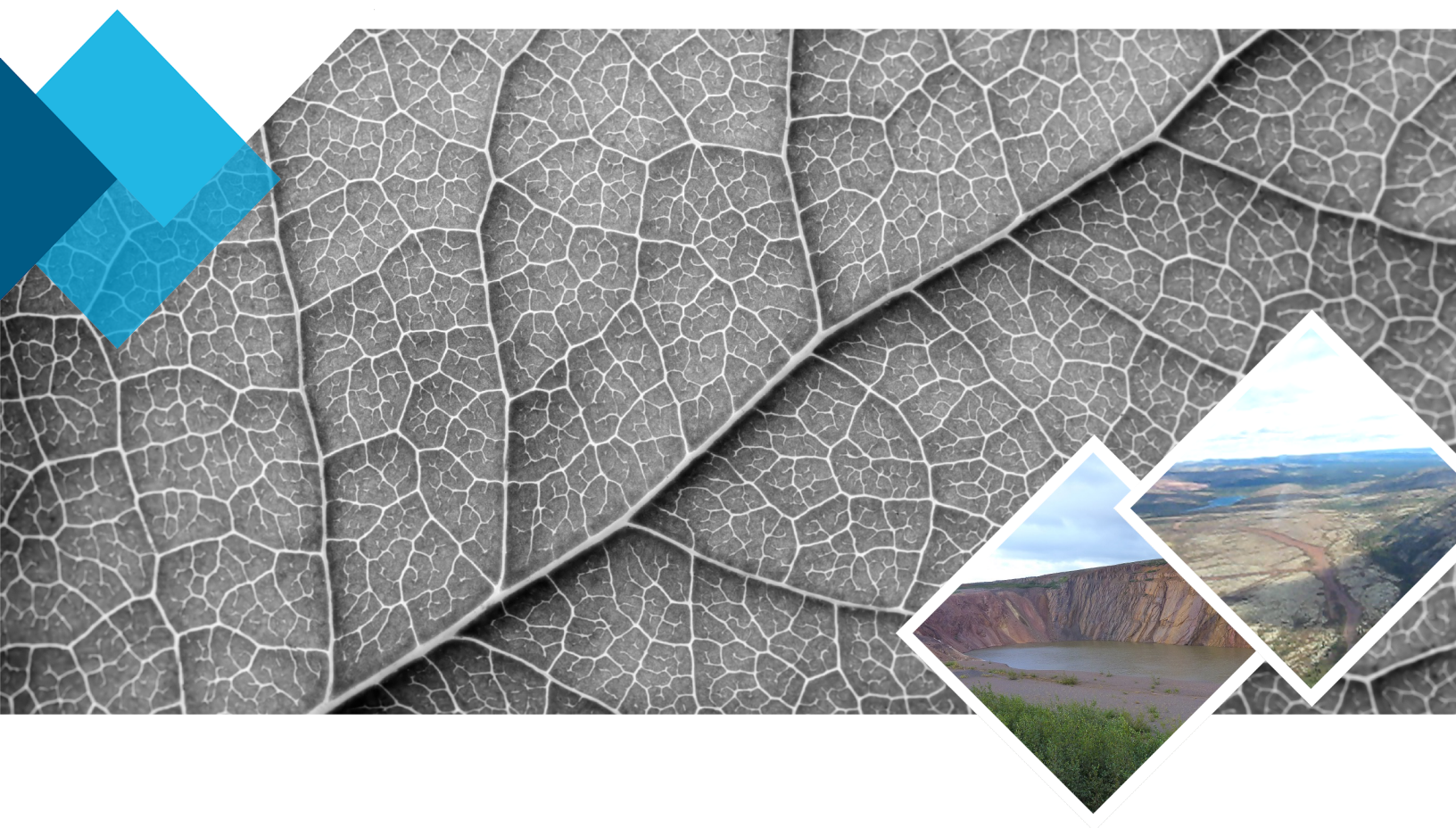




Hydrogeology Numerical Modeling for the Howse Deposit Project

TATA STEEL MINERALS CANADA LTD



Infrastructure

02 | 12 | 2016

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Internal ref. 640947

Hydrogeology Numerical Modeling for the Howse Deposit Project

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TEAM WORK

SNC-Lavalin Inc.

The modeling and report was done by Emmanuelle Millet, M.Sc.

Data analysis and interpretation, conceptual model and report were achieved by Abdel Mounem Benlahcen geo, PhD.

Data, model and report were verified by Christian Bélanger, Eng., M.Sc.A.

Table of Contents

1	Introduction	1
2	Summary of the site hydrogeology	2
2.1	Regional Setting and site context	2
2.2	Local Geology and Hydrogeology	7
2.2.1	Hydrostratigraphic units	7
2.2.2	Aquifer hydraulic characteristics	13
2.2.3	Groundwater Flow and Elevation	14
3	Groundwater Flow Numerical Model	23
3.1	Conceptual Model	23
3.1.1	Area of the Model	27
3.1.2	Hydrostratigraphic units	27
3.1.3	Groundwater Flow and Elevation	27
3.2	Modeling Software	28
3.3	Model Geometry and Grid	28
3.3.1	Domain and Grid	28
3.3.2	Model Layers	28
3.4	Hydraulic properties and boundary conditions	36
3.4.1	Hydraulic Properties	36
3.4.2	Boundary Conditions	36
3.4.3	Recharge Rate	37
4	Model Calibration and Results	41
4.1	Groundwater Flow Model Calibration	41
4.2	Howse Deposit Dewatering Model	45
4.3	Additional Sensitivity Analysis	54
4.3.1	Drain conductance	54
4.3.2	Storage coefficient	54
4.3.3	Vertical discretization	55
4.3.4	Pumping wells versus drain condition	55
4.4	Groundwater Flow Model Discussion	55

5	Conclusions and recommendations	58
6	References	61

List of tables

Table 2-1	Dewatering history for DSO mines in Schefferville Region	5
Table 2-2	Summary of Hydraulic Conductivities Obtained from Various Tests	14
Table 2-3	Piezometric Results	15
Table 2-4	Summary of Piezometric Monitoring	21
Table 3-1	Initial Hydraulic Conductivities	36
Table 3-2	Cyclic recharge applied to the model	38
Table 4-1	Initial and Calibrated Hydraulic Conductivities	43
Table 4-2	Main mining phases of the Howse deposit	45
Table 4-3	Dewatering Simulation and Sensitivity Analysis Results	46
Table 4-4	Simulated Drawdown at Three Mining Phases	54

List of figures

Figure 2-1	Aerial Photography of the Project Region	3
Figure 2-2	Relation of Pumping Rate to Water Table Elevation in Some Mines at Knob Lake Adapted from Stubbins and Munro (1965)	6
Figure 2-3	Surface Geology (Source: Wardle, R.J. 1982)	9
Figure 2-4	Longitudinal Cross-section of the geology at Howse deposit site (Source: TATA Steel, 2015)	11
Figure 2-5	Transversal cross-section (Line 696) of the geology at Howse deposit site (Source: TATA Steel, 2015)	12
Figure 2-6	Piezometric map of the Howse Deposit and Neighbouring Sites	17
Figure 2-7	Groundwater Level Monitoring in Boreholes	22
Figure 3-1	View of Model Domain	25
Figure 3-2	Surface Geology Layout (Layer 1, Top of the Model)	30
Figure 3-3	Geology of Layers 1 to 18	31
Figure 3-4	Geology of Layers 19 and 20	32
Figure 3-5	Geology of Layers 21 to 26	33
Figure 3-6	Vertical Model Grid –West-East Section	34
Figure 3-7	Vertical Model Grid –South-North Section	35
Figure 3-8	Boundary Conditions Applied to the Model Indicated by Brown Cells	39
Figure 3-9	Water Well Level Variations with Cyclic Recharge Applied to the Model	40
Figure 4-1	Calculated Versus Observed Heads at Steady State	42
Figure 4-2	Simulated Natural Piezometric Map	44
Figure 4-3	Piezometric Map during the Phase I of Pit Dewatering (Final Depth)	48
Figure 4-4	Piezometric Map during the Phase II of Pit Dewatering (Final Depth)	49
Figure 4-5	Piezometric Map during the Phase III of Pit Dewatering (Final Depth)	50

Figure 4-6	Groundwater Drawdown during Phase I of Pit Dewatering (Final Depth)	51
Figure 4-7	Groundwater Drawdown during Phase II of Pit Dewatering (Final Depth)	52
Figure 4-8	Groundwater Drawdown during Phase III of Pit Dewatering (Final Depth)	53

List of appendices

APPENDIX A

Pumping Test Results

APPENDIX B

Howse deposit mining phases

APPENDIX C

Sensitivity analysis on the exit boundary condition (steady state)

APPENDIX D

Variable recharge scenario (no dewatering)

APPENDIX E

Dewatering base case scenario (phase I, II, III)

Base Case Scenario Results

APPENDIX F

Sensitivity analysis on dewatering base case scenario

APPENDIX G

Well condition

This report consists of 50 pages including appendices and may not be reproduced in whole or in part without the permission of Legal entity.

1 Introduction

For the Howse deposit project, SNC-Lavalin was involved in the realization of hydrogeological modeling of the pit dewatering based on result investigations conducted by others and available data.

In autumn of 2014, SNC-Lavalin conducted a first hydrogeology numerical modeling for the Howse deposit dewatering. This first model was based on results from hydrogeological studies conducted by Golder (2014) and Geofor (2014). Following NRCan comments on the conceptual model elaborated and the model results, a complementary hydrogeological program was conducted in the fall of 2015 by Geofor in order to collect additional geological and hydrogeological data. The numerical model was then refined and updated (SNC-Lavalin, November 2015).

This report presents a major update of the last model following NRCan new comments received on June 2016 and later (October and November 2016) during the completion of this new model for the Howse pit dewatering.

Wetland and lakes within the project footprint were not considered in the present model for several reasons discussed in this report and in memorandums responding to NRCan's comments on previous conceptual model by Geofor (2016). However, the model uses conservative dewatering scenarios and presents the results in term of radius of influence of the drawdown in proximity to the lakes within the project footprint at different mine phases. Also, this report recommends an intensive groundwater monitoring program near lakes and wetland during each mine phase and model update at the end of each phase. This model represents a good base model that will be improved with new data collected during mining operations.

2 Summary of the site hydrogeology

2.1 Regional Setting and site context

The Howse deposit is located in Newfoundland and Labrador along the Labrador Trough, about 25 km to the northwest of Schefferville, Quebec, between Irony Mountain, Pinette Lake and the existing Tata Steel Minerals Canada Ltd. (TSMC) Timmins 4 mined deposit. As other DSO deposits in the region, the Howse deposit is located on a ridge slope, in this particular case on the Irony Mountain East ridge (Figure 2-1).

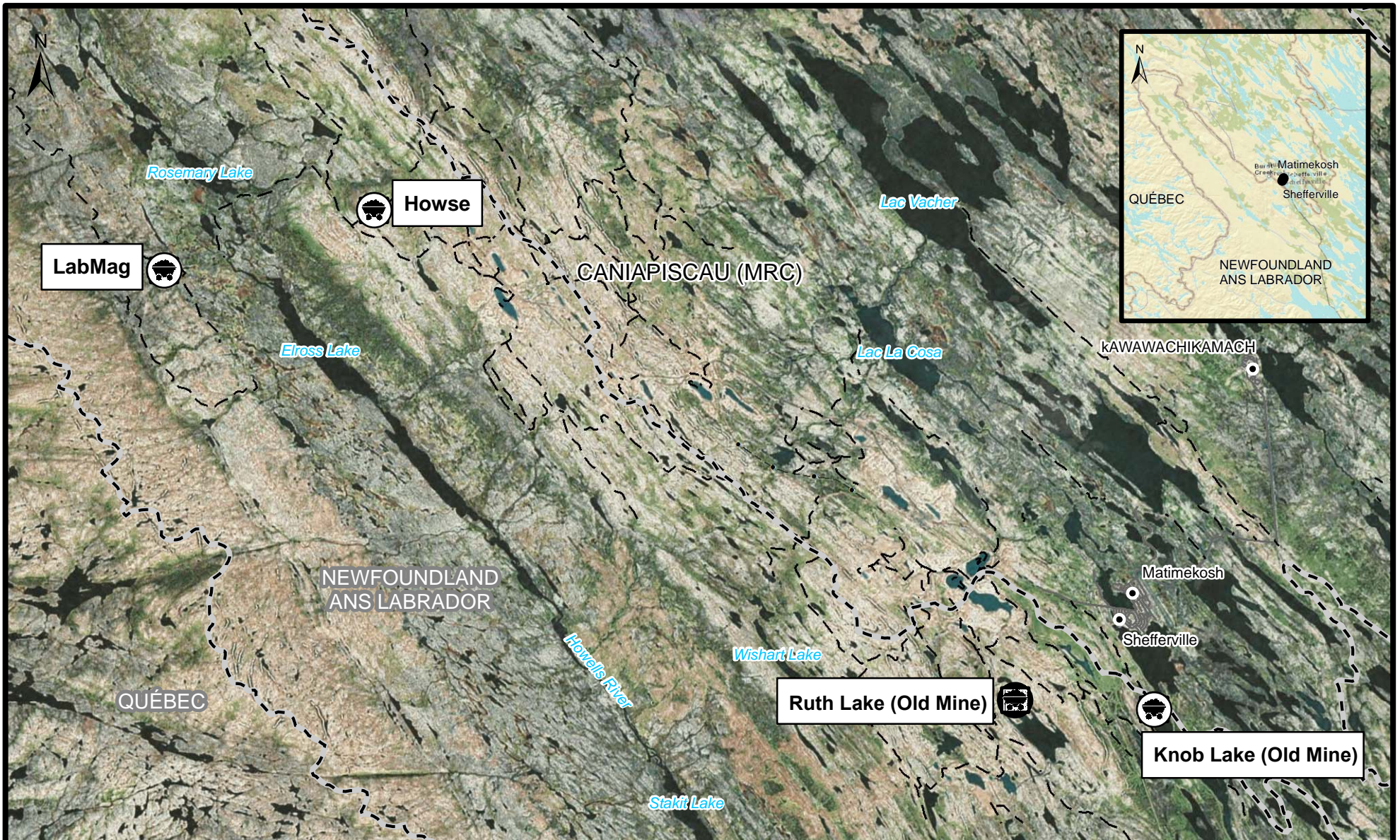
Drake (1983) describes the hydrogeological conditions prevailing in the iron formations, in the Schefferville area, where existing deposits are located along the ridge sides and penetrate the permafrost zone when present. Permafrost is absent in the area of the Howse Deposit (Journeaux Assoc, 2015), but it is present sporadically in nearby valleys, such as in the vicinity of Flemings and Timmins 3N.

The piezometric surface beneath the ridges generally lies within 30 m of the surface and apparently follows the topography (Stubbins and Munro 1965). Ridges are associated with recharge zones, although on the sides of some ridges, small springs may be found at the base of the Sokoman formation. Lakes and swamps in the valley bottom are discharge areas for the groundwater when its level is near the surface. Water budgets of several lakes have shown that a considerable volume of groundwater discharges into them, especially where the water table is at the surface in the lower-lying areas (Drake 1983).

Large thrust faults lying along the ridge sides are zones of locally higher permeability, alteration within the Sokoman formation and ore deposit. The deposits are consequently located on the ridges flanks close to the crest (Drake, 1983).

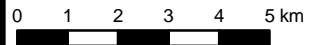
The lineaments are oriented in a northwest-southeast direction over the entire region as well as the iron formation.

The regional groundwater flows mainly from southeast to northwest and is controlled by the configuration of the regional hydrogeological setting, including natural boundaries. The region is underlain by synclinal layers affected by some geological structures. This configuration will greatly influence the groundwater flow.



Notes:

- 1- This drawing is to be read in conjunction with the accompanying report.
- 2- Service Layer Credits: Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
- Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



PROJECT

Hydrogeology Modeling - Howse project

TITLE

Figure 2-1
Aerial Photography
of the Project Region

DRAWN

E. Cazeneuve

VERIFIED

A. M. Benlahcen

DATE

3 nov. 2015

SCALE

1:150 000

CONSULTANT



SNC • LAVALIN

FILE

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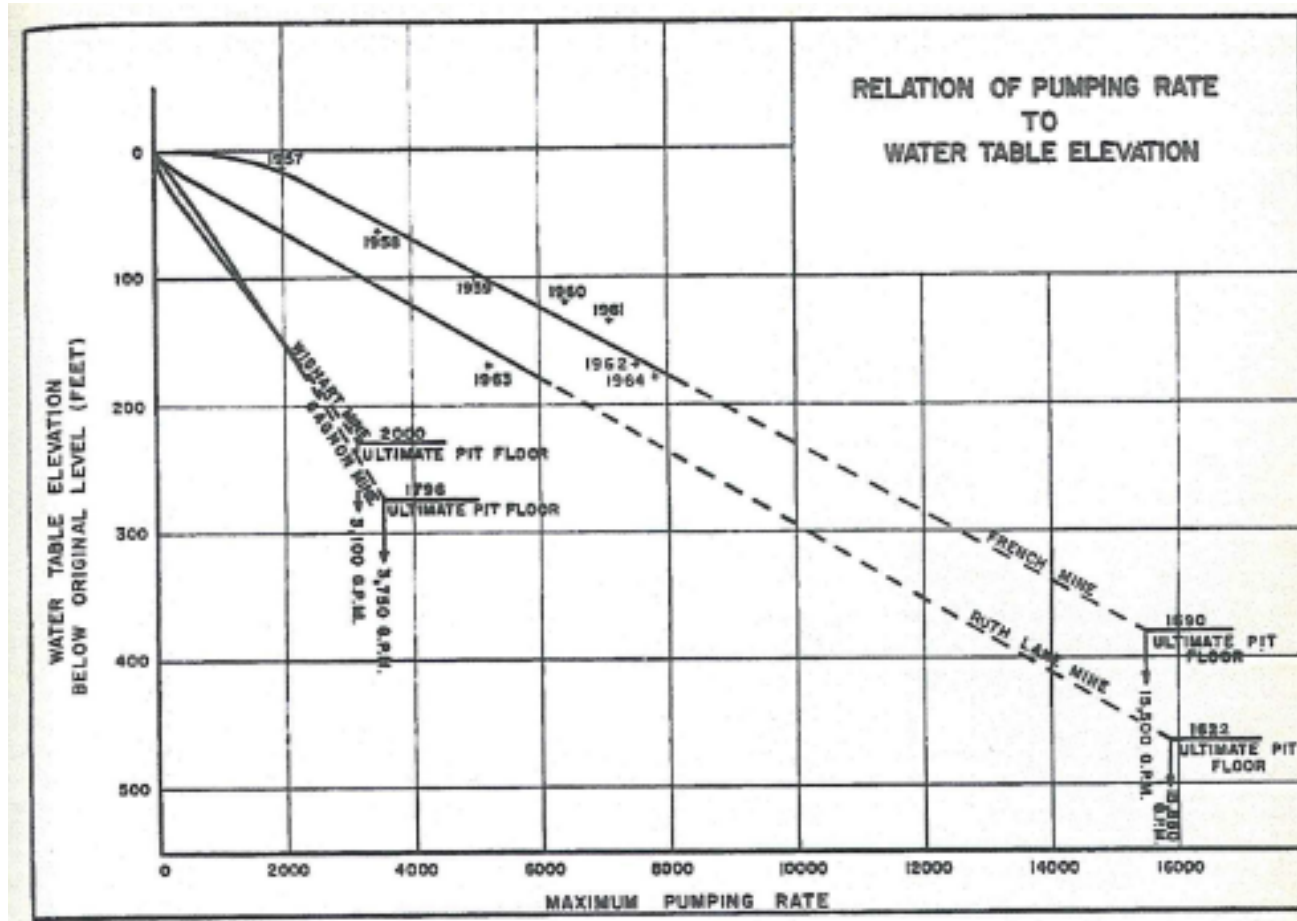
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Stubbins and Munro (1965) provided an overview of the historical mine dewatering in the area of Knob Lake, located 25 km south-east of the Howse deposit. The study mines included Wishart, Gagnon, French and Ruth mines, where the dewatering was very much depth correlated and increased with the mine pit floor depth (Figure 2-2). Table 2-1 summarizes these results. The dewatering rates varied from 16 874 to 86 547 m³/d for those old mines. This information is useful for comparison purposes with the present study area located nearby. Obviously, this wide range of dewatering rates is related to several factors for which data are unavailable such as: pit size; hydraulic conductivities of the geological units; fault zones; proximity to the water bodies; permafrost presence, and mining and dewatering operations.

Table 2-1 Dewatering history for DSO mines in Schefferville Region

Type of Data	Mine Site	Floor Depth (m)	Dewatering (m ³ /d)	Data References
Historical data of DSO mines	Wishart	69	16,874	Stubbins, J. B. and P. Munro. 1965. Historical information on mine dewatering of DSO (Knob Lake). The Canadian Institute of Mining and Metallurgy Bulletin, 58:814-822.
	Gagnon	83	20,412	
	French	116	84,370	
	Ruth	144	86,547	

Figure 2-2 Relation of Pumping Rate to Water Table Elevation in Some Mines at Knob Lake Adapted from Stubbins and Munro (1965)



2.2 Local Geology and Hydrogeology

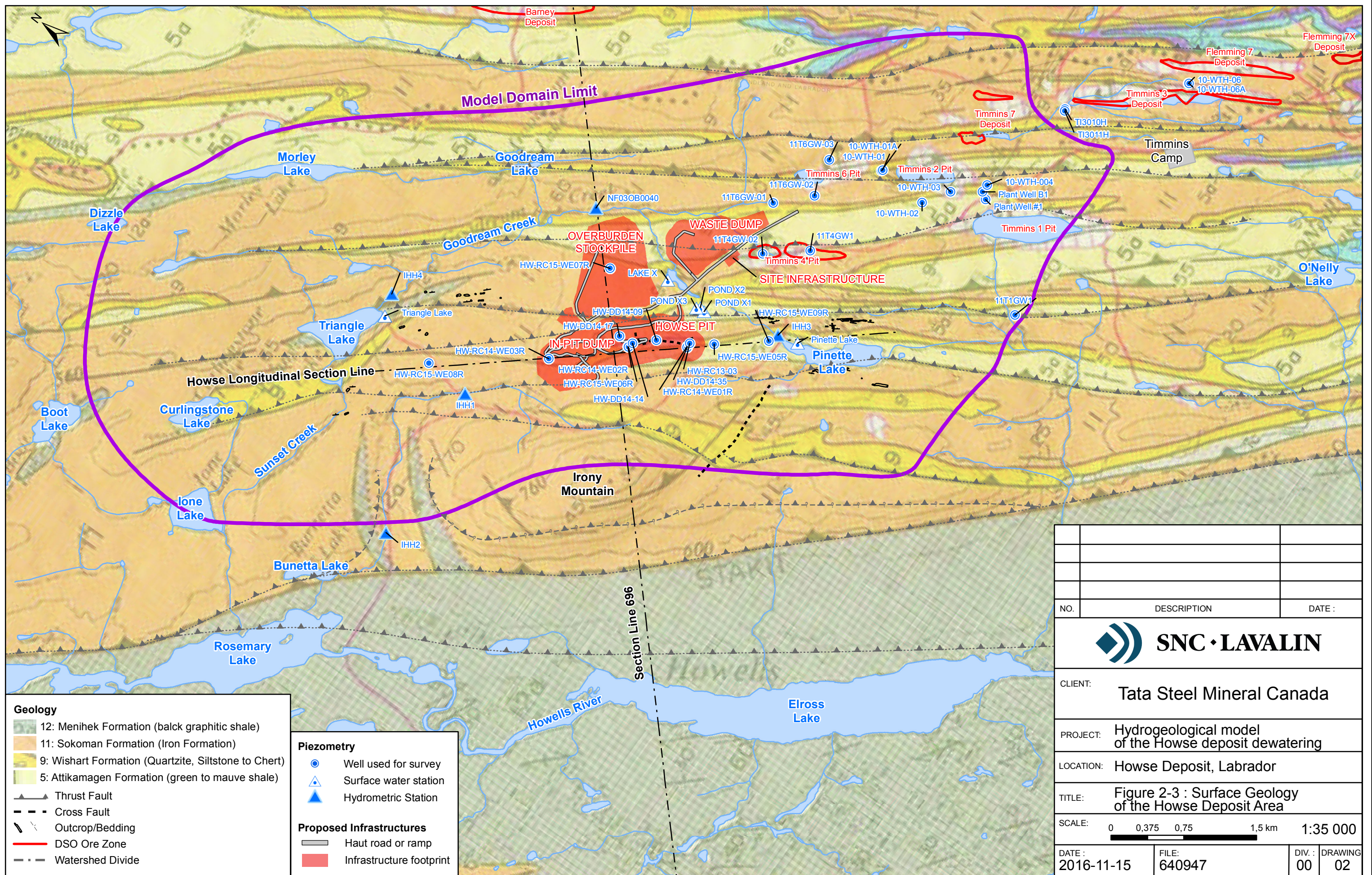
2.2.1 Hydrostratigraphic units

The project site is located in the Labrador Trough which consists of geological formations that were compressed into a series of synclines and anticlines, cut by steep angle reverse faults dipping primarily to the east. The main geological formations encountered in the area of Howse deposit and their thickness ranges (source: Tata Steel's geologist) are:

- › The overburden: uniform cover of till overlying variable thickness of sand and gravel, and ranges over the Howse deposit from 20 to 50 m of thickness.
- › The Sokoman Formation (Cherty iron formation): the thickness ranges from 110 to 120 m: The Sokoman is subdivided in three units: the Lower Iron Formation (LIF), predominantly a carbonate-silicate facies iron formation, the Middle Iron Formation (MIF) which is the main Ore zone, and the Upper Iron Formation (UIF);
- › The Wishart Formation (Quartzite, Siltstone to Chert): thickness ranging from 15 to 20 m;
- › Attikamagen Formation (Shale): stated in all the literature as over 300 m thickness;
- › Archaean basement (granodiorite gneiss), not encountered in the boreholes.

The surface geology map is presented in Figure 2-3 and the two cross-sections (longitudinal and transversal) along the Howse deposit are shown on Figures 2-4 and 2-5. The longitudinal cross-section also shows the groundwater depth in the Howse deposit area which varies between 41 and 95 m below ground surface.

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- Geology**
- 12: Menihek Formation (black graphitic shale)
 - 11: Sokoman Formation (Iron Formation)
 - 9: Wishart Formation (Quartzite, Siltstone to Chert)
 - 5: Attikamagen Formation (green to mauve shale)
- ▲ Thrust Fault
 - - - Cross Fault
 \ / Outcrop/Bedding
 — DSO Ore Zone
 - - - Watershed Divide

- Piezometry**
- Well used for survey
 - ▲ Surface water station
 - ▲ Hydrometric Station
- Proposed Infrastructures**
- ▬ Haut road or ramp
 - Infrastructure footprint

NO.	DESCRIPTION	DATE :
CLIENT:	Tata Steel Mineral Canada	
PROJECT:	Hydrogeological model of the Howse deposit dewatering	
LOCATION:	Howse Deposit, Labrador	
TITLE:	Figure 2-3 : Surface Geology of the Howse Deposit Area	
SCALE:	0 0,375 0,75 1,5 km 1:35 000	
DATE :	FILE:	DIV. : DRAWING
2016-11-15	640947	00 02

Figure 2-4 Longitudinal Cross-section of the geology at Howse deposit site (Source: TATA Steel, 2015)

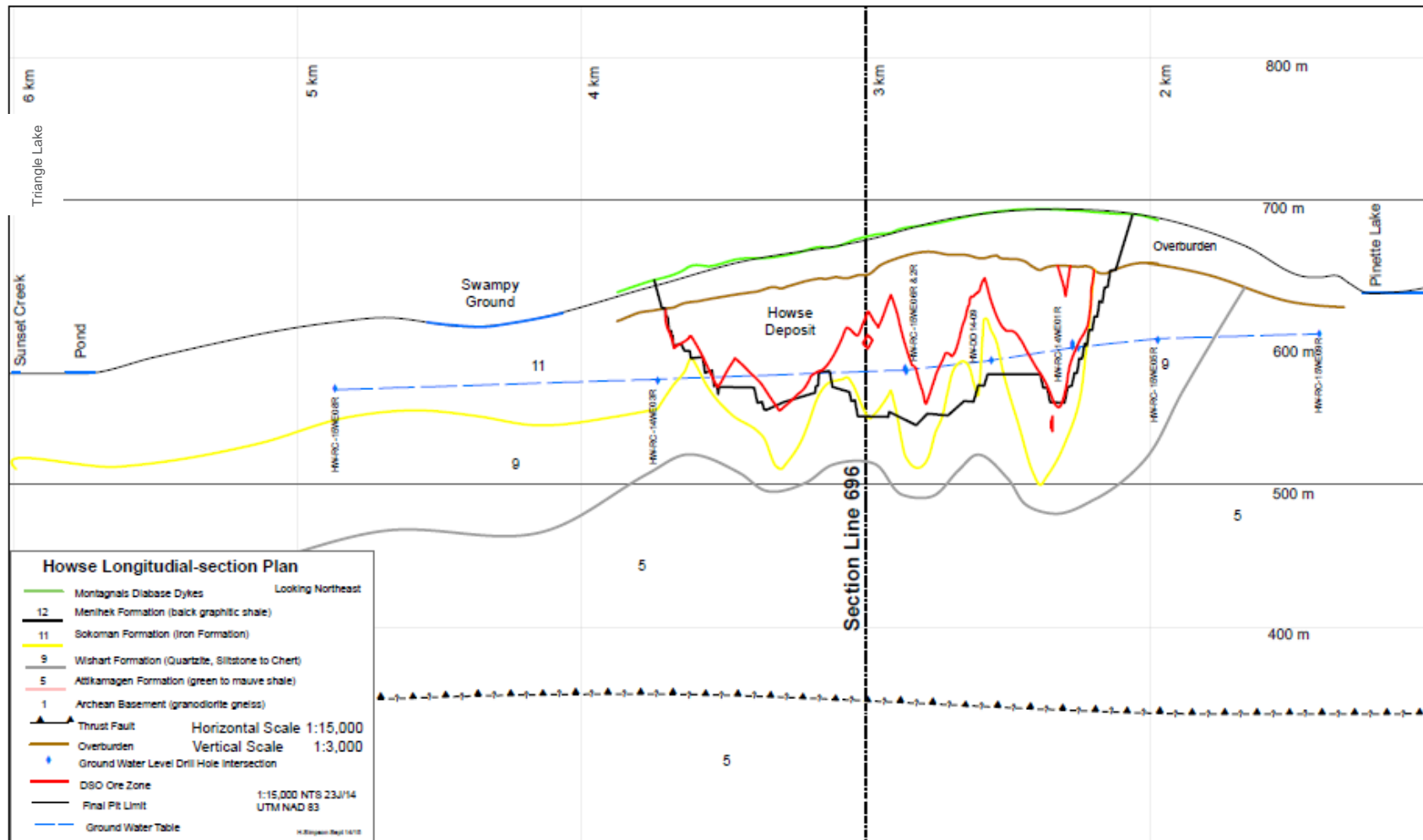
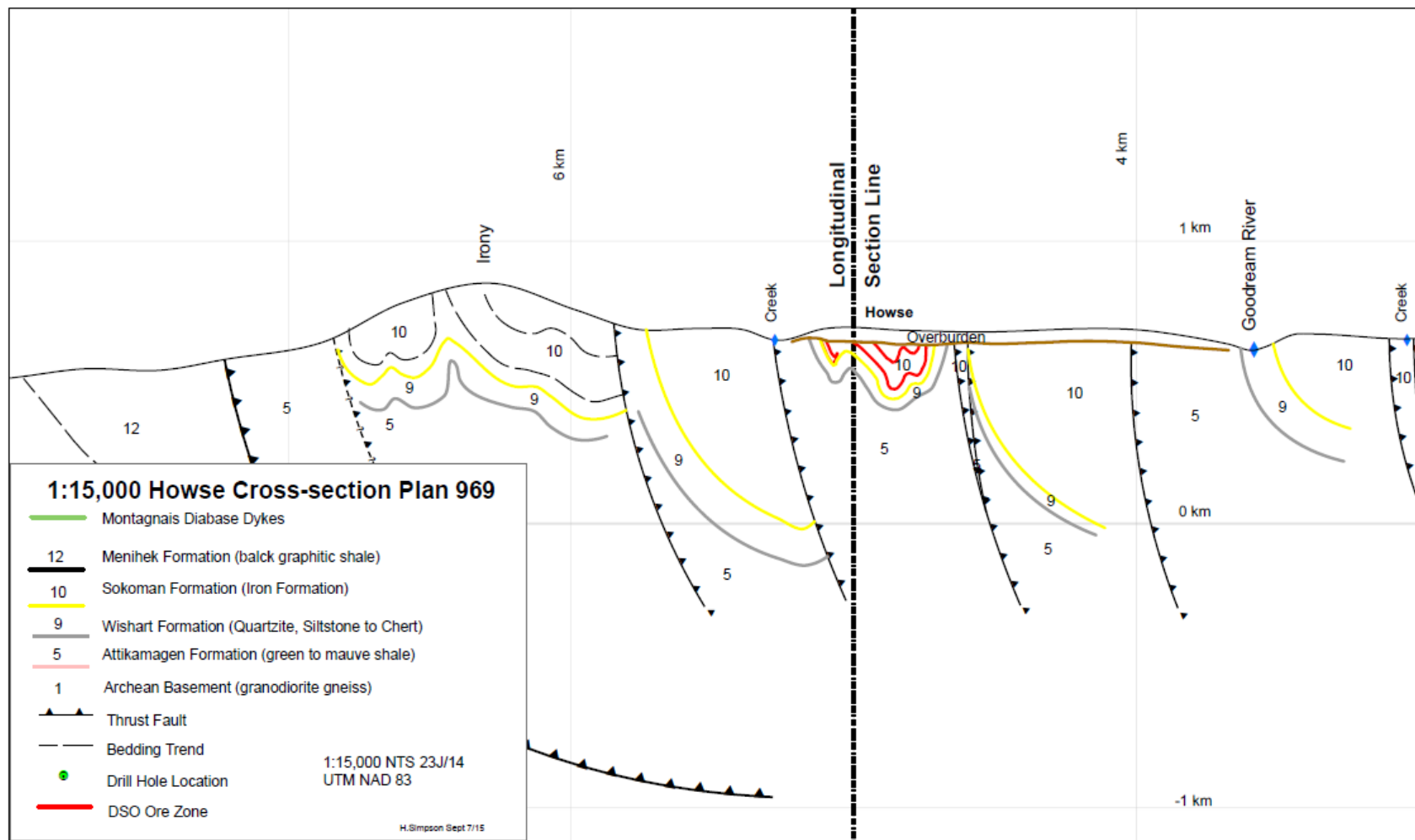


Figure 2-5 Transversal cross-section (Line 696) of the geology at Howse deposit site (Source: TATA Steel, 2015)



2.2.2 Aquifer hydraulic characteristics

Since 2014, many field investigations were conducted in the vicinity of the Howse deposits in order to assess the hydrogeological properties (hydraulic conductivity, storativity). The hydrogeological testing includes mainly packer tests (Golder, 2014) and pumping tests (Geofor, 2014 and Geofor, 2015). The detailed methodology, data compilation and interpretation as well as results for all geological boreholes and hydrogeological tests are presented in previous enumerated reports.

Golder (2014) conducted packer tests in two boreholes located within the perimeter of the proposed pit. The permeability testing was conducted at varying depth intervals from 6 to 26 m, either in falling head mode or in constant head mode (Golder, 2014). The hydraulic conductivity results for each borehole were interpreted by SNC-Lavalin using the boreholes' logs in order to attribute the permeability values obtained to the corresponding units tested. These results are summarized in Table 2-2.

Geofor (2014) conducted a 72-hour constant flow pumping test in two boreholes (HW-RC14-WE01R and HW-RC14-WE03R) located at each end of the proposed open pit. Their results were interpreted by Geofor and are summarized in Table 2-2.

Geofor (2015) conducted new pumping tests on three new boreholes. One within the perimeter of the proposed open pit (HW-RC15-WEO6R) and two located around this perimeter (HW-RC15-WEO7R and HW-RC15-WEO8R). The results interpreted by SNC-Lavalin are presented in Appendix A, and summarized in Table 2-2.

Generally, the recent results of hydraulic conductivity testing showed that the hydraulic conductivity of the Sokoman Formation which is the main formation in the area was relatively higher, and ranging from 1.6×10^{-6} m/s to 1.9×10^{-5} m/s with an average of 9.4×10^{-6} m/s. The shale of Attikamagen Formation had the lowest permeability values with an average of 5×10^{-8} m/s while the Wishart and fault zone recorded an intermediate conductivity value with an average of 1×10^{-7} m/s. In borehole HW-RC-14-WE03R, where a fault was reported within the Sokoman, the estimated permeability was the highest within the Howse deposit. The relatively lower permeability of the fault zones in borehole HW-GT13-001 may be explained by the nature of the fault coating materials reported less permeable in borehole logs. It can be also due to the polymer used to drill those holes (Golder, 2014).

Well Productivity

The step-drawdown tests conducted by Geofor in 2015 at the three pumping wells (HW-RC15-WEO6R, HW-RC15-WEO7R and HW-RC15-WEO8R) showed a slight decrease in specific capacity of the wells with flow rate increase. The results are presented in Appendix A.

The well HW-RC15-WEO6R located within the proposed open pit was pumped to a maximum of $1.1 \text{ m}^3/\text{min}$ (291 gpm) resulting in a 12.4 m final drawdown, and a specific capacity decreasing from 0.2 to $0.1 \text{ m}^3/\text{min}$ per meter.

The wells HW-RC15-WEO7R and HW-RC15-WEO8R located outside the proposed open pit were pumped to a maximum of 0.26 m³/min (75-85 gpm) resulting in a 13.6 m final drawdown, and a slight specific capacity decrease from 0.04 to 0.02 m³/min per meter.

Table 2-2 Summary of Hydraulic Conductivities Obtained from Various Tests

Reference	Test	Well Tested	K (m/s)	K average (m/s)	Geologic Formation
Golder, 2014	Packer test	HW-GT13-002	2E-07 - 6E-07	4.00E-07	Wishart
			4E-08 - 6E-08	5.00E-08	Attikamagen Shale
		HW-GT13-001	4E-08 - 5E-08		1.3E-07
			1E-07	Chert/Shale/fault zone	
			1E-07	Shale/fault zone	
Geofor, 2014	Pumping test	HW-RC14-WE01*	2.13E-06	9.40E-06	Sokoman (faulted Iron ore) /Wishart)
		HW-RC14-WE03*	3.34E-05		
Geofor, 2015	Pumping test	HW-RC15-WEO6R*	1.1E-05 - 2.4E-05	9.40E-06	Sokoman
		HW-RC14-WEO2R**	1.2E-05 - 1.9E-05		
		HW-RC15-WEO7R*	1.6E-06 - 1.1E-05		
		HW-RC15-WEO8R*	1.10E-05		

*Pumping well; ** Observation well

2.2.3 Groundwater Flow and Elevation

The regional piezometric map was up-dated based on recent data (fall 2015 and summer 2016) collected in the project area and data from previous studies on other mine sites nearby (2010 to 2014). Although the last data are not very recent, they nevertheless confirm the regional groundwater flow direction prevailing in the area on a large scale. The piezometric results are presented in Table 2-3 and Figure 2-6. Piezometric data of two periods (fall 2015 and summer 2016) varied slightly and confirm the groundwater static elevation in the Howse deposit area. The general groundwater elevation is higher in ridge sides to the southeastern area, in Timmins 3N and Fleming 7N areas (between 672 m in 10WTH-007 and 687 m in 10WTH-006), and decreases gradually to the northwestern area, reaching lower values in the Howse deposit area (between 603 m and 572 m). The furthest well located downgradient, between the Howse deposit and Triangle Lake (about 1000 m from the Howse deposit and 730 m from Triangle Lake) recorded a water elevation of 568 m.

The regional groundwater seems to flow in the longitudinal structures (Thrust faults) oriented parallel to the valley and recharged locally by the outcrop (permeable layers such as the Wishart) and the local groundwater flow when present. Abandoned mine pits may also be contributing to the groundwater recharge.

