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Robin Jones
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Dear Mr. Jones:

Browns Range Project
Water Supply Modelling

1 INTRODUCTION

The Browns Range Project (the Project) is being developed by Northern Minerals Ltd (NTU) as a Heavy Rare Earth Elements (HREE) Project. Klohn Crippen Berger Ltd. (KCB) was commissioned by NTU to undertake a number of studies to assist with development of a water supply for the Project. The initial phases of the Project involved the drilling and test pumping of water supply bores in the vicinity of the Project area (Figure 1). The Gardiner Sandstone aquifer was identified as a potential supply option.

During the hydrogeological scoping study (KCB, 2012), the Ringer Soak community groundwater supply bores and Banana Springs (groundwater-fed wetlands), located approximately 34 km and 12 km to the west of the Project area, respectively, were identified as being sourced from the Gardiner Sandstone aquifer. Therefore, KCB investigated the potential for impact on these receptors associated with the implementation of a water supply borefield by NTU in the Gardiner Sandstone aquifer.. In order to assess the potential impacts on these features, a numerical groundwater model was developed and simulated to assess the potential risks associated with long term pumping (10 year project life) of a proposed water supply borefield.

The objectives of the numerical model include:

- assess the extent of drawdown associated with long-term pumping from the Gardiner Sandstone aquifer;
- evaluate the long-term sustainability of the Gardiner Sandstone as a potential water supply option for the Project; and,
- identify potential impacts on Banana Springs and the Ringer Soak community water supply bores due to the development and operation of the proposed Project water supply borefield.

2 CONCEPTUALISATION

2.1 Project Area

The Browns Range Project is located approximately 150 km southeast of Halls Creek adjacent to the Northern Territory border in the Tanami region of Western Australia. The location of the Project area is presented in Figure 2.

2.2 Geology

The Browns Range Dome is a Paleoproterozoic dome formed by a granitic core intruding the Paleoproterozoic "Browns Range Metamorphics" (meta-arkoses, feldspathic metasandstones and schists); and, an Archaean orthogneiss and schist unit to the south. The dome, and the aureole of metamorphic units, are surrounded by the Paleoproterozoic Gardiner Sandstone of the Birrindudu Group. Sandstone units (age uncertain) from the Eastern Canning Basin margin (Billiluna Shelf) have been interpreted to be overlying the Gardner Sandstone to the southwest of the dome (Das, 2011). A generalised geological map of the area is presented in Figure 3.

The conceptual hydrogeological setting relevant to the Project is defined according to the Gardiner Sandstone and Browns Range Metamorphics, which is summarised in the following sections. Further details on the hydrogeological conceptualisation across the Project area is provided in the Stage 2 Hydrogeological Assessment report (KCB, 2014 – in preparation).

2.2.1 Gardiner Sandstone

The Gardiner Sandstone is characterised by medium to thick bedded sublithic to lithic arenite and quartz arenite ("sandstones") (Blake et al 1979). The sandstones are interlayered with subordinate shale and siltstone, with conglomerate common at the base of the unit. The sandstones are predominantly medium grained, with cross bedding and ripple marks common throughout (Das, 2011).

Hydrogeologically, the sandstones are characterised by low to very low primary porosity. Groundwater is associated with zones of secondary porosity, which may include faulting and associated fractures; and, along bedding planes. Aquifer hydraulic conductivities estimated from test pumping performed on bores constructed within the Gardiner Sandstone ranged from 0.8 m/d to 1.9 m/d. The groundwater flow direction is interpreted to be a reflection of the topography, which slopes gently from the east-southeast to the west-northwest, towards Sturt Creek. Recharge to the aquifer primarily occurs seasonally via direct infiltration from precipitation on the sandstone outcrop, and is estimated as a percentage of mean annual rainfall (typically 1-3%). Recharge is also likely to occur via infiltration from the overlying unconsolidated Quaternary alluvium (located adjacent to the surface water courses). Recharge from the alluvium to the Gardiner Sandstone aquifer has been conservatively estimated at 3-5% of mean annual rainfall (recharge from the alluvium to the sandstone may be higher due to residence time of water in the alluvium following rainfall events). A Project-specific assessment of recharge has not been conducted at the Project site. Estimates of recharge adopted in the numerical model are based on KCB's experience with similar hydrogeological settings. A summary of the hydraulic conductivities estimated from field testing is presented Table 2-1.

Table 2-1: Summary of Hydraulic Conductivities

Hole ID	Hydraulic Conductivity (m/d)	Hydraulic Conductivity (m/s)	Hydraulic Testing
Browns Range Metamorphics			
BRWWD002	0.0074	8.56×10^{-8}	Falling Head Test
BRAWD009	0.03	3.47×10^{-7}	72 Hour Pumping Test
BRR036P	1.9	2.19×10^{-5}	72 Hour Pumping Test
BRRWS002	0.0074	8.56×10^{-8}	72 Hour Pumping Test
BRGWD003	0.008	9.26×10^{-8}	Falling Head Test
BRGWD007	0.00027	3.13×10^{-9}	Falling Head Test
Gardiner Sandstone			
BRRWS007	0.8	9.26×10^{-6}	72 Hour Pumping Test
BRRWS0010	1.9	2.19×10^{-5}	72 Hour Pumping Test

2.2.2 Browns Range Metamorphics

Hydrogeological drilling completed by KCB (2013) identified that the lithologies of the Browns Range Metamorphics were characterised by low primary porosity. Minor localised secondary porosity, due to discrete geological structures (i.e. faulting, fracturing, shear zones), was identified during exploration drilling, geophysical surveys and hydrogeological test drilling. Hydraulic testing performed on bores installed in the Browns Range Metamorphics estimated hydraulic conductivities ranging from 2.7×10^{-4} m/d to 1.9 m/d. As per the Gardiner Sandstone aquifer, the groundwater flow direction in the Browns Range Metamorphics within the vicinity of the Project site is a reflection of the surface topography, with a flow gradient from northeast to southwest. The location of the Project site is adjacent to a prominent surface water catchment divide, with surface water flow from the majority of the Project area towards the southwest. The eastern extent of the Project site flows towards the east, across the border into the Northern Territory. As a result of the proximity of the Project site to the catchment divide, a relatively flat groundwater gradient is observed across the Browns Range Metamorphics aquifer.

Recharge for the Browns Range Metamorphics has been estimated at 1-3% of mean annual rainfall. A summary of the hydraulic conductivities for this aquifer is presented in Table 2-1.

2.3 Groundwater Abstraction

The water demand for the Project processing facility (provided by NTU), along with estimates for dust suppression has been approximated as 1.1 GL/yr (~35L/s). A contingency of 20% (0.22 GL/yr; total demand = 1.32 GL/yr) has been included in the simulation of the borefield production to accommodate potential additional Project demands. Field hydrogeological investigations (test drilling, bore installation, test pumping) conducted across the Project site has identified the Gardiner Sandstone unit as having the potential to meet the Project water demand.

Currently, two test production bores (BRRWS007 and BRRWS0010) have been installed in the Gardiner Sandstone. Hydraulic testing of these bores has provided a preliminary understanding of the hydraulic parameters associated with this aquifer. Additional production bores are planned for this unit to address the Project water demand (Figure 12). These proposed bores have been included in the predictive modelling scenarios, (and are referred to) as the “Stage 2B drill targets”, to allow assessment of water supply sustainability and the drawdown extent associated with the development of the proposed borefield. Construction details of these proposed production bores are based on the construction details of BRRWS007 and BRRWS0010.

3 NUMERICAL MODELLING

3.1 Model Setup

Visual MODFLOW version 2011.1 was the platform used to simulate the groundwater system and the proposed Project water supply borefield. Information gathered during the Stage 2 Hydrogeological Assessment field program has been used to develop the numerical model. Due to the limitations associated with the availability of hydrogeological data across the defined model domain, this numerical model is considered preliminary. Sensitivity analyses were conducted on key model input parameters to provide a range of results anticipated to reflect borefield operational conditions.

3.2 Model Domain

The extent of the model domain is presented in Figure 1 and comprises the Project exploration licence areas, Banana Springs, Ringer Soak, a reach of Sturt Creek and the western extent of the Browns Range Dome.

The model domain area is approximately 77 km by 76 km, covering a total area of 5,882 km^2, with the current production bores (BRRWS007 and BRRWS0010) located near the centre of the domain. This domain was established to allow for the inclusion of Sturt Creek, which provides the boundary conditions for simulating the regional groundwater flow direction. The model grid comprises a regular grid with a cell size of 250 m x 250 m, refined to 125 m x 125 m within the vicinity of the Project site. This refinement allowed for better resolution of the predicted water levels in the vicinity of the simulated borefield. The model grid is presented in Figure 4.

The model was constructed as a single layer model with the thickness ranging between 321 m and 686 m. The elevation of the bottom of the layer was approximately 20 m deeper than the deepest bore. The thickness of the layer was established in order to maintain a saturated profile below the production bores and prevent any potential interference with the base of the model. The Gardiner Sandstone and the Browns Range Metamorphics were assumed to extend to the base of the model.

3.1 Boundary Conditions

A general-head boundary condition was applied to Sturt Creek during the steady-state simulation and verification process to simulate the regional groundwater gradient across the model domain. The location of the general-head boundary is presented in Figure 5. The northern, eastern and southern boundaries of the model were simulated as inactive and effectively represent no flow boundaries in the model.

3.2 Hydraulic Parameters

Hydraulic conductivity and specific storage values were estimated from aquifer testing conducted on production bores across the Project site (Gardiner Sandstone and Browns Range Metamorphics). Four zones were created over which the hydraulic conductivity values were distributed. These zones include:

- Gardiner Sandstone – values obtained from analysis of test pumping results;
- Browns Range Metamorphics – values obtained from analysis of test pumping and falling head tests; and,
- Gambit low hydraulic conductivity zone – values obtained from falling head tests performed within the vicinity of this area.

A summary of the assigned hydraulic conductivities are presented in presented in Table 3-1, while their spatial distribution presented in Figure 6. These values were established during the model verification process to allow a reasonable correlation between simulated and observed groundwater levels across the model domain.

Table 3-1: Assigned Hydraulic Conductivities

Zone	K_x (m/d)	K_y (m/d)	K_z (m/d)
Gardiner Sandstone	1.7	1.7	1.7×10^{-1}
Browns Range Metamorphics	9×10^{-2}	9×10^{-2}	9×10^{-3}
Gambit Low K Zone	1×10^{-3}	1×10^{-3}	1×10^{-4}

Two zones of specific storage were established in the model domain. The Gardiner Sandstone and the Browns Range Metamorphics were assigned separate specific storage values, which are summarised in Table 3-2 and presented Figure 7.

