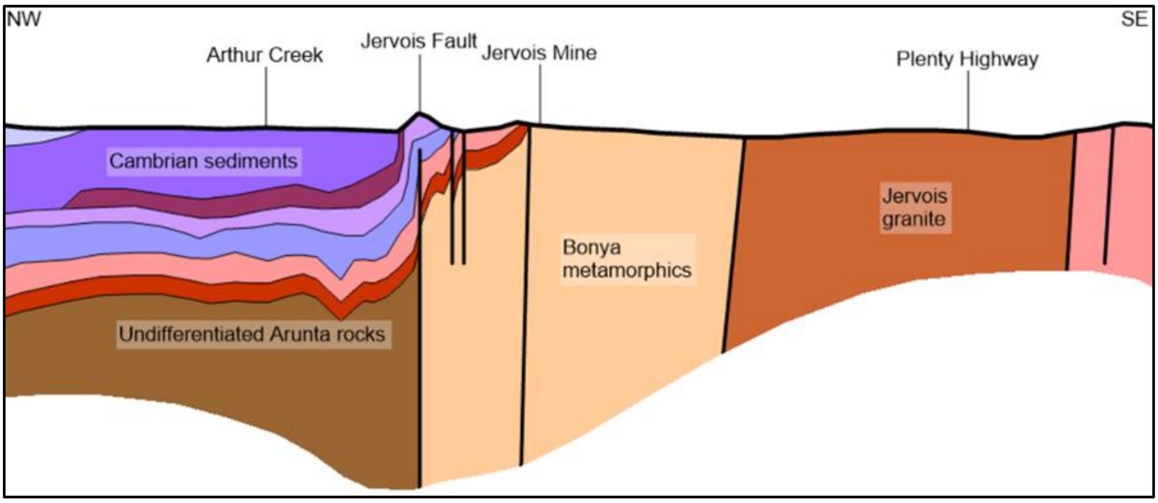
JERVOIS BASE METALS PROJECT
GROUNDWATER MODEL REVIEW

Prepared for:	KGL RESOURCES	5 July 2019



hydrogeologic

HydroGeoLogic Pty Ltd. (ABN 51 877 660 235)
PO Box 383, Highgate, South Australia, 5063. hugh@hydrogeologic.com.au

CONTENTS

HydroGeoLogic

Prepared by:	HydroGeoLogic Pty Ltd. (ABN 51 877 660 235) PO Box 383, Highgate, 5063, South Australia email: hugh@hydrogeologic.com.au mobile: +61 438 983 005	
Author	Hugh Middlemis (HydroGeoLogic)	
Version 1	5 July 2019	

THIS REPORT SHOULD BE CITED/ATTRIBUTED AS:

Middlemis H (2019). Jervois Base Metals Project Groundwater Model Review. Prepared by HydroGeoLogic for KGL Resources. 5 July 2019.

1. Introduction

1.1 Jervois Base Metals Project

The proposed Jervois Base Metals Project (JBMP) is sited about 380 km north-east of Alice Springs in Central Australia (Figure 1). The ore will be accessed via several open pits and underground mines that will require dewatering, with processing on site and a tailings storage facility (TSF).

