Troilus Mine Groundwater Model and Forecast of Mine Expansion Effects on Water Resources

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June 11, 2025
Project Number: 240433

BluMetric®

Executive Summary

BluMetric Environmental Inc. (BluMetric®) was retained by Troilus Gold Corporation ('Troilus') to conduct a study of groundwater flow at the Troilus mine site ('Mine Site') as part of the Environmental Impact Study. This study describes the methods and results for three-dimensional groundwater flow model that was developed for the analysis of baseline conditions and to predict impacts of various scenarios on groundwater and surface water interactions during various phases of the mine life at the Site.

A steady state three-dimensional groundwater model was developed and calibrated using FEFLOW to represent baseline regional groundwater flow prior to mining activities. This model characterized groundwater flow by estimating hydraulic heads and was used to conduct particle tracking analysis. Predictive modelling was done by changing the model to represent the planned infrastructure and setting seepage conditions reflect anticipated conditions during dewatering of the open pit mine, as well as post-closure. Based on the mining plan, groundwater flow conditions for three scenarios (Year 10, Year 21 and Mine closure, (WSP, 2024e)) of the mining operation were estimated.

Modeling results indicate that the drawdowns simulated in and near the pits are significant. The results also suggest that the area of influence from dewatering-induced drawdown will extend away from the pits as a result of the mining sequence plan. However, the presence of the tailings pond is expected to limit the drawdown between Pits 87 and SW. In addition, the proposed diversion of Bibou Creek will limit the drawdown towards the north-west by recharging the aquifer locally. The drawdown analysis during various phases of the mine life indicates that the effects of mining activities on the aquifer are expected to be limited in the study area, except for the pits and immediate vicinity.

The effects of mining activities on the Bibou Creek diversion channel are also dependent on the mining sequence plan. In the Year 10 scenario, limited impacts are predicted for the Bibou Creek diversion channel due to increased pit dewatering activities. However, no impacts are expected on the Bibou Creek diversion channel in Year 21 and Mine closure scenarios as a result of decreased pit dewatering activities. Similarly, dewatering to support mining activities is also predicted to have limited impacts on a minimal number of lakes. A groundwater and surface water monitoring plan has been developed to assess and effectively manage groundwater-surface water interactions within the study area.

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1 Introduction

1.1 Overview

BluMetric Environmental Inc. (BluMetric®) was retained by Troilus Gold Corporation ('Troilus') to contribute to the environmental impact study by developing and calibrating a 3-dimensional hydrogeological model and predicting scenarios of the aquifer and interaction with surface water bodies during various phases of the mine life at the Troilus mine site ('Mine Site') in Chibougamau, Quebec (Figure 1). The work was conducted in accordance with BluMetric's scope of work outlined in Proposal Number: 240433.

1.2 Scope of Work

Troilus is planning to restart mining operations at the Troilus site ('Mine Site"), operated between 1996 and 2010, situated 175 km north of Chibougamau within the James Bay territory of Eeyou Istchee, Northern Quebec. The planned restart includes the expansion of the existing J4 and 87 Pits, the development of two new pits (i.e., Pits X22 and SW), as well as the full (in the case of SW Pit) or partial backfilling with tailings and the diversion of the existing Bibou Creek. The regulatory agency requires an Environmental Impact Study for the approval of restart. This study includes the characterization of current condition of the aquifer and surface water bodies (i.e., lakes and streams) on the Mine Site, and the potential impacts to the aquifer and interaction with surface water bodies during various phases of the mine life after restart. Hydrogeological modelling studies can therefore provide the current and future hydrogeological scenarios that will enable Troilus to effectively plan for its restart.

The objectives of this hydrogeological study were as follows:

- To clarify the current hydrogeological context of the mine site in relation to the future expansion and operation of the open pits.
- Quantification of groundwater infiltration rate in the four planned pits.
- Assessment of the anticipated effect of pit dewatering on groundwater levels in the surrounding environment.
- Assessment of the potential impact of pit dewatering on the diversion of the Bibou Creek and other surface water bodies.

This report is structured as follows: Section 2 outlines the details of the study area; Section 3 presents the development and calibration of the 3-D hydrogeological model; Section 4 describes the various scenarios of the mine development; Section 5 presents the results of the predicted impacts from the various scenarios on the aquifer and surface water bodies during various phases of the mine life in the site; and Section 6 presents the overall conclusions from the modelling exercise, and provides recommendations for site management.

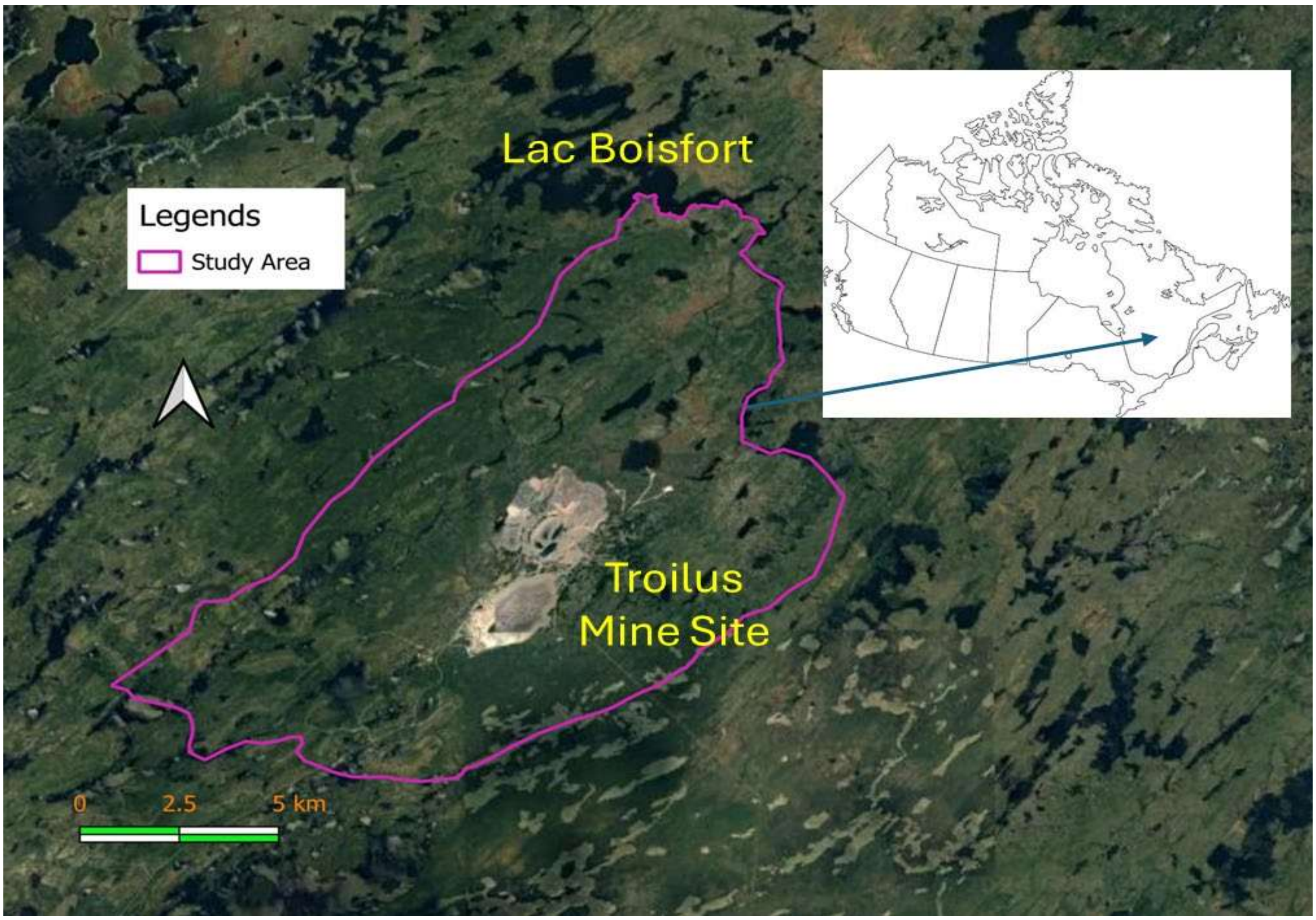

Figure 1: Location of the Study Area

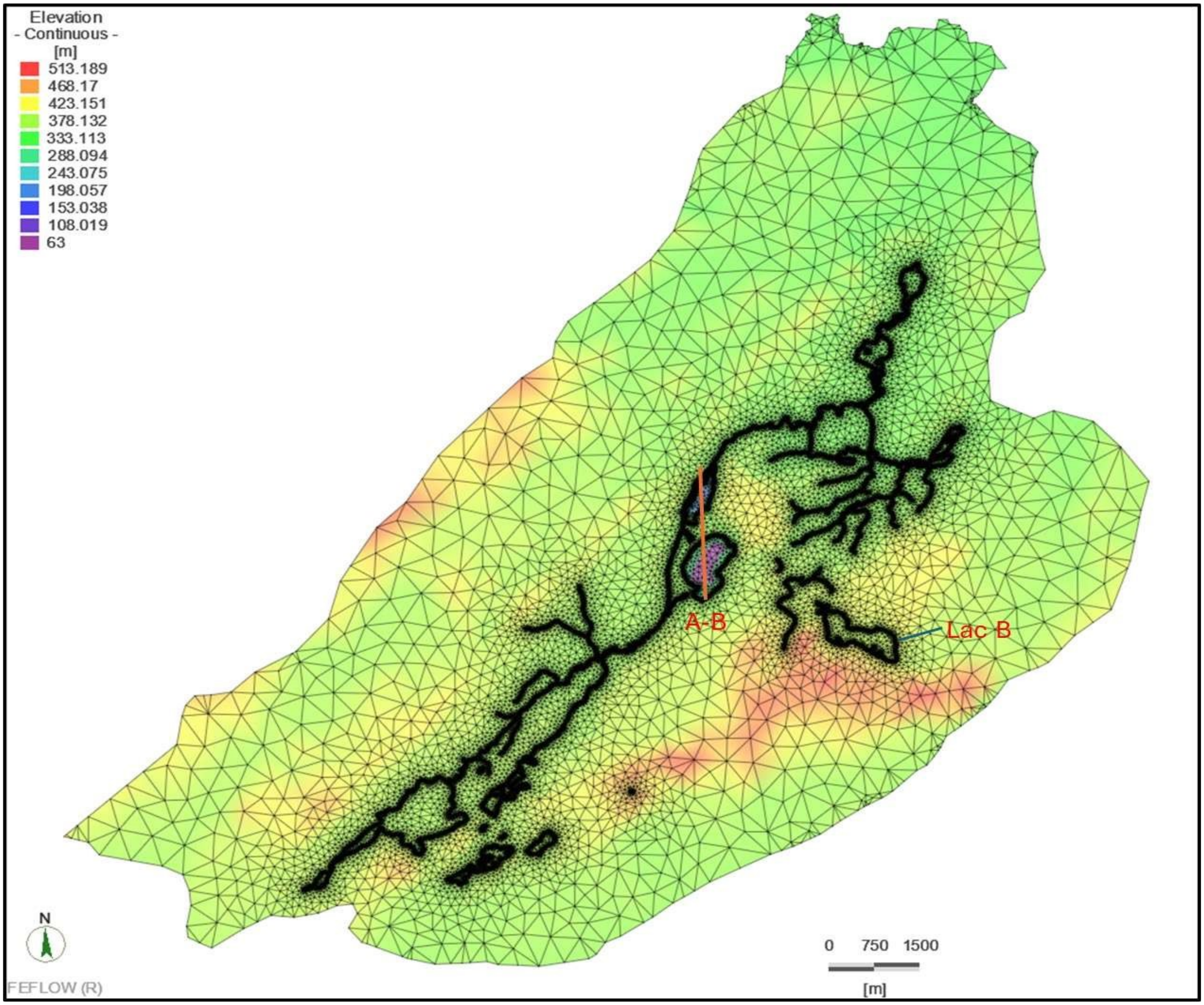

Figure 2: Current Elevation of the Study Area. The Cross-Section A-B Indicates the Pattern of Elevation Along the Pits J4 And 87 Shown in Figure 6

2 Study Area

2.1 Extents and Topography

The study area was derived from the local study area for the hydrogeology component of the Environmental and Social Impact Study. The area selected for the model is approximately 152.92 km^2. A 1-m resolution of Digital Elevation Map (DEM) was collected from Quebec's Ministry of Forests, Wildlife and Parks. Under current conditions, the ground elevations in the study area range from approximately 513 m above sea level (masl) in the topographic high region located to the south from the Lac B (PE29), to approximately 63 masl located at the bottom of Pit 87 (Figure 2). To the south of the exploited area, there are rocky hills aligned on a northeast/southwest axis with a maximum elevation of approximately 513 masl. A rocky hill aligned along a northeast/southwest axis with a maximum elevation of 430 masl is present to the north of the project development area. This elevation distribution results in a valley-like shape, with mining activities concentrated in the low-lying area of the valley, with an elevation ranging from 365 to 400 masl. The topography of the study area is undulating and irregular due to the presence of rocky outcrops intersecting the loose deposits (GEOCON, 1993). There are numerous lakes, wetlands and stream channels located in the area.

2.2 Surface Water

The study area contains numerous lakes of various sizes (ranging from 0.004 to 1.188 km^2). In this study the following lakes were considered based on location (i.e., proximity to the pits, stream channels) as potentially impacted by the future mining activities (Figure 3):

- Surface water bodies to the north-east of Pits J4 and 87:
  - Lac A (PE43) (Area 0.81 km^2);
  - Lac A1 (PE48) (Area 0.232 km^2);
  - Lac A2 (PE50) (Area 0.177 km^2);
  - Lac A3 (PE40) (Area 0.153 km^2);
  - Lac A4 (PE44) (Area 0.018 km^2).
- Surface water bodies to the east of Pits J4 and 87:
  - Lac B (PE29) (Area 0.498 km^2).
- Surface water bodies to the south of Pits J4 and 87:
  - Lac Amont (PE2) (Area 1.188 km^2);
  - Lac C (PE5) (Area 0.095 km^2);
  - Lac C1 (PE8) (Area 0.038 km^2);
  - Lac C2 (PE9) (Area 0.015 km^2);
  - Lac C3 (PE6) (Area 0.017 km^2);

- Lac C4 (PE7) (Area 0.009 km^2);
- Lac C5 (Area 0.129 km^2);
- Lac C6 (PE3) (Area 0.004 km^2);
- Lac C7 (Area 0.088 km^2).

- Surface water bodies to the north and northwest of Pits J4 and 87:
  - Lac D (Area 0.285 km^2);
  - Lac D1 (PE58) Area 0.107 km^2);
  - Lac D2 (PE60) (Area 0.515 km^2).

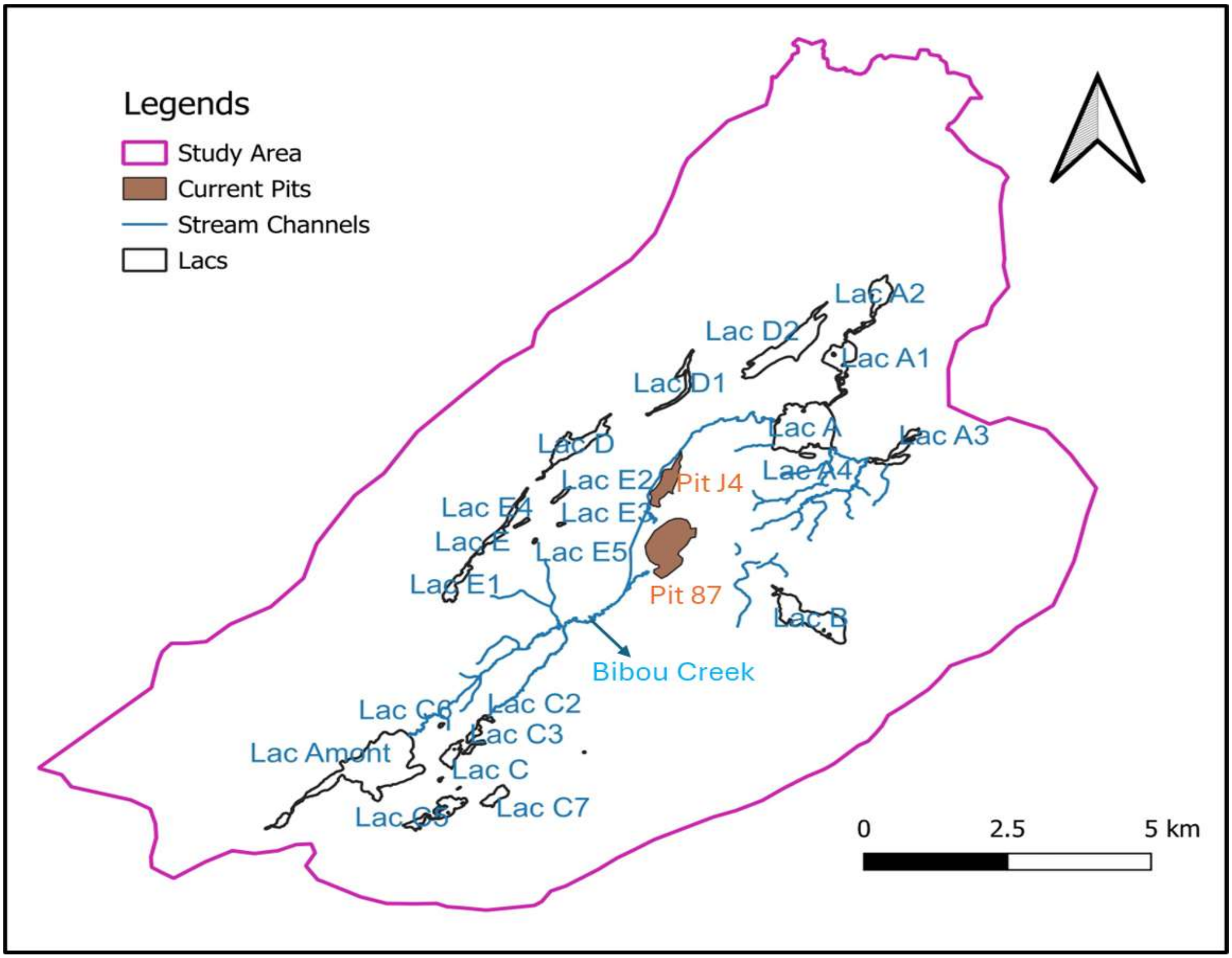

Figure 3: Surface Water Bodies and Current Pits in the Study Area

- Surface water bodies to the west of Pits J4 and 87:
  - Lac E (Area 0.109 km^2);
  - Lac E1 (Area 0.115 km^2);
  - Lac E2 (PE57) (Area 0.024 km^2);
  - Lac E3 (PE54) (Area 0.005 km^2);
  - Lac E4 (PE56) (Area 0.014 km^2);
  - Lac E5 (PE53) (Area 0.004 km^2).
- Bibou Creek (length 12.34 km);
- 28 small channels ranging from 83 m to 3911 m in length.

The surface runoff generated in the study area are discharged into the nearby lakes and streams depending on the topographical locations. The Bibou Creek receives water from the Lac Amont (PE2) and discharges water into the Lac A (PE43).

2.3 Groundwater

In 2020-2021, WSP-Golder conducted hydrogeological characterization work by performing packers tests, permeability tests, and monitoring of groundwater levels in the Mine Site (WSP-Golder, 2022a). Based on their investigation, they found groundwater levels are generally close to the ground surface and range from -0.6 m (artesian) to 16 m deep. The groundwater flow direction is controlled by topography and locally influenced by Pit 87. The lake water levels of the Pit 87 created a local drawdown of nearly 70 m compared to the surrounding piezometric level, while Pit J4 had much less local influence on the groundwater table because the lake water level in Pit J4 was relatively high and the hydraulic gradient was much lower. Groundwater level data, collected from the piezometric campaign in 2021 and 2022 by WSP, were used in this study (WSP, 2024a). These data were collected from the unconsolidated deposits and bedrock and are presented in Table 1. The locations, where groundwater levels were collected in the study area, are shown in Figure 4.

Table 1: Groundwater Data from Monitoring Wells/Boreholes used in the Model and its Calibration

Borehole/Monitoring Well	Unit	Head (m)	Year of Measurement
MW-21-01	Unconsolidated deposits	378.2	2021
MW-21-02	Bedrock	372.9	2021
MW-21-03	Unconsolidated deposits	371.9	2021
MW-21-04	Unconsolidated deposits	372.3	2021
MW-21-05	Bedrock	381.7	2021
MW-21-06	Unconsolidated deposits	396.3	2021
MW-21-07	Bedrock	432.1	2021
MW-21-10	Bedrock	381.6	2022
MW-21-11	Unconsolidated deposits	376.1	2022
MW-21-14	Unconsolidated deposits	366.1	2022
MW-21-15	Unconsolidated deposits	372.4	2022
MW-21-16	Unconsolidated deposits	379.2	2022
MW-21-18	Unconsolidated deposits	374	2022
MW-21-19	Unconsolidated deposits	375.5	2022
MW-21-23	Unconsolidated deposits	380.7	2022
GT20-J-02	Bedrock	362.4	2021
GT21-J-03	Bedrock	364.7	2021
GT21-J-04	Bedrock	362.2	2021
GT21-J-05	Bedrock	362.6	2021
TLG-ZJ419-157	Bedrock	366.2	2021
TLG-ZJ419-170	Bedrock	375.7	2021

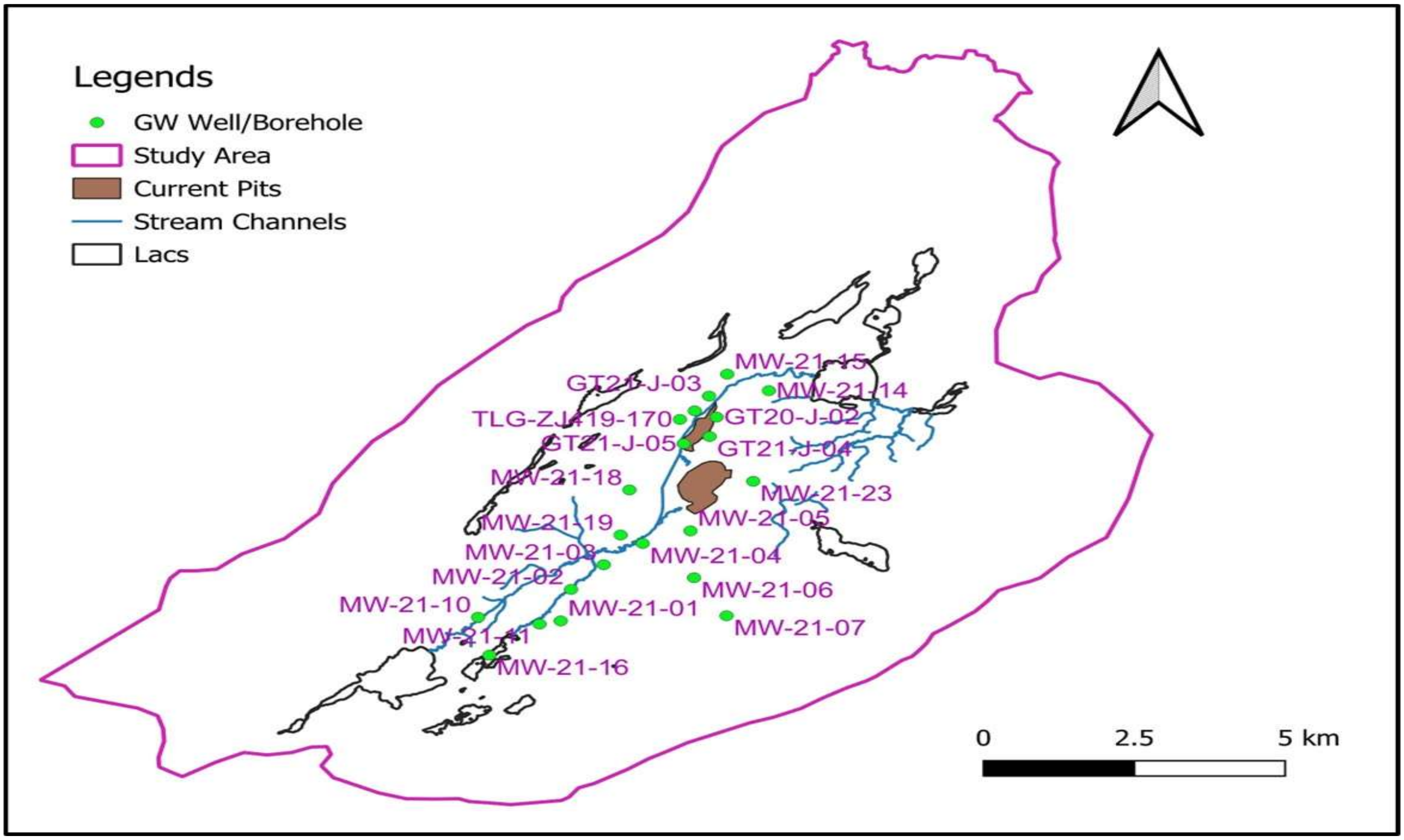

Figure 4: Groundwater Level Observations Available for 2021 and 2022

2.4 Surficial Geology

The surficial deposits in the mining site are mainly composed of juxta-glacial material of the fluvioglacial (esker – sand and gravel), glacial (till) and postglacial (peat or organic) type (Golder, 2022). The composition of various surficial deposits is shown in Figure 5. The study area is dominated by till (i.e., 65.62% of the study area). Additional information about the composition is presented in Table 2. These unconsolidated deposits cover the bedrock in most of the study area, except the outcrop area. The measured average thickness of unconsolidated deposits was 11.9 m based on 327 mining exploration; geotechnical and observation wells distributed throughout the Mine Site. Organic deposits of a few meters thick were sometimes observed (GEOCON, 1993). The anthropogenic area consists of thin surficial peat and organic silt ranging in gradation from silty sand to silt and sand, with varying amounts of gravel and traces of clay.

Based on the record of 327 surveys at the Mine Site, juxta-glacial and fluvioglacial deposit (average thickness of 5.3 m), and till (average thickness of 5.4 m) occupy the 2nd and 3rd deepest layer, respectively, over the bedrock. Due to the lack of stratification of the 2nd and 3rd layers in the whole study area, it was assumed that juxta-glacial/fluvioglacial and till deposits occupy the 2nd and 3rd deepest layer, respectively, across the whole study area except the outcrop area. The bedrock in the area primarily consists of an intermediate volcanic rock with isolated areas of granite, diorite, and mafic volcanic rock. The bedrock is encountered at depths between 0.4 and 23.0 meters below ground surface (WSP, 2024d).

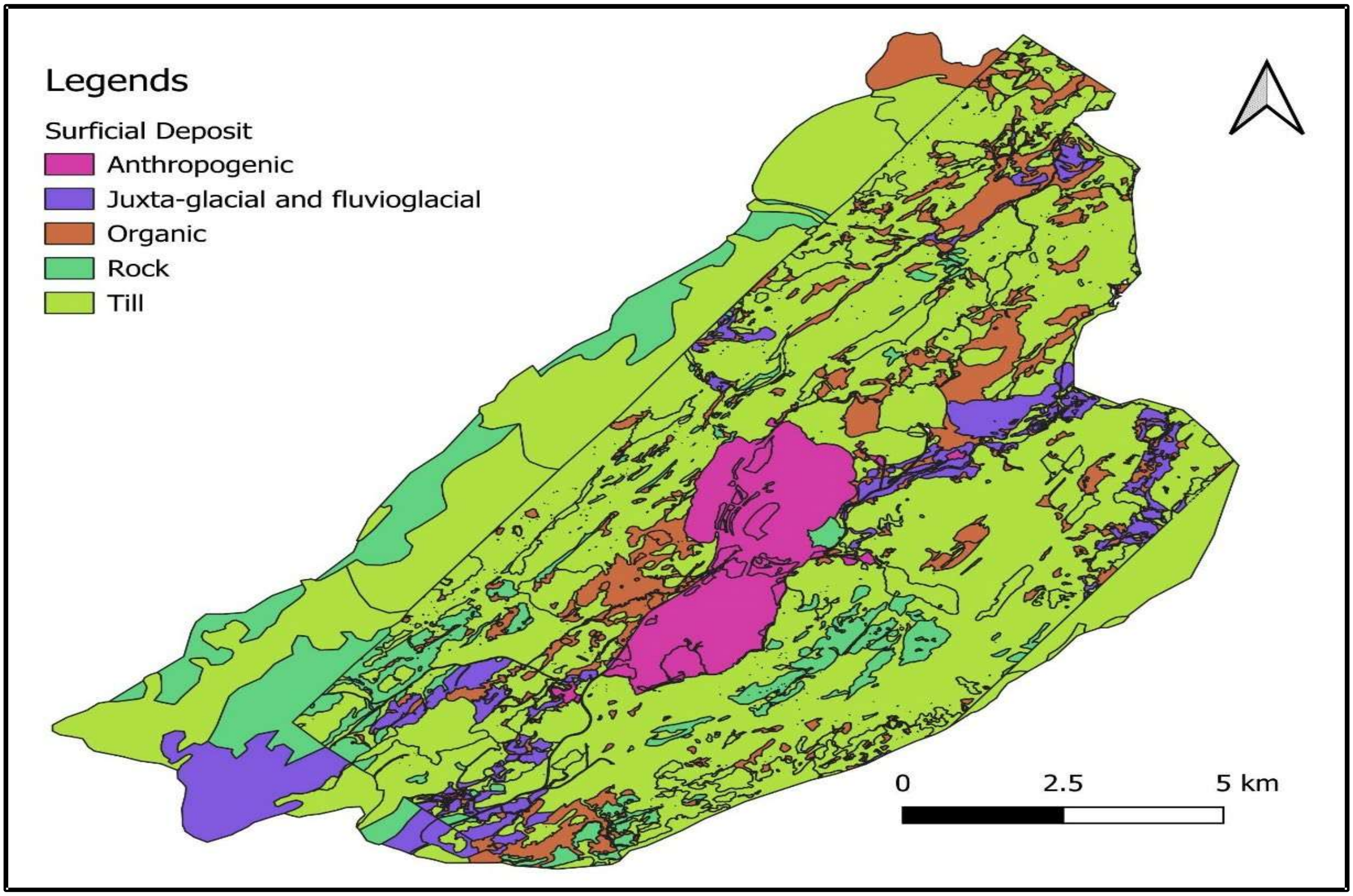

Figure 5: Surficial deposits of the Study Area

Table 2: The Composition of Surficial Deposits in the Study Area

Surficial Deposit Types	Area (km^2)	% of the Study Area
Till	100.35	65.62
Rock (Outcrop)	15.60	10.20
Organic	15.51	10.14
Juxta-glacial and fluvioglacial	10.24	6.70
Anthropogenic	11.22	7.34
Total	152.92	

2.5 Climate

Historical records of climate (i.e., precipitation and temperature) data were collected from two climate stations located approximately 140 km to the south of the study area, around the towns of Chibougamau and Chapais. Based on a 42-year period (1982–2023) of precipitation and temperature data collected from these two stations, the mean annual precipitation and temperature in the study area were 960 mm (611 mm of rain and 349 mm of snow) and -1°C, respectively (WSP, 2024b). July and September are the wettest months (130 mm and 120 mm, respectively; mean monthly precipitation) and January and February are the driest months (42 mm and 38 mm, respectively; mean monthly precipitation). Temperatures differ between 16.6 °C in July and -20.6 °C in January (mean monthly temperatures). On average, temperatures stay below zero from mid-October to mid-April.

2.6 Land Use

The study area is situated in the boreal zone (Golder, 2022). Currently, the majority of the study area is covered by forests and other plants. It is characterized by stands of black spruce and balsam fir in hillside environments. The presence of deciduous trees is essentially limited to white birch, trembling aspen and balsam poplar. Hypnaceous mosses and ericaceous shrub plants also populate the undergrowth. On the other hand, anthropogenic area (i.e., the Mine Site) covers approximately 7.34% (i.e., 11.22 km^2) of the study area. Approximately 10.54% (i.e., 16.13 km^2) of the study area is occupied by lakes, wetlands and stream channels.

2.7 Current Pits

Currently Pits J4 and 87 (Figure 3) exist in the study area. The surface area of the Pits J4 and 87 is approximately 0.213 and 0.6 km^2, respectively. The lowest bottom elevation of the Pit J4 is 200 masl, whereas for Pit 87 it is 63 masl (Figure 6). Pits J4 and 87 are not currently being mined. Pumping has been carried out from Pit J4 since Summer 2024 and the water level in the pits is regularly monitored. Based on June 2022 field-collected data, the water level in the Pits J4 and 87 was 353.57 m and 308.57 m, respectively (WSP, 2024c).

