow environment with respect to changes in water level and groundwater quality. The groundwater monitoring plan will identify locations to be monitored, analytical parameters to analyzed, and the frequency of measurements and sampling. It is expected that effects monitoring data will be evaluated against benchmarks developed for the Project in consideration of applicable water quality guidelines and objectives.

The monitoring plans will be developed during the permitting process in consultation with relevant permitting agencies, local governments, and local Indigenous groups. The monitoring strategy will include the following:

- Quantity, including:
    - Groundwater discharge rates to underground during dewatering;
    - Groundwater levels in observation points surrounding the mine workings to monitor the extent and magnitude of depressurization during dewatering and recovery during closure, including aquifers;
    - Underground seepage surveys to monitor for enhanced permeability zones that contribute to increased groundwater inflows; and
- Quality: groundwater water sampling of underground discharge collection points, monitoring wells, and water supply wells for parameters of interest for the Project.

Monitoring will occur throughout the Operations and Closure Phases, and for several years into post-closure, until groundwater conditions have been verified to be consistent with predictions and the Project can transition into the Post-Closure (passive care) Phase. Monitoring data will be used to trigger assessment of the need to implement additional water management strategies/features during the Project’s life cycle.

The groundwater monitoring plan will form part of a Project Environmental Monitoring Plan and will be developed during the permitting process in consultation with relevant permitting agencies, local governments, and local Indigenous groups. Ahead of this monitoring plan consultation, the following additional work will be completed:

- Additional geochemical testing of cemented rockfill and paste will be conducted in order to update the underground mine water quality source term. The mine water quality predictions will be updated to evaluate long-term post-closure water quality of the underground mine and the receiving aquifer, and how the composition of the mine pool changes over time. The results of groundwater quality monitoring will be used to refine these predictions through the life of the mine.
- Seepage flow estimates from Mine Seepage 1, 2, and 5. These flow measurements will be used as verification of groundwater model predictions for existing conditions.

As part of ongoing consultation and engagement with interested parties (including community representatives, Indigenous nations, and local government representatives), ODV will confirm interest in receiving regular updates on monitoring results and preferred mechanisms for sharing data and information. These groups will also be engaged on strategies to be employed if predicted effects and mitigation effectiveness are not as expected.

APPENDIX 7.5-1 HYDROGEOLOGY EXISTING CONDITIONS REPORT

APPENDIX 7.5-2 QUESNEL RIVER MILL GROUNDWATER MODELLING REPORT

APPENDIX 7.5-3 MINE SITE GROUNDWATER MODELLING REPORT

APPENDIX 7.5-4 MINE SITE GROUNDWATER QUALITY ASSESSMENT REPORT

APPENDIX 7.5-5 QUESNEL RIVER MILL WATER SUPPLY WELL TECHNICAL MEMO