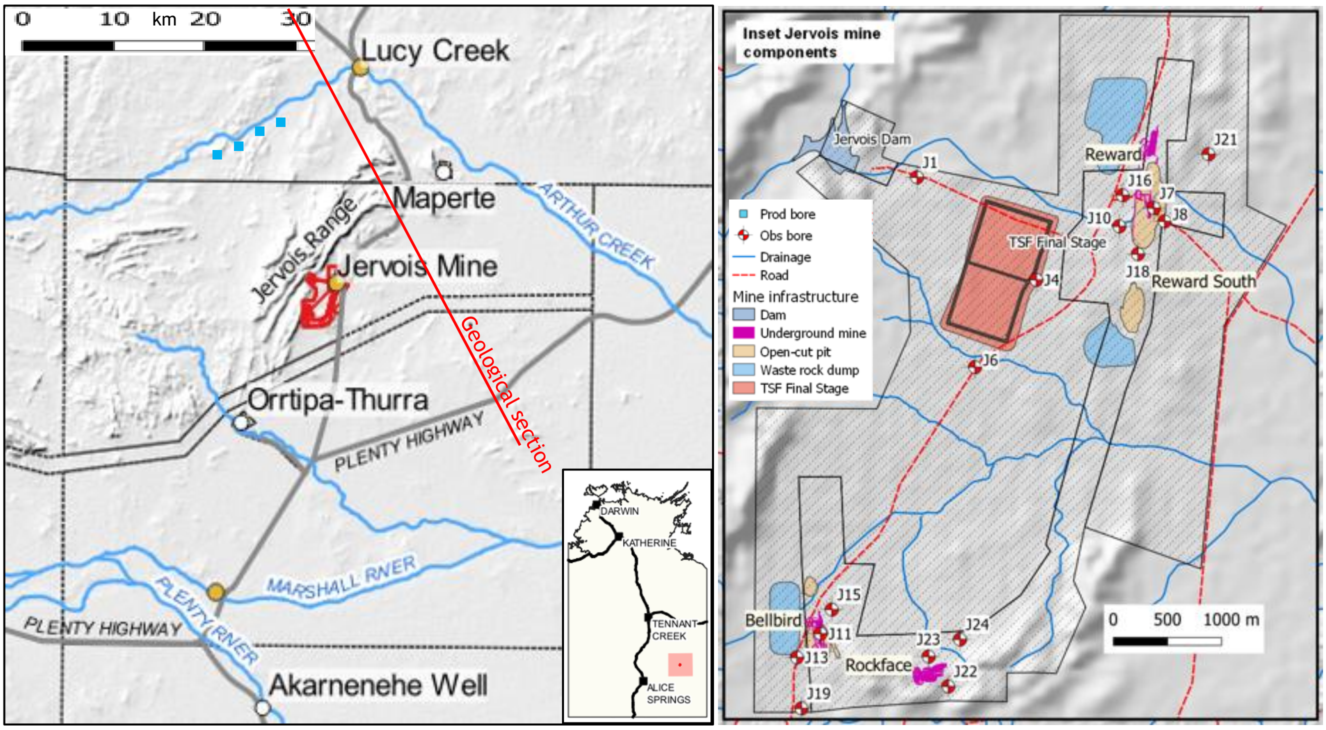


Figure 1 - Project locality, site facilities and bores (after Knapton 2019)

The mineralisation is hosted in the Arunta Block Bonya Metamorphics, a low-yielding fractured rock aquifer, while a water supply borefield is sited about 20 km north near Arthur Creek in the high yielding southern Georgina Basin Carbonate Aquifer (Figure 2).