Table 2-3 Piezometric Results

Hole id	Northing	Easting	Well depth	Water depth (TOC)	Water elevation	Date	Water depth (TOC)	Water elevation (masl)	Date
	(m) zone 19		(m)	(m)	(masl)		(m)	(m)	(m)
New wells of 2015 in the Howse deposit area									
HW-RC15-WE05R	6085454	619903	181.4	76.4	602.7	04/11/2015	76,1	602,9	22/06/2016
HW-RC15-WE06R	6086132	619339	168.2	90.5	581.8	04/11/2015	90,9	581,4	22/06/2016
HW-RC15-WE09R	6085028	620275	97.6	39.4	607.1	04/11/2015	40,5	605,9	22/06/2016
HW-RC15-WE08R	6087650	617942	73.2	44.5	568.5	04/11/2015	45,4	567,7	22/06/2016
HW-RC15-WE07R	6086780	619859	97.6	58.4	597.8	04/11/2015	58,9	597,2	22/06/2016
Existing wells in the Howse deposit									
HW-DD14-09	6085950	619571	150.0	95.1	586.5	04/11/2015	95,4	586,2	22/06/2016
HW-DD14-14	6086123	619393	102.0	89.5	584.7	04/11/2015	89,5	584,6	22/06/2016
HW-DD14-17	6086270	619367	101.0	84.8	580.9	04/11/2015	85,7	579,9	22/06/2016
HW-DD14-35	6085652	619706	94.5	86.4	598.3	04/11/2015	85,6	599,1	22/06/2016
HW-RC13-03	6085655	619755	180.0	87.4	596.1	04/11/2015	87,0	596,4	22/06/2016
HW-RC14-WE01R	6085660	619715	164.0	88.8	595.4	04/11/2015	88,5	595,7	22/06/2016
HW-RC14-WE02R	6086138	619338	182.0	90.1	581.0	04/11/2015	90,3	580,7	22/06/2016
HW-RC14-WE03R	6086703	618737	180.0	67.3	572.8	04/11/2015	68,4	571,7	22/06/2016
Surface water in the Howse deposit area									
LAKE X	6086239	620132	NA	NA	658.6	Oct-14	NA	NA	NA
POND X1	6085741	620106	NA	NA	661.8	Oct-14	NA	NA	NA
POND X2	6085797	620114	NA	NA	662.0	Oct-14	NA	NA	NA
POND X3	6085827	620085	NA	NA	662.5	Oct-14	NA	NA	NA
Pinette Lake	6084782	620439	NA	NA	635.7	Oct-14	NA	NA	NA
Triangle Lake	6088305	618045	NA	NA	584.2	Oct-14	NA	NA	NA
Boreholes at the neighbouring sites									
11T6GW1 (Timmins 6)	6085872	621425	92.4	42.7	622.4	10/09/2011	NA	NA	NA
11T6GW2 (Timmins 6)	6085581	621746	103.7	48.8	635.8	Oct-15	NA	NA	NA
11T6GW3 (Timmins 6)	6085690	622131	103.7	61.3	642.8	Oct-15	NA	NA	NA
11T4GW2 (Timmins 4)	6085630	620945	97.6	61.1	616.8	11-Oct-11	NA	NA	NA
Plant Well #1	6084167	622800	103.7	27.9	652.6	14-Oct-11	NA	NA	NA
Plant Well B1	6084242	622843	97.6	18.4	663.4	30-Oct-11	NA	NA	NA

Hole id	Northing	Easting	Well depth	Water depth (TOC)	Water elevation	Date	Water depth (TOC)	Water elevation (masl)	Date
	(m) zone 19		(m)	(m)	(masl)		(m)	(m)	(m)
10-WTH-02 (Timmins 2)	6084662	622372	140.2	33.3	659.7	5-Oct-10	NA	NA	NA
10-WTH-1A (Timmins 2)	6085195	622376	79.3	51.1	648.2	29-Oct-10	NA	NA	NA
10-WTH-001 (Timmins 2)	6085191	622387	73.2	53.8	645.3	Oct-15	NA	NA	NA
10-WTH-003 (Timmins 2)	6084499	622639	94.5	32.7	650.1	07/10/2010	NA	NA	NA
10-WTH-004 (Timmins 2)	6084244	622926	61.0	20.9	653.5	26/10/2010	NA	NA	NA
TI3010H (Timmins 3)	6084096	624039	74.0	19.3	674.8	27/10/2009	NA	NA	NA
TI3011H (Timmins 3)	6084085	624021	110.0	16.7	677.8	31/10/2009	NA	NA	NA
10-WTH-006 (Fleming 7)	6083256	625028	134.1	52.9	686.3	05/11/2010	NA	NA	NA
10-WTH-006A (Fleming 7)	6083251	625032	140.2	54.8	684.5	12/11/2010	NA	NA	NA

TOC: Top of casing

NA: Not Applicable

masl: meter above sea level

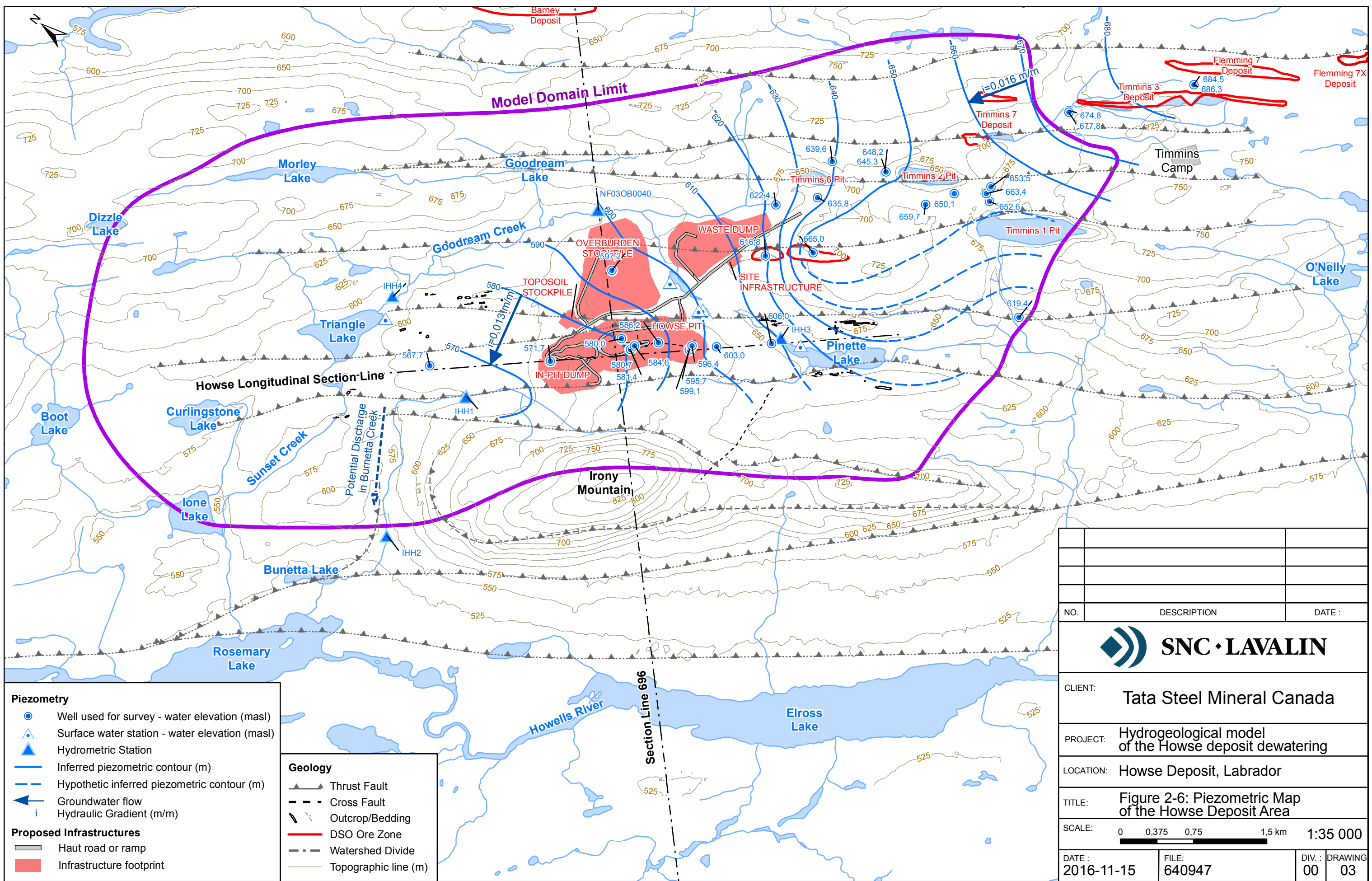
Source of 2016 piezometric data : Geofor, June 2016

Source of 2015 piezometric data : Geofor, November 2015

Source of 2014 piezometric data : Geofor, January 2014

Source of 2010-2011 piezometric data : Groupe Hémisphères and Geofor Environnement, 2011

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Piezometry

- Well used for survey - water elevation (masl)
- ▲ Surface water station - water elevation (masl)
- ▲ Hydrometric Station
- Inferred piezometric contour (m)
- - - Hypothetic inferred piezometric contour (m)
- ← Groundwater flow
- i Hydraulic Gradient (m/m)

Proposed Infrastructures

- Haut road or ramp
- Infrastructure footprint

Geology

- Thrust Fault
- Cross Fault
- Outcrop/Bedding
- DSO Ore Zone
- Watershed Divide
- Topographic line (m)

NO.	DESCRIPTION	DATE :
SNC · LAVALIN		
CLIENT:	Tata Steel Mineral Canada	
PROJECT:	Hydrogeological model of the Howse deposit dewatering	
LOCATION:	Howse Deposit, Labrador	
TITLE:	Figure 2-6: Piezometric Map of the Howse Deposit Area	
SCALE:		1:35 000
DATE :	FILE:	DIV. : DRAWING
2016-11-15	640947	00 03

At the Howse deposit, the groundwater depth varies approximately from 41 m to 95 m below ground surface. Two shallow boreholes between 29 and 35 m in depth (HW-RC14-WE02OB & HW-RC14-WE03OB) were dry and suggest the absence of a shallow and local aquifer. During drilling campaigns a large number of exploration holes no shallow aquifer was observed by the geologists and the drillers (Geofor, July 2016). Golder (2014) either did not point out the presence of a surficial aquifer in their report. Also, borehole (HW-RC15-WE07R) installed near the valley bottom and surrounded by wetlands showed that the groundwater level value of 59 m below ground surface is still deep at this location.

Groundwater flows are influenced by the topography with a horizontal hydraulic gradient of 0.013 m/m in the area of the Howse deposit, and 0.016 m/m upgradient, to the south-east of the project area;

Field observations by Geofor and Tata Steel's geologist pointed out the existence of a fault perpendicular to the main geological structures, along Burnetta Creek (it can be noticed in Figure 3-2), through which the groundwater may be discharging and feeding the creek and Burnetta Lake downgradient. Geofor mentioned that the low water temperature of Burnetta Lake in summer (6 degree Celsius, in comparison to Pinette Lake's water, over 12 degrees Celsius) can also be a clue to the possible groundwater discharge. This condition may contribute to lowering the groundwater level downgradient the Howse deposit.

Groundwater Levels Monitoring

Two continuous and three discontinuous water level monitoring in deep boreholes (depth between 95 and 182 m) were conducted within the perimeter of the planned pit from July to September 2015. One of the monitored boreholes (HW-RC14-WE03R) is located downgradient at the northern extremity of the pit and the other boreholes are located upgradient at its southern extremity (HW-DD14-09, HW-RC14-WE01R, HW-DD14-35 and HW-RC13-03). The results for boreholes located at the southern extremity of the pit indicated a gradual decrease of groundwater level with time, reaching of magnitude of 2.3 m. At borehole HW-RC14-WE03R located downgradient, groundwater level increased by about 1.7 m. This water level increase is probably due to a direct response to local precipitation or surface runoff over an unconfined or semiconfined aquifer at this part of the Howse deposit. Table 2-4 summarizes the groundwater monitoring results in the five boreholes within the Howse. Figure 2-7 presents the groundwater level evolution in these boreholes during the monitoring.

Recent study carried out by Journeaux Ass. (2015) about eventual presence of permafrost in the Howse deposit area has shown that discontinuous permafrost, if any, should occur in erratic and isolated small lenses or pockets but not in any extensive identifiable layers. Based on this study the Howse area will be considered permafrost free.

Recent data collected from boreholes HW-RC14-WE03R and HW-RC13-03 (one year data from June 2015 to June 2016; Geofor, 2016) show an annual groundwater table variation between 2 and 3.5 m.

Pinette Lake, Triangle Lake and wetlands

Pinette Lake, Triangle Lake and few wetlands are located within the project footprint. Wetlands in the study area occur in the valley's bottom and depressions. Their soil consists of clay and silt which make them poorly drained (personal communication from Gilles Fortin of geofor). They are principally fed by precipitation, runoff and baseflow near surface.

The Pinette Lake is located 820 m upgradient from the Howse deposit. Its elevation is about 636 m, and has a maximum depth of 4.5 m. Lake-bed sediments are dominated by silt with few blocks (Groupe Hemispheres, 2014).

The groundwater elevation at the well, HW-RC15-WE09R, installed 160 m from Pinette Lake, is 606 m (June 2016). Therefore, the hydraulic head difference between the groundwater at this location and the lake's bottom is 25 m. This condition implies that Pinette Lake is unlikely connected to groundwater within this short distance. The presence of impermeable base (shale formation) underneath the lake supports this assumption.

Concerns were raised on possible groundwater discharge into Triangle Lake located 1720 m downgradient the Howse deposit. This eventual condition would impact the lake when dewatering of the deposit starts. This hypothesis hasn't been confirmed with specific field investigations.

Triangle Lake elevation is about 584 m, and has a maximum depth of 12 m. The groundwater elevation at the well, HW-RC15-WE08R, installed between Triangle Lake and the Howse deposit (700 m from Triangle Lake and about 1000 m from Howse deposit) is 568 m (June 2016). Therefore, the hydraulic head difference between the groundwater at this location and the lake's bottom is about 16 m. Based on a hydraulic gradient of 0.01 m/m (similar to hydraulic gradient observed in the area downgradient near Howse deposit), groundwater would reach an elevation of 561 m under the lake. Based on this observations and the fact that surface topography is almost flat between the well location and Triangle Lake (there is no great surface topography variation), it is unlikely that groundwater flow changes direction and flow towards the Lake. However, if conductive faults exist in this area, they may contribute to groundwater discharge into the lake. The investigation on this matter requires elaborated hydrogeological program and long term groundwater monitoring period, in order to get conclusive results.

It is reported that lake-bed sediments are dominated by silt with few blocks (Groupe Hemispheres, 2014) which may slow the drawdown progress and reduce the impact.

Piezometry monitoring for a long period of time in boreholes nearby the pit and the lakes would lead to an evaluation of the effective recharge and discharge, and a better understanding of the groundwater/surface water interaction zones in this area.

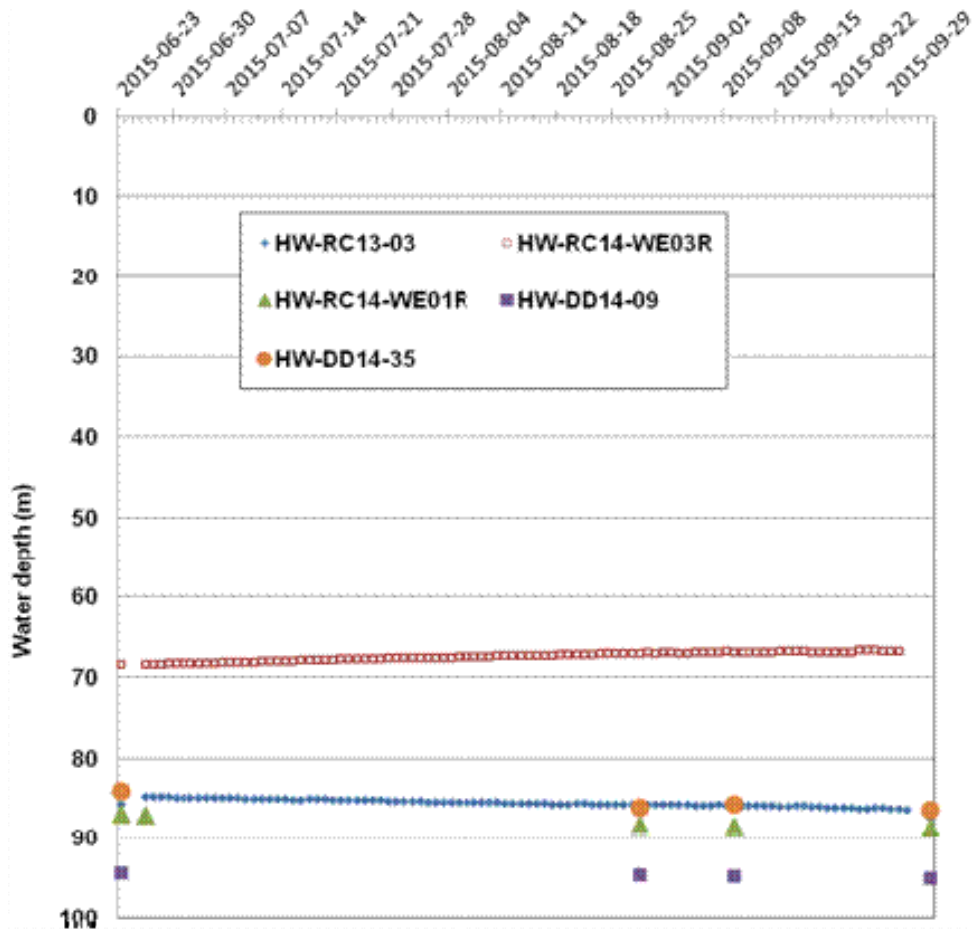
Table 2-4 Summary of Piezometric Monitoring

Borehole ID.	Initial depth (m)	Final depth (m)	Water level variation (m)
	June 23 2015	October 2/4 2015	
HW-RC14-WE03R*	68.40	66.74	+1.66
HW-RC13-03*	85.69	87.37	-1.68
HW-RC14-WE01R**	87.05	88.76	-1.71
HW-DD14-09**	94.40	95.08	-0.68
HW-DD14-35**	84.14	86.41	- 2.27

* Continuous measurements

** Instantaneous measurements

Figure 2-7 Groundwater Level Monitoring in Boreholes



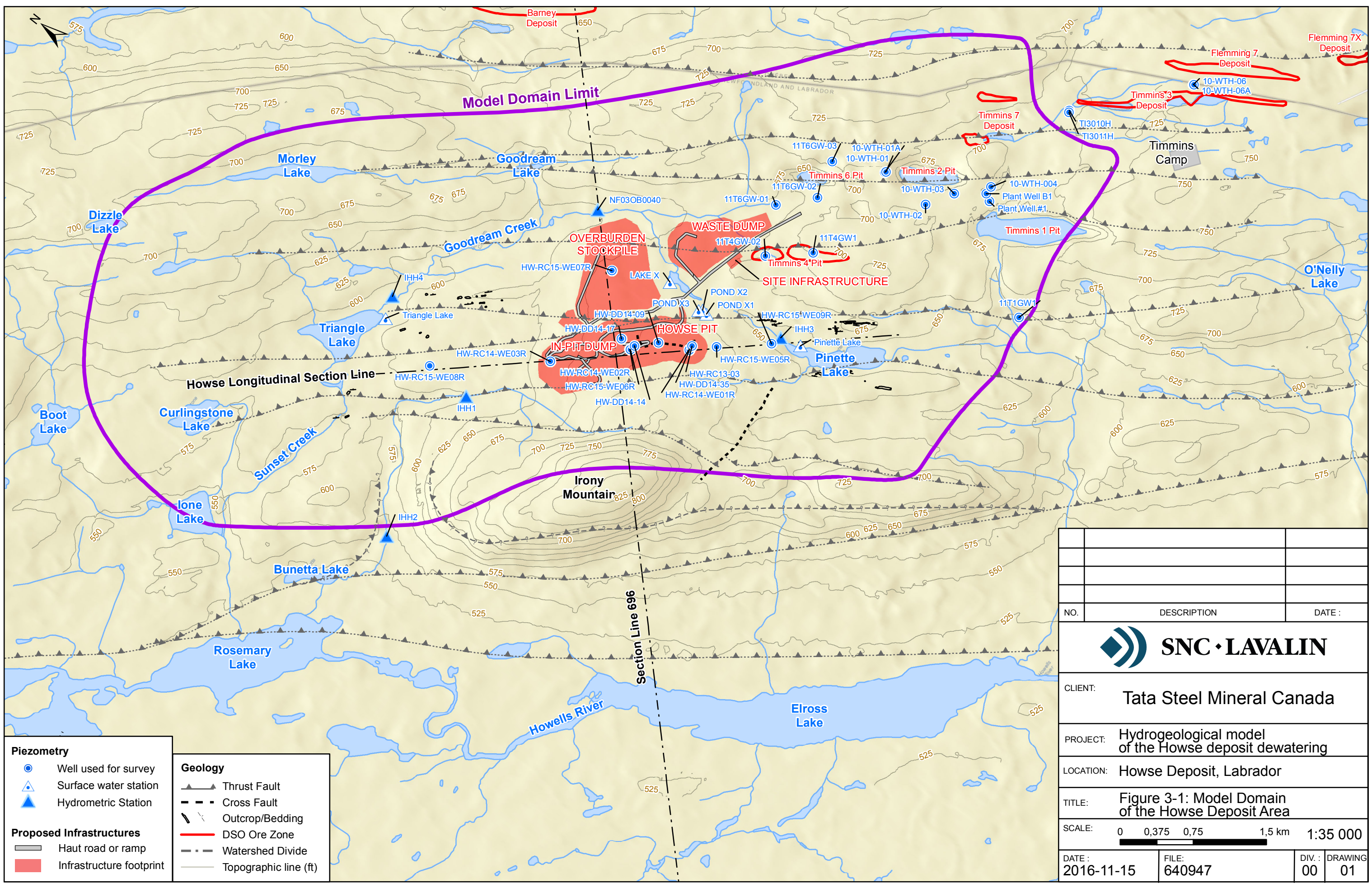
3 Groundwater Flow Numerical Model

3.1 Conceptual Model

In order to estimate the flow rate and drawdown resulting from the dewatering of the Howse deposit, a conceptual model of the groundwater flowing through the deposit was built and transposed into a numerical model. The model of the natural groundwater flow of the aquifer was calibrated with hydrogeological parameters determined with field data collected at the site. Following the calibration of the natural groundwater flow model in steady-state condition, three phases of the open pit was introduced into the model, in transient flow regime, to simulate the dewatering of the future mine pit at three mining phases including the final one.

The purpose of building a conceptual model is to represent the field system with a simple model as close as possible to the field condition so that the numerical model will be more accurate. This conceptual model is based on the data collected on the hydrogeology conditions which are described in details in the previous chapter and summarized in the following one.

Figure 3-1 is at a larger scale to show the regional groundwater system starting from the southeast of the domain. The conceptual model of the groundwater system is described below.



V:\Projets\640947 - Tata - Howse Modelling\4 - Realisation\4.7 - Cad\DaoSig\SIG\MXD\640947 - Fig1 - ModelDomain.mxd

Piezometry		Geology	
	Well used for survey		Thrust Fault
	Surface water station		Cross Fault
	Hydrometric Station		Outcrop/Bedding
Proposed Infrastructures			DSO Ore Zone
	Haut road or ramp		Watershed Divide
	Infrastructure footprint		Topographic line (ft)

NO.	DESCRIPTION	DATE :
CLIENT:	Tata Steel Mineral Canada	
PROJECT:	Hydrogeological model of the Howse deposit dewatering	
LOCATION:	Howse Deposit, Labrador	
TITLE:	Figure 3-1: Model Domain of the Howse Deposit Area	
SCALE:	0 0,375 0,75 1,5 km 1:35 000	
DATE :	FILE:	DIV. : DRAWING
2016-11-15	640947	00 01

3.1.1 Area of the Model

The area of interest was defined to include natural hydrogeological boundaries. The groundwater regional basin or watershed was delimited using some of the surface water watershed limits. The new model domain was enlarged in order to reduce the effect of specified hydraulic head boundaries that were applied near lakes in previous model. Due to the regional watershed morphology, the model was enlarged in the northwest-southeast direction. The new model covers an area of about 4 km by 10 km (see Figure 3-1) and its limits are:

- › Ridges along the provincial border to north;
- › Ridge of Irony Mountain to the south;
- › Ridges to the southeast, along Elross Creek's limit of the domain;
- › A limit to the northwest was set downstream beyond Triangle Lake (near Boot Lake).

3.1.2 Hydrostratigraphic units

The project site is located in the Labrador geosynclinals which consist of geological formations that were compressed into a series of synclines and anticlines, cut by steep angle reverse faults that dip primarily to the east. The main geological formations encountered in the area of interest are:

- › Overburden: ranges over the Howse deposit from 20 to 50 m of thickness;
- › Sokoman Formation (Cherty iron formation) with Ruth Formation: thickness ranges from 110 to 120 m, and includes the ore zone;
- › Wishart Formation: 15 to 20 m of thickness;
- › Shale Formation : over 300 m of thickness.

The vertical extension of the new model was increased to include the horizontal formations underneath the pit (Wishart and Shale formations)

3.1.3 Groundwater Flow and Elevation

The regional groundwater flow is controlled by the lineaments that are oriented in a northwest-southeast direction. Also, the impermeable Attikamagen Formation (shale) acts as a barrier to groundwater flow. This configuration will influence greatly the groundwater flow which is mainly from southeast to northwest.

The groundwater level data on a large scale suggest that the regional groundwater flow originates from recharge areas located in the southeast. Locally, groundwater recharge is occurring from the watershed divide located to the south along Irony Mountain and through permeable outcrop (Wishart and fractured Sokoman). The flow is towards local bottom valley and to the northwest globally. The Burnetta Creek to the south was suggested as possible groundwater discharge (Geofor, 2015) through geological structures and the permeable zones. To the southeast of the domain the horizontal hydraulic gradient is 0.016 m/m and decreases slightly towards the Howse deposit area, where it reaches 0.013 m/m.

3.2 Modeling Software

The 3D numerical groundwater flow model selected for the current study is Visual Modflow 2015 Pro version. The original Modflow code was developed by the U. S. Geological Survey in 1984. MODFLOW is considered an international standard for practical applications in three-dimensional groundwater flow and contaminant transport simulation. It is widely used within the groundwater modeling community, and well-documented. The model uses the finite-difference numerical technique for solving groundwater flow equations. Simulations were done in steady-state and transient flow regimes.

3.3 Model Geometry and Grid

3.3.1 Domain and Grid

The groundwater flow domain grid was built to include the regional groundwater domain. The presence of groundwater divides to the north and south of the study area were considered as natural boundaries in order to reduce the total number of cells and increase the calculation efficiency. The entire domain dimensions are around 4 km by 10 km.

The grid is composed of 120 rows and 200 columns, which represents 24,000 rectangular cells per layer. The discretization of the mesh in the XY dimension is regular and the size of a cell is about 60 m. The discretization of the mesh in the Z dimension varies with depth. The uppermost layers are about 10 m deep, and the base layers are about 30 m deep.

Surface elevations have been extracted from 1: 50,000 scale topographic maps. The bottom limit of the model was set to a constant elevation of 300 m, which includes the shale unit. Figure 3-2 shows the model limit and grid.

3.3.2 Model Layers

A simplified groundwater flow model for the study was developed based on regional surface geological map of the Government of Newfoundland and Labrador (Wardle, R.J. 1982) and on recent geological cross-sections obtained from TATA Steel's geologist. The model is tri-dimensional, and is composed of five (5) main hydrostratigraphic zones and longitudinal fault zones north and south of the Howse deposit (Figures 3-2 to 3-7):

- › Overburden;
- › Sokoman formation representing the dominant hydrostratigraphic unit in the domain;
- › Wishart formation, represents the surrounding formation;
- › Shale formation at the base , and
- › Fault zones.

The model is composed of 26 layers of variable thickness. The first 4 layers represent the overburden. The subsequent 22 layers are made of different hydraulic properties areas to represent the geological units of the domain. The inclination of these different units was neglected in the study for simplicity of the model. As mentioned, the previous vertical model extension was increased to include the horizontal formations underneath the pit (Wishart and Shale formations) but also to reach the final pit depth adjusted to 195 m (previously was 160 m).

Figures 3-6 and 3-7 show the general configuration of the layers in the east-west and north-south axes respectively.

Figure 3-5 Geology of Layers 21 to 26

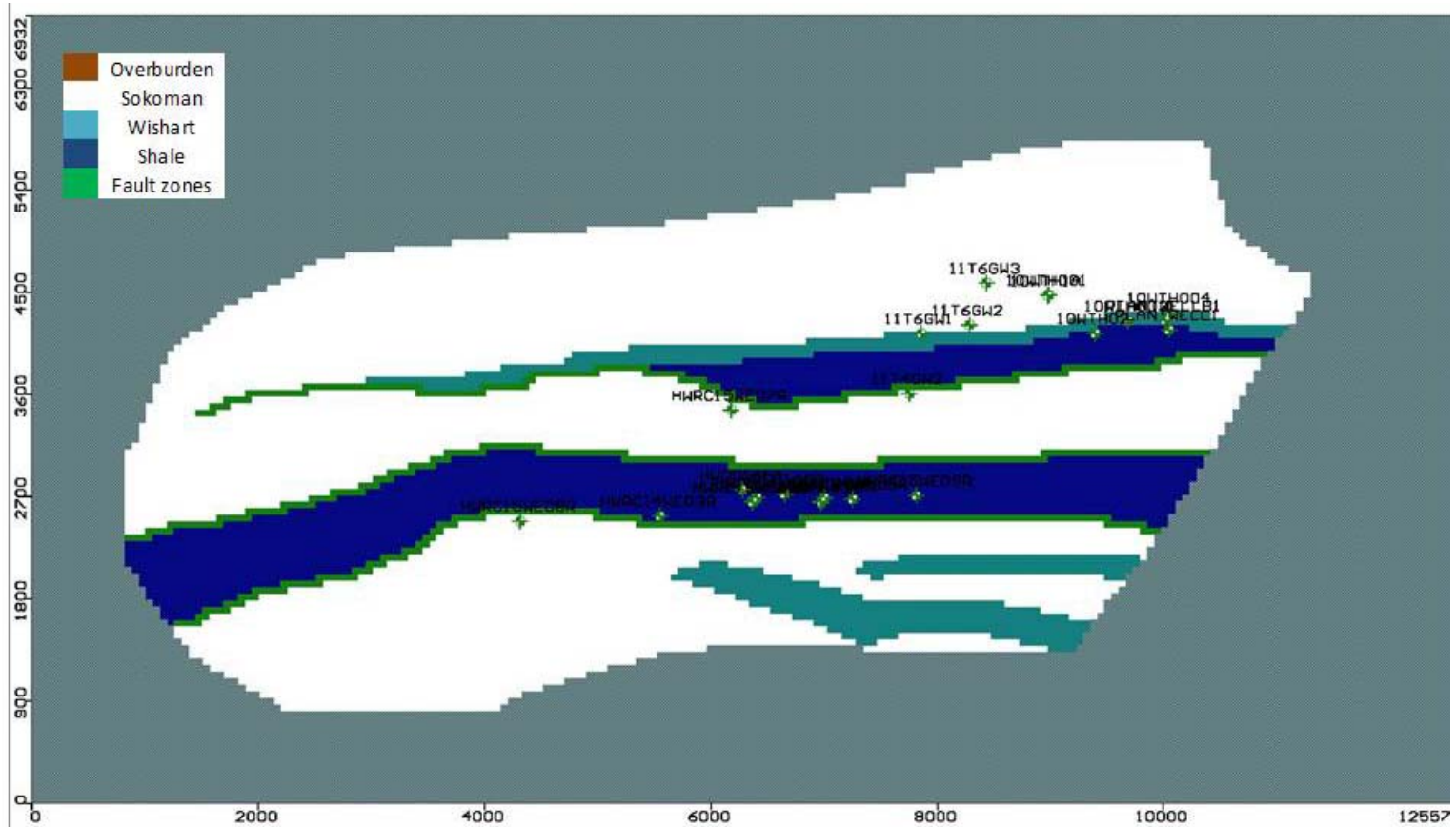


Figure 3-6 Vertical Model Grid –West-East Section

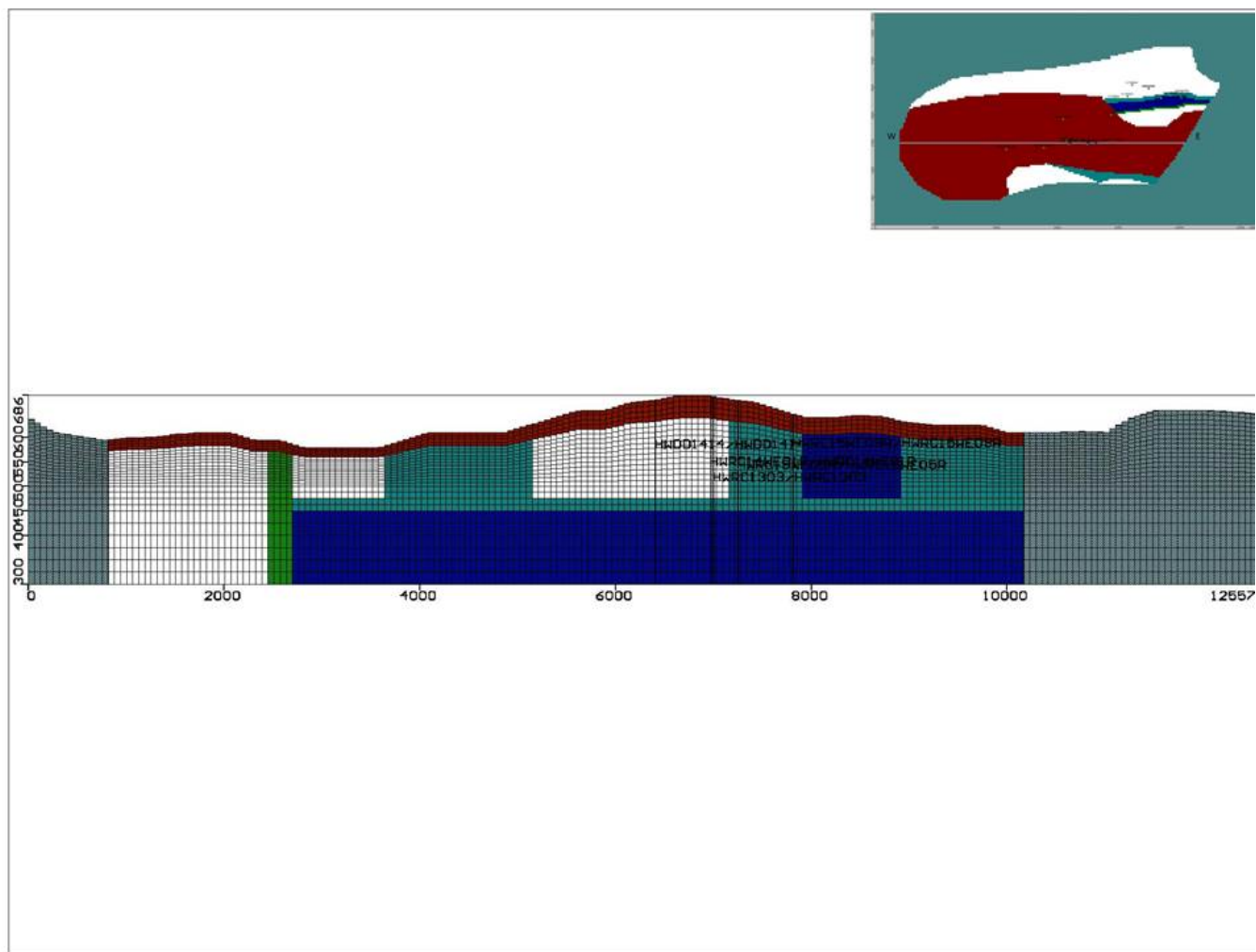
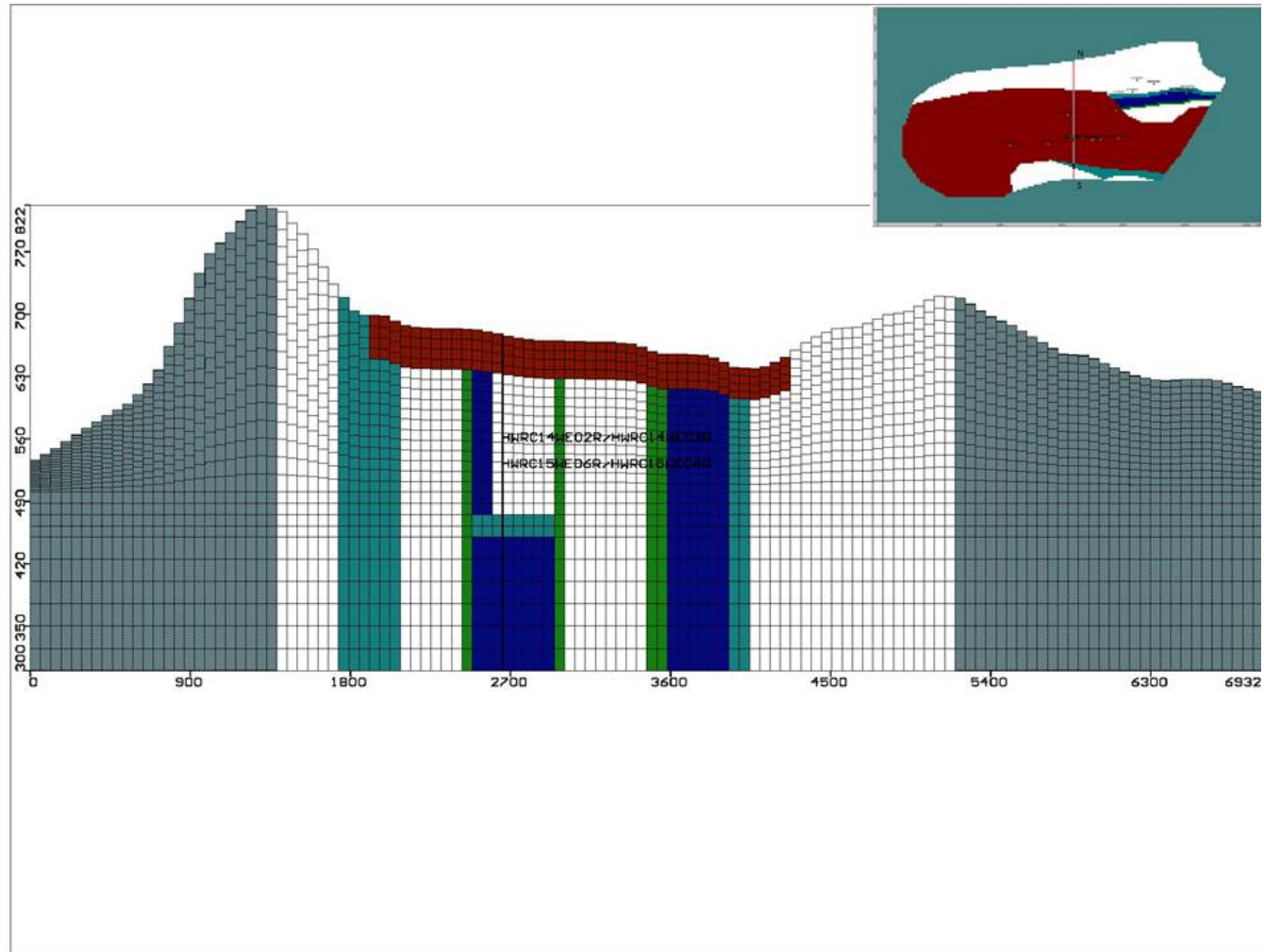


Figure 3-7 Vertical Model Grid –South-North Section



3.4 Hydraulic properties and boundary conditions

3.4.1 Hydraulic Properties

The hydraulic properties of the model's hydrostratigraphic units have been derived from the results of hydraulic testing, and borehole logs of the local hydrogeological studies on site (Golder, 2014; Geofor, 2014 and 2015) and on neighboring sites (Groupe Hémisphères and Geofor, April 2011).

The first 4 layers of the model are mostly composed of active cells with a uniform hydraulic conductivity for the overburden. A maximum value for fine sand of 1×10^{-5} m/s was considered based on literature (Sanders, 1998).

The distribution of the hydraulic conductivity of subsequent layers was assigned according to the regional surface geological map. The flow is governed by more permeable stratigraphic units aligned generally in the axis NW-SE.

The fault zones are represented by intermediate permeability values, while the Sokoman including the iron ore units is represented with a relatively higher permeability values.

For example, the spatial distribution of the iron formation units including the Cherty unit (Sokoman) which occupies most of the territory is presented in Figure 3-3 for the entire area of study. Table 3-1 gives the initial hydraulic conductivities used in the model.

Table 3-1 Initial Hydraulic Conductivities

Zone	Layer	Kx (m/s)	Ky (m/s)	Kz (m/s)
		Initial	Initial	Initial
Overburden	1 to 4	1.0E-05	1.0E-05	1.0E-05
Sokoman	1 to 26	9.4E-06	9.4E-06	9.4E-06
Wishart	1 to 26	8.4E-06	8.4E-06	8.4E-06
Shale	1 to 26	5.0E-08	5.0E-08	5.0E-08
Fault zones	1 to 26	2.0E-07	2.0E-07	2.0E-07

3.4.2 Boundary Conditions

The limits and characteristics of the groundwater flow domain were determined according to the regional hydrogeological settings. The groundwater regional basin or watershed was delimited using some of the surface water watershed limits, considered as groundwater divide, and consequently as no-flow boundaries.

A constant head boundary of 665 m, based on water levels measured in the area of Timmins 1 and 2 was imposed to the eastern border of the model, representing the main water inflow into the domain (see Figure 3-8).

A constant hydraulic head of 460 m was set at the west boundary, representing the main discharge area of the aquifer. Although this value of 460 m is lower than the potential value

obtained by extending the upstream gradient (more likely around 520 m), it allows the best fit possible for the model calibration. Since no data were available in this newly added area to support this choice, the boundary was set far from the area of interest so that imposed stresses to the interior part of the system do not reach the boundaries. Based on the groundwater modeling reference book 'Applied Groundwater Modeling' (Anderson & Woessner, 1992), in such simulation, fitting the grid to the exact shape of the boundary is not crucial to the modeling effort.

Appendix C presents a sensitivity analysis on the exit boundary regarding the value and the position of that limit as well as the recharge rates. In a first place, a constant head value of 520 m was tested instead of the initial 460 m. In the second place the limit was relocated to the southwest corner of the model to evaluate the impact of another discharge limit location. With a value of 520 m, it appears that the water table is 50 m higher than the observed values. By changing the location of the discharge boundary, it seems that the discharge flow is limited by formations of lower permeability, resulting in two distinct zones on the calibration curve (see Appendix C).

Surface water bodies in the domain were not considered for the reasons described in the previous sections.

3.4.3 Recharge Rate

In the previous model the infiltration rate to deep groundwater was 109 mm/year, representing 20 % of the net water depth available (546.2 mm) after deducting evapotranspiration and sublimation (estimation based on literature review by Geofor, November 2015). This recharge was considered to be low, and was increased to 150 mm/year in the new model version.

An initial recharge rate of 150 mm/year was applied to the entire domain of the model. In a first step, the constant recharge of 150 mm/year was applied for the steady scenario in order to calibrate the model without the pit.

In a second step, a variable recharge was applied to the model, in transient state flow regime, in order to access the sensitivity of this parameter variation on the dewatering. A lower recharge rate was used during winter (8 months per year) to simulate the frozen soil. During thaw season (four months per year), a higher recharge rate was applied to the model so that the annual average recharge is equal to 150 mm (Table 3-2).

Table 3-2 Cyclic recharge applied to the model

		Recharge on a monthly basis (mm)
Winter	January	30
	February	30
	March	30
	April	30
	May	30
Summer	June	390
	July	390
	August	390
	September	390
Winter	October	30
	November	30
	December	30
Average annual recharge (mm)		150

Effects of a variable recharge are noticeable on the water well levels (see Figure 3-9). Water level variations are 2.5 m on average which is consistent and similar to the groundwater annual variation recorded in monitoring wells.