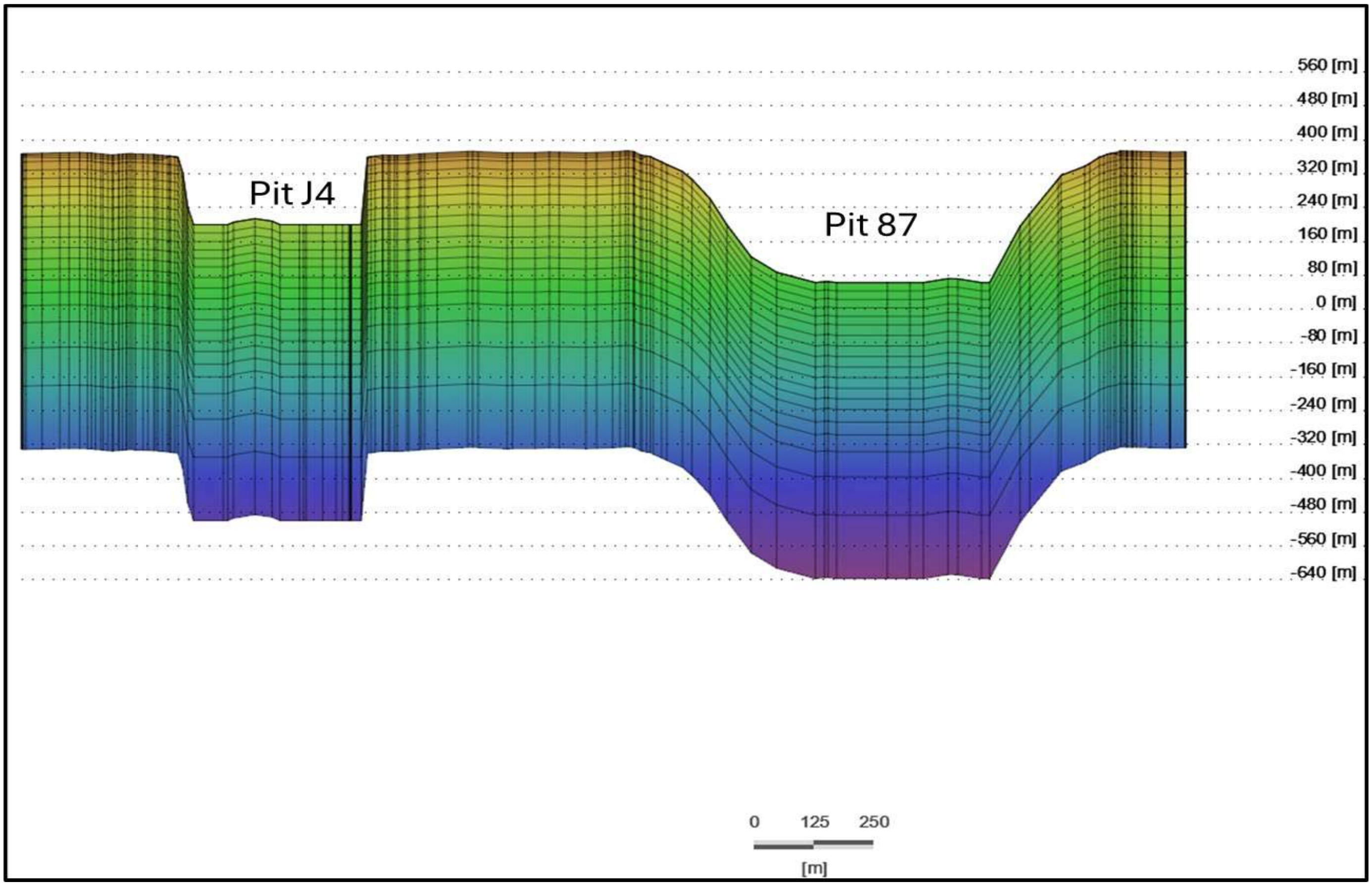

Figure 6: Cross Section (A-B in Figure 2) of the Pits J4 and 87

3 Development and Calibration of a 3-Dimensional Groundwater Model

Based on available data (watershed-specific data (ground surface elevation, overburden, soil types, and stratification), hydrological data (stream water, lake water, and groundwater levels), and climate data (recharge induced from precipitation, temperature, evaporation, and evapotranspiration), a 3-D numerical groundwater flow model was developed for the study area using the industry standard finite element code FEFLOW 8.1, which also provides the tools for particle tracking and water budget analysis. Groundwater flow of constant density through porous overburden and bedrock (equivalent porous media) is represented in the model using Darcy's equation. Steady state groundwater flow equations are solved using the Direct Solver. This solver uses a Parallel Direct Solver (PARADISO) routine for solving unsymmetric sparse systems of linear equations. A maximum error tolerance (averaged absolute error of hydraulic head) of 0.001 was prescribed as the solver convergence criteria. In this study, steady state regime was used in model simulation for all various scenarios of the mine life. This provides the worst case scenario of model simulation for generating model outputs.

3.1 Model Domain

The model domain is represented by a triangular finite element mesh of 2,392,962 elements. It extends a maximum distance of approximately 16,791 m from north to south and approximately 18,415 m from east to west (Figure 7). It is located in the Universal Traverse Mercator (UTM) Zone 18N between grid positions of 526408.41 m and 544823.20 m east, and 5644156.71 m and 5660947.97 m north.

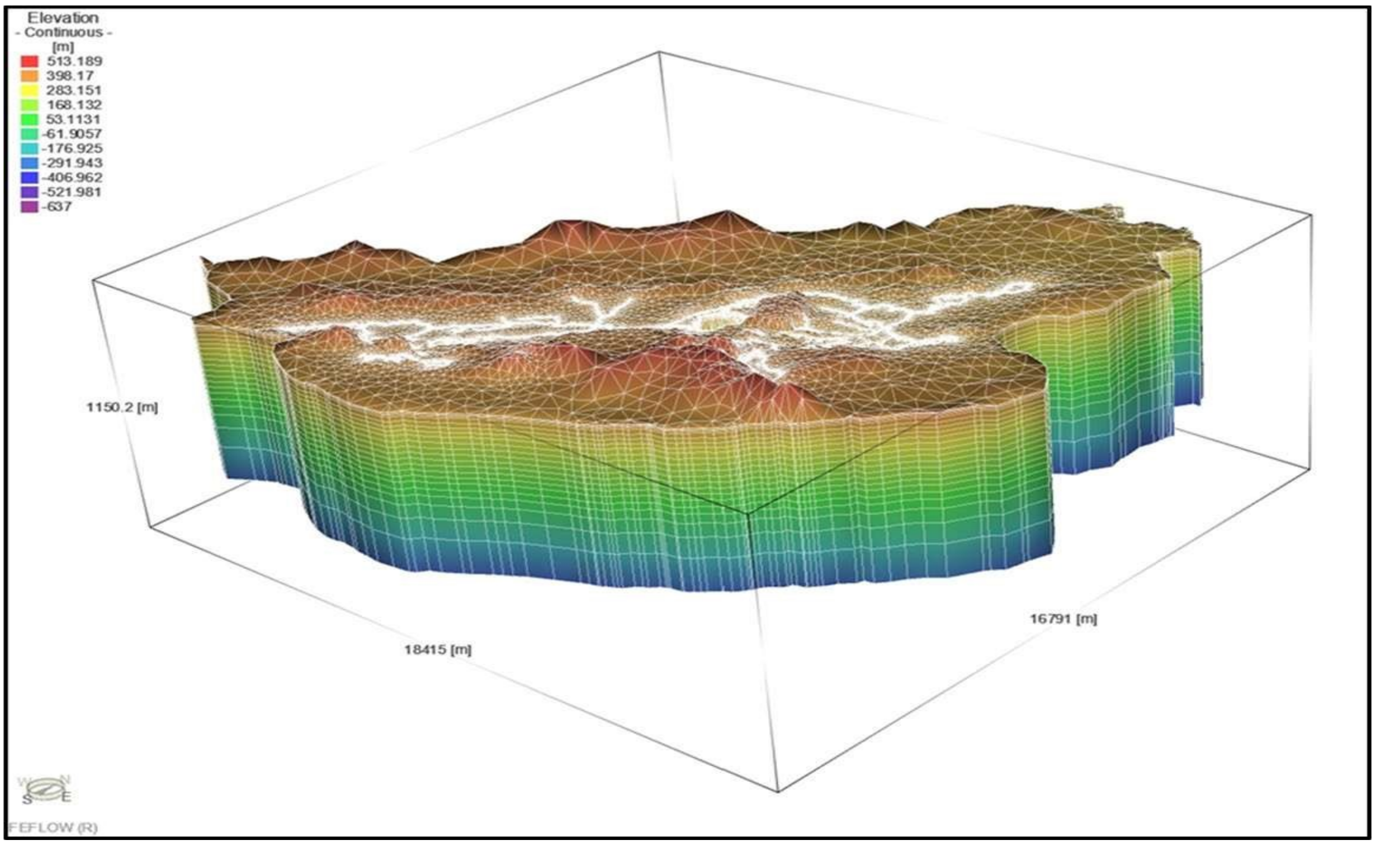

Figure 7: The 3-D Model Domain of the Study Area

The model mesh was refined throughout the area of the pits, lakes, and stream channels. In this area, the elements were refined as low as 2.5 m, while outside the area, the element size varies from 20 m to 700 m (close to the domain edge). In Figure 7, the lowest bottom elevation in layer 22 of Pit 87 is -637 masl (i.e., 637 m below sea level), which is not shown here for better visualization of the whole model domain. The total depth of the model domain is 700 m. Vertically; the model is divided into 22 layers. The first three layers vary in thickness depending on the overburden. The thickness of the layers increases with depth. The minimum thickness of 0.1 to 0.5 m was used in Layer 1, while the maximum thickness of 150 m was used in Layer 22. Figure 8 shows the layer thicknesses in the model domain.

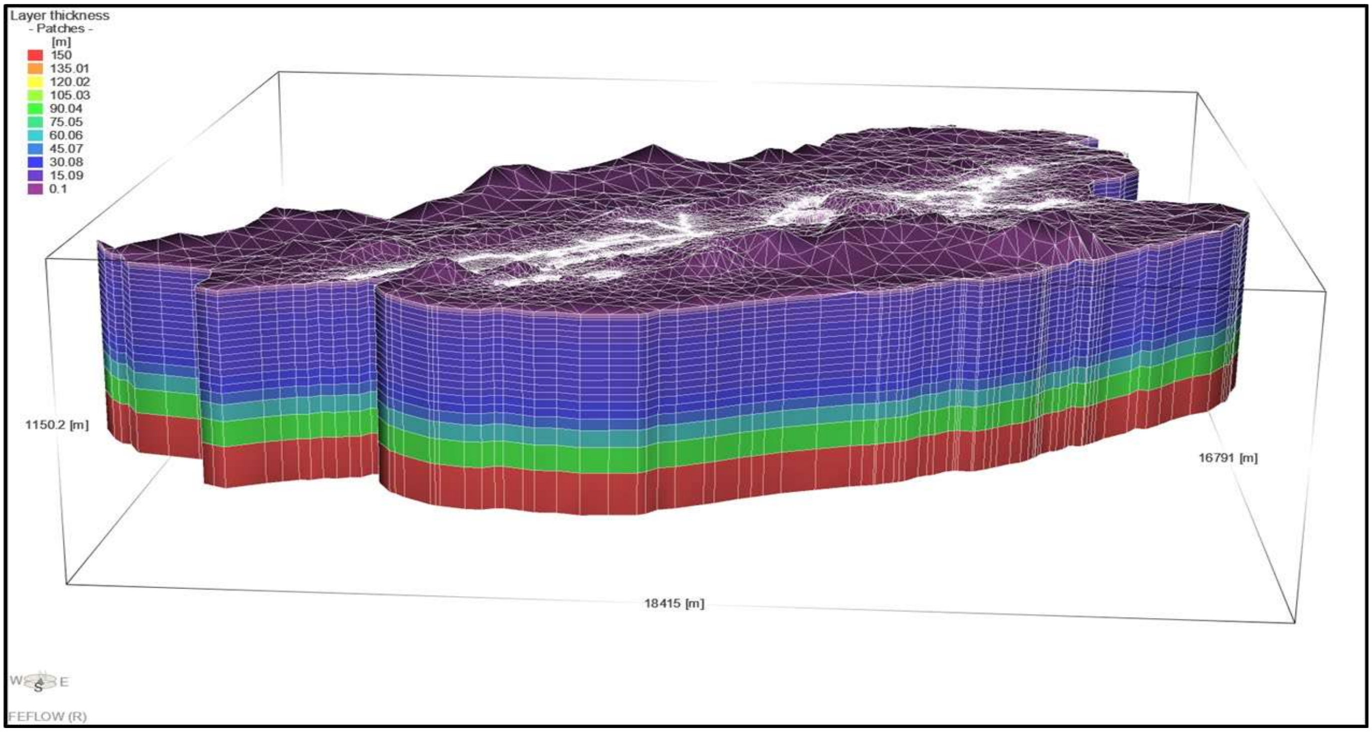

Figure 8: The Layer Thicknesses in the Model Domain with 6X Vertical Exaggeration

3.2 Material Properties

3.2.1 Recharge

Recharge was assigned to Layer 1 of the model domain as per the polygons of the unconsolidated deposits. The recharge rates (Table 3) were taken from WSP (2024c) for model development and later used during the model calibration (explained in Section 3.4). WSP (2024c) estimated recharge using surface water balance calculations. For this calculation, WSP used monthly meteorological data for the period of 1990-2022 from the DayMet database. The calculation includes estimation of snowmelt (Valery, 2010), evapotranspiration (Oudin et al., 1992) and runoff using the Runoff Curve Number method (Monfet, 1979).

In this study, recharge rate was estimated for the lakes and pit lakes (J4 and 87) as 600 mm/a. Based on 42-year period (1982–2023) of precipitation, the mean annual precipitation in the study area was set at 960 mm. Based on available mean annual (1957-1966) lake evaporation data across Canada (Hydrological Atlas of Canada, 2024), the mean annual lake evaporation in the study area was approximately 360 mm. By deducting the mean annual lake evaporation from the mean annual precipitation, mean annual recharge rate was calculated for lakes and pit lakes. Figure 9 shows the distribution of recharge rates in the model domain.

Table 3: Recharge Rates Collected from WSP (2024c) for this Study

Surficial Deposit Types	Recharge Rate (mm/a)
Till	128
Rock (Outcrop)	110
Organic	35
Juxta-glacial and fluvioglacial	219
Anthropogenic	55

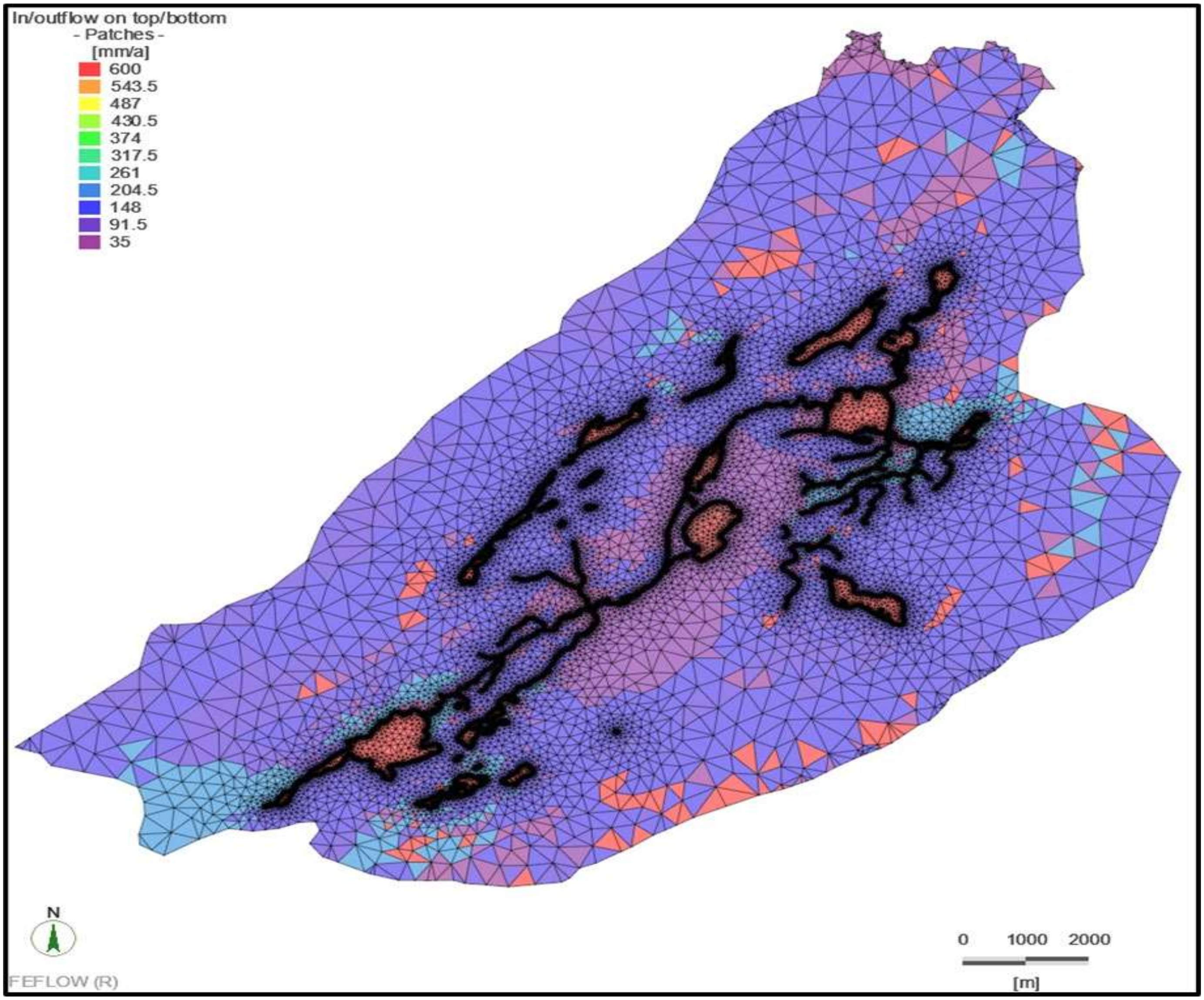

Figure 9: The Distribution of Mean Annual Recharge Rates in Layer 1 of the Model Domain

3.2.2 Hydraulic Conductivity

In this study, the initial values of hydraulic conductivities of various unconsolidated deposits and bedrock were taken from WSP (2024c) for model development. It is mentioned that unconsolidated deposits occupy the top 3 layers over the bedrock except the outcrop. Similar to WSP (2024c), the bedrock was classified based on depth, into four zones as shallow rock, intermediate rock 1, intermediate rock 2 and deep rock. The hydraulic conductivity of the bedrock was assigned as per the following Table 4.

Table 4: Rock Hydraulic Conductivity Zones used in the Numerical Model

Zone	Layer	Depth (m)
Shallow Rock	1-6	0-60
Intermediate Rock 1	7-10	60-150
Intermediate Rock 2	11-16	150-300
Deep Rock	17-22	300-700

3.3 Boundary Conditions

The following boundary conditions were defined for the model domain.

3.3.1 Constant Head Boundary Condition

The north, north-eastern, south-eastern, and south-western boundaries of the model domain are surrounded by numerous large lakes. At the edge of these lakes, a constant head boundary condition corresponding to the elevation of the lakes was set to the entire thickness of the model. These boundary conditions were used to represent regional flow. In Figure 10, the blue-coloured circles indicate constant head boundary conditions. Constant head boundary conditions were assumed along all streams in the model domain, with the constant head value equal to the land elevation at the point of assignment. In addition, constant head boundary conditions were assumed for Pit J4 lake (i.e., 353.57 m) and Pit 87 lake (308.57 m). The constant head boundary condition fixes the head value in selected nodes regardless of the system conditions surrounding them, thus acting as an infinite source of water entering the system, or as an infinite sink for water leaving the system.

3.3.2 No-Flow Boundary Condition

A no-flow boundary condition was automatically applied to remaining nodes at the edge of the model domain. In Figure 10, where there are no blue-coloured circles at the edge of the model domain, no-flow boundary conditions exist at these nodes. A no-flow boundary condition was prescribed at the base of the model to represent the basement rocks, considered to be impervious. Lateral no-flow boundaries represent inferred groundwater flow divides.

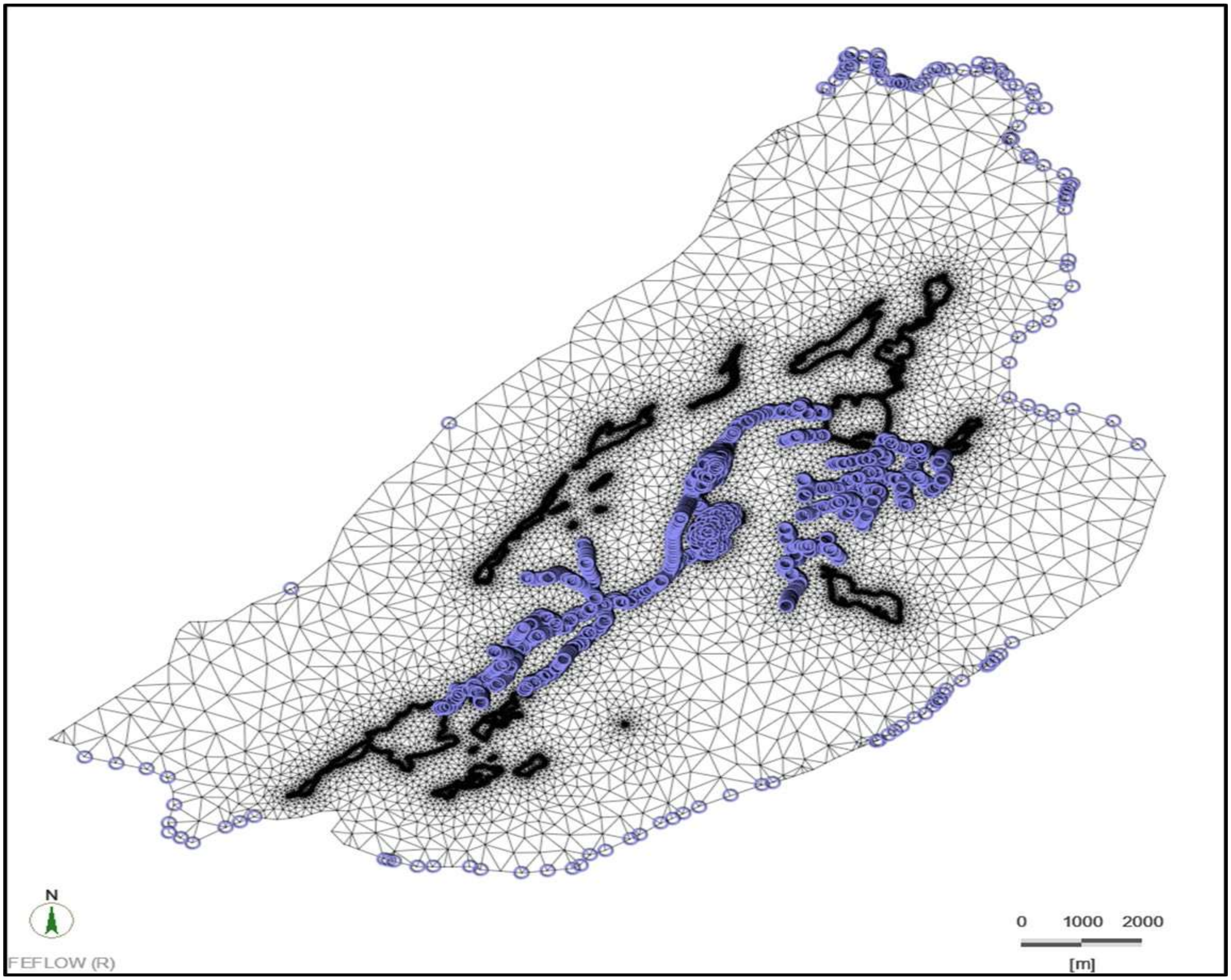

Figure 10: Constant Head Boundary Conditions in the Model Domain

3.3.3 Fluid Transfer Boundary Condition

Fluid transfer boundary conditions were assumed for the lakes located in the model domain. In this boundary condition, for each lake, a reference surface water level was defined as the boundary condition, and a transfer rate (a conductance term describing the properties of a clogging layer) was set. Transfer rate (Φ) was calculated using the following equation (1).

$\Phi = K/d$ Equation (1)

Where K is the hydraulic conductivity of the clogging layer and d is the thickness of the clogging layer.

Where possible, surface water levels for each lake were derived from field measurements. When no measurement was available, the surface water elevation of a lake was assumed to be equivalent to the value of its surface in the digital elevation model (DEM) of the area. The only available surface water level (380.9 m) was for Lac Amont (PE2). For the rest of the lakes, their reference surface water levels were assumed to be equivalent to the value of their surfaces in the 1-m DEM. The thickness of the clogging layer was considered as the thickness of unconsolidated deposits beneath the lake bottom over the bedrock. In Figure 11, the light, green-coloured circles indicate fluid transfer boundary conditions.

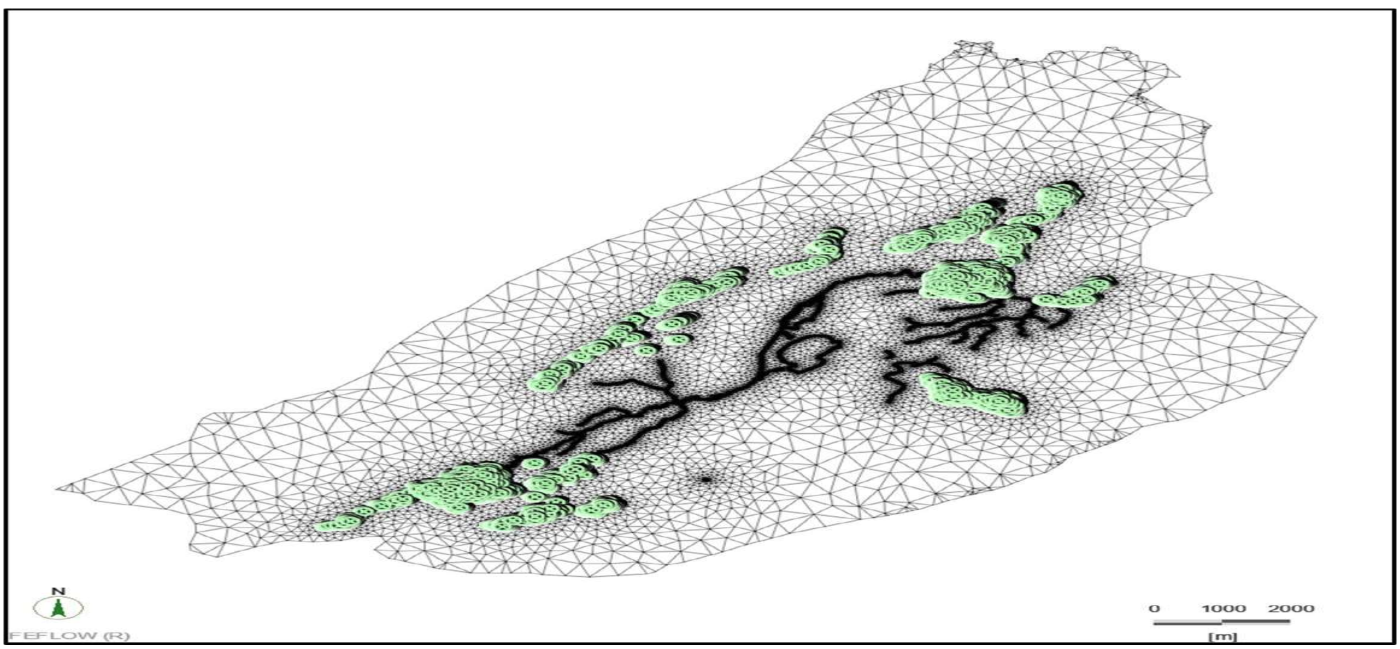

Figure 11: Fluid Transfer Boundary Conditions in the Model Domain

3.4 Model Calibration and Results

The initial groundwater head was assumed at ground surface for model calibration. The developed numerical model was calibrated using a trial-and-error process with the aim of minimising the error between measured and simulated heads. In this process, the hydraulic conductivity and recharge rate were adjusted to obtain an optimum result. In addition, sensitivity analyses of multiple modelling parameters were performed to assess the relative impact to the model output (explained in Section 3.5). Due to the limited amount of observational data, only model calibration could be completed, while model validation could not be performed. Since there were very few temporal groundwater levels at monitoring wells, transient model calibration could not be conducted resulting in only steady-state model calibration. Steady-state calibration represents average long-term hydrogeological conditions.

The model was calibrated using groundwater levels at 21 boreholes and monitoring wells (Table 1). The calibrated hydraulic conductivity of the unconsolidated deposits and bedrock in the numerical model are presented in Table 5. The vertical hydraulic conductivities (Kv) were one order lower than the horizontal hydraulic conductivities (Kh). The initial recharge rates that were used as per Table 3 produced an optimum result during model calibration. Therefore, the initial recharge rates were not changed.

Table 5: Hydraulic Conductivity of the Unconsolidated Deposits and Bedrock in the Calibrated Numerical Model

Hydraulic property zone	Kh (m/s)	Kv (m/s)
Juxta-glacial and Fluvioglacial (layer 1)	2×10^{-4}	2×10^{-5}
Juxta-glacial and Fluvioglacial (layer 2)	1×10^{-4}	1×10^{-5}
Till (layer 1)	1×10^{-4}	1×10^{-5}
Till (layer 3)	1×10^{-5}	1×10^{-6}
Organic	5×10^{-6}	5×10^{-7}
Shallow Rock (layers 1 &2)	2×10^{-5}	2×10^{-6}
Shallow Rock (layer 3)	2×10^{-6}	2×10^{-7}
Shallow Rock (layers 4-6)	5×10^{-7}	5×10^{-8}
Intermediate Rock 1	2×10^{-7}	2×10^{-8}
Intermediate Rock 2	2×10^{-8}	2×10^{-9}
Deep Rock	2×10^{-9}	2×10^{-10}
Anthropogenic Area	3×10^{-6}	3×10^{-7}

The observed and model simulated heads at 21 boreholes and monitoring wells are provided in Table 6. In this table, there are a few large discrepancies between the observed and simulated heads. This happened due to the temporal variability of measurements of head. In steady state calibration, the hydraulic head was simulated in average conditions. Therefore, climatic and recharge conditions applied to the model are not representative of the climate and recharge conditions under which all measurements were taken. Despite the local discrepancies in the groundwater flow regime, this model calibration can be qualified as adequate at the scale of interest.

The coefficient of determination (R^2), coefficient of efficiency (NSE: Nash-Sutcliffe efficiency), mean error, and root mean squared error (RMSE) were used to evaluate the goodness-of-fit of this hydrogeologic model. During calibration (Figure 12), R^2 = 0.89, NSE = 0.82, mean error = 4.0 m, and RMSE = 6.21 m were obtained. US EPA (2007) stated that a R^2 value between 0.6 and 0.7 can show fair performance for hydrogeological models. Santhi et al. (2001) and Van Liew et al. (2003) suggested values of $R^2 \geq 0.6$ and NSE ≥ 0.5 are acceptable for model evaluation. In addition, total water balance during model calibration was used as an indicator of the model performance. The total water balance error was less than 1% during calibration, which indicates adequate model performance. Based on these evaluation criteria, the developed model calibration was deemed satisfactory.

Table 6: Observed and Model Simulated Heads in Model Calibration

Borehole/Monitoring Well	Observed Head (m)	Simulated Head (m)	Error (m)
MW-21-01	378.2	377.9	0.3
MW-21-02	372.9	372.5	0.4
MW-21-03	371.9	371.6	0.3
MW-21-04	372.3	370.9	1.4
MW-21-05	381.7	375.1	6.6
MW-21-06	396.3	399.0	-2.7
MW-21-07	432.1	420.0	12.1
MW-21-10	381.6	380.6	1.0
MW-21-11	376.1	376.9	-0.8
MW-21-14	366.1	356.8	9.3
MW-21-15	372.4	363.5	8.9
MW-21-16	379.2	378.4	0.8
MW-21-18	374.0	374.9	-0.9
MW-21-19	375.5	371.6	3.9
MW-21-23	380.7	366.0	14.7
GT20-J-02	362.4	354.6	7.8
GT21-J-03	364.7	363.4	1.3
GT21-J-04	362.2	353.6	8.6
GT21-J-05	362.6	361.0	1.6
TLG-ZJ419-157	366.2	365.0	1.2
TLG-ZJ419-170	375.7	367.3	8.4

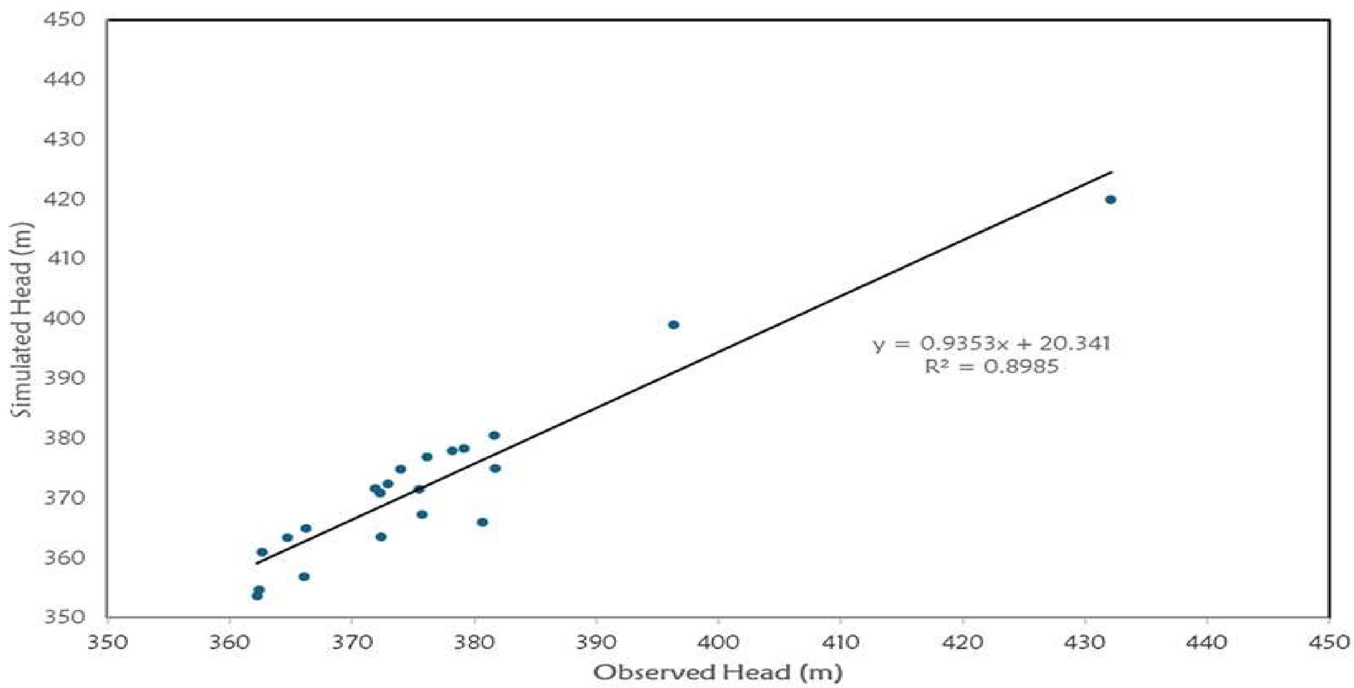

Figure 12: Observed and Simulated heads during Model Calibration

3.5 Sensitivity Analysis

A sensitivity analysis assesses how the uncertainty in the output of a mathematical model or system can be attributed to different sources of uncertainty in the inputs. In this study, sensitivity analysis was conducted using the OAT (One-Factor-At-a-Time) method (Saltelli et al., 2000). The OAT method is chosen because it is the simplest method for conducting sensitivity analysis. Using other methods (e.g., factorial design, pilot points), many runs are required to conduct a sensitivity analysis of twelve calibrated parameters in the developed FEFLOW model of 22 layers. Using the OAT method, each calibrated parameter was changed by a small amount at a time from a reference (i.e., base) value while keeping the remaining parameters constant, and then the corresponding change in the modeling output (i.e., groundwater head) was computed. Then, the relative influence on the calibration results (RMSE) was evaluated for each parameter change. Based on the change in RMSE, relative sensitivity of each parameter was determined by calculating the normalized sensitivity coefficient (NSC) or relative sensitivity coefficient. This sensitivity coefficient is dimensionless and calculated using the following equation (2) (Hamby, 1994).

$$NSC = \frac{(R_a - R_n)/R_n}{(P_a - P_n)/P_n} \qquad \text{Equation (2)}$$

Where NSC is the normalized sensitivity coefficient, R_a and P_a are the model output and parameter values after a particular model run using the changing parameter's value, respectively, and R_n and P_n are the model output and parameter nominal (reference) values, respectively. Parameters having NSC value of less than 0.01 (i.e., 1%) were not considered sensitive during this analysis.

