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HANCOCK GALILEE PTY LTD

Kevin's Corner Project Environmental Impact Statement

N1 Groundwater Technical Report

ALPHA COAL PROJECT AND KEVIN'S CORNER PROJECT: REGIONAL GROUNDWATER MODEL

for

URS Australia Pty Ltd

by

NTEC Environmental Technology

Report 1045-1-RevB

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Project Team:

Lloyd Townley

Attila Kovacs

Aaron Brunt

Amandine Bou

NTEC Services Pty Ltd
ACN 069 270 846
trading as
NTEC Environmental Technology

PO Box 425
Claremont WA 6910
Australia

Telephone: + 61 8 9381 8855
Facsimile: +61 8 9381 8822
Internet: www.ntec.com.au
E-mail: perth@ntec.com.au

EXECUTIVE SUMMARY

This report presents the results of numerical modelling of groundwater flow, to assess the potential impacts of the proposed Alpha and Kevin's Corner projects.

Rather than presenting a single model, the report describes a number of models that have been used to develop an understanding of the likely impacts of these projects on regional groundwater, and vice versa.

The proposed mines are large mines. They will lead to the development of cones of depression, i.e. areas where the water table is lower than prior to mining. Groundwater will report to the mines, with implications for mine dewatering. The potential for groundwater to provide a reliable water supply for the project has also been considered.

Because of the nature of the regional hydrogeology, the cone of the depression is will extend to the west of the proposed mines, towards the area where GAB aquifers are known to outcrop. Drawdown will be greatest to the northwest of the proposed Kevin's Corner underground mine, but this will not occur for many years after commencement of mining, and details of the mine plan may affect the extent to which drawdown occurs.

It is unlikely that groundwater inflows to mines will be sufficient to provide a reliable water supply. Uncertainty in model parameters leads to the conclusion that inflow rates to the various parts of the mines will vary year to year, according to changes in the mine schedule. Predictions are particularly sensitive to estimates of specific yield, especially above the proposed Kevin's Corner underground, and hydraulic conductivities in a number of key hydrostratigraphic units. Data collected during recent development of the Alpha Test Pit was extremely helpful, but more field data will be required to allow robust predictions of groundwater flows.

Following closure of the proposed mines, the Kevin's Corner underground mine will flood, and all open cut mines will become mine pit lakes. The water level in mine pit lakes is predicted to be about 280 mAHD, some tens of metres below crest level.

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1 INTRODUCTION

1.1 Scope

This report presents the results of groundwater flow modelling undertaken by NTEC Environmental Technology ("NTEC") to assess the combined impacts of the Alpha Coal Project and Kevin's Corner Project on groundwater, and vice versa.

The Alpha Coal Project is owned by Hancock Coal Pty Ltd, while the Kevin's Corner Project is owned by Hancock Galilee Pty Ltd. The owners are referred to collectively herein as "Hancock".

NTEC was engaged in 2010 by JBT Consulting Pty Ltd ("JBT") to provide groundwater modelling services, complementary to hydrogeological consulting services being provided by JBT. Initially the focus was on the Alpha Coal Project. However at a later date, it was decided to develop a regional scale model that could also assess the impacts of the Kevin's Corner Project. NTEC's role at the time was to provide modelling results that could be integrated in groundwater assessment reports being prepared by JBT.

Recently, Hancock engaged URS Australia Pty Ltd ("URS") to manage all hydrogeological investigations associated with the projects. JBT and NTEC have since been reporting separately to URS.

This report has been prepared at the request of URS to summarise the results of all groundwater flow modelling activities undertaken in relation to the proposed projects. The focus of this report is on modelling. The report does not include a complete discussion of geology and hydrogeology, since these subjects have been described by JBT (2011a).

1.2 Proposed Mining Projects

The proposed projects are located in the Galilee Basin, Queensland, Australia, approximately 130 km southwest of Clermont and 360 km southwest of Mackay. The nearest residential area is the township of Alpha, located approximately 50 km south of the project area (Figure 1[1]). The projects are located within two separate Mining Lease Applications (MLAs).

It is proposed to mine coal at the Alpha Coal Project using draglines, shovels and trucks, while at Kevin's Corner two relatively small open cut mines will be developed, with the bulk of mining to occur via underground longwall mining techniques. Mine plans are shown in Figure 2.

[1] All Figures are in Appendix A.

1.3 Objectives

The objectives of this report are to present the results of a modelling study, designed to assess:

- The potential impacts of the Alpha Coal Project and Kevin's Corner Project on regional groundwater, including aquifers known to be part of the Great Artesian Basin ("GAB"), and
- The potential impacts of groundwater on these projects, specifically through the need for management of groundwater reporting to the mines, and the possible need for a project water supply to complement groundwater reporting to the mines.

The objectives are general rather than specific. The spatial extent of mining requires a regional scale model, and since regional scale models cannot predict local impacts with precision, the objectives do not include the prediction of impacts at specific locations.

1.4 Groundwater Modelling Guideline

Groundwater modelling in Australia is generally undertaken and reviewed in the context of a guideline commissioned in 2000 by the Murray-Darling Basin Commission (MDBC). The "MDBC guideline" was intended to reduce the level of uncertainty surrounding modelling by promoting transparency in methodologies and encouraging consistency and best practice.

The MDBC guideline (Middlemis et al., 2001) is currently being reviewed. NTEC understands the intent and the details of the existing guideline, and also understands why new guidelines are being developed, and how new guidelines may affect modelling in the future.

The work undertaken for this project is based on a detailed understanding of the algorithms implemented in commercially available groundwater flow modelling software. This understanding has led to models being revised on several occasions, in order to confirm that the results are robust.

Every modelling project could be improved if more data were available, or if the final level of understanding had been available earlier. This project is no exception. NTEC is confident, however, that the predictions made here are consistent with current guidelines, and consistent with the level of information available.

1.5 Approach

As is often the case during development of large projects, many investigations have been undertaken in parallel, and new results have been made available as recently as the beginning of August 2011.

The modelling described in this report has not been undertaken in a linear fashion, starting from available data and leading directly to a robust predictive model. Rather, progression to the current level of understanding has involved several iterations of what might be described as a “modelling process”.

From the point of view of supporting future decisions, what matters most is the level of confidence that now exists about the potential impacts of the proposed projects on groundwater, and the potential impacts of groundwater on the projects. The approach taken in this report is therefore to focus on the current level of understanding, without presenting a full chronological description of all activities that have led to this level of understanding.

Some aspects of earlier activities remain important, especially those that have affected the choice of groundwater modelling software and methodologies. Some commentary will therefore be provided to explain the methods used, and some reference will be made to earlier predictions that are now believed to be incorrect.

2 HYDROGEOLOGICAL SETTING AND DATA

2.1 Introduction

This section relies heavily on investigations undertaken by JBT, who were engaged by Hancock to assess the hydrogeology of the region near the proposed Alpha and Kevin's Corner mines. Sections 2.2 to 2.5 include text prepared and presented by JBT (2011a).

2.2 Climate

Mean annual rainfall at Barcaldine Post Office, approximately 131 km west of the project site, is 497 mm. Rainfall is highly seasonal, with the dry season peaking in August and September and the wet season peaking between December and February (JBT, 2011a, Section 3.1.1).

The SILO data drill has been used to generate synthetic data for the project area (JBT, 2011a, Section 3.1.2). Mean annual rainfall is 535 mm, and mean annual evaporation is 2290 mm.

The fact that evaporation exceeds rainfall by a factor of 4 is significant, especially when considering the importance of recharge during mining, and the development of mine pit lakes after closure.

2.3 Topography

The broad topographical setting of the project area consists of flat to undulating topography, with elevations in the range 305 to 330 mAHD (Figure 3). Hills and Tertiary sand plains provide higher relief on the western and eastern margins, formed by the hills of the Great Dividing Range to the west and the Drummond Range to the east.

Lagoon Creek drains from south to north through the middle of both MLAs. It is joined in MLA 70425 (Kevin's Corner) by Sandy Creek, and further to the north, by Little Sandy Creek. The catchment area of Lagoon Creek above the Alpha MLA is 1470 km^2.

2.4 Regional Geology

The projects are located within the Galilee Basin, to the east of the eastern boundary of the Great Artesian Basin ("GAB").

The geology within the project area consists mainly of sediments, dipping 1 to 2 degrees westward. There are six coal seams in the project area, designated A to F, from upper to lower. Interburden is generally named after the adjacent coal seams, e.g. the C-D sandstone lies between the C and D coal seams.

The Rewan Formation (see JBT, 2011a, Section 3.4.2.2) is particularly significant, as it is the lowest confining unit of the hydrogeological GAB. The Rewan Formation Dunda Beds are shown in dark blue in Figure 1, outcropping to the west of the MLAs, and just inside the northwest corner of MLA 70425. The Rewan Formation comprises grey-green to brown-purple siltstone and fine-grained sandstone and has an average thickness of 175 m.

Coal is located within Permian sediments, specifically within the Bandanna Formation and Colinlea Sandstone. The latter are underlain by the Joe Joe Formation and basement rock of the Drummond Basin.

2.5 Groundwater Levels and Piezometric Heads

JBT (2011a, Section 3.5.1) discusses available groundwater level data from more than 250 exploration bores within MLAs 70425 and 70426. The groundwater levels are measurements of levels in open bores, i.e. they measure an average piezometric head over the length of the borehole, or to be more precise, they measure a level which may be the result of redistribution of water between different hydrostratigraphic layers, caused by drilling of the bore. Measurements have been made at different times.

The data show a general trend with water levels declining from west to east, consistent with the existence of a water table that is a “subdued reflection of topography”. The data suggest that groundwater at the elevation of the water table flows towards Lagoon Creek, and perhaps locally towards Sandy and Little Sandy Creeks (JBT, 2011a, Figure 3-10).

A number of vibrating wire piezometers (“VWPs”) were installed in 2009, mostly targeting the D-E sandstone and the C-D sands (Bandanna Formation) (JBT, 2011a, Section 3.5.2). The direction of flow at depth appears to be northwards, perhaps towards the north-northeast.

JBT (2011a) does not report on groundwater levels in the wider region. All reported data are inside or adjacent to the MLAs.

JBT (2011a, Section 3.11) summarises transient data available for model calibration. Since groundwater levels measured on site since December 2009 have not responded to rainfall events, JBT concludes that there are no regional scale transient data that can be used for calibration of a regional model.

Measurements obtained during recent development of a test pit, known as the Alpha test pit, are discussed below. These data are particularly useful.

2.6 Recharge

JBT (2011a) discusses the difficulty of estimating recharge. A study by Kellett et al. (2003) provides useful guidance on recharge processes in the area of the GAB intake beds.

Recharge is likely to occur in all parts of the landscape, in low-lying areas where Colinlea Sandstone outcrops to the east of Lagoon Creek but also along the Great Dividing Range, to the west of the leases.

No independent estimates of recharge are available. It is not uncommon to assume 1 to 3% of mean annual rainfall.

2.7 Hydraulic Properties

JBT (2011a, Section 3.10) summarises a number of site investigations designed to obtain estimates of hydraulic properties. These include studies in 1982-83 and 1984 for Bridge Oil Limited, as well as more recent aquifer (pumping) tests conducted by JBT for Hancock. Hydraulic properties have been estimated for C-D sandstone and D-E sandstone, i.e. the focus has been on hydrostratigraphic units in contact with coal seams, rather than on thick aquitards that are likely to control regional flows.

JBT (2011a) also presents a summary of hydraulic properties in the GAB, in this case for both aquifers and aquitards. These estimates are based on early modelling of the GAB in 1976.

In earlier correspondence and internal reports, JBT provided estimates of hydraulic properties to NTEC, as shown in Table 2-1.

Table 2-1: Baseline hydraulic properties

Unit	Kxy		Kz		Ss	Sy or n
	(m/s)	(m/d)	(m/s)	(m/d)	(m^{-1})	(-)
GAB	5.80E-05	5	5.80E-06	0.5	0.0005	0.05
Rewan Formation	1.00E-07	0.0086	1.00E-08	0.00086	0.0001	0.05
Bandanna Formation	1.60E-06	0.14	1.60E-07	0.014	0.00016	0.05
D seam	1.00E-06	0.086	1.00E-07	0.0086	0.005	0.02
D-E sandstone	3.00E-06	0.26	3.00E-07	0.026	3.5E-06	0.05
E seam	1.60E-06	0.14	1.60E-07	0.014	0.005	0.02
Sub E sandstone	1.20E-05	1.04	1.20E-06	0.104	0.0001	0.05
Joe Joe Formation	1.00E-07	0.0086	1.00E-08	0.00086	0.0001	0.05
Basement	1.00E-07	0.0086	1.00E-08	0.00086	0.0001	0.05

2.8 Alpha Test Pit

Hancock developed the Alpha Test Pit ("ATP") for the purpose of obtaining a bulk sample of coal. A description of hydrogeological data obtained during development of the ATP has been provided by JBT (2011b), in August 2011.

The location of the test pit is shown in Figure 2. The ATP is approximately 300 m long and 250 m wide at crest level (Figure 4). It is approximately 66 m deep, from a surface RL of 308 mAHD to the final floor at RL 242 mAHD.

Overburden removal and infrastructure development commenced in November 2010. Progress was delayed by rain, so the majority of test pit development occurred between May and July 2011.

Twelve dewatering bores were constructed adjacent to the test pit. Direct seepage into the pit was removed via a sump pump. Groundwater response to pumping was observed in bores AVP-07 and AVP-08 (Figure 4), and also in AMB-01 (to the south) and AVP-05 (2.7 km to the north-northwest). Pumping rates and observed changes in head are described by JBT (2011b).

Pumping commenced on 21 April 2011 in TP-11 and continued until 20 July 2011. Approximately 38.8 ML was pumped during this period, an average of about 4.9 L/s (0.43 ML/d). However for most of the period from about 3 June to 20 July, i.e. about half the length of dewatering, pumping was at about 8 L/s (0.7 ML/d).

The volume of water pumped from the pit was estimated to be 1 L/s from 23 June when water first appeared at the floor of the pit. The rate of pumping was increased to 2.5 L/s on 1 July (when the D Seam was first intersected) and this rate continued until the end of mining on 13 July. The total volume of in-pit dewatering was estimated to be 3.6 ML.

JBT estimates that evaporation during the period of development of the ATP could have accounted for another 2.85 ML of inflow to the pit.

In summary, JBT estimates that a total of 45.27 ML of water would have been removed during development of the ATP. This does not include any water removed with overburden, interburden or coal.

The Alpha Coal Project is situated in a low permeability environment, with a relatively dry climate. It is difficult to estimate hydraulic properties in such environments, so the data provided during development of the ATP provide a rare opportunity to interpret data at a significant scale, over a period of months, in order to infer hydraulic properties of aquifers and aquitards.

3 CONCEPTUALISATION

3.1 Regional Hydrogeological System

The regional hydrogeological system is described in detail by JBT (2011a). Section 3.4.2 of that report describes stratigraphy and hydrostratigraphy, and Section 3.4.4 describes GAB hydrostratigraphy.

The regional hydrogeology is characterised by a series of aquifers and aquitards.

