APPENDIX 6A

Hydrogeology Modelling Report

Valentine Gold Project: Hydrogeology Modelling

Final Report

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Executive Summary

Hydrogeology modelling was conducted to identify changes to groundwater levels and flow pathways to inform the assessment of potential effects of the Valentine Gold Project on groundwater and surface water resources. The modelling was conducted using MODFLOW-NWT and was calibrated to baseline conditions within acceptable industry standards.

The construction and operation of the Project will require the open pits to be dewatered to control groundwater inflows (and surface water inflows which are considered outside of this report). The dewatering of the open pit will result in the drawdown of the water table by up to 1.0 m over an area extending approximately up to 1.6 km from the Leprechaun pit and up to 1.3 km from the Marathon pit. The drawdown areas are extended to the north in the vicinity of the Leprechaun pit, and to the south in the vicinity of the Marathon pit. Increased infiltration in the waste rock piles and the tailings management facility results in some mounding within the waste rock piles, which also limits the drawdown in the direction of the waste rock piles.

A sensitivity analysis of the hydraulic conductivity of the Victoria Lake Thrust Fault shows that increasing the hydraulic conductivity of the fault by an order of magnitude above the bulk hydraulic conductivity may more than double the groundwater inflow rate to the open pits. Additional testing to confirm the hydraulic conductivity of the faults is recommended, so that appropriate groundwater inflow mitigation measures to the pits can be developed, if necessary.

The fate of groundwater recharging beneath the waste rock piles and low-grade ore stockpiles during operation was determined by conducting particle tracking in the groundwater flow model. Flow rates to seepage collection ditches, the open pit, or surface water receivers are generated for use in the Water Quantity and Quality Modelling, and Assimilative Capacity reports to assess the effects on surface water. Groundwater originating from the TMF and travelling to Victoria River is attenuated by a factor of 0.0018 during operation.

Upon the termination of Project activities (i.e., the decommissioning, rehabilitation and closure phase of the Project), the open pits will be allowed to fill to form pit lakes. The groundwater model was used to predict the groundwater inflow rates to the open pits for use in the water balance. Groundwater levels around the open pits are expected to recover, but a permanent lowering of the water table is expected in limited areas, based on maintaining a pit lake level that is many metres below the pre-development water table surface where hills at the sides of the pits are excavated.

Rehabilitation of the TMF at closure will alter the distribution of groundwater recharge originating from the TMF. The attenuation factor of solutes originating from the TMF and discharging to Victoria River 100 years after closure is 0.039.

Groundwater discharge to surface water features associated with Project facilities represents a minor component of the overall surface water flow systems. The modelling results will be considered in the assessment of potential effects on the receiving environment.

Abbreviations

3D	Three-dimensional
ECCC	Environment and Climate Change Canada
EIS	Environmental Impact Statement
EPM	Equivalent Porous Media
HGO	High-Grade Ore
HSU	Hydrostratigraphic Unit
LGO	Low-Grade Ore
m	metre
Marathon	Marathon Gold Corporation
MODFLOW-NWT	MODFLOW-Newton Formulation
NL	Newfoundland and Labrador
Project	Valentine Gold Project
RCL	Red Cross Lake
RGC	Rogerson Lake Conglomerate
RMSE	Root Mean Square Error
SDG	Silurian-Devonian Granitoids

SPG	Snowshoe Pond Granite
TMF	Tailings Management Facility
USGS	United States Geological Survey
VLQ	Valentine Lake Quartz Monzonite
VLS	Victoria Lake Supergroup

1.0 INTRODUCTION

Marathon Gold Corporation (Marathon, the Proponent) proposes the construction, operation, and decommissioning, rehabilitation and closure of an open pit gold mine and associated ancillary activities, collectively known as the Valentine Gold Project (the Project). The Project is located in the central region of the Island of Newfoundland. The Project is centered on a topographic ridge that divides the Valentine Lake watershed to the north and west, and the Victoria Lake Reservoir and Victoria River watersheds to the south and east, respectively. Valentine Lake drains to the Victoria River and subsequently to Red Indian Lake. Victoria Lake Reservoir, which formerly drained to the Victoria River, was diverted to the southeast to flow through the Bay D'Espoir hydroelectric watershed.

The Project can be broadly divided into three complexes from north to south, the Marathon Complex, the Process Plant and Tailings Management Facility (TMF) Complex, and the Leprechaun Complex. The Project components include an open pit, waste rock pile, topsoil, overburden, and low grade ore (LGO) stockpiles at each of the Marathon and Leprechaun complexes, and ore processing facilities including crushing and process plants, high grade ore (HGO) stockpiles, TMF, and other associated buildings and processes at the Process Plant and TMF Complex. Project activities include the removal or relocation of existing infrastructure currently located within the Project Area.

1.1 STUDY OBJECTIVES

This Report entitled "Valentine Gold Project: Hydrogeology Modelling" (Hydrogeology Modelling report) has been prepared to assess the potential effects of the construction, operation, and decommissioning, rehabilitation and closure phases of the Project on groundwater resources and the consequent indirect effects on surface water resources.

To evaluate the effects of the Project, a groundwater flow model has been developed to provide estimates of:

- Changes in groundwater levels (drawdown), including changes to water table position and groundwater flow, due to dewatering of the open pits
- The time to fill the open pits from groundwater inflow once mining operations are terminated
- Changes to groundwater flow and discharge to watercourses and lakes during baseline, operation, and decommissioning, rehabilitation and closure
- Groundwater recharge and flow pathways from LGO stockpiles, waste rock piles and the TMF developed for the Project under operation and decommissioning, rehabilitation and closure

This Hydrogeology Modelling report forms part of the supporting documentation for the Environmental Impact Statement (EIS) completed for the Project.

2.0 BACKGROUND

This section provides an overview of the existing conditions that were used as background for the groundwater model development. Data collected in support of the Project and existing, publicly available regional hydrogeological information were reviewed for the period 2011 through 2020. The following data and reports were reviewed to characterize existing conditions for groundwater resources for the Project:

- Aquifer Test Analysis, Water Supply Well, Victoria Lake Exploration Camp. Prepared for Northeast Well Drilling Ltd. (Stantec 2011)
- Valentine Lake Project: Preliminary Baseline Hydrogeology Assessments (Stantec 2017 and Stantec 2019)
- Pre-Feasibility Geotechnical Investigation: Marathon & Leprechaun Deposits (Terrane 2020)
- Hydrogeology Baseline Report, Marathon Valentine Gold Project, Central Newfoundland (GEMTEC 2020)
- Valentine Lake Project: Hydrology and Surface Water Quality Monitoring Baseline Report (Stantec 2020e)

Additional information used in support of baseline water resource characterization was derived from:

- Geological / hydrogeological mapping information from GeoScience OnLine Atlas (Newfoundland and Labrador Department of Natural Resources [NLDNR] 2020)
- Historical Weather Data from Buchans Reference Climate Stations (Environment and Climate Change Canada [ECCC] 2020)

2.1 CLIMATE

The study area has a climate typical of the Island of Newfoundland. The nearest permanent weather monitoring station is located approximately 60 km northeast of the Project at the ECCC Buchans Station (Station ID 8400698). Weather statistics under climate normal conditions for the period 1981 to 2010 indicate a mean daily temperature of 3.8°C, mean annual precipitation of 1236.2 mm, with mean annual rainfall of 877 mm and the mean annual snowfall of 359.3 cm.

2.2 REGIONAL GEOLOGICAL CONTEXT

The Island of Newfoundland is located at the northeastern extent of the Appalachian orogeny (Ryan 1983). The Island of Newfoundland can be segmented into three orogenic belts including the Western Platform, the Mobile Belt, and the Avalon Platform where the Mobile Belt representing the remnants of the Iapetus Ocean (Colman-Sadd 1980). The study area is located in the axial region of the Paleozoic Mobile Belt which is characterized by Ordovician and Silurian sedimentary and volcanic rocks of ophiolitic sequences and island arcs (Colman-Sadd 1980). Metamorphism is present throughout the region ranging from low to moderate in the vicinity of the study area (Tettelaar and Dunsworth 2016) to high-grade in the marginal zones that flank the mobile belt (Colman-Sadd 1980).

2.2.1 Surficial Geology

A map of the surficial geology of the study area is shown on Figure 2-1 based on the maps prepared by Smith (2011). In general, morainal glacial till is the dominant overburden material. The till blankets much of the study area with a hummocky texture that can also be discontinuous and thin, typically less than 1.5 metres (m) thick (GEMTEC 2020), and is observed underlying organic and glaciofluvial deposits. In areas of higher topography, bedrock is observed to outcrop and is sometimes covered by vegetation, for instance in the southwest of the study area near the fork of Victoria Lake (GEMTEC 2020).

Till in the study area is composed of particle sizes ranging from clay to boulders, but in some areas may be sandy or gravelly such as the glaciofluvial and glacial outwash deposits specific to the Victoria River valley running through the site (GEMTEC 2020). The till is well to poorly drained and sandy loam to loam in texture. The poorly drained deposits are generally reserved to the undulated topography associated with organic or peaty soils (Newfoundland and Labrador Department of Natural Resources (NLDNR) 2020).

Exploration drilling indicates that the overburden within investigation site is characterized by the glacial till, ranging in thickness from 0.1 m to 17.1 m (average of 3.8 m), overlaid by a thin root mat. The thickest accumulations of till were observed in the hummocky and blanketed regions with the thinnest areas associated with the area of the proposed mine pits.

Aside from glacial till and exposed bedrock, peaty, organic-rich soil has been observed overlying till or bedrock in areas with poor drainage (GEMTEC 2020).

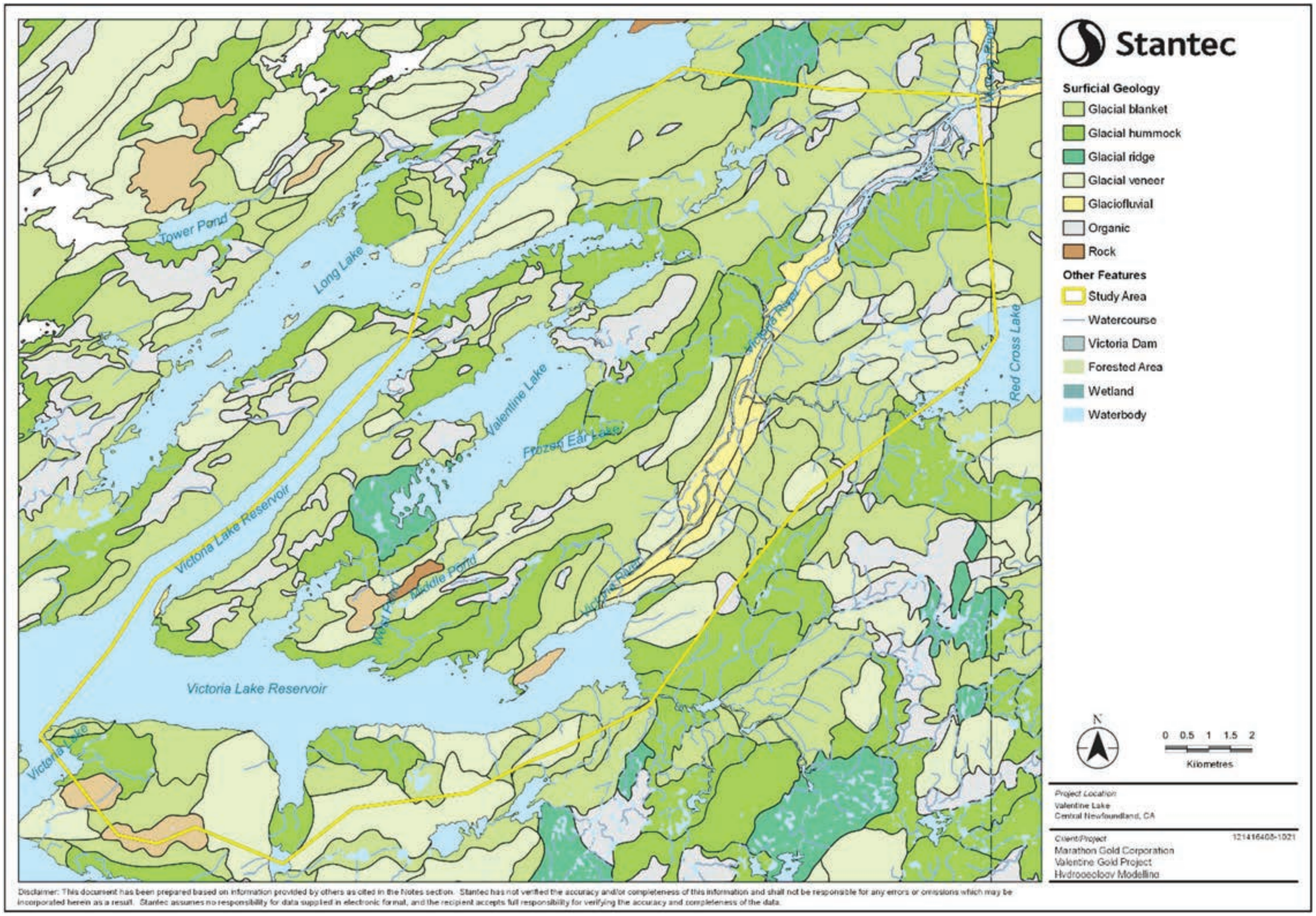

Figure 2-1 Surficial Geology

2.2.2 Bedrock Geology

The study area is located at the convergence of the Victoria Lake Supergroup (VLS), the Valentine Lake Quartz Monzonite (VLQ), and the Rogerson Lake Conglomerate (RGC), as shown on Figure 2-2.

The Cambrian-Ordovician VLS is comprised of island and back-arc volcanic rock, and volcanic or non-volcanic derived clastic rocks from a variety age ranges (Tettelaar and Dunsworth 2016). Within the study area, the VLS comprises of dark shale and siltstone containing thin, felsic, tuffaceous laminations. The shale layers mix with felsic volcanic blocks near the major thrust faults. The Victoria Lake Supergroup is separated into northern and southern terranes by the Rogerson Lake Conglomerate. The northern terrane consists of volcano-sedimentary rock. The southern terrane consists of volcanic, volcaniclastic and epiclastic rocks. Textures vary greatly in the VLS from mafic flows to volcanic breccias and tuff (Evans and Kean 2002). The VLS has been intruded by granodioritic to gabbroic plutons.

The Neoproterozoic (Precambrian)VLQ intrusive suite predates the hosting volcanic and sedimentary rock (Tettelaar and Dunsworth 2016), and lays to the north of the RGC which runs lengthwise through the site. The primary classification of the VLQ within the investigation site is quartz monzonite.

The Silurian RGC stretches 160 km lying unconformably between the VLS and VLQ. It is lays overturned on top of the VLQ. The RGC was interpreted to have filled in a depression that was laterally bounded by faults. (Tettelaar and Dunsworth 2016).

The Red Cross Lake (RCL) Instrusion is hosted by the VLS and lies to the south of the Victoria Lake Thrust Fault (Figure 2-2). This suite of layered mafic-ultramafic intrusion includes peridotite, troctolite, and olivine gabbro (Vulcan Minerals Inc, n.d.).

Regional low-grade metamorphism has occurred ranging from the lower to upper greenschist facies (Tettelaar and Dunsworth 2016) as a result of low temperature and moderate pressure conditions and is expected to decrease the hydraulic conductivity of the bedrock. Deep and penetrative foliation is observed on a regional scale within the site as a result of regional deformation and RGC has experienced heterogeneous ductile deformation (Tettelaar and Dunsworth 2016).