Based on the sensitivity analysis, it was found that recharge rate of till, organic deposit, rock and anthropogenic area (which is mainly thin surficial peat and organic silt) are sensitive parameters to the model output (NSE value within 0.02 to 0.07). The model was also found to be sensitive to changes in hydraulic conductivity from layer 1 to layer 10. Hydraulic conductivity of till (NSC value of 0.17) was found to be the most sensitive parameter because this study area is a till dominated area. It was also found that the effect of sensitivity decreases with depth. In Layer 1, hydraulic conductivity of till, organic and anthropogenic area had significant effect (NSE value more than 0.03) on the model output, whereas hydraulic conductivity of juxta-glacial and fluvioglacial deposits, and rock (outcrop) had very little effect (NSC value less than 0.01).

4 Generation of Scenarios

Four scenarios were generated and simulated to fulfill the objectives of this study, including a base case scenario. These scenarios are described below.

4.1 Base Case Scenario

The base case scenario represents the scenario that was generated during model calibration under steady state condition. It reproduces the observed hydraulic heads as closely as possible for current natural and pre-mining conditions at the site. The outcome (hydraulic head distribution over the entire model domain) from steady state simulation was considered representative of the current condition and used as the baseline condition to simulate the changes in hydraulic head distribution at various phases of the mine life. Hydraulic head measurements for the year 2021 and 2022 were used to calibrate the base case scenario, as these were the only head measurements available prior to mining activities in the area.

4.2 Year 10 Scenario

In the Year 10 scenario, the topography of the model was modified to incorporate the planned pits, mining infrastructures (waste rock pile, stockpile, overburden, tailing storage facilities (TSF)) as per the Year 10 mining sequence plan (WSP, 2024e) and the diversion channel of the Bibou Creek (Figure 13). The elevation of the study area during the Year 10 scenario is shown in 14. The elevation difference from the base case scenario to the Year 10 scenario is shown in Figure 15. In this figure, the negative sign indicates the increase in elevation in the Year 10 scenario. In the Year 10 scenario, the elevation would decrease by about 441.75 m in Pit 87, whereas the elevation would increase by about 78.5 m in the waste rock pile, located just west beside the TSF. Recharge rates in the pits and waste rock pile area were considered as 110 mm/a, and 219 mm/a, respectively as per WSP (2024c). Figure 16 shows the distribution of recharge rates in the model domain under this scenario.

The existing pits (i.e., J4 and 87) will increase laterally and vertically. The surface area of the pits J4 and 87 will increase approximately from 0.213 to 1.29 km^2 and from 0.6 to 1.71 km^2, respectively. One new pit, SW, will be excavated in this period. The surface area of Pit SW will be approximately 0.68 km^2. The excavation of Pit SW will result in a few small lakes and stream channels around the pit destroyed or filled up. All three pits will be operating during this year. The cross section of the Pits being J4, 87 and SW, and waste rock piles is shown in Figure 17. Seepage boundaries were applied to all nodes within the pits to keep them constantly dry.

A constant head boundary condition with a value of 432.6 m, located in the centre of the TSF, was used to simulate the presence of a body of water in the tailing pond. In addition, the Bibou Creek will be diverted at 0.8 km chainage of the current Bibou Creek location for the expansion of the pits (Figure 18). The main diversion channel will be approximately 9.7 km long. The updated Bibou Creek will be approximately 10.5 km long, including the main diversion channel. Compared to the existing Bibou Creek, it will be shorter by approximately 1.84 km. The diversion channel will be placed between approximately 500 m and 880 m west from the existing Bibou Creek in the area of Pits J4 and 87. It will be placed in mostly till dominated unaltered area (recharge rate of 128 mm/a), whereas the existing Bibou Creek is surrounded by the mostly anthropogenic area (which is mainly thin surficial peat and organic silt) in the area of Pits J4 and 87 of the base case scenario.

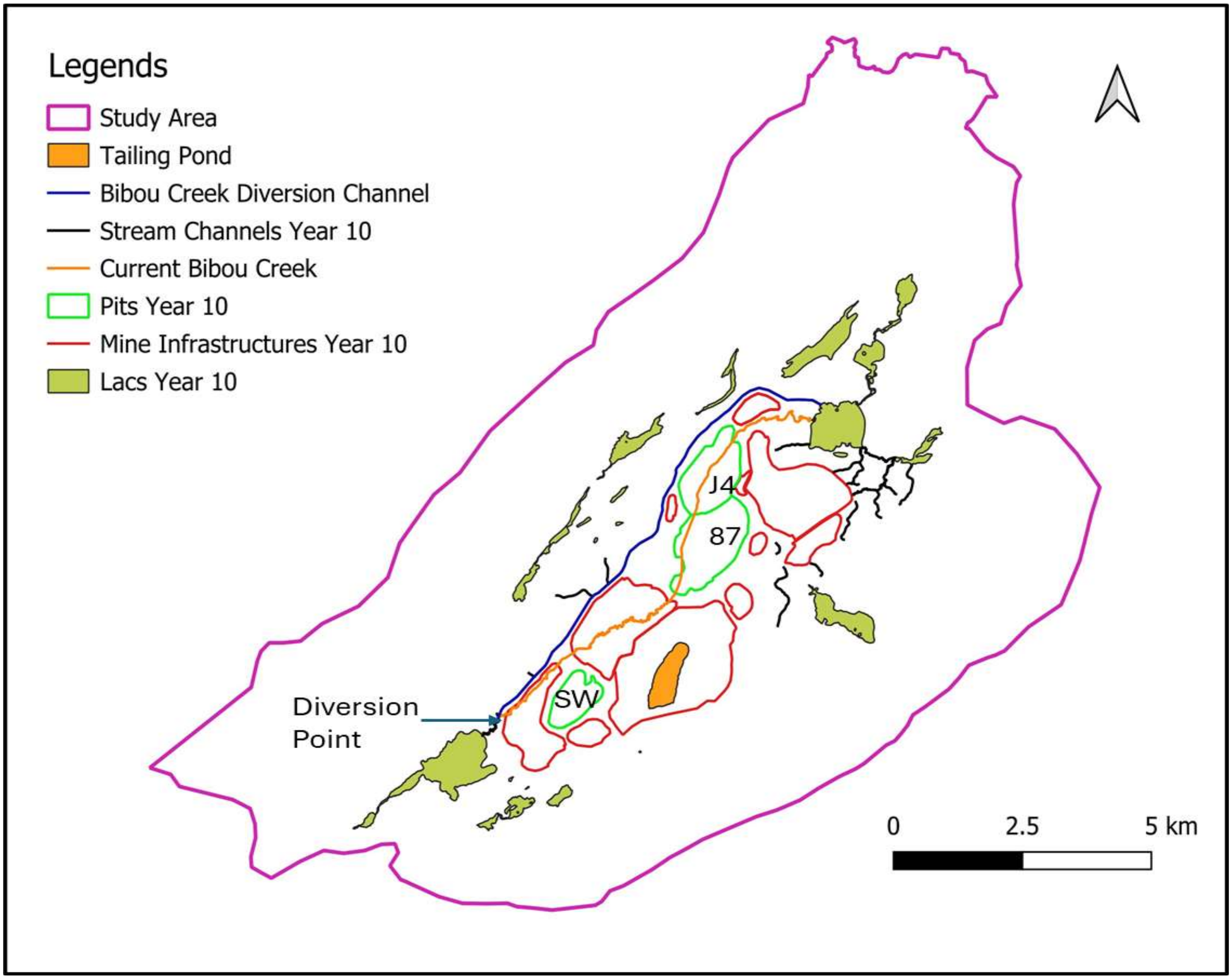

Figure 13: Pits, Mine Infrastructure, Bibou Creek Diversion Channel, and Tailing Pond in the Year 10 Scenario

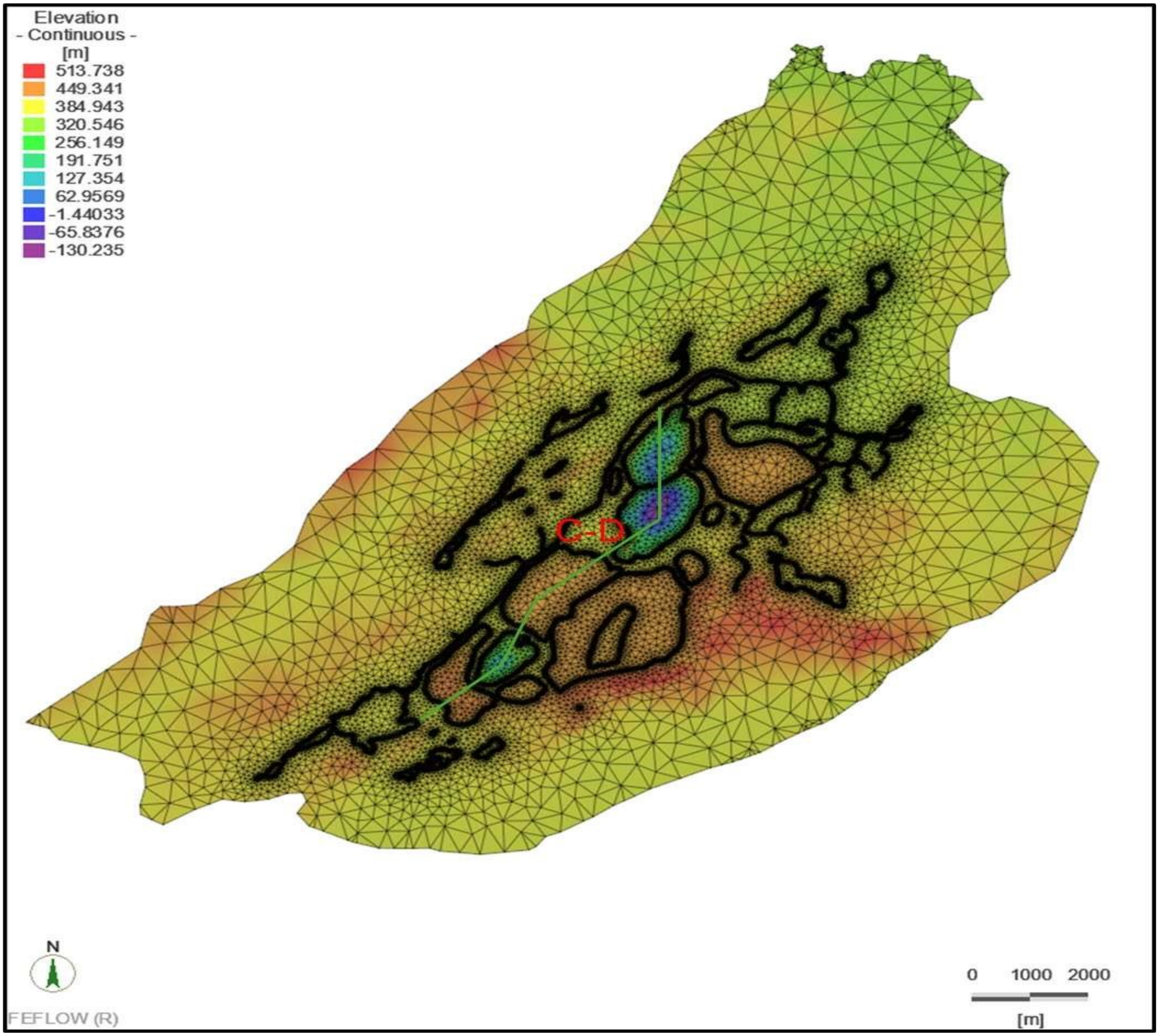

Figure 14: Elevation of the Study Area in the Year 10 Scenario

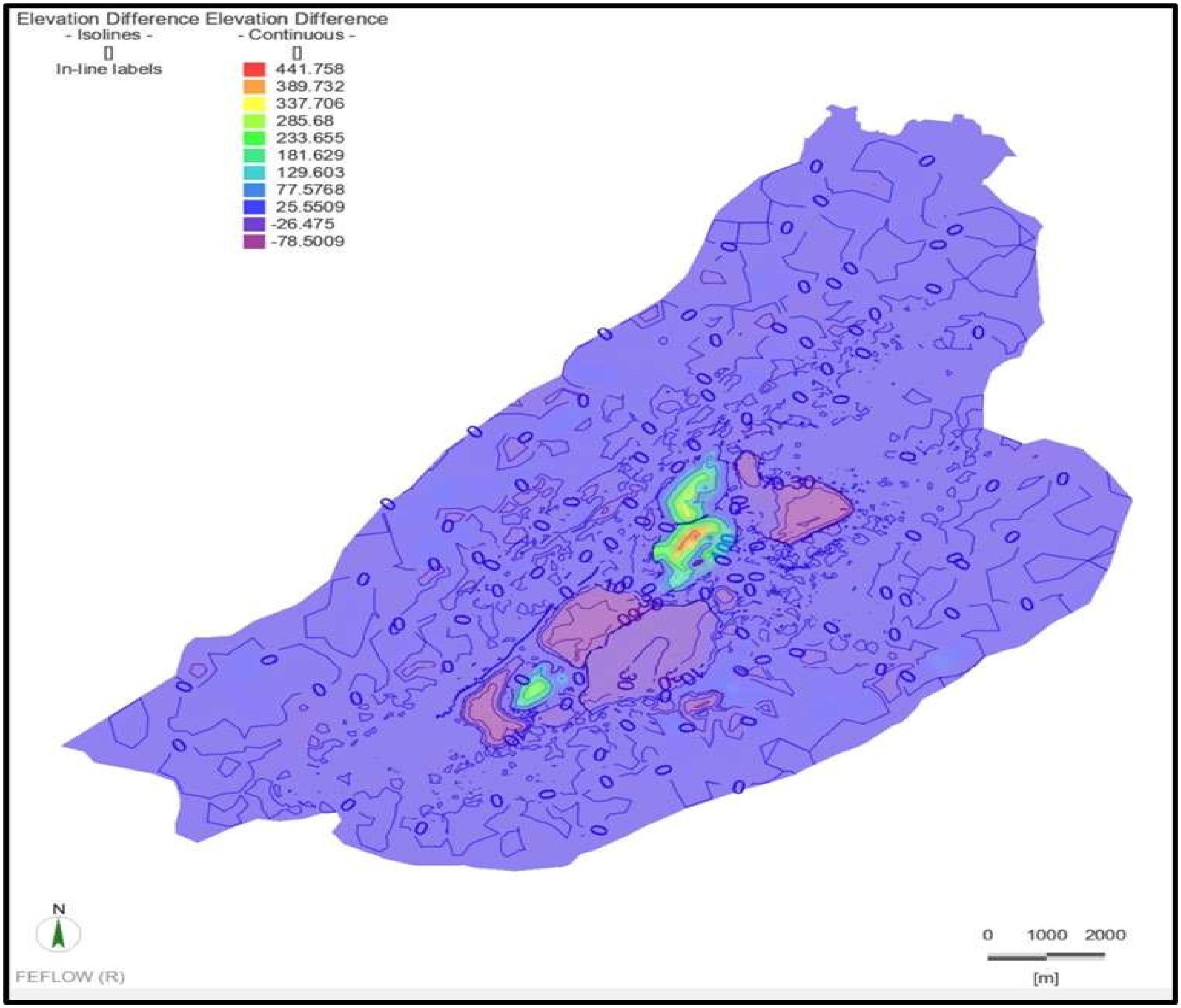

Figure 15: Elevation Difference from the Base Case Scenario to the Year 10 Scenario. Here Negative Sign Indicates Increase in Elevation in the Year 10 Scenario Compared to Base Case

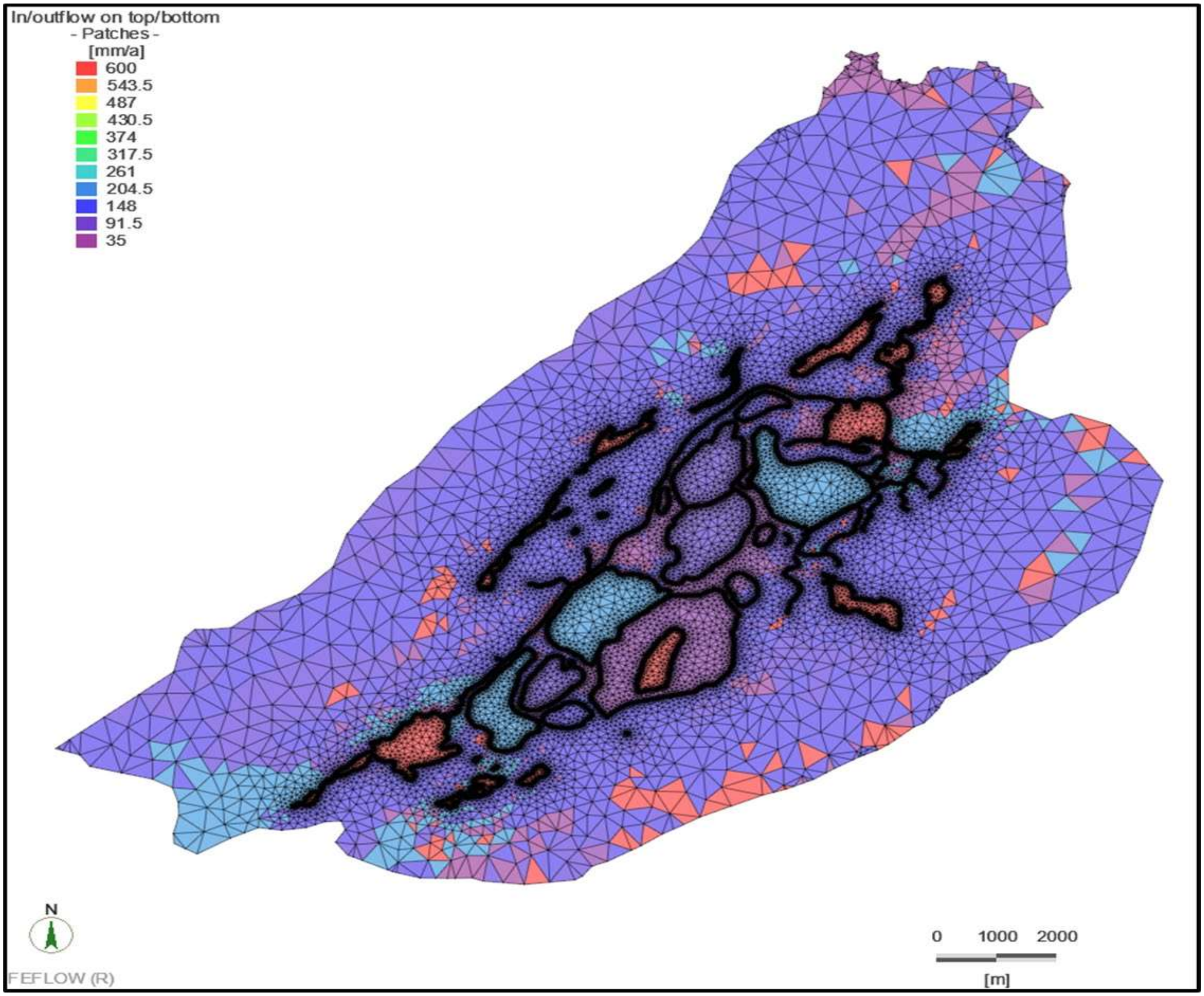

Figure 16: The Distribution of Mean Annual Recharge Rates in the Layer 1 of the Model Domain in the Year 10 Scenario

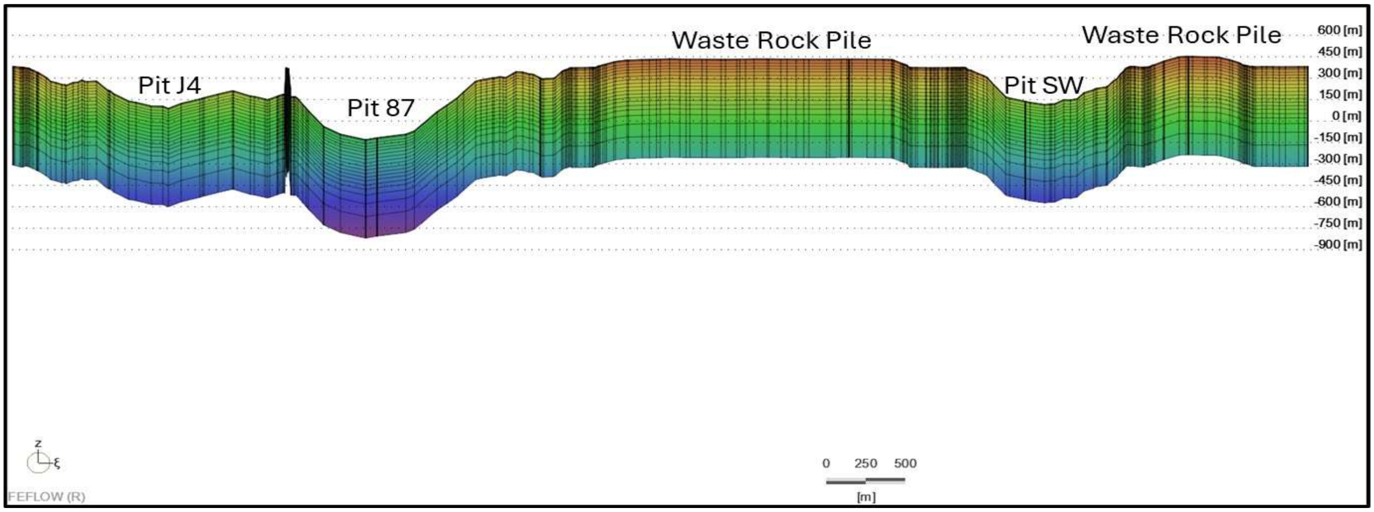

Figure 17: Cross Section (C-D In Figure 14) of the Pits J4, 87 And SW, and Waste Rock Piles under the Year 10 Scenario

The bed of the diversion channel was assigned in the model as per the design profile (Figure 18) prepared by WSP (2024e). The bed of the diversion channel will be set up approximately 2 to 17 m below the existing ground surface. In the model, the bed elevation was adjusted accordingly. The deeper depth of the bed will be set up beside the Pit J4. For the fish passage, a water depth of 0.14 to 0.19 m was designed along the diversion channel for 7Q10 low flow event (WSP, 2024e). 7Q10 indicates the annual minimum 7-day average flow rate with a 10-year occurrence interval. 7Q10 low flow depths were considered in this scenario to estimate the worst case impact on the Bibou Creek diversion channel due to mining activities. These low flow water depths were added with bed elevation, and the total elevation was considered as the constant head boundary condition along the channel. The model was run under steady state condition. The model domain is shown in Figure 19.

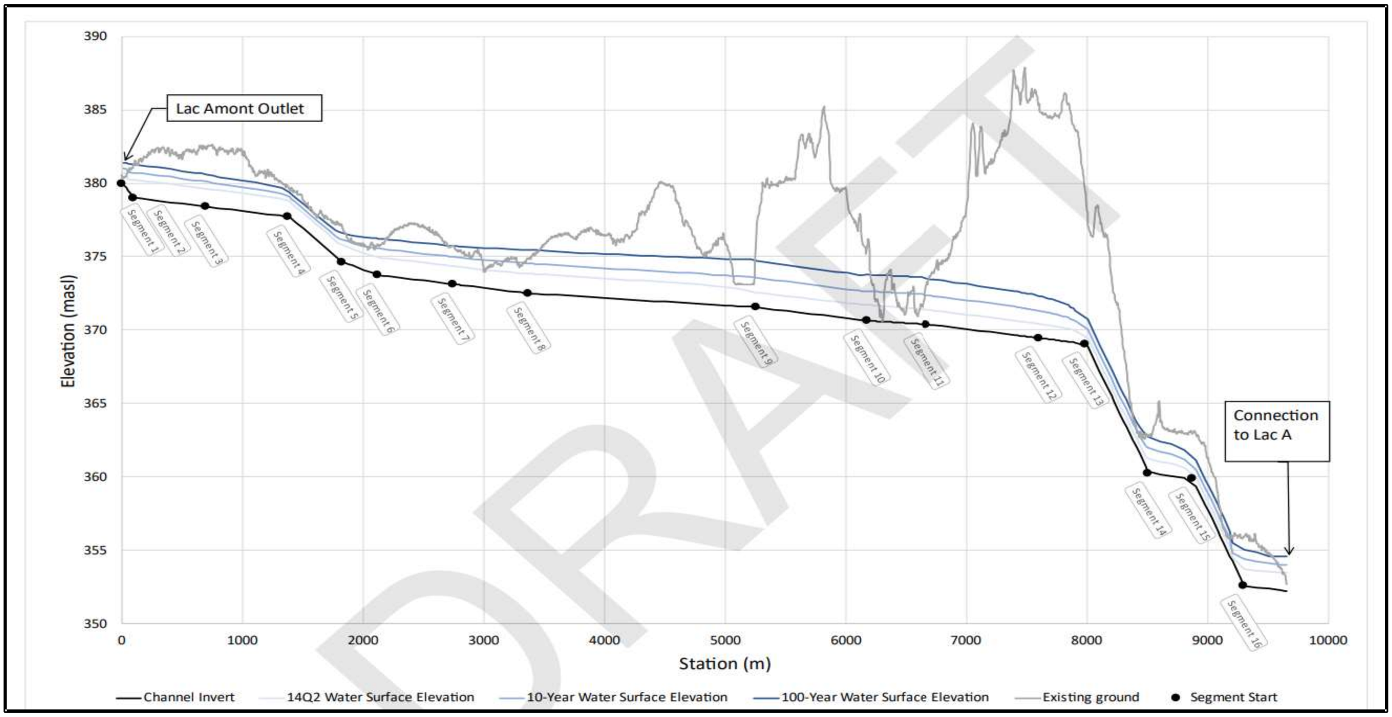

Figure 18: Bibou Creek Diversion Channel Profile (Taken From WSP, 2024e)

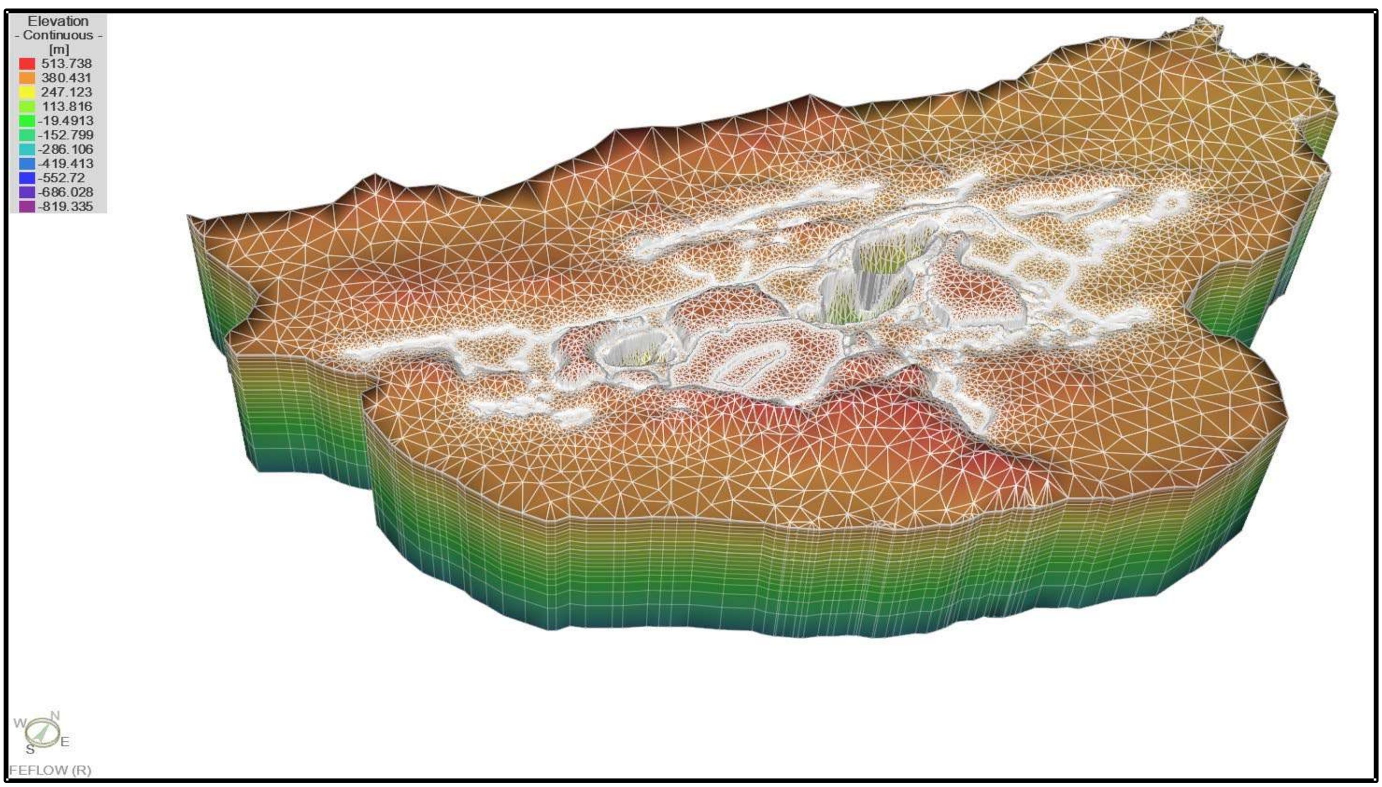

Figure 19: The Model Domain of the Study Area In The Year 10 Scenario

4.3 Year 21 Scenario

Similar to the Year 10 scenario, in the Year 21 scenario, the topography of the model was modified to incorporate the planned pits and mining infrastructures as per the Year 21 mining sequence plan (WSP, 2024e) (Figure 20). The elevation of the study area in the Year 21 scenario is shown in Figure 21. Compared to the base case scenario, in the Year 21 scenario, the elevation decreases by about 278.3 m in Pit 87, whereas the elevation increases by about 124 m in the waste rock pile, located just west beside the TSF (Figure 22).

The difference between the Year 10 and Year 21 scenarios is that, in the Year 21 scenario, Pit SW will be completely filled by mine tailing collected from the TSF and then waste rock will be placed over mine tailing. The Pit J4 will be filled up to elevation of 169 masl by mine tailing, whereas the Pit 87 will be filled up to elevation of 98 masl. The surface area of the Pit 87 will slightly increase approximately from 1.71 to 1.80 km^2. One new pit, X22, will be excavated. The surface area of Pit X22 will be approximately 0.59 km^2. Pit X22 will be operating during this scenario.

