REPORT NO. 212011/6

NYRSTAR MYRA FALLS

PHASE II LYNX SIS CONCEPTUAL DESIGN UPDATE

Submitted to:

Nyrstar Myra Falls

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July 2018

EXECUTIVE SUMMARY

This report provides a performance assessment of an interim Phase II Lynx Seepage Interception System (SIS) at Nyrstar Myra Falls (NMF) and presents an updated conceptual design for interception of shallow seepage in the Lynx reach (Phase II Lynx SIS).

2018 Hydrogeological Field Investigation

A fence of shallow pumping wells (PW18-01 to -05) was installed in the Lynx reach between the Duck Pond and the Super Pond to intercept acidic seepage observed discharging to Myra Creek (interim Phase II Lynx SIS). In addition, three nested monitoring wells (MW18-06S/D to -08S/D) were installed to better characterize the hydrogeological conditions in this area.

Groundwater in the new MW18 and PW18 wells is moderately impacted with slightly acidic pH and moderately elevated zinc concentrations (0.5 to 2.5 mg/L). Higher observed zinc concentrations in the shallow piezometers suggest a surface source such as recharge from local PAG waste rock and/or leakage from the Duck Pond. However, none of the new MW18 and PW18 wells intercepted the strongly acidic seepage and high metal concentrations observed earlier in the year.

Interim Phase II Lynx SIS Seepage Collection

The interim Phase II Lynx SIS consisted of a vacuum pumping system installed in PW18-01 to -04 and was operated for 29 days in June 2018. The shallow pumping wells proved to be relatively productive and the surrounding shallow colluvial sediments appeared to be hydraulically well connected to the shallow glaciofluvial sediments.

A total of 27,500 m^3 of groundwater was extracted at an average pumping rate of around 11 L/s resulting in a total captured Zn load of 16.4 kg. Loads of cadmium and copper captured were 1-3 orders of magnitude lower than zinc loads. The PW18 wells captured an estimated ~10% of the total average Zn load estimated to discharge from groundwater to Myra Creek in the Lynx reach. No seepage to Myra Creek was observed during the operation of the interim Phase II SIS.

Numerical Assessment of Phase II Lynx SIS

A numerical groundwater flow model was constructed and calibrated to evaluate capture efficiency of five different SIS scenarios including:

- Scenario 0: Operation of existing fence of wells (PW18-01 to PW18-04) using submersible pumps (to maximize pumping capacity).

- Scenario 1: Shallow drain (~5m deep) along PW-18 alignment.
- Scenario 2: Two high-capacity pumping wells (~10 m deep) along PW18 alignment.
- Scenario 3: Shallow drain (~5m deep) along northeasterly alignment.
- Scenario 4: Two high-capacity pumping wells (~10 m deep) along northeasterly alignment.

The model predicts that all five scenarios prevent discharge of impacted groundwater originating from the Duck Pond area to Myra Creek. The limited pumping capacity of the PW18 wells (24 L/s) may not be adequate to reverse the hydraulic gradient during all receding flow conditions. However, particle tracking simulations suggest that impacted shallow groundwater from the Duck Pond area is still captured.

Shallow drains are slightly more efficient in producing the required drawdown and provide full capture of potentially perched seepage compared to a fence of pumping wells. Leakage from Myra Creek was simulated to be less than 2 L/s for most scenarios and can be maintained at low rates by setting the pumping level in the SIS equal to the creek level.

Recommended Design for Phase II Lynx SIS

Scenario 0 represents the most cost-effective solution and initial testing has demonstrated that this fence of PW18 wells is effective in eliminating discharge of impacted groundwater in this area during low flow conditions. Furthermore, groundwater modeling suggests that this fence of pumping wells is also expected to be able to control seepage during most high flow conditions.

RGC recommends that the four PW-18 pumping wells (PW18-01 to PW18-04) be equipped with submersible pumps (to maximize pumping capacity) and be operated during the upcoming high flow season (October 2018 to March 2019). If the PW18 pumping wells are effective in eliminating the discharge of impacted groundwater to Myra Creek, then this fence of PW18 wells should be adopted as the Phase II Lynx SIS. If this fence of PW18 wells is not sufficient, then a shallow (5 m deep) drain along the PW18 alignment (Scenario 1) should be implemented.

RGC furthermore suggests that the Phase II SIS should only be operated if the groundwater captured and/or seeps discharging into Myra Creek exceed a certain threshold water quality. Appropriate discharge limits for operation of the Phase II Lynx SIS should be developed in consultation with the regulatory agencies.

Recommendations for monitoring during the upcoming high flow season (October 2018 to March 2019) are provided in section 7.2.

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PHASE II LYNX SIS PERFORMANCE ASSESSMENT AND CONCEPTUAL DESIGN UPDATE

1 INTRODUCTION

1.1 TERMS OF REFERENCE

This report provides a performance assessment of an interim Phase II Lynx Seepage Interception System (SIS) at Nyrstar Myra Falls (NMF) and provides an updated conceptual design for interception of shallow seepage in the Lynx reach (Phase II Lynx SIS). The report was completed by Robertson GeoConsultants (RGC) for NMF's Environment Department. This report is an addendum to a report titled "Lynx SIS Performance Assessment and Conceptual Design Update", submitted in May 2018.

1.2 REPORT OBJECTIVES

The specific objectives of this report are to:

- Determine potential sources and pathways of impacted groundwater ("seepage") to Myra Creek in the Lynx reach (near car bridge).
- Assess efficiency of the interim Phase II Lynx SIS installed and operated in June 2018, including groundwater volumes and metal loads recovered.
- Complete numerical assessment of alternative designs of Phase II Lynx SIS (including the interim solution) for winter high flow and receding flow conditions.
- Recommend an updated conceptual design for the Phase II Lynx SIS.
- Recommend an approach for implementation of a Phase II Lynx SIS by summer 2019.

1.3 REPORT ORGANIZATION

The remainder of this report includes the following sections:

- **Section 2. Background,** summarizes groundwater quality conditions and associated impacts on Myra Creek in the Lynx reach.

- **Section 3. 2018 Hydrogeological Field Investigation,** summarizes the results of the May 2018 hydrogeological field program, including installation of monitoring wells and interim Phase II Lynx SIS (shallow pumping wells) in the Lynx reach.
- **Section 4. Hydraulic Testing of Interim Phase II Lynx SIS,** presents findings of initial operation of the interim Phase II Lynx SIS for low flow conditions.
- **Section 5. Numerical Assessment of Phase II Lynx SIS,** summarizes findings of numerical groundwater flow modeling to assess performance of alternative designs of a Phase II Lynx SIS during high flow and receding flow conditions.
- **Section 6. Updated Conceptual Design of Phase II Lynx SIS,** provides an updated conceptual design for a seepage interception system intended to capture shallow seepage discharging into Myra Creek within the Lynx reach (car bridge area).
- **Section 7. Key Findings,** summarizes key findings of the hydrogeological field investigation and numerical modeling study.
- **Section 8. Recommendations,** describes the recommended design and further testing of the Phase II Lynx SIS and provides recommendations for monitoring during the upcoming high flow period.

2 BACKGROUND

2.1 GROUNDWATER QUALITY IN LYNX REACH

Detailed groundwater sampling in the Lynx reach during the 2014 Hydrogeological Drilling Program (RGC, 2015) identified elevated metal concentrations in perched seepage in shallow sediments and groundwater from the underlying, deeper sediments of the Myra Valley Aquifer (MVA). Routine sampling of groundwater and seeps in this area during high precipitation events later confirmed these observations.

The highest concentrations of metals in groundwater are observed at the downstream end of the Lynx reach near the Super Pond. Samples from wells MW14-04S and MW14-04D have routinely shown zinc (Zn) concentrations in excess of 100 mg/L Zn. Seepage from Potentially Acid Generating (PAG) waste rock in the Lynx TDF embankment berm is the primary source of Zn (and other metals such as Cd and Cu) to groundwater in this area. Secondary sources are local PAG waste near the mill, local PAG waste rock in the ETA/Cookhouse area, remnants of tailings/waste rock historically placed in the Super Pond area ("so called "Superpile"), and mine water from the Lynx 10L East adit.

Water samples are also routinely collected in Myra Creek from Stations MC-S11 to MC-TP4 and analyzed for dissolved Zn. Detailed analysis of the monthly sampling campaigns indicates that 50% of the Zn load in Myra Creek at MC-TP4 during high flow conditions (daily flow in Myra Creek > 9 m^3/s) is related to groundwater that discharges to the creek from the Lynx Reach. During low flow (< 4 m^3/s), seepage from the Lynx Reach was inferred to contribute up to 20% of the total zinc loading in Myra Creek (RGC, 2016a). The increased zinc loading to Myra Creek during high flow is likely caused by generally higher flows of impacted groundwater due to increased groundwater levels and gradients as well as flows of highly-impacted, perched seepage from the Super Pond area.

2.2 SHALLOW GROUNDWATER SEEPAGE TO MYRA CREEK

In past years, acidic seepage was usually observed expressing after heavy rainfall events (>80 mm in 24 hrs) at the berm toe of the Super Pond with water quality similar to perched groundwater found in the Super Pond area (low pH and elevated metals and SO_4). These seeps are collected in "25 Sump" and pumped to the Super Pond for treatment. In addition, seeps with low pH and elevated metal concentrations have been observed to express closer to Myra Creek and were sampled on December 12, 2014 following a high flow event (RGC, 2015; RGC, 2018).

It was previously presumed that the metal loading from groundwater to Myra Creek within the Lynx reach originates from the shallow (perched) aquifer within the Super Pond Area (RGC, 2016). More specifically, during high precipitation events, groundwater levels in the shallow (perched) aquifer were observed to increase rapidly resulting in a hydraulic gradient towards the creek. This perched seepage was believed to produce the observed seepage along the Super Pond berm in the range of several liters per second.

However, during the winter of 2017/2018, the previously identified seeps along the berm of the Super Pond were not observed. For example, during the November 19, 2017 high flow event, only minimal discharge (<0.5 L/s) was observed near the top of the berm adjacent to the Pipebridge. Furthermore, water quality sampling showed neutral conditions and low metal concentrations in this berm seepage. Surface water runoff on the Super Pond road was observed infiltrating into the road and likely emerged again a few meters below on the berm.

On January 29, 2018, acidic seepage was sampled at three locations along the creek bank between the car and pipe bridges. These seeps were active for several weeks which was not previously observed. These recent conditions triggered the implementation of an interim Phase II Lynx SIS in May 2018, comprised of several shallow extraction wells (see section 3 for more details).

2.3 LYNX SIS

RGC (2015) proposed a SIS downgradient of the Lynx TDF comprised of a fence of seepage recovery wells. The fence of pumping wells that recover impacted groundwater from the MVA is referred to as the Phase I Lynx SIS. In addition, construction of a shallow drain has been proposed to intercept perched seepage in colluvial sediments to augment Phase I (RGC, 2016; RGC 2018). The shallow SIS component is referred to as Phase II Lynx SIS.

2.3.1 Phase I

The Phase I SIS has been operational since end of September 2017. It consists of a fence of three (3) seepage interception wells: PW14-01, PW14-03, and PW14-04. PW14-03 is located about 150 m downstream of the mill and PW14-01 and PW14-04 are west and east of the Super Pond, respectively (see Figure 2-1 for locations and RGC, 2018, for further details).

The SIS wells are screened within the permeable sediments of the MVA and submersible pumps, controls and discharge lines were installed in 2017 to operate the recovery wells (see Table 2-1). The available maximum drawdown during low flow season ranges from around 2 to 7.5 m assuming a minimum water level above the pump intake of 0.5 m.

Table 2-1. Phase I Lynx SIS - Pumping Well Specifications.

Pumping Well ID	Well Depth [m]	Design Capacity		Diameter [inch]		Rated Power [HP]
		[US GPM]	[L/s]	Pump	Motor	
PW14-01	31	600	38	7	6	25
PW14-03	33	475	30	6	6	20
PW14-04	19	475	30	7	6	20

To operate the pumping wells, a water level above the pump intake is specified rather than a pump speed selected as with more conventional systems. A water level sensor installed within the well string monitors the water level in the well near continuously. The control unit (variable frequency drive or VFD) then continually adjusts the pump speed to maintain the selected water level. This allows maximizing drawdown in the pumping wells during all flow conditions without manual adjustments of the pumping rate. This control system is particularly advantageous for a very dynamic groundwater flow system such as the MVA.

2.3.2 Phase II

For the Phase II Lynx SIS, a (shallow) drain has been proposed to be constructed between Myra Creek and the Super Pond to prevent shallow, impacted groundwater from the Super Pond and ETA areas from entering the creek. A conceptual layout of the proposed drain was presented in RGC (2016).

The main objective of this report is to update this original conceptual design of a Phase II Lynx SIS, considering the findings from the 2018 hydrogeological field investigation in the Lynx reach (see section 3) and operation of an interim Phase II Lynx SIS comprised of four shallow extraction wells (see section 4).

3 2018 HYDROGEOLOGICAL FIELD INVESTIGATION

3.1 OVERVIEW

In consultation with the Ministry of Environment (MOE), an interim mitigation plan was developed to prevent the uncontrolled discharge of acidic seepage to Myra Creek. Owing to geotechnical constraints and limited time available, construction of a shallow rock drain (as per conceptual design of the Phase II Lynx SIS proposed in RGC, 2016) was not possible. Instead, a fence of shallow pumping wells was installed to allow extraction of shallow groundwater as an interim solution. In addition, three nested monitoring wells were installed to better characterize the hydrogeological conditions in this area. This hydrogeological field investigation was completed from May 9th to 13th, 2018.

The specific objectives of this 2018 hydrogeological field investigation in the Lynx reach were as follows:

- Determine stratigraphy in the upper portion of the MVA (<18 m) in proximity of the Duck Pond[1] and acidic seeps observed between the Super Pond and Myra Creek.
- Refine groundwater flow field and further delineate groundwater quality impacts in the shallow groundwater in this reach.
- Assess potential sources contributing to the acidic seeps discharging to Myra Creek (incl. leakage from ETA runoff, Duck Pond leakage, diversion ditch leakage, and/or perched seepage from Super Pond area).
- Install shallow pumping wells (<11 m) along Myra Creek (interim Phase II Lynx SIS) designed to capture groundwater seeps currently expressing at the creek bank.
- Perform hydraulic testing to determine aquifer parameters in shallow aquifer.

3.2 DRILLING METHODS AND WELL INSTALLATION

3.2.1 General

The drilling program commenced on May 9th, 2018 and was completed on May 13th, 2018. Drilling and well installation was supervised by Amanda Schevers from RGC. Amec Foster Wheeler field staff Angeleen Ramey assisted in the drilling supervision and conducted geotechnical logging of the soil. Alexander Trapp from RGC assisted with well development, water quality sampling, and slug testing. On-site support during the program was provided by NMF’s Environmental Management team.

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[1] The Duck Pond was constructed in 2016 immediately upstream of the car bridge. It is an unlined settling pond storing acidic runoff from the ETA area.

A photo log illustrating the drilling and related tasks completed during the program is provided in Appendix A.

3.2.2 Drilling and Well Locations

Five pumping wells (PW18-01, 02, 03, 04, 05) were installed along the northern bank of Myra Creek in the Lynx reach. In addition, three nested monitoring wells (MW18-06S/D, -07S/D, -08S/D) were installed upstream and downstream of the Duck Pond during the drilling program (see Figure 3-1 for locations). Well locations were modified slightly from the original drilling plan to accommodate operational preferences of site staff and avoid interference with surface and subsurface infrastructure.

3.2.3 Drilling Method

Drilling was completed by Blue Max Drilling Inc. (Courtenay, BC) with a Boart Longyear LS250 Sonic Track drill rig and support vehicle. Soil core integrity was maintained during drilling by advancing the core barrel and outer casing with clean water from the rig when necessary. Soil cores were extruded into three-meter long clear plastic sample bags for logging.

Monitoring wells were completed using a 4-inch core barrel and a combination of 6-inch and 7-inch casing to install the nested wells. Pumping wells were drilled using a 6-inch core barrel and 9-inch casing.

3.2.4 Logging (Stratigraphy) and Sampling

Soil cores were logged by first establishing the relative proportions of fines, sands, gravels and/or cobbles, followed by descriptions of the colour, angularity, moisture, and consistency in accordance with visual-manual procedures described in ASTM D2488. The naming of soil horizons follows the Unified Soil Classification System (USCS). Selected samples were sieved onsite to assist in soil classification. Borehole logs are provided in Appendix B.

3.2.5 Well Installation Procedure

All monitoring wells were completed with 50 mm (2”) diameter, flush-threaded Schedule 40 PVC pipe using 10-slot screen sections and capped at the base with slit end caps. “Nested” monitoring wells were installed at all three locations (see Table 3-1). The term ‘nested’ refers to wells installed in the same borehole. The suffix “S” and “D” for the nested wells denotes the ‘shallow’ and ‘deep’ well, respectively.

Pumping wells were completed with 150 mm (6”) diameter, flush threaded Schedule 80 PVC pipe using 20-slot screen sections and capped at the base with non-perforated end caps.

Table 3-1 summarizes the well construction details. Washed and bagged 10/20 filter sand was used as a filter pack around the well screen to 0.6 m above the top of the screen. A 1 m bentonite seal was placed above the filter pack using coated bentonite pellets. The steel casing was gradually removed during well installation to prevent caving.

3.2.6 Surface Completion

At surface, the monitoring well PVC was cut to leave a 0.9 m stick-up above ground surface. These wells were protected at surface with a 200 mm diameter steel casing with a lockable lid. The steel casing at all monitoring wells were cemented at surface for additional stability. The PVC of the pumping wells was cut to leave a stick-up between 0.35 m to 0.94 m above ground surface. Large boulders were placed around wells MW18-08S/D, PW18-02, PW18-03, and PW18-04 to protect surface completions.

The name of each well was written on the inside and outside of each casing. Well locations and top-of-PVC (TOPVC) elevations were surveyed after well completion by a NMF surveyor (see Table 3-1). Note that several existing monitoring wells in the vicinity were surveyed as well and TOPVC elevations are inconsistent with earlier surveys. The error appears to be systematic and was accounted for in this study, but all 2018 wells should be resurveyed to verify the TOPVC.

Table 3-1. 2018 Well Installation Details (TOPVC elevations estimated).

Well ID	UTM Location NAD 1983 UTM		Borehole Depth	Screen top	Screen bottom	Screened Stratigraphy	Ground Surface Elevation	PVC Stickup	Top of PVC	Static Water Level (May 2018)	
	Easting	Northing	m bgs	m bgs	m bgs		m (MD)	m ags	m (MD)	m bgs	m (MD)
MW18-06S	311917	5494405	18.29	6.71	9.75	gravel with silt and sand (GW-GM)	3366.49	0.91	3367.40	3.89	3362.60
MW18-06D	311917	5494405	18.29	15.24	18.29	sand with silt and gravel (SW-SM)	3366.45	0.91	3367.36	3.85	3362.60
MW18-07S	311966	5494382	17.07	4.57	7.62	silty gravel with sand (GM)	3364.99	1.09	3366.08	2.85	3362.14
MW18-07D	311966	5494382	17.07	13.56	15.09	silty gravel with sand (GM), gravel with silt and sand (GW-GM)	3365.02	1.10	3366.12	2.87	3362.15
MW18-08S	312002	5494417	18.29	3.05	6.10	clayey gravel with sand (GC), gravel with clay and sand (GW-GC)	3365.14	1.11	3366.25	3.85	3361.29
MW18-08D	312003	5494417	18.29	7.32	10.36	gravel with sand (GW), sand with gravel (SW)	3365.14	1.12	3366.26	3.84	3361.30
PW18-01	312050	5494425	11.28	1.52	10.67	clayey sand with gravel (SC), gravel with sand (GW), gravel (GP), boulders, clayey gravel with sand (GC)	3363.59	0.67	3364.26	2.75	3360.84
PW18-02	312041	5494422	11.28	1.52	10.67	silty gravel with sand (GM), boulders, clayey gravel (GC), gravel (GW and GP)	3363.82	0.94	3364.76	2.97	3360.85
PW18-03	312033	5494418	11.28	1.52	10.67	clayey gravel with sand (GC), gravel with silt and sand (GP-GM and GW-GM), gravel with sand (GW)	3364.04	0.35	3364.39	3.16	3360.88
PW18-04	312025	5494415	11.58	1.52	10.67	sand with gravel (SW), silty sand with gravel (SM), clayey gravel with sand (GC), gravel with silt and sand (GW-GM)	3364.24	0.60	3364.84	3.19	3361.05
PW18-05	311947	5494395	11.28	1.52	10.67	sand (SP), gravel with sand (GP and GW), sand with gravel (SW), boulders	3366.03	0.57	3366.61	4.28	3361.76

Notes:

DTW	depth to water
bgs	below ground surface
MD	mine datum
ags	above ground surface

3.3 WELL DEVELOPMENT AND INITIAL TESTING

3.3.1 Well Development

Monitoring wells were developed by RGC staff to remove residual drill water and fines within the well and in the immediate vicinity of the well screen. Development was completed from May 12th to May 13th, 2018.

Wells were developed by inserting Waterra tubing into the well and pumping water to the surface using a Waterra Hydrolift pump. Visual turbidity and field measurements of pH, electrical conductivity (EC), and total dissolved solids (TDS) were collected during each development. Well development was concluded when the turbidity had decreased substantially, the pH and EC had stabilized, and at least three well volumes had been purged (see Table 3-2).

Flow rates during well development ranged from 0.01 L/s to 0.3 L/s.

Table 3-2. Development Details for 2018 Wells.

Well ID	Date developed	Liters removed	Ideal purge volume, L	Final pH	Final EC, µS/cm	TDS, ppm	Comments
MW18-06S	13-May-18	400	36	5.5	302	178	
MW18-06D	13-May-18	600	81	5.6	178	85	
MW18-07S	12-May-18	60	10	6.5	261	129	initial pH probe unreliable - developed twice, very slow recharge ~1L/min
MW18-07D	12-May-18	480	75	6.5	89	45	initial pH probe unreliable - developed twice
MW18-08S	12-May-18	300	13	5.8	238	119	initial pH probe unreliable - developed twice
MW18-08D	12-May-18	500	40	5.9	239	119	initial pH probe unreliable - developed twice
PW18-01	12-May-18	700	450	6.2	217	95	
PW18-02	12-May-18	400	420	6.1	170	86	pH and EC values from sampling date (5/14/2018)
PW18-03	13-May-18	1,020	390	6.0	173	87	developed for 68 mins - assuming 15 L/min pumping rate
PW18-04	13-May-18	1,300	390	6.1	173	88	developed for 87 mins - assuming 15 L/min pumping rate
PW18-05	13-May-18	6,800	330	5.4	278	139	developed with pump on drill rig - 2.5 L/s pumping rate

Ideal purge volume is three times the well volume
All wells developed using Waterra Hydrolift with tubing unless otherwise specified

3.3.2 Slug Testing

The new MW18 series wells were slug tested to determine the in situ hydraulic conductivity (K) of the screened materials. Falling head (FH) and rising head (RH) slug tests were completed at the three monitoring well locations. Wells were screened in well graded sand and gravel ranging from trace to 20% fines. Slug tests were completed using a 91 cm long slug with a 31.8 mm diameter, which has a theoretical displacement of 34.8 cm in a 2” well casing. Water level recovery was monitored at short time intervals (0.125 or 0.5 seconds) using a Solinst pressure transducer (Levelogger®).

All analytical solutions were fitted to observed data (Appendix C) using the AQTESOLV Pro 4.5 software. Wells that showed overdamped behaviour (MW18-06S and MW18-07S) were analyzed using the Hvorslev (1951) analytical solution for confined conditions. All other wells showed an oscillatory response that is classified as underdamped and is typical for highly conductive formations. These oscillatory responses were analyzed using the McElwee-Zenner (1998) and Springer-Gelhar (1991) solutions.

Estimated K values are provided in Table 3-3.

Table 3-3. Slug Test Results Summary for 2018 Wells.

Well ID	Screen top m bgs	Screen bottom m bgs	Screened Geology	Hydraulic Conductivity, K (m/s)				Analytical Method
				Slug Test			Best Engineering Judgment	
				FH	RH	Average		
MW18-06S	6.71	9.75	gravel with silt and sand (GW-GM)	5.7E-05	2.2E-04	1.4E-04	2.2E-04	Hvorslev (Confined)
MW18-06D	15.24	18.29	sand with silt and gravel (SW-SM)	4.4E-04	7.5E-04	5.9E-04	5.9E-04	McElwee-Zenner
MW18-07S	4.57	7.62	silty gravel with sand (GM)	1.8E-05	7.3E-06	1.2E-05	7.3E-06	Hvorslev (Confined)
MW18-07D	13.56	15.09	silty gravel with sand (GM), gravel with silt and sand (GW-GM)	8.0E-04	6.5E-04	7.3E-04	7.3E-04	Springer-Gelhar
MW18-08S	3.05	6.10	clayey gravel with sand (GC), gravel with clay and sand (GW-GC)	3.5E-03	1.7E-03	2.6E-03	2.6E-03	Springer-Gelhar
MW18-08D	7.32	10.36	gravel with sand (GW), sand with gravel (SW)	7.8E-04	1.8E-03	1.3E-03	1.3E-03	Springer-Gelhar

Notes:

FH	Falling head slug test
RH	Rising head slug test

3.4 INITIAL GROUNDWATER MONITORING

3.4.1 *Groundwater Levels and Inferred Flow Field*

A synoptic survey of groundwater levels in the Lynx reach was completed by NMF staff on June 5th, 2018. Figure 3-2 shows the observed groundwater levels and inferred groundwater flow field in the shallow portion of the aquifer.

In general proximity of the Duck Pond and the car bridge, groundwater in the shallow MVA flows in a northeasterly direction towards the (actively pumped) PW14-01 and PW14-04 recovery wells. The average hydraulic gradient in this area was about 0.01 m/m. The geodetic groundwater levels in the shallow and deep piezometers showed very little difference (< 3 cm) suggesting insignificant vertical hydraulic gradients within the upper 18m of the MVA.

3.4.2 *Groundwater Quality*

All MW18 and PW18 well series were sampled for water quality after sufficient development. The initial round of sampling was conducted by RGC staff using a Waterra Hydrolift pump. Field measurements of pH, EC, and temperature were collected with a calibrated Hanna HI98129 Combo tester. Groundwater samples were field filtered and preserved in the onsite laboratory before being shipped to Maxxam Analytics in Burnaby, BC.

Groundwater results are summarized in Table 3-4. A charge balance analysis and comparison of duplicate samples indicated that the data are reliable and can be interpreted with confidence.

Figure 3-3 shows the field parameters and dissolved zinc concentrations observed in the various new wells during this initial round of groundwater quality sampling. In general, groundwater in the new MW18 and PW18 wells is slightly acidic (field pH ranging from 5.2 to 6.1) and showed moderately elevated zinc concentrations, ranging from 0.5 to 2.5 mg/L. In all three nested monitoring wells, the shallow piezometers generally showed higher zinc concentrations than the deeper piezometer suggesting a surface source (e.g. recharge from local PAG waste rock and/or leakage from the Duck Pond.

Table 3-4. Initial Groundwater Quality Results for 2018 Wells.

Well ID	Date Sampled	Field Data		Laboratory Data & Dissolved Metals					
		pH,	EC[1], µS/cm	pH,	EC[2], µS/cm	SO_4, mg/L	Cd, mg/L	Cu, mg/L	Zn, mg/L
MW18-06S	5/14/2018 9:25	5.2	356	6.4	340	138	0.00803	0.0118	2.39
MW18-06D	5/14/2018 9:40	5.3	242	6.7	224	84	0.00338	0.00118	1.28
MW18-07S	5/14/2018 10:20	6.8	145	7.4	344	111	0.00766	0.00875	2.83
MW18-07D	5/13/2018 16:35	5.5	172	7.2	132	27	0.00476	0.00194	1.30
MW18-08S	5/13/2018 15:45	5.7	248	6.8	282	108	0.00421	0.00136	2.45
MW18-08D	5/13/2018 15:28	5.8	245	7.0	279	99	0.00332	0.00178	1.84
PW18-01	5/14/2018 16:30	6.0	192	7.0	222	71	0.00272	0.00265	0.904
PW18-02	5/14/2018 16:15	6.1	170	7.0	191	56	0.00123	0.00133	0.501
PW18-03	5/14/2018 15:43	6.0	173	7.0	200	58	0.00113	0.0000940	0.845
PW18-04	5/14/2018 14:25	6.1	173	7.0	197	59	0.00119	0.000229	0.902
PW18-05	5/14/2018 9:15	5.4	278	7.0	305	108	0.00326	0.00404	1.32

Notes:

[1] Electrical Conductivity (µS/cm) at field temperature

[2] Electrical Conductivity (µS/cm) at laboratory temperature

Metal and sulfate results reported as dissolved concentrations

Dissolved cadmium and copper concentrations were only slightly elevated (typically < 0.005 mg/L) in all MW18 and PW18 wells.

Note that none of the new MW18 and PW18 wells intercepted the strongly acidic seepage with highly elevated cadmium and copper concentrations observed earlier in the year discharging to Myra Creek immediately downgradient of the car bridge (see RGC, 2018). The lack of highly impacted groundwater in the new MW18 and PW18 wells during this initial survey might be a result of removal of the source of acidic seepage, either due to changes in surface water management (i.e. no storage of acidic runoff in Duck Pond) and/or generally drier flow conditions reducing generation of acidic runoff from local PAG waste rock. Additional water quality monitoring in the new wells during high flow conditions will be required to confirm seasonal water quality trends in the shallow portion of the MVA in the Lynx reach.

4 HYDRAULIC TESTING OF INTERIM PHASE II LYNX SIS

4.1 INITIAL TESTING OF PW18-02

A 5-day constant rate pumping test was completed at PW18-02 from May 16 to May 21, 2018. An air operated double diaphragm 3” Wilden Pump with a suction hose was used to pump from PW18-02 at a rate of 4 L/s. Drawdown in all pumping wells and surrounding monitoring wells was monitored routinely.

A final drawdown of 0.71 m at PW18-02 was observed after 6 days of pumping. Adjacent wells PW18-01, PW18-03, and MW16-04 showed drawdowns of 0.54 m, 0.53 m, and 0.53 m, respectively, indicating only little well losses in the pumping well (PW18-02).

This initial pumping test suggests that the shallow pumping wells are relatively productive (~5.7 L/s per meter of drawdown). Note, however, that drill logs and air lift testing suggested limited well yield from the upper 5-6 m of sediments typically comprised of colluvium with variable fines content (10-25%).

During this initial test of PW18-02, field pH and EC were collected routinely (see Table 4-1) and groundwater quality samples were taken after 2, 4, and 5 days of pumping. Field pH had stabilized at around 5.5 at the end of the pumping test which is similar to field pH observed in surrounding monitoring wells.

Table 4-1. Field Parameters for PW18-02 Pumping Test.

Date/Time	Field Parameters			Notes
	pH	EC, µS/cm	Temp ° C	
5/15/18 14:53	5.70	167	7.7	Pump On 14:32
5/15/18 14:59	6.17	157	8.8	
5/15/18 16:30	6.11	159	7.1	Pump Off 16:32
5/16/18 9:41	7.55	155	7.3	Pump On 9:05
5/16/18 13:10	5.77	165	8	
5/16/18 16:55	5.55	206	6.7	
5/17/18 9:54	5.54	216	6.9	
5/21/18 9:54	5.54	180	7.7	Pump Off 11:25

With ongoing pumping, Zn concentrations at PW18-02 stabilized at around 1.8 mg/L with pH values determined by the laboratory of around 7.2. Note that a total of 1,730 m^3 of groundwater was pumped, which was likely almost entirely derived from aquifer storage assuming an aquifer porosity of 0.25. Zinc concentrations only increased slightly from initial parameters and remained very stable throughout pumping, further suggesting that pumped groundwater was derived from aquifer storage with only little or no dilution by leakage from Myra Creek.

Table 4-2. Water Quality at PW18-02 during initial Testing.

Sample ID	***Sample Date***	**Dissolved Sulphate (SO_4) [mg/L]**	**Conductivity [uS/cm]**	**pH [pH]**	**Dissolved Cadmium (Cd) [mg/L]**	**Dissolved Copper (Cu) [mg/L]**	**Dissolved Zinc (Zn) [mg/L]**
PW18-02 Initial Test	5/14/2018	56.4	191	6.98	0.00123	0.00502	0.501
	5/18/2018	69.3	203	6.77	0.00515	0.178	1.84
	5/20/2018	68.9	200	6.69	0.00555	0.18	1.89
	5/20/2018	68.4	200	6.7	0.00559	0.176	1.86
	5/21/2018	63.2	198	6.86	0.00523	0.185	1.84

Three days before start of testing (May 12), acidic seepage (pH 4.5) was observed to discharge at a rate of around 1 L/min just above the creek stage at the MW13-19 Seep location. No further acidic seepage was observed after start of initial testing at PW18-02. This suggests that pumping of PW18-02 effectively reversed hydraulic gradients to prevent discharge to the creek locally. Furthermore, field pH in surrounding shallow monitoring wells indicated non-acidic groundwater conditions due to removal of the potential source (leakage from Duck Pond and ditches) and/or drying up of the shallow groundwater system that generally conveys the more contaminated groundwater.

A total of around 1,730 m^3 were pumped from PW18-02 over 5 days. The total Zn load removed from groundwater was estimated to be 3.2 kg. Estimates of removed loads for other contaminants are presented in Table 4-3.

Table 4-3. Contaminant Loads captured during Initial Testing of PW18-02.

Sample ID	**Time Pumped [days]**	**Avg Pumping Rate [L/s]**	**Volume Removed [m^3]**	**Dissolved Sulphate (SO_4) [kg]**	**Dissolved Cadmium (Cd) [kg]**	**Dissolved Copper (Cu) [kg]**	**Dissolved Zinc (Zn) [kg]**
PW18-02	5	4.0	1,728	117.4	0.01	0.31	3.2

4.2 INITIAL OPERATION OF INTERIM PHASE II LYNX SIS

4.2.1 Setup

The interim Phase II Lynx SIS was operated for 29 days from June 5 to July 4, 2018 and consisted of a vacuum pump system provided by Canadian Dewatering. Drop tubes were installed in PW18-01 to -04 and connected to a central vacuum pump. Extracted groundwater was directed into the 25 Sump and from there pumped to the Super Pond. On June 8th, 2018, the discharge line was moved and groundwater discharged directly into the Super Pond. Pumping rates for all PW18 wells combined were determined from routine totalizer readings.

Water levels in surrounding monitoring wells were measured routinely and Leveloggers installed in PW18-02, MW11-04, MW13-19, MW16-04, MW16-05, and MW-G to record water levels in 15-minute intervals. Zn surveys of Myra Creek consisting of water quality samples in 50 m intervals were completed on June 5 just before turning on the pumping system and on July 3 one day before ending the interim operation of the PW18 wells.

4.2.2 Water Levels and Inferred Flow Field

The system was operated at maximum capacity with an average pumping rate of around 11 L/s combined.

Figure 4-1 shows time trends of groundwater levels recorded at PW18-02, MW13-19, MW11-04, and MW16-04 as well as the creek stage recorded at the car bridge. All wells monitored clearly respond to pumping at the PW18 wells suggesting that the aquifer is hydraulically well connected in this area. Note that at MW13-19, which is located in close proximity to PW18-02 but screened in the deeper glaciofluvial aquifer, the observed drawdown is only around 0.2 m. This suggests that the deeper Myra Valley Aquifer (glaciofluvial) is not well connected to the shallow glaciofluvial sediments.