Table 3-1: Regional hydrostratigraphy

Hydrostratigraphic Unit	Description	Thickness	Hydrogeology
	Alluvium	15-20 m	Unconfined aquifer
	Argillaceous sandstones and clays	40 m	Unconfined aquifer
Clematis Sandstone	Quartz sandstone, minor siltstone and mudstone	140 m	Confined aquifer at base of GAB, unconfined where it outcrops
Rewan Formation (Dunda Beds)	Green-grey mudstone and labile sandstone	175 m	Aquitard, which acts as confining layer at the base of the hydrogeological GAB
Bandanna Formation and Colinlea Sandstone	Sandstone and coal	10-30 m sandstone	Confined aquifers and aquitards, depending on relative hydraulic conductivities, but unconfined where they outcrop
		1-2.5 m coal A Seam	
		10 m A-B Sandstone	
		6-8 m coal B Seam	
		70-90 m B-C Sandstone	
		2-3 m coal C Seam	
		5-20 m C-D sandstone, siltstone and mudstone	
D Seam	Coal	4.5-6 m	Aquifer
D-E Sandstone	Sandstone	15 m	Aquifer
E Seam	Coal	0.1-0.4 m	Aquifer
Sub E Sandstone	Sandstone and coal	15-20 m	Aquifer
		0.5-5 m coal F Seam	
Joe Joe Formation	Labile and quartz sandstone		Aquitard
Basement			Aquitard

3.2 Groundwater Flow under Pre-Mining Conditions

JBT (2011a) describes the hydrogeological conceptual model prior to mining (Figure 5a). Based on information presented in previous sections, the pre-mining conceptual groundwater model is summarised (JBT, 2011a, Sections 5.1.1 and 5.2.1) as follows:

- Groundwater occurs beneath the MLAs in coal seam and sandstone (interburden and floor) aquifers. The sandstone aquifers, which occur between and below the coal seams, are the major groundwater sources.
- The sandstone aquifers become cleaner (greater quartz content) and coarser with increasing depth.
- The coal seams confine the underlying sandstone aquifers.
- Groundwater occurrence in the units overlying the Permian deposits (Tertiary sediments and Quaternary alluvium) is sporadic, and the units are not regarded as significant regional aquifers.
- Recharge occurs in topographically elevated areas and causes shallow groundwater to flow towards Lagoon Creek. In the area to be mined, the groundwater flow direction (on the western side of Lagoon Creek) is to the north-northeast. The gradient is small (approximately 0.1%).
- Groundwater in the Permian Bandanna Formation and Colinlea Sandstone is encountered under confined conditions, even adjacent to Lagoon Creek. This suggests that groundwater does not necessarily discharge to Lagoon Creek under average conditions, but may reach surface if structures such as joints or faults exist that allow upward movement of water.

3.3 Groundwater Flow During Mining

JBT (2011a, Section 5.1.2 and 5.2.2) proposes the following conceptual model during mining (Figures 5b and 5c).

For the Alpha Coal Project:

- The process of mining will remove overburden, interburden and coal, thereby physically transporting some moisture with the rock.
- Groundwater will flow into the pit through the pit wall, from the Tertiary sediments (where water occurs), from the sediments of the B-C and C-D sandstone, and from the C and D coal seams.
- Groundwater will flow up through the pit floor from the underlying D-E sandstone aquifer. The majority of groundwater reporting to the floor of the pit will be derived from the D-E sandstone, rather than from underlying sandstone units (Sub E sands and Sub F sandstone).

- A cone of depression will develop around the open pit, at the level of the water table, extending preferentially north and south (along strike) and to the west, but the extent of the cone of depression to the east will be limited because the aquifers outcrop to the east and in this area the aquifers will be locally dewatered.
- A cone of depressurisation in the D-E sandstone will propagate to a significant distance, especially down dip to the west. This will cause further depressurisation of hydrostratigraphic units above and below the D-E sandstone. Water will be released from confined storage as these units depressurise, but they will remain saturated.
- Because the D Seam confines the underlying D-E sandstone, it will be important to encourage depressurisation of the D-E sandstone during mining. If the D-E sandstone were to remain pressurised, the upward pressure from groundwater could exceed the weight of overlying material (i.e. the weight balance would be exceeded), causing the floor of the mine to heave. It seems likely that depressurisation of the D-E sandstone will be required to allow mining to proceed safely to depth.

For the Kevin’s Corner Project:

- Groundwater will flow into the underground workings through the walls and floor, from the goaf (roof) as overlying strata collapse into the workings, and from even higher hydrostratigraphic units deformation propagates upwards towards the surface. Inflow will derive from Tertiary sediments (where water occurs), from the sediments of the B-C and C-D sandstone, and from the C and D Seams.
- A cone of depression will extend to the east and west, however propagation of the cone of depression at the level of the water table will be limited due to the presence of outcropping Rewan Formation (in the west) and Joe Joe Formation (in the east). This will have the effect of producing a cone of depression that is elongated in the north-south direction (along geological strike of the coal measures and sandstone).
- The depth and extent of the cone of depression will be controlled and to some extent limited by the flow processes that occur in the zone of deformation. If the zone overlying longwall panels becomes highly fractured, then there will be a tendency for relatively rapid drainage towards the underground mine, with implications both at the surface, and in the mine. If fracturing is minor, and/or disconnected, or if the fractures desaturate, it is possible that drainage may be limited, and/or significantly delayed. Very slow drainage could mean that recovery occurs while there is still a tendency for drainage.
- A cone of depressurisation in the D-E sandstone will propagate to a significant distance, especially down dip to the west. This will cause further

depressurisation of hydrostratigraphic units above and below the D-E sandstone. Water will be released from confined storage as these units depressurise, but they will remain saturated.

3.4 Recovery Following Mine Closure

JBT (2011a, Section 5.1.2 and 5.2.2) proposes the following conceptual model after the end of mining.

- A water table will develop over time in in-pit waste dumps. Sources of water will include direct rainfall infiltration, and inflow from the D-E sandstone that will underlie the in-pit dump.
- Rehabilitation of the surface of the in-pit dump may limit direct infiltration (via capping, revegetation, and/or grading of the surface to encourage runoff and limit surface ponding). This may be required to manage stability of the dump.
- Mine pit lakes will develop in open cut mines, and lake levels will rise until a dynamic equilibrium is reached, with the final level well below the initial pre-mining water table elevation.
- Underground workings will eventually be flooded.
- The cone of depression will expand until an equilibrium is reached with recharge inside the cone of depression balanced by evaporation from the surface of the mine pit lakes.

4 GROUNDWATER FLOW MODELLING

4.1 Introduction

In most reports on groundwater flow modelling, a section on development of a conceptual hydrogeological model is followed by a description of "the" groundwater model, as if there is only one.

In this section, and in this report in general, the focus is on "groundwater modelling", rather than on "the model". Groundwater modelling is a process rather than an end result. It is rare that one model can answer all the questions that need to be addressed. Rather, through the process of modelling, those undertaking the modelling develop an understanding of a hydrogeological system and a feeling for the responsiveness of the system – i.e. the way the system is likely to respond to proposed changes.

During the course of this project, the objectives have changed. At the start of the project, the objective was to consider the impacts of the Alpha Coal Project, an open cut mine. Discussions between several parties led to agreement that a regional groundwater flow model would be developed using FEFLOW Version 6. FEFLOW is commercial finite element software developed by DHI-WASY in Germany (DHI-WASY, 2011). NTEC has had considerable experience using FEFLOW, over a period of 15 years. FEFLOW has been used to predict the movement of groundwater near many open cut and underground mines.

By the time it was decided to extend the model to include the impacts of the Kevin's Corner Project, including an extensive underground mine, the choice of software was again discussed. A decision was made to continue using FEFLOW. By this point in time, NTEC had learned of difficulties related to the representation of underground mines, and on advice from DHI-WASY chose to adopt a pseudo-unsaturated approach rather than a saturated approach which is more common.

Results with the pseudo-unsaturated model showed the sensitivity of model predictions to hydraulic properties (hydraulic conductivities and porosities) in materials overlying the longwall mine. In order to check that FEFLOW results were of the right order of magnitude, a new regional scale model was developed using MODFLOW-SURFACT Version 4.0 (HydroGeoLogic Inc., 2011). The results agreed to within 10 or 20%, a difference that could be explained by a number of differences in the way the two models were set up, so it was again decided that modelling should continue using FEFLOW.

When the results of the Alpha Test Pit became available, in mid July 2011, a local scale model was set up using FEFLOW. However model calibration is currently easier using BeoPEST (Schreüder, 2009), as implemented in Groundwater Vistas

Version 6 (Environmental Simulations Inc., 2011), a graphical interface to MODFLOW-SURFACT. For this reason, a second local scale model was set up using MODFLOW-SURFACT and BeoPEST was used to calibrate the model, prior to confirmation using the local scale FEFLOW model. The estimated model parameters have been used to support the choice of model parameters in further regional scale modelling using FEFLOW.

It was stated above that the focus of this report would be on results, i.e. on the current level of understanding, rather than on a chronology of events leading to this level of understanding. However, the chronology is important because it explains the following:

- Extensive groundwater modelling has been undertaken to assess the potential impacts of the Alpha Coal Project and the Kevin's Corner Project.
- The model used to predict impacts during and after mining is a regional scale groundwater flow model developed using FEFLOW.
- This model has been compared with another regional scale model developed using MODFLOW-SURFACT, using both early and recent estimates of hydraulic properties.
- A local scale model near the Alpha Test Pit was developed using MODFLOW-SURFACT, and this model was calibrated against field data.
- A local scale model near the Alpha Test Pit was developed using FEFLOW, and this model was shown to compare well with the MODFLOW-SURFACT model, thereby supporting the decision to use FEFLOW as the primary simulator.

In this project, more than in many others, the focus has been on modelling, rather than on "the model".

4.2 Local Scale Model Near Alpha Test Pit

Collection of data during recent dewatering of the Alpha Test Pit has provided data that are in some sense equivalent to a large-scale long term aquifer (pumping) test. The act of excavating a test pit is perfectly analogous to the act of developing a mine. From the time that water-bearing strata are intersected, there exists the possibility that seepage could occur into the mine. At the same time, the installation of 12 dewatering bores around the perimeter of the test pit is perfectly analogous to dewatering in many mining projects.

4.2.1 MODFLOW-SURFACT model

In order to take advantage of the data provided in July 2011, a decision was made to construct a local scale model using MODFLOW-SURFACT, using the Groundwater

Vistas interface, and to use BeoPEST to find model parameters that would provide the best fit to the data. Calibration is described in Section 5 below.

A regular model grid was chosen, with a finite difference grid 2 km in the west-east direction and 1.6 km in south-north direction, as shown in Figure 6. The model has 62 columns, 56 rows and 10 layers.

The structure of the model was based on the construction log of AVP-07, because unlike AVP-08, this borehole shows exposures of both the C and D Seams (about 14 m and 7 m thick, respectively).

The model layering is shown in Table 4-1. For convenience, the materials were grouped into three zones, as shown, so that hydraulic properties could be estimated independently for each of these zones.

Table 4-1: Layering in local scale MODFLOW-SURFACT model

Model layer	Thickness (m)	Zone	Description
1	18.5	Bandanna Fm	Silty clay
2	11	Bandanna Fm	Laterite
3	14.5	Bandanna Fm	Claystone
4	4	Bandanna Fm	Carbonaceous siltstone
5	13.5	C Seam	Stony coal
6	3	Bandanna Fm	Fine-grained C-D Sandstone
7	8	D Seam	Stony coal
8	7.4	D-E Sandstone	D-E Sandstone
9	1.6	D-E Sandstone	Stony coal
10	50	D-E Sandstone	Mudstone

Measured pumping daily pumping rates were defined for the 12 dewatering bores for 91 days from 21 April to 20 July 2011, inclusive (JBT, 2011b, Figure 4).

Drain nodes were defined as shown in Figure 6. The elevation of drain nodes was set equal to the elevation of the floor of the pit, as it fell during excavation (JBT, 2011b, Figure 4).

The bottom and lateral boundaries were assumed to be no flow boundaries, i.e. in the case of the lateral boundaries, so far away from the Alpha Test Pit that they would not affect the solution.

Initial heads were set to 299 mAHD everywhere.

The model was set up as a normal saturated flow model, allowing layers to drain.

The model was run as a transient run with a nominal daily time step.

4.2.2 FEFLOW model

A local scale model was also constructed of the region near the Alpha Test Pit using FEFLOW. Since a regional scale FEFLOW model had already been set up, this was done in order to demonstrate that FEFLOW and MODFLOW-SURFACT are capable of predicting effectively the same results.

A regular finite element mesh was created, covering a domain 2 km square, as shown in Figure 7. The model has 10 layers and 11 slices, with a total of 94,259 nodes and 168,520 elements.

Layering is identical to that described in Section 4.2.1.

Pumping bores were defined as multi-layer wells connected from slice 5 to slice 9, with pumping rates as above.

Initial heads were set to 299 mAHD everywhere.

The model was set up as a saturated flow model. Slice 1 was set to “phreatic”, slice 11 to “fixed” and all intermediate slices to “unspecified”. These settings allow the water table to fall, such that lower layers become “phreatic”, so as to cause specific yield to affect storage calculations.

The model was run as a transient run with adaptive time-stepping.

4.3 Regional Scale Model

4.3.1 FEFLOW model

FEFLOW is well suited to the assessment of open pit mine dewatering where a combination of pumping from perimeter bores and in-pit sumps may be required. It also allows simulation of underground mining. FEFLOW allows:

- simulation of groundwater flow in conditions dominated by complex geological structure;
- a refined mesh in areas with complex geometry and/or steep gradients in piezometric head (near mines);
- a coarse mesh in the far field;
- representation of complex time-varying boundary conditions (which is particularly important during simulation of dewatering of a mine and filling of a final void during recovery); and
- time-varying properties in aquifers and aquitards (to represent in pit placement of waste rock as backfill and the influence of deformation above underground mining).

Modelling strategy

In order to predict the cumulative impact of the Alpha and Kevin's Corner mining operations, it was necessary to represent the long-term mine plans for all open pit and underground mining within one groundwater model.

Modelling was undertaken separately to simulate:

- mine inflows and regional depressurisation during mining, and
- recovery of groundwater levels and the evolution of mine pit lakes following the end of mining.

FEFLOW provides three methodologies for simulating regional scale groundwater flow in unconfined aquifers.

- The first option requires prior knowledge about which layers are confined and unconfined, but this method works best in regional flow systems where the water table is relatively steady. This is not the case in many mining situations.
- The second option, known as BASD (Best Adaptation to Stratigraphic Data) or the "moving mesh" option, allows layers and slices (the surfaces between layers) to move adaptively, such that the uppermost slice always corresponds to the water table. There is growing evidence that this option is difficult to use in complex mining situations where the water table can fall to elevations far below its initial level.
- The third option is to run the model in an unsaturated or pseudo-unsaturated mode. This appears to be the best way to use FEFLOW for a region that contains both open cut and underground mines.

A decision was made to run FEFLOW in a pseudo unsaturated mode, where the upper layers desaturate (partially drain) as the water table falls during mining. One disadvantage of running FEFLOW in this mode is that recharge cannot be applied to the uppermost slice.

Model geometry

There are no natural physical boundaries near the proposed mines that could be used as lateral boundaries for a numerical model. For this reason, the model domain was chosen to be square, 100 km x 100 km in extent (Figure 8). The domain boundaries are believed to be far enough away from the proposed mines that the impact of mining would not be felt at the boundaries.

The proposed Alpha pit was positioned near the centre of the model domain. The domain extends 40 km to the south of the Alpha open pit, and 27 km, 40 km and 45 km to the north, west and east of the Kevin's Corner underground mine, respectively. The model domain extends 35 km into the GAB.

A finite element mesh was designed to align with mine plans and with existing surface drainage, so that hydraulic properties and boundary conditions could be assigned in easily identifiable zones. The mesh was refined along the zone boundaries. Each slice has 23,589 nodes and each layer has 46,012 triangular prismatic finite elements (Figure 8).

For the purpose of adequately representing hydrostratigraphy, the model domain was divided into 13 layers, representing nine hydrostratigaphic units (Table 4-2, Figure 9). The Rewan Formation (an aquitard) was divided into two layers, and the Bandanna Formation (an aquifer overlying the primary target for mining, the D Seam) was divided initially into four layers.

Top and bottom elevations were assigned to all model layers based on known and estimated elevations of the tops and bottoms of hydrostratigraphic layers. Where no surface elevations were available, layers were defined using an assumed average layer thickness. The weathered zone was assumed to have the same hydraulic properties as the underlying unweathered rock formations, and hydrostratigraphic layers were assumed to outcrop at the ground surface based on the dip observed below the weathered zone.

The base of mining was in slice 9. The model was extended to a depth of 1500 m, i.e. to RL -1200 mAHD. This is deeper than is often assumed, especially given the level of uncertainty about the nature of the basement, but a decision was made at an early stage of modelling to include and assess the effect of basement, rather than simply assuming that basement would have no effect.

Table 4-2: Layering in regional scale FEFLOW model

Model layers	Hydrostratigraphic unit
1	GAB
2-3	Rewan Formation
4-7	Bandanna Formation
8	D Seam
9	D-E Sandstone
10	E Seam
11	Sub E Sandstone
12	Joe Joe Formation
13	Basement

Hydraulic properties

Hydraulic properties of the Bandanna and Colinlea formations were estimated initially based on a number of pumping tests undertaken on site during previous groundwater investigations. Where no field data were available, parameters were estimated based on lithology. Vertical hydraulic conductivities were assumed to be one order of magnitude (a factor of 10) lower than horizontal hydraulic conductivities, although the anisotropy ration (the ratio of horizontal to vertical hydraulic conductivity) could be much higher than 10, especially in aquitards such as the Rewan Formation.