Figure 3-8 Boundary Conditions Applied to the Model Indicated by Brown Cells

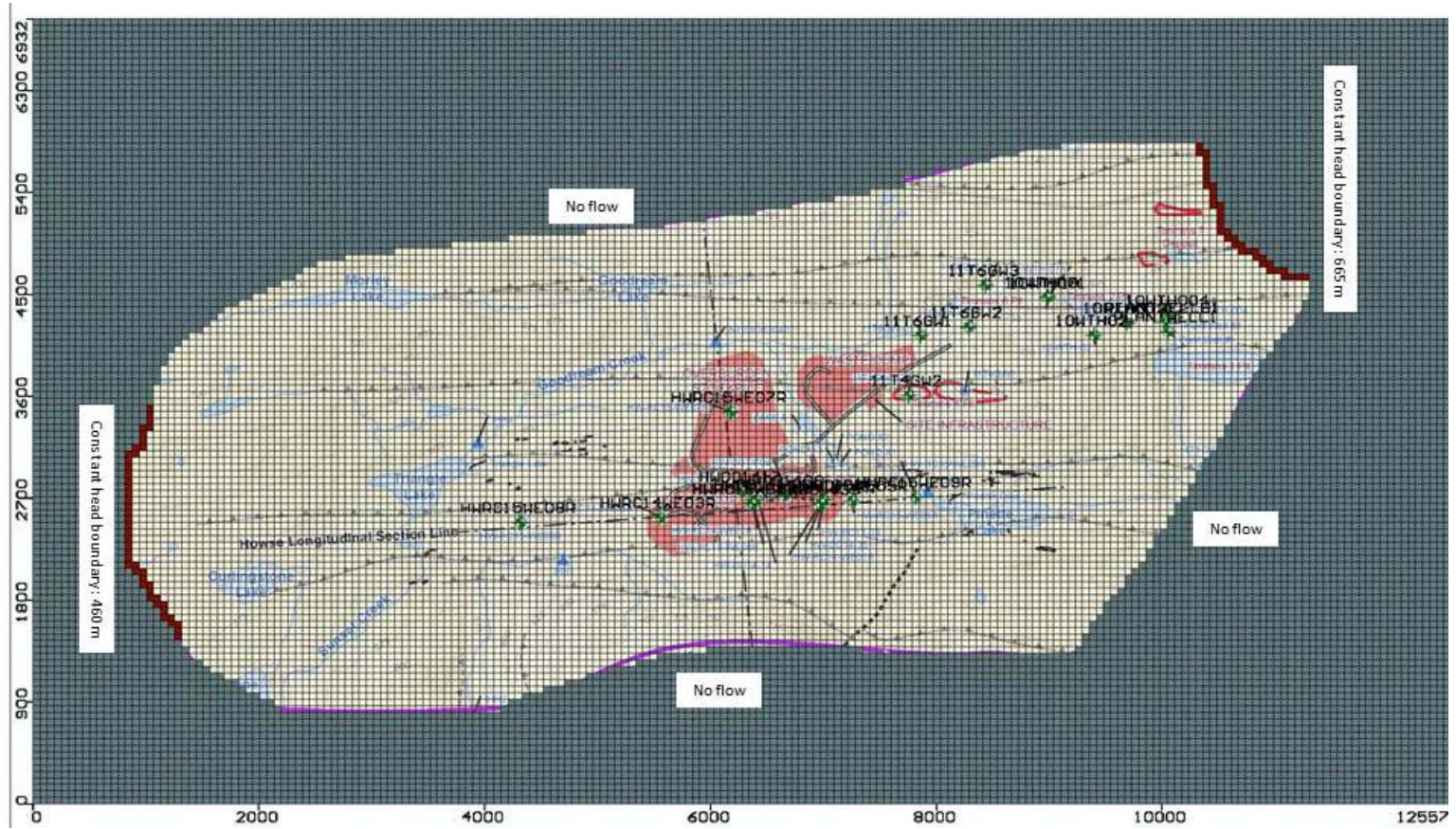
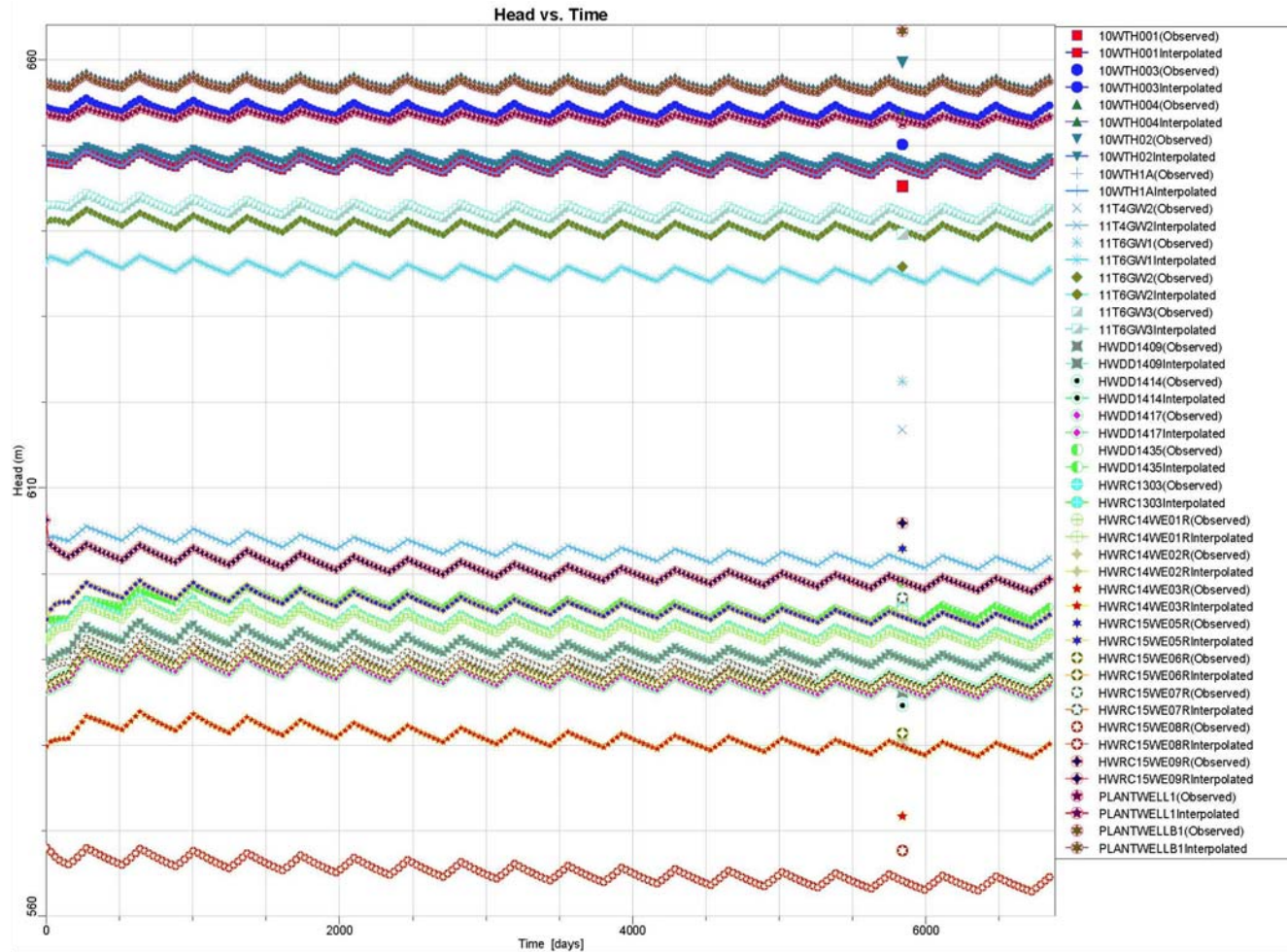


Figure 3-9 Water Well Level Variations with Cyclic Recharge Applied to the Model



4 Model Calibration and Results

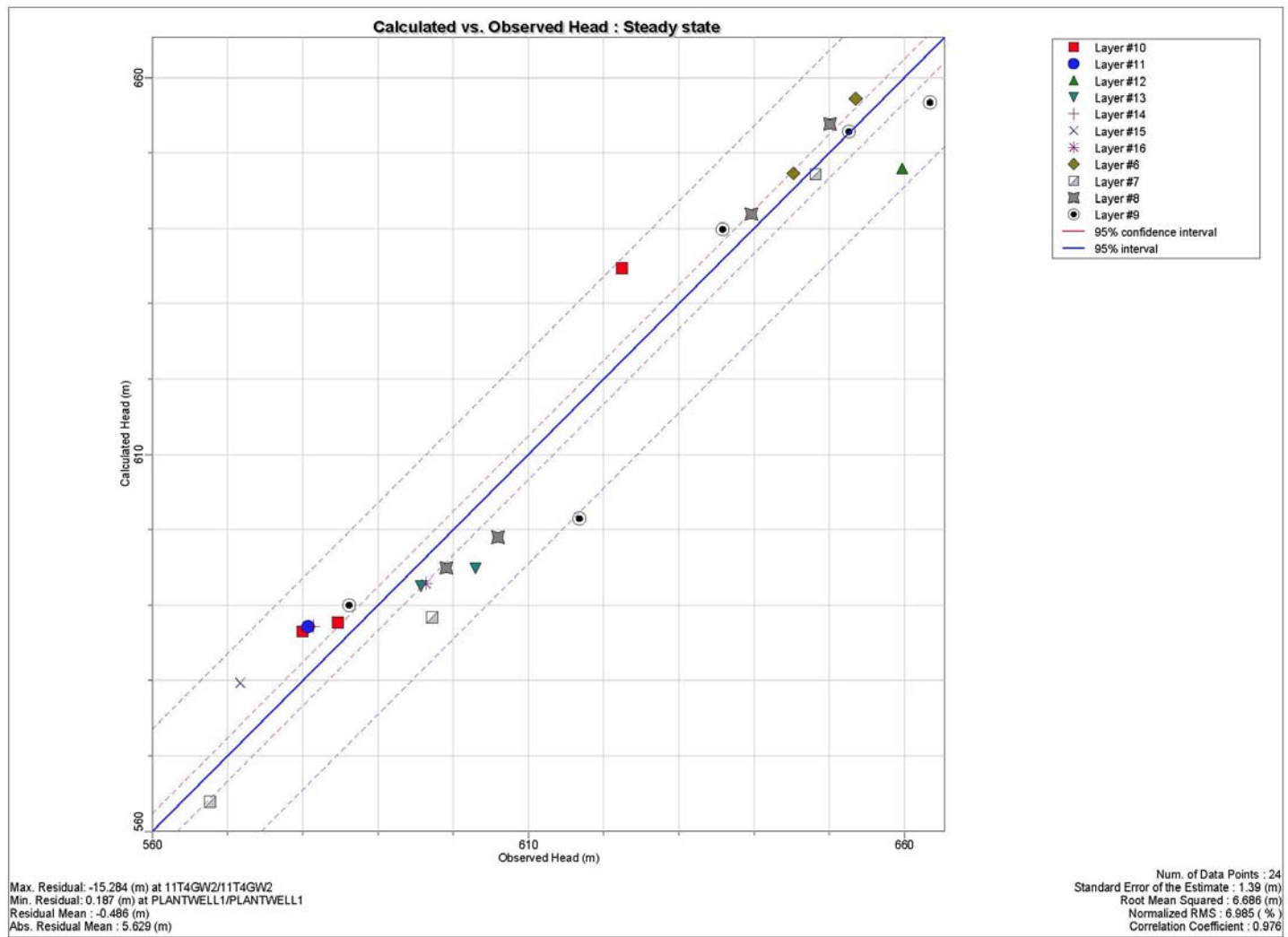
4.1 Groundwater Flow Model Calibration

The model calibration process consists in adjusting hydraulic gradient values and boundary conditions to obtain a best fit of the groundwater heads and flow directions observed in the field, within an acceptable error limit.

First, a calibration was done by comparing piezometric map based on field data and simulated piezometric map. Simulated hydraulic heads were also compared to observed heads using a calibration curve. The results presented on Figure 4-1, showed a good fit between the simulated and observed hydraulic heads with an error percentage calculated by means of the normalized Root Mean Squared (RMS) lower than 10%. This RMS value indicates that the model calibration result is acceptable.

Figure 4-2 presents the calibrated piezometric contours and regional groundwater flow direction. As illustrated on Figure 3-8, the simulated main regional groundwater flow component is towards the northwest region of the domain which corresponds to the natural flow. The simulated hydraulic gradient over the domain was about 0.02 m/m and very close to the general values observed on a large scale (0.013-0.016 m/m).

Figure 4-1 Calculated Versus Observed Heads at Steady State



The initial hydraulic conductivity values were increased to better represent the expected groundwater flow patterns of the area and to be able to incorporate a recharge of at least 150 mm/year without creating an overflow. Initial and calibrated hydraulic conductivities are given in Table 4-1.

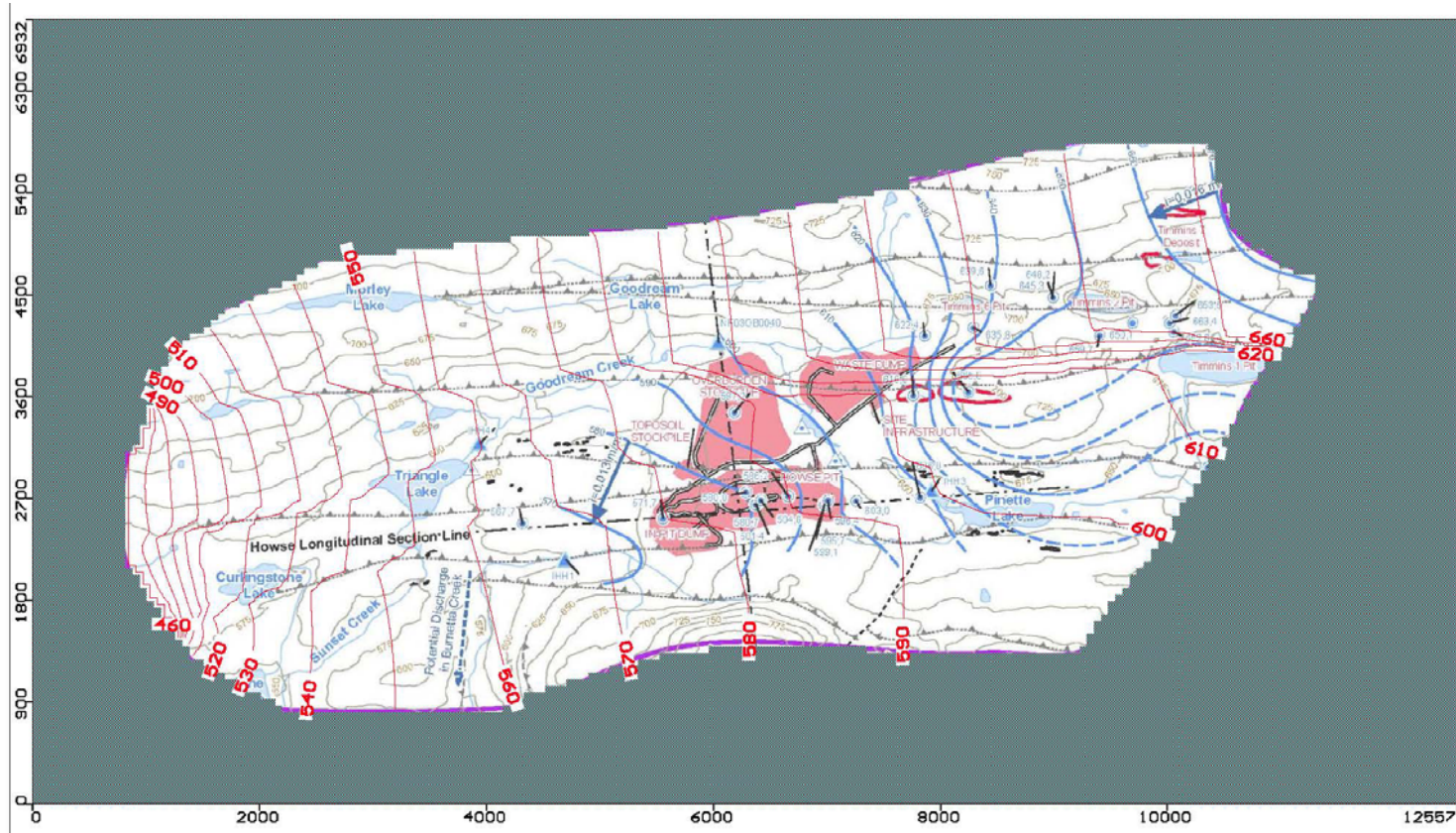
Figure 4-2 presents simulated groundwater levels based on measured groundwater levels for steady-state groundwater regime prior to dewatering activities.

Table 4-1 Initial and Calibrated Hydraulic Conductivities

Zone	Layer	Kx (m/s)		Ky (m/s)		Kz (m/s)	
		Initial	Calibrated	Initial	Calibrated	Initial	Calibrated
Overburden	1 to 4	1.0E-05	2.0E-05	1.0E-05	2.0E-05	1.0E-05	2.0E-05
Sokoman	1 to 26	9.4E-06	1.5E-05	9.4E-06	1.5E-05	9.4E-06	1.5E-05
Wishart	1 to 26	4.0E-07	8.4E-06	4.0E-07	8.4E-06	2.0E-07	8.4E-06
Shale	1 to 26	5.0E-08	5.0E-08	5.0E-08	5.0E-08	5.0E-08	5.0E-08
Fault zones	1 to 26	1.3E-08	5.0E-07	1.3E-08	5.0E-07	1.3E-08	5.0E-07

As mentioned previously, many set of parameters were tested to represent the expected groundwater flow patterns of the area. These parameters included hydraulic conductivity, recharge rate as well as position and head values of discharge boundary. The appendix C presents a sensitivity analysis on the discharge boundary.

Figure 4-2 Simulated Natural Piezometric Map



4.2 Howse Deposit Dewatering Model

After obtaining the calibrated natural groundwater flow model, the open pit was incorporated into the model to simulate the dewatering of the future mine pit during three main mining phases (see Appendix B: Howse Deposit mining phases). During the first mining phase (Phase I), mainly the northwest part of the deposit will be mined with a final depth around elevation 580 m. Then, during Phase II, mining will go deeper in the northwest area of the deposit whereas mining of the center part will start. Finally, during Phase III, the center and the southeast of the deposit will both be mined whereas the northwestern part will be completely filled with waste. The drain package method of Modflow was used to simulate the drawdown at each of the final pit phases under pumping conditions (see Table 4-2).

Table 4-2 Main mining phases of the Howse deposit

	Phase I	Phase II	Phase III
Deposit mining periods	5 years	6 years	6 years
Final northwest Pit elevation (m)	580	550	680
Final center pit elevation (m)	600	580	480
Final southeast pit elevation (m)	-	-	520

Simulations were carried out in transient state flow regime to evaluate the flow rates and the radius of influence of the dewatering activities at the final pit floor of each mine phase.

In addition to the base case of the calibrated model, sensitivity analyses were carried out by increasing the hydraulic conductivity of the hydrostratigraphic units to emphasize the flow along bedding planes and by increasing the recharge rate for one of the scenarios (Appendix F1 and F2 respectively). More details on the sensitivity analyses scenarios are available in Appendix F.

Table 4-3 presents the pumping rate at the end of each mining phase. The deeper the pit is, the higher the flow rate with a peak flow of 11,500 m³/day at the end of phase III, when the deepest pit elevation is reached (480 m elevation, in the center area).

The sensitivity analyses results indicate that the increase of hydraulic conductivity by one order of magnitude (x10) for only the Shale and the Wishart units (case 1), increases the pumping rate by a factor of 1.9. The increase of recharge (case 2) by 50 mm/yr increases the pumping rate by a factor of 1.2.

Consequently, flow rate may reach higher values ranging from 13,000 to 22,000 m³/day with higher hydraulic conductivity and recharge values (cases 1 and 2). Table 4-3 summarizes the flow rate results taking into account these non-negligible factors, and shows the influence of permeability and recharge rate increase (possibility that could occur due to the geological and structural heterogeneities within the study area).

Table 4-3 Dewatering Simulation and Sensitivity Analysis Results

Scenario	Flow rates (m ³ /day)				Note (see Appendix C on sensitivity analysis for more details)	Pumping rate increase
	End of Phase I	End of Phase II	End of Phase III	Safety factor of 1.25 on Phase III		
Base case: Calibrated model	1132	7150	11423	14279	› Kx, Ky, Kz › Variable recharge of 150 mm/y	n/a
Sensitivity analysis Case 1	1641	9565	22162	27703	› Kx, Ky, Kz multiplied by 10 for the Shale and Wishart formations › Variable recharge of 150 mm/y	1.9
Sensitivity analysis Case 2	5449	10162	13257	16571	› Kx, Ky, Kz › Variable recharge of 200 mm/y	1.2

Groundwater dewatering simulation results for the base case are presented in terms of piezometry (Figures 4-3 to 4-5) and drawdown (Figures 4-6 to 4-8). Groundwater dewatering simulation results for the other scenarios are presented also in terms of drawdown in Appendix F. Table 4-4 summarizes the drawdown results for the three mining phases.

Simulation results show that dewatering rate increases with the pit floor depth (Phases I, II and III). It can be seen in Figure 4-7 (Phase II) and Figure 4-8 (Phase III) that larger drawdowns are observed in the vicinity of the pit. The results also indicate that drawdowns will increase with the vertical and horizontal pit progression (mining phases). Due to the presence of longitudinal thrust faults both to the north and south of the pit, drawdowns are oriented east-west.

During the Phase I of mining (expected period between 2018 and 2022), mainly the northwest part of the deposit will be mined to a final depth elevation of 580 m. Drawdown is negligible and basically limited to the area of the pit; and no drawdown is expected in the deep aquifer in the valley including lakes. The maximum drawdown at the center of the pit is around 3 m (Table 4-4) while it is below 1 m in the formations underneath both main lakes (Triangle Lake and Pinette Lake located about 2.7km and 1.8km respectively from the pit center). The dewatering rate is estimated to 1132 m³/day

It will be expected during the first years of mining (Phase I) that the dewatering rate will be lower than the estimated rate for the final pit depth. The groundwater level at the Howse deposit is deep. During the first years, dewatering will be limited to water accumulated in the pit basically from direct precipitations and infiltration through the unsaturated geological units until the pit floor reaches the water table. After, dewatering rate will increase gradually with pit floor depth and reach its maximum rate at its final depth.

During the Phase II of mining (expected period between 2022 and 2025), mining will go deeper in the northwest part of the deposit to reach an elevation of 550 m whereas the mining of the

center part will start, to reach a final elevation of 580 m. The final simulated drawdown of the deep aquifer at the center of the pit reaches 35 m and decreases with distance (for example respectively 20 m and 16 m at 1000 m downgradient and upgradient from the pit center).

Because of the presence of both the Shale (lower permeability) at the surface and the Sokoman formation (higher permeability) underneath in some location (such as underneath the Pinette Lake area), a different drawdown was noticed for each of the formations.

Drawdown of the deep aquifer (Sokoman) is about 11 m underneath Pinette Lake area and 9 m underneath Triangle Lake area. The drawdown in the surficial shale underneath Pinette Lake area is about 6 m. The final dewatering rate is estimated to 7150 m³/day.

During the Phase III of mining (expected period between 2025 and 2033), the center and the southeast of the deposit will both be exploited respectively to final depth elevations of 480 m and 520 m. The northwestern part will be filled with waste. The final simulated drawdown of the deep aquifer reaches its maximum at the center of the pit of about 110 m and decreases with distance (for example 50 m at 1000 m downgradient and upgradient from the pit center).

Drawdown of the deep aquifer (Sokoman) is about 35 m underneath Pinette Lake area (distance of 1800m) and 18 m underneath Triangle Lake area (distance of 2700m). However, the drawdown within the surficial shale underneath Pinette Lake area is only 15 m. The final dewatering rate is estimated to 11423 m³/day.

Simulated drawdowns for sensitivity analysis cases (higher hydraulic conductivity and recharge values) follow a similar pattern of the base case with relatively extended drawdowns.

Figure 4-3 Piezometric Map during the Phase I of Pit Dewatering (Final Depth)

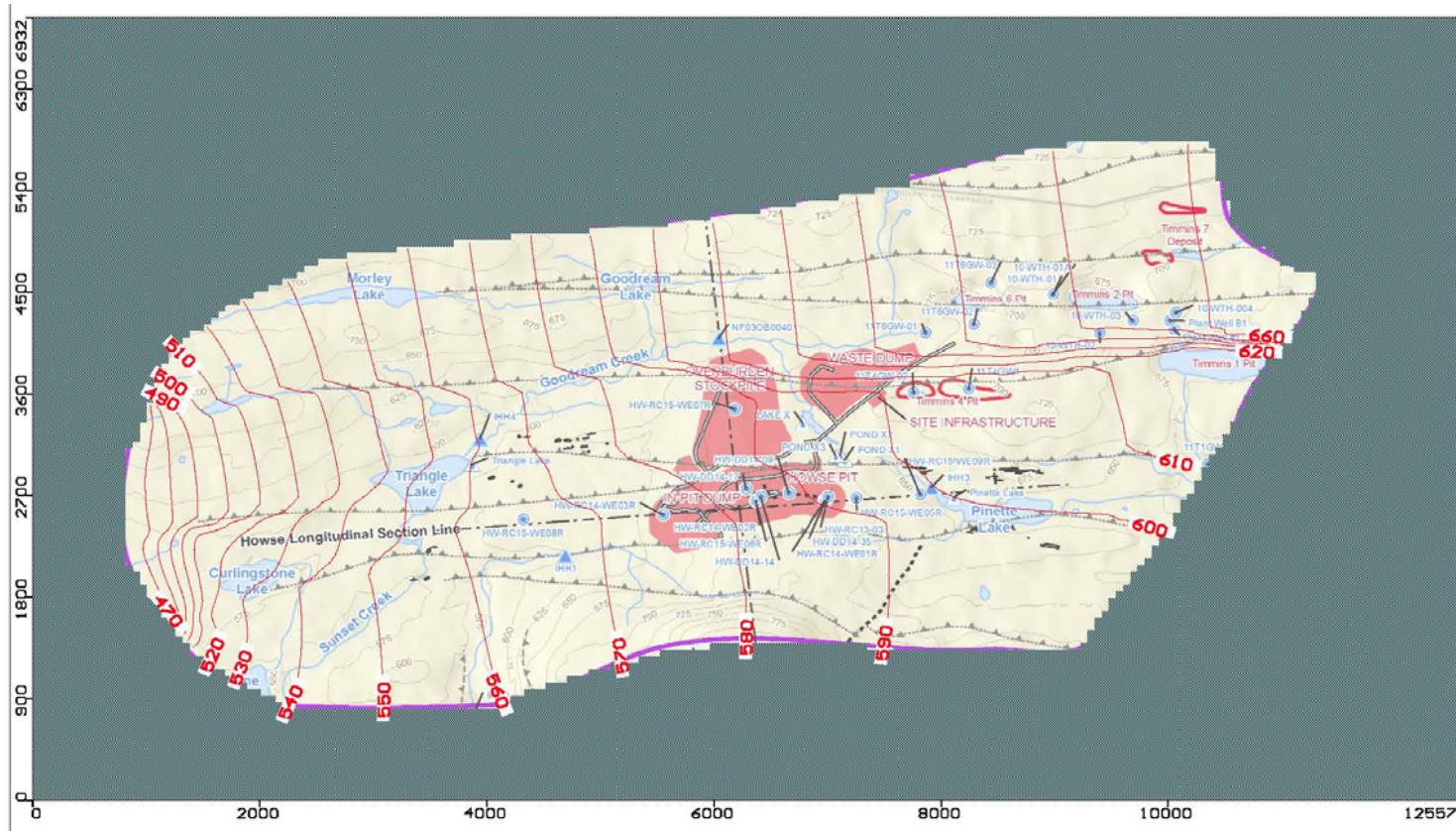


Figure 4-4 Piezometric Map during the Phase II of Pit Dewatering (Final Depth)

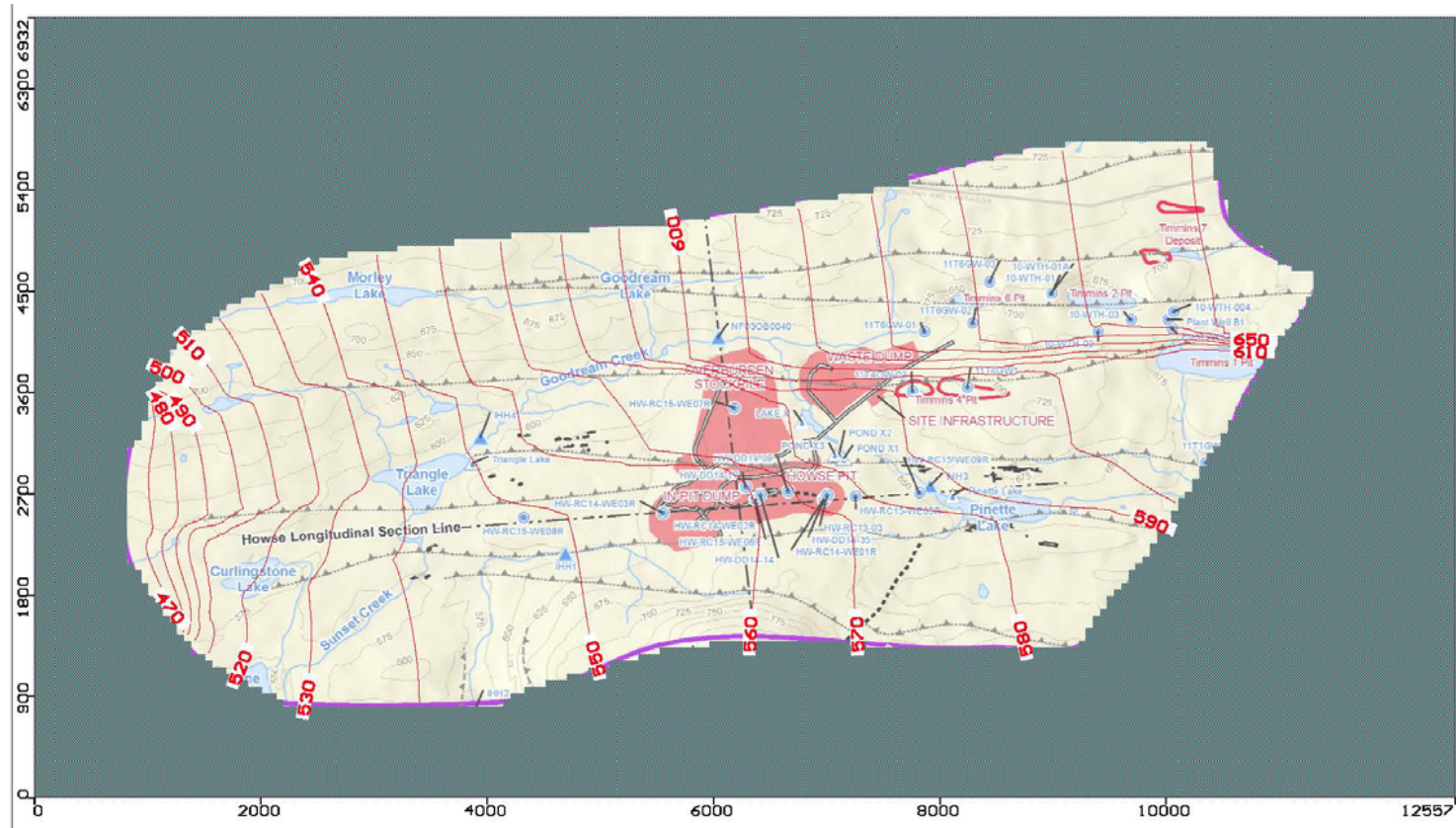


Figure 4-5 Piezometric Map during the Phase III of Pit Dewatering (Final Depth)

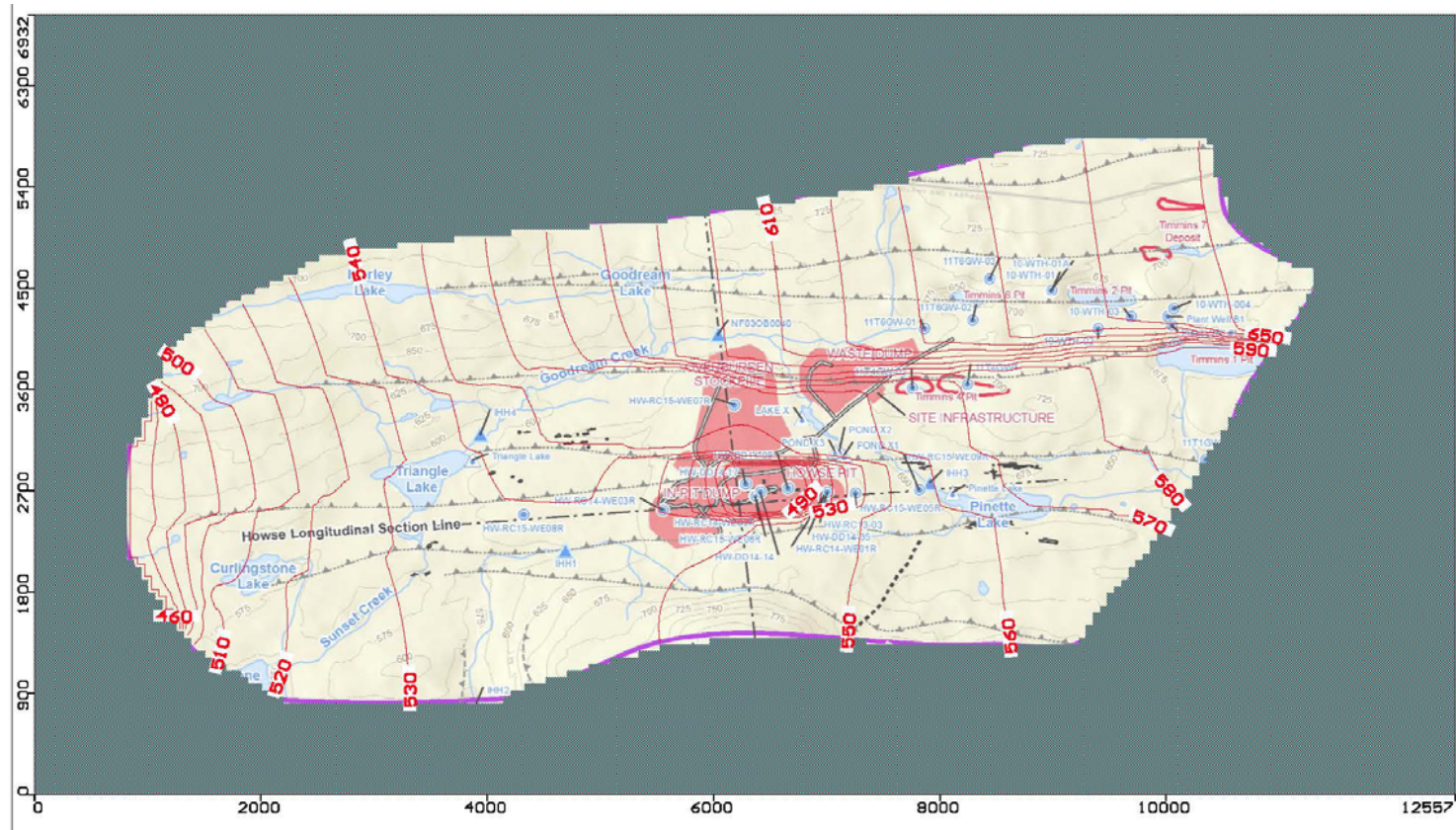


Figure 4-6 Groundwater Drawdown during Phase I of Pit Dewatering (Final Depth)

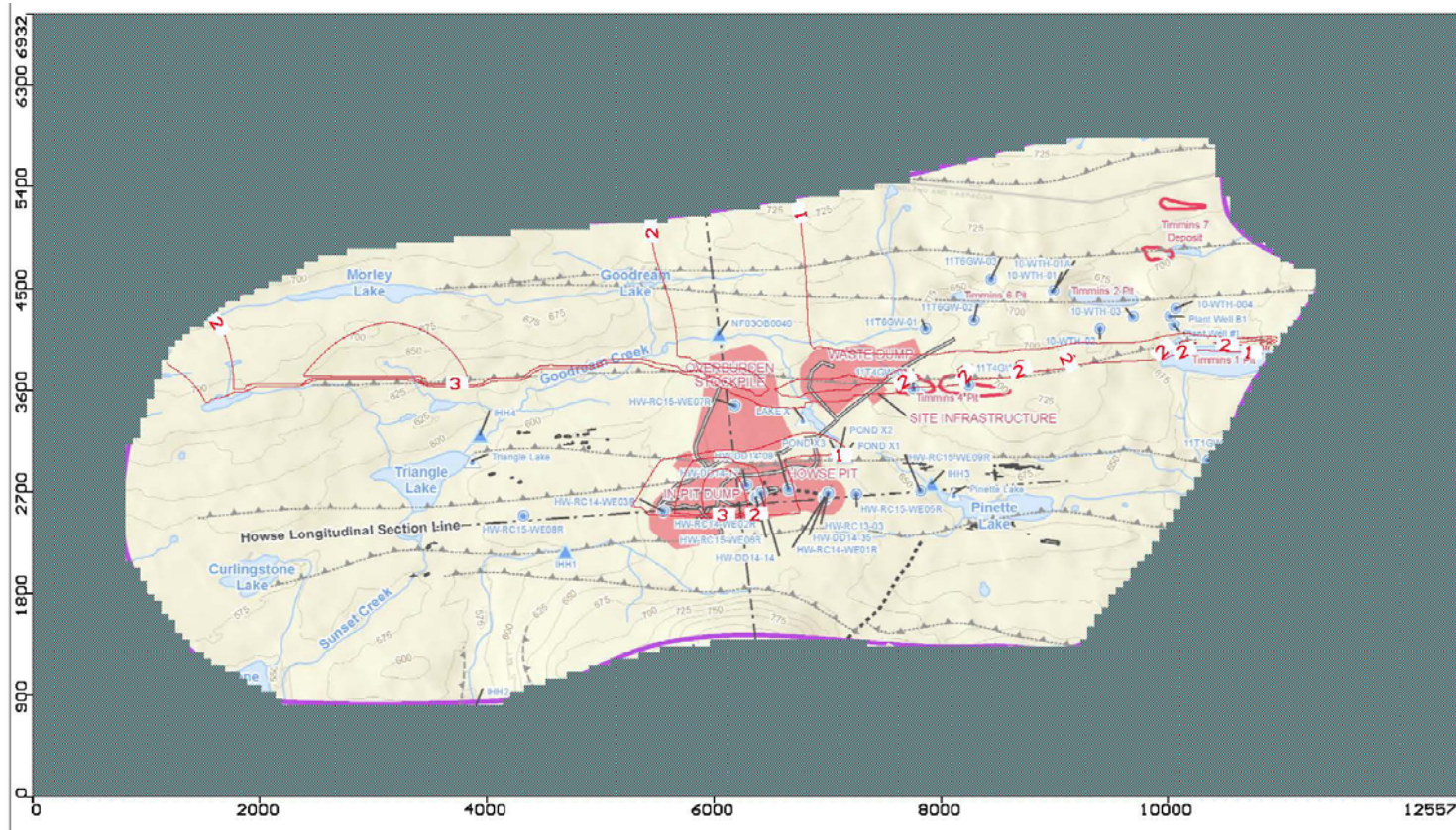


Figure 4-7 Groundwater Drawdown during Phase II of Pit Dewatering (Final Depth)

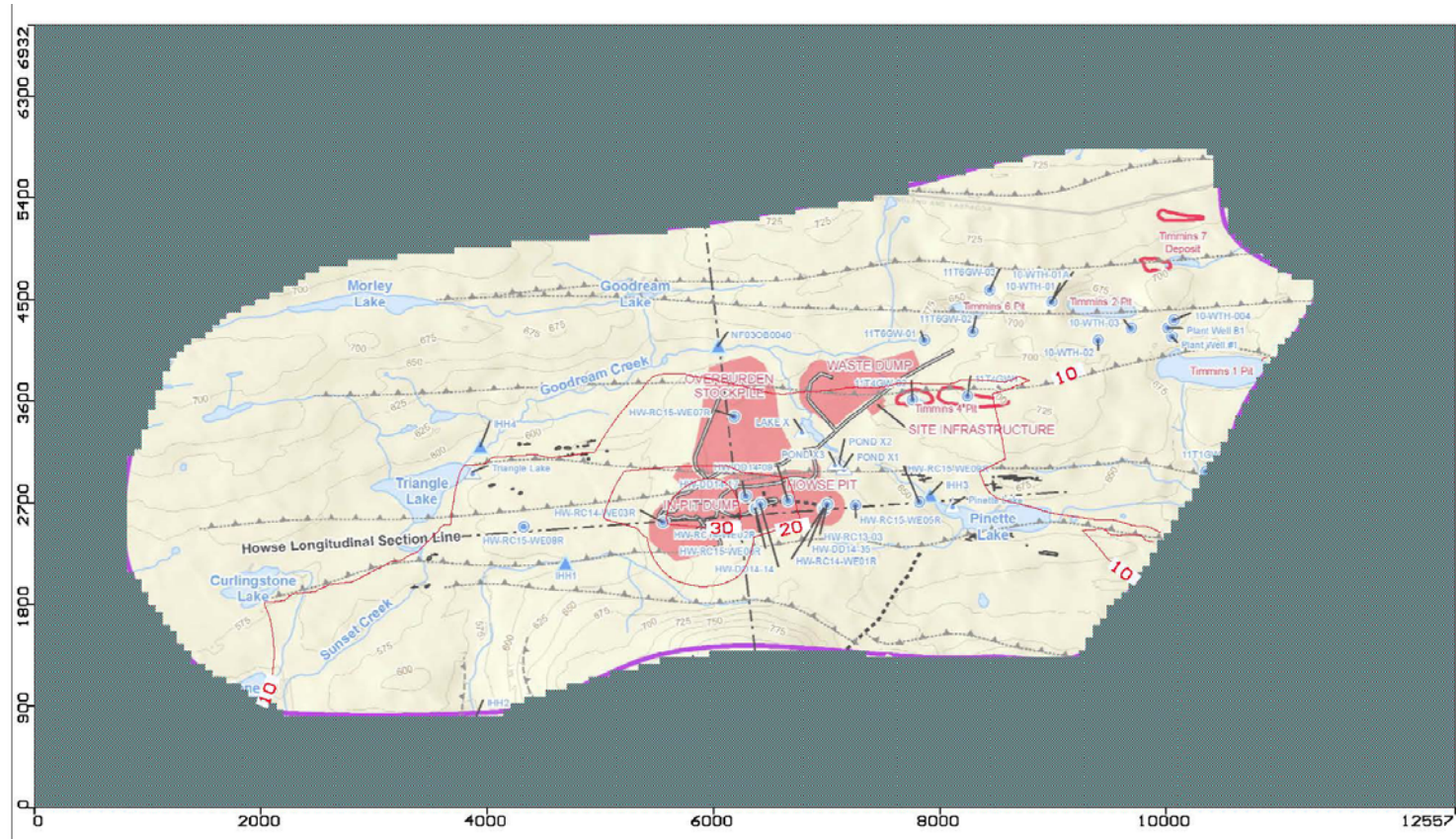


Figure 4-8 Groundwater Drawdown during Phase III of Pit Dewatering (Final Depth)

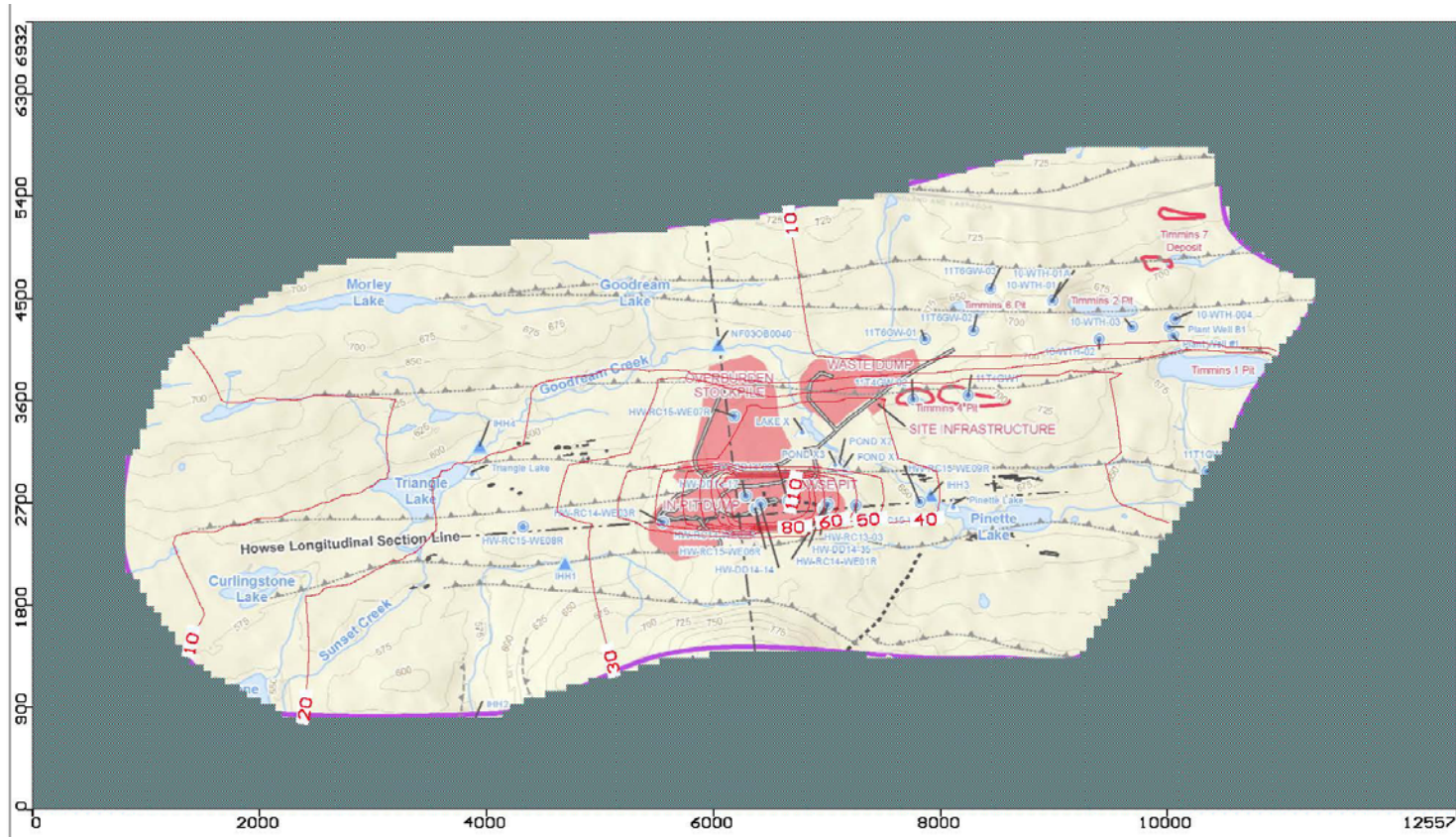


Table 4-4 Simulated Drawdown at Three Mining Phases

	Drawdown (m)						
	at the pit center	at distance of 500 m		at distance of 1000 m		Underneath Triangle Lake (2700 m)	Underneath Pinette Lake (1800 m)
		<i>Downgradient</i>	<i>Upgradient</i>	<i>Downgradient</i>	<i>Upgradient</i>	<i>Downgradient</i>	<i>Upgradient</i>
Phase I	3	< 1	< 1	1.5	1.5	< 1	< 1
Phase II	35	30	22	20	16	9	6 ⁽¹⁾ < D < 11 ⁽²⁾
Phase III	110	75	80	50	50	18	15 ⁽¹⁾ < D < 35 ⁽²⁾

(1) Simulated drawdowns in the upper Shale unit

(2) Simulated drawdowns in the Wishart and Sokoman units, at the final pit depth

4.3 Additional Sensitivity Analysis

Simulation results showed higher drawdowns around the pit area, in comparison to the base case results. Therefore, in order to validate the model response from this point of view, more sensitivity analyses were carried out.

The variations of the following parameters were tested to access their effects on the drawdown:

- › Drain conductance (Appendix F3),
- › Storage coefficient (Appendix F4),
- › Vertical discretization (Appendix F5),
- › Pumping wells versus drain condition (Appendix G).

4.3.1 Drain conductance

A sensitivity analysis was carried out on the conductance value used in the drain condition of the pit (Appendix F3). Firstly, a higher conductance value (50,000 m²/d) was used to assure no resistance from the geological formation to the water exit. Then, the initial value was reduced to evaluate the effect on the flow rates and drawdowns.

The results indicate that a low conductance value leads to a fall of the drained flow and does not allow to reach the expected drawdowns within the deposit. Beyond a range of values (between 10 and 1,000 m²/day), the conductance seems to have no more impacts on flow rates and drawdowns.

Thus, using a high conductance value allow a conservative approach to evaluate flow rates and drawdowns.

4.3.2 Storage coefficient

Specific Yield (Sy) is known as the storage term for an unconfined aquifer. It is defined as the volume of water that an unconfined aquifer releases from storage per unit surface area per unit decline in the water table. Sy is generally equal to the porosity for an unconfined aquifer. A

sensitivity analysis was carried out on S_y to evaluate its effects on pumping rates and drawdowns (Appendix F4).

By reducing the specific yield by two (from 0.05 to 0.025), some impacts are noticeable:

- › Water level variations in observation wells are more important, 5 m on average instead of 2.5 m.
- › Flow rates are slightly lower than those resulting from the base case (10,054 m³/d instead of 11 423 m³/d at the end of Phase III).

As a result, S_y seems to have no significant effect on the model results, and since water levels variations with the initial value are more realistic (about 2.5 m based on field observations), the initial value of 0.05 has been kept.

4.3.3 Vertical discretization

During dewatering, important vertical variations of the water table require locally refined mesh. In order to evaluate the sensitivity of this parameter on drawdowns cells were divided by 5 on the uppermost layers, decreasing cell thickness from 10 to 2 m (Appendix F5).