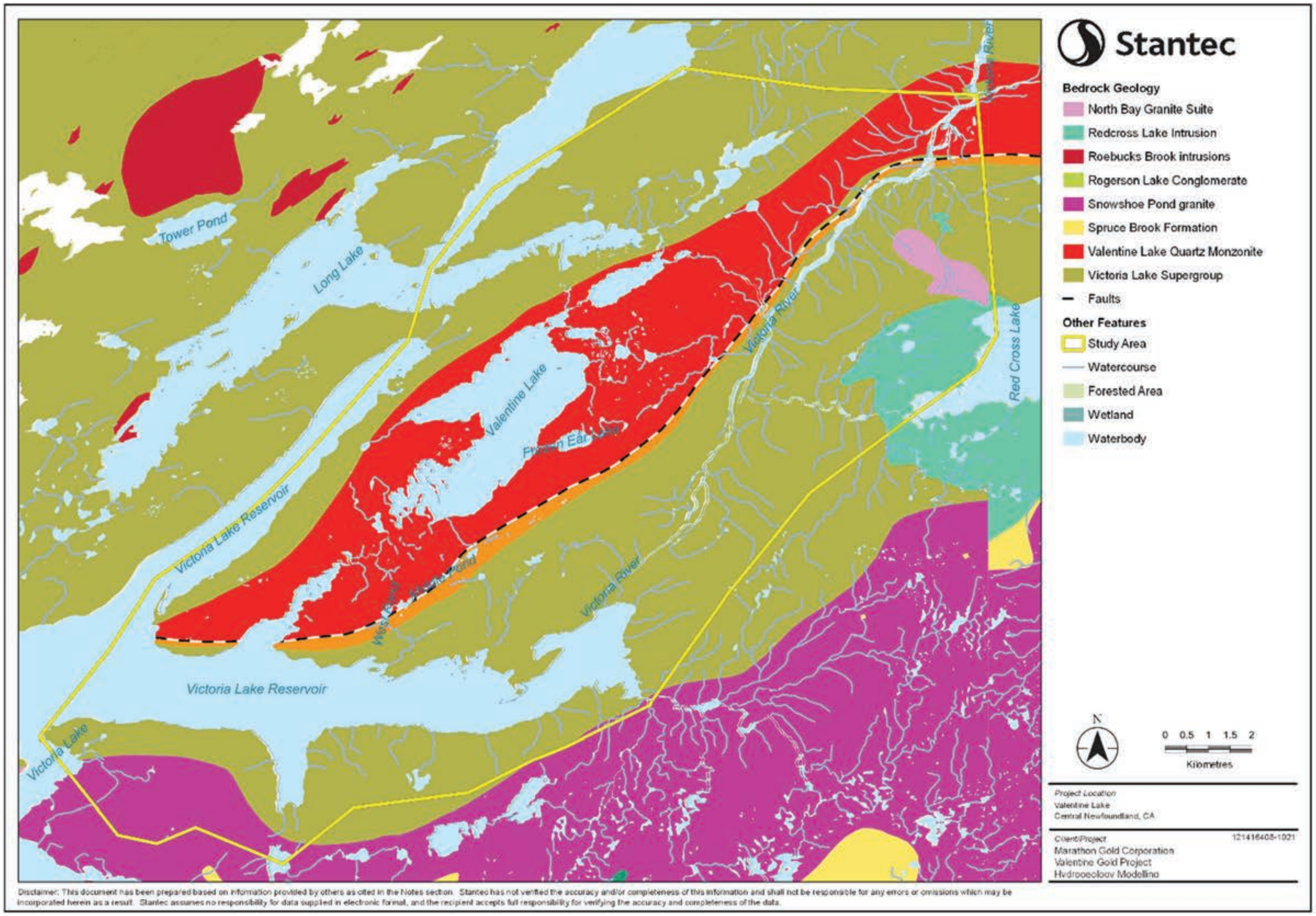

Figure 2-2 Bedrock Geology

3.0 CONCEPTUAL MODEL

3.1 MODELLING APPROACH

A conceptual model water was developed to guide the creation of a numerical groundwater model that accurately represents the natural environment. The conceptual model reflects the fundamental hydrogeological concepts while considering pertinent geological, hydrogeological and hydrological data. Understanding boundary conditions and how they may be entered into a numerical model is also important at this stage. Ideally, the initial conceptual model is created in the simplest form and complexities are only added when necessary.

Geological maps were used to delineate the contact boundaries between geologic units, which were subsequently interpreted as separate hydrostratigraphic units (HSU). Given the nearly vertical dip of the local geology and geologic structures such as faults, these geologic contacts were interpreted to penetrate vertically downwards through the bedrock.

The conceptual model constituents were then imported into the graphical user interface ModelMuse, which was created by the United States Geological Survey (USGS).

3.2 CONCEPTUAL MODEL BOUNDARIES

The boundaries of the conceptual model are considered to extend at least as far as the proposed domain for the groundwater flow model. These boundaries are considered to coincide with the groundwater divides of the local groundwater flow system. Based on the assumption that the piezometric surface is a subdued replica of the topographic surface, these lateral extents were set to equate to the boundaries of the watershed. The watershed was delineated using the topography by crossing contour lines at right angles, and with the bathymetry unknown, the domain either enclosed water bodies or transect the center. The vertical limits of the conceptual model were constrained by the topographic surface and a depth sufficiently deeper than the proposed open pits for the mine or deepest borehole.

The conceptual and groundwater flow models were developed using the geologic, hydrologic, and hydrogeologic data collected by Stantec (2017, 2019) in addition to the results of previous investigations and reports conducted by Terrane (2020) and GEMTEC (2020).

3.3 HYDROSTRATIGRAPHY

There are seven primary HSUs considered in the development of the conceptual model. These units are based on the surficial geology and the six lithostratigraphic units of the bedrock. The overburden HSU overlies the entire domain and was considered to be less than 10 m thick and in some areas, less than 1 m. The hydrostratigraphic units that were based on lithostratigraphic units as shown on Figure 2-2 include:

- Red Cross Lake Intrusion (RCL)

- Rogerson Conglomerate (RGC)
- Silurian-Devonian Granitoids (SDG)
- Snowshoe Pond Granite (SPG)
- Valentine Lake Quartz Monzonite (VLQ)
- Victoria Lake Supergroup (VLS)

Multiple HSUs were considered to have equivalent hydraulic properties based on similar lithology and to reduce complexity, and it was assumed that these lithostratigraphic units have been subjected to the same degree of faulting and jointing resulting in similar secondary permeability.

Upon development of the 3D groundwater flow model, the 6 lithology-based HSUs were expanded into 18 units based on depths below the bedrock surface, including:

- Upper bedrock (0 m to 20 m)
- Intermediate bedrock (20 m to 120 m)
- Deep bedrock (120 m to 370 m)

3.3.1 Overburden

Within the study area, bedrock is generally overlain by overburden consisting of loose to compact, silty sand with gravel and minor cobbles, boulders, and clay (GEMTEC 2020). The relatively coarse grain size for the matrix of the glacial till suggests that hydraulic conductivity will be on the upper end of the expected range of 1×10^{-12} to 2×10^{-6} (Domenico and Schwartz 1998). For the purpose of this investigation, the overburden will be modelled as a continuous layer of varying thickness based on prior information sourced from exploration activities. Hydraulic conductivity testing of the overburden was completed at five wells, and ranged from 4.6×10^{-7} to 2.8×10^{-5} m/s (GEMTEC 2020).

3.3.2 Victoria Lake Supergroup

The VLS HSU covers majority of the model domain, including underneath the majority of the surface water features. The lithology varies from volcanic to sedimentary rock, which suggest that there will be both heterogeneity and anisotropy in hydraulic conductivity. Greenschist facies metamorphism is present and will likely reduce the primary hydraulic conductivity of this unit.

Two monitoring wells were installed in this hydrostratigraphic layer in addition to a third well supplying the existing exploration camp. Hydraulic conductivity estimates from testing of this unit range from 7.9×10^{-7} m/s to 8.6×10^{-5} m/s in the upper and intermediate bedrock.

3.3.3 Valentine Lake Quartz Monzonite

The VLQ HSU is an elongated intrusive suite in the center of the domain that runs parallel to the long axis of the southwest-northeast trend of this formation. This unit encompasses both the Marathon and Leprechaun pits.

Quartz monzonite is a felsic crystalline rock that would be expected to have low hydraulic conductivity unless significantly fractured. Hydraulic conductivity testing has been conducted at 11 wells completed in the VLQ (GEMTEC 2020). The geometric means of hydraulic conductivity from well tests range from 3.9×10^{-10} m/s to 1.7×10^{-6} m/s and generally decreases with depth; however, well tests show that the deepest wells had higher hydraulic conductivity than wells in the 170 m to 296 m range.

3.3.4 Rogerson Lake Conglomerate

The RGC HSU is elongated in the NE-SW direction and forms the footwall of the Valentine Lake Thrust Fault. This HSU contacts both pits and separates the southern terrane of the Victoria Lake Supergroup from the Valentine Lake Quartz Monzonite.

The Rogerson Lake Conglomerate consists of conglomerate deposits and coarse sandstones, suggesting a relatively higher hydraulic conductivity than the other HSUs, particularly the crystalline units. Hydraulic conductivity testing was conducted at three wells completed in the Rogerson Lake Conglomerate. The geometric means of hydraulic conductivity from well tests range from 1.3×10^{-6} m/s to 1.5×10^{-5} m/s (GEMTEC 2020). This aligns with the expected range for sandstones of 3×10^{-10} m/s to 6×10^{-6} m/s (Domenico and Schwartz 1998).

3.3.5 Red Cross Lake Intrusion

The RCL HSU covers a small proportion of the model domain and is located in the northeast lying just south of the Victoria Lake Thrust Fault.

The texture of RCL is coarse grained and crystalline, therefore low primary hydraulic conductivity is expected. Hydraulic conductivity testing has been conducted at three wells completed within RCL. The hydraulic conductivity ranges from 8.7×10^{-7} m/s to 1.7×10^{-6} m/s in the upper 80 m and 6.2×10^{-9} m/s in a 260 m deep well (GEMTEC 2020). These values align well with the empirical ranges suggesting that there is physical weathering within the top 80 m and the deeper bedrock is relatively unfractured.

3.3.6 Silurian-Devonian Granitoids (North Bay Granite)

The SDG HSU covesr a small portion of model domain and is located in the northeast adjacent to the RCL. There is little information available on the hydraulic properties of the SDG, but the general range in hydraulic conductivity for weathered granite are 3.3×10^{-6} m/s to 5.2×10^{-5} m/s (Domenico & Schwartz 1990), and lower for more competent bedrock.

The conceptual model assumes that the upper 20 m of the SDG is weathered with the intermediate and deeper bedrock more competent. For the purpose of reducing the complexity of the conceptual model, and given the size and location within the domain, hydraulic properties have been assumed to be the same as VLQ.

3.3.7 Snowshoe Pond Granite

The SPG HSU is a large granitic intrusion that covers a small portion of model domain and is located in the southeast end of the domain on the south side of Victoria Lake Reservoir.

The conceptual model assumes that the upper 20 m of SPG is weathered with the intermediate and deeper bedrock more competent. For the purpose of reducing the complexity of the conceptual model, and given the size and location being on the other side of Victoria Lake Reservoir from the open pits, hydraulic properties have been assumed to be the same as VLQ.

4.0 MODEL CONSTRUCTION AND CALIBRATION

This section describes the construction of the hydrogeology model using the hydrostratigraphic units of the conceptual model described in Section 3.0. The calibration of the model using available information on water levels and stream flow measurements collected as part of the baseline monitoring programs is also described.

The MODFLOW-Newton (NWT) (Niswonger et al. 2011) numerical modeling code was used for this modeling exercise. MODFLOW is the most commonly used groundwater code in the world and has been documented and tested extensively (Wels et al. 2012). There are a variety of modules and packages available to be used in MODFLOW that gives it the versatility to be adapted to many hydrogeologic problems. The MODFLOW-NWT formulation was selected for this case due to its ability to solve the saturated groundwater flow equations under complex hydrogeological conditions while avoiding numerical instability that is associated with the drying (i.e., lowering the water table below the bottom of a model cell) of active cells.

An equivalent porous media (EPM) approach was used to parametrize and simulate the flow within the overburden and bedrock. EPM represents the hydraulic properties of an elementary unit as a whole, including the matrix, macropores, and fractures, as opposed to modeling these features discretely. Hilly landscapes are generally characterized by a layer of overburden underlaid by weathered bedrock that may extend tens of metres (Rempe and Dietrich 2014). To capture this phenomenon, upper bedrock was parameterized separately from the more competent bedrock. Cook (2003) demonstrates that regional connectivity occurs within the upper bedrock and decreases progressively with depth due to the decreased frequency of fractures and permeability. Therefore, groundwater flow through the bedrock is expected to be dominated by the upper bedrock zone.

4.1 MODEL DOMAIN

The extent of the model domain corresponds with the natural hydrogeological and hydrological boundaries, as shown on Figure 4-1. The extents mark the location of the groundwater divide, such that there is no lateral flow through the boundary. The groundwater divide is assumed to coincide with the hydrological watershed boundaries based on the assumption that the water table reflects a subdued replica of the topography. Where large water bodies were encountered at the outlet of watersheds, the groundwater divide was assumed to transect the center where groundwater flow is dominated by the vertical direction. The domain extents occur on the opposite side of general head boundaries from the proposed pits and beyond the zone of influence of pit drainage.

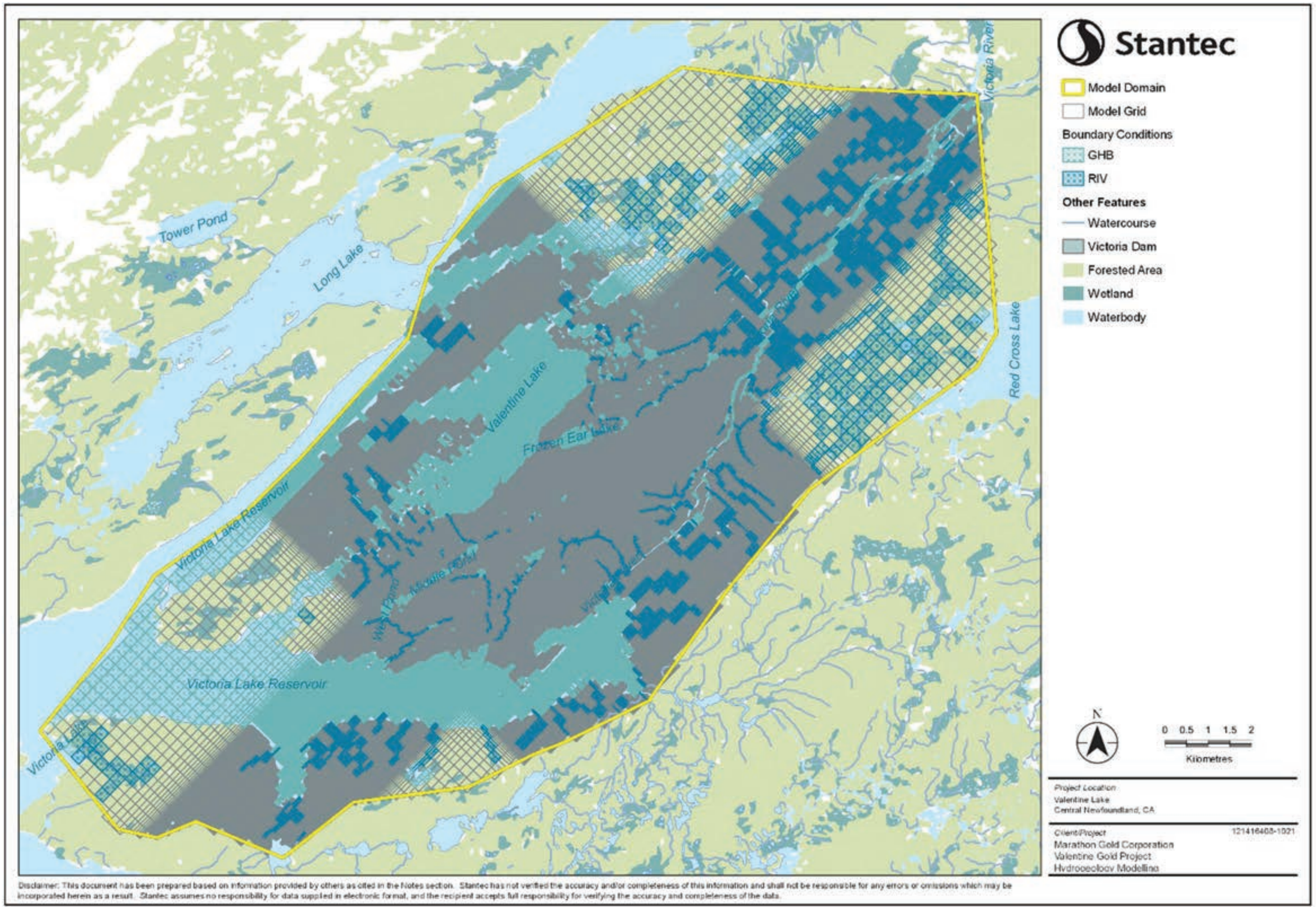

Figure 4-1 Model Domain and Boundary Conditions, showing location of General Head Boundary (GHB) and River (RIV)

The model grid is generally spaced at 250 m and is refined down to 25 m in the area encapsulating the Marathon and Leprechaun pits. The refinement allows the model to simulate the anticipated changes in groundwater flow near the open pits where hydraulic conditions change most rapidly. The grid axis was rotated -44 degrees to better align with natural and geologic features such as the long axis of the watershed, geologic contacts, and faults. This orientation also reduced the number of total cells, and refined cells, thereby increasing the efficiency when running the model.

