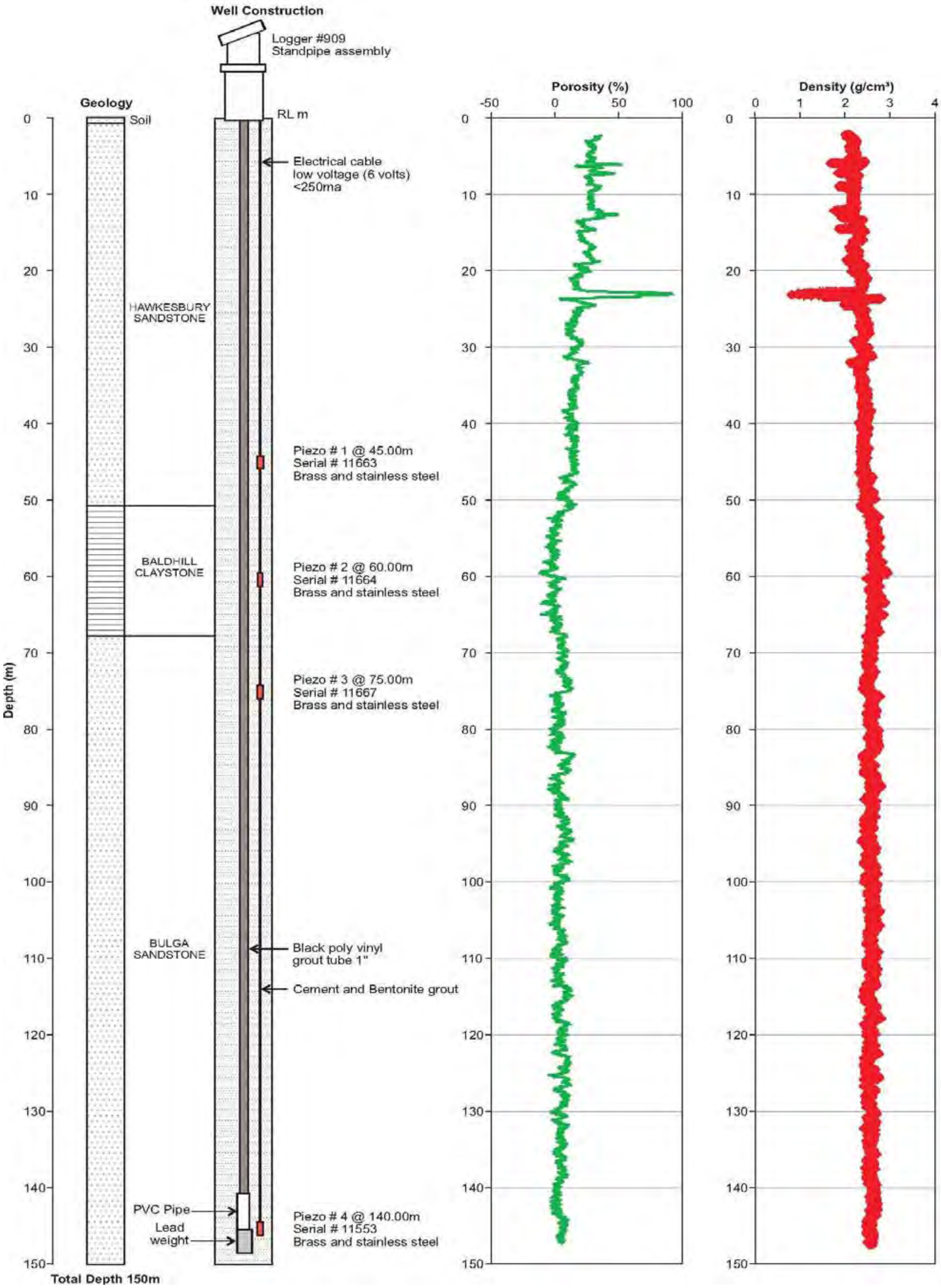
APPENDIX B

PIEZOMETER CONSTRUCTION DETAILS



VW PIEZOMETER INSTALLATION – NRE-1A

Bore / Piezo: NRE A

Page 1 of 1

Project: Wongawilli

Location: NRE 1

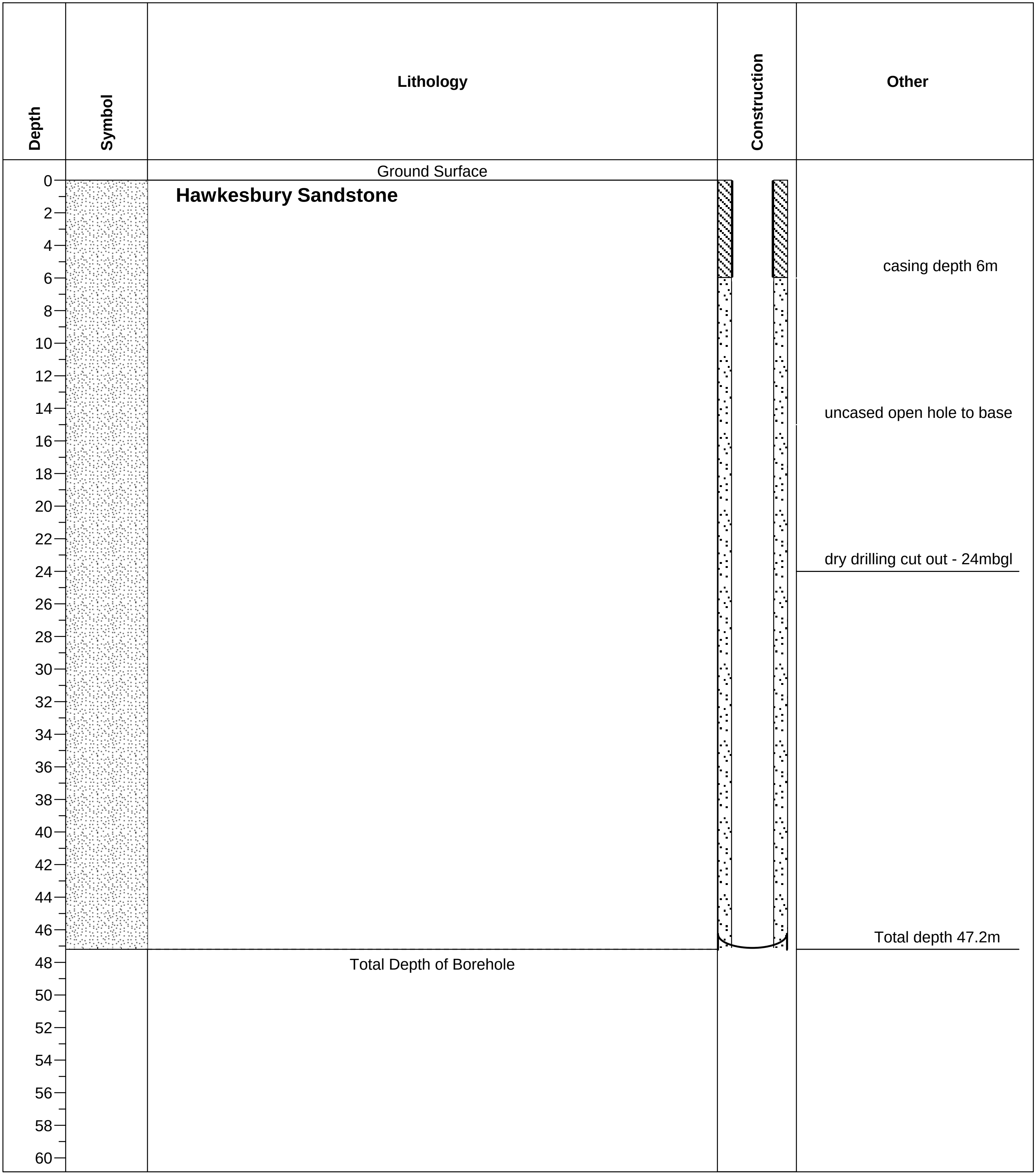
Coordinates: E 303692 N 6196033

Project Number: GUJ1

Datum:

Elevation: 376.18m

Logged By: H Chandra



Ground Surface

Hawkesbury Sandstone

casing depth 6m

uncased open hole to base

dry drilling cut out - 24mbgl

Total depth 47.2m

Total Depth of Borehole

Driller: Rob Budd

Drilling Method: open hole hammer

Drilling Equipment: open hole hammer

Drilling Start: 21/11/09

Drilling Finish: 21/11/09

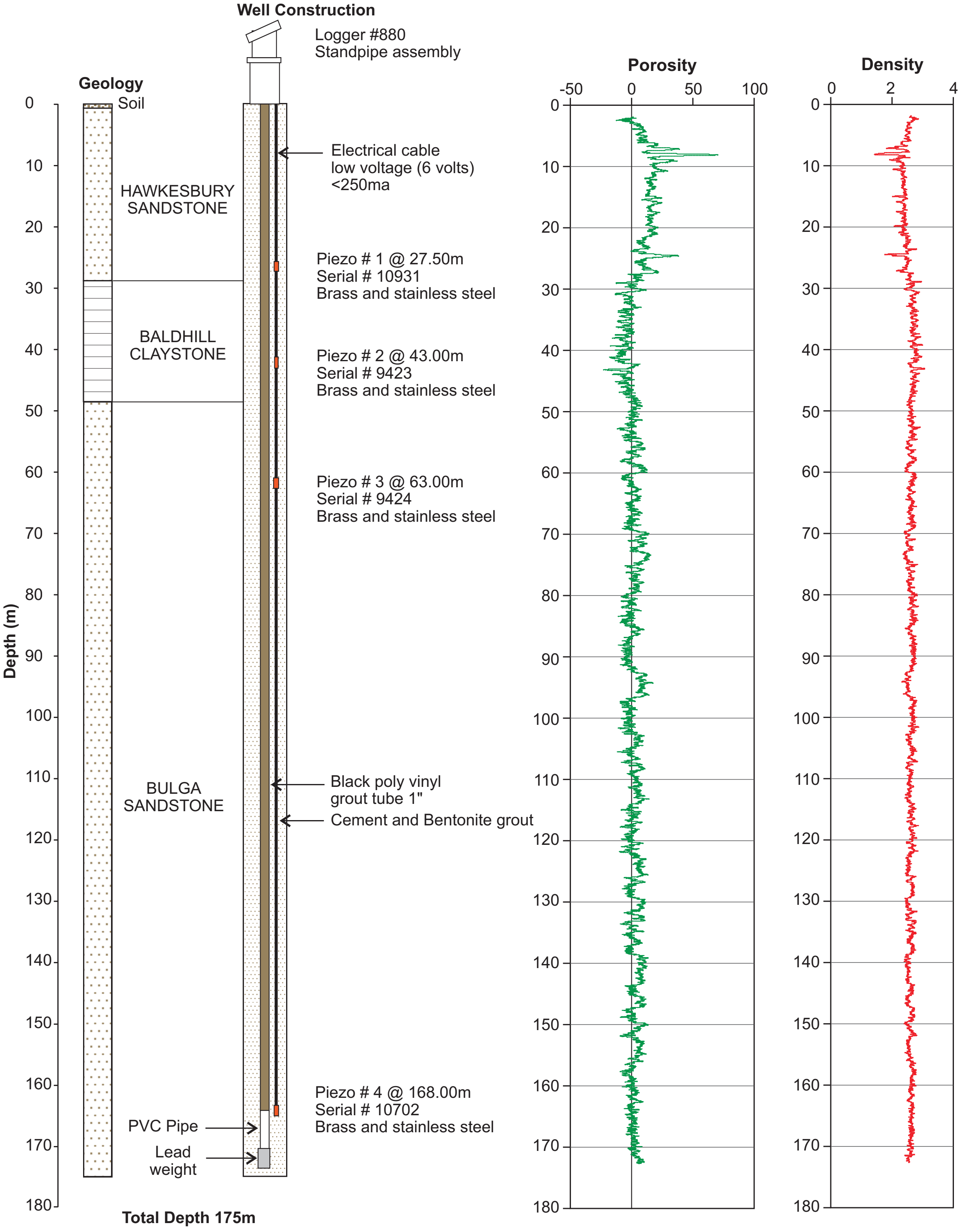


Figure 3: VW Piezo Installation - NRE NE-1B

GeoTerra

Bore / Piezo: NRE C

Page 1 of 1

Project: Wongawilli

Location: NRE 1

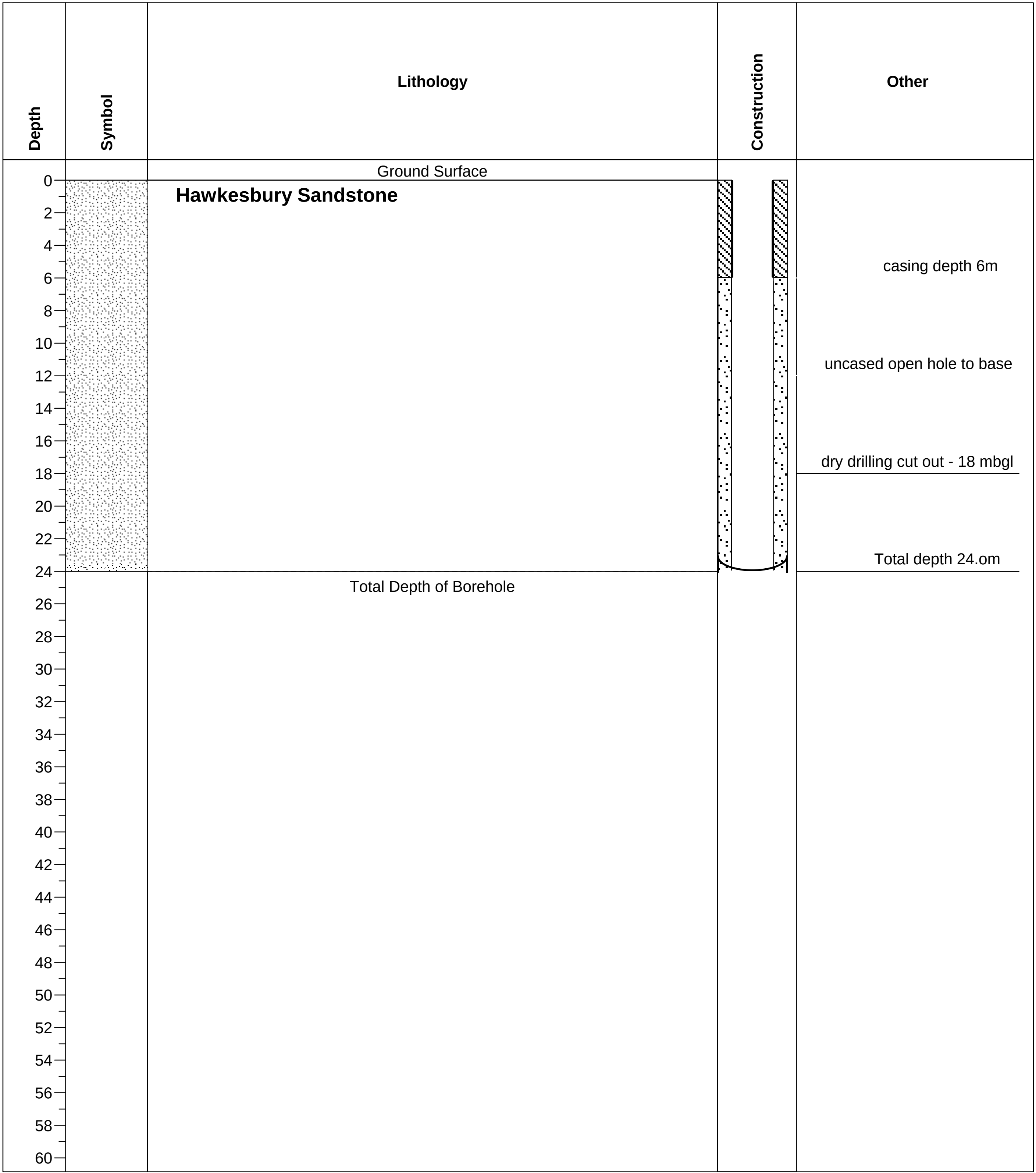
Coordinates: E 303233 N 6198797

Project Number: GUJ1

Datum:

Elevation: 362.72

Logged By: H Chandra



Ground Surface

Hawkesbury Sandstone

Total Depth of Borehole

casing depth 6m

uncased open hole to base

dry drilling cut out - 18 mbgl

Total depth 24.om

Driller: Rob Budd

Drilling Method: open hole hammer

Drilling Equipment: open hole hammer

Drilling Start: 3/12/09

Drilling Finish: 3/12/09

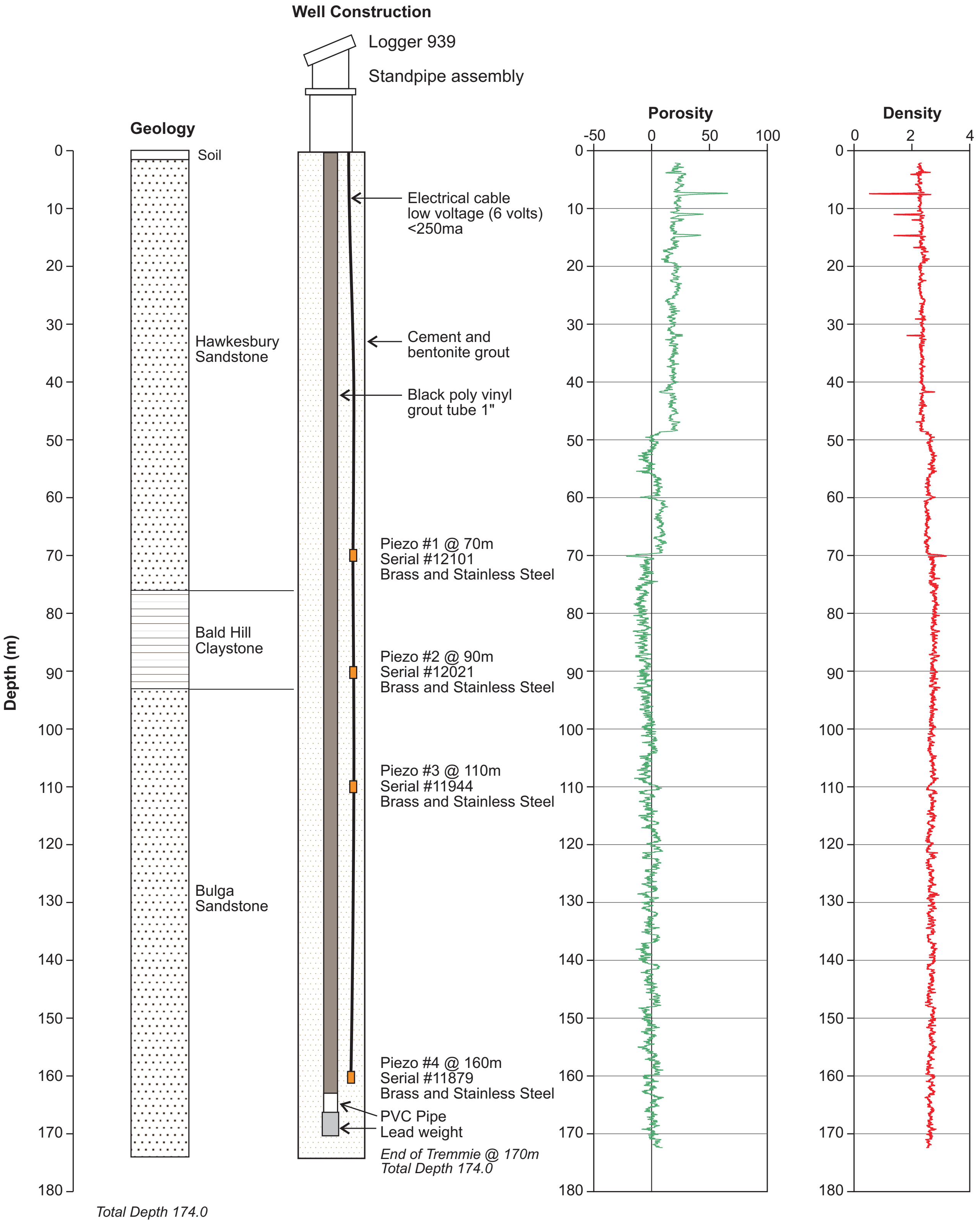


Figure 3: VW Piezo installation - NRE 1D.

Bore / Piezo: NRE D

Page 1 of 1

Project: Wongawilli

Location: NRE 1

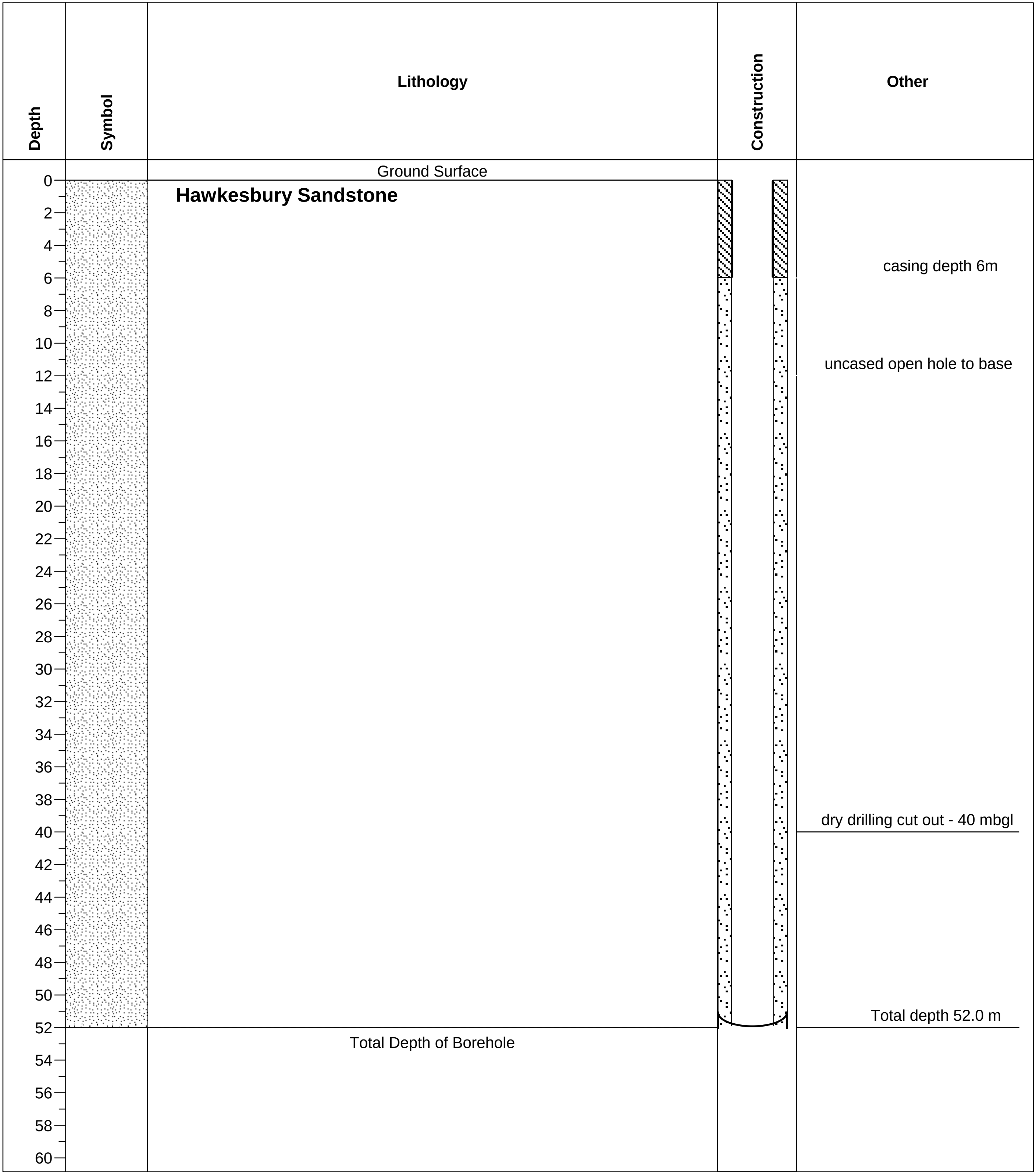
Coordinates: E 301870 N 6198509

Project Number: GUJ1

Datum:

Elevation: 348.83

Logged By: H Chandra



Driller: Rob Budd

Drilling Method: open hole hammer

Drilling Equipment: open hole hammer

Drilling Start: 6/11/09

Drilling Finish: 6/11/09

Bore / Piezo: NRE E **Page 1 of 1**

Project: Wongawilli

Location: NRE 1

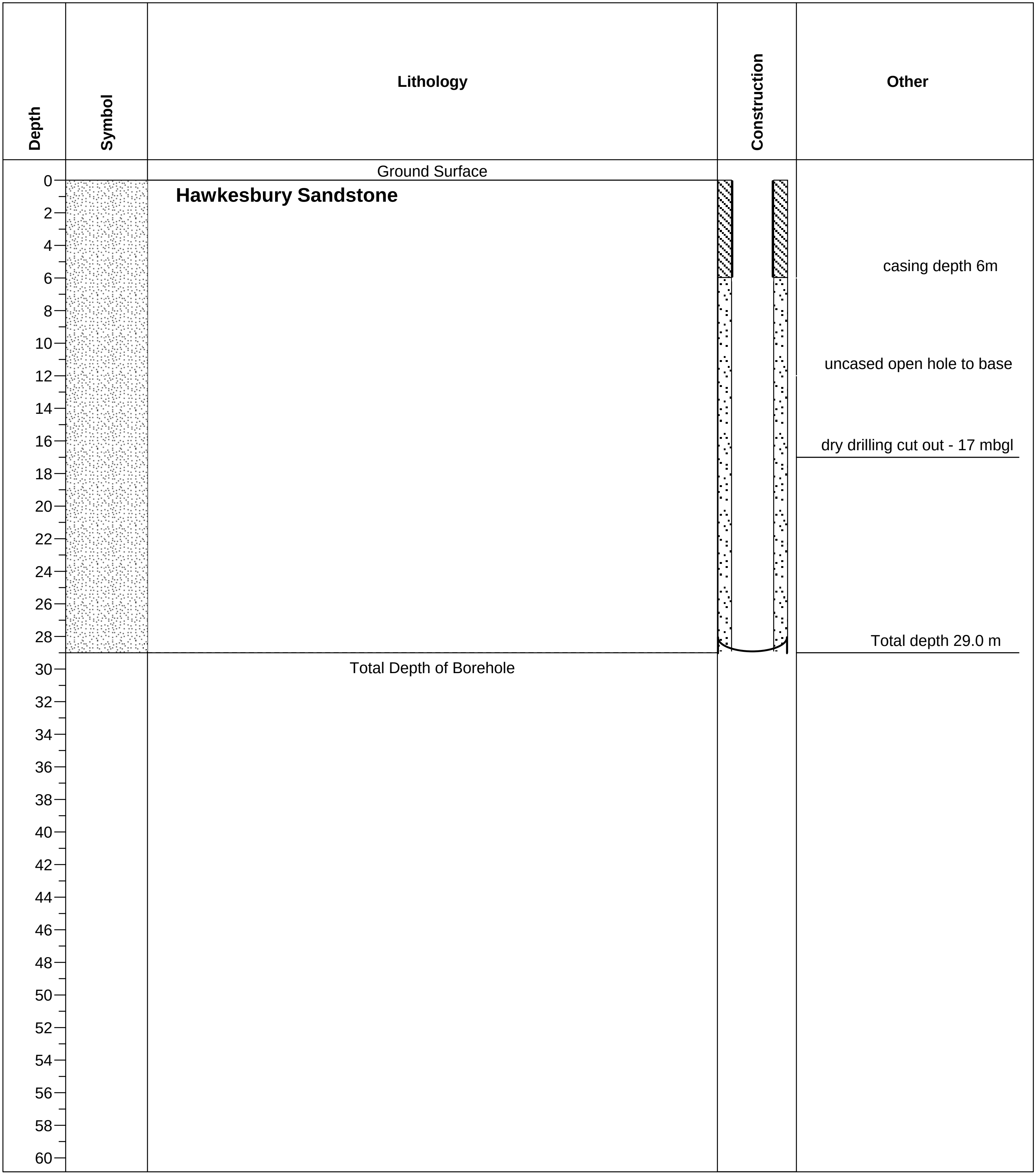
Coordinates: E 296727 N 6202286

Project Number: GUJ1

Datum:

Elevation: 329.24

Logged By: H Chandra



Driller: Rob Budd

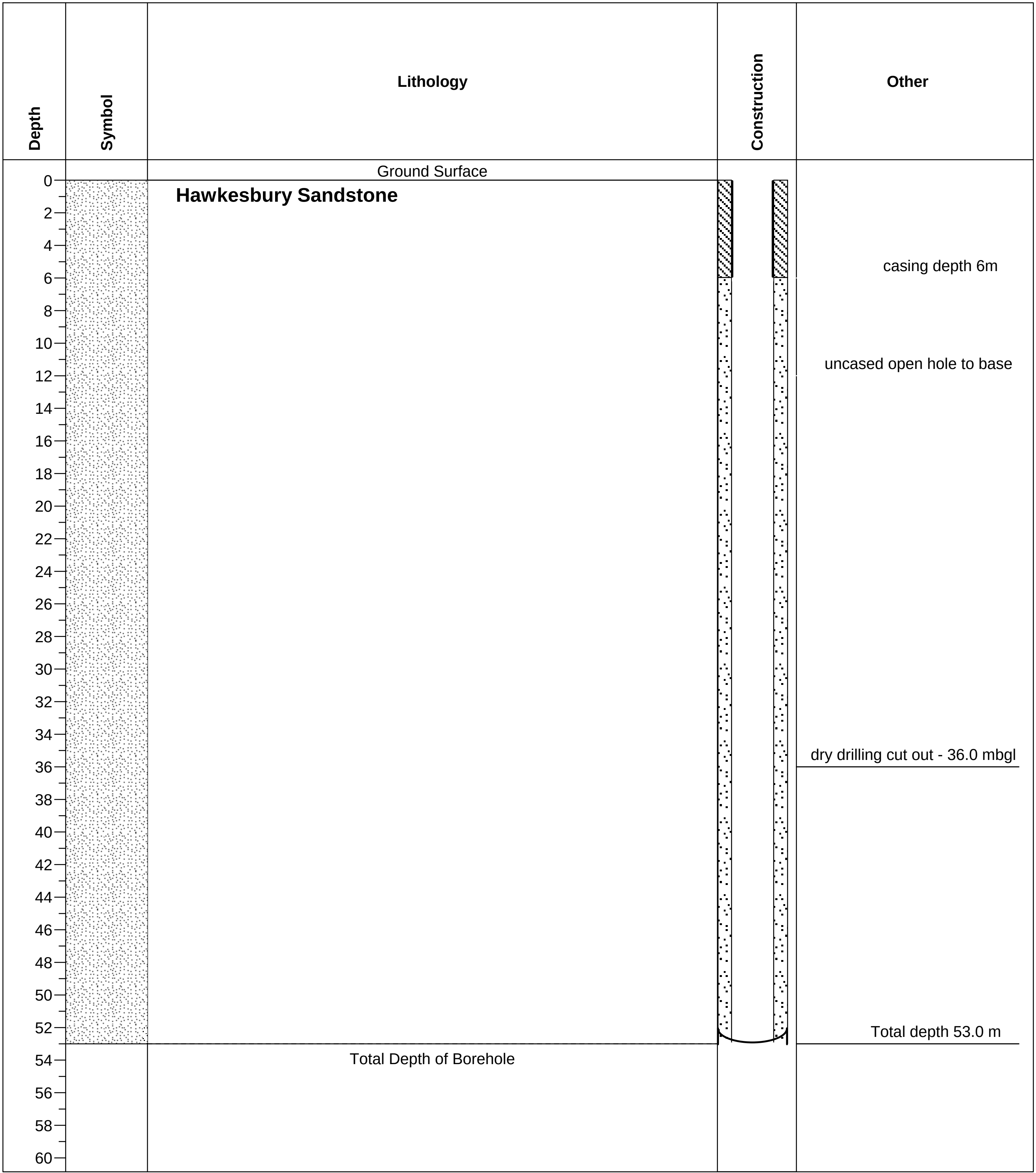
Drilling Method: open hole hammer

Drilling Equipment: open hole hammer

Drilling Start: 6/11/09

Drilling Finish: 6/11/09

Bore / Piezo: NRE G **Page 1 of 1**
Project: Wongawilli
Location: NRE 1
Coordinates: E 296949 N 6205678
Project Number: GUJ1
Datum:
Elevation: 363.03
Logged By: H Chandra



Ground Surface

Hawkesbury Sandstone

Total Depth of Borehole

casing depth 6m

uncased open hole to base

dry drilling cut out - 36.0 mbgl

Total depth 53.0 m

Driller: Rob Budd
Drilling Method: open hole hammer
Drilling Equipment: open hole hammer
Drilling Start: 20/10/09
Drilling Finish: 20/10/09

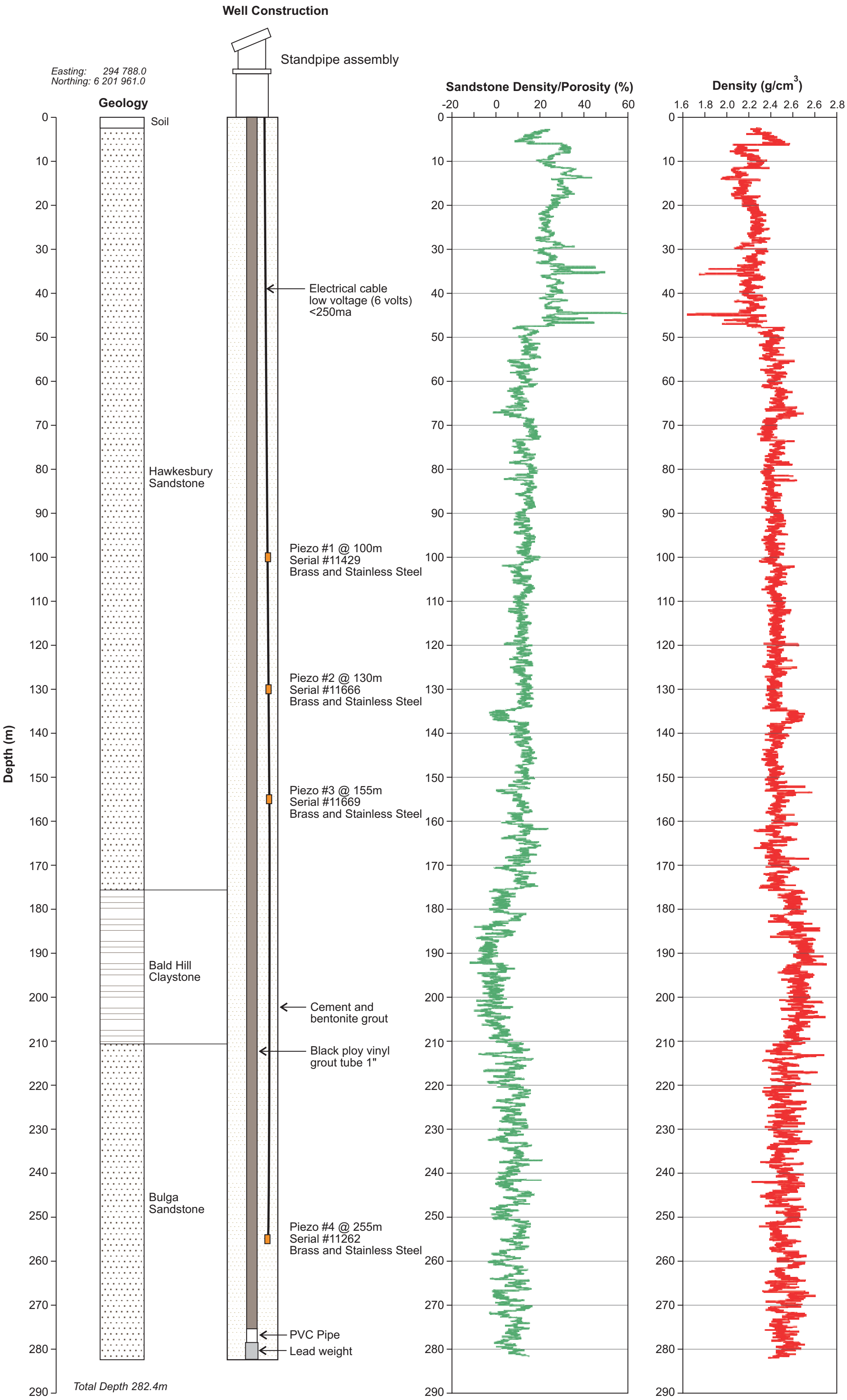
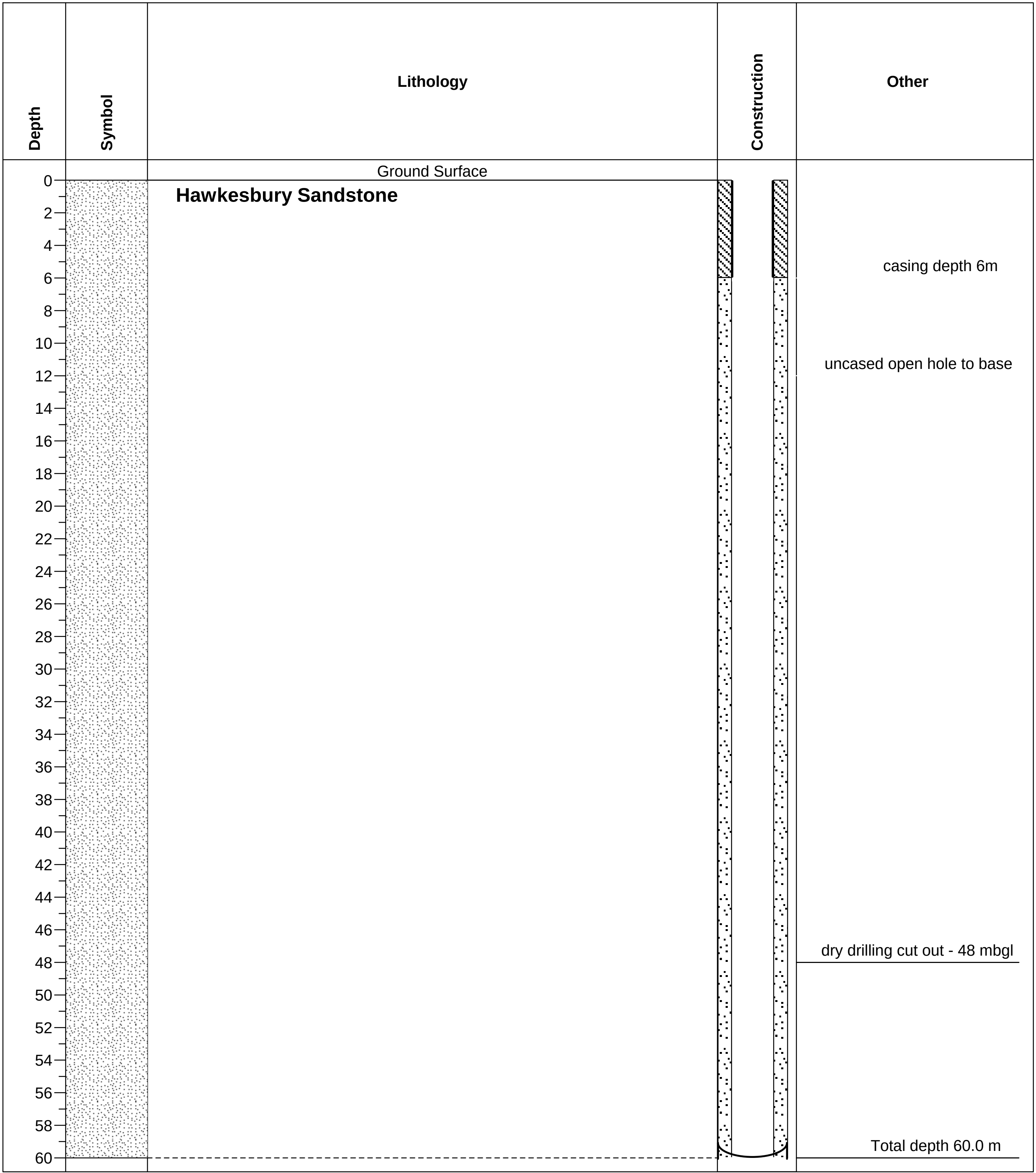


Figure 3: VW Piezo installation - NRE NE-3.

Bore / Piezo: NE 3
Page 1 of 1
Project: Wongawilli
Location: NRE 1
Coordinates: E 294803 N 6201954
Project Number: GUJ1
Datum:
Elevation: 359.27
Logged By: H Chandra



Hawkesbury Sandstone

casing depth 6m

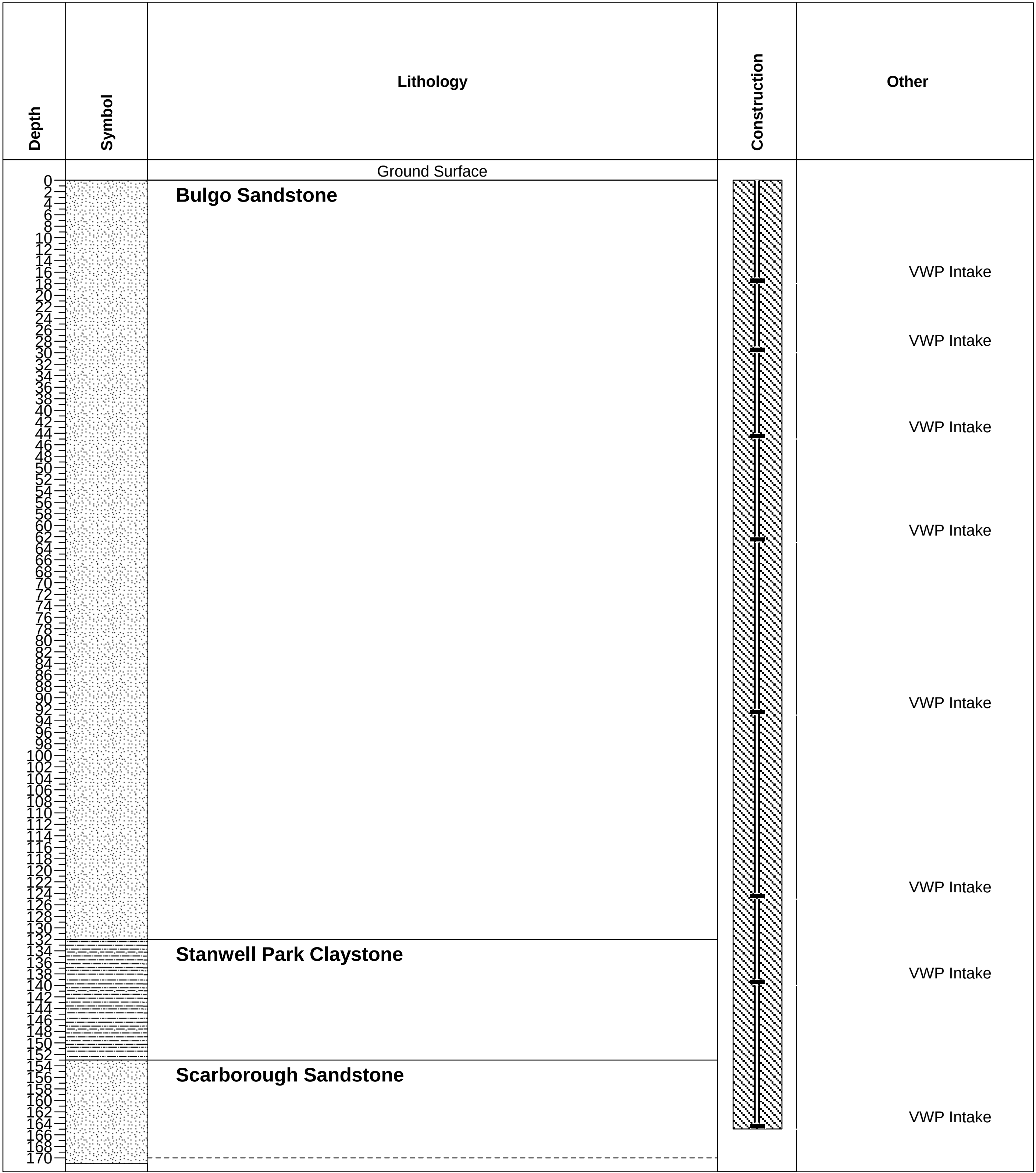
uncased open hole to base

dry drilling cut out - 48 mbgl

Total depth 60.0 m

Driller: Rob Budd
Drilling Method: open hole hammer
Drilling Equipment: open hole hammer
Drilling Start: 5/12/09
Drilling Finish: 5/12/09

Bore / Piezo: GW1 **Page 1 of 1**
Project: Wongawilli Seam Major Expansion
Location:
Coordinates: E 3030693 N 6196913
Project Number: NRE1
Datum: **Elevation:** 318.2
Logged By: R Cartwright



Driller: Roger Ritchie
Drilling Method: open hole hammer
Drilling Equipment:
Drilling Start: 23 August 2012
Drilling Finish: 23 August 2012

GeoTerra

Bore / Piezo: GW1A **Page 1 of 1**

Project: Wongawilli Seam Major Expansion

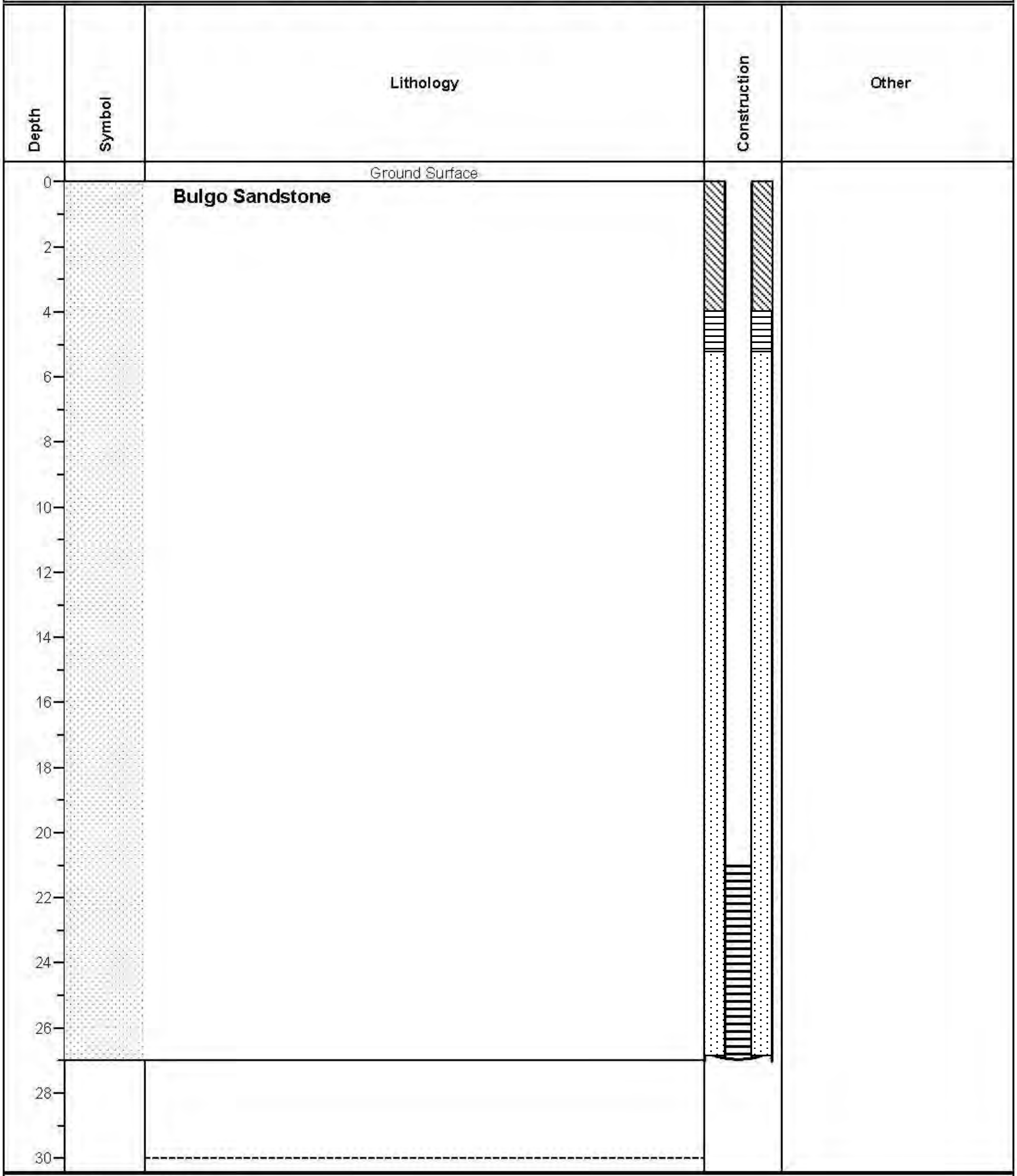
Location:

Coordinates: E 303742 N 6196983

Project Number: NRE1

Datum: **Elevation:** 311.7

Logged By: R Cartwright



Driller: Roger Ritchie

Drilling Method: open hole hammer

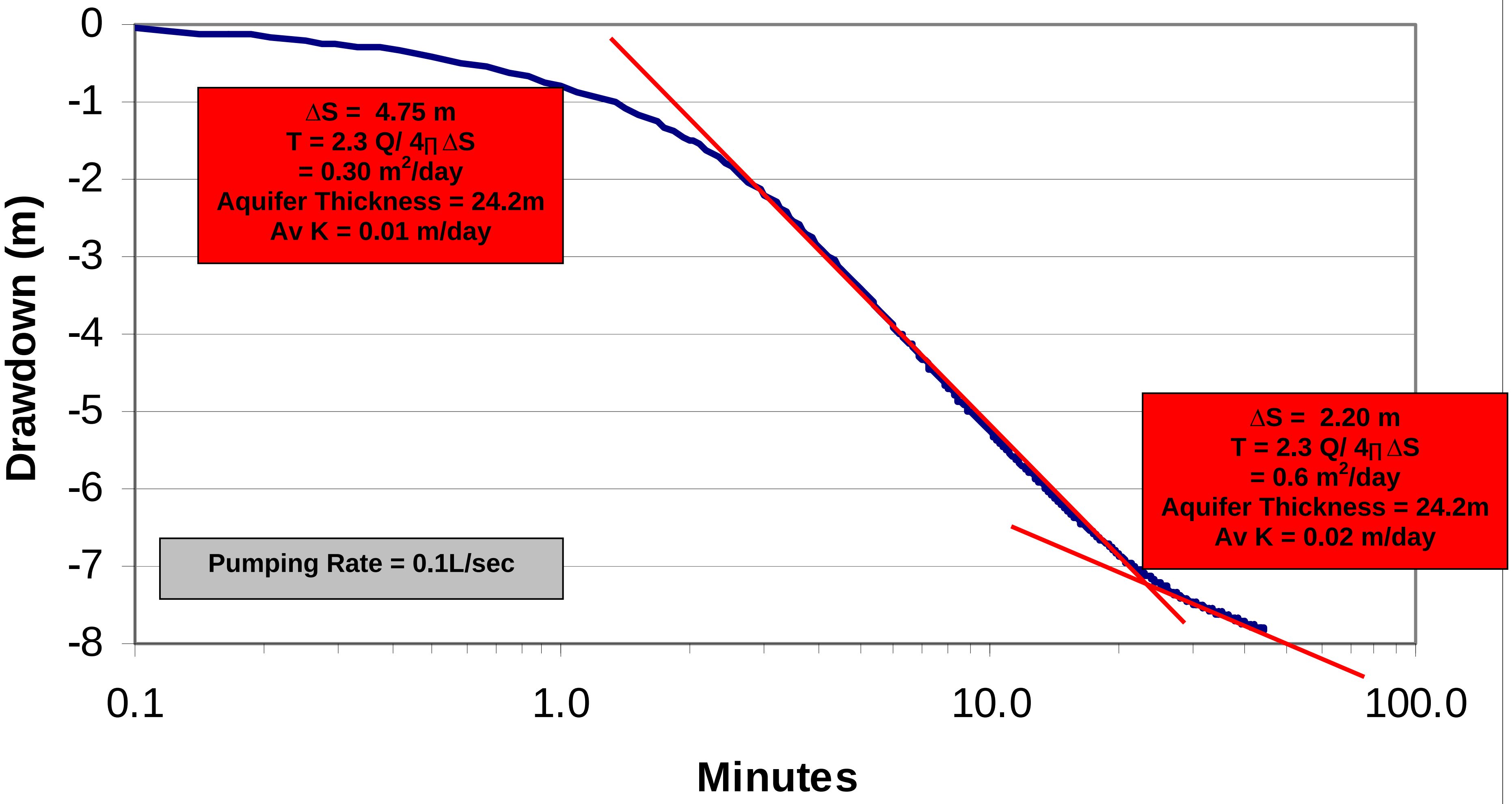
Drilling Equipment:

Drilling Start: 22 August 2012

Drilling Finish: 22 August 2012

APPENDIX C

HYDRAULIC PARAMETER INVESTIGATIONS

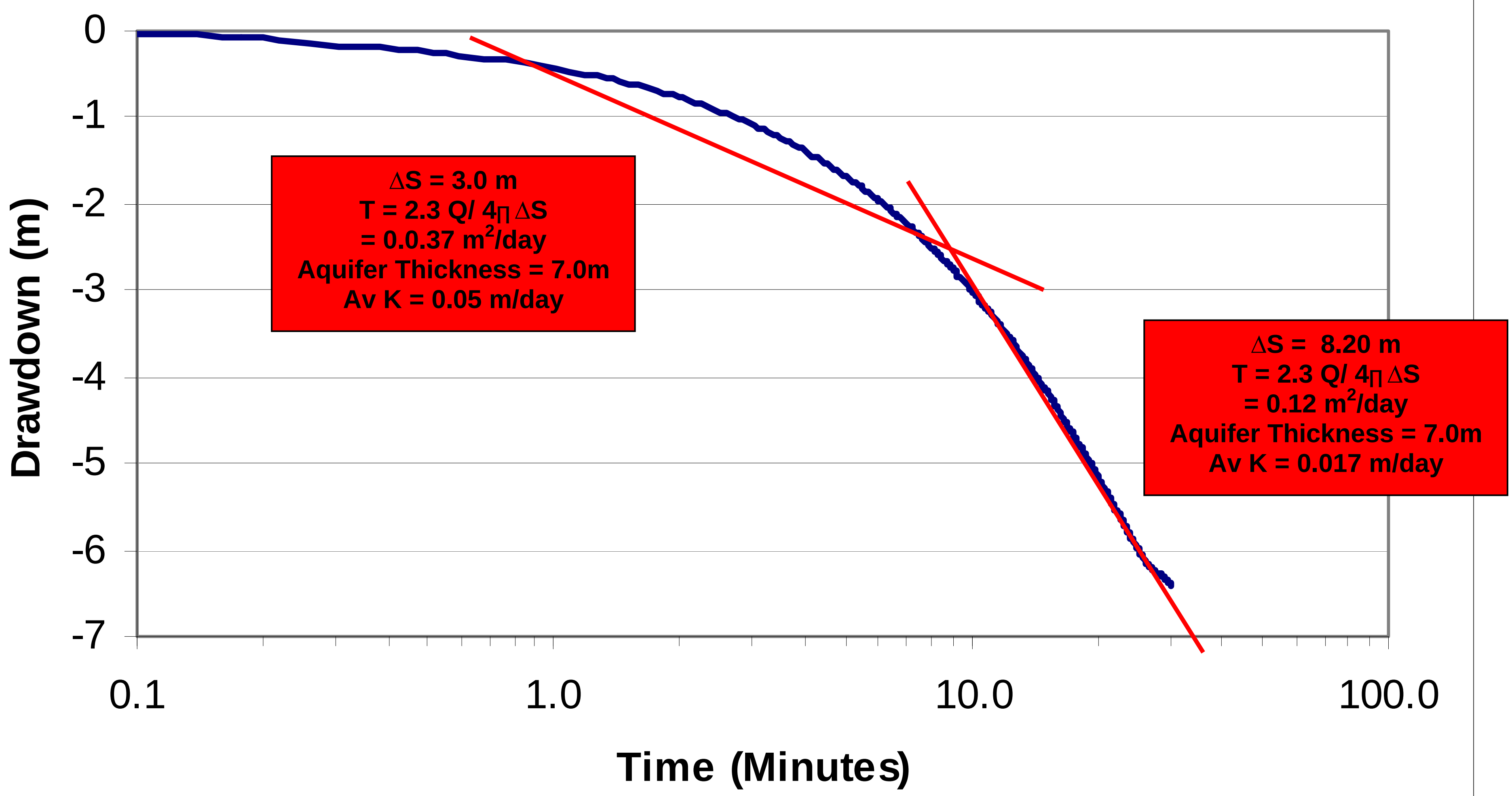


ΔS = 4.75 m
T = 2.3 Q/ 4∏ ΔS
= 0.30 m^2/day
Aquifer Thickness = 24.2m
Av K = 0.01 m/day

ΔS = 2.20 m
T = 2.3 Q/ 4∏ ΔS
= 0.6 m^2/day
Aquifer Thickness = 24.2m
Av K = 0.02 m/day

Pumping Rate = 0.1L/sec

Project	**GUJ1**	**GUJARAT COKING COAL LTD**	
Drawn	**A Dawkins**		**GeoTerra**
Date	**17.01.2011**	**Constant Rate Pumping Test**	**NRE A**
Scale	**NTS**		



ΔS = 3.0 m
$T = 2.3 Q/ 4\prod \Delta S$
= 0.0.37 m^2/day
Aquifer Thickness = 7.0m
Av K = 0.05 m/day

ΔS = 8.20 m
$T = 2.3 Q/ 4\prod \Delta S$
= 0.12 m^2/day
Aquifer Thickness = 7.0m
Av K = 0.017 m/day

Pumping Rate = 0.07L/sec

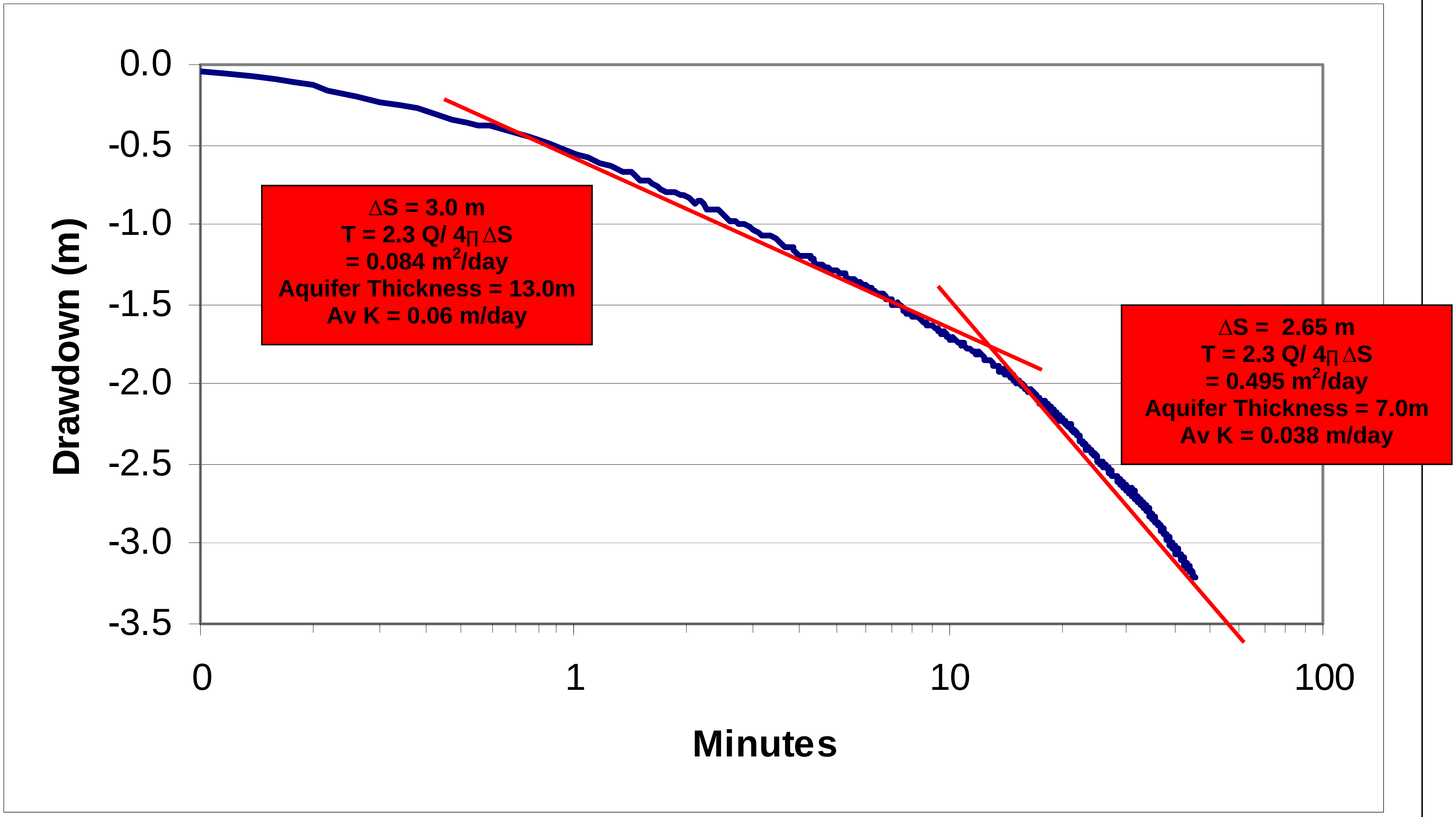
Project	**GUJ1**
Drawn	**A Dawkins**
Date	**17.01.2011**
Scale	**NTS**

GUJARAT COKING COAL LTD

Constant Rate Pumping Test

GeoTerra

NRE C

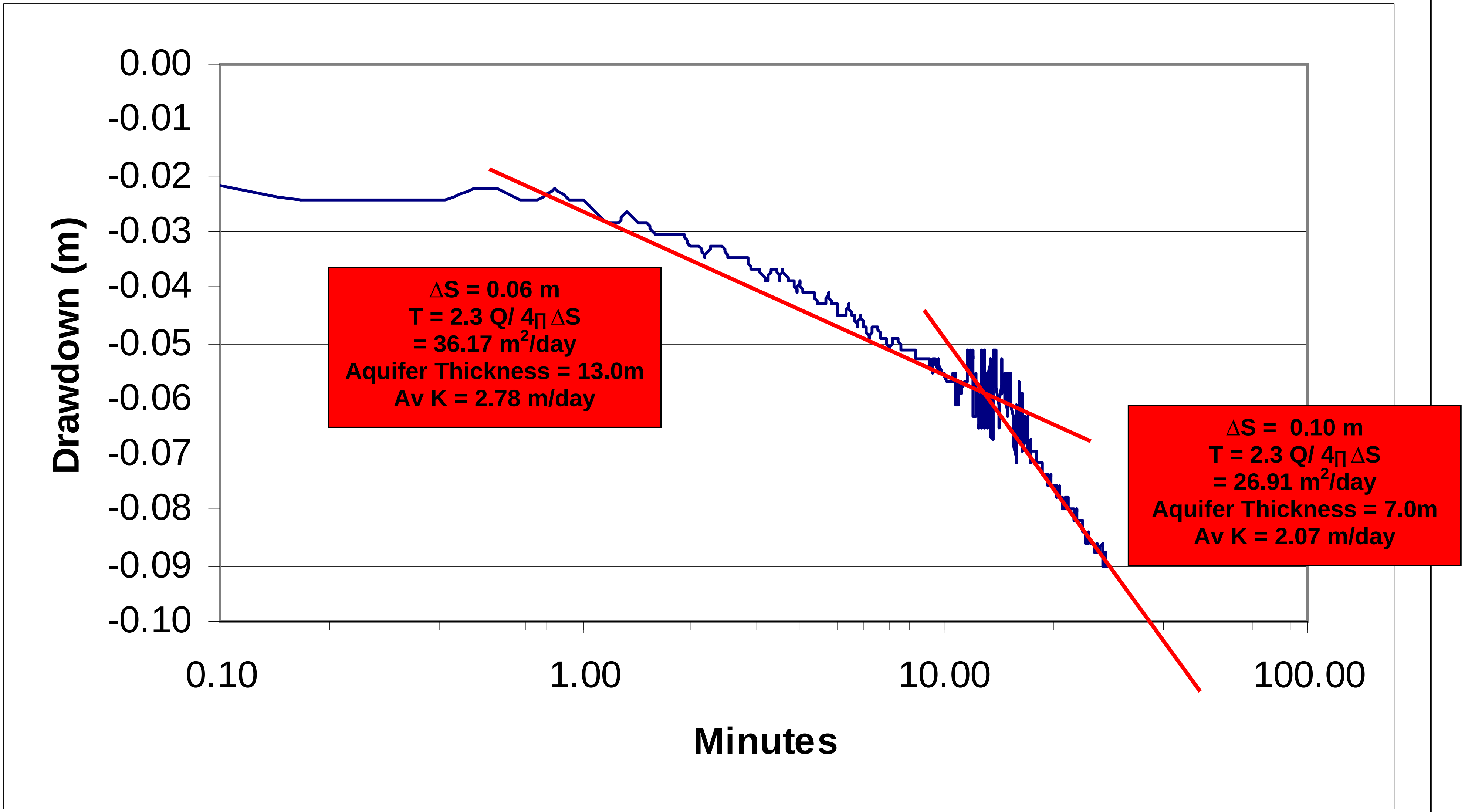


$\Delta S = 3.0$ m
$T = 2.3 Q/ 4\prod \Delta S$
$= 0.084$ m^2/day
Aquifer Thickness = 13.0m
Av K = 0.06 m/day

$\Delta S = 2.65$ m
$T = 2.3 Q/ 4\prod \Delta S$
$= 0.495$ m^2/day
Aquifer Thickness = 7.0m
Av K = 0.038 m/day

Pumping Rate = 0.09L/sec

Project	**GUJ1**	**GUJARAT COKING COAL LTD**	**GeoTerra**
Drawn	**A Dawkins**		
Date	**17.01.2011**	**Constant Rate Pumping Test**	**NRE D**
Scale	**NTS**		



ΔS = 0.06 m
$T = 2.3 Q/ 4∏ \Delta S$
$= 36.17 m^2/day$
Aquifer Thickness = 13.0m
Av K = 2.78 m/day

ΔS = 0.10 m
$T = 2.3 Q/ 4∏ \Delta S$
$= 26.91 m^2/day$
Aquifer Thickness = 7.0m
Av K = 2.07 m/day

Pumping Rate = 0.13L/sec

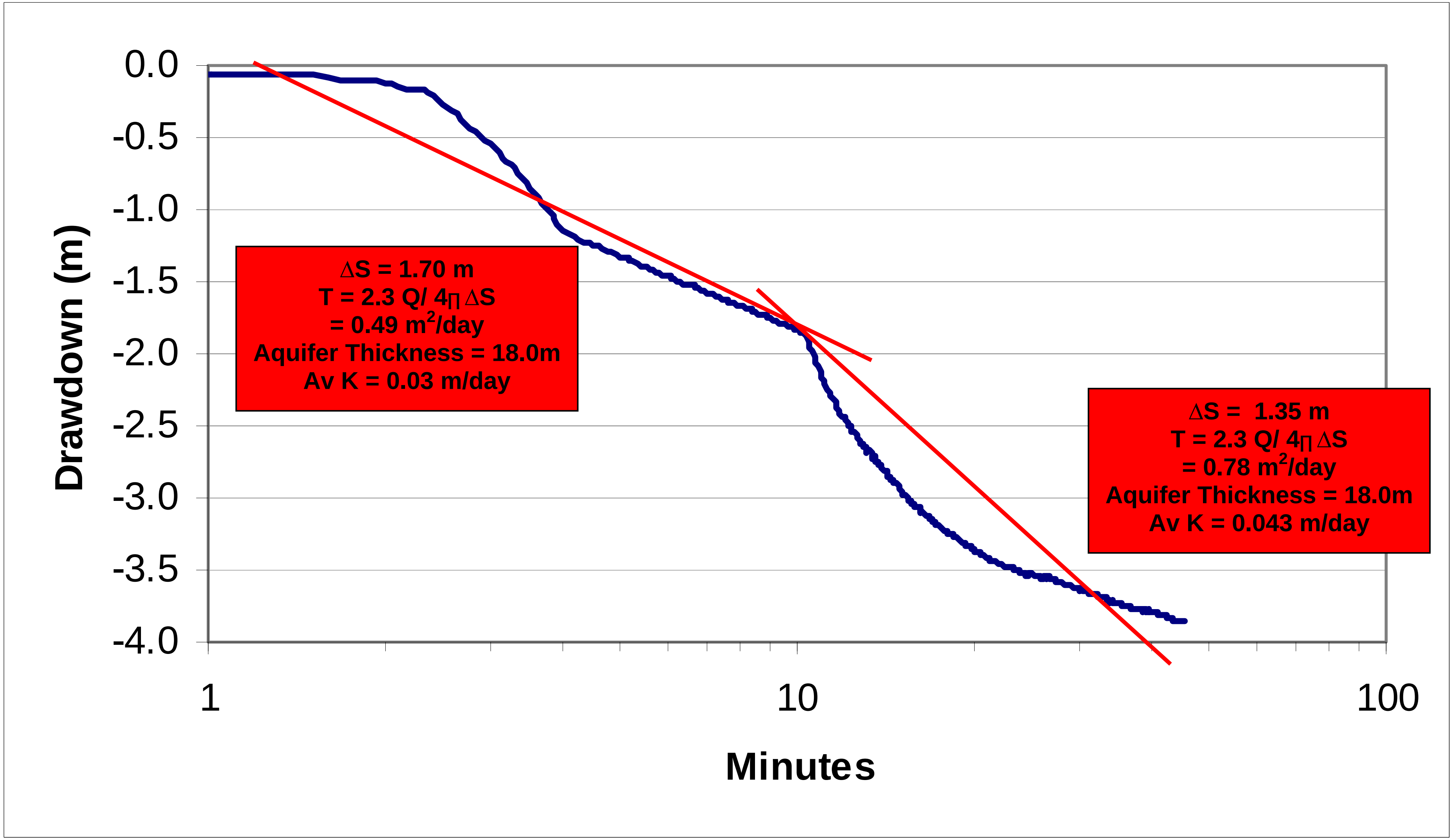
Project	**GUJ1**
Drawn	**A Dawkins**
Date	**17.01.2011**
Scale	**NTS**

GUJARAT COKING COAL LTD

Constant Rate Pumping Test

GeoTerra

NRE E



$\Delta S = 1.70$ m
$T = 2.3\ Q/\ 4\Pi\ \Delta S$
$= 0.49\ m^2/day$
Aquifer Thickness = 18.0m
Av K = 0.03 m/day

$\Delta S = 1.35$ m
$T = 2.3\ Q/\ 4\Pi\ \Delta S$
$= 0.78\ m^2/day$
Aquifer Thickness = 18.0m
Av K = 0.043 m/day

Pumping Rate = 0.05L/sec

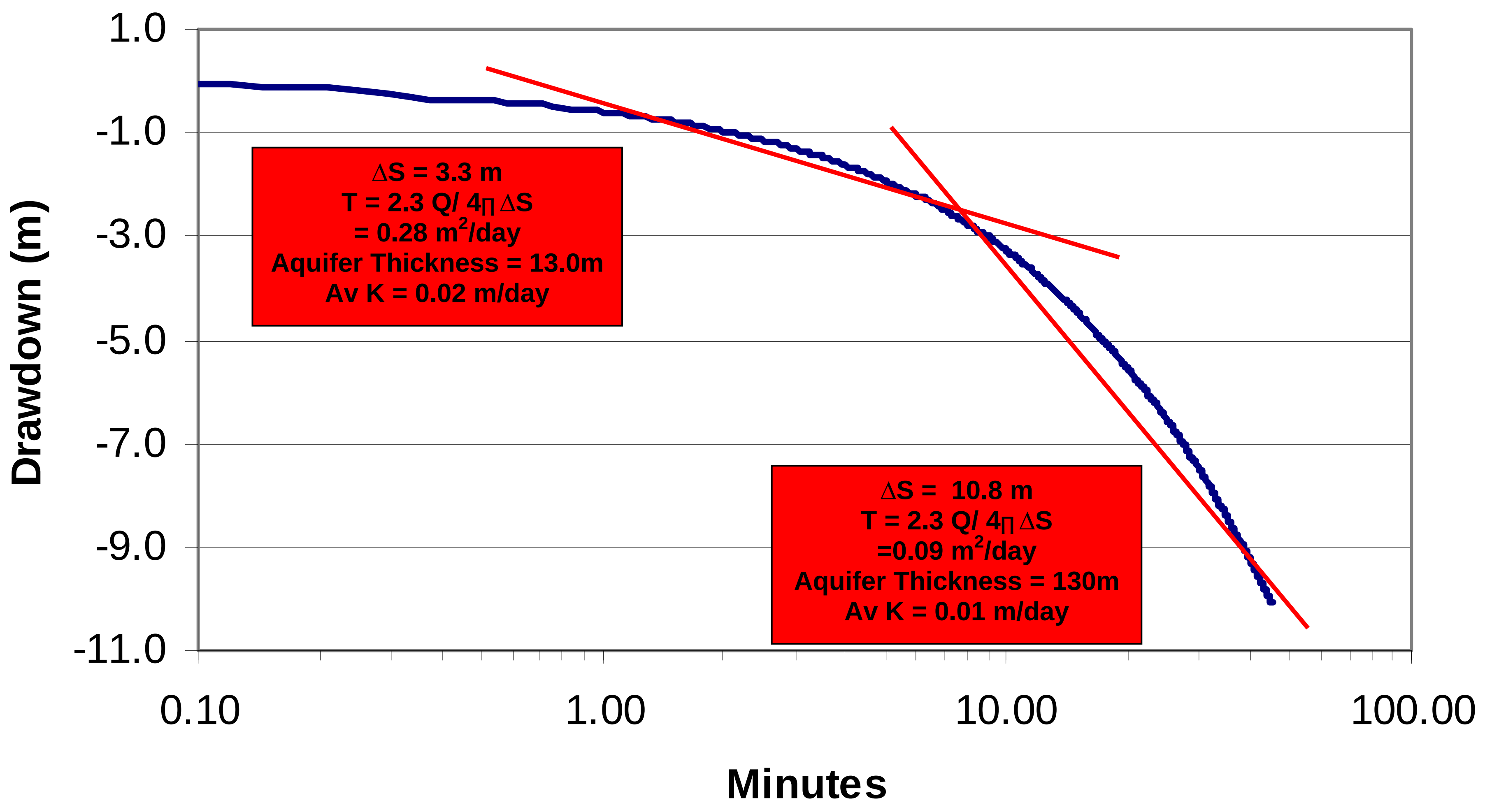
Project	**GUJ1**
Drawn	**A Dawkins**
Date	**17.01.2011**
Scale	**NTS**

GUJARAT COKING COAL LTD

Constant Rate Pumping Test

GeoTerra

NRE G



ΔS = 3.3 m
T = 2.3 Q/ 4∏ ΔS
= 0.28 m^2/day
Aquifer Thickness = 13.0m
Av K = 0.02 m/day

ΔS = 10.8 m
T = 2.3 Q/ 4∏ ΔS
=0.09 m^2/day
Aquifer Thickness = 130m
Av K = 0.01 m/day

Pumping Rate = 0.06L/sec

Project	**GUJ1**	**GUJARAT COKING COAL LTD**	**GeoTerra**
Drawn	**A Dawkins**		
Date	**17.01.2011**	**Constant Rate Pumping Test**	**NE3**
Scale	**NTS**		

APPENDIX D

FEFLOW GROUNDWATER MODELLING

20 November, 2012

GUJARAT NRE COKING COAL LTD

NRE No.1 Colliery: Wonga East and Wonga West Groundwater Modelling

Submitted to:
Andrew Dawkins
Geoterra Pty Ltd
77 Abergeldie Street
Dulwich Hill NSW 2203

REPORT

Report Number. 107636001-003-Rev4

Distribution:

Danyil Skora
Gujarat NRE Coking Coal LTD

A world of capabilities delivered locally

Golder Associates

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APPENDICES

1.0 INTRODUCTION

Gujarat NRE Coking Coal Ltd (Gujarat) operates the NRE No.1 Colliery which is located approximately 13 km northwest of Wollongong. Mining operations include continued underground mining with a proposed expansion of eleven longwall panels in the Wonga East area and seven longwall panels in the Wonga West area. The proposed expansion extends the existing underground operation by the extraction of coal from the Wongawilli Seam as well as limited first workings within the Balgownie and Bulli seams.