As no field data were available on the unsaturated properties of any of the rock formations included in the model, capillary parameters were assumed representative of loam sediments. The Van Genuchten capillary function was used to represent saturation (α = 3.6 m-1, n = 1.7), and a linear relationship was assumed for relative hydraulic conductivity, as recommended by DHI-WASY as a way of allowing upper layers to desaturate in a regional model.

Storage in the unsaturated zone depends on porosity, n (not to be confused with the coefficient n in the Van Genuchten capillary function). Porosity takes the place of specific yield, a parameter that would be used in a model that does not allow partial saturation.

Estimating hydraulic properties based on lithology and assuming uniform anisotropy are simplifications. There are many uncertainties with respect to the assumed hydraulic parameters. Baseline properties in early model simulations were as shown in Table 2-1.

Early estimates of seepage into the proposed Alpha and Kevin's Corner mines were so large, however, that all estimates of hydraulic properties were questioned. Questions were asked about:

- Horizontal and vertical hydraulic conductivities;
- Specific yield (porosity), especially in the Bandanna Formation, overlying the longwall mine; and
- Specific storativity, especially in the Joe Joe Formation and basement, because the deep model domain appeared to be causing a significant amount of water to come from confined compressible storage.

Hancock are currently undertaking additional field and laboratory work to provide support for revised estimates of hydraulic properties. Meanwhile, regional scale modelling has continued using hydraulic properties estimated using data from the Alpha Test Pit.

Recharge

The average annual rainfall in the area is 535 mm. Average annual evaporation (class A pan) is 2,293 mm. Estimates of recharge generally fall between 1 and 3% of average annual rainfall, with localised values up to 5% of rainfall reported.

During the period of mining, no recharge was applied. This is believed to be a reasonable approach, because mine inflows during mining are driven by steep gradients induced by dewatering of the mine, and mine inflows are far greater than any possible contribution of recharge. There is, however, another practical reason for not applying recharge, i.e. the fact that when FEFLOW is run in an unsaturated or pseudo-unsaturated mode, recharge to the uppermost slice can cause heads to rise to unrealistically high levels.

Rainfall, runoff and evaporation were taken into account for post mining (final void) simulations, but only locally within the catchment areas that contribute runoff towards mine pit lakes in final voids.

Boundary and initial conditions

Fixed head boundary conditions were assumed along all sides of the model domain at an elevation of 300 mAHD, prior to and during mining. The lateral boundaries were chosen based on an assumption that they would be far enough away from the mines so that no flow would occur from the boundary to the mine during the period of mining. This assumption can be checked by computing the flow through fixed head boundaries throughout any model run, and by comparing the magnitude of this flow with other flows near the mine.

Initial conditions prior to mining were chosen based on an assumption that the water table is located initially at 300 mAHD throughout the region. In essence, the whole region is assumed to be hydrostatic, with zero regional groundwater flow. This approximation was required because of lack of knowledge of regional water table elevations, but is believed to be sufficient to allow predictions of the impact of mining.

Because mining will progress westwards during the life of the proposed project, numerical modelling requires the mine schedule to be approximated in both space and time. The extraction of coal and overburden at the Alpha open pit and of coal at the Kevin's Corner underground mine has been approximated by an initial 6-year mining stage in financial years 2013-2018, followed by five 5-year mining stages to mid 2043 (Table 4-3, Figure 2).

Table 4-3: Mining stages

Mining stage	Years from start	Financial years ending 30 June
1	0-6	2013-2018
2	6-11	2019-2023
3	11-16	2024-2028
4	16-21	2029-2033
5	21-26	2034-2038
6	26-31	2039-2043

Representation of mining

All currently available commercial groundwater modelling software assumes that the ground that contains groundwater is permanently fixed in place. No commercial software has been designed specifically to facilitate the representation of mining projects.

The process of coal mining starts with removal of part of the ground. Coal is removed for washing and shipment to markets. Waste rock remains on site and can influence hydrological and hydrogeological processes, during and after the end of mining.

- In open cut coal mining, waste rock or “spoil” comes from overlying layers (“overburden”) and from layers between the coal seams (“interburden”). The spoil is typically placed inside the pits, ultimately leaving a relatively long linear final void, at the location of the high wall. Handling of coal and spoil with draglines allows the release of some water from within the spoil, such water draining to sumps in the floor of the pit. Some moisture is retained within the coal and spoil. The majority of water that reports to the pit does so because the floor of the pit is now a local low point in the hydrogeological system, thus groundwater flow occurs towards this local sink.
- In underground coal mining, longwall mining equipment removes a target seam, and little waste is brought to the surface. Some moisture is retained within the coal that is mined. As longwall panels progress forwards within a seam, the roof of the seam collapses behind the roof supports, ultimately causing subsidence at the land surface. If mining proceeds from shallow depths towards deeper depths, groundwater inflows to the mine are likely to increase as the bottom of the mine becomes lower in the local flow field. If mining starts deep and proceeds up dip, the lowest point in the flow field is established early and mine inflows may decrease throughout the life of the mine.
- Behind a longwall miner, the seam itself is rapidly filled with rubble. Initially the roof of the seam spalls, and slabs of rock fall the height of the seam to the floor. The roof continues to spall until the broken rock fills the space available and provides support to the roof. This region is known as the “goaf”. Deformation continues above the goaf, through a combination of downward and horizontal movement (vertical and horizontal “strain”). Depending on the structure and mechanical strength of the geological materials, vertical fractures can open up above the goaf, but at an elevation where “arching” causes horizontal compressive stresses (a so-called “confining” zone), vertical fractures remain closed and the capacity of the rock to transmit groundwater may be no more than before mining. Above the confining zone, horizontal fractures along bedding planes can open up, leading to enhanced horizontal hydraulic conductivity. The net result of longwall mining is “subsidence” at the land

surface, which results in an undulating perturbation to the original land surface, with maximum subsidence over the middle of panels and minimum or zero subsidence over the pillars than separate the panels.

In order to use commercial groundwater modelling software to simulate mining, it is necessary to use the capabilities of the software to vary hydraulic properties and boundary conditions as a function of time, to capture the essential features of the mining process.

The most common way to represent the floor of a mine is as a “seepage face” boundary condition. In FEFLOW, a seepage face boundary is a fixed head boundary condition where head at a node is set equal to elevation, on condition that the resulting groundwater flow at that node is a net outward flow, out of the ground and in this case, into a mine. Seepage face boundary conditions are set when an area is being mined, and released after the end of that stage of mining.

In the Alpha and Kevin’s Corner open pits, seepage face nodes were defined at all nodes at the bottom of the D Seam (slice 9) within the areas of the pits. Seepage face nodes were also defined at nodes around the walls of open cut mines, in all slices. In slices 5 to 8 (in the Bandanna Formation), seepage face nodes provide an opportunity for slices 5 to 7 to desaturate in the high wall, with seepage reporting to the mine wall at the base of the aquifer. In slices 2, 3 and 4 (at the top, middle and bottom of the Rewan Formation), the seepage face will release water to the pit in early time steps, after which groundwater will drain vertically to a water table in the Bandanna Formation, rather than out of the pit wall.

In the Kevin’s Corner underground mine, seepage face conditions were defined at the roof and floor of the D Seam (slices 8 and 9) to allow groundwater inflow across these surfaces.

Within the volume of an open cut mine, hydraulic properties are sometimes changed to emulate what would happen in a mine when rock is removed from a mine. In the case of underground mining, hydraulic properties can be changed in the seam that it mined, and also in the goaf and higher zones above the mine. Because mining proceeds down dip, and because both backfill and previously mined longwall panels will drain down dip towards the active areas of mining, the hydraulic properties of the mined areas are unlikely to be important until after the end of mining, when water levels recover.

With mining assumed to progress in six stages in 31 years, mining is assumed to occur effectively instantaneously at the start of each stage. This causes rapid inflow into that part of the mine at the start of a stage, and a gradual decline in inflow rate towards a steady flow more characteristic of what might happen in reality. If a mine plan could be represented at yearly, monthly or weekly time intervals, instead of

5-year intervals, the time variation in inflow would be more smooth. Nevertheless, even with a coarse representation of a mine plan, cumulative inflow rates are known to be reasonably accurate.

The six stages of mining (a period of 31 years) were simulated as a set of six consecutive runs. Hydraulic properties were read from lookup tables. Boundary conditions and constraints were set up as time-varying conditions. The final conditions from each run became initial conditions for the next. Inflows to each part of the mine were computed using FEFLOW "observation point groups".

4.3.2 MODFLOW-SURFACT model

A second regional scale model has been developed using MODFLOW-SURFACT, but in less detail than the FEFLOW model.

The initial motivation for developing the MODFLOW-SURFACT model was when predictions of mine inflows were initially large. An independent check was needed, and MODFLOW-SURFACT results were indeed comparable to FEFLOW results. The same sensitivity analyses were repeated with both FEFLOW and MODFLOW-SURFACT to show the impact of assuming 5% porosity in the Bandanna Formation, and the impact of specific storativity in basement on overall water balance.

The regional scale model also covers an area 100 km square. The model has 312 rows, 274 columns, 11 layers and a total of 940,368 finite difference cells.

Layering is similar to in FEFLOW, in Section 4.3.1 above, but since the MODFLOW-SURFACT model was developed at a time when the FEFLOW model had only two layers in the Bandanna Formation, the MODFLOW-SURFACT model mimics that earlier version of the FEFLOW model.

All boundary and initial conditions are analogous, as is the representation of the mine. Even though MODFLOW-SURFACT does have a capability for representing time-varying aquifer properties, this capability was not used.

The model is run as a saturated flow model. One of the strengths of MODFLOW-SURFACT is its ability to allow cells to dry out and later rewet them. While this capability is not specifically needed for this project, at least during the period of mining, the software is generally robust.

5 CALIBRATION

5.1 Local Scale Model Near Alpha Test Pit

JBT (2011b) describes an attempt to infer hydraulic properties using Winflow Version 3.28. Winflow is a two-dimensional ("2D") model that simulates a single aquifer, so parameters have been estimated for a single aquifer. The resulting estimates are:

- Hydraulic conductivity (horizontal) = 0.2 m/d, averaged over an "aquifer" thickness of 40 m
- Aquifer storage coefficient (combining the effects of drawdown at the water table, i.e. specific yield, and compressibility, i.e. specific storativity) = 0.001

The real opportunity provided by data obtained during development of the ATP, however, is for separate estimates to be obtained of several hydrostratigraphic units intersected by the pit and monitoring bores.

5.1.1 Calibration of MODFLOW-SURFACT model using BeoPEST

The local scale MODFLOW-SURFACT model described in Section 4.2.1 has been used to estimate hydraulic properties of three types of materials, specifically for the three zones defined in Table 4-1.

BeoPEST is a recent implementation of the parameter estimation software, PEST. It is accessible using Groundwater Vistas Version 6.

Observation points were defined at five locations: in the C-D and D-E Sandstone at both AVP-07 and AVP-08, and also for a fully screened piezometer at the location of AVP-08. These observation points correspond to the locations where heads were observed during development of the ATP.

BeoPEST requires a set of initial estimates for model parameters, and adjusts them systematically until it finds a "best" set of parameters, a set that minimises a chosen objective function. The objective function is generally the sum of the squares of differences between observed and modelled (predicted) heads. This leads to a type of generalised least squares estimation.

Initial estimates of hydraulic properties are shown in Table 5-1 and the final (best) estimates are shown in Table 5-2. The initial estimates do not correspond perfectly with those in Table 2-1, but a robust parameter estimation method should be independent of initial guesses.

Hydraulic conductivities are generally smaller.

- Kxy in the Bandanna Formation is 25 smaller, and the anisotropy ratio Kxy:Kz is 20;

- Kxy in the coal seams is estimated to be relatively large, but the anisotropy ratio is almost 10,000; and
- Kz in the D-E sandstone is estimated to be large, possibly influenced by bore construction, such that observed heads in two VWPs in the same borehole are closer than they might be without the influence of the bore.

Specific yield is lower in the Bandanna Formation, and specific storativity is much lower in all units.

Table 5-1: Initial estimates of hydraulic properties

Unit	Kxy	Kz	Ss	Sy
	(m/d)	(m/d)	(m^{-1})	(-)
Bandanna Formation	0.1	0.01	0.00001	0.05
C and D seams	0.01	0.001	0.0001	0.02
D-E sandstone	1	0.1	0.00001	0.05

Table 5-2: Best estimates of hydraulic properties

Unit	Kxy	Kz	Ss	Sy
	(m/d)	(m/d)	(m^{-1})	(-)
Bandanna Formation	0.004	0.0002	0.00000035	0.03
C and D seams	0.09	0.00001	0.0000019	0.3
D-E sandstone	0.1	7.6	0.0000035	0.03

Figure 10 shows the fit achieved between observed and predicted heads during development of the ATP. This plot is the best result that BeoPEST could achieve.

Figure 11 shows predicted heads in the D Seam after 91 days, using the best estimates of hydraulic properties.

5.1.2 Check of FEFLOW model

The same best estimates of hydraulic properties (Table 5-2) were then used in the local scale FEFLOW model, to check that FEFLOW would also give similar predictions.

The results are shown in Figure 12. They show a similar fit between observed and predicted heads, which provides some degree of confidence in FEFLOW as a predictive model.

5.2 Regional Scale Model

NTEC believes that there are insufficient regional data to attempt to calibrate the regional scale model.

A number of techniques have been used by consultants in recent years to attempt to calibrate regional scale models in relatively flat and dry areas. They include:

- Covering the land surface with seepage face nodes or drain cells, along drainage lines, applying rainfall recharge and allowing drainage lines to flow as if in steady flow, even though drainage lines are essentially dry most of the time. Adding more recharge will not flood the land surface, but will change the curvature of the water table between drainage lines. Without observations of the water table elevation to support the curvature, this methodology will appear physically reasonable along drainage lines, but may not reduce uncertainty in the absolute values of recharge versus hydraulic conductivities.
- Running a steady state model initially with all nodes at the uppermost surface fixed a little below the land surface (to ensure that the water table is a "subdued reflection of topography"), computing net flux through those nodes, and assigning those fluxes (or some spatial average thereof) as estimates of recharge. This methodology will appear to produce physically reasonable results, but without independent estimates of recharge and measurements of water table elevations, the methodology may not reduce uncertainty in the absolute values of recharge versus hydraulic conductivity.

In the case of the Alpha Coal Project and Kevin's Corner Project, the quantity of greatest interest is drawdown. Absolute levels are not as important. Furthermore, the drawdown caused by open cut and underground mining will be substantial, much larger than natural variations in water table elevation near the surface.

By far the most useful measurements for calibration are measurements of fluxes of water. The opportunity to calibrate even a local scale model near the Alpha Test Pit is rare. In this test, pumping rates were measured, the rate of removal of water from the pit sump was measured, and heads were measured. This test provides more information than is very often available.

6 PREDICTIONS

6.1 Potential Impacts During Mining

Based on extensive modelling with four separate models, including sensitivity analysis and calibration of a local scale model using data collected during development of the Alpha Test Pit, a decision was made to predict the potential impacts of the Alpha Coal Project and the Kevin's Corner Project using a regional scale FEFLOW model, with parameters strongly influenced by calibration of a local scale MODFLOW-SURFACT model.

The FEFLOW model is as described in Section 4.3.1, with best estimates of hydraulic properties (the "base case") as shown in Table 6-1

Table 6-1: Adopted base case hydraulic properties

Unit	Kxy	Kz	Ss	Sy or n
	(m/d)	(m/d)	(m^{-1})	(-)
GAB	5	0.5	0.00001	0.05
Rewan Formation	0.0004	0.00004	0.00000035	0.03
Bandanna Formation	0.004	0.0002	0.00000035	0.03
D seam	0.09	0.00001	0.0000019	0.3
D-E sandstone	0.1	7.6	0.0000035	0.03
E seam	0.09	0.00001	0.0000019	0.3
Sub E sandstone	0.1	7.6	0.0000035	0.03
Joe Joe Formation	0.0004	0.00004	0.00000035	0.03
Basement	0.0004	0.00004	0.00000035	0.03

Several other sets of hydraulic properties are used, within the volume of the open cut mine, in areas of backfill in open pits, and in the underground mine, in or above the goaf. Both higher and lower values of hydraulic conductivity and porosity have been assigned in areas where these are appropriate. Because the proposed width of longwall panels is generally greater than the depth of mining below the surface, damage is likely to extend to the surface. For this reason, the base case assumes a significant degree of connection to the surface.