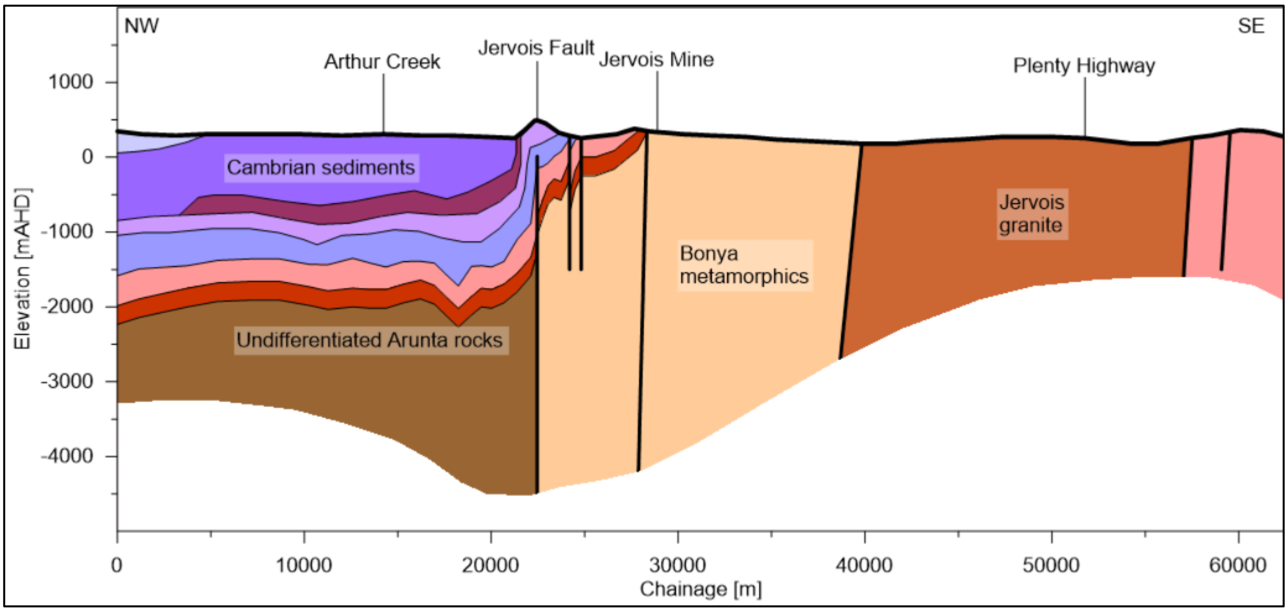


Figure 2 - Geological cross-section (after Knapton 2018, Figure 3-5)

1.2 Peer Review

This report summarises the outcomes of an independent peer review of the Jervois Base Metals Project hydrogeological and groundwater modelling impact assessment that was conducted by Cloud GMS. The main evidentiary basis for this peer review is the groundwater assessment report (sometimes referred to as 'GA' in this review):

- Knapton A (2019). Jervois Base Metals Mine Groundwater Impact Assessment Supplement version 0.1. Prepared by CloudGMS for Nitro Solutions on behalf of KGL Resources. June 2019.

This is a targeted desktop review with a focus on the groundwater modelling that forms the quantitative basis of the groundwater assessment, rather than a comprehensive hydrogeological review. It was conducted by Hugh Middlemis (HydroGeoLogic), in accordance with the best practice principles and procedures of the Australian Groundwater Modelling Guideline (Barnett et al. 2012), and with consideration of the recent guidance on uncertainty analysis (Middlemis and Peeters, 2018). The review outcomes are summarised in section 2, including the modelling guideline compliance summary checklist (Table 1).

2. Review Outcome Summary

Table 1 - Groundwater Model Compliance: 10-point essential summary – Jervois Project

Question	Y/N	Comments re Jervois Base Metals Project groundwater model
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Class 1-2 model confidence level is claimed. Independent analysis for this review indicates that Class 1-2 is justified (Table 2 below). Appropriate for impact assessment.
2. Are the objectives satisfied?	Yes	Competent model design consistent with best practice, and steady state calibration to groundwater levels. Sound application to scenarios for mine dewatering, TSF seepage, and post-mining. Potential causal pathways for impacts on receptors carefully considered, including remote community and pastoral water supply bores, and GDEs (vegetation, stygofauna). Fairly low risk context for GDE impacts given depth to water table around 15m generally. Strong focus on third party users potentially affected. Basic sensitivity-uncertainty analysis conducted.
3. Is the conceptual model consistent with objectives and confidence level?	Yes	Conceptualisation sound, consistent with data, objectives and confidence level for mining impact assessment and licensing purpose. Conservative assumptions applied where needed.
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	Georgina Basin and Jervois area have been investigated since 1970s. Project site investigations, drilling, testing and modelling since 2018, including comprehensive chemical analysis but no major/long term pumping stress test. Reasonable knowledge base, carefully considered to develop a sound conceptual model. Competent hydrogeologists and modellers have evaluated the data, conceptualisation, model design, execution & outcomes.
5. Does the model design conform to best practice?	Yes	The model software (FEFLOW), design, extent, layers, mesh, boundaries and parameters and modelling methodology are consistent with best practice design and execution.