Table 3-2: Assigned Specific Storage Values

Zone	Ss (1/m)
Gardiner Sandstone	1.91×10^{-3}
Browns Range Metamorphics	2.42×10^{-4}

Due to the limited data availability for a large extent of the model domain, bulk hydraulic conductivities and storage values were assigned across the domain. Further assumptions associated with the numerical model are presented in Table 4-3.

3.3 Recharge

Specific aquifer recharge studies have not been undertaken at the Project site; therefore, the recharge applied in the model has been based on anecdotal information and experience with similar hydrogeological settings. As previously discussed, recharge has been estimated as a function of the mean annual rainfall. Long-term rainfall data for the Halls Creek weather station, approximately 150 km northwest of the Project site (Bureau of Meteorology, 2013) has been used to estimate aquifer recharge. A summary of the rainfall data is provided in Table 3-3.

Table 3-3: Rainfall Data Summary

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Mean Rainfall (mm)	150.7	143.0	82.7	21.4	12.8	5.4	6.0	1.9	4.6	17.6	37.4	82.2	556.4

Three recharge zones were assigned based on an understanding of the hydrogeological setting across the Project area. A summary of these recharge rates is provided in Table 3-4, while the spatial distribution is presented in Figure 8.

Table 3-4: Groundwater Model Recharge Summary

Zone	Rainfall (mm/year)	% Recharge	Recharge (mm/year)
Country Rock (Gardiner Sandstone and Browns Range Metamorphics)	556.4	1.5%	7.7
Alluvium (creek beds across the Project site)	556.4	3%	16.2
Sturt Creek	556.4	4%	22.2

3.4 Model Verification

A steady-state model simulation was completed to assess if the established model domain provided a general representation of the current site hydrogeological conditions. This simulation was also undertaken to provide the starting groundwater levels for subsequent transient simulations (i.e. predictive simulations).

Verification of the model domain was undertaken by comparing simulated water levels with observed water levels. Given the large model domain area, the contrasting geological terrain and the potential unknown structural features over which the water levels were measured, the resultant simulated steady-state conditions generally showed a good correlation to observed groundwater levels. A groundwater level contour map of the steady-state levels is presented in Figure 9. Table 3-5 presents the observed and simulated groundwater levels from the steady-state verification, while Figure 10 presents a graphical representation of this comparison. The location of the observation bores is presented in Figure 11.

Table 3-5: Steady-State Model Verification Results

Bore ID	Observed Water Level (mAHD)	Calculated Water Level (mAHD)	Residual (m)
Banana Springs	390.91	406.08	15.17
BRAR0030	419.50	421.85	2.34
BRAWD009	422.	422.37	0.07
BRBR0016	428.33	428.66	0.32
BRGWD007	430.41	431.34	0.93
BRR0002	416.54	408.42	-8.11
BRR0004	420.17	416.83	-3.33
BRR0005	421.23	423.01	1.78
BRR0007	433.32	430.40	-2.91
BRR0036	424	417.88	-6.11
BRRWS001	415.38	416.36	0.98
BRRWS0010	409.04	412.85	3.80
BRRWS002M	437.21	427.65	-9.55
BRRWS007M	417	415.58	-1.41

The scaled RMS Error between the simulated and observed water levels for the verified steady-state conditions was 12.61%. This correlation comprised a maximum residual of 15.17 m, a minimum residual of 0.074 m and an average residual of 4.21 m. Given the limitations associated with this preliminary model (e.g. limited hydrogeological data, large model extent) the RMS Error is considered adequate for the purpose of this model.

The heads calculated from the steady-state verification were used as the initial heads for the transient simulations. Model input parameters adjusted in the verification process included horizontal conductivity, vertical conductivity, specific yield and recharge.

3.5 Sensitivity Analysis

Due to the limitations associated with the model input parameters, particularly hydraulic conductivity and recharge, conservative sensitivity analyses were conducted using these parameters to provide a range of results likely to be representative of site conditions. These parameters were varied individually with the model simulated to assess the variation in results due to those changes. The sensitivity analyses were based on:

- **Hydraulic conductivity**. The hydraulic conductivities of each zone were decreased by an order of magnitude (K / 10).
- **Recharge**. The recharge was varied by half the values used for steady-state verification.

The results of the sensitivity analyses are discussed in Section 4.2.

3.6 Predictive Simulations

The model domain developed during the steady-state simulation and verification was used to undertake predictive simulation of water supply borefields. The verified steady-state groundwater level was used as the initial head for the predictive simulation. Two scenarios were simulated to assess possible impacts on Banana Springs and the Ringer Soak water supply bores; and, water supply sustainability for the Project. These scenarios comprise:

- Base Case – pumping from the established test production bores for the duration of the Project life (10 years) – 21 L/s total abstraction; and,
- Scenario A – pumping from a seven bore water supply borefield, including the two established test production bores, with each bore pumping at 6 L/s for the duration of the Project life (10 years) – 42 L/s total abstraction.

Assumptions and limitations associated with the predictive simulation (proposed borefield and model are summarised in Table 4-3). Summaries of the two predictive simulations are provided in the following sections.

3.6.1 Base Case BRRWS007 and BRRWS010 – 21L/s

The Base Case predictive simulation is based on a borefield comprising BRRWS007 and BRRWS010, the established test production bores, with both bores pumping at the pumping rate applied during the 72-hour constant-rate pumping test (21 L/s – BRRWS007 at 15L/s and BRRWS010 at 6L/s). The objective of this simulation is to assess the potential drawdown extents and sustainability of the proposed abstraction rate associated with the established production bore network over the Project duration.

3.6.2 Stage 2B Borefield – 42 L/s (Scenario A)

Hydrogeological drilling, conducted as part of the Stage 2 hydrogeological assessment (KCB, 2014 – in progress) field program, within the Gardiner Sandstone aquifer indicate that this unit has potential for additional high yielding (>6 L/s) bores. Additionally, monitoring of groundwater level drawdown in the monitoring bores adjacent to the production bores during the 72 hour constant rate test indicate that limited drawdown migration away from the production bores was observed. This indicates the potential for establishing a closer network of bores in the borefield as drawdown interference from simultaneous pumping from adjacent production bores may be limited.

A simulation of a borefield network comprising five production bores in addition to BRRWS007 and BRRWS010; and, within the vicinity of these bores was undertaken. Selection of the locations of the five proposed production bores was based on existing and approved tracks, with the bores to be installed adjacent to these tracks. The proposed production bores were simulated with a construction depth of 150 mbGL and a screened interval from 10 to 150 mbGL (comparable to BRRWS010). The locations of these bores are presented in Figure 12 and summarised in Table 3-6.

Table 3-6: Simulated Production Bore Network and Pumping Rates

Bore ID	Location		Simulated Pumping Rate (L/s)	Screened Interval	Total Depth	Status
	Easting	Northing		(mbGL)	(mbGL)	
BRRWS007	486096	7905551	6	69-93	93	Established
BRRWS010	485053	7907930	6	12-96	102	Established
BRRWS011	488024	7905834	6	10-150	150	Proposed
BRRWS018	485562	7910965	6	10-150	150	Proposed
BRRWS016	486704	7903953	6	10-150	150	Proposed
BRRWS013	485982	7908208	6	10-150	150	Proposed
BRRWS0021	486136	7906721	6	10-150	150	Proposed
Total:			42			

Note/s:
m: meters
Coordinate System : GDA94, Zone 52
mbGL : meters below ground level

4 SIMULATION RESULTS

4.1 Base Case Simulation

Figure 13 presents the predicted groundwater level and interpreted drawdown at Banana Springs associated with the borefield operation for the duration of the Project life (10 years). Negligible drawdown in groundwater levels was predicted at Banana Springs. A drawdown of 0.65 m and 0.37 m was simulated at BRRWS007 and BRRWS010, respectively.

4.2 Stage 2B Borefield – 42 L/s (Scenario A)

The predicted groundwater levels associated with the simulation of the Stage 2B borefield for the duration of the Project life (10 years) is presented in Figure 14.

Results from the predictive simulation indicate that a maximum drawdown of approximately 0.7 m was simulated across the borefield after 10 years of operation; with negligible drawdown at Banana Springs. Based on these results, the model indicates that this groundwater abstraction scenario will be a sustainable, given the assumptions and limitations provided in Table 4-3, for the proposed Project life.

The model conservatively assumes that the aquifer is homogeneous using an equivalent porous media approach (i.e. aquifer parameters identified during the hydraulic testing program are bulked across the entire Gardiner Sandstone unit). In reality, permeability in the Gardiner Sandstone is likely to be governed by discrete fracture systems that are typically discontinuous and variable interconnectivity. Additionally, seasonal variability in the recharge flux has not been incorporated into the model. It is anticipated that groundwater levels would vary seasonally across the Project site, with the natural seasonal fluctuations likely to be an order of magnitude greater than the simulated drawdown at Banana Springs. Given these assumptions and interpreted Project site conditions, it is unlikely that long term pumping from the borefield will result in discernable impacts on Banana Springs.

4.3 Sensitivity Analysis

4.3.1 Hydraulic Conductivity

Due to the extent of the proposed Project water supply aquifer (Gardiner Sandstone aquifer), and limitations in the available hydraulic parameter data across the aquifer extent, a sensitivity analysis based on the hydraulic conductivity was undertaken. This analysis was conducted by conservatively varying the Gardiner Sandstone hydraulic conductivity by decreasing by an order of magnitude (K / 10).

A summary of the predicted drawdown results simulated from the sensitivity analysis is provided in Table 4-1. Figure 15 presents the drawdown contours associated with the decreased hydraulic conductivity simulations.

Table 4-1: Sensitivity Analysis Results – Hydraulic Conductivity (10 year Simulation)

Bore ID	Verified K – Drawdown (m)	K/10 – Drawdown (m)
Banana Springs	negligible	negligible
BRRWS007	0.72	3.22
BRRWS010	0.67	3.33

Based on the results of the hydraulic conductivity sensitivity analysis the drawdown associated with the development of the Project water supply borefield will range from 0.67 m to 3.33 m at the borefield, and negligible drawdown at Banana Springs, for the 10 year operation duration. Further hydraulic testing of the Gardiner Sandstone aquifer within the vicinity of the proposed borefield should be undertaken to obtain a more accurate simulation of borefield drawdown levels.

4.3.2 Recharge

Sensitivity analyses were also undertaken on the Scenario A predictive simulation by conservatively varying the rate of recharge. Recharge was varied by halving (x 0.5) the verified recharge value. The results of the sensitivity analysis simulation indicate that the groundwater levels drawdown is negligible at Banana Springs when the recharge is halved. Table 4-2 presents the water level variations at Banana Springs for the Base Case and sensitivity analysis simulations.

Table 4-2: Recharge Sensitivity Results

Bore ID	Verified Recharge – Drawdown (m)	Recharge/2 – Drawdown (m)
Banana Springs	negligible	negligible
BRRWS007	0.72	0.84
BRRWS010	0.67	0.78

4.4 Limitations and Assumptions

Key limitations, assumptions and consequences of predictive simulations are presented and summarised in Table 4-3.