The results showed that increasing the vertical discretization burdens compilation time and have no significant impact on drawdowns and flow rates (11,895 m³/d instead of 11 423 m³/d at the end of Phase III).

4.3.4 Pumping wells versus drain condition

Ten pumping wells have been tested to simulate dewatering operations instead of using a drain condition (Appendix G). Flow rates and drawdowns were similar to those obtained with a drain condition at the end of Phase I and II. However, for the Phase III, pumping wells failed to achieve the required drawdown for the pit. As a result, the use of the drain condition was validated.

4.4 Groundwater Flow Model Discussion

Although there are some limitations as it is the case of any model, the actual model is considered a best representation of the complex hydrogeological system of the Howse deposit based on available data.

Conceptual Model & Boundary conditions

The enlargement of the model has reduced the stress of boundaries on simulation results. However, it does increase some level of uncertainty by including unknown areas.

In order to limit the effect of boundary conditions on drawdown results, particularly near Triangle Lake, the model was enlarged along the east-west direction. In fact, a north-south enlargement was not realistic in a conceptual point of view due to the presence of topographic ridges (Irony Mountain to the south and the Goodream watershed ridges to the north).

The presence of observation wells located near the Flemming 7 and Timmins deposits has allowed attributing a fixed head boundary condition as an inflow for the model in the south-eastern section. However, the presence of topographic trough further southeast (Elross Creek watershed) did not allowed to determine the boundary condition in this subwatershed. Only one observation well was available in this area (11TGW1), therefore insufficient to determine a piezometric pattern.

The western enlargement of the model beyond Triangle Lake represented a challenge due to the absence of observation wells beyond this lake. Calculating the outflow boundary condition value, based on hydraulic gradient obtained near Howse deposit, did not allow a good calibration fit (simulated heads were too high). The outflow boundary was conditioned to obtain a good calibration fit. Nevertheless, using a relatively low value for the outflow boundary presumes the existence of other unknown discharge areas (potentially around Burnetta Creek or so between Boot Lake and Lone Lake).

Piezometric Data

The groundwater model was constructed using several assumptions which have an influence on the results. While hydrogeological data was available in the immediate vicinity of the deposit, other areas of the groundwater domain were limitedly investigated, for which extrapolation of hydraulic characteristics had to be conducted. Therefore, the model domain had to be limited to the predetermined Goodream and Elross creek watersheds where the hydrogeological data could be determined. Beyond these areas no scientific references were available to further extend the model. Few piezometric values of past surveys were used to fill up the gap with between actual available piezometric readings. . In fact, several pre-existing piezometers and wells in the area modeled were not available during recent hydrogeological investigations. They were either frozen due to permafrost, abandoned, in pumping conditions for water supply purposes, or destroyed by construction activities (Geofor, 2015).

Surface water and deep aquifer

The groundwater model represents the deep aquifer hydraulic conditions, based on available data, with no interaction with surface water. It is a 3D simplified representation of a complex environment such as the one of the Howse deposit.

Many lakes are present within the project footprint. Simulated drawdowns of the pit seem to indicate extended drawdown in the geological units underneath the lake areas (Pinette Lake and Triangle Lake). However, the model does not simulate the interactions between these surface waters and the deep aquifer. The direct effect on lakes cannot be confirmed without knowing for instance the sediment nature at the bottom of the lakes and hydraulic properties of the formations underneath.

Distribution of Hydraulic Conductivity

Hydraulic conductivity distribution of the model is based on hydraulic tests conducted in the area of the Howse deposit and on the regional geological map. A unique hydraulic conductivity value is used for each hydrostratigraphic unit. However, in reality the permeability of a formation can vary depending on several factors (nature and configuration of the deposits, dip and direction of formation, heterogeneity, horizontal and vertical extension of faults, etc.). Variability of the hydraulic conductivity can affect simulation results. Moreover, geology of the region is particularly complex (deep faults which impact flow, high hydraulic conductivity contrasts) and the model can only represent a simplified version of the true pictures.

5 Conclusions and recommendations

The current groundwater flow modeling study has allowed for the evaluation of dewatering flow rates of the Howse deposit and the groundwater drawdown in the project area. This new model is an up-date of two previous models. The new model is based on new parameter conditions such as:

- › Validating and up-dating the regional piezometric map using available and recent data;
- › Enlarging the model size to reduce the effect of constant head boundaries on the groundwater drawdown near lakes;
- › Up-dating the final pit floor from 160 m to 195 m;
- › Extending the depth of the model to include the Wishart and Attikamagen (shale) Formations at its base;
- › Calibrating the model under the new conditions and new hydraulic conductivities values for the Wishart and the shale;
- › Modeling three phases of the pit floor depth instead of one final pit depth;
- › Modeling under transient state condition using MODFLOW software with a cyclic recharge during a year, representing a period of eight months of frozen soil and a period of four months of unfrozen soil.

Data review results indicate that:

- › At the Howse deposit, the groundwater level is deep, and varies between 41 m to 95 in depth. Its annual fluctuation is between 2 and 3.5 m;
- › Based on the hydraulic gradient (0.016 m/m) near a well installed 160 m from the Pinette Lake and hydraulic head difference between the groundwater at this location and the lake's bottom of about 25 m, the Pinette Lake is unlikely to be connected to groundwater. The presence of impermeable base (Shale Formation) underneath the lake would act as a water flow barrier.
- › Estimated hydraulic gradient (0.013 m/m) near a well installed about 700 m from Triangle Lake, indicates hydraulic head difference between the groundwater at this location and the lake's bottom of about 16 m. Based on the fact that surface topography is almost flat between the well location and Triangle Lake no great changes in hydraulic gradient is expected. Therefore, under this condition no groundwater discharge into the lake would occur unless conductive faults exist in the area.

Model results allowed the following conclusions:

- › Dewatering rate increases with the pit floor depth (Phases I, II and III);
- › The radius of influence (simulated drawdown) due to dewatering is oriented NW-SE and seems to be influenced by the longitudinal structures in the area of study;
- › During the Phase I of mining (expected period 2018-2022), mainly the northwest part of the deposit will be mined to a final depth elevation of 580 m. Drawdown is basically limited to the area of the pit, and no drawdown is expected in the deep aquifer in the valley including lakes area. The dewatering rate is estimated to 1132 m³/day;

- › During the Phase II of mining (expected period 2022-2025), mining will go deeper in the northwest part of the deposit to reach an elevation of 550 m whereas the mining of the center part will start, to reach final elevation of 580 m. The final simulated drawdown of the deep aquifer at the center of the pit reaches values of 35 m and decreases with distance (for example respectively 20 m and 16 m at 1000 m downgradient and upgradient from the pit center). Drawdown of the deep aquifer (Sokoman) is about 11 m underneath Pinette Lake area and 9 m underneath Triangle Lake area. The drawdown in the surficial shale underneath Pinette Lake area is about 6 m. The final dewatering rate is estimated to 7150 m³/day;
- › During the Phase III of mining (expected period 2025-2033), the center and the southeast of the deposit will both be mined respectively to final depth elevations of 480 m and 520 m. The northwestern part will be filled with waste. The final simulated drawdown of the deep aquifer at center of the pit reaches 110 m and decreases with distance (for example 50 m at 1000 m downgradient and upgradient from the pit center). Drawdown of the deep aquifer (Sokoman) is in about 35 m underneath Pinette Lake area (distance of 1800m) and 18 m underneath Triangle Lake area (distance of 2700m). However, the drawdown within the shale unit underneath Pinette Lake is only 15 m. The final dewatering rate is estimated to 11423 m³/day;
 - Sensitivity analyses were conducted on the hydraulic conductivity, the recharge and the boundary conditions in order to study their effect on the model results for each mine phase:
 - An increase of recharge from 150 mm to 200 mm, increases the flow rate by a factor of 1.2;
 - An increase in hydraulic conductivity of the Shale and Wishart units by 10 times increases the flow rate by a factor of 1.9;

For the purpose of the mining operations, an adequate groundwater monitoring is recommended in order to validate the simulated radius of influence and to detect any potential link between surface water (lakes) and the deep aquifer.

- › Monitoring of the groundwater would include :
 - Installation of multilevel observation wells at increasing distance and different directions from the Pinette Lake and Triangle Lake going to towards the future pit.
 - Continuous monitoring in these wells should be conducted by means of permanent levelloggers in order to evaluate the drawdown progression during the mine lifespan and detect any impact on groundwater underneath lakes;
- › Monitoring of the water level of the lakes and flows of its tributaries (lake inflow and outflow) to evaluate any real impact due the dewatering ;
- › Monitoring of the wetlands: Installation of shallower wells in the wetland areas to monitor any potential aquitard underneath;
- › Monitoring of the dewatering flow rate variation with the seasons and mining phases (optimization of the pump well locations and pumping only when necessary upon the seasons to reduce the drawdown cone outside the pit area);

- › Biannual report on data collected during the monitoring and pertinent observations on the pit size evolution, lakes and wetlands ;
- › Hydrogeological model up-date at the end of each of the mining phases (Phase I and Phase II) using new data (recorded flowrates and drawdowns, new well logs) collected during the monitoring to better evaluate the impact of the next pit phase.

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1. Use of report

a. Use of report

This report has been prepared, and the work mentioned herein was carried out by SNC-Lavalin GEM Québec Inc. (SNC-Lavalin) exclusively for the client (the Client), to whom the report is addressed, and who took part in developing the scope of work and understands the limitations. The methodology, findings, recommendations and results cited in this report are based solely on the scope of work and are subject to the requirements of time and budget, as described in the offer of services and/or the contract under which this report was issued. Use of this report or any decision based on its content by third parties is the sole responsibility of the third parties. SNC-Lavalin is not responsible for any damage incurred by third parties due to the use of this report or of any decision based on its content. The findings, recommendations and results cited in this report (i) have been prepared in accordance with the skill level normally demonstrated by professionals operating in similar conditions in the sector, and (ii) are determined according to the best judgment of SNC-Lavalin, taking into account the information available at the time the report was prepared. The professional services provided to the Client and the findings, recommendations and results cited in this report are not subject to any guarantee, express or implied. The findings and results cited in this report are only valid on the date of the report and may be based in part on information provided by third parties. This report may require modifications in case of inaccurate information, discovery of new information or changes in project parameters. The results of this study are in no way a guarantee that the site in the study is free of contamination. This report must be considered as a whole and its parts or sections must not be taken out of context. If discrepancies were to appear between the draft and the final version of this report, the final version shall prevail. Nothing in this report is mentioned with the intention to provide or constitute legal advice. The content of this report is confidential and proprietary. It is prohibited for any person other than the Client to reproduce or distribute this report, to use or take a decision based on its content, in whole or in part, without the express written permission of the Client and SNC-Lavalin.

b. Modifications to project

The evidence, interpretations and recommendations contained in this report relate to the specific project as described in the report and do not apply to any other project or any other site. If the project is modified from a perspective of design, dimensioning, location or level, SNC-Lavalin must be consulted to confirm that the recommendations already given remain valid and enforceable.

c. Number of soundings

The recommendations in this report are intended only as a guide for the design engineer. The number of soundings to determine all subsurface conditions that may affect construction (costs, techniques, equipment, schedule) should normally be greater than that for the purpose of design. The number of sample sites and chemical analyzes as well as the sampling frequency and choice of parameters can influence the nature and extent of corrective actions as well as treatment or disposal technology and cost. Contractors bidding or subcontracting the work should rely on their own research and their own interpretations of the surveys' factual results to assess how underground conditions can affect their work and the cost of work.

d. Interpretation of data, comments and recommendations

Unless otherwise noted, data and results interpretation, comments and recommendations contained in this report are based, to the best of our knowledge, on environmental policies, criteria and regulations in force at the location of the project and on the production date of the report. If these policies, criteria and regulations are subject to change after submission of the report, SNC-Lavalin must be consulted to review the recommendations in the light of these changes. When no policy, criteria or regulation is available to allow for the interpretation of data and analytical results, comments or recommendations expressed by SNC-Lavalin are based on the best knowledge of the rules accepted in professional practice. The analyzes, comments and recommendations contained in this report are based on data and observations collected on the site, which come from sample work on the site. It is understood that only the data collected directly at the survey sites, sample sites and on the sample date are accurate and that any interpolation or extrapolation of these results to all or part of the site carries the risk of errors, which may themselves influence the nature and extent of the actions required on the site.

2. Sounding reports and interpretation of subsurface conditions

a. Soil and rock descriptions

The soil and rock descriptions given in this report are from classification and identification methods commonly accepted and used in the practice of geotechnical engineering. The classification and identification of soil and rock involves judgment. SNC-Lavalin does not guarantee that the descriptions will be identical in all respects to those made by another geotechnician possessing the same knowledge of geotechnical rules, but ensures accuracy only to what is commonly used in geotechnical practice.

b. Condition of soil and rock at sounding sites

The sounding reports only provide subsurface conditions and only at sounding sites. The boundaries between different layers on sounding reports are often approximate, rather corresponding to the transition zones and therefore subject to interpretation. The precision of subsurface conditions depends on the sounding method, frequency and method of sampling and consistency of the terrain encountered. The spacing between surveys, the sampling frequency and the type of sounding also reflect budgetary considerations and timelines that are outside the control of SNC-Lavalin.

c. Condition of soil and rock between sounding sites

The soil and rock formations are variable over a considerably large area. Subsurface conditions between sounding sites are interpolated and may vary significantly from the conditions encountered at sounding sites. SNC-Lavalin can guarantee the results at the site where sounding are conducted. Any interpretation of the conditions presented between sounding sites carries risks. These interpretations can lead to the discovery of conditions that are different from those that were expected. SNC-Lavalin cannot be held responsible for the discovery of different soil and rock conditions from those described elsewhere than at the site where soundings are conducted.

d. Groundwater levels

The groundwater levels provided in this report only correspond to those observed at the site and on the date indicated in the report and depends on the type of piezometric installation used. These conditions may vary based on the season or due to construction work on the site or on adjacent sites. These variations are beyond the control of SNC-Lavalin.

3. Contamination levels

The contamination levels described in this report (if within the scope) correspond to those detected at the site and on the date indicated in the report. These levels can vary based on the season or due to activities on the study site or on adjacent sites. These variations are beyond our control. Contamination levels are determined from the results of chemical analyzes of a limited number of soil, surface water or groundwater samples. The nature and degree of contamination between sample site may vary greatly. The chemical composition of groundwater at each sample site is likely to change due to groundwater flow, surface recharge conditions, stress of the formation investigated (i.e. pump or injection wells near the site) and natural seasonal variability. The accuracy of groundwater contamination levels depends on the frequency and the number of analyzes. The list of parameters analyzed is based on our best knowledge of the history of the site and the contaminants likely to be found on the site and is also a reflection of budgetary considerations and timelines. The fact that a parameter has not been analyzed does not exclude its presence at a concentration above the background noise or the detection limit of this parameter.

4. Study and work monitoring

a. Final phase verification

All design and construction details are not known at the time of issue of the report. It is therefore recommended that SNC-Lavalin's services be retained to provide light on the possible consequences of construction on the final work.

b. Inspection during execution

It is recommended that SNC-Lavalin's services be retained during construction to verify and confirm that groundwater conditions throughout the site do not differ from those given in the report and that the construction work will not have an adverse effect on the conditions of the site.

5. Changing conditions

The soil conditions described in this report are those observed during the study. Unless otherwise stated, these conditions are the basis for recommendations in the report. Soil conditions can be significantly affected by construction work (traffic, excavation, etc.) on the site or on adjacent sites. Excavation may expose the soil to changes due to humidity, drying or freezing. Unless otherwise indicated, the soil must be protected from these changes or rearrangements during construction. When conditions encountered at the site differ significantly from those provided in this report, due to the heterogeneous nature of the subsurface or due to construction work, it is the responsibility of the Client and the user of this report to notify SNC-Lavalin of changes and give SNC-Lavalin the opportunity to review the report's recommendations. Recognizing a change in ground conditions requires experience. It is therefore recommended that an experienced geotechnical engineer be dispatched to the site to see if conditions have changed significantly.

6. Drainage

Groundwater drainage is often required for both temporary and permanent project facilities. An incorrect drainage design or execution can have serious consequences. SNC-Lavalin cannot under any circumstance take responsibility for the effects of drainage unless SNC-Lavalin is specifically involved in the detailed design and monitoring of the drainage system's construction.

7. Environmental characterization – Phase I

This report was written after diligent research and evaluation of point data sources or information obtained from third parties that may present uncertainties, gaps or omissions. These sources of information are subject to change over time, for example, according to the progress of activities on the site and surrounding area. Phase I includes no testing, sampling or characterization analysis by a laboratory. Subject to exceptions, Phase I is based on the observation of visible and accessible components on the property and those nearby and could bring environmental harm to the quality of the land in the study. The property titles mentioned in this report are used to identify the former owners of the study site and cannot under any circumstance be considered as an official document for reproduction or other uses. Finally, any sketch, plan view or diagram appearing in the report or any statement specifying dimensions, capacities, quantities or distances are approximate and are included to help the reader visualize the property.

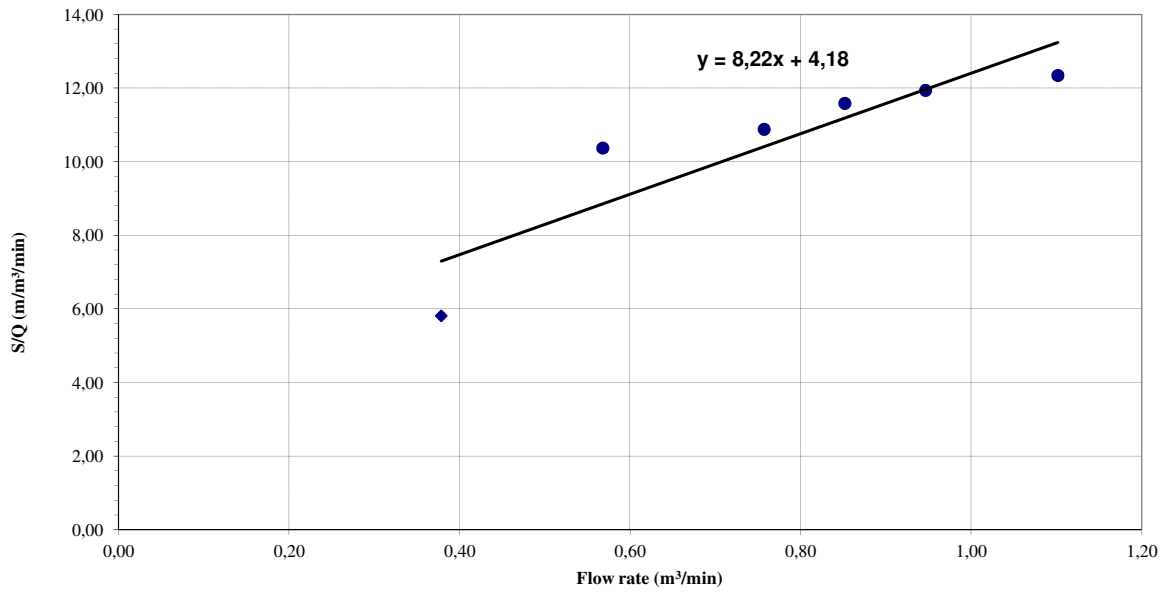
APPENDIX A

Pumping Test Results

1. Step Test Results - Well HW-RC15-WEO6R

Step no.	Duration	Flow	Flow	Drawdown	Specific Drawdown	Specific Capacity
			min	gpm	Q (m ³ /min)	s (m)
1	60	100	0,38	2,2	5,81	0,17
2	60	150	0,57	5,89	10,37	0,10
3	60	200	0,76	8,24	10,88	0,09
4	60	225	0,85	9,87	11,59	0,09
5	60	250	0,95	11,3	11,94	0,08
6	60	291	1,10	13,6	12,35	0,08

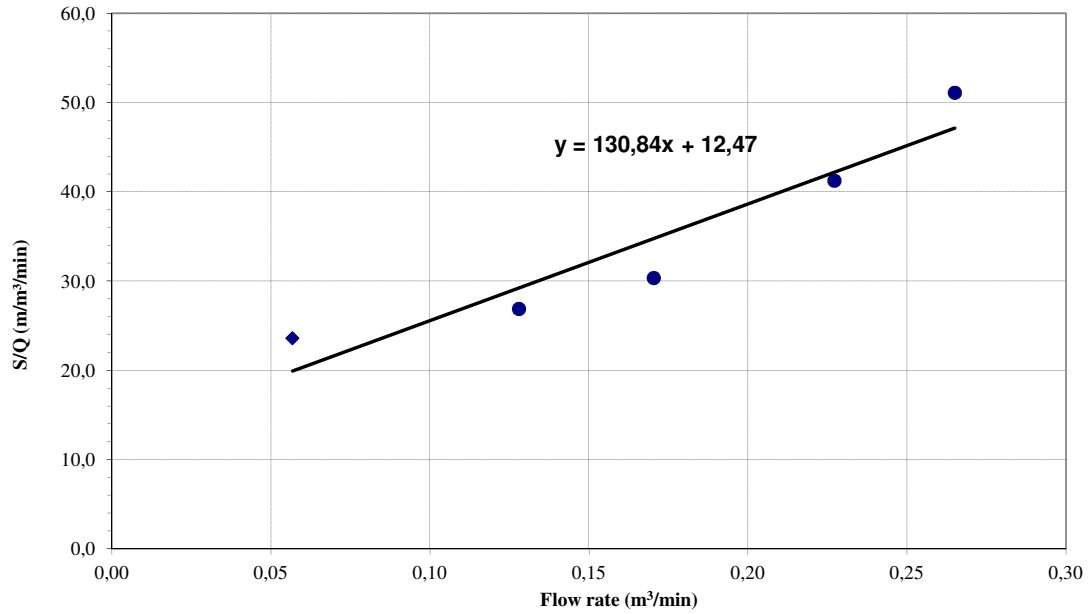
2. Graph of Specific Drawdown vs pumping flow rate



1. Step Test Results - Well HW-RC15-WEO7R

Step no.	Duration	Flow	Flow	Drawdown	Specific Drawdown	Specific Capacity
	min	gpm	Q (m ³ /min)	s (m)	S/Q (m/m ³ /min)	Q/S (m ³ /min/m)
1	30	15	0,06	1,34	23,6	0,04
2	30	33,8	0,13	3,44	26,9	0,04
3	30	45	0,17	5,17	30,4	0,03
4	30	60	0,23	9,37	41,3	0,02
5	30	70	0,26	13,54	51,1	0,02

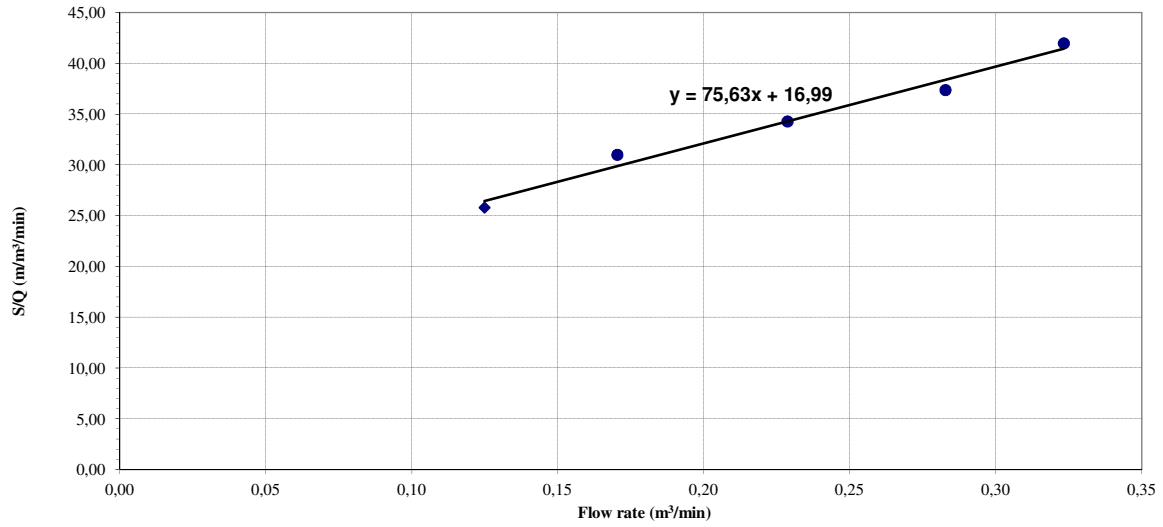
2. Graph of Specific Drawdown vs pumping flow rate



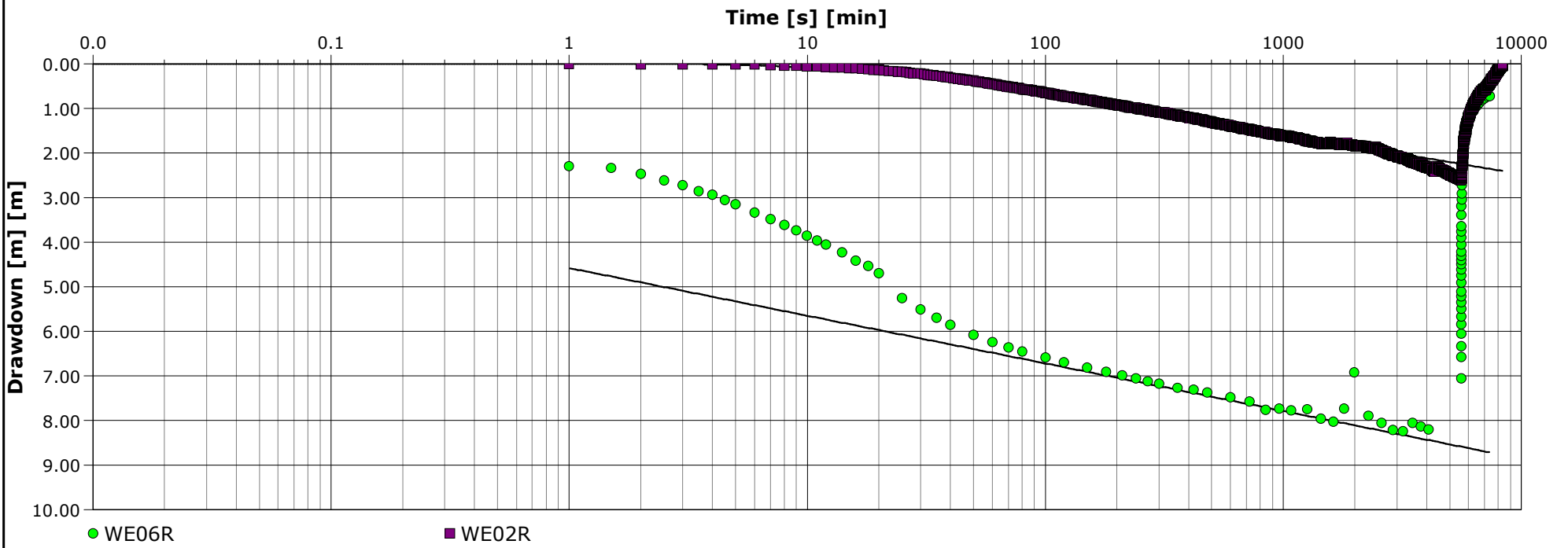
1. Step Test Results - Well HW-RC15-WEO8R

Step no.	Duration	Flow	Flow	Flow	Flow	Drawdown	Specific Capacity	Specific Drawdown
	min	gpm	m ³ /d	Q (l/s)	Q (m ³ /min)	s (m)	S/Q (m/m ³ /min)	Q/S (m ³ /min/m)
1	30	33	180	2,1	0,12	3,22	25,78	0,04
2	30	45	245	2,8	0,17	5,28	31,00	0,03
3	30	60,4	329	3,8	0,23	7,84	34,29	0,03
4	30	74,7	407	4,7	0,28	10,57	37,38	0,03
5	30	85,4	466	5,4	0,32	13,57	41,98	0,02

2. Graph of Specific Drawdown vs pumping flow rate



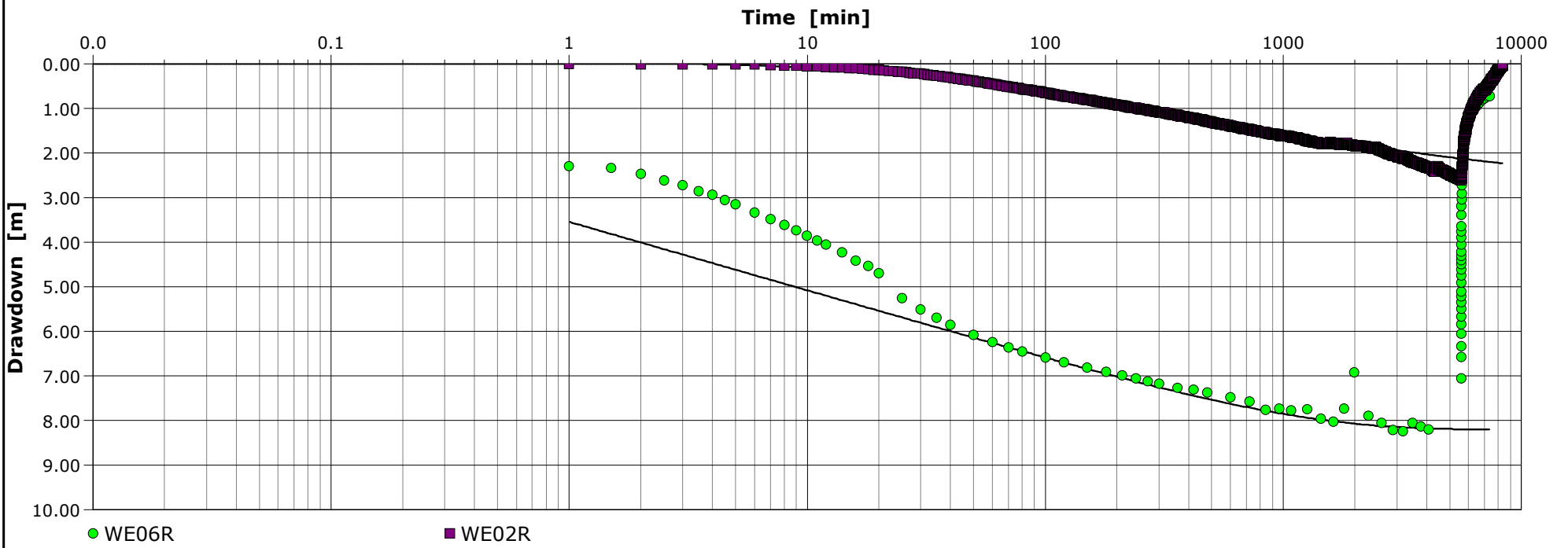
Location: Howse Deposit	Pumping Test: Pumping Test 2 (WE06R)	Pumping well: WE06R
Test conducted by: Geofor		Test date: 22/09/2015
Analysis performed by: AB	Theis	Date: 21/09/2015
Aquifer Thickness: 81.00 m	Discharge: variable, average rate 637.83 [m ³ /d]	



Calculation after Theis

Observation well	Transmissivity [m ² /s]	K [m/s]	Storage coefficient	Radial distance to PW [m]
WE06R	1.26×10^{-3}	1.56×10^{-5}	3.86×10^{-4}	0.15
WE02R	1.50×10^{-3}	1.85×10^{-5}	9.85×10^{-2}	6.08
Average	1.38×10^{-3}	1.71×10^{-5}	4.95×10^{-2}	

Location: Howse Deposit	Pumping Test: Pumping Test 2 (WE06R)	Pumping well: WE06R
Test conducted by: Geofor		Test date: 22/09/2015
Analysis performed by: AB	Hantush	Date: 21/09/2015
Aquifer Thickness: 81.00 m	Discharge: variable, average rate 637.83 [m ³ /d]	

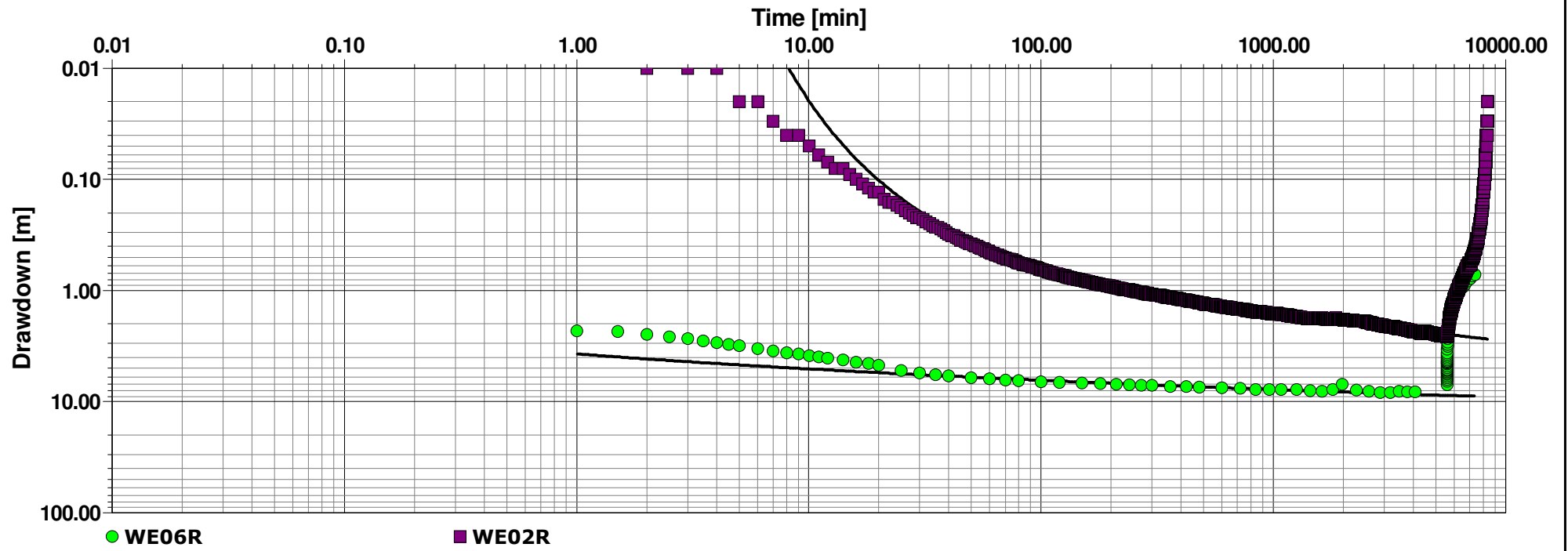


Calculation after Hantush

Observation well	Transmissivity [m ² /s]	K [m/s]	Storage coefficient	Hydr. resistance [min]	Radial distance to PW [m]
WE06R	8.78×10^{-4}	1.08×10^{-5}	2.56×10^{-2}	7.41×10^4	0.15
WE02R	1.50×10^{-3}	1.85×10^{-5}	9.85×10^{-2}	1.67×10^5	6.08
Average	1.19×10^{-3}	1.47×10^{-5}	6.21×10^{-2}	1.20×10^5	

Le modèle Hantush ne juxtapose pas les données de descente avec la remontée

Location: Howse Deposit	Pumping Test: Pumping Test 2 (WE06R)	Pumping well: WE06R
Test conducted by: Geofor		Test date: 22/09/2015
Analysis performed by: AB	Double Porosité	Date: 21/09/2015
Aquifer Thickness: 81.00 m	Discharge: variable, average rate 637.83 [m ³ /d]	

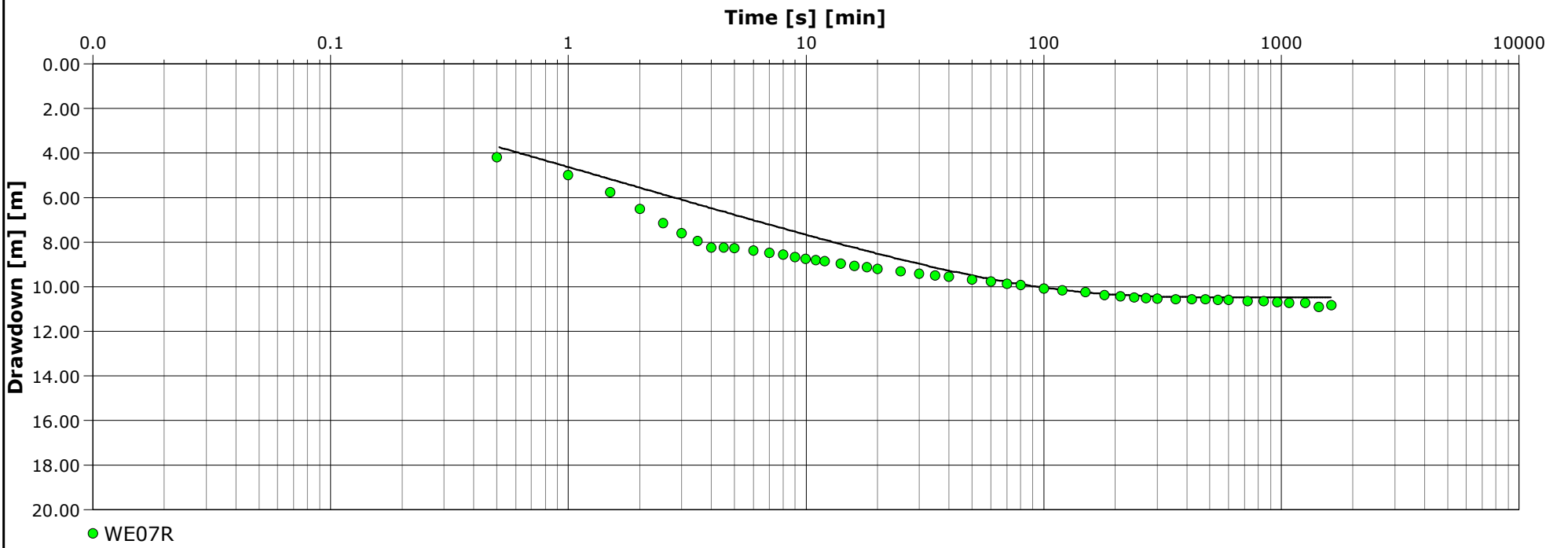


Calculation after Double Porosity

Observation well	Transmissivity [m ² /s]	K [m/s]	Specific storage	Sigma	Lambda	Radial distance to PW [m]
WE06R	1.00×10^{-3}	1.23×10^{-5}	3.38×10^{-4}	2.96×10^1	6.67×10^{-2}	0.15
WE02R	1.00×10^{-3}	1.23×10^{-5}	1.48×10^{-1}	1.00×10^0	6.67×10^{-2}	6.08
Average	1.00×10^{-3}	1.23×10^{-5}	7.41×10^{-2}	1.53×10^1	6.67×10^{-2}	

Location: Howse Deposit		Pumping Test: Pumping Test 2 (WE06R)			Pumping well: WE06R			
Test conducted by: Geofor				Test date: 22/09/2015				
Aquifer Thickness: 81.00 m		Discharge: variable, average rate 637.83 [m ³ /d]						
	Analysis Name	Analysis performed by	Date	Method name	Well	T [m ² /s]	K [m/s]	S
1	Theis	AB	21/09/2015	Theis	WE06R	1.26×10^{-3}	1.56×10^{-5}	3.86×10^{-4}
2	Theis	AB	21/09/2015	Theis	WE02R	1.50×10^{-3}	1.85×10^{-5}	9.85×10^{-2}
3	Hantush	AB	21/09/2015	Hantush	WE06R	8.78×10^{-4}	1.08×10^{-5}	2.56×10^{-2}
4	Hantush	AB	21/09/2015	Hantush	WE02R	1.50×10^{-3}	1.85×10^{-5}	9.85×10^{-2}
5	Double Porosité	AB	21/09/2015	Double Porosity	WE06R	1.00×10^{-3}	1.23×10^{-5}	3.38×10^{-4}
6	Double Porosité	AB	21/09/2015	Double Porosity	WE02R	1.00×10^{-3}	1.23×10^{-5}	1.48×10^{-1}
Average						1.19×10^{-3}	1.47×10^{-5}	6.19×10^{-2}

Location: Howse Deposit	Pumping Test: Pumping Test 2 without recovery(WE07R)	Pumping well: WE07R
Test conducted by: Geofor		Test date: 15/09/2015
Analysis performed by: AB	Hantush	Date: 21/09/2015
Aquifer Thickness: 38.00 m	Discharge: variable, average rate 296.51 [m ³ /d]	

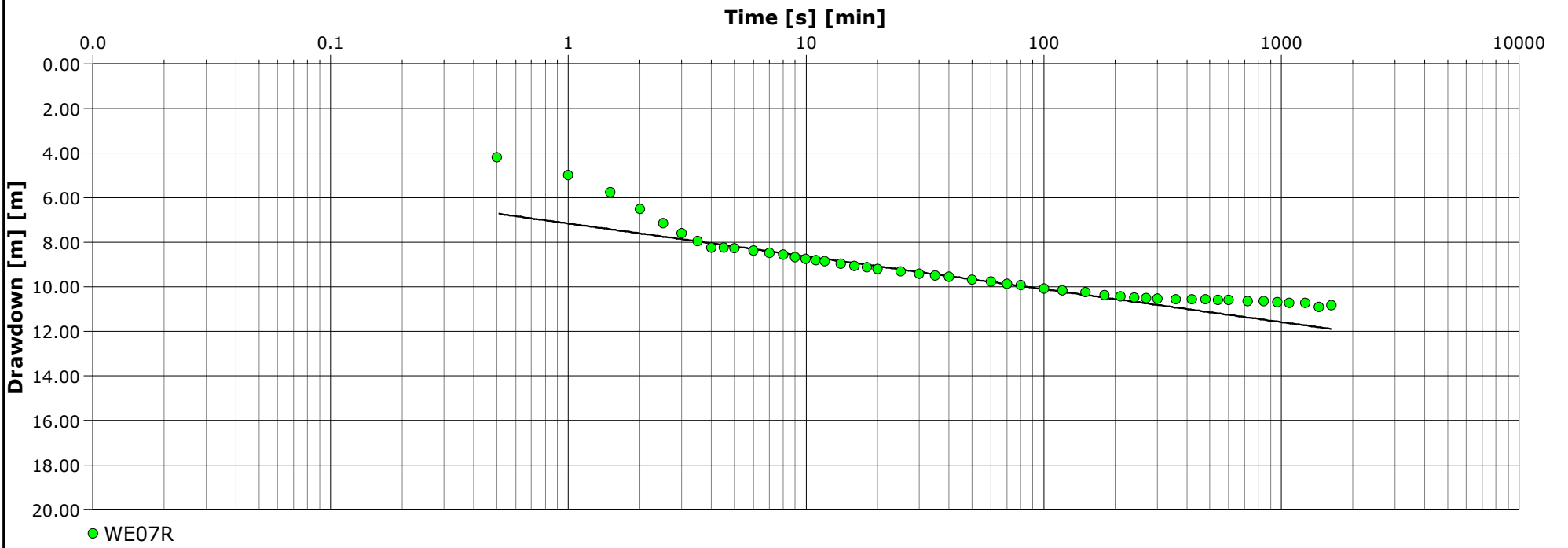


Calculation after Hantush

Observation well	Transmissivity [m ² /s]	K [m/s]	Storage coefficient	Hydr. resistance [min]	Radial distance to PW [m]
WE07R	2.03×10^{-4}	5.34×10^{-6}	2.31×10^{-1}	5.58×10^2	0.06

Le modèl Huntush ne juxtapore pas les données de descente aec la remonteé

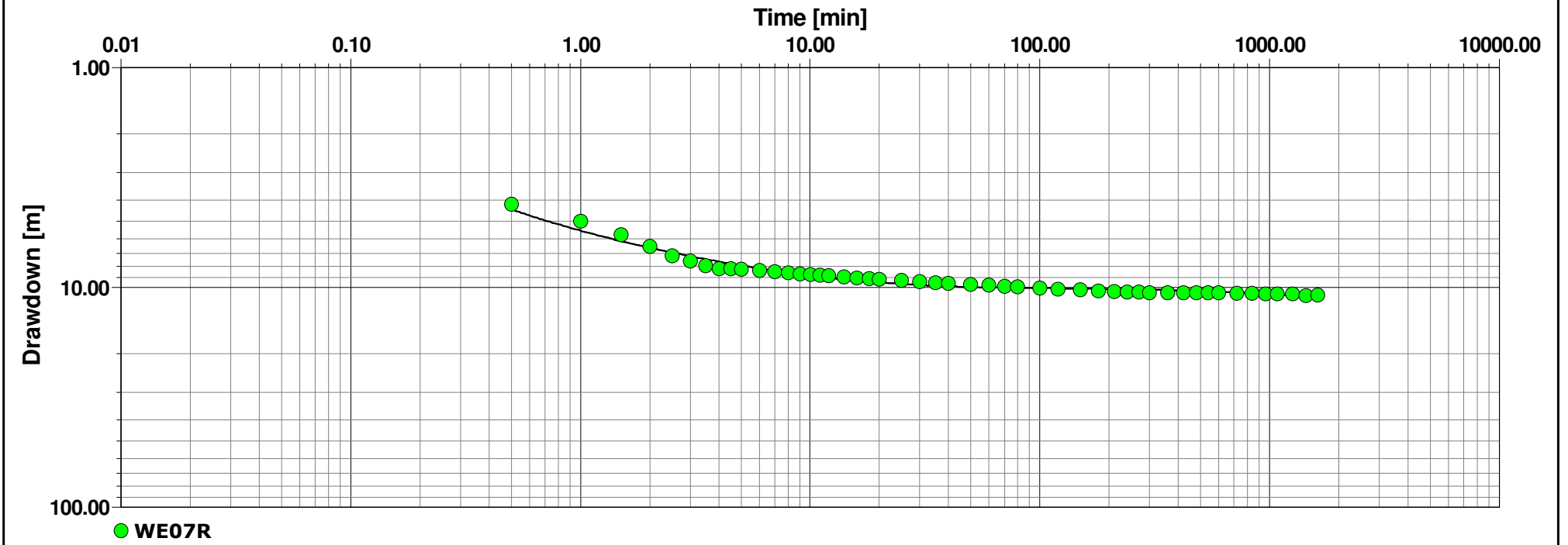
Location: Howse Deposit	Pumping Test: Pumping Test 2 without recovery(WE07R)	Pumping well: WE07R
Test conducted by: Geofor		Test date: 15/09/2015
Analysis performed by: AB	Theis	Date: 21/09/2015
Aquifer Thickness: 38.00 m	Discharge: variable, average rate 296.51 [m ³ /d]	



