

Vivian Sand Project

Hydrogeology and Geochemistry Assessment
Clean Environment Commission Hearing

February 28, 2023

Technical Panel

Technical Panel

Technical Panel Members:

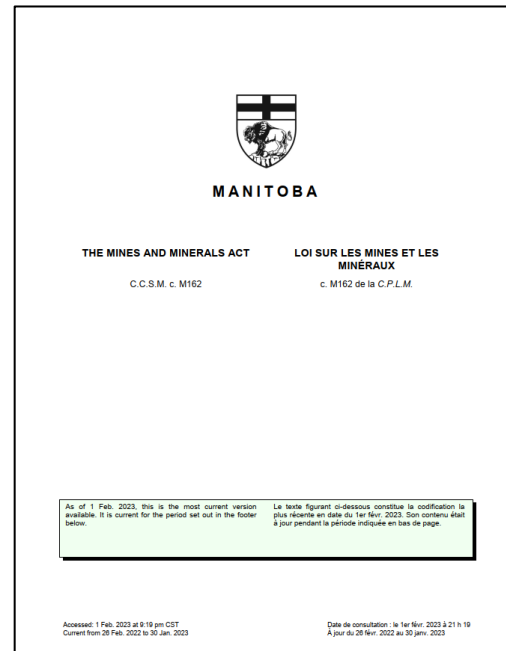
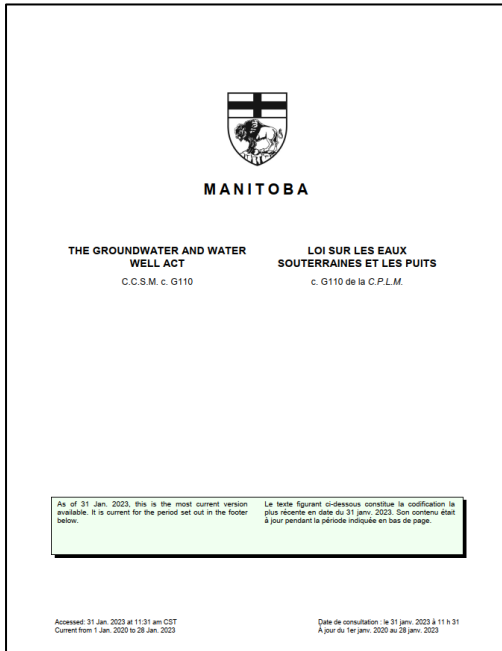
- Mr. Ryan Mills, M.Sc., P.Geo. (MB, AB, BC)
- Dr. Miln Harvey, Ph.D., P.Eng. (MB, ON, NS)
- Dr. Cheibany Ould Elemine, Ph.D., P.Geo. (BC, SK, NWT/NU)
- Dr. Tom Meuzelaar, Ph.D.

Additional Qualified Professionals and Reviewers:

- Dr. Grant Ferguson, Ph.D., P.Geo. (SK)
- Dr. Xinglong Ran, M.Sc., Ph.D. (AB)
- Dr. Getachew Mohammed, Ph.D., P.Eng. (AB)
- Dr. Mehrnoush Javadi, M.Sc., Ph.D.
- Mr. Stephen Dickin, P.Geo. (MB, BC)
- Ms. Kun Jia, M.Sc., P.Geo. (MB, BC)
- Mr. Chris Donnelly, M.Sc., P.Geo. (BC)
- Mr. Reuben Dandurand, M.Sc., G.I.T. (BC)

Regulatory Requirements and Technical Guidance Documents

Regulatory Requirements and Technical Guidance Documents



Manitoba Acts and Regulations:

- *The Environment Act*
- *The Mines and Minerals Act*
 - *Drilling Regulation, 1992*
- *The Groundwater and Well Act*
 - Groundwater and Water Well (General Matters) Regulation
 - Well Standards Regulation
- *The Water Rights Act*

Standard Methods:

- ASTM D2488 – Description and Identification of Soils
- ASTM D4044 – Slug Testing
- ASTM D6034 – Constant Rate Pumping Test
- ASTM D4448 – Groundwater Sampling Protocols

Regulatory Requirements and Technical Guidance Documents

Groundwater Modelling Guidelines:

- Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Projects (BC Ministry of Environment, 2012)
- Australian Groundwater Modelling Guidelines (Australian Government National Water Commission, 2012)
- ASTM D5447-93: Standard Guide for Application of a Groundwater Flow Model to a Site-Specific Problem

Geochemistry Assessment Guidelines (Water Quality and Solid Phase):

- Federal and Provincial Drinking Water Guidelines
- Provincial Guidelines for the Protection of Aquatic Life and Wildlife
- CCME Water Quality Guidelines for Protection of Agriculture and Aquatic Life
- MEND Prediction Manual 1.20.1 (MEND 2009)
- Global Acid Rock Drainage Guide (The International Network for Acid Prevention)
- BC 1997 Guideline for Prediction of Acid Rock Drainage and Metal Leaching (ARD/ML)

Field Investigation

Field Investigation

Comprehensive field investigation completed in 2020:

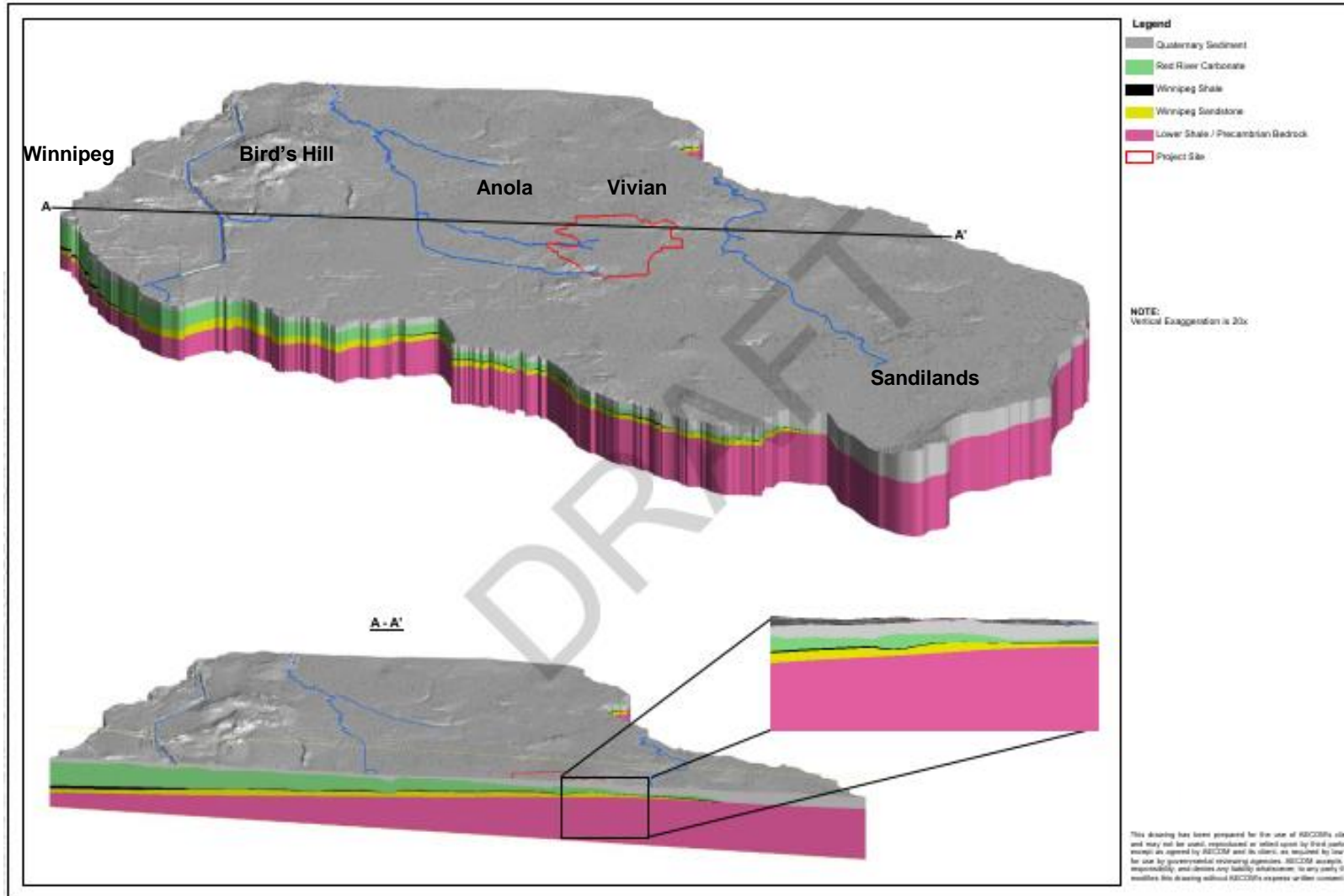
- Homeowner Well Survey
- Borehole drilling, logging and surveying
- Collection of soil and rock samples for laboratory testing
- Installation of pumping well and observation wells
- Groundwater level monitoring
- Groundwater quality monitoring
- Aquifer testing (slug tests, step test and constant rate pumping test)

Conceptual Hydrogeological Model

Conceptual Hydrogeological Model

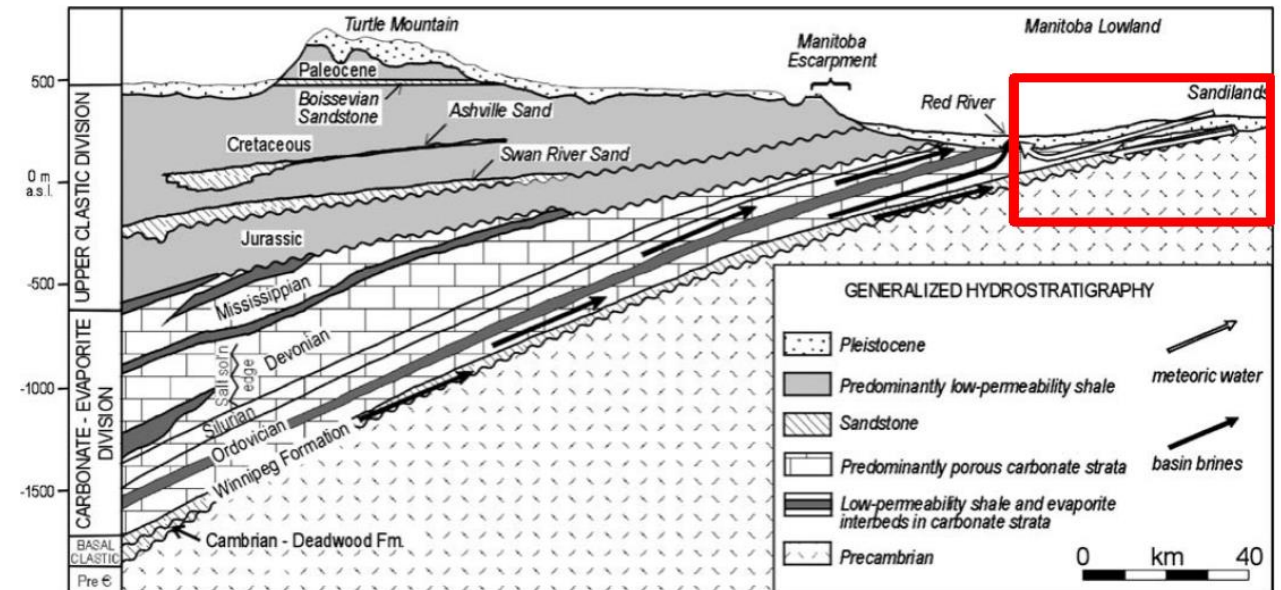
- The conceptualization of the groundwater flow system incorporated the following information:
 - Regional geological mapping of Quaternary Sediments and Bedrock
 - Federal and Provincial borehole databases
 - Measured groundwater elevations from borehole database and field investigation
 - Conceptual understanding of hydrostratigraphy and groundwater flow directions
 - Conceptual understanding of interaction between groundwater and surface water systems
 - Measured groundwater quality from provincial observation well network and field investigation

Conceptual Hydrogeological Model



Groundwater Flow

- There are two regional groundwater flow systems beneath southern Manitoba:
 - A regional system flowing to the east and northeast from recharge areas in the northern US
 - An intermediate system in southeastern Manitoba with groundwater recharging along the outcrop area beneath the Sandilands area flowing northwest toward the Red River
- These two flow systems converge beneath the Red River
- Mapped groundwater elevations show a flow divide beneath the Red River with upward hydraulic gradients