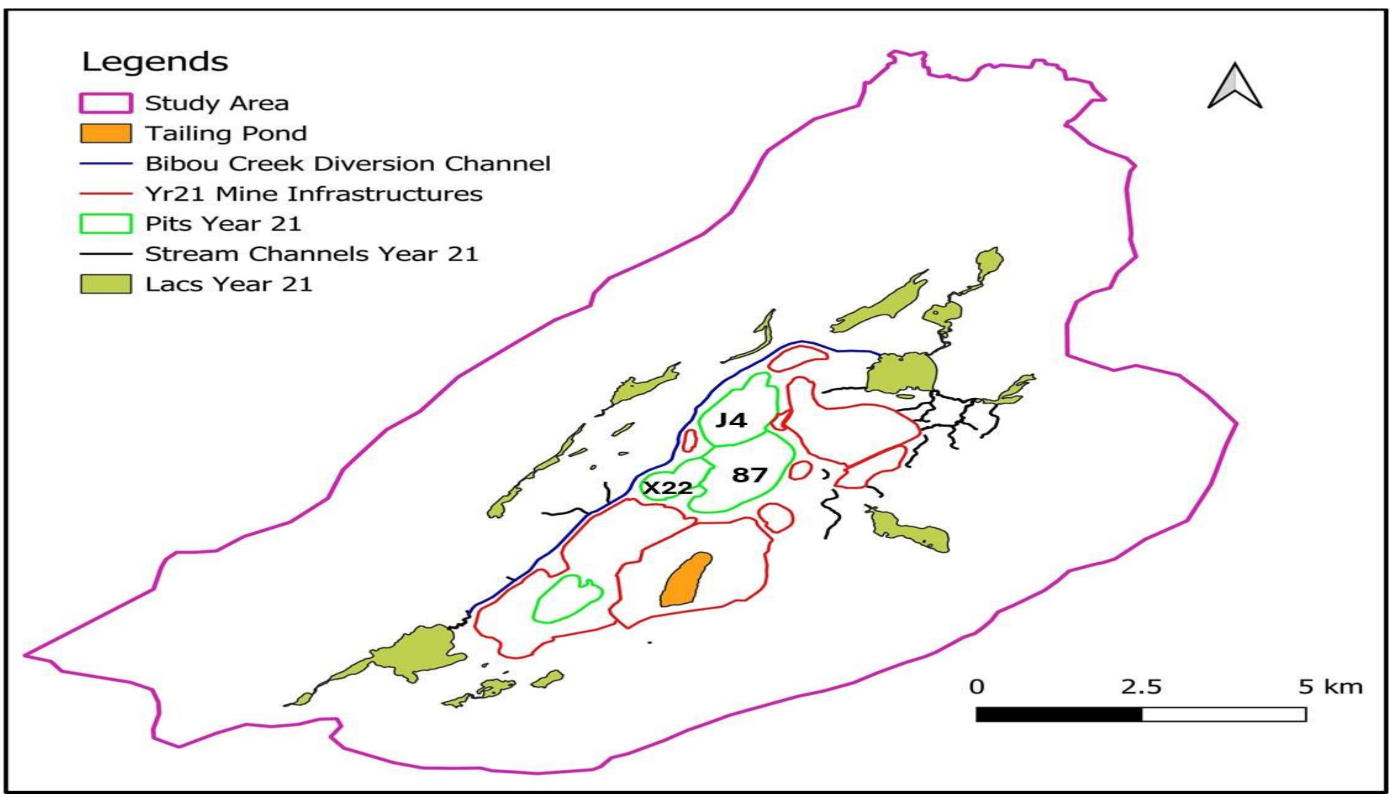

Figure 20: Pits, Mine Infrastructure, Bibou Creek Diversion Channel, and Tailing Pond in the Year 21 Scenario

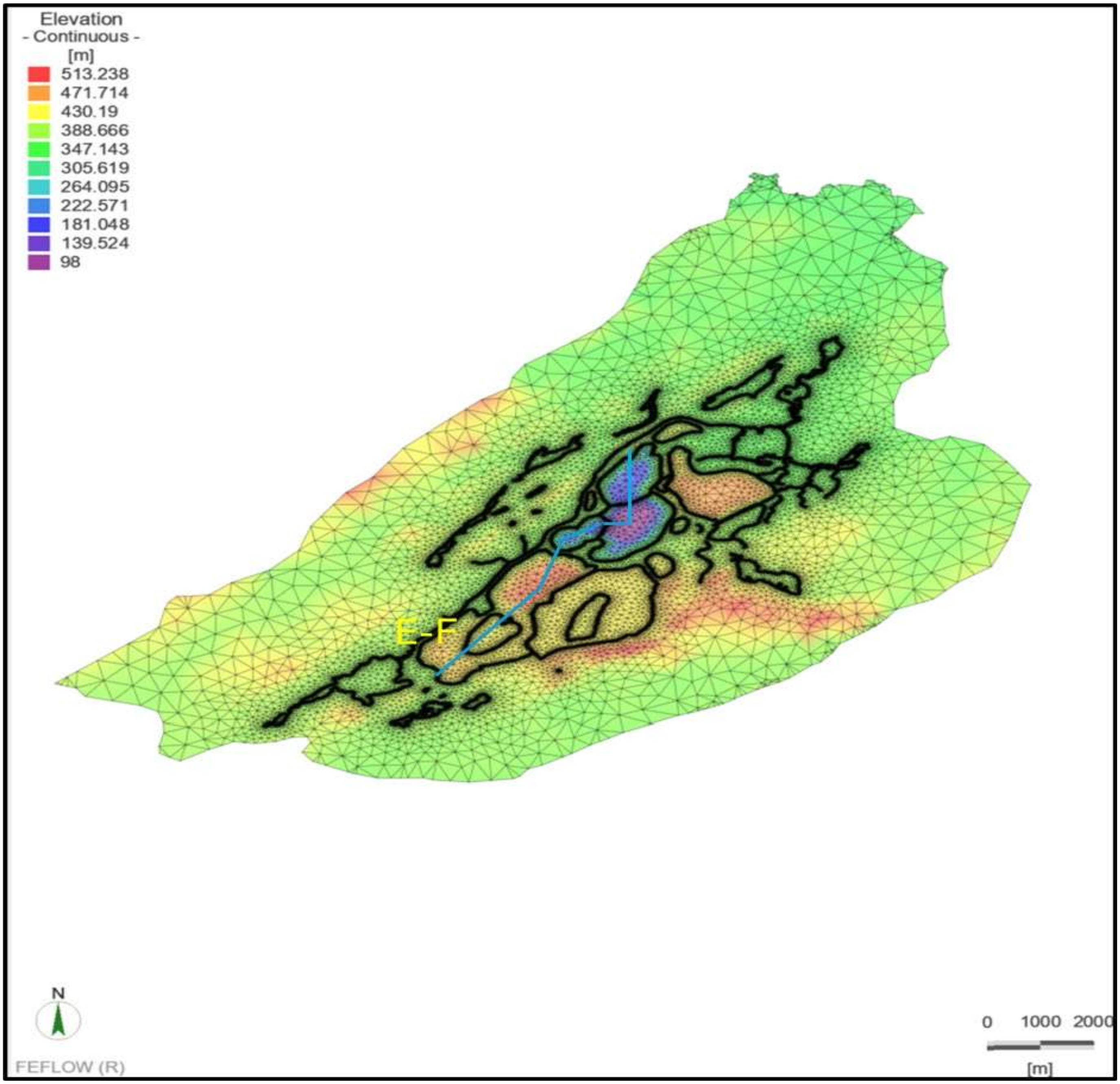

Figure 21: Elevation of the Study Area lin the Year 21 Scenario

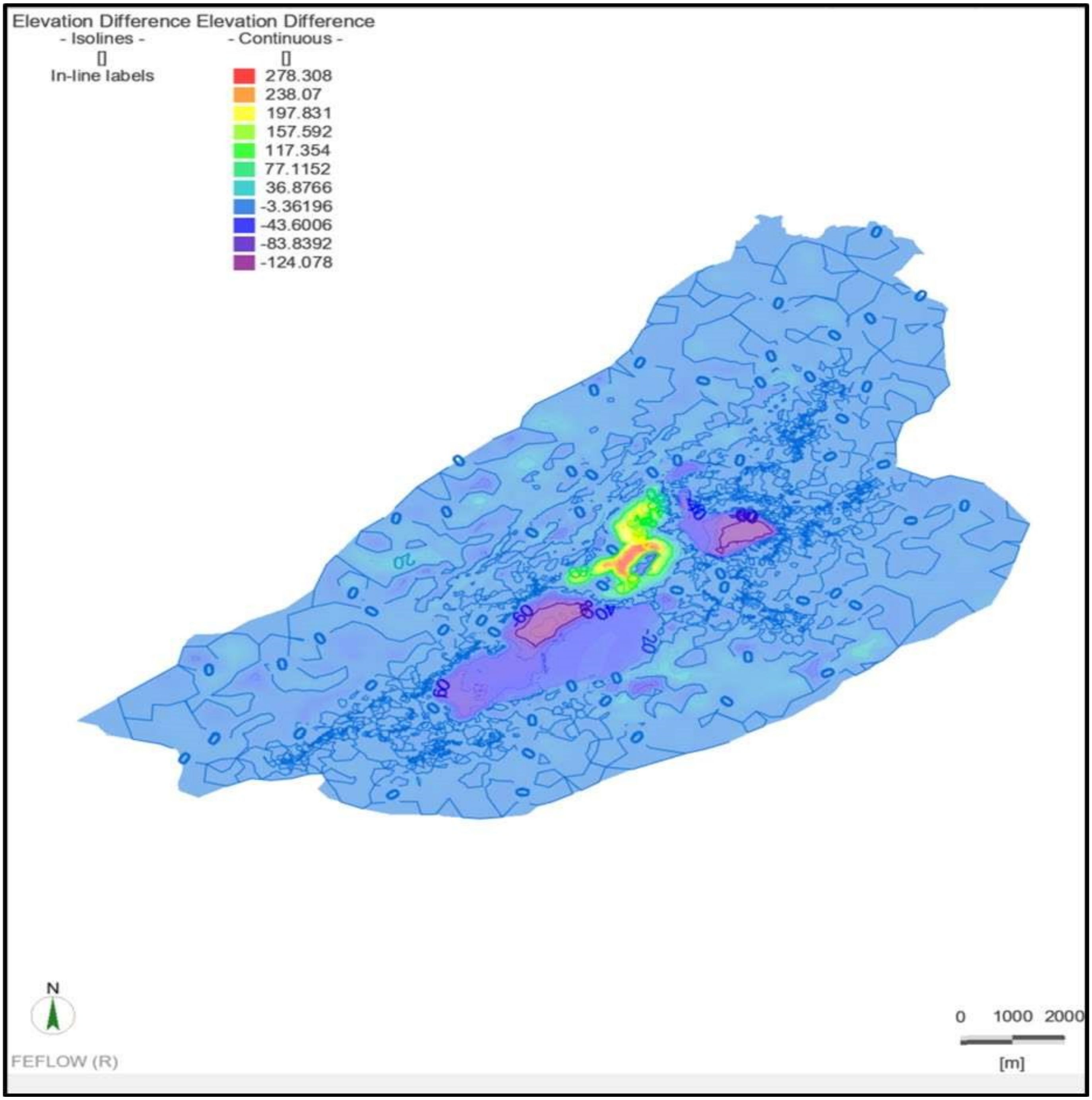

Figure 22: Elevation Difference from the Base Case Scenario to the Year 21 Scenario. Here Negative Sign indicates increase in Elevation in the Year 21 Scenario

The cross section of the Pits J4, 87 and X22 is shown in Figures 23. Seepage boundaries were applied to all nodes within the pits to keep them dry. The model was run under steady state condition.

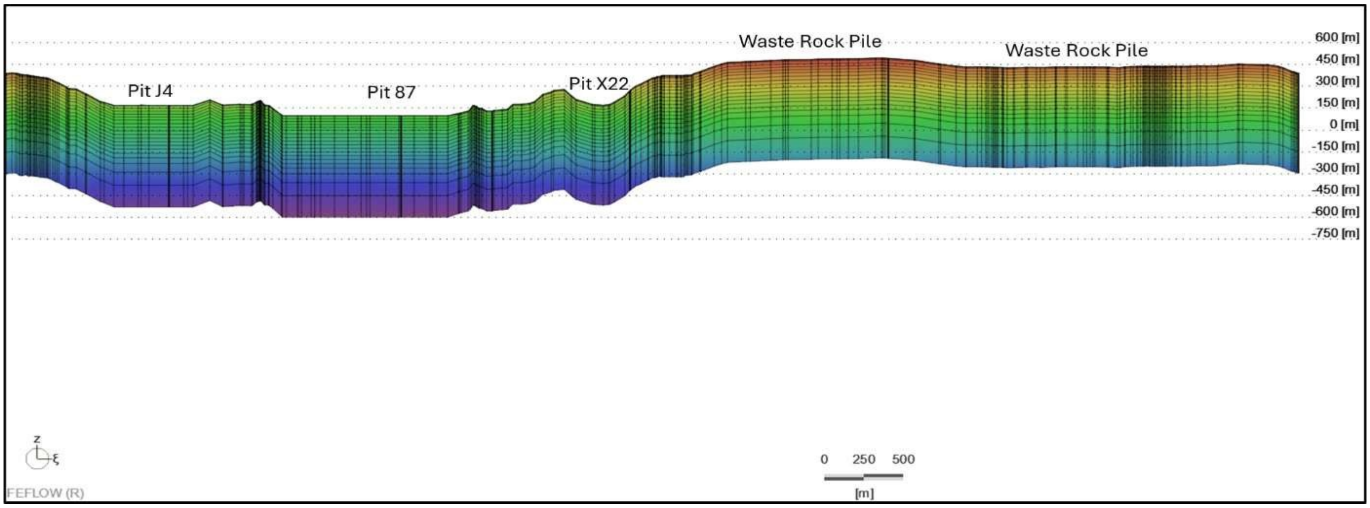

Figure 23: Cross section (E-F in Figure 21) of the pits J4, 87 and X22, and Waste rock piles under the Year 21 scenario

4.4 Mine Closure Scenario

In the final mining phase model, the topography of the model will be the same as the Year 21 scenario. The only difference will be under the mine closure scenario, all three pits (J4, 87 and X22) will be converted into pit lakes. The pit water level will be monitored to reach 363.1 m. A constant head boundary condition with a value of 363.1 m was used to simulate the presence of a body of water in the pits. During the Year 21 scenario the lowest bottom elevation of pit 87 was 98 m, it will take significant amount of time to reach water level at 363.1 m in Pit 87. Therefore, the mine closure scenario represents the end stage of the mine life. Recharge rate for the pit lakes (J4, 87 and X22) was considered as 600 mm/a. The model was run under steady state condition.

5 Scenario Based Modelling Results

This section presents the results from the model calibration and predictions for the various scenarios during future mine stages, listed in Section 4. The calibrated numerical model described in Section 3 was used as the basis for the predictive model used to evaluate the effects of future mining scenarios on groundwater conditions and surface water bodies. Particle tracking analyses were conducted to investigate the hydraulic connections between the future pit locations and the surrounding surface water bodies. From water budget analysis, groundwater infiltration rate in the pits and their surrounding hydraulically connected surface water bodies were estimated.

5.1 Base Case Scenario

The resulting hydraulic head field in overburden predicted by the calibrated model is shown in Figure 24 and in Figure 25 for condition in bedrock. The hydraulic head (potentiometric surface) in overburden varies by about 128 meters between the highest hydraulic head located to the south-west from the Lac B (436.15 masl) and the lowest hydraulic head (groundwater elevation) at Pit 87 (308.57 masl) of the model domain. Groundwater generally appears to flow outward from storage in high topographic areas at the south-east of the model domain.

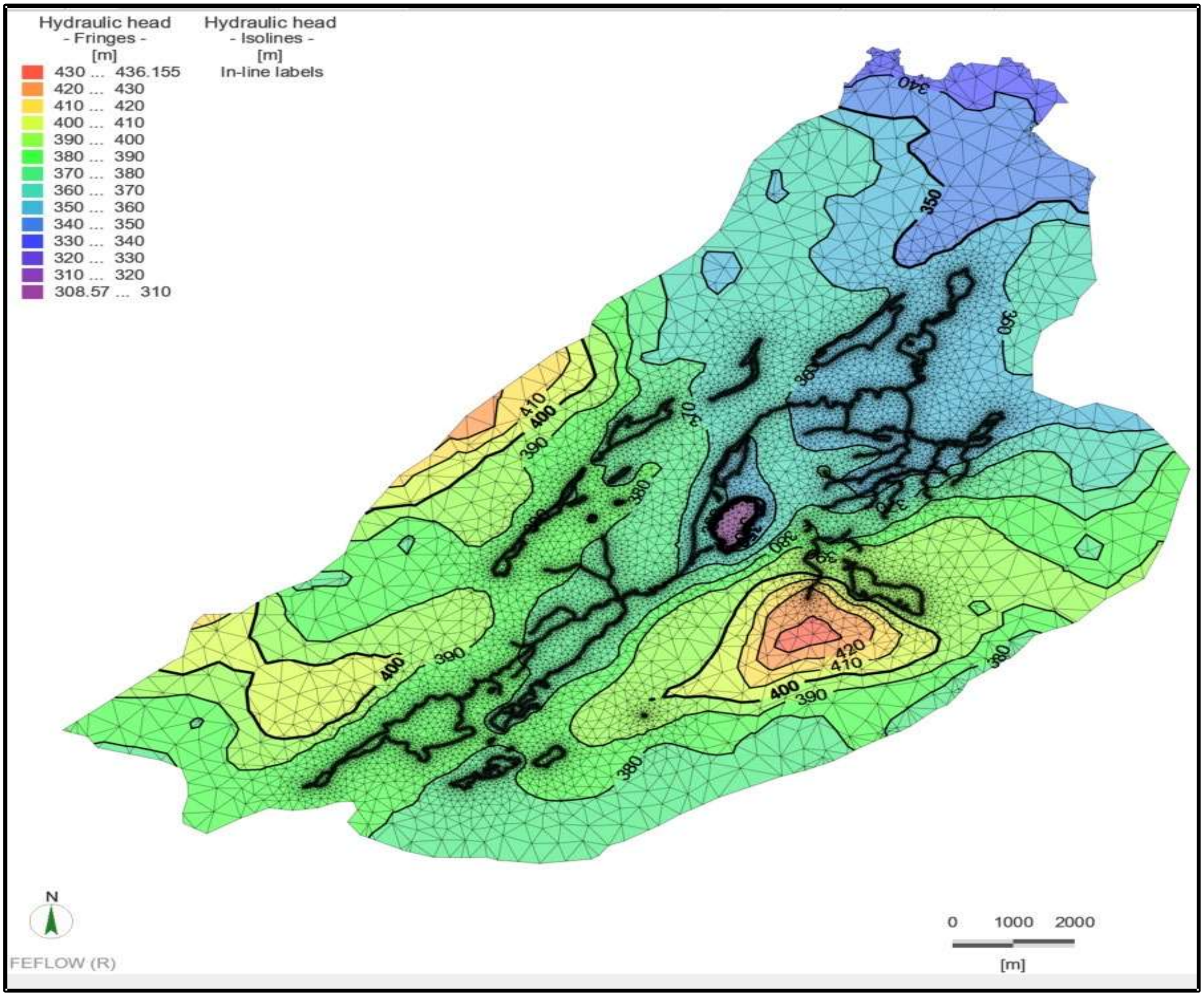

Figure 24: Hydraulic Head (Groundwater Level) in the Base Case Scenario (Overburden)

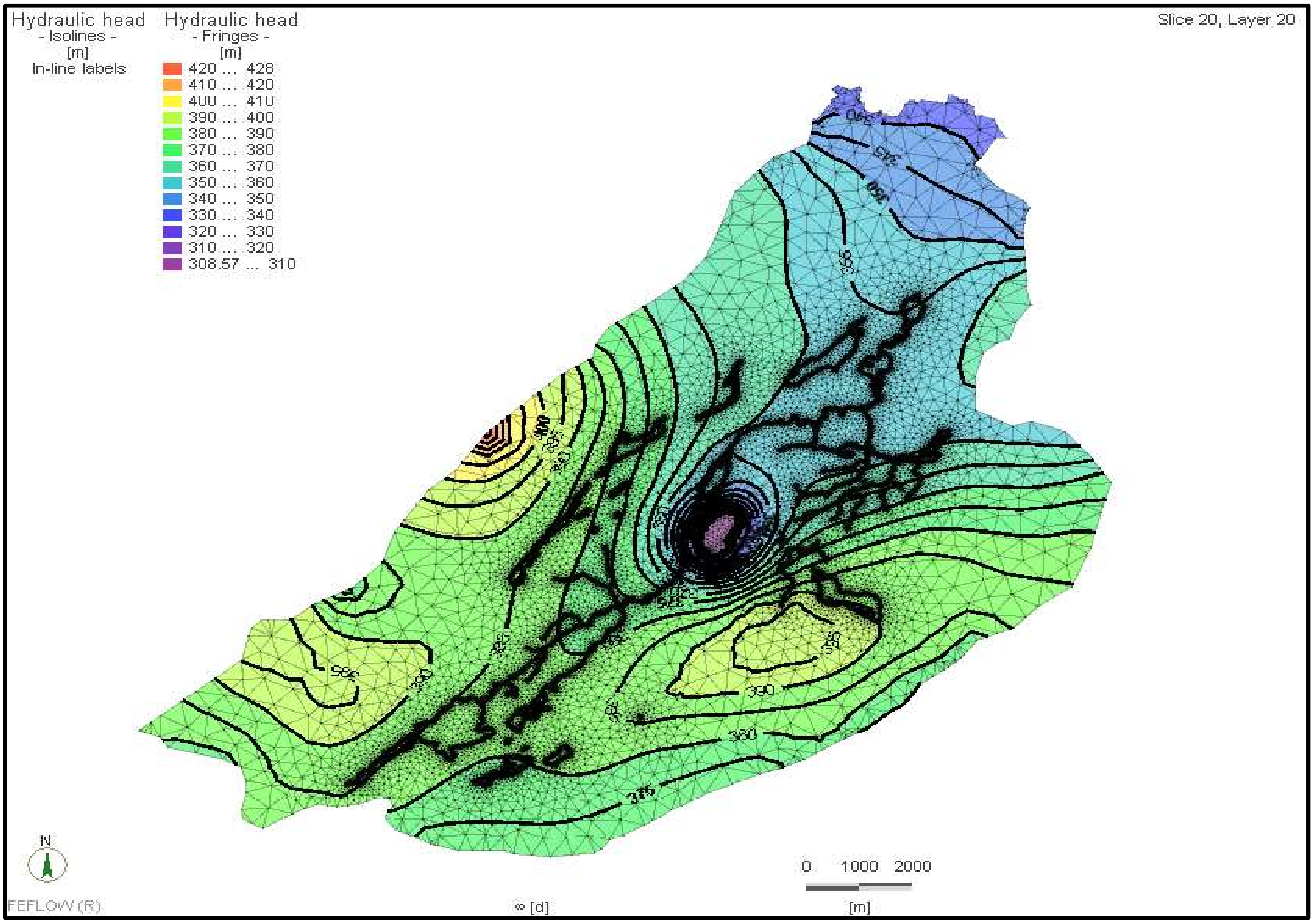

Figure 25: Hydraulic Head in the Base Case Scenario (Bedrock)

In bedrock, the hydraulic head varies by about 120 meters between the highest hydraulic head located to the central-west part of the model domain near the model boundary (428 masl) and the lowest hydraulic head at Pit 87 (308.57 masl). Forward and backward particle tracking analyses were conducted to investigate the baseline hydraulic connections between the existing pit locations and the surrounding surface water bodies. In these analyses, particles were released and tracked forward and backward in time as they moved through the geologic structures throughout the subsurface. A large number of imaginary particles were released at all depths of Pits J4 and 87 in order to capture all existing interactions. The results of these analyses are presented in Figure 26 for Pit J4 and Figure 27 for Pit 87. The particle tracking analyses, illustrated in Figures 26 and 27, indicate that both Pits J4 and 87 are hydraulically connected to the Bibou Creek. A large number of imaginary particles were released at all depths of the Bibou Creek, and particles were tracked forward (Figure 28) and backward (Figure 29) in time. These tracking results also support the hydraulic connection of the Bibou Creek to both pits.

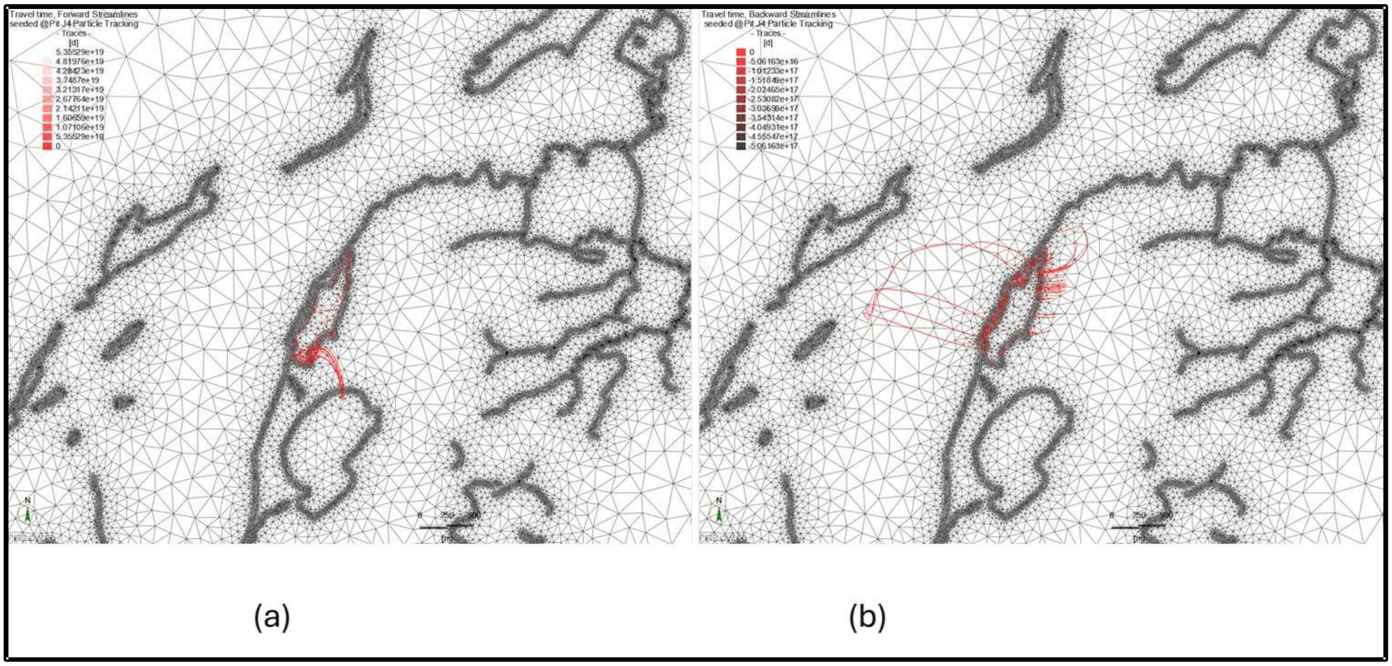

Figure 26: Forward (A) and Backward (B) Particle Tracking for Pit J4 in the Base Case Scenario

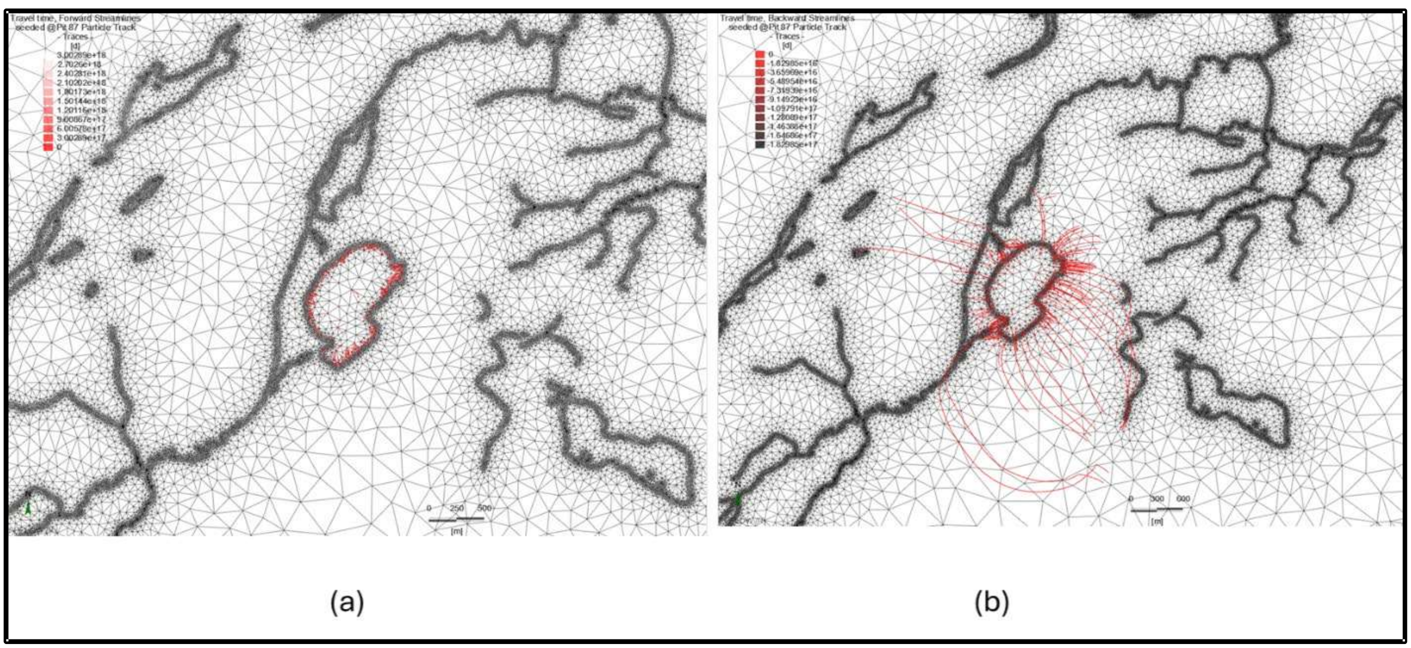

Figure 27: Forward (A) and Backward (B) Particle Tracking for Pit 87 in the Base Case Scenario

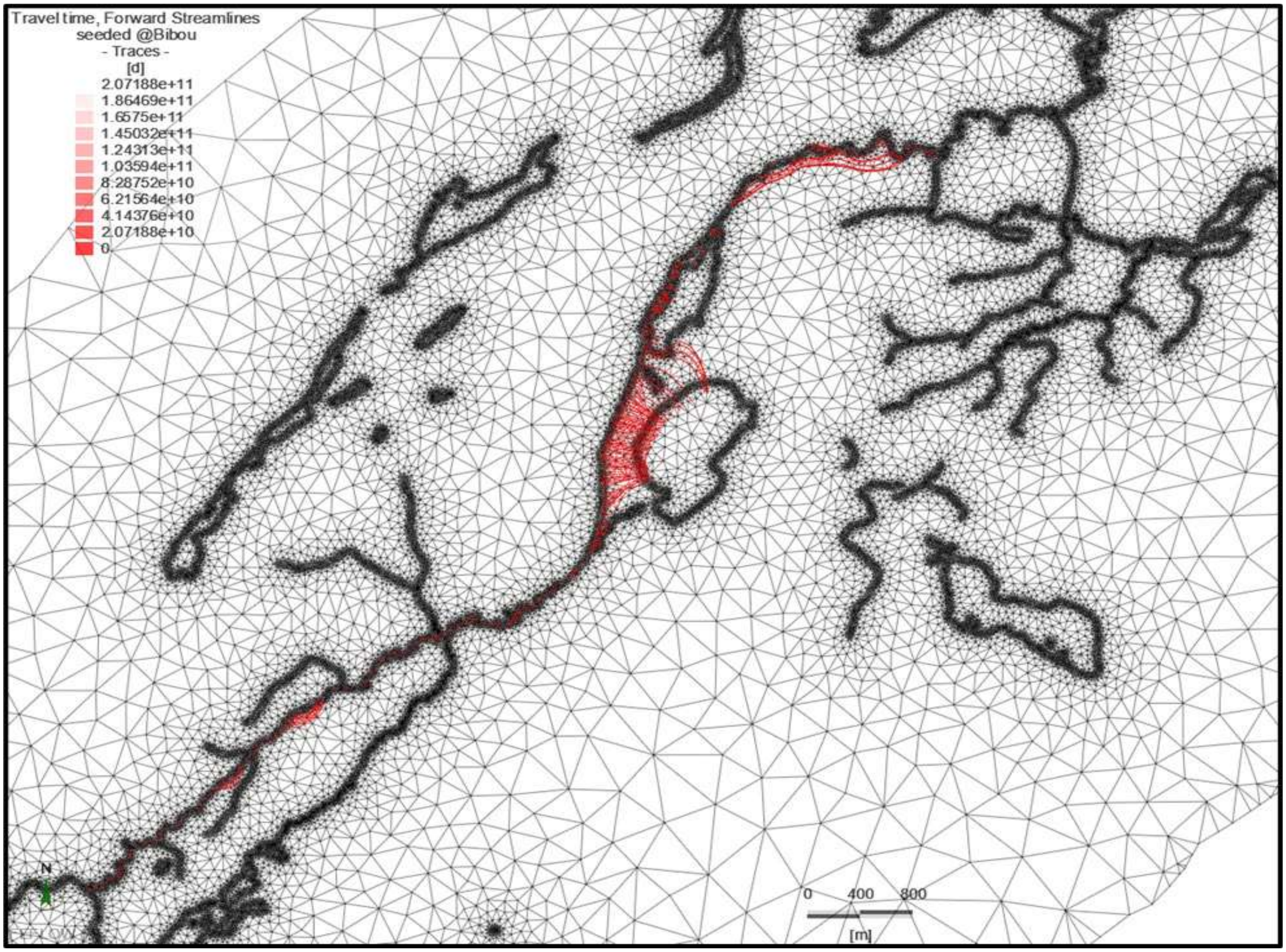

Figure 28: Forward Particle Tracking for the Bibou Creek Diversion Channel in the Base Case Scenario

As part of the water budget analysis, the simulated groundwater infiltration rate for the Pits J4 and 87 under the base case scenario was 1,633.3 and 2,197.8 m^3/d, respectively. The simulated groundwater infiltration rate for the Bibou Creek (i.e., groundwater contribution) was 1,401.6 m^3/d.

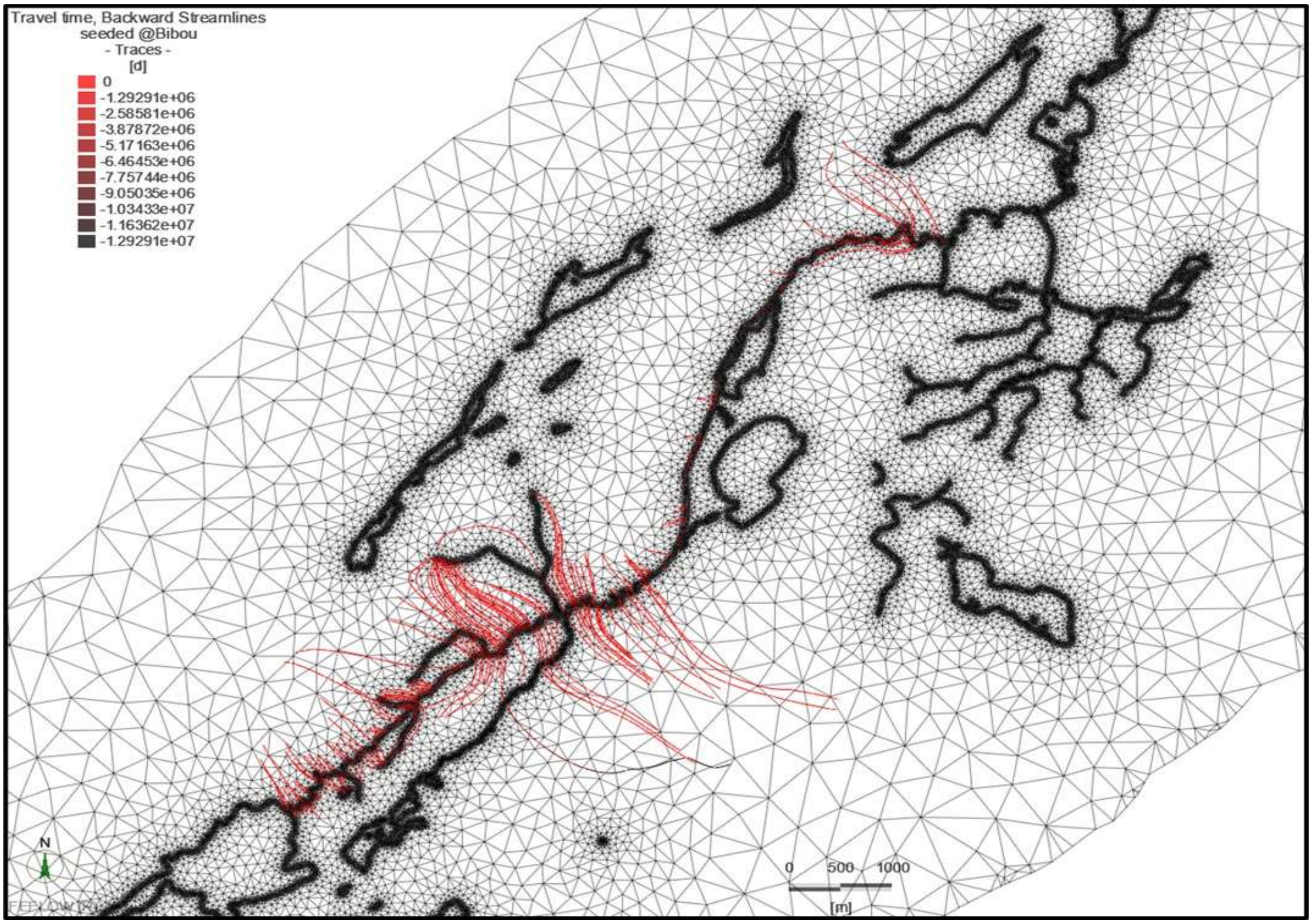

Figure 29: Backward Particle Tracking for the Bibou Creek Diversion Channel in the Base Case Scenario

5.2 Year 10 Scenario

In the Year 10 scenario, the hydraulic head field in overburden predicted by the calibrated model is shown in Figure 30. In this scenario, the hydraulic head in overburden varies by about 568 meters between the highest hydraulic head located to the south-west from lac B (438.07 masl) and the lowest hydraulic head in Pit 87 (-130.23 masl) of the model domain. Whereas the hydraulic head in bedrock (Figure 31) varies by about 570 meters between the highest hydraulic head located to the central-west part of the model domain near the model boundary (428 masl) and the lowest hydraulic head in Pit 87 (-142.44 masl).