Calculation after Theis

Observation well	Transmissivity [m ² /s]	K [m/s]	Storage coefficient	Radial distance to PW [m]
WE07R	4.34×10^{-4}	1.14×10^{-5}	2.01×10^{-4}	0.06

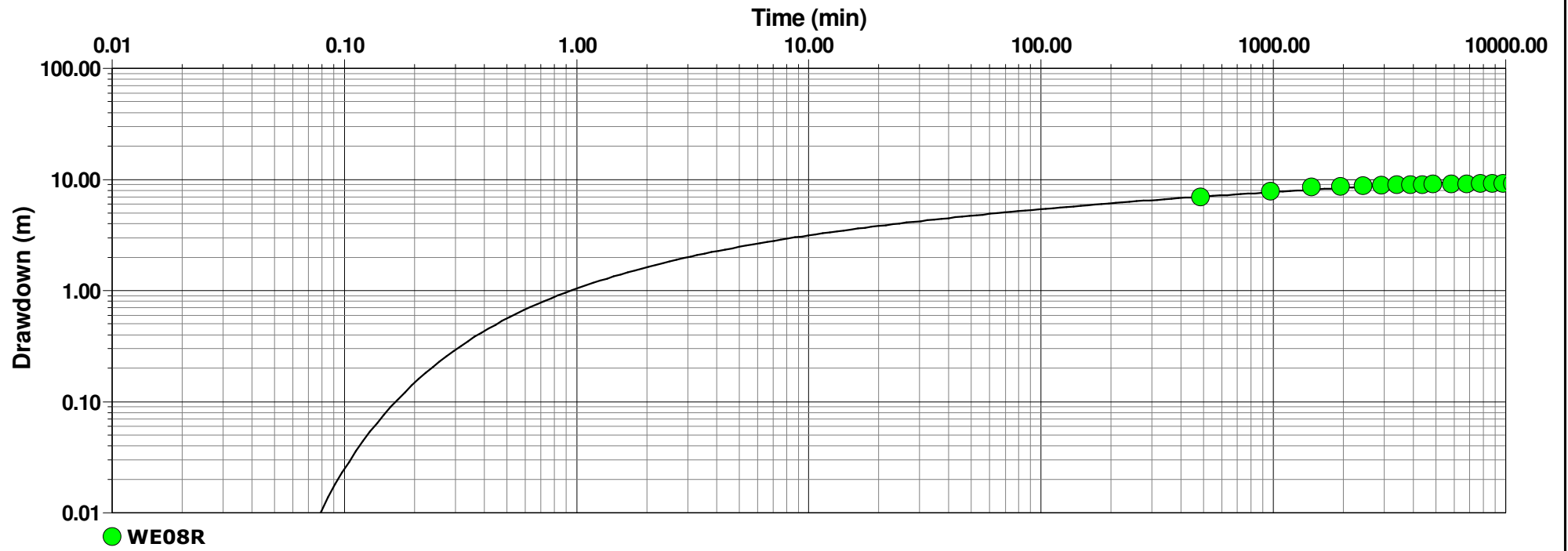
Location: Howse Deposit	Pumping Test: Pumping Test 2 without recovery(WE07R)	Pumping well: WE07R
Test conducted by: Geofor		Test date: 15/09/2015
Analysis performed by: AB	Double Porosité	Date: 21/09/2015
Aquifer Thickness: 38.00 m	Discharge: variable, average rate 296.51 [m ³ /d]	



Calculation after Double Porosity						
Observation well	Transmissivity [m ² /s]	K [m/s]	Specific storage	Sigma	Lambda	Radial distance to PW [m]
WE07R	1.66×10^{-4}	4.36×10^{-6}	2.01×10^{-1}	7.74×10^1	3.25×10^{-3}	0.06

Location: Howse Deposit		Pumping Test: Pumping Test 2 without recovery(WE07R)			Pumping well: WE07R			
Test conducted by: Geofor				Test date: 15/09/2015				
Aquifer Thickness: 38.00 m		Discharge: variable, average rate 296.51 [m ³ /d]						
	Analysis Name	Analysis performed by	Date	Method name	Well	T [m ² /s]	K [m/s]	S
1	Theis	AB	21/09/2015	Theis	WE07R	4.34×10^{-4}	1.14×10^{-5}	2.01×10^{-4}
2	Hantush	AB	21/09/2015	Hantush	WE07R	2.03×10^{-4}	5.34×10^{-6}	2.31×10^{-1}
3	Double Porosit�	AB	21/09/2015	Double Porosity	WE07R	1.66×10^{-4}	4.36×10^{-6}	2.01×10^{-1}
Average						2.68×10^{-4}	7.04×10^{-6}	1.44×10^{-1}

Location: Howse Deposit	Pumping Test: Pumping Test (without recovery) HW-RC15-WEO8	Pumping well: WE08R
Test conducted by: Geofor		Test date: 13/09/2015
Analysis performed by: A.B.	Theis	Date: 17/09/2015
Aquifer Thickness: 28.00 m	Discharge: variable, average rate 318.6 [m ³ /d]	



Calculation after Theis

Observation well	Transmissivity [m ² /s]	K [m/s]	Storage coefficient	Radial distance to PW [m]
WE08R	3.11×10^{-4}	1.11×10^{-5}	4.70×10^{-3}	0.06

WEO6R

Recovery analysis

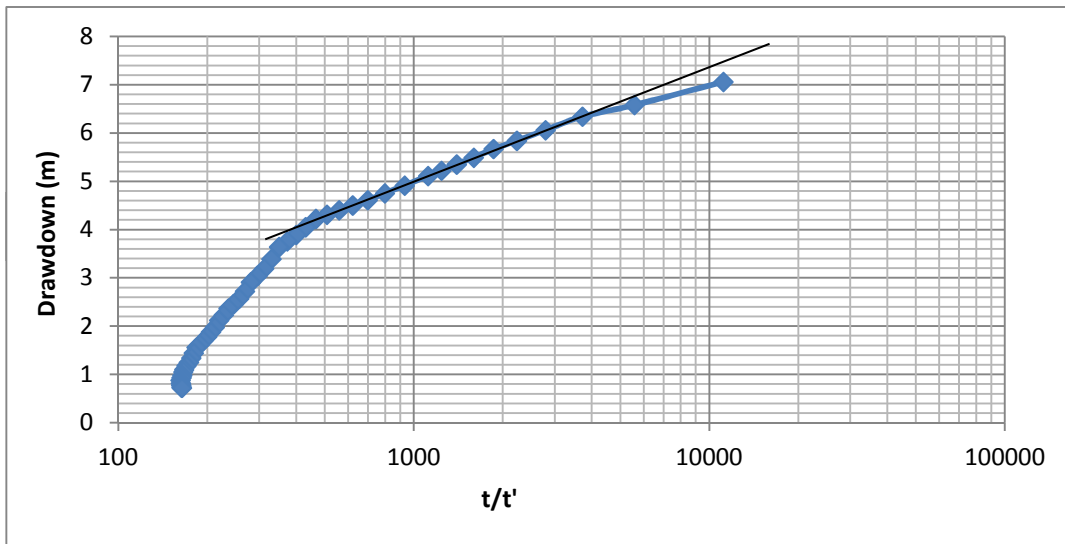
Thickness (m)	81
production time (min)	Well discharge (m3/d)
5576	954
8340	0

t/t'	Drawdown (m)
T1000	5
T10000	7
residual drawdown for a cycle of t/t'	2

t: time pumping started and t':time since pumping ceased

	0.06062809	m2/min
T	0.00101047	m2/s
K	1.2475E-05	m/s

Graph of residual drawdown vs t/t'



WEO7R

Recovery analysis

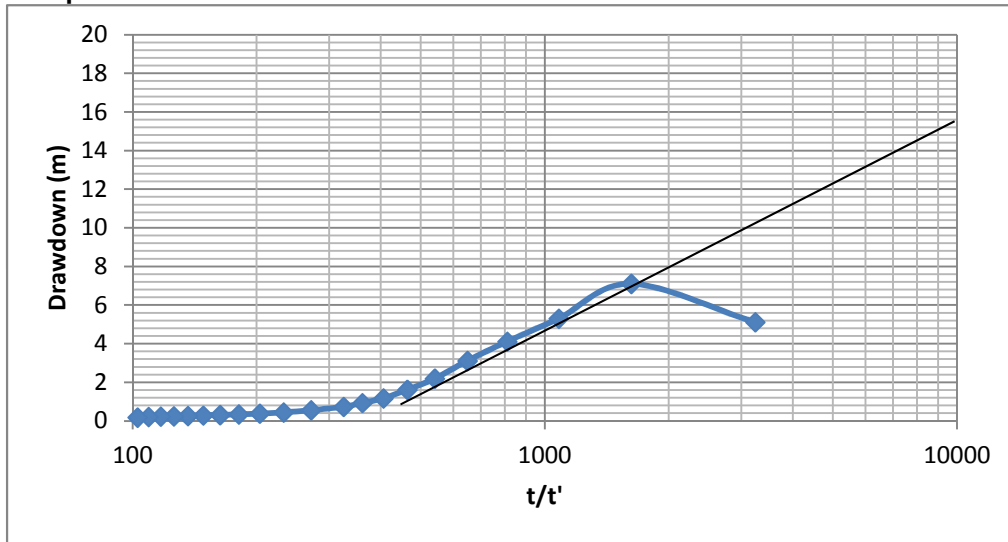
Thickness (m)	38
production time (min)	well discharge (m ³ /d)
1620	302
1650	0

t/t'	Drawdown (m)
T1000	5
T10000	15.8
residual drawdown for a cycle of t/t'	10.8

t: time pumping started and t':time since pumping ceased

	0.00355417	m ² /min
T	5.9236E-05	m ² /s
K	1.5588E-06	m/s

Graph of residual drawdown vs t/t'



WEO8R Recovery analysis

Thickness (m)	28
production time (min)	well discharge (m3/d)
1620	354
1800	0

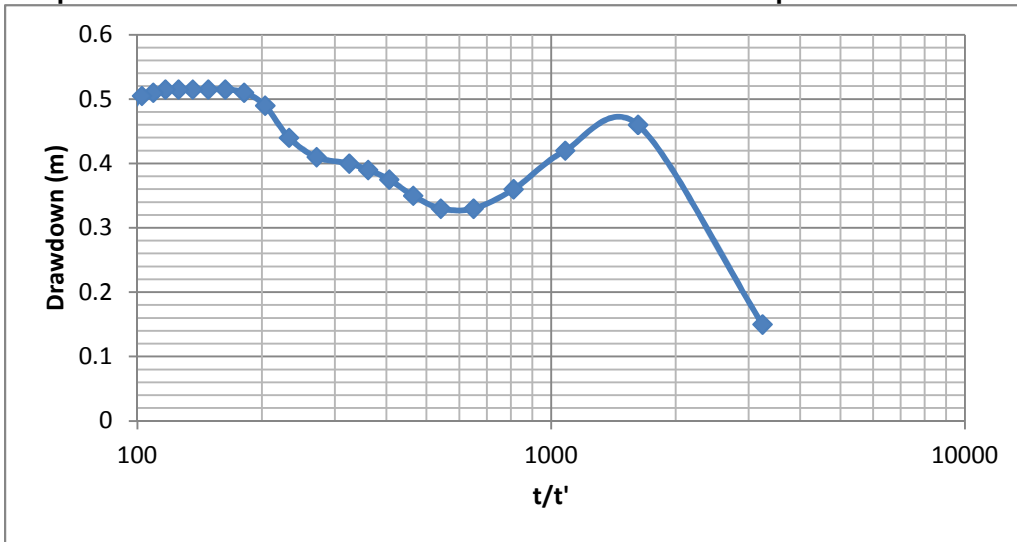
t/t'	Drawdown (m)	
T1000	8.71	8.75
T10000	9.06	9.34
residual drawdown for a cycle of t/t'	0.35	0.59

t: time pumping started and t':time since pumping ceased

	0.12855551	m2/min
T	0.00214259	m2/s
K	7.6521E-05	m/s

Graph of residual drawdown vs t/t'

Results are not representative



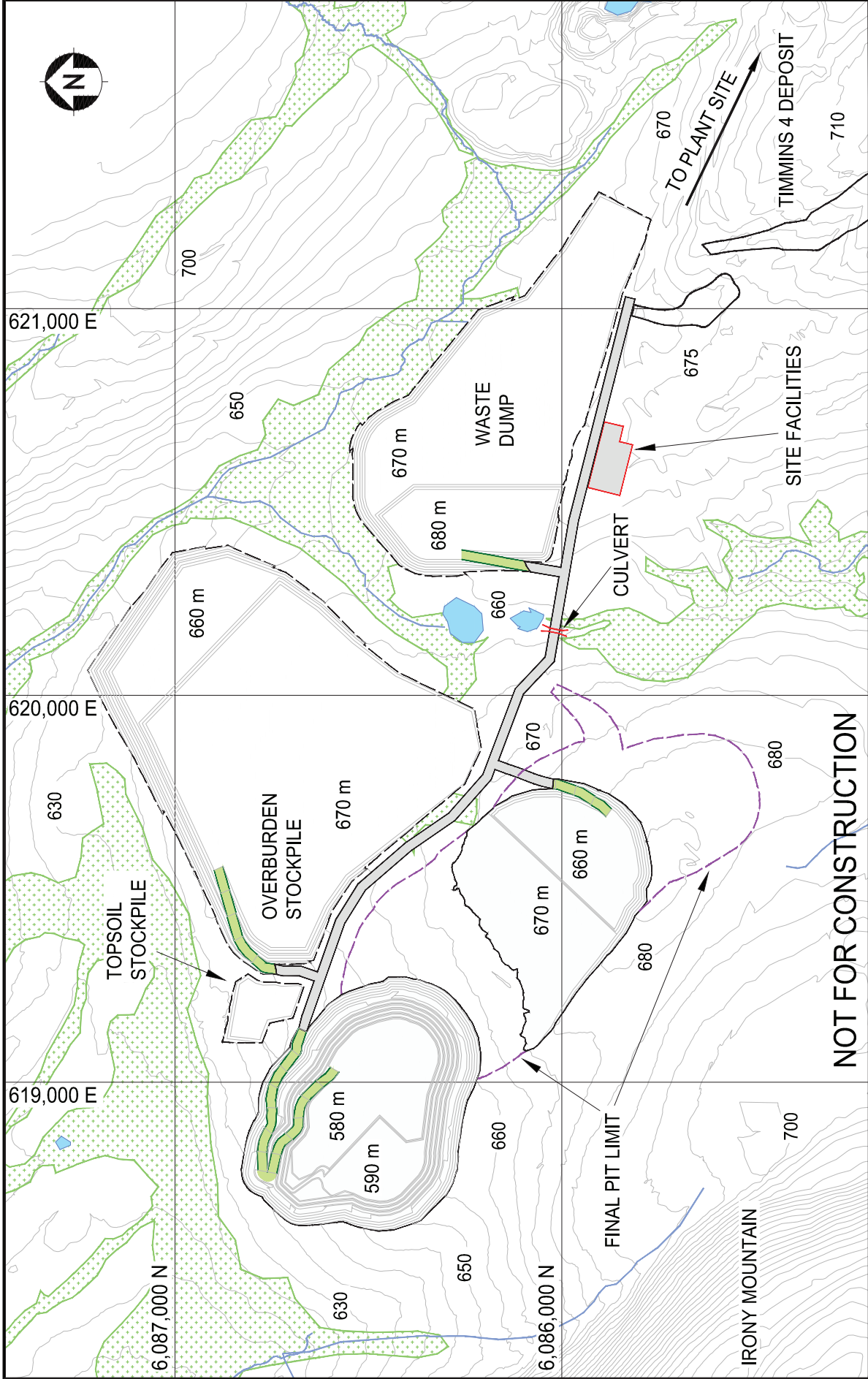
APPENDIX B

Howse deposit mining phases

Howse deposit mining phases

	Phase I 2018 - 2022_Winter (see PO4-W.dxf)	Phase II 2022 - 2028_Summer (see PO6.dxf without in- pit Dump)	Phase III 2028 - 2033_final (see PO9.dxf)
Mining Periods	5 years	6 years	6 years
Simulation periods in Modflow	From 1000 to 2825 days	From 2825 to 4650 days	From 4650 to 6840 days
Relative Pit position	NW + slightly on the center	NW + center	Center + SE
Natural elevation - no pit (m)	635 - 675	635 - 680	660 - 680
Average bottom pit elevation (m)	NW : 580-590 / C: 660-670	NW: 550 / C: 580	NW 680 almost entirely/ C: 480/SE: 520 m

Before t=1000 days, there is no dewatering operations, only a transient recharge.



NOT FOR CONSTRUCTION

LEGEND

- FINAL PIT LIMIT
- CURRENT PIT LIMIT
- PIT / DUMP RAMP
- DUMP / STOCKPILE FOOTPRINT
- WETLANDS
- TOPOGRAPHY CONTOURS (5 m)
- CREEKS
- MINE HAUL ROAD
- CULVERT

UTM NAD83 ZONE 19

125 250 500
Metres

CHECKED	RICHARD BONICI, Eng.	DATE	10/08/15
APPROVED	ANDRE BOLLARD, Eng.	DATE	10/08/15
SCALE	n/a	DEPARTMENT	MINING

TATA

MET-CHEM

HOWSE DSO DEPOSIT

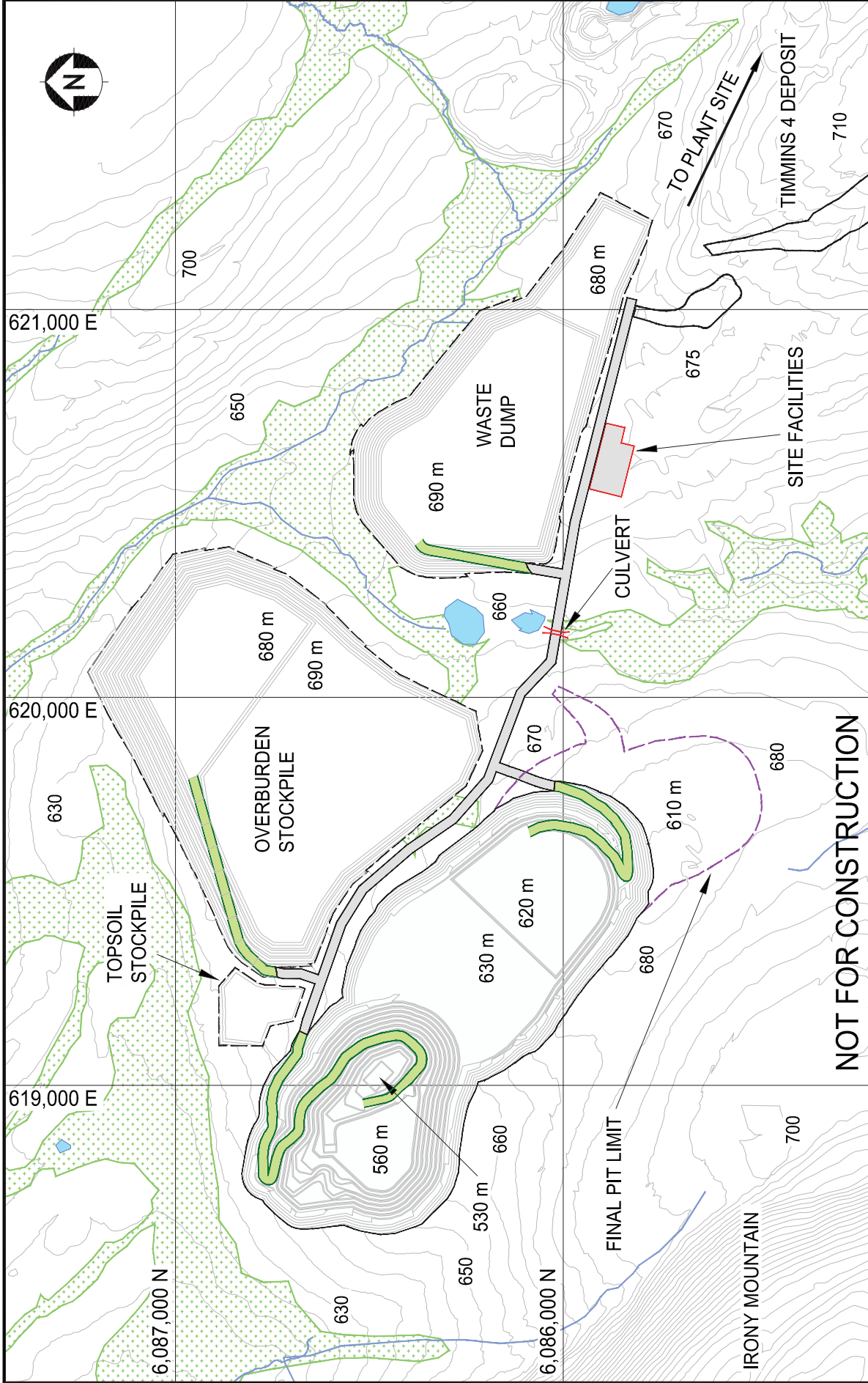
FEASIBILITY STUDY
END OF FY-2022 (Winter)

DRAWING NO. A4-2014-049-520-MN
REV. B

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NO.	DATE/BY	TITLE / NAME	REVISIONS
B	01/09/15	MODIFIED MINE PLAN	
A	10/08/15	FOR FEASIBILITY STUDY REPORT	

RESPONSIBLE ENGINEER	JEFFREY CASSOFF, Eng.
DESIGNED	JEFFREY CASSOFF, Eng.
DRAWN	JEFFREY CASSOFF, Eng.
CLIENT APPROVAL	



NOT FOR CONSTRUCTION

LEGEND

- FINAL PIT LIMIT
- CURRENT PIT LIMIT
- PIT / DUMP RAMP
- DUMP / STOCKPILE FOOTPRINT
- TOPOGRAPHY CONTOURS (5 m)
- MINE HAUL ROAD
- WETLANDS
- CREEKS
- CULVERT

UTM NAD83 ZONE 19

Metres

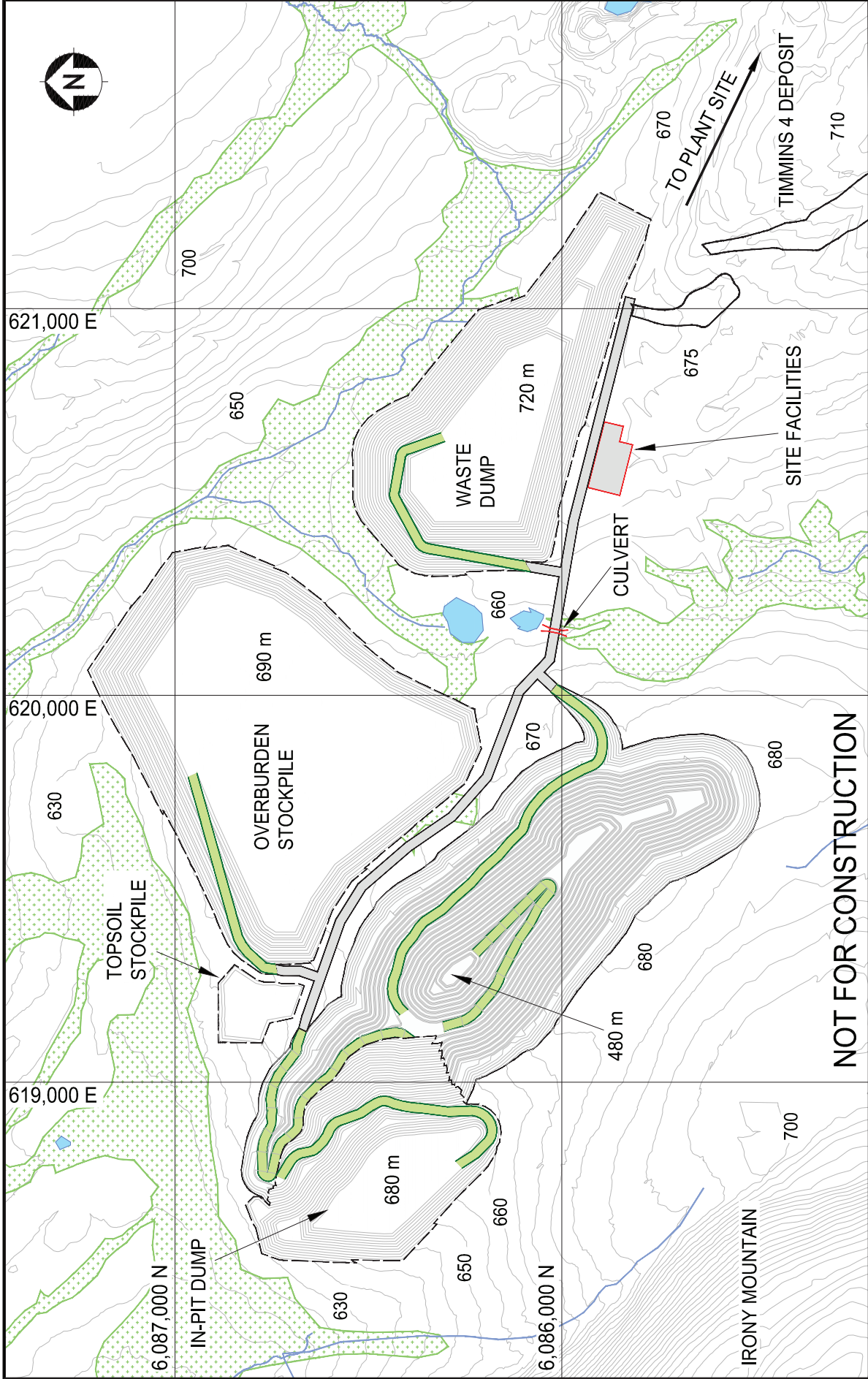
HOWSE DSO DEPOSIT

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NO.	DATE/BY	TITLE / NAME	REVISIONS
B	01/08/15	MODIFIED MINE PLAN	
A	10/08/15	FOR FEASIBILITY STUDY REPORT	

RESPONSIBLE ENGINEER	DATE	CHECKED	DATE
JEFFREY CASSOFF, Eng.	05/08/15	RICHARD BONICI, Eng.	10/08/15
DRAWN	05/08/15	ANDRE BOLLARD, Eng.	10/08/15
CLIENT APPROVAL	05/08/15	SCALE	n/a

FEASIBILITY STUDY	END OF FY-2025
HOWSE DSO DEPOSIT	
DRAWING NO.	A4-2014-049-521-MN
REV.	B



LEGEND

- FINAL PIT LIMIT
- CURRENT PIT LIMIT
- PIT / DUMP RAMP
- DUMP / STOCKPILE FOOTPRINT
- TOPOGRAPHY CONTOURS (5 m)
- MINE HAUL ROAD
- WETLANDS
- CREEKS
- CULVERT

UTM NAD83 ZONE 19

125 250 500
Metres

NOT FOR CONSTRUCTION

TATA

MET-CHEM

HOWSE DSO DEPOSIT

FEASIBILITY STUDY
END OF FY-2033

NO.	DATE/BY	TITLE / NAME	REVISIONS
B	01/09/15	MODIFIED MINE PLAN	
A	10/08/15	FOR FEASIBILITY STUDY REPORT	

RESPONSIBLE ENGINEER	DATE	CHECKED	DATE
JEFFREY CASSOFF, Eng.	05/08/15	RICHARD BONICI, Eng.	10/08/15
JEFFREY CASSOFF, Eng.	05/08/15	ANDRE BOLLARD, Eng.	10/08/15
JEFFREY CASSOFF, Eng.	05/08/15	SCALE	n/a
CLIENT APPROVAL	DATE	DEPARTMENT	MINING

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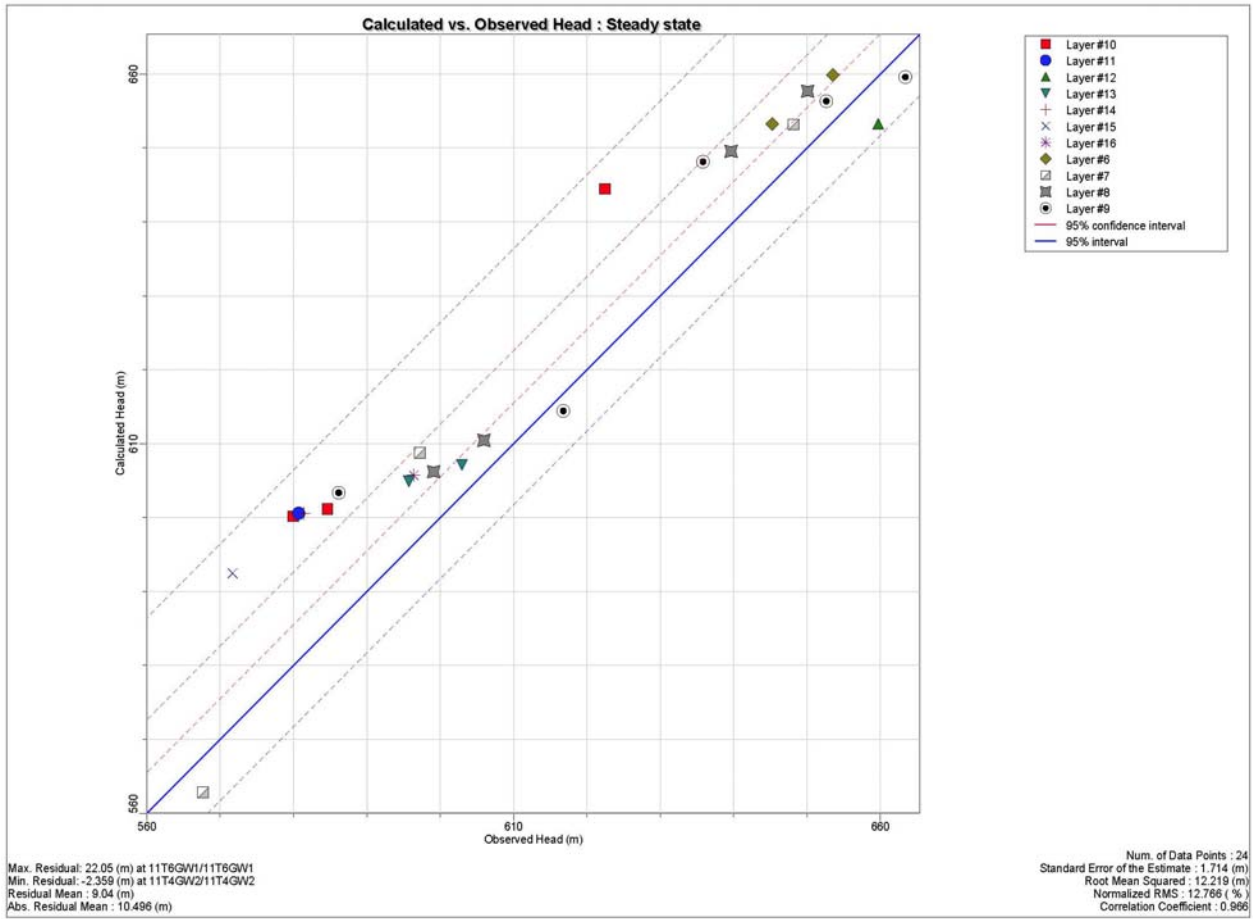
DRAWING NO. A4-2014-049-524-MN

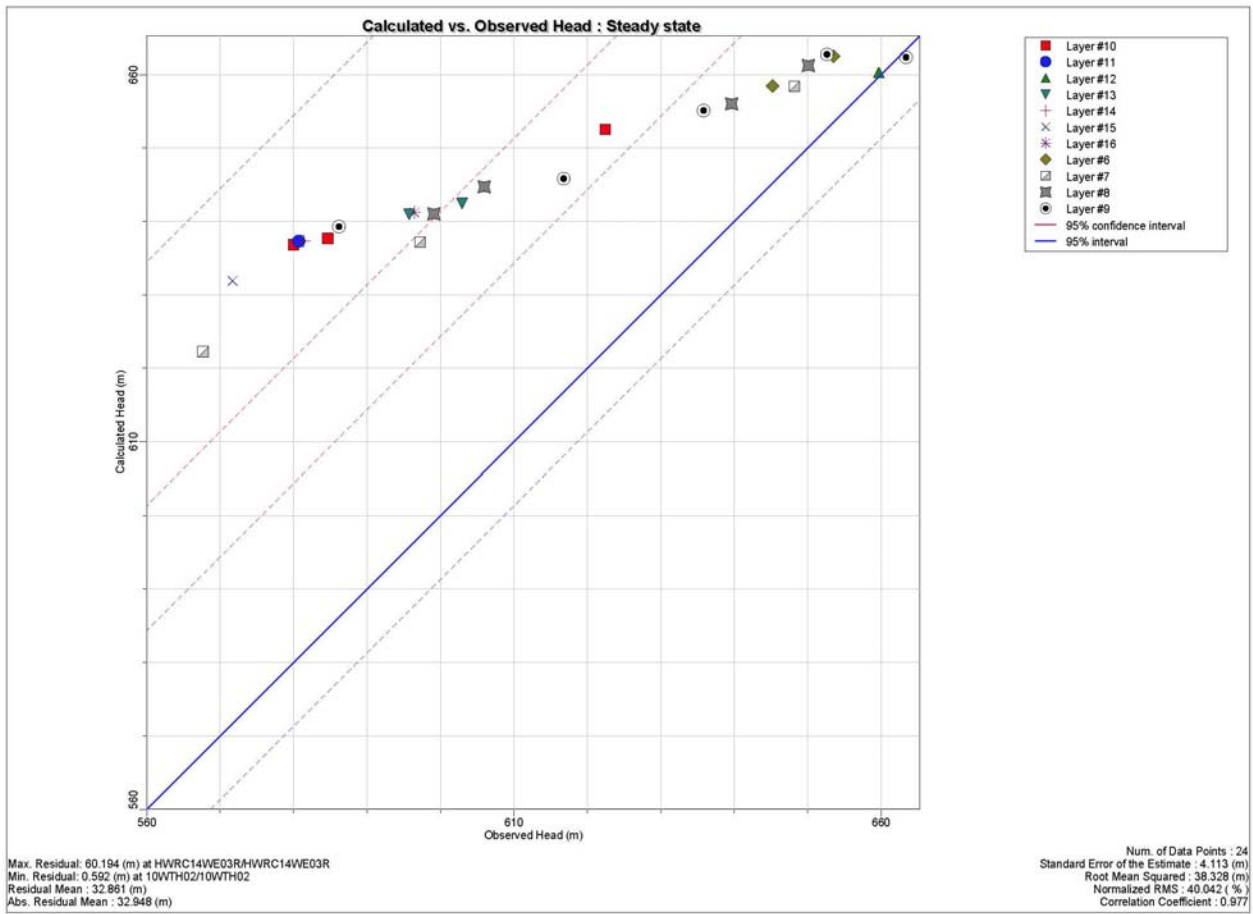
REV. B

APPENDIX C

Sensitivity analysis on the exit boundary condition (steady state)

- › C1: Limit position
- › C2: Limit value

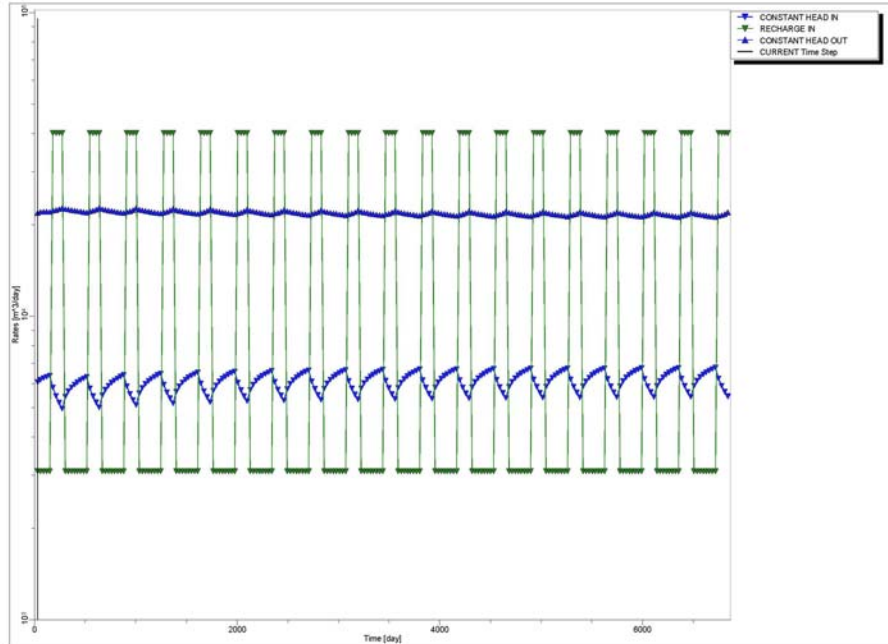




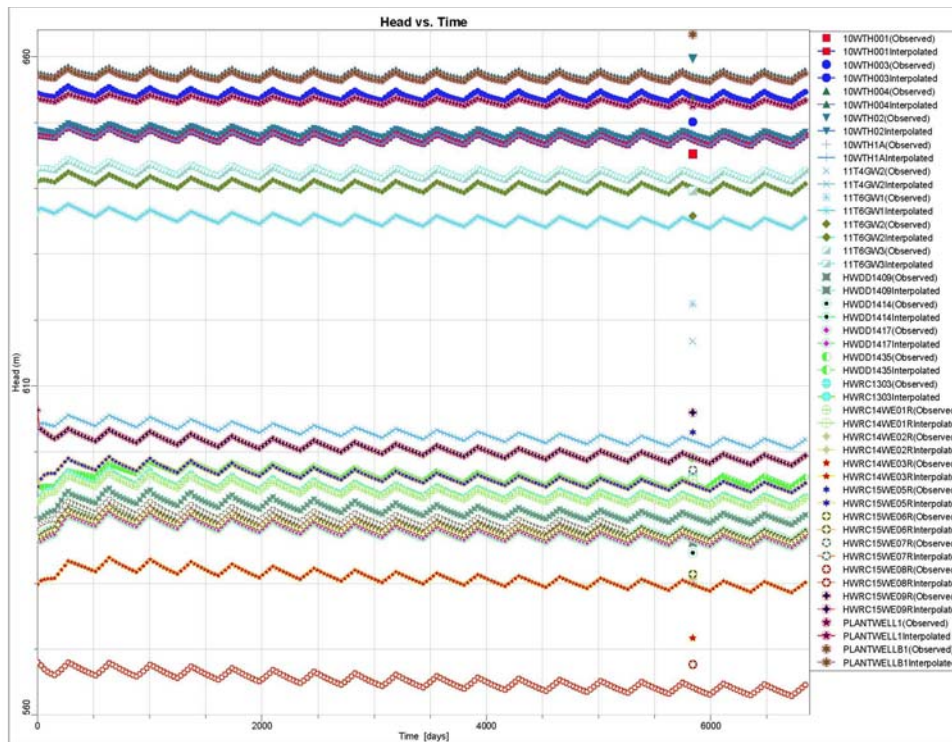
APPENDIX D

Variable recharge scenario (no dewatering)

Simulated Rates (m³/d) vs Time



Simulated Heads at observation wells vs Time



APPENDIX E

Dewatering base case scenario (phase I, II, III)

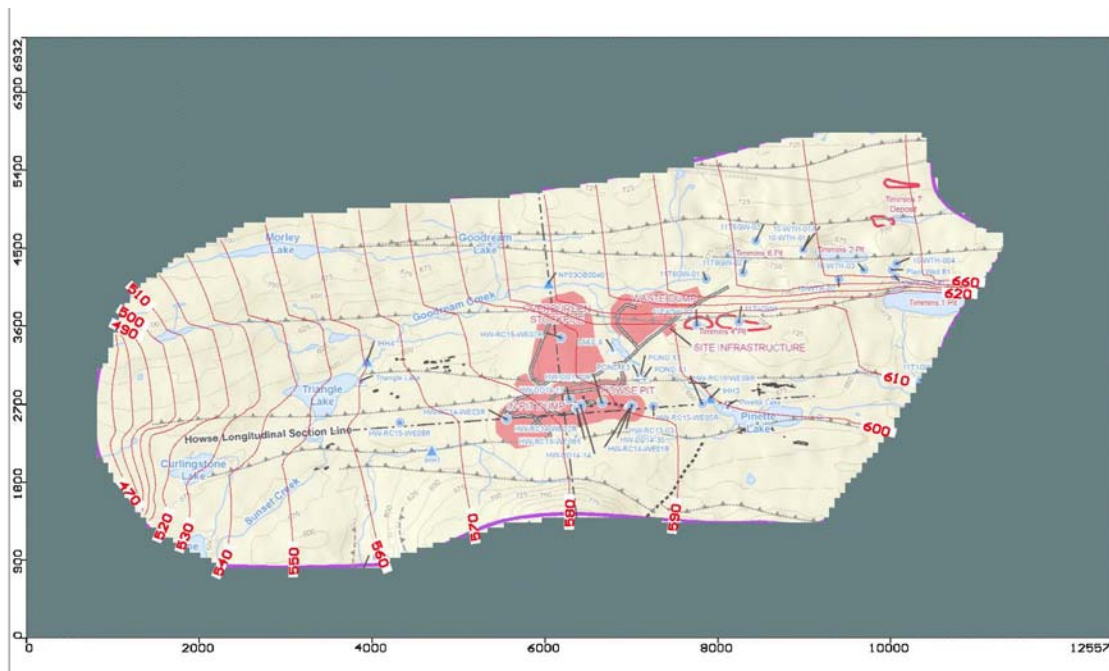
Base Case Scenario Results

Base Case Scenario Results

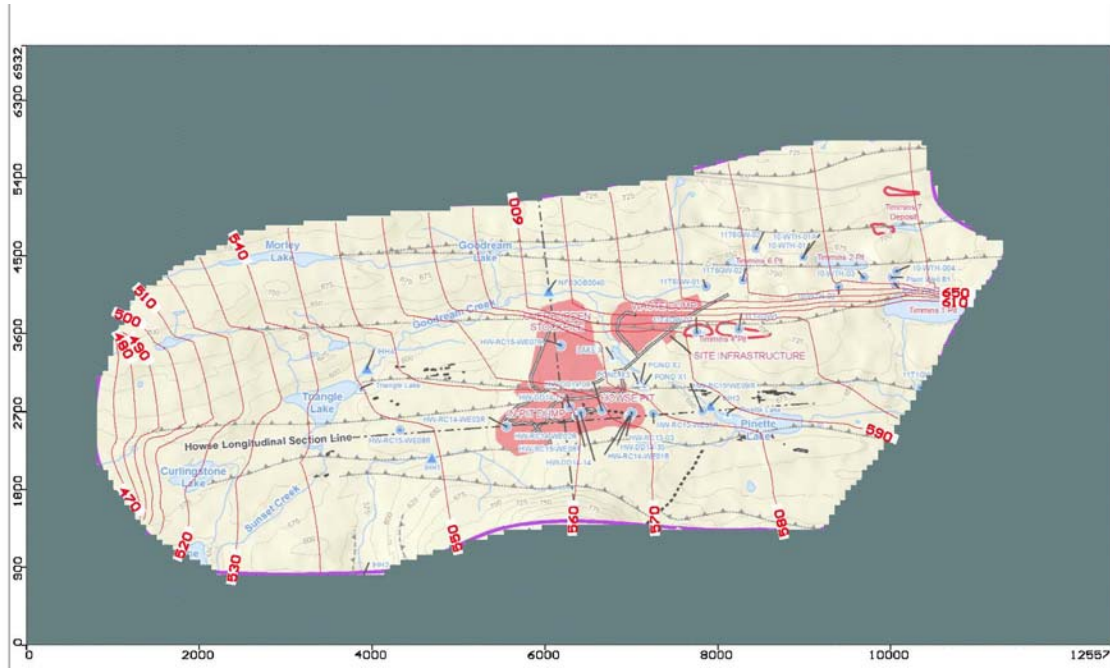
Simulated Natural Piezometric Map



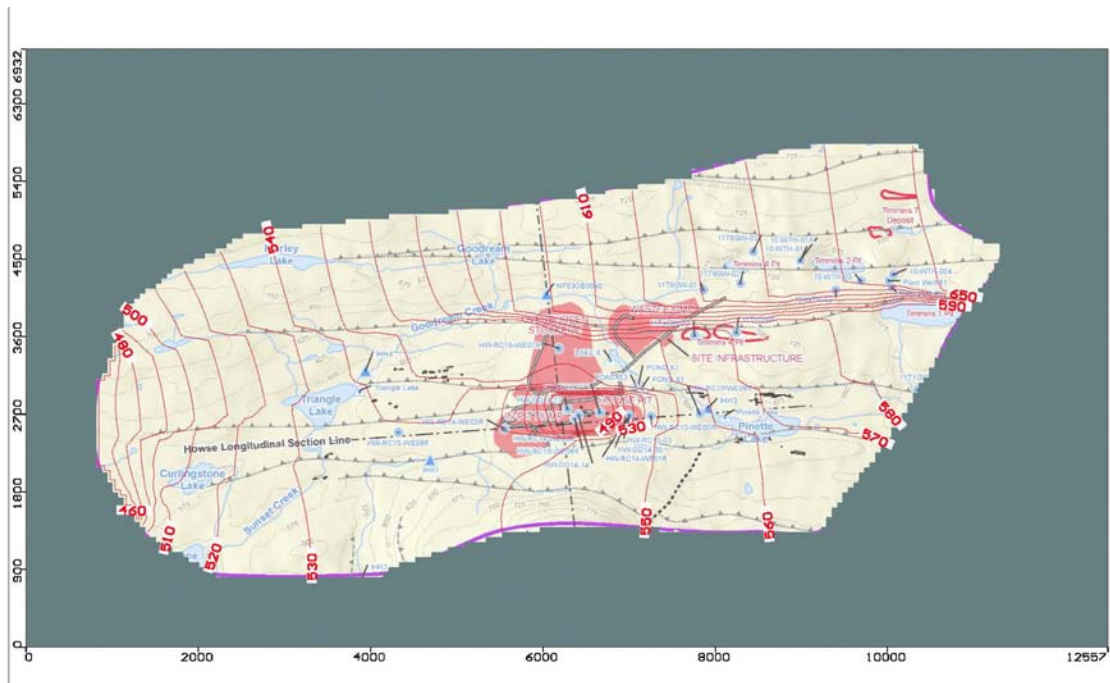
Piezometric Map during Pit Dewatering (Final Depth - Phase I (t=2825d))