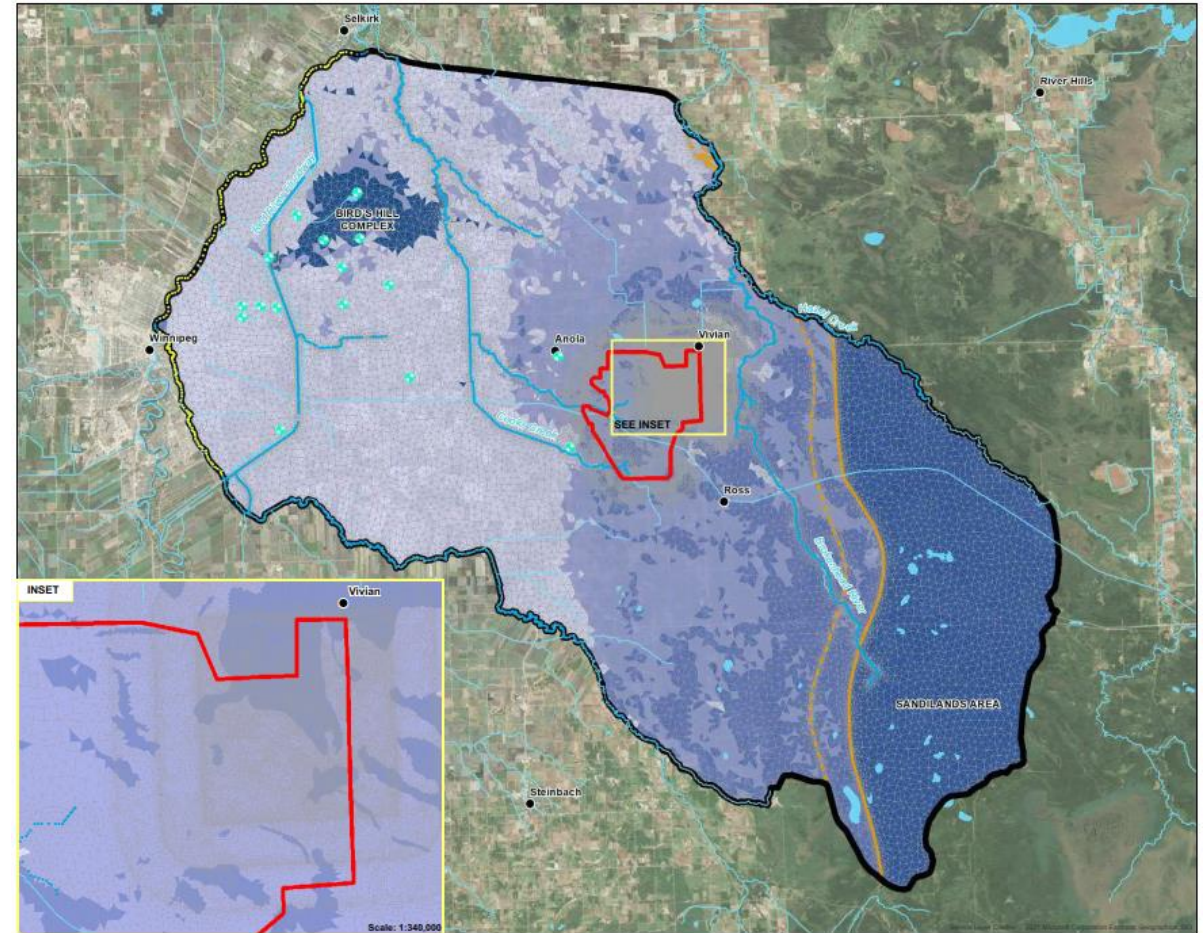


Numerical Groundwater Model

Numerical Groundwater Model

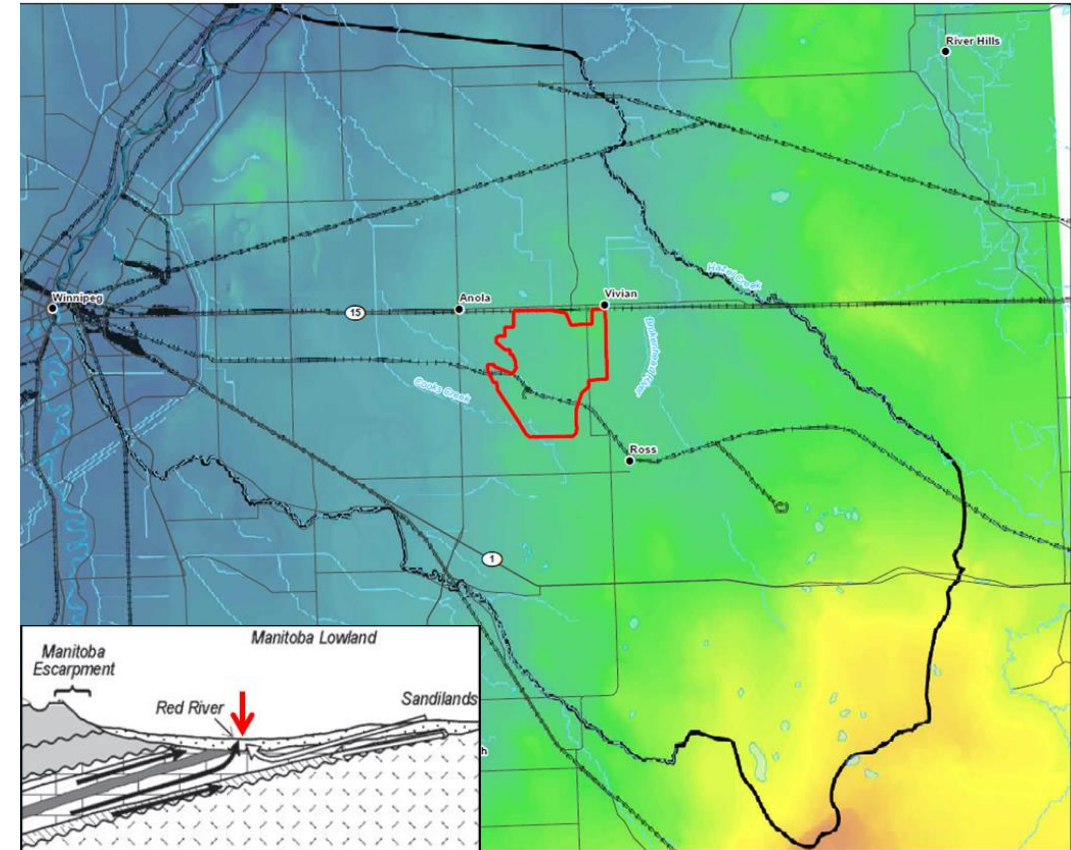
- Regional-scale groundwater model developed using FEFLOW™
- 3,200 km² (approx. 80 km x 40 km)
- Translates the conceptual model into a numerical framework to calculate groundwater levels, flow pathways and to simulate future response to natural and anthropogenic activities (i.e., recharge, pumping, drawdown, etc.)
- Represents natural hydrologic features that affect groundwater flow (e.g., groundwater recharge, rivers, extraction wells, etc.)
- FEFLOW™ is commonly used in hydrogeological analysis for developing regional-scale models to analyze environmental impacts to groundwater systems

Think of this like a weather forecasting tool for groundwater



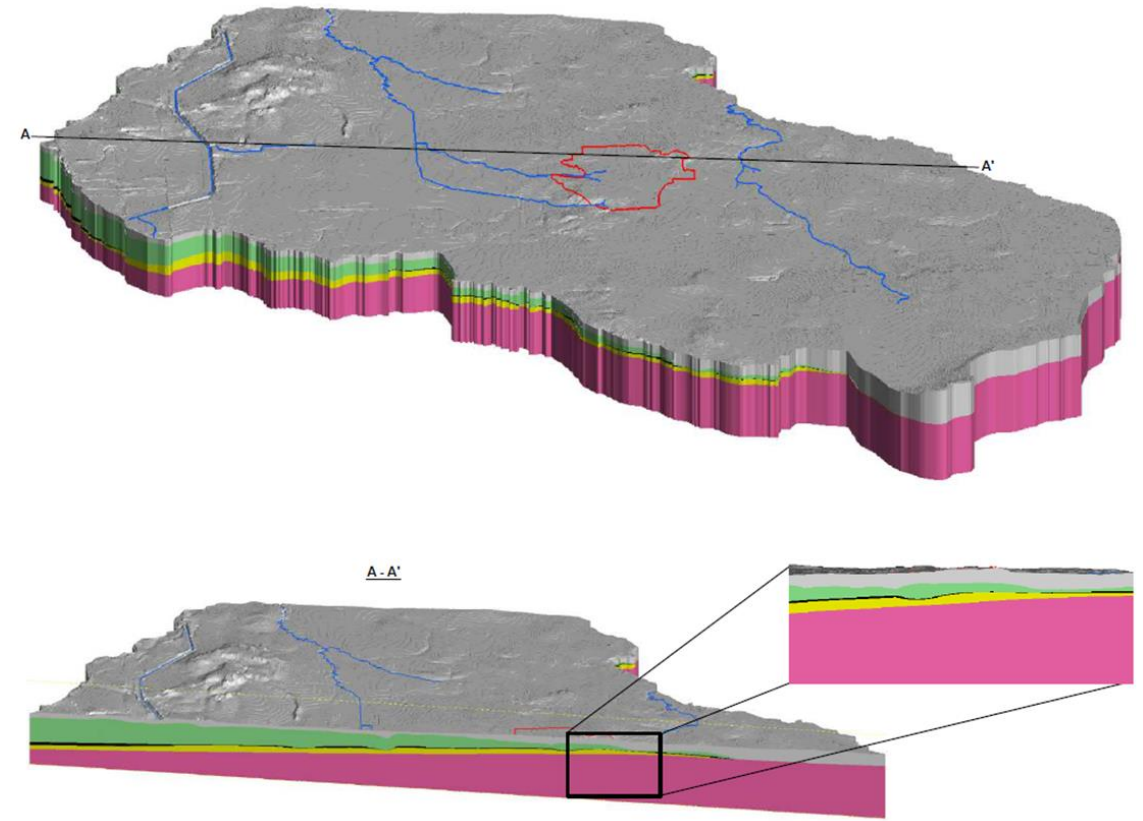
Groundwater Model Domain

- Model domain was defined with hydrologic boundaries far from the Project Area (i.e., 10s of km away)
- Using natural hydrologic boundaries:
 - SE – Sandilands recharge area
 - NE – Hazel Creek
 - SW – Seine River
 - NW – Red River and Red River Floodway
- This is where water naturally enters and exits the groundwater flow system
- They are far enough away from the Project Area to have no impact on model predictions



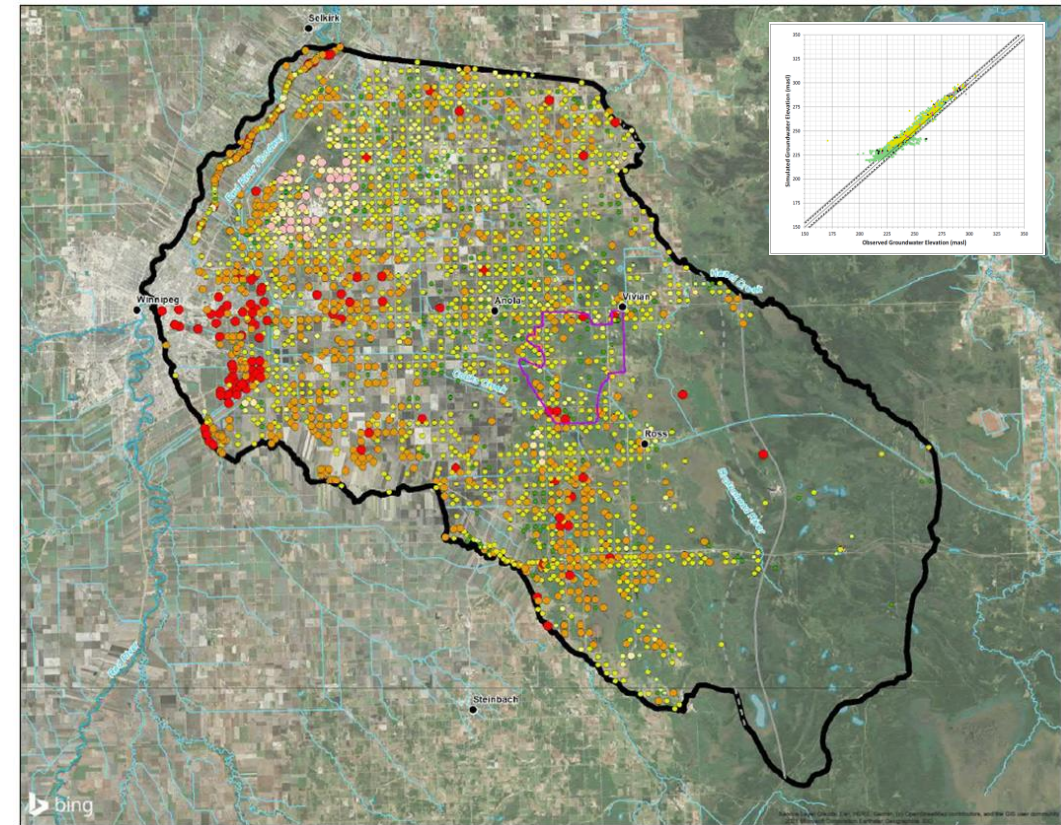
Model Layers and Properties

- Layers and properties were assigned to the model based on the Conceptual Hydrogeological Model:
 - Quaternary Sediments (Layers 1-3)
 - Sedimentary Bedrock Layers (Layers 4-6)
 - Red River Carbonate
 - Winnipeg Shale
 - Winnipeg Sandstone
 - Precambrian Bedrock (Layer 7)
 - Represents the basal aquitard for the groundwater flow system (i.e., it contributes very little flow to the sedimentary bedrock system)



Model Calibration

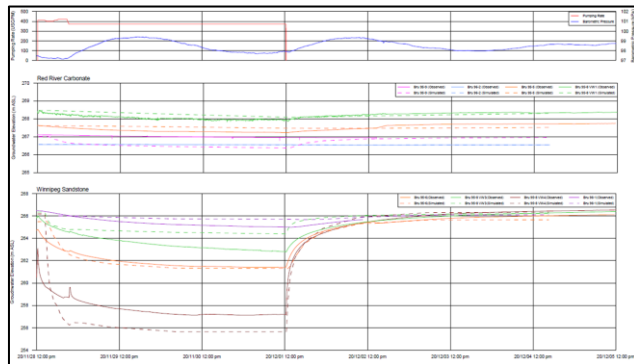
- The numerical groundwater model was calibrated by adjusting recharge and aquifer properties to produce results that reasonably replicated field-measured data
- Utilized both steady-state and transient calibration
- Calibration statistics are well within industry standard guidelines:
 - Mean Error (ME) = 3 m (~ 0 m)
 - NRMS Error = 1.7% ($< 10\%$)
 - Correlation Coefficient = 0.986 (> 0.90)
 - Simulated mass balance = 0.003% ($< 0.1\%$)
- Therefore, this is a well calibrated model