A number of comments are made about the base case parameters in Section 5.1.1.

6.1.1 Predictions of mine inflows

From the time mining commences, groundwater will flow into the mines. Figure 13 shows cumulative inflow volumes during a period of 31 years, aggregated for four areas: the Alpha open cut mine, Kevin's Corner underground mine, and the northern and southern Kevin's Corner open pits.

The results suggest that cumulative inflow to the Alpha open cut will be of the order of 265 GL, or 23.4 ML/d over 31 years. Cumulative inflow to the Kevin's Corner underground mine will be about 125 GL, or 11 ML/d.

Based on earlier predictions, with very different hydraulic properties, it was suggested that predictions of mine inflows could not be made using 5-year mine planning intervals. While that comment may have been correct at that time, when significantly higher inflow rates were being predicted, the same is not true now. Lower hydraulic conductivities and storage coefficients lead to a slower response to sudden changes. Furthermore, integrating the inflows produces a relatively smooth curve, which supports the argument that the adopted representation of the mine plan sufficient.

6.1.2 Predictions of drawdown

As discussed in Section 3.3, mining will cause a cone of depressurisation at depth and a cone of depression at the water table. The two are different, because vertical hydraulic conductivities are sufficiently small to ensure that leakage from surficial aquifers towards the cone of depressurisation, specifically from the GAB (Clematis Sandstone) aquifer, will be slow.

Figure 14 shows drawdown in slice 8, at the top of the D Seam, after 31 years. The cone of depressurisation can be seen to extend further to the west than the east, because of the dip of the beds.

Figure 15 shows drawdown in the uppermost (GAB) aquifer. This Figure is constructed by showing drawdown in layer 1 of the model, in an area where layer 1 has finite thickness and represents the GAB aquifer. Drawdown in the GAB is not predicted to be zero, but it is localised. The peak drawdown just reaches 15 m.

The precise mechanism for the cone of depression being in this location and of this magnitude is not clear. The geological model on which the regional scale FEFLOW model is smooth, and based on regionalised data. The geological model does not match the complex shapes of the outcrop areas shown in Figure 15.

The reason any effect is seen is that depressurisation at depth, due to mining in the D Seam, will cause depressurisation in the Bandanna Formation, even in areas to the west of the longwall mine, where there is no risk of deformation propagating to the surface. This is illustrated in Figure 16, which shows the spatial distribution of pressure in a cross section oriented northwest to southeast, from the sensitive area of the GAB through Kevin's Corner underground mine and the southern open cut. The Figure also shows a P = 0 surface, which corresponds to the water table. The

Figure shows that the volume above the underground mine will not necessarily drain, in fact in this simulation a lot of water remains in that zone. Furthermore, the water table in the GAB aquifer appears to be relatively unaffected.

If any groundwater dependent ecosystems (“GDEs”) occur within the cone of depression (at the water table) or anywhere directly above longwall mining, they would almost certainly be at risk. GDEs beyond the cone of depressurisation are unlikely to be affected.

6.2 Potential Impacts After Mine Closure

Following closure of the proposed mines, groundwater will continue to flow towards the mines, being the lowest points in the regional hydrogeological system.

6.2.1 Regional cone of depression

The cone of depression surrounding the mines may continue to expand. Water table elevations will rise near the mines, but may fall further away. The radius of influence will depend on how recharge mechanisms respond to a slightly lower water table. Sometimes a slightly lower water table can lead to slightly more recharge, a phenomenon known as “induced recharge”. The size of a cone of depression depends on recharge within the area of the cone.

6.2.2 Evolution of mine pit lakes

The Kevin’s Corner underground mine will flood. Mine pit lakes will form in all other open cuts, and the lake levels will eventually reach a dynamic equilibrium with the climate. Final levels will depend more on the surface catchment areas of the mine pit lakes than on regional groundwater flows, as the final levels depend on direct rainfall, surface runoff and evaporation, as well as on the geometry of the pits, as defined by level-area-volume curves.

Analysis of the evolution of mine pit lakes was undertaken using an earlier regional scale FEFLOW model than is described here. The results suggest a final equilibrium water level in mine pit lakes of around 280 mAHD. It may take 250-300 years for this level to be reached.

6.3 Implications for Project Water Supply

One of the reasons for predicting mine inflows is to assess the potential for groundwater inflows to mines to act as a project water supply.

Using base case parameters, it is predicted that average inflow rates into the mines over a period of 31 years are 23.4 ML/d and 11 ML/d into the Alpha and Kevin’s Corner mines, respectively.

As shown in Figure 13, the slope of a plot of cumulative inflow volume against time varies with time. The inflow rate to the Alpha open cut tends to increase with time, while the inflow rate to the Kevin's Corner longwall mine tends to decrease with time.

Average inflow rates into four mining areas are different in every 5-6 year period (Table 6-2).

Table 6-2: Average mine inflow rates

Years	Inflow rate (ML/d)			
	Alpha open cut	Kevin's Corner underground	Kevin's Corner northern pit	Kevin's Corner southern pit
1-6	7	7	2	2
7-11	23	35	0	20
12-16	26	7	0	5
17-21	26	7	0	2
22-26	64	13	0	0
27-31	18	9	0	2

Variability in the mine inflow rate is one potential influence on the viability of mine inflows as a potential water supply. The variability is likely to be magnified when uncertainty in the groundwater flow model is taken into account.

All estimates of inflow rates are sensitive to many assumptions and choice of model parameters. Inflow to the Kevin's Corner longwall mine has been shown to be sensitive to estimates of hydraulic conductivity and porosity above the mine. The higher the porosity, the more water can drain vertically downwards to the underground. The lower the hydraulic conductivity, the more the tendency for drainage to be delayed, so that by the end of mining a significant proportion of water in the pore space is still stored high above the level of mining.

Inflow rates clearly depend on the mine schedule in different mines. If one mine is developed to a lower level first, inflows to that mine reduce the potential for inflows to other mines later. The fact that mine plans and schedules always change suggests that the time series of inflows should not be relied upon.

Some aspects of model setup can also affect the estimates of inflow. At the instant that each new 5-year period of mining commences in the Alpha open cut, the porosity inside the volume to be mined is reduced to a very small value. This means that when new model boundary conditions are activated, setting head inside the area of the mine equal to the elevation of the floor of the mine, heads are instantaneously lowered inside the volume of the mine (the void) but the yield of water from porosity is negligibly small.

7 SENSITIVITY ANALYSIS

7.1 Uncertain Model Parameters

Some of the base case model parameters presented in Table 6-1 are unusual, especially the Kz in the D-E and Sub E sandstones. Many other simulations have been performed, to assess the impacts of these parameters. Higher values of hydraulic conductivity imply larger inflows to the mines, so it is not surprising that sensitivity runs with lower values of hydraulic conductivity imply lower estimates of cumulative inflows to the mines.

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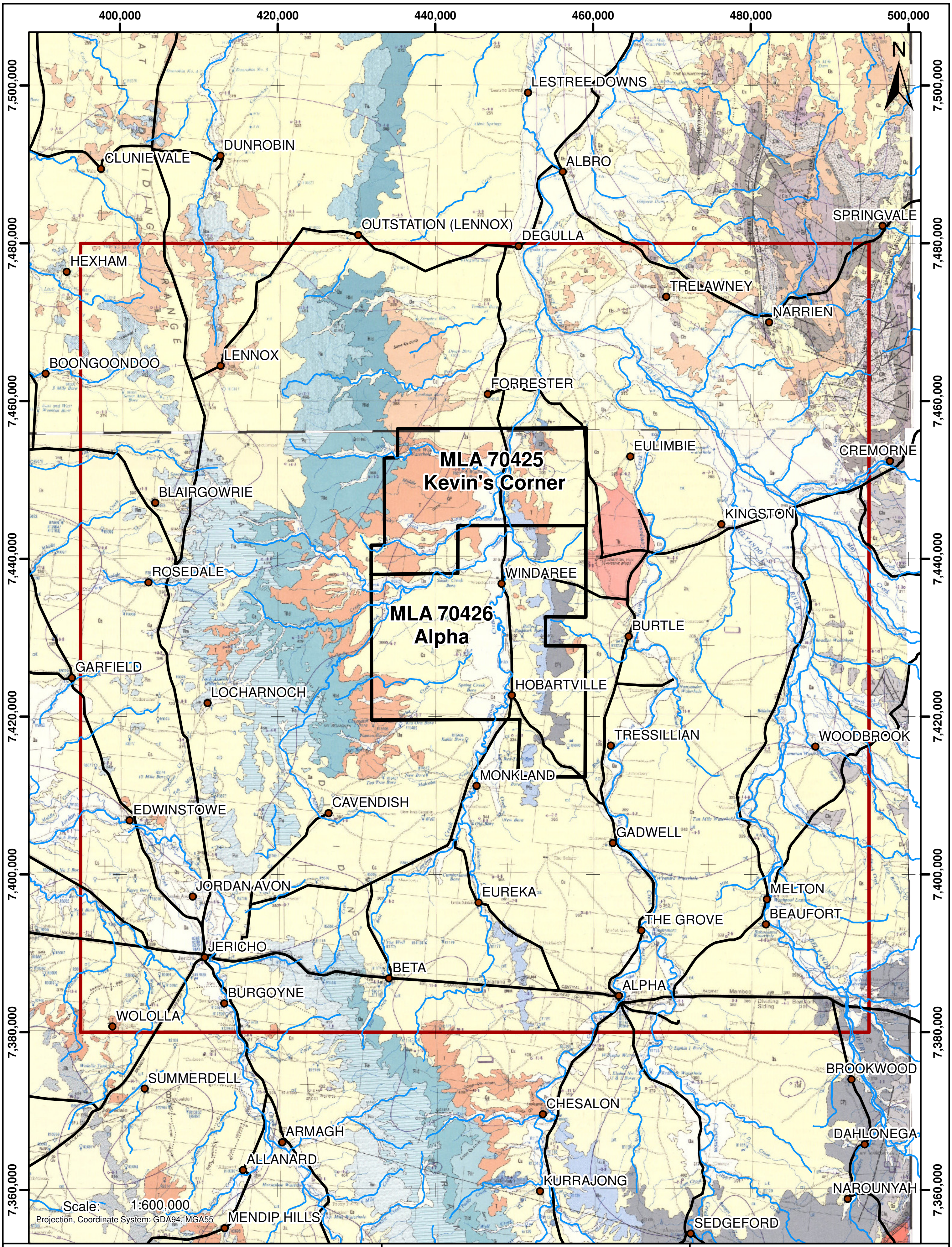
- Andrew Brooker of NTEC, who contributed to early interpretation and utilisation of hydrostratigraphic data.

10 APPENDIX A FIGURES



Legend

Mining Tenement	Watercourse
Model Domain	Major Roads
	Populated Places

Source: Australia 1:250,000 Geological Series - Galilee and Jericho (Geological Survey of Queensland) and Geoscience Australia

NTEC ENVIRONMENTAL TECHNOLOGY

Location Map

Figure 1

File Name: 1015_5W_003.mxd

Author: AM

Date: 25/08/2011

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Alpha Coal Project

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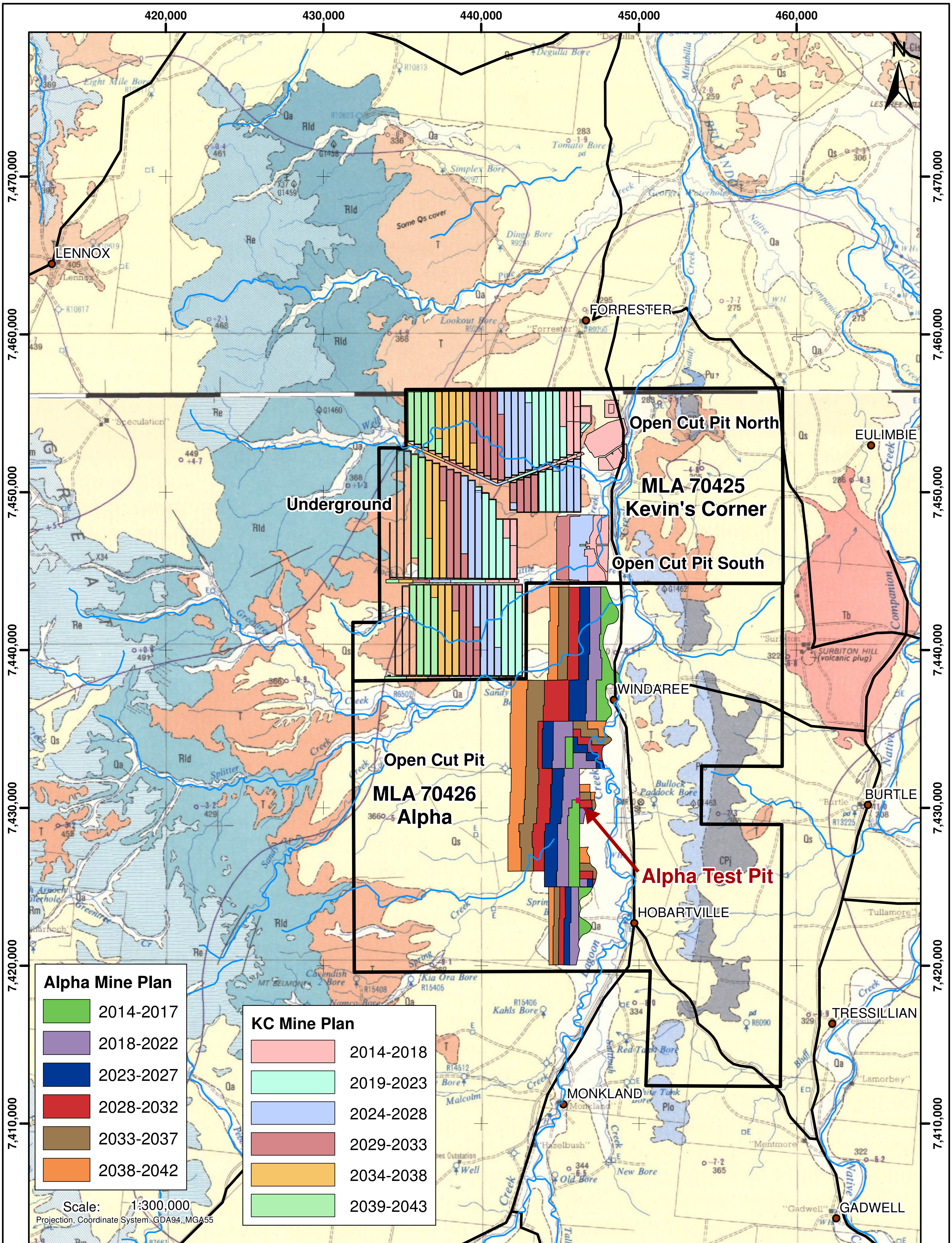

Legend

- Mine Plan Outline
- Mining Tenement
- Model Domain
- Watercourse
- Populated Places

Source: Australia 1:250,000 Geological Series - Galilee and Jericho (Geological Survey of Queensland) and Geoscience Australia