The proposed workings are located beneath the Sydney Catchment Authority managed, restricted access, Metropolitan Special Area. Golder Associates (Golder) has been engaged to develop a numerical model to assist in the assessment of the groundwater-surface water bodies that may already have been affected by mining to date and to predict possible effects associated with the proposed works. The modelling was conducted to assess the relative changes in the groundwater regime and recharge to surface water bodies due to the proposed mining.

The area of interest for this study comprises two locations within the model domain – Wonga East, located near the Illawarra Escarpment and Wonga West, situated to the West of Cataract Dam. The majority of existing mine workings in the area are located within the Bulli seam covering the entire area from, and including, Wonga East to Wonga West. The historical extraction methods comprise bord and pillar excavations and longwall panels. The vast majority of the existing workings are single seam operations except for one area in the Wonga East region with multi-seam extraction, where the Balgownie Seam underlying the Bulli Seam was exploited (Balgownie Workings) which led to increased subsidence effects. One longwall (LW4) has been extracted in the Wongawilli seam at Wonga East

The proposed workings are pre-dominantly located within the Wongawilli Seam and underlie existing Bulli Seam workings. Multi-seam extraction of the nature proposed is relatively new to the Southern Coalfield and there is a degree of uncertainty in the prediction of resulting subsidence.

The possible extent of subsidence induced fracturing and associated change in physical characteristics affecting water flow behaviour (for example, hydraulic conductivities) as a result of the proposed workings have been assessed in geotechnical studies undertaken by others. We have relied on these assessments in our modelling.

2.0 STUDY AREA

The study area, located inland of Wollongong, NSW, is situated within the restricted entry water catchment areas surrounding Cataract Dam. It comprises large areas of previous underground mining, with smaller areas in which mining is proposed to be continued or to start. The proposed workings are located in two areas – Wonga East near the Illawarra Escarpment, and Wonga West near Cataract Dam (Figure 1).

2.1 Topography and Drainage

The study area is dominated by plateau and valley topography characteristic of the Sydney Basin. Drainage of the plateaus is generally via deeply incised drainage lines into the Cataract Dam (Figure 2). The creeks are ephemeral in the upper reaches but are flowing throughout the year at lower elevations. The area is heavily wooded and elevations range from approximately 285 – 415 m Australian Height Datum (AHD).

Valley infill and headwater swamps are present within the study area, and are primarily located at the headwaters of the streams, before the streams become increasingly more incised.

2.2 Rainfall and Recharge

Rainfall, evaporation and runoff data was extracted from a draft report by WRM (2012) on surface water modelling. The mean annual rainfall isohyets produced by WRM were based on 1969–1990 rainfall data from the Bureau of Meteorology. A simplified spatial distribution schematic of rainfall is presented in Figure 3.

Rainfall data in the study area show a noticeable decrease in rainfall from around 1,750 mm/year in the East to around 1,000 mm/year in the West. Mean annual pan evaporation at Cataract Dam is approximately 1,420 mm/year.

Data for two long term streamflow stations, one in the northern catchment at Loddon River, and one in the southern catchment at Bellambi Creek, were evaluated by WRM[1]. They concluded that "while baseflow is a notable feature in the stream flows, it contributes a relatively small portion of total streamflow volume" and "At both catchments, over 90% of the total streamflow volume comes from the largest 40% of daily flows. "

However, during some periods flows were observed to be different in the two catchment areas, possibly due to spatially variable rainfall. "The Loddon River catchment exhibits a significantly higher runoff to rainfall ratio". It is noted, however, that available data is limited, and that some water can be expected to flow as subsurface flow within the rocky and fractured stream-beds, and so will not be registered at the gauging stations.

Recharge for the numerical model was approximated using this information.

2.3 Surface Water Features

The study area is located within the Metropolitan Special Area (managed by the Sydney Catchment Authority) and contains Cataract Dam which is used to supply drinking water to Sydney and Wollongong.

The Wonga West area contains both valley infill and headwater upland swamps along the Wallandoola and Lizard Creek streamlines. The Wonga East area contains one headwater swamp (Geoterra, 2012).

Ephemeral 1st and 2nd order tributary creeks present within the Wonga West area drain into 3rd order streams in the Wallandoola and Lizard Creek catchments. In the Wonga East area, 1st and 2nd order tributary creeks drain into the 3rd and 4th order Cataract Creek catchment.

Cataract Creek drains directly into Cataract Reservoir at Wonga East. Lizard Creek and Wallandoola Creek flow from the south-east to the Cataract River over the proposed Wonga West workings. Inspections of Cataract Creek, Lizard Creek and Wallandoola Creek have indentified potential mining impacts (cracking of bars, localised loss of surface water flows) in Lizard and Wallandoola Creeks, however no flow of water into the mine has been related to loss of flow from any of the creeks (Seedsman, 2012).

2.4 Land Use

In Wonga East the proposed workings underlie the Cataract Creek catchment and channels in essentially undeveloped bushland apart from limited fire access and power transmission access trails. The Wonga East area is fully contained within the SCA surface water catchment area that drains directly into Cataract Dam.

The Wonga West area is essentially undeveloped bushland with mine surface infrastructure and access road associated with the Gujarat NRE No. 1, No. 4 and No. 5 shafts.

2.5 Existing Mine Workings and Current Case Status

Mining in the area has been undertaken since the early 20th century. Early mines were developed as bord and pillar workings within the Bulli Seam – see Figure 4 for the regional extent of such mines around the study area. Due to the relatively narrow workings, large areas retain a measure of support within the bord and pillar workings which generally only lead to very limited subsidence / fracturing above the workings. Pillar extraction has also been conducted.

Besides the (historic) bord and pillar workings, there are also several longwall developments in the study area (Figure 5). The majority of the longwalls were developed within the Bulli Seam. Their panel widths range up to 190 m wide near or under the water storage dams (Geoterra, 2012).

Where wider panel longwall mining was undertaken, subsidence was assessed to exist above them up into the lower and mid Bulgo Sandstone. Over time, conceptual models have been developed outlining the vertical extent and nature of subsidence.

As a result of subsidence and the induced fracturing and delamination in the study area, hydraulic parameters can be expected to have been changed, and the current day groundwater/surface water system can be expected to reflect these ‘disturbed’ conditions.

Refer to Section 4.0, for details regarding the observed and inferred effects of subsidence on subsurface strata and related changes in hydraulic parameters.

2.6 Related Mine Studies in the Surrounding Area

Several comparable studies have been undertaken for mines in the wider area (for example, The Metropolitan Coal Project Review Report (NSW Planning Commission, 2008), Metropolitan Coal Project Groundwater Assessment (Heritage Computing, 2008), Bulli Seam Operations Groundwater Assessment (Heritage Computing, 2010). These reports have been assessed and parameters published in these studies were used to establish initial hydraulic properties used in this study.

3.0 GEOLOGICAL SETTING

The geology of the study area is presented in detail in (Geoterra, 2012). A summary is presented below.

The study area is located in the Southern Coalfield which is situated in the Southern Sydney Basin. The Illawarra Coal Measures, which are targeted for extraction are overlain by sedimentary sequences of the Narrabeen and Hawkesbury Groups. These sequences are characterised by an inter-layering of sandstone, shale, conglomerate and claystone units (Figure 6).

In more detail it is noteworthy that the Wonga West area differs from the Wonga East area. The strata dips down towards the west in a S-shaped fashion, within increasing overburden thicknesses. Wonga East is located just west of the Illawarra Escarpment, and is characterised by less overburden over the coal strata with a depth of cover ranging from 235 – 325 m.Overburden above the proposed working in Wonga West is reaching between 460 – 520 m (Figure 7 and Figure 8).

Wonga East is also characterised by deeply incised valleys which expose strata down to the Bald Hill Claystone and upper Bulgo Sandstone in Cataract Creek.

The Study Area is predominantly covered by shallow colluvium, with thin to absent alluvial sedimentary deposits on the valley floors. Quaternary unconsolidated alluvial sediments are also present within both valley fill and headwater upland swamp areas, and are generally less than 2 m thick. These deposits comprise humic clayey sands overlying weathered Hawkesbury Sandstone. The Quaternary sediments in the Wonga East and Wonga West areas are, in turn, sequentially underlain by the:

- Hawkesbury Sandstone (absent to 181 m thick) - eroded in the headwater valleys of Cataract and Bellambi Creeks in the Wonga East area, with outcrops in the west of the Wonga East area;
- Narrabeen Group, consisting of the following units
  - Newport and Garie Formations (4.6-36 m thick)
  - Bald Hill Claystone (17-42 m thick)
  - Bulgo Sandstone (113-154 m thick);
  - Stanwell Park Claystone (15-26 m thick)
  - Scarborough Sandstone (16-31 m thick);
  - Wombarra Claystone (35-61 m thick)
  - Coal Cliff Sandstone (8-13 m thick);
- Illawarra Coal Measures. The major coal seams in sequentially lower order are:

- Bulli Seam (2.0-4.7 m thick) – worked extensively by longwall and bord and pillar methods, varies from 205-290 m depth of cover at Wonga East and 425-500 m at Wonga West;
- Loddon Sandstone (5-8 m thick);
- Balgownie Seam (0.8-1.5 m thick) – limited longwall extraction has been conducted in Wonga East;
- Lawrence Sandstone (16-17 m thick);
- Cape Horn Seam (0.1-0.4 m thick);
- Eckersley Formation and Hargraves Coal Member (6-8 m thick);
- Wongawilli Seam (6.2-10.5 m thick) – predominantly mined in the southern area of the Southern Coalfields, yet to be been mined within the Gujarat lease. The Wongawilli Seam varies from 237-321 m depth of cover at Wonga East and 457-512 m at Wonga West.
- Kembla Sandstone (5.0-9.0 m thick);
- American Creek Coal Member (0.3-3.5 m thick);
- Allens Creek Formation (14-15 m thick);
- Darkes Forest Sandstone (5.0-9.0 m thick);
- Bargo Claystone (10-12 m thick);
- Tongarra Seam (1.5-2.0 m thick);
- Wilton Formation (minimum 4 m thick).

The general layer thicknesses are summarised in Table 1.

Table 1: Geological Model Layer Thickness

Name	Thickness (m)	Layer
Hawkesbury Sandstone (Upper 1)	20.0	1
Hawkesbury Sandstone (Upper 2)	17.0	2
Hawkesbury Sandstone (Lower 1)	43.0	3
Hawkesbury Sandstone (Lower 2)	77.0	4
Newport and Gary Formation	12.2	5
Bald Hill Claystone	20.1	6
Bulgo Sandstone (Upper 1)	51.0	7
Bulgo Sandstone (Upper 2)	20.0	8
Bulgo Sandstone (Lower 1)	48.0	9
Bulgo Sandstone (Lower 2)	23.0	10
Stanwell Park Claystone	17.1	11
Scarborough Sandstone	19.5	12
Coalcliff Sandstone / Wombarra Claystone (Upper)	49.0	13
Coalcliff Sandstone / Wombarra Claystone (Lower)	27.7	14
Bulli Coal Seam	2.3	15
Loddon Sandstone	9.5	16
Balgownie Coal Seam	1.2	17
Lawrence Sandstone	17.0	18
Eckersley Formation	7.6	19
Wongawilli Coal Seam	9.7	20
Kembla Sandstone	9.0	21
Generalised Sedimentary Unit	50.0	22

Some igneous intrusive activity and faulting is known to have occurred in the study area. A large doleritic intrusion is known to exist at depth at the central eastern edge of the study area. However, the exact nature and extent of the intrusion is not known. Several dykes are also known to be present in the area.

Faulting is also recorded in the area with faults trending mainly E - W and NW – SE. Throws of up to 90 m have been recorded, but details about their vertical extent and associated hydraulic properties are not available.

4.0 SUBSIDENCE AND GROUNDWATER CHARACTERISATION IN MODEL

4.1 Subsidence

4.1.1 Existing Workings

Subsidence effects are expected to modify the hydraulic conductivity values for the overburden above existing workings. For the purposes of modelling, the effects of fracturing and subsidence above workings have been applied in the model by modifying hydraulic conductivity values above the existing workings as follows shown in Table 5, Table 6 and Table 7.

The extent of fracture development and hydraulic conductivity increase above the existing workings is primarily dependent on the degree of extraction and resultant goaf and subsidence development above the workings. As can be noted from Table 7, the least development of horizontal and vertical fracturing is present over the bord and pillar workings, followed by the less than 155 m wide longwalls, then the less than 186 m wide longwalls and up to 490 m wide pillar extraction areas in the Bulli Coal Seam.

Additional overburden fracture propagation and increased hydraulic conductivity is developed where both the Bulli and Balgownie Coal Seam workings have been extracted.

As shown in Table 7, extraction of the proposed Wongawilli Coal Seam longwalls will subsequently increase the height of fracturing and permeabilities above the existing and proposed workings in direct relationship to the degree of subsidence, which principally relates to the width of extraction and the size and scale of the existing Bulli and, where present, Balgownie workings.

4.1.2 Proposed Workings

There are three types of proposed workings – narrow / short longwall extraction mining of the Wongawilli Seam in Wonga East area, wider / longer longwall extraction of the Wongawilli Seam in Wonga West area and narrow first workings and pillar extraction works in the Bulli Seam in the V-Mains area (Figure 9 and Figure 10).

Areas1 and 2 in Wonga East are scheduled for extraction within the Wongawilli Seam in longwall panel sets of three and seven. Areas 3 and 4 in Wonga West are proposed longwall extraction areas in the Wongawilli Seam, largely underlying the existing longwall panels in the Bulli seam. 'V-Mains' is a small triangular area marked for extraction in the Bulli seam to the south of the existing Wonga West 300 series workings.

The proposed workings would normally have subsidence similar to that observed in the existing workings if they were the only workings in the area, however, the majority of these workings will undermine existing workings and are hence predicted to have a different subsidence pattern. In the Wonga East area, the proposed extraction will interact with the existing area of subsidence to increase subsidence and the degree of fracturing of the strata overlying the Wongawlli Seam. The proposed workings are predicted to lead to surface subsidence of up to 1.2 m at Wonga East and 2.55 m at Wonga West (Seedsman, 2012). Maximum subsidence or pillar collapse is expected where the proposed workings are located beneath the existing Balgownie workings. The areas of the proposed workings that are not located below the existing Balgownie workings are expected to subside to an extent similar to that above the small longwalls of the 500 series in Wonga West.

Given the limited data with respect to hydrogeological parameters in existing zones of subsidence and the uncertainty in the prediction of multi-seam subsidence (Seedsman, 2012), there is uncertainty in assigning the vertical extent of fracture zones, and fracture intensity, for the proposed workings. Based on the information provided to us, the following assumptions have been made regarding hydraulic conductivity above the proposed workings:

- Bald Hill Claystone and the Newport Formation (immediately above the Bald Hill Claystone) were considered to be unaffected except for a localised area over the Balgownie longwalls and Wongawilli Seam longwall WE-A2-LW4 in Wonga East.
- As shown in Table 7, extraction of the proposed Wongawilli Coal Seam longwalls will subsequently increase the height of fracturing and permeabilities above the existing and proposed workings in direct relationship to the degree of subsidence, which principally relates to the width of extraction and the size and scale of the existing Bulli and, where present, Balgownie workings.
- For V-Mains in the Bulli Coal Seam, conductivities were increased up to the Stanwell Park Claystone with a slightly higher horizontal conductivity in the Lower Bulgo Sandstone to represent delamination.

4.2 Groundwater

To establish current conditions as well as monitor potential effects of proposed mining, twenty swamp piezometers, eight open standpipe and seven vibrating wire array piezometers (VWPs) were installed during the hydrogeological investigation program, the details of which are presented in Geoterra (2012). Drilling extended to 325 m below surface. Low flow pumping tests were conducted in all open standpipe piezometers seated in the upper to middle Hawkesbury Sandstone. In addition, packer tests over 5.5 m intervals were conducted in six bores to 281 m below surface (SCT Operations, 2009).

The results of testing indicated generally slightly higher hydraulic conductivity values in the East, and lower ones in the West. Conductivity values are similar to those reported for other mines in the wider area (BHPIC, 2010; Heritage Computing, 2010) and also represent increasing permeabilities with increasing depth of cover for the same lithology.

Based on a combination of on-site tests as well as regional studies (Heritage Computing, 2010) hydraulic conductivities in the eastern section of the Southern Coalfields vary from 0.03 m/s to 1E-06 m/s, whilst the western region around Tahmoor (Geoterra, 2012), which has a generally greater depth of cover, ranges from 9.3E-06 m/s to 1.6E-09 m/s.

The available groundwater data is sourced from locations shown in Table 2 (data supplied by GeoTerra) and Figure 11.

Table 2: NRE1 Groundwater Monitoring Bores and Groundwater Levels

BORE	Easting	Northing	Date	SWL (mbgl)	Ground Elevation (mAHD)	VWP Intake (mbgl)	Lithol*	Head (m)	Water Level (mAHD)
NREA	303692	6196033	15/01/2010	21.78	376.18		up HS		354.40
NRE A VWP	303680	6196034							
Piezo #1			21/12/2009		376.23	45	low HS	12.13	343.4
Piezo #2			21/12/2009		376.23	60	BHCS	37.02	353.2
Piezo #3			21/12/2009		376.23	75	up BS	49.72	350.9
Piezo #4			21/12/2009		376.23	140	mid BS	110.45	346.7
NRE B VWP	303939	6197567							
Piezo #1			21/12/2009		372.69	27.5	HS	21.11	366.3
Piezo #2			21/12/2009		372.69	43	up BS	21.93	351.6
Piezo #3			21/12/2009		372.69	63	mid BS	9.96	319.6
Piezo #4			21/12/2009		372.69	168	SPCS	86.25	290.9
NREC	303233	6198797	15/01/2010	13.95	362.72		mid HS		348.77
NRED	301870	6198509	15/01/2010	28.29	348.83		mid HS		320.54
NRE D VWP	301875	6198493							
Piezo #1			21/12/2009		348	70	NP	9.57	287.6
Piezo #2			21/12/2009		348	90	BHCS	35.46	293.5
Piezo #3			21/12/2009		348	110	up BS	42.00	280.0
Piezo #4			21/12/2009		348	160	low BS	54.17	242.2
NREE	296727	6202286	15/01/2010	11.91	329.24		up HS		317.33
NRE F	NOT	DRILLED	_	_	_				_
NREG	296949	6205678	15/01/2010	29.64	363.03		up HS		333.39
NE3	294803	6201954	15/01/2010	39.34	359.27		up HS		319.93
GW1A	303733	6196982	20/08/2012	24.00	329		up HS		305.00

BORE	Easting	Northing	Date	SWL (mbgl)	Ground Elevation (mAHD)	VWP Intake (mbgl)	Lithol*	Head (m)	Water Level (mAHD)
GW1	303697	6196905	1/09/2012		333	18	up BS	4	319.0
						30	up BS	6	309.0
						45	BS	20	308.0
						63	mid BS	29	299.0
						93	mid BS	43	283.0
						125	low BS	69	277.0
						140	SPCS	76	269.0
						165	ScS	21	189.0
NE3 VWP	294794	6201945							
Piezo #1			21/12/2009		360.23	100.0	mid HS	33.94	294.2
Piezo #2			21/12/2009		360.23	130.0	low HS	61.95	292.2
Piezo #3			21/12/2009		360.23	155.0	NP	78.96	284.2
Piezo #4			21/12/2009		360.23	255.0	mid BS	125.34	230.6
501 VWP	298771	6201856							
Piezo #1			30/11/2009		326.18	325	ScS	-5.20	-4.0
Piezo #2			30/11/2009		326.18	325	ScS	-6.90	-5.7
Piezo #5			30/11/2009		326.18	226	mid BS	15.43	115.6
502 VWP	298598	6202049							
Piezo #11			30/11/2009		319.32	222	mid BS	189.24	286.6
Piezo #12					319.32	167	up BS	0.00	0
Piezo #13			30/11/2009		319.32	167	up BS	128.90	281.2
Piezo #14			30/11/2009		319.32	100	low HS	67.98	287.3

BORE	Easting	Northing	Date	SWL (mbgl)	Ground Elevation (mAHD)	VWP Intake (mbgl)	Lithol*	Head (m)	Water Level (mAHD)
Piezo #15			30/11/2009		319.32	100	low HS	65.19	284.5
514	297917	6204280	14/07/2009	20.99	308.23		mid BS		287.24
BHP DDH120 (VWP214)	294825	6206962	1/12/2009		302.6	424.52	Bulli		206.10
BHP DDH124 (VWP224)	295215	6207858	1/12/2009		299.7	455.67	Bulli		213.72

*HS=Hawkesbury Sandstone, BHCS=Bald Hill Claystone, BS=Bulgo Sandstone, SPCS=Stanwell Park Claystone, NP=Newport, ScS=Scarborough Sandstone, Bulli=Bulli Coal Seam

5.0 CONCEPTUAL HYDROGEOLOGICAL MODEL

The study area is part of the Southern Coalfields which are contained within the southern region of the Sydney Basin. The basin is dominated by interlayered sandstone and siltstone/shale sequences containing coal layers at depth.

In the Wollongong area the landscape is dominated by a North-South trending escarpment where the Upper Narrabeen and overlying units outcrop. The sedimentary units are generally shallow dipping towards the west to north-west. To the west of the escarpment the landscape is dominated by deeply incised plateaus, with dammed lakes in the valleys of the lower reaches of Cataract Creek and Cataract River.

Intrusive bodies ranging from kilometre-wide in diameter intrusions to sills and dykes. Faults of variable length and extent of throw are also known to be present in the area, however detailed in-situ information regarding the faults hydraulic properties are not available.

Coal mining has taken place in the area, especially in the Bulli seam, since the early 20th century. Originally the workings were undertaken as bord and pillar excavations as well as limited pillar extraction and later longwall mining was introduced. The former will have led to depressurisation within the coal seam without any significant subsidence and depressurisation of the overburden above the bord and pillar workings. Longwall mining in contrast will have led to depressurisation not only in the mined coal seam but also subsidence and depressurisation above the workings, with the extent and height of the depressurisation relating to the extent and interconnection of subsidence over the longwalls.

Within the study area, there are differences between the Wonga West and Wonga East areas in terms of the geology and also in terms of the historical mining activity. In the Wonga West area, overburden is considerable thicker. Existing monitoring data suggests that in the Wonga West area, the Bald Hill Claystone (which overlies the major, spanning, Bulgo Sandstone) has restricted depressurisation of the overlying Hawkesbury Sandstone and the associated potential effects on the overlying streams and water supply dams.

In the Wonga East area overburden is less, the escarpment is closer and the old bord and pillar workings have been partially undermined by longwalls in the Balgownie seam and LW4 in the Wongawilli seam, all of which has led to more subsidence /stress-relaxation throughout the shallow units and up to surface, particularly in the area of the Balgownie longwalls. Furthermore, erosion in the deep valleys has exposed the upper Narabeen Group, locally eroding through the Bald Hill Claystone to the Bulgo Sandstone.

Limited information is available with respect to the state of flooding of the existing workings. The model assumes NRE 1 workings (existing and proposed) and Appin workings (to the north of Wonga West) to be dry, with the old Cordeaux workings to the West of the NRE1 workings, and old Bulli workings to the East, to be partially flooded.

Rainfall is variable across the area, and is highest in the East and diminishing towards the West (Figure 3). Recharge is a function of rainfall as well as run-off behaviour, which can vary between adjacent valleys. Recharge is expected to be higher over the fully collapsed Bulli / Balgownie seam in the Wonga East area compared to the deeper / less subsided Wonga West Bulli seam workings.

Headwater and valley fill swamps are present in parts of the study area and their water levels are perched (Geoterra, 2012) and therefore separated from the deeper regional groundwater level located in the Hawkesbury Sandstone.

6.0 GROUNDWATER MODEL SETUP

6.1 Software

Modelling was undertaken using FEFLOW, a finite element groundwater modelling package developed by WASY Institute for Water Resources Planning and Systems Research in Berlin, Germany. FEFLOW has become an industry standard in the context of finite element models for groundwater flow and mass and contaminant transport simulations. The finite element code allows areas that involve complex structural geometry to be represented reasonably accurately, without a loss of computational efficiency.

FEFLOW offers the following advantages:

- The capability to simulate groundwater flow in conditions dominated by irregular geological structure;
- An enhanced capability to represent three-dimensional geometry accurately.

6.2 Model structure

6.2.1 Extent

The extent of the model follows the catchment boundaries and is shown in Figure 13.

6.2.2 Layers

Model construction was based on supplied topography and Bulli and Wongawilli Coal Seam elevation data, This was combined with the stratigraphic data in Table 1 and was simplified to allow for model construction on the given scale. Some geological units were subdivided to accommodate the required parameter changes in connection with subsidence occurring over existing and proposed mine workings. The model consists of 22 layers and 23 slices (boundaries between layers), which allows a detailed representation of stratigraphy and subsidence effects on the overburden. The stratigraphy – layer relationships are listed in Table 3. Layer elevation variations are shown in two cross-sections in Figure 7 and Figure 8.

The incised valleys at Wonga East into which six model layers are known to daylight required extreme thinning of the upper layers and localised assignment of higher hydraulic conductivities in those areas to allow for sufficient recharge through the Bald Hill Claystone and the exposed Bulgo Sandstone.