On June 8, groundwater and creek levels responded to rainfall (~60 mm over 2 days) and increased by around 0.4 m at the pumping and monitoring wells (see Figure 4-1). However, groundwater levels remained below creek levels indicating no discharge to the creek. Note that the system had to be shut down for 1.5 hours around noon on June 8th to prevent the 25 Sump from overflowing and potentially discharging to Myra Creek. This is evident from a sudden recovery in groundwater levels in and near the pumping wells. The additional recovery in water levels at greater distance (MW11-04), however, is only around 0.1 m. During the shut-off period, groundwater levels remained below the creek stage suggesting no groundwater discharge to Myra Creek.

Figure 4-2 shows the inferred drawdown in the pumping wells and nearby monitoring wells in response to pumping of the four PW18 wells. Observed drawdown in the PW18 wells ranged from 1.2 to 1.4 m. Monitoring wells MW16-04 and 16-05, located in close proximity (<15 m) to the pumping well fence and screened in shallow colluvium (< 5m depth) showed a drawdown of 1.07 m and 0.65 m, respectively. A drawdown of 0.33 m was observed in the shallow monitoring well MW11-04 located at about 25 m distance towards the Super Pond. At MW18-08 the shallow and deep piezometers responded equally to pumping, indicating that the shallow colluvium and underlying sallow glaciofluvial sediments are well connected at this location.

Figure 4-3 shows the inferred groundwater flow field and capture zones on June 29, 2018. Both, the PW14 and PW18 wells were operating at this time. Groundwater flow is generally down-valley with lateral inflow from the sidehills. Due to operation of the Phase I SIS (PW14 wells) groundwater flow is converging towards the valley center where it is partly captured by the pumping wells. The PW14 wells capture groundwater originating from the Mill and ETA/Cook House areas as well as the Lynx TDF/Berm and Super Pond area.

In the Lynx area, around the car bridge, groundwater generally follows the valley center, i.e. parallel to Myra Creek suggesting none or only minimal discharge to Myra Creek. Operation of the Phase II SIS (PW18 wells) results in a localized cone of depression downstream of the car bridge and capture of groundwater originating from the Duck Pond Area.

4.2.3 Groundwater Quality and Captured Loads

Water quality samples were collected routinely from a common discharge pipe and hence represent an aggregate sample from the four pumping wells PW18-01, 02, 03, and 04. Table 4-4 summarizes water quality results obtained during the 29 days of operating the interim Phase II Lynx SIS. Initial concentrations of sulphate and zinc after 1 day of operating the system are 65.2 mg/L SO_4 and 0.941 mg/L Zn, respectively. This is thought to be representative of moderately impacted groundwater within the area upstream of the car bridge (e.g. BK01-13S/D). Note that acidic runoff which was previously stored in the Duck Pond and conveyed to the 25 Sump via an unlined ditch was removed in early May 2018 eliminating this potential source of acidic seepage to Myra Creek.

With ongoing pumping, Zn and SO_4 concentrations decreased by ~50% suggesting some dilution by Myra Creek water and/or less impacted groundwater (e.g. from south of Myra Creek) due to pumping. Future monitoring of water quality in this area will be required to better understand the cause for this dilution and potential seasonal changes in local groundwater quality.

Note that during the rainfall event on June 8, acidic water (field pH 3.5 and field EC 600 µS/cm) was observed pooling upstream and downstream of the Duck Pond. Runoff that had pooled in the Duck Pond showed a pH of 4.9 and a conductivity of 300 µS/cm.

Table 4-4. Groundwater Quality Results for Initial Operation of Interim Phase II Lynx SIS.

Sample Date	**Dissolved Sulphate (SO_4)** **[mg/L]**	**Conductivity** **[uS/cm]**	**pH** **[pH]**	**Dissolved Cadmium (Cd)** **[mg/L]**	**Dissolved Copper (Cu)** **[mg/L]**	**Dissolved Zinc (Zn)** **[mg/L]**
6/5/2018	65.2	184	7.02	0.00171	0.0122	0.941
6/8/2018	44.5	165	7.24	0.0018	0.0335	0.844
6/11/2018	40.8	142	7.19	0.00148	0.0332	0.7
6/18/2018	37.8	136	7.19	0.00126	0.0284	0.616
6/24/2018	32.4	132	7.21	0.00128	0.0271	0.595
7/3/2018	31.7	124	7.03	0.000952	0.0187	0.474

Table 4-5 summarizes the performance of the interim Phase II Lynx SIS. Over the 29 days of operation, a total of 27,500 m^3 of groundwater was removed by the PW18 wells resulting in a total captured Zn load of 16.4 kg. Loads of cadmium and copper captured by the interim Phase II SIS were 1-3 orders of magnitude lower than zinc loads.

Table 4-5. Summary of Interim Phase II Lynx SIS Performance.

Sample ID	**Time Pumped** **[days]**	**Avg Pumping Rate** **[L/s]**	**Volume Removed** **[m^3]**	**Dissolved Sulphate (SO_4)** **[kg]**	**Dissolved Cadmium (Cd)** **[kg]**	**Dissolved Copper (Cu)** **[kg]**	**Dissolved Zinc (Zn)** **[kg]**
PW18-All	29	11.0	27,562	980.7	0.03	0.71	16.4

Table 4-6 compares contaminant loads removed by the Phase I (PW14) and Phase II (PW18) Lynx SIS wells to observed zinc loads from groundwater to Myra Creek within the Lynx Reach (RGC, 2016). The Phase I Lynx SIS wells recover highly impacted groundwater originating from the Mill Area, Lynx TDF, and beneath the Super Pond at a combined rate of 80.7 kg/d Zn (in June 2018). This compares to a load of 0.57 kg/d Zn captured by the PW18 wells. In other words, the Interim Phase II SIS captured less than 1% of the zinc load that was removed by the PW14 wells. This is due to the low concentrations of zinc (and other metals) observed in that part of the aquifer during low flow conditions.

Table 4-6. Comparison of Contaminant Loads intercepted by Phase I and Interim Phase II Lynx SIS.

Station	Dissolved Sulphate (SO4) [kg/d]	Dissolved Cadmium (Cd) [kg/d]	Dissolved Copper (Cu) [kg/d]	Dissolved Zinc (Zn) [kg/d]
PW14-01	755.76	0.05	0.59	32.73
PW14-03	258.9	0.024	1.04	18.1
PW14-04	941.9	0.077	2.48	29.9
Sum PW14	**1956.6**	**0.153**	**4.10**	**80.7**
PW18-ALL	**33.8**	**0.001**	**0.02**	**0.57**
Discharge from Groundwater to Myra Creek in Lynx Reach (2016 Load Balance Model)				
High Flow	NA	NA	NA	34.5
Low Flow	NA	NA	NA	4.8
Average	NA	NA	NA	**15.4**
Discharge from Groundwater to Myra Creek in Upper Old TDF Reach (2016 Load Balance Model)				
High Flow	NA	NA	NA	22.3
Low Flow	NA	NA	NA	9.8
Average	NA	NA	NA	**12.6**

Zinc surveys are routinely completed in Myra Creek consisting of collecting water quality samples at 50 m intervals. These longitudinal surveys suggest that within the Lynx Reach, Myra Creek receives on average around 4.8 kg/d of Zn from groundwater during low flow conditions. The zinc load captured by the PW18 wells during the June trial (0.57 kg/d) represented about 10% of the total Zn load from groundwater to Myra Creek in the Lynx reach.

Zn survey results from June 5th (before pumping) and July 3rd, 2018 are shown in Figures 4-4 and 4-5 respectively. On June 5th, the Shack Seeps were discharging at very low flow rates (~ 1 liter per minute) and field conductivity was elevated between the MW13-19 and Pipe Bridge Seeps locations. Zinc concentrations of the Shack Seeps were ~ 2 mg/L and non-acidic.

The creek survey completed on July 3rd also includes four additional samples collected between the car bridge and Arnica Creek (upstream end of mine site). Note that zinc concentrations are low and Myra Creek considered unimpacted up to chainage MC-200 where the zinc concentration increases by one order of magnitude to 0.00419 mg/L. Zinc concentrations remain constant within the Lynx

Reach and only start increasing within the Upper Old TDF Reach. Zinc concentrations of samples collected at the known seep locations are not elevated. Final zinc concentration at the downstream end of the site (MC-TP4) was observed at 0.029 mg/L.

Relatively low zinc concentrations within the Lynx Reach have been observed at previous surveys during low flow conditions. However, the additional (upstream) samples suggest that the loading from groundwater to Myra Creek observed in the Lynx Reach had mostly entered the creek upstream of the car bridge. This suggests that the interim Phase II Lynx SIS effectively prevented discharge to the creek in the area downstream of the car bridge and/or groundwater quality in the area had generally improved due to (i) operation of the interim Phase II SIS and/or (ii) general (seasonal) decline in groundwater discharge in the area due to drier conditions.

5 NUMERICAL ASSESSMENT OF PHASE II LYNX SIS

5.1 MODELING OBJECTIVES AND SCOPE

The specific objectives of the groundwater modeling presented in this section are as follows:

- Determine capture efficiency of the interim Phase II Lynx SIS (pumping from the recently installed PW18 wells) during high flow and receding flow conditions.
- Evaluate capture efficiency of various drain layouts and determine drain flow rates.
- Evaluate capture efficiency and pumping rates of high-capacity pumping wells within the car bridge area.

To achieve these objectives, a numerical groundwater flow model was constructed, and the following tasks completed:

- Calibration of a groundwater flow model for the Lynx Reach to low and high flow conditions to obtain aquifer parameters and boundary conditions.
- Model validation and refinement of calibration (if necessary) with data collected during operation of the interim Phase II Lynx SIS.
- Simulation of operation of interim Phase II Lynx SIS during high flow and receding conditions with calibrated flow model.
- Simulation of operating various shallow drain and pumping well scenarios in high flow and receding conditions using calibrated flow model.

5.2 MODEL PARAMETERS AND NUMERICAL METHODS

A 3D numerical groundwater flow model was developed using the software FEFLOW (Diersch, 2014). FEFLOW is based on the finite element method, has been verified with various benchmark problems, and is widely accepted within the mining industry.

Horizontally, the model domain extends from Arnica Creek in the Mill and ETA/Cook House Areas to the Upper OLD TDF at chainage MC 0+250. At the sidehills, the model domain extends to an elevation of around 3,400 m MD.

The numerical groundwater flow model is spatially discretized using a total of 1,294,510 elements (741,632 nodes). The mesh is locally refined around areas with high contrasts in hydraulic conductivity, steep hydraulic gradients and well boundary conditions. Vertically the model is discretized in 7 layers (8 slices) and extends from the current surface (most recent DEM received from Nyrstar) to the inferred bedrock surface.

Hydrostratigraphic units and their respective initial hydraulic parameters are summarized in Table 5-1. Initial hydraulic conductivities (K) used for the glaciofluvial sediments were inferred from hydraulic testing of the PW14 wells (RGC, 2014). The initial K used for colluvium and fill was inferred from various slug tests performed in monitoring wells screened within the shallow colluvium and fill. The hydraulic conductivity of the underlying bedrock is thought to be orders of magnitude lower. Therefore, groundwater flow within the upper bedrock is considered low and was not simulated here. Further, hydraulic conductivity of the respective hydrostratigraphic units is considered to be homogeneous and isotropic. In other words, flow in the aquifer is highly idealized and local heterogeneities are not resolved.

Table 5-1. Initial Hydraulic Conductivity for Lynx Groundwater Flow Model.

Hydrostratigraphic Unit	Layer	Initial Hydraulic Conductivity [m/s]		
		Upstream (PW14-03)	Middle Reach (PW14-01)	Downstream Reach (PW14-04)
Infrastructure/ Colluvium/Fill	1	5.0E-05	5.0E-05	5.0E-05
Colluvium/Fill	2	5.0E-05	5.0E-05	5.0E-05
Glaciofluvial Sediments (Myra Valley Aquifer)	2 to 6	3.6E-04	4.0E-04	3.7E-04
Silty Glaciofluvial Sediments (Myra Valley Aquifer)	7	1.0E-06	1.0E-06	1.0E-06

Layer 1 represents infrastructure such as tailings and berms. Where no infrastructure is present, layer 1 denotes colluvial soil or fill. Layer 2 contains the colluvial deposits and fill material present in the Lynx Area. Layer 3 to 6 represent the permeable glaciofluvial sediments of the Myra Valley Aquifer (MVA) where the majority of groundwater flow is inferred to occur. The bottom layer (layer 7) contains the lower portion of the glaciofluvial aquifer which exhibits a higher fines content and hence lower permeability.

Groundwater recharge from precipitation over the model domain is directly applied to the uppermost slice of the model in form of a flux boundary condition. Lateral groundwater inflow from the sidehills was included using flux boundary conditions with flow rates obtained from earlier watershed modelling (RGC, 2016). The upstream and downstream boundaries are defined by constant head boundary conditions meaning that groundwater levels are fixed at these locations.

Groundwater abstraction by the Phase I (PW14) pumping wells is simulated using well boundary conditions at the respective nodes. For the PW18 wells, multilayer well boundary conditions were used to allow groundwater abstraction from the various numerical model layers and hydrostratigraphic units intercepted by the well screen.

All simulations were carried out assuming steady-state conditions.

5.3 MODEL CALIBRATION, VALIDATION, AND SENSITIVITY ANALYSIS

The model was calibrated against groundwater levels observed during synoptic water level surveys completed for various flow conditions. During model calibration, aquifer parameters and boundary conditions were changed systematically, and the goodness-of-fit compared visually and with calibration statistics. The model calibration and validation sequence were as follows:

- Calibration of groundwater model against winter low flow conditions: Two datasets (pumping and non-pumping of PW14 wells) were available allowing for strong calibration of hydraulic parameters within the radius of influence of the pumped wells (majority of Lynx Reach).
- Calibration against high flow conditions: Hydraulic conductivities of the hydrostratigraphic units obtained from low flow model calibration were not changed during this part of the calibration. Groundwater recharge and lateral groundwater inflow from the side hills were increased to reflect the significant increase in rainfall observed during periods of high flow. Further, the hydraulic head boundary conditions at the upstream and downstream boundaries of the model domain were increased to reflect the overall elevated groundwater levels observed.
- Model validation: Interim operation of the PW18 wells in June 2018 was simulated to test the predictive capabilities of the calibrated groundwater model and to locally refine calibration if required.

Synoptic groundwater level surveys during the following flow conditions were used for model calibration and validation:

- High Flow (Nov 19, 2017): Daily precipitation values of 70 and 87 mm were recorded on the two days preceding the survey and sustained rainfall up to 50 mm/d occurred during the preceding week. At the time of the groundwater level survey, all three SIS wells were operational and pumping ~75 L/s combined.
- Low Flow (Mar 30, 2018): No major rain events were recorded in the 2 months preceding the survey and the maximum daily precipitation was recorded at 18.1 mm within that period. All three SIS pumping wells had been operating consistently for the five weeks preceding the survey and were capturing a combined average of 46.5 L/s on March 30th.
- Low Flow Non-Pumping (Apr 5, 2018): This winter low flow survey took place after a period of five days of not operating the SIS wells.
- Low Flow & Interim Operation of Phase II Lynx SIS (June 2018): Routine observations of groundwater levels within the Lynx Reach during operation of the PW18 SIS wells were used to determine maximum drawdown values.

Figure 5-1 shows the simulated groundwater flow field in the Myra Valley Aquifer for low flow conditions with no pumping. A scatter plot of simulated versus observed groundwater levels is shown in Figure 5-2. The 1:1 regression line (for ideal calibration) is also shown for reference. Overall, the simulated groundwater levels agree well with observed levels and the normalized root mean squared error (NRMSE) of 5% is considered acceptable for the purpose of this study. When simulating operation of the PW14 wells, equally good calibration statistics were achieved. The model slightly under-predicts drawdown in the immediate vicinity of the PW14 wells. Simulated drawdown at more distant wells, however, agrees well with observed values. Calibrated aquifer parameters are summarized in Table 5-2.

Table 5-2. Calibrated Hydraulic Conductivity for Lynx Groundwater Flow Model.

Hydrostratigraphic Unit	**Layer**	**Calibrated Hydraulic Conductivity [m/s]**		
		Upstream (PW14-03)	**Middle Reach (PW14-01)**	**Downstream Reach (PW14-04)**
Infrastructure/ Colluvium/Fill	1	5.0E-05	5.0E-05	5.0E-05
Colluvium/Fill	2	5.0E-05	5.0E-05	5.0E-05
Glaciofluvial Sediments (Myra Valley Aquifer)	2 to 6	1.0E-04	4.7E-04	5.6E-04
Silty Glaciofluvial Sediments (Myra Valley Aquifer)	7	1.0E-06	1.0E-06	1.0E-06

Drawdown observed in the area downstream of the car bridge due to operation of the four PW18 wells (in June 2018) was used for model validation. A scatter plot of simulated versus observed drawdown in the PW18 wells and surrounding monitoring wells is shown in Figure 5-3. The model under-predicts drawdown within the PW18 wells which can be attributed to well losses which are not simulated with the numerical model.

Sensitivity analyses demonstrated that equivalent good calibration statistics can be achieved by increasing and decreasing the hydraulic conductivity of the colluvium within the radius of influence of the PW18 wells to $5x10^{-4}$ and $1x10^{-5}$ m/s respectively (not shown here). Furthermore, a threefold increase in K of the glaciofluvial sediments underlying the area immediately downstream of the car bridge also yielded similarly good calibration statistics (not shown here). This uncertainty in K of the colluvium/fill and glaciofluvial sediments is carried forward to all predictive simulations. Table 5-3 summarizes the hydraulic parameter sets used in this study.

Table 5-3. Hydraulic Conductivity for Lynx Groundwater Flow Model used for Sensitivity Analyses.

Sensitivity Scenario	Hydraulic Conductivity [m/s]		
	Local Colluvium/Fill	Middle (PW14-01)	Downstream (PW14-04)
Base Case	5.0E-05	4.7E-04	5.6E-04
K Colluvium 5E-4 m/s	5.0E-04	4.7E-04	5.6E-04
K Colluvium 1E-5 m/s	1.0E-05	4.7E-04	5.6E-04
GF *3	5.0E-05	1.5E-03	1.5E-03
GF /3	5.0E-05	1.7E-04	1.7E-04

Backward particle tracking simulations were performed to determine the origin of the groundwater expressing as seepage downstream of the car bridge. Particles were released at known seep locations along Myra Creek and the model computes the trajectory to the particle starting location (backwards). Figure 5-4 shows the simulated flow field and computed particle trajectories for receding flow conditions with and without pumping the Phase I (PW14) wells. During receding flow conditions with pumping the PW14 wells, the model suggests that the groundwater expressing at the seep locations originates from the Duck Pond/ETA area. This agrees well with our conceptual understanding of groundwater flow within the area and groundwater quality observations. Water quality of the acidic seepage observed along the creek bank in early 2018 was similar to acidic runoff collected in the Duck Pond and transmitted to the 25 Sump via unlined ditches. If the PW14 wells are not pumping, backwards particle tracking indicates that groundwater seepage to the creek originates from the ETA area, closer to the Super Pond.

Note that groundwater within the ETA area is moderately impacted by remnant, uncovered tailings and PAG rock. Groundwater quality samples routinely contain around 2 mg/L of zinc (BK13-01S), which is thought to be representative of the aquifer underlying the ETA. This water quality is similar to groundwater and seep water concentrations observed downstream of the car bridge after acidic runoff stored in the Duck Pond and associated ditches was removed.

Note also that NMF is planning to remove any remaining PAG waste rock/tailings in the ETA/Cookhouse area as part of closure works. This could potentially remove the source of elevated metal concentrations currently observed in surface runoff and shallow groundwater in the ETA/Cookhouse area and seepage discharging near the car bridge.

5.4 PREDICTIVE SIMULATIONS FOR PHASE II LYNX SIS

The calibrated flow model for the Lynx area was used to assess the performance of alternative designs of the Phase II Lynx SIS. This numerical assessment focused on winter high flow conditions when groundwater levels are higher (by up to 3 m) and seepage to Myra Creek is most prevalent.

5.4.1 Phase II Lynx SIS Scenarios

A total of five different SIS designs were evaluated to intercept shallow seepage in the Lynx area downstream of the car bridge (see Table 5-4 and Figure 5-5).

The first SIS design option (Scenario 0) represents the existing interim Phase II SIS comprised of the recently installed four shallow pumping wells (PW18-01 to PW18-04). Note that this scenario is limited to a maximum pumping rate of 6 L/s per well (due to the diameter of the pumping wells (6” PVC)), or a combined total of 24 L/s. Although initial testing has demonstrated that this option can control seepage during low flow conditions (June 2018, see section 4), this option may not have adequate pumping capacity to prevent seepage discharging to Myra Creek during high flow conditions.

Table 5-4. Design Options for Phase II Lynx SIS.

Scenario	Seepage Interception Option
0	Operation of PW18 Wells
1	Shallow Rock Drain along PW18 Alignment
2	Replacement of PW18 Wells with 2 High-Capacity Wells
3	Shallow Rock Drain along Northeast Alignment
4	2 High-Capacity Pumping Wells along Northeast Alignment

The second SIS design option (Scenario 1) assumes the use of a shallow drain (approximately 5 m deep) along the same alignment as the PW18 wells (immediately south of access road, see Figure 5-5). There is no limit to the pumping rate from this drain because a large diameter sump with appropriately sized sump pump would be used to maintain the required target pumping level in the drain. This option is aligned right along Myra Creek at the known seep locations and hence also provides full capture of any perched seepage or surface water runoff which is not simulated.

The third SIS design option (Scenario 2) assumes the use of two high capacity pumping wells (up to 30 L/s per well for a combined total of up to 60 L/s) along the same alignment as Scenario 0. The two high capacity wells would be approximately 10 m deep and spaced approximately 18 m apart.

The remaining two SIS design options (Scenarios 3 and 4) assume a more northeasterly alignment (see Figure 5-5). This alignment is more perpendicular to the regional flow field resulting in reduced pumping or drain flow rates. Furthermore, this alignment is generally more distant from Myra Creek potentially reducing inflow to the SIS (and dilution) from Myra Creek.

Scenario 3 assumes the use of a shallow drain (again approximately 5 m deep) while Scenario 4 assumes the use of two high capacity wells (approximately 10 m deep and spaced 18 m apart).

5.4.2 Flow Conditions Evaluated

Performance of the various seepage interception scenarios was evaluated for three flow conditions as follows:

- **High Flow:** Representative of groundwater conditions following periods of sustained heavy precipitation and extreme rainfall events (>80 mm in 24 hrs). Groundwater levels are elevated by up to 3 m compared to low flow conditions while creek levels increase by around 2 m.
- **Receding Flow:** Following periods of heavy sustained precipitation, creek levels usually recede within days while groundwater levels remain elevated for weeks. During this period hydraulic gradients towards the creek are greatest resulting in increased groundwater discharge to Myra Creek.
- **Receding Flow and PW14 Off:** This flow condition assumes that the Phase I SIS wells (PW14) are not being operated during receding flow conditions. As a result, hydraulic gradients are the highest and groundwater flow to Myra Creek downstream of the car bridge is at a maximum. This scenario represents worst-case conditions that only occur for short periods of time if there is insufficient storage capacity in the Super Pond and/or power supply.

5.4.3 Results

The simulated pumping level in the aquifer (in proximity of the drain or pumping wells) and predicted pumping rates for the various SIS options for high flow, receding flow (w/ pumping PW14) and receding flow (w/o pumping PW14) are summarized in Tables 5-5 to 5-7. The simulated flow field and capture zone (using particle tracking) for the five SIS scenarios for high flow conditions is shown in Figure 5-6. The simulated flow field and captures zones for receding flow conditions with and without PW14 operation are shown in Figures 5-7 and 5-8.

The results of the design modeling can be summarized as follows:

- The model predicts that all five scenarios evaluated will be able to intercept the shallow groundwater in the colluvium and uppermost glaciofluvial sediments for high flow and receding flow conditions, and thus prevent discharge of impacted groundwater originating from the Duck pond area to Myra Creek.
- The model predicts that the interim Phase II Lynx SIS (PW14 wells operated by a suction pump with a maximum pump capacity of 11 L/s) is not able to maintain hydraulic control. i.e. reverse hydraulic gradients, for receding flow conditions.
- The limited maximum pumping capacity of the PW-18 wells (24 L/s combined) may still not be adequate to reverse the hydraulic gradient during high flow and receding flow conditions. However, particle tracking suggests that the interim Phase II SIS is still capturing all of the impacted shallow groundwater from the Duck Pond area, except for the single case of high K in glaciofluvial sediments and receding flow conditions w/o pumping PW14 wells.
- The shallow drain along the PW18 alignment (Scenario 1) is slightly more efficient in producing the required drawdown than the interim solution using PW18 wells (Scenario 0). For example, the drain is predicted to extract 17.7 L/s under high flow conditions (to achieve a pumping level of 3360 m MD) while the four PW18 wells are predicted to require pumping 24 L/s to achieve the same drawdown. Note that the actual pumping rate required in a shallow drain may be even lower, if the lower K colluvium extends deeper than assumed in the flow model.
- The northeasterly alignment for the Phase II SIS is generally slightly more efficient, both for the case of drains (Scenario 3) and pumping wells (Scenario 4), than the PW18 alignment (Scenarios 0 to 2). For example, the drain for Scenario 4 is predicted to extract 16.3 L/s under high flow conditions (to achieve a pumping level of 3360 m MD) compared to 18.7 L/s for Scenario 1. Note that the northeasterly alignment is also about 10 m shorter resulting in reduced construction costs (in the case of a drain).
- For all SIS options evaluated, the groundwater flow captured in a given SIS (drain or fence of pumping wells) generally increases with increased drawdown (lower geodetic pumping level). However, the capture zone does not increase significantly with increased drawdown in the SIS. For the high flow and receding flow conditions evaluated here, maintaining a pumping level in the aquifer at (or slightly below) the creek level appears to be adequate to prevent discharge of groundwater to Myra Creek.
- The predicted flow from Myra Creek towards the Phase II Lynx SIS is a function of two factors: (i) the hydraulic gradient between the creek level and the pumping level in the

drain/pumping wells and (ii) the hydraulic conductivity in the colluvium. For the base case estimate of $K_{colluvium} = 5x10^{-5}$ m/s, leakage from Myra Creek is less than 2 L/s, provided the pumping level in the SIS is kept within 1 m below the creek. However, leakage rates from Myra Creek to the SIS may increase to as high as 10-15 L/s, assuming a $K_{colluvium} = 5x10^{-4}$ m/s. Note that leakage from Myra Creek to the SIS could be effectively reduced to negligible flows, even for high K in colluvium, by setting the pumping level in the SIS equal to the creek level.

- The Phase II SIS performance is relatively robust to the uncertainty in the hydraulic conductivity of the aquifer materials (colluvium and glaciofluvial sediments). A higher K generally produces higher inflow rates but seepage capture is still maintained (except potentially for the interim solution (Scenario 0, see above)).

Table 5-5. Simulated Drain Flow and Pumping Rates for High Flow Conditions (Myra Creek Stage at Car Bridge 3361 m MD).

Local Hydraulic Conductivity [m/s]		Pumping Level [m MD]	Drain Flow/ Pumping Rate [L/s]	Flow from Myra Creek [L/s]	Full Hydraulic Control
Colluvium	Glaciofluvial				
Scenario 0: Interim Operation of PW18 Wells					
5.00E-05	Base Case	3360.8	11.0	NA	✓
5.00E-05	Base Case	3359.9	24.0	NA	✓
5.00E-04	Base Case	3360.3	24.0	NA	✓
1.00E-05	Base Case	3359.8	24.0	NA	✓
5.00E-05	GF /3	3358.3	24.0	NA	✓
5.00E-05	GF *3	3360.5	24.0	NA	✓
Scenario 1: Shallow Rock Drain along PW18 Alignment					
5.00E-05	Base Case	3359.5	24.8	2.1	✓
		3359.0	30.8	2.6	✓
		3360.0	18.7	1.6	✓
5.00E-04	Base Case	3359.5	39.5	11.2	✓
		3359.0	50.7	14.2	✓
		3360.0	28.3	8.2	✓
1.00E-05	Base Case	3359.5	23.0	0.5	✓
		3359.0	28.3	0.6	✓
		3360.0	17.7	0.4	✓
5.00E-05	GF *3	3359.5	42.6	2.9	✓
		3359.0	53.7	3.7	✓
		3360.0	31.5	2.2	✓
Scenario 2: Replacement of PW18 Wells with 2 High-Capacity Pumping Wells					
5.00E-05	Base Case	3360	24.0	1.2	✓
5.00E-05	Base Case	3359.5	34.0	2.4	✓
5.00E-05	GF *3	3360	38.0	2.0	✓
Scenario 3: Shallow Rock Drain Preferred Alignment					
5.00E-05	Base Case	3359.5	21.3	1.8	✓
		3359.0	26.3	2.2	✓
		3360.0	16.3	1.4	✓
5.00E-04	Base Case	3359.5	34.2	9.3	✓
		3359.0	43.5	11.6	✓
		3360.0	24.9	7.1	✓
1.00E-05	Base Case	3359.5	19.8	0.4	✓
		3359.0	24.3	0.5	✓
		3360.0	15.4	0.4	✓
5.00E-05	GF *3	3359.5	39.2	2.6	✓
		3359.0	49.1	3.3	✓
		3360.0	29.2	2.0	✓
Scenario 4: 2 High-Capacity Pumping Wells along Preferred Alignment					
5.00E-05	Base Case	3360.0	26.0	0.8	✓
5.00E-05	Base Case	3359.5	34.0	1.4	✓
5.00E-05	GF *3	3360.0	40.0	1.5	✓

Table 5-6. Simulated Drain Flow and Pumping Rates for Receding Flow Conditions w/ pumping PW14 (Myra Creek Stage at Car Bridge 3360 m MD).

Local Hydraulic Conductivity [m/s]		Pumping Level [m MD]	Drain Flow/ Pumping Rate [L/s]	Flow from Myra Creek [L/s]	Full Hydraulic Control
Colluvium	Glaciofluvial				
Scenario 0: Interim Operation of PW18 Wells					
5.00E-05	Base Case	3360.3	11.0	NA	No
5.00E-05	Base Case	3359.5	24.0	NA	✓
5.00E-04	Base Case	3359.4	24.0	NA	✓
1.00E-05	Base Case	3359.5	24.0	NA	✓
5.00E-05	GF /3	3357.8	24.0	NA	✓
5.00E-05	GF *3	3360.1	24.0	NA	No
Scenario 1: Shallow Rock Drain along PW18 Alignment					
5.00E-05	Base Case	3359.5	19.6	< 0.1	✓
		3359.0	25.6	< 0.1	✓
5.00E-04	Base Case	3359.5	22.1	< 0.1	✓
1.00E-05	Base Case	3359.5	20.1	< 0.1	✓
5.00E-05	GF *3	3359.5	33.4	< 0.1	✓
		3360.0	22.3	< 0.1	✓
		3359.0	44.5		✓
5.00E-05	GF /3	3359.5	10.5	< 0.1	✓
		3359.0	13.5	< 0.1	✓
		3360.0	7.4	< 0.1	✓
Scenario 2: Replacement of PW18 Wells with 2 High-Capacity Pumping Wells					
5.00E-05	Base Case	3359.5	26.0	< 0.1	✓
5.00E-05	GF *3	3359.5	40.0	< 0.1	✓
Scenario 3: Shallow Rock Drain Preferred Alignment					
5.00E-05	Base Case	3359.5	17.0	< 0.1	✓
5.00E-04	Base Case	3359.5	19.9	< 0.1	✓
1.00E-05	Base Case	3359.5	17.4	< 0.1	✓
5.00E-05	GF *3	3359.5	30.9	< 0.1	✓
5.00E-05	GF /3	3359.5	8.9	< 0.1	✓
Scenario 4: 2 High-Capacity Pumping Wells along Preferred Alignment					
5.00E-05	Base Case	3360	20.0	< 0.1	✓
5.00E-05	Base Case	3359.5	28.0	< 0.1	✓
5.00E-05	GF *3	3360	30.0	< 0.1	✓
5.00E-05	GF *3	3359.5	44.0	< 0.1	✓
5.00E-04	Base Case	NA	24.0	< 0.1	✓

Table 5-7. Simulated Drain Flow and Pumping Rates for Receding Flow Conditions w/o pumping PW14 (Myra Creek Stage at Car Bridge 3360 m MD).

Local Hydraulic Conductivity [m/s]		Pumping Level [m MD]	Drain Flow/ Pumping Rate [L/s]	Flow from Myra Creek [L/s]	Full Hydraulic Control
Colluvium	**Glaciofluvial**				
Scenario 0: Interim Operation of PW18 Wells					
5.00E-05	Base Case	3361.7	11.0	< 0.1	No
5.00E-05	Base Case	3360.8	24.0	< 0.1	No
5.00E-04	Base Case	3360.1	24.0	< 0.1	No
1.00E-05	Base Case	3361.2	24.0	< 0.1	No
5.00E-05	GF /3	3359.2	24.0	< 0.1	✓
5.00E-05	GF *3	3361.4	24.0	< 0.1	No
Scenario 1: Shallow Rock Drain along PW18 Alignment					
5.00E-05	Base Case	3359.0	41.8	< 0.1	✓
5.00E-05	Base Case	3360.0	29.7	< 0.1	✓
5.00E-05	Base Case	3360.0	25.9	< 0.1	✓
5.00E-04	Base Case	3359.5	35.8	< 0.1	✓
5.00E-05	GF *3	3359.5	62.1	< 0.1	✓
5.00E-05	GF *3	3360.0	51.0	< 0.1	✓
Scenario 2: Replacement of PW18 Wells with 2 High-Capacity Pumping Wells					
5.00E-05	Base Case	3359.5	48.0	< 0.1	✓
5.00E-05	Base Case	3360	40.0	< 0.1	✓
5.00E-05	GF *3	3360	66.0	< 0.1	✓
5.00E-05	GF *3	3359.5	78.0	< 0.1	✓
Scenario 3: Shallow Rock Drain Preferred Alignment					
5.00E-05	Base Case	3359.5	30.9	< 0.1	✓
5.00E-05	Base Case	3360	25.8	< 0.1	✓
5.00E-04	Base Case	3359.5	32.2	< 0.1	✓
1.00E-05	Base Case	3359.5	32.4	< 0.1	✓
5.00E-05	GF *3	3359.5	57.1	< 0.1	✓
Scenario 4: 2 High-Capacity Pumping Wells along Preferred Alignment					
5.00E-05	Base Case	3359.5	48.0	< 0.1	✓
5.00E-05	Base Case	3360.0	40.0	< 0.1	✓
5.00E-05	GF *3	3360.0	60.0	< 0.1	✓
5.00E-05	GF *3	3359.5	80.0	< 0.1	✓

6 UPDATED CONCEPTUAL DESIGN OF PHASE II LYNX SIS

6.1 CONCEPTUAL DESIGN OF OPTIONS

The general layout and alignment of the five Phase II Lynx SIS scenarios are described in section 5.4.1. Additional design details are provided below, considering the results of the numerical assessment of the different SIS options presented in section 5.