A key limitation to the numerical model is the availability of data across the model domain. The model domain was established to incorporate the Gardiner Sandstone aquifer extent and the boundary condition along the western extent of the aquifer. However, limited hydraulic parameter data is available between the Project site and the western extent of the aquifer, therefore, aquifer parameters obtained from the hydraulic testing program was bulked across the aquifer extent. The same limitation in hydraulic parameter data also occurs for the Browns Range Metamorphics aquifer, also resulting in the application of hydraulic testing results across the aquifer extent.

Table 4-3: Model Limitations, Assumptions and Consequences Summary

Data/Area	Limitations	Assumptions	Consequences
Regional Groundwater Level Data	No regional water level data was available beyond the Project area (exploration licence area)	Regional water levels developed from steady-state calibration	Potentially inaccurate modelled water levels
		Regional water levels to generally follow topography	
Regional Structural Data	No data pertaining to regional structures	Homogeneous aquifer with no structures	Potential no flow boundaries not modelled
			Potential preferential flow paths not modelled
Abstraction Rates	Sustainable yields based on 72 hour pumping test	Calculated sustainable yields sustainable for 10 years	Potential decline in bore yields over time
Recharge Data	Limited site-specific rainfall records and no recharge studies	Assigned generally accepted values	Potentially inaccurate modelled water levels
Hydraulic Parameters	Insufficient regional data	Bulk hydraulic parameter values have been assigned on a regional scale using data attained from the test pumping program conducted	Potentially inaccurate modelled scenarios, inaccurate water levels and calibration
Scenario A Proposed Borefield Network	Drilling has not been conducted at proposed site; actual groundwater yield and aquifer characteristics may not be represented in the model	Homogenous aquifer parameter based on hydraulic testing conducted to date	Potentially inaccurate groundwater level drawdown simulation from proposed borefield

5 CONCLUSIONS

A groundwater model was constructed for the Browns Range Project to evaluate potential impacts on the groundwater system from the development of a Project water supply borefield; and, to assess the sustainability of the water supply for the duration of the Project water demand (10 years). A steady-state model was developed and verified for hydraulic conductivity, storage and recharge. The verified steady-state model formed the basis of the predictive simulation, while the steady-state groundwater level was used as the initial groundwater level for predictive simulations.

Two predictive simulations were undertaken. A Base Case simulation comprising the established test production bores (BRRWS007 and BRRWS010), with a total abstraction rate of 21 L/s; and, Scenario A, comprising a borefield network of seven production bores (including the Base Case bores), with a total abstraction rate of 42 L/s (6 L/s from each bore). Both simulations were conducted for a duration of 10 years.

Results from the Base Case simulation indicated that drawdown was not observed at Banana Springs after 10 years, while a maximum drawdown of 0.65 m was observed at the borefield.

Results from Scenario A also indicated that drawdown was not observed at Banana Springs after 10 years of borefield operation. Maximum drawdown simulated at the borefield was 0.72 m. Due to the limitations associated with the available hydraulic parameter data across the Gardiner Sandstone aquifer, sensitivity analysis was conducted on the model by conservatively varying the hydraulic conductivity by an order of magnitude below the verified parameter value. The range of results provided by this sensitivity analysis is interpreted to represent anticipated drawdown associated with borefield operation. The results of the sensitivity analysis indicate that drawdown at the borefield range from 0.67 m to 3.33 m; while drawdown at Banana Spring after 10 years of borefield operation is negligible.

Sensitivity analysis was also conducted by conservatively decreasing the recharge by 50%. Results from this simulation and the verified recharge parameter simulation range from 0.67 m to 0.84 m at the borefield; and, negligible drawdown at Banana Springs for the 10 year borefield operation duration.

The predicted drawdowns resulting from the verified model parameters and sensitivity analysis provide a reasonable estimate for the anticipated Project water supply borefield development and operation. Based on these results the extent of drawdown from the borefield will likely have limited impact on Banana Springs and the Ringer Soak community water supply bores; while the proposed abstraction from the borefield (42 L/s) for the Project life (10 years) is consider sustainable. Although, sensitivity analyses were undertaken to conservatively estimate groundwater level drawdowns from the borefield, it is recommended that additional hydraulic testing should be undertaken to assess the distribution of aquifer parameters across the Gardiner Sandstone aquifer; particularly within the vicinity of the proposed borefield and between the borefield and Banana Springs.

Yours truly,
KLOHN CRIPPEN BERGER LTD.

Chris Strachotta
Associate & Manager – Western Australia

CS

APPENDIX I

Figures

Figure 1 Water model project study area

Figure 2 Location of project area

Figure 3 Geology map

Figure 4 Model grid

Figure 5 General head distribution

Figure 6 Hydraulic conductivity distribution

Figure 7 Storage distribution

Figure 8 Recharge distribution

Figure 9 Steady-state water levels

Figure 10 Calculated vs observed head

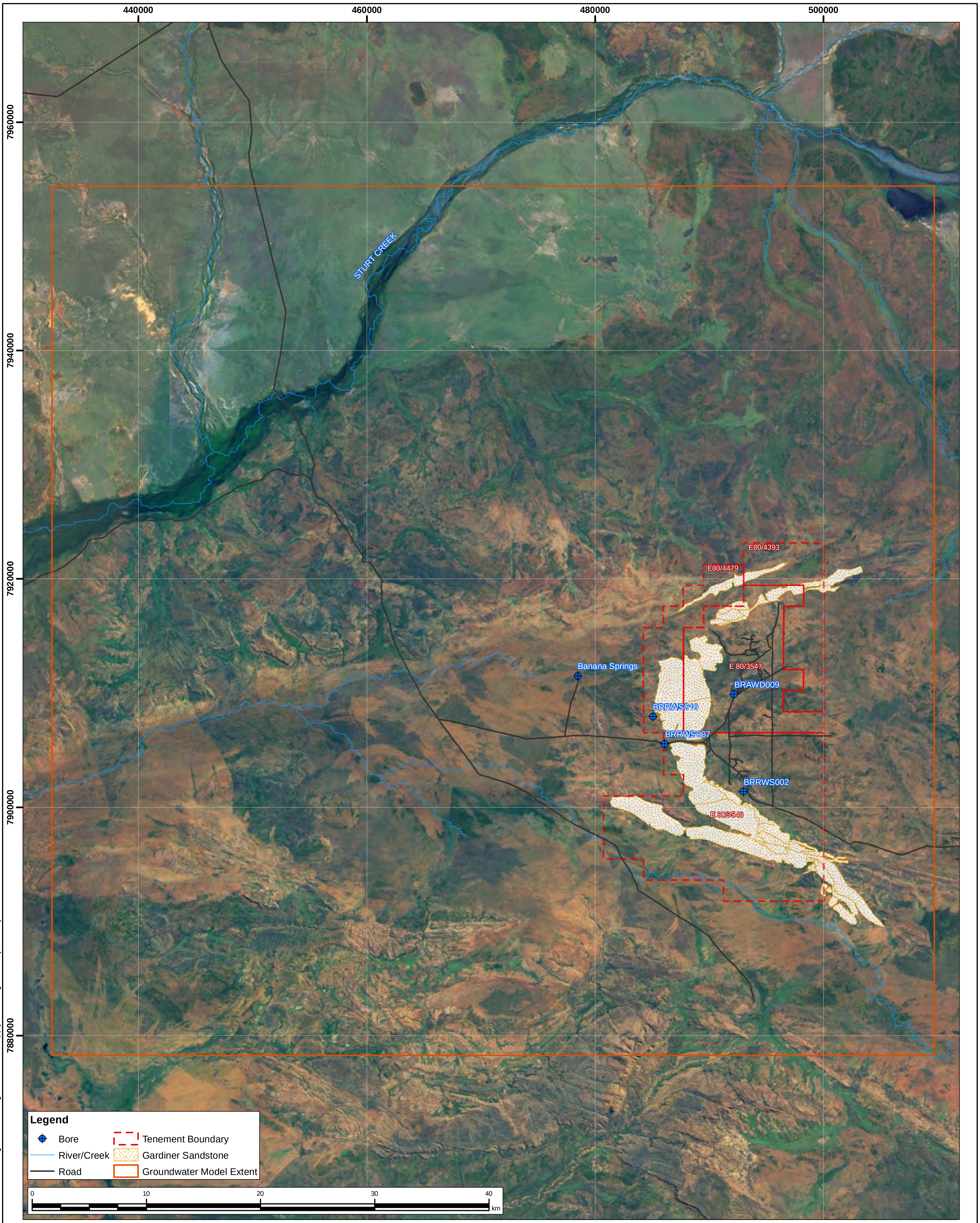
Figure 11 Observation bores

Figure 12 Water supply bores

Figure 13 Base case water level contour map

Figure 14 Scenario A: Borefield at 42L/s

Figure 15 Reduced hydraulic conductivity sensitivity water level contour map



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Notes:
1. Background image sources: Esri GIS user community
2. Tenement and Pit Location courtesy of Nothern Minerals
3. Project infrastructure coutesy of Northern Minerals 15/10/2013
4. Geology layer coutesy of Northen Minerals

NOT FOR CONSTRUCTION

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 52
3. Vertical Datum: Mean Sea Level
4. Scale: 1:300,000