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Mine Plans

Figure 2

File Name: 1015_5W_005.mxd

Author: AM

Date: 29/08/2011

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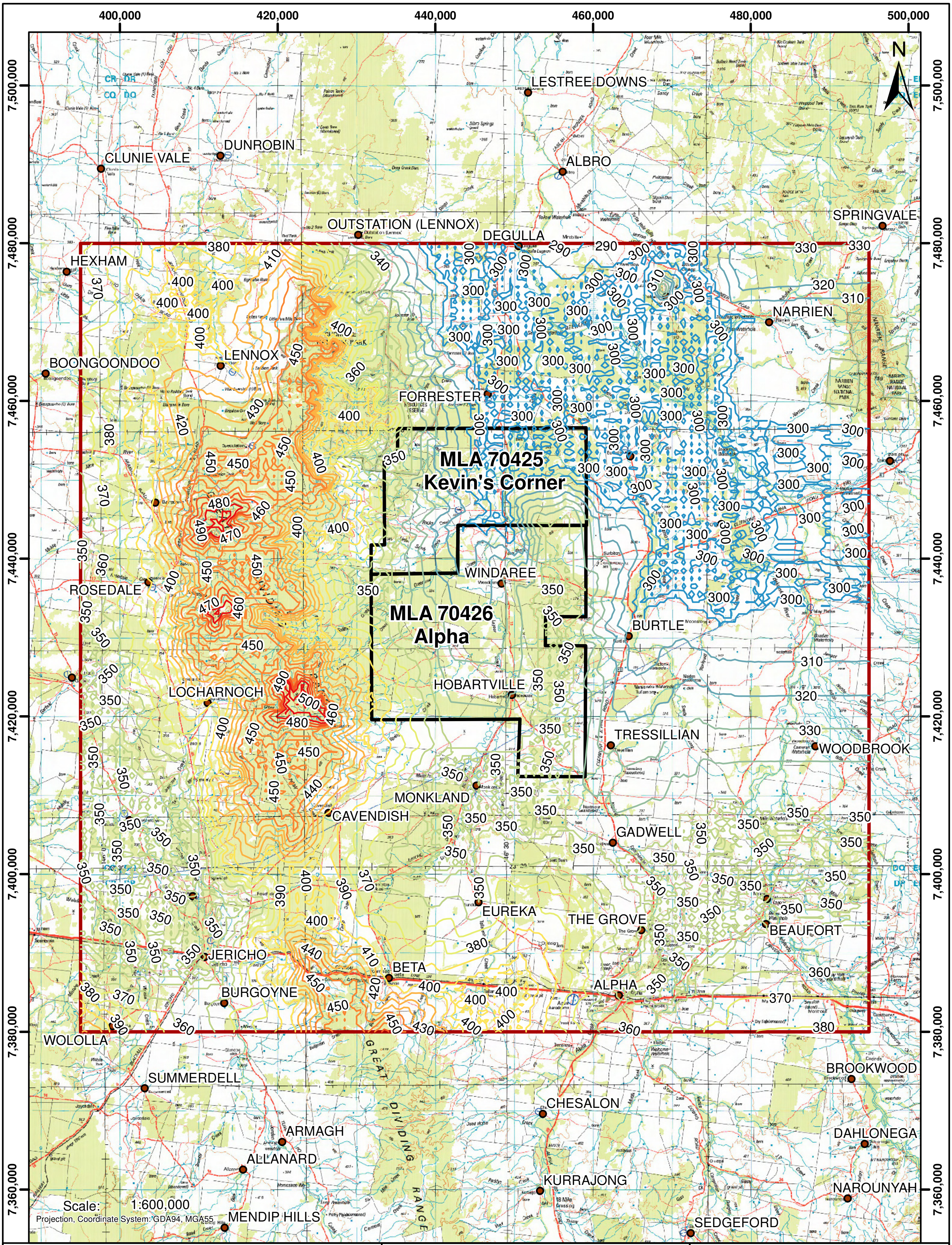

Legend

Topographic 10m Contours (mAHD)

- 290, 300
- 310, 320
- 330, 340
- 350, 360
- 370, 380
- 390, 400
- 410, 430
- 440, 460
- 470, 480
- 490, 500
- Mining Tenement
- Model Domain
- Populated Places

Source: Geoscience Australia

NTEC ENVIRONMENTAL TECHNOLOGY

Topography

Figure 3

File Name: 1015_5W_004.mxd
Author: AM
Date: 25/08/2011

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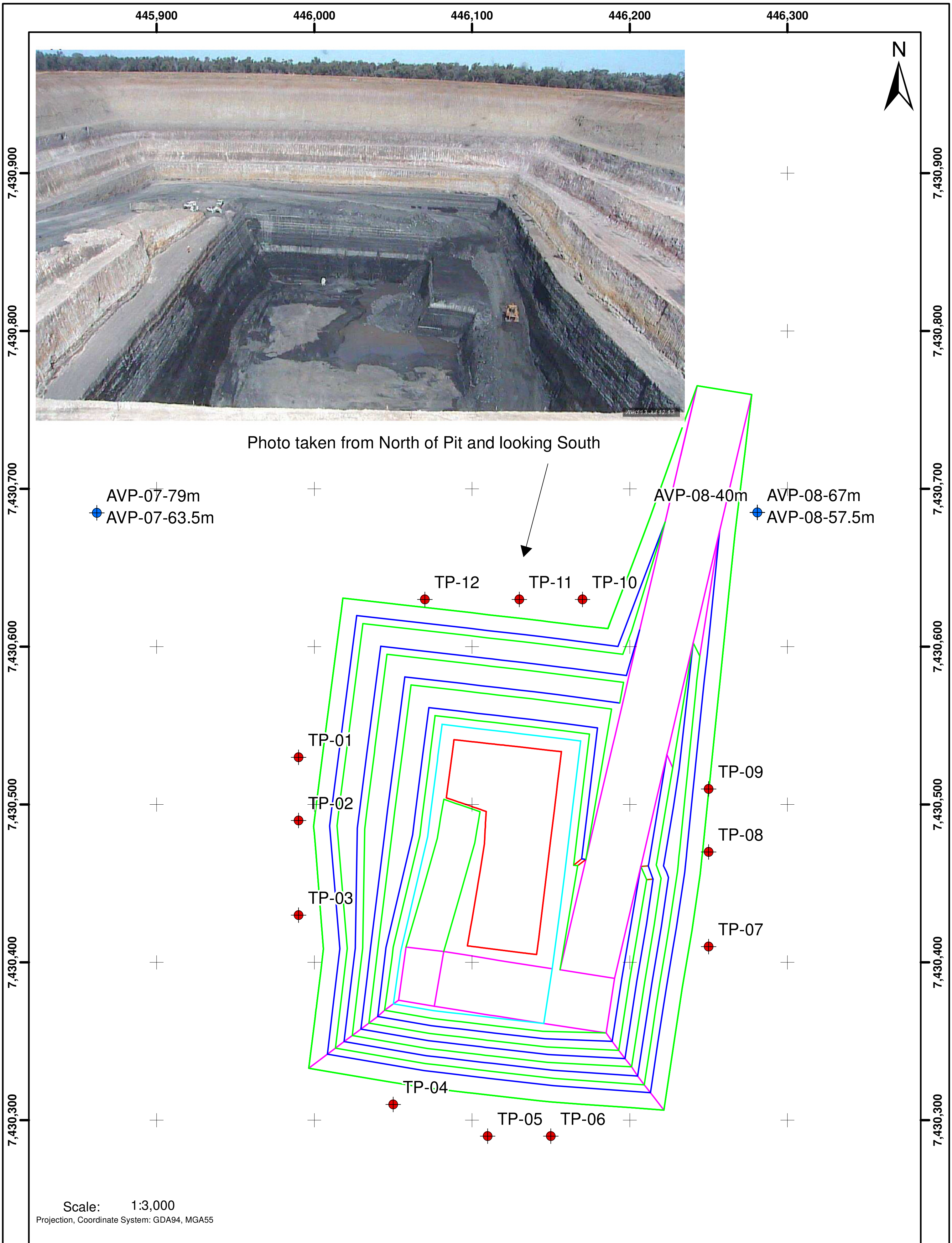

Legend

- Dewatering Bore
- Monitoring Bore

NTEC ENVIRONMENTAL TECHNOLOGY

Alpha Test Pit

Figure 4

File Name: 1015_5W_006.mxd
Author: AM   Date: 30/08/2011

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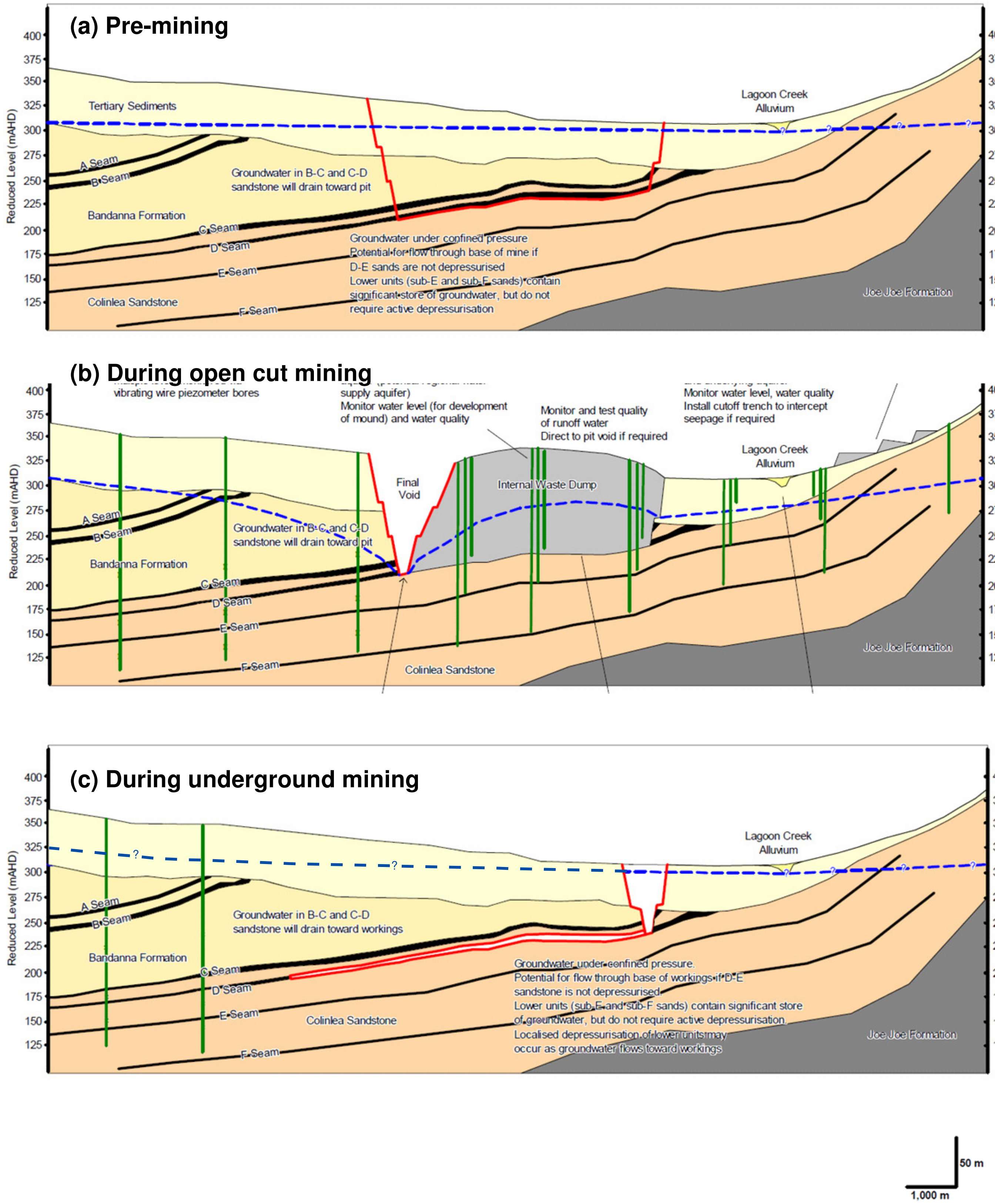

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Conceptual Model

Figure 5

File Name: 1015_5W_018.mxd

Author: AM Date: 01/09/2011

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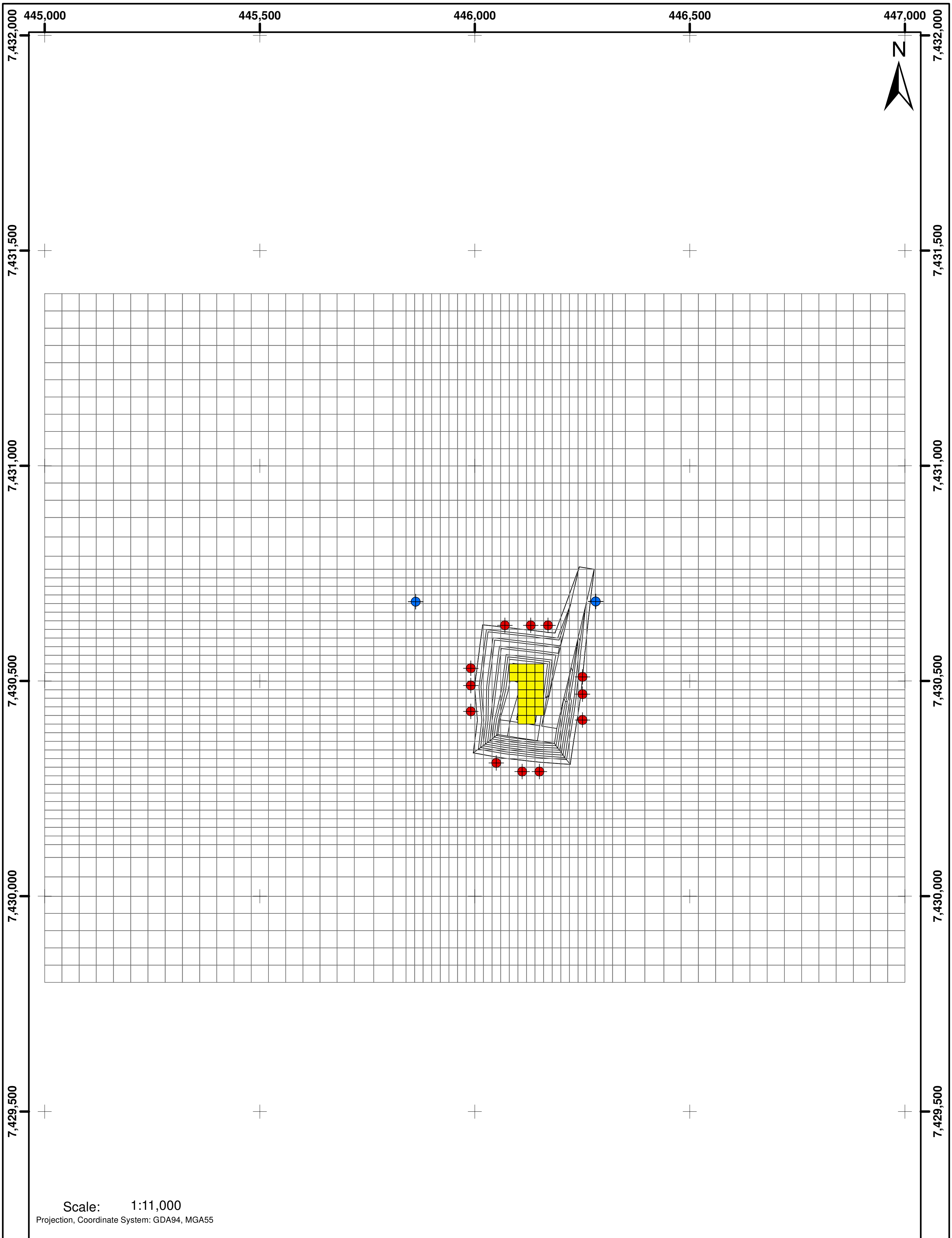

Legend

- Finite Difference Model Grid
- Model Drain Cell
- Dewatering Bore
- Monitoring Bore