Table 3: Model Layers

Slice ID	Layer ID	Name	Elevation Notes	Thickness	Slice height above/ below Bulli Floor (m)
1		Topography			
	1	Hawksbury Sandstone (Upper)		20 m	
2		Bottom of Upsidence Cracking	20 mbgl*	*37 m average*	399.2
	2	Hawksbury Sandstone (Upper)		17 m	
3		Hawksbury Sandstone (Central)			382.2
	3	Hawksbury Sandstone (Lower)		43 m	
4		Bottom of Upsidence Delamination	80 mbgl	*120 m average*	339.2
	4	Hawksbury Sandstone (Lower)		77 m	
5		Hawksbury Sandstone (Bottom)			262.2
	5	Newport and Gary Formation		12.2 m average	
6		Newport and Gary Formation (Bottom)			250
	6	Bald Hill Claystone		20.1 m average	
7		Bulgo Sandstone (Top)			229.9
	7	Bulgo Sandstone (Upper)		51 m	
8		Extension of upper delamination in multiseam extraction		*71 m average*	178.9
	8	Bulgo Sandstone (Upper)		20 m	
9		Bulgo Sandstone (Central)	to 159 m above Bulli Top		158.9
	9	Bulgo Sandstone (Lower)		48 m	
10		Extension of Upper Cracking Boundary	to 111 m above Bulli Top	*71 m average*	110.9
	10	Bulgo Sandstone (Lower)		23 m thick	
11		Bulgo Sandstone (Bottom)			87.9
	11	Stanwell Park Claystone		17.1 m average	
12		Scarborough Sandstone (Top)			70.8
	12	Scarborough Sandstone		19.5 m average	

Slice ID	Layer ID	Name	Elevation Notes	Thickness	Slice height above/ below Bulli Floor (m)
13		Coalcliff Sandstone (Top)	51 m above Bulli Top		51.3
	13	Coalcliff Sandstone / Wombarra Claystone		49 m average	
14		30 m heavy-cracking zone above Bulli Seam	30 m above Bulli Top		30
	14	Coalcliff Sandstone / Wombarra Claystone		27.7 m	
15		Bulli Coal Seam Roof			2.3
	15	Bulli Coal Seam		2.3 m average	
16		Bulli Coal Seam Floor	Data source: Gujarat		0
	16	Loddon Sandstone		9.5 m average	
17		Balgownie Coal Seam Roof			-9.5
	17	Balgownie Coal Seam		1.2 m average	
18		Balgownie Seam Floor			-10.7
	18	Lawrence Sandstone		17.0 m average	
19		Lawrence Sandstone (Bottom)			-27.7
	19	Eckersley Formation		7.6 m average	
20		Wongawilli Coal Seam Roof			-35.3
	20	Wongawilli Coal Seam		9.7 m average	
21		Wongawilli Coal Seam Floor			-45
	21	Kembla Sandstone including coal		9 m	
22		Bottom of Kembla Sandstone			-54
	22	Generalised Sedimentary Unit		50 m	

6.2.3 Existing mines

The existing mines were classified into three groups for the purpose of assigning the degree and extent of subsidence-induced fracturing and associated increase of hydraulic conductivity.

Bord and Pillar workings were considered to have negligible subsidence effects and only little fracturing was imposed on the layer directly above, plus delamination above the fracturing.

The small longwalls with wide pillars mined under, or in the immediate vicinity of, the Cataract Reservoir were considered to have caused limited subsidence and/or disruption to overlying strata. In these areas, subsidence effects were considered to extend to a height of approximately 100 m above the workings. The extensive longwalls, especially in Wonga West, were considered to have caused some surface subsidence and more extensive fracturing and delamination in the overburden materials to a height of approximately 150 m above the workings.

In the Wonga East area where the Balgownie longwalls have undermined the earlier Bulli seam workings it was necessary to simplify the complex situation to a possible ‘average’ equivalent. The main concern was the potential ‘partial’ collapse of the spanning Bulgo Sandstone. Seedsman (Addendum, 2012) discussed three main scenarios (see Seedsman, 2012). For the modelling, an increase in fracturing / hydraulic conductivity of half an order of magnitude compared to the prevailing conditions was assigned as a worst case scenario to the Bulgo Sandstone in the overburden above the Balgownie longwalls (Seedsman, 2012).

All seam extractions were modelled as having been mined or fully collapsed over their entire thickness.

Note that barriers were modelled to extend around the existing NRE1 workings, hydraulically separating these from neighbouring mines. Due to the uncertainly in the width and nature of these barriers, i.e. whether they are only remnant rock / coal, or whether they are at least in part cemented structures, a conservative approach was adopted modelling these barriers as ‘natural material’. The thickness of those barriers, where recorded, were in the order of 40 m. In the model the thickness is variable, based on elements size, and on the order of approximately 30 -100 m.

6.2.4 Faults and Intrusive bodies

Several faults and intrusive bodies, ranging from several-kilometre-wide doleritic intrusions to dykes are present in the study area (Figure 12). Some of these have been mapped, but hydrogeological parameters are not known about these features. The inclusion of these types of features would require knowledge as to the nature of their influence on groundwater flow – that is, whether the faults in question tends to act as conduits facilitating groundwater flow or as “low hydraulic conductivity walls” retarding groundwater flow. Initial attempts to include these features devolved into a circular loop of calibrating hydrogeological parameters to unknown feature properties. Given the uncertainty in connection with these features and the already high complexity of the model these features were not subsequently included into the model.

A large doleritic body is present at the eastern edge of the model, east of former BHP workings. Only limited information is available regarding this intrusion, which indicates a large variability in properties. Given the already large variability of hydraulic conductivity in the area near the escarpment with its incised valleys, this body was not further considered, as it was assessed to not have a quantifiable influence on the model results.

Several dykes are known to be present in the area, with two being prominent: a large SW-NE trending dyke with weathered periphery was shown on maps to be located amongst the old BHP workings to the NE of the Gujarat mines. It was not considered in the modelling as it is outside the area of subsidence. The other dyke was reported to be located between the proposed V-Main workings and the old BHP Cordeaux workings to the South. This was only modelled as a clearly defined separation between the workings, no changes in hydraulic conductivity was applied.

Several small and two ‘large’ faults were identified on maps. One is located to the west and north of the Wonga East area, with reported throws of between 20 and 90 m. Where high throws were reported old bord and pillar workings are shown to have stayed clear of the area, but workings were progressed towards the fault once throws of less than 20 m were recorded. It was considered unlikely that the fault is a high hydraulic conductivity feature, as workings would likely not have been extended in close proximity to the fault, if there was an inflow issue.

Another large fault has been recorded immediately north of existing Wonga West workings in the Bulli seam. Again little is known about its hydrogeological features, but the throw is recorded to be in the order of 90 m, with upthrow to the north. No increase of inflows into the existing workings has been reported, indicating that the feature possibly does not have high hydraulic conductivity. However, off-set of layers with thicknesses on a meter to tens of meter scale can be expected to have some influence on the groundwater regime to the north of the Wonga West workings, as the off-set clearly disrupts the continuity of the coal seams, which are considered to be the main high hydraulic conductivity layers. It is not known whether the fault extends to surface. However, given the complexity of this issue, the offset was not considered in the Feflow model, and observation points north of this fault were not used in the calibration of the model.

6.3 Boundary conditions

Transfer boundaries with high conductivity transfer rates (equivalent to gravelly material) were used to represent creeks.

Cataract Reservoir was represented using constant head boundaries.

Part of the existing Bulli seam and the proposed mine workings in the Wongawilli and Bulli seam within the NRE1 lease and within the existing BHP Appin workings at the northern boundary of the model domain were presumed to be dry / pumped out at present, and those areas were represented using seepage boundary conditions. All other workings such as the old Cordeaux and Bulli workings were assumed to be flooded.

Recharge was applied as 2% of rainfall in each of the three recharge zones (eastern, central and western areas), leading to a slight decrease in recharge from East to West, with the exception of the area above the fully collapsed Bulli / Balgownie seam in Wonga East where recharge was set to a higher value of 4% of rainfall.

6.4 Observation / Calibration Points

The existing VWPs (Table 2) were used as calibration points for the model. Geological borehole logs (for the deep VWPs) were available.

Furthermore it should be noted that in FEFLOW observation points are placed onto slices and not within layers. This can introduce some error, especially where slices are boundaries between materials with large differences in hydraulic conductivity.

Due to the already large complexity of the model, no additional slices were introduced to ‘fine-tune’ calibration where this issue was thought to possibly have a noticeable effect.

6.5 Parameters

Hydraulic parameters adopted for the modelling were based on packer testing (GeoTerra, 2012) and results of extensive groundwater model calibration and sensitivity analyses carried out for the Metropolitan Mine (Heritage Computing, 2010) and BHPB Bulli Seam Environmental Assessments.

Fracturing and subsidence effects were generalised with fracturing and delamination zones above the proposed and existing workings applied in the groundwater model as specified in Section 4.1. The spatial extent of the subsidence zones above the proposed workings are illustrated in Figure 14.

Hydraulic conductivities used in the model for undisturbed areas are summarised in Table 5. The hydraulic conductivities applied in the model to represent the subsidence effects of the existing and proposed mining are summarised in Table 6 and Table 7 respectively. The cell colours illustrate the change in hydraulic conductivity (see Table 4 for colour code).

Figure 15 through to Figure 18 show the conductivity zones for each layer of the model.

Table 4: Colour Code to Tables 6 and 7

Cell Colour	Order of Magnitude Increase in Hydraulic Conductivity
⬜	0
🟦	<0.5
🟦	0.5
🟦	1.0
🟦	1.5
🟦	2.0
🟦	>2.0

Table 5: Original Unsubsided Overburden

Layer	Formation	Top of Model Layer Height above/below top of Bulli Seam	Western Area		Central Area		Eastern Area		East Area Incised Valley		Storativity
			Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	
1	Hawkesbury Sandstone Upper	417	1.50E-06	1.50E-07	7.50E-06	7.50E-07	1.50E-05	1.50E-06	absent	absent	0.01
2	Hawkesbury Sandstone Upper	397	1.50E-06	1.50E-07	7.50E-06	7.50E-07	1.50E-05	1.50E-06	absent	absent	0.01
3	Hawkesbury Sandstone Lower	380	8.10E-09	9.38E-10	4.05E-08	4.69E-09	8.10E-08	9.38E-09	7.64E-07	1.09E-08	0.01
4	Hawkesbury Sandstone Lower	338	8.10E-09	9.38E-10	4.05E-08	4.69E-09	8.10E-08	9.38E-09	7.64E-07	1.09E-08	0.01
5	Newport Formation	260	1.04E-09	1.04E-10	5.20E-09	5.20E-10	1.04E-08	1.04E-09	7.64E-07	1.09E-08	0.01
6	Bald Hill Claystone	248	1.16E-10	3.59E-11	5.80E-10	1.80E-10	1.16E-09	3.59E-10	7.64E-07	1.09E-08	0.01
7	Bulgo Sandstone Upper	228	7.64E-08	1.09E-09	3.82E-07	5.45E-09	7.64E-07	1.09E-08	7.64E-07	1.09E-08	0.01
8	Bulgo Sandstone Upper	177	7.64E-08	1.09E-09	3.82E-07	5.45E-09	7.64E-07	1.09E-08	not	affected	0.01
9	Bulgo Sandstone Lower	157	8.10E-10	1.16E-10	8.10E-10	1.16E-10	8.10E-10	1.16E-10	not	affected	0.01
10	Bulgo Sandstone Lower	108	8.10E-10	1.16E-10	8.10E-10	1.16E-10	8.10E-10	1.16E-10	not	affected	0.01
11	Stanwell Park Claystone	86	4.28E-10	4.28E-12	4.28E-10	4.28E-12	4.28E-10	4.28E-12	not	affected	0.01
12	Scarborough Sandstone	68	1.16E-08	1.16E-09	1.16E-08	1.16E-09	1.16E-08	1.16E-09	not	affected	0.01
13	Coalcliff Sandstone	49	6.37E-10	4.05E-12	6.37E-10	4.05E-12	6.37E-10	4.05E-12	not	affected	0.01
14	Coalcliff Sandstone	28	6.37E-10	4.05E-12	6.37E-10	4.05E-12	6.37E-10	4.05E-12	not	affected	0.01
15	Bulli Seam	0	1.16E-08	1.16E-09	1.16E-08	1.16E-09	1.16E-08	1.16E-09	not	affected	0.03
16	Loddon Sandstone	-2.5	2.00E-10	2.31E-11	2.00E-10	2.31E-11	2.00E-10	2.31E-11	not	affected	0.01
17	Balgownie Seam	-12	1.16E-08	1.16E-09	1.16E-08	1.16E-09	1.16E-08	1.16E-09	not	affected	0.01
18	Lawrence Sandsone	-14	7.64E-08	1.09E-09	7.64E-08	1.09E-09	7.64E-08	1.09E-09	not	affected	0.01
19	Eckersly Formation	-30	9.77E-09	1.04E-10	9.77E-09	1.04E-10	9.77E-09	1.04E-10	not	affected	0.01
20	Wongawiili Seam	-38	1.16E-08	1.16E-09	1.16E-08	1.16E-09	1.16E-08	1.16E-09	not	affected	0.03
21	Kembla sandstone	-47	7.64E-09	2.31E-10	7.64E-09	2.31E-10	7.64E-09	2.31E-10	not	affected	0.01

Kh : Horizontal Conductivity, Kv : Vertical Conductivity

Table 6: Subsided Bulli and Balgownie Workings

Layer	Formation	Top of Model Layer Height above/below top of Bulli Seam	Balgownie Longwall		Western Longwalls[1]		Central and Eastern Narrow Longwalls[2]		Bord & Pillar Workings		Storativity
			Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	
1	Hawkesbury Sandstone Upper	417	1.05E-04	1.05E-05	1.05E-05	1.05E-06	1.05E-04	1.05E-05	original (W)	original (W)	0.03
2	Hawkesbury Sandstone Upper	397	1.05E-04	7.50E-06	1.05E-05	7.50E-07	7.50E-05	7.50E-06	original (W)	original (W)	0.02
3	Hawkesbury Sandstone Lower	380	5.67E-07	original (E)	5.67E-08	original (W)	4.05E-07	original (E/C)	original (W)	original (W)	0.02
4	Hawkesbury Sandstone Lower	338	4.05E-07	original (E)	4.05E-08	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.02
5	Newport Formation	260	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
6	Bald Hill Claystone	248	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
7	Bulgo Sandstone Upper	228	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
8	Bulgo Sandstone Upper	177	3.82E-06	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
9	Bulgo Sandstone Lower	157	5.67E-09	5.80E-10	4.05E-09	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.02
10	Bulgo Sandstone Lower	108	8.10E-09	8.12E-10	2.30E-09	5.80E-10	4.05E-09	original (E/C)	original (W)	original (W)	0.02
11	Stanwell Park Claystone	86	4.28E-09	4.28E-11	3.00E-09	3.00E-11	3.00E-09	2.14E-11	original (W)	original (W)	0.02
12	Scarborough Sandstone	68	5.80E-07	5.80E-08	1.16E-07	5.79E-09	7.00E-08	5.80E-09	original (W)	original (W)	0.02
13	Coalcliff Sandstone	49	3.19E-08	2.03E-10	1.00E-08	1.00E-08	6.00E-09	3.00E-09	3.19E-09	2.03E-11	0.03
14	Coalcliff Sandstone	28	6.37E-08	4.05E-10	4.00E-08	4.00E-08	9.00E-09	9.00E-09	6.00E-09	6.00E-11	0.03
15	Bulli Seam	0	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	0.03[#]
16	Loddon Sandstone	-2.5	1.16E-07	8.10E-08	9.00E-10	original (W)	7.00E-10	original (E/C)	original (W)	original (W)	0.01
17	Balgownie Seam	-12	1.16E-05	1.16E-05	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
18	Lawrence Sandsone	-14	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
19	Eckersly Formation	-30	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
20	Wongawiili Seam	-38	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.03[#]
21	Kembla sandstone	-47	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01

[1] width and length range: 190x760 m to 190x1,450 m [2] width and length range: 145x670 m to 145x1,010 m [#] 0.9 for mined areas

Kh : Horizontal Conductivity, Kv : Vertical Conductivity

(E)-East (W)-West (C)-Central

Table 7: Subsided Proposed Wongawilli Seam Workings

Layer	Formation	Top of Model Layer Height above/below top of Bulli Seam	Proposed Wonga East - over Balgownie[3]		Proposed Wonga West[3]		V- Main		Storativity
			Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	
1	Hawkesbury Sandstone Upper	417	1.05E-03	1.05E-04	1.05E-04	1.05E-05	1.50E-05	1.50E-06	0.03
2	Hawkesbury Sandstone Upper	397	1.05E-03	3.75E-05	1.05E-04	3.75E-06	1.50E-05	7.50E-07	0.02
3	Hawkesbury Sandstone Lower	380	3.97E-06	original (E)	2.84E-07	original (W)	5.67E-08	original (W)	0.02
4	Hawkesbury Sandstone Lower	338	2.03E-06	original (E)	2.03E-07	original (W)	4.05E-08	original (W)	0.02
5	Newport Formation	260	original (E)	original (E)	original (W)	original (W)	original (W)	original (W)	0.01
6	Bald Hill Claystone	248	original (E)	original (E)	original (W)	original (W)	original (W)	original (W)	0.01
7	Bulgo Sandstone Upper	228	3.82E-07	original (E)	original (W)	original (W)	original (W)	original (W)	0.01
8	Bulgo Sandstone Upper	177	2.67E-05	5.45E-09	3.82E-07	original (W)	original (W)	original (W)	0.02
9	Bulgo Sandstone Lower	157	5.67E-08	4.06E-09	4.00E-09	5.80E-10	original (W)	original (W)	0.02
10	Bulgo Sandstone Lower	108	8.10E-08	8.12E-09	1.20E-08	3.40E-09	4.05E-09	original (W)	0.02
11	Stanwell Park Claystone	86	4.28E-08	4.28E-10	2.10E-08	2.10E-10	2.14E-09	2.14E-11	0.02
12	Scarborough Sandstone	68	5.80E-06	5.80E-07	1.20E-06	5.80E-08	1.16E-07	1.16E-08	0.03
13	Coalcliff Sandstone	49	1.59E-07	1.01E-09	1.00E-07	1.00E-07	3.19E-08	2.03E-10	0.03
14	Coalcliff Sandstone	28	3.19E-07	2.03E-09	4.00E-07	4.00E-07	6.37E-08	4.05E-10	0.03
15	Bulli Seam	0	1.16E-05	1.16E-05	1.20E-05	1.20E-05	1.16E-05	1.16E-05	0.03[#]
16	Loddon Sandstone	-2.5	1.16E-07	8.10E-08	1.02E-08	1.20E-09	2.00E-09	original (W)	0.03
17	Balgownie Seam	-12	1.16E-05	1.16E-05	5.80E-07	5.80E-08	original (W)	original (W)	0.03
18	Lawrence Sandsone	-14	5.80E-07	5.80E-08	3.80E-06	5.40E-08	original (W)	original (W)	0.03
19	Eckersly Formation	-30	3.82E-06	5.45E-08	4.90E-07	5.20E-09	original (W)	original (W)	0.03
20	Wongawiili Seam	-38	1.16E-05	1.16E-05	1.20E-05	1.20E-05	original (W)	original (W)	0.03[#]
21	Kembla sandstone	-47	7.64E-08	original (E)	7.60E-08	original (W)	original (W)	original (W)	0.01

[3] hydraulic conductivities superimposed on existing disturbed material longwall size up to 390x2,500 m [#] 0.9 for mined areas

Kh : Horizontal Conductivity, Kv : Vertical Conductivity

(E)-East (W)-West (C)-Central

7.0 MODEL RESULTS

7.1 Overview

The purpose of this modelling study was to assess the influence that the proposed extraction of Wonga East, Wonga West and VMains may have on current conditions, in addition to the effects of the existing workings.

Accordingly one of the main aims of the study has been to assess whether the Bald Hill Claystone is sufficient to limit the effects of depressurisation on Cataract Dam in the Wonga West area. Because of the limited extent of available data and the uncertainties regarding subsidence over multi-seam coal extractions, it is only possible to provide predicted values for changes in groundwater levels and groundwater inflows to/outflows from surface water bodies.

A quasi-steady state model was developed to reflect the current case (existing workings). Calibration of the model was performed using measured water levels presented in Table 2 with resultant heads shown in Figure 19.

Three transient models were then run for the following cases:

1) **Stage 1 -** The 6.5 years from current case to end of mining of Wonga East (Areas 1 and 2) and V Mains (all three areas modelled simultaneously);

2) **Stage 2 -** The resultant heads from Stage 1 were then used as initial conditions for the second scenario which represented the subsequent 8 years to end of mining for Wonga West (Areas 3 and 4, both areas modelled simultaneously).

3) **Recovery** - The resultant heads from Stage 2 were then used as initial conditions for a 10-year recovery model with no pumping from the NRE1 (or Appin) workings.

7.2 Calibration for Current Case

Calibration results (modelled head versus measured heads) are shown in Figure 20. The largest discrepancies between the modelled and actual hydraulic heads are associated with the following factors:

- the limitations of the model in terms of representing the complex subsidence pattern associated with the existing Balgownie longwalls in Wonga East, and the uncertainty in variability of subsidence effects above the longwalls of variable size in Wonga West;
- the requirement within FEFLOW to place observation points on layer boundaries rather than within layers, and the decision (based on modelling efficiency) not to discretise lower hydraulic conductivity units into sub-layers; and
- areas of the model where numerous zones of different hydraulic conductivities border each other, and for which the exact locations of boundaries in relation to monitoring bores/piezometers are not known accurately.

7.3 Estimated Depressurisation Resulting from Proposed Workings

Depressurisation resulting from the proposed workings has been evaluated at four elevations: Upper Hawkesbury Sandstone, Lower Hawkesbury Sandstone, Upper Bulgo Sandstone and Wongawilli Coal Seam. The estimated depressurisation at the corresponding model surfaces for end-of-mining is discussed in the following sections.

7.3.1 Stage 1 Mining in Area 1, Area 2 and VMains

Stage 1 development was modelled as the simultaneous introduction of all proposed Wonga East and the V Mains workings in Wonga West area for 6.5 years.

Contours of drawdown (relative to current steady-state conditions) are shown in Figure 21 to Figure 27. Drawdown at the end-of-mining of Stage 1 is shown for the Upper Hawkesbury Sandstone (Figure 21), Lower Hawkesbury Sandstone (Figure 22), Upper Bulgo Sandstone (Figure 23), Lower Bulgo Sandstone

(Figure 24), Scarborough Sandstone (Figure 25), Bulli Coal Seam (Figure 26) and Wongawilli Coal Seam (Figure 27).

Drawdown in relation to the introduction of the VMain workings extends mainly in a southerly direction, due to the already existing depressurisation in and above the existing Wonga West workings immediately to the North.

Drawdown at the end of mining, in the Upper and Lower Hawkesbury at Wonga East is less than 5 m. The Upper Bulgo Sandstone has a drawdown of 6 m in Wonga West over VMains and 8 m in Wonga East. The Lower Bulgo Sandstone has a drawdown of 50 m in Wonga West over VMains and 30 m in Wonga East. Drawdown in the Scarborough Sandstone is 110 m over VMains in Wonga West and less than 50 m in Wonga East. The Bulli Coal Seam experiences 130 m of drawdown in Wonga West and 50 m drawdown in Wonga East, whilst the Wongawilli Coal Seam experiences 60 m drawdown in Wonga West and 50 m drawdown in Wonga East.

Figure 28 shows a drawdown cross-section passing through the proposed workings in VMains and Wonga East at the end-of-mining of Stage 1. The depressurisation zone surrounding the proposed workings is restricted to below the Upper Bulgo Sandstone except in Wonga East where the fracturing of the spanning Bulgo Sandstone, and the partial erosion of the Bald Hill Claystone has lead to a more permeable connection between the workings and the surface.

7.3.2 Stage 2 Mining in Area 3 and Area 4

Stage 2 development was modelled as the simultaneous introduction of the two stages of proposed development in the Wonga West area, and over an additional 8 years. Mining was considered to be completed in Wonga East with only the access drift between Wonga West and East being kept dry.

Contours of drawdown (relative to current steady-state conditions) are shown in Figure 29 to Figure 35. Drawdown at the end-of-mining of Stage 2 is shown for the Upper Hawkesbury Sandstone (Figure 29), Lower Hawkesbury Sandstone (Figure 30), Upper Bulgo Sandstone (Figure 31), Lower Bulgo Sandstone (Figure 32), Scarborough Sandstone (Figure 33), Bulli Coal Seam (Figure 34) and Wongawilli Coal Seam (Figure 35).

Drawdown of less than 12 m occurs in the Upper and Lower Hawkesbury Sandstone in Wonga West. Drawdown in the Upper Bulgo Sandstone, below the Bald Hill Claystone, is up to 100 m in Wonga West but has decreased to 5 m in Wonga East, where mining has ceased and the recovery starts to occur. Similarly, drawdown in the Lower Bulgo Sandstone is 180 m in Wonga West but only 10 m in Wonga East.

The Scarborough Sandstone has drawdown of 140 m over the Wonga West Wongawilli workings, 100 m over VMains and 20 m in Wonga East.

Drawdown in the Bulli Coal Seam is shown to be up to 120 m in the west and up to approximately 20 m in the east.

Drawdown in the Wongawilli Coal Seam, which contains the majority of the proposed workings in Wonga West and East, is up to 90 m in the west and up to approximately 40 m in the east along the access rift. Note that the access rift between the Wonga West and East workings was modelled by applying seepage boundaries to the nodes, but no subsidence was modelled to occur above the first workings.