Question	Y/N	Comments re Jervois Base Metals Project groundwater model
6. Is the model calibration satisfactory?	Yes	Steady state calibration performance acceptable; SRMS 6.9%. No transient calibration, but fairly low risk context for fractured rock aquifer (mine site), and for moderate water supply extraction volumes from extensive Georgina Basin. Limitations addressed via sensitivity and uncertainty analysis. Model to measured offsets mostly less than 5m around mine site. Some regional bores with offsets exceeding 10m, but not in key areas. Limitations include no flux constraints on calibration and no transient calibration. Sensitivity analysis identified recharge near the J-fold area and along Arthur Creek downstream of Lucy Creek Station as key parameters.
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Model parameter values are consistent with the available drilling and testing information. Anisotropy factors applied, consistent with hydrogeology. Bonya fractured rock at mine site is low-yielding, so no major pumping stress-test data is not crucial and inflows are plausible. Georgina Basin aquifer character well known, confirmed by site-specific drilling & testing for water supply borefield near Arthur Creek on Lucy Creek Station.
8. Do the model predictions conform to best practice?	Yes	Overall methodology is consistent with best practice and suitable for guiding impact assessment, management plans and licensing decision making. Post-mining scenario well-executed, including particle tracking demonstrating capture of flow paths from TSF. Groundwater level effects due to mine dewatering and TSF generally do not extend beyond about 3 km from mine site by end of 10-year mine life. Extent of 2m drawdown increases post-mining to around 10 km from mine. Water supply borefield drawdown about 2m at 6 km distance, but effects on receptors generally less than 3m (rate of change potential concern at 0.2-0.4 m/a), and rapid recovery on cessation of pumping. Groundwater levels at GDE veg sites generally do not exceed the 15m criterion. Drawdown impacts on remote community and pastoral bores up to 1-2 m. Monitoring and management measures proposed.
9. Is the uncertainty associated with the simulations/predictions reported?	Yes	Uncertainty assessment focus on water supply borefield is warranted given most extraction and potential for impacts is focused there. Analysis limited to hydraulic conductivity and specific yield parameters, but predictions not highly sensitive or uncertain. No climate change uncertainty scenarios. Can be characterised as basic uncertainty assessment, consistent with best practice guidance for the fairly low risk context.
10. Is the model fit for purpose?	Yes	My professional opinion is that the Jervois Base Metals Project hydrogeological and groundwater modelling assessment has been conducted consistent with best practice. It is fit for the purpose of mine dewatering & groundwater supply environmental impact assessment and to inform management strategies and licensing.

3. Discussion

The report (Knapton 2019) is well-written and provides adequate explanations of the conceptual model, and the numerical model design and execution.

The FEFLOW model domain, layer setup, mesh design, boundary conditions and parameters applied are consistent with the available information and conceptualisation. The conceptualisation appears to be sound, and has been implemented aptly in the model. The steady state calibration performance is adequate statistically, but there is no transient calibration. The simulated groundwater flow patterns reflect the hydrogeological conceptualisation and the measured groundwater levels.

The impact assessments and interpretations are largely supported by the data available and the evidence presented. The ongoing monitoring and other investigations will provide additional data for future model refinements and improvements in performance and for comprehensive uncertainty analysis. Such progressive updates should, in turn, be used to guide future monitoring and management programs.

The sensitivity/uncertainty runs focus on the water supply borefield, where there is some potential for impacts on third parties and GDEs. This is justified, in that there is a fairly low risk context in relation to the fractured rock mine site aquifer conditions (e.g. generally low permeability, low yields and sub-potable to stock quality water, few nearby users and those are not materially affected by predicted drawdown). The methodology applied could be characterised as a basic uncertainty assessment, consistent with best practice guidance in this case (Barnett et al. 2012; Middlemis and Peeters, 2018). In any case, the ongoing monitoring program is well-designed to provide the data in due course for model improvements and improved assessment of uncertainties.