Scenario 0 comprises four 6-inch diameter PVC pumping wells (PW18-01 to PW18-04). These wells have already been installed but have not been equipped with submersible pumps. For routine operation, these wells would be equipped with 4” submersible pumps with a simple float switch and control valve to regulate flow. Each submersible pump should be sized to maximize the available pump capacity (assumed to be at least 6 L/s each).

Scenario 1 comprises a 40 m long rock drain along the alignment of the PW14 wells. Figure 6-1 illustrates the proposed drain design in long section. The drain would be about 5 m deep and a minimum 1 m wide at the base. The invert elevation of the drain pipe would be at approximately 3358.5 m MD. For costing purposes, it was assumed that the drain would be constructed in an open trench excavation with 1:2 side slopes. Alternative construction methods such as the use of lateral steel braces or use of slurry trench technology are available and could be evaluated during later stages of design, if necessary.

The water collected in the drain would be conveyed to a precast concrete manhole (“dry sump”) from where it would be pumped to the Super Pond for treatment using a submersible sump pump. For costing purposes, it was assumed that the sump pump can extract up to 50 L/s. The sizing of the pump should be finalized after construction and testing of the drain. During high flow conditions, the lower portion of the drain (including the drain pipe) would be flooded and the water level in the drain regulated by a Variable Flow Drive (VFD). During low flow conditions, the water level in the sump could be lowered to below the drain invert elevation to maximize drawdown.

Scenario 2 (and Scenario 4) comprises two 8” diameter pumping wells. Figure 6-2 shows a conceptual design of these pumping wells. These high capacity wells would be drilled using a minimum 12” diameter borehole and completed using a welded well assembly of 8” stainless steel wire-wrap screen (slot 20) from 1 to 10 m depth. The annulus of the borehole would be backfilled with clean filter sand (20-40) to provide an artificial filter pack. The wells would be equipped with submersible pumps and VFD controls (like the Phase I Lynx wells) to allow automated regulation of the pumping rate as a function of the required groundwater levels. For costing purposes, it was assumed that the submersible pumps can extract up to 30 L/s each. The sizing of the pumps should be finalized after construction and testing of the pumping wells.

Scenario 3 comprises a 30m long rock drain along a north-eastern alignment (from the car bridge towards the Super Pond). Figure 6-3 illustrates the proposed drain design for Scenario 3 in long section. The drain design for this scenario is generally the same as for Scenario 1, except it is 10 m shorter.

6.2 COMPARISON OF OPTIONS

This section provides a qualitative comparison of the five different options evaluated for the Phase II Lynx SIS. The following three general criteria were considered in this evaluation:

- Constructability
- Performance
- Cost.

Table 6-1 summarizes the salient features of this comparison. A summary of this qualitative comparison is provided below.

6.2.1 Constructability

In general, all options considered represent standard technologies for seepage control and are routinely constructed at industrial and mine sites. Scenario 0 is already in place and drilling of larger, higher capacity pumping wells has also been completed successfully on site using a Dual Rotary drill rig (see PW-14 wells).

The shallow drain system is similar in concept to the outer drain system also installed successfully along the Old TDF. Note that the proposed drain in the Lynx reach is slightly deeper than the NOD (5 m versus 4 m) which could result in increased complexity during construction (e.g. higher pumping requirements, deeper shoring requirements).

Construction of the shallow drain using open trench technology would require a larger excavation and may not be possible in close proximity of existing surface infrastructure (e.g. the road embankment and conveyor footings). The drain alignment for both Scenario 1 and 3 have been selected to stay clear of this surface infrastructure. However, a more detailed assessment of the constructability of the proposed drain alignments proposed in Scenarios 1 and 3 should be completed during detailed design.

In summary, all options are considered standard technology but Scenario 0 ranks highest in terms of constructability (already constructed). Further geotechnical assessment is required to determine whether construction of the proposed shallow drain along the two alignments causes any concern.

Table 6-1. Qualitative Comparison of Phase II SIS Options

Criterion	Scenario 0 Fence of PW18 wells	Scenario 1 Shallow Drain at PW18 alignment	Scenario 2 Two 8" wells along PW18 alignment	Scenario 3 Shallow Drain along north-east alignment	Scenario 4 Two 8" wells along north-east alignment
Constructability	Standard well installation (already in place)	Routine construction; potential issues due to surface and subsurface infrastructure	Standard well installation	Routine construction; potential issues due to surface and subsurface infrastructure	Standard well installation
Performance	Potential limit in pump capacity during receding flow conditions; may not control perched seepage	Full capture predicted for all flow scenarios; will capture perched seepage	Full capture predicted for all flow scenarios; may not capture perched seepage	Full capture predicted for all flow scenarios; will capture perched seepage	Full capture predicted for all flow scenarios; may not capture perched seepage
Cost	$50,000 - $100,000 Interception wells already installed; equip with 4 submersible pumps & controls	$150,000 - $250,000 Install 40m long and 6m deep drain and 1 sump station; equip with sump pump and pump control	$100,000 - $150,000 Drill/Install two high capacity wells & equip w/ 2 submersible pumps and pump controls	$125,000 - $225,000 Install 30m long and 6m deep drain and 1 sump station; equip with sump pump and pump control	$100,000 - $150,000 Drill/Install two high capacity wells & equip w/ 2 submersible pumps and pump controls

6.2.1 Performance

The following three performance criteria were considered:

- Extent of capture zone
- Capture efficiency
- Risk of seepage bypass (in particular perched seepage)

The first two criteria were evaluated numerically using the calibrated flow model for the Lynx area (see section 5.4.3). The predicted extent of the capture zone is very similar for all five scenarios evaluated and covers the most likely source area of the observed highly impacted (acidic) seeps observed immediately downstream of the car bridge, i.e. the Duck Pond and associated acidic runoff.

As noted in section 5.5.3, the only scenario potentially not providing adequate capture was Scenario 0. However, this scenario only allowed limited by-pass assuming very high gradients (receding flow without PW14 pumping) and the presence of higher than expected K for the glaciofluvial sediments. Additional monitoring during high flow conditions would be required to verify whether Scenario 0 would indeed allow by-pass during such (rare) high flow conditions.

The modeling also indicated that a drain is generally more efficient in providing capture than pumping wells. In other words, a drain requires less pumping (lower extraction rate) to achieve the same drawdown in the aquifer. This aspect could potentially be even more pronounced in practice (in the field) due to heterogeneity in the local sediments.

A related aspect of SIS performance is the potential for seepage by-pass due to the development of perched conditions in very shallow sediments which may potentially develop during periods of high precipitation. Such perched seepage would be intercepted by a drain but may not be captured by a fence of pumping wells. Note that there is presently insufficient information to evaluate the potential for seepage by-pass due to local heterogeneity and/or perched condition.

In summary, a shallow drain is generally preferred over the use of a fence of pumping wells, because (i) it reduces pumping (and treatment) requirements and (ii) it reduces the potential for seepage by-pass. Scenario 1 is generally preferred over Scenario 3 because this drain alignment provides greater opportunity to intersect potential perched seepage feeding the acidic seeps observed during past high flow events.

6.2.2 Cost

For this comparison, a preliminary costing of the five scenarios was completed based on RGC’s experience with similar projects (both at Myra Falls and elsewhere). Table 6-1 summarizes RGC’s preliminary cost estimates to implement the five options. These cost estimates include the cost of drain/sump construction, drilling/installation of pumping wells, and installation of pumps and pump controls. The cost of power supply and operating costs are not included in these preliminary cost estimates.

As expected, Scenario 0 has the lowest estimated cost because the wells are already installed. However, submersible pumps and controls would still be required to operate the system.

In general, the drain scenarios are estimated to cost about 30% more than the well scenarios because of higher cost of construction and larger pump equipment. However, these cost estimates are preliminary, and the cost differential may change with more detailed costing (during later stages of design).

6.3 RECOMMENDED DESIGN OF PHASE II LYNX SIS

Based on the qualitative options analysis described above, Scenario 0 represents the most cost-effective solution. Initial testing of the fence of PW18 wells has demonstrated that Scenario 0 is effective in eliminating discharge of impacted groundwater in this area during low flow conditions (see section 4). Furthermore, this fence of pumping wells is also predicted to control seepage during most high flow and receding flow conditions (see section 5). However, the fence of 6" diameter pumping wells is limited in its pumping capacity and there is a small potential that this SIS will not be able to control shallow, potentially perched seepage during some receding flow conditions.

Scenario 1 (shallow drain along PW18 alignment) is judged to provide the most robust solution to intercepting shallow, impacted groundwater discharging to Myra Creek in the Lynx area downstream of the car bridge. However, this solution is the most expensive solution and may not be required.

RGC recommends that the four existing pumping wells (PW18-01 to PW18-04) be equipped with submersible pumps (to maximize pumping capacity) and be operated during the upcoming high flow season (October 2018 to March 2019). If the PW18 pumping wells are effective in eliminating the discharge of impacted groundwater to Myra Creek, then this fence of PW18 wells should be adopted as the Phase II Lynx SIS. If this fence of PW18 wells is not sufficient, then a shallow (5 m deep) drain along the PW18 alignment (Scenario 1) should be implemented.

It should be emphasized that the water quality in groundwater and seeps discharging to Myra Creek in this area has shown a significant improvement in water quality over the last few months, notably an increase in pH and a decrease in metal concentrations. This is believed to be a result of improved management of ARD runoff from the ETA collected in the Duck Pond (see section 4). It is conceivable that additional improvements in ARD management in the ETA may further improve groundwater quality in the car bridge area such that a shallow interception system may no longer be required.

Figure 6-4 provides a flow chart (or decision tree) that illustrates the recommended steps to implement the Phase II Lynx SIS. As outlined in this flow chart, RGC suggests that the Phase II SIS should only be operated if the groundwater captured and/or seeps discharging into Myra Creek exceed a certain threshold water quality. Such a threshold could be based on numerical standards in the groundwater/seeps ("discharge limits") or based on water quality standards in Myra Creek ("receiving water quality standards").

Potential discharge limits that could be applied to decide whether to operate the Phase II SIS may include (i) effluent discharge limits or (ii) Metal & Diamond Mining Effluent Regulations (MDMER) limits, both of which are already in use at the Myra Falls mine site. Alternatively, a load-based approach could be selected in which the water quality threshold for operation of the Phase II Lynx

SIS is selected to protect a desired water quality objective in Myra Creek. Such a threshold could be derived by using the water and load balance model developed for Myra Falls (RGC, 2016).

RGC recommends that appropriate discharge limits or load-based thresholds for operation of the Phase II Lynx SIS be developed in consultation with the regulatory agencies.

7 KEY FINDINGS

7.1 2018 HYDROGEOLOGICAL DRILLING INVESTIGATION

In consultation with the Ministry of Environment (MOE), an interim mitigation plan was developed to control the uncontrolled discharge of acidic seepage to Myra Creek. A fence of shallow pumping wells was installed to allow extraction of shallow groundwater as an interim solution. In addition, three nested monitoring wells were installed to better characterize the hydrogeological conditions in this area. This hydrogeological field investigation was completed from May 9th to 13th, 2018 and findings are summarized as follows:

- Groundwater in the shallow MVA flows in a northeasterly direction towards the (actively pumped) PW14-01 and PW14-04 recovery wells.
- Groundwater in the new MW18 and PW18 wells is slightly acidic with moderately elevated zinc concentrations (0.5 to 2.5 mg/L). Shallow piezometers generally showed higher zinc concentrations than the deeper piezometer suggesting a surface source (e.g. recharge from local PAG waste rock and/or leakage from the Duck Pond).
- None of the new MW18 and PW18 wells intercepted the strongly acidic seepage observed earlier in the year.

7.2 INTERIM LYNX PHASE II SEEPAGE COLLECTION

The interim Phase II Lynx SIS was operated for 29 days from June 5 to July 4, 2018 and consisted of a vacuum pump system provided by Canadian Dewatering. Drop tubes were installed in PW18-01 to -04 and connected to a central vacuum pump. Extracted groundwater was directed into the 25 Sump and from there pumped to the Super Pond. Finding from pumping the interim Phase II SIS wells are as follows.

- Shallow pumping wells are relatively productive (~5.7 L/s per meter of drawdown) and the shallow sediments (colluvium and talus) are hydraulically well-connected to the underlying glaciofluvial sediments in the area.
- The deeper glaciofluvial sediments of the Myra Valley Aquifer (> 25m) are not well connected to the shallow glaciofluvial sediments.
- Water Quality of the initially captured groundwater is thought to be representative of only moderately impacted groundwater within the ETA area (e.g. ~ 2 mg/L of Zn at BK01-13S/D). With ongoing pumping, Zn and SO_4 concentrations decreased by ~50% suggesting some dilution by Myra Creek water and/or less impacted groundwater (e.g. from south of Myra Creek) due to pumping. Alternatively, groundwater conditions in this area improved due to (i)

operation of the interim Phase II SIS and/or (ii) general (seasonal) decline in groundwater discharge in the area due to drier conditions.

- A total of 27,500 m^3 of groundwater was removed by the PW18 wells resulting in a total captured Zn load of 16.4 kg. Loads of cadmium and copper captured by the interim Phase II SIS were 1-3 orders of magnitude lower than zinc loads.
- Based on earlier load balance modelling and zinc surveys completed in Myra Creek, the PW18 wells captured an estimated ~10% of the total average (low flow conditions) Zn load from groundwater to Myra Creek.

7.3 NUMERICAL ASSESSMENT OF PHASE II LYNX SIS

A numerical groundwater flow model was constructed, calibrated, and validated using groundwater level observations obtained during various flow conditions. The calibrated groundwater model was then used to evaluate the capture efficiency of five different SIS scenarios as follows:

  - Scenario 0: Operate existing interim Phase II SIS wells (PW18-01 to PW18-04) with submersible pumps with a total pumping capacity of 24 L/s.
  - Scenario 1: Shallow drain (approximately 5 m deep) along the same alignment as the PW18 wells.
  - Scenario 2: Two high capacity pumping wells (up to 30 L/s per well for a combined total of up to 60 L/s) along the same alignment as Scenario 0.
  - Scenario 3: Shallow drain (approximately 5 m deep) along a more northeasterly alignment.
  - Scenario 4: Two high capacity pumping wells (up to 30 L/s per well) along the same alignment as Scenario 3.

- The model predicts that all five scenarios prevent discharge of impacted groundwater originating from the Duck pond area to Myra Creek.
- The model predicts that the interim Phase II Lynx SIS (PW14 wells operated by a suction pump with a maximum pump capacity of 11 L/s) is not able to maintain hydraulic control. i.e. reverse hydraulic gradients, for receding flow conditions.
- The limited maximum pumping capacity (24 L/s) of the interim Phase II SIS may still not be adequate to reverse the hydraulic gradient during all receding flow conditions. However, particle tracking suggests that impacted, shallow groundwater from the Duck Pond area is still captured.

- The shallow drain along the PW18 alignment (Scenario 1) is slightly more efficient in producing the required drawdown than the interim solution using PW18 wells (Scenario 0). The actual pumping rate required in a shallow drain may be even lower, if the lower K colluvium extends deeper than assumed in the flow model.
- The northeasterly alignment is generally slightly more efficient, both for the case of drains and pumping wells. However, due to the larger distance from Myra Creek these options may not capture perched groundwater flow or surface runoff in close proximity to the creek.
- The base case estimate for leakage from Myra Creek is less than 2 L/s, provided the pumping level in the SIS is kept within 1m below the creek. Leakage could be effectively reduced to negligible flows, even for high K in colluvium, by setting the pumping level in the SIS equal to the creek level.

7.4 COMPARISON OF PHASE II LYNX SIS OPTIONS

Based on the qualitative options analysis, Scenario 0 represents the most cost-effective solution. Initial testing of the fence of PW18 wells has demonstrated that Scenario 0 is effective in eliminating discharge of impacted groundwater in this area during low flow conditions (see section 4). Furthermore, this fence of pumping wells is also predicted to control seepage during most high flow and receding flow conditions (see section 5). However, the fence of 6” diameter pumping wells is limited in its pumping capacity and there is a small potential that this SIS will not be able to control shallow, potentially perched seepage during some receding flow conditions.

Scenario 1 (shallow drain along PW18 alignment) is judged to provide the most robust solution to intercepting shallow, impacted groundwater discharging to Myra Creek in the Lynx area downstream of the car bridge. However, this solution is the most expensive solution and may not be required.

8 RECOMMENDATIONS

8.1 RECOMMENDED DESIGN AND IMPLEMENTATION OF PHASE II LYNX SIS

RGC recommends that the four PW-18 pumping wells (PW18-01 to PW18-04) be equipped with submersible pumps (to maximize pumping capacity) and be operated during the upcoming high flow season (October 2018 to March 2019). During operation of the interim Phase II Lynx SIS, RGC recommends to routinely monitor groundwater, seep water, and creek water quality (see section 8.2 below). Depending on the observations made during high flow conditions, the following steps are recommended (see Figure 6-4):

- If Scenario 0 is effective in eliminating the discharge of impacted groundwater to Myra Creek, then operation of the fence of PW18 wells should be continued and adopted as the Phase II Lynx SIS.
- If the existing fence of pumping wells (PW18-01 to PW18-04) is not sufficient to control discharge of impacted groundwater to Myra Creek, then Scenario 1 should be implemented.
- Furthermore, RGC suggests that the Phase II SIS should only be operated if the groundwater captured and/or seeps discharging into Myra Creek exceed a certain threshold water quality. Appropriate discharge limits for operation of the Phase II Lynx SIS should be developed in consultation with the regulatory agencies.

Finally, RGC recommends to actively manage acidic runoff from the ETA area and prevent acidic water from pooling in the Duck Pond and associated ditches during operation of the interim Phase II Lynx SIS.

8.2 RECOMMENDED MONITORING

RGC recommends that the following monitoring be completed during the upcoming high flow period (October 2018 to March 2019):

- Continue near-continuous water level monitoring (using data loggers) in the Lynx reach to assess temporal trends of capture zones and hydraulic gradients between the shallow aquifer and Myra Creek.
- Complete monthly synoptic groundwater level surveys in Lynx reach to infer flow fields and capture zones.
- Continue monthly Zn surveys along Myra Creek (including ETA reach up to Arnica Creek) if creek flow conditions allow safe access.

- Collect monthly water quality samples and analyze for general chemistry and dissolved during the upcoming high period (from October 2018 to March 2019) in the following monitoring wells:
    - existing shallow monitoring wells MW11-04, MW16-02, MW16-03, MW16-04, MW16-05, and MW11-04 wells,
    - newly installed MW18 series of monitoring wells (MW18-06S/D, MW18-07S/D and MW18-08S/D).
- Collect monthly water quality samples from the discharge of the actively pumped PW18 pumping wells and analyze for general chemistry and dissolved metals.
- Routinely measure field pH and EC of MW13-19 A/B and Shack Seeps and estimate flow rates. Keep records of field measurements to determine periods when seeps were active and document changes in water quality. Collect monthly water quality samples and analyze for general chemistry, dissolved and total metals.
- If impacted runoff is stored or pooling upstream of the interim Phase II Lynx SIS, measure field pH and EC of runoff.

9 CLOSURE

Robertson GeoConsultants Inc. (RGC) is pleased to submit this report 'Lynx Phase II SIS Conceptual Design Update'. We trust that the information provided in this report meets NMF's requirements.

Should you have any questions or if we can be of further assistance, please do not hesitate to contact the undersigned.

Respectfully Submitted,

ROBERTSON GEOCONSULTANTS INC.

Prepared by:

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Junior Geoscientist

Reviewed by:

Christoph Wels, Ph.D., M.Sc., P.Geo.

Principal Hydrogeologist

10 REFERENCES

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Springer, R. K. and Gelhar, L. W. (1991), Characterization of large-scale aquifer heterogeneity in glacial outwash by analysis of slug test with oscillatory responses, Cape Code, Massachusetts, U.S. Geol. Surv. Water Resour. Invest. Rep. 91-4034, 36.

Figures

S:\Files\Projects\212000 Nyrstar\212011 2017 Closure Planning Support\GIS_CAD\Maps\Report 6\Figure2-1_GroundwaterMonitoringNetwork13July_2.mxd

Lynx Groundwater Monitoring Network

0 50 100 200 Meters

Scale 1:2,000

NAD83 UTM Zone10N

N W E S

Legend

● Monitoring Well
⬟ Pumping Well
● Surface Water Station
💧 Seep or Surface Water

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Client: nyrstar	Figure: 2-1
Project: Phase II Lynx SIS Conceptual Design Update	Last Update: Jul 30, 2018
Report: RGC 212011/6	Drawn: L.R.
Original File: Figure2-1_GroundwateMonitoringNetwork13July_2.mxd	

S:\Files\Projects\212000 Nyrstar\212011 2017 Closure Planning Support\GIS_CAD\Maps\Report 6\Figure3-1_GroundwaterMonitoringNetwork13July.mxd

Lynx Groundwater Monitoring Network

Legend

- 🔴 Monitoring Well
- ⬠ Pumping Well
- ● Surface Water Station
- 💧 Seep or Surface Water

N W E S

0 15 30 60 Meters

Scale 1:1,000

NAD83 UTM Zone10N

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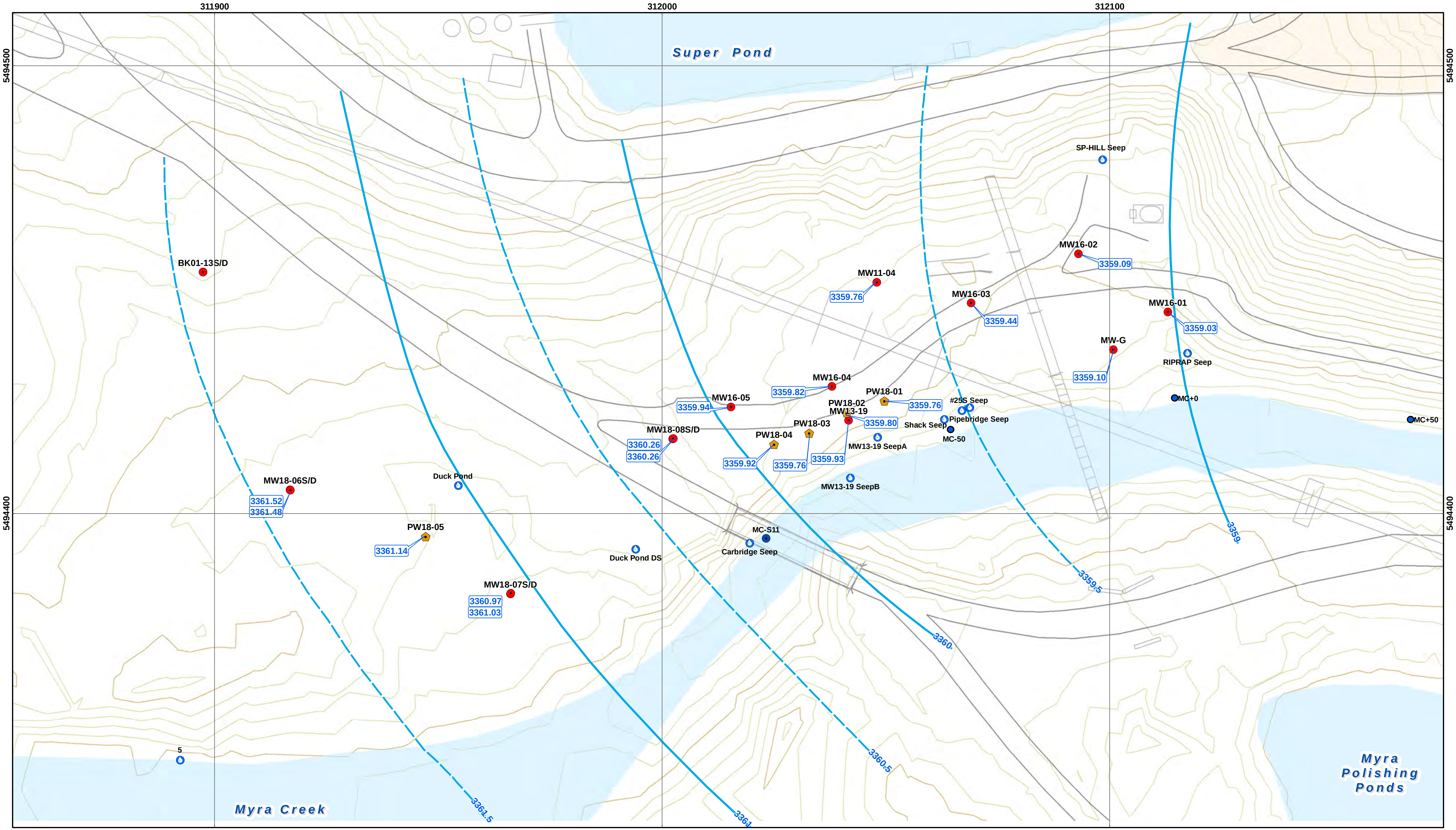
Client: nyrstar	Figure: 3-1
Project: Phase II Lynx SIS Conceptual Design Update	Last Update: Jul 30, 2018
Report: RGC 212011/6	Drawn: L.R.
Original File: Figure3-1_GroundwateMonitoringNetwork13July.mxd	



S:\Files\Projects\212000 Nyrstar\212011 2017 Closure Planning Support\GIS_CAD\Maps\Report 6\Figure3-2_LYNX_GWL_for5June2018-2.mxd

Groundwater Levels and Inferred Groundwater Flow Field, June 5, 2018

Scale 1:800

0 20 40 80 Meters

NAD83 UTM Zone10N

Legend

●	Monitoring Well
⬟	Pumping Well
●	Surface Water Station
○	Seep or Surface Water
●	Creek Monitoring Station
– –	GWL Contour

Note: 2018 Wells TOC Elevation ESTIMATE ONLY

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Client: nyrstar	**Figure: 3-2**
Project: Phase II Lynx SIS Conceptual Design Update	Project No: 212011
Report No: 212011/6	Last Update: Jul 30, 2018
Nyrstar Myra Falls, BC, Canada	Drawn: L.R.

Original File: Figure3-2_LYNX_GWL_for5June2018-2.mxd

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MW18-06S	
6.71 to 9.75 m bgs	
pH	5.2
EC, uS/cm	356
SO_4, mg/L	138
Zn, ug/L	2,390

MW18-06D	
15.24 to 18.29 m bgs	
pH	5.3
EC, uS/cm	242
SO_4, mg/L	84
Zn, ug/L	1,280

MW18-08S	
3.05 to 6.10 m bgs	
pH	5.7
EC, uS/cm	248
SO_4, mg/L	108
Zn, ug/L	2,450

MW18-08D	
7.32 to 10.36 m bgs	
pH	5.8
EC, uS/cm	245
SO_4, mg/L	99
Zn, ug/L	1,840

PW18-04	
1.52 to 10.67 m bgs	
pH	6.1
EC, uS/cm	173
SO_4, mg/L	59
Zn, ug/L	902

PW18-01	
1.52 to 10.67 m bgs	
pH	6.0
EC, uS/cm	192
SO_4, mg/L	71
Zn, ug/L	904

PW18-02	
1.52 to 10.67 m bgs	
pH	6.1
EC, uS/cm	170
SO_4, mg/L	56
Zn, ug/L	501

PW18-03	
1.52 to 10.67 m bgs	
pH	6.0
EC, uS/cm	173
SO_4, mg/L	58
Zn, ug/L	845

PW18-05	
1.52 to 10.67 m bgs	
pH	5.4
EC, uS/cm	278
SO_4, mg/L	108
Zn, ug/L	1,320

MW18-07S	
4.57 to 7.62 m bgs	
pH	6.8
EC, uS/cm	145
SO_4, mg/L	111
Zn, ug/L	2,830

MW18-07D	
13.56 to 15.09 m bgs	
pH	5.5
EC, uS/cm	172
SO_4, mg/L	72
Zn, ug/L	1,300

Initial Groundwater Quality, May 2018

Scale 1:1,000

0 25 50 100 Meters

NAD83 UTM Zone10N

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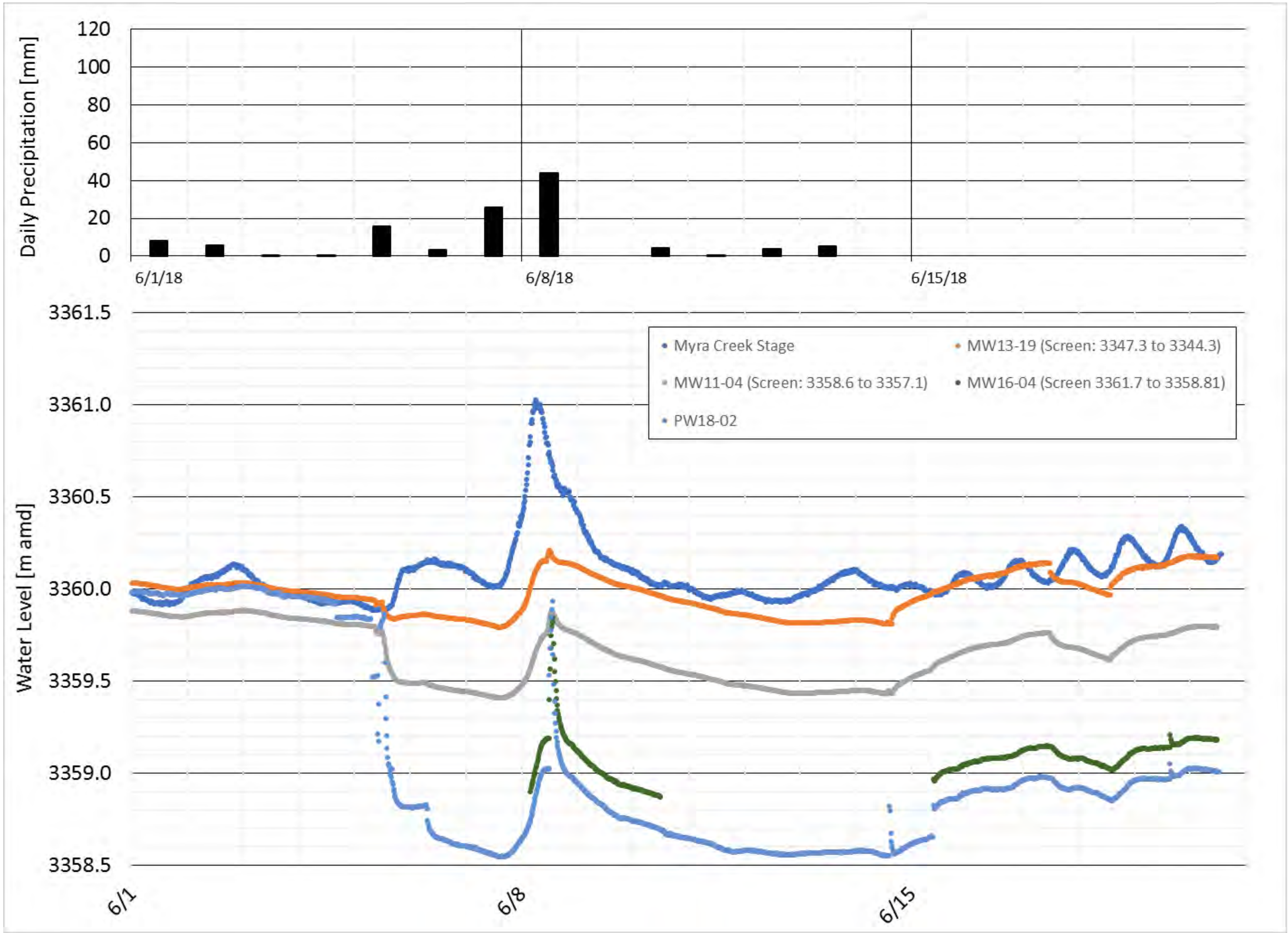
Legend

- ● Monitoring Well
- ⬟ Pumping Well
- ● Surface Water Station

Client: nyrstar	**Figure: 3-3**
Project: Phase II Lynx SIS Conceptual Design Update	Project No: 212011
Report No: 212011/6	Last Update: Jul 30, 2018
Nyrstar Myra Falls, BC, Canada	Drawn: L.R.
Original File: Figure3-3_LYNX_WQ_for29June2018-V2.mxd	



Groundwater Levels Time Trends June 2018
(MW11-04, MW13-19, MW16-04, and PW18-02)

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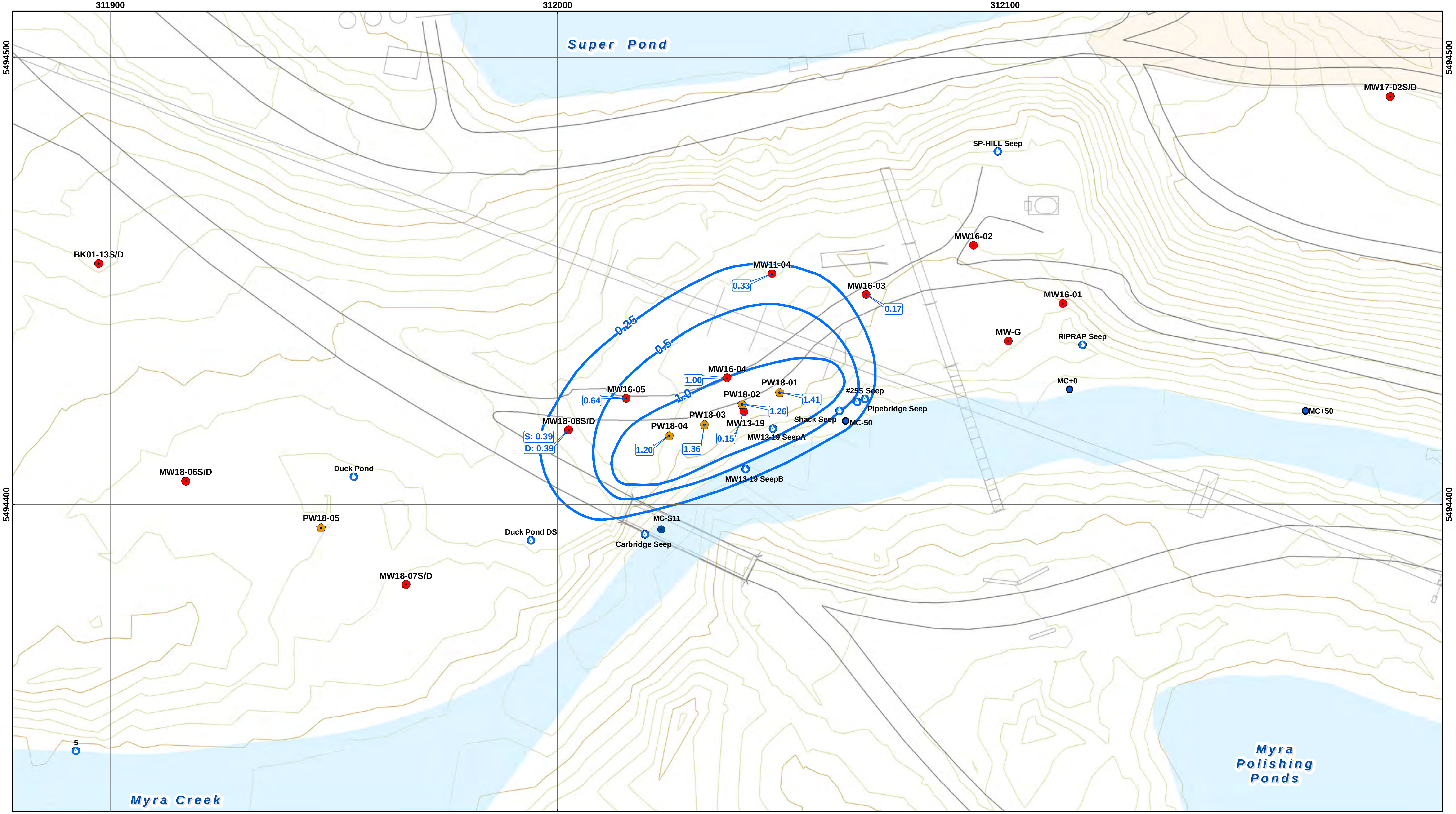
Client: Nyrstar Myra Falls	**Figure: 4-1**
Project: Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: June 2018
Original File	