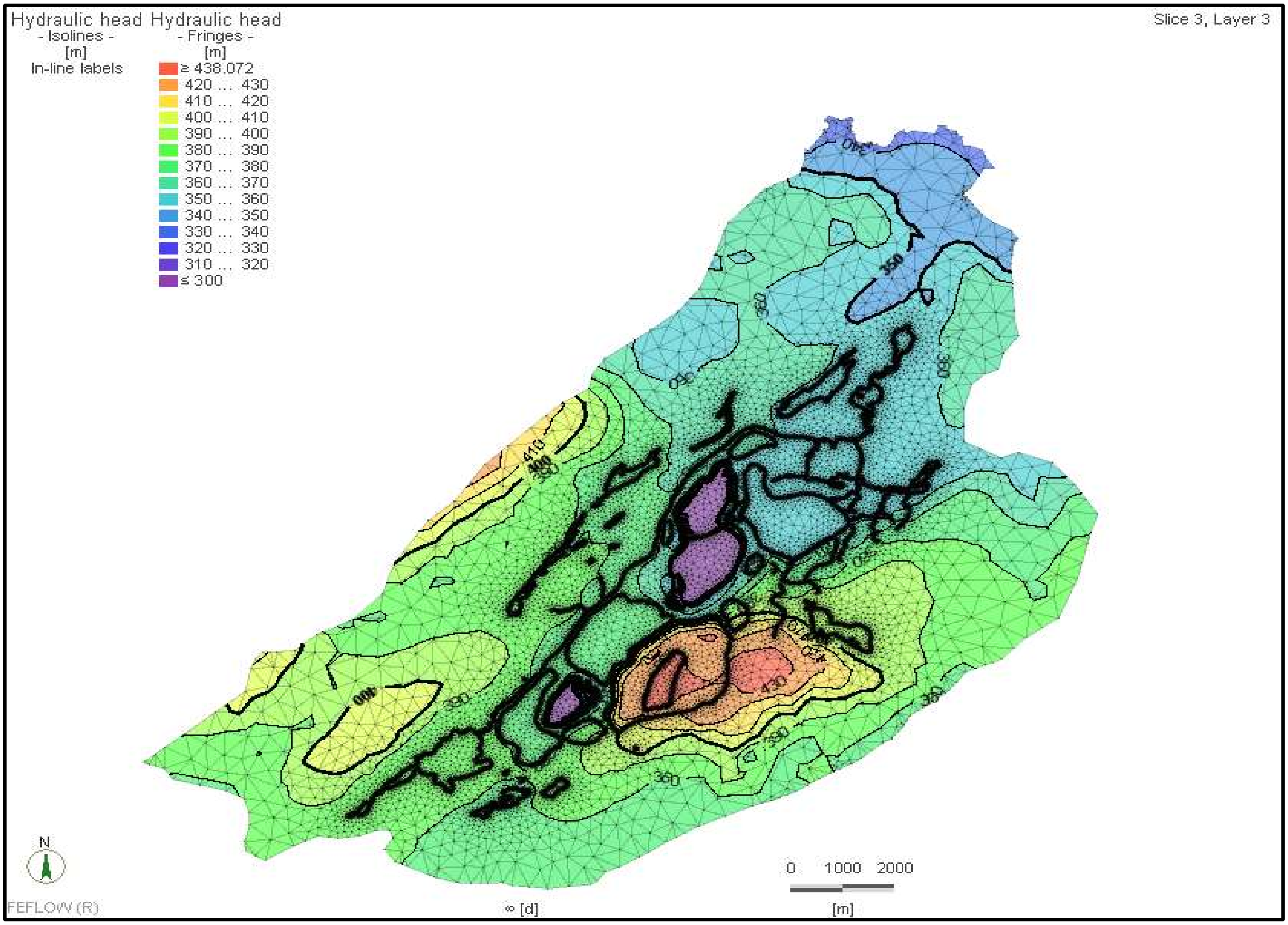

Figure 30: Hydraulic Head Distribution for Year 10 Scenario (Overburden)

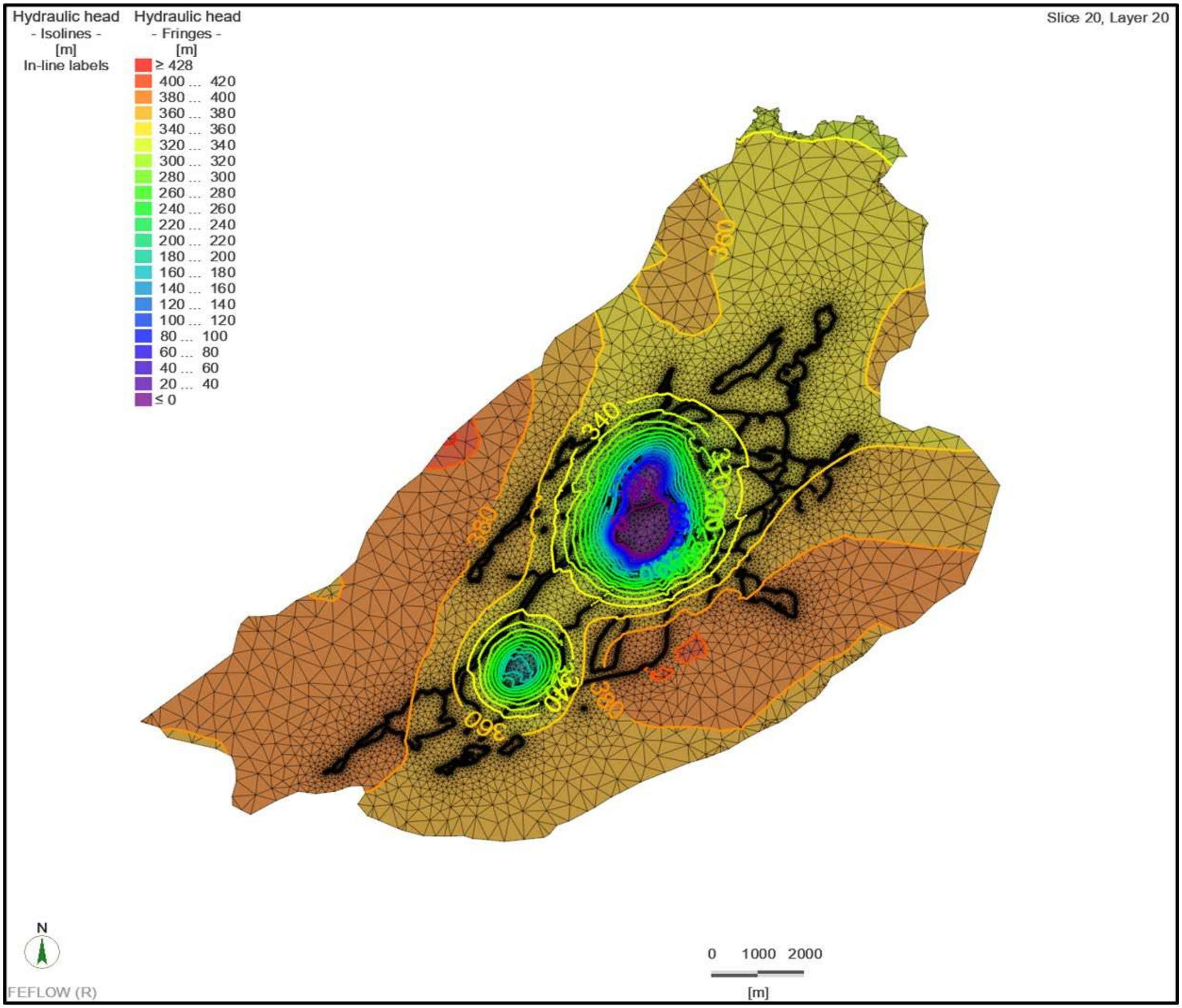

Figure 31: Hydraulic Head Distribution for Year 10 Scenario (Bedrock)

Comparing the hydraulic head in the Year 10 scenario with that in the base case scenario, a maximum drawdown in overburden would occur in Pit 87 (approximately 438.8 m) (Figure 32). However, a resurgence of groundwater level (approximately 38.67 m) in overburden would occur in the tailing storage facilities because of the tailing pond having a constant head of 432.6 m (Figure 33). This is shown with the forward and backward particle tracking analyses for the tailing pond. Particle tracking analyses were done for the mine life (22 years or 8030 days). Based on particle tracking analyses, no particle reaches the tailing pond therefore, the backward particle tracking result is not possible (Figure 34).

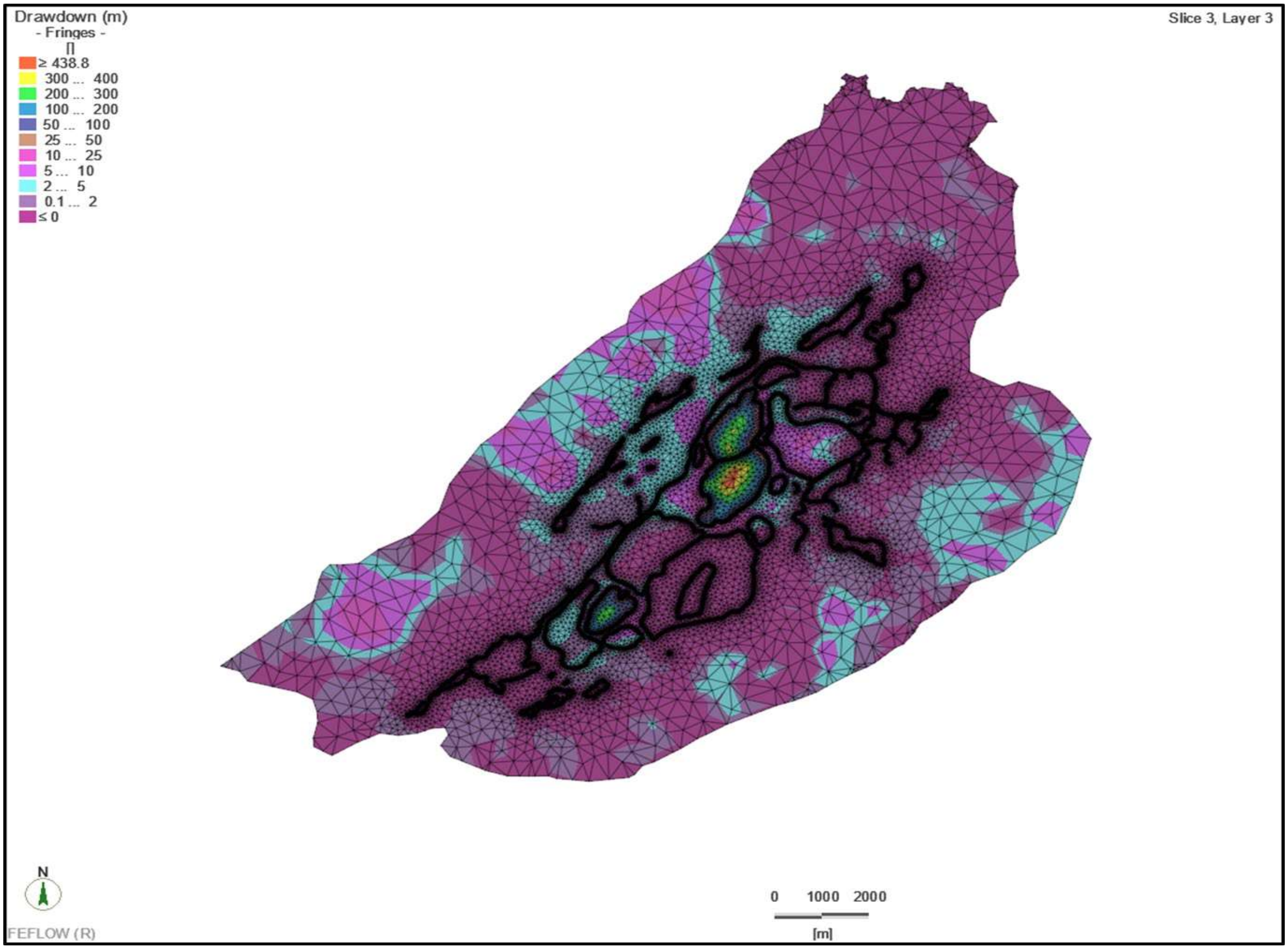

Figure 32: Predicted Drawdown for Year 10 Scenario Relative to Base Case Scenario (Overburden)

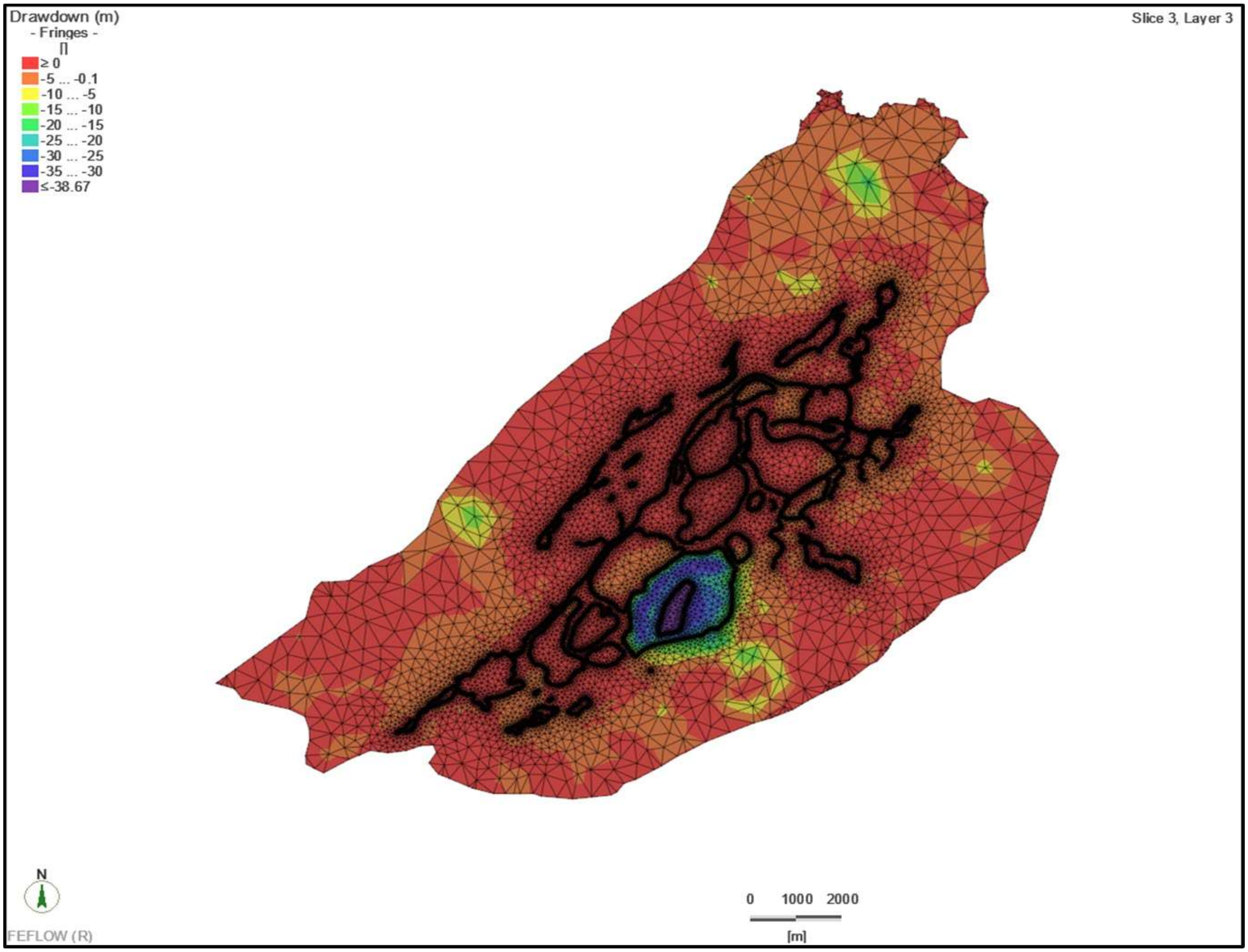

Figure 33: Predicted Rise of Groundwater Distribution for Year 10 Scenario Relative to Base Case Scenario (Overburden). Here Negative Sign indicates increase in Groundwater Head

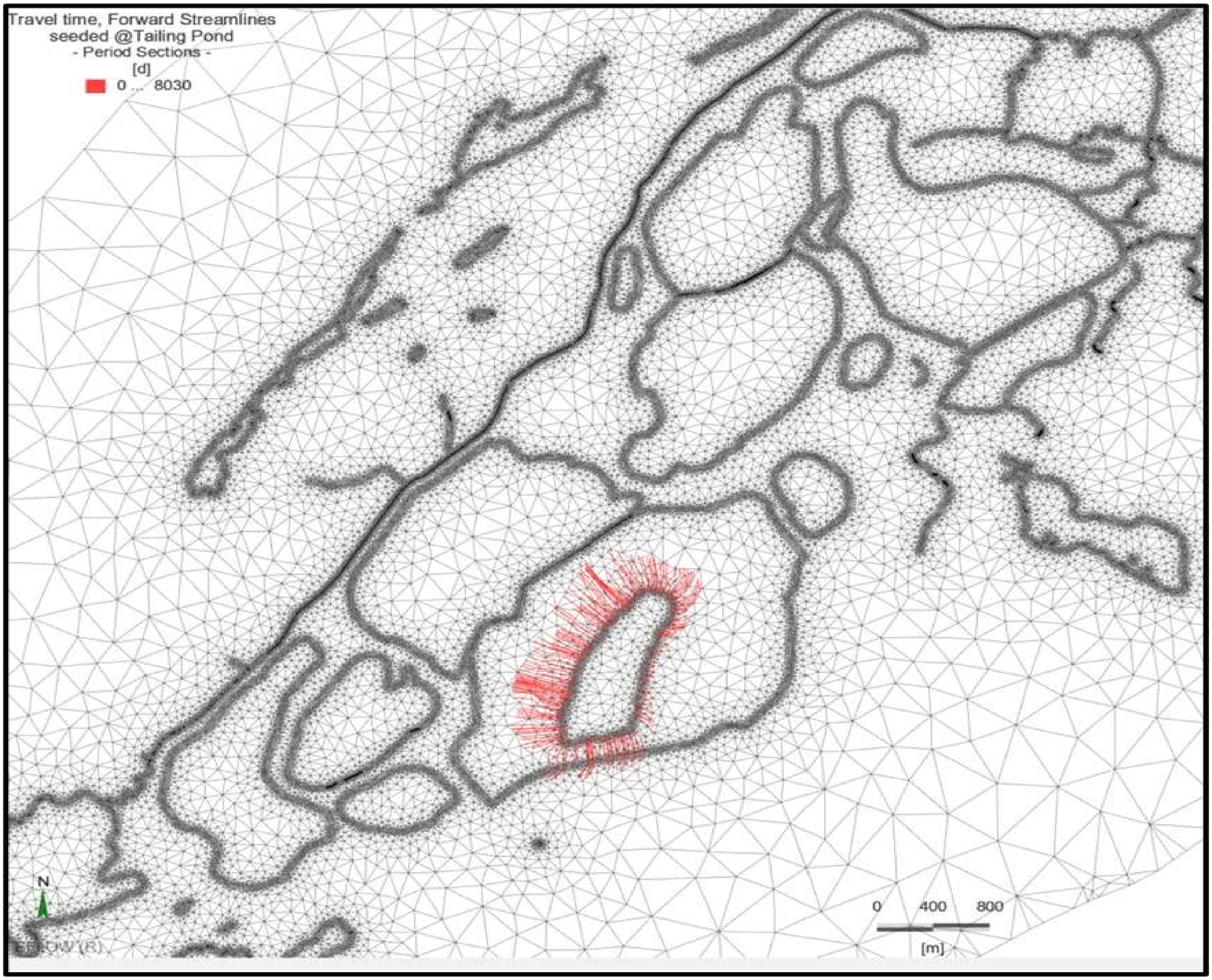

Figure 34: Forward Particle Tracking for the Tailing Pond for Year 10 Scenario

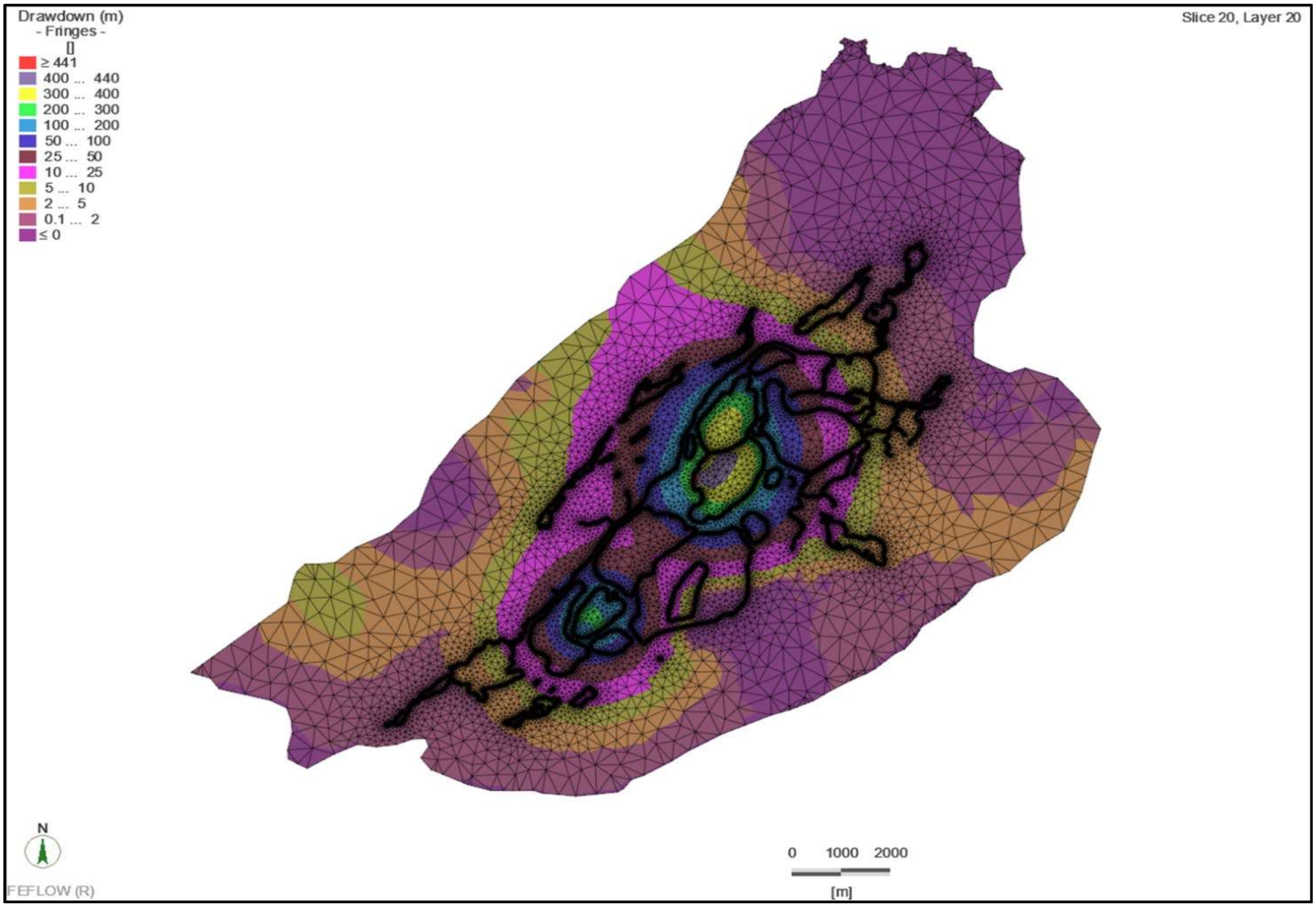

Figure 35: Predicted Drawdown for Year 10 Scenario Relative to Base Case Scenario (Bedrock)

Comparing the hydraulic head in bedrock in the Year 10 scenario with that in the base case scenario, a maximum drawdown (approximately 441 m) in bedrock would occur in Pit 87 (Figure 35).

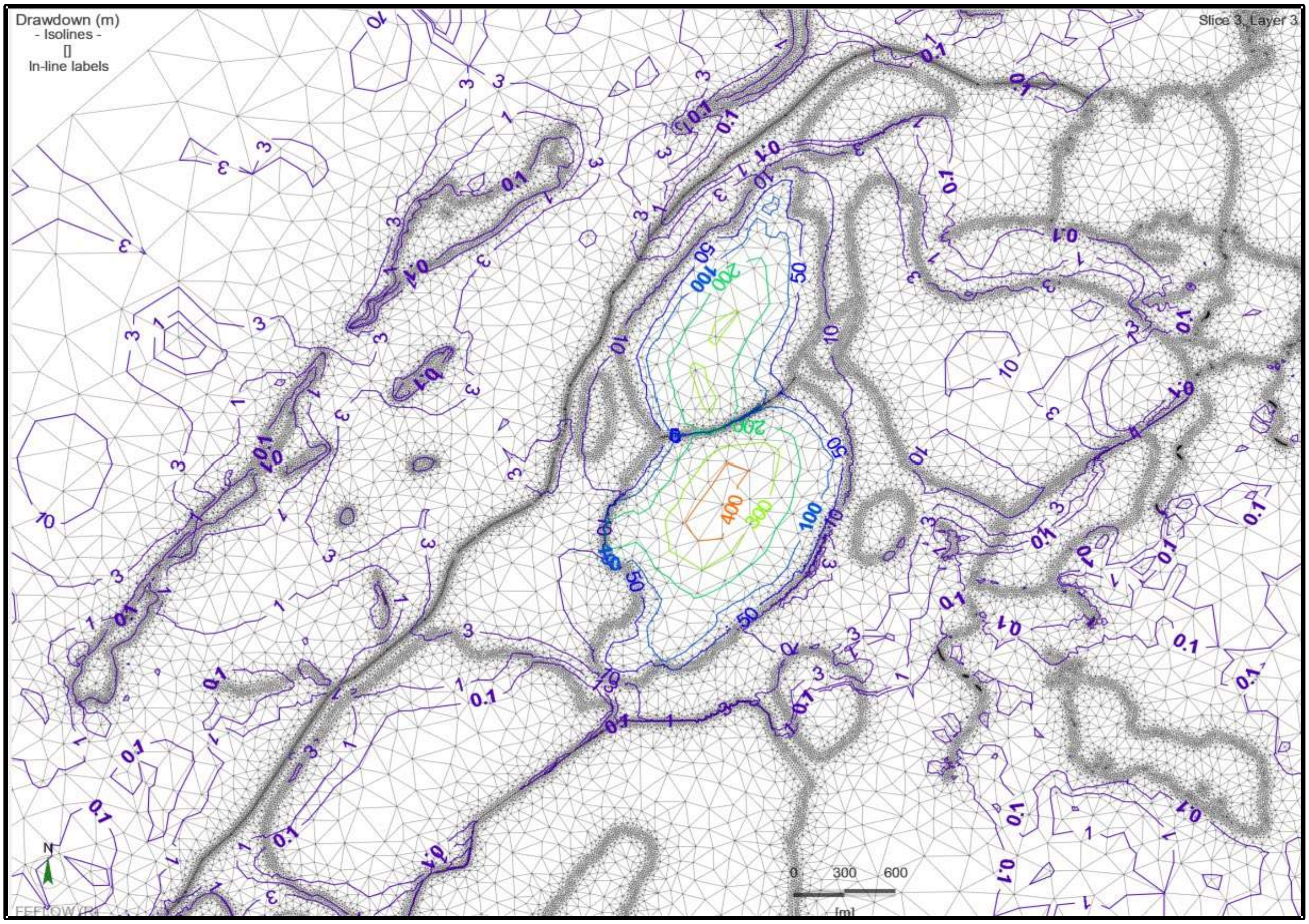

Figure 36: Predicted Extent of Drawdown Due to Dewatering of Pits J4 And 87 Under the Year 10 Scenario (Overburden)

Figure 36 shows the predicted extent of drawdown (up to 0.1 m drawdown) induced by pit dewatering in Pits J4 and 87. The drawdown would extend mainly along the north-east/south-west axis of the site and reach approximately 2,074 m west from Pit 87, 2,755 m south-west from Pit 87, 1,484 m east from Pit 87, and 145 m south from Pit 87. The drawdown would extend about 2,000 m east from Pit J4, 1,145 m west from Pit J4, and 140 m north from Pit J4. The drawdown would extend near the Lac (Lake) A and the Lac (Lake) A4. The bed of the diversion channel is planned to be set up approximately 2 to 17 m below the existing ground surface. Therefore, hydraulic head in the Year 10 scenario would decrease compared to the base case scenario. In turn, setting the bed of diversion channel below the existing ground surface would affect the extent of drawdown along with pit dewatering. The drawdown extent would cross the Bibou Creek diversion channel and indicates that both Pits J4 and 87 would be hydraulically connected to the Bibou Creek diversion channel. The particle tracking results of Pits J4 (Figure 37) and 87 (Figure 38) also support the hydraulic connection of the Bibou Creek diversion channel to both pits.