CLIENT
northern minerals
Klohn Crippen Berger

PROJECT
NORTHERN MINERALS LTD
BROWNS RANGE PROJECT

TITLE
WATER SUPPLY MODEL
PROJECT STUDY AREA

PROJECT No.	FIG No.	REV
M09812A03	FIGURE 1	A

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PROJECT
NORTHEN MINERALS LTD
BROWNS RANGE PROJECT

TITLE
WATER SUPPLY MODEL
LOCATION OF PROJECT AREA

PROJECT No.	FIG No.	REV
M09812A03	FIGURE 2	A

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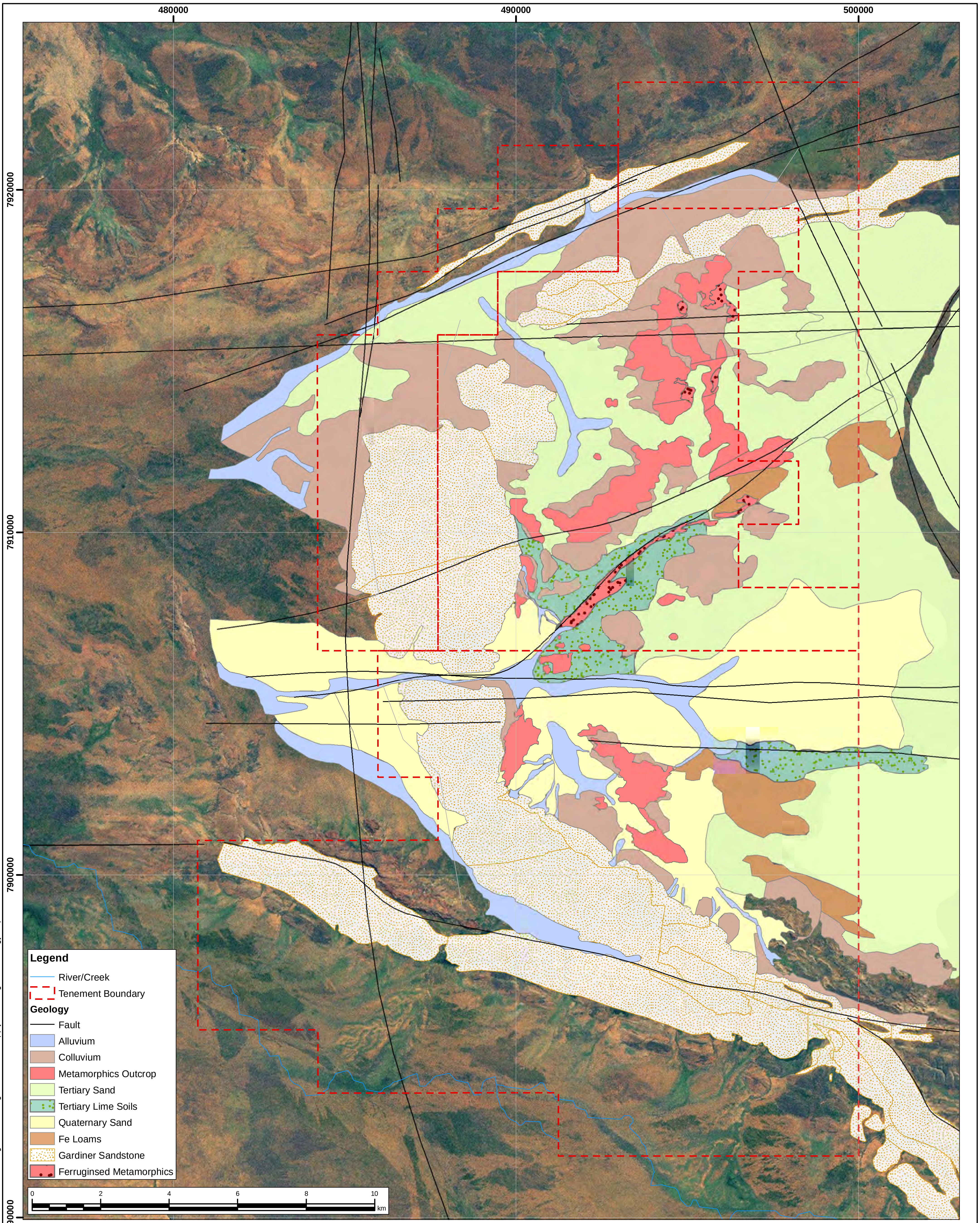

20/01/2014, nturner, Z:\D\BNE\M09812A03 - Browns Range\400 Drawings\MXD\Water Supply Model\Figure 5 Geology Map.mxd

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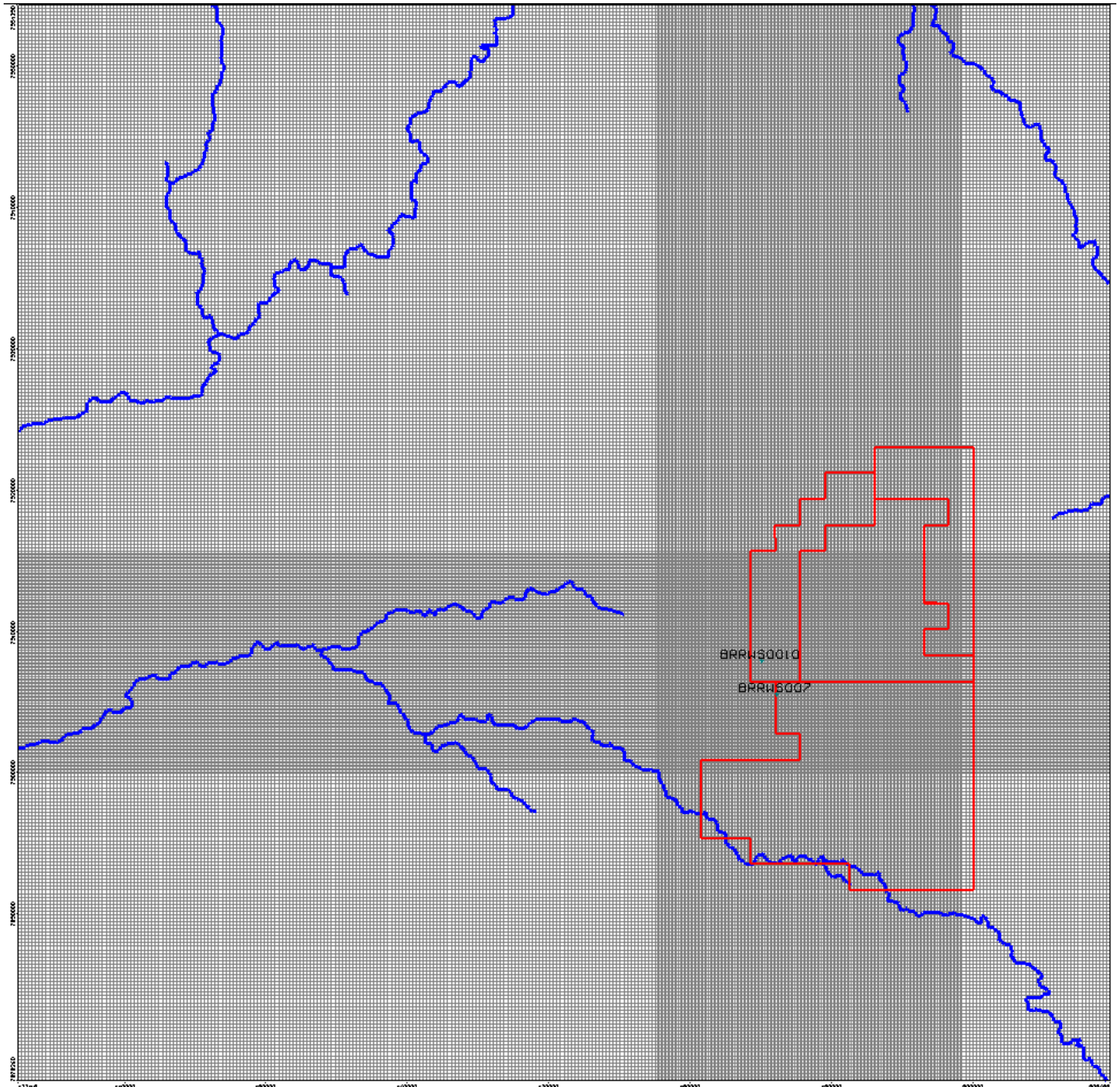
northern minerals

Klohn Crippen Berger

PROJECT
NORTHERN MINERALS LTD
BROWNS RANGE PROJECT

TITLE
WATER SUPPLY MODEL
GEOLOGY MAP

PROJECT No.	FIG No.	REV
M09812A03	FIGURE 3	A



Tenement Boundary	Creek/River

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CLIENT

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Klohn Crippen Berger

PROJECT

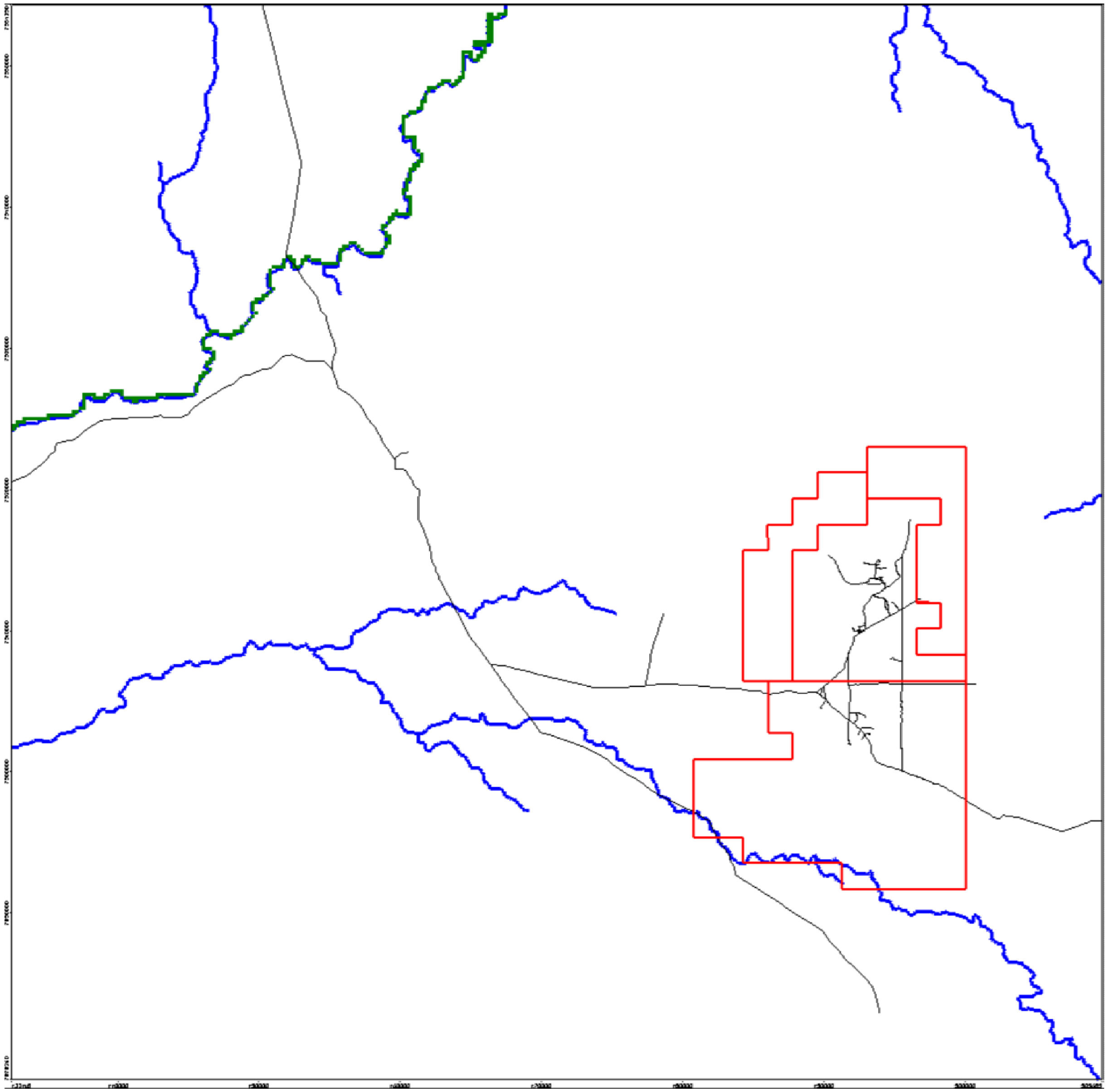
Northern Minerals Ltd
Browns Range Project