Figure 36 shows a drawdown cross-section passing through the proposed workings in Wonga West at the end-of-mining of Stage 2. There is a slight extension of the depressurisation zone into the Lower Hawkesbury but it is mainly restricted by the Bald Hill Claystone.

7.3.3 Ten-Year Recovery

After Stage 2, boundary conditions representing removal of water from all mines in the model domain (including the Appin workings to the north of Wonga West) were removed from the model which was then run for a further 10 years. Figure 37 to Figure 43 show changes in water levels from current case (initial conditions) to ten years after mining has ceased (levels above current case are shown as negative values).

Model results for the Upper and Lower Hawkesbury show full recovery in Wonga East and recovery commencing in Wonga West. Total heads in the Upper and Lower Bulgo Sandstone were modelled to be still below current levels in the Wonga West area during the 10-year recovery period, while all other areas show rises in head levels between the current day situation and after 10 years of recovery.

The Bulli and Wongawilli Coal Seams show significant recovery after 10 years, in both the Wonga West and the Wonga East areas.

7.3.4 Effects on surface water features

The model has been used to interpret potential changes to stream flow, however the resolution of the model in terms of actual flow volume is limited, i.e., streams are modelled as transfer boundary conditions allowing for the potential recharge or discharge of water into and out of the model domain. Creeks are modelled as being always flowing. Based on modelling results, the potential effects of the proposed mine workings on Cataract reservoir are considered to be negligible. Modelled effects on the creeks manifested as a reduction in discharge to the creek (recharge from the creek into the model remained unchanged). Quantities shown in Table 8 represent a total reduction along the full length of the creek.

Table 8: Effects on Creeks

Creek	Modelled Reduction in Discharge to Creek (ML/d)
Cataract	0.07
Bellambi	0.03
Wallandoola	0.25
Lizard	0.10

Geoterra (2012) and other studies carried out for swamps indicate that they have perched water tables which are separated from the deeper regional water table by 10 – 20 m. These perched water table systems have not been specifically represented in the regional model.

In the Wonga West area, the model indicates possible 12 m drawdown in the Hawkesbury Sandstone at the end of mining. In the Wonga East area, Cataract Creek and Cataract River cross the area that has already been impacted by subsidence. At Wonga East, the model predicts drawdown of up to 8 m in the Upper Bulgo Sandstone, and 5 m in the overlying Hawkesbury Sandstone.

In the area of Bellambi Creek and the Cataract River upstream of Cataract Reservoir, the model indicates negligible drawdown in the Hawkesbury Sandstone and Bulgo Sandstone. This is further illustrated by the modelled groundwater flow directions in the Upper and Lower Hawkesbury Sandstones, shown in Figure 44 to Figure 55 for all four creeks for current case, Stage 1 and Stage 2 (note that the scale of the velocity vectors varies between the figures).

7.4 Mine Inflow Rates

Model-generated flow rates into the proposed Wongawilli Seam workings at the end of mining are presented in Table 9.

Table 9: Model-Generated Inflow Rates (ML/d)

	Current Bulli Seam Workings	End of Mining Wongawilli Seam Workings
Wonga East	0.2	1.4
Wonga West	0.9	1.7

The modelled current groundwater inflows to the existing workings are relatively close to the monitored 0.6 ML/day of water pumped out of the workings, which with 0.11 ML/day of extracted moisture in air and 0.1 ML/day of moisture in extracted coal, represents approximately an average of 0.81 ML/day of groundwater make to the workings.

7.5 Sensitivity Analysis

An additional scenario is presented here to further explore sensitivity to parameters and possible variations in the hydrogeological model.

Scenario 2 was modelled as a case that had increased subsidence over the proposed workings in Wonga East and decreased subsidence above the Bald Hill Claystone in Wonga West. The parameter set is shown in Table 10.

Table 10: Scenario 2 - Changed Parameters (compared to Scenario 1)

Layer	Formation	Proposed Wonga East - over Balgownie		Proposed Wonga West		V- Main	
		Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)
1	Hawkesbury Sandstone Upper	3.0E-03	2.5E-05	original (W)	original (W)	original (W)	original (W)
2	Hawkesbury Sandstone Upper	3.0E-03	2.5E-05	original (W)	original (W)	original (W)	original (W)
3	Hawkesbury Sandstone Lower	1.9E-05	2.7E-07	original (W)	original (W)	original (W)	original (W)
4	Hawkesbury Sandstone Lower	1.9E-05	2.7E-07	original (W)	original (W)	original (W)	original (W)
5	Newport Formation	1.9E-05	2.7E-07	original (W)	original (W)	original (W)	original (W)
6	Bald Hill Claystone	1.9E-05	2.7E-07	original (W)	original (W)	original (W)	original (W)
7	Bulgo Sandstone Upper	3.8E-05	5.4E-07	3.8E-07	original (W)	original (W)	original (W)
8	Bulgo Sandstone Upper	3.8E-05	5.4E-07	3.8E-07	5.4E-09	original (W)	original (W)
9	Bulgo Sandstone Lower	8.1E-08	1.2E-08	4.0E-09	5.8E-10	original (W)	original (W)
10	Bulgo Sandstone Lower	8.1E-08	1.2E-08	1.2E-08	3.4E-09	4.0E-09	original (W)
11	Stanwell Park Claystone	2.1E-07	2.1E-09	2.1E-08	2.1E-10	2.1E-09	2.1E-11
12	Scarborugh Sandstone	5.8E-06	5.8E-07	1.2E-06	5.8E-08	1.2E-07	1.2E-08
13	Coalcliff Sandstone	3.2E-07	2.0E-09	1.0E-07	1.0E-07	3.2E-08	2.0E-10
14	Coalcliff Sandstone	3.2E-07	2.0E-09	4.0E-07	4.0E-07	6.4E-08	4.0E-10
15	Bulli Seam	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05
16	Loddon Sandstone	1.2E-07	8.1E-08	1.02E-08	1.2E-09	2.0E-09	original (W)
17	Balgownie Seam	1.2E-05	1.2E-05	5.8E-07	5.8E-08	original (W)	original (W)
18	Lawrence Sandsone	5.8E-07	5.8E-08	3.8E-06	5.4E-08	original (W)	original (W)
19	Eckersly Formation	3.8E-06	5.4E-08	4.9E-07	5.2E-09	original (W)	original (W)
20	Wongawiili Seam	1.2E-05	1.2E-05	1.2E-05	1.2E-05	original (W)	original (W)
21	Kembla sandstone	7.6E-08	original (W)	7.6E-08	original (W)	original (W)	original (W)

Stage 1 drawdown in Wonga West increased to 20 m in the Upper Hawkesbury Sandstone (Figure 56). This induced a larger reduction in discharge to Cataract Creek (to 0.4 ML/d) and, to a lesser extent, Bellambi Creek (to 0.2 ML/d). Modelled inflows to the proposed Wonga East Wongawilli workings were 1.4 ML/d.

Drawdowns in the Upper and Lower Hawkesbury Sandstones were negligible in Wonga West with negligible effects on Wallandoola and Lizard Creeks. There was less drawdown in the Upper Bulgo Sandstone (Figure 57), whilst drawdown in Scarborough Sandstone, Bulli and Wongawilli Coal Seams drawdown remained relatively unchanged. Modelled inflows to the proposed Wonga West Wongawilli workings were 1.7 ML/d.

7.6 Results Summary

The modelling undertaken gives indicative results with respect to effects of proposed mine workings on existing ground and surface waters in the study area. The main results of modelling are as follow:

- In the Wonga West area, based on the geotechnical assessment and the derived hydraulic parameters, the proposed longwalls will significantly depressurise the strata below the Bald Hill Claystone. Geotechnical studies indicate that the current hydraulic conductivity of this unit is unlikely to be unaffected by subsidence as a result of the proposed workings.

  With the unfractured Bald Hill Claystone intact, the model indicated that near-surface depressurisation and effects on the Cataract reservoir are estimated to be negligible.

- In the Wonga East area, the geotechnical studies indicate that the Bulgo Sandstone (the main spanning unit in the area) has been at least partially subsided and fractured as a result of existing workings. As a result, the proposed workings, which will increase the subsidence / fracturing, indicate depressurisation of the order of 10 – 20 m near-surface.

It should be noted that because of the lack of available data, model results should be regarded as predictive only. Note also that the results, especially the extent of the magnitude of depressurisation outside the immediate vicinity of the proposed workings, are sensitive to the current state of existing workings, such as whether they are hydraulically separated from each other, and whether they are dry or flooded (those assumptions were outlined previously).

8.0 RECOMMENDATIONS

The following recommendations are made:

- Additional data would be required if further modelling is required to more accurately assess the likely impacts of the proposed workings. Additional data would include (but would not be limited to) a detailed assessment of the current status of all existing workings with regards to flooded / naturally dry / pumped dry, as the extent of flooding /pumping has been shown to have noticeable effect on the extent of depressurisation in areas throughout the extensively mined catchment.

- Continued monitoring of the areas should be carried out around and between the Wonga West and Wonga East proposed workings and the water supply dams, with respect to water levels in the dams as well as potential mine inflows.

9.0 LIMITATIONS

Model performance is dictated by data availability. The limited piezometric data and borehole geological information available for this modelling study has resulted in simplifications and assumptions to be made regarding model structure and parameters. For example, some parameter values have been taken from published literature and some geology formations have been simplified which limits the capabilities of the model.

All existing workings were assumed to be flooded, except for locations in the existing NRE1 workings which were considered to be pumped and the BHP Appin workings north of Wonga West.

The Bald Hill Claystone, where currently considered intact, was assumed to remain unaffected by subsidence above the proposed (Wonga West) workings. As a result, the model indicates negligible drawdown in overlying strata, and we have therefore concluded that there is likely to be negligible impact on surface water flows in this area. However, we note that if subsidence develops in this area and causes changes in the hydraulic conductivity of more brittle strata overlying the Bald Hill Claystone, this may cause changes to near surface recharge and discharge patterns. Specific details of likely changes in hydraulic conductivity and a more localised model would be required to assess these possible impacts.

The effects of fracturing were represented by changes in hydraulic conductivity. For each layer, those changes were applied uniformly through the extent of the fracturing zone (i.e., individual fractures have not been modelled). Those parameter changes, and the extent of fracturing zones have been applied using general rules (outlined in Section 4.2) and will not necessarily capture the full extent of localised drawdown due to localised fracture flow.

Due to some limitations in the ability of the software to resolve thin layers for the full extent of the cross-sections, several individual lithologies have been incorporated into fewer (and thicker) layers with conductivities gauged to be representative of the combined components.

The parameters and changes thereof used in this study largely depended on available published data from other studies undertaken in the wider vicinity of the study area and from geotechnical studies undertaken for proposed workings. It should be noted that the geotechnical studies clearly state that multiseam (longwall) mining is a relatively new concept in Australia. Accordingly not much experience or precedence is present. Hence there is a larger than normal degree of uncertainty in connection with the prediction of subsidence above such workings. All hydraulic parameters chosen are naturally affected by the geotechnical uncertainty plus a further uncertainty in correlating changes in hydraulic parameters with the predicted subsidence effects. Only thorough monitoring of the groundwater levels can determine the validity of the parameters chosen in this study.

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Report Signature Page

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Scott Weeks Senior Numerical Modeller	Scott Fidler Principal

MCN-SWW/SF/sww

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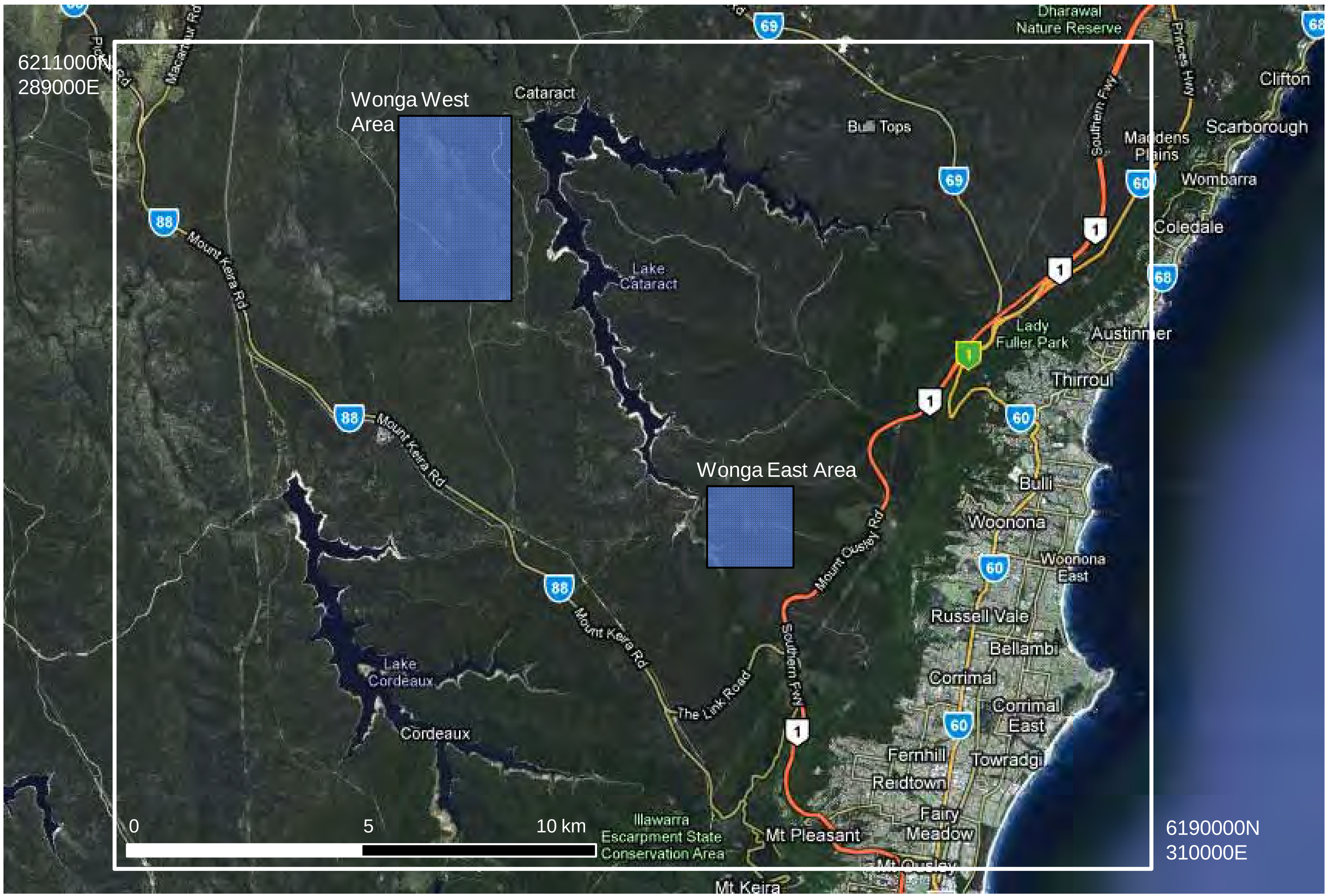
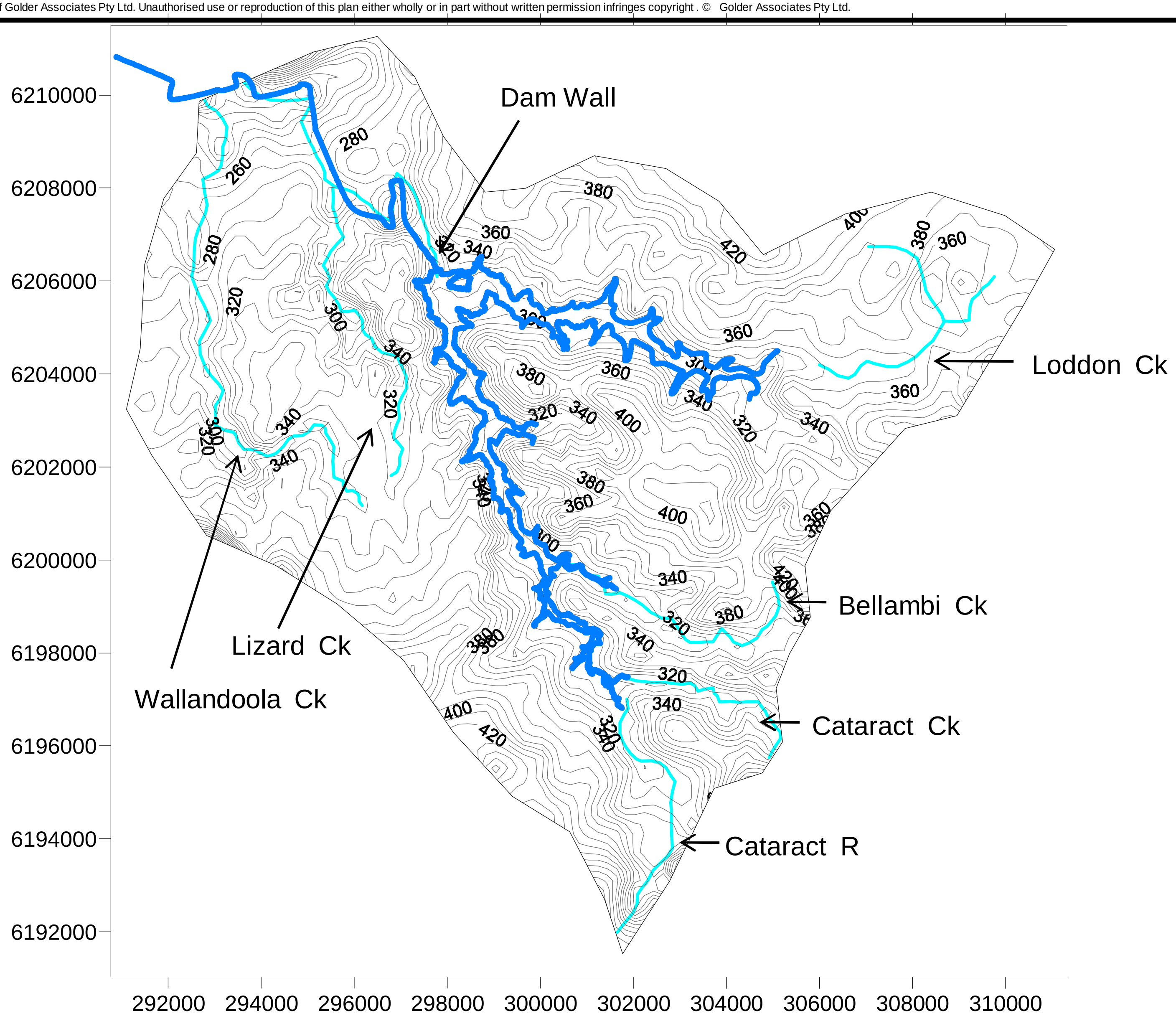
FIGURES



🟦 Study Areas

CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Location of Study Area**	
CHECKED	DATE		
SCALE As shown		PROJECT No 107636001	FIGURE No 1 · REV No · A4



▬	**Cataract Reservoir**
▬	**Creeks**
—320—	**Elevation (mAHD)**

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CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Topography and Main Water Bodies**	
CHECKED	DATE		
SCALE As shown		PROJECT No 107636001	FIGURE No 2
		REV No	A4

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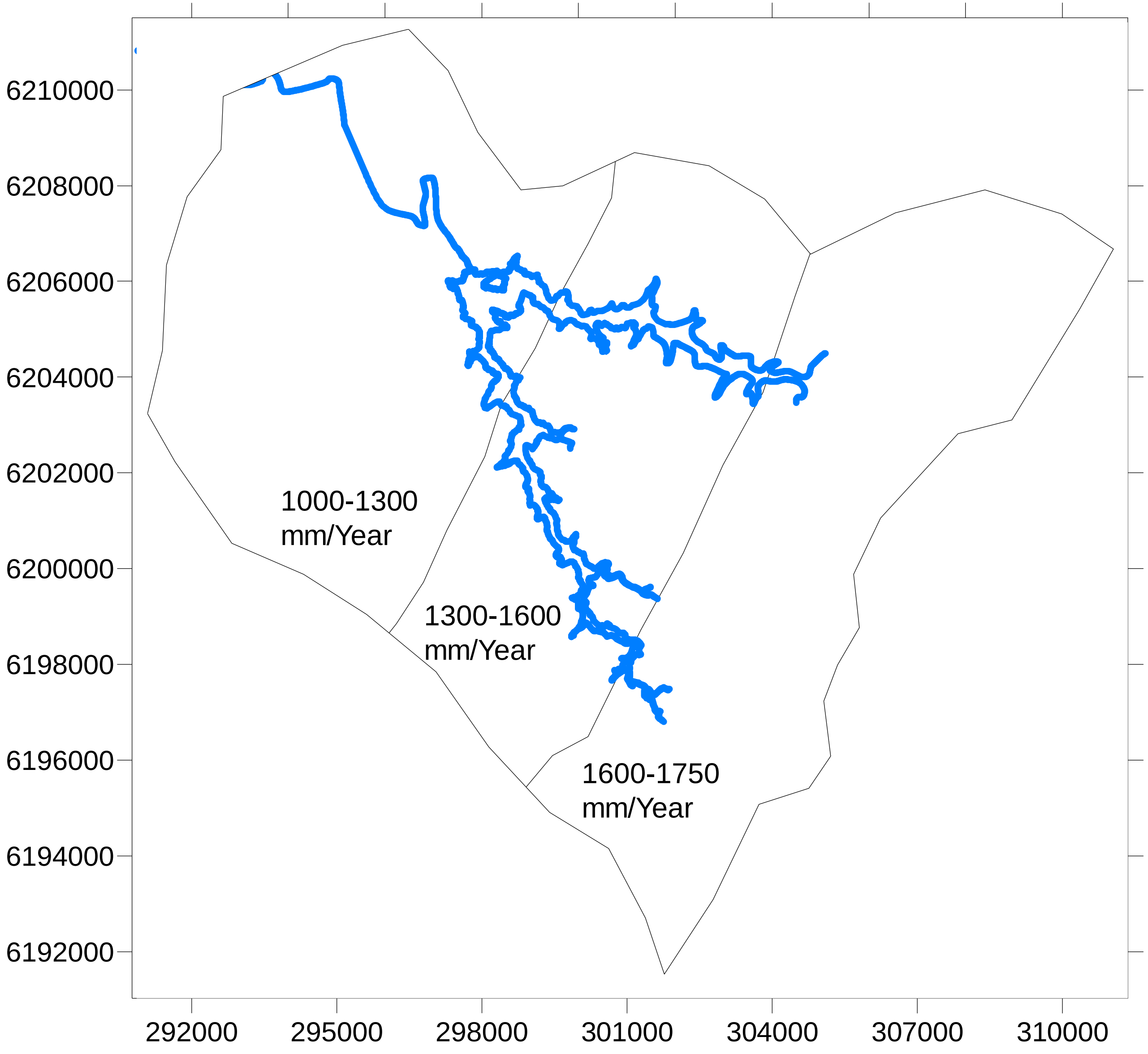
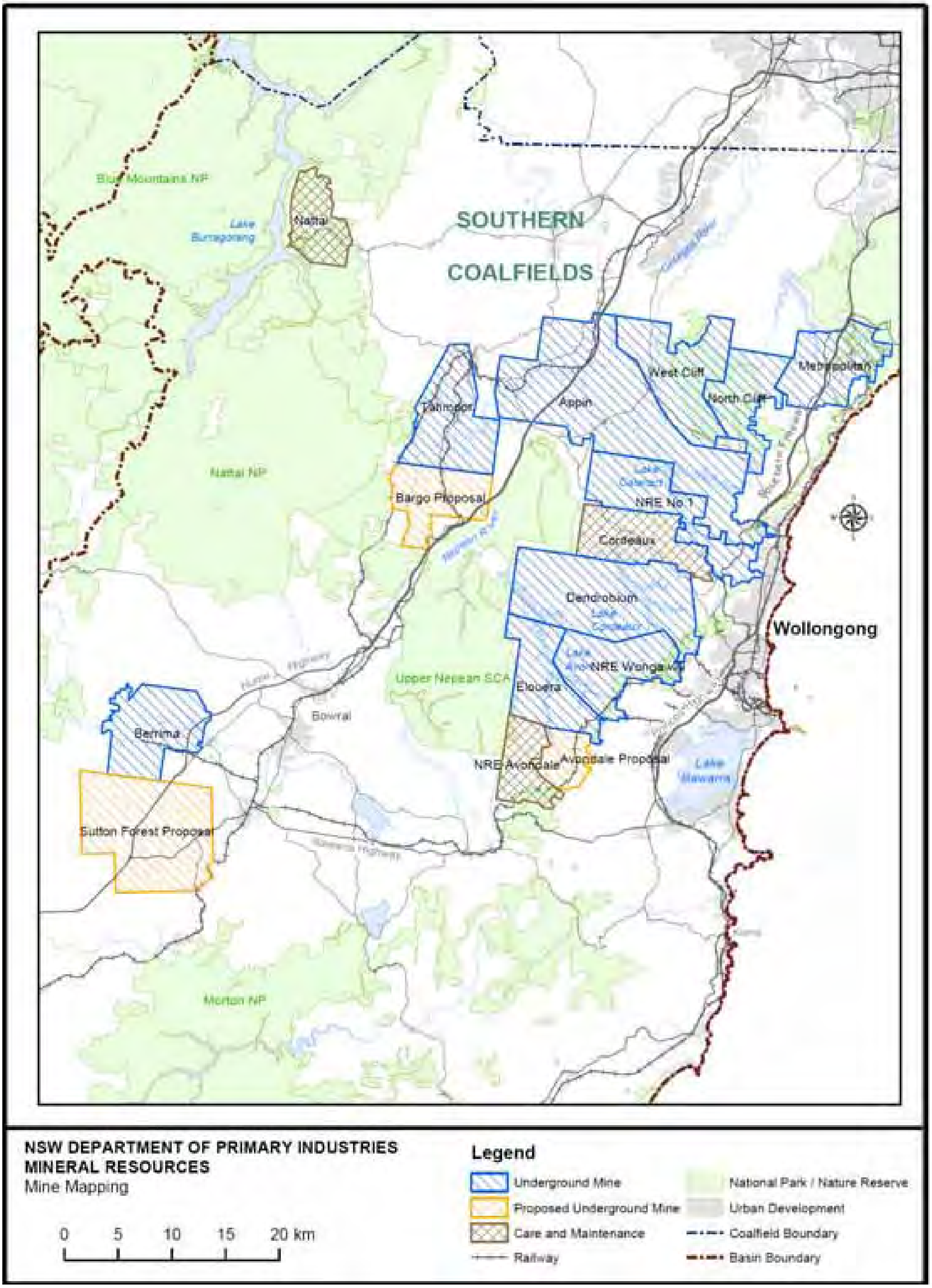