The ground surface interpreted from LiDAR data collected within the Study Area, and was assigned to the model at the top of model layer 3. The top two model layers were initially set as inactive in the model, and were reserved for use in simulating the Project infrastructure (waste rock piles, LGO stockpiles, and TMF), which are placed above the existing ground surface. The top of bedrock surface was interpreted from monitoring well and borehole logs, and bedrock outcrop information.

The HSUs described in Section 3.0 were imported to ModelMuse software and were subsequently divided into three hydstrostratigraphic layers, in addition to the overlying overburden HSU, as presented in Table 4-1. The HSUs were discontinuous across the model domain with vertical contact boundaries assumed between the three major HSUs (VLS, VLQ, RGC). The Intrusive HSUs were also simplified to have vertical geologic contacts. Overburden was the only horizontally oriented HSU, and where thin or discontinuous, it was given a thickness of 0.1 m.

Table 4-1 Relationship of Hydrostratigraphic Layers and Model Layers

Hydrostratigraphic Layer	Model Layers	Thickness (m)
Waste Rock/Tailings Management	1 – 2	Inactive for Baseline Model
Overburden	3 – 4	0.1 - 15
Upper Bedrock	5	20
Intermediate Bedrock	6 – 10	100
Deep Bedrock	11 – 15	250

4.2 DISTRIBUTION OF HYDROGEOLOGIC PARAMETERS

The hydraulic conductivity and recharge rate were initially assigned to the model based on results from field testing programs and the approximate range of recharge that would be expected for this region given the annual precipitation. The geometric mean of hydraulic conductivity values from well tests were assigned to HSUs and layers based on the depth of the well test and host rock. The HSUs were assumed to be uniform and isotropic initially. However, vertical anisotropy in hydraulic conductivity was added later in the calibration process.

4.3 BOUNDARY CONDITIONS

4.3.1 Model Boundary

The extents of the model domain, which coincide with the watershed delineation, were assigned a no-flow boundary condition (Neumann boundary condition). This is based on the assumption that the water table follows a subdued trend of the topography and that groundwater divide coincides with the watershed boundaries.

No-flow boundaries also extended through the center of large water bodies as the primary flow direction at the center is generally considered to be primarily vertical.

A no-flow boundary condition was applied to the base of the model as groundwater is considered to be significantly impeded by the reduced hydraulic conductivity at depth.

4.3.2 Recharge

Vegetation cover and overburden material are important factors in determining whether precipitation will be released to the atmosphere as evapotranspiration, recharge the surficial aquifer, or become surface runoff. In the Atlantic region of Canada, recharge is typically in the range of 10% to 30% of annual precipitation.

To model the real recharge conditions, a constant flux boundary condition (Neumann boundary condition), or recharge boundary condition, was applied to the top surface of the model domain. This is a simplifying assumption as recharge often varies with topographic gradient, vegetation and overburden material properties. Recharge was adjusted as part of the calibration of the model.

4.3.3 Lakes

As presented in Figure 4-1, there are a large number of lakes and ponds within the study area. The largest and most influential to the functioning of the model are Victoria Lake Reservoir and Valentine Lake. General head boundary conditions were assigned to all lakes with head equal to the top of model surface (based on lidar data). This condition assumes that lake levels remain relatively constant throughout the year; however, minor fluctuations would have limited impact on model results.

The surface water – groundwater interaction between the aquifer and lake is governed by the MODFLOW *conductance* parameter, which essentially models a sediment layer on the bed of the lake that affects the flux of water from the aquifer into the lake. As the sediment layer is assumed to have been derived of the glacial till which is the primary constituent of the overburden, the conductance was set to equal the hydraulic conductivity of the overburden layer in which the lake feature resides.

4.3.4 Watercourses

There is a large concentration of watercourses and ponds present in the model domain as shown on Figure 4-1, particularly in the Victoria River Valley to the south of the Victoria Lake Thrust Fault. The largest river in the watershed, the Victoria River, was assigned a MODFLOW General Head Boundary (Dirichlet boundary condition) with head equal to model top. The river feature extended from the model surface down to the overburden – bedrock interface. The remaining watercourses were assigned the MODFLOW River or Drain Package depending on origin of baseflow, size, and order of the watercourse. For small first and second order streams that were not originating from a substantial surface water body, the Drain package was assigned, to simulate conditions where a stream may only gain and not lose. For larger second order or greater streams, streams with headwaters originating in lakes, or the stream gauged rivers used for calibration, the River package was used which allows the river bed and stage to be parameterized such that the following conditions may occur:

- The head in the cell is above the river stage
- The head in the cell is between the riverbed and stage
- The head in the cell is below the riverbed

Under the first condition, there will be a flow of water into the river from the aquifer (negative flux). Under the second condition, there will be a variable flow of water from the river into the aquifer depending on the gradient between head and stage (positive flux). Under the third condition, there will be a constant flow of water from the river into the aquifer depending on the gradient between head and stage (positive flux).

A conductance parameter must be set for the River Package boundary condition. Conductance relates the head – stage gradient to flowrate and is dependent on stream width, and the thickness and hydraulic conductivity of riverbed sediments. These variables are related by the following equation:

$$\text{Conductance} = \frac{K\ L\ W}{M}$$

where: K = hydraulic conductivity of riverbed sediment (m/d)
L = length of the watercourse in within the cell (m)
W = the width of the watercourse (m)
M = the thickness of the riverbed sediment (m)

For the purpose of this model, conductance was set to the hydraulic conductivity of the overburden assuming that the riverbed will be comprised of coarser, better sorted material and consequently the overburden hydraulic conductivity will be the limiting factor to the rate of surface water – groundwater exchange.

The elevations of the riverbeds were calculated as the model top – 0.3 m, assuming that the river has not incised into the overburden significantly based on field photos. Similarly, the stage was calculated as model top as a simplification, which assumes that the stream depth is 0.3 m.

Drains were parameterized in a similar fashion in order to simulate the equivalent amount of stream gain, while negating the stream loss. Drain elevation was set to equal river stage (model top). No riverbed elevation is set or necessary for the Drain package as stream loss is not calculated.

Following calibration of the baseline conditions and the addition of the open pits, the nearby River-assigned watercourses were set as drains to more accurately represent the drawdown conditions due to pit drainage.

4.4 CALIBRATION

4.4.1 Calibration Methodology

The objective of this investigation is to create a numerical model that adequately captures the real groundwater regime for the site. The conceptual model provided the framework to setup the initial steady-state groundwater flow model. The logical progression is to use model calibration to fine-tune the parameterization and boundary conditions of the model.

Model calibration was conducted automatically and iteratively under stead state conditions using PEST software (Doherty 2009) for model-independent parameter estimation and uncertainty analysis. A hybrid approach was utilized so that automated parameter estimation was combined with professional judgement and interpretation of calibration results. Evaluation was based on the comparison between observed and simulated values for groundwater levels and baseflow rates in watercourses. With each iteration, parameters were adjusted to reduce residuals between simulated and measured conditions. PEST selects parameter values from a pre-established range based on professional judgment, empirical results for similar lithologies, and the range of hydraulic conductivity values yielded for well tests.

The hybrid calibration approach used the following steps:

1. A MODFLOW file was created using the most recent version of the model.
2. PEST master, instruction, and template files were constructed or adjusted. At this stage, the initial values and ranges for the parameters subjected to calibration were set.
3. PEST was run to estimate the best assortment of parameters so that root mean square error (RMSE) is minimized.
4. Review the model results and statistics.
5. Review the sensitivity analysis and adjust the insensitive parameters.
6. Repeat steps 2 through 5 until adequate model result are achieved

Twenty-four parameters were automatically adjusted by PEST during the calibration procedure, including:

- The horizontal hydraulic conductivities of the following HSUs including the upper, intermediate, and deep bedrock for: VLQ, VLS, RGC, RCL, SDG, and SPG
- The recharge rate for the model domain
- The vertical anisoptropy of the VLQ, VLS, RGC, RCL, SDG, and SPG units

These parameters were automatically adjusted using PEST generally within the specified range. For horizontal hydraulic conductivity, this range was generally two orders of magnitude in the positive and negative direction from the geometric mean yielded by the well tests. For global recharge, the range spanned from <1% to 30% of annual precipitation. There were no parameters that were manually adjusted; however, following analysis of the results, parameter ranges and initial values were adjusted to yield more realistic results.

4.4.2 Calibration to Water Levels

To facilitate the evaluation of calibration, comparison between measured and simulated values of physical parameters that are indicative to the functioning of the groundwater system were necessary. For this investigation, groundwater levels in pertinent wells and baseflow rates in watercourses were used for this purpose.

Groundwater elevations from the baseline groundwater datasets provided by Stantec (2019) and GEMTEC (2020) were used to provide 200 measured values of static groundwater levels. Where continuous data was available, average annual values were used. Groundwater level observations were weighted based on reliability. For instance, wells that were measured on a single occasion were given a weight of 1, whereas wells that were continuously logged throughout a year so that seasonal variations could be subtracted were given a weight of 5. Generally, for the purpose of a regional scale groundwater model, the error associated with seasonal variation is negligible when compared to the residuals yielded from the model. This does not imply that the model is inaccurate, rather that the model does not includethe heterogeneities present in the subsurface that can affect groundwater levels.

The location of wells with groundwater level observations are displayed in Figure 4-2 (a to c). The water level residuals and statistics following calibration are displayed in Table 4-2. A plot of the simulated vs measured groundwater levels is displayed in Figure 4-3 relative to a line of perfect fit for comparison. The closer a point is to that line means that there is less of a residual. For a model to have satisfactory agreement with field observations, the line of perfect fit should bisect the data points and the spread should be minimized around the line.

The statistical measures used to evaluate the performance of the model are summarized in Table 4-2 and include the standard error of the estimate and the root mean square error (RMSE). Four statistical measures were used to evaluate the quality of fit between simulated results and measured targets, including:

- Mean Residual
- Mean Absolute Residual
- Normalized Root Mean Squared Error
- Correlation coefficient

Normalized RMSE is generally regarded as the best measure for the level of agreement between simulated and measured conditions (Anderson and Woessner 1991). The RMSE is essentially the standard deviation of residuals calculated as the average of the squared residuals. The normalized RMSE is compared to the overall range of observations to evaluate the overall hydraulic response of the model (Spitz and Morena 1996). The recommended threshold for the ratio between the RMSE and the observations range is 10%. The normalized RMSE is 2.7% for the calibrated model, suggesting the model calibration is suitable for the simulation of the study area.