Model Parameters

- Calibrated values for model parameters (recharge, hydraulic conductivity) are within range of values for all historical data
- Thus, model predictions are simulated within expected bounds of the conceptual hydrogeological model
- The model is therefore a useful tool for simulating future conditions and evaluating impacts on groundwater quantity

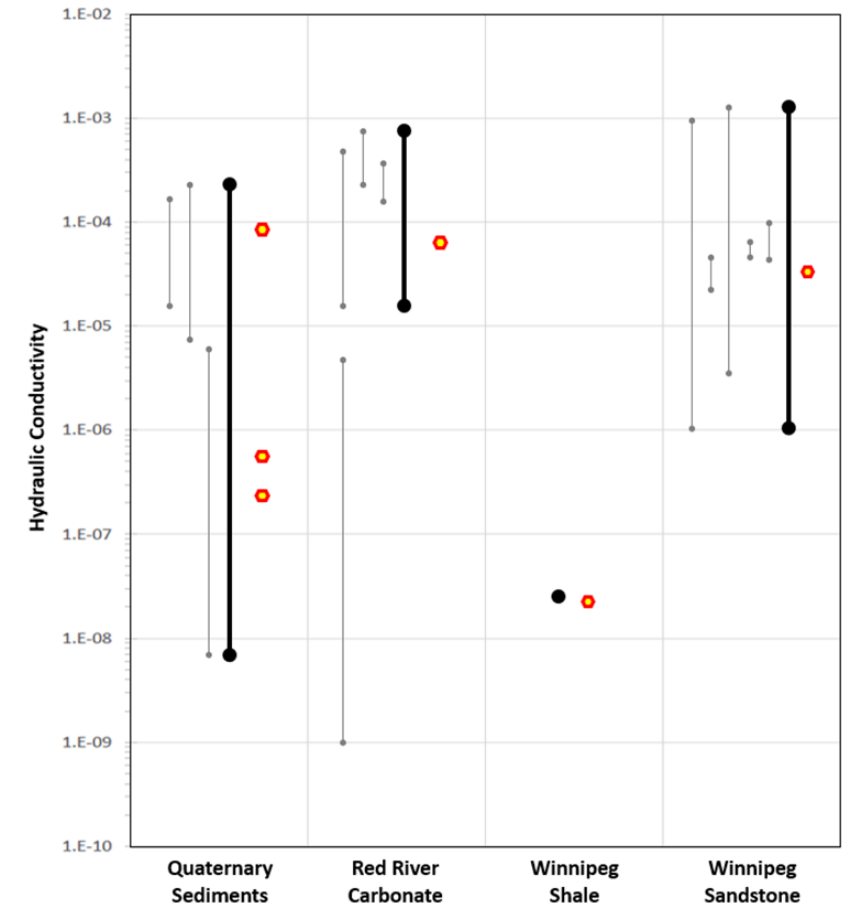
Calibrated Transient Water Levels



Measured vs Calibrated Recharge

Recharge Area	Calibrated Value mm/year	Estimated Value mm/year
Sandilands Area	189	37 - 504
Coarse Grained Sediments	100	44 - 173
Medium Grained Sediments	50	44 - 173
Fine Grained Sediments	6	44 - 173
Bird's Hill Complex	250	

Measured vs Calibrated Conductivity



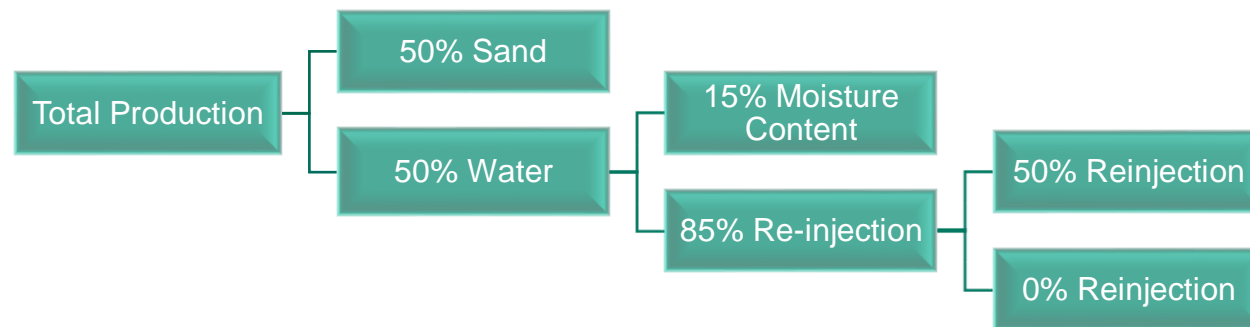
Sensitivity Analysis

- The model was used to assess the sensitivity of model output to changes in:
 - Recharge zones
 - Hydraulic conductivity
 - Carbonate
 - Shale
 - Sandstone
- Identifies data that is most important data for model calibration (i.e., data that needs to be well characterized)
- Helps us make conservative decisions during system design

Observation Point Name	30-10-8E1	29-10-8E1	31-10-8E1	32-10-8E1	36-10-7E1	20-10-8E1	G05SA015	33-10-8E1	3-11-7E1	G05OJ175
Distance to Production Well (m)	146	1,504	1,537	2,186	2,223	2,313	2,916	3,515	4,416	7,462
Sensitivity Analysis - Simulated Groundwater Elevation (m) in Red River Carbonate										
Base Case (Scenario 1)	262.9	269.1	268.2	270.2	266.6	269.2	269.8	270.1	263.1	259.4
Recharge - 20%	262.0	268.2	267.3	269.3	266.0	268.7	269.2	269.5	262.9	259.0
Recharge + 20%	263.5	269.6	269.0	270.9	267.1	269.5	270.2	270.4	263.2	259.6
Carbonate K = Min (1.5×10^{-5})	257.5	269.4	269.3	271.6	267.6	269.5	271.0	270.8	263.4	260.1
Carbonate K = Max (8.25×10^{-4})	256.6	258.8	256.4	258.3	255.1	259.6	259.3	259.8	252.2	250.2
Shale K ÷ 10	262.5	268.8	268.2	270.5	266.6	269.1	269.8	270.2	263.0	259.4
Shale K x 10	262.6	268.8	267.9	269.8	266.4	269.1	269.6	269.9	263.1	259.3
Sandstone K = Min (1.0×10^{-6})	260.7	269.1	268.6	270.9	266.9	269.3	270.0	270.4	263.1	259.5
Sandstone K = Max (1.0×10^{-4})	264.6	268.7	267.7	269.4	266.1	268.9	269.4	269.6	262.8	259.1
Sensitivity Analysis - Simulated Drawdown (m) in Red River Carbonate										
Base Case (Scenario 1)	7.5	2.1	2.2	1.3	1.3	0.9	0.8	0.4	0.1	0.0
Recharge - 20%	7.9	2.4	2.4	1.5	1.6	1.3	1.1	0.6	0.2	0.0
Recharge + 20%	7.2	2.0	1.8	1.1	1.0	0.9	0.6	0.3	0.1	0.0
Carbonate K = Min (1.5×10^{-5})	14.4	3.5	2.7	1.8	1.2	1.2	0.6	0.3	0.0	0.0
Carbonate K = Max (8.25×10^{-4})	1.5	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.4	0.2
Shale K ÷ 10	7.6	2.2	2.1	1.2	1.3	1.0	0.8	0.4	0.1	0.0
Shale K x 10	7.8	2.4	2.4	1.6	1.4	1.1	0.9	0.5	0.1	0.0
Sandstone K = Min (1.0×10^{-6})	10.3	2.9	2.5	1.5	1.3	1.1	0.8	0.4	0.1	0.0
Sandstone K = Max (1.0×10^{-4})	4.5	0.9	1.4	0.6	1.0	0.5	0.6	-0.1	0.2	0.0
Observation Point Name	30-10-8E1	29-10-8E1	31-10-8E1	32-10-8E1	36-10-7E1	20-10-8E1	G05SA014	33-10-8E1	3-11-7E1	G05OJ163
Distance to Production Well (m)	146	1,504	1,537	2,186	2,223	2,313	2,916	3,515	4,416	7,462
Sensitivity Analysis - Simulated Groundwater Elevation (m) in Winnipeg Sandstone										
Base Case (Scenario 1)	262.9	269.1	267.9	269.7	266.4	269.2	269.4	269.8	263.2	259.1
Recharge - 20%	262.0	268.2	267.1	268.9	265.8	268.7	268.9	269.3	262.9	258.8
Recharge + 20%	263.6	269.6	268.6	270.3	266.9	269.5	269.8	270.1	263.4	259.4
Carbonate K = Min (1.5×10^{-5})	257.5	269.4	268.6	270.8	267.2	269.5	270.1	270.5	263.6	260.0
Carbonate K = Max (8.25×10^{-4})	256.6	258.8	256.4	258.2	255.0	259.6	259.3	259.7	252.4	250.2
Shale K ÷ 10	262.5	268.8	266.7	268.3	265.1	269.1	268.8	268.4	262.3	258.1
Shale K x 10	262.6	268.8	267.8	269.7	266.4	269.1	269.6	269.9	263.1	259.3
Sandstone K = Min (1.0×10^{-6})	260.2	269.1	268.6	270.8	266.9	269.3	270.0	270.3	263.1	259.5
Sandstone K = Max (1.0×10^{-4})	264.6	268.7	267.1	268.6	265.6	268.9	268.8	268.9	262.7	258.6
Sensitivity Analysis - Simulated Drawdown (m) in Winnipeg Sandstone										
Base Case (Scenario 1)	7.5	2.1	2.2	1.4	1.2	0.9	0.8	0.4	0.2	0.0
Recharge - 20%	7.9	2.4	2.5	1.7	1.5	1.3	1.1	0.6	0.3	0.1
Recharge + 20%	7.2	2.0	1.8	1.2	1.0	0.9	0.6	0.4	0.1	0.0
Carbonate K = Min (1.5×10^{-5})	14.3	3.5	2.9	1.9	1.3	1.2	0.8	0.4	0.1	0.0
Carbonate K = Max (8.25×10^{-4})	1.5	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.4	0.2
Shale K ÷ 10	7.6	2.2	2.5	1.7	1.6	1.0	0.9	0.6	0.6	0.2
Shale K x 10	7.8	2.4	2.4	1.6	1.4	1.1	0.9	0.5	0.1	0.0
Sandstone K = Min (1.0×10^{-6})	10.7	2.9	2.5	1.5	1.3	1.1	0.8	0.4	0.1	0.0
Sandstone K = Max (1.0×10^{-4})	4.5	0.9	1.4	0.7	0.9	0.5	0.6	-0.1	0.3	0.1

Model Predictions

- Conducted scenario analysis to simulate response of groundwater flow system to planned and highly conservative operational scenarios:
 - Scenario 1: Steady-state, degradation of Winnipeg Shale, 0% re-injection
 - Scenario 2: Steady-state, degradation of Winnipeg Shale, 50% re-injection
 - Scenario 3: Steady-state, no degradation of Winnipeg Shale, 0% re-injection
 - Scenario 4: Transient, degradation of Winnipeg Shale, 0% re-injection
 - Scenario 5: Transient, degradation of Winnipeg Shale, 50% re-injection



- Net pumping was simulated as (extraction – re-injection)
- Simulated drawdown at observation wells to assess drawdown impacts (spatially and over time)