▬ **Cataract Reservoir**

CLIENT	Gujarat
PROJECT	Groundwater Modelling
DRAWN	SWW
DATE	Nov 2011
CHECKED	
DATE	
TITLE	**Mean Annual Rainfall Zones (summarised from WRM, 2010)**
SCALE	As shown
PROJECT No	107636001
FIGURE No	3
REV No	
	A4



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CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

TITLE Current and Proposed Coal Mining Areas in the Southern Coalfield (NSW Govt , 2008)

SCALE As Shown

PROJECT No 107636001

FIGURE No 4

REV No T

A4

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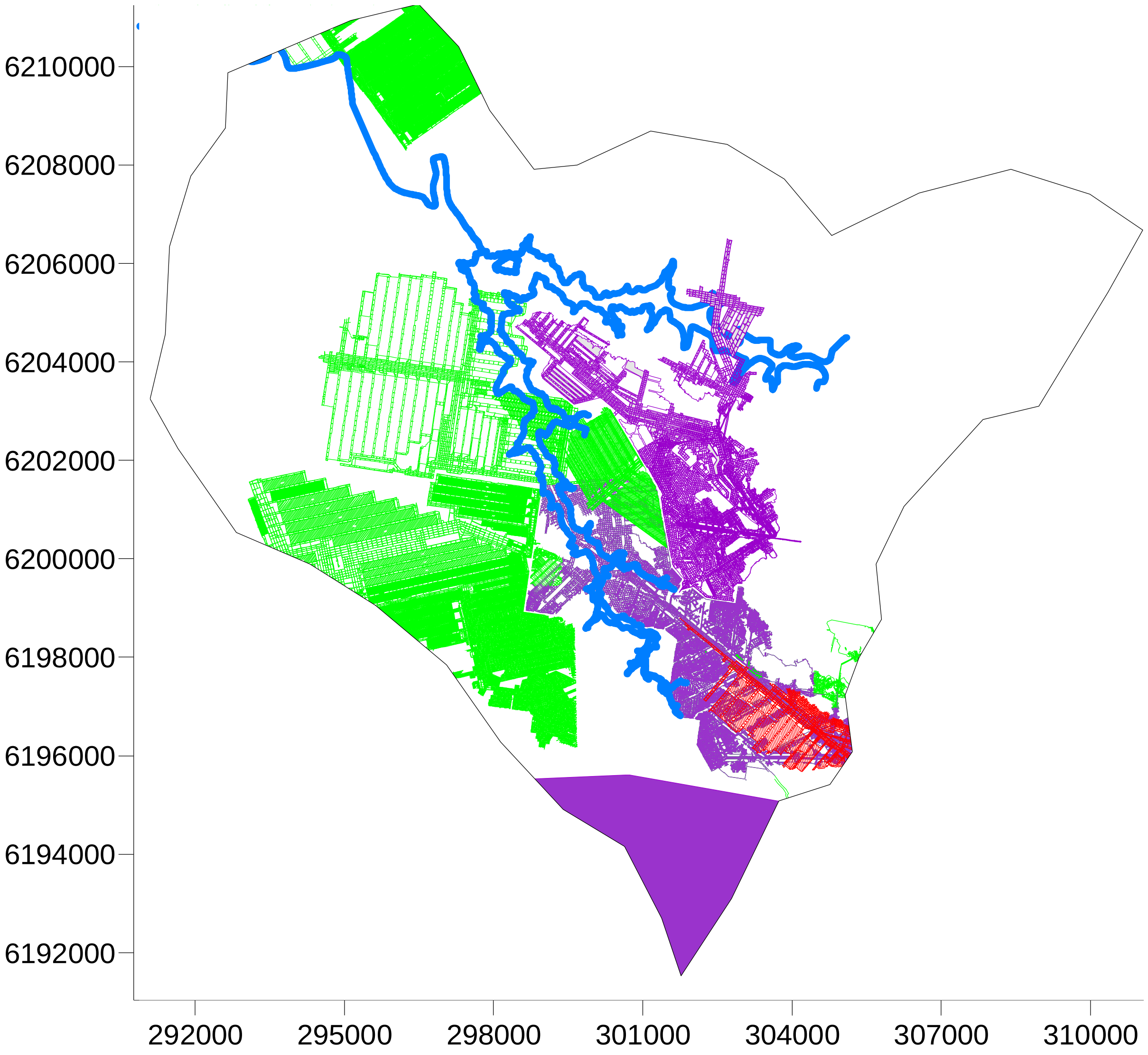
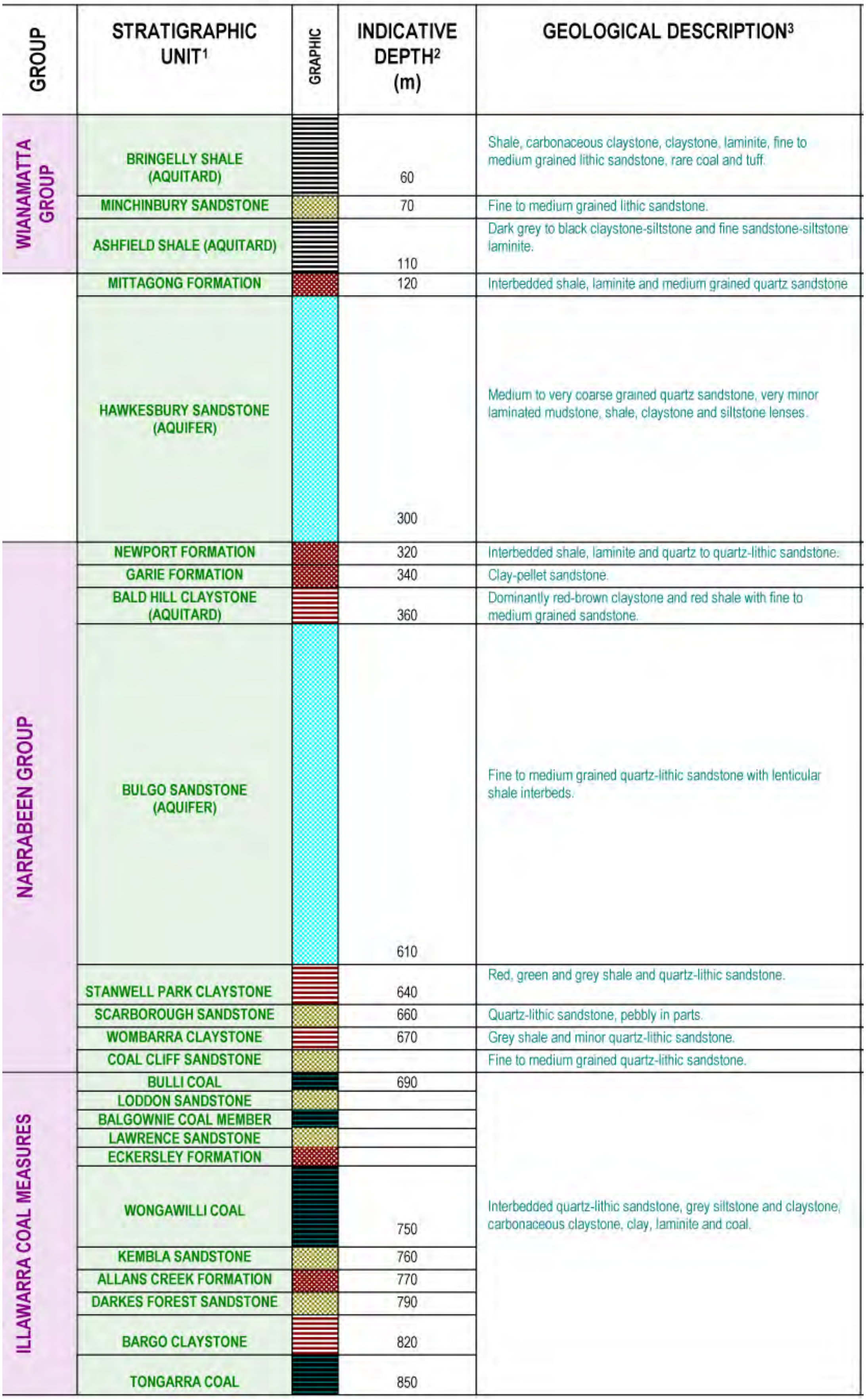


🟦 **Cataract Reservoir**
🟩 **Bulli Longwall**
🟪 **Bulli Bord and Pillar**
🟥 **Balgownie Longwall**

Golder Associates	CLIENT Gujarat		PROJECT Groundwater Modelling			
	DRAWN SWW	DATE Nov 2011	TITLE **Existing Workings by Seam and Type**			
	CHECKED	DATE				
	SCALE As shown		PROJECT No 107636001	FIGURE No **5**	REV No	**A4**



GROUP	STRATIGRAPHIC UNIT[1]	GRAPHIC	INDICATIVE DEPTH[2] (m)	GEOLOGICAL DESCRIPTION[3]
WIANAMATTA GROUP	BRINGELLY SHALE (AQUITARD)	▤	60	Shale, carbonaceous claystone, claystone, laminite, fine to medium grained lithic sandstone, rare coal and tuff.
	MINCHINBURY SANDSTONE	▒	70	Fine to medium grained lithic sandstone.
	ASHFIELD SHALE (AQUITARD)	▤	110	Dark grey to black claystone-siltstone and fine sandstone-siltstone laminite.
	MITTAGONG FORMATION	▩	120	Interbedded shale, laminite and medium grained quartz sandstone
	HAWKESBURY SANDSTONE (AQUIFER)	▦	300	Medium to very coarse grained quartz sandstone, very minor laminated mudstone, shale, claystone and siltstone lenses.
NARRABEEN GROUP	NEWPORT FORMATION	▩	320	Interbedded shale, laminite and quartz to quartz-lithic sandstone.
	GARIE FORMATION	▩	340	Clay-pellet sandstone.
	BALD HILL CLAYSTONE (AQUITARD)	☰	360	Dominantly red-brown claystone and red shale with fine to medium grained sandstone.
	BULGO SANDSTONE (AQUIFER)	▦	610	Fine to medium grained quartz-lithic sandstone with lenticular shale interbeds.
	STANWELL PARK CLAYSTONE	☰	640	Red, green and grey shale and quartz-lithic sandstone.
	SCARBOROUGH SANDSTONE	▒	660	Quartz-lithic sandstone, pebbly in parts.
	WOMBARRA CLAYSTONE	☰	670	Grey shale and minor quartz-lithic sandstone.
	COAL CLIFF SANDSTONE	▒		Fine to medium grained quartz-lithic sandstone.
ILLAWARRA COAL MEASURES	BULLI COAL	■	690	Interbedded quartz-lithic sandstone, grey siltstone and claystone, carbonaceous claystone, clay, laminite and coal.
	LODDON SANDSTONE	▒		
	BALGOWNIE COAL MEMBER	■		
	LAWRENCE SANDSTONE	▒		
	ECKERSLEY FORMATION	▩		
	WONGAWILLI COAL	■	750	
	KEMBLA SANDSTONE	▒	760	
	ALLANS CREEK FORMATION	▩	770	
	DARKES FOREST SANDSTONE	▒	790	
	BARGO CLAYSTONE	☰	820	
	TONGARRA COAL	■	850	

Source: The Design of a Hydrological and Hydrogeological Monitoring Program to Assess the Impact of Longwall Mining in SCA Catchments

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CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

TITLE Simplified stratigraphy of the Southern Sydney Basin (NSW DIPNR)

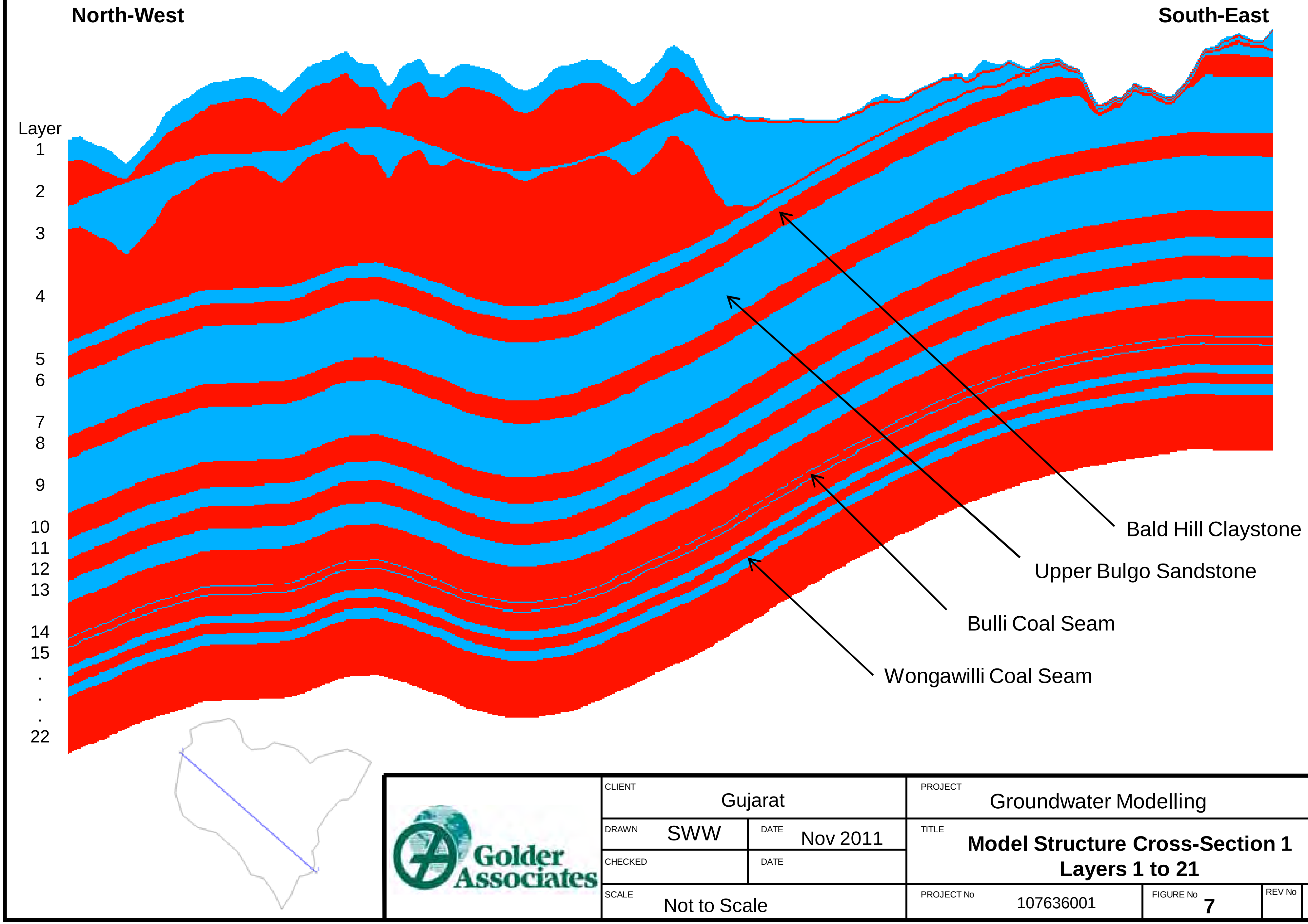
SCALE Not to Scale

PROJECT No 107636001

FIGURE No 6

REV No T

A4



CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Model Structure Cross-Section 1 Layers 1 to 21**	
CHECKED	DATE		
SCALE Not to Scale		PROJECT No 107636001	FIGURE No 7

REV No

A4

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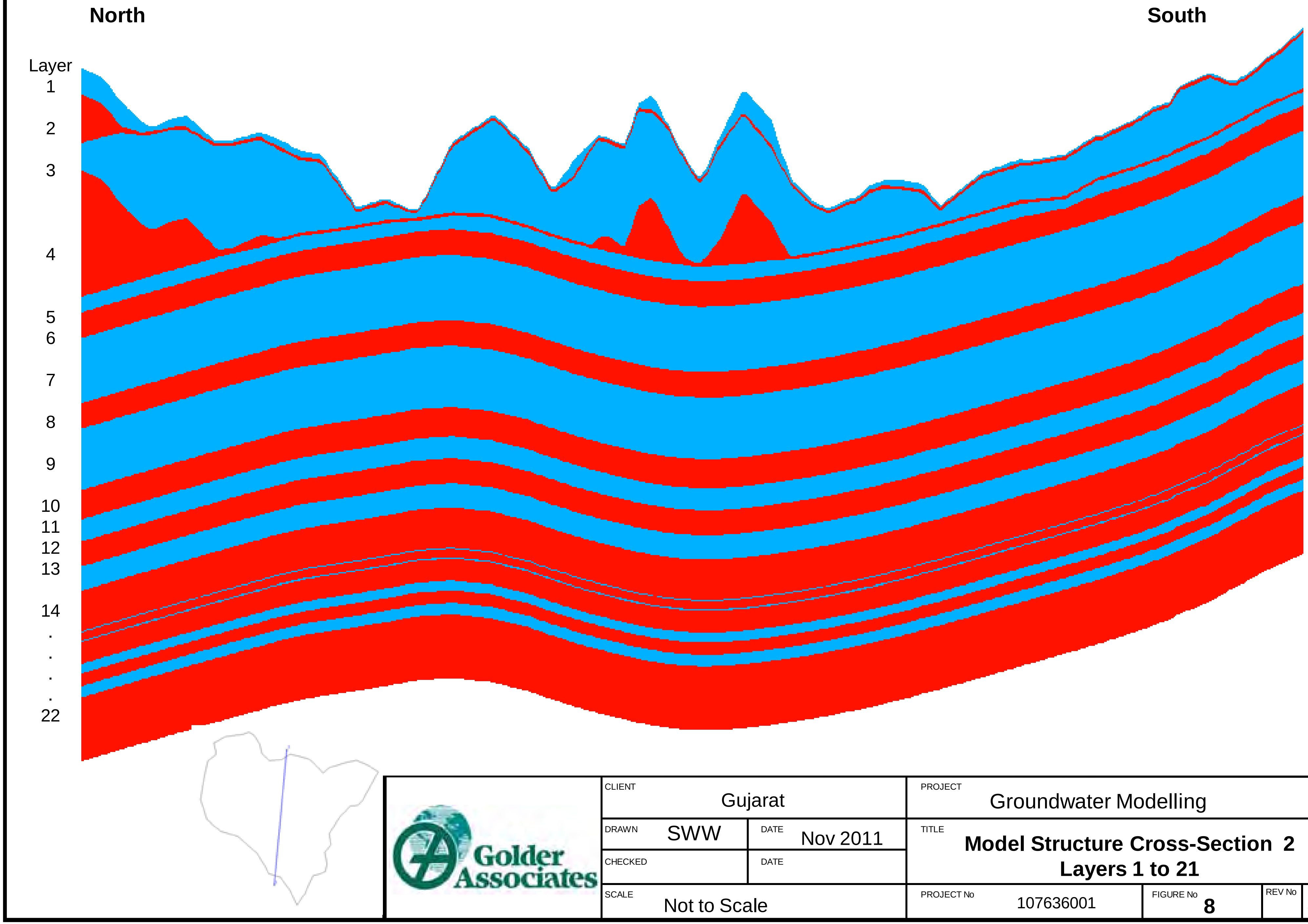

CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Model Structure Cross-Section 2 Layers 1 to 21**	
CHECKED	DATE		
SCALE Not to Scale		PROJECT No 107636001	FIGURE No 8 · REV No · A4

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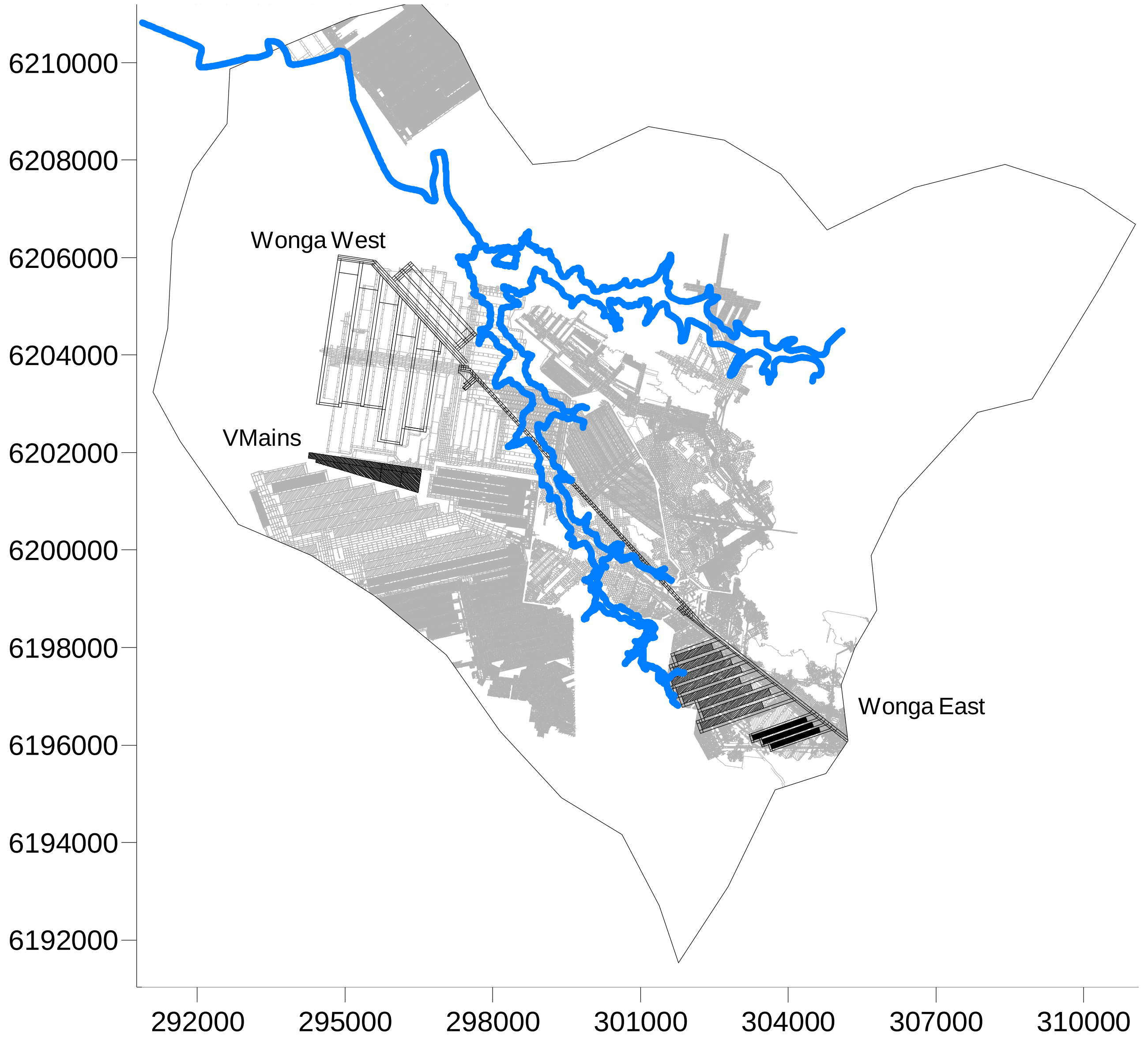