S:\Files\Projects\212000 Nyrstar\212011 2017 Closure Planning Support\GIS_CAD\Maps\Report 6\Figure4-2_LYNX_Drawdowns_June2018.mxd

Legend

🔴	Monitoring Well
⬟	Pumping Well
●	Surface Water Station
○	Seep or Surface Water
●	Creek Monitoring Station
—	Drawdown Contour

Observed Drawdown during Operation of Interim Phase II Lynx SIS

Scale 1:800

0 20 40 80 Meters

NAD83 UTM Zone10N

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Client: nyrstar	**Figure: 4-2**
Project: Phase II Lynx SIS Conceptual Design Update	Project No: 212011
Report No: 212011/6	Last Update: Jul 27, 2018
Nyrstar Myra Falls, BC, Canada	Drawn: L.R.
Original File: Figure4-2_LYNX_Drawdowns_June2018.mxd	

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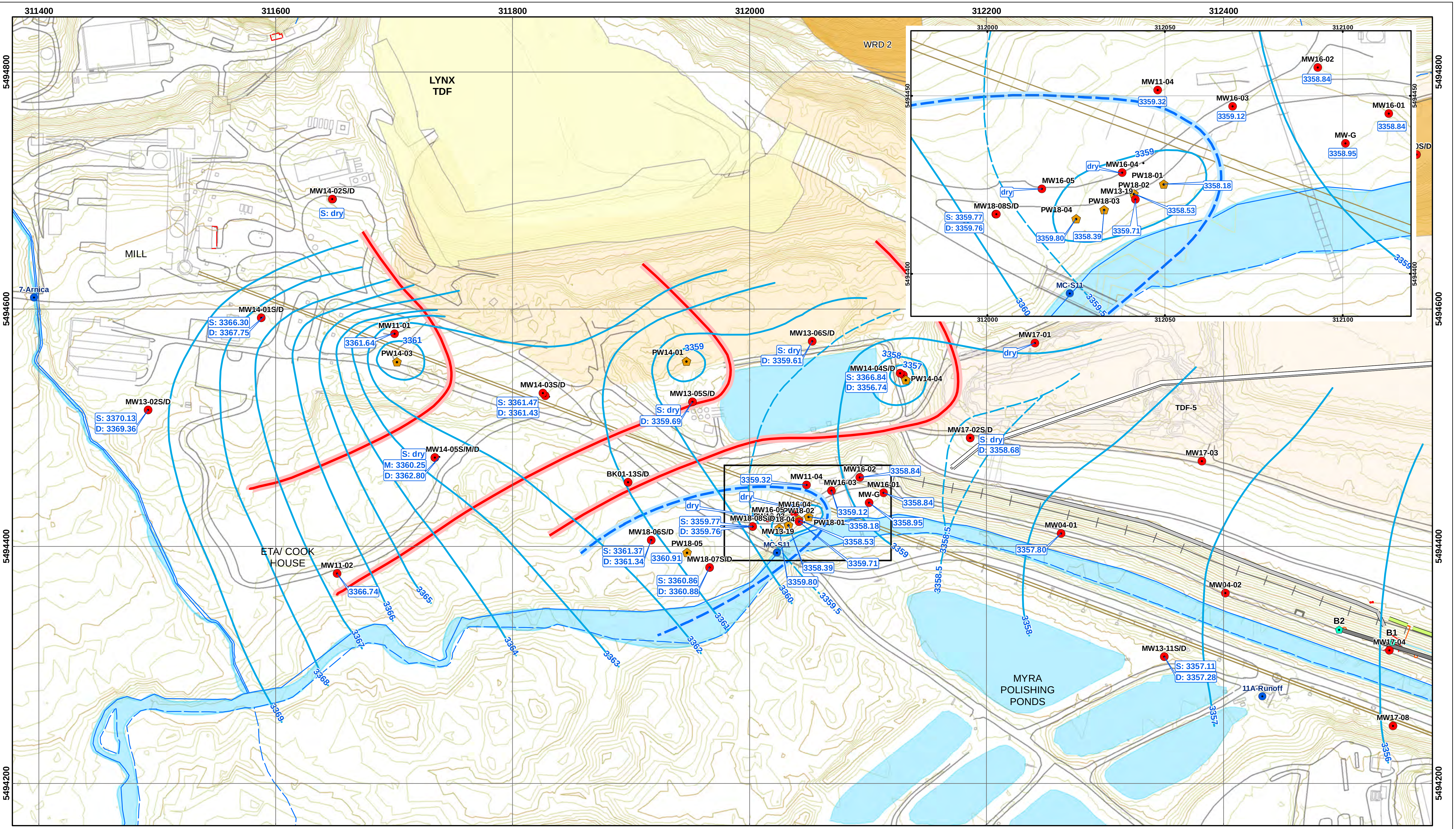

Groundwater Levels and Inferred Groundwater Flow Field, June 29, 2018

Legend

●	Monitoring Well
⬟	Pumping Well
- - -	GWL Contour
—	Inferred Capture Zone (PW14 wells)
— —	Inferred Capture Zone (PW18 wells)

Scale 1:3,000

0 75 150 300 Meters

NAD83 UTM Zone10N

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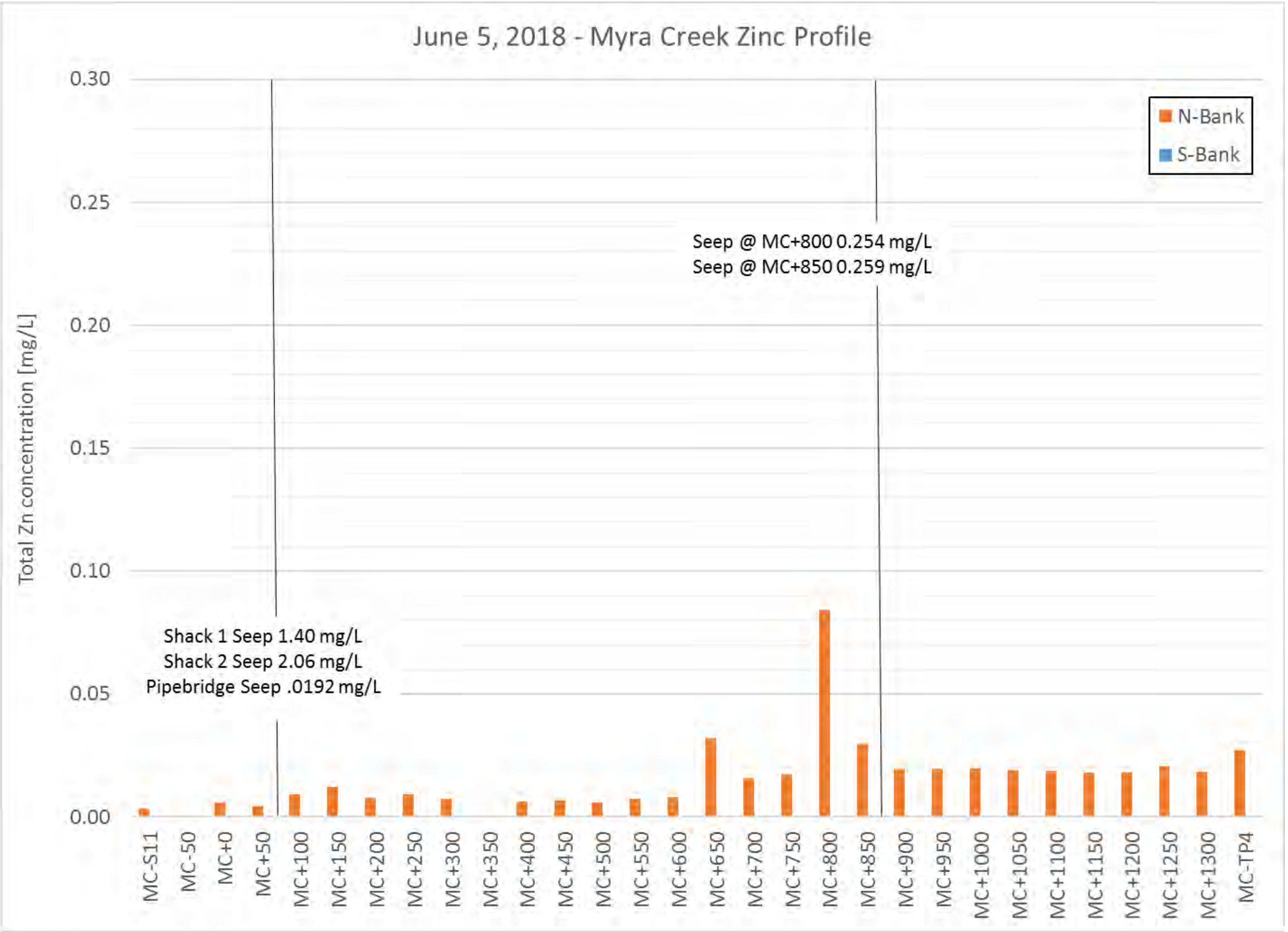
Client: nyrstar	**Figure: 4-3**
Project: Phase II Lynx SIS Conceptual Design Update	Project No: 212011
Report No: 212011/6	Last Update: Jul 30, 2018
Nyrstar Myra Falls, BC, Canada	Drawn: L.R.

Original File: Figure4-3_LYNX_GWL_for29June2018_2.mxd



Seep @ MC+800 0.254 mg/L
Seep @ MC+850 0.259 mg/L

Shack 1 Seep 1.40 mg/L
Shack 2 Seep 2.06 mg/L
Pipebridge Seep .0192 mg/L

Myra Creek Zinc Profile – June 5, 2018

Client: Nyrstar Myra Falls	**Figure: 4-4**
Project: Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: July 2018
Original File	

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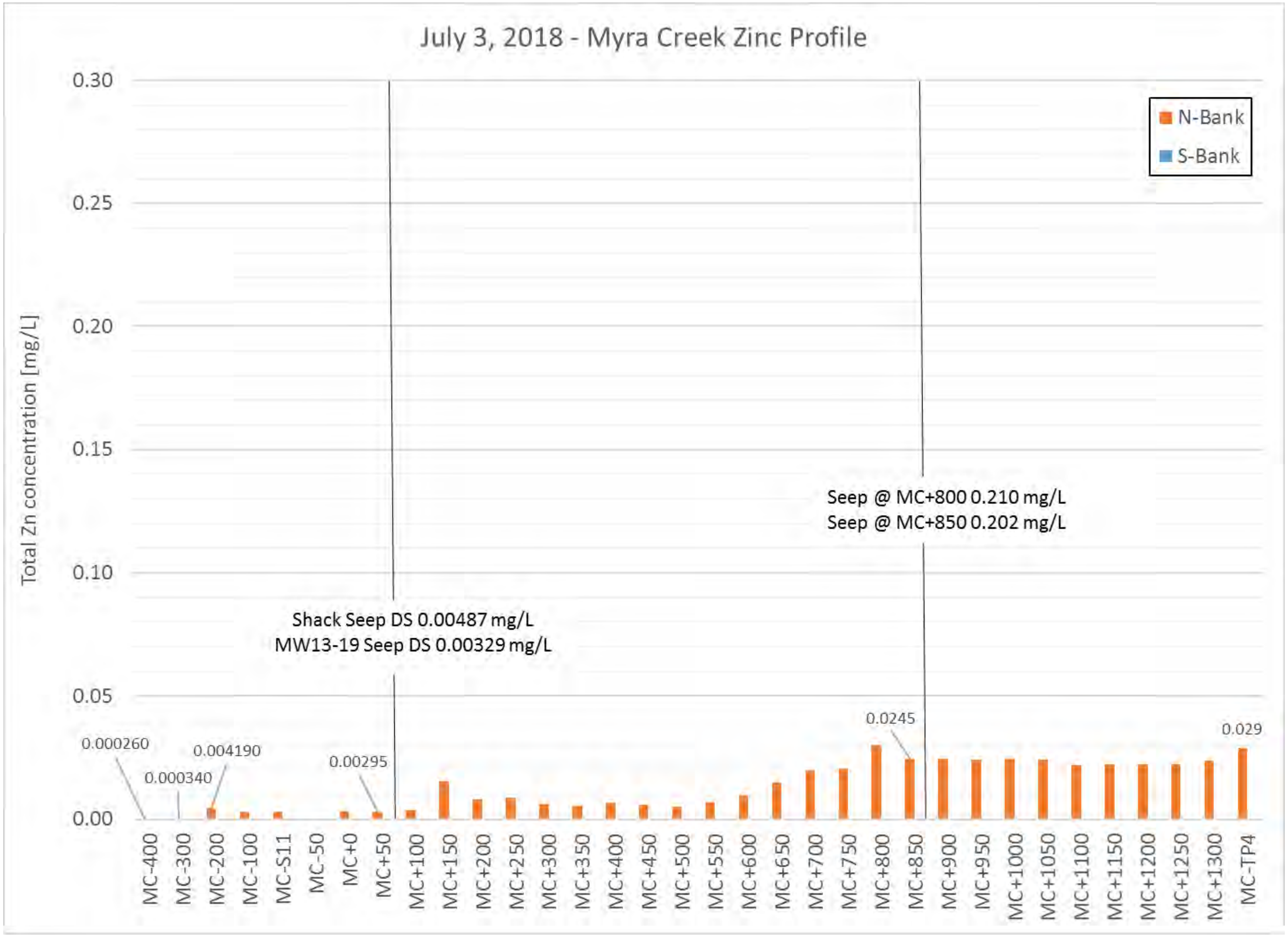
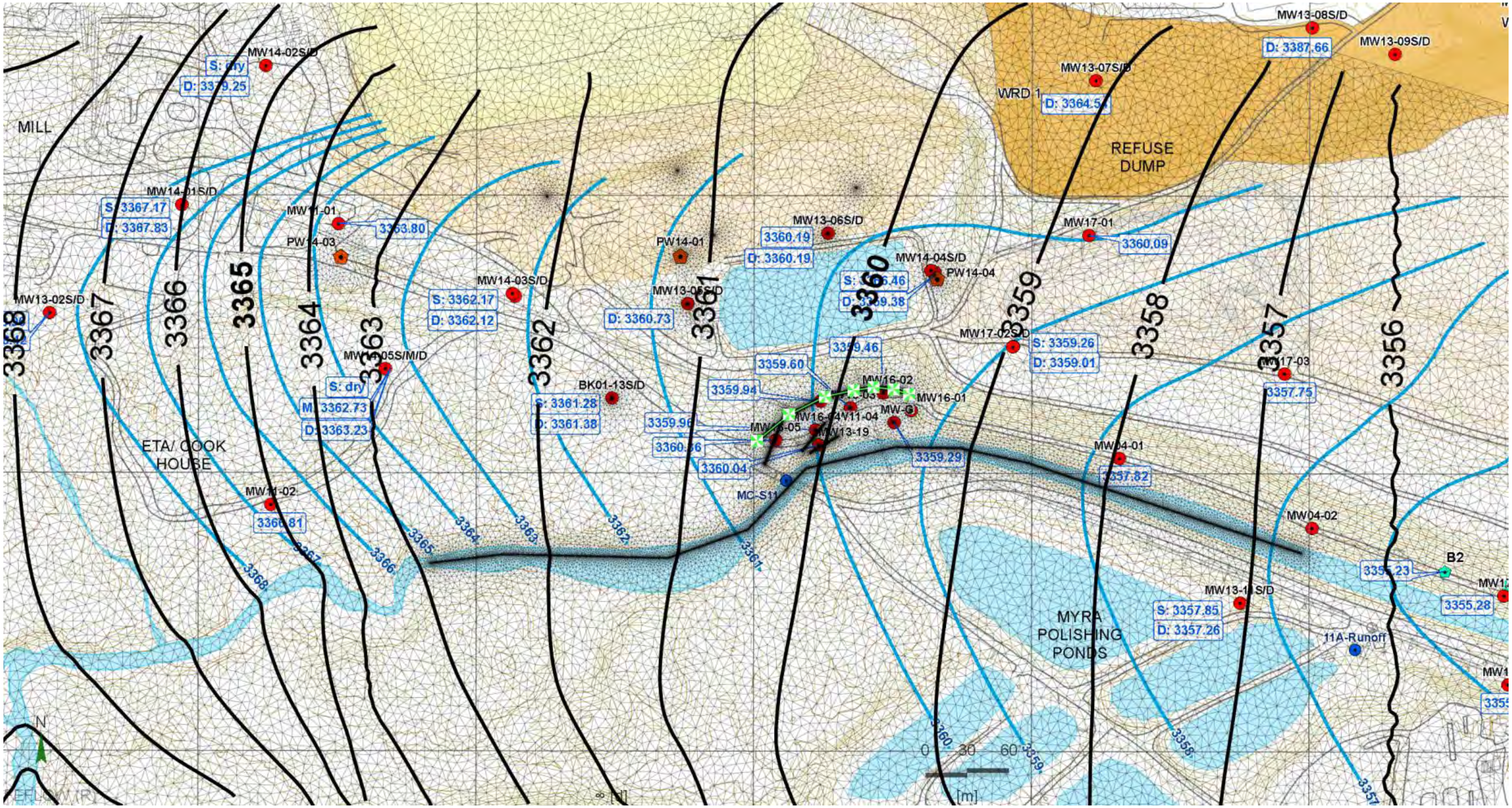


Myra Creek Zinc Profile – July 3, 2018

Robertson GeoConsultants Inc.

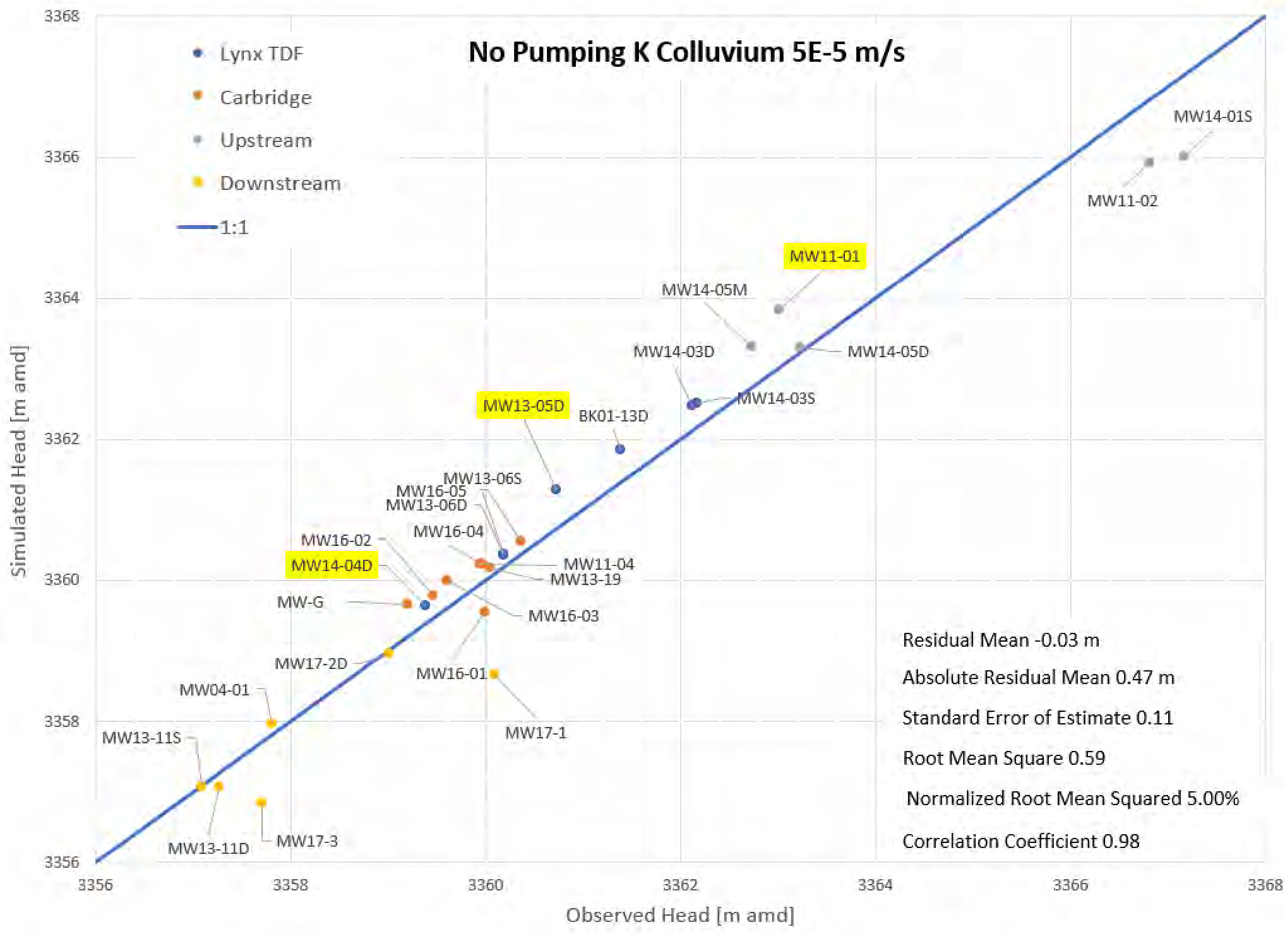
Client: Nyrstar Myra Falls	**Figure: 4-5**
Project: Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: July 2018
Original File	



Simulated and Inferred Groundwater Flow Field for April 5, 2018 (PW14 Wells not Pumping)

Robertson GeoConsultants Inc.

Client: Nyrstar Myra Falls	**Figure: 5-1**
Project: Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: July 2018
Original File	



Residual Mean -0.03 m

Absolute Residual Mean 0.47 m

Standard Error of Estimate 0.11

Root Mean Square 0.59

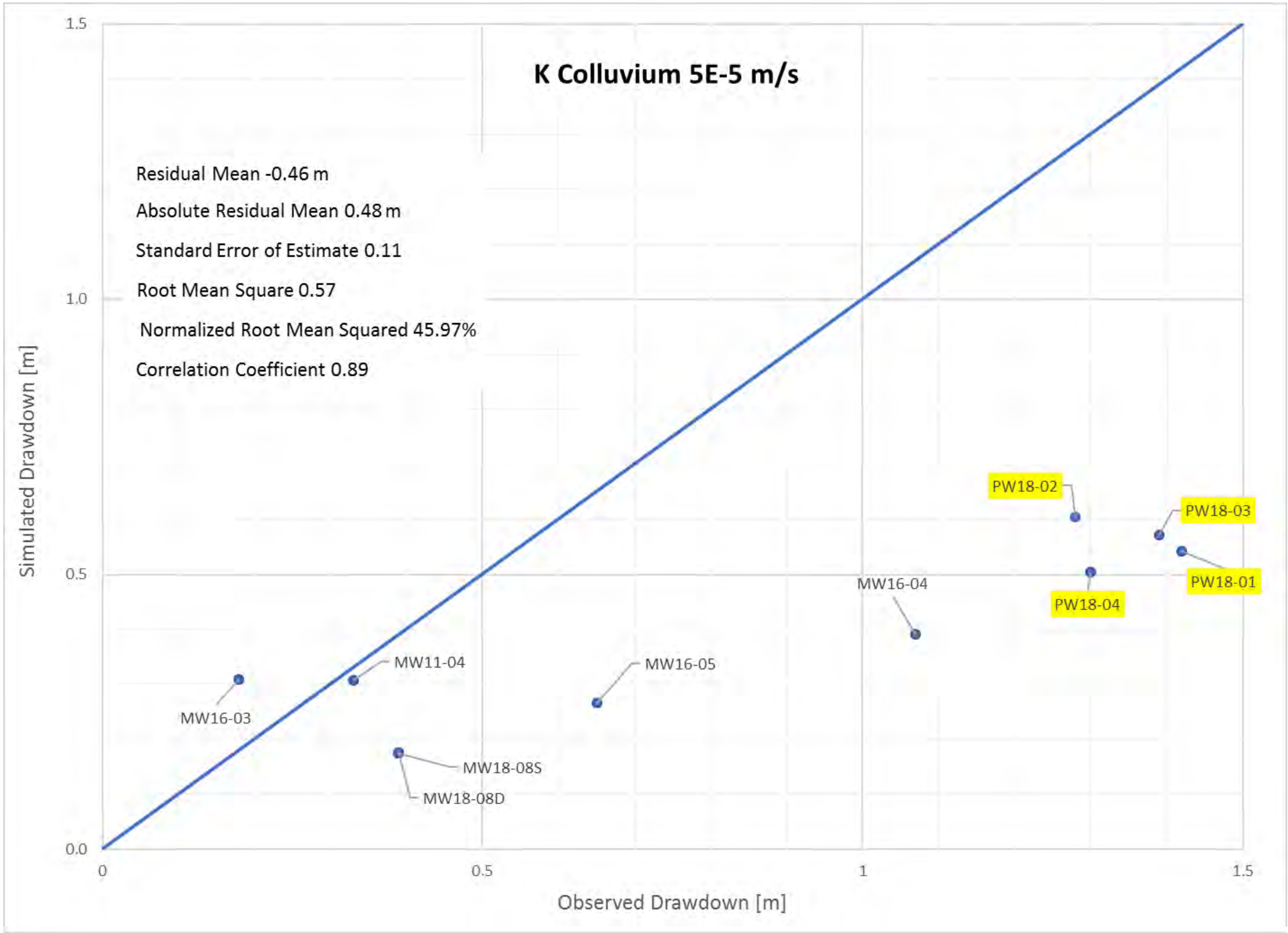
Normalized Root Mean Squared 5.00%

Correlation Coefficient 0.98

Low Flow Calibration (PW14 Wells not Pumping)
Hydraulic Head Scatter Plot

Robertson GeoConsultants Inc.

Client: Nyrstar Myra Falls	**Figure: 5-2**
Project: Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: July 2018
Original File	

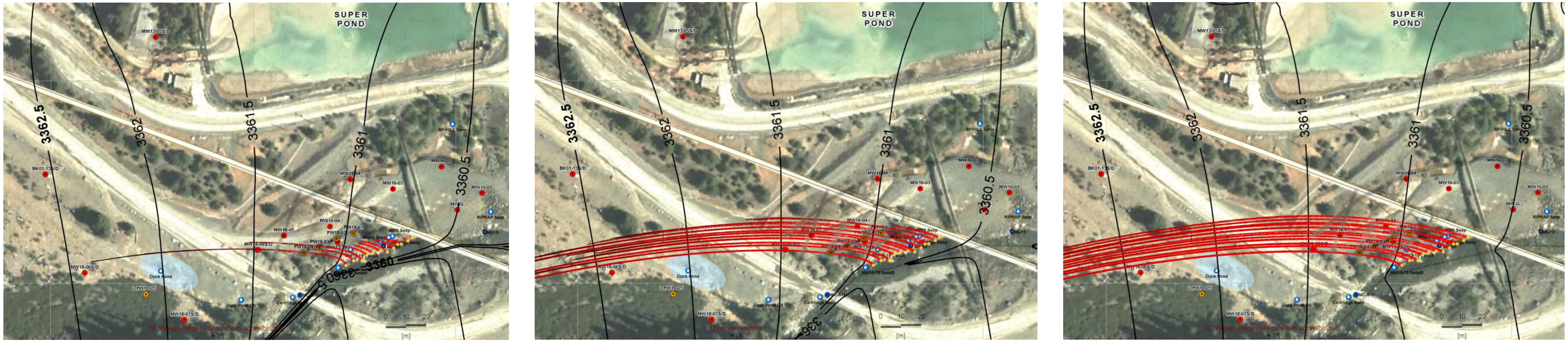


Interim Phase II Lynx SIS Calibration
Drawdown Scatter Plot

Robertson GeoConsultants Inc.

Client: Nyrstar Myra Falls	**Figure: 5-3**
Project: Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: July 2018
Original File	

Receding Flow Conditions & Phase I Lynx SIS (PW14) Pumping

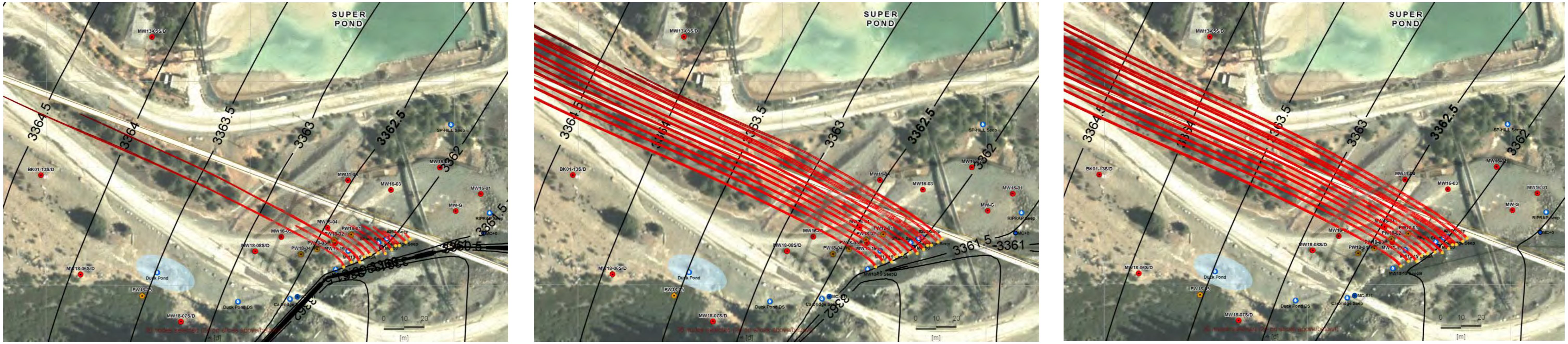


Slice 1

Slice 2

Slice 3

Receding Flow Conditions & Phase I Lynx SIS (PW14) Not-Pumping



Slice 1

Slice 2

Slice 3

Simulated Flow Field for Receding Flow Conditions Backward Particle Tracking from Seep Locations Base Case K

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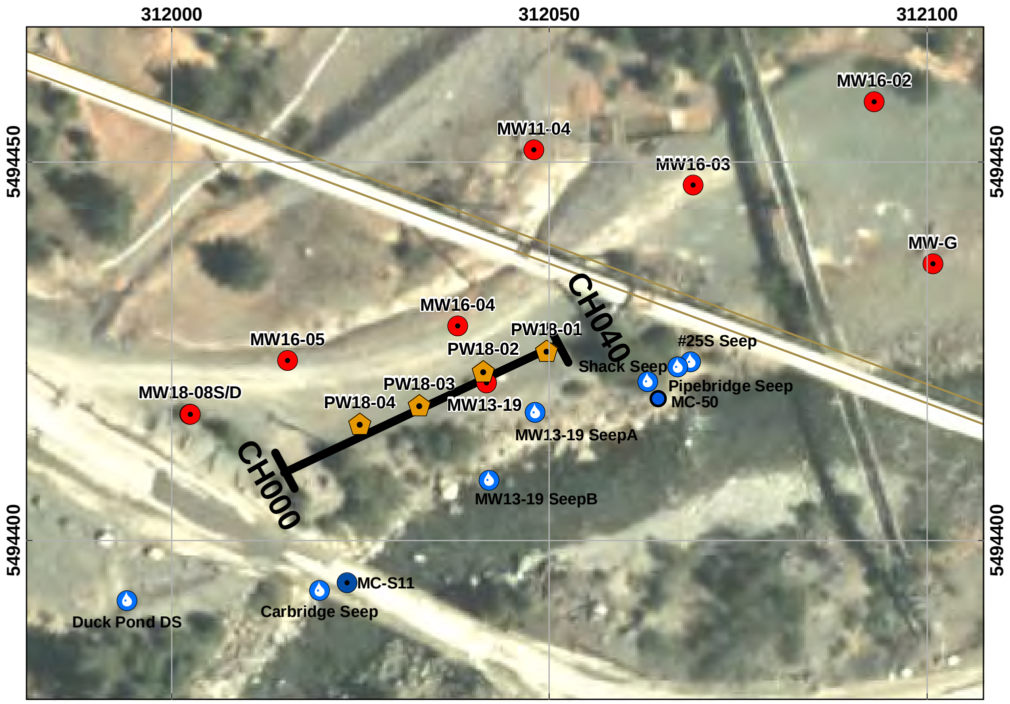
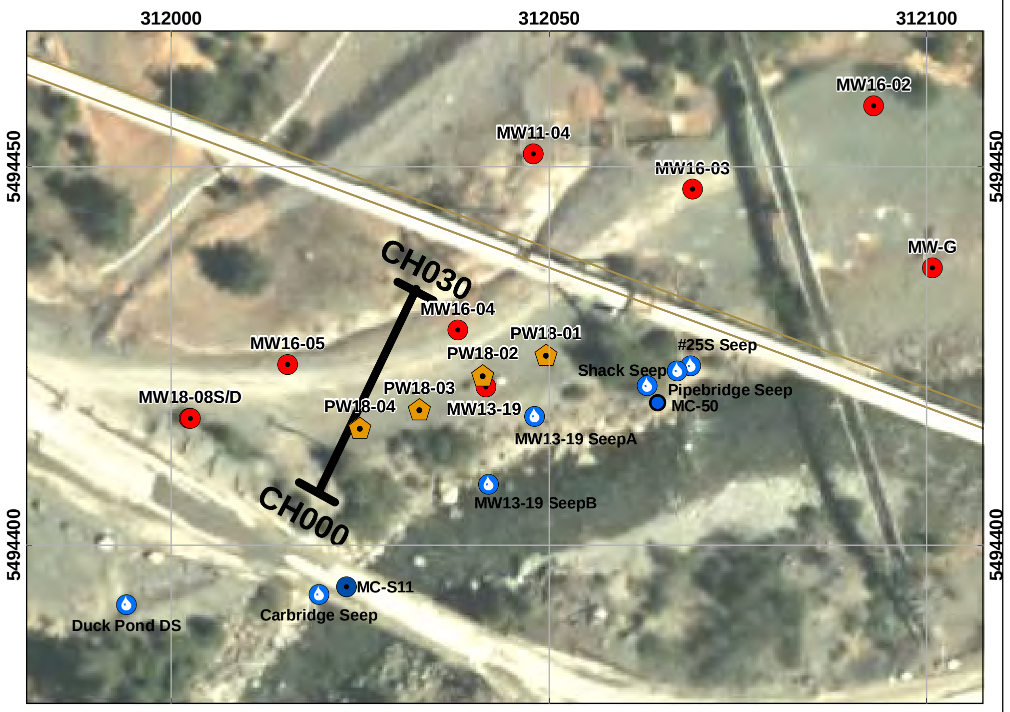
Client: nyrstar	Figure: 5-4
Project: Phase II Lynx SIS Conceptual Design Update	Project No: 212011
Report No: 212011/6	Last Update: July 27, 2018
Nyrstar Myra Falls, BC, Canada	Drawn:
Original File: Receding Flow Base Case_27July2018.pptx	

S:\Files\Projects\212000 Nyrstar\212011 2017 Closure Planning Support\GIS_CAD\Maps\Report 6\Figure5-4_LYNX_Scenarios_July2018.mxd