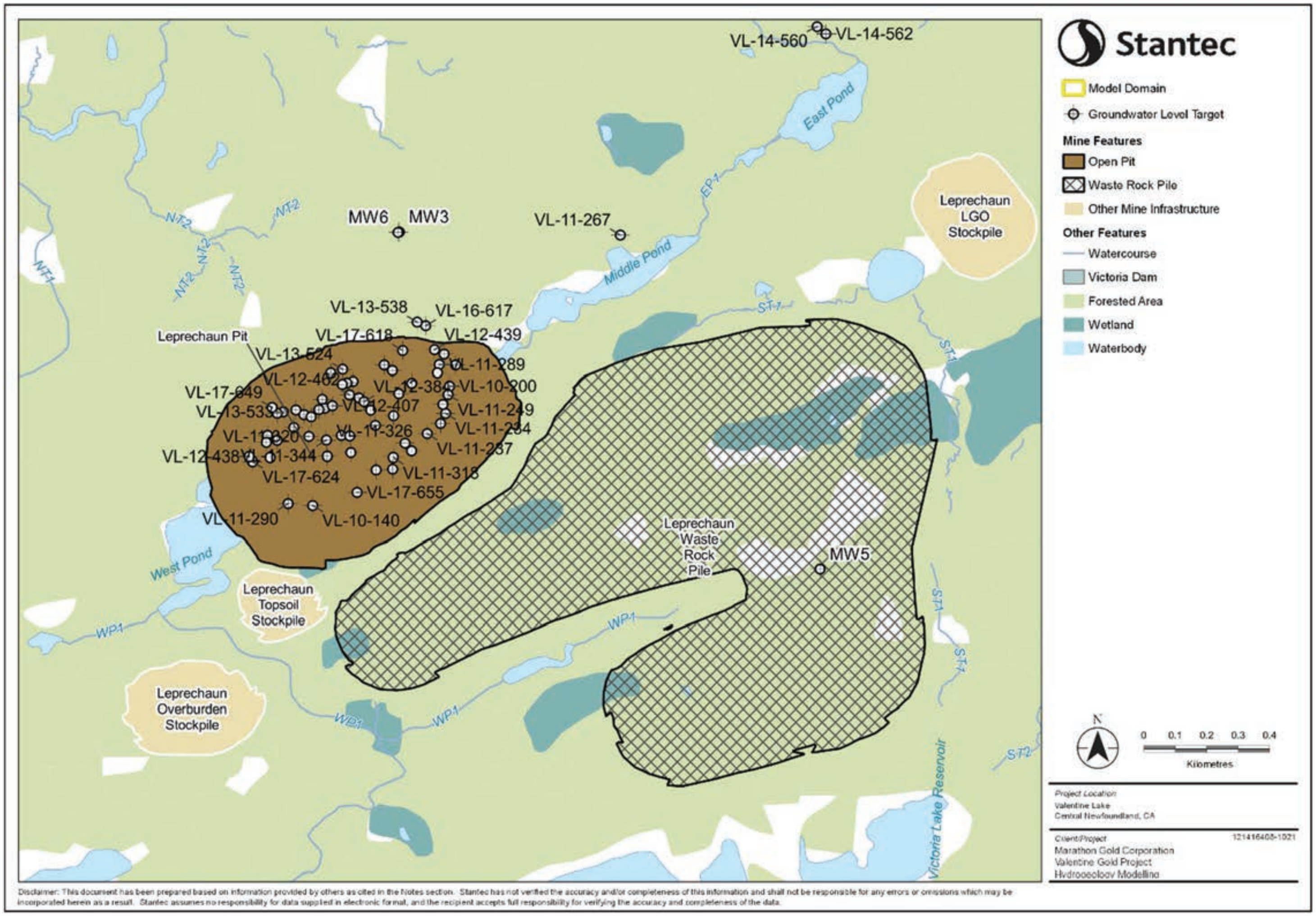

Figure 4-2a Groundwater Level Target Locations – Leprechaun Complex

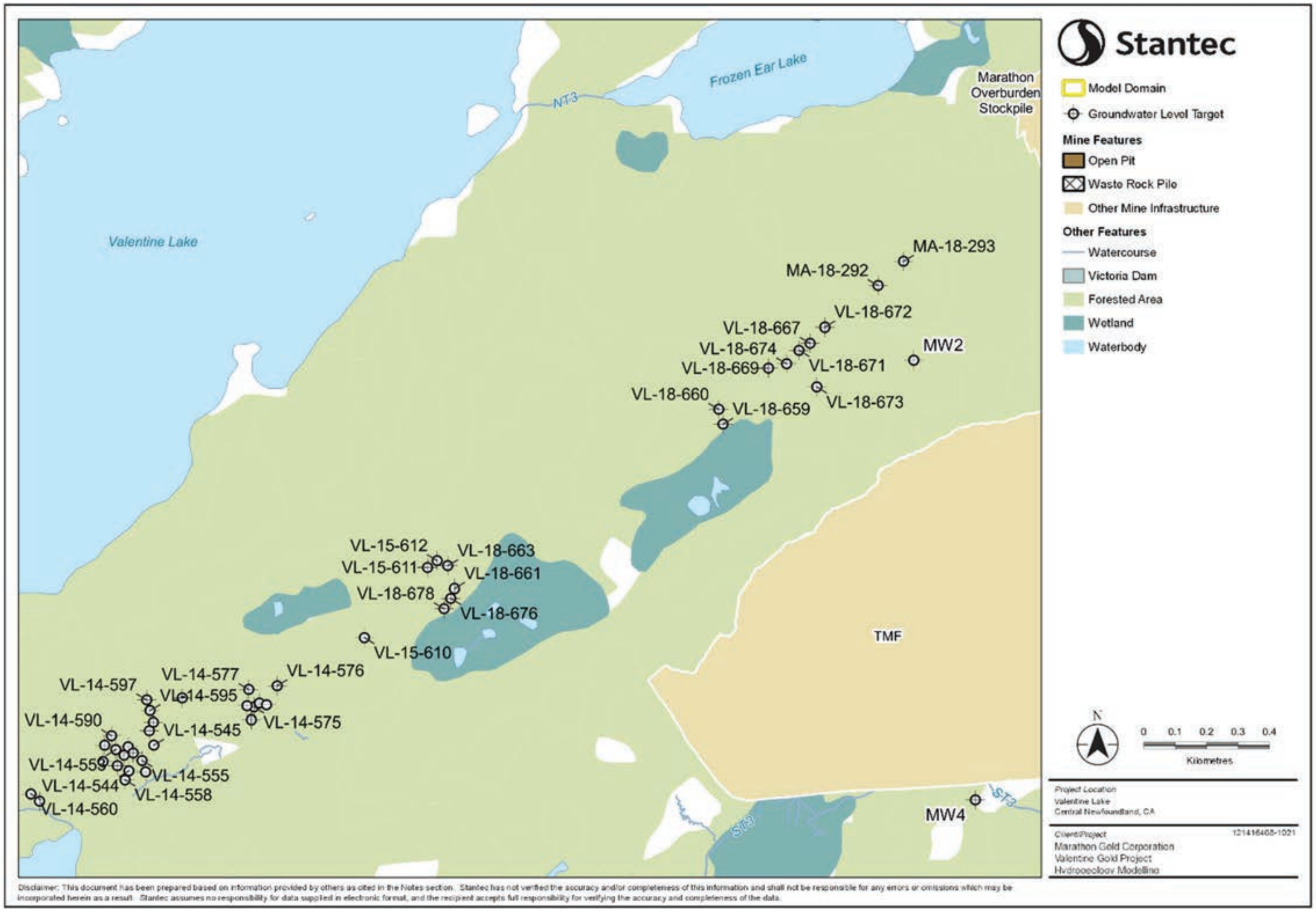

Figure 4-2b Groundwater Level Target Locations – Process Plant and TMF Complex

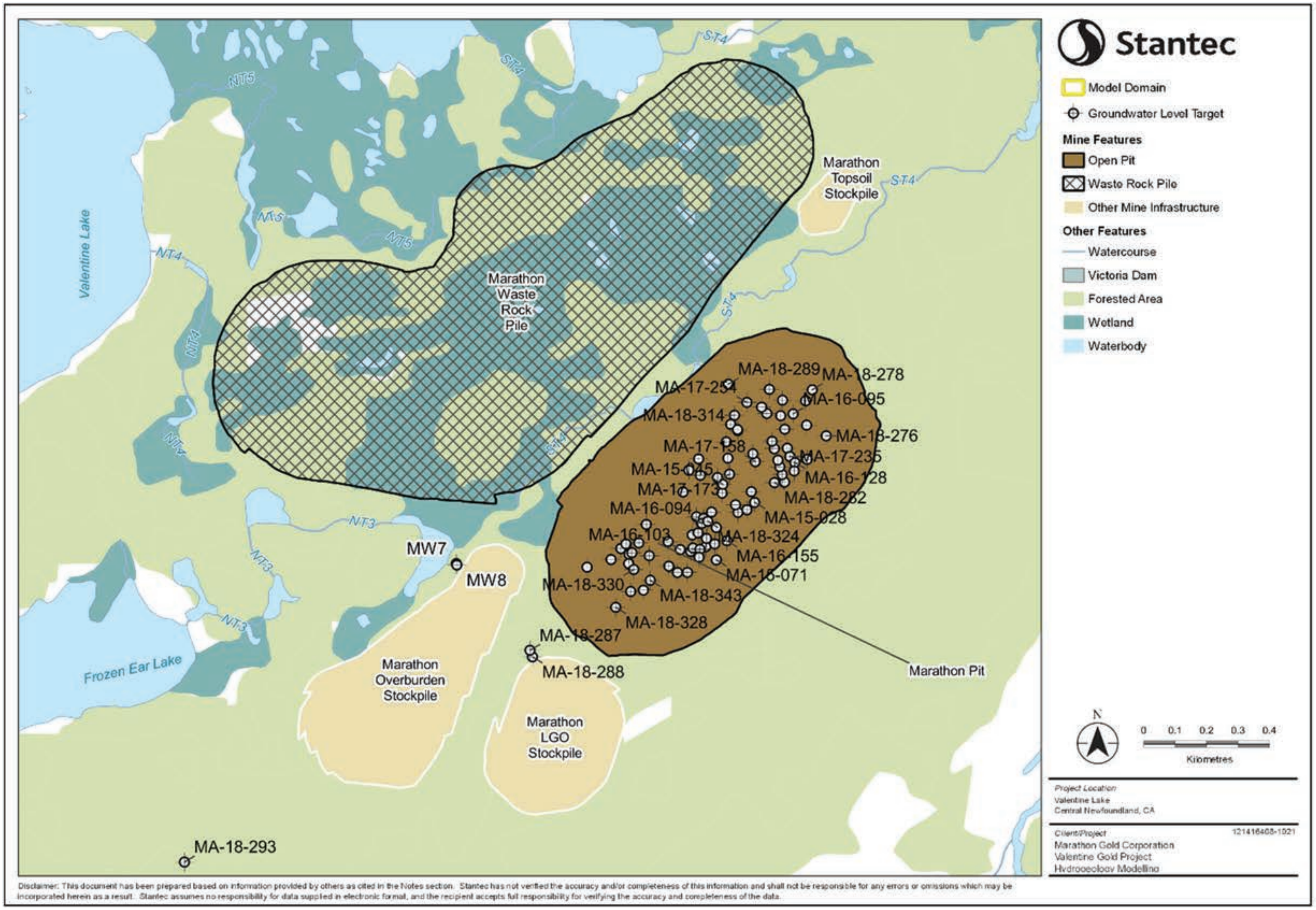

Figure 4-2c Groundwater Level Target Locations – Marathon Complex

Table 4-2 Water Level Calibration Residuals

Well ID	Target Water Level (m amsl)	Simulated Water Level (m amsl)	Residual (m)
MW1	311.00	308.08	2.92
MW2	418.10	411.97	6.13
MW3	384.60	381.60	3.00
MW4	364.50	366.43	-1.93
MW5	363.00	361.34	1.66
MW6	379.10	380.81	-1.71
MW7	341.75	347.51	-5.76
MW8	342.20	347.83	-5.63
VL10168	385.79	387.17	-1.38
VL11319	385.54	385.29	0.25
VL11237	389.29	389.89	-0.60
VL11275	390.92	391.75	-0.83
VL11234	392.59	392.05	0.55
VL11286	397.73	393.45	4.28
VL12409	398.09	395.35	2.73
VL11289	394.41	393.89	0.52
VL11291	393.67	393.29	0.38
VL10200	393.07	392.61	0.46
VL11249	392.36	392.47	-0.11
VL11241	392.26	391.78	0.48
VL11318	384.34	384.56	-0.22
VL17656	384.01	386.74	-2.74
VL10153	384.08	383.85	0.22
VL17655	383.97	383.69	0.28
VL10140	384.22	383.15	1.06
VL12439	400.69	396.59	4.10
VL16617	400.92	401.96	-1.04
VL13538	400.98	404.02	-3.04
VL17618	403.65	398.12	5.53
VL12502	400.79	396.29	4.50
VL17619	403.27	397.40	5.87
VL12447	395.40	392.21	3.19
VL12384	391.86	390.78	1.08
VL11360	386.83	388.68	-1.85

Table 4-2 Water Level Calibration Residuals

Well ID	Target Water Level (m amsl)	Simulated Water Level (m amsl)	Residual (m)
VL11339	385.22	385.58	-0.36
VL11326	386.15	387.16	-1.01
VL12406	392.84	391.24	1.60
VL12395	392.82	392.49	0.33
VL11290	383.88	383.20	0.68
VL11336	384.06	385.37	-1.32
VL11342	384.55	385.28	-0.73
VL11332	383.82	383.98	-0.16
VL11327	383.93	384.06	-0.13
VL11344	384.55	385.07	-0.52
VL11320	384.32	385.05	-0.73
VL12468	388.48	386.57	1.91
VL12398	386.87	385.19	1.68
VL17643	387.45	386.53	0.92
VL17651	387.33	385.68	1.65
VL11293	385.71	384.59	1.12
VL17624	385.07	384.07	1.00
VL12438	385.76	384.75	1.01
VL12462	399.07	393.73	5.34
VL13521	402.00	395.91	6.08
VL17650	401.64	395.63	6.01
VL13524	399.89	394.87	5.02
VL13527	399.49	392.22	7.27
VL12444	398.66	395.30	3.36
VL12465	398.97	392.67	6.30
VL12410	396.63	391.19	5.44
VL12407	396.50	391.59	4.91
VL13537	395.54	391.03	4.51
VL17645	394.02	389.86	4.16
VL17652	387.93	389.86	-1.93
VL12504	397.06	391.24	5.83
VL13533	396.23	391.27	4.95
VL13532	398.27	391.09	7.18
VL17649	398.74	391.26	7.48

Table 4-2 Water Level Calibration Residuals

Well ID	Target Water Level (m amsl)	Simulated Water Level (m amsl)	Residual (m)
VL11267	392.66	388.92	3.74
VL14599	400.57	397.30	3.27
VL14600	399.95	398.66	1.29
VL14545	407.00	405.33	1.66
VL14555	400.39	402.52	-2.13
VL14556	401.06	401.86	-0.80
VL14595	409.89	404.64	5.25
VL14597	403.22	401.11	2.10
VL14572	410.40	407.39	3.02
VL14576	424.83	423.22	1.60
VL15610	430.39	429.45	0.94
VL15611	428.74	428.02	0.72
VL18663	433.41	429.20	4.21
VL15612	430.87	428.28	2.59
VL18660	425.77	422.46	3.31
VL18659	426.71	425.48	1.23
VL18672	412.37	406.27	6.10
VL14562	383.93	382.08	1.84
VL14560	384.97	380.93	4.03
VL14556_1	398.75	401.86	-3.12
VL14569	399.66	397.54	2.12
VL14553	403.28	399.49	3.79
VL14554	406.16	401.89	4.28
VL14542	402.99	400.69	2.31
VL14544	399.67	399.58	0.09
VL14558	396.83	398.03	-1.20
VL14589	403.94	402.24	1.70
VL14590	403.45	397.93	5.52
VL14596	414.14	405.84	8.30
VL14598	412.80	406.63	6.18
VL14577	423.10	418.90	4.21
VL14575	421.11	416.84	4.28
VL14604	415.99	414.82	1.17
VL14602	421.76	417.88	3.88

Table 4-2 Water Level Calibration Residuals

Well ID	Target Water Level (m amsl)	Simulated Water Level (m amsl)	Residual (m)
VL14605	422.90	417.90	5.00
VL14601	420.51	416.66	3.86
VL18661	430.71	433.15	-2.45
VL18676	430.62	432.58	-1.96
VL18678	430.14	432.18	-2.04
VL18669	422.48	414.67	7.80
VL18674	418.55	413.82	4.73
VL18671	416.68	410.27	6.41
VL18667	418.17	409.18	8.99
VL18673	418.57	417.18	1.39
MA18293	400.15	390.61	9.55
MA18292	405.81	396.07	9.74
MA17158	351.60	350.85	0.74
MA17218	349.83	349.76	0.07
MA17250	344.54	345.11	-0.57
MA18282	355.06	354.31	0.75
MA18288	365.14	363.03	2.11
MA18287	355.09	361.78	-6.68
MA16129	357.17	355.17	2.00
MA16111	354.28	354.19	0.09
MA18307	354.72	353.25	1.47
MA16141	353.42	352.61	0.80
MA14012	353.01	351.67	1.34
MA14009	350.53	350.16	0.37
MA14019	348.85	346.20	2.64
MA17186	350.22	349.27	0.94
MA18306	353.52	352.32	1.21
MA17235	354.61	353.25	1.37
MA16128	356.18	354.26	1.91
MA18291	355.82	354.89	0.93
MA16130	357.34	354.79	2.55
MA17225	345.65	345.31	0.34
MA17251	344.33	344.57	-0.24
MA17201	342.37	343.21	-0.84

Table 4-2 Water Level Calibration Residuals

Well ID	Target Water Level (m amsl)	Simulated Water Level (m amsl)	Residual (m)
MA16095	349.05	347.32	1.73
MA18276	354.58	353.12	1.47
MA18278	345.50	345.63	-0.12
MA18266	347.48	346.64	0.84
MA17254	343.30	343.88	-0.58
MA18289	339.38	342.26	-2.88
MA18314	344.41	343.93	0.48
MA18310	345.47	345.22	0.25
MA18312	345.69	345.81	-0.12
MA17199	346.67	346.54	0.14
MA17169	347.92	347.81	0.12
MA17173	349.88	350.22	-0.34
MA18297	353.94	353.31	0.63
MA15028	353.96	354.43	-0.47
MA17246	353.50	354.25	-0.75
MA15031	354.40	354.12	0.28
MA18295	354.01	353.53	0.48
MA17241	351.00	351.39	-0.39
MA15045	350.43	350.37	0.05
MA17248	348.99	349.60	-0.62
MA18311	349.30	349.11	0.18
MA17253	347.31	347.37	-0.06
MA17260	347.74	348.30	-0.57
MA17231	352.67	352.65	0.02
MA16100	344.74	343.80	0.93
MA18263	349.77	350.85	-1.09
MA15064	359.74	357.74	2.00
MA18336	356.15	358.52	-2.37
MA18340	352.47	355.99	-3.52
MA16120	357.54	355.16	2.37
MA18329	353.21	356.31	-3.10
MA18337	351.28	355.35	-4.07
MA18334	350.24	355.04	-4.81
MA18332	352.94	355.72	-2.78