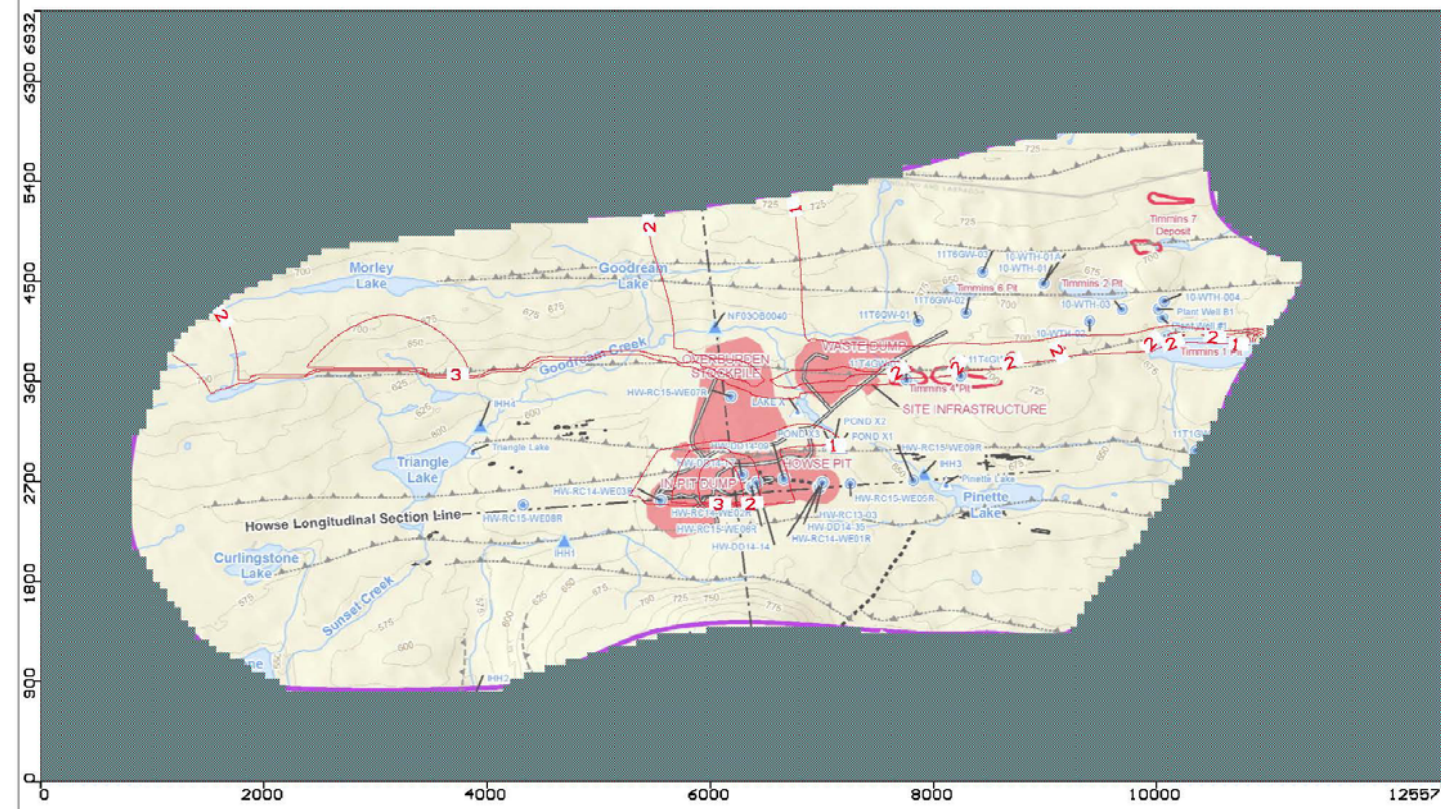
Piezometric Map during Pit Dewatering (Final Depth - Phase II (t=6450d))



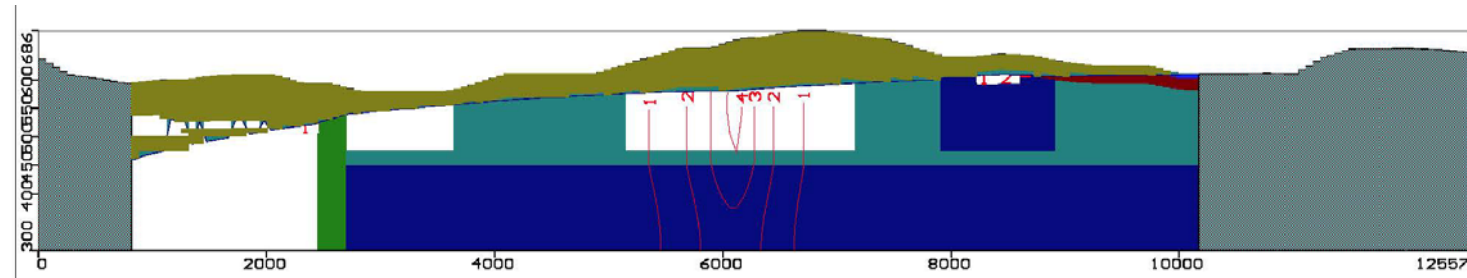
Piezometric Map during Pit Dewatering (Final Depth - Phase III (t=6840d))



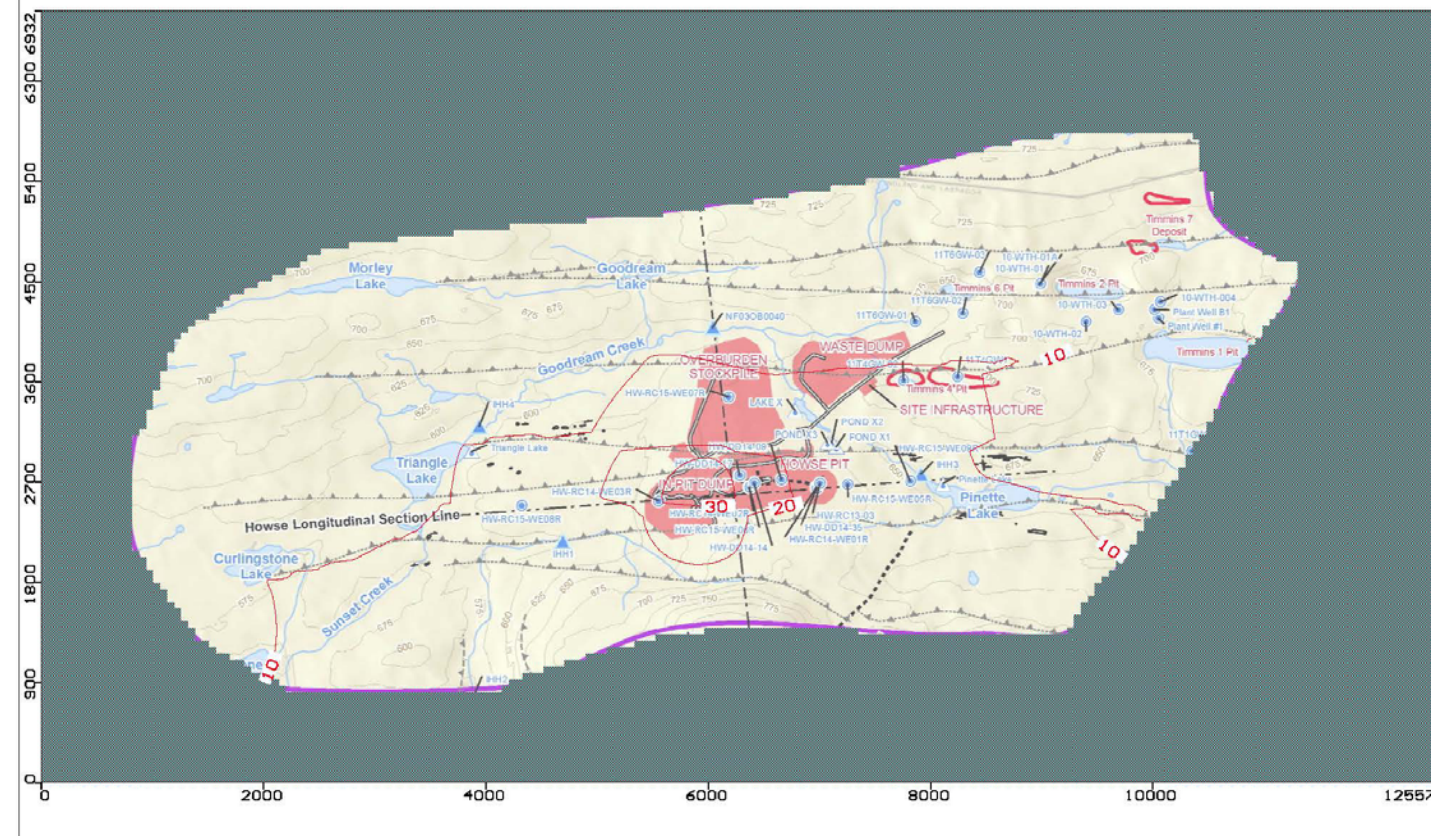
Groundwater Drawdown – End of Phase I



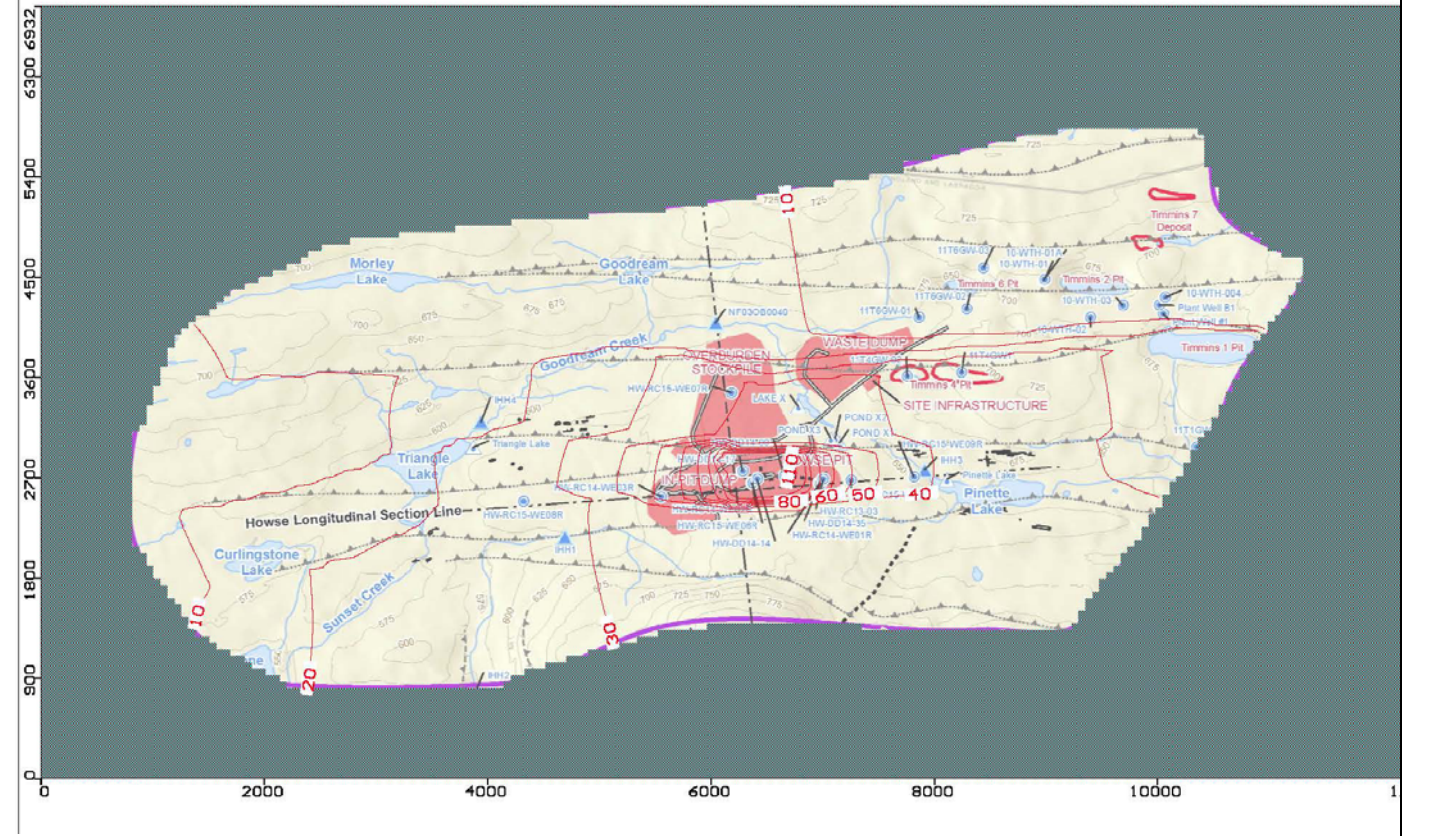
Groundwater Drawdown – End of Phase I - West-East Section



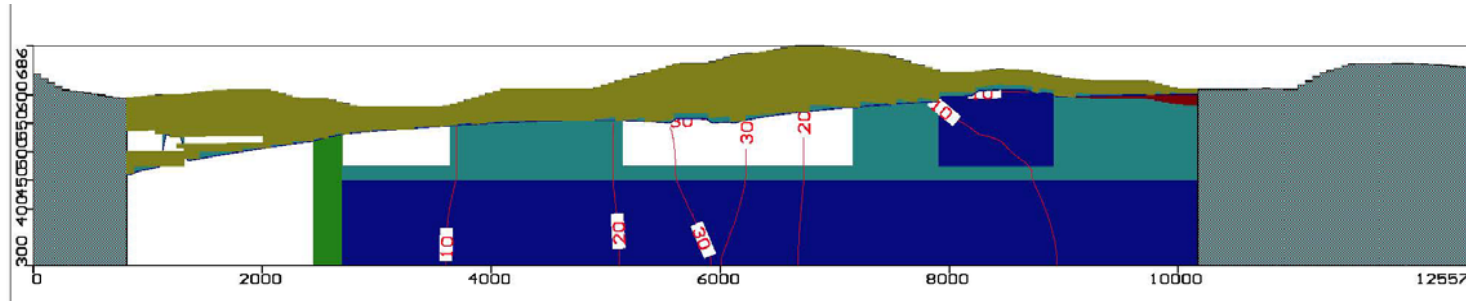
Groundwater Drawdown – End of Phase II



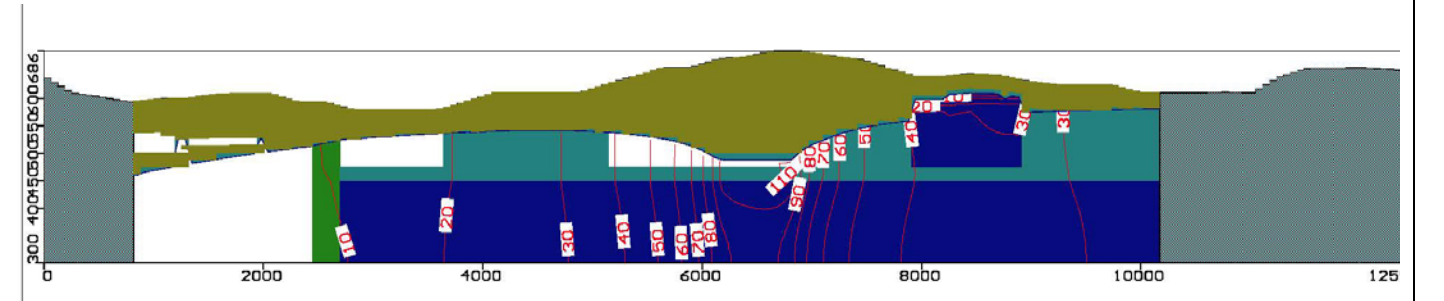
Groundwater Drawdown – End of Phase III



Groundwater Drawdown – End of Phase II - West-East Section



Groundwater Drawdown – End of Phase III - West-East Section



APPENDIX F

Sensitivity analysis on dewatering base case scenario

- › F1: Hydraulic conductivity
- › F2: Recharge
- › F3: Drain conductance
- › F4: Storage coefficient
- › F5: Vertical discretization

F1: Hydraulic conductivity

1) **Case 1:** Increase Kxyz for the Shale (x10) and the Wishart (x10)

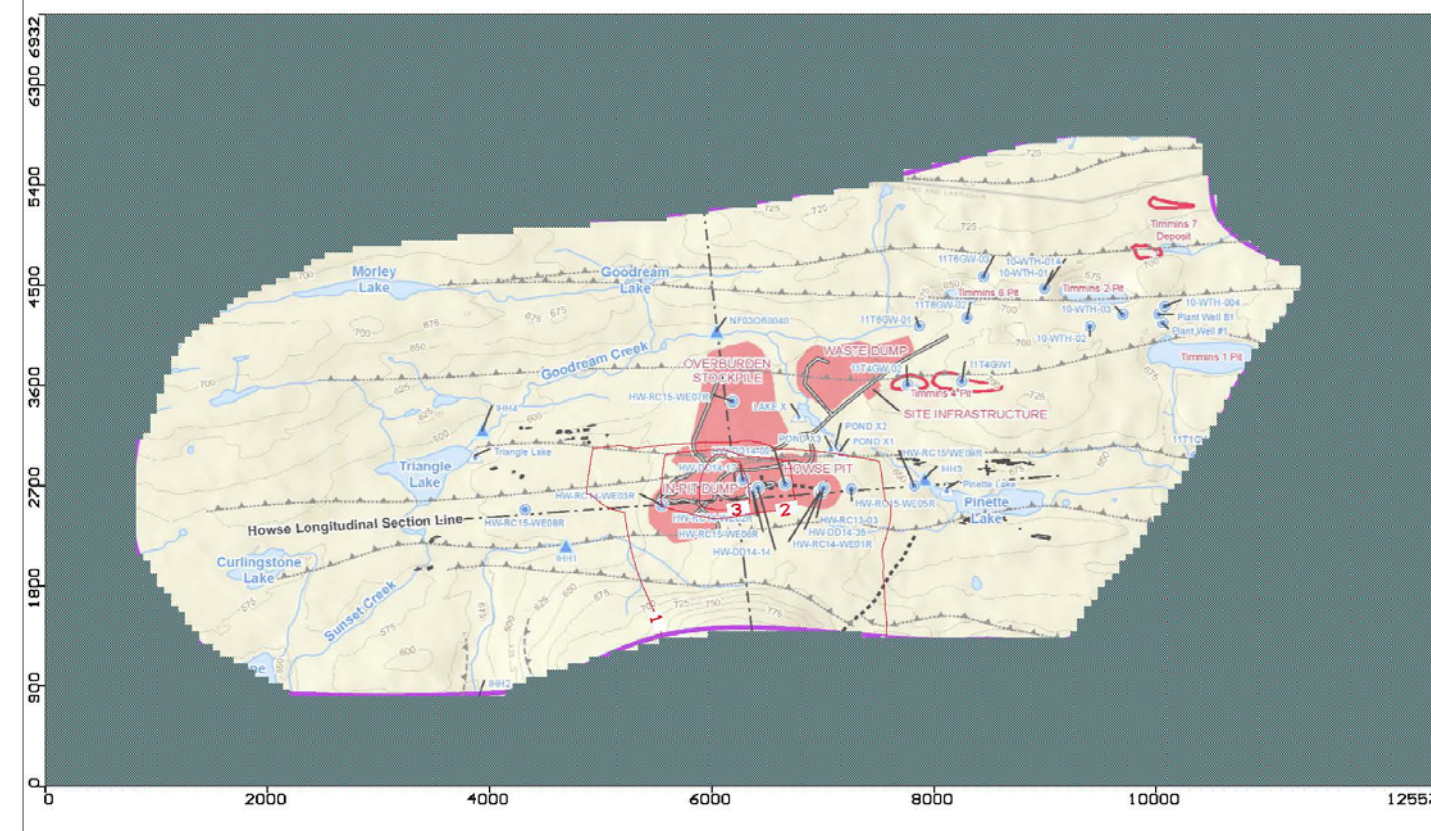
TableB1 Sensitivity analysis – Case 1

Zone	Kx (m/s)		Ky (m/s)		Kz (m/s)	
	Calibrated	Sensitivity analysis	Calibrated	Sensitivity analysis	Calibrated	Sensitivity analysis
Overburden	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05
Sokoman	1.5E-05	1.5E-05	1.5E-05	1.5E-05	1.5E-05	1.5E-05
Wishart	8.4E-06	8.4E-05	8.4E-06	8.4E-05	8.4E-06	8.4E-05
Shale	5.0E-08	5.0E-07	5.0E-08	5.0E-07	5.0E-08	5.0E-07
Faults zones	5.0E-07	5.0E-07	5.0E-07	5.0E-07	5.0E-07	5.0E-07

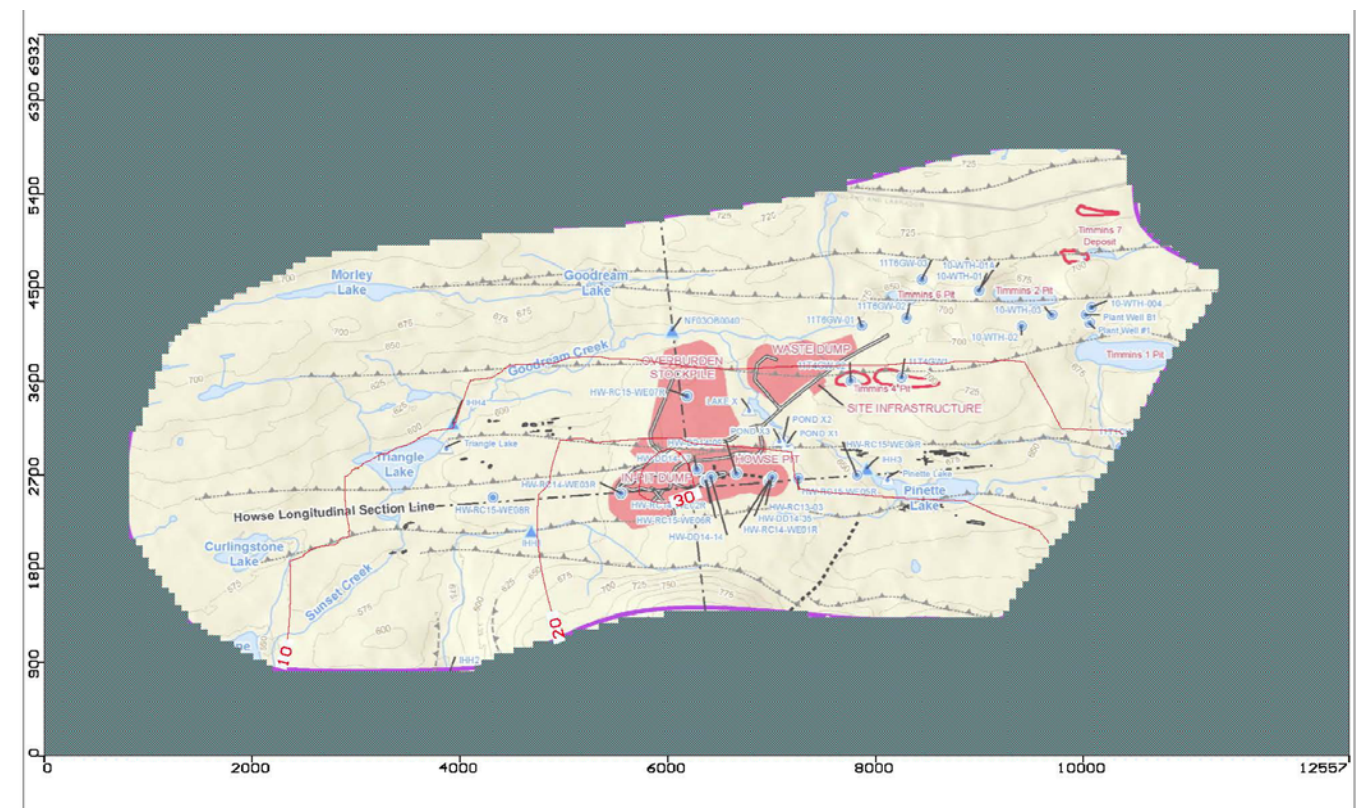
Recharge (mm/year)	Calibrated
R(1)	150

(Highlighted values were modified)

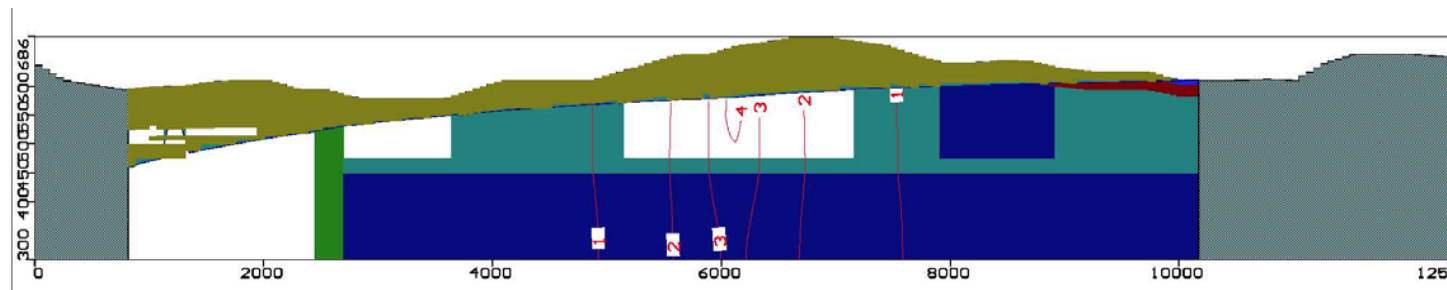
Groundwater Drawdown – End of Phase I



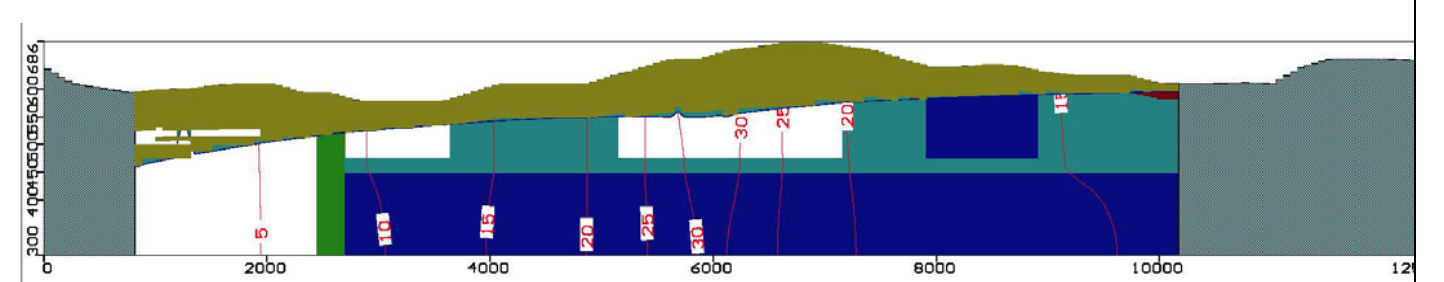
Groundwater Drawdown – End of Phase II



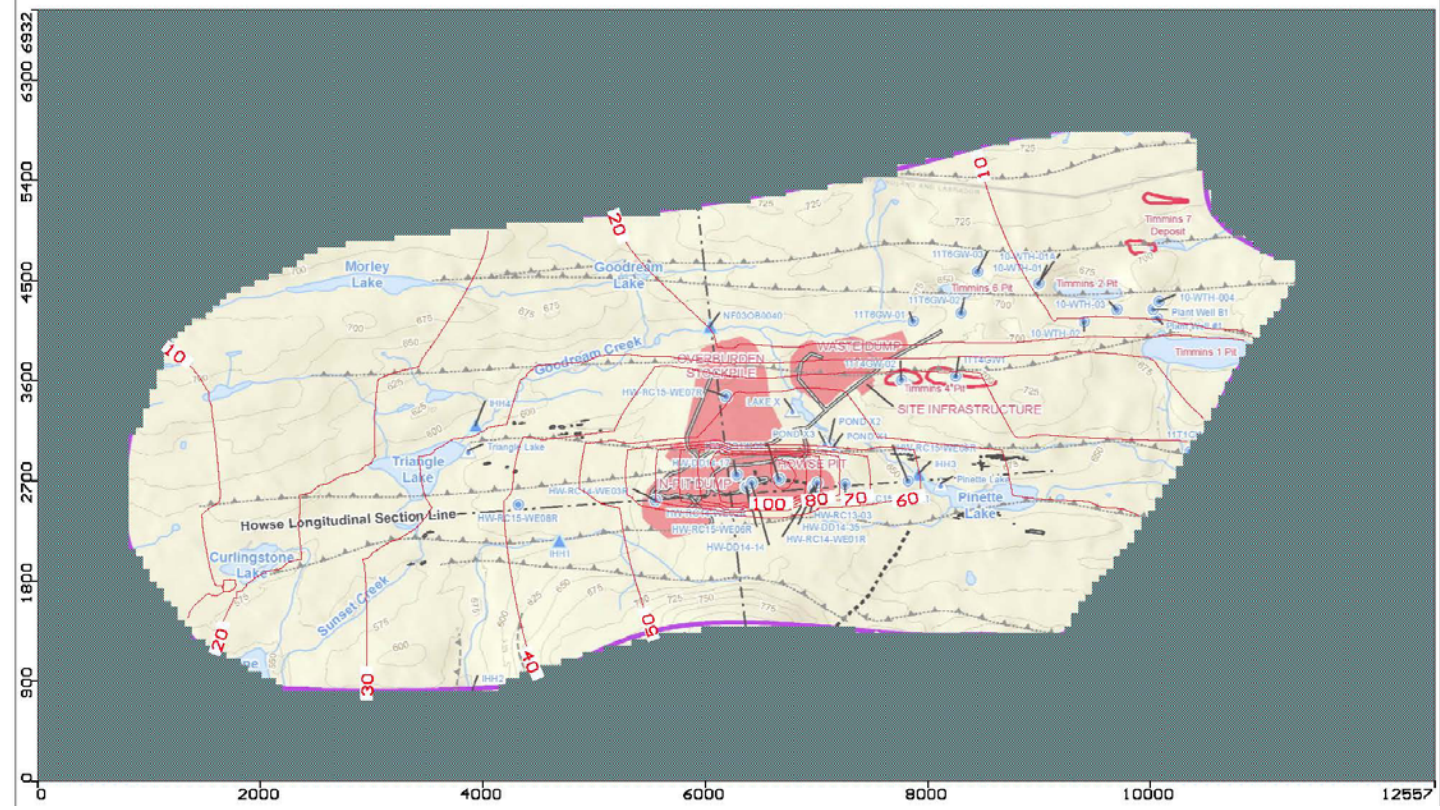
Groundwater Drawdown – End of Phase I - West-East Section



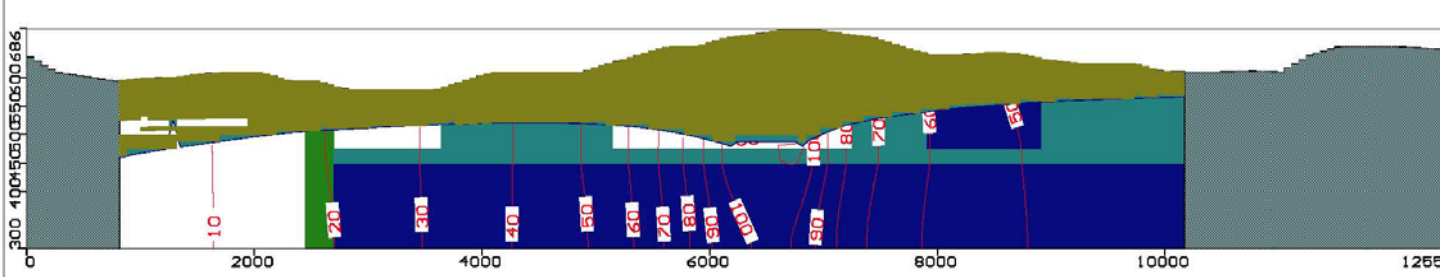
Groundwater Drawdown – End of Phase II - West-East Section



Groundwater Drawdown – End of Phase III



Groundwater Drawdown – End of Phase III - West-East Section



F2: Recharge

2) **Case 2:** Increase recharge to 200 mm/y

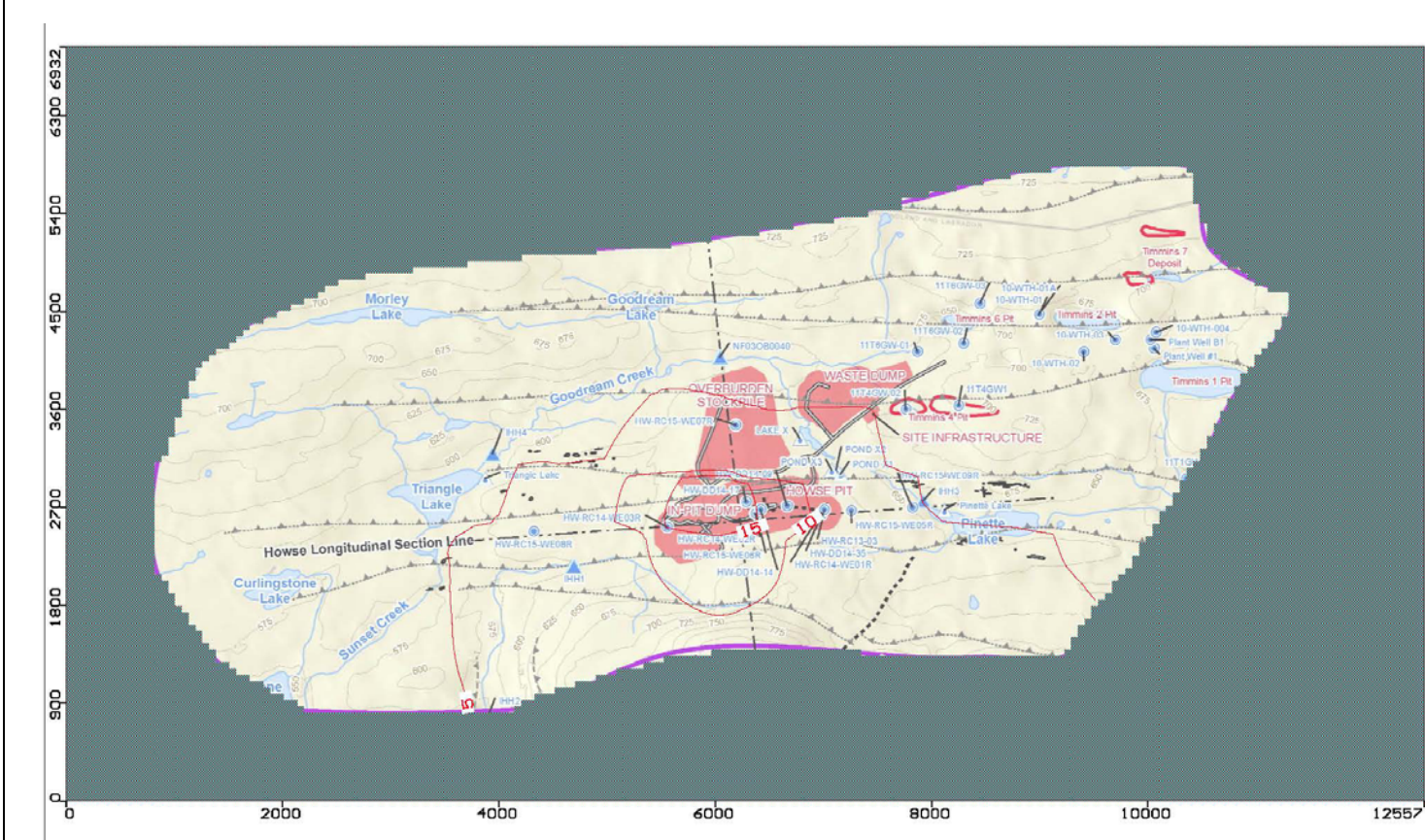
Table B2 Sensitivity analysis – Case 2

Zone	Kx (m/s)		Ky (m/s)		Kz (m/s)	
	Calibrated	Sensitivity analysis	Calibrated	Sensitivity analysis	Calibrated	Sensitivity analysis
Overburden	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05
Sokoman	1.5E-05	1.5E-05	1.5E-05	1.5E-05	1.5E-05	1.5E-05
Wishart	8.4E-06	8.4E-06	8.4E-06	8.4E-06	8.4E-06	8.4E-06
Shale	5.0E-08	5.0E-08	5.0E-08	5.0E-08	5.0E-08	5.0E-08
Faults zones	5.0E-07	5.0E-07	5.0E-07	5.0E-07	5.0E-07	5.0E-07

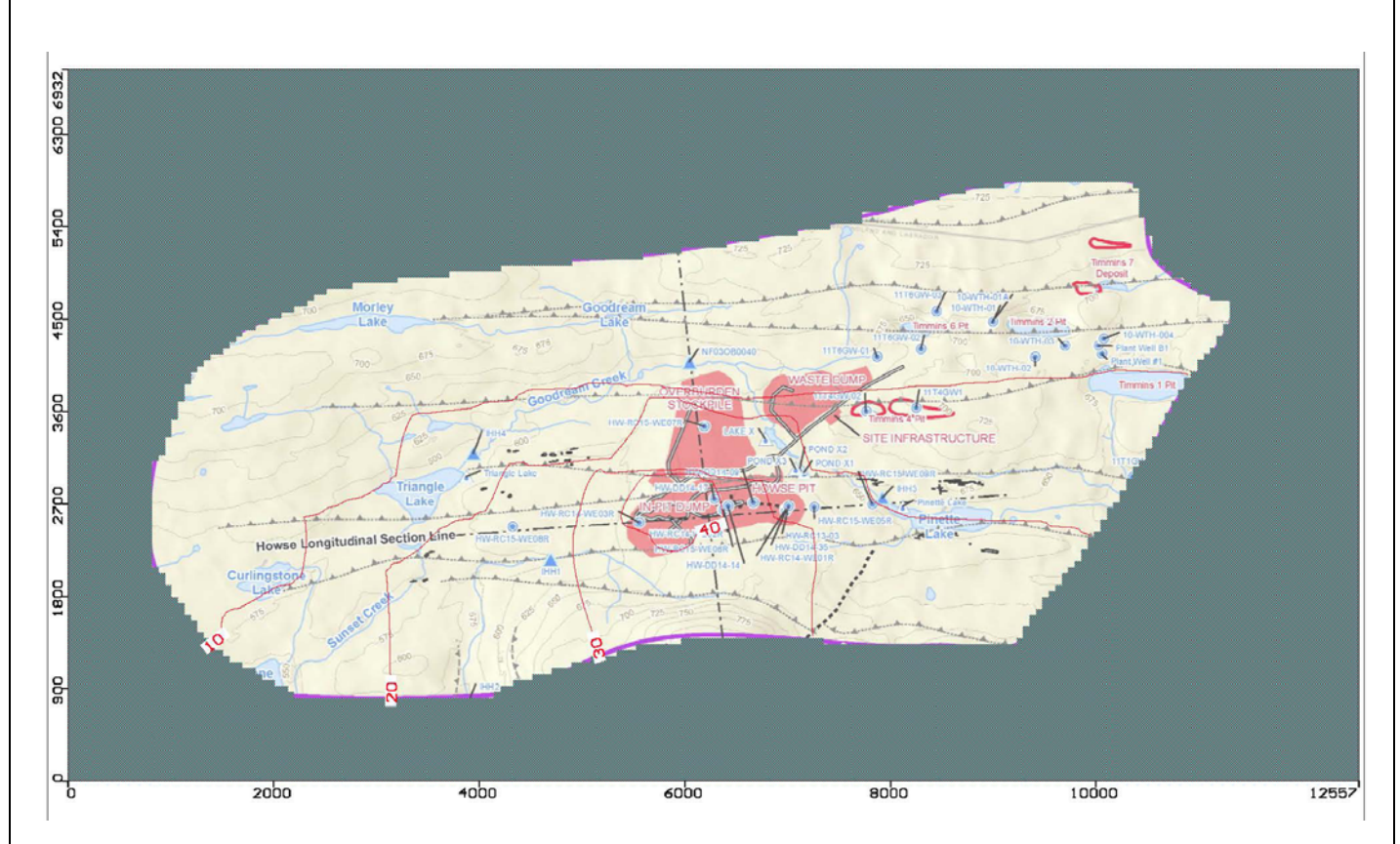
Recharge (mm/year)	Calibrated	Sensitivity analysis
R(1)	100	200

(Highlighted values were modified)