TITLE

Model Grid

PROJECT No: **M09812A03**

FIG. No: **FIGURE 4**



Tenement Boundary

Creek

General Head Boundary

Roads

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PROJECT

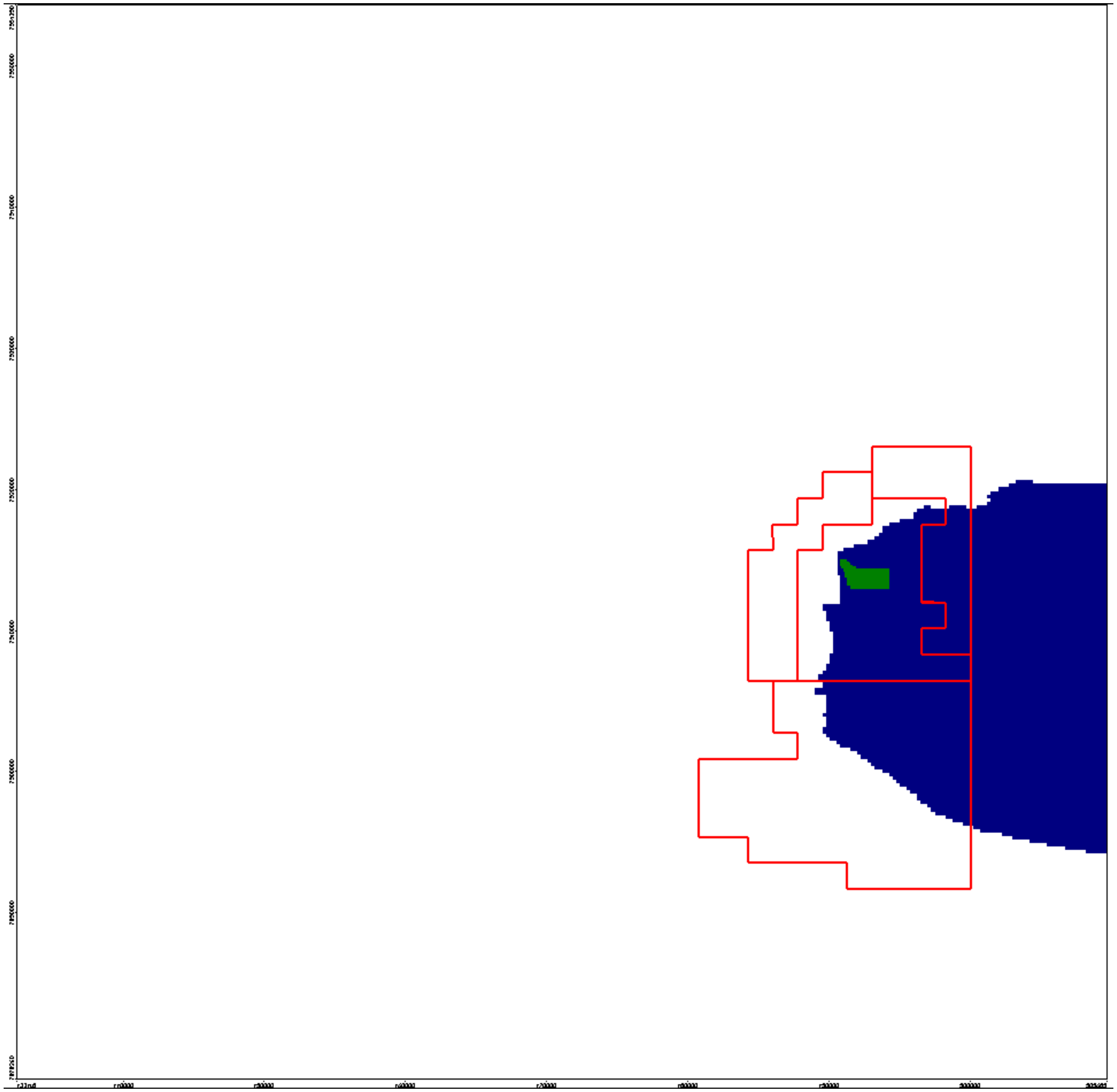
Northern Minerals Ltd
Browns Range Project

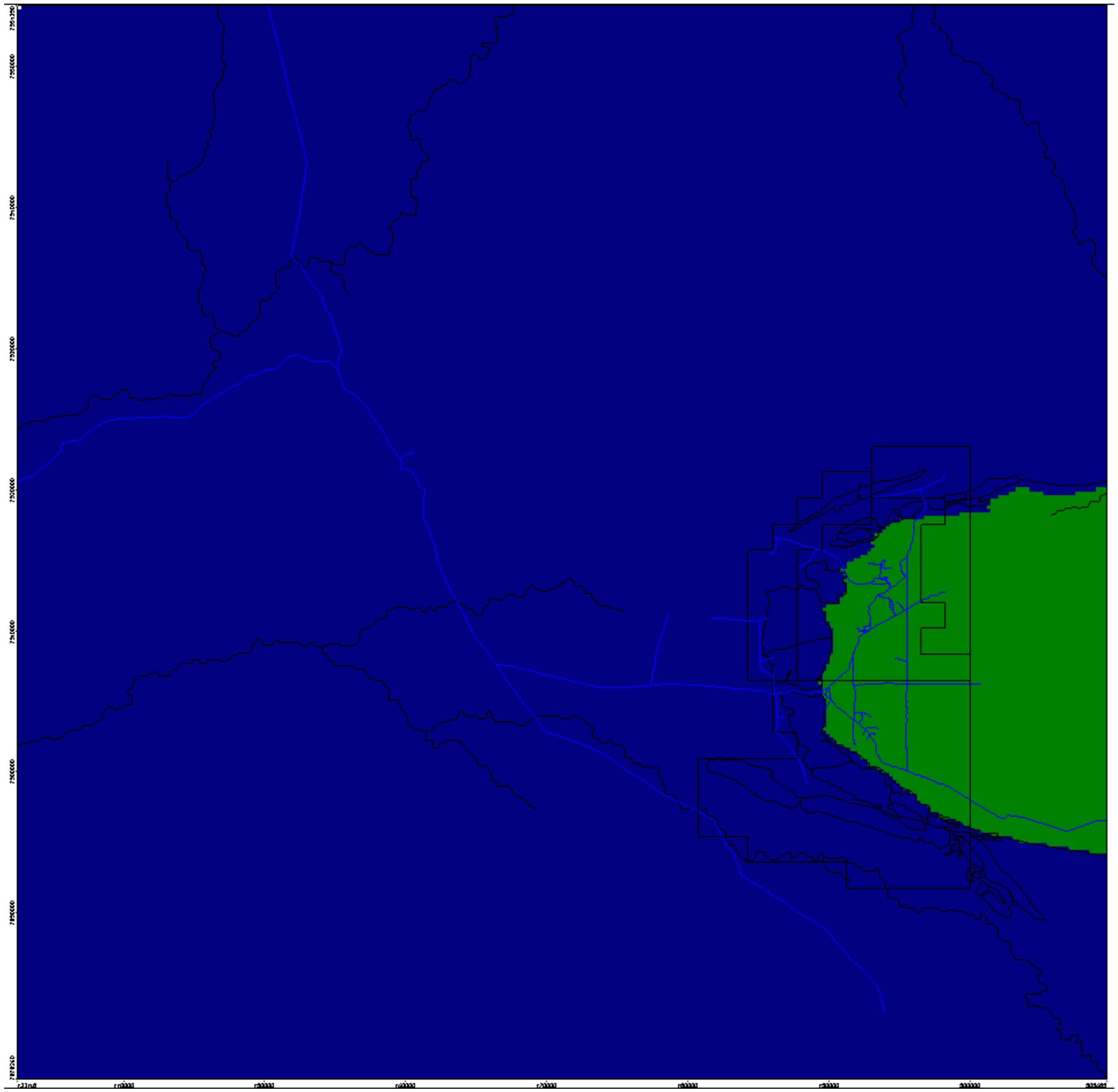
TITLE

General Head Distribution

PROJECT No: **M09812A03**

FIG. No: **FIGURE 5**





Blue	Gardiner Sandstone - 0.00191
Green	Browns Range Metamorphics - 0.000242

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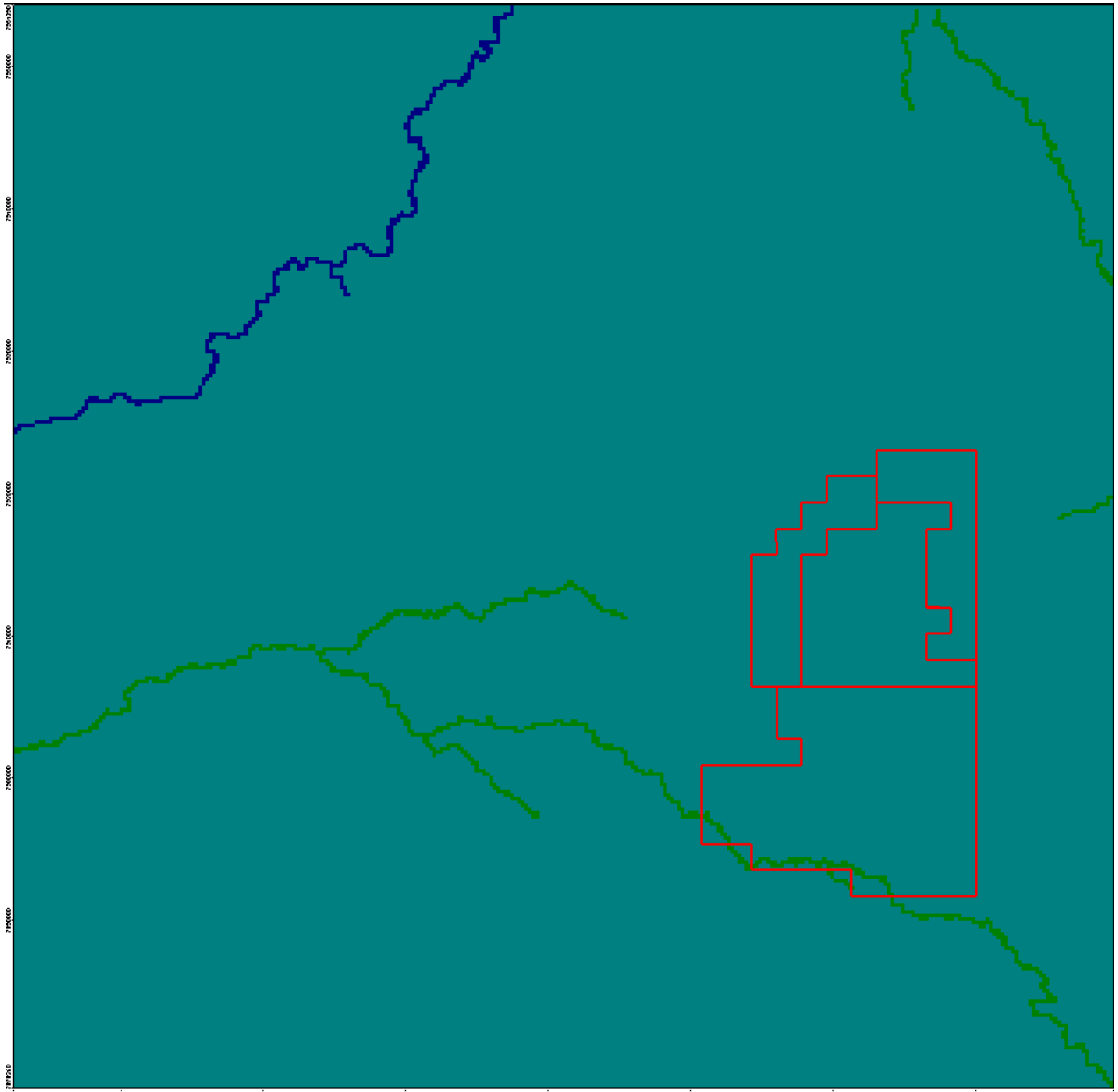
PROJECT: **Northern Minerals Ltd**
Browns Range Project