Table 4-2 Water Level Calibration Residuals

Well ID	Target Water Level (m amsl)	Simulated Water Level (m amsl)	Residual (m)
MA16126	352.28	355.40	-3.12
MA18342	351.49	354.90	-3.41
MA18330	355.22	356.44	-1.22
MA18343	355.51	357.58	-2.06
MA18345	349.06	353.36	-4.30
MA16106	352.99	355.46	-2.47
MA18347	355.14	356.89	-1.75
MA17191	352.39	354.54	-2.15
MA16103	354.64	354.86	-0.22
MA16118	358.47	358.46	0.02
MA17258	354.58	356.16	-1.57
MA18316	350.35	350.20	0.15
MA16110	352.78	353.81	-1.03
MA18323	354.81	355.92	-1.10
MA17255	354.49	355.82	-1.33
MA16143	358.35	355.89	2.46
MA15071	360.77	361.16	-0.40
MA17259	354.70	356.53	-1.83
MA17262	354.47	354.68	-0.20
MA18268	354.51	354.49	0.02
MA18335	352.91	353.27	-0.36
MA17227	352.83	353.56	-0.73
MA16094	352.61	353.20	-0.59
MA18324	353.35	353.92	-0.58
MA17233	353.06	354.55	-1.49
MA16155	361.53	358.68	2.85
MA16117	354.95	356.93	-1.98
MA18328	356.79	359.75	-2.96
MA18333	352.04	356.70	-4.66
VL09134	384.21	384.11	0.10
Residual Statistics			
Sum of Squared Error (m^2)		299.058	
Mean Error (m)		-0.611	
Absolute Mean Error (m)		2.135	

Table 4-2 Water Level Calibration Residuals

Well ID	Target Water Level (m amsl)	Simulated Water Level (m amsl)	Residual (m)
Root Mean Squared Error (m)		2.843	
Normalized Mean Squared Error (%)		2.7	

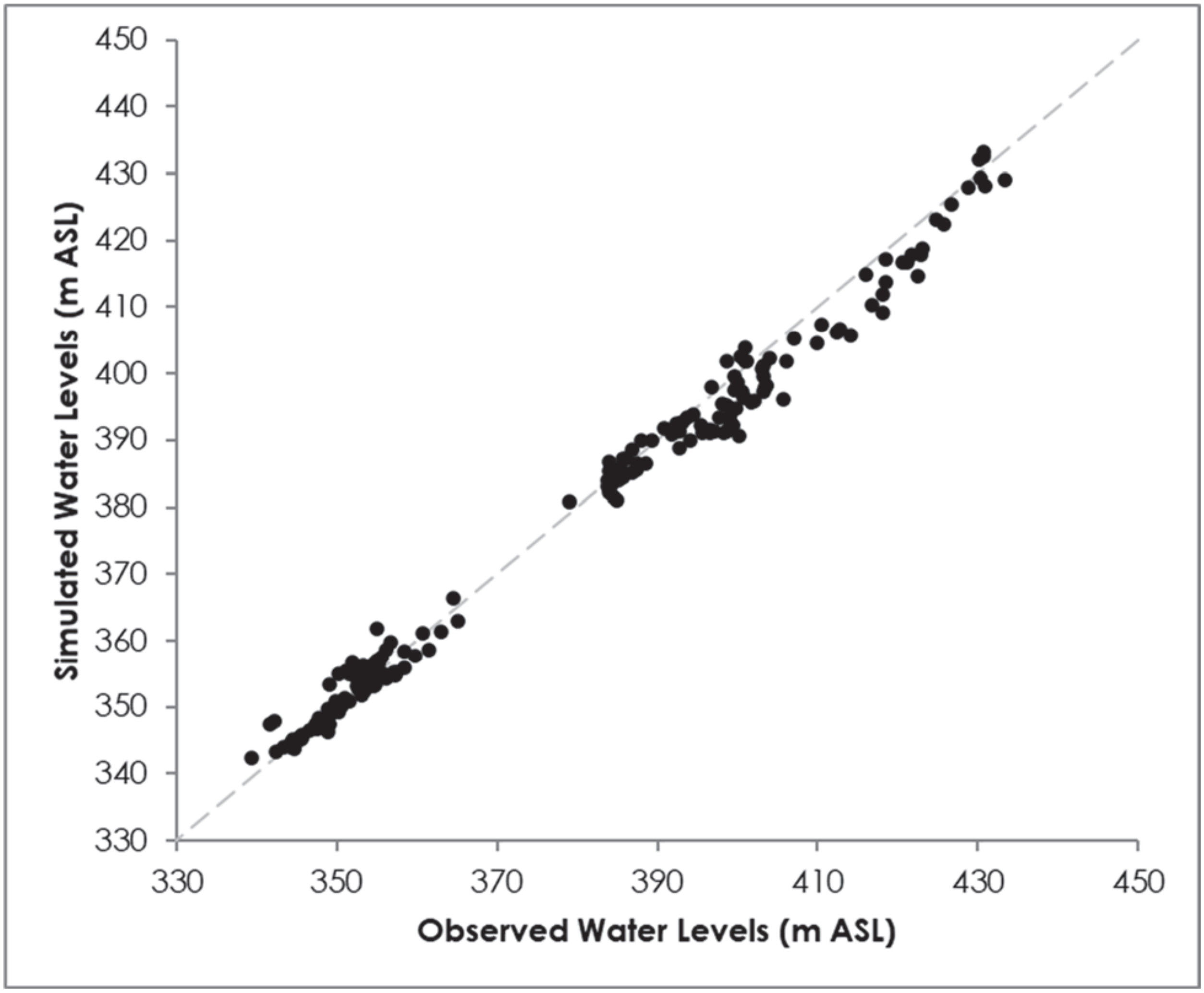

Figure 4-3 Comparison of Observed and Simulated Water Levels at end of Calibration

4.4.3 Calibrated Model Parameters

The final hydrogeologic parameters resulting from the calibration process are presented in Table 4-3. The expected ranges were based on observations, professional judgement, and empirical data from literature when data was unavailable.

The expected range for recharge was determined from the calculation of 10 to 30% of annual precipitation, which is typically observed in the Atlantic provinces of Canada.

Table 4-3 Parameter Values from Calibrated Model

Parameter	Vale at End of Calibration	Expected Range	Sensitivity to Observations
Recharge (mm/yr)			
Recharge	381	110 - 440	9.56
Hydraulic Conductivity (m/s)			
Overburden	1.2×10^{-5}	1.0×10^{-12} – 2.0×10^{-6}	1.5
VLS Upper Bedrock	9.9×10^{-7}	8.0×10^{-7} – 8.6×10^{-5}	0.17
VLS Intermediate Bedrock	1.2×10^{-6}	1×10^{-11} – 6×10^{-6} A	2.5
VLS Deep Bedrock	1.8×10^{-11}	1×10^{-11} – 6×10^{-6} A	0.0046
VLQ Upper Bedrock	9.6×10^{-7}	8.8×10^{-7} – 1.3×10^{-6}	0.64
VLQ Intermediate Bedrock	3.7×10^{-9}	2.5×10^{-8} – 1.7×10^{-6}	0.022
VLQ Deep Bedrock	1.3×10^{-11}	5.8×10^{-10} – 1.7×10^{-7}	0.013
RGC Upper Bedrock	3.5×10^{-7}	1.3×10^{-6} – 1.5×10^{-5}	0.066
RGC Intermediate Bedrock	2.3×10^{-7}	1.9×10^{-8} – 1.9×10^{-6}	0.40
RGC Deep Bedrock	2.1×10^{-9}	8×10^{-9} – 3×10^{-4}	0.0082
RCL Upper Bedrock	3.5×10^{-8}	8×10^{-9} – 3×10^{-4}	0.0047
RCL Intermediate Bedrock	1.9×10^{-9}	8.7×10^{-8} – 1.7×10^{-6}	0.0067
RCL Deep Bedrock	1.4×10^{-10}	6.2×10^{-10} – 6.2×10^{-8}	0.0047
SDG Upper Bedrock	2.1×10^{-8}	8×10^{-9} – 3×10^{-4} A	0.0049
SDG Intermediate Bedrock	1.9×10^{-8}	8×10^{-9} – 3×10^{-4} A	0.0072
SDG Deep Bedrock	9.5×10^{-9}	8×10^{-9} – 3×10^{-4} A	0.0049
Vertical Anisotropy (Kz/Kx)			
Overburden Vertical Anisotropy	0.1	0.05 – 5	0.0010
Bedrock Vertical Anisotropy	0.05	0.05 – 5	0.057
Conductance Multiplier (Applied to Overburden Kx; m^2/s)			
Wetland Conductance	1	0.001 - 1	0.11
Lake Conductance	1	0.001 - 1	0.018
River Conductance	27.1	1 - 100	0.069

The expected ranges for hydraulic conductivity were primarily based on well-tests in the different aquifers. However, professional judgement was use when there was a lack of observations. When a single observation, or a low spread in observed values, then an order of magnitude was added in both positive and negative directions.

The expected ranges for vertical anisotropy were based on professional judgement. Given that there are organic and clay layers in the overburden, with the possible presence of macropores and till fractures, vertical anisotropy was assumed to range from less than 1 to greater than 1. With strong lithological variations in the VLS, compaction, and vertical bedding and fault orientations, the vertical anisotropy could range from less than 0 to greater than 1.

Hydraulic conductivity was generally estimated to be lower than what was observed in well tests, but within the appropriate range given lithology and level of weathering. Furthermore, hydraulic conductivity generally decreased with depth from shallow to intermediate to deep bedrock for each lithostratigraphic unit. The exception to this is the intermediate and deep bedrock of the SPG unit, which are relatively insensitive HSUs. The more sensitive HSUs, VLS, VLQ, and RGC all displayed a progressively decreasing hydraulic conductivity value of at least an order of magnitude which was proposed by the conceptual model.

There were a few instances where calibrated values exceeded the expected range. The calibrated overburden hydraulic conductivity was an order of magnitude higher than the expected limit for glacial till based on literature; however, field observations note that the till is silty and sandy which would increase hydraulic conductivity. Additionally, there may be presence of macropores and fractures in the overburden, which would increase bulk hydraulic conductivity and connectivity to upper bedrock.

The calibrated hydraulic conductivity for the RGC unit was within an order of magnitude below the expected hydraulic conductivity range for the upper and deep bedrock. Given how close these values are to the observed range, the calibrated value holds as reasonable. Generally speaking, the RGC has a low hydraulic conductivity for a conglomerate as previously predicted in the conceptual model, but this is explained by the observed ductile deformation (Tettelaar and Dunsworth 2016) relative to the brittle deformation that would have occurred in the adjacent VLQ. Ductile deformation would result in a lower frequency of faults and a lower bulk hydraulic conductivity. The relatively stable calibrated hydraulic conductivity with depth also supports that there is little presence of fractures in the RGC in the upper and intermediate bedrock. The calibrated hydraulic conductivity for RCL in the intermediate and deep bedrock is lower than the expected range but it should be noted that observations were insensitive to these parameters during calibration.

4.4.4 Calibration Uncertainty

The uncertainty of the calibration process was evaluated through the review of the relative sensitivities of the calibrated parameters. These measures were automatically calculated by PEST and indicate to what degree each of the parameters were sensitive to the calibration. The sum of all relative sensitivities equals one, so they can be considered proportions of the total. A sensitivity value equal to 0 is indicative that the parameter had little influence on the outcome of the calibration and calibration is completely dependent on a parameter if its value is equal to one. The relative sensitivities for the groundwater flow model are displayed in Figure 4-4.

The most sensitive parameter is the recharge followed by the overburden layers, VLQ, and then VLS consecutively (Figure 4-4). Generally, the shallower layers are more sensitive than the deep, presumably because majority of the wells are completed at shallower depths. It should also be noted that there is an inverse relationship between the most sensitive parameters, hydraulic conductivity, and recharge. For instance, if attempting to keep water levels constant, an increased recharge would have to be associated with an increased hydraulic conductivity in the sensitive shallow layers. Aside from the overburden, VLQ, and VLS layers, the remaining HSUs exhibited nearly negligible relative sensitivities. This is likely due to the locations of these HSUs relative to the wells used in the calibration process.

The hydraulic properties of the thrust faults, particularly the Victoria Lake Thrust Fault, which runs through the open pits, is a source of uncertainty in the calibration. There are a number of factors affecting the hydraulic conductivity within a fault-plane. The material textures in the fault are important, for instance, if there is coarse grained debris or presence of cement or mineralization. High pressure on a fault plane can have a sealing effect with less void space, or contrastingly there could be a zone of debris between the fault blocks with excessive void space providing a preferential flow path for groundwater.

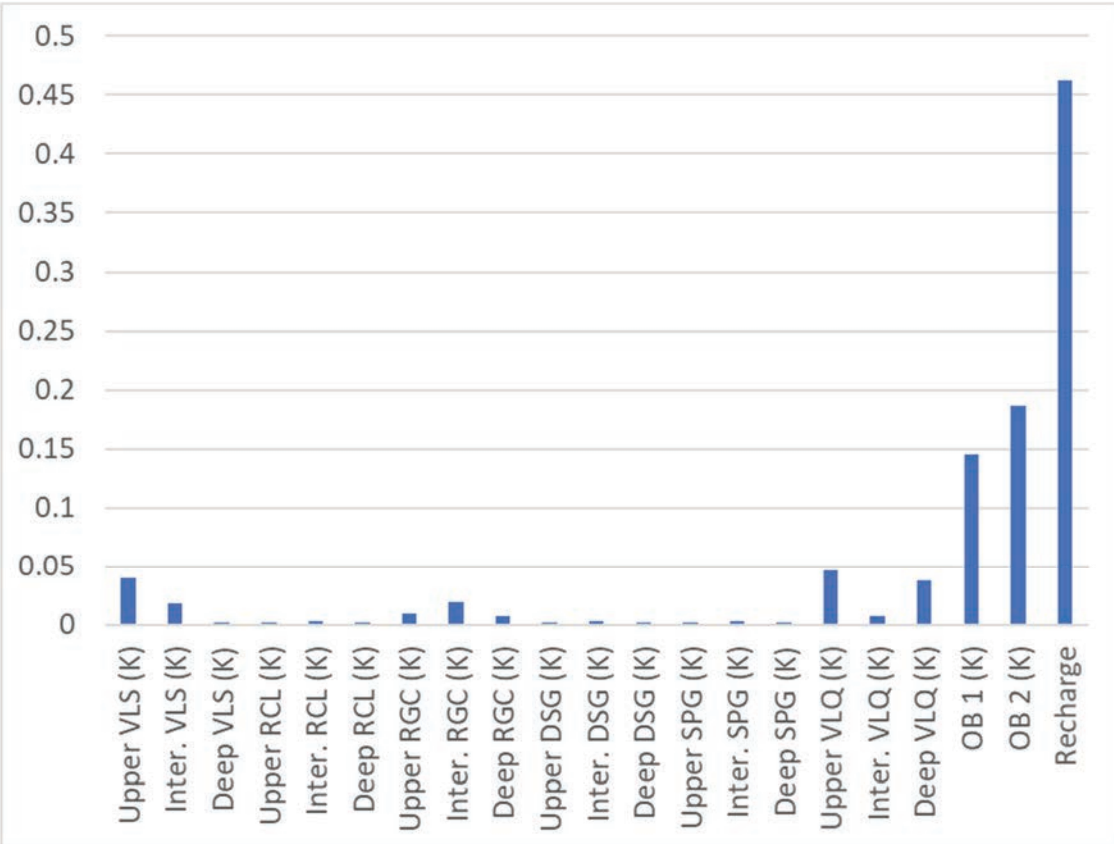

Figure 4-4 Relative Sensitivities of Calibrated Parameters

5.0 MODEL APPLICATIONS

The calibrated groundwater flow model was used to quantify baseline groundwater levels and flow and groundwater discharge to the receiving environment under baseline conditions. The baseline model results were then used to compare to model predictions during construction, operation and decommissioning, rehabilitation and closure phases of the Project. Section 5.1 presents the results from the baseline simulations using the calibrated model. Model modifications were then completed to allow simulation of the following phases:

- Operation – dewatering of open pits and groundwater discharge and seepage collection associated with the ore stockpiles, waste rock piles, and TMF
- Closure – filling of the open pit and groundwater discharge associated with the waste rock piles, and TMF

Model modification and results for the operation and closure periods of the Project are discussed in Sections 5.2 and 5.3, respectively.