Simulation Results – 2021 Model

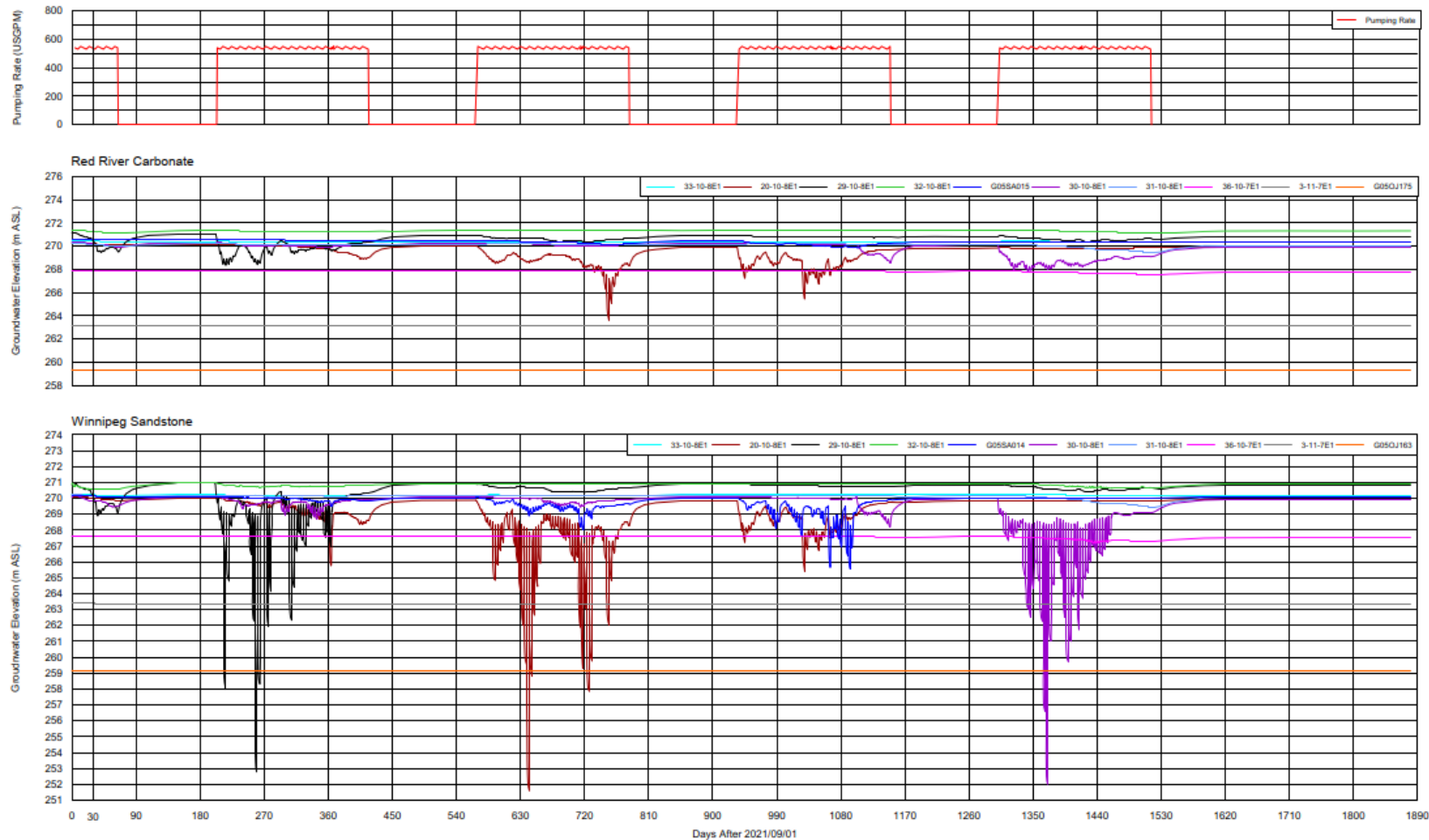
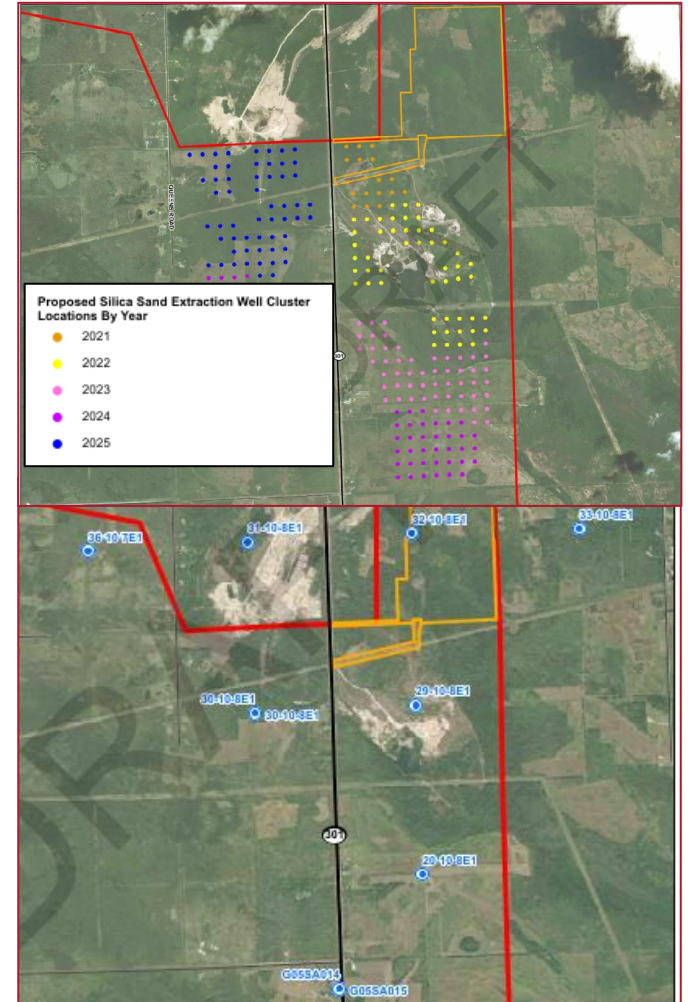


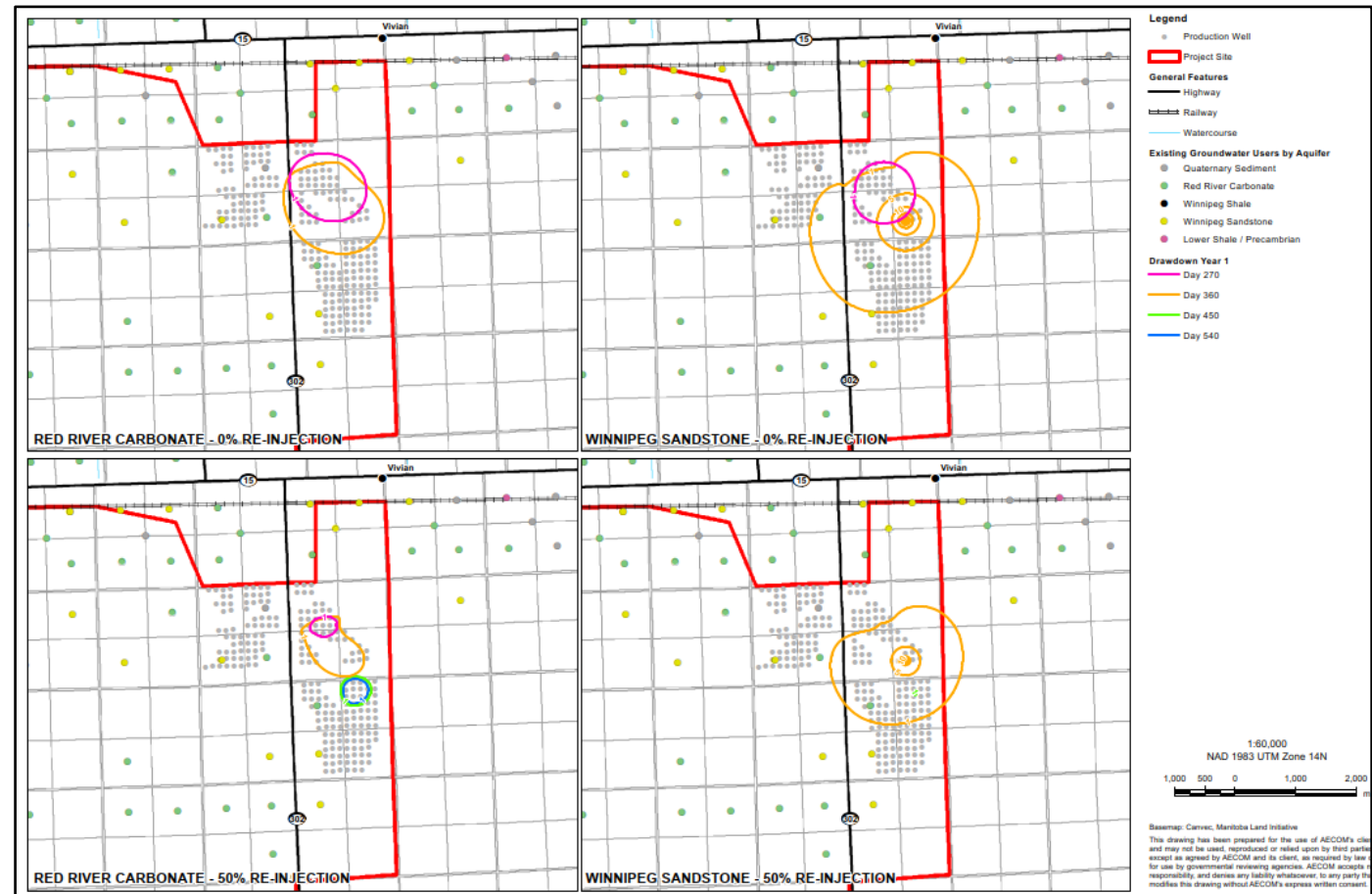
Figure 6-7. Simulated Drawdown and Recovery Hydrograph with 0% Re-Injection (Operations and Post-Closure)

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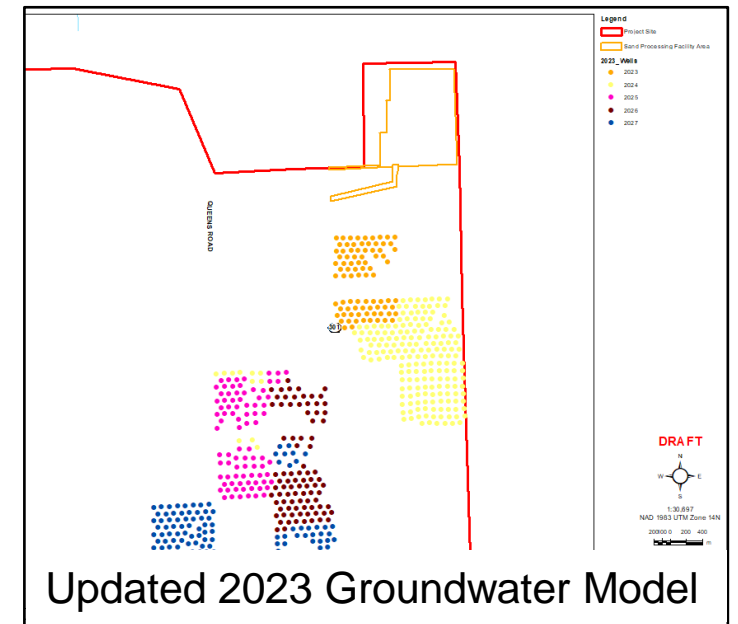
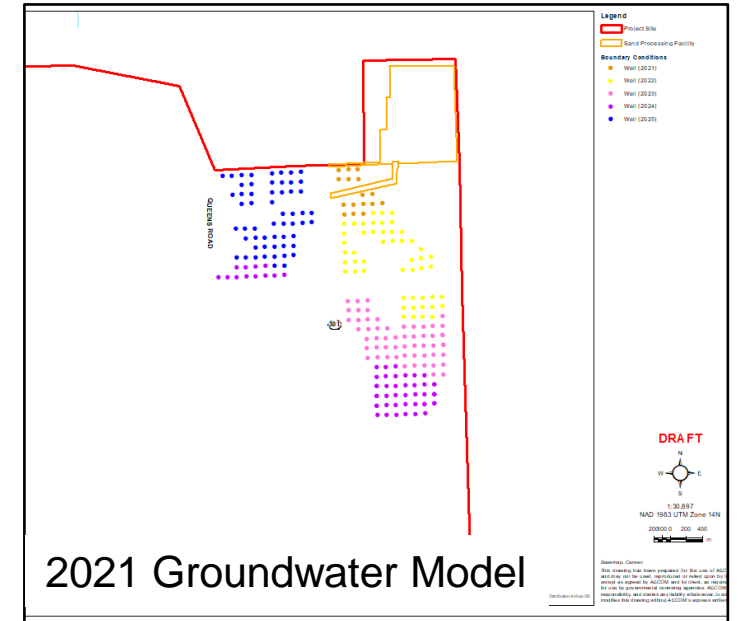
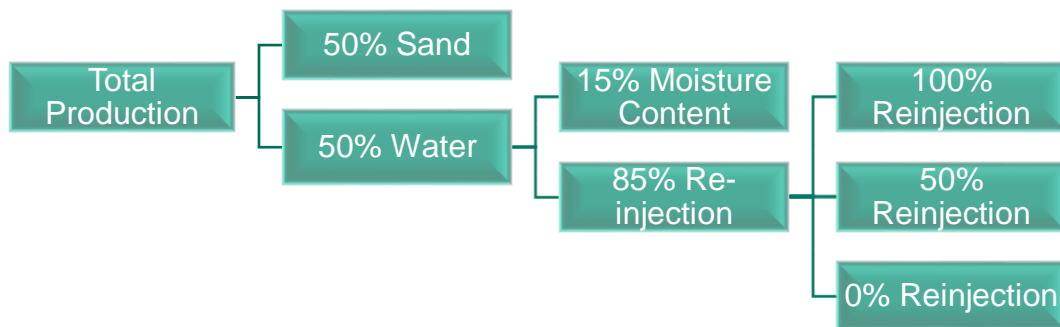
Simulation Results – 2021 Model

- Scenario 1 most conservative
- Largest drawdown was in proximity to extraction wells, but magnitude of drawdown rapidly diminishes with distance
- Groundwater elevations recover within 20 days of shutting down the well cluster; but, was within 80% recovery in 2 days
- Lower net withdrawal rates will reduce the depth and spatial extent of drawdown impacts