NTEC ENVIRONMENTAL TECHNOLOGY

Alpha Test Pit
Finite Difference Model
Figure 6

File Name: 1015_5W_007.mxd
Author: AM Date: 30/08/2011

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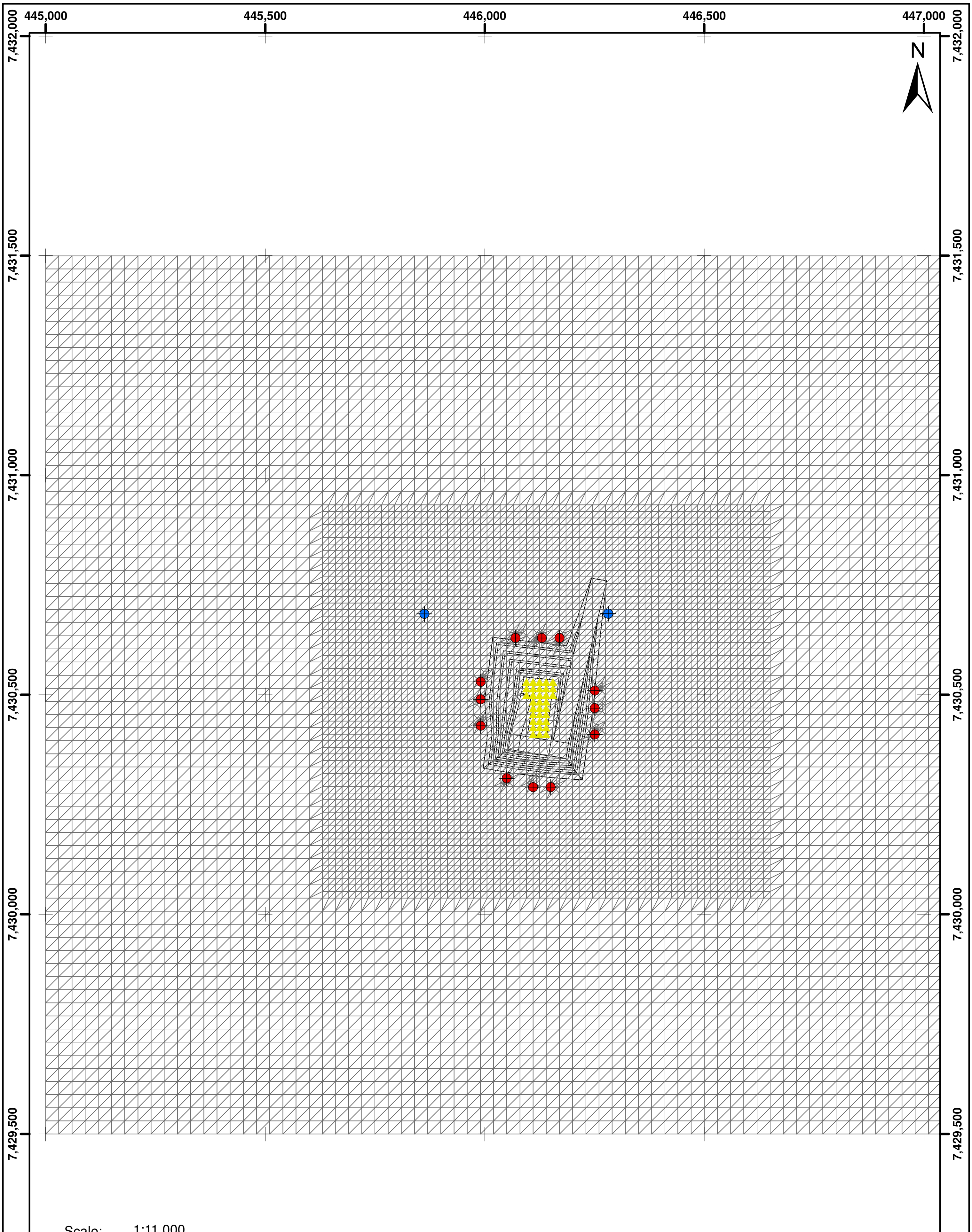

Scale: 1:11,000

Projection, Coordinate System: GDA94, MGA55

Legend

- Pit Trial Model Mesh
- Seepage Face Nodes
- Dewatering Bore
- Monitoring Bore

NTEC ENVIRONMENTAL TECHNOLOGY

Alpha Test Pit
Finite Element Model
Figure 7

File Name: 1015_5W_009.mxd
Author: AM Date: 30/08/2011

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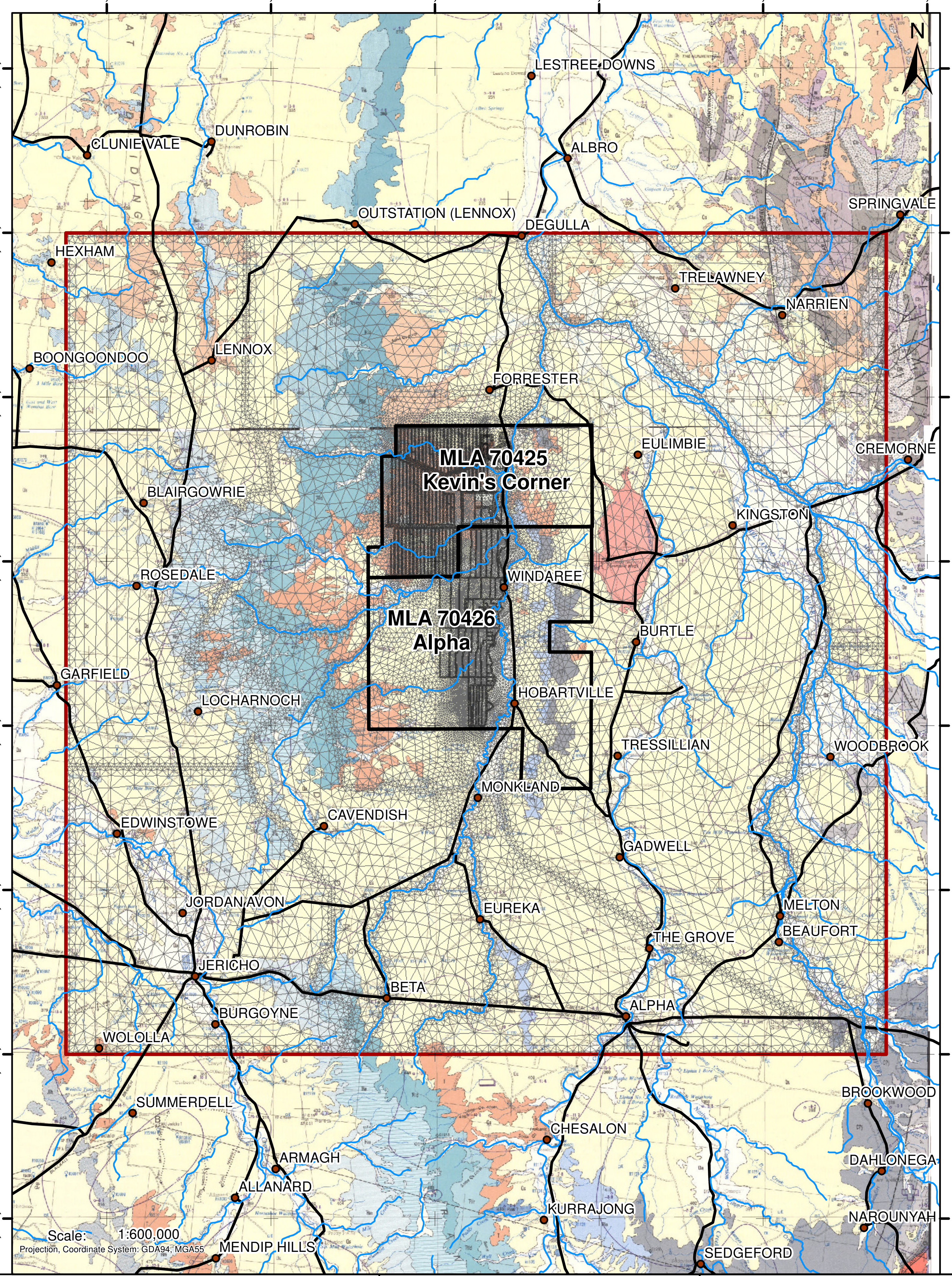

Legend

- Finite Element Mesh
- Watercourse
- Mining Tenement
- Major Roads
- Mine Plan Outline
- Populated Places

Source: Australia 1:250,000 Geological Series - Galilee and Jericho (Geological Survey of Queensland) and Geoscience Australia

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File Name: 1015_5W_010.mxd
Author: AM Date: 30/08/2011

Regional Scale Finite Element Model

Figure 8

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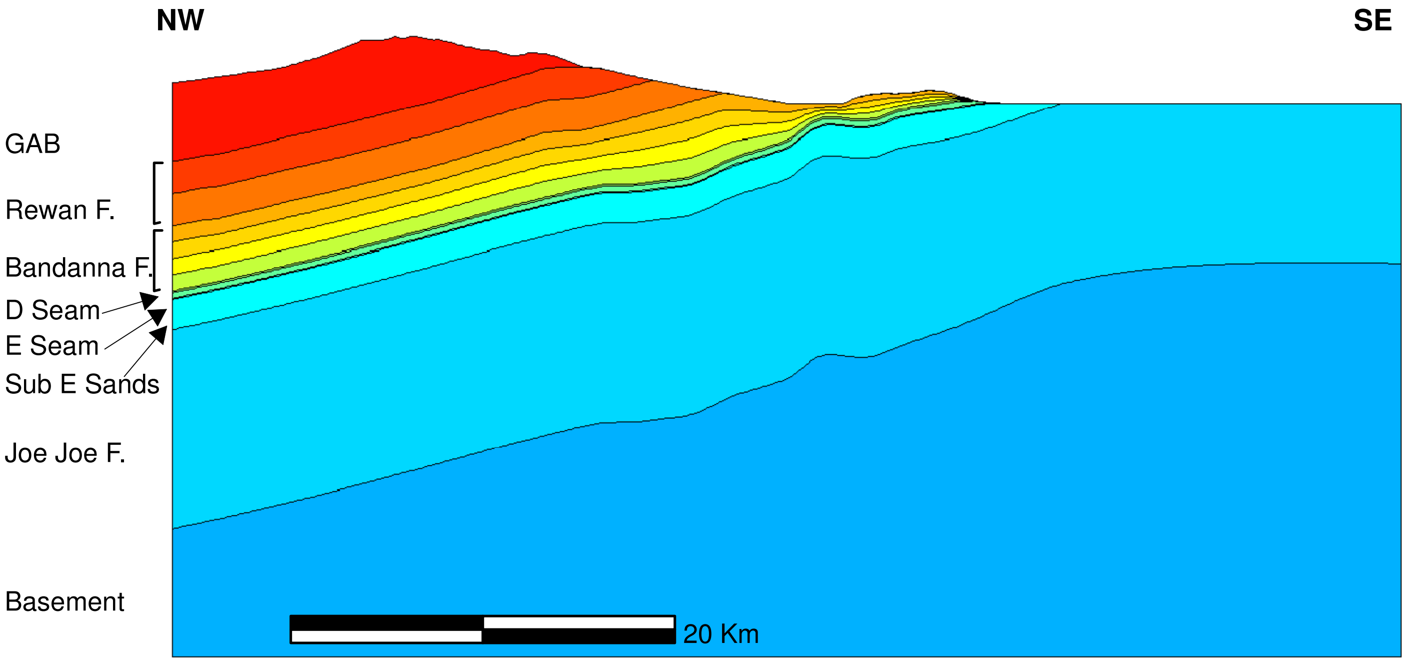

Vertical Exaggeration: 20:1

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Hydrogeological Cross-Section

Figure 9

File Name: 1015_5W_019.mxd

Author: AM Date: 01/09/2011

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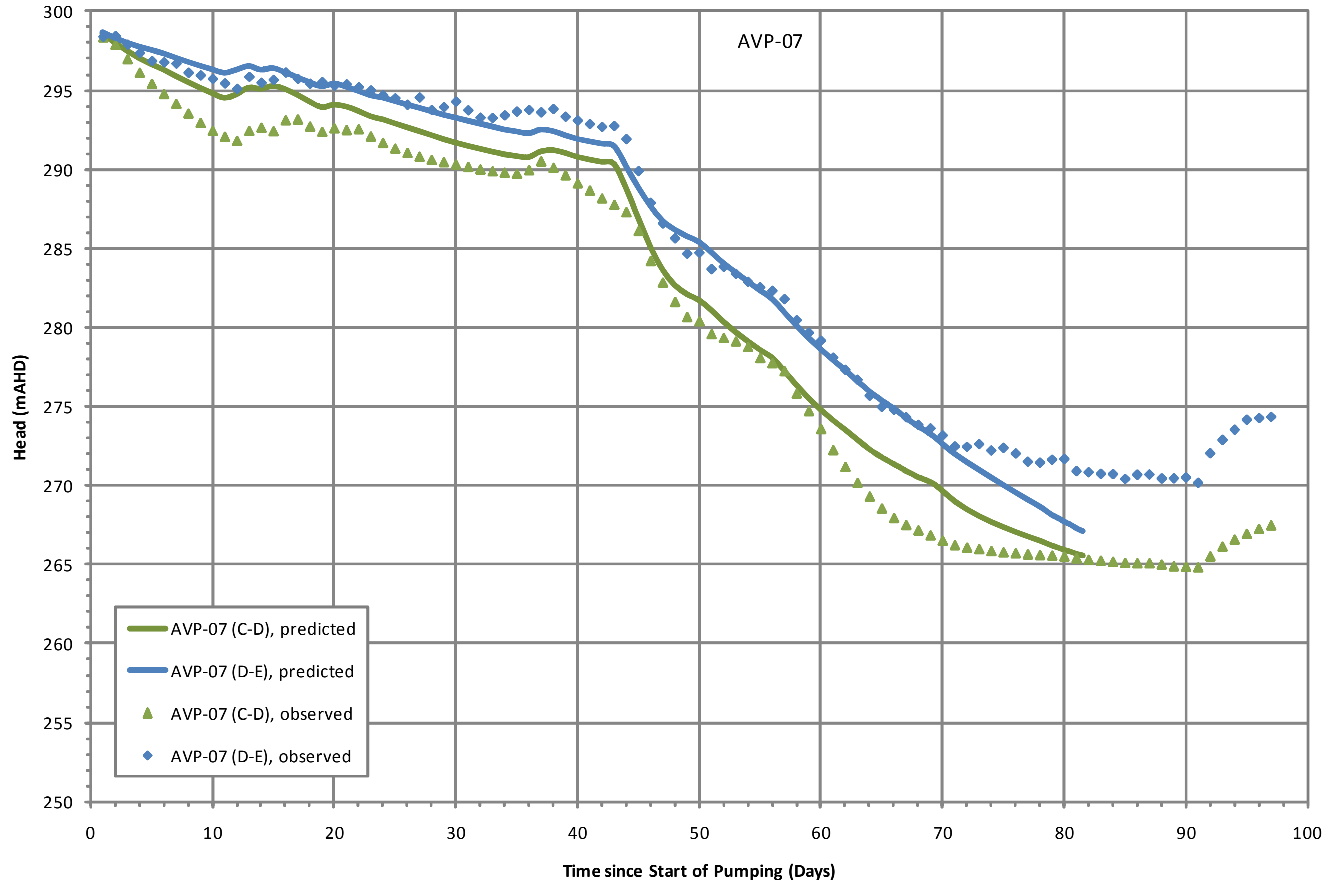