5.1 BASELINE CONDITIONS

The calibrated groundwater flow model discussed in Section 4.0 was used to estimate the water table elevation (i.e., the top of the saturated water column) and groundwater flow under baseline conditions.

Figure 5-1 shows the water table elevation under baseline conditions from the calibrated groundwater flow model. The model provides a good representation of groundwater flow conditions with groundwater in the area of the open pits flowing radially from the water table high near the local topographic highs towards Valentine Lake, Victoria Lake Reservoir, or Victoria River.

An estimate of groundwater discharge to the primary lakes and watercourses was determined from the model and is presented in Table 5-1. The discharge rates were used to quantify changes to groundwater discharge during the operation and decommissioning, rehabilitation and closure phases, as presented in Sections 5.2 and 5.3.

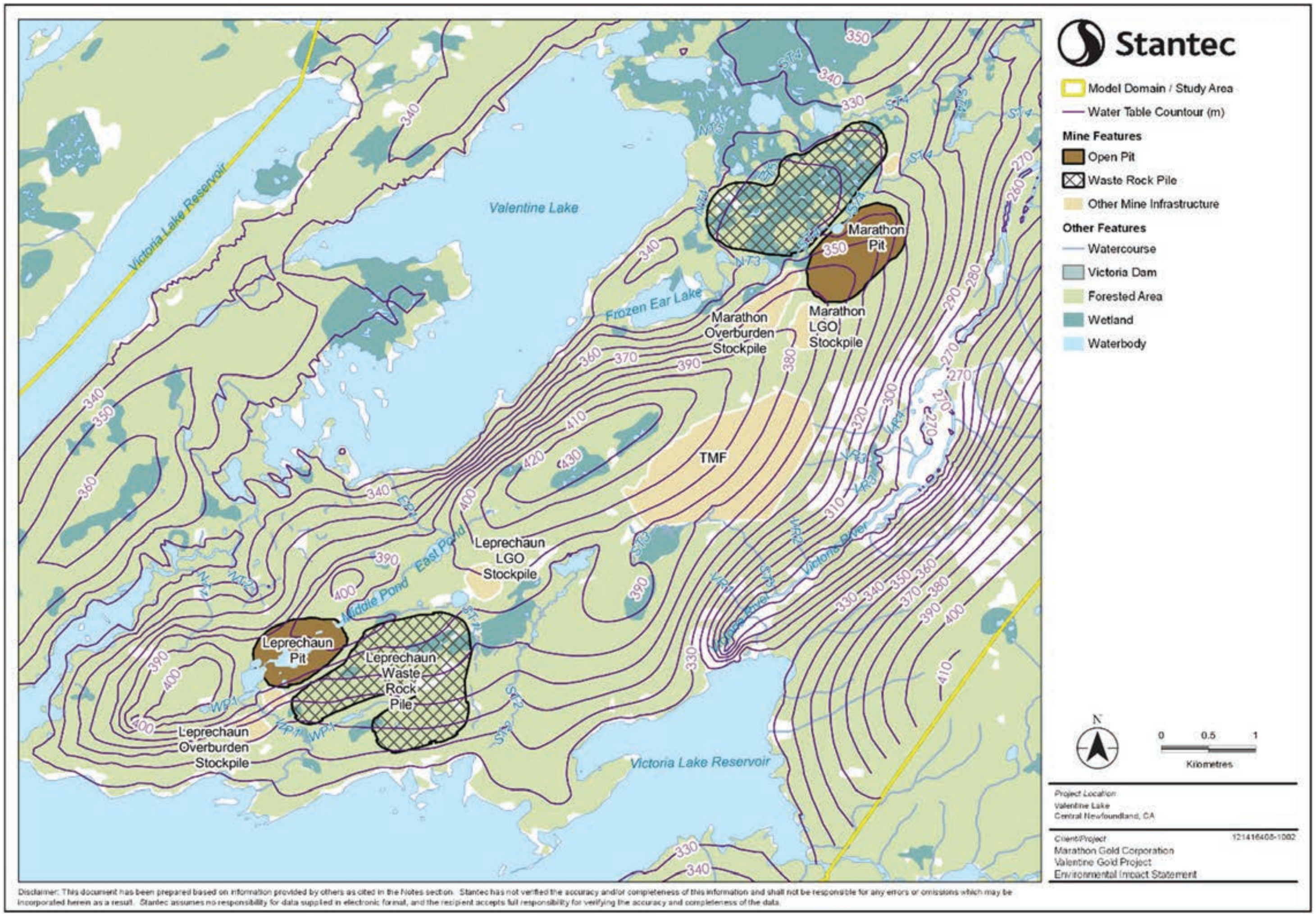

Figure 5-1 Baseline Water Table Elevation Contours

In Table 5-1 a positive number indicates groundwater discharge in the model to the surface water feature and a negative value indicates that the surface water feature is recharging the groundwater flow system. Baseflow values presented in the table represent the groundwater contributions to the features, and do not include contributions from surface water storage.

Table 5-1 Baseline Groundwater Baseflow to Surface Water Features

Water Feature	Net Flow from Groundwater to Feature (m^3/d)
Unnamed Tributary to Victoria Lake Reservoir NT1	332.6
Unnamed Tributary to Victoria Lake Reservoir NT2	61.2
Frozen Ear Lake and Tributaries NT3	2874.2
Unnamed Tributary to Valentine Lake NT4	357.4
Unnamed Tributary to Valentine Lake NT5	408.4
Middle and East Pond and Tributaries EP1	919.9
West Pond and Tributaries WP1	2167.9
Unnamed Tributary to Victoria Lake Reservoir ST1	782.5
Unnamed Tributary to Victoria Lake Reservoir ST2	2872.6
Unnamed Tributary to Victoria River ST3	1306.4
Unnamed Tributary to Victoria River ST4	5201.6
Unnamed Tributary to Victoria River VR1	0.002
Unnamed Tributary to Victoria River VR2	0.2
Unnamed Tributary to Victoria River VR3	153.5
Unnamed Tributary to Victoria River VR4	12

5.2 OPERATION

The groundwater model was modified from the baseline condition to simulate the effects of the Project during operation on groundwater levels and flow. The fate of groundwater originating from LGO stockpiles, waste rock piles, and the TMF were also simulated during operation. As part of these simulations, the model was used to predict groundwater inflows to the open pits. The resulting model was used to evaluate the groundwater inflows into the pit, the zone of influence, and the associated effects on water table and baseflow to streams.

5.2.1 Model Setup

The following modifications were added to the calibrated baseline conditions groundwater model to simulate operating conditions:

- The Marathon and Leprechaun open pits were added to the domain
- The general head boundaries and rivers in the vicinity of the pits were switched to drains as they are unlikely to maintain their constant heads or stages given the drop in water table associated with the pit drainage

- The Victoria Lake Thrust Fault plane was added to the model to evaluate its effect on pit discharges

5.2.1.1 Open Pit Dewatering

To evaluate the effects of groundwater inflows to the open pits, the calibrated steady-state groundwater flow model was modified to include the extents and depths of the open pits for the fully developed extent of the pits.

Model cells that were intersected by the walls or floor of the open pits were identified and assigned as a seepage face boundary condition in the model. The seepage face was assigned using the MODFLOW DRAIN package at these locations. Model cells that were located above the DRAIN cells within the footprint of the open pits were set as inactive cells.

The conductance of the DRAIN cells was specified based on the hydraulic conductivity in the cells multiplied by the width, length and thickness of the cell. Blasting effects on the hydraulic conductivity of the bedrock were assumed to be localized to the first 25 m of the exposed bedrock face, coinciding with the width of the drain cells, and were incorporated as part of the conductance value for the drains.

5.2.1.2 Victoria Lake Thrust Fault Sensitivity Analysis

To investigate the sensitivity of the presence of the Victoria Lake Thrust Fault, an extensive fault plane connecting the pits to Victoria Lake was added at the interface of the RGC and VLQ HSUs. Several iterations were completed to provide a range of possible outcomes. This approach mitigates the uncertainty in the hydraulic properties of the fault plane, which may belong to either of the following scenarios:

- An enhanced hydraulic conductivity and act as a conduit, improving connectivity to the lake
- A sealing surface with reduced hydraulic conductivity that impedes flow through the interface

For both scenarios, the vertical anisotropy of hydraulic conductivity was considered to be equal to 1 within cells representing the fault plane. The thickness of the fault plane was set to be equal to the cell width within the refined zone (25 m). The true fault plane thickness is expected to be <5 m; therefore, this a conservative evaluation on the effects of a fault.

In the first scenario, horizontal and vertical hydraulic conductivity was set to that of the Upper VLQ increased by an order of magnitude. The VLQ properties were used as a reference point rather than RGC because it had the higher calibrated hydraulic conductivity and would yield a more conservative result. In the second scenario, horizontal and vertical hydraulic conductivity was set to that of the Upper VLQ reduced by an order of magnitude.

5.2.1.3 Waste Rock Piles and LGO Stockpiles

The Project includes two waste rock piles and two LGO stockpiles. Recharge through these features has the potential to affect groundwater quality and as a result the model was used to determine the discharge location and flux of water recharging the groundwater flow system from beneath these features.

The waste rock and LGO were simulated in the model by activating the two top inactive model layers above the ground surface layer within the footprint of the piles. The waste rock and LGO deposited were assigned hydraulic conductivity of $1{\times}10^{-3}$ m/s, representing coarse material. Recharge was applied to the top of the piles at an annual average rate of 82% of net precipitation, based on calculations presented in the Water Quantity and Water Quality modelling reports (Stantec 2020a,b).

Seepage collection ditches were incorporated in the model using the ditch profiles provided in the Water Management Plan (Stantec 2020c). The ditches were represented in the model using the MODFLOW DRAIN package. The stage of the drains was assigned to the base of the ditches, simulating no significant standing water in the ditches.

The model was used to better understand the fate of groundwater that originates from the waste rock piles and LGO stockpiles and to estimate discharge rates to the receiving environment. A forward particle tracking approach was used, where a particle was released from each model cell within the footprint of these features. The travel paths of the particles were simulated through the model domain until they arrived at a receptor, such as a lake or watercourse.

5.2.1.4 TMF

In addition to the waste rock piles and LGO stockpiles, seepage from the base of the TMF was also simulated in the groundwater model. The TMF was simulated in the model by activating the two top inactive model layers above the ground surface layer within the footprint of the TMF. The bottom layer of tailings (i.e., tailings at the base of the TMF) was assigned a hydraulic conductivity of $1{\times}10^{-8}$ m/s, based on representing consolidated tailings. The upper layer of unconsolidated tailings was assigned a hydraulic conductivity of $1{\times}10^{-6}$ m/s.

Recharge was applied to the top of the TMF at the average annual recharge rate of 381 mm/yr, applied to undisturbed areas elsewhere in the model. In addition, the tailings pond is assumed to operate at a constant level, and will act as a constant head boundary in the model during operation. To be conservative, the tailings pond was specified in the top model layer as a constant head boundary with a water level elevation of 354.3 m amsl. This corresponds to the normal operating level of the TMF reclaim pond at the end of operation and will result in a conservative estimate of the seepage rates over the operating period of the TMF.

Seepage collection ditches were incorporated in the model using the ditch profiles provided in the Water Management Plan (Stantec 2020c). The ditches were represented in the model using the MODFLOW DRAIN package. The stage of the drains was assigned to the base of the ditches, simulating no significant standing water in the ditches.

Seepage fate from the TMF was originally simulated using particle tracking to generate conservative estimates of mass loading to Victoria River. However, based on the predicted water quality in the TMF, and the relatively small receiving water volume in Victoria River downstream of the Victoria Dam, this method was deemed overly conservative for this location, and a contaminant transport approach using MT3D was applied. This method accounts for the partial attenuation of solutes from seepage, based on mixing of the solute with upgradient groundwater and recharge. A conservative solute was simulated as a non-depleting source within the TMF, and transport was simulated downstream for a period of 100 years. The average concentration of the simulated conservative solute in the Victoria River was compared to the source concentration to determine the attenuation ratio for the solute.

5.2.2 Results

Results of the groundwater flow modelling indicate that as dewatering progresses with development of the open pits, the average annual groundwater inflow rate to the open pits will increase, with a maximum rate of 1,350 m^3/d at the Leprechaun pit, and 1,846 m^3/d at the Marathon pit at the end of the operation phase. The change in water table elevation due to dewatering (e.g., drawdown) of the open pits at the end of mining in comparison to existing conditions is shown on Figure 5-2. Dewatering of the open pits is predicted to lower the water table by up to 1 m over an area extending up to 1.6 km from the Leprechaun pit and up to 1.3 km from the Marathon pit. The drawdown areas are extended to the north in the vicinity of the Leprechaun pit, and to the south in the vicinity of the Marathon pit. The induced infiltration of surface water to the shallow overburden and bedrock limits the extent of the drawdown. Increased infiltration in the waste rock piles results in some mounding within the waste rock piles, which also limits the drawdown in the direction of the waste rock piles.

Figure 5-2 also presents the predicted zone of influence of the TMF and waste rock piles on groundwater levels compared to existing conditions. As identified by the -1 m drawdown contour, mounding of the water table within the area of the TMF is predicted to extend up to 475 m north of the limits of the TMF, and is contained within the limits of the Leprechaun and Marathon waste rock piles. Drawdown due to the operation of the seepage collection ditches around the perimeter of the TMF and waste rock piles are predicted to lower the water table up to 1 m in the immediate vicinity of the collection ditches only.

Groundwater drawdowns of up to 1 m are predicted to occur beneath wetlands located north of the Leprechaun pit, and south of the Marathon pit (Figure 5-2) from the effects of the pits and contact water collection ditches.

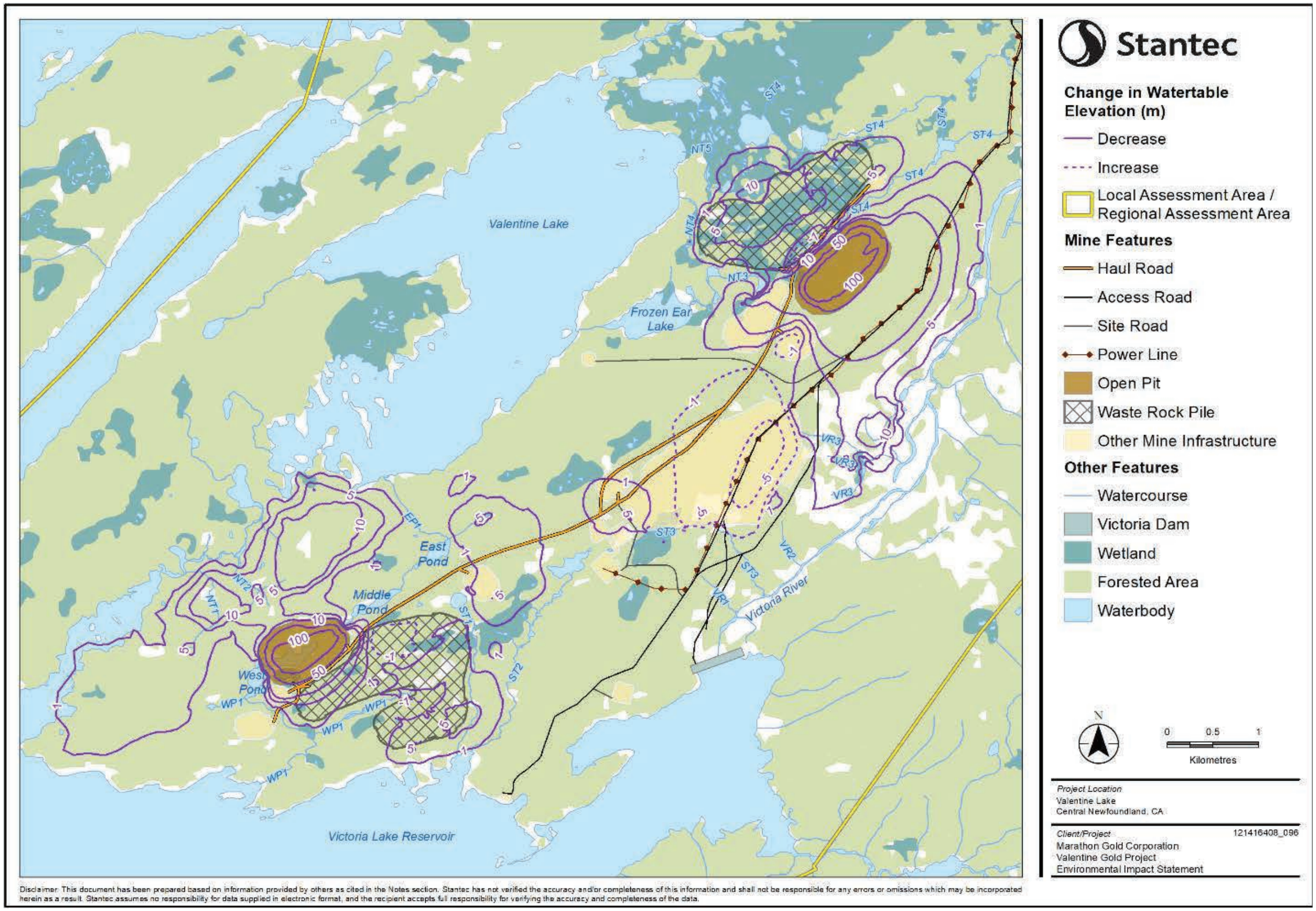

Figure 5-2 Change in Water Table Elevation at End of Project Operation

The results of the sensitivity analysis of the hydraulic conductivity of the Victoria Lake Thrust Fault on groundwater inflow rates to the open pit under dewatering conditions is presented on Table 5-2. As shown on the table, the inflow rate to the pit is relatively insensitive to decreases in the hydraulic conductivity of the fault. However, increasing the hydraulic conductivity of the fault by an order of magnitude above the bulk hydraulic conductivity may more than double the groundwater inflow rate. Therefore, additional testing to confirm the hydraulic conductivity of the faults is recommended, so that appropriate groundwater inflow mitigation measures to the pits can be developed, if necessary.