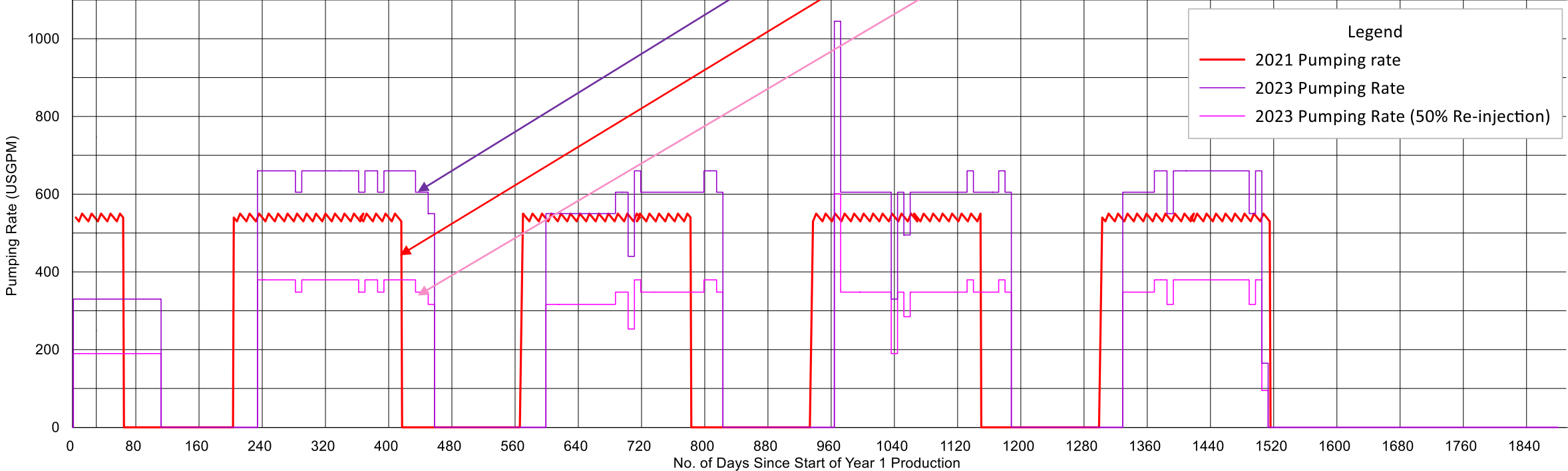
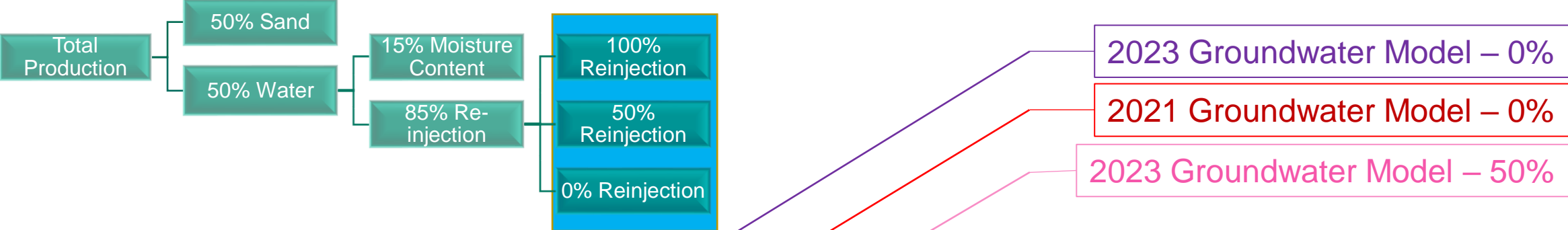


Groundwater Model Update

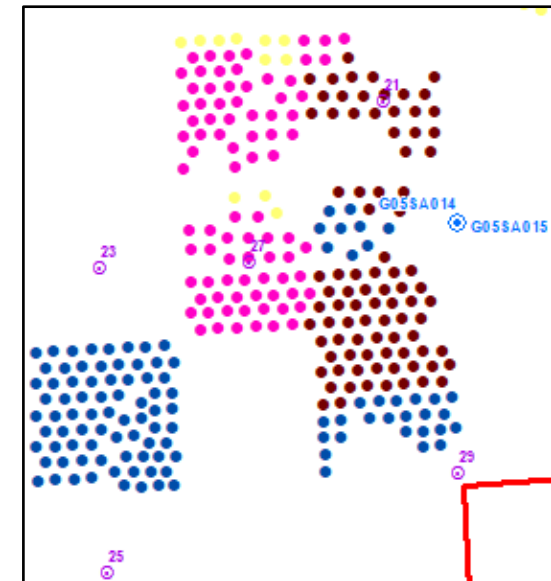
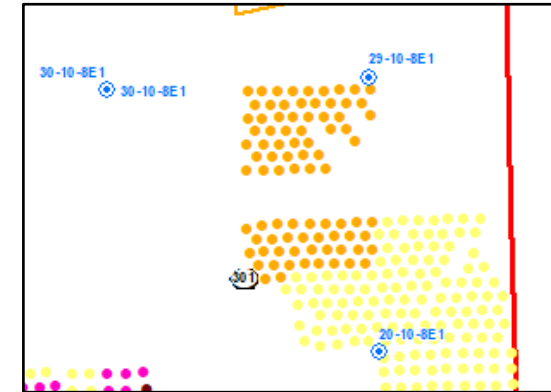
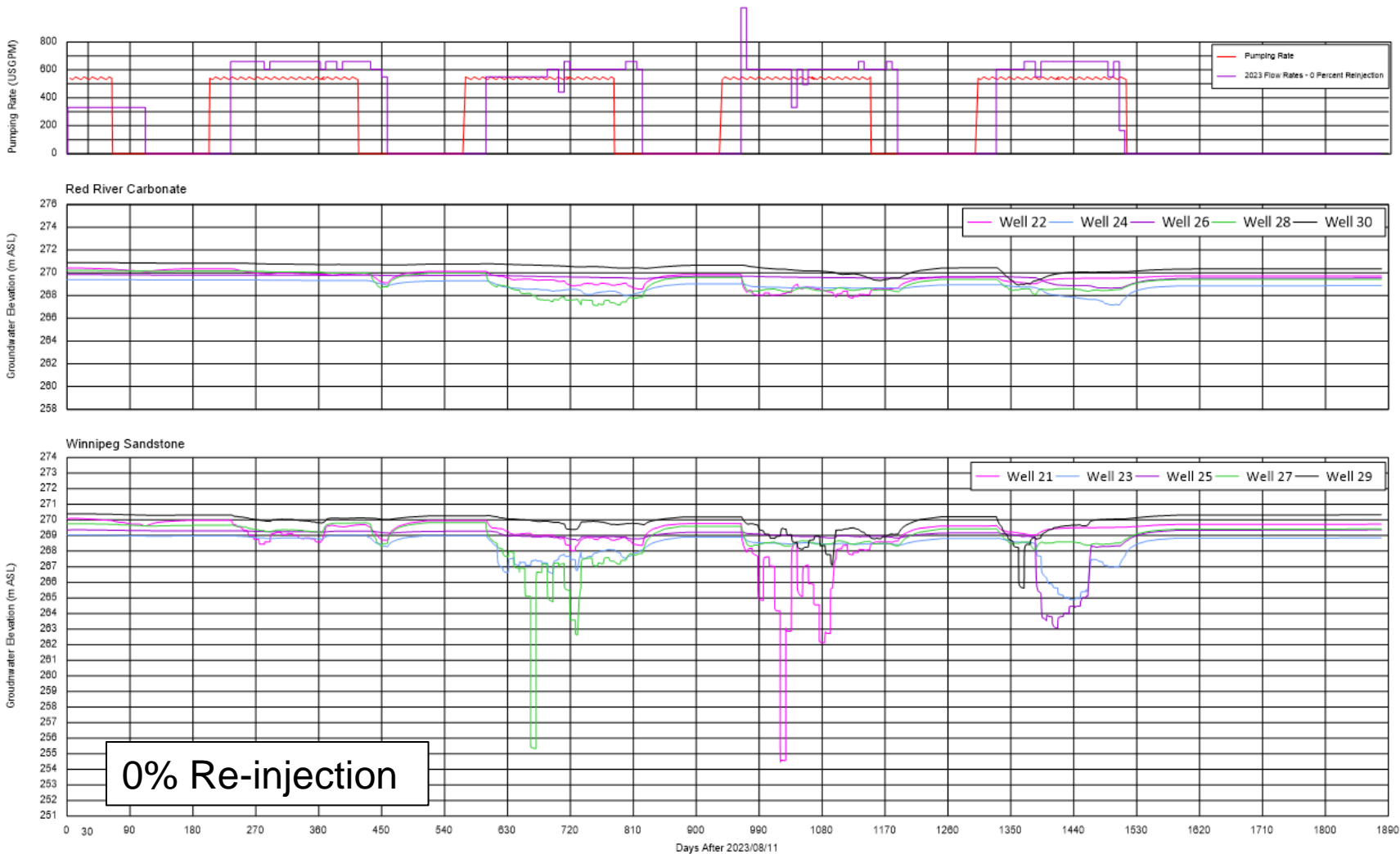
- Same as the 2021 Groundwater Model, except:
 - Revised extraction well locations, rates and schedule
 - Refined mesh around extraction wells
 - Groundwater levels at additional monitoring locations
- Three forecast model scenarios:
 - 0% Re-injection (of the 85% available)
 - 50% Re-injection (of the 85% available)
 - 100% Re-injection (of the 85% available)



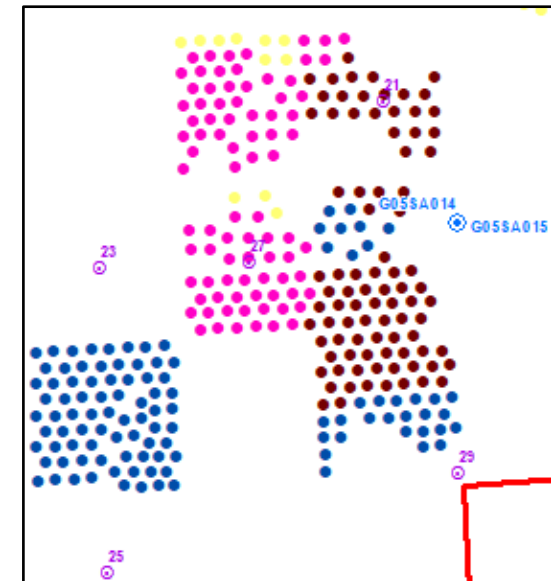
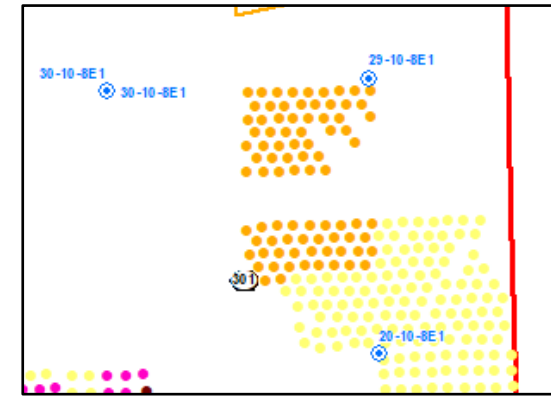
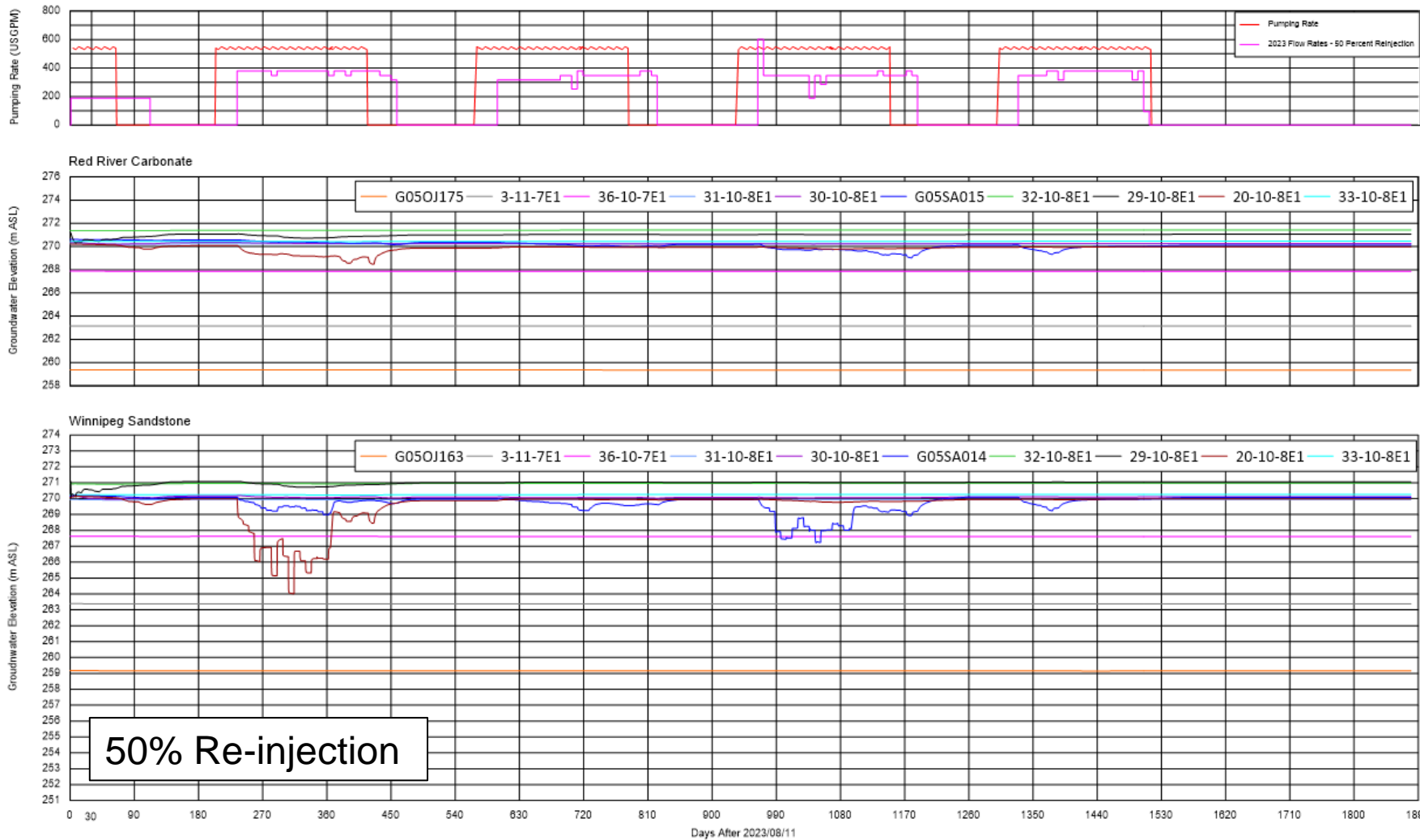
Extraction Rates – Updated Model