Scenario 0:
Operation of PW18 Wells

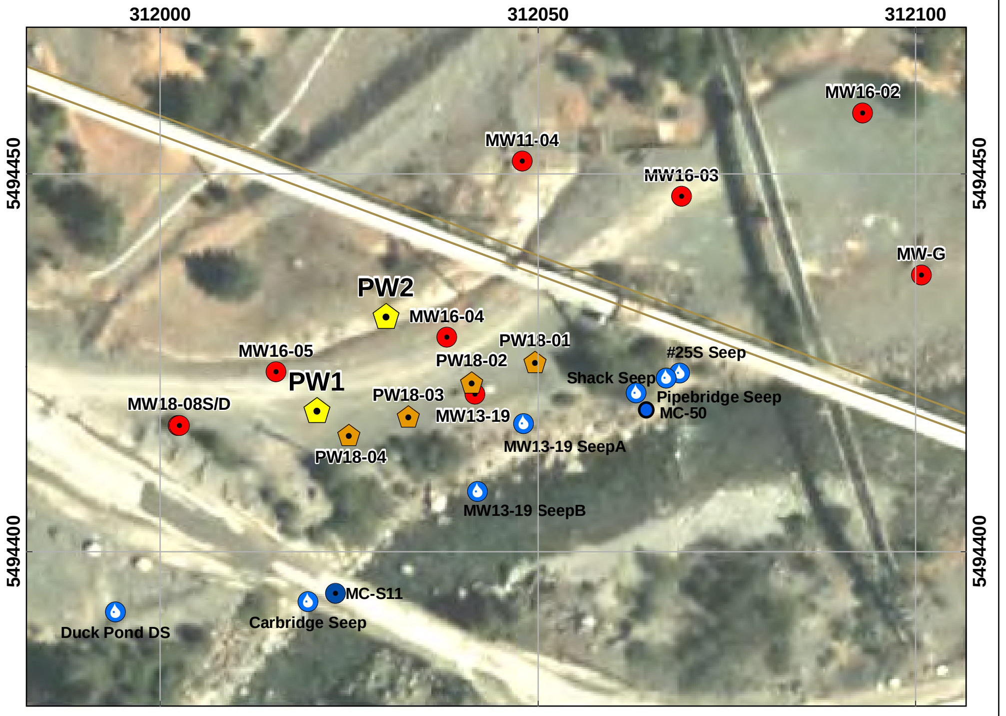


Scenario 1:
Shallow Rock Drain along PW18 Alignment



Scenario 3:
Shallow Rock Drain along Preferred Alignment

Scenario 2:
Replacement of PW18 Wells with 2 High-Capacity Wells



Scenario 4:
2 High-Capacity Pumping Wells along Preferred Alignment

Legend

⬠	Proposed High-Capacity Pumping Well
⊢⊣	Proposed Shallow Drain
●	Monitoring Well
⬠	Pumping Well
●	Surface Water Station
💧	Seep or Surface Water

Phase II Lynx SIS Design Options

N
W E
S

Scale 1:1,000
0 5 10 20 30 40 50 Meters

NAD83 UTM Zone10N

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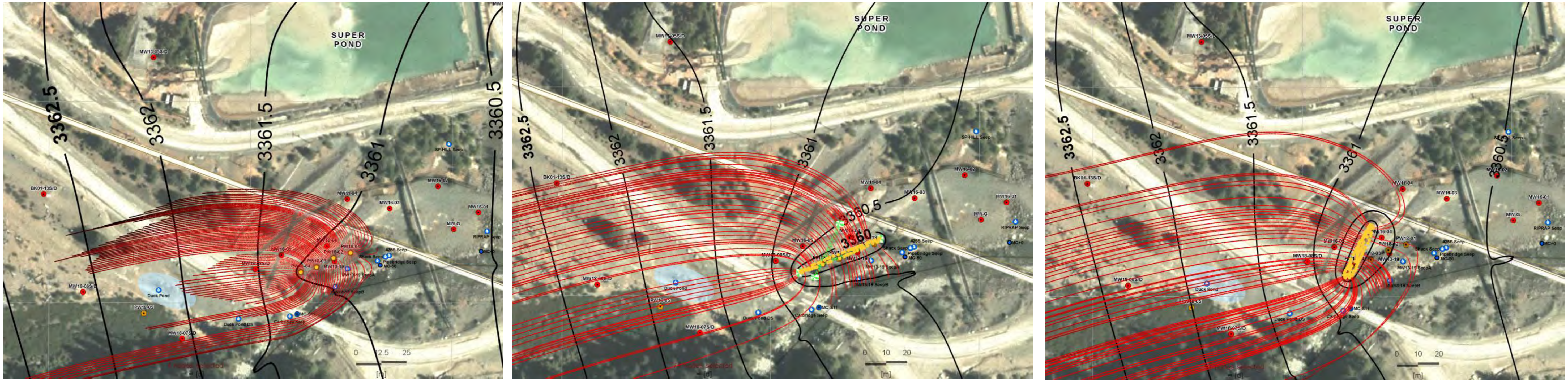
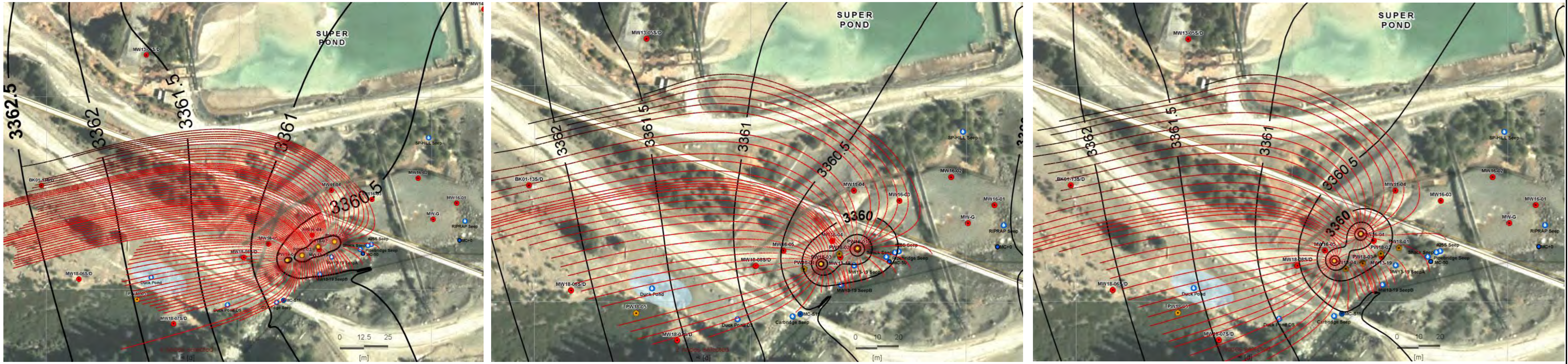
Client: nyrstar	Figure: 5-5
Project: Phase II Lynx SIS Conceptual Design Update	Project No: 212011
Report No: 212011/6	Last Update: Jul 30, 2018
Nyrstar Myra Falls, BC, Canada	Drawn: L.R.
Original File: Figure5-4_LYNX_Scenarios_July2018.mxd	



Interim SIS: 4 Pumping Wells at 11 L/s total

Scenario 1: Shallow Rock Drain along PW18 Alignment (Q= 24.8 L/s)

Scenario 3: Shallow Rock Drain along Northeast Alignment (Q= 21.3 L/s)



Scenario 0: 4 Pumping Wells at 24 L/s total

Scenario 2: 2 Pumping Wells at 34 L/s total

Scenario 4: 2 Pumping Wells at 34 L/s total

Simulated Flow Field & Capture Zone for High Flow Conditions
Pumping Level = 3359.5 m MD (Base Case K) – Slice 2

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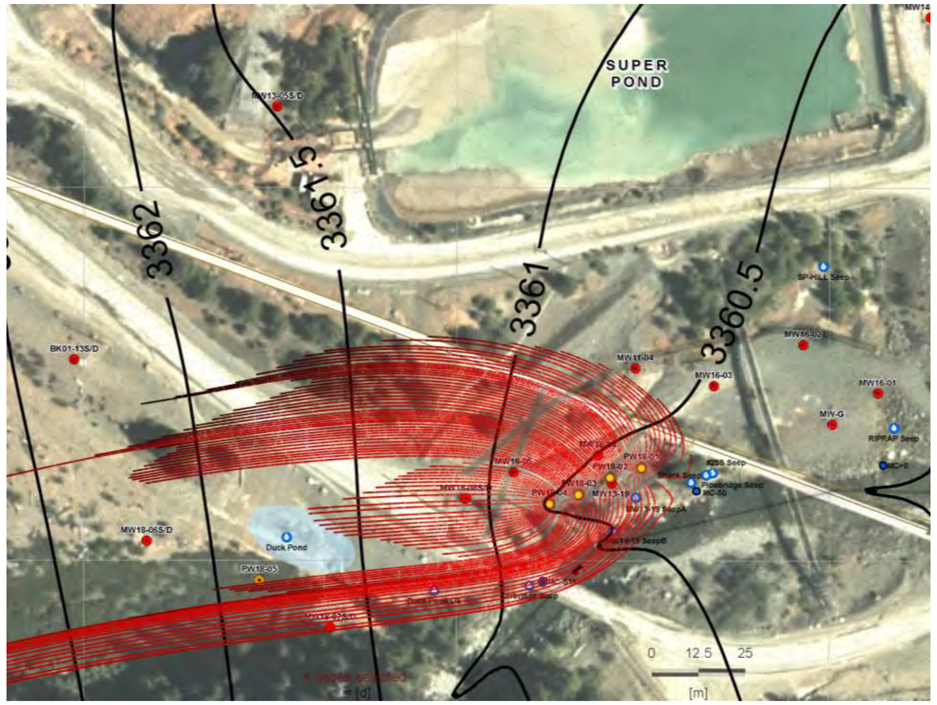
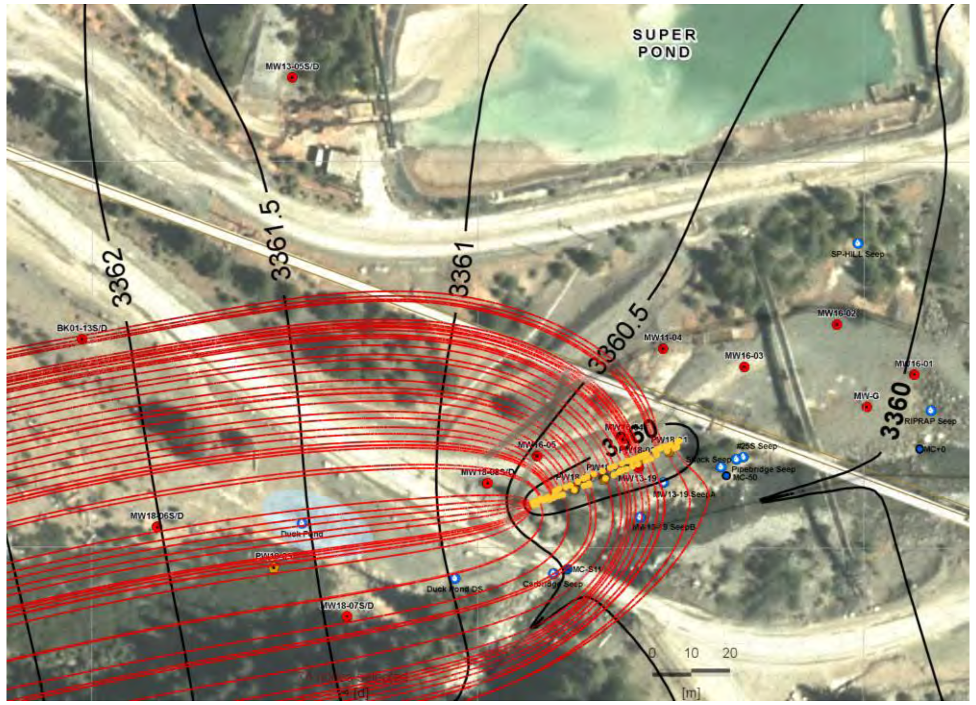
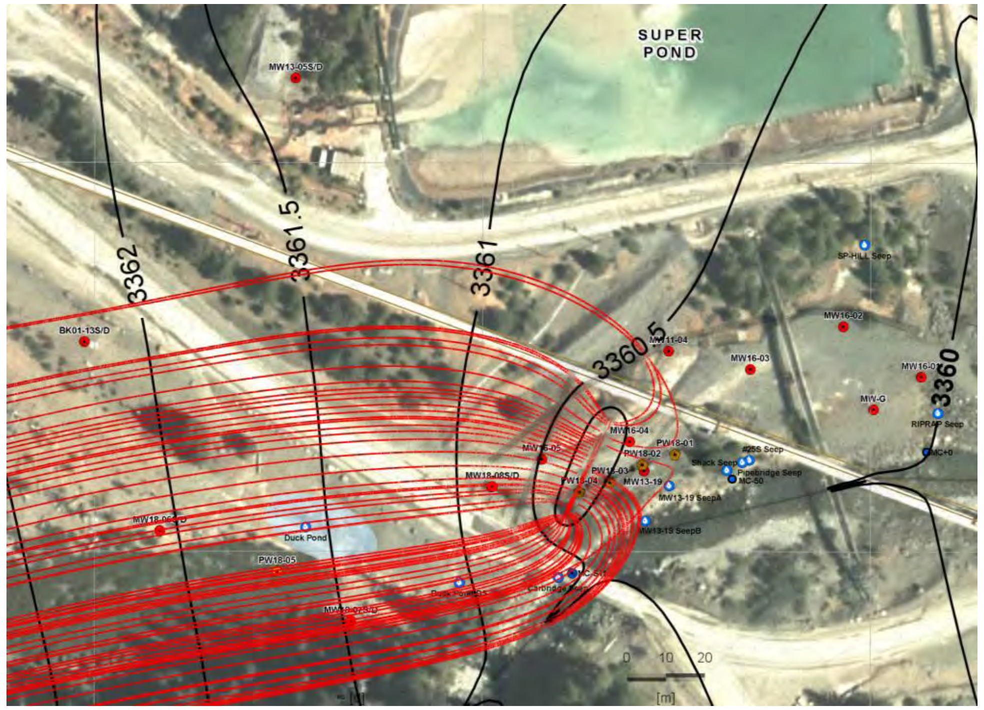
Client: nyrstar	**Figure: 5-6**
Project: Phase II Lynx SIS Conceptual Design Update	Project No: 212011
Report No: 212011/6	Last Update: July 27, 2018
Nyrstar Myra Falls, BC, Canada	Drawn:
Original File:Receding Flow Base Case_27July2018.pptx	



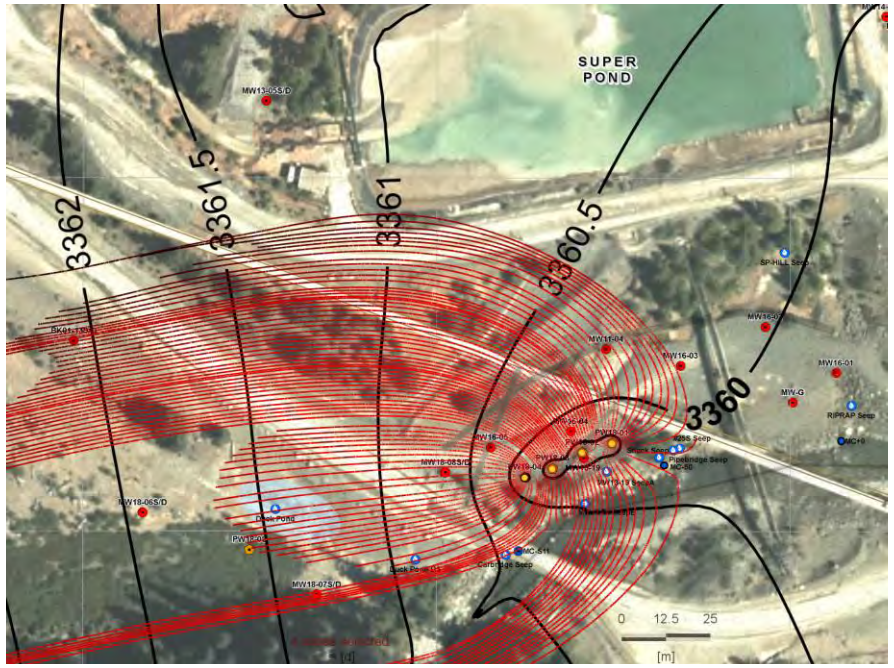
Interim SIS: 4 Pumping Wells at 11 L/s total



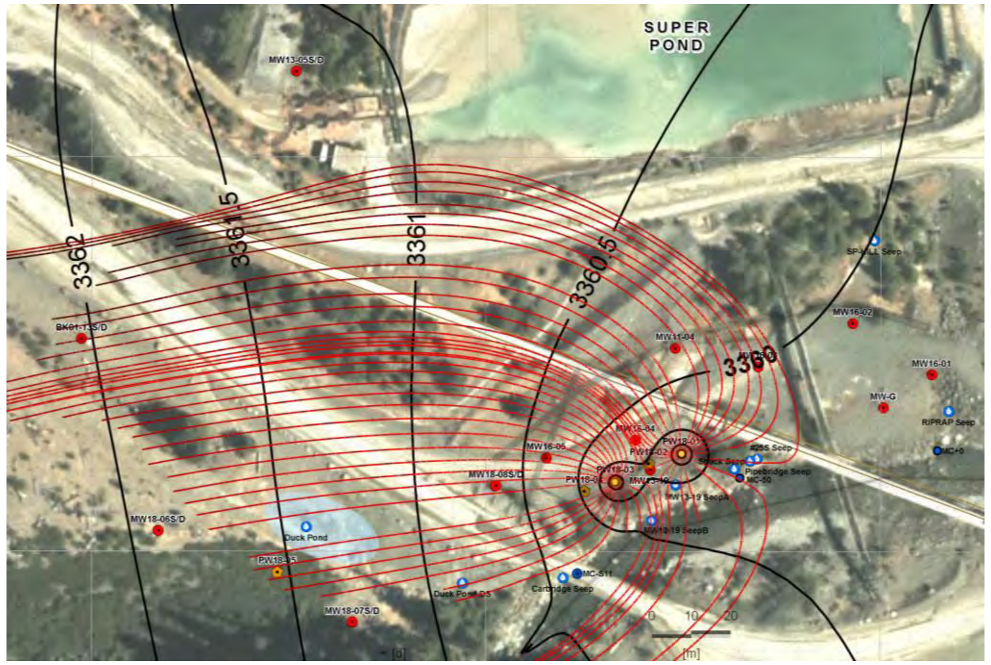
Scenario 1: Shallow Rock Drain along PW18 Alignment (Q= 19.6 L/s)



Scenario 3: Shallow Rock Drain along Northeast Alignment (Q= 17.0 L/s)



Scenario 0: 4 Pumping Wells at 24 L/s total



Scenario 2: 2 Pumping Wells at 26 L/s total

Scenario 4: 2 Pumping Wells at 28 L/s total

Simulated Flow Field & Capture Zone for Receding Flow Conditions
Pumping Level = 3359.5 m MD (Base Case K) – Slice 2

Robertson GeoConsultants Inc.

Client: nyrstar	**Figure: 5-7**
Project: Phase II Lynx SIS Conceptual Design Update	Project No: 212011
Report No: 212011/6	Last Update: July 27, 2018
Nyrstar Myra Falls, BC, Canada	Drawn:
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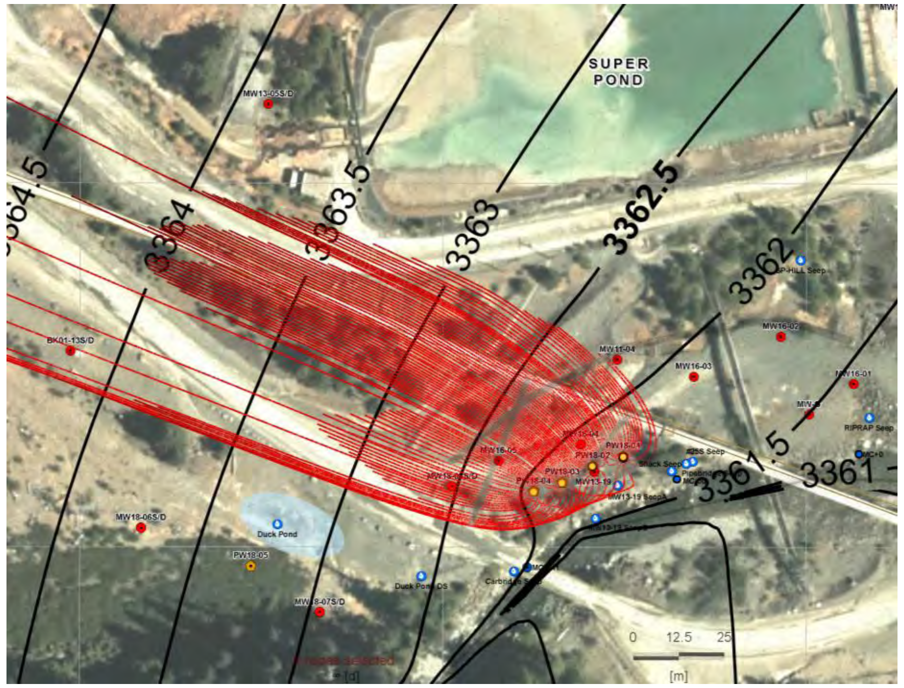
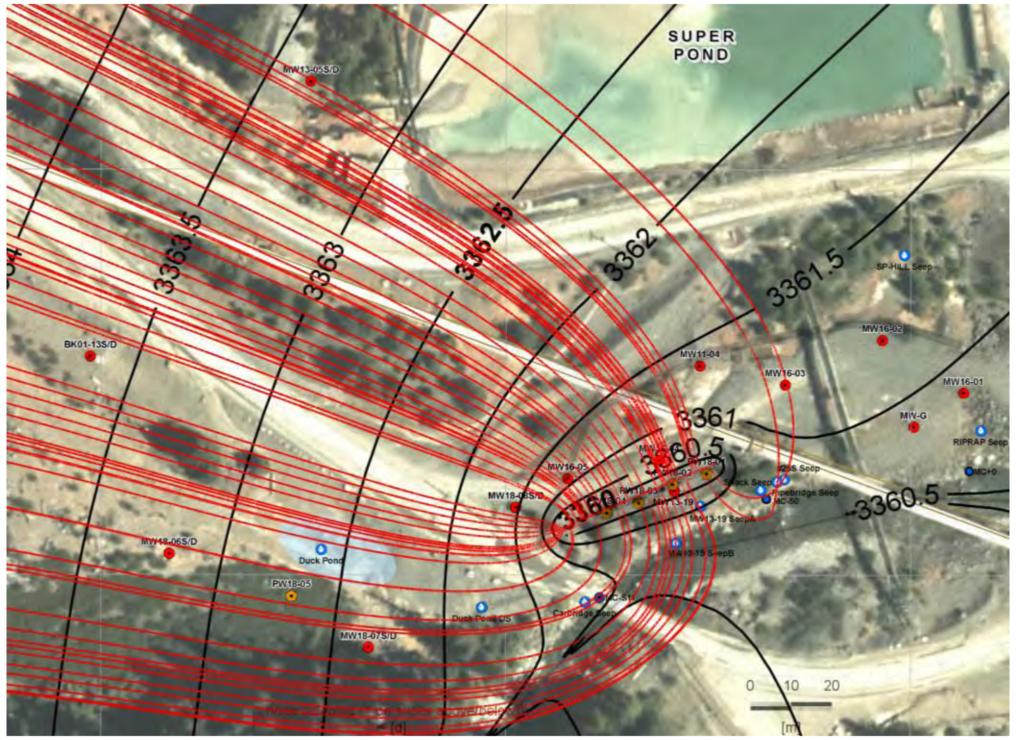
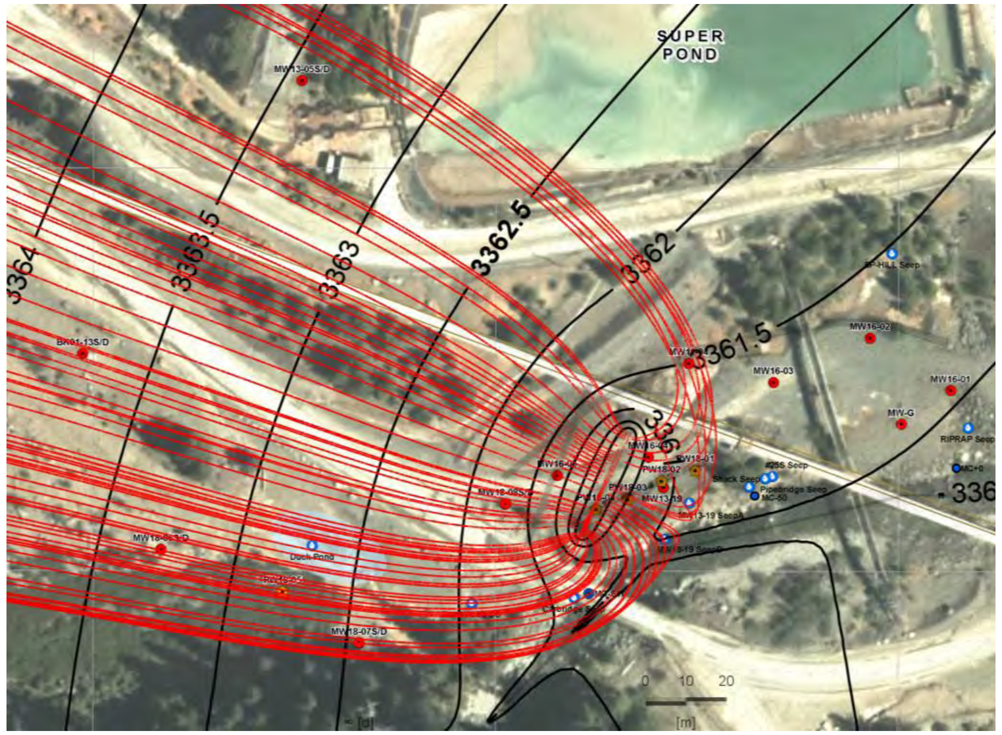


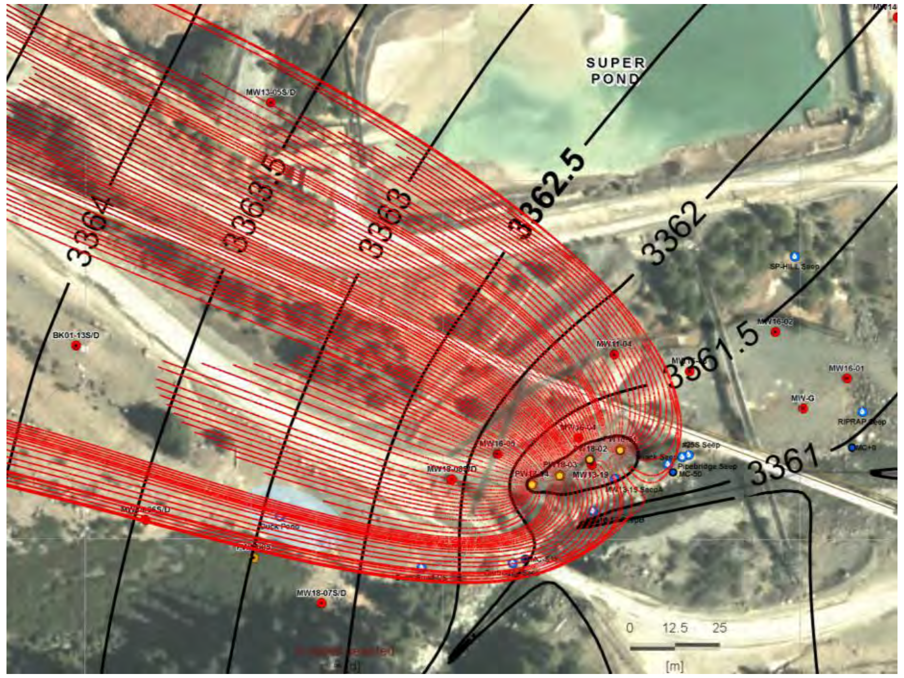
Interim SIS: 4 Pumping Wells at 11 L/s total



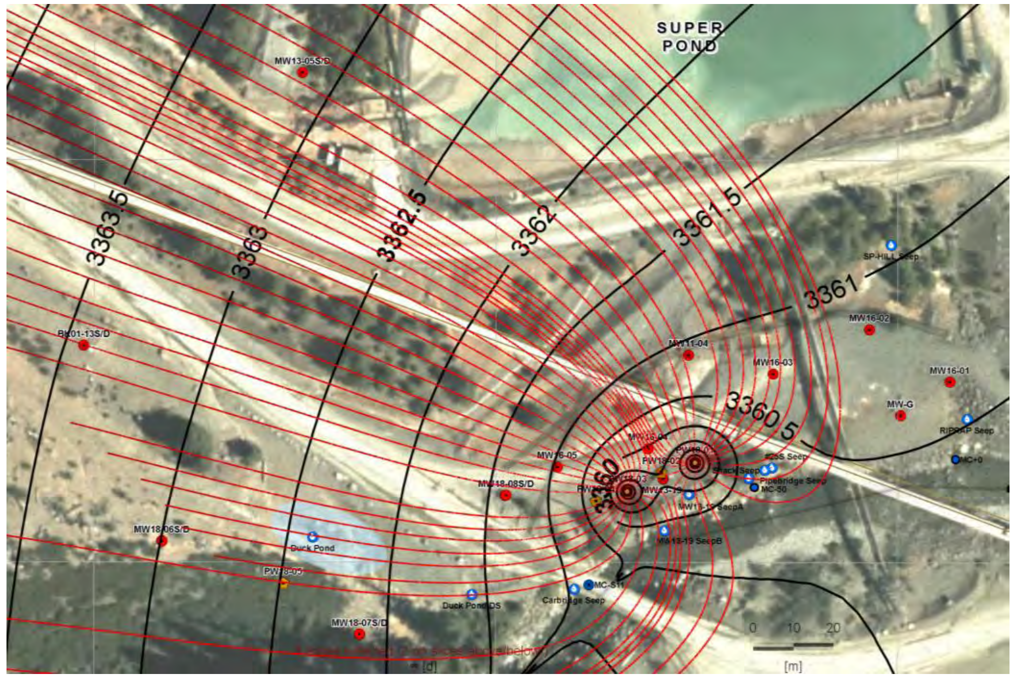
Scenario 1: Shallow Rock Drain along PW18 Alignment (Q= 35.8 L/s)



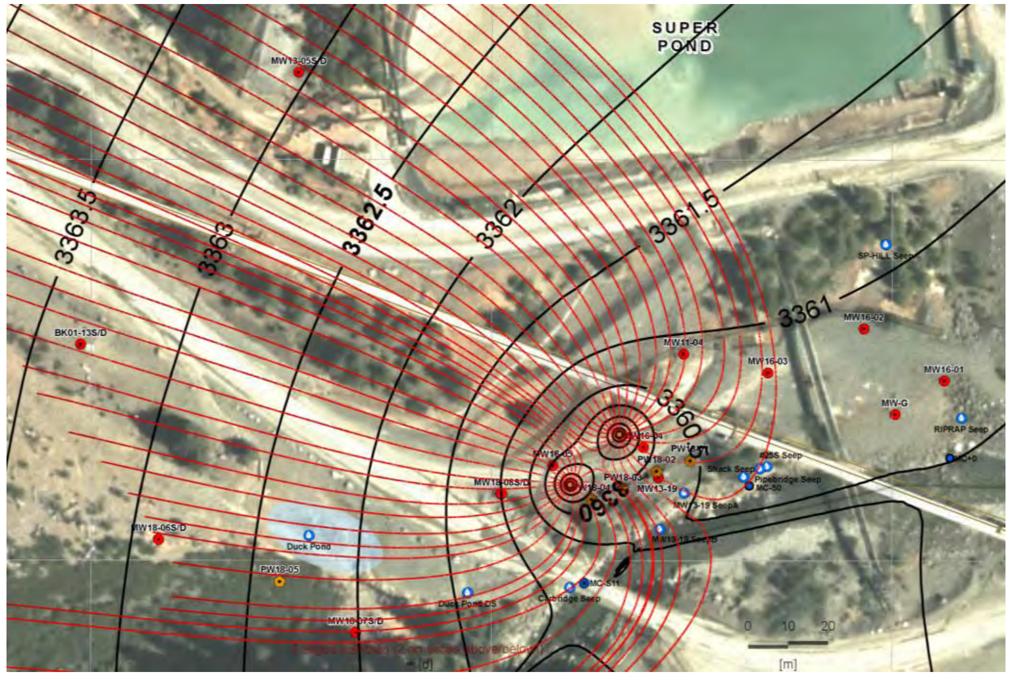
Scenario 3: Shallow Rock Drain along Northeast Alignment (Q= 30.9 L/s)



Scenario 0: 4 Pumping Wells at 24 L/s total



Scenario 2: 2 Pumping Wells at 48 L/s total

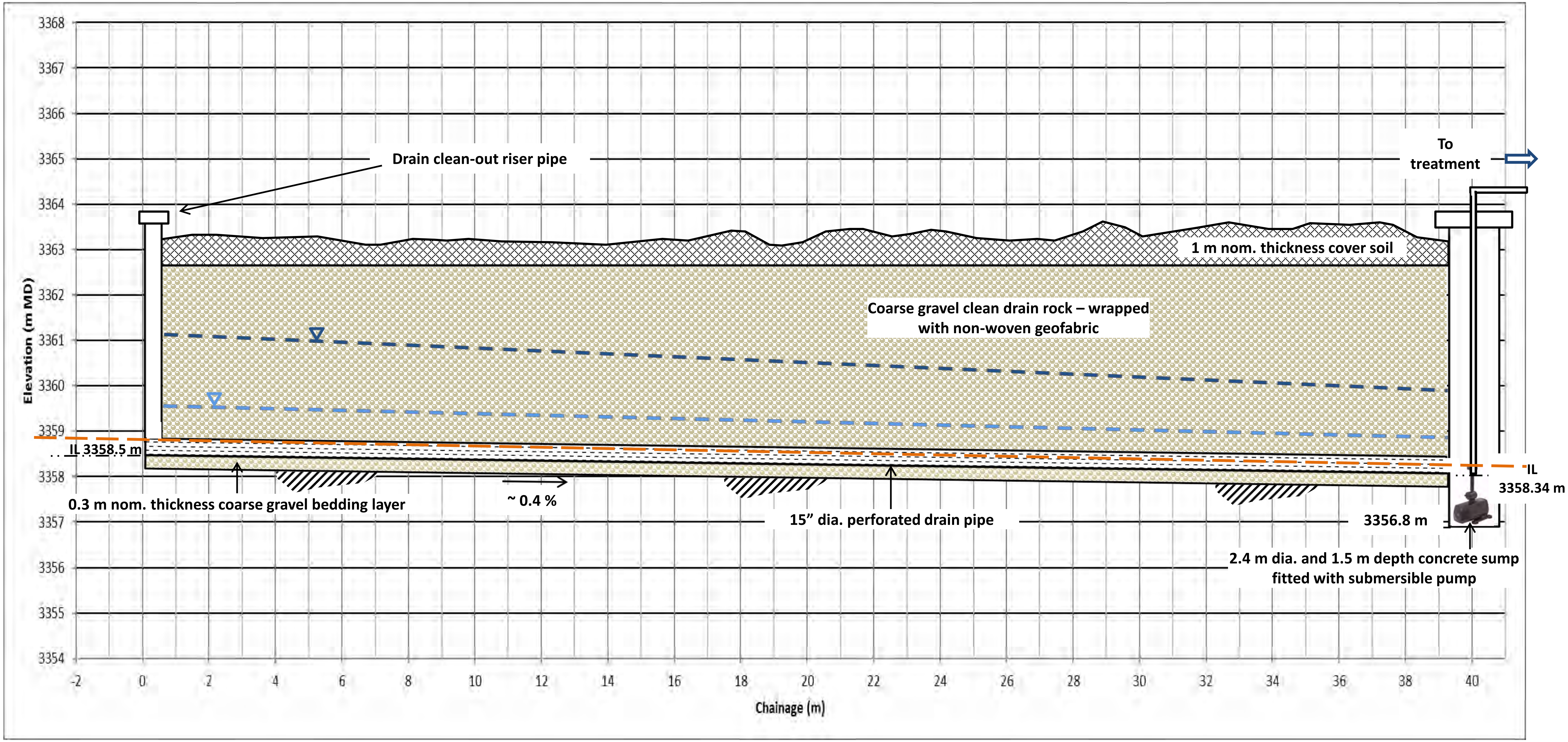


Scenario 4: 2 Pumping Wells at 48 L/s total

Simulated Flow Field and Capture Zone for Receding Flow Conditions & PW14 Off Pumping Level = 3359.5 m MD (Base Case K) – Slice 2

Robertson GeoConsultants Inc.