Table 5-2 Groundwater Inflow Rates to Open Pits (m^3/d) - Operation

Pit Location	Groundwater Inflow Rate Excluding Faults	Groundwater Inflow Rate With Enhanced Permeability Faults	Groundwater Inflow Rate With Reduced Permeability Faults
Leprechaun	1,350	3,089	1,278
Marathon	1,846	3,021	1,629

The effects of the open pits at their full extent, the waste rock piles and the TMF on the groundwater discharge to surface water features are assessed by comparing the predicted operation and baseline discharge rates presented in Table 5-3.

Table 5-3 Estimated Groundwater Discharge to Water Features under Baseline and Operation Phase

Water Feature	Net Flow from Groundwater to Feature (m^3/d)	
	Baseline	Operation
Unnamed Tributary to Victoria Lake Reservoir NT1	332.6	623.7
Unnamed Tributary to Victoria Lake Reservoir NT2	61.2	768.6
Frozen Ear Lake and Tributaries NT3	2874.2	2349.8
Unnamed Tributary to Valentine Lake NT4	357.4	13
Unnamed Tributary to Valentine Lake NT5	408.4	367.6
Middle and East Pond and Tributaries EP1	919.9	547.4
West Pond and Tributaries WP1	2167.9	751.6
Unnamed Tributary to Victoria Lake Reservoir ST1	782.5	614.9
Unnamed Tributary to Victoria Lake Reservoir ST2	2872.6	2469.3
Unnamed Tributary to Victoria River ST3	1306.4	208.1
Unnamed Tributary to Victoria River ST4	5201.6	3113.4
Unnamed Tributary to Victoria River VR1	0.002	206.4
Unnamed Tributary to Victoria River VR2	0.2	387
Unnamed Tributary to Victoria River VR3	153.5	962.3
Unnamed Tributary to Victoria River VR4	12	1947.4
Unnamed Tributary to Victoria Lake Reservoir NT1	332.6	623.7

The direction of groundwater discharge to each surface water feature from baseline conditions to end of operation remains consistent with water features receiving groundwater. The rate of groundwater discharge is generally decreased for water features closest to the open pits, particularly for West Pond and tributaries, and Middle and East Ponds and tributaries, due to the removal of a portion of the ponds where they are overprinted by the Leprechaun pit. Similarly, the flows in the unnamed tributary to Victoria River (ST4) are also decreased due to the overprinting of a portion of the watercourse by the Marathon pit. Several small first or second-order watercourses (NT1, NT2, ST3) are predicted to not receive any groundwater inflows during operation either due to dewatering of the open pits, or to the interception of baseflow by ditches that collect seepage from the waste rock piles, stockpiles or the TMF. The main channel of the Victoria River is predicted to receive slightly more groundwater inflow during operation due to the increased seepage predicted from the TMF. The effect of changes in groundwater discharge on surface water levels and flow are generally offset by flows from seepage collection ditches.

Seepage from the base of the waste rock piles and LGO stockpiles during operation will move the receiving environment following the flow paths presented on Figure 5-3. The associated groundwater flow rates to the receiving environment from these areas is presented on Table 5-4. These rates are used in determining the water quantity and water quality in the receiving surface water in the Water Quantity and Water Quality Modelling reports (Stantec 2020a,b) and the Assimilative Capacity Report (Stantec 2020d).

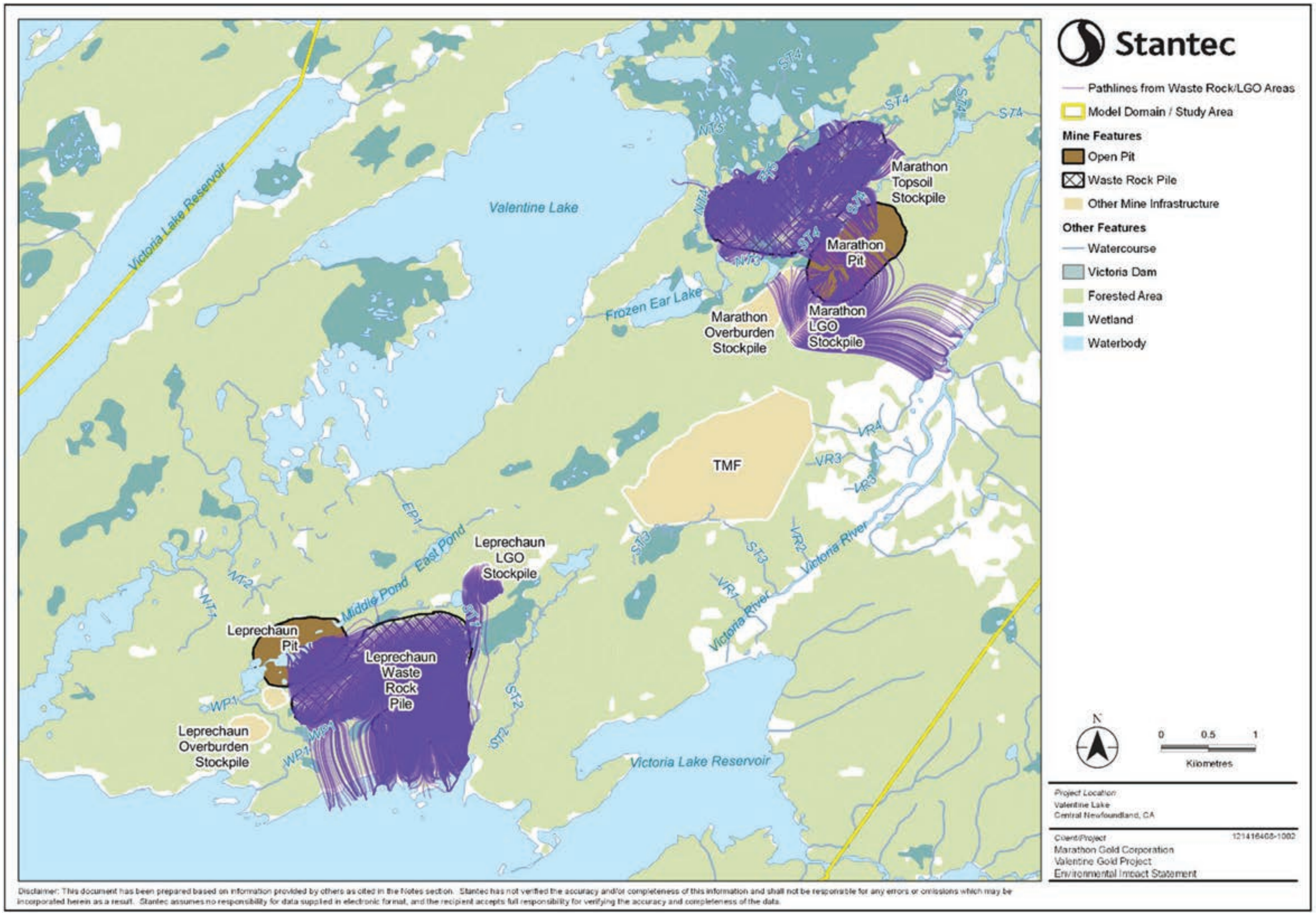

Figure 5-3 Particle Traces Illustrating Flow Paths from Waste Rock Piles and LGO Stockpiles at End of Project Operation

Table 5-4 Estimated Groundwater Seepage Rates (as percentage of total infiltration from Waste Rock Piles and LGO Stockpiles) - Operation Phase

Receptor	Waste Rock Pile	Low-Grade Ore Stockpile
Leprechaun Complex		
Leprechaun Pit	8.2%	0.0%
TMF Ditch	0.0%	0.0%
LP-SP-01A	0.0%	54.0%
LP-SP-01B	0.3%	20.5%
LP-SP-02A	26.1%	7.5%
LP-SP-02B	4.3%	0.0%
LP-SP-03A	8.0%	0.0%
LP-SP-03B	4.5%	0.0%
LP-SP-04	0.0%	0.0%
Victoria Lake Reservoir	30.6%	0.0%
Marathon Complex		
Marathon Pit	10.9%	52.6%
MA-SP-01A	0.0%	3.7%
MA-SP-01B	0.0%	2.8%
MA-SP-01C	2.3%	0.0%
MA-SP-02	27.6%	0.0%
MA-SP-03	15.2%	0.0%
MA-SP-04	6.8%	0.0%
Frozen Ear Lake and Tributaries NT3	7.9%	5.7%
Unnamed Tributary to Valentine Lake NT5	1.9%	-
Unnamed Tributary to Victoria River ST4	9.4%	-
Unnamed Tributary to Victoria River VR4	-	17.2%

The predicted attenuation ratio of seepage from the base of the TMF discharging to Victoria River at the end of operation (i.e., Year 12) is 0.0014. This indicates that at Year 10, if a solute is released from the TMF at a concentration of 1 mg/L, it will be attenuated to a concentration of 0.0014 mg/L (or 1.4 µg/L) when it is discharged to Victoria River. This represents the concentration that would be added to the background concentration and flow rates in Victoria River as part of an assimilative capacity assessment.

5.3 DECOMMISSIONING, REHABILITATION AND CLOSURE

In the decommissioning, rehabilitation and closure phase of the Project, the main effect to groundwater levels and flow is expected to result from the filling of the open pits once dewatering is terminated. The groundwater model was subsequently modified to evaluate the filling time of the open pit from groundwater inflow only, and to simulate the effects on groundwater levels and flow and the fate of groundwater originating from the waste rock piles, and TMF once the open pit has fully recovered to the intended design elevation.

5.3.1 Model Setup

Starting with model simulations from the end of operation (excluding the effects of faults), the following modifications were completed to represent the filling of the open pits, variations in recharge rates related to the closure of the waste rock piles, and rehabilitation of the TMF, as discussed below.

5.3.1.1 Open Pit Filling by Groundwater

The groundwater inflow to the open pits after dewatering is terminated was simulated to provide estimated volumes for use in the water balance model. Groundwater inflow was simulated by adjusting the stage of the DRAIN cells representing the seepage faces described in Section 5.2. The stage of the water level forming a pit lake was specified at 25 m intervals over the entire depth of the open pit.

The Leprechaun pit lake is expected to discharge naturally at an elevation of approximately 377 m amsl through an overflow channel to Victoria Lake Reservoir. The Marathon pit lake is expected to discharge naturally at an elevation of approximately 330 m amsl through an overflow channel to Valentine Lake. Steady-state model runs were conducted at each of the pit lake stages to predict the groundwater inflow rate into the open pits.

5.3.1.2 Waste Rock Piles and TMF

In the post-closure portion of the decommissioning, rehabilitation and closure phase of the Project, the waste rock benches and plateaus are rehabilitated with a soil cover and vegetated to promote runoff and reduce infiltration. The LGO stockpiles are removed and rehabilitated with soil from the overburden and toposoil stockpiles thereby depleting these piles. The groundwater recharge rate for LGO, overburden, and topsoil stockpiles was assumed to return to the baseline rate determined during the calibration of the model. For the waste rock piles, the recharge rate was decreased in post-closure period based on the increased runoff due to rehabilitation of the piles, resulting in reductions in infiltration.

The TMF will also be rehabilitated with a soil cover and vegetated to promote runoff and reduce infiltration. This results in a decreased recharge rate in the model for post-closure period.

Similar to the operation case, seepage from the base of the waste rock piles is simulated using a conservative particle tracking method, and seepage from the TMF is simulated using a solute transport approach.

5.3.2 Results

Following completion of the operation phase, dewatering of the open pits will cease and water levels will begin to rise within the open pits until an overflow elevation is reached. The water level will rise to a maximum water elevation of approximately 377 m above mean sea level (amsl) at Leprechaun pit, and approximately 330 m amsl at Marathon pit, and will represent the local water table elevation at closure. The groundwater inflow rates to the open pits as the pits fill are presented on Table 5-5.

Table 5-5 Estimated Groundwater Discharge to Water Features under Baseline and Operation Phase

Pit Lake Water Level Elevation (masl)	Marathon Pit (m^3/d)	Leprechaun Pit (m^3/d)
75.4	1846	-
100	1846	-
109.4	1846	1350
125	1846	1350
150	1846	1350
175	1846	1350
200	1846	1350
225	1846	1349
250	1789	1349
275	1662	1320
300	1479	1246
325	1186	1121
333	991	1060
350	-	918
375	-	596
380	-	468

The simulated drawdown (relative to baseline conditions) after the pits have filled to their expected overflow levels (i.e., the minimum pit edge elevation) are presented on Figure 5-4. As shown, at the end of closure, the water table is predicted to return to near baseline conditions except in the northwest corner of the Leprechaun pit. The northwest corner of the Leprechuan pit is expected to have an exposed rock wall approximately 30 m above the overflow elevation and will result in a permanently lowered water table elevation at this location following closure. This also has the effect of lowering the water table at the base of the cliff downgradient of the Leprechaun pit.