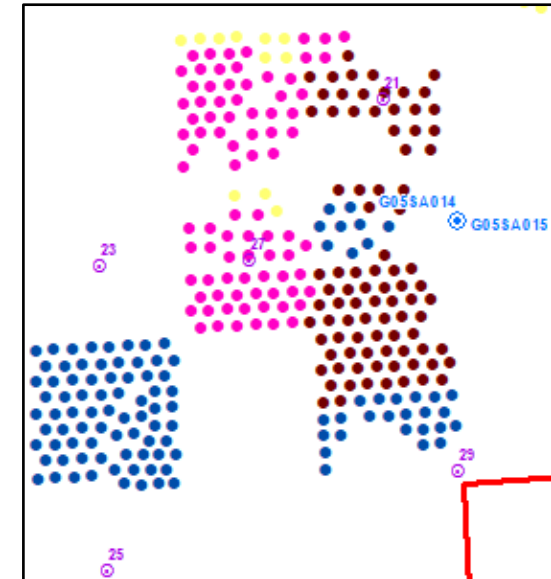
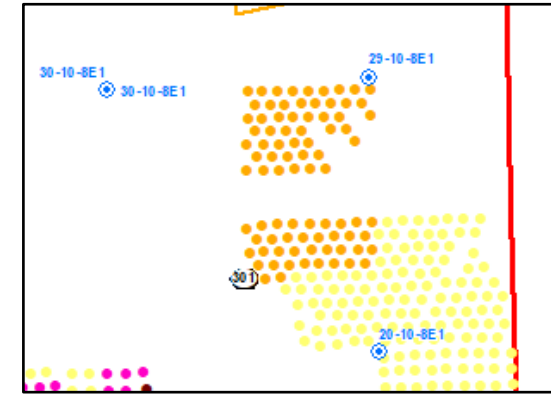
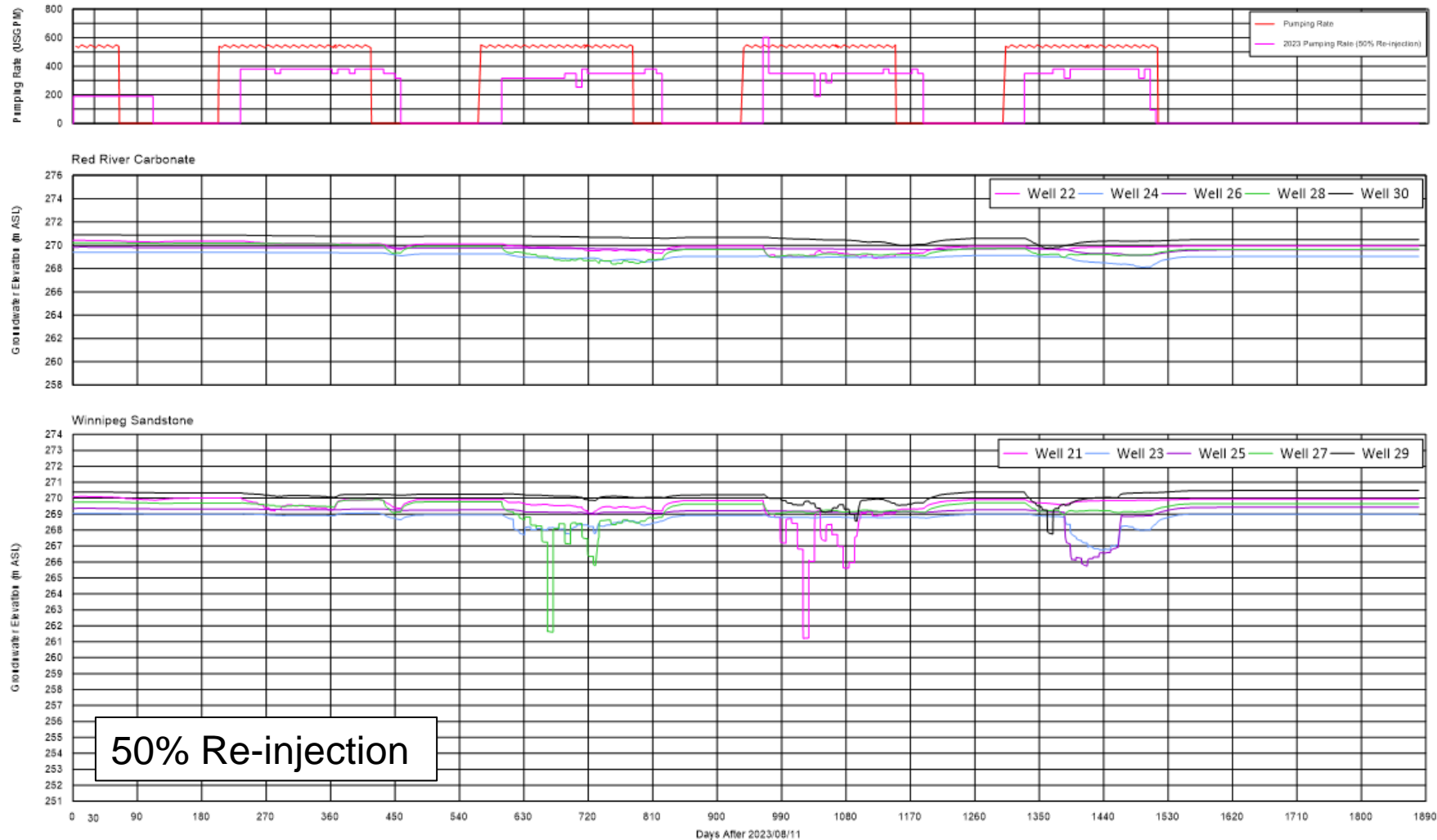
Simulation Results – Updated Model



Simulation Results – Updated Model

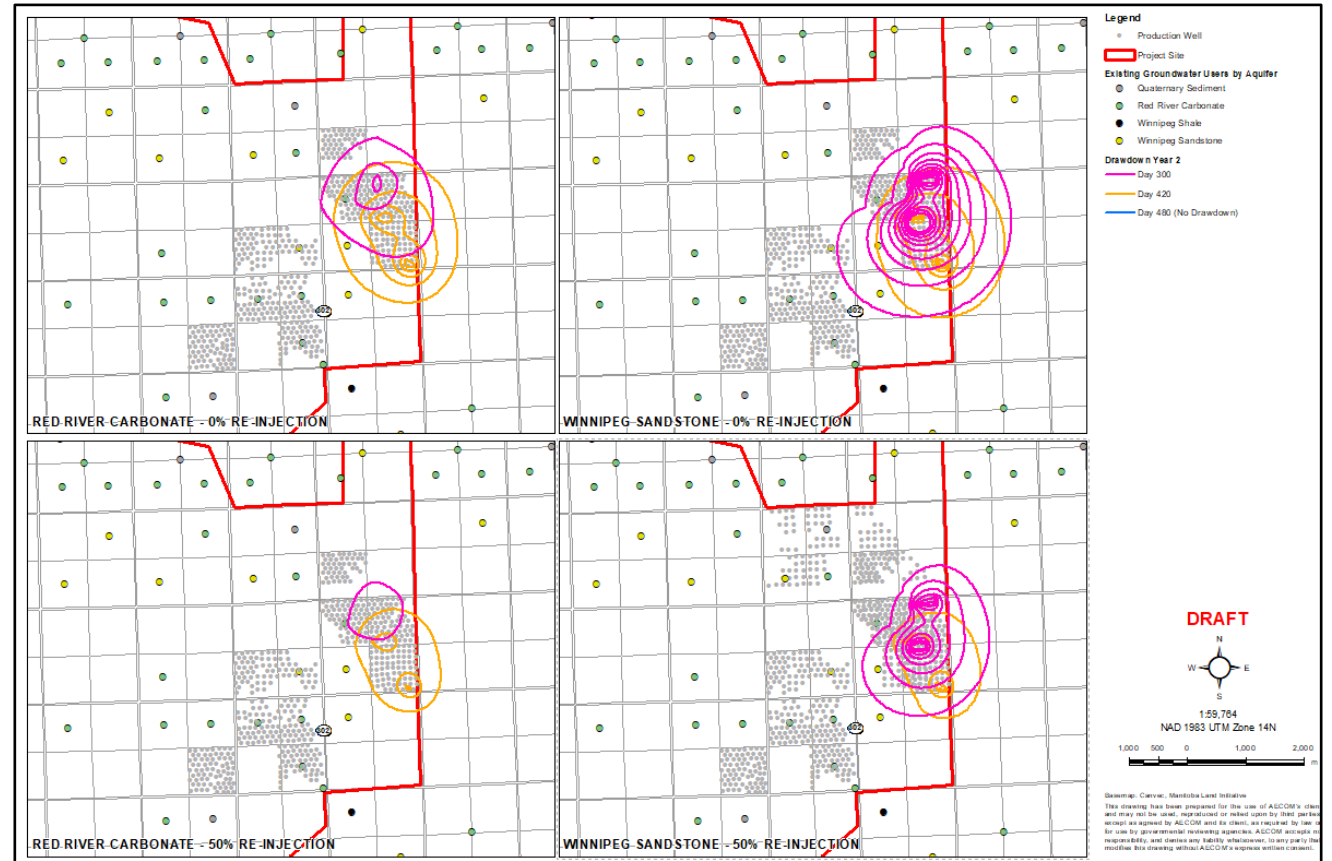


Simulation Results – Updated Model



Simulation Results – Updated Model

- Model modified to simulate revised sand extraction plan
- Drawdown responses and recovery are consistent with a highly conductive aquifer
- Location of drawdown impacts slightly different due to revised well locations
- Magnitude and spatial extent of drawdown comparable with the 2021 study
- Conclusions and recommendations remain valid



Geochemical Assessment

Geochemical Assessment – Solid Phase

Objectives:

- Determine the risk of excavated and mined material to release acid and/or metals when exposed to atmospheric conditions (oxygen and water) at **ground surface**
- Develop mitigations and control measures to prevent acid and/or metal release

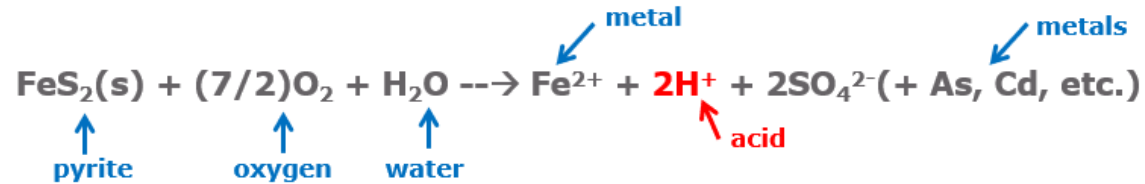
Background:

- Excavated material will not generate acid in their current location because of lack of oxygen in subsurface and saturation with water
- Any metals that could be released from excavated material should already be present in groundwater

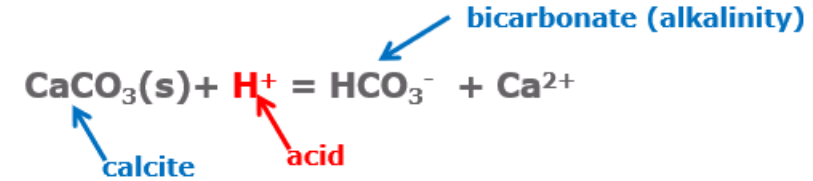
Geochemical Assessment – Solid Phase

Background:

Acid Generation Mechanism (Sulphide oxidation (Pyrite))



Acid Neutralization Mechanism (carbonate dissolution (calcite))



Results:

Acid neutralization (pH increases) and metals precipitation

Minerals such as aluminosilicates are also neutralizing but are less effective in neutralizing acid than carbonates

Geochemical Assessment – Solid Phase

Sampling Plan:

- Developed based on industry standards (MEND 2009, INAP 2014)
- 9 Samples (3 Red River Carbonate, 3 Winnipeg Shale and 3 Winnipeg Sandstone Samples)
- Replicate created at the laboratory
- Estimated tonnage of carbonate and shale waste rock over 5 years: ~3,600 tonnes