The overall prediction scenario methodology, including the post-mining scenario and selected sensitivity/uncertainty assessments, and the results presentations, are consistent with best practice. The study is fit for the purpose of guiding mining impact assessment and management plans and licensing decision making. The modelling assessments provide good detail on water balance issues and drawdown impacts on third party bores and careful consideration of impacts on potential groundwater dependent ecosystems.

4. Model Confidence Level Classification

Although the “model confidence level classification” is identified as a key issue in the groundwater modelling guidelines (Barnett et al. 2012), there are identified limitations with the concept, as outlined in the draft IESC report on groundwater modelling uncertainty, along with methods to address its limitations (Middlemis and Peeters, 2018).

The groundwater assessment report claims a Class 1-2 model confidence level classification, as expected for the study purpose of impact assessment and management, and related licensing.

This review conducted an independent assessment of the model confidence level classification, consistent with the guidelines but based on the method outlined in Middlemis and Peeters (2018). This review finds that a Class 1-2 model confidence level is indeed justified (Table 2), confirming the Jervois model as suitable for impact assessment scenario modelling purposes.

Table 2 - Jervois Base Metals Project groundwater model confidence level

Model Confidence Class characteristics: Jervois Base Metals Project

Class		Data		Calibration		Prediction		Quantitative Indicators
1 (simple)		Not much / Sparse coverage		Not possible.	~	Timeframe >> Calibration	√	Predictive Timeframe >10x Calib'n.
	√	No metered usage.		Large error statistic.	~	Large stresses/periods.	√	Predictive Stresses >5x Calib'n.
	√	Low resolution topo DEM.		Inadequate data spread.	~	Poor/no verification.		Mass balance > 1% (or one-off <5%)
		Poor aquifer geometry.		Targets incompatible with model purpose.	√	Transient prediction but steady-state calibration.		Properties <> field values.
		Basic/Initial conceptualisation.						Poor performance stats / no review
2 (impact assessment)	~	Some data / OK coverage.	x	Weak seasonal match.	x	Predictive Timeframe > Calib'n.	x	Predictive Timeframe = 3-10x Calib'n.
	x	Some usage data.	x	Some long term trends wrong.	x	Different stresses &/or periods.	x	Predictive Stresses = 2-5x Calib'n.
	~	Some Baseflow estimates and some K & S measurements.	√	Partial performance (e.g. some stats / part record / model-measure offsets).	~	No verification but key simulations constrained by data	√	Mass balance < 1% (all periods)
	~	Some high res. topo DEM and adequate aquifer geometry.	~	Head & Flux targets constrain calibration.	x	Calib. & prediction consistent (transient or steady-state).	~	Some properties maybe <> field values.
	~	Sound conceptualisation, reviewed & stress-tested.	~	Non-uniqueness, sensitivity and qualitative uncertainty addressed.	√	Magnitude & type of stresses outside range of calib'n stresses.	~	Some poor performance or coarse discretisation in key areas/times.
3 (complex simulator)	x	Plenty data, good coverage.	x	Good performance statistics	x	Timeframe ~ Calibration	x	Predictive Timeframe <3x Calib'n.
	x	Good metered volumes (all users).	x	Most long term trends matched.	x	Similar stresses &/or periods.	x	Predictive Stresses <2x Calib'n.
	x	Local climate data & baseflows.	x	Most seasonal matches OK.	x	Good verification or all simulations constrained by data	√	Mass balance < 0.5% (all periods)
	x	Kh, Kv & Sy measurements from range of tests.	x	Calibration to present day head and flux targets.	x	Steady state prediction only when calibration in steady state.	~	Properties ~ field measurements.
	x	High res. topo DEM all areas & good aquifer geometry.	~	Non-uniqueness minimised &/or parameter identifiability &/or minimum variance or RCS assessed.	~	Suitable computational methods applied & parameters are consistent with conceptualisation	~	No poor performance or coarse discretisation in key areas (grid/time).
	x	Mature conceptualisation.	~	Sensitivity &/or Qualitative Uncertainty	~	Quantitive uncertainty analysis	√	Review by experienced Hydro/Modeller.