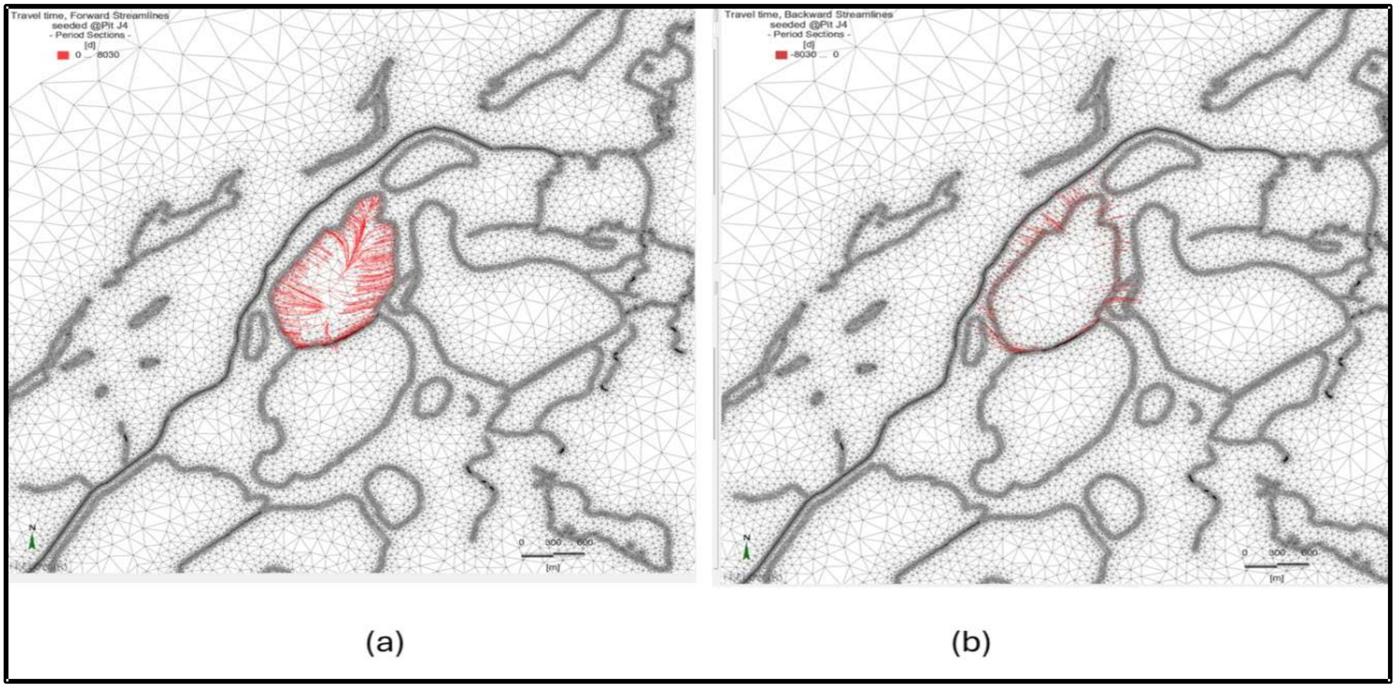

Figure 37: Forward (A) and Backward (B) Particle Tracking for Pit J4 For Year 10 Scenario

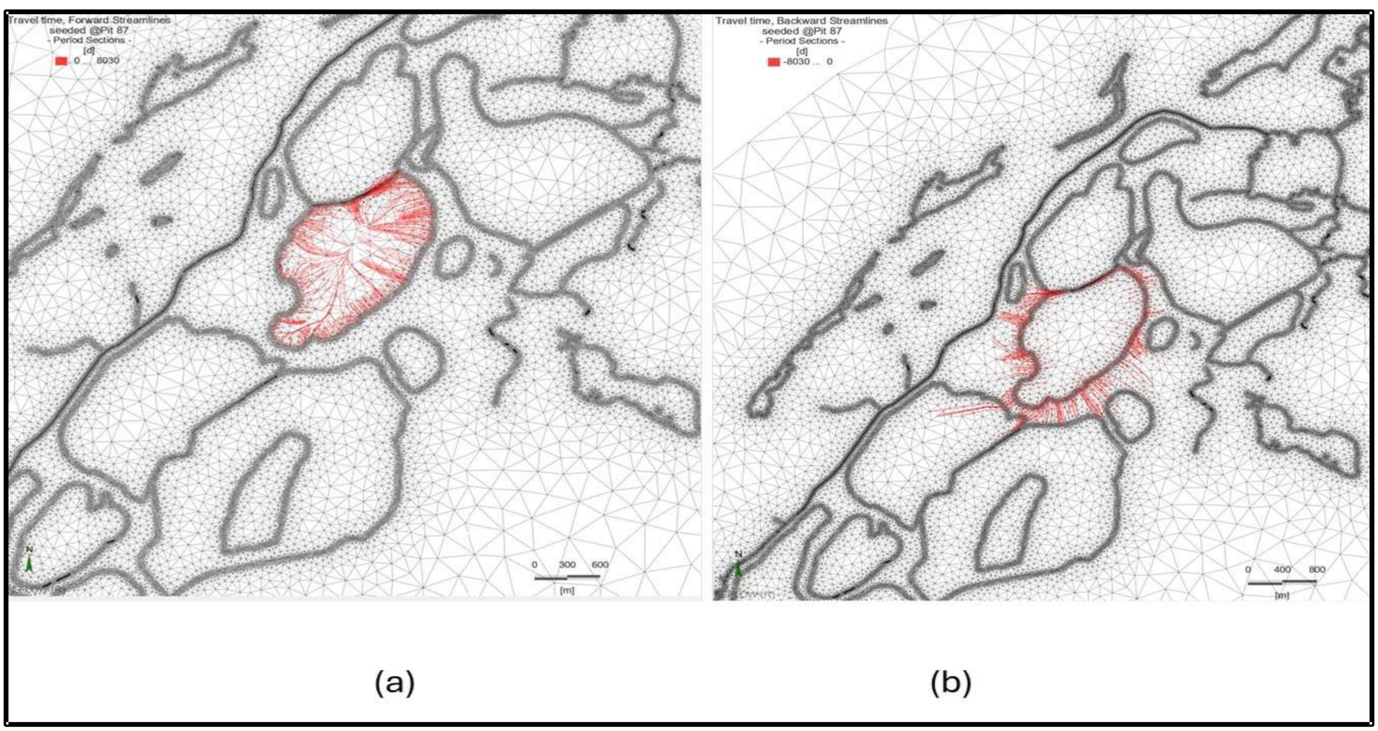

Figure 38: Forward (A) and Backward (B) Particle Tracking for Pit 87 for Year 10 Scenario

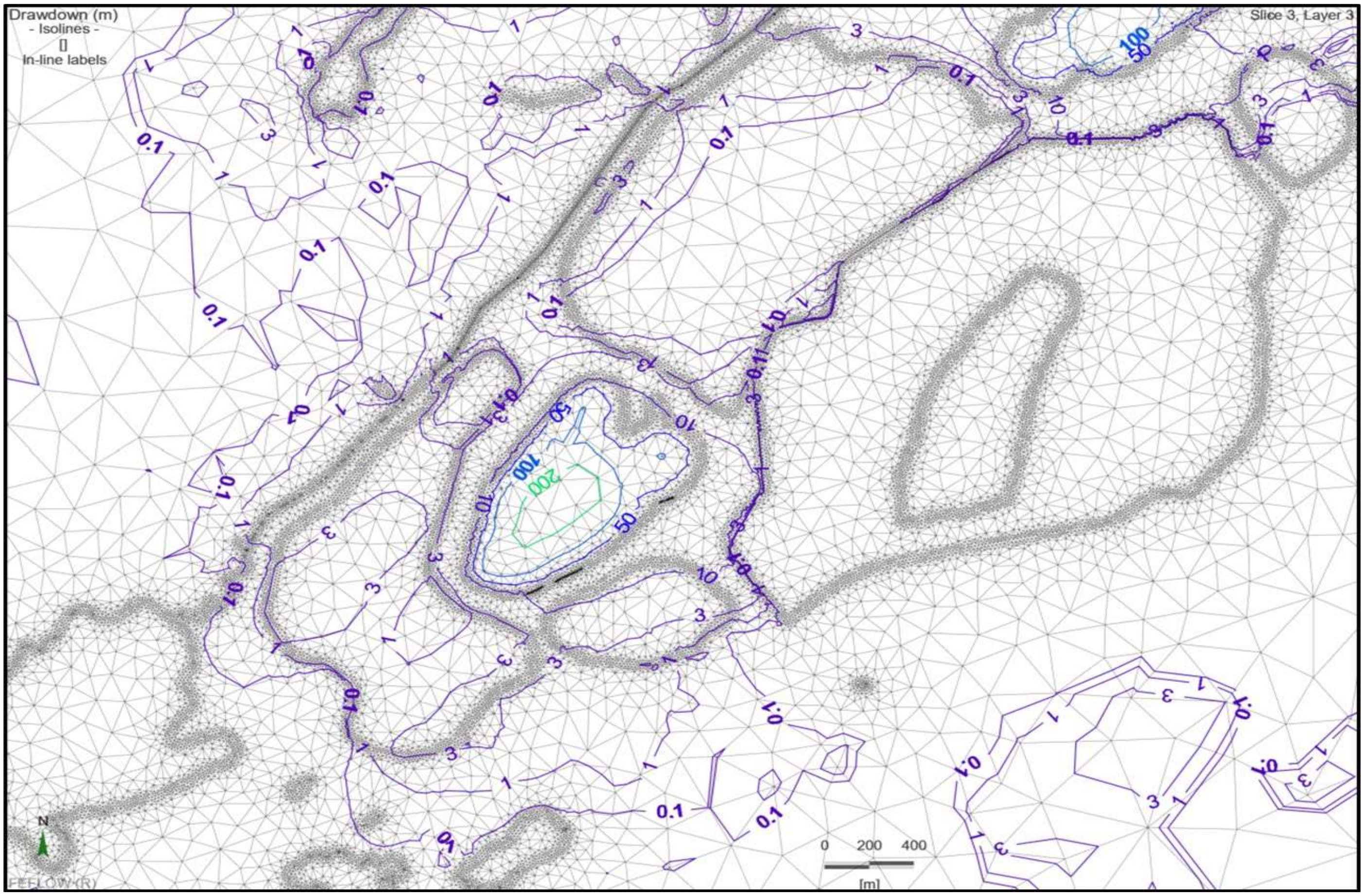

Figure 39: Predicted Extent of Drawdown Due to Dewatering of Pit SW Under the Year 10 Scenario (Overburden)

Figure 39 shows the predicted extent of drawdown (up to 0.1 m drawdown) induced by pit dewatering in Pit SW. The drawdown would extend approximately 1,450 m east from Pit SW, 1,337 m south-west from Pit SW, and 197 m west from Pit SW. However, the drawdown would not cross the Bibou Creek diversion channel because Pit SW appears to not be hydraulically connected to any surface water bodies during this scenario based on particle tracking results analysis (Figure 40). Pit SW is approximately 505 m away from the Bibou Creek diversion channel and its surface layer elevation is below the nearby Bibou Creek diversion channel, resulting in Pit SW not being hydraulically connected to the Bibou Creek diversion channel. The particle tracking results of Bibou Creek diversion channel (Figures 41 and 42) also support the lack of hydraulic connection of the Bibou Creek diversion channel to Pit SW. The drawdown would extend near the Lac (Lake) Amont and the Lac (Lake) C7.

A conclusion is that the model predicts the flow of particles from areas of high hydraulic head into the pits. This highlights the sensitivity of the pits as they are the areas of the lowest hydraulic head and will greatly influence surrounding zones. The resulting drawdown highlights the sensitivity of the pits (Figure 32).

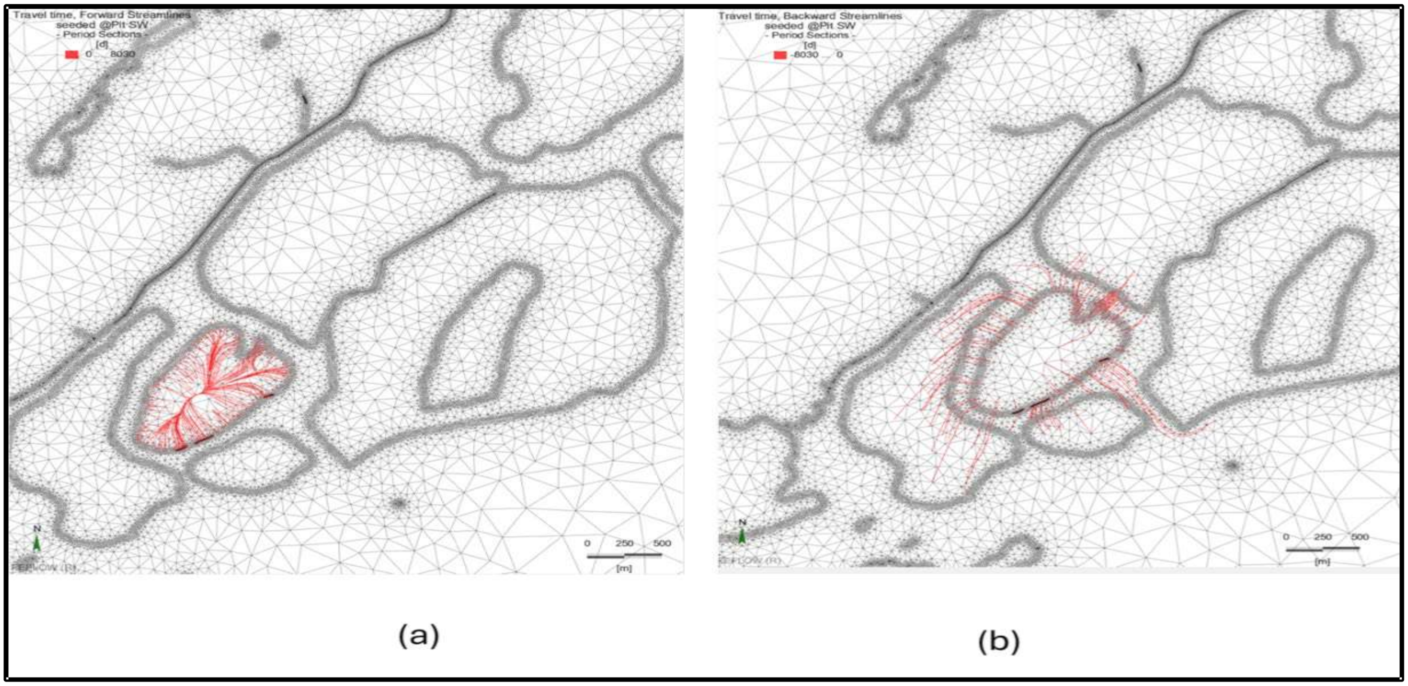

Figure 40: Forward (A) and Backward (B) Particle Tracking for Pit SW for Year 10 Scenario

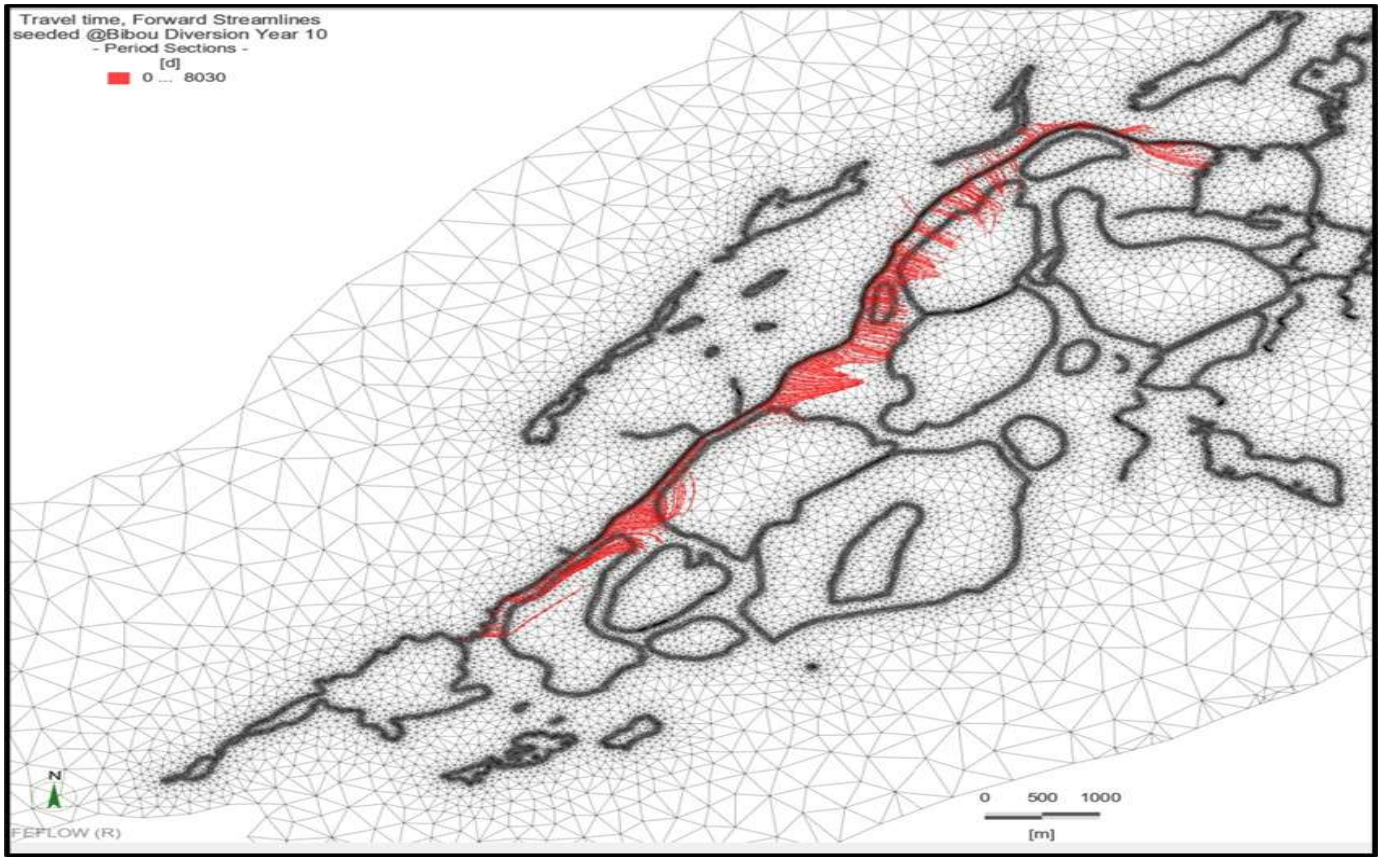

Figure 41: Forward Particle Tracking for the Bibou Creek Diversion Channel for Year 10 Scenario

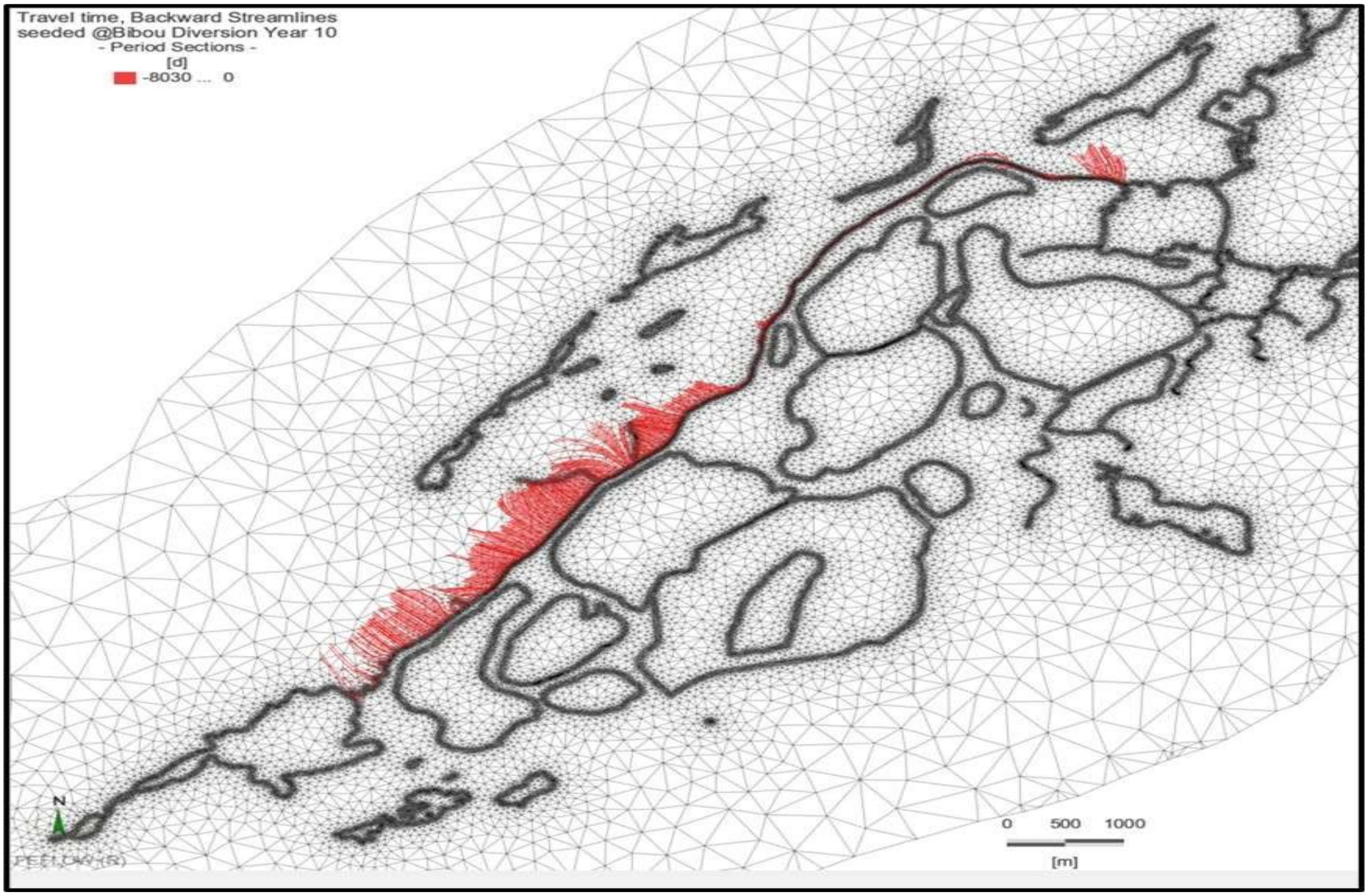

Figure 42: Backward Particle Tracking for the Bibou Creek Diversion Channel for Year 10 Scenario

Regarding the water budget analysis, the simulated groundwater infiltration rate for Pits J4, 87 and SW would be 2,306.6, 3,087.3 and 2,997.9 m^3/d, respectively (Table 7). Groundwater infiltration rates in the Pits J4 and 87 would increase significantly (by 41.2% (i.e., 673.3 m^3/d) for Pit J4, by 40.5% (i.e., 889.5 m^3/d) for Pit 87) because of increased mining activities (dewatering) compared to the base case scenario. The simulated groundwater infiltration rate for the Bibou Creek diversion channel would be 1039.4m^3/d. Compared to the base case scenario, it would decrease significantly (by 25.8% (i.e., 363.2 m^3/d)) because of increased mining activities.

Based on particle tracking analyses (Figures 37 and 38) Pits J4 and 87 would be hydraulically connected to the Bibou Creek diversion channel. The Bibou Creek diversion channel is the main contributor of groundwater infiltration rate into Pit J4. Compared to the base case scenario, the simulated groundwater infiltration rate in Pit J4 would increase by 673.3 m^3/d. Simulated groundwater infiltration rate for the Bibou Creek diversion channel would decrease by almost similar amount due to Pit J4 receiving a major portion of water from the Bibou Creek diversion channel. However, the simulated groundwater infiltration rate for the Bibou Creek diversion channel would decrease by 363.2 m^3/d, due to the bed of the diversion channel being approximately 2 to 17 m below the existing ground surface. The diversion channel is planned to be placed in mostly till dominated area which has higher recharge rate (recharge rate of 128 mm/a) than the deposits (i.e., organic, anthropogenic area) where the existing Bibou Creek is located. Therefore, more recharge would occur along and around the diversion channel beside Pits J4 and 87 due to higher recharge rate of till. In addition, hydraulic head in the Year 10 scenario would decrease compared to the base scenario, and result in higher hydraulic gradient between surface water and groundwater around the Bibou Creek diversion channel area. In turn, a higher amount of groundwater would be discharged to the Bibou Creek diversion channel. Therefore, the simulated groundwater infiltration rate for the Bibou Creek diversion channel would decrease by lesser amount than anticipated. Simulated groundwater infiltration rates to the Bibou Creek diversion during various scenarios is presented in Table 8.

Table 9 presents simulated groundwater infiltration rate to selected lakes which may be impacted by mining activities in the various scenarios. Few lakes have a negative groundwater infiltration rate. The negative sign indicates that these lakes contribute more water to the aquifer than receive water from the aquifer. It also indicates that these are mainly surface runoff dominated lakes. Only subsurface (i.e., groundwater) assessment was considered in this study, surface runoff component was not considered.

5.3 Year 21 Scenario

In the Year 21 scenario, the hydraulic head field in overburden predicted by the calibrated model is shown in Figure 43. The hydraulic head in overburden would vary by about 341 meters between the highest hydraulic head located to the south-west from the lac (Lake) B (439.43 masl) and the lowest hydraulic head in Pit 87 (97.6 masl) of the model domain. Whereas, in bedrock the hydraulic head (Figure 44) would vary by about 330 meters between the highest hydraulic head located to the central-west part of the model domain near the model boundary (428 masl) and the lowest hydraulic head in Pit 87 (97.6 masl)

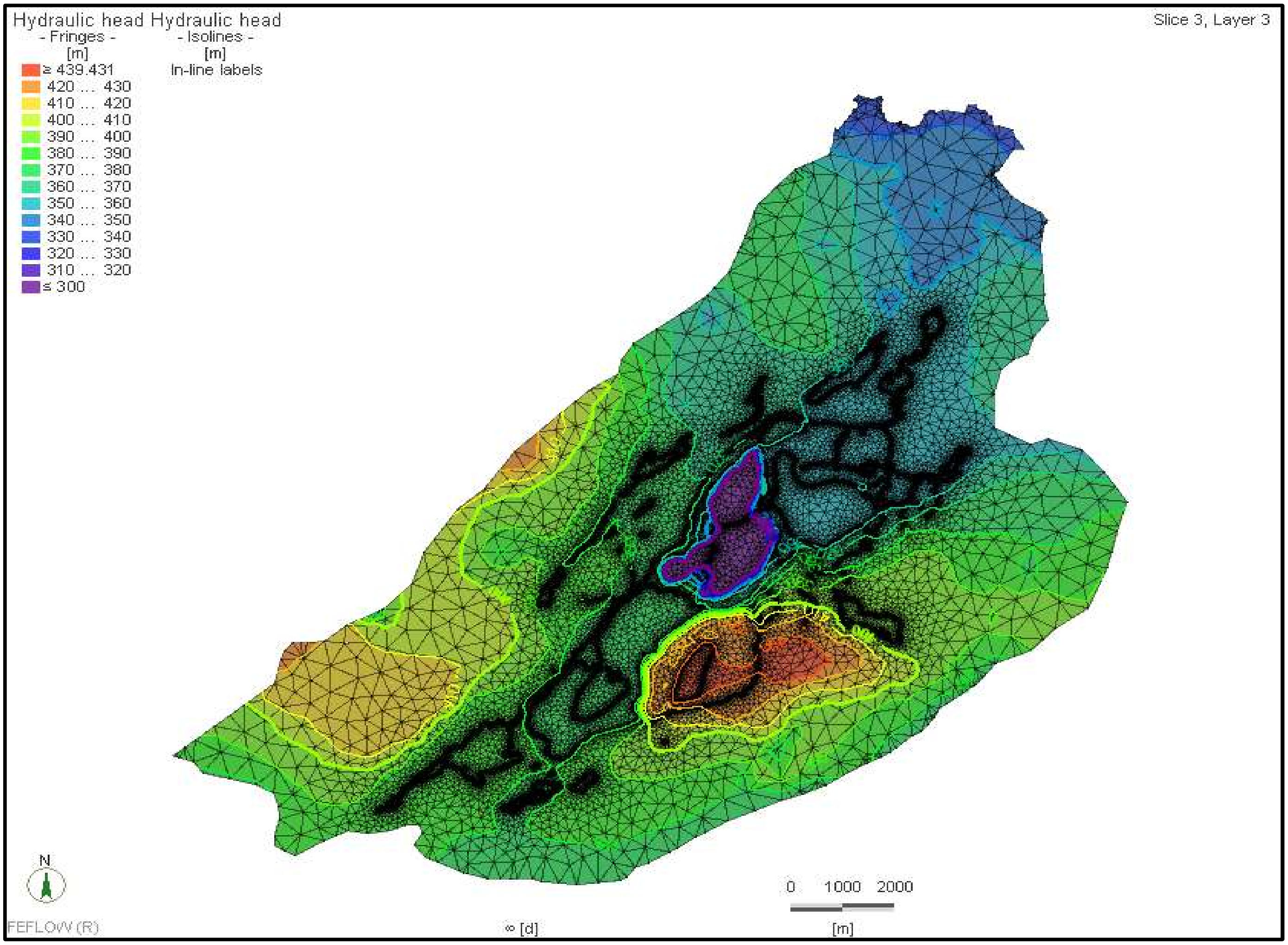

Figure 43: Hydraulic Head Distribution for Year 21 Scenario (Overburden)

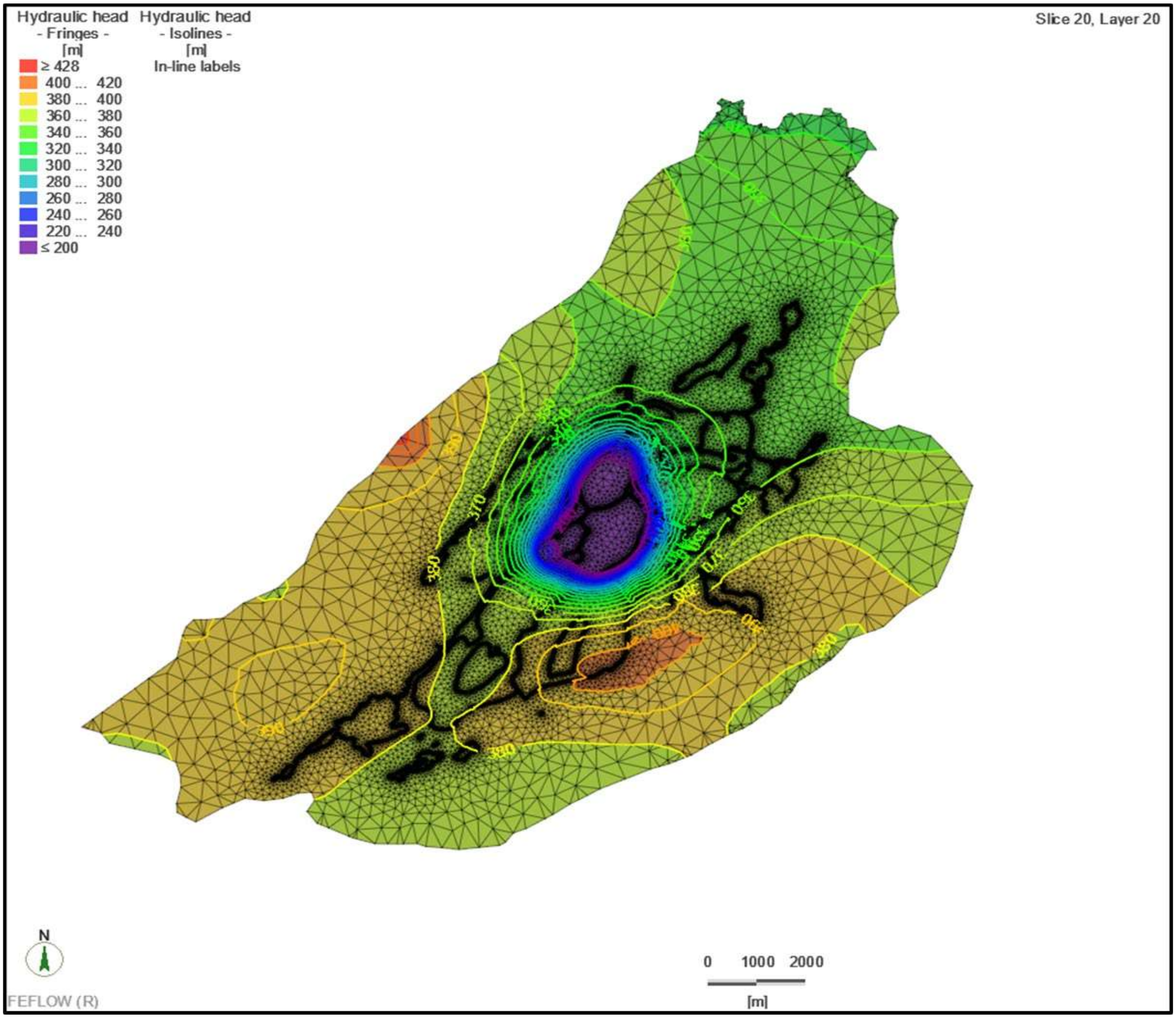

Figure 44: Hydraulic Head Distribution for Year 21 Scenario (Bedrock)

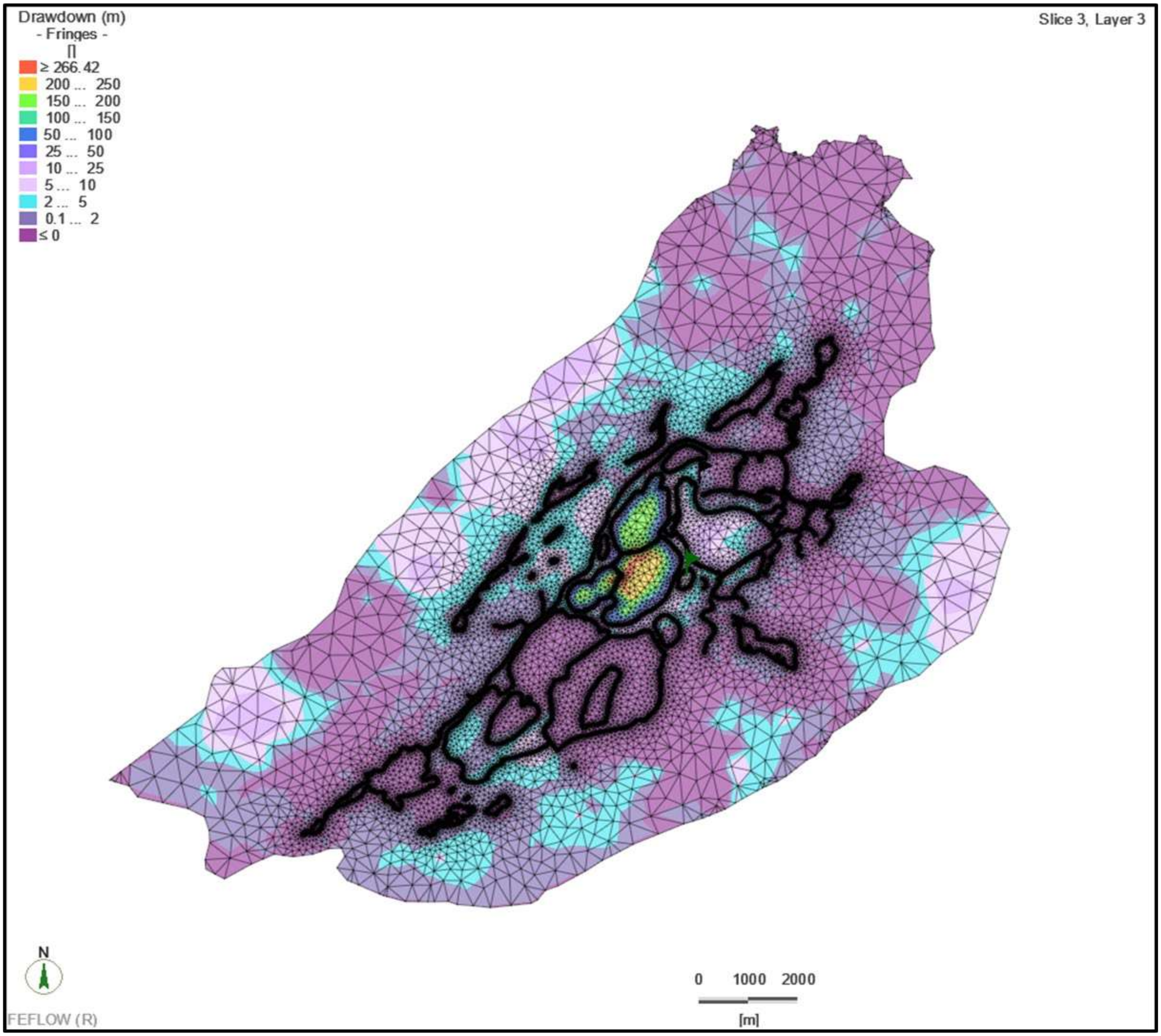

Figure 45: Predicted Drawdown for Year 21 Scenario with Respect to the Base Case Scenario (Overburden)

When the hydraulic head in overburden in the Year 21 scenario is compared with that of the base scenario, maximum drawdown (approximately 266.42 m) in overburden would occur in Pit 87 (Figure 45). Similar to the Year 10 scenario, a resurgence of groundwater level (approximately 38.67 m) in overburden would occur in the tailing storage facilities due to the tailing pond having a constant head of 432.6 m (Figure 46).