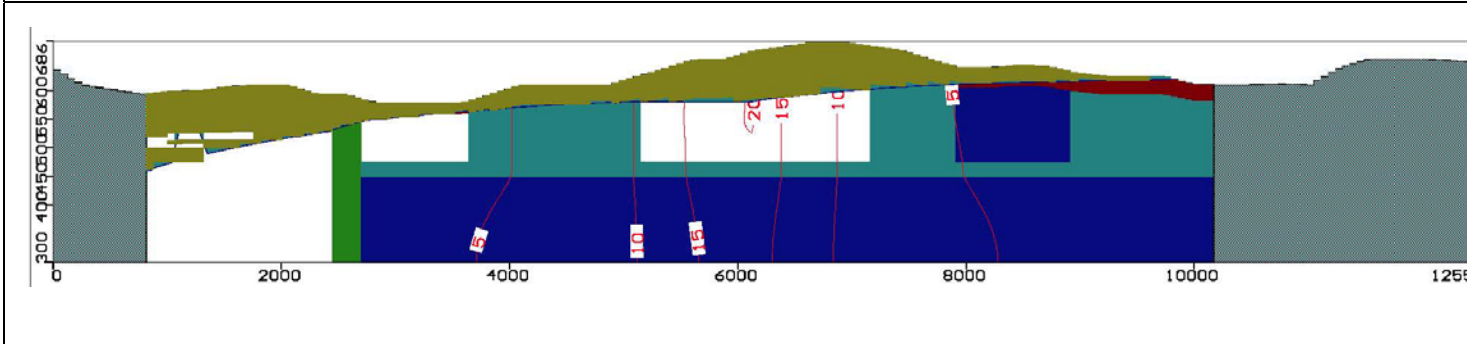
Groundwater Drawdown – End of Phase I



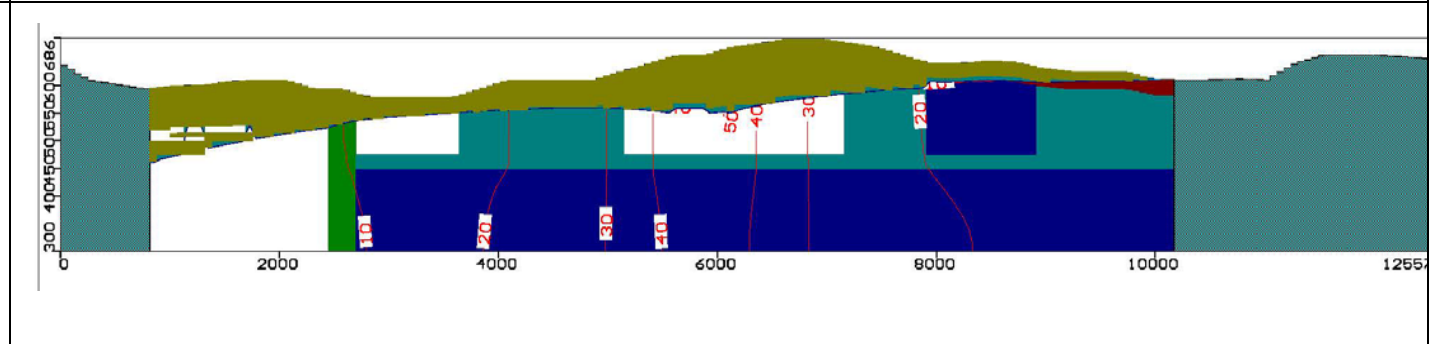
Groundwater Drawdown – End of Phase II



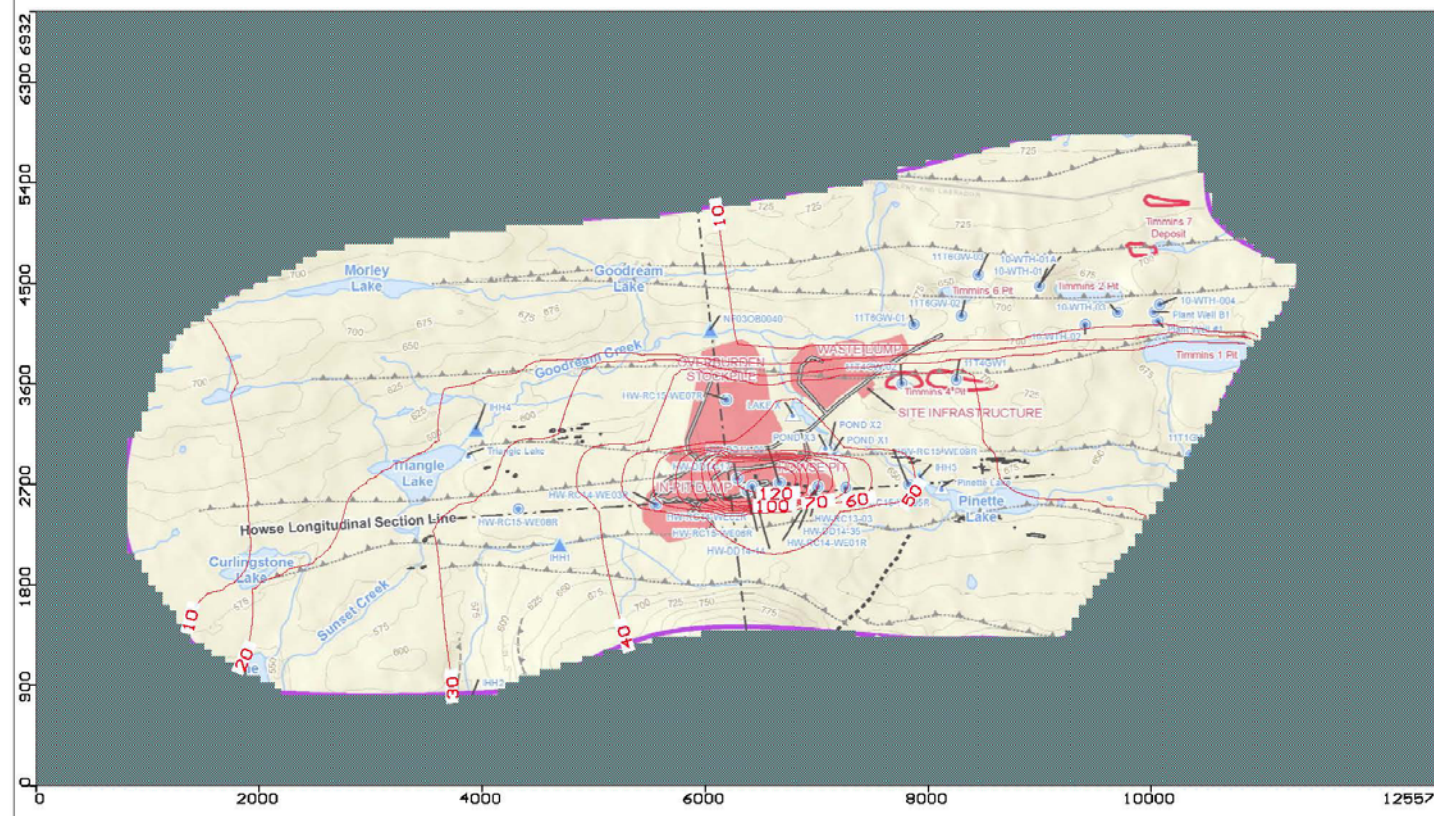
Groundwater Drawdown – End of Phase I - West-East Section



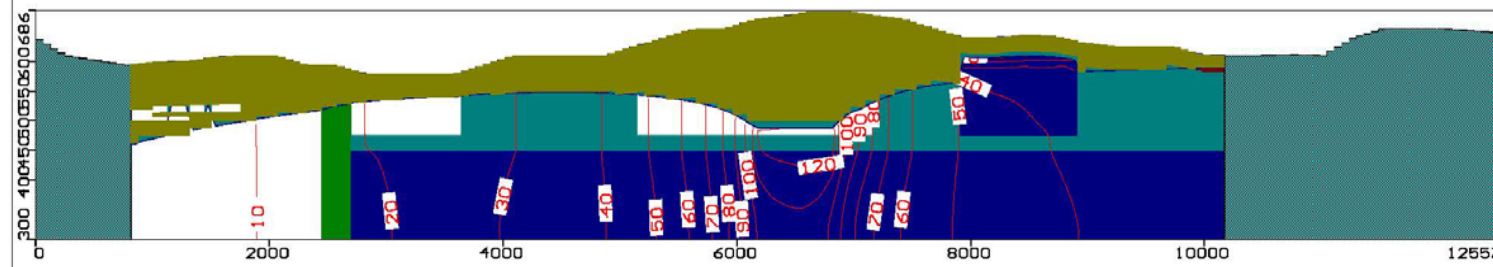
Groundwater Drawdown – End of Phase II - West-East Section



Groundwater Drawdown – End of Phase III

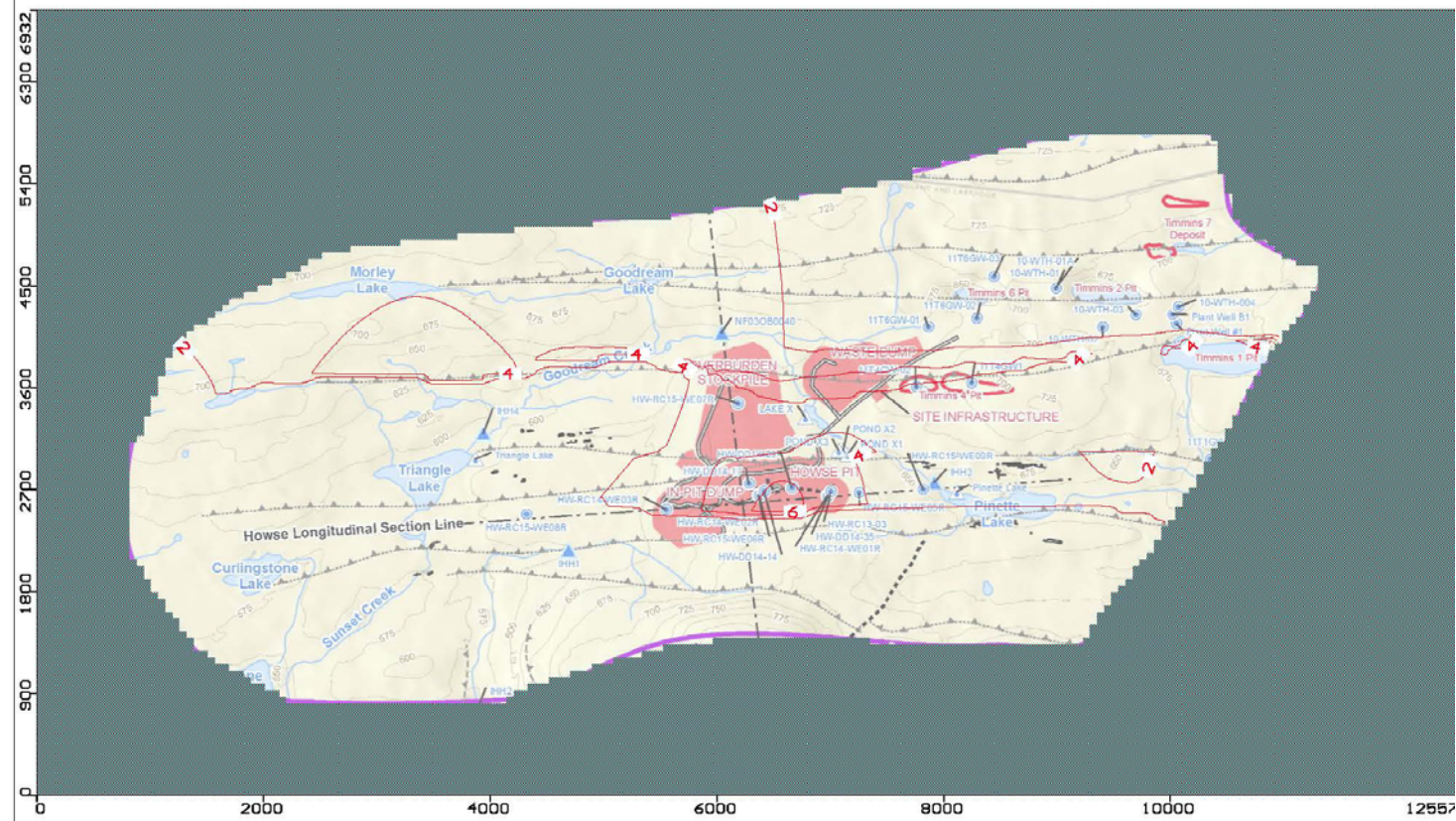


Groundwater Drawdown – End of Phase III - West-East Section

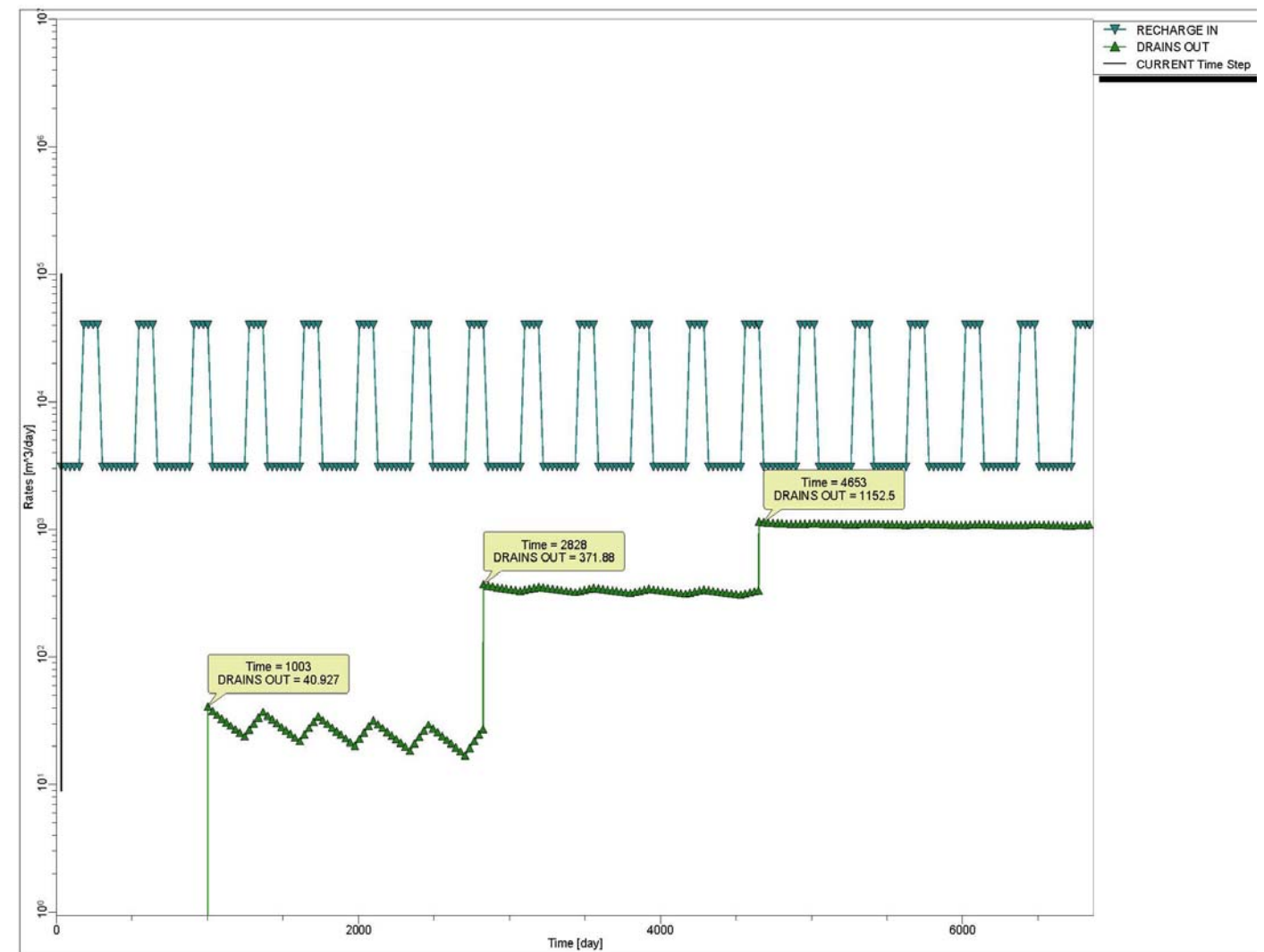


F3: Drain Conductance

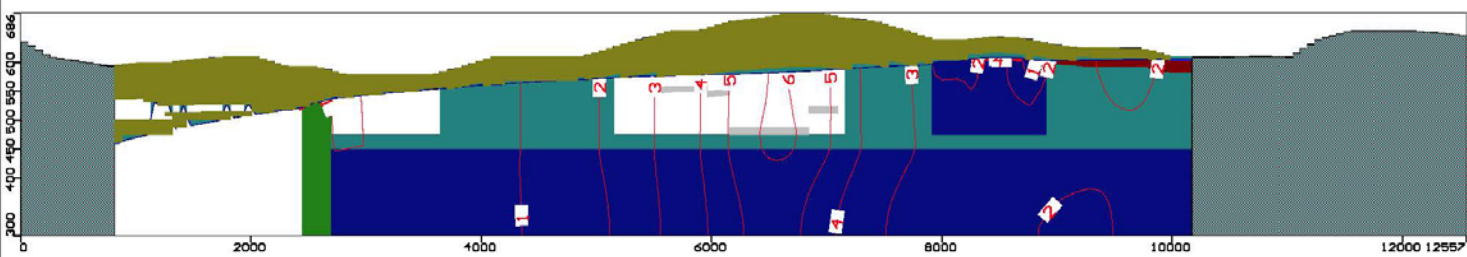
Conductance of 0.1 m²/d – Groundwater Drawdown – End of Phase III



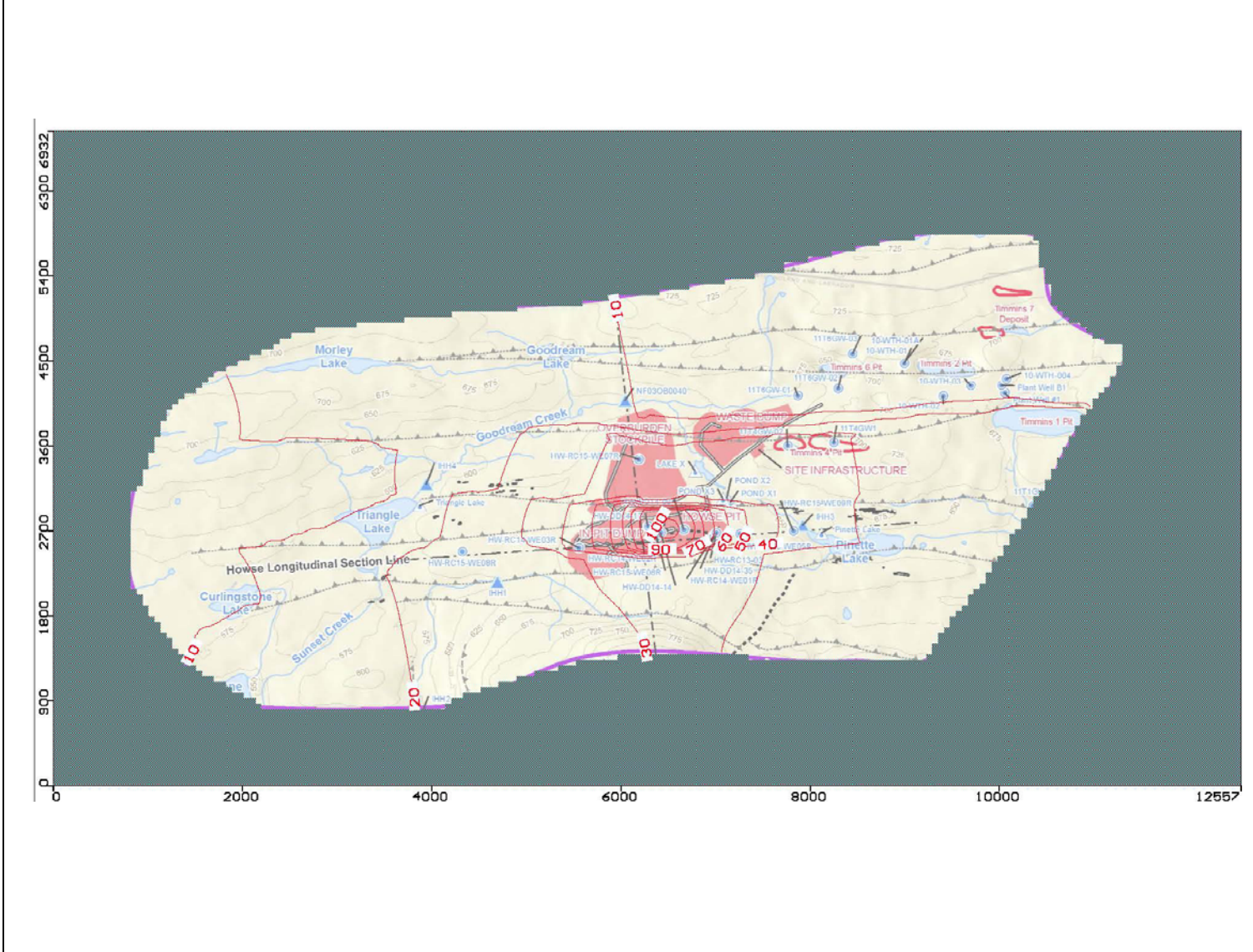
Rates (m³/d) vs Time (d)



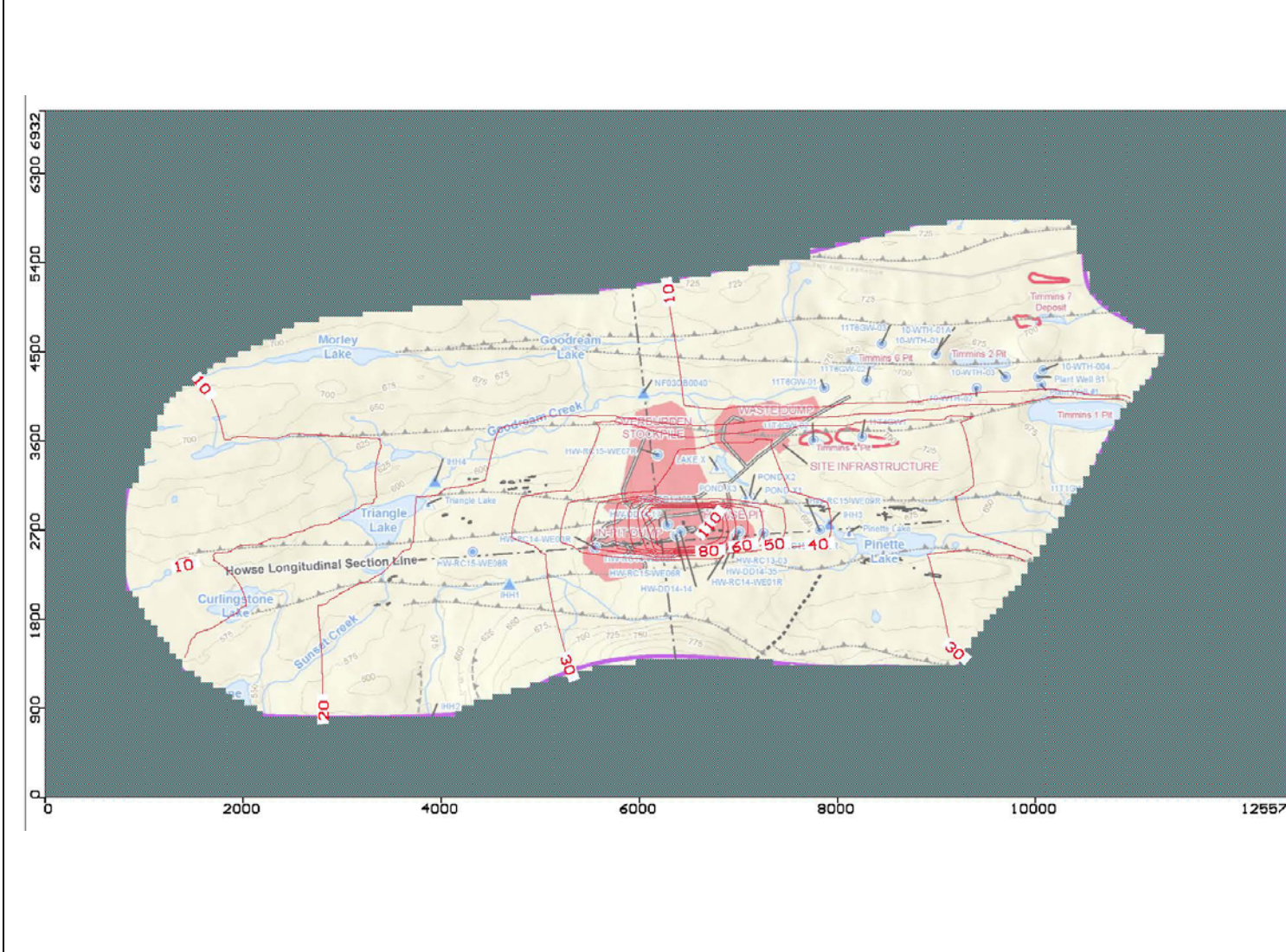
Conductance of 0.1 m²/d – Groundwater Drawdown – End of Phase III - West-East Section



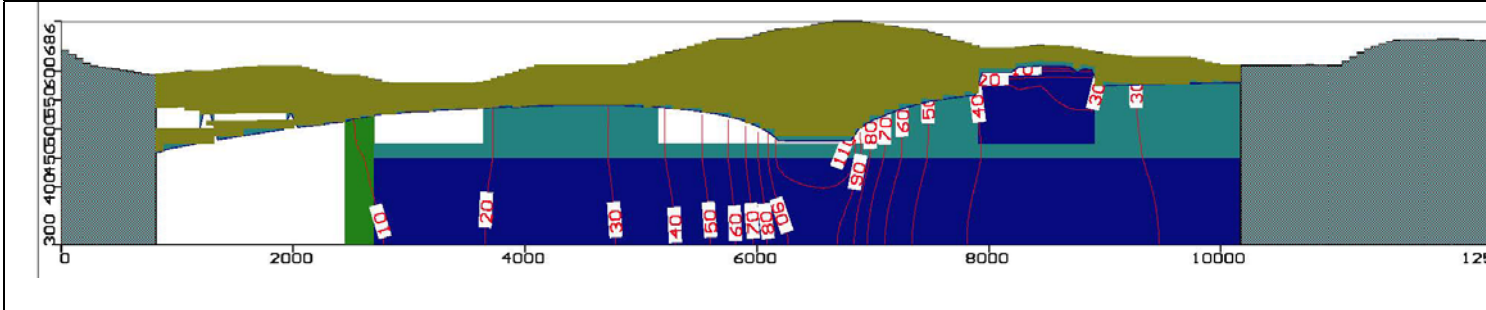
Conductance of 10 m²/d – Groundwater Drawdown – End of Phase III



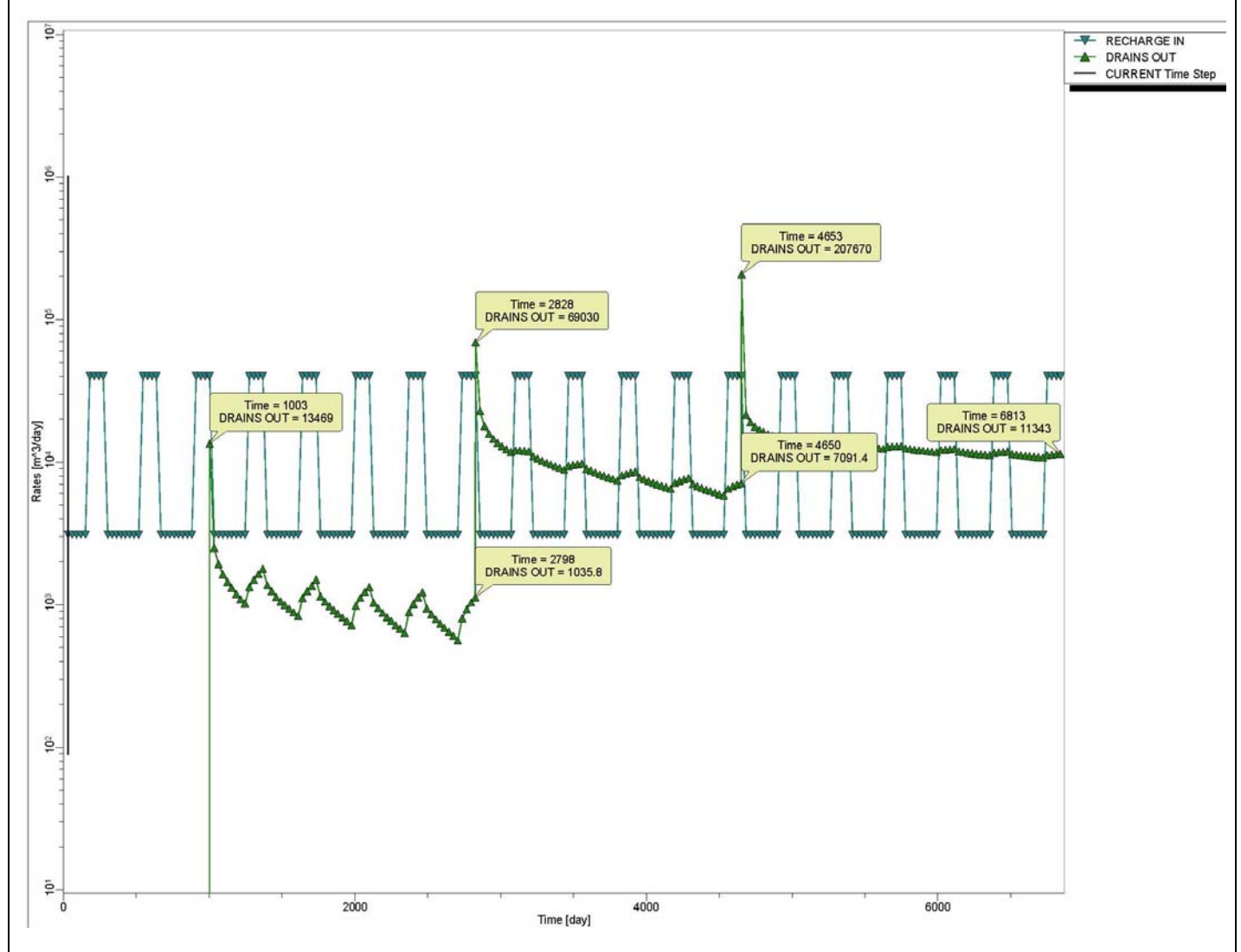
Conductance of 1000 m²/d – Groundwater Drawdown – End of Phase III



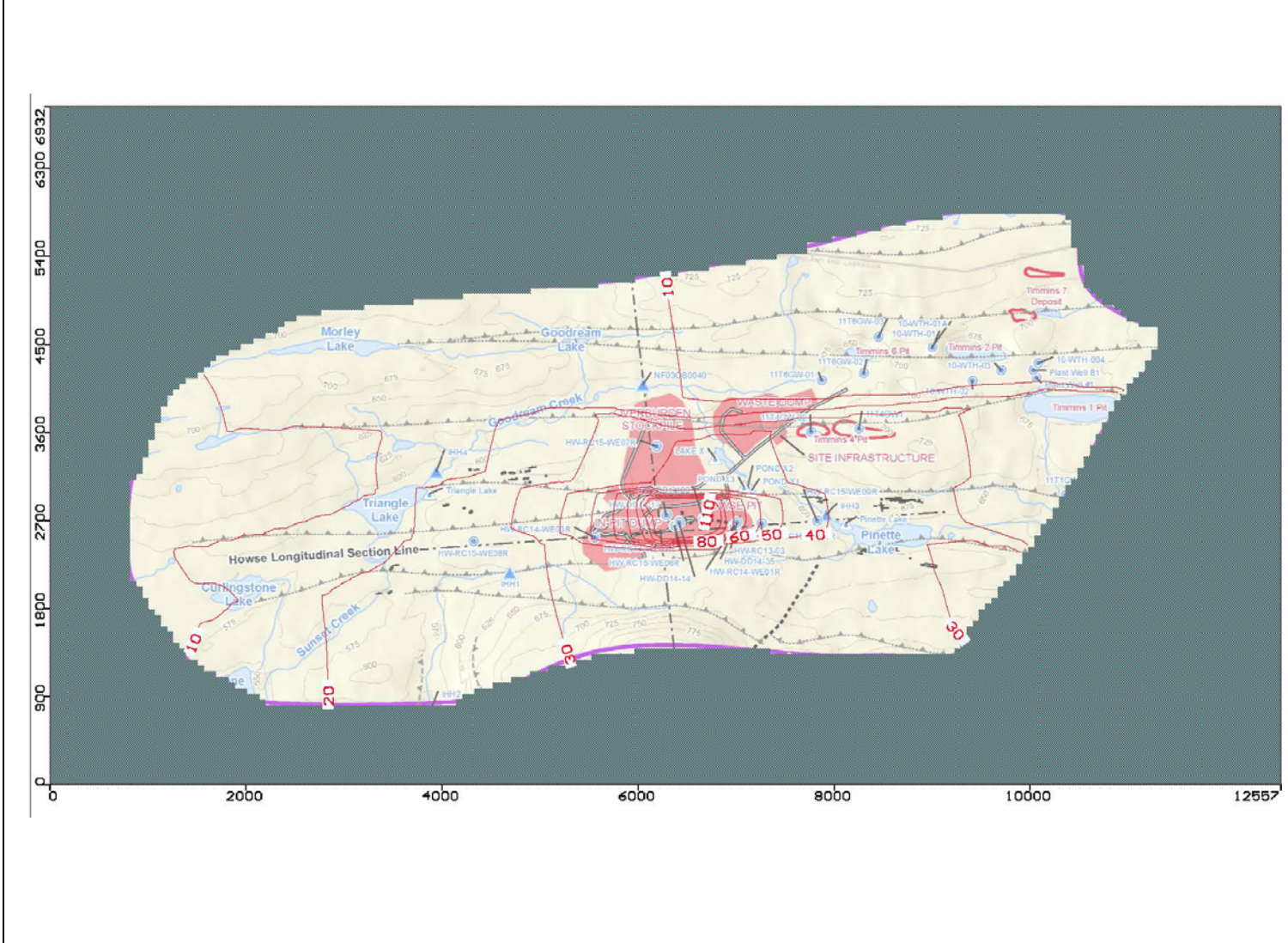
Conductance of 1000 m²/d – Groundwater Drawdown – End of Phase III - West-East Section



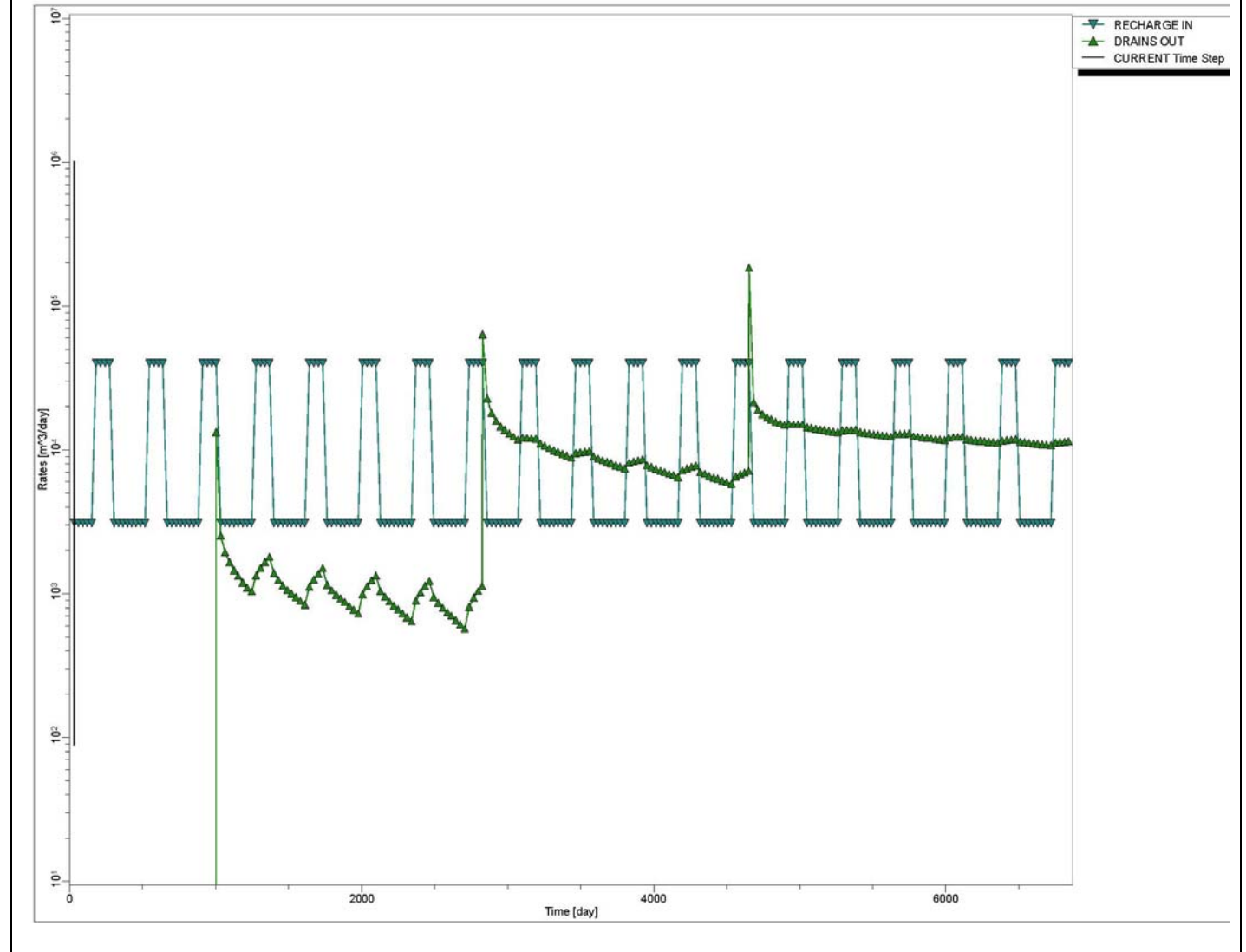
Rates (m³/d) vs Time (d)



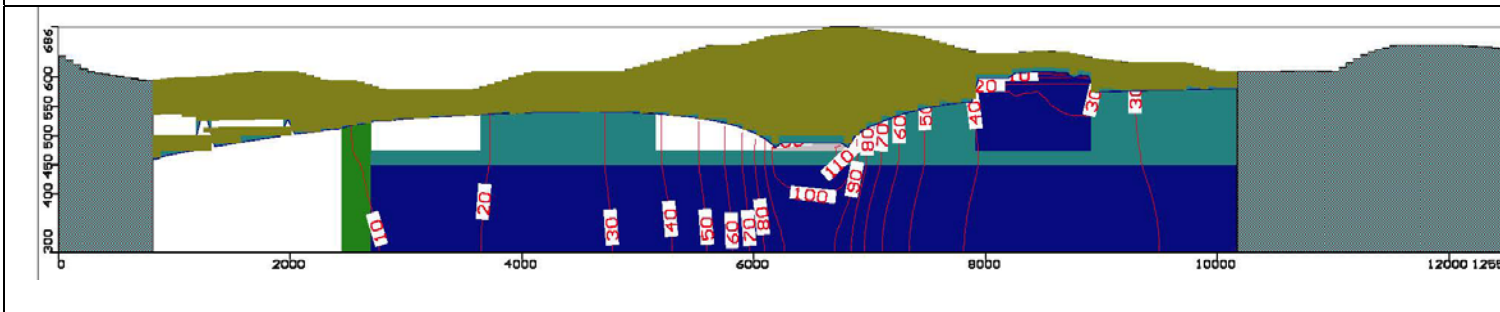
Conductance of 25,000 m²/d – Groundwater Drawdown – End of Phase III



Rates (m³/d) vs Time (d)



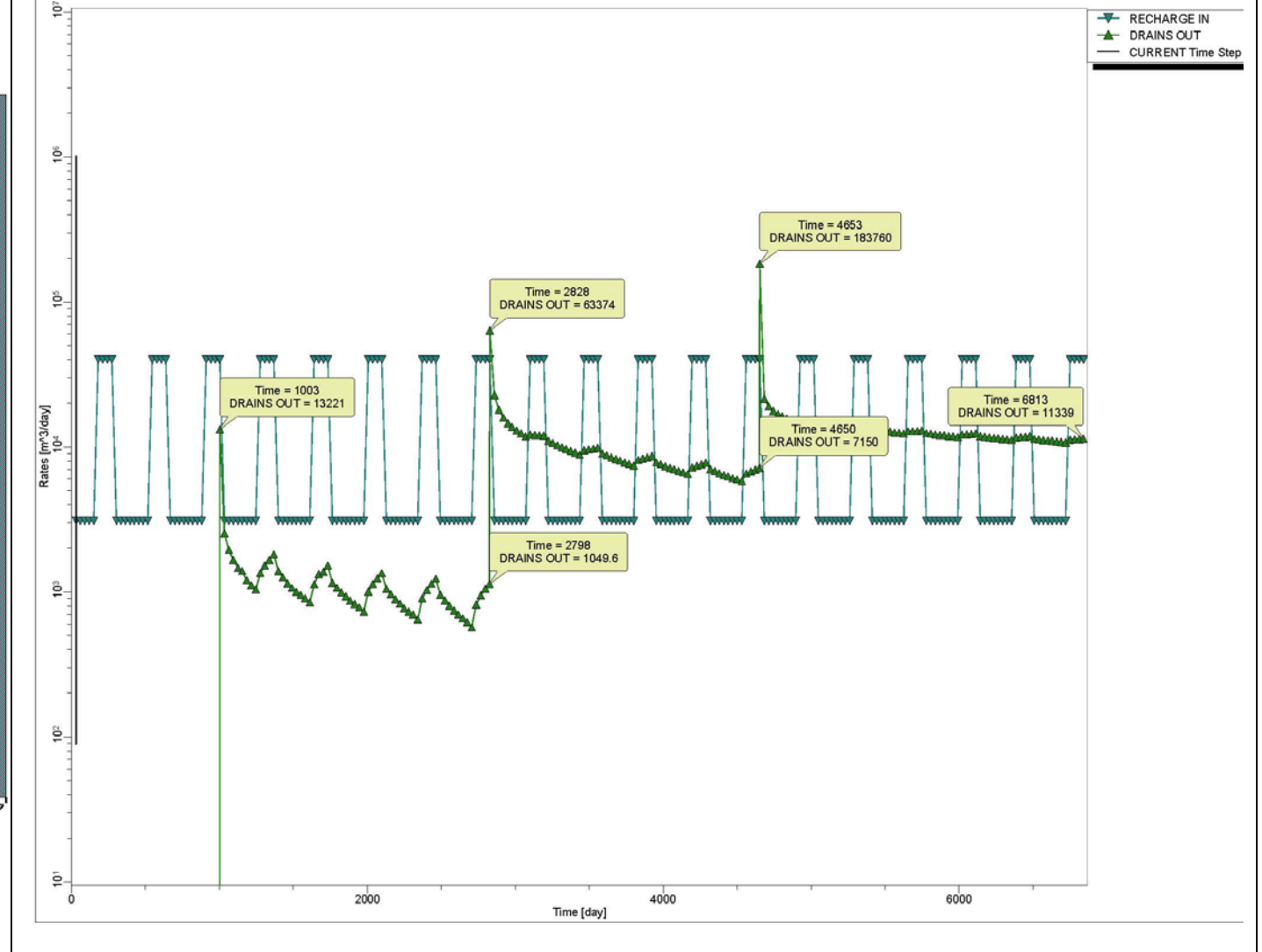
Conductance of 25,000 m²/d – Groundwater Drawdown – End of Phase III - West-East Section



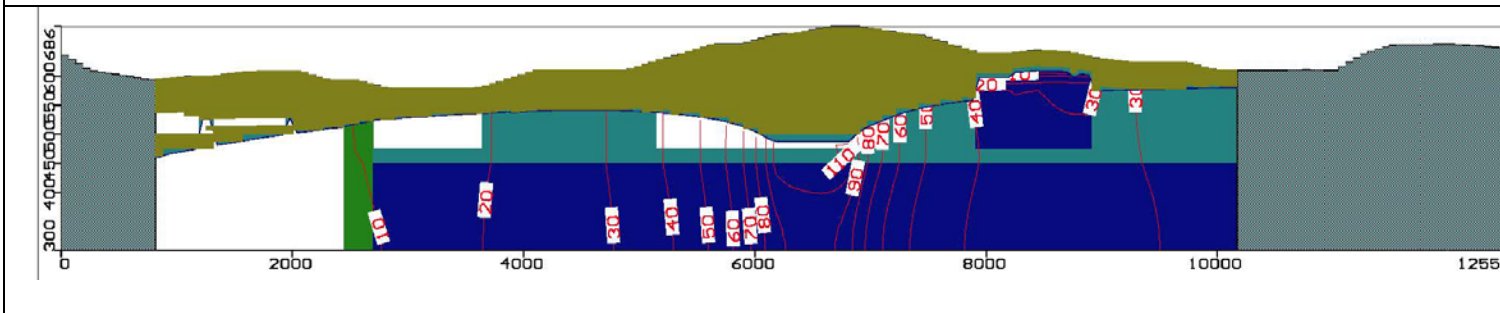
Conductance of 50,000 m²/d (Base Case)– Groundwater Drawdown – End of Phase III



Rates (m³/d) vs Time (d)