(after Table 2-1 of AGMG (Barnett et al. 2012) and Figure 5 of IESC uncertainty guidance (Middlemis & Peeters 2018))

	Criterion met at higher Class
~	Criterion partially met at the relevant Class
√	Criterion met at the relevant Class
x	Criterion not met by current model study

5. Conclusion

My professional opinion is that the Jervois Base Metals Project hydrogeological and groundwater modelling assessment has been conducted consistent with best practice. It is fit for the purpose of mine dewatering and groundwater supply environmental impact assessment and to inform management strategies and licensing.

6. Declarations

For the record, the peer reviewer, Hugh Middlemis, is an independent consultant specialising in groundwater modelling. He is a civil engineer with a master's degree in hydrology and hydrogeology and more than 38 years' experience. Hugh was principal author of the first Australian groundwater modelling guidelines (Middlemis et al. 2001) that formed the basis for the latest guidelines (Barnett et al. 2012) and was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling best practice. He is principal author on two guidance reports on modelling uncertainty (Middlemis and Peeters 2018; and Middlemis et al. 2019).

We assert no conflict of interest issues in relation to this work. Hugh Middlemis has not worked on the Jervois Base Metals Project or for KGL Resources or for Nitro Solutions.

We note the following in relation to previous interactions with Anthony Knapton and/or CloudGMS (in rough chronological order):

- Hugh Middlemis and Anthony Knapton worked together during their employment at Aquaterra's Adelaide office for an overlapping period of about 3 months in 2013, prior to the establishment of the independent consultancies HydroGeoLogic and CloudGMS of which they are now principals (2013).
- Hugh Middlemis (HydroGeoLogic) and Anthony Knapton (CloudGMS) worked together on a Murray-Darling Basin Authority (MDBA) contract to investigate recharge effects due to vegetation clearance in the Mallee (SA and Vic.), including consideration of unsaturated zone processes (2015).
- Hugh Middlemis (HydroGeoLogic) and Anthony Knapton (CloudGMS) have worked together on several campaigns to develop and apply a Mike-SHE groundwater model of a tailings storage facility for a base metals mining project in Victoria (2015-ongoing).
- Hugh Middlemis (HydroGeoLogic) and Anthony Knapton (CloudGMS) together conducted independent reviews of FEFLOW models developed by CDM Smith for mining projects in SA and Sri Lanka (2016, 2018).
- Hugh Middlemis (HydroGeoLogic) conducted independent reviews of groundwater models developed by Anthony Knapton for government catchment management projects in the NT (2015), and for mining projects in NT, WA and QLD (2017-19).
- Hugh Middlemis (HydroGeoLogic) and Anthony Knapton (CloudGMS) together investigated and modelled seepage from a produced formation water pond in SA's Cooper Basin for Senex Energy (2018).
- Hugh Middlemis was engaged by EMM Consulting to review the FEFLOW groundwater model developed by Anthony Knapton (CloudGMS) for the geotechnical elements of the Snowy 2.0 pumped hydro EIS (2018-19).

7. References

Knapton A (2018). Jervois Base Metals Project Mine Site Groundwater Investigation draft version 0.5. Prepared by CloudGMS for Nitro Solutions on behalf of KGL Resources. September 2018.

Knapton A (2019). Jervois Base Metals Mine Groundwater Impact Assessment Supplement. Prepared by CloudGMS for Nitro Solutions on behalf of KGL Resources. June 2019.

Barnett B, Townley L, Post V, Evans R, Hunt R, Peeters L, Richardson S, Werner A, Knapton A and Boronkay A. (2012). Australian Groundwater Modelling Guidelines. Waterlines report 82, National Water Commission, Canberra.

Middlemis H and Peeters LJM. (2018). Uncertainty analysis - Guidance for groundwater modelling within a risk management framework. Prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development.