Client: nyrstar	Figure: 5-8
Project: Phase II Lynx SIS Conceptual Design Update	Project No: 212011
Report No: 212011/6	Last Update: July 27, 2018
Nyrstar Myra Falls, BC, Canada	Drawn:
Original File:Receding Flow Base Case_27July2018.pptx	



Legend

▽ Low Flow – 30 March 2018

▽ High Flow – 19 November 2018

– – Approx. Myra Creek bed level

Notes

- Conceptual design only

Conceptual Design of Shallow Drain for Scenario 1 (along PW18 Alignment)

Myra Falls Mine Site

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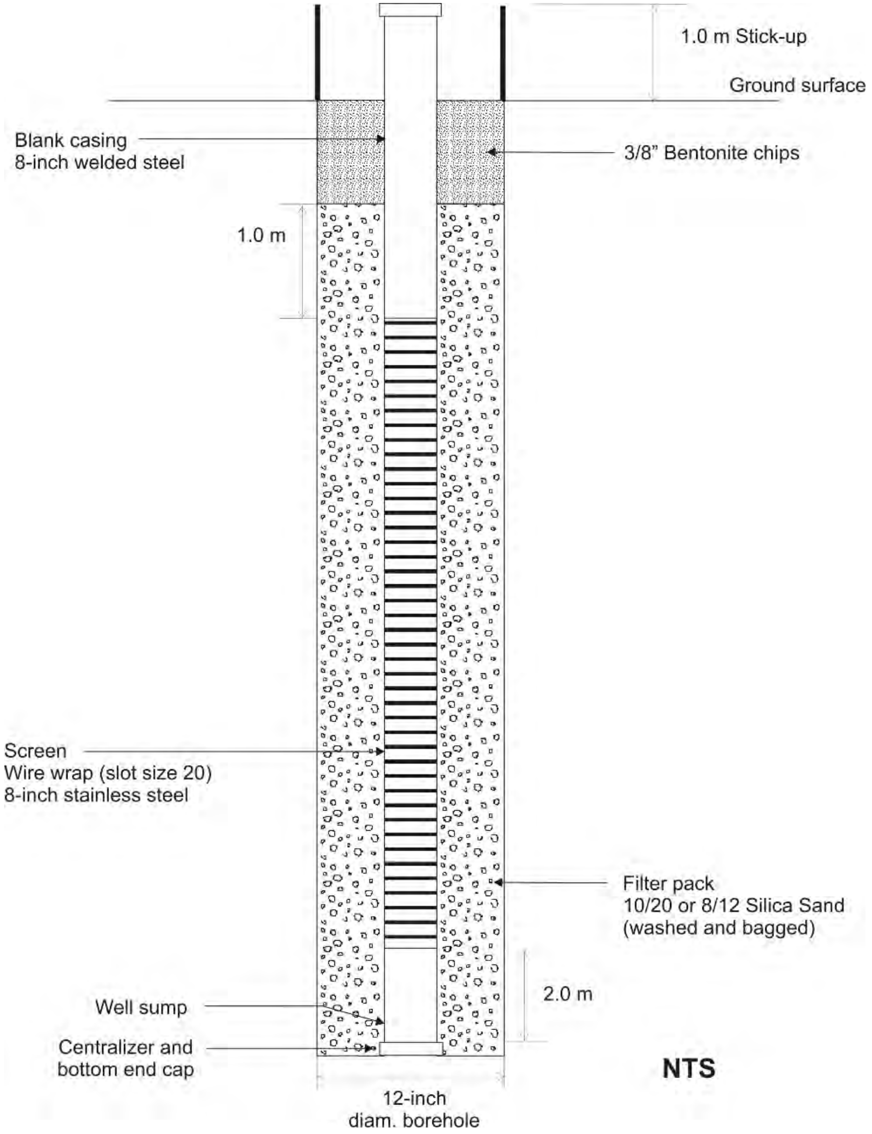
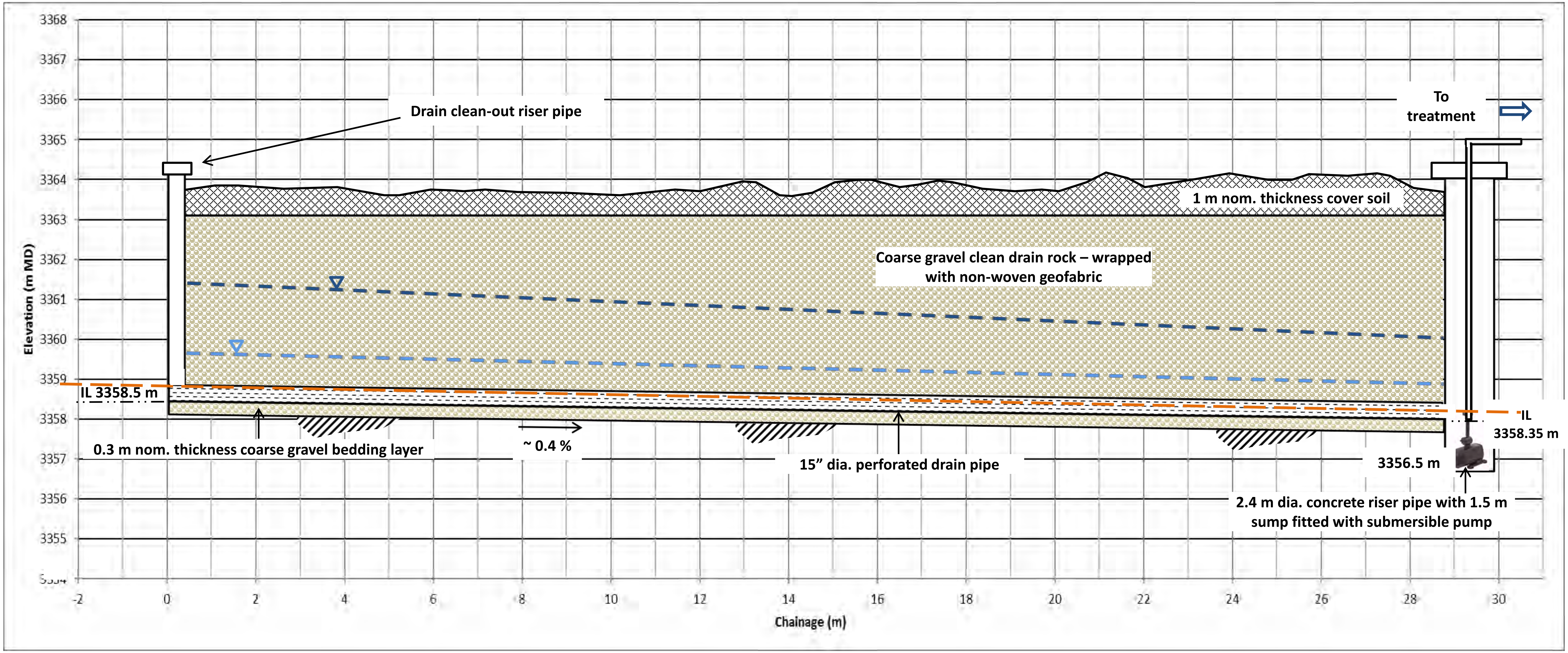
Client: nyrstar	**Figure: 6-1**
Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: July 2018
Original File:	



Conceptual Design of Pumping Wells (for Scenario 2&4)

Robertson GeoConsultants Inc.

Client: Nyrstar Myra Falls	**Figure: 6-2**
Project: Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: July 2018
Original File	



Legend

▽ Low Flow – 30 March 2018

▽ High Flow – 19 November 2018

– – Approx. Myra Creek bed level

Notes

- Conceptual design only

Conceptual Design of Shallow Drain for Scenario 3 (Northeast Alignment)

Myra Falls Mine Site

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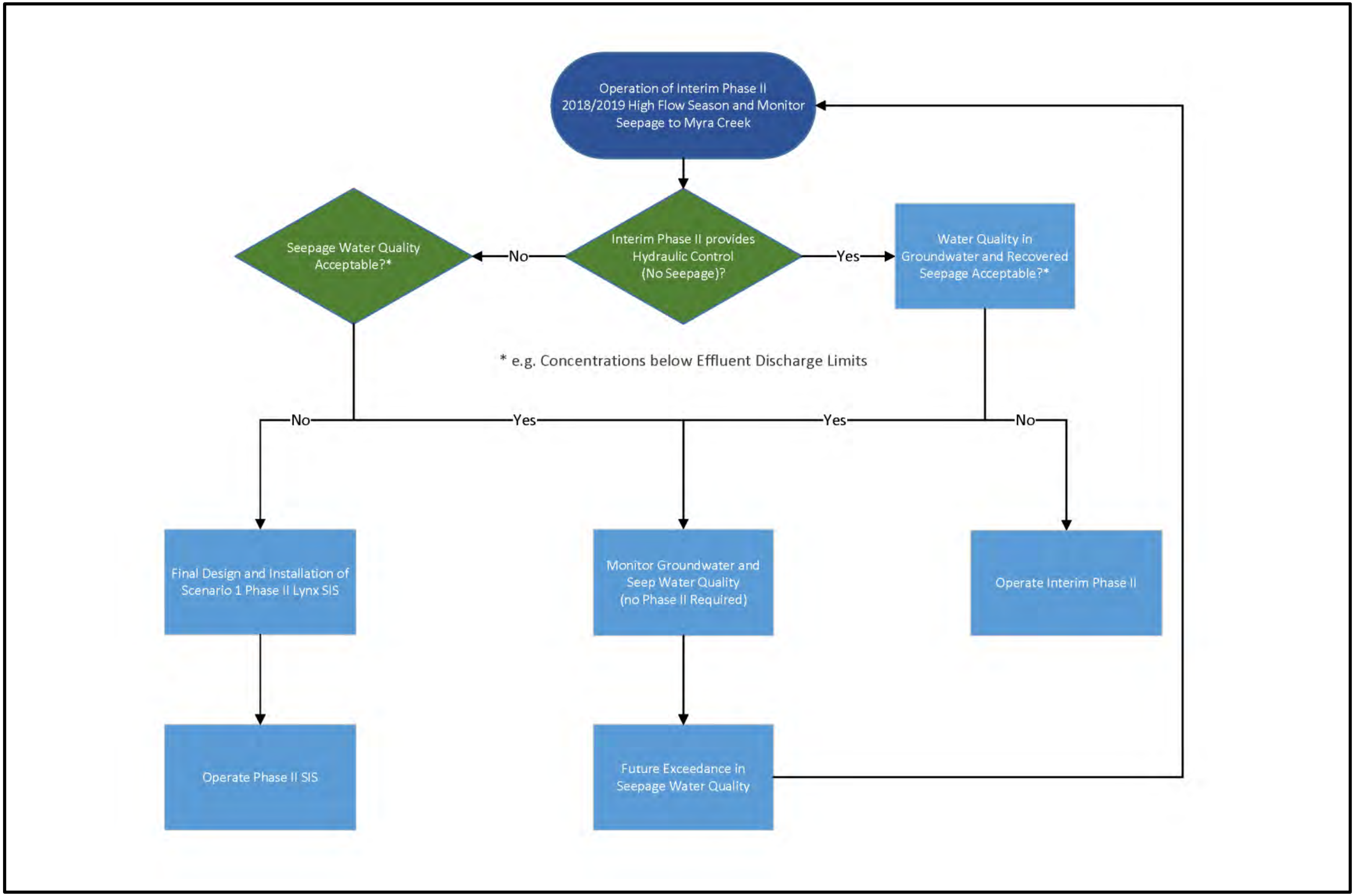
Client: nyrstar	**Figure: 6-3**
Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: July 2018
Original File:	



Recommended Approach for Implementation of Phase II Lynx SIS

Robertson GeoConsultants Inc.

Client: Nyrstar Myra Falls	**Figure: 6-4**
Project: Phase II Lynx SIS Update	Project No: 212011
Report No: 212011/6	Last Update: July 2018
Original File	

Appendix A

Drilling Photo Log

Photo 1: Boart Longyear LS250 Sonic Track drill rig.

Photo 2: Site set-up at MW18-07S/D during drilling. Drill rods and casing were carried from the rack to the drill rig. The John Deere 323d Terrain Loaded was used to transport drill equipment and materials between drillling locations.

Photo 3: 6” Schedule 80 PVC (left) and 20-slot screen section used for pumping well installations (right).

Photo 4: End cap used for pumping wells (left). 10/20 filter sand used for all installations (right).

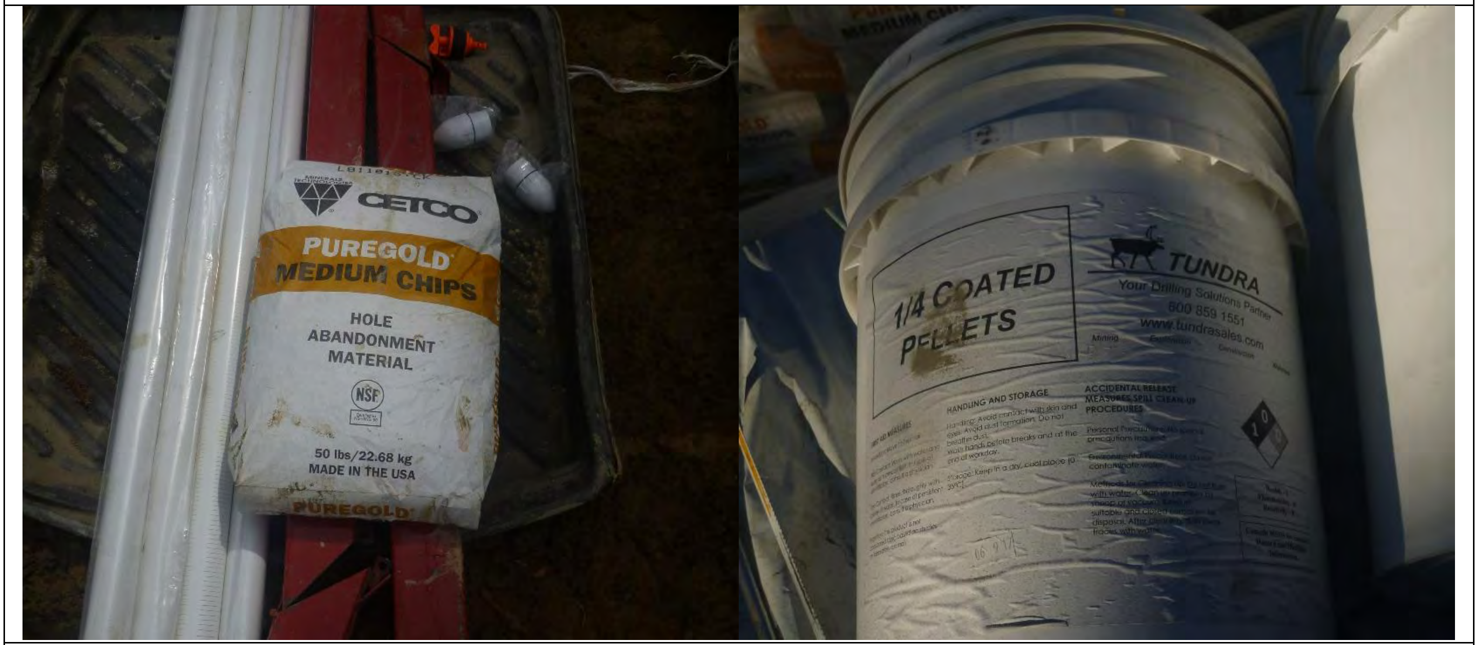


Photo 5: Bentonite chips with 2” Schedule 40 PVC, steel protective casing, J-plugs, and monitoring well end caps (left). Bentonite pellets used to seal all pumping and monitoring wells (right).

Photo 6: 2” monitoring wells with red protective casing at MW18-06S/D (top left), MW18-07S/D (top right), and MW18-08S/D (bottom left). All locations are nested installations with both shallow and deep wells installed together in one borehole.

Photo 4: Pumping well installations at PW18-01, PW18-02, PW18-03, and PW18-05.

Photo 5: Soil cores at MW18-06S/D (from 0’ to 60’).

Photo 6: Soil cores at MW18-07S/D (from 0’ to 60’).

Photo 7: Soil cores at MW18-08S/D (from 0 to 60’).

Photo 8: Soil cores at PW18-01 (from 0 to 37’).

Photo 9: Soil cores at PW18-02 (from 0 to 37').

Photo 10: Soil cores at PW18-03 (from 0 to 37’).

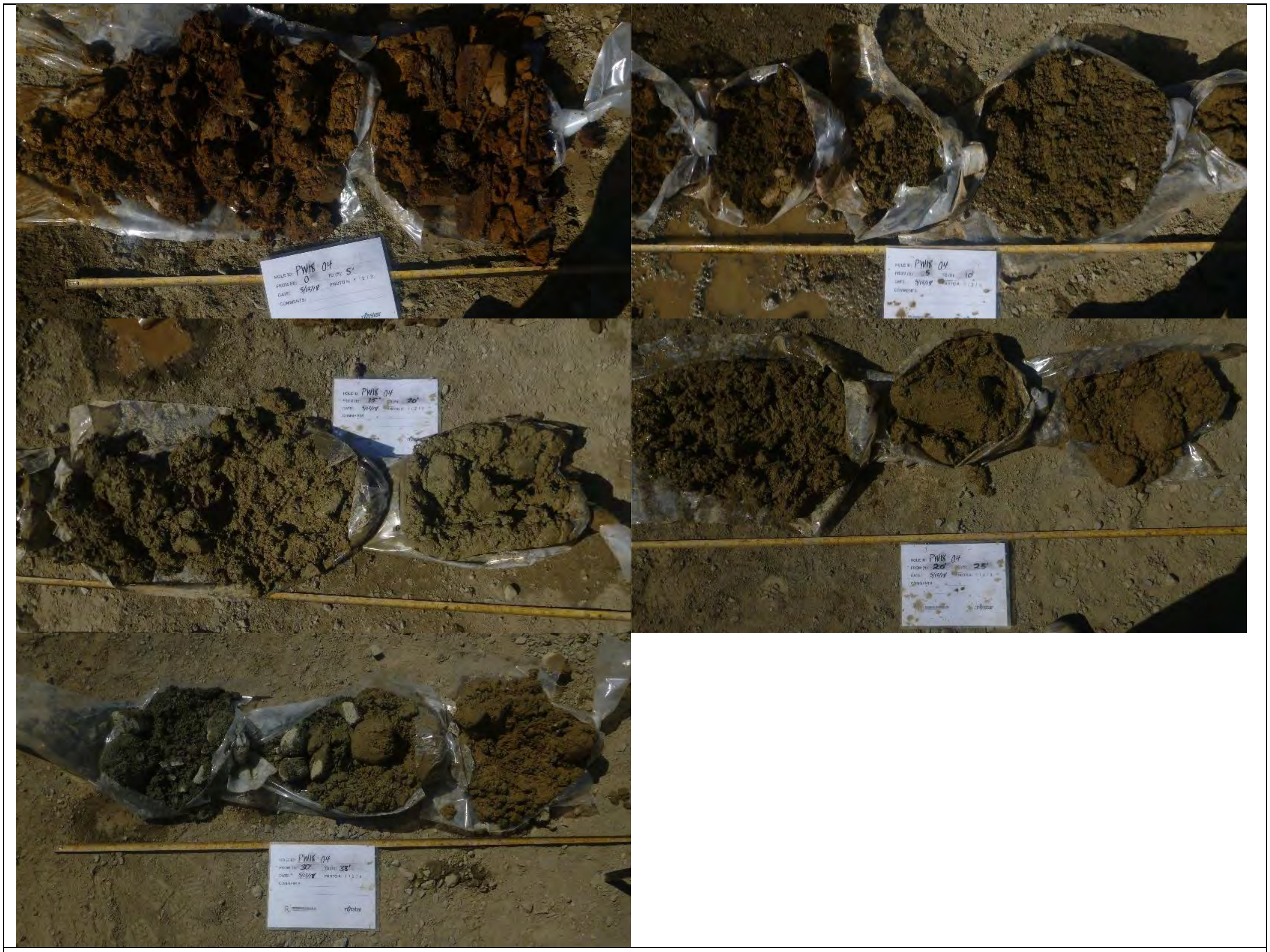


Photo 11: Soil cores at PW18-04 (from 0 to 38’).

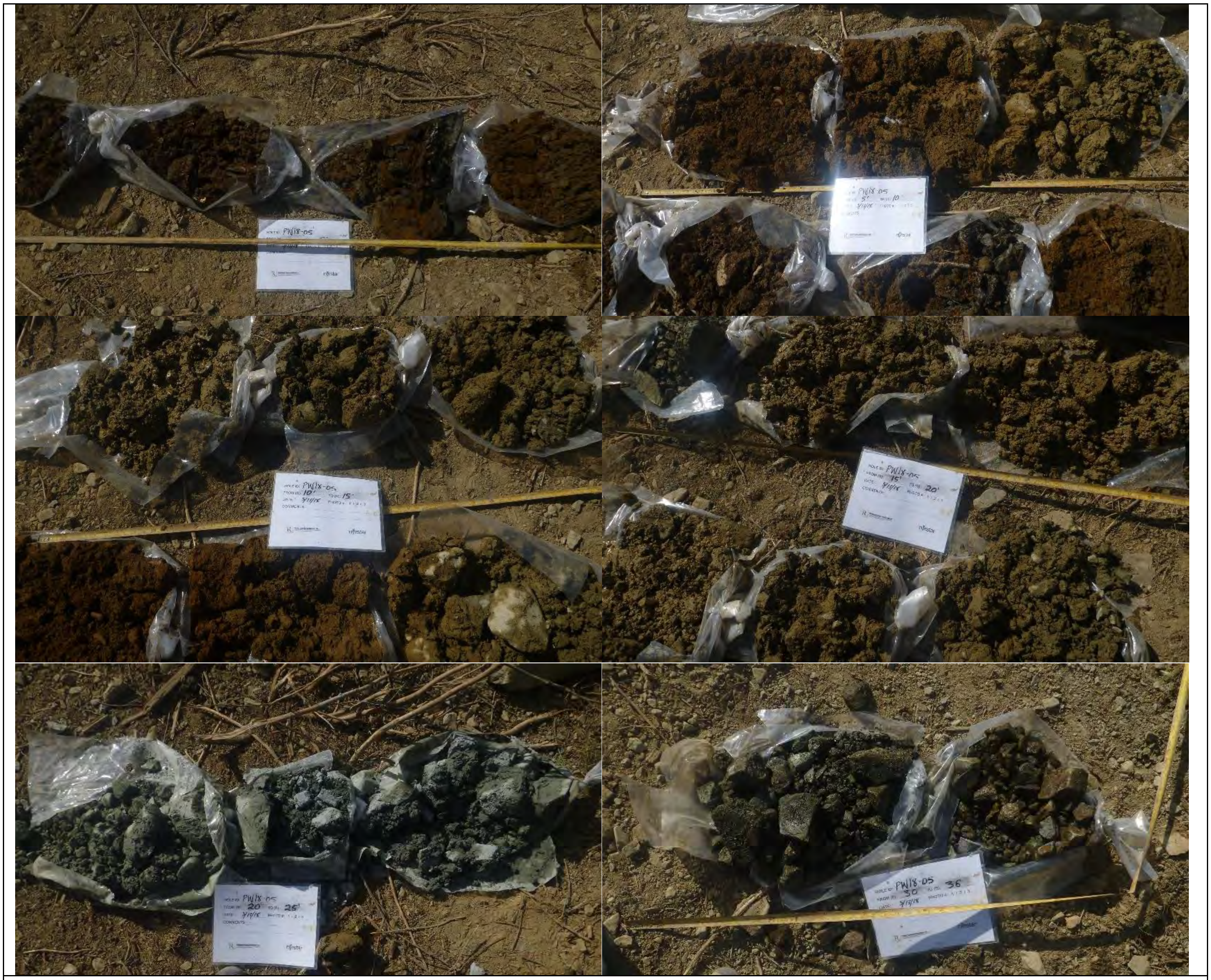


Photo 12: Soil cores at PW18-05 (from 0 to 36’).

Appendix B

Borehole Logs

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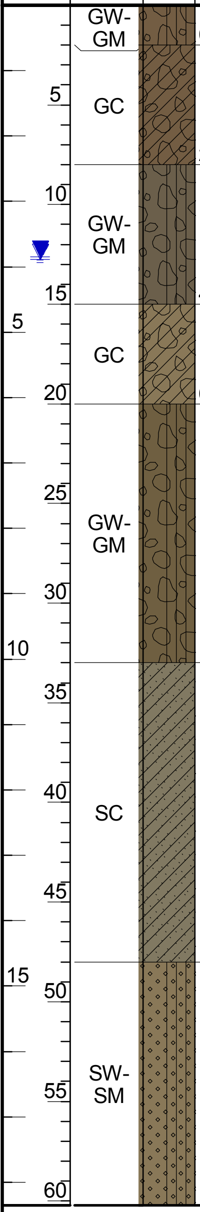
WELL NUMBER MW18-06S/D

PAGE 1 OF 1

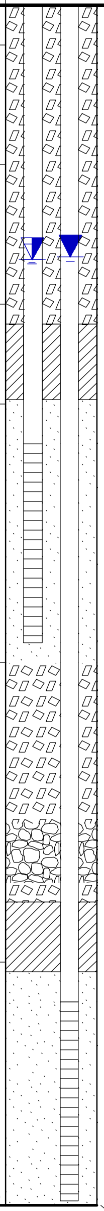
CLIENT Nyrstar
PROJECT NAME 2018 Lynx Seepage Drilling
PROJECT NUMBER 212011
PROJECT LOCATION Myra Falls
DATE STARTED 5/10/18 **COMPLETED** 5/11/18
GROUND ELEVATION 3366 m **HOLE SIZE** 6"/7"
DRILLING CONTRACTOR Blue Max Drilling
NORTHING 5494405 **EASTING** 311917
DRILLING METHOD Sonic
GROUND WATER LEVELS:
LOGGED BY Amanda Schevers **CHECKED BY** Christoph Wels
▽ **SHALLOW STATIC** 3.89 m bgs / Elev 3362.11 m (5/16/18)
NOTES Drill water pH 8.0, EC 39 uS/cm
▼ **DEEP STATIC** 3.85 m bgs / Elev 3362.15 m (5/16/18)
WELL STICK-UP **SHALLOW** 0.91 m **DEEP** 0.91 m

DEPTH (m/ft)	U.S.C.S.	MATERIAL DESCRIPTION	Elevation [m asl]
0.61	GW-GM	WELL GRADED GRAVEL WITH SILT AND SAND (GW-GM): fine to coarse gravel, 40% sand, 10% fines, non plastic, angular to subangular, brown (10YR 4/3), wet, loose, iron oxide staining, organics present (roots, rootlets, bark)	3365.39
2.44	GC	CLAYEY GRAVEL (GC): poorly graded fine to coarse gravel, 10% sand, 40% fines, medium plasticity, subrounded, brown (10YR 4/3), medium dense, iron oxide staining, primarily coarse gravel, high oxidation in top 60 cm of interval, black ash in top 30 cm (recorded forest forest fire onsite)	3363.56
4.57	GW-GM	WELL GRADED GRAVEL WITH SILT AND SAND (GW-GM): fine to coarse gravel, 30% sand, 10% fines, non plastic, angular, dark grayish brown (2.5Y 4/2), wet, loose, occasional oxide staining on gravel	3361.43
6.10	GC	CLAYEY GRAVEL WITH SAND (GC): well graded fine to coarse gravel, 30% sand, 25% fines, high plasticity, angular to subangular, light olive brown (2.5Y 5/3), moist, medium dense, 10% cobbles (largest 11 cm)	3359.90
10.06	GW-GM	WELL GRADED GRAVEL WITH SILT AND SAND (GW-GM): fine to coarse gravel, 40% sand, 10% fines, low plasticity, subangular, olive brown (2.5Y 4/3), moist, loose	3355.94
14.63	SC	CLAYEY SAND WITH GRAVEL (SC): poorly graded fine to coarse sand, 15% gravel, 20% fines, medium plasticity, subangular, moist, loose to medium dense, primarily fine to medium sand, colour grades from dark greenish gray (GLEY 1 4/10Y) to olive gray (5Y 5/2), cobble from 10.4-11 m, gravel increases with depth (35% in bottom 60 cm of interval), till (?)	3351.37
18.35	SW-SM	WELL GRADED SAND WITH SILT AND GRAVEL (SW-SM): fine to coarse sand, 40% gravel, 10% fines, non plastic, subangular to subrounded, light olive brown (2.5Y 5/3), wet, loose	3347.65

GRAPHIC LOG



WELL DIAGRAM & DRILLING NOTES



3.0 m dry

6.1 m dry

9.1 m pH 5.5, EC 225

12.2 m pH 5.4, EC 352

15.2 m pH 5.8, EC 348

18.3 m pH 6.2, EC 221

Bottom of hole at 18.35 m.

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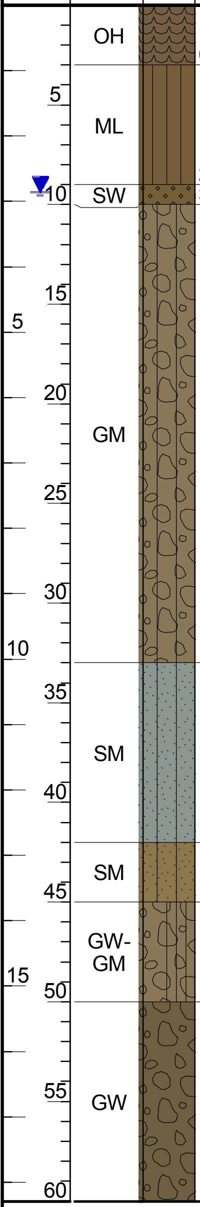
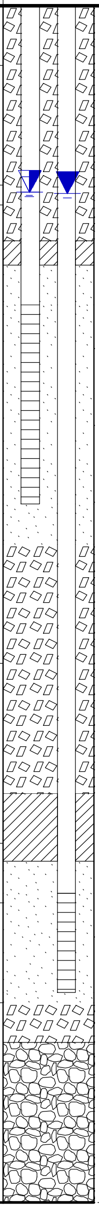
WELL NUMBER MW18-07S/D

PAGE 1 OF 1

CLIENT Nyrstar
PROJECT NAME 2018 Lynx Seepage Drilling
PROJECT NUMBER 212011
PROJECT LOCATION Myra Falls
DATE STARTED 5/10/18 **COMPLETED** 5/10/18
GROUND ELEVATION 3364.54 m **HOLE SIZE** 6"/7"
DRILLING CONTRACTOR Blue Max Drilling
NORTHING 5494382 **EASTING** 311966
DRILLING METHOD Sonic
GROUND WATER LEVELS:
LOGGED BY Amanda Schevers **CHECKED BY** Christoph Wels
▽ **SHALLOW STATIC** 2.85 m bgs / Elev 3361.69 m (5/16/18)
NOTES Drill water pH 6.7, EC 40 uS/cm
▼ **DEEP STATIC** 2.87 m bgs / Elev 3361.67 m (5/16/18)
WELL STICK-UP **SHALLOW** 1.09 m **DEEP** 1.10 m



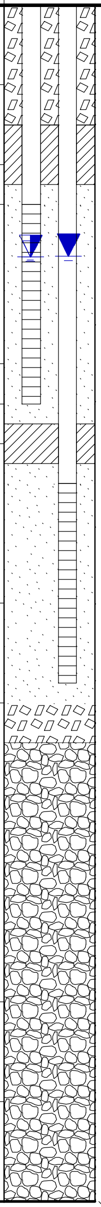


DEPTH (m)	U.S.C.S.	MATERIAL DESCRIPTION	Elevation [m asl]	WELL DIAGRAM & DRILLING NOTES
0.91	OH	ORGANIC SOIL WITH SAND (OH): fines, 20% sand, medium plasticity, brown (10YR 4/3), moist, soft, fine sand, abundant organic matter (peat, bark, roots, rootlets) giving spongy texture, pockets of grey fines throughout	3363.63	
2.74	ML	SILTY SAND (ML): fines, 20% sand, low plasticity, dark yellowish brown (10YR 4/4), moist, soft to medium stiff, occasional pockets of heavily oxidized material (brown 7.5YR 4/4), fine sand with pockets of medium sand throughout, roots and rootlets	3361.80	0-3.0 m 70% recovery
3.05	SW	WELL GRADED SAND (SW): fine to coarse sand, 10% gravel, 5% fines, subangular, olive brown (2.5Y 4/4), moist, loose, primarily fine to medium sand, fine gravel	3361.49	3.0 m dry
10.06	GM	SILTY GRAVEL WITH SAND (GM): well graded fine to coarse gravel, 30% sand, 20% fines, low plasticity, angular to subrounded, light olive brown (2.5Y 5/3), wet, loose to medium dense, trace roots and rootlets, trace pockets of iron oxidation	3354.48	5.5 m pH 5.4, EC 455 8.4 m pH 6.3, EC 313
12.80	SM	SILTY SAND WITH GRAVEL (SM): well graded fine to medium sand, 15% gravel, 20% fines, low plasticity, wet, soft, greenish gray (GLEY 1 5/10Y), coarse subrounded gravel	3351.74	10.7-12.2 m 30% recovery 11.3 m pH 6.7, EC 257
13.72	SM	SILTY SAND WITH GRAVEL (SM): well graded fine to coarse sand, 40% gravel, 15% fines, low plasticity, subangular to subrounded, light olive brown (2.5Y 5/4), wet, loose	3350.82	
15.24	GW-GM	WELL GRADED GRAVEL WITH SILT AND SAND (GW-GM): fine to coarse gravel, 40% sand, 10% fines, non plastic, angular to subangular, light olive brown (2.5Y 5/3), wet, loose, occasional oxidation on gravel clasts	3349.30	14.6 m pH 7.7, EC 130
18.29	GW	WELL GRADED GRAVEL WITH SAND (GW): fine to coarse gravel, 40% sand, 5% fines, subangular to subrounded, wet, loose, colour grades from olive gray (5Y 5/2) to olive brown (2.5Y 4/3), angular to subangular at colour change, trace to 5% fines	3346.25	

Bottom of hole at 18.30 m.