TITLE: **Storage Distribution**

PROJECT No: **M09812A03**

FIG. No: **FIGURE 7**



Regional Recharge - 7.7 mm/year	
Sturt Creek - 22.2 mm/year	
Alluvial Channels - 16.6 mm/year	

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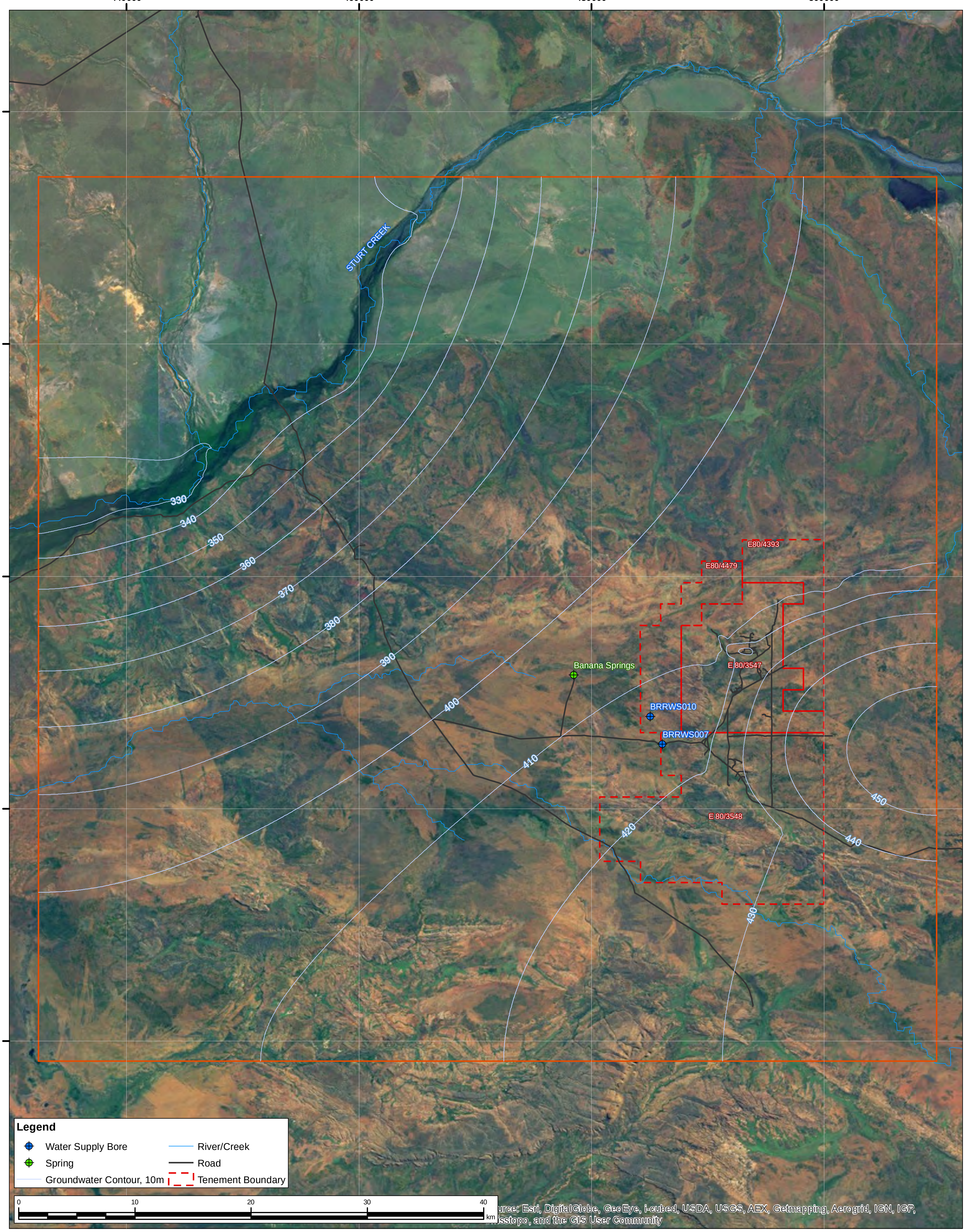
PROJECT: Northern Minerals Ltd
Browns Range Project

TITLE: Recharge Distribution

PROJECT No: M09812A03

FIG. No: FIGURE 8



N

Notes:
1. Background image sources: Esri GIS user community
2. Tenement and Pit Location courtesy of Nothern Minerals
3. Project infrastructure coutesy of Nothern Minerals 15/10/2013

NOT FOR CONSTRUCTION

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 52
3. Vertical Datum: Mean Sea Level
4. Scale: 1:300,000

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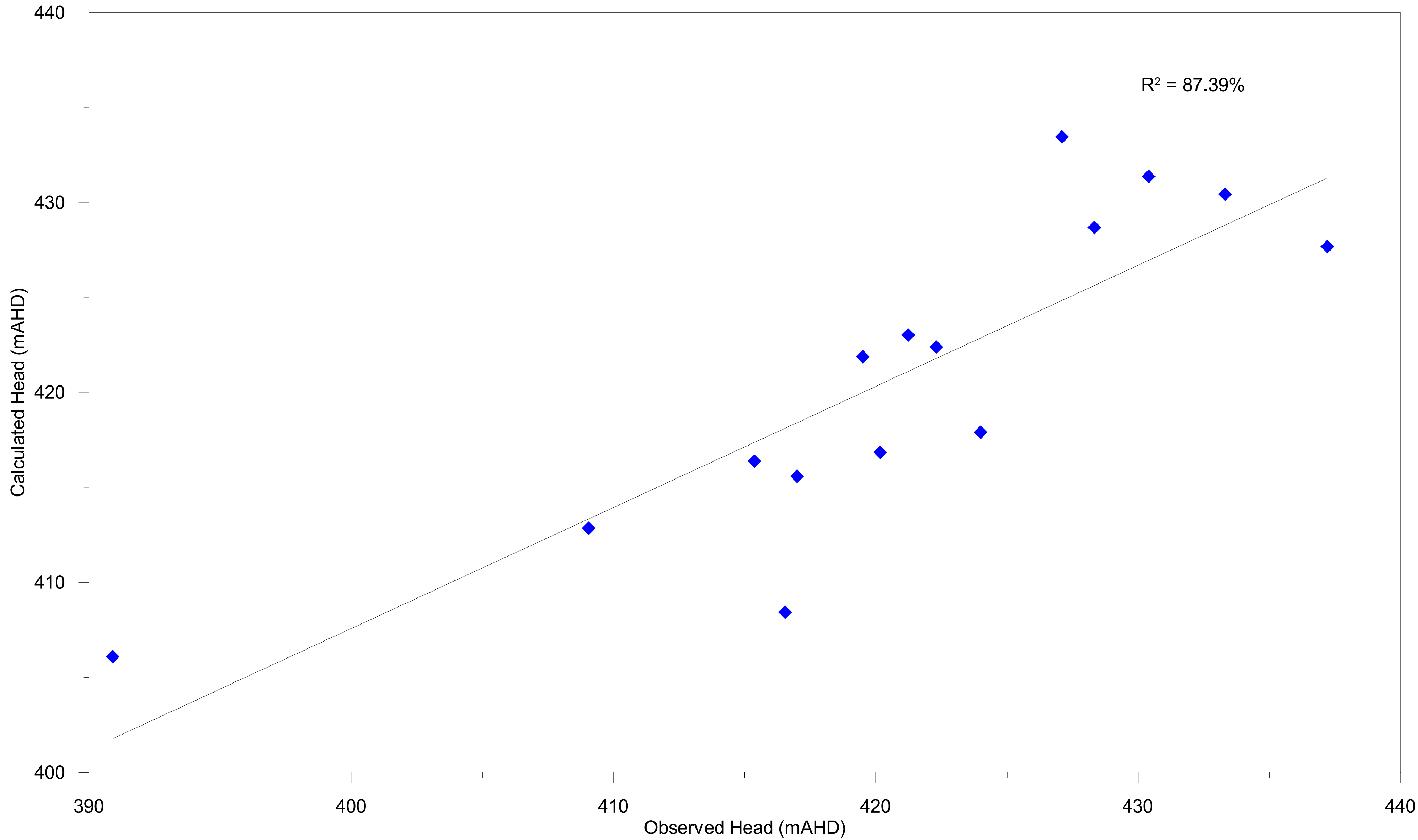
PROJECT
NORTHERN MINERALS LTD
BROWNS RANGE PROJECT

TITLE
WATER SUPPLY MODEL
STEADY-STATE WATER LEVELS

PROJECT No.	FIG No.	REV
M09812A03	FIGURE 9	A

22/01/2014, nturner, Z:\DBNE\M09812A03 - Browns Range\400 Drawings\MXD\Water Supply Model\Figure 9 Steady State Water Levels.mxd



TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JANUARY 2014

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PROJECT

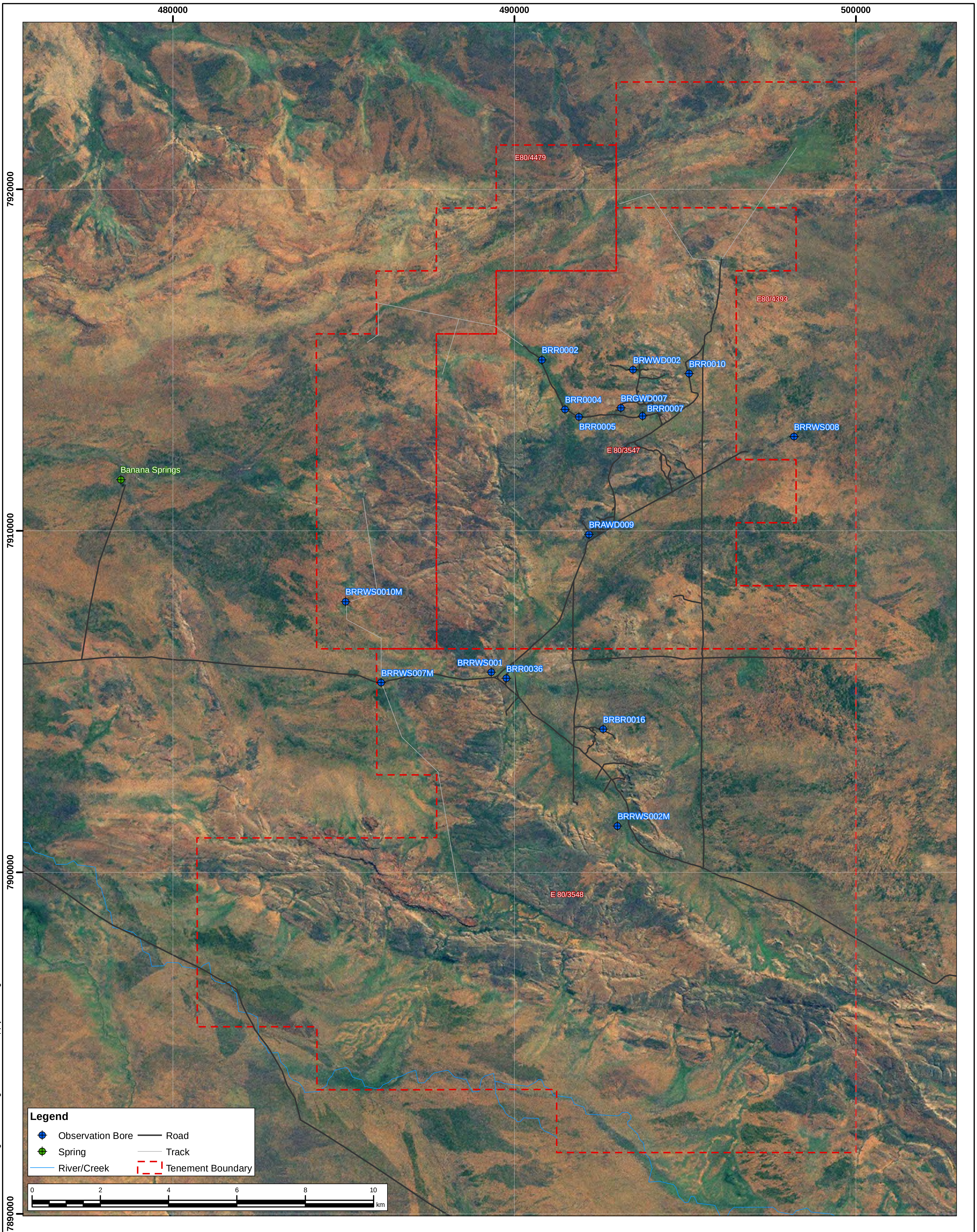
Northern Minerals Ltd
Browns Range Project

TITLE

Calculated vs Observed Head

PROJECT NO. **M09812A03**

FIGURE NO. **FIGURE 10**



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NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 52
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

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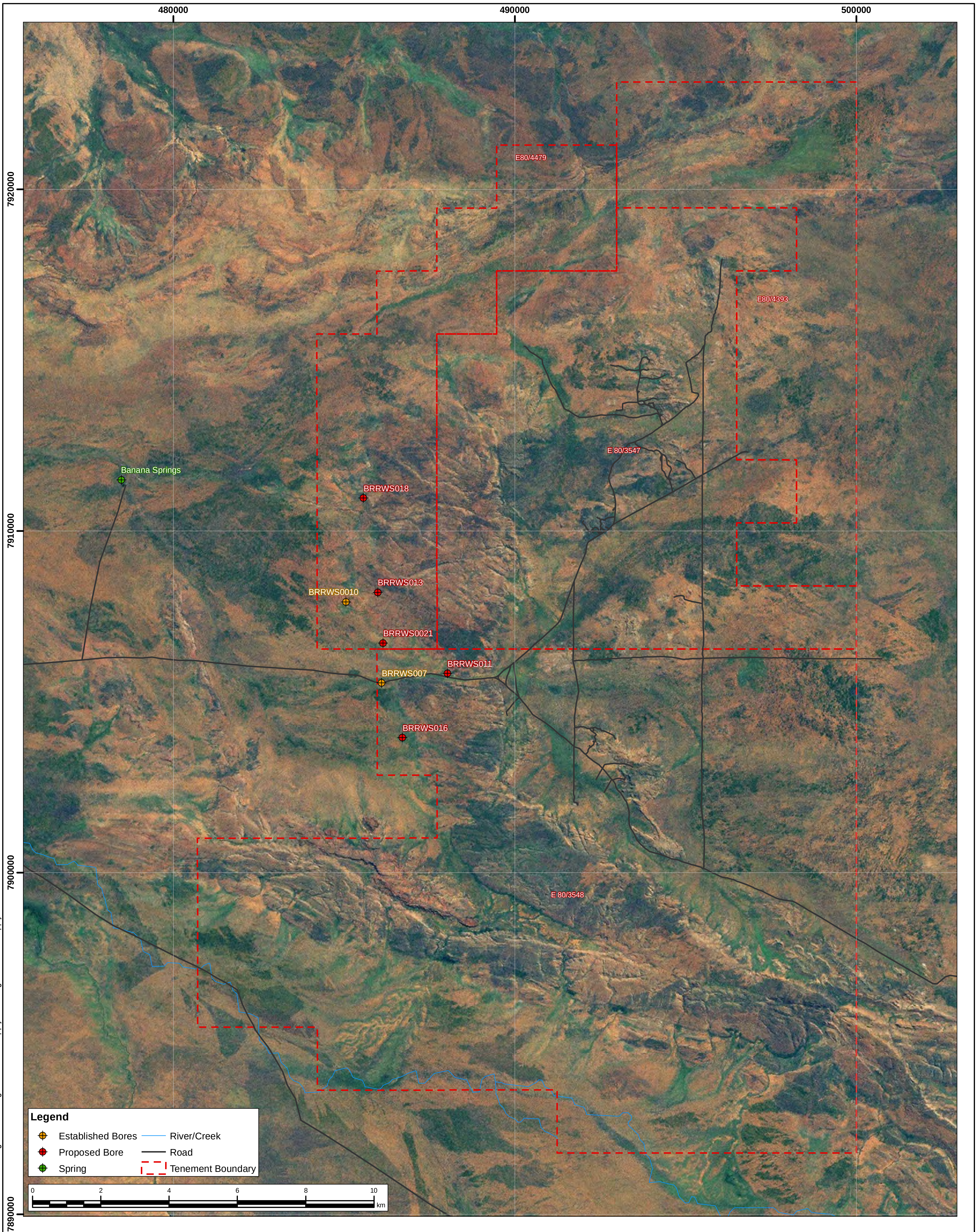
PROJECT
NORTHERN MINERALS LTD
BROWNS RANGE PROJECT

TITLE
WATER SUPPLY MODEL
OBSERVATION BORES

PROJECT No.	FIG No.	REV
M09812A03	FIGURE 11	A

22/01/2014, nturner, Z:\DBNE\M09812A03 - Browns Range\400 Drawings\MXD\Water Supply Model\Figure 2 Observation Bores.mxd



21/01/2014, nturner, Z:\D\BNE\M09812A03 - Browns Range\400 Drawings\MXD\Water Supply Model\Figure 3 Water Supply Bores.mxd

N

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3. Project infrastructure coutesy of Nothern Minerals 15/10/2013

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NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 52
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

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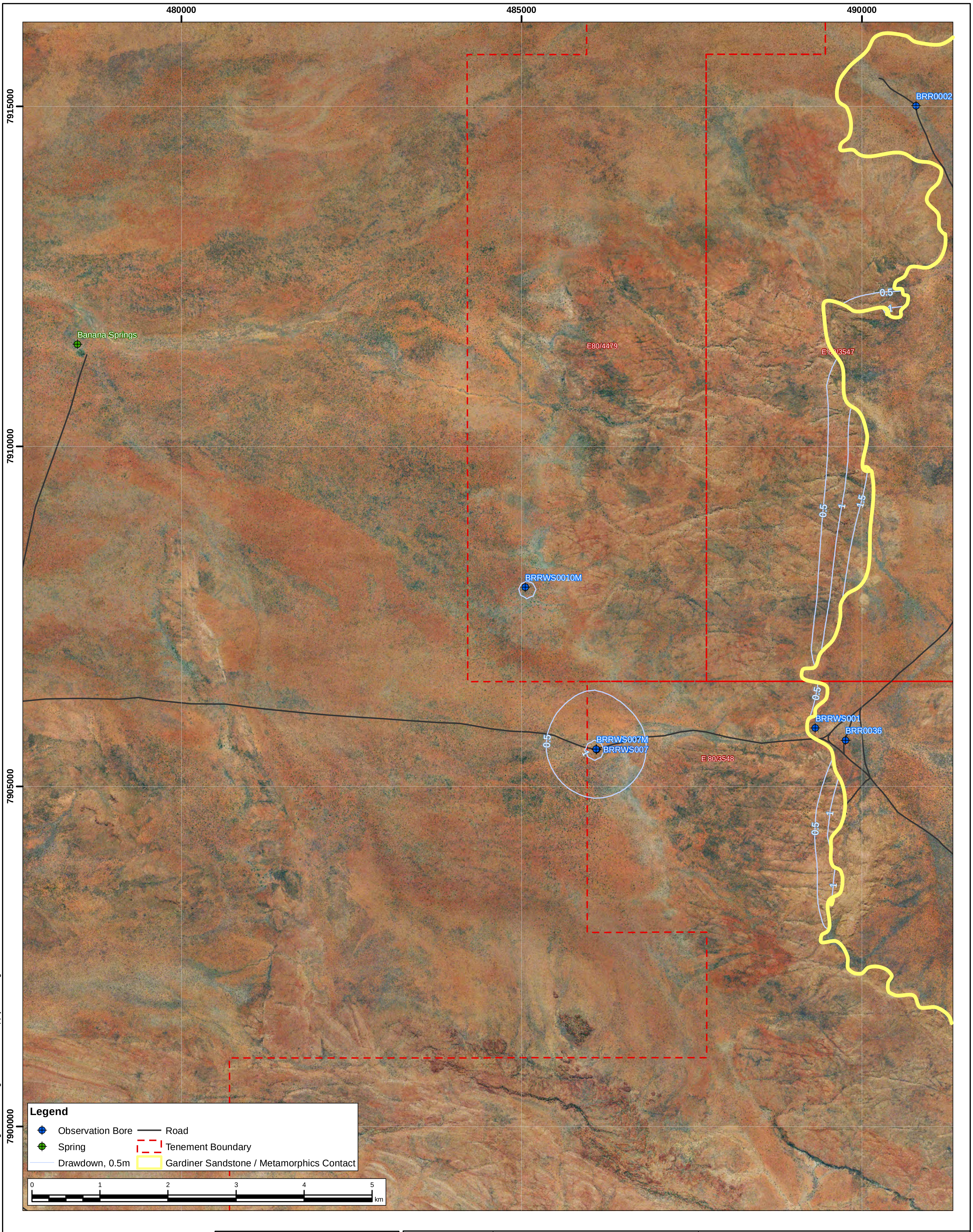
PROJECT
NORTHERN MINERALS LTD
BROWNS RANGE PROJECT