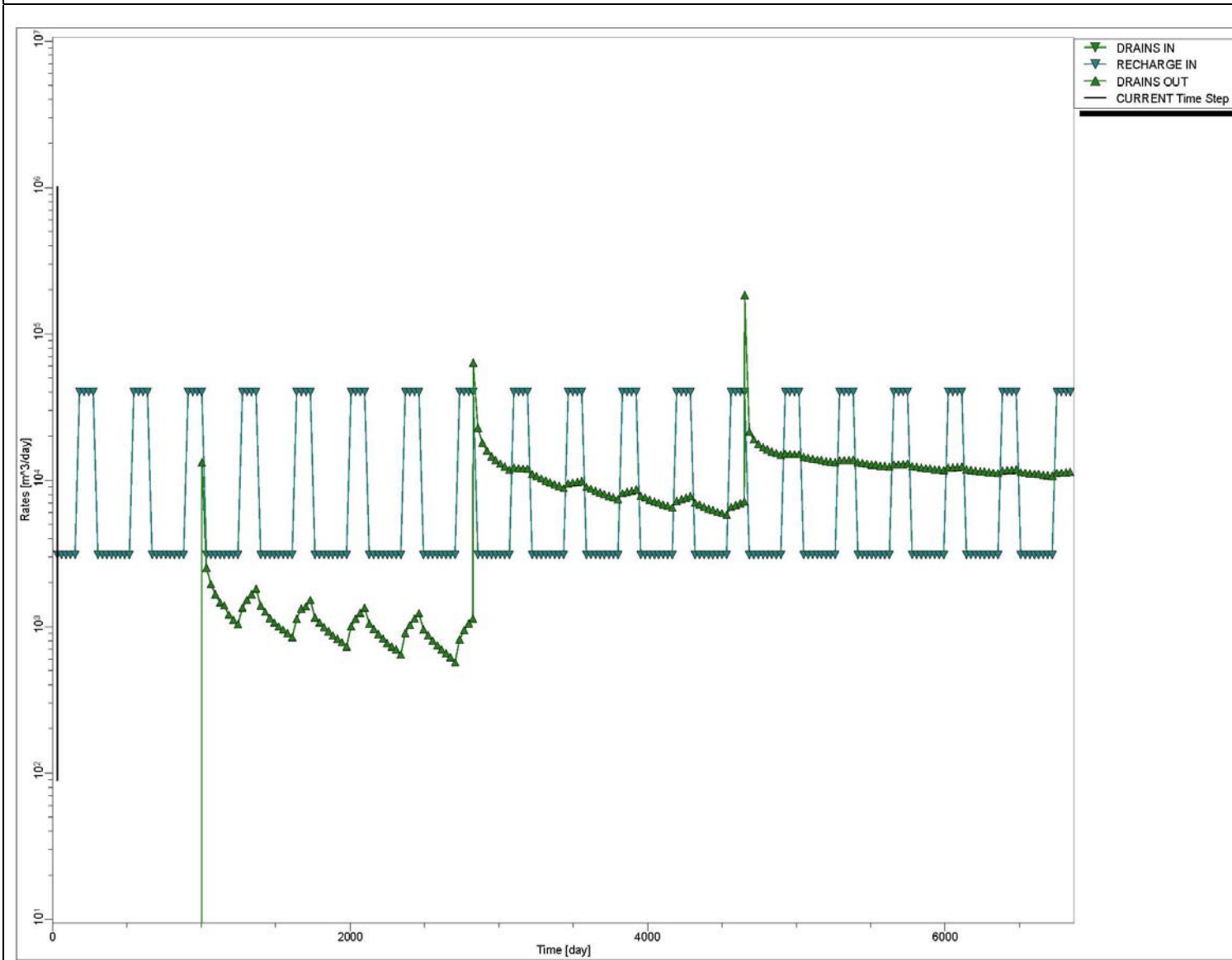


Conductance of 50,000 m²/d (Base Case) – Groundwater Drawdown – End of Phase III - West-East Section

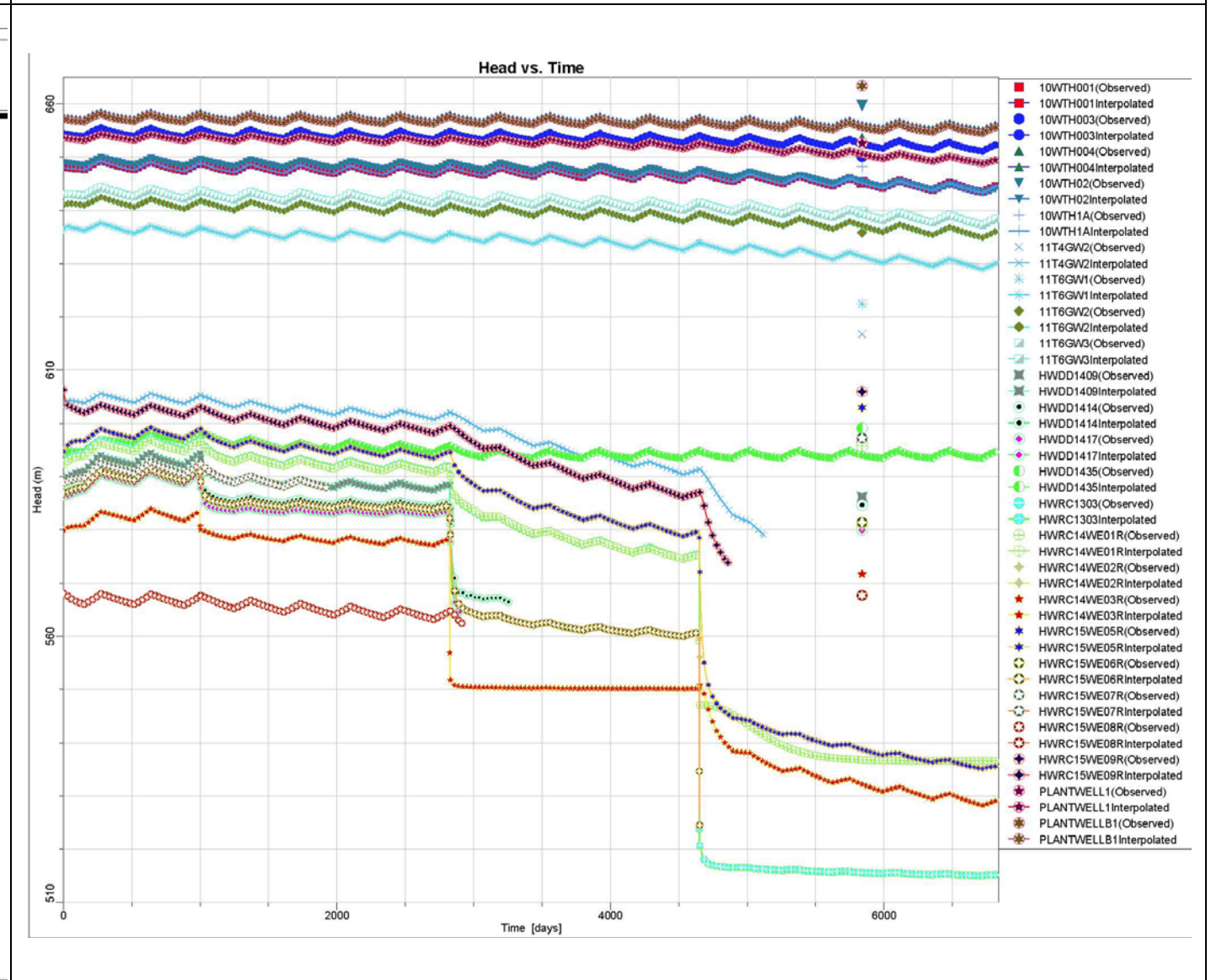


F4: Storage Coefficient

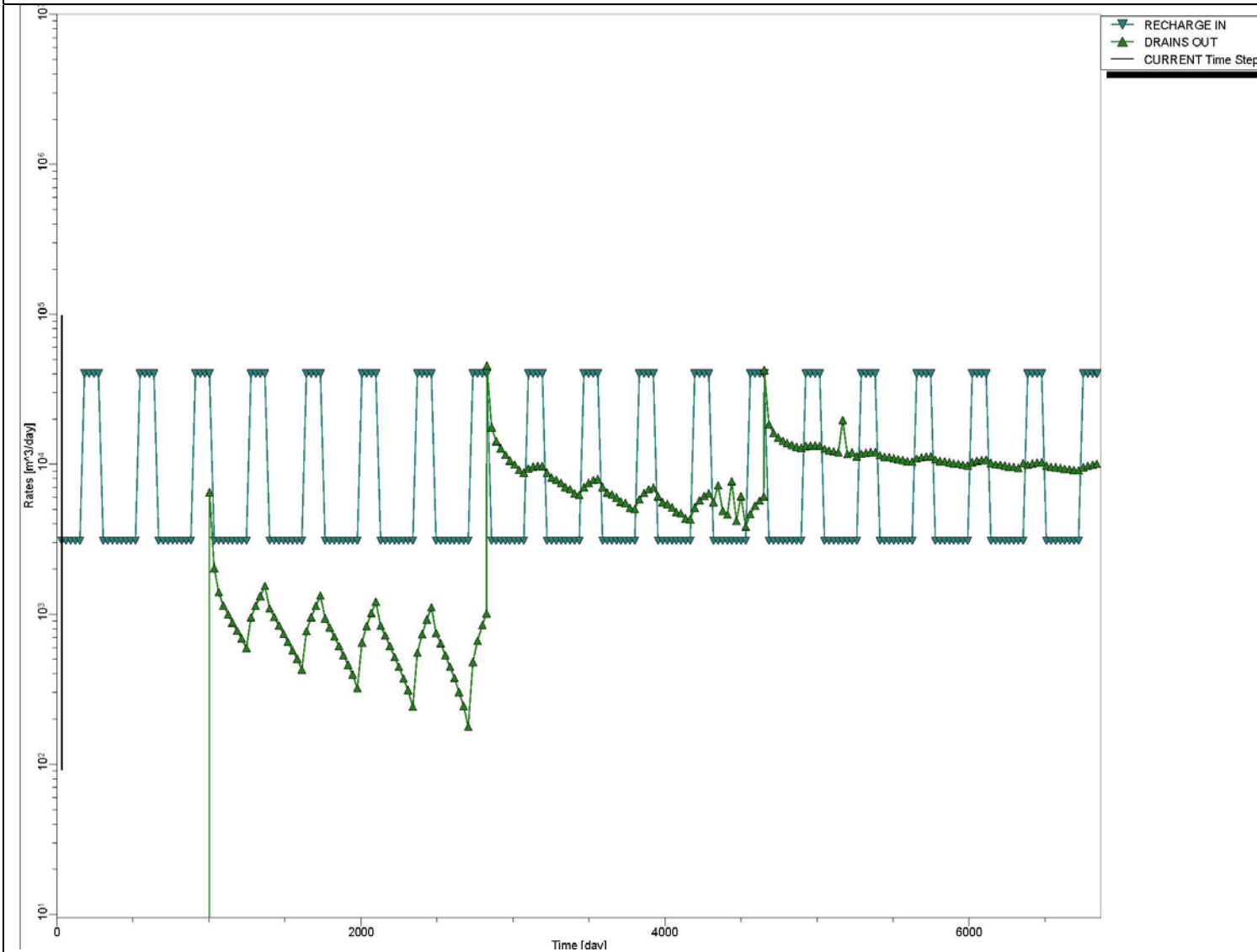
Sy = 0.05 – Rates (m³/d) vs Time (d) (Base Case)



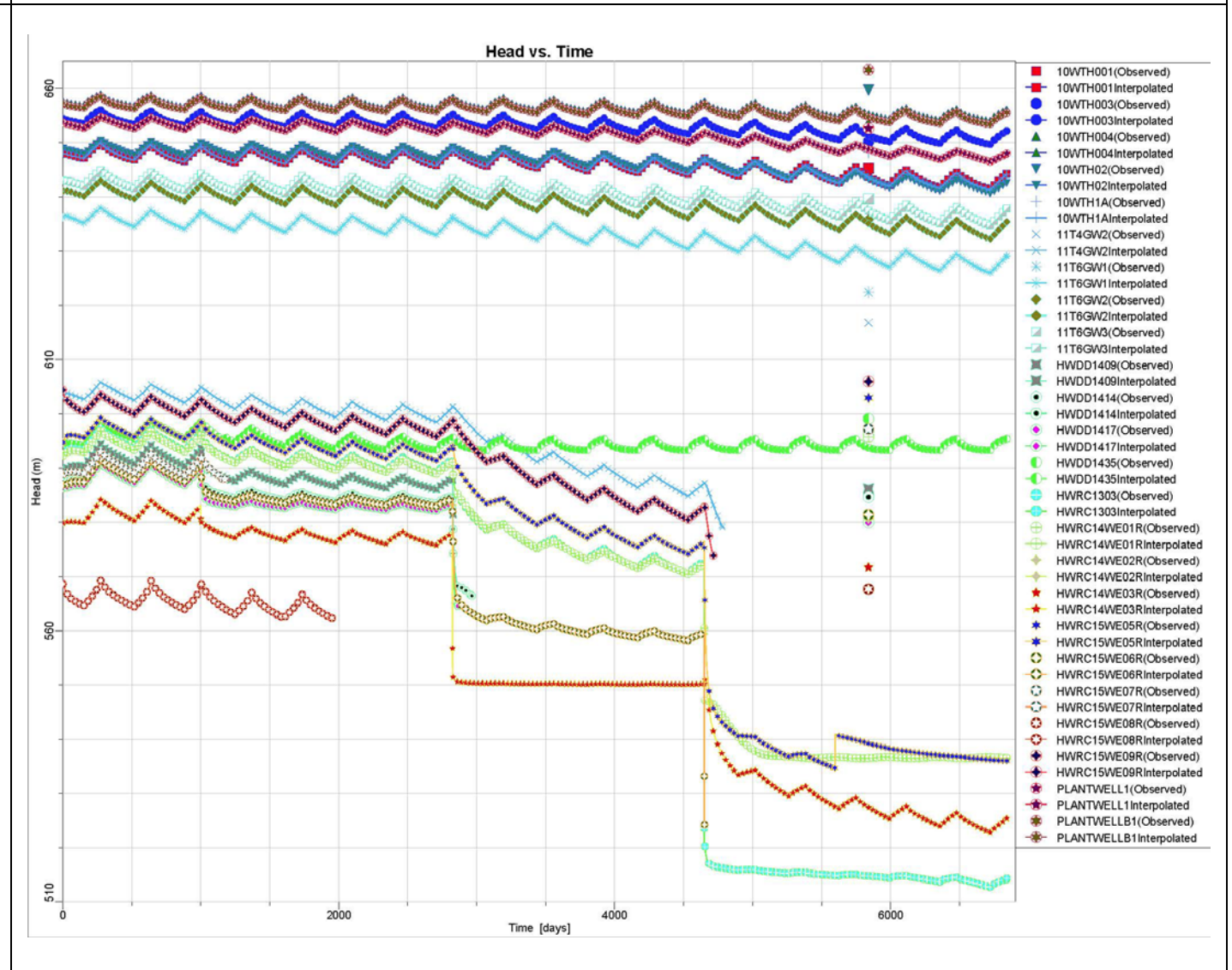
Sy = 0.05 – Heads (m) vs Time (d) (Base Case)



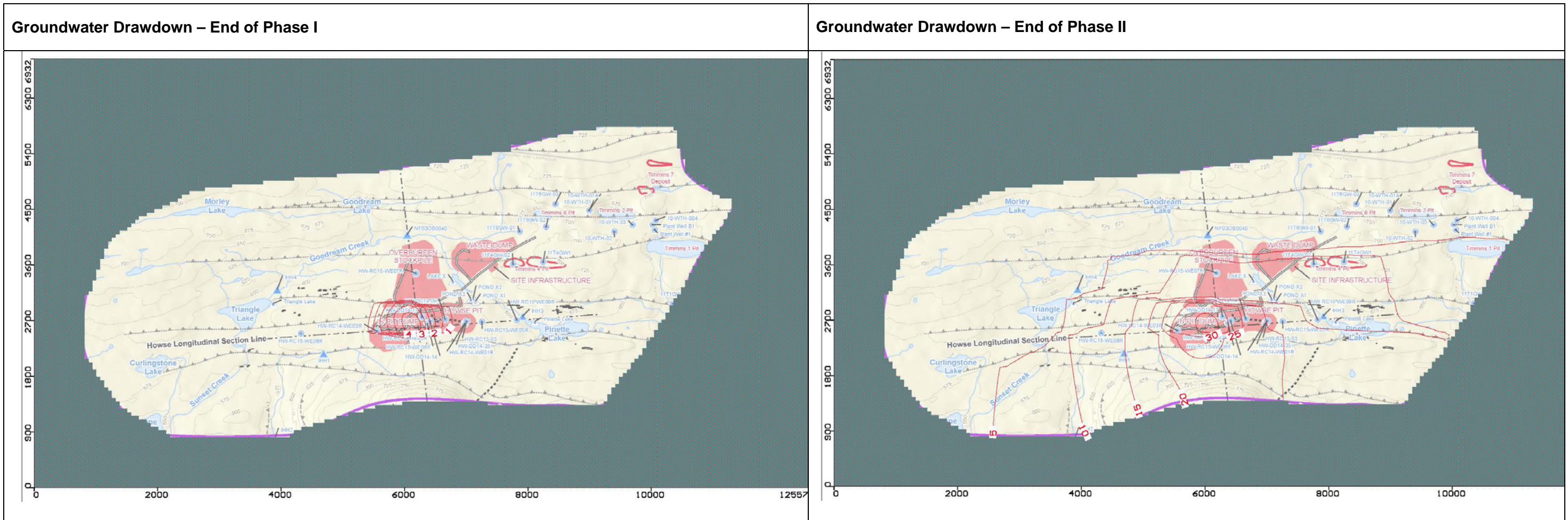
Sy = 0.025 – Rates (m³/d) vs Time (d)



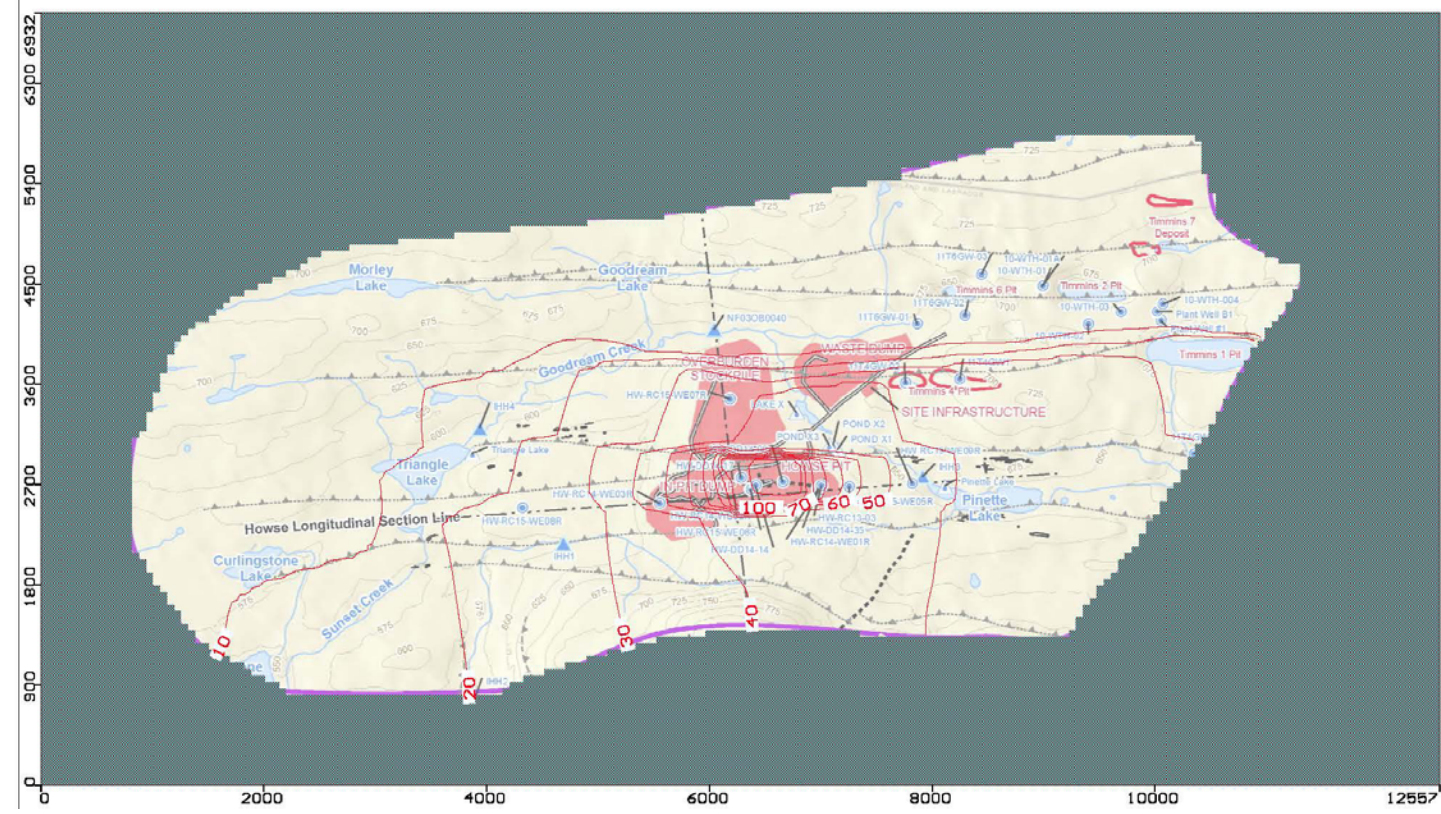
Sy = 0.025 – Heads (m) vs Time (d)



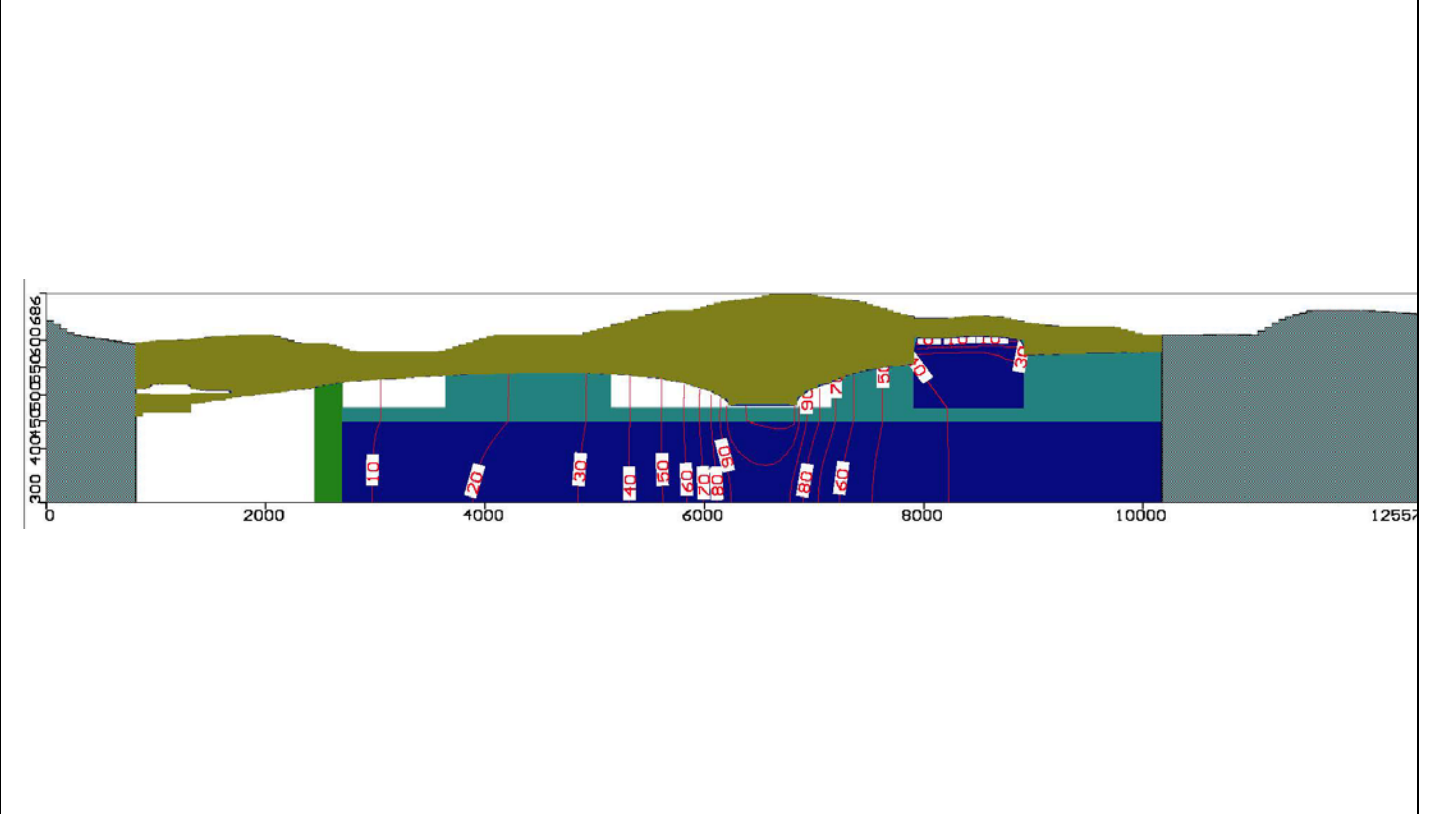
F5: Vertical Discretization



Groundwater Drawdown – End of Phase III

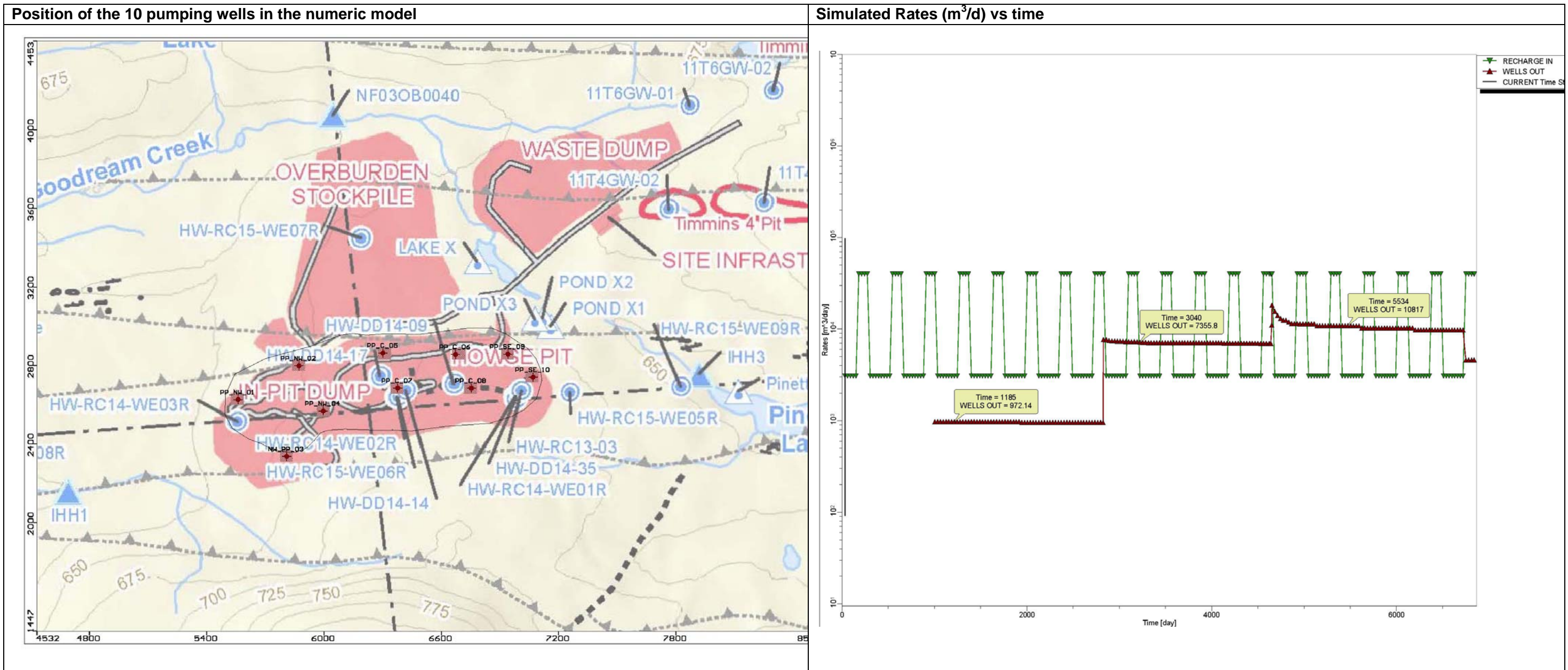


Groundwater Drawdown – End of Phase III - West-East Section

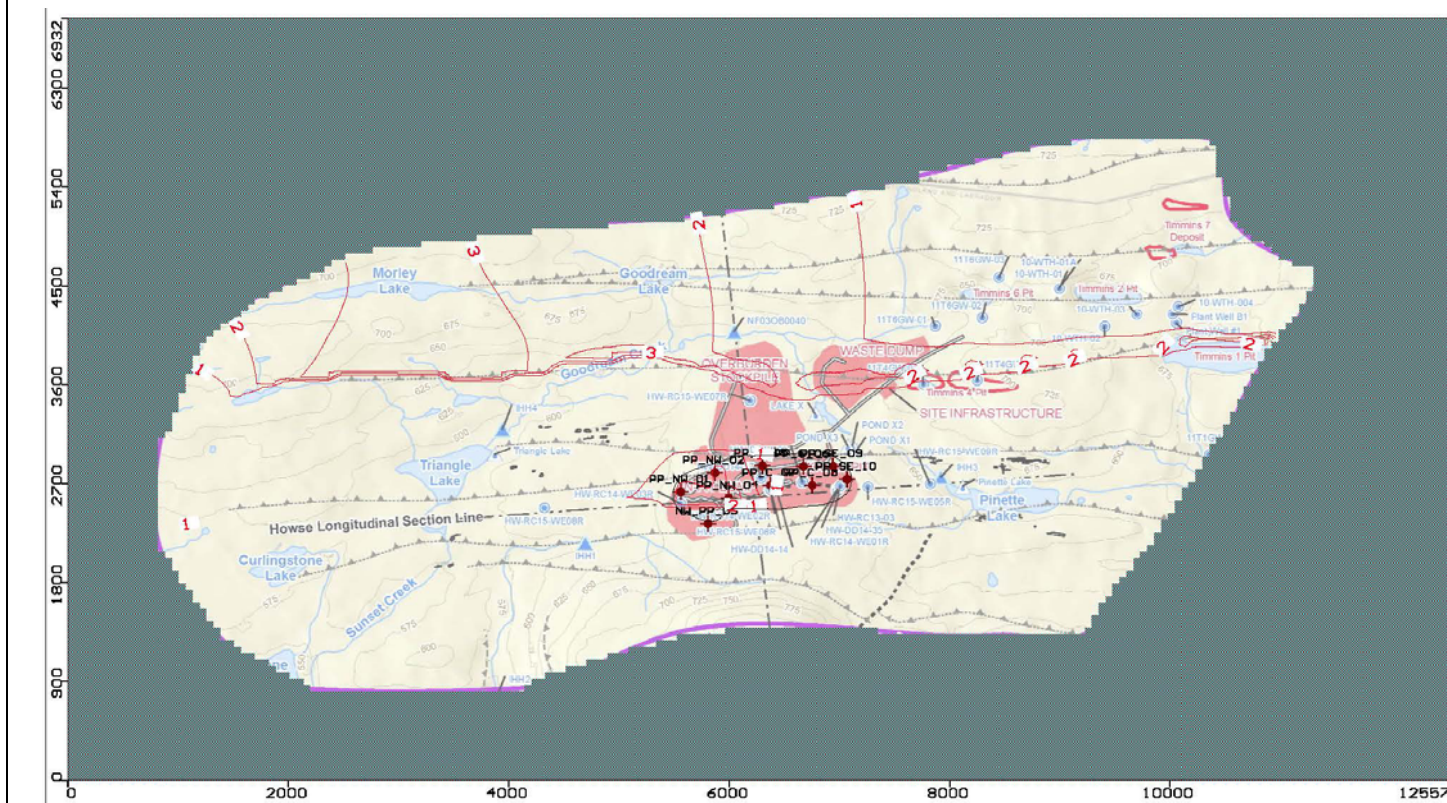


APPENDIX G

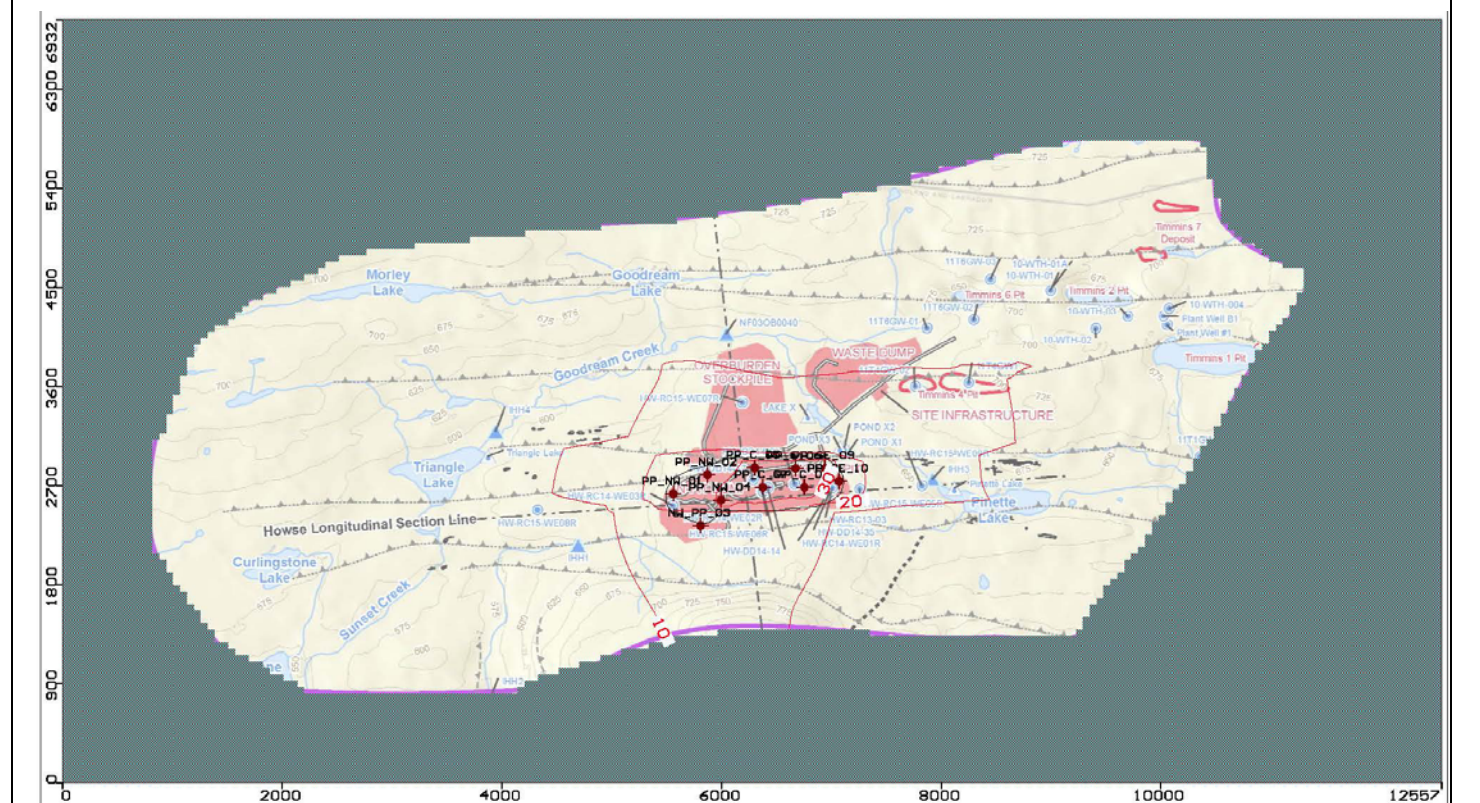
Well condition



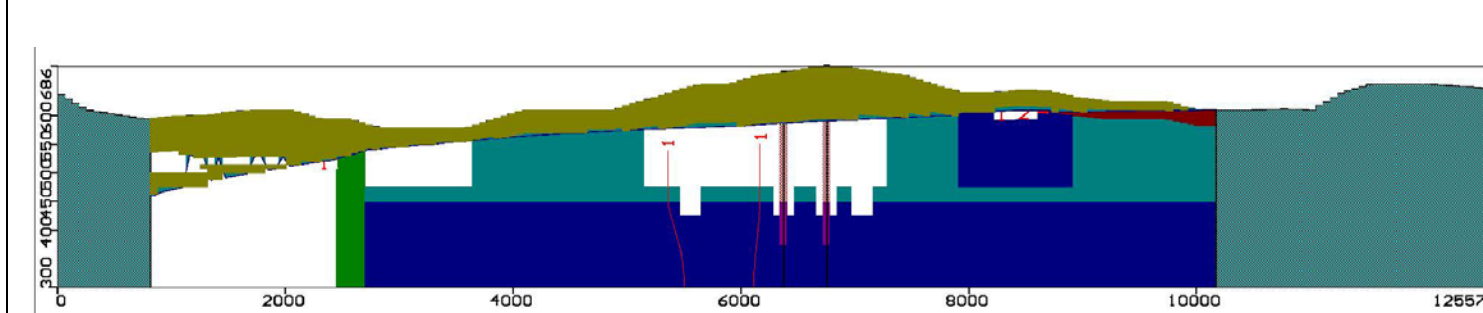
Groundwater Drawdown – End of Phase I



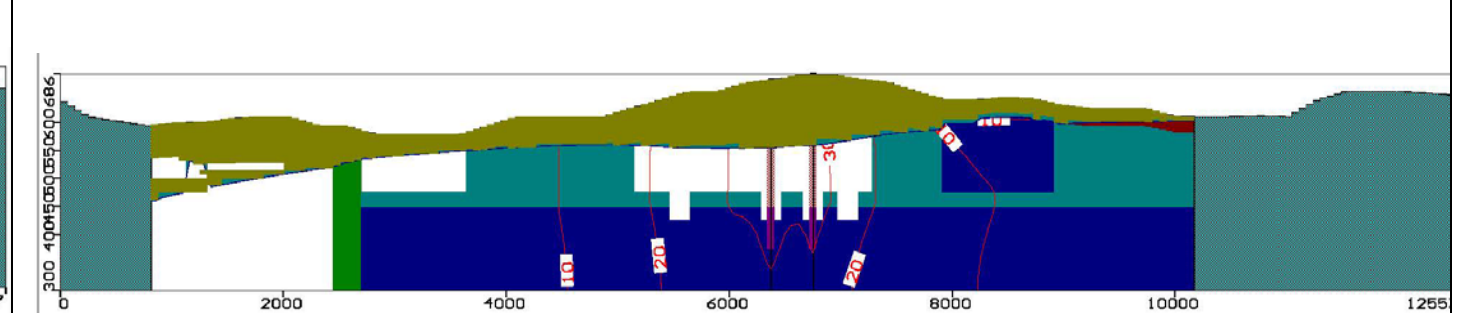
Groundwater Drawdown – End of Phase II

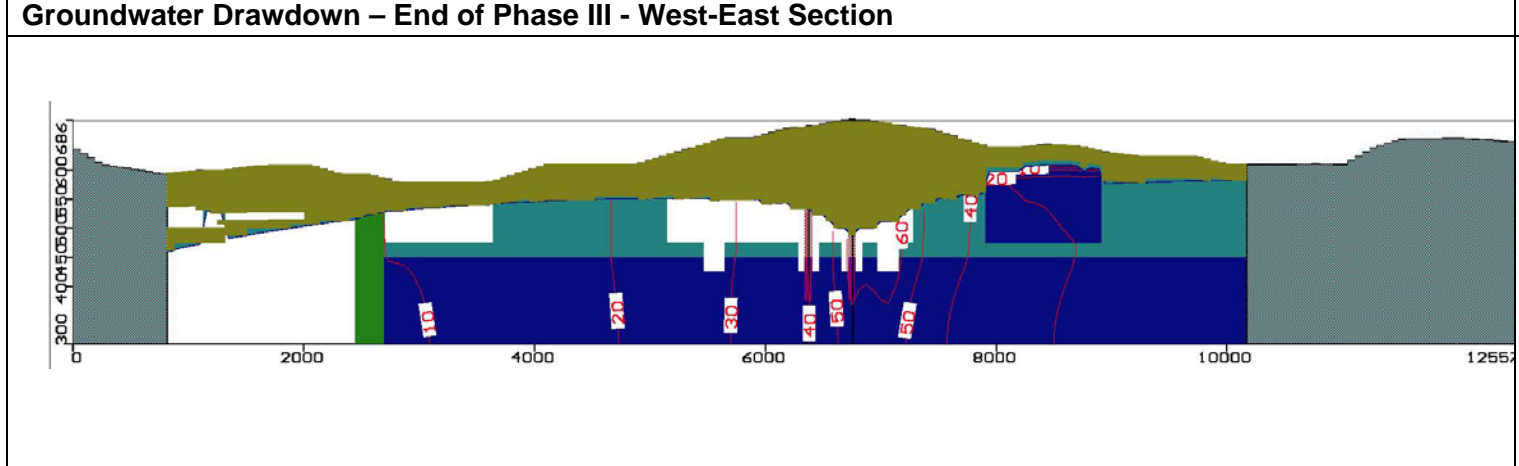
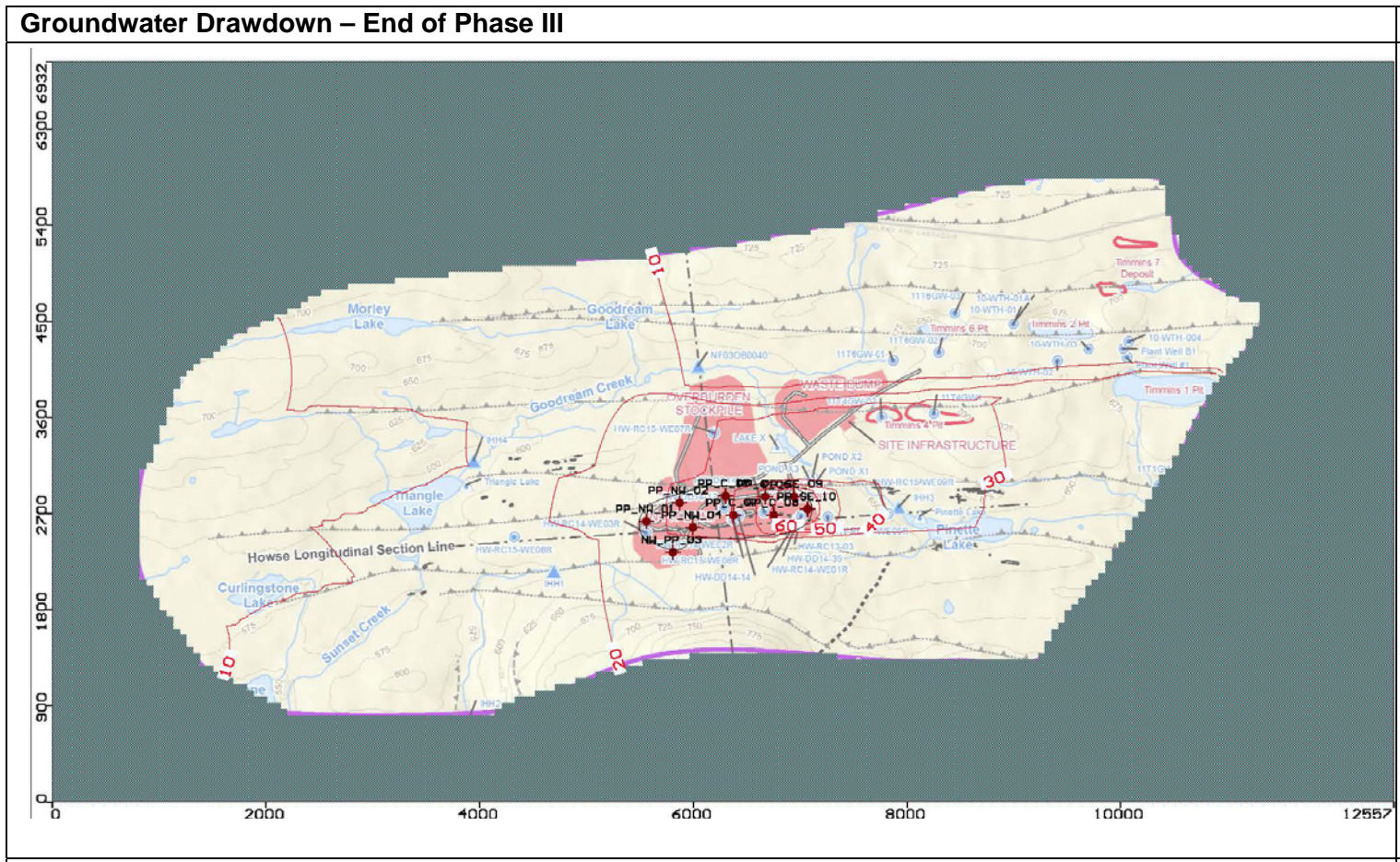


Groundwater Drawdown – End of Phase I - West-East Section



Groundwater Drawdown – End of Phase II - West-East Section







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