WELL NUMBER MW18-08S/D

CLIENT Nyrstar
PROJECT NAME 2018 Lynx Seepage Drilling
PROJECT NUMBER 212011
PROJECT LOCATION Myra Falls
DATE STARTED 5/9/18 **COMPLETED** 5/10/18
GROUND ELEVATION 3364.65 m **HOLE SIZE** 6"/7"
DRILLING CONTRACTOR Blue Max Drilling
NORTHING 5494417 **EASTING** 312002
DRILLING METHOD Sonic
GROUND WATER LEVELS:
LOGGED BY Amanda Schevers **CHECKED BY** Christoph Wels
▽ **SHALLOW STATIC** 3.85 m bgs / Elev 3360.80 m (5/15/18)
NOTES Drill water pH 8.5, EC 42 uS/cm
▼ **DEEP STATIC** 3.84 m bgs / Elev 3360.81 m (5/15/18)
WELL STICK-UP **SHALLOW** 1.11 m **DEEP** 1.12 m



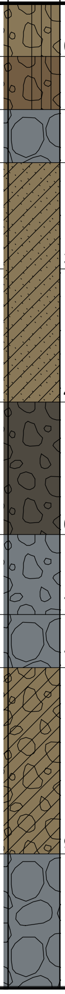
DEPTH (m/ft)	U.S.C.S.	MATERIAL DESCRIPTION	Elevation [m asl]	WELL DIAGRAM & DRILLING NOTES
1.22	SW-SM	WELL GRADED SAND WITH SILT AND GRAVEL (SW-SM): fine to coarse sand, 30% gravel, 10% fines, non plastic, subangular, dry, very loose, 20% cobbles (largest 15 cm), colour grades from light olive brown (2.5Y 5/3) to grayish brown (10YR 5/2), wet in top 30 cm, piece of cardboard present, 30 cm boulder at bottom of interval, (FILL)	3363.43	difficult drilling - boulder
2.44	GW-GC	WELL GRADED GRAVEL WITH CLAY AND SAND (GW-GC): fine to coarse gravel, 40% sand, 10% fines, medium plasticity, subangular, dark yellowish brown (10YR 4/4), moist, very loose, iron oxide staining, 30 cm layer of black organic matter (roots, bark, and peat) at top of interval, likely start of natural ground	3362.21	
3.05	GW-GC	WELL GRADED GRAVEL WITH CLAY AND SAND (GW-GC): fine to coarse gravel, 40% sand, 10% fines, medium plasticity, angular to subangular, olive (5Y 4/4), moist, very loose, iron oxide staining, occasional 1-2 cm pieces of weakly cemented material	3361.60	3.0 m dry
5.49	GC	CLAYEY GRAVEL WITH SAND (GC): well graded fine to coarse gravel, 25% sand, 15% fines, high plasticity, angular to subangular, olive gray (5Y 5/2), moist, loose, 25% cobbles (largest 16 cm), strong odor (not diesel, but chemical - almost like burning rubber)	3359.16	3.0-6.1 m 60% recovery
6.10	GW-GC	WELL GRADED GRAVEL WITH CLAY AND SAND (GW-GC): fine to coarse gravel, 30% sand, 10% fines, medium plasticity, subangular, dry, loose, greenish gray (GLEY 1 5/10Y), 20% cobbles (largest 13 cm)	3358.55	6.1 m pH 9.4, EC 90
6.71		Dacite (?) cobbles, dark greenish/bluish gray, fine grained	3357.94	difficult drilling 6.7-8.5 m soft/loose material
9.14	GW	WELL GRADED GRAVEL WITH SAND (GW): fine to coarse gravel, 30% sand, trace fines, angular, wet, loose, 20% cobbles (largest 12 cm), all same lithology (dacite?), dark greenish/bluish gray	3355.51	6.1-9.1 m 50% recovery
10.67	SW	WELL GRADED SAND WITH GRAVEL (SW): fine to coarse sand, 40% gravel, 5% fines, angular to subangular, light olive brown (2.5Y 5/3), wet, very loose, 10% cobbles (largest 10 cm), 20 cm of well graded fine to medium sand on top of interval	3353.98	9.1 m pH 8.6, EC 151
15.24	SW-SC	CLAYEY SAND WITH GRAVEL (SW-SC): well graded fine to coarse gravel, 30% sand, 20% fines, high plasticity, subangular, light olive brown (2.5Y 5/3), wet, medium dense to dense, 15% cobbles (largest 12 cm), colour grades from light olive brown (2.5Y 5/3) to dark greenish gray (GLEY 1 4/10Y), trace bark at 13.1 m where colour change occurs, fines slightly higher after colour change	3349.41	9.1-12.2 m 80% recovery 12.2 m pH 6.5, EC 280
16.76	GC	CLAYEY GRAVEL WITH SAND (GC): well graded fine to coarse gravel, 30% sand, 15% fines, medium plasticity, subangular to subrounded, wet, loose, 20% cobbles, greenish gray (GLEY 1 5/10Y)	3347.89	15.2 m pH 7.7, EC 235
18.29	GW	WELL GRADED GRAVEL WITH SAND (GW): fine to coarse gravel, 45% sand, 5% fines, subangular to subrounded, grayish brown (2.5Y 5/2), wet, loose	3346.36	18.3 m pH 7.7, EC 148

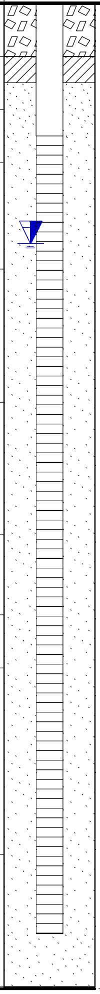
Bottom of hole at 18.30 m.

WELL NUMBER PW18-01

PAGE 1 OF 1

CLIENT Nyrstar
PROJECT NAME 2018 Lynx Seepage Drilling
PROJECT NUMBER 212011
PROJECT LOCATION Myra Falls
DATE STARTED 5/11/18 **COMPLETED** 5/12/18
GROUND ELEVATION 3363.11 m **HOLE SIZE** 9"
DRILLING CONTRACTOR Blue Max Drilling
NORTHING 5494425 **EASTING** 312050
DRILLING METHOD Sonic
GROUND WATER LEVELS:
LOGGED BY Amanda Schevers **CHECKED BY** Christoph Wels
▽ **SHALLOW STATIC** 2.75 m bgs / Elev 3360.36 m (5/15/18)
NOTES Drill water pH 7.8, EC 582 uS/cm
▼ **DEEP STATIC** --- ()
WELL STICK-UP **SHALLOW** 0.67 m **DEEP**





DEPTH (m/ft)	U.S.C.S.	MATERIAL DESCRIPTION		Elevation [m asl]	WELL DIAGRAM & DRILLING NOTES
2	GW-GM	WELL GRADED GRAVEL WITH SILT AND SAND (GW-GM): fine to coarse gravel, 30% sand, 10% fines, non plastic, subangular to subrounded, light olive brown (2.5Y 5/3), wet, loose, (FILL)	0.61	3362.50	
4	GW-GM	WELL GRADED GRAVEL WITH SILT AND SAND (GW-GM): fine to coarse gravel, 20% sand, 10% fines, non plastic, subangular, brown (10YR 4/3), moist, medium dense, iron oxide staining, 40% cobbles (largest 18 cm), organics in top 1 m (roots, rootlets, peat), (FILL)	1.22	3361.89	
6		COBBLE/BOULDER dacite	1.83	3361.28	
2 8 ▽ 10	SC	CLAYEY SAND WITH GRAVEL (SC): well graded fine to coarse sand, 35% gravel, 15% fines, low plasticity, subangular, light olive brown (2.5Y 5/3), moist, medium dense, trace organics (rootlets), fill?	3.05	3360.06	3.0 m dry
12 4 14	SC	CLAYEY SAND WITH GRAVEL (SC): well graded fine to coarse sand, 40% gravel, 15% fines, medium plasticity, subangular, light olive brown (2.5Y 5/3), moist, medium dense	4.57	3358.54	4.6 m pH 6.7, EC 342
16 18 6 20	GW	WELL GRADED GRAVEL WITH SAND (GW): fine to coarse gravel, 40% sand, trace fines, angular to subangular, very dark gray (2.5Y 3/1), wet, loose, 10% cobbles (largest 16 cm), oxide staining on gravel	6.10	3357.01	6.1 m pH 6.2, EC 427
22	GP	POORLY GRADED GRAVEL (GP): gravel, trace sand, 10% cobbles (largest 16 cm), primarily coarse gravel	7.01	3356.10	
24		COBBLE/BOULDER 33 cm and 20 cm core recovered, bluish gray, fine grained, dacite (?)	7.62	3355.49	7.6 m pH 6.9, EC 496
8 26 28 30 32	GC	CLAYEY GRAVEL WITH SAND (GC): well graded fine to coarse gravel, 30% sand, 15% fines, medium plasticity, subangular, light olive brown (2.5Y 5/3), wet, medium dense, 15% cobbles (largest 30 cm), top 30 cm heavily washed (or transition from talus to clayey material), bottom 60 cm heavily washed gravel	9.75	3353.36	9.1 m pH 7.0, EC 374
10 34 36		COBBLE/BOULDER >45 cm boulder recovery	11.28	3351.83	

Bottom of hole at 11.30 m.

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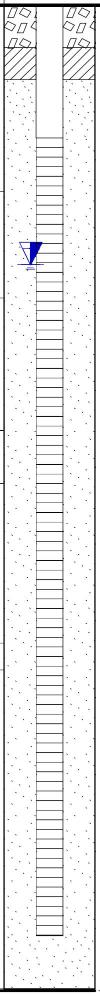
WELL NUMBER PW18-02

PAGE 1 OF 1

CLIENT Nyrstar
PROJECT NAME 2018 Lynx Seepage Drilling
PROJECT NUMBER 212011
PROJECT LOCATION Myra Falls
DATE STARTED 5/12/18 **COMPLETED** 5/12/18
GROUND ELEVATION 3363.33 m **HOLE SIZE** 9"
DRILLING CONTRACTOR Blue Max Drilling
NORTHING 5494422 **EASTING** 312041
DRILLING METHOD Sonic
GROUND WATER LEVELS:
LOGGED BY Amanda Schevers **CHECKED BY** Christoph Wels
▽ **SHALLOW STATIC** 2.97 m bgs / Elev 3360.36 m (5/15/18)
NOTES Drill water pH 7.4, EC 120 uS/cm
▼ **DEEP STATIC** --- ()
WELL STICK-UP **SHALLOW** 0.94 m **DEEP**



DEPTH (m/ft)	U.S.C.S.	GRAPHIC LOG	MATERIAL DESCRIPTION	Elevation [m asl]	WELL DIAGRAM & DRILLING NOTES
2 4 6 2	GM	2.13	SILTY GRAVEL WITH SAND (GM): well graded fine to coarse gravel, 30% sand, 15% fines, non plastic, angular to subangular, olive brown (2.5Y 4/3), moist, loose to medium dense, 15% cobbles (largest 15 cm) increasing with depth, heavily washed in top 60 cm, minor oxide staining on gravel, (FILL)	3361.20	difficult drilling
8 ▽10		3.35	COBBLE/BOULDER olive gray (5Y 5/2), cobbles with silty/clayey sand, very hot from drilling - likely rock powder mixed with drill water, max recovery 30 cm	3359.98	3.0 m dry
12 4 14 16	GM	4.88	SILTY GRAVEL WITH SAND (GM): well graded fine to coarse gravel, 30% sand, 15% fines, non plastic, subangular, light olive brown (2.5Y 5/3), moist, loose to medium dense, iron oxide staining, 20% cobbles (largest 22 cm)	3358.45	4.6 m 50L of clean drill water then pumped dry
18	GC	5.49	CLAYEY GRAVEL (GC): poorly graded fine to coarse gravel, 10% sand, 25% fines, subangular, olive gray (5Y 5/2), moist, medium dense, 15% cobbles (largest 20 cm), occasional oxide staining on fracture surfaces, potentially large boulder with abundant rock powder	3357.84	
6 20 22 24		7.32	COBBLE/BOULDER large dacite boulders wtih occasional quartz veins, max recovery 40 cm	3356.01	6.1 m pH 6.8, EC 402
	GW	7.62	WELL GRADED GRAVEL (GW): fine to coarse gravel, trace sand, angular to subangular, iron oxide staining	3355.71	
8 26 28 30 32 10 34 36	GP	11.28	POORLY GRADED GRAVEL (GP): fine to coarse gravel, 10% sand, subangular, grayish brown (2.5Y 5/2), moist, loose, iron oxide staining, 10% cobbles (largest 18 cm)	3352.05	9.1 m 5.98, EC 209 - switched pH probes 10.7 m pH 6.2, EC 177

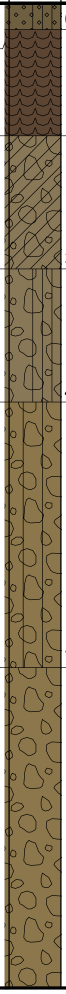
Bottom of hole at 11.30 m.

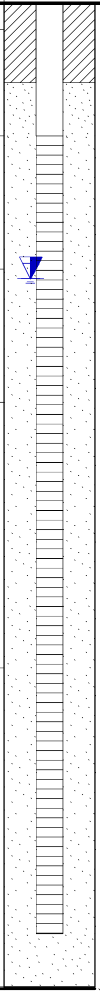
Robertson GeoConsultants
Consulting Engineers and Scientists for the Mining Industry

WELL NUMBER PW18-03

PAGE 1 OF 1

CLIENT Nyrstar
PROJECT NAME 2018 Lynx Seepage Drilling
PROJECT NUMBER 212011
PROJECT LOCATION Myra Falls
DATE STARTED 5/12/18 **COMPLETED** 5/13/18
GROUND ELEVATION 3363.9 m **HOLE SIZE** 9"
DRILLING CONTRACTOR Blue Max Drilling
NORTHING 5494418 **EASTING** 312033
DRILLING METHOD Sonic
GROUND WATER LEVELS:
LOGGED BY Amanda Schevers **CHECKED BY** Christoph Wels
▽ **SHALLOW STATIC** 3.16 m bgs / Elev 3360.74 m (5/15/18)
NOTES Drill water pH 7.0, EC 46 uS/cm
▼ **DEEP STATIC** --- ()
WELL STICK-UP **SHALLOW** 0.35 m **DEEP**





DEPTH (m/ft)	U.S.C.S.	GRAPHIC LOG	MATERIAL DESCRIPTION	Elevation [m asl]	WELL DIAGRAM & DRILLING NOTES
2	SW-SM		WELL GRADED SAND WITH SILT AND GRAVEL (SW-SM): fine to coarse sand, 40% gravel, 10% fines, non plastic, trace cobbles, subangular, olive brown (2.5Y 4/3), wet, loose, (FILL) 0.30	3363.60	
4	OH		ORGANIC SOIL (OH): peat, 10% gravel, 10% sand, non plastic, moist, medium dense, colour grades from dark brown (7.5YR 3/3) to brown (7.5YR 4/4) after first 30 cm, abundant bark, roots and rootlets 1.52	3362.38	
2 6 8 10 ▽	GC		CLAYEY GRAVEL WITH SAND (GC): poorly graded fine to coarse gravel, 30% sand, 25% fines, medium plasticity, subangular, light olive brown (2.5Y 5/3), moist, medium dense to dense, 30 cm cobble at 2.7 m, till (?) 3.05	3360.85	▽ 3.0 m dry
12 4 14	GP-GM		POORLY GRADED GRAVEL WITH SILT AND SAND (GP-GM): fine to coarse gravel, 35% sand, 10% fines, low plasticity, subangular, light olive brown (2.5Y 5/3), moist, loose to medium dense 4.57	3359.33	4.6 m pH 6.10, EC 299
16 18 6 20 22 24	GW-GM		WELL GRADED GRAVEL WITH SILT AND SAND (GW-GM): fine to coarse gravel, 25% sand, 10% fines, non plastic, subangular, light olive brown (2.5Y 5/4), wet, loose, 15% cobbles (largest 20 cm), higher coarse gravel content, top 30 cm heavily washed from drilling 7.62	3356.28	6.1 m pH 6.2, EC 186 7.6 m pH 6.2, EC 177
8 26 28 30 32 10 34 36	GW		WELL GRADED GRAVEL WITH SAND (GW): fine to coarse gravel, 40% sand, trace fines, angular to subangular, light olive brown (2.5Y 5/4), wet, loose, 20% cobbles (largest 30 cm), heavily washed and disturbed (entire sample dropped from core barrel on first retrieval attempt), talus or glaciofluvial (?) 11.28	3352.62	9.1 m pH 6.4, EC 164 11.3 m pH 7.16, EC 131

Bottom of hole at 11.30 m.

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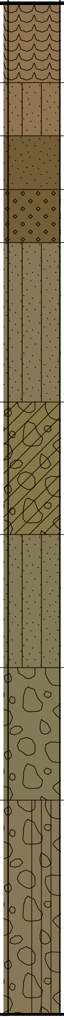
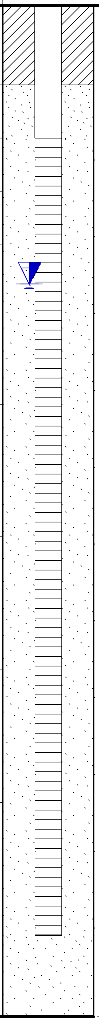
WELL NUMBER PW18-04

PAGE 1 OF 1

CLIENT Nyrstar
PROJECT NAME 2018 Lynx Seepage Drilling
PROJECT NUMBER 212011
PROJECT LOCATION Myra Falls
DATE STARTED 5/13/18 **COMPLETED** 5/13/18
GROUND ELEVATION 3364.35 m **HOLE SIZE** 9"
DRILLING CONTRACTOR Blue Max Drilling
NORTHING 5494415 **EASTING** 312025
DRILLING METHOD Sonic
GROUND WATER LEVELS:
LOGGED BY Amanda Schevers **CHECKED BY** Christoph Wels
▽ **SHALLOW STATIC** 3.19 m bgs / Elev 3361.16 m (5/15/18)
NOTES
▼ **DEEP STATIC** --- ()
WELL STICK-UP **SHALLOW** 0.60 m **DEEP**



DEPTH (m/ft)	U.S.C.S.	MATERIAL DESCRIPTION	Elevation [m asl]	WELL DIAGRAM & DRILLING NOTES
0.91	OH	GRAVELLY ORGANIC SOIL (OH): poorly graded peat, 30% gravel, 10% sand, medium plasticity, subangular to subrounded, yellowish brown (10YR 5/4), moist, medium dense, poorly graded, coarse gravel, abundant organic matter (bark, roots, rootlets), (FILL)	3363.44	
1.52	SM	SILTY SAND (SM): poorly graded fine sand, 20% fines, non plastic, yellowish brown (10YR 5/4), moist, medium dense, poorly graded, abundant organic matter (bark, twigs, roots, rootlets), 5 cm layer on top with black peat	3362.83	
2.13	SP	POORLY GRADED SAND (SP): fine sand, 5% fines, olive brown (2.5Y 4/4), moist, medium dense, darker laminations throughout	3362.22	
2.74	SW	WELL GRADED SAND WITH GRAVEL (SW): fine to coarse sand, 40% gravel, 5% fines, subangular, olive brown (2.5Y 4/4), moist, loose	3361.61	
4.57	SM	SILTY SAND WITH GRAVEL (SM): poorly graded fine sand, 25% gravel, 15% fines, angular to subangular, light olive brown (2.5Y 5/3), moist, medium dense, poorly graded, 25% cobbles in bottom 50 cm	3359.78	3.0 m dry
6.10	GC	CLAYEY GRAVEL WITH SAND (GC): poorly graded fine to coarse gravel, 35% sand, 15% fines, subangular, olive (5Y 5/4), wet, loose to medium dense, poorly graded	3358.25	4.6 m pumped dry after 20 seconds
7.62	SM	SILTY SAND WITH GRAVEL (SM): well graded fine to coarse sand, 40% gravel, 15% fines, non plastic, subangular, olive (5Y 5/3), wet, loose, 30 cm cobble at 22.5 m	3356.73	6.1 m pH 6.4, EC 475
9.14	SW	WELL GRADED GRAVEL WITH SILT AND SAND (SW): fine to coarse sand, 35% sand, 10% fines, non plastic, angular to subangular, olive (5Y 5/3), wet, loose, 10% cobbles (largest 16 cm)	3355.21	7.7 m pH 5.9, EC 241
11.58	GW-GM	WELL GRADED GRAVEL WITH SILT AND SAND (GW-GM): fine to coarse gravel, 35% sand, 10% fines, non plastic, subangular to subrounded, light olive brown (2.5Y 5/3), wet, loose, 10% cobbles (largest 17 cm), heavily washed and disturbed (material dropped from core barrel twice)	3352.77	9.1 m pH 5.9, EC 250

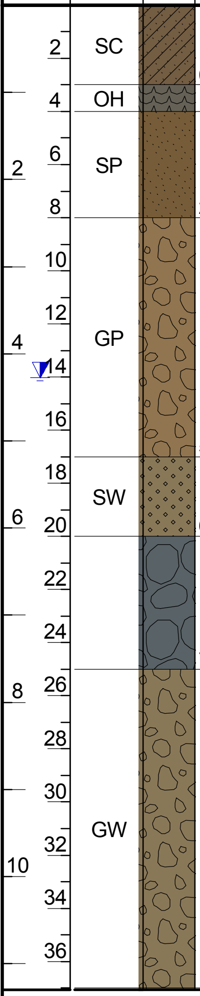


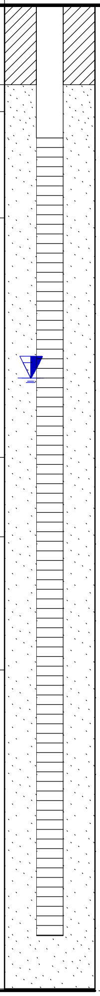
Bottom of hole at 11.60 m.

WELL NUMBER PW18-05

PAGE 1 OF 1

CLIENT Nyrstar
PROJECT NAME 2018 Lynx Seepage Drilling
PROJECT NUMBER 212011
PROJECT LOCATION Myra Falls
DATE STARTED 5/13/18 **COMPLETED** 5/14/18
GROUND ELEVATION 3366.12 m **HOLE SIZE** 9"
DRILLING CONTRACTOR Blue Max Drilling
NORTHING 5494395 **EASTING** 311947
DRILLING METHOD Sonic
GROUND WATER LEVELS:
LOGGED BY Amanda Schevers **CHECKED BY** Christoph Wels
▽ **SHALLOW STATIC** 4.28 m bgs / Elev 3361.85 m (5/16/18)
NOTES
▼ **DEEP STATIC** --- ()
WELL STICK-UP **SHALLOW** 0.58 m **DEEP**



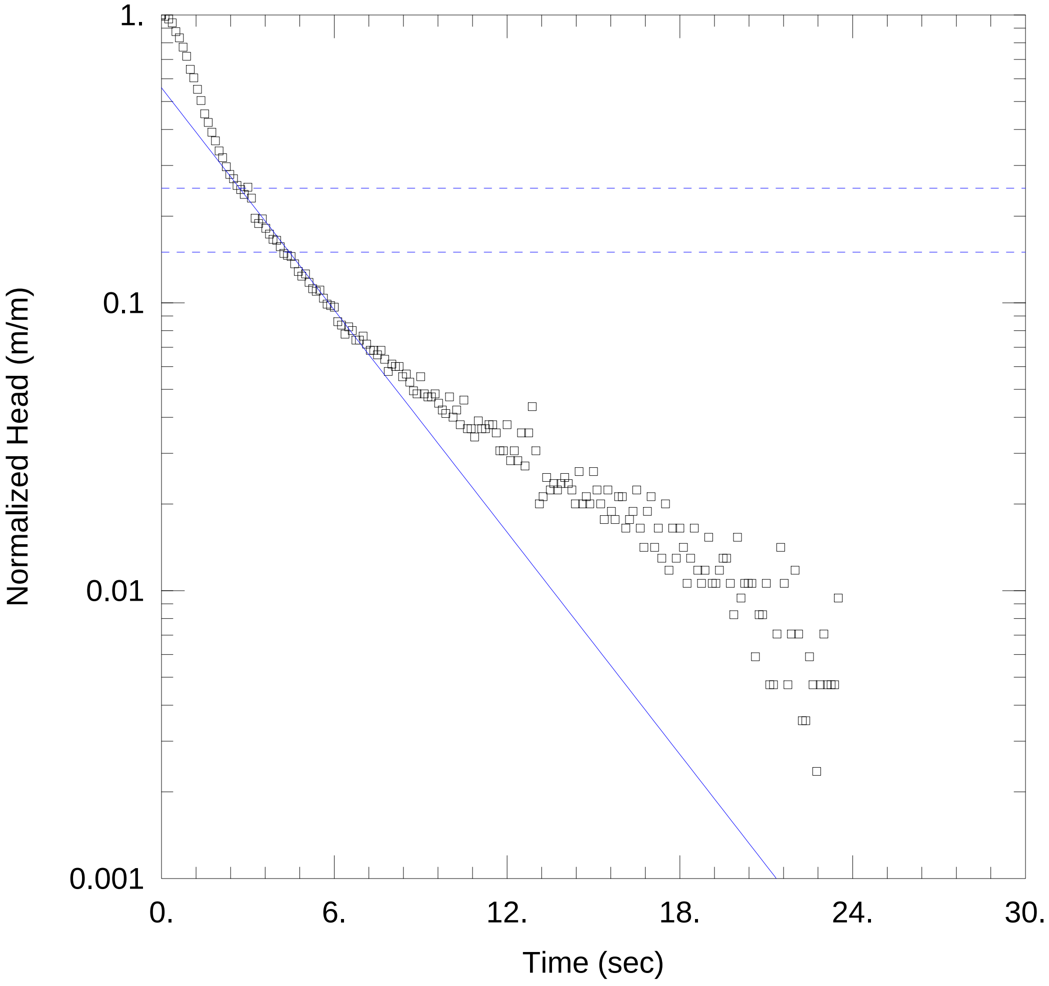


DEPTH (m)	U.S.C.S.	MATERIAL DESCRIPTION	Elevation [m asl]	WELL DIAGRAM & DRILLING NOTES
0.91	SC	SILTY SAND WITH GRAVEL (SC): poorly graded fine to medium sand, 15% gravel, 20% fines, non plastic, subangular, brown (10YR 4/3), moist, loose, poorly graded, 20 cm of poorly graded gravel with sand at top of interval (fine to coarse, subangular), sand increases and fines decrease to 15% in bottom 30 cm, (FILL)	3365.21	
1.22	OH	ORGANIC SOIL (OH): poorly graded fines, high plasticity, dark gray (5Y 4/1), moist, medium dense, poorly graded, ash and burnt wood with strong odor, high organic content (bark, roots) layered with dark fines	3364.90	
2.44	SP	POORLY GRADED SAND (SP): fine sand, 5% fines, dark yellowish brown (10YR 4/4), dry, loose, abundant bark, roots and rootlets, occasional layers (3-6 cm thick) of oxidized material throughout	3363.68	
5.18	GP	POORLY GRADED GRAVEL WITH SAND (GP): fine to coarse gravel, 25% sand, 5% fines, subangular, yellowish brown (10YR 5/4), wet, loose to medium dense, 40% cobbles (largest 12 cm), boulder from 4.5-5 m	3360.94	3.0 m dry 4.6 m dry
6.10	SW	WELL GRADED SAND WITH GRAVEL (SW): fine to coarse sand, 40% gravel, 5% fines, subangular, brown (10YR 4/3), wet, loose	3360.02	6.1 m pH 5.9, EC 591, pumped dry after 40L
7.62		COBBLE/BOULDER boulder (cobbles and rock powder recovered)	3358.50	7.6 m pH 5.5, EC 296
11.28	GW	WELL GRADED GRAVEL WITH SAND (GW): fine to coarse gravel, 20% sand, angular to subangular, brown (10YR 4/3), wet, loose, iron oxide staining, 20% gravel (largest 14 cm), fine to medium sand	3354.84	9.1 m pH 6.1, EC 393 10.7 m pH 5.5, EC 367

Bottom of hole at 11.30 m.

Appendix C

Hydraulic Testing Results



WELL TEST ANALYSIS

Data Set: S:\...\MW18-06S_FH_Translation.aqt
Date: 06/18/18 Time: 11:41:57

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-06S_FH_T
Test Date: 5/15/2018

AQUIFER DATA

Saturated Thickness: 5.85 m
Anisotropy Ratio (Kz/Kr): 1.

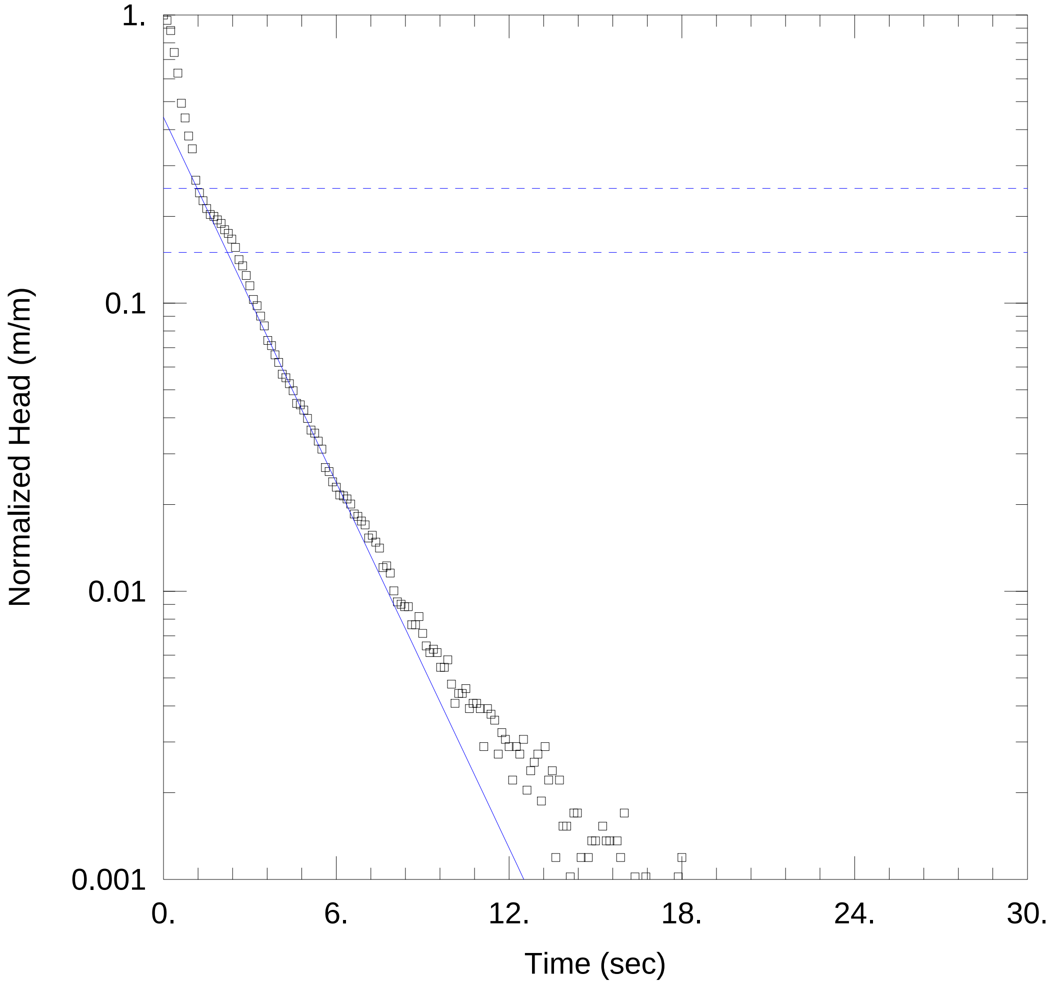
WELL DATA (MW18-06S_FH)

Initial Displacement: 0.0849 m
Static Water Column Height: 5.85 m
Total Well Penetration Depth: 5.86 m
Screen Length: 3.05 m
Casing Radius: 0.0254 m
Well Radius: 1. m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev

K = 5.747E-5 m/sec
y0 = 0.0474 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-06S_RH.aqt
Date: 06/18/18 Time: 11:47:28

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-06S_RH
Test Date: 5/15/2018

AQUIFER DATA

Saturated Thickness: 5.85 m
Anisotropy Ratio (Kz/Kr): 1.

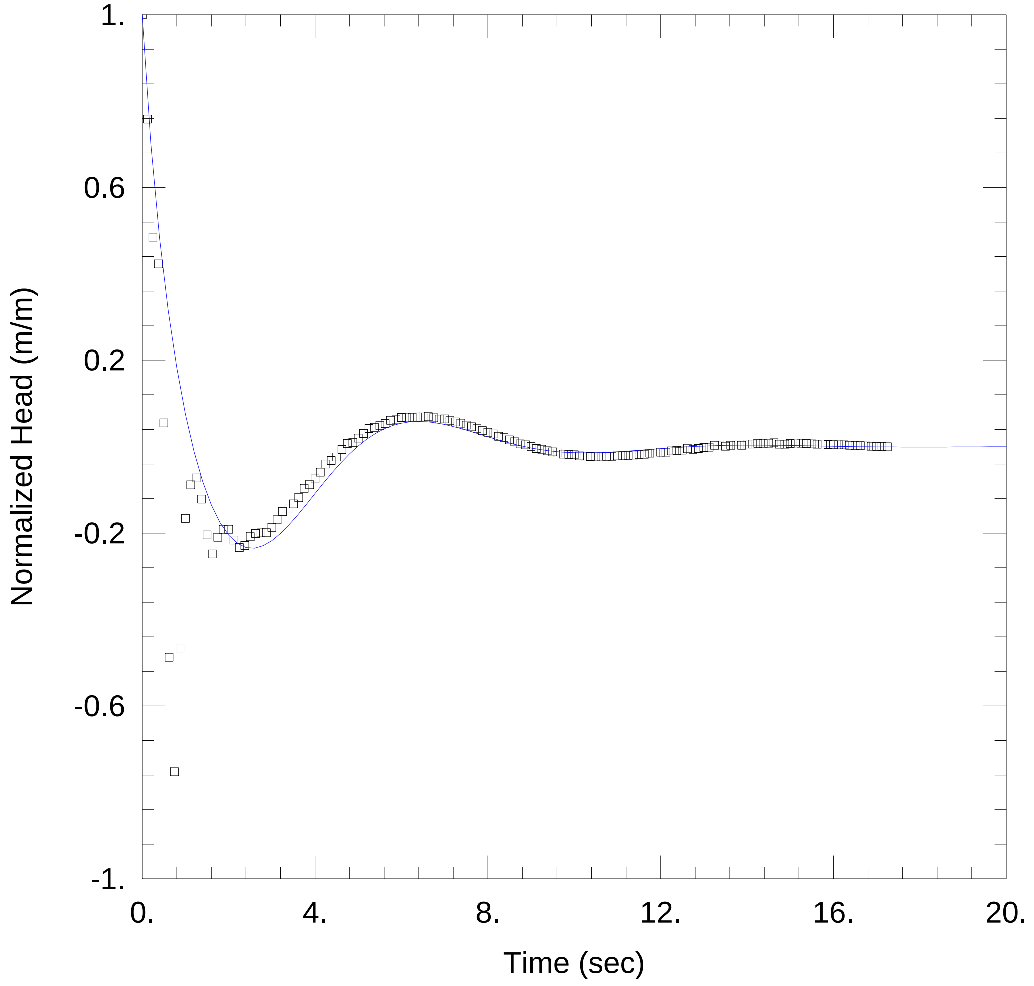
WELL DATA (MW18-06S_RH)

Initial Displacement: -0.5881 m
Static Water Column Height: 5.85 m
Total Well Penetration Depth: 5.86 m
Screen Length: 3.05 m
Casing Radius: 0.0254 m
Well Radius: 0.08895 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev

K = 0.0002176 m/sec
y0 = -0.2595 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-06D_FH.aqt
Date: 06/18/18
Time: 11:38:42

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-06D_FH
Test Date: 5/13/2018

AQUIFER DATA

Saturated Thickness: 14.42 m
Anisotropy Ratio (Kz/Kr): 1.