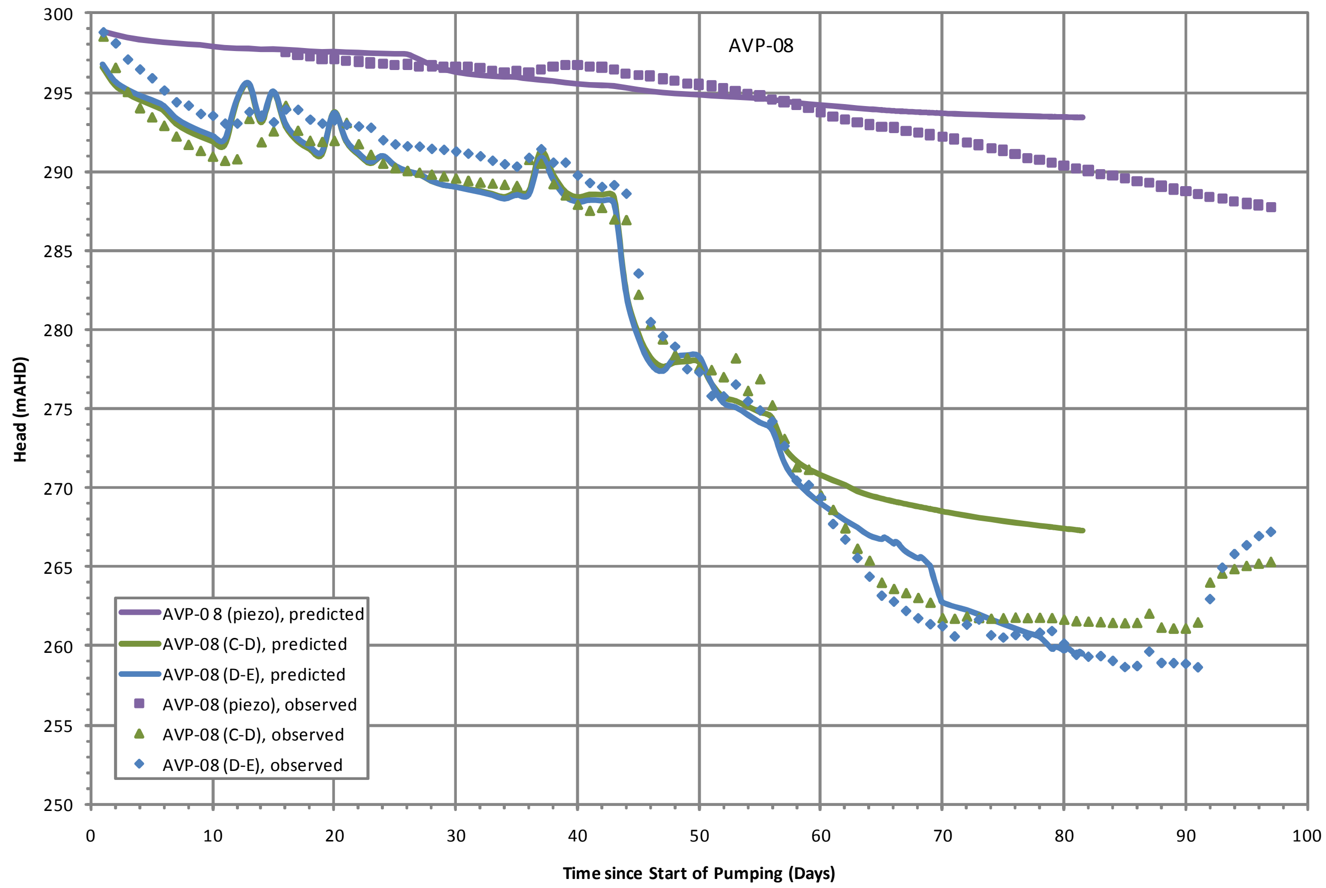

Source: N:\1045\5_Work\Model\
Target1045_3_1_AM_20110826.xlsx

NTEC ENVIRONMENTAL TECHNOLOGY

Calibration Results
Finite Difference Model
Figure 10

File Name: 1015_5W_013.mxd
Author: AM Date: 30/08/2011

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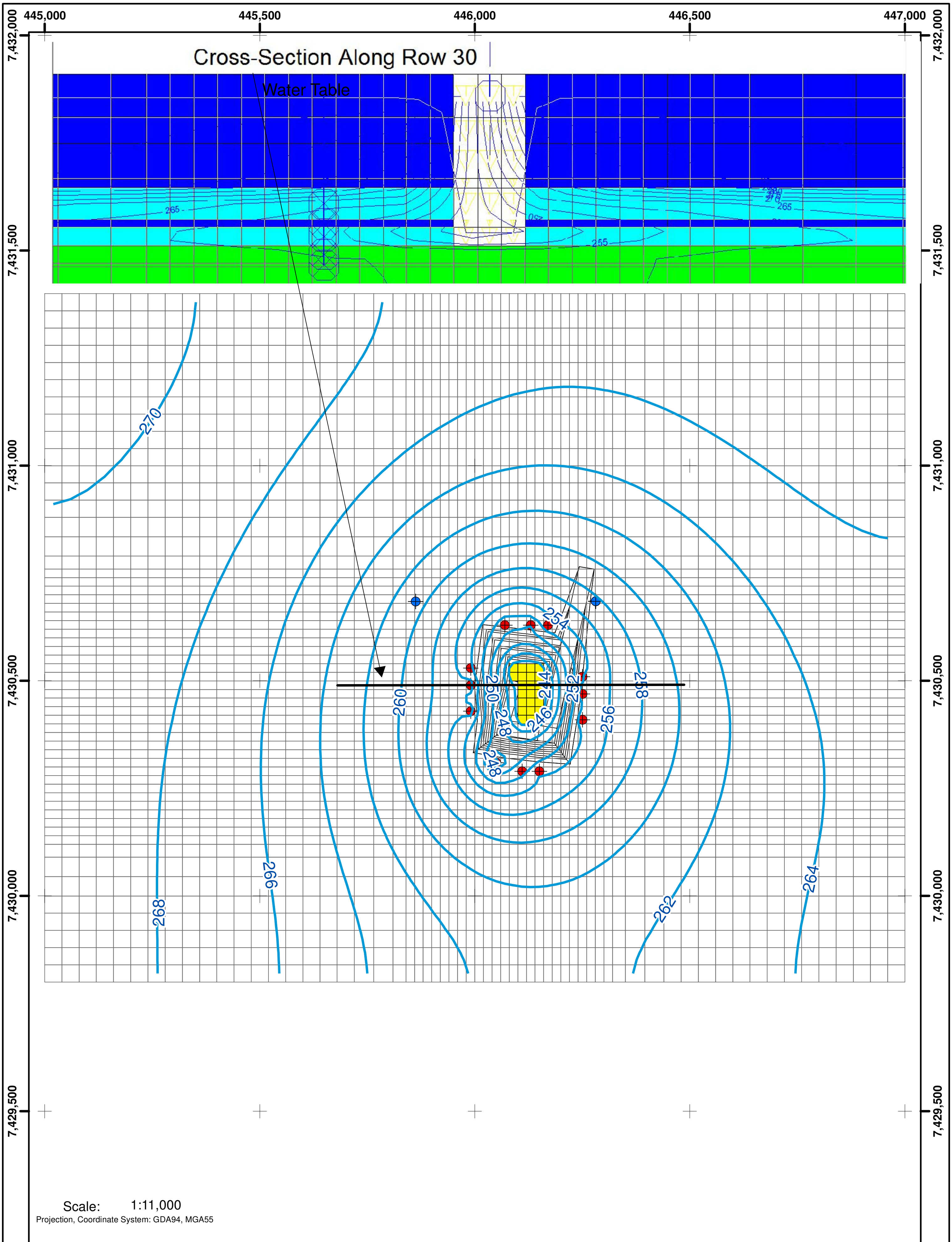

Legend

- Piezometric Head (mAHD) 2 m Interval Contours
- Drain Cell
- Finite Difference Model Grid
- Dewatering Bore
- Monitoring Bore

NTEC ENVIRONMENTAL TECHNOLOGY

Predicted Heads - Seam D

Figure 11

File Name: 1015_5W_008.mxd
Author: AM   Date: 26/08/2011

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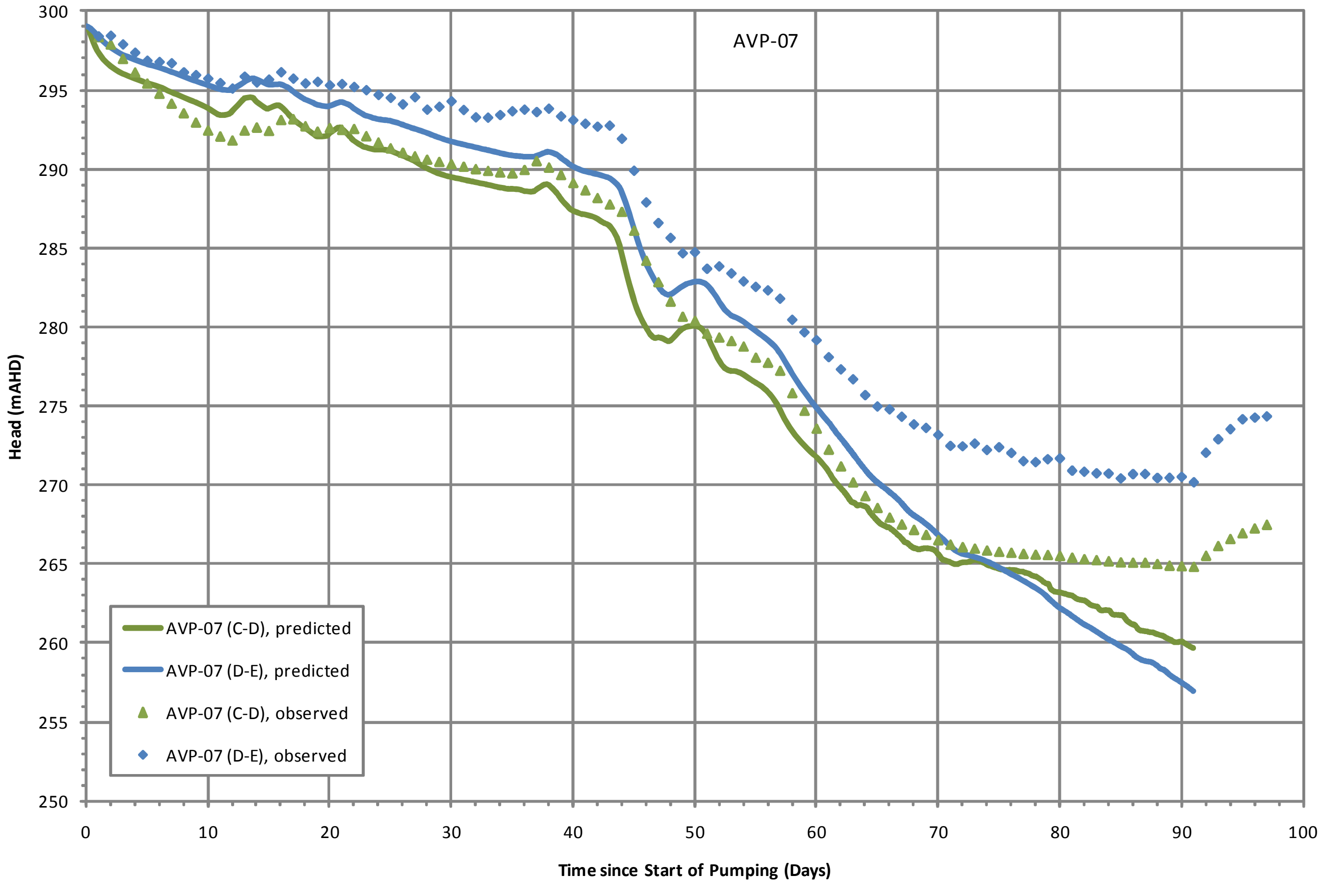

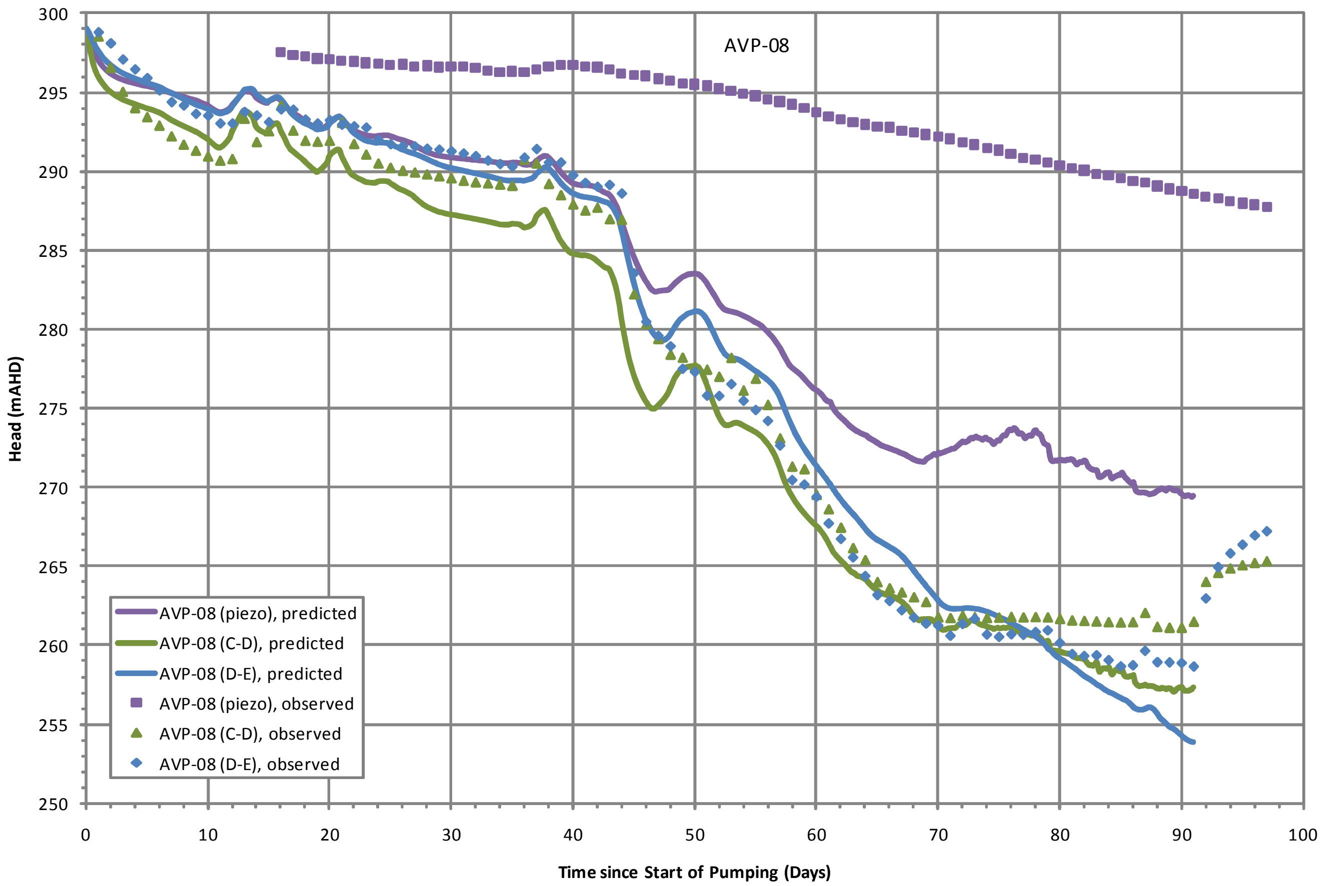

Source: N:\1045\5_Work\Model\Model_FEFLOWTimesteps_withMine_Calibrated1708.xlsx

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Calibration Results
Finite Element Model
Figure 12

File Name: 1015_5W_012.mxd
Author: AM Date: 30/08/2011

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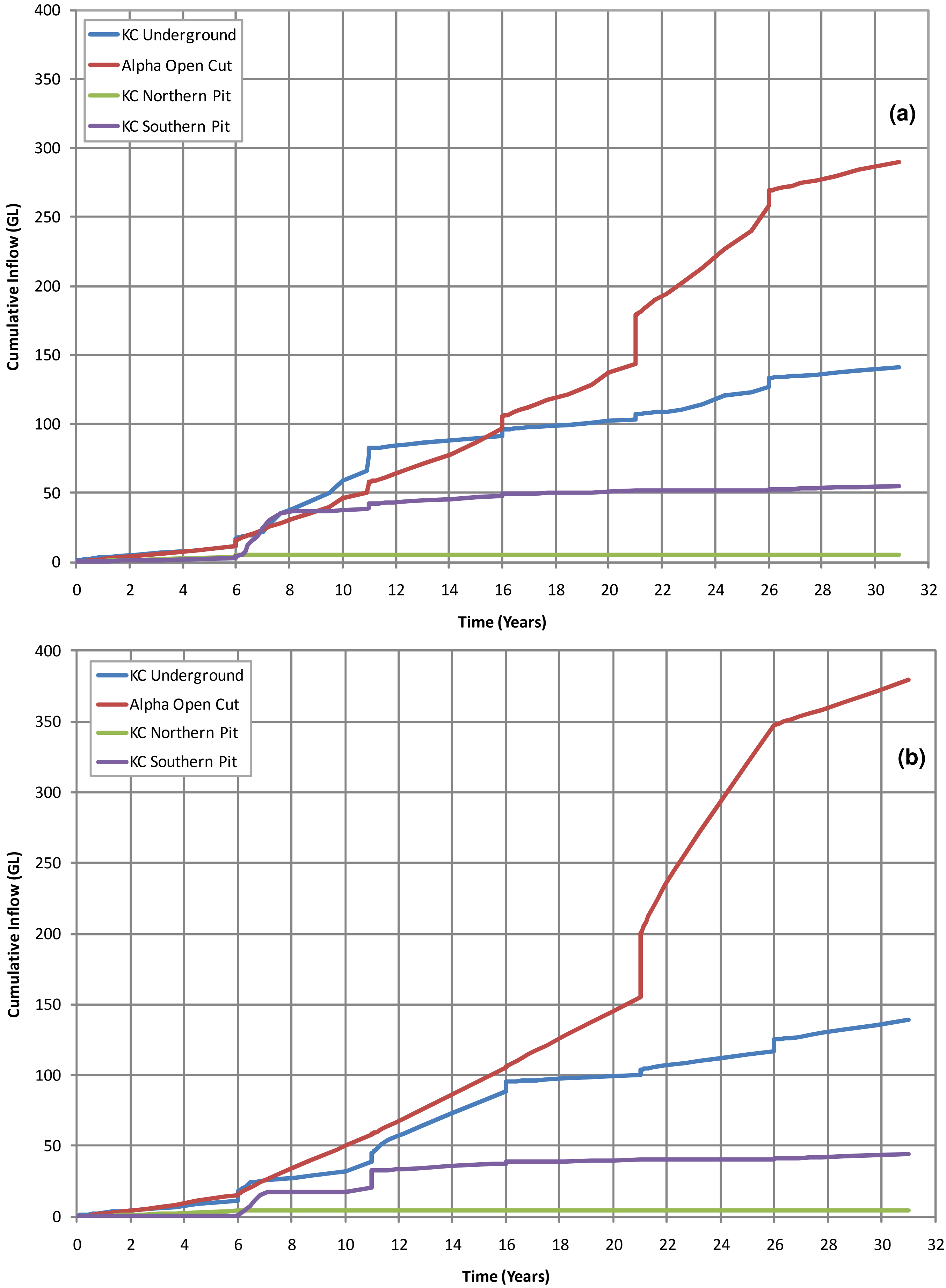