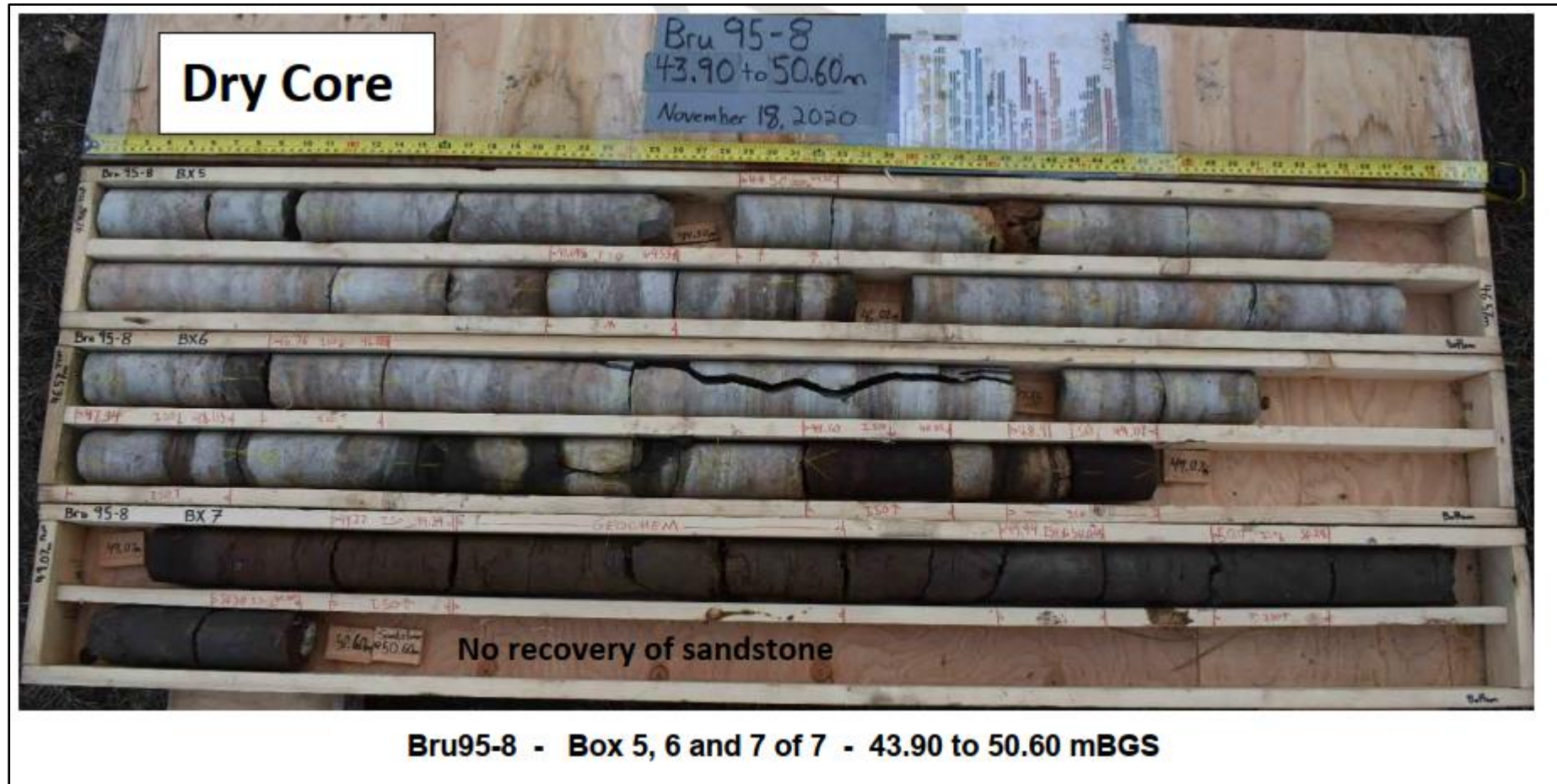
Table 1: Recommended Sampling Frequency (Source: MEND 2009)

Tonnage of Unit (metric tonnes)	Minimum Number of Samples
< 10,000	3
< 100,000	8
< 1,000,000	26
< 10,000,000	80

- Boreholes sampled: Bru 95-3, Bru 95-8, Bru 121-1 and Bru 146
- Samples documented, stored in sampling bags and shipped for laboratory testing
- QAQC include replicates, methods blanks, lab control sample and matrix spike

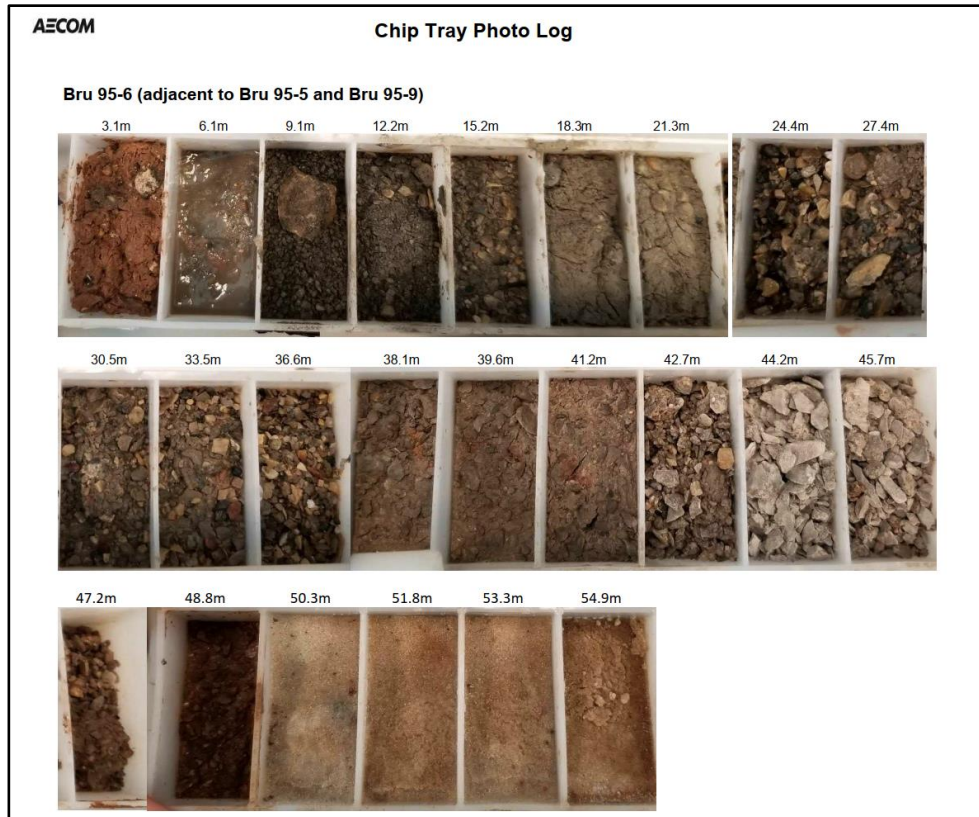
Geochemical Assessment – Solid Phase

Bru 95-8 Core



Geochemical Assessment – Solid Phase

Chip Tray Log (Bru 95-8)



Shale Core (Bru 95-8)

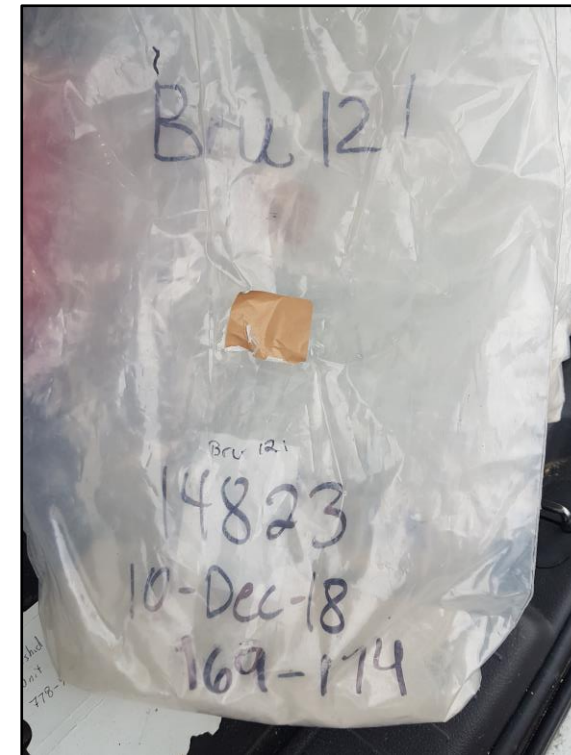


Geochemical Assessment – Solid Phase

Rock Core in Sample Bags



Sand in Sample Bags



Geochemical Assessment – Solid Phase

Laboratory Testing:

- Acid Base Accounting (ABA) to determine acid potential.
- X-Ray Diffraction (XRD) to determine the presence of acid producing and neutralizing minerals.
- Total recoverable metal analysis by ICP-MS to determine metal content of rock samples.
- Shake Flask Extraction (SFE) leach test to determine short-term release of acidity and metals under oxidizing and vigorous conditions following MEND protocols.

Hydrostratigraphic Unit	Average Paste pH	Average Total Sulphur (wt.%)	Average Sulphide Sulphur (wt.%)	Average Modified Sobek NP (Kg CaCO ₃ /t)	Average NPR	Material Classification
Red River Carbonate	8.1	0.05	<0.01	836	512.8	Non-PAG
Winnipeg Shale	7.6	0.31	<0.01	13	1.6	Uncertain (2) Non-PAG (1)
Winnipeg Sandstone	7.9	0.01	<0.01	4	11.1	Non-PAG

Notes:

NP: Neutralization Potential

NPR: Neutralization Potential Ratio

Geochemical Assessment – Solid Phase

Results: Shake Flask Extraction (SFE) Leach Test

- No acidity was stored in the samples (neutral SFE pH)
- Limited metal release: selenium exceedance of drinking water in shale, aluminum and selenium of aquatic life all three hydrostratigraphic units

Table 3: Metal Exceedances in SFE Leachates

Hydrostratigraphic Unit	Drinking Water		Agricultural/ Irrigation		Livestock		Aquatic Life	
	CDWQ MAC	MWQSOG MAC	CCME	MWQSOG	CCME	MWQSOG	CCME (Acute)	MWQSOG (Acute)
Red River Carbonate	-	Se (1 marginal)	-	-	-	-	Al, Se	-
Winnipeg Shale	As (1), Se (1)	As (1), Se (2)	-	U (1)	-	As (1 marginal)	Se	U
Winnipeg Sandstone	Fe (1 marginal AO)	Fe (1 marginal AO)	-	-	-	-	Al, Se (1), Fe (1)	-

Note: SFE used samples crushed to 85% passing ¼” (6.3 mm) material at 3:1 L:S ratio. Sample shaken for 24 hours under highly oxidizing conditions. Provides very conservative estimate of leachate quality. Interpretation must consider site specific conditions that differ from the laboratory.

Geochemical Assessment – Water Quality

Geochemical Assessment – Water Quality

Objectives:

- Determine baseline water quality
- Assess effect of operations on water quality
- Understand the role of Winnipeg Shale in hydrogeological system

Sampling Plan:

- 20 water quality samples and one duplicate from several monitoring wells and 3 private wells
- 13 water samples for isotope analysis
- Field parameters measured in the field
- Water quality samples field-filtered and analyzed by ALS Environmental Laboratories
- Isotope samples analyzed at University of Saskatchewan
- QAQC: duplicates, matrix spike, method blank

Geochemical Assessment – Water Quality

Water Quality Analysis:

- In-situ parameters: pH, temperature, conductivity, specific conductivity, dissolved oxygen, oxidation-reduction potential, salinity and turbidity
- Generals: alkalinity, dissolved organic carbon, total dissolved solids, total suspended solids, turbidity and hardness
- Anions and nutrients
- Dissolved metals
- Biological oxygen demand, chemical oxygen demand
- Polycyclic aromatic hydrocarbons
- Phenols
- Petroleum hydrocarbons
- Deuterium and Oxygen-18

Geochemical Assessment – Water Quality

Results: Groundwater Origin and Chemistry

- Groundwater has a meteoric origin, neutral pH and sub-oxic redox conditions
- Groundwater is fresh: < 500 mg/L TDS, Cl & SO₄ < 40 mg/L, Na < 100 mg/L
- Groundwater met drinking water guidelines except turbidity (MAC), iron and manganese (AO)
- Many parameters below the detection limit in most samples including selenium (16/20 < DL)

Geochemical Assessment – Water Quality

Results: Groundwater Chemistry

Table 4: Summary of Water Quality Exceedances

Hydrostratigraphic Unit	Drinking Water		Agricultural/Irrigation			Livestock		Aquatic Life	
	CDWQ	MWQSOG	CCME	FIGQG	MWQSOG	CCME	MWQSOG	CCME	MWQSOG
Red River Carbonate	Turbidity (MAC), Fe (AO)	Turbidity (MAC), Fe (AO)	-	S (as H ₂ S), Fe	-	-	-	F, Fe	-
Winnipeg Shale*	Turbidity (MAC), Fe (AO)	Turbidity (MAC), Fe (AO)	Mo	Cd	Mo	-	-	F, Fe, Cu, Zn	-
Winnipeg Sandstone*	Turbidity (MAC), Mn (AO), Fe (AO)	Turbidity (MAC), Fe (AO)	B	S (as H ₂ S), Fe	B	-	-	F, Fe	-

* One exceedance in four samples, except fluoride

Geochemical Assessment – Water Quality

Impact of Re-injection of Excess Oxygenated Water on Water Quality:

- Slight increase of pH and groundwater conditions become oxidizing
- Decrease of ammonia, iron, aluminum and manganese concentrations
- Decrease of iron, aluminum and manganese was attributed to oxidation and formation of amorphous oxyhydroxides (i.e., ferrihydrite, diaspore and manganite) in wells
- Amorphous phases attenuate metal concentrations through co-precipitation, especially selenium (ferrihydrite)
- Requires unlimited supply of oxygen to promote reactions, which will not occur in subsurface
- Therefore, oxidation of sulphide minerals in saturated environments is not plausible

Geochemical Assessment – Water Quality

Impact of Aquifer Mixing on Water Quality:

- Simulated mixtures of Red River Carbonate and Winnipeg Sandstone aquifers were fresh water meeting CDWQ, except iron and manganese (already exceeding in baseline)

Upward Mixing:

- Simulated water quality change in Red River Carbonate due to upward mixing shows that iron concentration decreased below the CDWQ guideline when the Winnipeg Sandstone proportion was > 80%. Manganese concentration exceeded CDWQ when the proportion was > 70%.
- Decreasing concentration of chloride, calcium, magnesium, arsenic, iron, uranium and strontium with increasing proportion of water from the Winnipeg Sandstone aquifer.