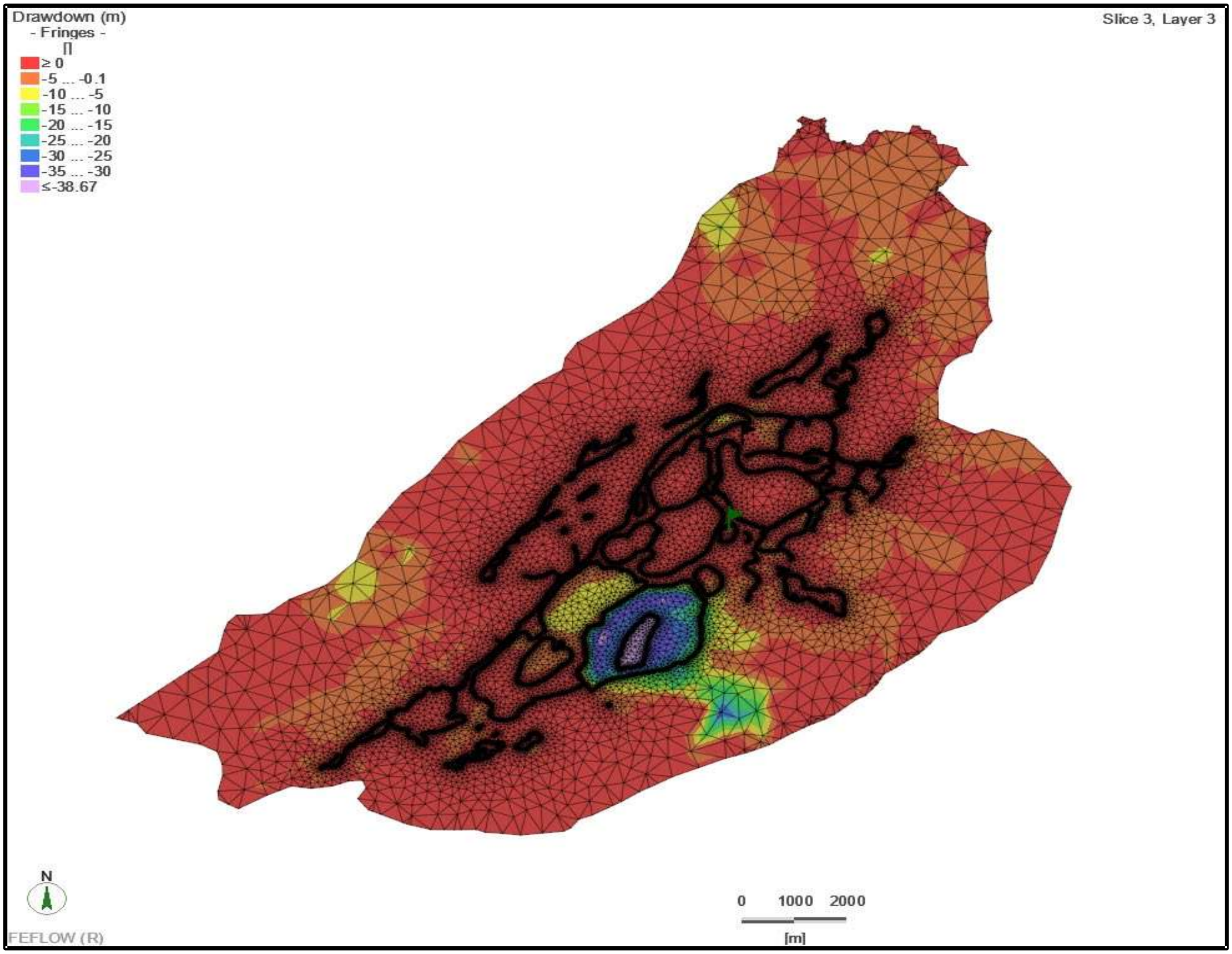

Figure 46: Predicted Rise of Groundwater for Year 21 Scenario Relative to Base Case Scenario (Overburden). Here Negative Sign Indicates Increase in Groundwater Head

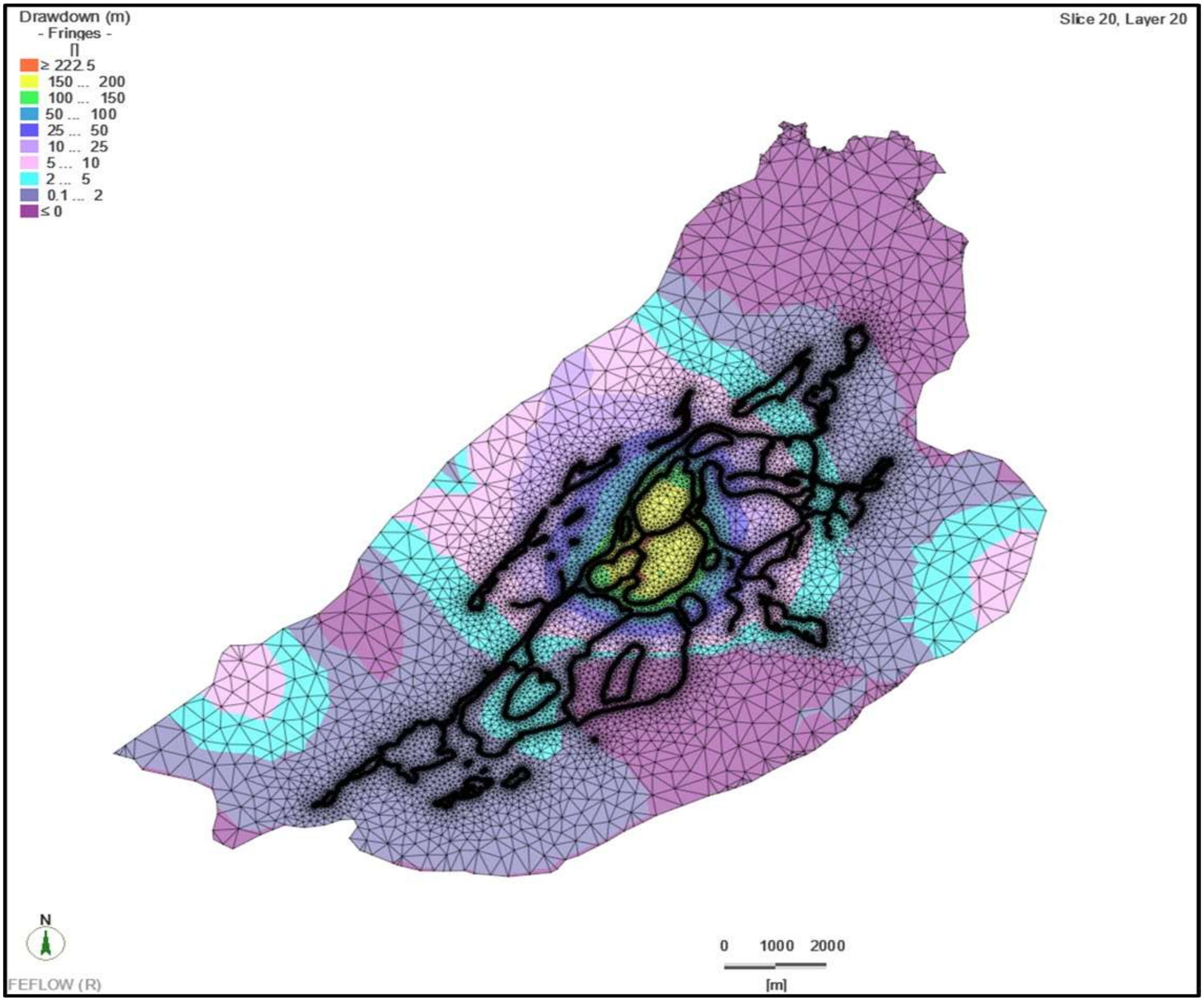

Figure 47: Predicted Drawdown for Year 21 Scenario with Respect to the Base Case Scenario (Bedrock)

Comparing the hydraulic head in bedrock in the Year 21 scenario with that in the base case scenario, a maximum drawdown (approximately 222.5 m) in bedrock would occur in Pit 87 (Figure 47).

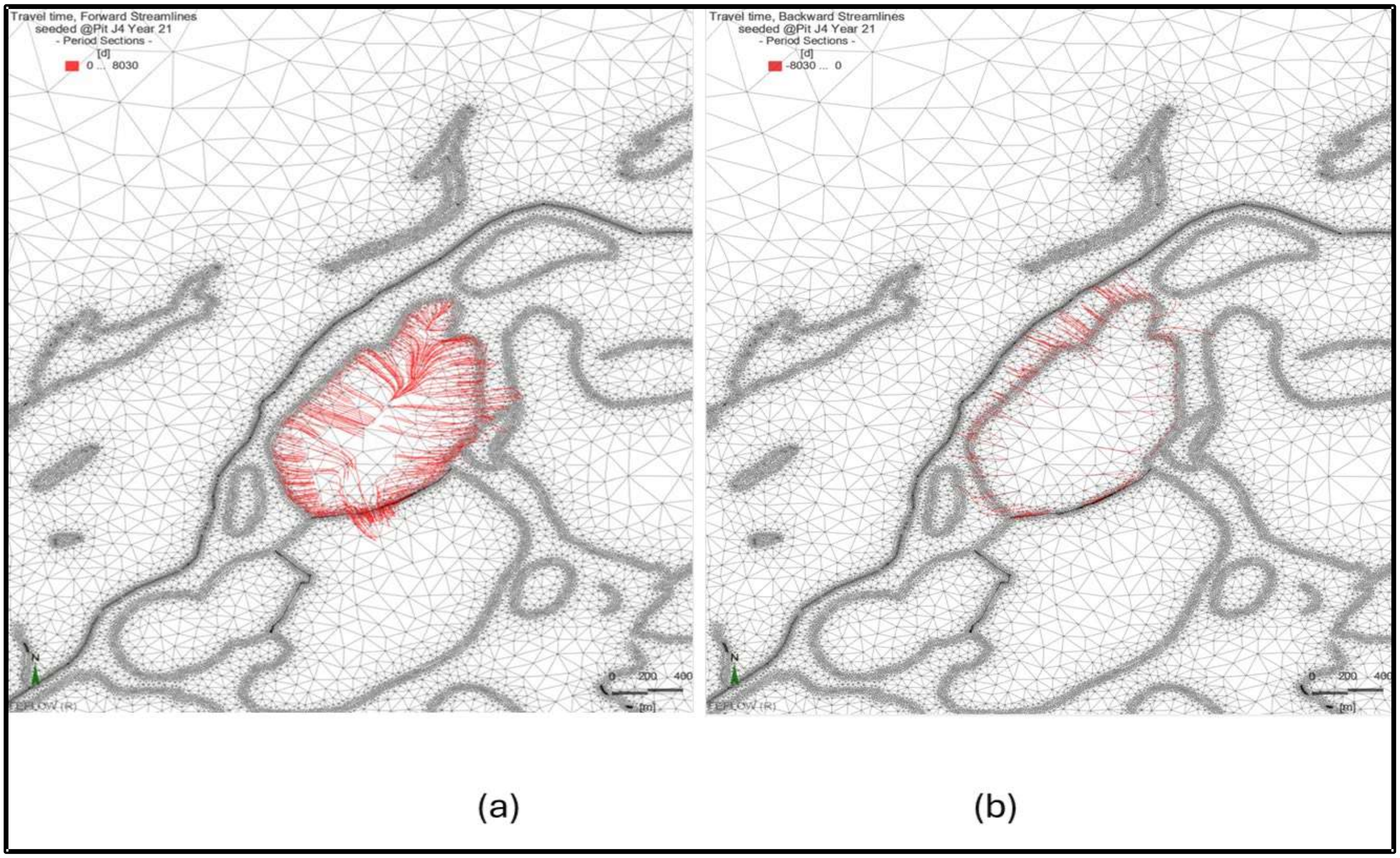

Figure 48: Forward (A) and Backward (B) Particle Tracking for Pit J4 in Year 21 Scenario

In this scenario, Pits J4 (Figure 48) and X22 (Figure 49) would be hydraulically connected to the Bibou Creek diversion channel based on 22 years (i.e., mine life) of forward and backward particle tracking analyses.

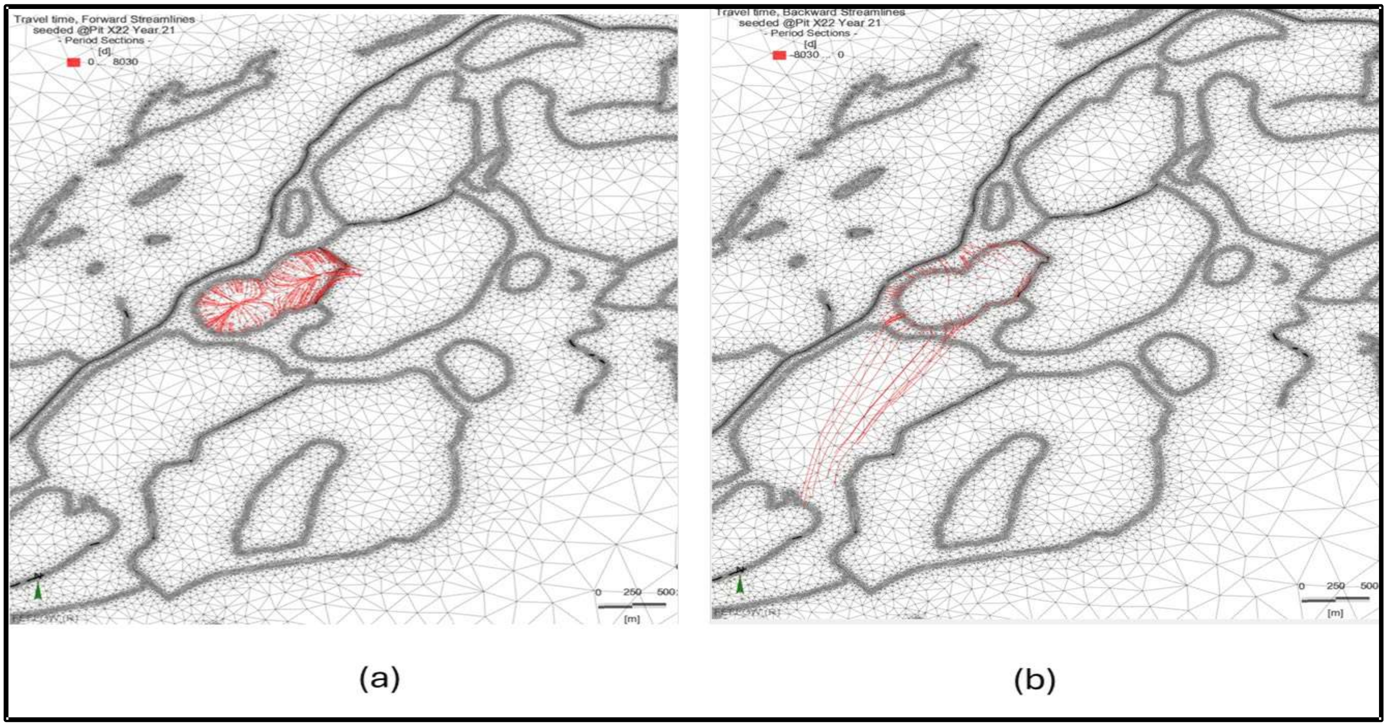

Figure 49: Forward (a) and Backward (b) Particle Tracking for Pit X22 in Year 21 Scenario

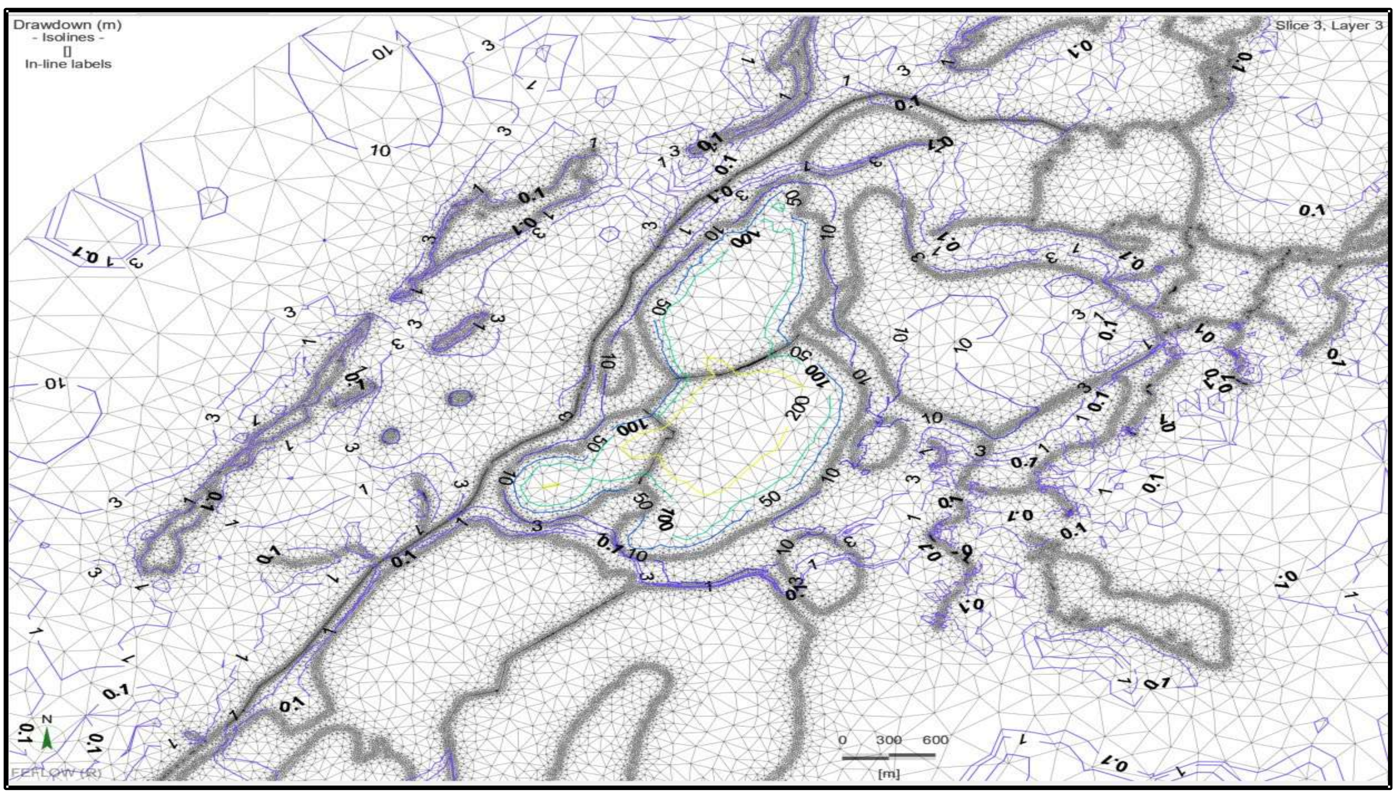

Figure 50: Predicted Extent of Drawdown Due to Dewatering of Pits X22 and 87 Under the Year 21 Scenario (Overburden)

Figures 50 shows the predicted extent of drawdown (up to 0.1 m) induced by pit dewatering in Pits X22 and 87. The drawdown would extend approximately 1,855 m west from Pit 87, 1,414 m east from Pit 87 and 40 m south from the Pit 87. From Pit X22, the drawdown would extend about 1620 m west, 1901 m south-west, and 171 m south. The drawdown extent would cross the Bibou Creek diversion channel.

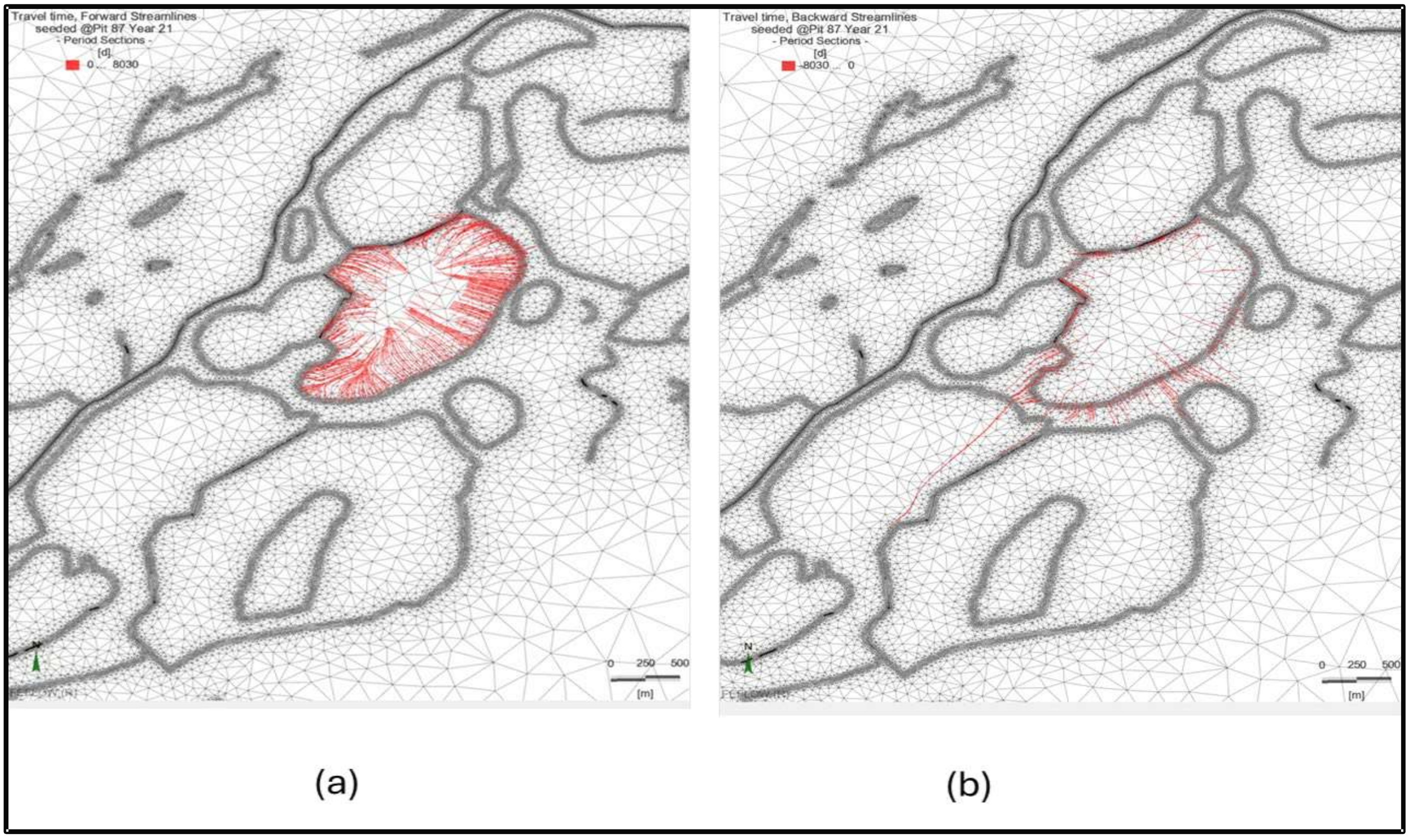

Figure 51: Forward (A) and Backward (B) Particle Tracking for Pit 87 in Year 21 Scenario

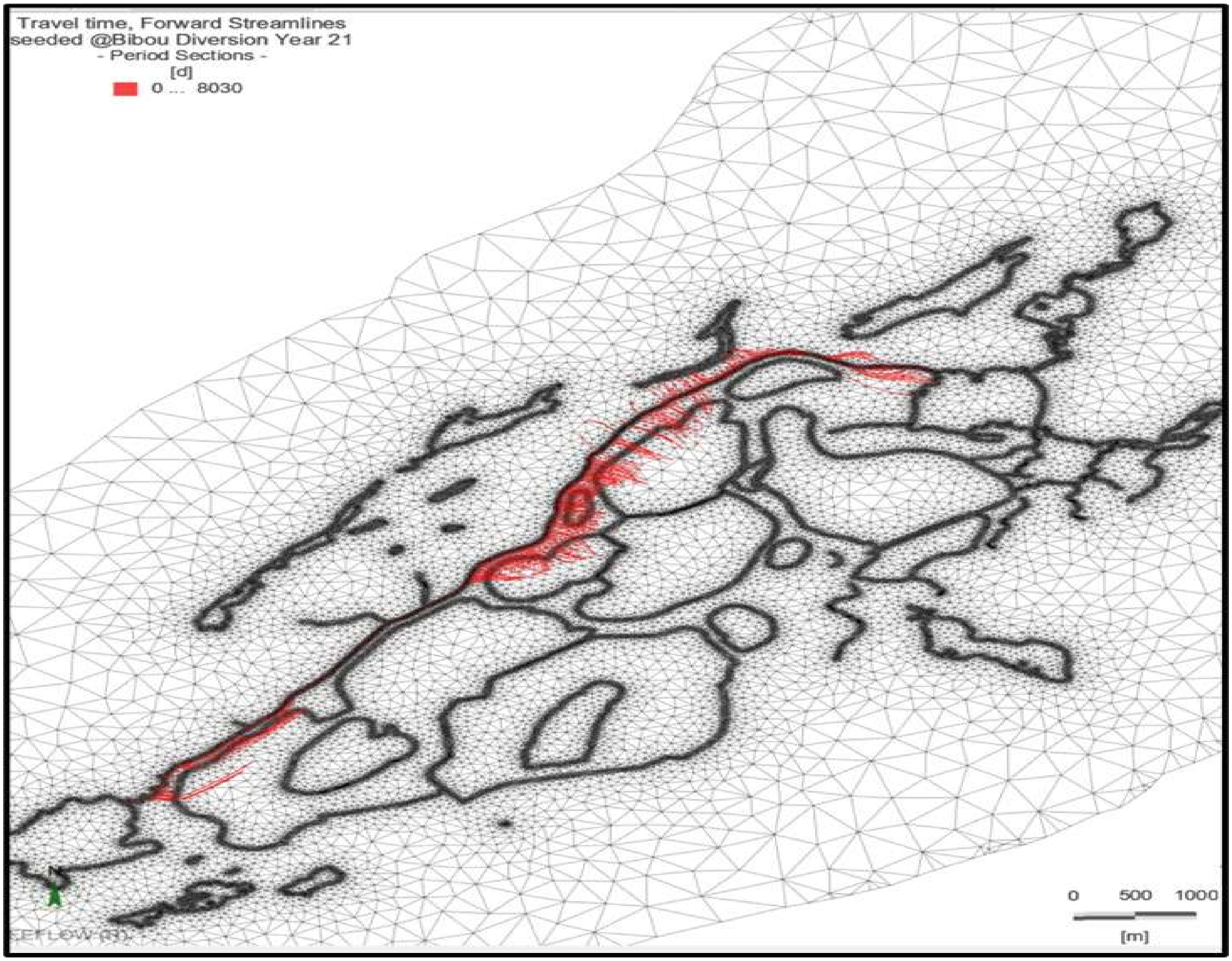

Figure 52: Forward Particle Tracking for the Bibou Creek Diversion Channel in Year 21 Scenario

On the water budget analysis aspect, the simulated groundwater infiltration rate for Pits J4, 87 and X22 would be 2,046.3, 2,950.9 and 1,965.6m^3/d, respectively (Table 7). The simulated groundwater infiltration rates in the Pits J4 and 87 would increase significantly (by 25.3% (i.e., 413 m^3/d) for Pit J4, by 34.3% (i.e., 753.1 m3/d) for Pit 87) compared to the base case scenario. The simulated groundwater infiltration rate for the Bibou Creek diversion channel would be 2254 m^3/d. Compared to the base case scenario, it would increase significantly (by 60.8% (i.e., 852.4 m^3/d)) because of decreased mining activities (only active Pits 87 and X22) than the Year 10 scenario (active Pits J4, 87 and SW). (Table 7). Compared to the Year 10 scenario, it also would increase significantly (i.e., by 1,214.6 m^3/d).

In the Year 21 scenario, Pit 87 would not be hydraulically connected to the Bibou Creek diversion channel (Figure 51). Therefore, Pit 87 would not receive any water from the Bibou Creek diversion channel but receive groundwater from Pit X22. The forward particle tracking results for the Bibou Creek diversion channel (Figure 52) also confirm that there would be no hydraulic connection of Pit 87 with the Bibou Creek diversion channel. The results show that the Bibou Creek diversion channel would contribute to Pit x22, which is located west of Pit 87. In this scenario, the simulated groundwater infiltration rate for Pit J4 would decrease compared to that for Pit J4 in the Year 10 scenario because of its inactivity. In the Year 10 scenario, Pits J4 and 87, which would be hydraulically connected to the Bibou Creek diversion channel, would receive a combined 5,393.9 m^3/d of groundwater. In the Year 21 scenario, Pits J4 and X22, which would be hydraulically connected to the Bibou Creek diversion channel, would receive a combined 4,011.9 m^3/d of groundwater. Therefore, in the Year 21 scenario, a smaller amount (i.e., 1,382 m^3/d) of groundwater would infiltrate to those pits, which would be hydraulically connected to the Bibou Creek diversion channel. Of the 1382 m^3/d of groundwater infiltration rate, an additional 1,214.6 m^3/d (i.e., 87.8%) of groundwater would infiltrate to the Bibou Creek diversion channel in the Year 21 scenario. This indicates that the effects of mining activities on the Bibou Creek diversion channel also depend on the mining sequence plan.

5.4 Mine Closure Scenario

The hydraulic head field in overburden predicted by the calibrated model in the mine closure scenario is shown in Figure 53. The hydraulic head in overburden would vary by about 102 meters between the highest hydraulic head located to the south-west from the lac (Lake) B (440.5 masl) and the lowest hydraulic head located to the north in the Lac (Lake) Boisfort (338.5 masl), which was used as a constant head boundary condition of the model domain. Whereas the hydraulic head in bedrock (Figure 54) would vary by about 90 meters between the highest hydraulic head located to the central-west part of the model domain near the model boundary (428 masl) and the lowest hydraulic head located to the north in the Lac (Lake) Boisfort (338.5 masl).

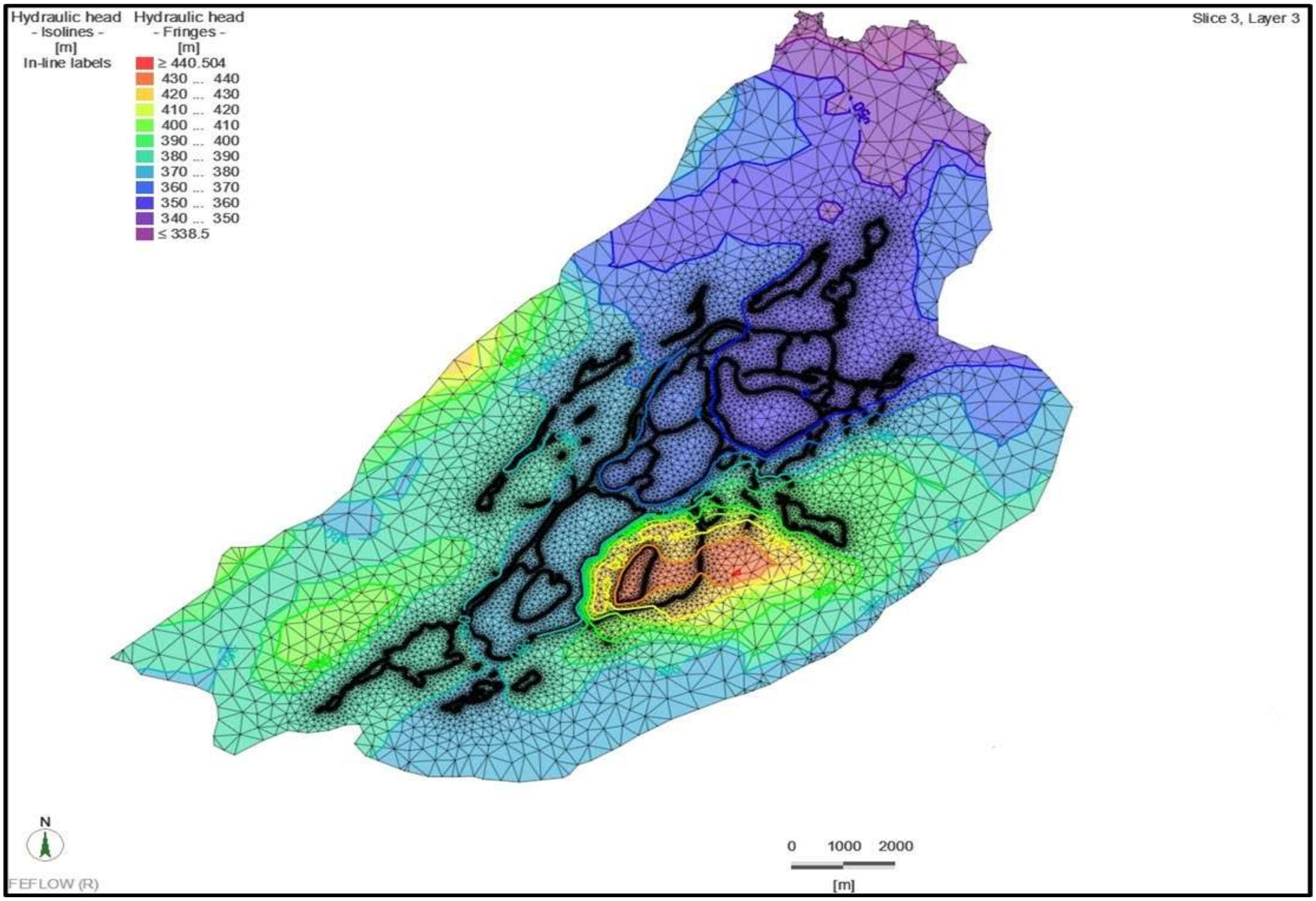

Figure 53: Hydraulic Head Distribution for Mine Closure Scenario (Overburden)

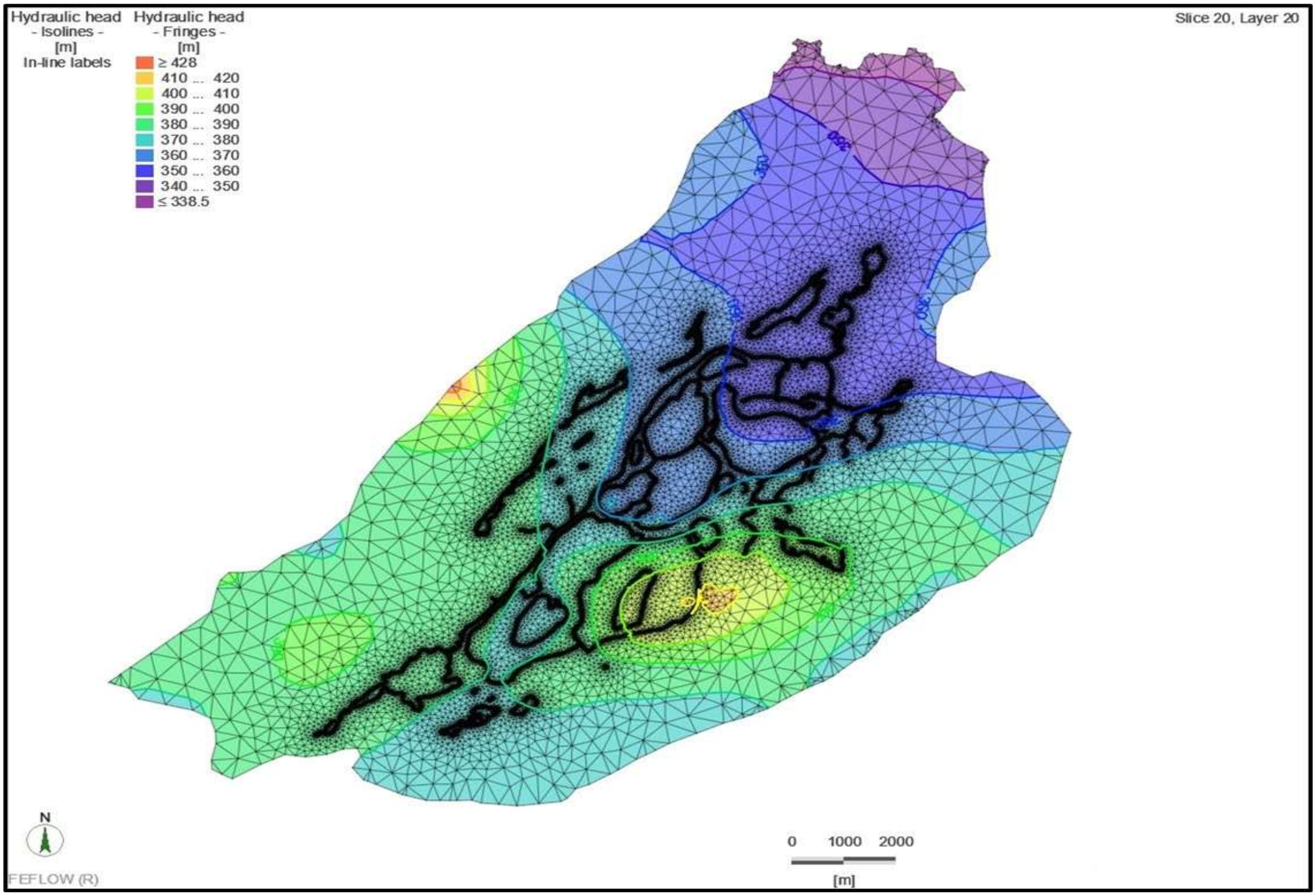

Figure 54: Hydraulic Head Distribution for Mine Closure Scenario (Bedrock)