Source: N:\1045\5_Work\Model\
All_stages_Scenario_9.xlsx
and All_stages_Scenario_10.xlsx

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Cumulative Inflow

Figure 13

File Name: 1015_5W_014.mxd
Author: AM Date: 30/08/2011

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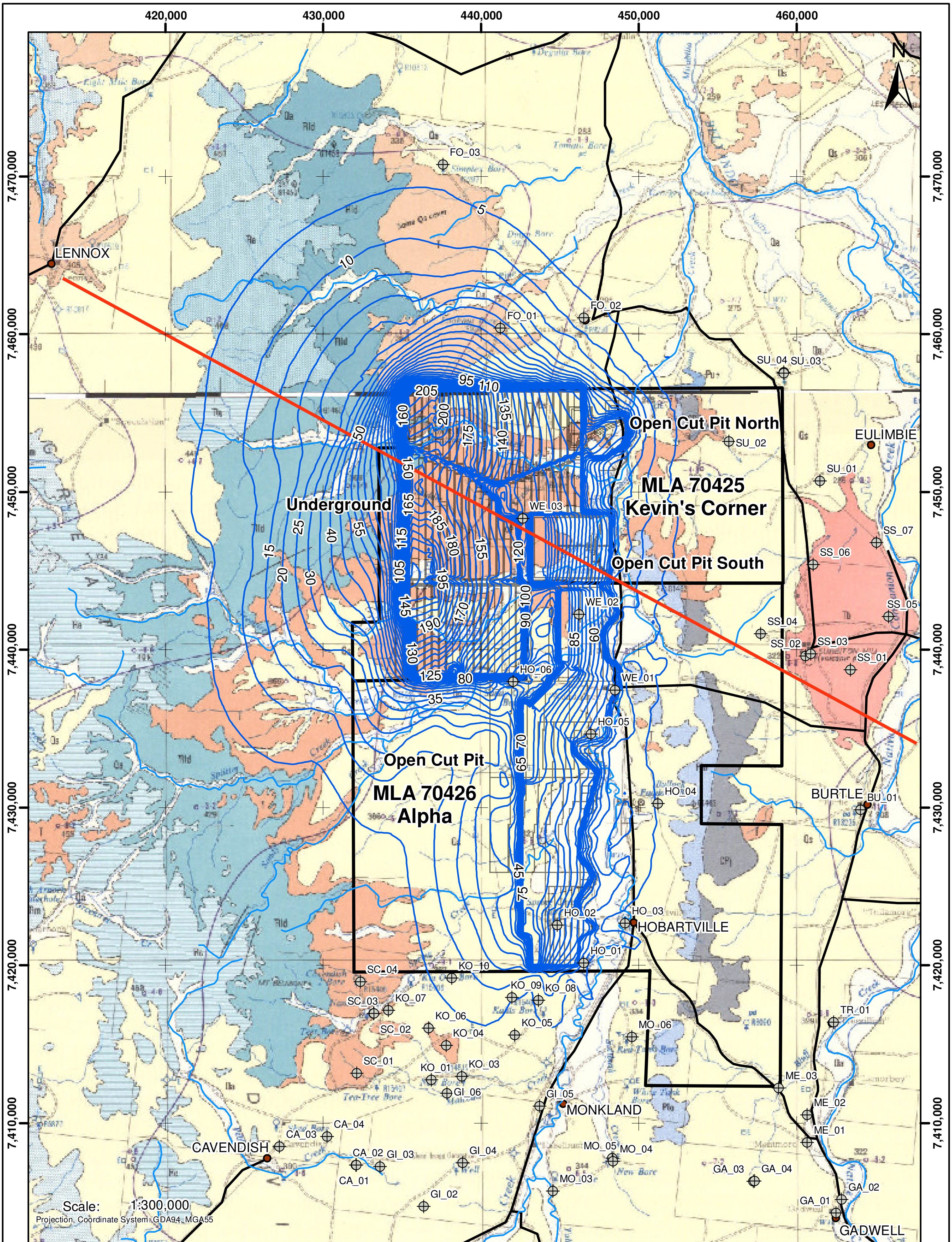

Legend

- Drawdown (Slice 8) 5m Interval Contours
- Mine Plan Outline
- Mining Tenement
- Cross Section
- Watercourse
- Populated Places
- Water Bore

Source: Australia 1:250,000 Geological Series - Galilee and Jericho (Geological Survey of Queensland) and Geoscience Australia

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Predicted Depressurisation Slice 8 after 31 Years

Figure 14

File Name: 1015_5W_011.mxd

Author: AM Date: 12/09/2011

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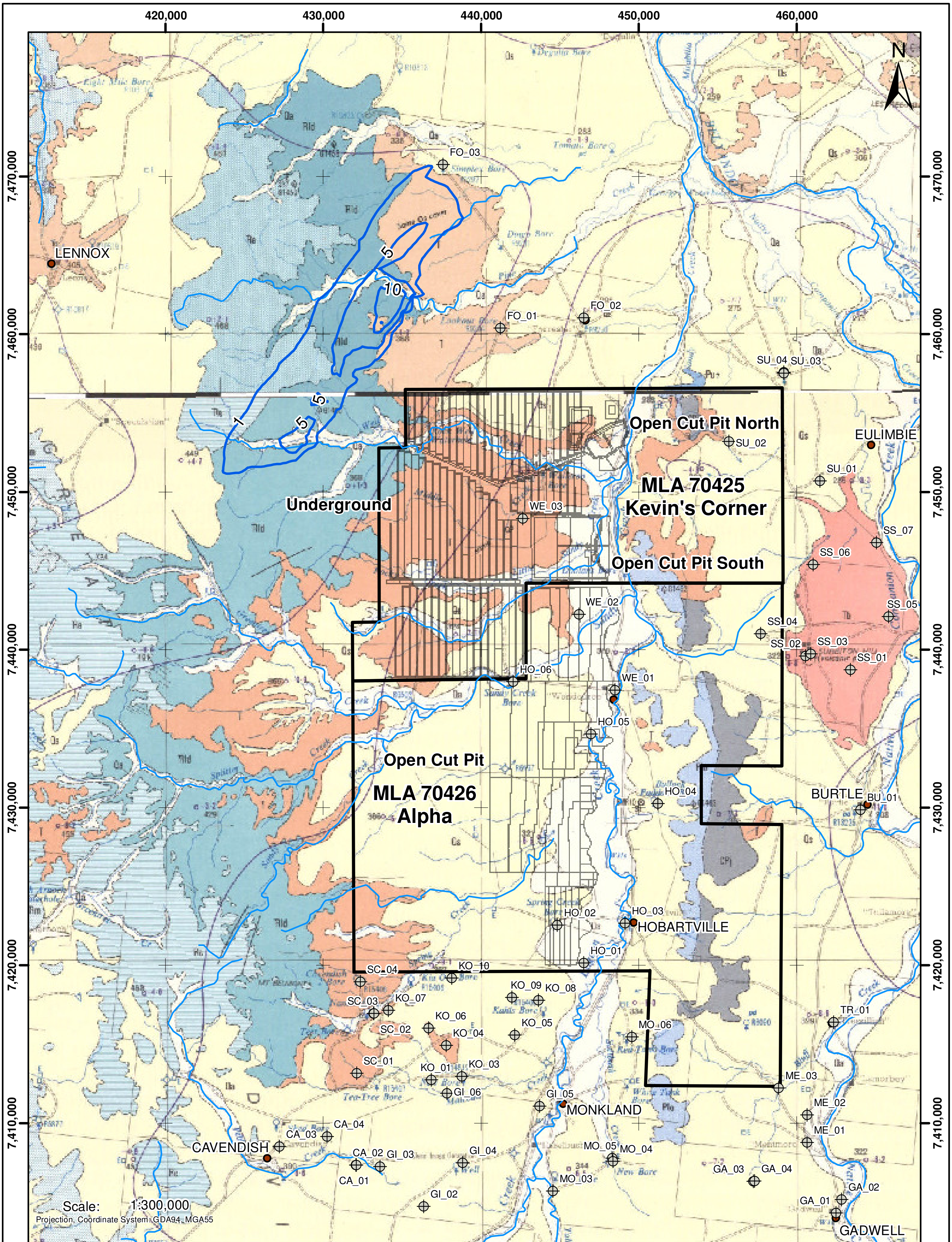

Legend

- Drawdown (Slice 2) Contours
- Mine Plan Outline
- Mining Tenement
- Watercourse
- Populated Places
- Water Bore

Source: Australia 1:250,000 Geological Series - Galilee and Jericho (Geological Survey of Queensland) and Geoscience Australia

NTEC ENVIRONMENTAL TECHNOLOGY

Predicted Drawdown
Slice 2 after 31 Years
Figure 15

File Name: 1015_5W_015.mxd
Author: AM
Date: 12/09/2011

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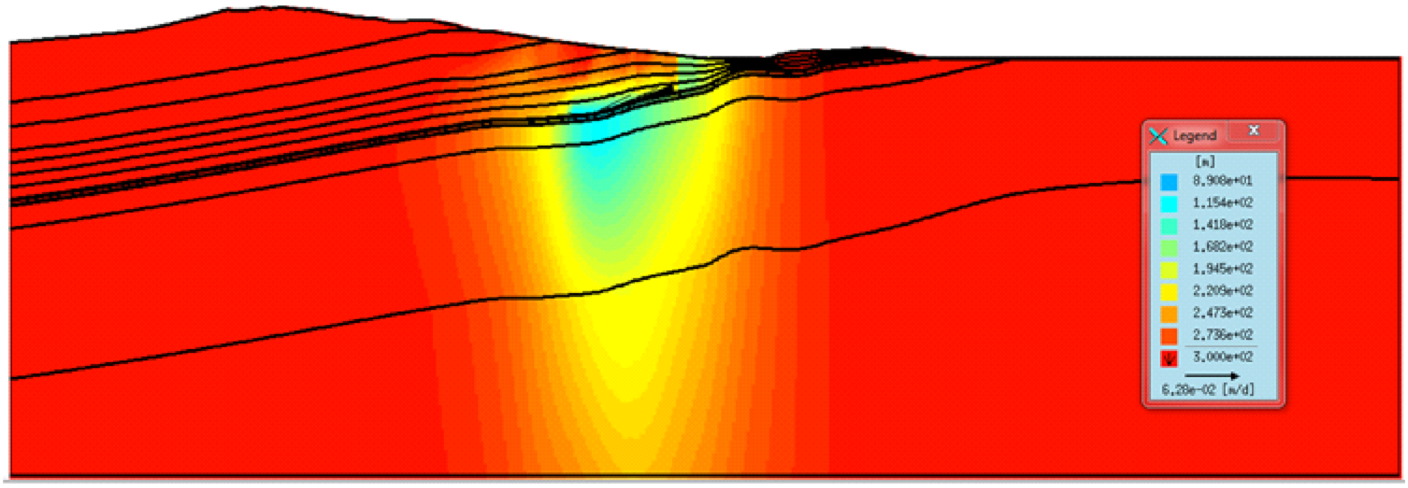
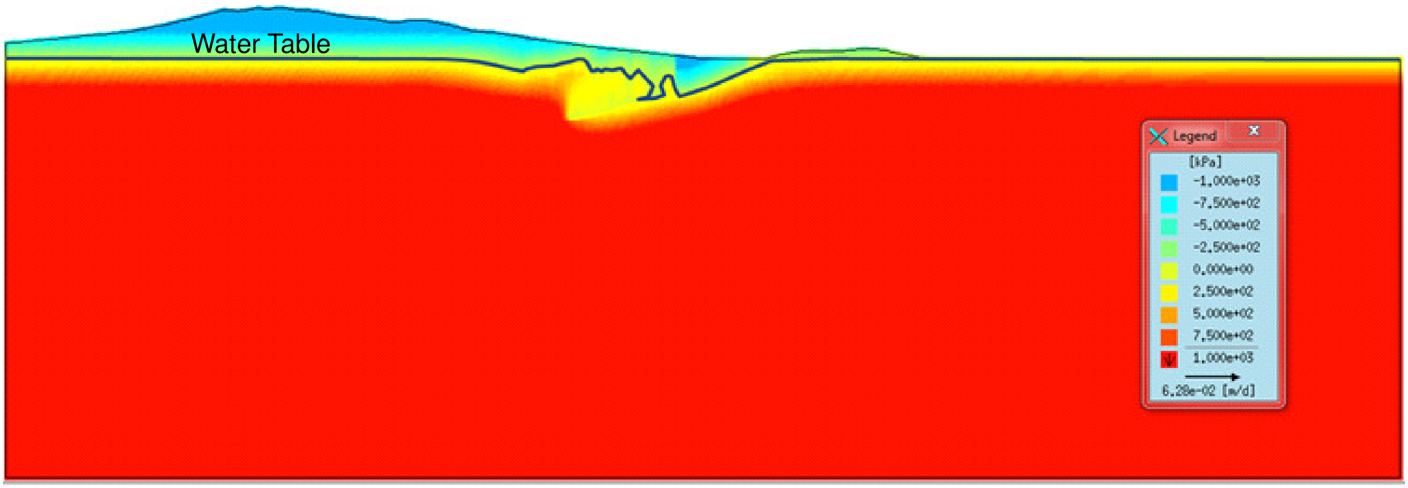
Piezometric Heads



Pressures



NTEC ENVIRONMENTAL TECHNOLOGY	Cross Section through Kevin's Corner Figure 16	
File Name: 1015_5W_020.mxd Author: AM Date: 01/09/2011	URS Alpha Coal Project	A4

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ABOUT THIS REPORT

NTEC Environmental Technology provides consulting services to the mining and water industries, including assessment of the potential environmental impacts of proposed projects, often using numerical simulation models to provide quantitative predictions of hydrological and other processes.

NTEC Environmental Technology employs highly qualified staff with expertise in impact assessment and simulation methodologies. As members of professional organisations including IEAust, AusIMM, IAH, IAHR, NGWA and AGU, we strive to apply our skills diligently, and to maintain our level of skill through continuing professional development.

Much of our work lies at the interface between the natural and the built environment. While the built environment is designed by engineers, using materials whose properties can be controlled during manufacture, the natural environment is fundamentally different. The geometry and properties of the natural environment can never be fully characterised. Processes that have occurred in the past and may occur in the future can only be inferred from a limited number of uncertain measurements. The history of previous activities at a project site is often poorly documented, adding a further layer of complexity.

Our work combines analysis and prediction: analysis of systems based on available information, and prediction of the response of those systems to man-made changes. We are skilled in selection and application of methods for sensitivity and uncertainty analysis. Uncertainty is inherent in the problems we work on, hence estimating and managing that uncertainty is always part of our work.

This report has been prepared for you, our client:

- to meet specific requirements discussed with you before and during preparation of the report, and
- using information provided by you and otherwise available in the public domain.

Before you rely on analyses and predictions contained in this report, we encourage you to understand the uncertainties identified within the report and the methodologies we have used to address them. If you remain uncertain about the results, it is your responsibility to ask us to clarify. If you or any other party misinterpret the results, NTEC Environmental Technology cannot be held responsible for such misinterpretation.

This report should not be used for any purpose other than that for which it was intended.