TITLE
WATER SUPPLY MODEL
WATER SUPPLY BORES

PROJECT No.	FIG No.	REV
M09812A03	FIGURE 12	A



1/30/2014, kvermaak, Z:\DBNE\M09812A03 - Browns Range\400 Drawings\MXD\Water Supply Model\Figure 13 Base Case Simulation.mxd

N

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NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 52
3. Vertical Datum: Mean Sea Level
4. Scale: 1:50,000

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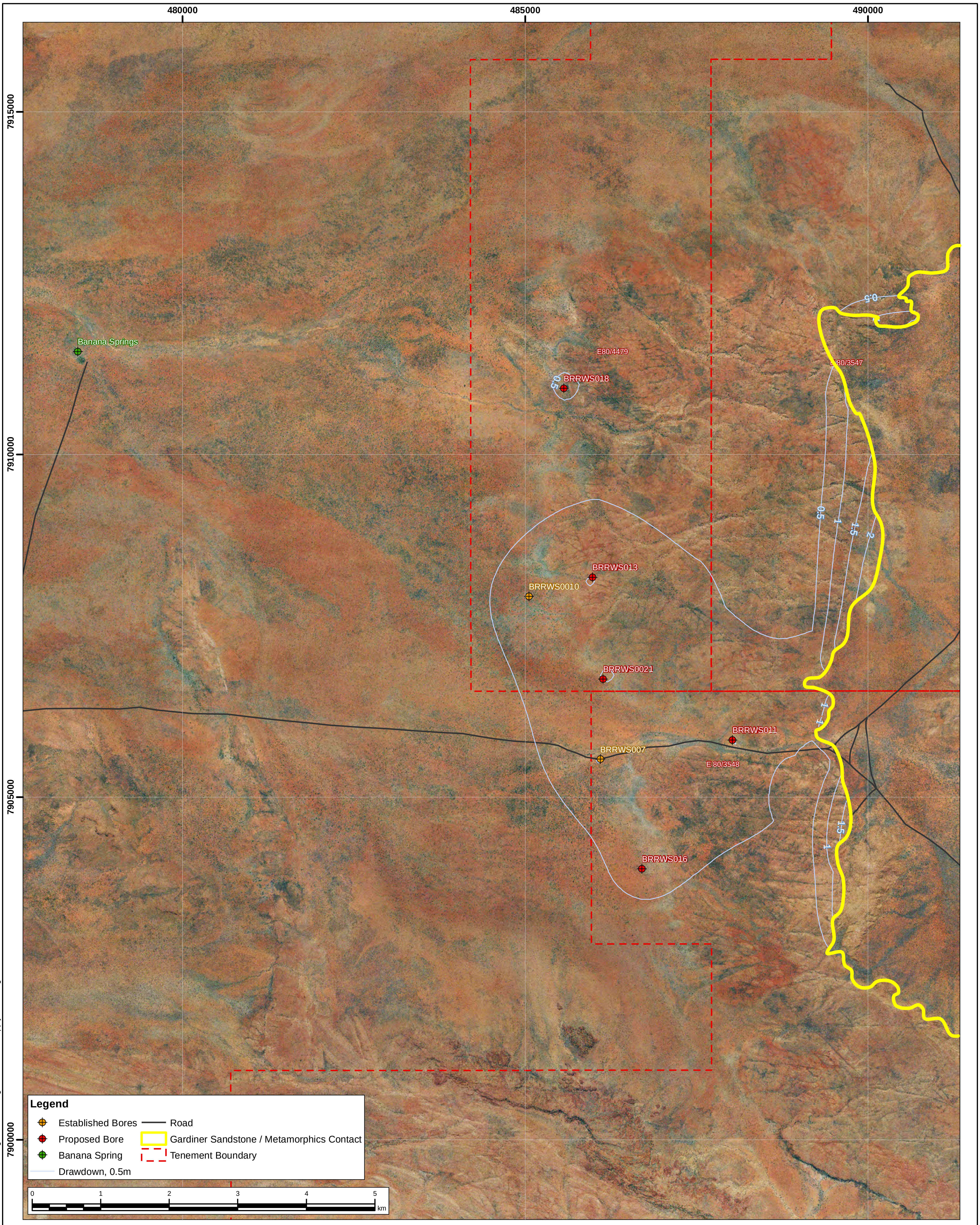
PROJECT
NORTHERN MINERALS LTD
BROWNS RANGE PROJECT

TITLE
WATER SUPPLY MODEL
BASE CASE WATER LEVEL CONTOUR MAP

PROJECT No.	FIG No.	REV
M09812A03	FIGURE 13	A



1/30/2014, kvermaak, Z:\DBNE\M09812A03 - Browns Range\400 Drawings\MXD\Water Supply Model\Figure 14 BRRWS007 and BRRWS010.mxd

N

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NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 52
3. Vertical Datum: Mean Sea Level
4. Scale: 1:50,000

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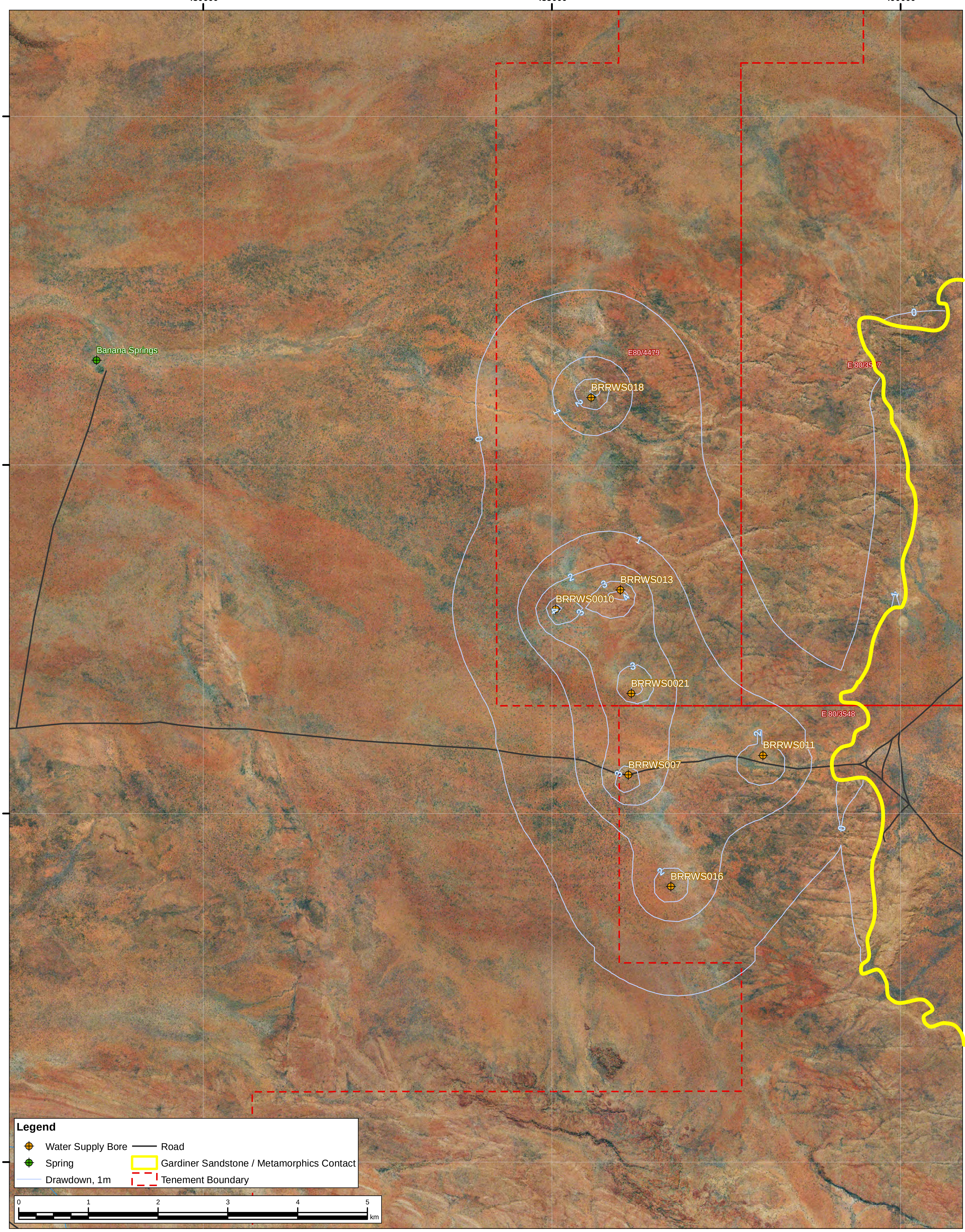
PROJECT

NORTHERN MINERALS LTD
BROWNS RANGE PROJECT

TITLE

WATER SUPPLY MODEL
SCENARIO A: BOREFIELD AT 42L/s

PROJECT No.	FIG No.	REV
M09812A03	FIGURE 14	A



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Notes:
1. Background image sources: BR.geotiff.tif
2. Tenement and Pit Location courtesy of Nothern Minerals
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NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 52
3. Vertical Datum: Mean Sea Level
4. Scale: 1:50,000

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PROJECT
NORTHERN MINERALS LTD
BROWNS RANGE PROJECT

TITLE
WATER SUPPLY MODEL
REDUCED HYDRAULIC CONDUCTIVITY
SENSITIVITY WATER LEVEL CONTOUR MAP

PROJECT No.	FIG No.	REV
M09812A03	FIGURE 15	A

1/30/2014, kvermaak, Z:\DBNE\M09812A03 - Browns Range\400 Drawings\MXD\Water Supply Model\Figure 15 Reduced Hydraulic Conductivity.mxd