Geochemical Assessment – Water Quality

Downward Mixing:

- Simulated water quality change in the Winnipeg Sandstone aquifer due to downward mixing shows that iron concentration marginally exceeded the CDWQ guideline when the Red River Carbonate proportion was > 30%. Manganese concentration decreased below CDWQ when the proportion was > 30%.
- Decreasing concentration of sulphate, sodium and zinc with increasing proportion of water from the Red River Carbonate aquifer

Impact Assessment

Impact Assessment

Table 7-C. Classification of Residual Effects on Groundwater Quantity

Measurement Indicator	Criterion	Rating / Effect Size (Operations)	Rating / Effect Size (Post-Closure)
Groundwater Quantity	Direction	Negative	Neutral
	Magnitude (Drawdown)	6 m in Red River Carbonate 25 m in Winnipeg Sandstone	N/A
	Geographic Extent	Local	N/A
	Duration	Temporary	Permanent
	Reversibility	Reversible	N/A
	Frequency	Periodic	Continuous
	Probability of Occurrence	Certain	Certain

Impact Assessment

Table 7-D. Classification of Residual Effects on Groundwater Quality

Measurement Indicator	Criterion	Rating / Effect Size (Operations)	Rating / Effect Size (Post-Closure)
Groundwater Quality	Direction	Positive to Negative	Positive to Negative
	Magnitude	Small changes in concentrations	Small changes in concentrations
	Geographic Extent	Maximum Disturbance Footprint	Maximum Disturbance Footprint
	Duration	Temporary	Permanent
	Reversibility	Reversible	Irreversible
	Frequency	Periodic	Continuous
	Probability of Occurrence	Possible	Possible

Impact Assessment

Recommended development and implementation of four (4) plans:

- Groundwater Monitoring and Impact Mitigation Plan
- Progressive Well Abandonment Plan
- Waste Characterization and Management Plan
- Water Management Plan

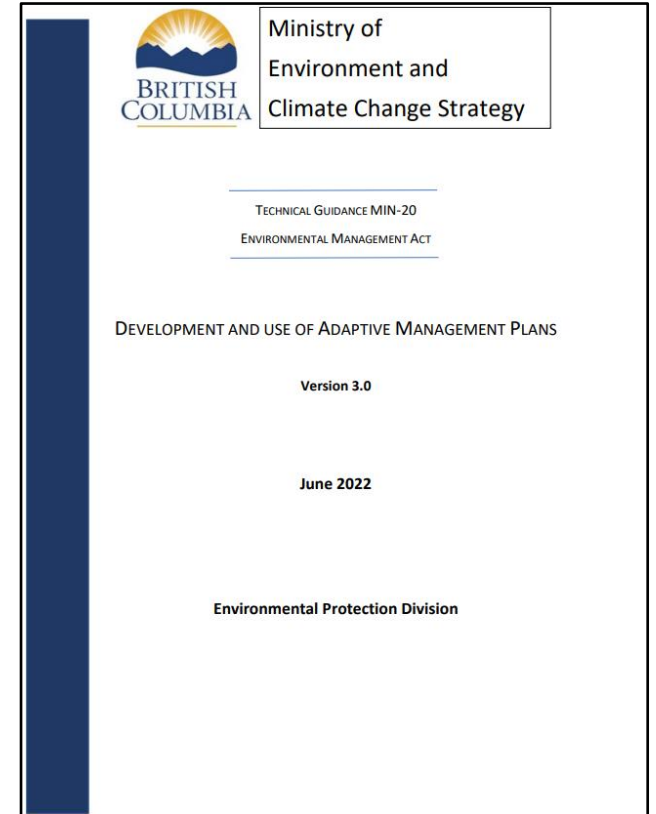
With implementation of these plans, potential adverse effects on groundwater quantity and quality are anticipated to be mitigated. Adaptive management measures will be applied to manage and reduce uncertainty.

Monitoring, Characterization, Management, and Mitigation Plans

Adaptive Management

“Adaptive Management Plans (AMPs) allow for decisions to be made in the face of uncertainty and provides a means to systematically reduce uncertainties and improve management practices over time by learning from the outcomes of operational activities”

BC Ministry of Environment and Climate Change Strategy
Technical Guidance MIN-20 v3.0 (June 2022)



Adaptive Management

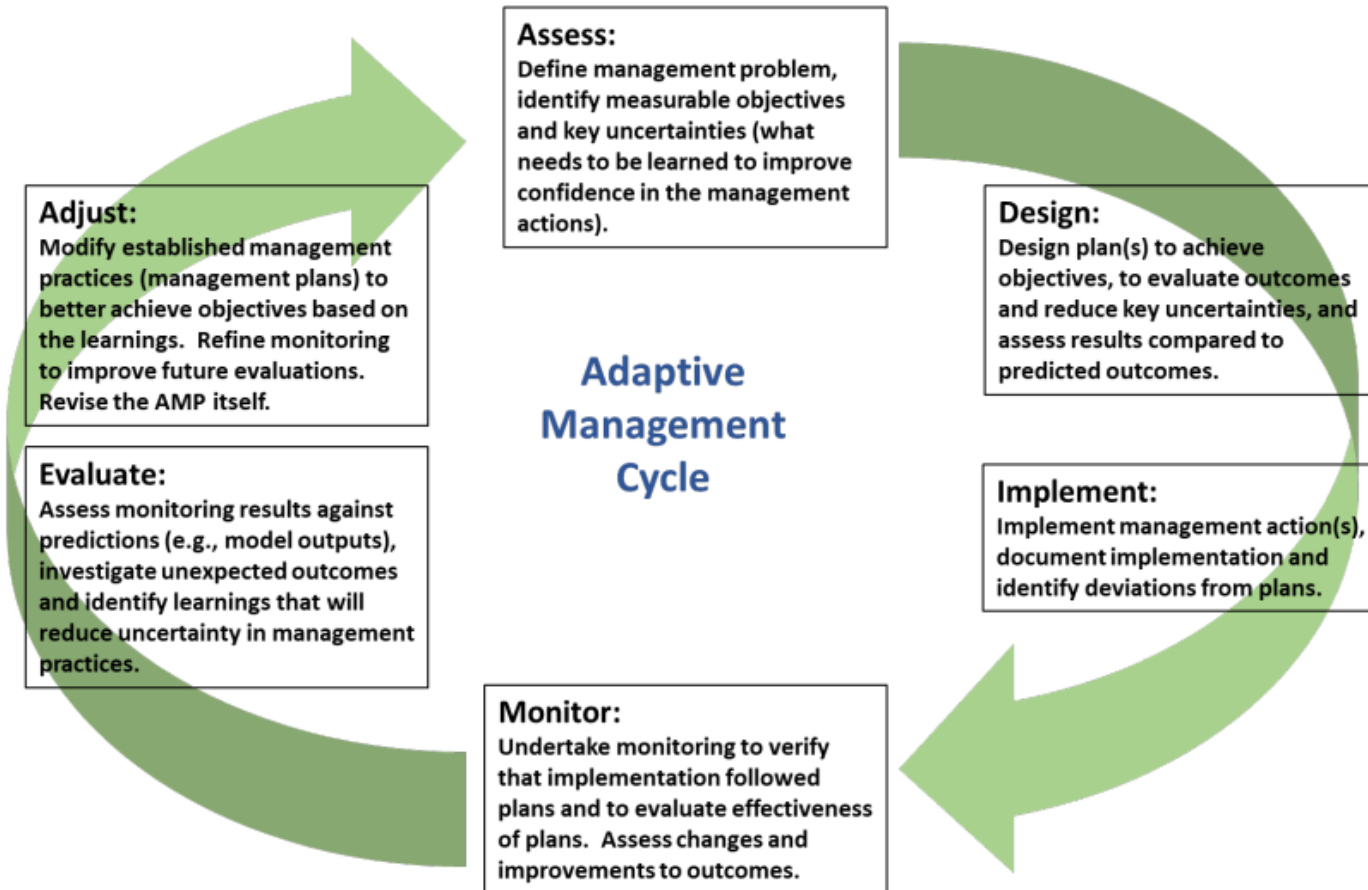


Figure 1. Adaptive Management Cycle

Groundwater Monitoring and Impact Mitigation Plan

Objectives:

- Water supply well survey.
- Monitoring of groundwater quantity and quality (locations, parameters, frequency, etc.).
- Assessing field performance against the design goals and objectives to direct the continuous improvement of monitoring networks and groundwater evaluation tools including the numerical groundwater model over time.
- Establish protocols for receiving and responding to well owner complaints
- Establish Trigger Action Response Plan (TARP) that identifies mitigation measures and guides their implementation to avoid and/or mitigate any unacceptable impacts.
- Establish protocols for assessing the effectiveness of the mitigation measures over time.
- Establish a framework for reporting findings to the community and regulatory agencies.

Groundwater Monitoring and Impact Mitigation Plan

Groundwater Level Monitoring Frequency:

Well Type	Frequency Prior to Operations	Frequency During Operations	Frequency for Year 1 Post-Operations	Frequency for Years 2-5 Post-Operations
Background Groundwater Monitoring Zone	Continuous (Once Per Hour)	Continuous (Once Per Hour)	Continuous (Once Per Hour)	Continuous (Once Per Day)
Operational Performance Monitoring Zone	Continuous (Once Per Minute)	Continuous (Once Per Minute)	Continuous (Once Per Minute)	Continuous (Once Per Day)
Local Groundwater Monitoring Zone	Continuous (Once Per Day)	Continuous (Once Per Day)	Continuous (Once Per Day)	Continuous (Once Per Day)
Regional Groundwater Monitoring Zone	Continuous (Once Per Hour)	Continuous (Once Per Hour)	Continuous (Once Per Hour)	Continuous (Once Per Day)

Groundwater Monitoring and Impact Mitigation Plan

Groundwater Quality Monitoring Frequency:

Groundwater Monitoring Zone	Frequency Prior to Operations	Frequency During Operations	Frequency for Year 1 Post-Operations	Frequency for Years 2-5 Post-Operations
Background Groundwater Monitoring Zone	Twice	Once Per Quarter	Once Per Quarter	Once Per Quarter
Operational Performance Monitoring Zone	Twice	Once Per Month	Once Per Month	Once Per Quarter
Local Groundwater Monitoring Zone	Twice	Once Per Quarter	Once Per Quarter	Once Per Quarter
Regional Groundwater Monitoring Zone	Twice	Once Per Quarter	Twice Per Year	Once Per Year

Groundwater Monitoring and Impact Mitigation Plan

Data Review by Qualified Professional:

- Ongoing, Monthly and Annually
- Compare water levels to thresholds
- Compare water quality to applicable criteria
- Compare data to TARP thresholds and respond accordingly
- Respond to any well owner queries

Comprehensive Annual Report:

- Operational activities
- Water level and water quality results
- Summary of status of TARP events and responses
- Summary of any well owner complaints and responses

Progressive Well Abandonment Plan

Objectives:

- Establish a framework for tracking the drilling, installation, operation and closure of all boreholes, monitoring wells and extraction wells over the life of the Vivian Sand Project.
- Describe protocols for timely abandonment of all boreholes, monitoring wells and extraction wells over the life of the Vivian Sand Project.
- Assess and monitor the effectiveness of the mitigation measures over time.
- Establish a framework for reporting findings to the community and regulatory agencies.

Waste Characterization and Mgmt. Plan

Objectives:

- Summarize characteristics of each type of waste material that will be extracted.
- Describe protocols for identifying, sampling, characterizing and managing waste materials to minimize the risk of ML/ARD and impacts to environment.
- Define appropriate end uses for each type of waste material.
- Describe measures that can be implemented to mitigate ML/ARD and incremental impacts to the environment.
- Describe protocols for monitoring surface water and groundwater quality to assess field performance against the design goals and objectives of the management plan.

Waste Characterization and Mgmt. Plan

Sampling and Testing:

- Prior to operations and early operations sampling frequency:
 - 1 sample per 2,000 tonnes of quaternary sediments
 - 1 sample per 700 tonnes of Red River Carbonate
 - 1 sample per 200 tonnes of Winnipeg Shale
- Operational sampling frequency:
 - 1 sample per 5,000 tonnes of quaternary sediments
 - 1 sample per 2,000 tonnes of Red River Carbonate
 - 1 sample per 500 tonnes of Winnipeg Shale

Waste Characterization and Mgmt. Plan

Waste Rock Management:

- All waste stored in covered bins/tanks and hauled to offsite landfill or licensed facility for disposal
- Eliminates potential environmental risks
- Eliminates the need for surface water monitoring

Monitoring:

- Groundwater monitoring as per *Groundwater Monitoring and Impact Mitigation Plan*

Reporting:

- Develop annual report summarizing waste characterization, classification and management
- Describe the results of geochemical testing and volume of waste generated
- Outline any required improvements

Water Management Plan

Objectives:

- Establish objectives for management of surface water, groundwater, slurry and process water during operations and closure.
- Describe the configuration of Project elements and the storage and flow of water.
- Describe the operational management strategy for water and solids.
- Establish a framework for monitoring of water, solids, and slurry to assess field performance against the design goals and objectives of this Water Management Plan.
- Establish the parameters, frequency and locations where monitoring of flows/quality will occur.
- Identify best management practices to ensure groundwater and surface water are preserved.
- Establish a framework for reporting findings to the community and regulatory agencies on a regular basis.
- Prepared after license is issued and submitted in advance of operations.

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