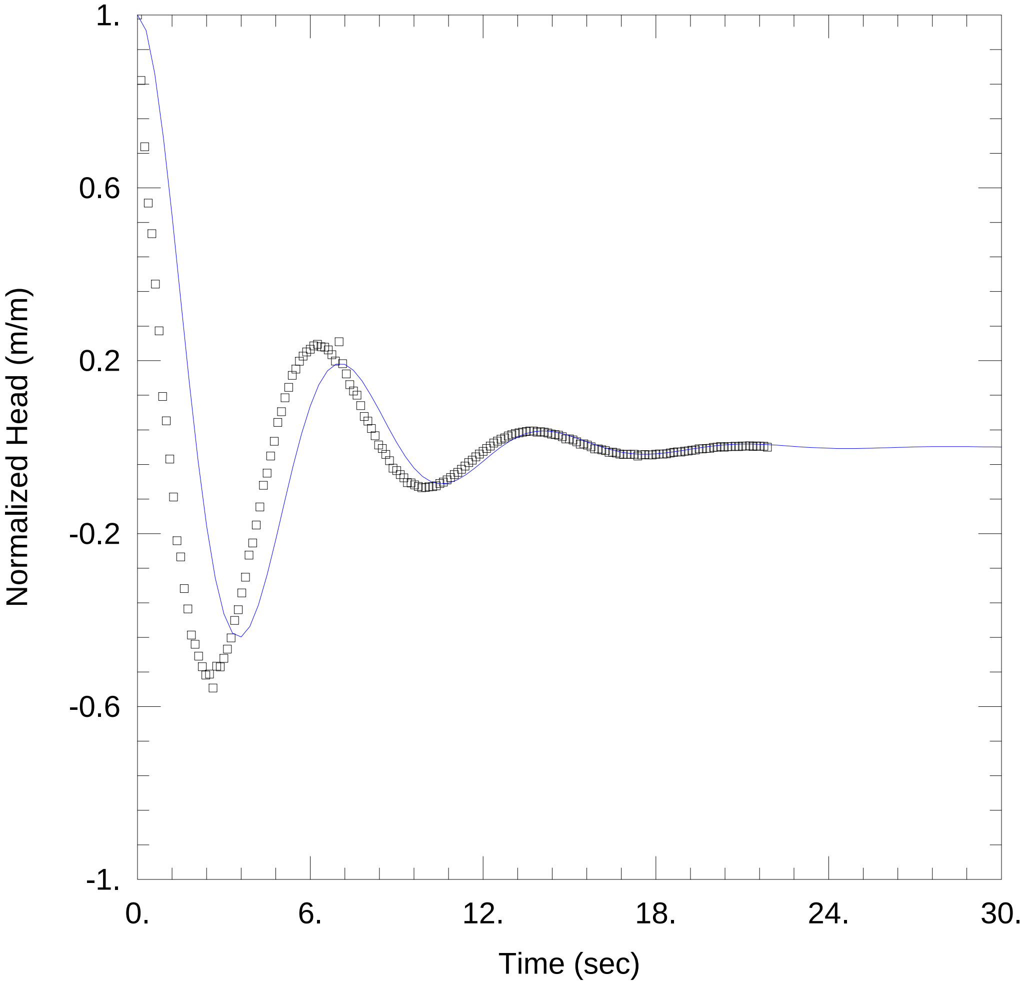
WELL DATA (MW18-06D_FH)

Initial Displacement: 0.5635 m
Static Water Column Height: 14.42 m
Total Well Penetration Depth: 14.42 m
Screen Length: 3.05 m
Casing Radius: 0.0254 m
Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Confined
Solution Method: McElwee-Zenner

K = 0.0004374 m/sec
ß = -2. m
A = 2.
v(0) = -1. m/sec



WELL TEST ANALYSIS

Data Set: S:\...\MW18-06D_RH.aqt
Date: 06/18/18
Time: 11:39:37

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-06D_RH
Test Date: 5/13/2018

AQUIFER DATA

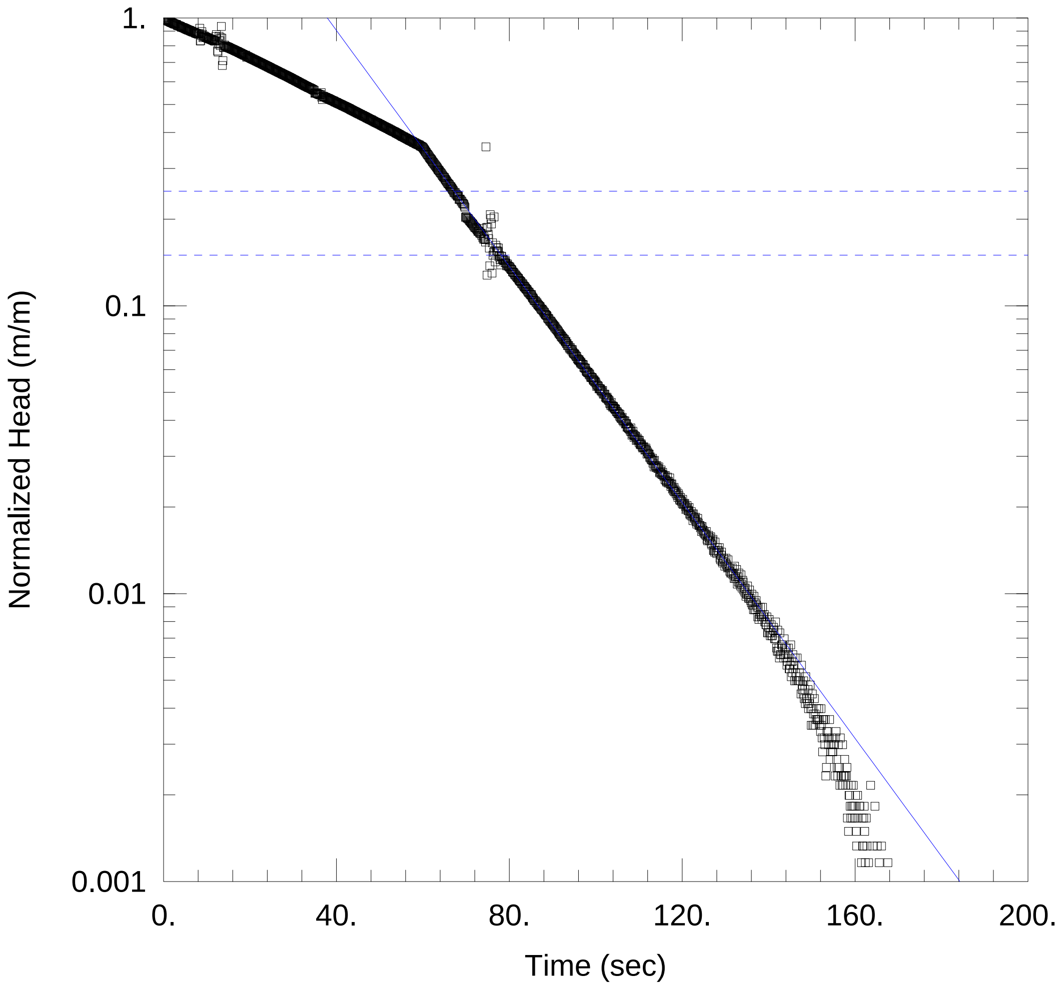
Saturated Thickness: 13. m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW18-06D_RH)

Initial Displacement: -0.2761 m
Static Water Column Height: 14.42 m
Total Well Penetration Depth: 14.42 m
Screen Length: 3.05 m
Casing Radius: 0.0254 m
Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 0.0007451 m/sec
Le = 11.54 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-07S_FH.aqt
Date: 06/18/18 Time: 11:48:29

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-07S_FH
Test Date: 5/15/2018

AQUIFER DATA

Saturated Thickness: 7.21 m Anisotropy Ratio (Kz/Kr): 1.

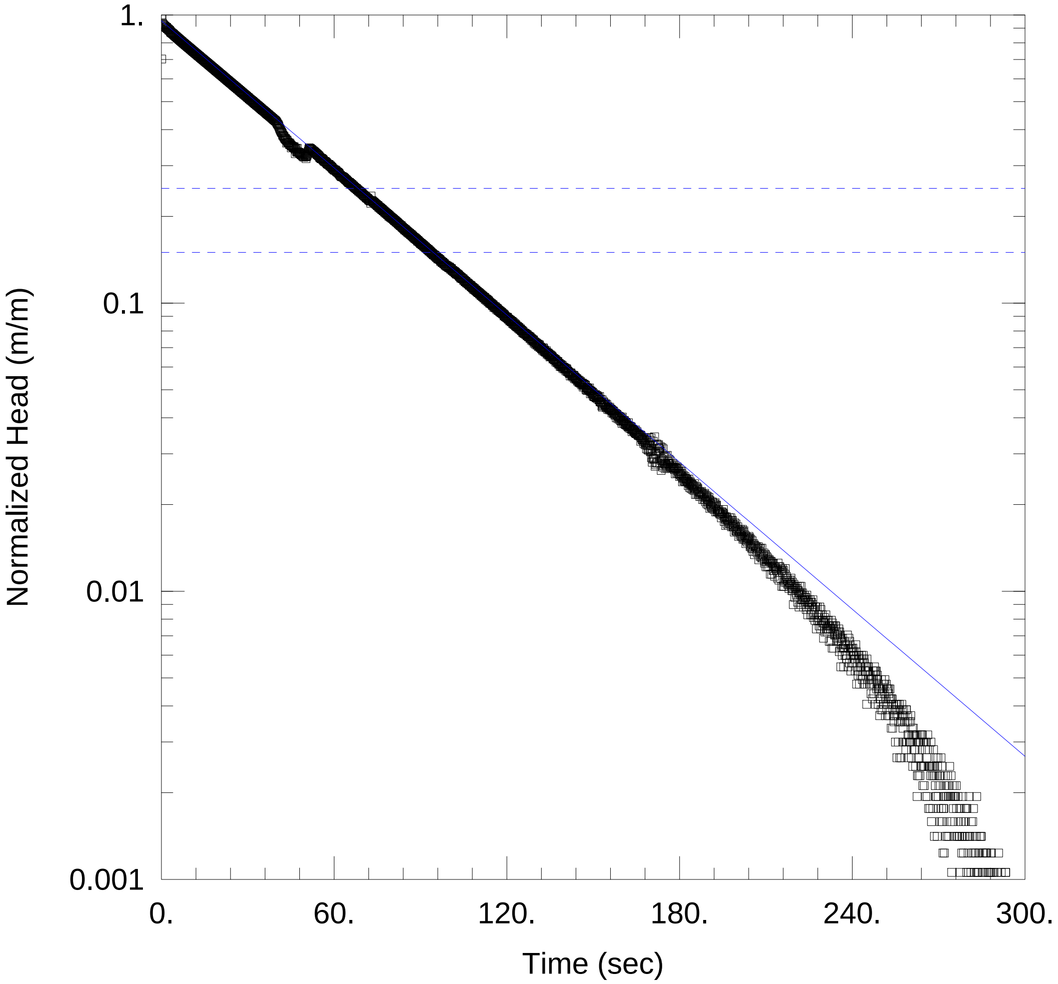
WELL DATA (MW18-07S_FH)

Initial Displacement: 0.6025 m Static Water Column Height: 4.77 m
Total Well Penetration Depth: 4.77 m Screen Length: 3.05 m
Casing Radius: 0.0254 m Well Radius: 0.08895 m

SOLUTION

Aquifer Model: Confined Solution Method: Hvorslev

K = 1.765E-5 m/sec y0 = 3.599 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-07S_RH.aqt
Date: 06/18/18 Time: 11:48:46

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-07S_RH
Test Date: 5/15/2018

AQUIFER DATA

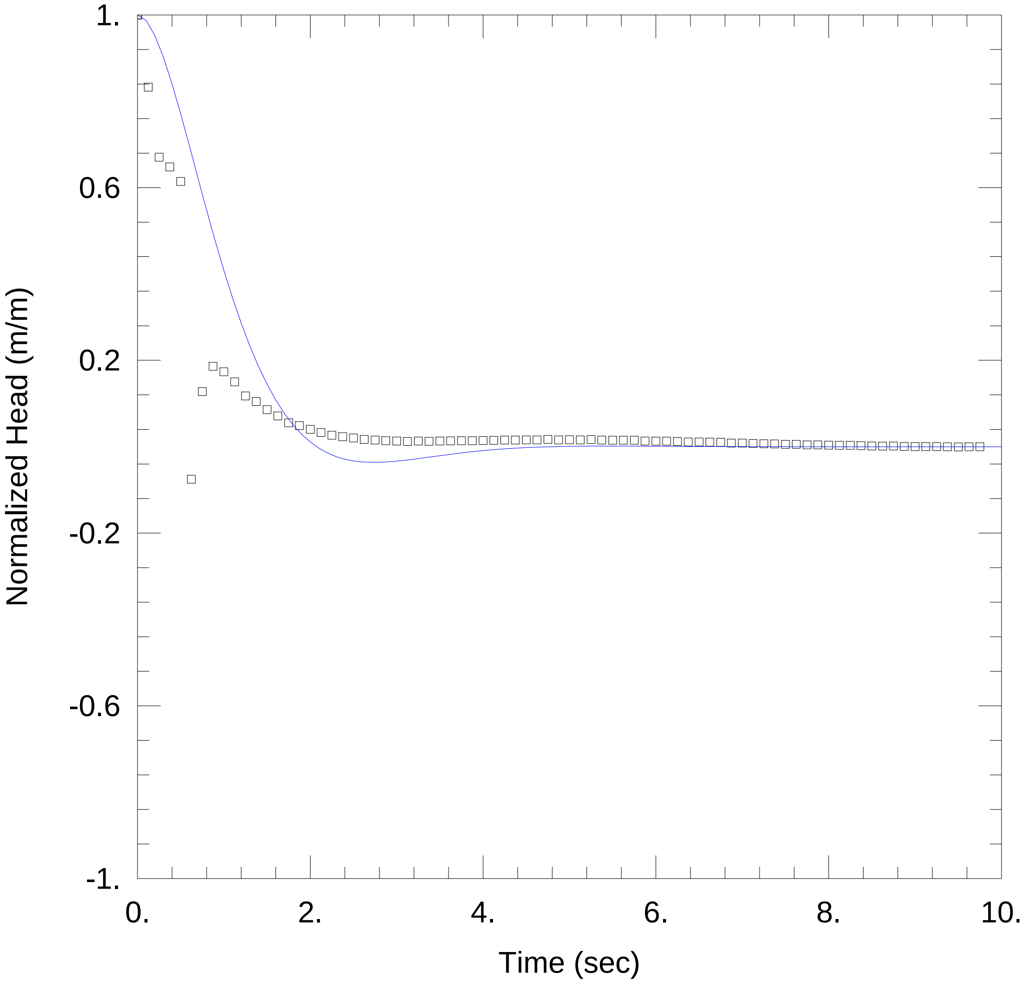
Saturated Thickness: 7.21 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW18-07S_RH)

Initial Displacement: -0.5675 m
Static Water Column Height: 4.77 m
Total Well Penetration Depth: 4.77 m
Screen Length: 3.05 m
Casing Radius: 0.0254 m
Well Radius: 0.08895 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev
K = 7.326E-6 m/sec
y0 = -0.5413 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-07D_FH.aqt
Date: 06/18/18 Time: 11:47:46

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-07D_FH
Test Date: 5/15/2018

AQUIFER DATA

Saturated Thickness: 12.19 m
Anisotropy Ratio (Kz/Kr): 1.

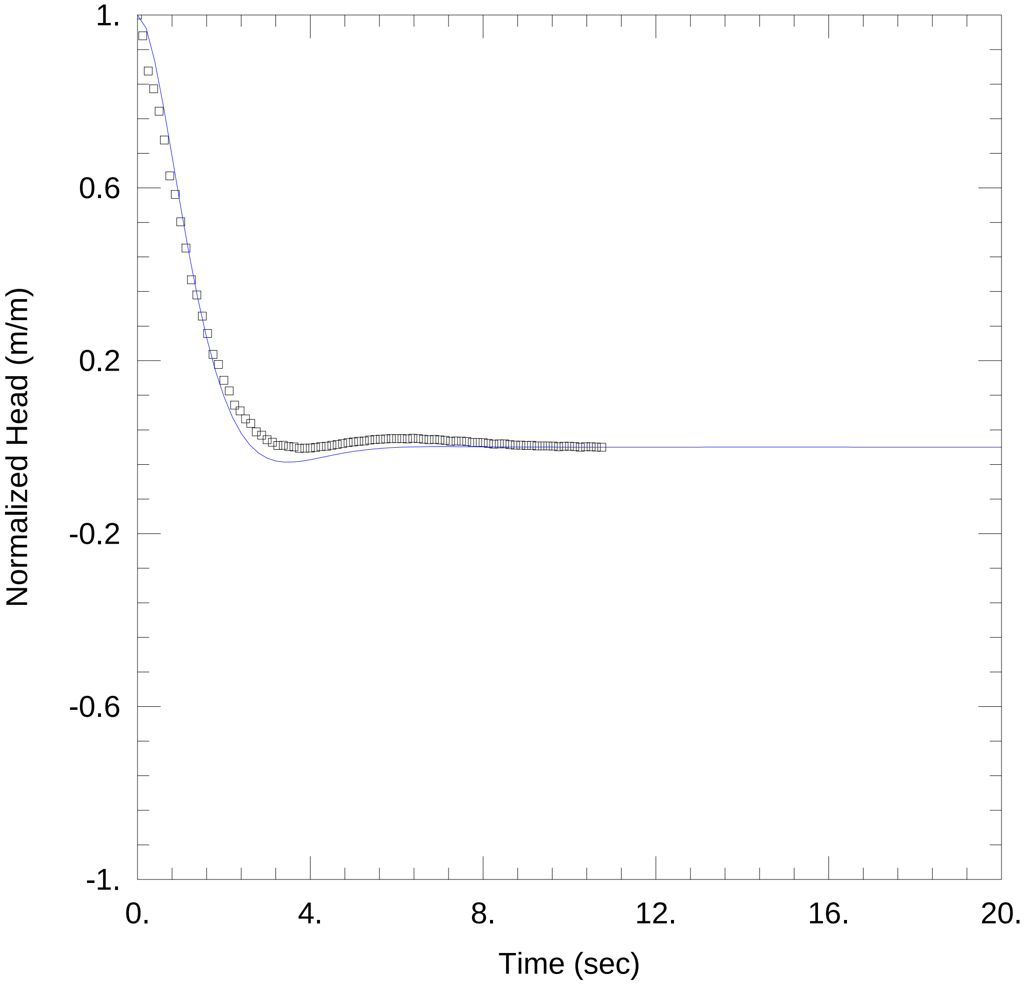
WELL DATA (MW18-07D_FH)

Initial Displacement: 0.6056 m
Total Well Penetration Depth: 13.71 m
Casing Radius: 0.0254 m
Static Water Column Height: 12.19 m
Screen Length: 1.52 m
Well Radius: 0.08895 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar

K = 0.0008024 m/sec
Le = 3.514 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-07D_RH.aqt
Date: 06/18/18 Time: 11:48:05

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-07D_RH
Test Date: 5/15/2018

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 1.

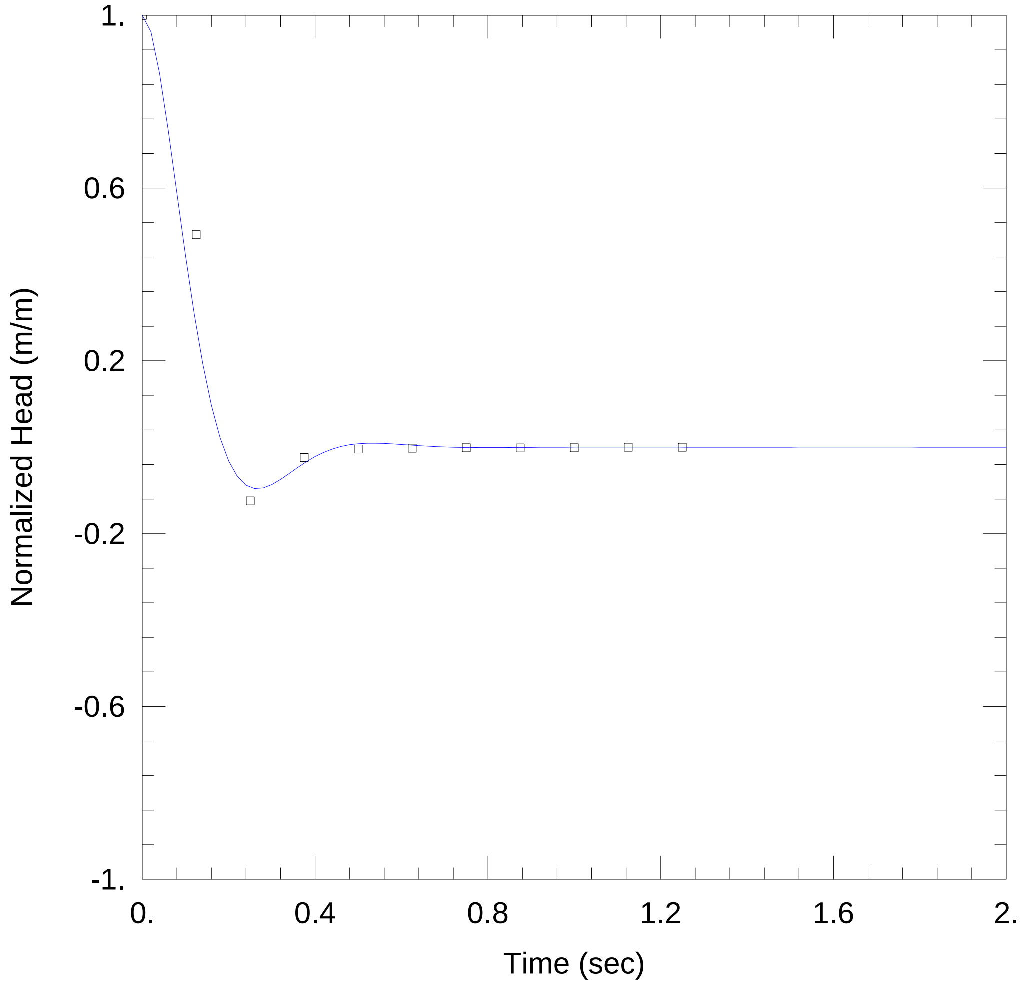
WELL DATA (MW18-07D)

Initial Displacement: -0.4164 m
Static Water Column Height: 12.19 m
Total Well Penetration Depth: 12.18 m
Screen Length: 1.52 m
Casing Radius: 0.0254 m
Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar

K = 0.0006495 m/sec
Le = 5.615 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-08S_FH.aqt
Date: 06/18/18 Time: 11:49:44

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-08S_FH
Test Date: 5/15/2018

AQUIFER DATA

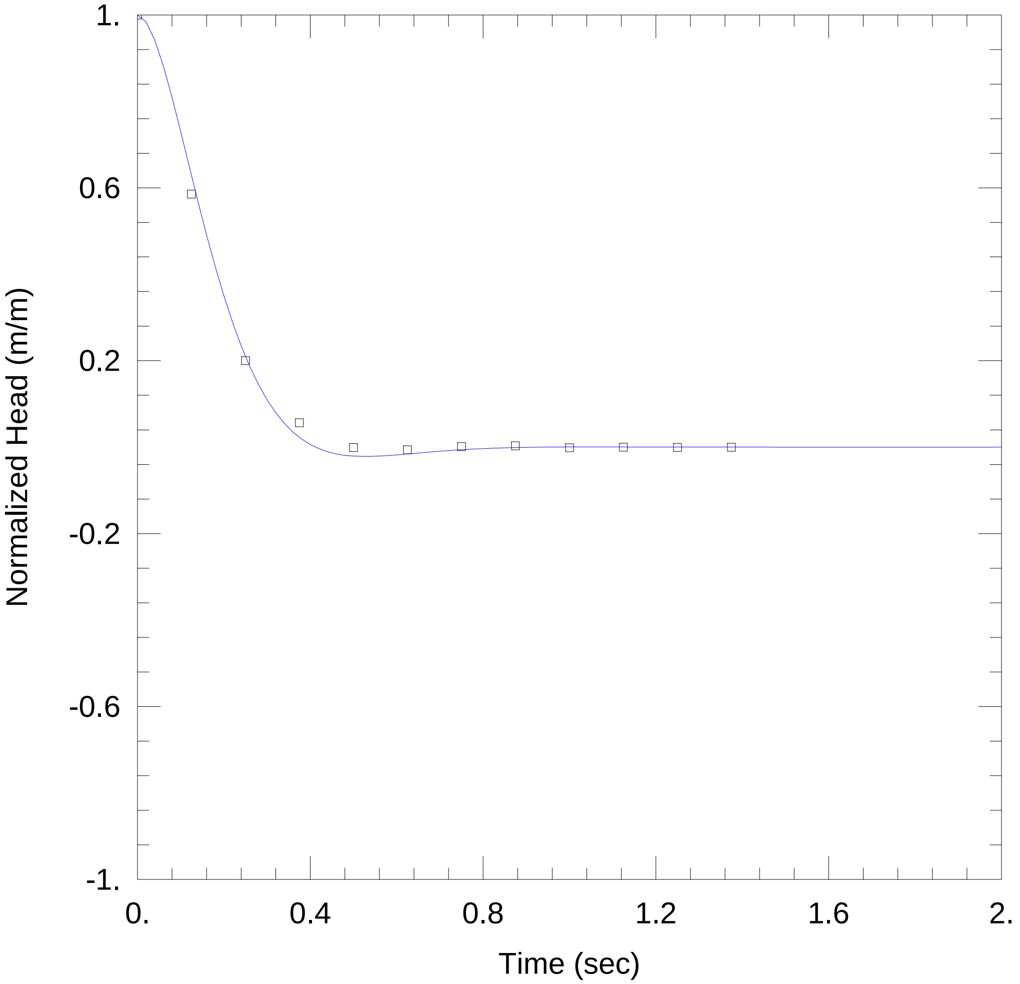
Saturated Thickness: 6.9 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW18-08S_FH)

Initial Displacement: 0.3481 m
Static Water Column Height: 2.33 m
Total Well Penetration Depth: 2.33 m
Screen Length: 2.33 m
Casing Radius: 0.0254 m
Well Radius: 0.08895 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 0.003536 m/sec
Le = 0.04527 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-08S_RH.aqt
Date: 06/18/18 Time: 11:49:57

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-08S_RH
Test Date: 5/15/2018

AQUIFER DATA

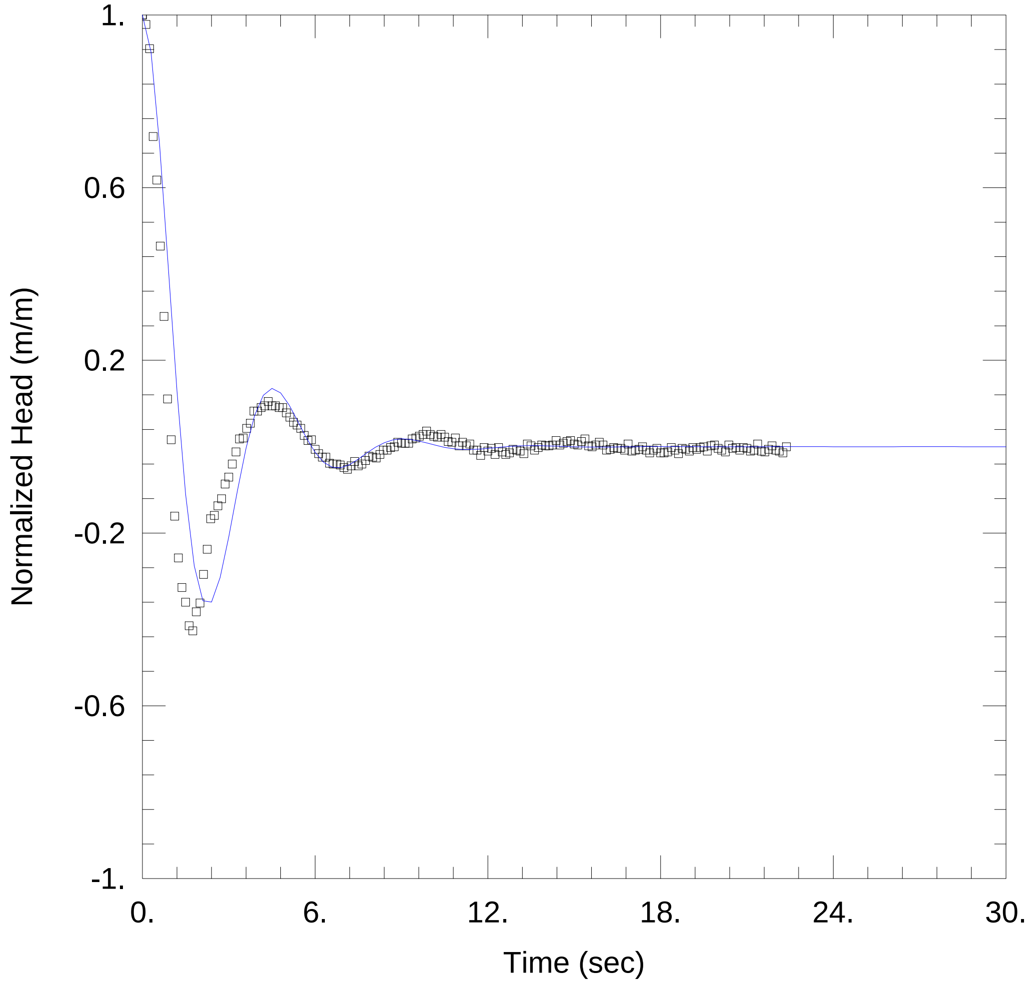
Saturated Thickness: 6.9 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW18-08S)

Initial Displacement: -0.2284 m
Static Water Column Height: 2.33 m
Total Well Penetration Depth: 2.33 m
Screen Length: 2.33 m
Casing Radius: 0.0254 m
Well Radius: 0.08895 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 0.001747 m/sec
Le = 0.1105 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-08D_FH.aqt
Date: 06/18/18 Time: 11:49:19

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-08D_FH
Test Date: 5/15/2018

AQUIFER DATA

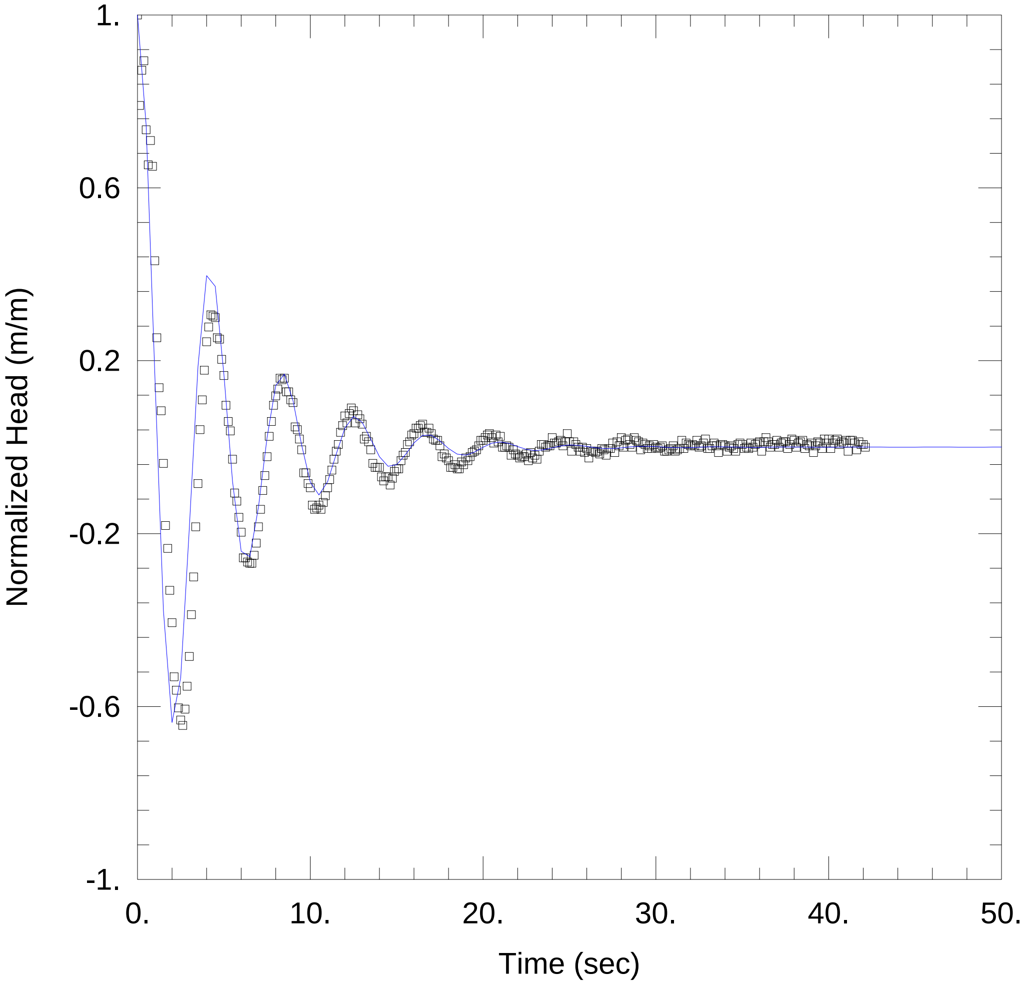
Saturated Thickness: 6.9 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW18-08D_FH)

Initial Displacement: 0.0497 m
Static Water Column Height: 6.59 m
Total Well Penetration Depth: 6.6 m
Screen Length: 3.05 m
Casing Radius: 0.0254 m
Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 0.0007778 m/sec
Le = 4.607 m



WELL TEST ANALYSIS

Data Set: S:\...\MW18-08D_RH.aqt
Date: 06/18/18 Time: 11:49:07

PROJECT INFORMATION

Company: Robertson GeoConsultants
Client: Nyrstar
Project: 212011
Location: Myra Falls
Test Well: MW18-08D_RH
Test Date: 5/15/2018

AQUIFER DATA

Saturated Thickness: 6.9 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW18-08D)

Initial Displacement: -0.032 m
Static Water Column Height: 6.59 m
Total Well Penetration Depth: 6.6 m
Screen Length: 3.05 m
Casing Radius: 0.0254 m
Well Radius: 0.0762 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar

K = 0.001796 m/sec
Le = 4.279 m