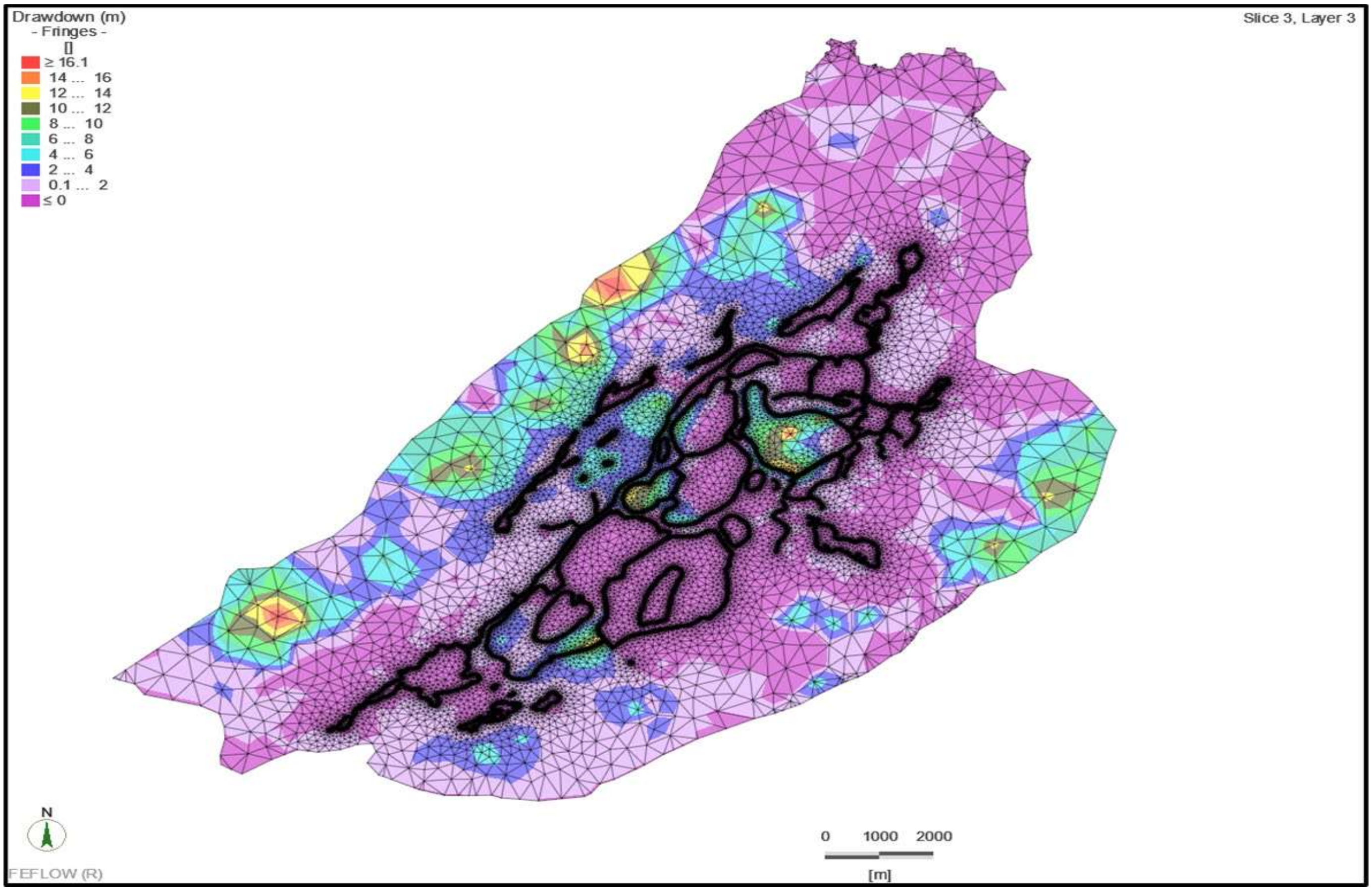

Figure 55: Predicted Drawdown for Mine Closure with Respect to the Base Case Scenario (Overburden)

When the hydraulic head in overburden in the mine closure scenario is compared with that for the base scenario, the maximum drawdown (approximately 18.84 m) in overburden would occur in the waste rock pile, located just east of Pit J4 (Figure 55). A resurgence of groundwater level (approximately 54.53 m) in overburden would occur in Pit 87 because a constant head boundary condition with a value of 363.1 m was used to represent the pit lake (Figure 56). Comparing the hydraulic head in bedrock in the mine closure scenario with that in the base case scenario, a maximum drawdown (approximately 8.45 m) in bedrock would occur in the north-west part of the model domain near the model boundary (Figure 57).

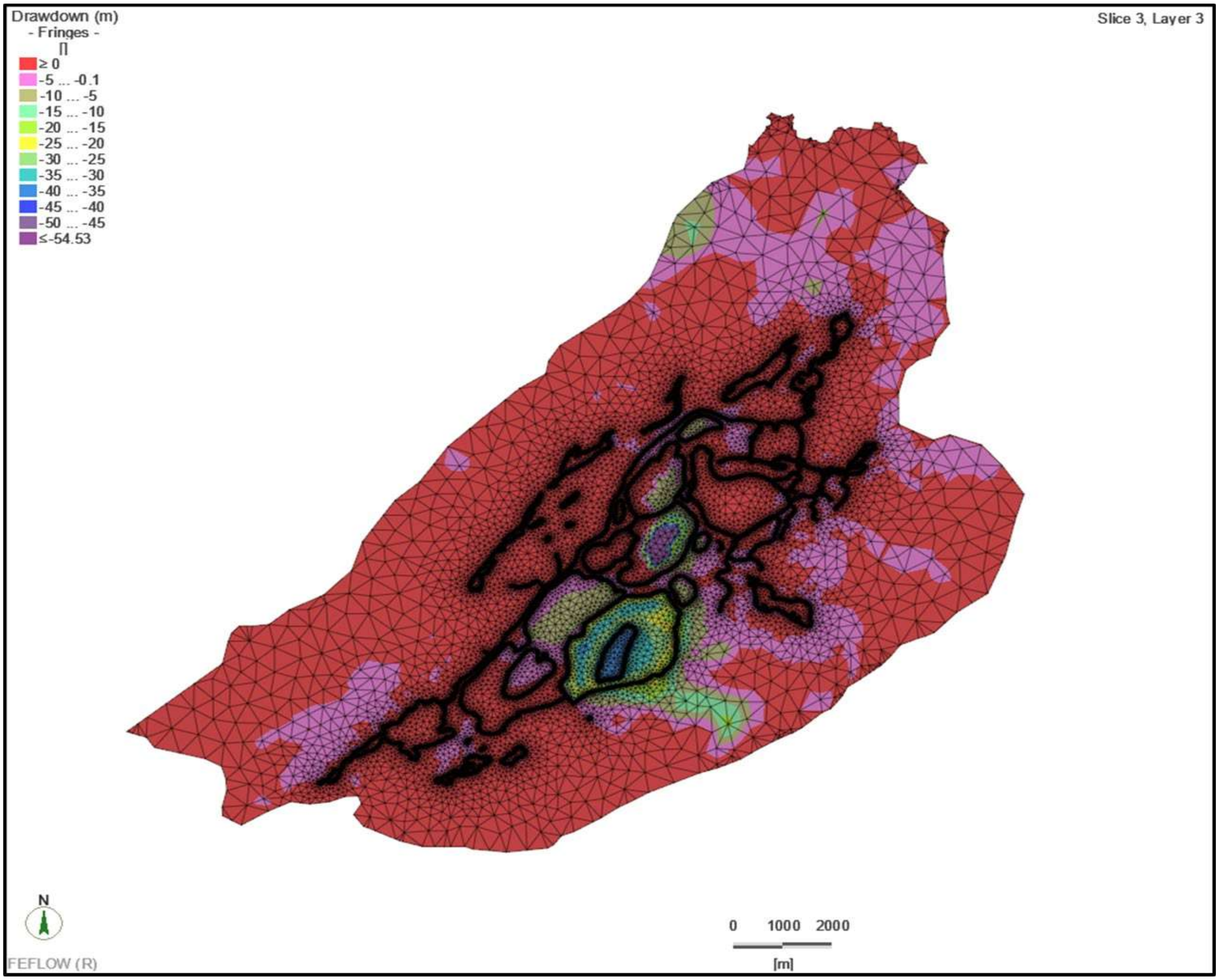

Figure 56: Predicted Rise of Groundwater for Mine Closure Scenario Relative to Base Case Scenario (Overburden). Here Negative Sign Indicates Increase in Groundwater Head

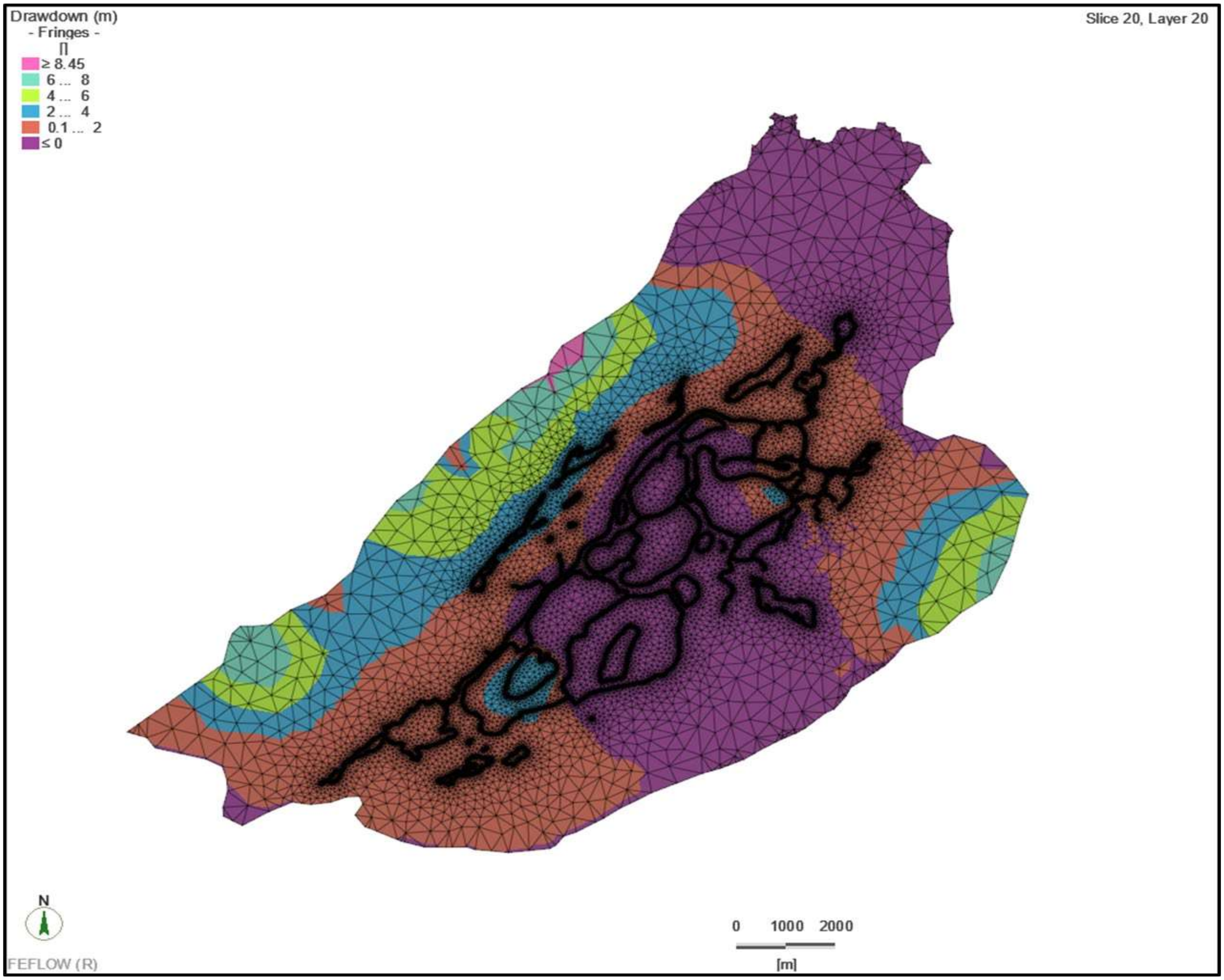

Figure 57: Predicted Drawdown for Mine Closure Scenario with Respect to the Base Case Scenario (Bedrock)

In this scenario, Pits J4, 87 and SW will be converted into pit lakes and maintained at the same water level (i.e., 363.1 m) in pits. Therefore, particle tracking analysis was done for 3 pits together. Figures 58 and 59 indicate Pits J4 and X22 would be hydraulically connected to the Bibou Creek diversion channel based on 200 years (i.e., 73,000 days) of forward and backward particle tracking analyses. However, Pit 87 would not be hydraulically connected to the Bibou Creek diversion channel. Therefore, Pit 87 would not receive any water from the Bibou Creek diversion channel. This is verified from the forward particle tracking results for the Bibou Creek diversion channel (Figure 60).

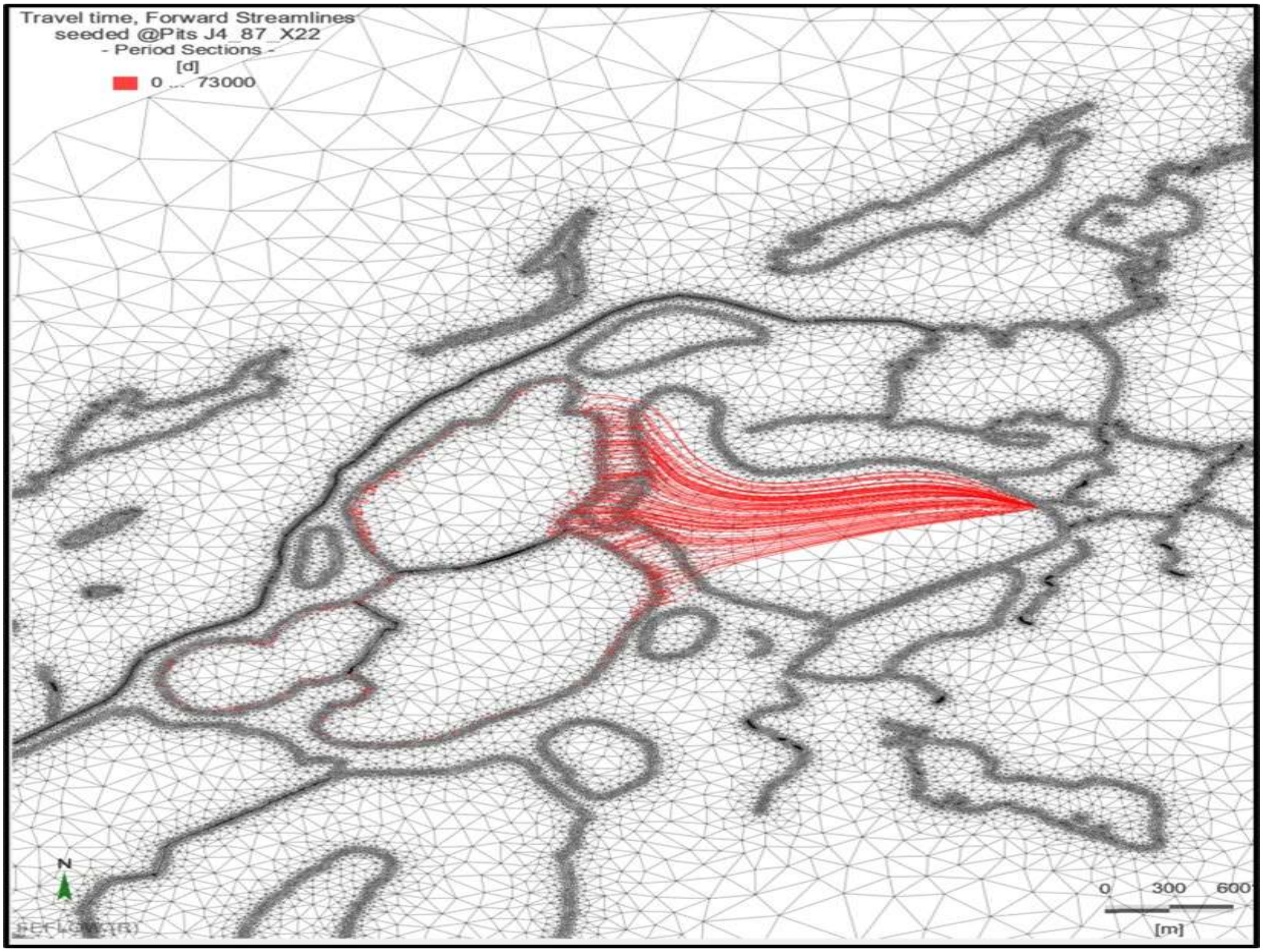

Figure 58: Forward Particle Tracking for Pits J4, 87 And X22 for Mine Closure Scenario

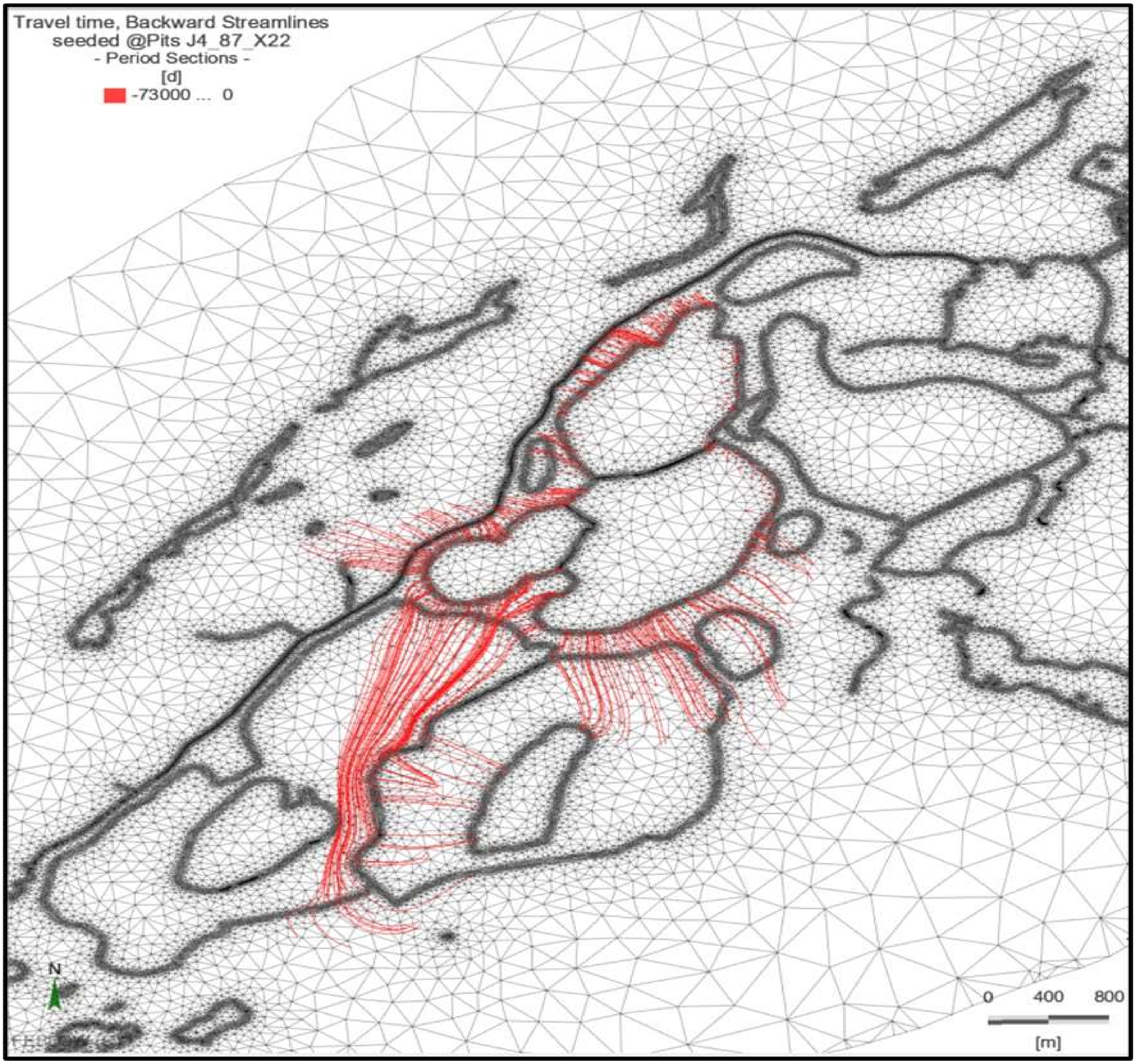

Figure 59: Backward Particle Tracking for Pits J4, 87 And X22 for Mine Closure Scenario

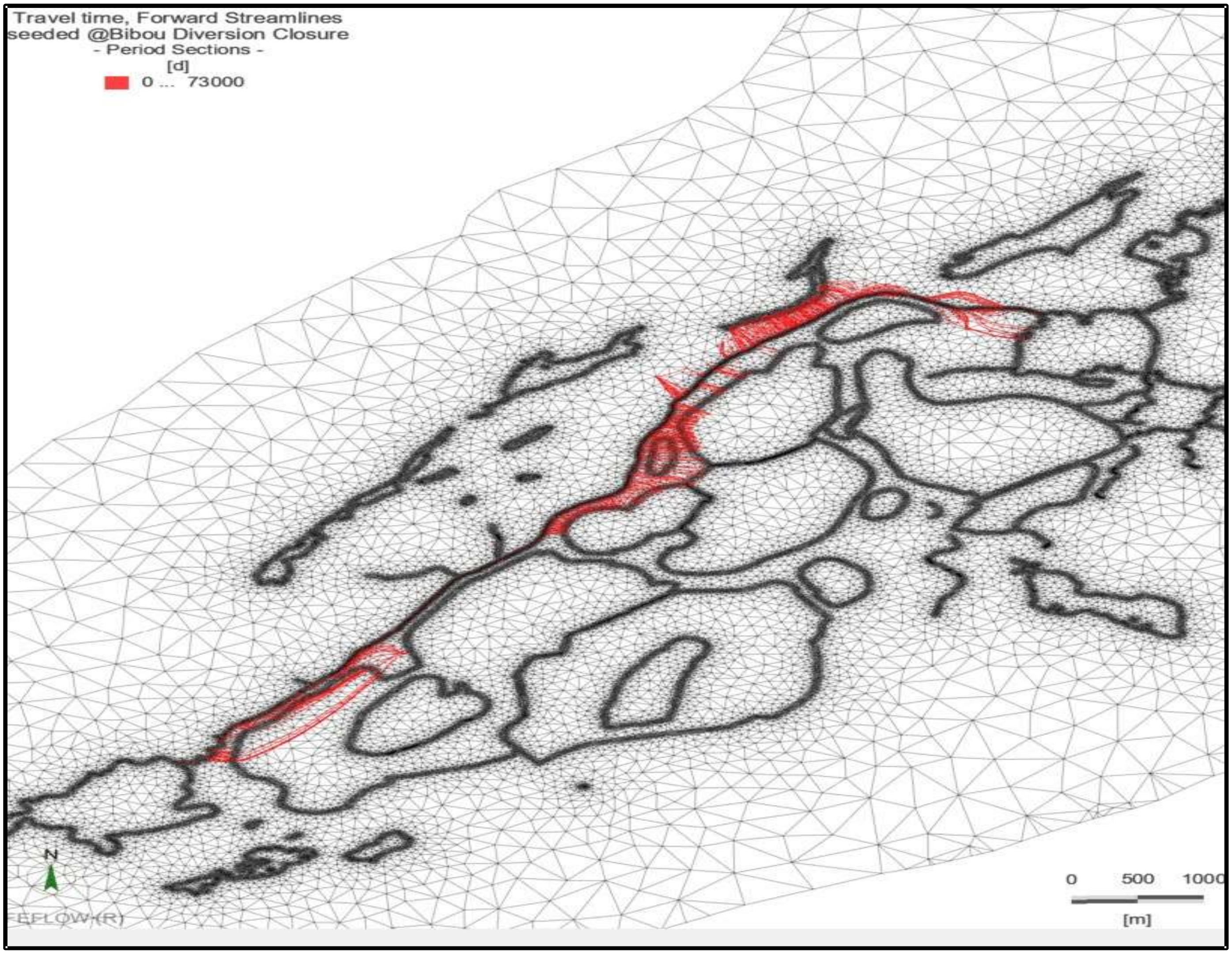

Figure 60: Forward Particle Tracking for the Bibou Creek Diversion for Mine Closure Scenario

From a water budget analysis standpoint, the combined simulated groundwater infiltration rate for Pits J4, 87 and X22 would be 1,401.9m^3/d (Table 7). On the other hand, the simulated groundwater infiltration rate for the Bibou Creek diversion would be 3,897.7 m^3/d. Compared to the base case scenario, the infiltration rate would increase significantly (i.e., 178.1%) (Table 8). Compared to the Year 10 and 21 scenarios, it also would increase significantly with no mining activity.

Table 7: Groundwater infiltration rates in the pits during various phases of mine development

Pit	Groundwater Infiltration Rate (m^3/d)			
	Base case	Year 10	Year 21	Mine Closure
J4	1633.3	2306.6	2046.3	1401.9
87	2197.8	3087.3	2950.9	
X22	-		1965.6	
SW	-	2997.9	-	-
Total	**3831.1**	**8391.8**	**6962.8**	**1401.9**

Table 8: Groundwater Infiltration Rates in The Bibou Creek/Bibou Creek Diversion Channel During Various Phases of the Mine. The Values Within Parenthesis Indicate the Change In Groundwater Infiltration Rate (In Percentage) With respect to the Base Case Scenario. Negative Sign Indicates Decrease In Groundwater Infiltration Rate

Stream	Groundwater Infiltration Rate (m^3/d)			
	Base case	Year 10	Year 21	Mine Closure
Bibou Creek/Bibou Creek Diversion	1401.6	1039.4 (-25.8%)	2254.0 (60.8%)	3897.7 (178.1%)

Table 9: Groundwater Infiltration Rates in Several Lakes During Various Phases of the Mine. The Values with the Parenthesis Indicate the Change in Groundwater Infiltration Rate (In Percentage) With Respect to the Base Case Scenario. Negative Sign Indicates Decrease in Groundwater Infiltration Rate

Lac (Lake)	Groundwater Infiltration Rate (m^3/d)			
	Base case	Year 10	Year 21	Mine Closure
A (PE43)	824.6	735.1 (-10.8%)	696 (-15.6%)	708.7 (-14.1%)
A4 (PE44)	140.3	88.9 (-36.6%)	88.2 (-37.1%)	88.5 (-36.9%)
B (PE29)	783.2	754.5 (-3.7%)	827.6 (5.7%)	827.5 (5.6%)
Amont (PE2)	2042.5	2021.7 (-1.0%)	1934.9 (-5.3%)	1928.8 (-5.7%)
C7	-342	-330.6 (3.3%)	-396.1 (-15.8%)	-431.7 (-26.2%)

Lac (Lake)	Groundwater Infiltration Rate (m^3/d)			
	Base case	Year 10	Year 21	Mine Closure
D	549.2	466.8 (-15%)	327.2 (-40.4%)	339.1 (-38.2%)
D1 (PE58)	519.8	679.2 (30.7%)	652.5 (25.5%)	778.3 (49.7%)
D2 (PE60)	107.4	217.5 (102.4%)	83.6 (-22.2%)	85.1 (-20.8%)
E2 (PE57)	193.1	160.7 (-16.8%)	89.7 (-53.5%)	117.3 (-39.2%)
E3 (PE54)	-141.2	-10.6 (92.5%)	-10.6 (92.5%)	-10.6 (92.5%)
E5 (PE53)	-226.9	-7.8 (96.6%)	-7.8 (96.6%)	-7.8 (96.6%)

6 Conclusions and Recommendations

A 3-Dimensional numerical groundwater model was developed using FEFLOW, as part of an Environmental Impact Study, by predicting scenarios of the aquifer and surface water bodies during various phases of the mine life at the Troilus Mine site in Chibougamau, Quebec. Four scenarios (i.e., base case, Year 10, Year 21, mine closure) were generated as per the mining sequence plan. Modeling results indicate that the drawdowns simulated in and near the pits are significant. In the Year 10 scenario, during the most active phase of the mine life when 3 pits will operate simultaneously, the maximum drawdown (438.8 m) in overburden would occur in Pit 87 with respect to the base case (i.e., pre-mining) scenario.

The extent of drawdown effect from the pits is dependent on the mining sequence plan and site topography. In the Year 10 scenario, the drawdown would extend a maximum of approximately 2,755 m in the south-west direction from Pit 87, 2,000 m in the east direction from Pit J4, 1,450 m in the east direction from Pit SW. In the Year 21 scenario, when 2 pits will operate at the same time, the drawdown would extend maximum approximately 1,855 m west from pit 87, and 1,901 m south-west from pit X22. However, the presence of the tailing pond limits the drawdown between Pits 87 and SW. In addition, the proposed diversion of Bibou Creek limits the drawdown to the north-west by recharging the aquifer. Therefore, the effects of mining activities on the aquifer are limited in the study area, except in and near the pits.

The simulated groundwater infiltration rate for Pits J4, 87 and SW would be 2,306.6, 3,087.3 and 2,997.9 m^3/d, respectively, in the Year 10 scenario. Simulated groundwater infiltration rates in the Pits J4 and 87 would increase significantly (41.2% for Pit J4, 40.5% for Pit 87) due to mining activities (dewatering) compared to the base case scenario. The simulated groundwater infiltration rate for the Bibou Creek diversion channel in the Year 10 scenario would be 1,039.4m^3/d. Compared to the base case scenario, the infiltration rate would decrease significantly (25.8%) because of increased mining activities (i.e., dewatering of 3 pits). The simulated groundwater infiltration rate for the Bibou Creek diversion channel would be 2,254 m^3/d in the Year 21 scenario. Compared to the base case scenario, it would increase significantly (60.8%) because of decreased mining activities (i.e., dewatering of 1 pit, and other pits would fill up with tailings). This output indicates that the groundwater infiltration rate in the Bibou Creek diversion channel depends on the amount of mining activities (i.e., pit dewatering), which is related to the mining sequence plan. In other words, groundwater infiltration rate in the Bibou Creek diversion channel would decrease when pits are at their lowest configuration in elevation (i.e., Year 10 scenario) because the Bibou Creek diversion channel would contribute more to groundwater recharge. In contrast, groundwater infiltration rate in the Bibou Creek diversion channel would increase when pits are filled with tailings (i.e., Year 21 scenario) and subsequently with water (i.e., mine closure scenario) because the Bibou Creek diversion channel would contribute less to groundwater recharge.

The following recommendations are proposed for better site -assessment of pit dewatering during various phases of mine life:

- Installing Wells and Monitoring Groundwater Levels: More groundwater wells need to be installed near the pits. Groundwater levels need to be monitored by installing pressure transducers/loggers in observation wells located around the pits. This will provide a comprehensive picture of the impact of pit dewatering on groundwater levels.
- Monitoring Water Levels and Flow of the Bibou Creek: Water levels and flow of Bibou Creek need to be monitored upstream of the SW Pit and downstream of the J4 Pit to obtain continuous information on water losses to groundwater during the various operating phases of mine life. Monitoring needs to continue until the diversion is built. Then, monitoring the flow of the diversion upstream and downstream of the site will make it possible to determine whether the diversion minimize the loss of surface water to groundwater.
- Lake Water Level Monitoring: The water level of Lac (Lake) Amont, Lac (Lake) A, Lac (Lake) A4, and Lac (Lake) C7 need to be monitored by installing pressure data loggers during the various operating phases of mine life. This will provide a more comprehensive picture of the impact of pit dewatering on the water level of lakes.
- Pits Lake Water Level Monitoring: After mine closure, pit lake water levels (J4, 87, X22) need to be monitored regularly in order to avoid flooding of surface water.

7 Closing Statements

This report has been prepared for the exclusive use of Troilus Gold Corporation in accordance with the scope of work detailed therein.

The opinions and recommendations provided by BluMetric in this report have relied in good faith on the information provided by others as noted in the report and has not been independently verified for accuracy or completeness. BluMetric has also assumed that the information provided is factual and accurate.

The limitations noted apply to the report body, appendices and all report tables and figures. BluMetric agrees that the report represents its professional judgement as described above and that the information has been prepared for the specific purpose and use described in the report.

The findings presented in this report are based on the conditions observed and reported by others at specified dates and locations, and for the types of analysis completed. Unless otherwise stated, the findings in this report cannot be extended to previous or future site conditions, portions of the study area that were not investigated directly, or types of analysis not performed.

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Respectfully submitted,
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Appendix A

Model Limitations

Groundwater modeling incorporates an unavoidable amount of uncertainty as it is a simplified representation of an often-complex natural hydrogeological system. This section highlights the uncertainties in relation to the model development, model calibration and prediction simulations, and possible methods of resolution by subsequent data acquisition, field monitoring, further analysis and/or modeling. Below is a list of model limitations:

- Due to the lack of stratification for the whole study area, this study assumed that Juxta-glacial and fluvioglacial deposit and till occupy the 2nd and 3rd layer, respectively, across the whole study area except the outcrop area.
- Due to the lack of field measured lake water level data, the lakes reference surface water level was assumed to be equivalent to the value of its surface in the DEM.
- Climate data, used to estimated recharge rates, were used from 2 stations which were 140 km away from the mine site.

The following strategies would help to improve the accuracy of this model.

1. Additional monitoring wells having at least one full year of recorded groundwater levels.
2. In-detailed soil stratifications for Layer 2 and 3 of the whole model domain.
3. Field measured stream and lake water levels would help to update boundary conditions.
4. Mine site's climate station data would improve the recharge value in the study area.

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