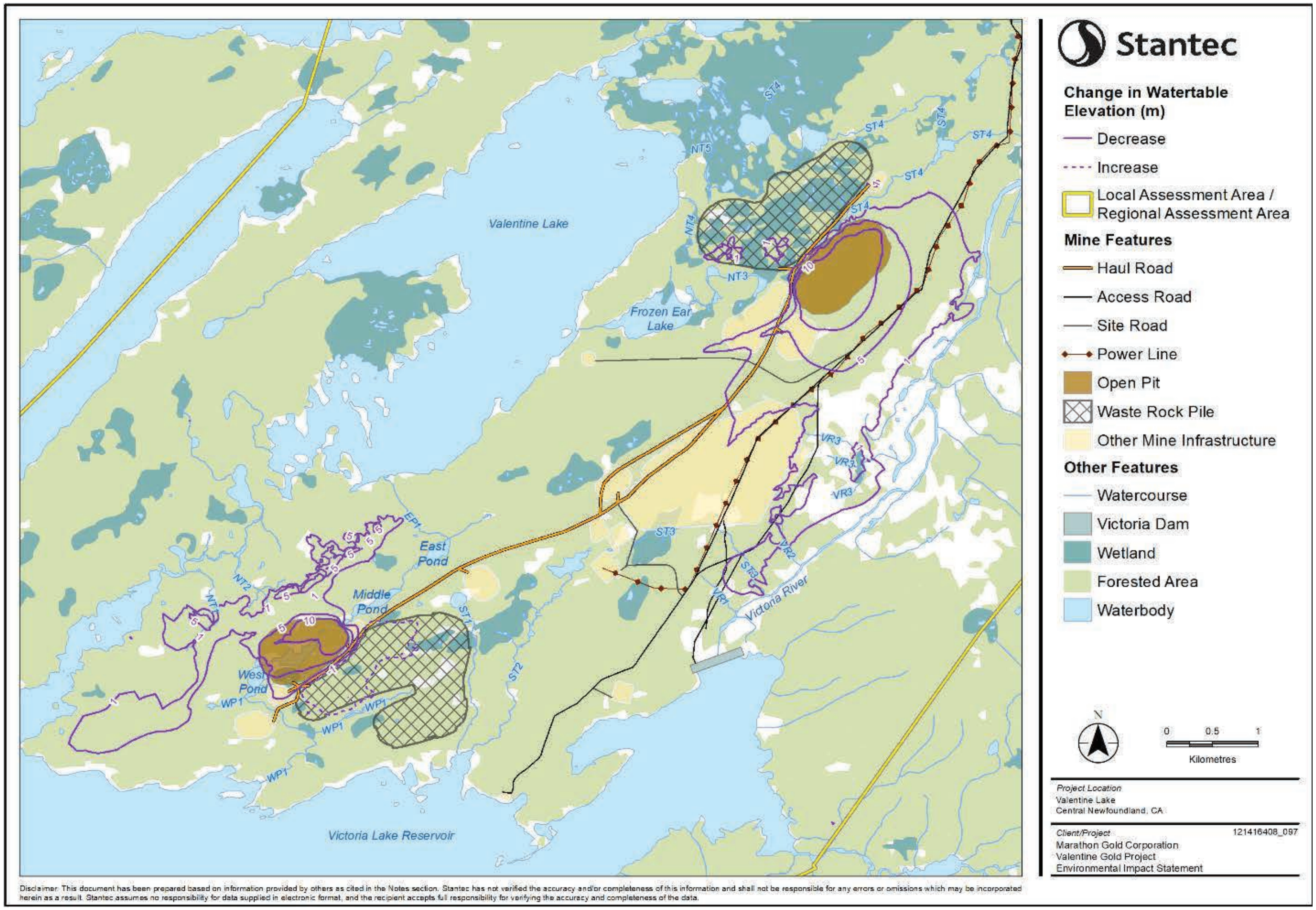

Figure 5-4 Change in Water Table Elevation Following Closure

The mounding of the water table beneath the TMF and waste rock piles is limited by the seepage collection ditches around the perimeter of these features and nearby surface water features. Mounding of the water table is generally confined to the footprint of the TMF and waste rock piles. Drawdown due to the presence of the seepage collection ditches around the perimeter of the TMF, waste rock piles and ore stockpiles is predicted in the direct vicinity of the collection ditches. The drawdown shown on Figure 5-4 assumes that the seepage collection ditches have been decommissioned. Without the seepage collection ditches, the mounding of the water table extends to the surface water features around the base of the TMF.

Table 5-6 presents the comparison of baseline groundwater discharge rates to those at closure of the TMF and waste rock piles on the baseflow of watercourses and lakes at closure (i.e., after the pit lake is full). The operation and closure of the seepage collection ditches around the perimeter of the TMF and waste rock piles were simulated in the model because the seepage collection ditches will not be decommissioned until the water quality meets applicable regulatory discharge criteria. The seepage collection ditches are predicted to collect groundwater during closure and will have relatively minor changes to baseflows at water features compared to the operation simulation. The predicted effects of the removal of the ditches on baseflow rates are shown on Table 5-6, and result in flow rates in nearby water features that are similar to baseline conditions.

Table 5-6 Estimated Groundwater Discharge to Water Features under Baseline and Post-Closure Portion of Closure Phase (i.e., Pit-Full) Conditions (m^3/d)

Surface Water Feature	Baseline	End of Post-Closure (with ditches)	End of Post-Closure (without ditches)
Unnamed Tributary to Victoria Lake Reservoir NT1	332.6	625.8	623.8
Unnamed Tributary to Victoria Lake Reservoir NT2	61.2	769.5	769.5
Frozen Ear Lake and Tributaries NT3	2874.2	2330.4	2481.1
Unnamed Tributary to Valentine Lake NT4	357.4	173	327.1
Unnamed Tributary to Valentine Lake NT5	408.4	367.7	548.6
Middle and East Pond and Tributaries EP1	919.9	560.7	565.8
West Pond and Tributaries WP1	2167.9	953.5	1197
Unnamed Tributary to Victoria Lake Reservoir ST1	782.5	616.6	972.5
Unnamed Tributary to Victoria Lake Reservoir ST2	2872.6	2468.7	2525.8
Unnamed Tributary to Victoria River ST3	1306.4	139.5	852.6
Unnamed Tributary to Victoria River ST4	5201.6	3355	3691.9
Unnamed Tributary to Victoria River VR1	0.002	206.2	206.3
Unnamed Tributary to Victoria River VR2	0.2	348.7	361.4
Unnamed Tributary to Victoria River VR3	153.5	879.4	627.9
Unnamed Tributary to Victoria River VR4	12	2043.1	2050.4

The groundwater flow to the receptors are predicted to return to near baseline rates once the pits are full, except for Middle and East Pond and tributaries (EP1), West Pond and tributaries (WP1), and the unnamed tributary to Victoria River (ST4). These features are overprinted by open pit areas, permanently reducing the footprint of these streams. The predicted changes to the groundwater flow rates are relatively small compared to the overall anticipated flow rates in the surface water features. The presence of the TMF is predicted to change the baseflow to tributaries to Victoria River downgradient of the TMF. The larger unnamed tributary ST3 will recover some of the baseflow lost during operation once the drainage ditches around the TMF are removed. Several smaller tributaries, VR1, VR2, VR3 and VR4, are all expected to receive higher baseflow starting in operation due to the presence of the TMF, and these effects continue throughout closure.

Seepage from the base of the waste rock piles and LGO stockpiles during the post-closure period in the decommissioning, rehabilitation and closure phase will move the receiving environment following the flow paths presented on Figure 5-5. The associated groundwater flow rates to the receiving environment from these areas is presented on Table 5-7. These rates are used in determining the water quantity and water quality in the receiving surface water in the Water Quantity and Water Quality Modelling reports (Stantec 2020a,b) and the Assimilative Capacity Report (Stantec 2020d).

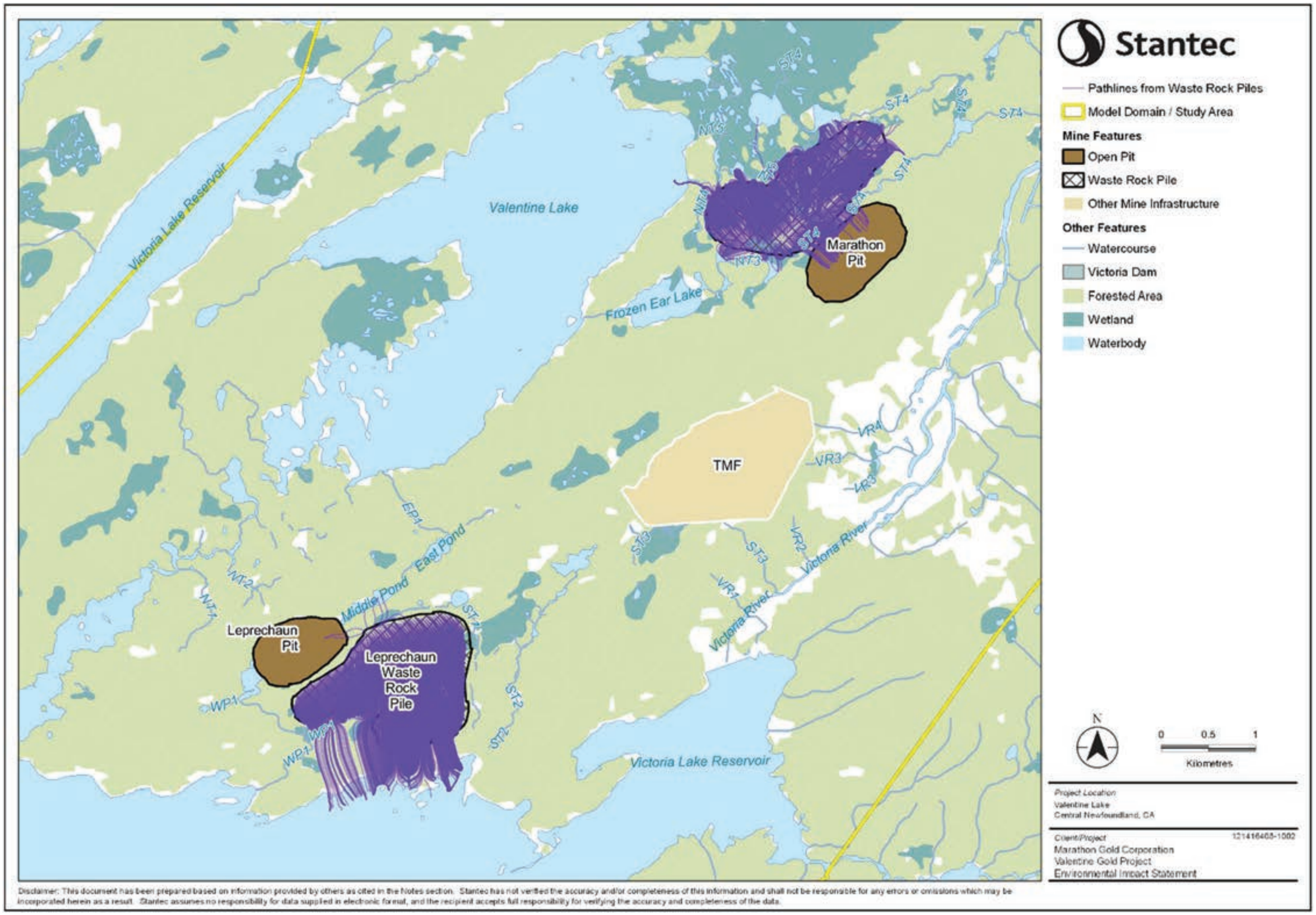

Figure 5-5 Particle Traces Illustrating Flow Paths from Waste Rock Piles and LGO Stockpiles at End of Project Operation

Table 5-7 Estimated Groundwater Seepage Rates from Waste Rock Piles (as % of Total Infiltration) - Post-Closure Period

Water Management Receptor	Percentage of Recharge from Waste Rock Pile
Leprechaun Complex	
Leprechaun Pit	0.1%
LP-SP-01A	0.0%
LP-SP-01B	0.1%
LP-SP-02A	34.7%
LP-SP-02B	0.0%
LP-SP-03A	8.6%
LP-SP-03B	6.7%
Marathon Complex	
Marathon Pit	7.2%
MA-SP-01A	0.0%
MA-SP-01B	0.0%
MA-SP-01C	1.5%
MA-SP-02	26.5%
MA-SP-03	15.4%
MA-SP-04	23.0%
Frozen Ear Lake and Tributaries NT3	2.5%
Unnamed Tributary to Valentine Lake NT5	0.4%
Unnamed Tributary to Victoria River ST4	2.1%
Unnamed Tributary to Victoria River VR4	3.3%

The predicted attenuation ratio of seepage from the base of the TMF discharging to Victoria River after 100 years of post-closure conditions is 0.039. This indicates that if a solute is released from the TMF at a concentration of 1 mg/L, it will be attenuated to a concentration of 0.039 mg/L (or 39 µg/L) when it is discharged to Victoria River 100 years later. This represents the concentration that would be added to the background concentration and flow rates in Victoria River as part of an assimilative capacity assessment.

5.4 PREDICTION CONFIDENCE

The approach used in model simulations completed for this Project was to incorporate conservative assumptions for predicting effects that may result from the Project. This report presents the assumptions made in developing these conservative predictions, and discusses the high level confidence of these predictions.

The modelling was conducted using an EPM approach. As discussed in Section 4.0, this is appropriate based on the regional scale of the modelling, and considering that flow was predicted to occur primarily through the shallow weathered bedrock, which is highly fractured, and therefore behaves like a porous medium.

A steady-state modelling approach was selected for the open pit dewatering as this provides the most conservative estimate of groundwater drawdown at the end of operation and as a result the potential effects on groundwater levels and reductions in groundwater discharge to surface water receivers. The steady-state modelling approach provides average annual groundwater inflow rates and may “under predict” Project inflows in the early phases of open pit development. However, while increased inflows due to storage in the aquifer materials and the slightly higher hydraulic gradients may be expected during the initial dewatering period, this not expected to be an issue for the Project and the use of the multiple steady-state model runs reduces this potential effect and the model provides reliable long term representation of groundwater inflows over the life of the mine.

Groundwater recharge rates at the waste rock piles and LGO stockpiles to the receiving environment are conservatively “over predicted” as all recharge applied within these areas are assumed to be carried through to the final receptors.

The groundwater flow modelling was conducted using a model calibrated to water levels and baseflow targets to establish baseline conditions. Predictions made using the model are based on several conservative assumptions to reduce the influence of uncertainty in the predictions. Therefore, the confidence in the predictions made using the model is considered high.

6.0 CONCLUSIONS

Hydrogeology modelling was conducted to identify changes to groundwater levels and flow pathways to inform the assessment of potential effects of the Project on groundwater and surface water resources. The modelling was conducted using MODFLOW-NWT and was calibrated to baseline conditions within acceptable industry standards.

The construction and operation of the open pits will require the open pit to be dewatered due to groundwater inflows (and surface water inflows which are considered outside of this report). The dewatering of the open pit will result in the of drawdown of the water table by up to 1.0 m over an area extending approximately up to 1.6 km from the Leprechaun pit and up to 1.3 km from the Marathon pit. The drawdown areas are extended to the north in the vicinity of the Leprechaun pit, and to the south in the vicinity of the Marathon pit. Increased infiltration in the waste rock piles and the TMF results in some mounding within the waste rock piles, which also limits the drawdown in the direction of the waste rock piles.

A sensitivity analysis of the hydraulic conductivity of the Victoria Lake Thrust Fault shows that increasing the hydraulic conductivity of the fault by an order of magnitude above the bulk hydraulic conductivity may more than double the groundwater inflow rate. Additional testing to confirm the hydraulic conductivity of the faults is recommended, so that appropriate groundwater inflow mitigation measures to the pits can be developed, if necessary.

The fate of groundwater recharging beneath the waste rock piles and LGO stockpiles during operation was determined by conducting particle tracking in the groundwater flow model. Flow rates to seepage collection ditches, the open pit, or surface water receivers are generated for use in the Water Quantity and Quality Modelling, and Assimilative Capacity reports to assess the effects on surface water. Groundwater originating from the TMF and travelling to Victoria River is attenuated by at factor of 0.0018 during operation.

Upon the termination of Project activities (i.e., the closure phase of the Project), the open pit will be allowed to fill to form a pit lake. The groundwater model was used to predict the groundwater inflow rates to the open pit for use in the water balance. Groundwater levels around the open pits are expected to recover, but a permanent lowering of the water table is expected in limited areas, based on maintaining a pit lake level that is many metres below the pre-development water table surface where hills at the sides of the pits are excavated.

Rehabilitation of the TMF at closure will alter the distribution of groundwater recharge originating from the TMF. The attenuation factor of solutes originating from the TMF and discharging to Victoria River 100 years after closure is 0.039.

Groundwater discharge to surface water features associated with Project facilities represents a minor component of the overall surface water flow systems. The modelling results will be considered in the assessment of potential effects on the receiving environment.

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