━ Cataract Reservoir

▨ Existing Workings

■ Proposed Workings

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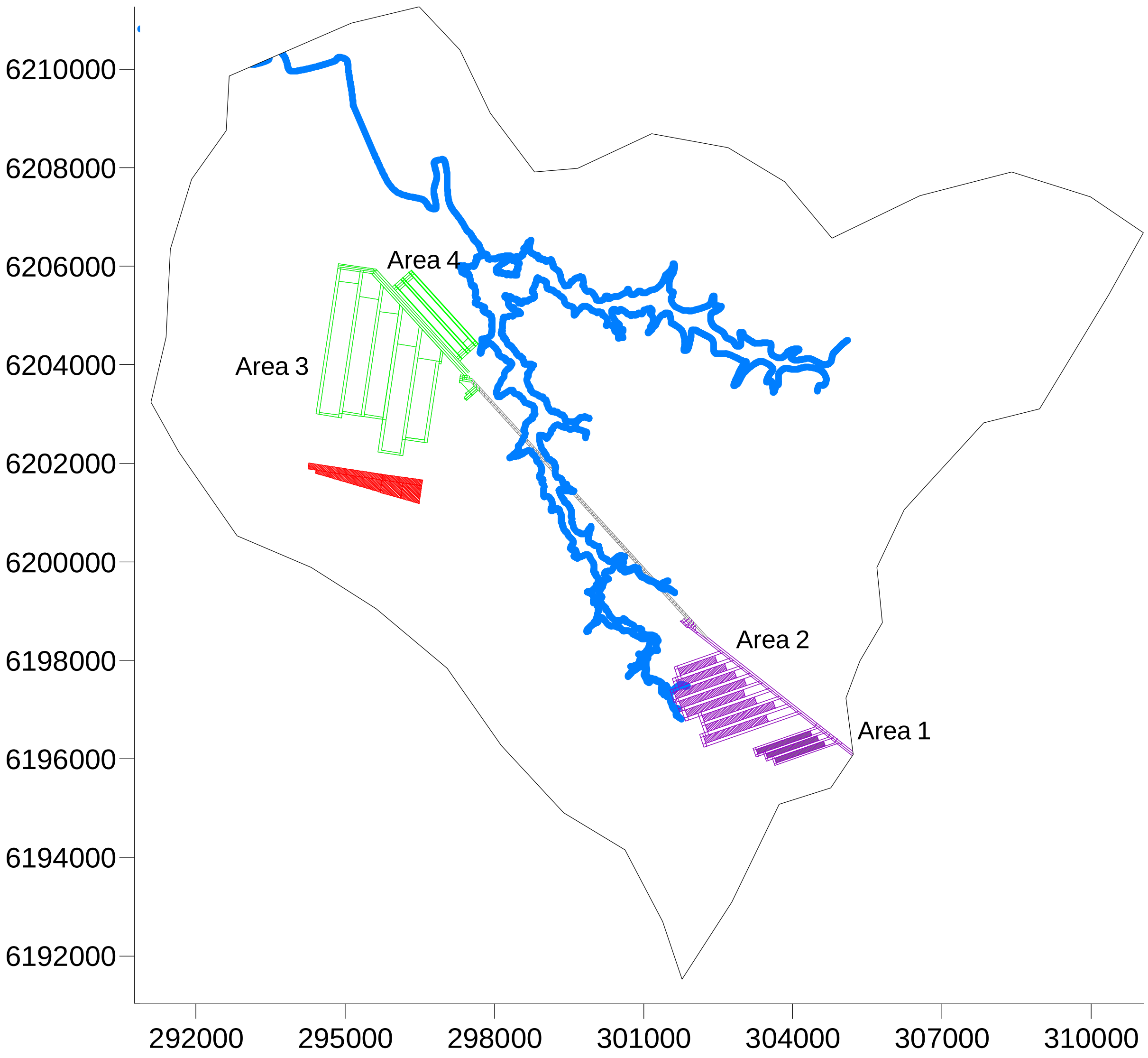
CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Proposed and Existing Workings**	
CHECKED	DATE		
SCALE As shown		PROJECT No 107636001	FIGURE No 9 · REV No · A4



🟦 **Cataract Reservoir**
🟩 **Wonga West Longwall**
🟪 **Wonga East Longwall**
🟥 **VMains Pillar Extraction**

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CLIENT Gujarat
PROJECT Groundwater Modelling
DRAWN SWW
DATE Nov 2011
CHECKED
DATE
TITLE **Proposed Workings by Type**
SCALE As shown
PROJECT No 107636001
FIGURE No **10**
REV No
A4

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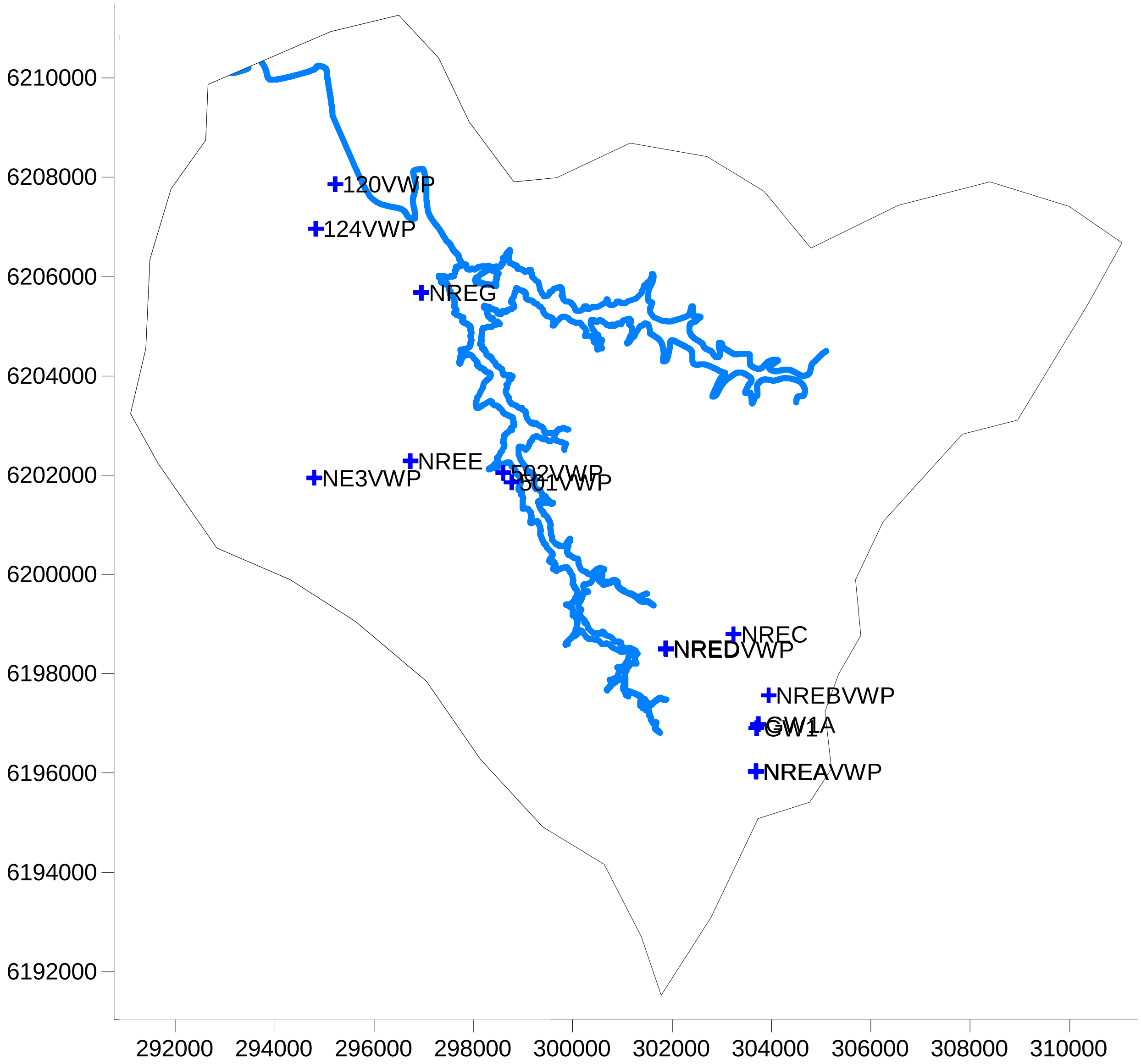

━ **Cataract Reservoir**

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CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

TITLE **Monitoring Bores**

CHECKED

DATE

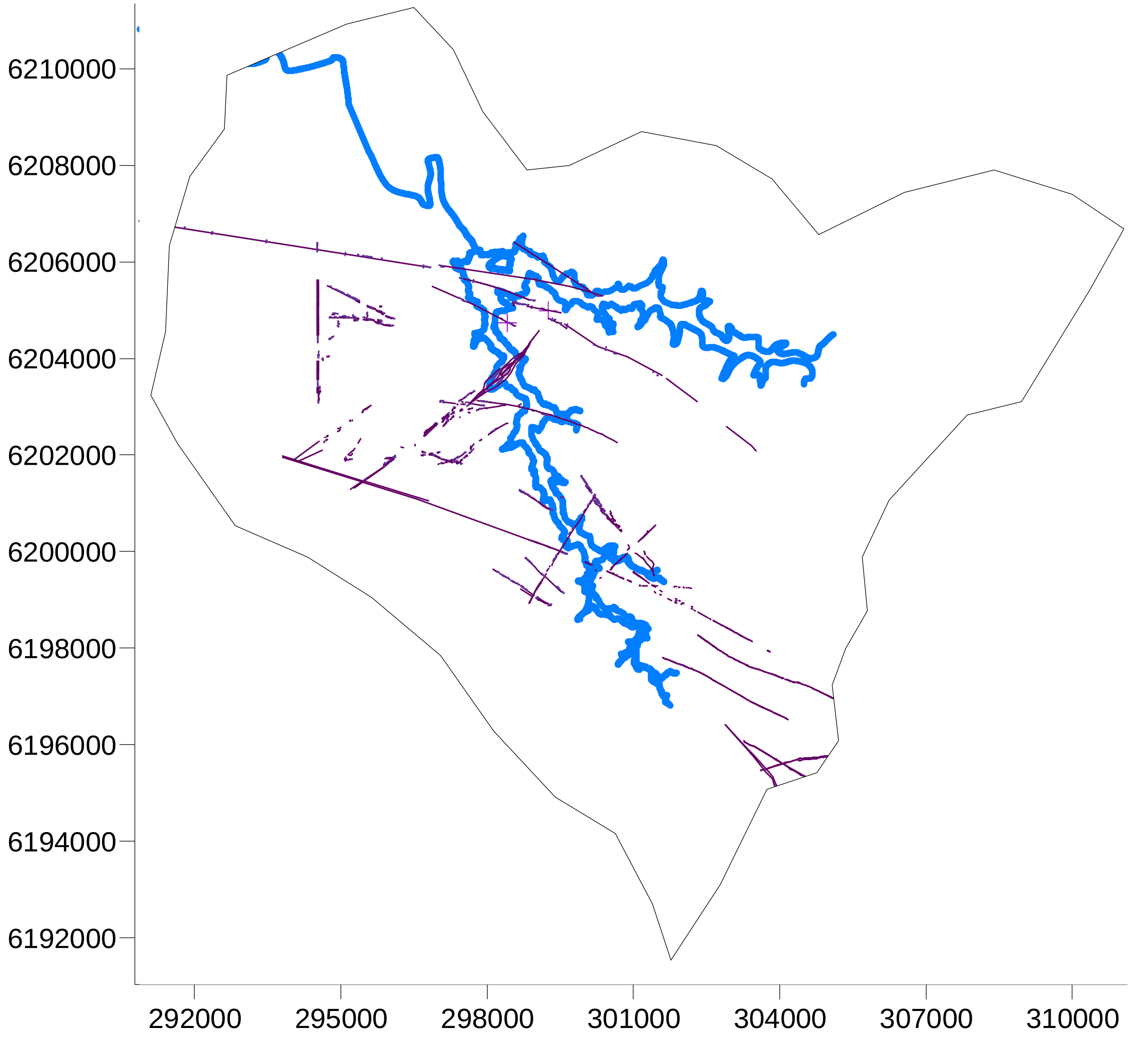
SCALE As shown

PROJECT No 107636001

FIGURE No 11

REV No

A4



▬ Cataract Reservoir

▬ Fault/Dyke

CLIENT	Gujarat
PROJECT	Groundwater Modelling
DRAWN	SWW
DATE	Nov 2011
CHECKED	
DATE	
TITLE	**Locations of Faults and Dykes**
SCALE	As shown
PROJECT No	107636001
FIGURE No	**12**
REV No	
	A4

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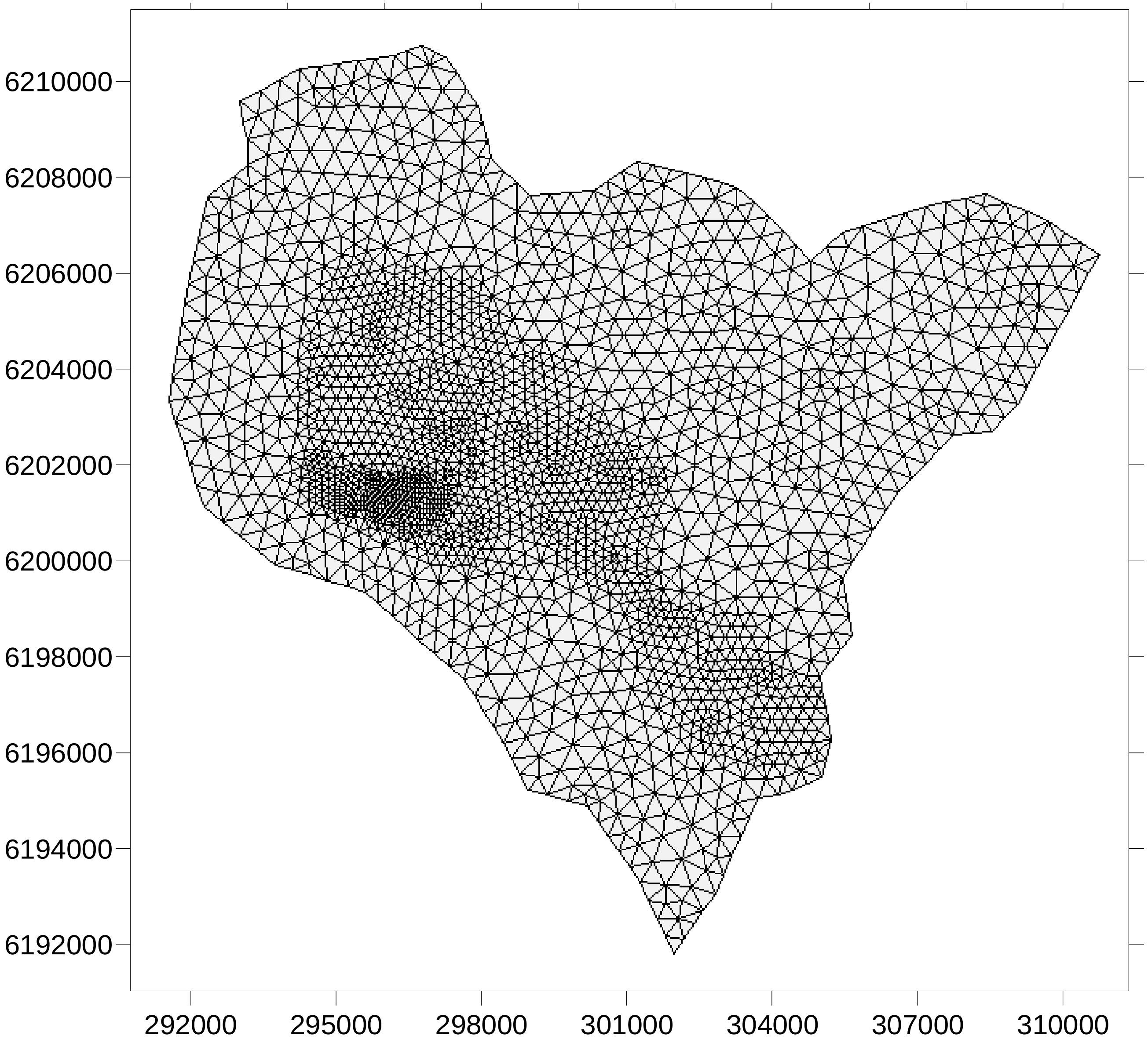
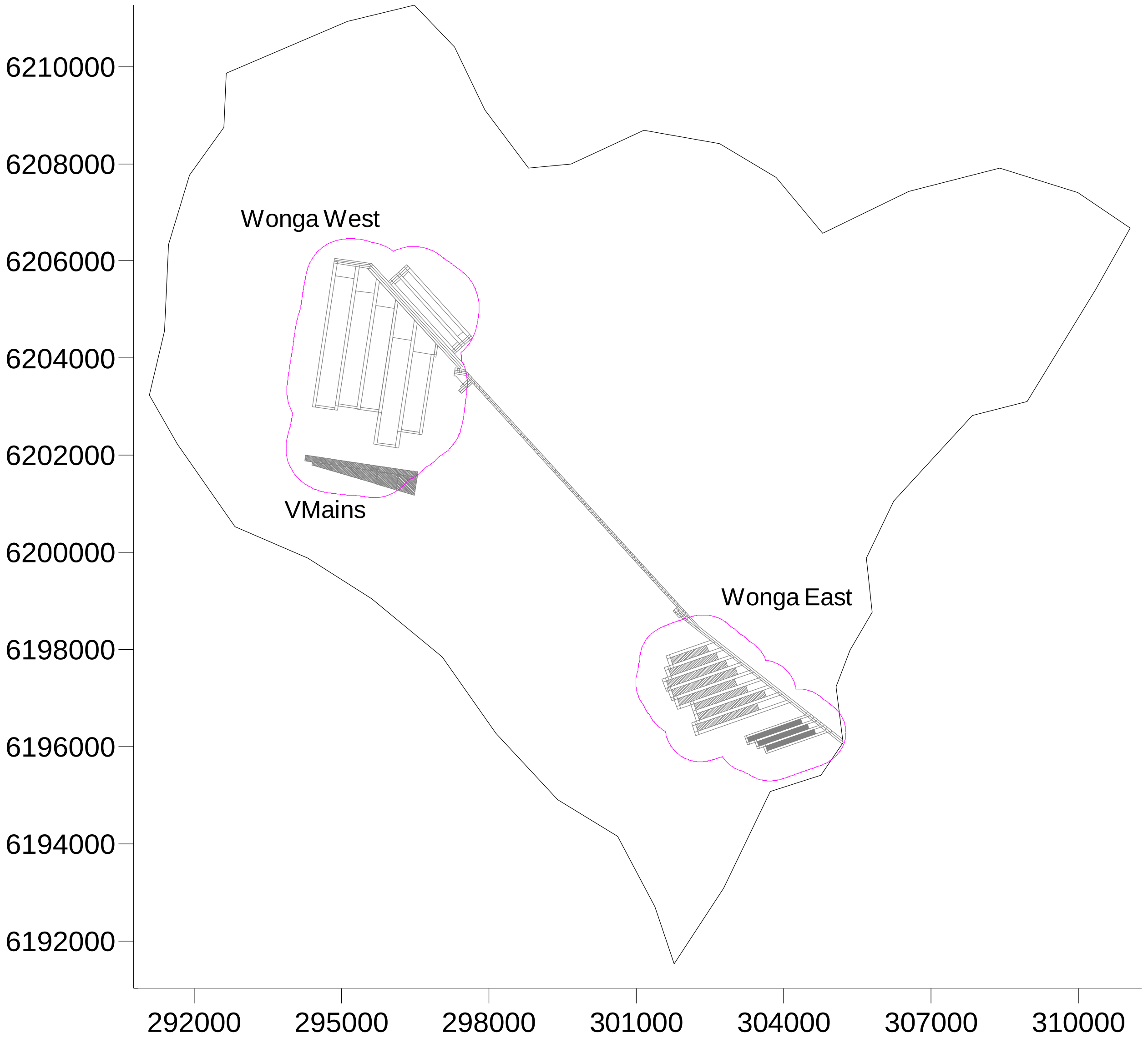


CLIENT	Gujarat		PROJECT	Groundwater Modelling	
DRAWN SWW	DATE Nov 2011		TITLE	**Model Mesh and Extent**	
CHECKED	DATE				
SCALE As shown			PROJECT No 107636001	FIGURE No 13	REV No	**A4**



— Subsidence Zone

▬ Proposed Workings

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CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

TITLE **Extent of 20mm subsidence over longwall extractions (Seedsman, 2010)**

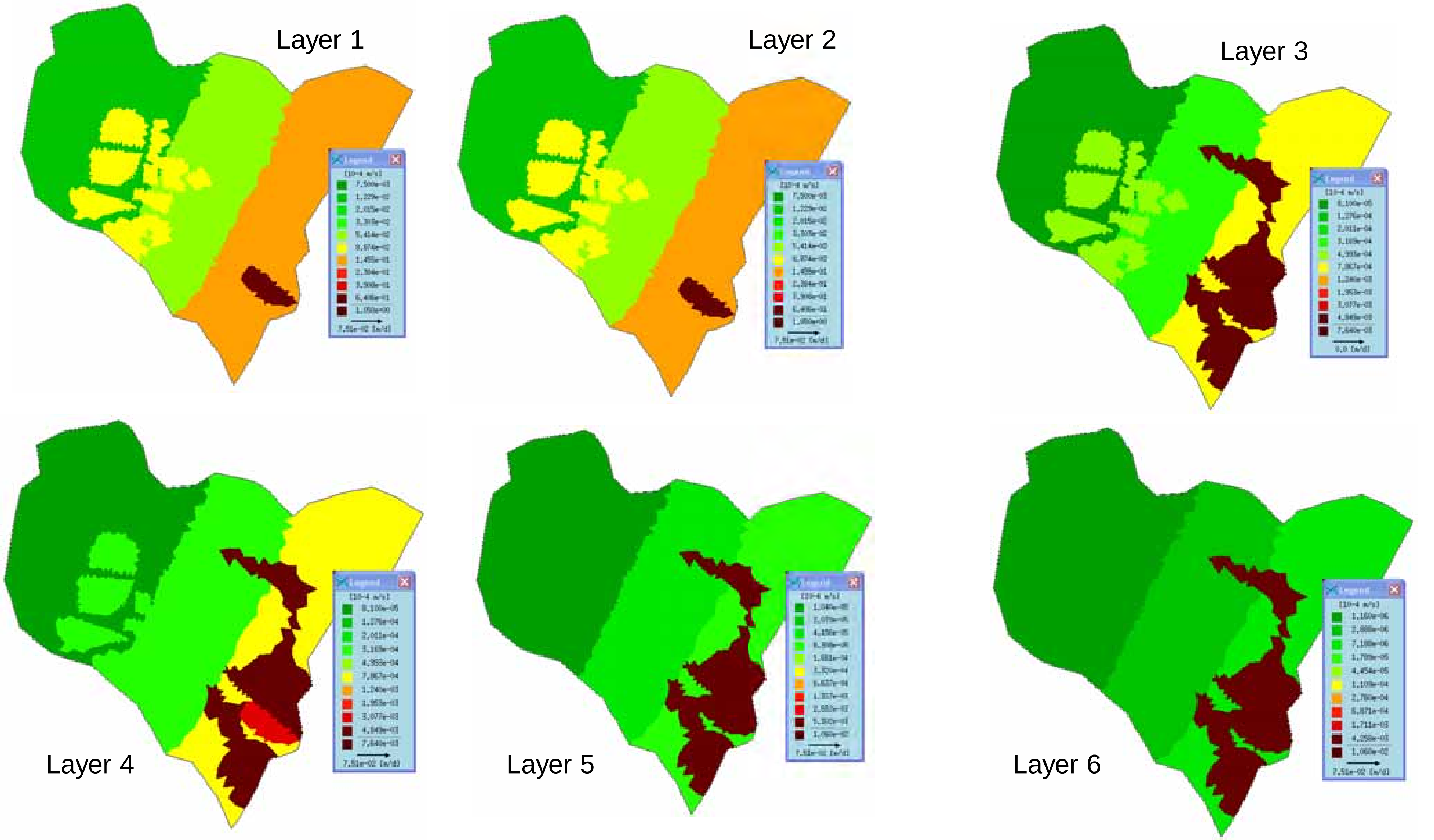
SCALE

PROJECT No 107636001

FIGURE No **14**

REV No

A4



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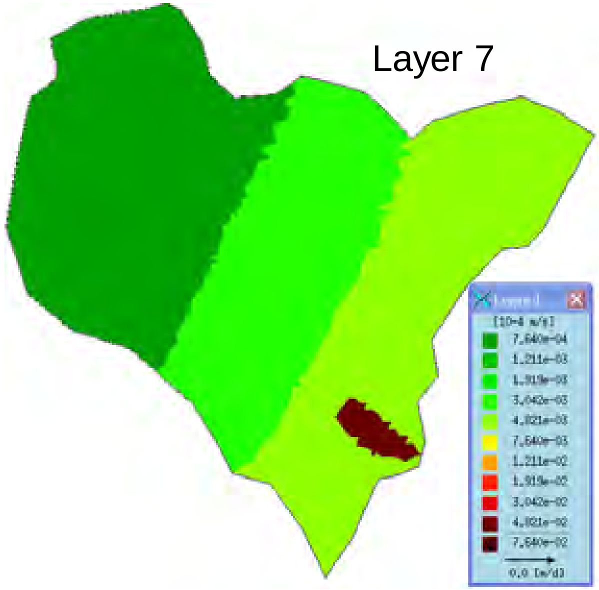
CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Model Structure Layers 1 to 6**	
CHECKED	DATE		
SCALE Not to Scale		PROJECT No 107636001	FIGURE No 15 · REV No · **A4**



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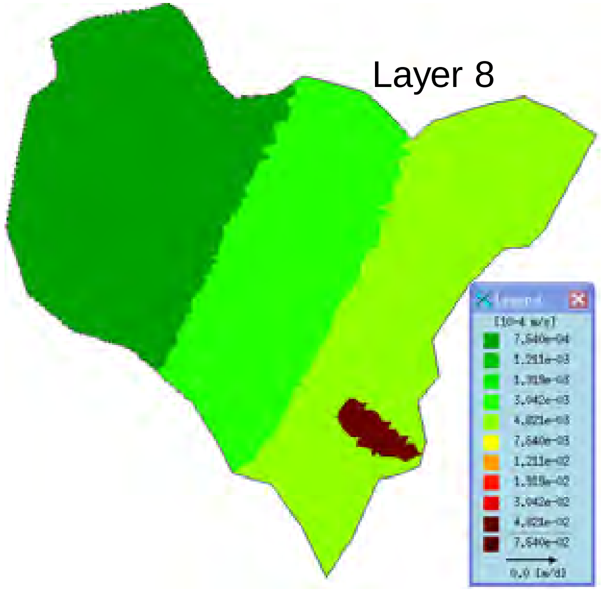

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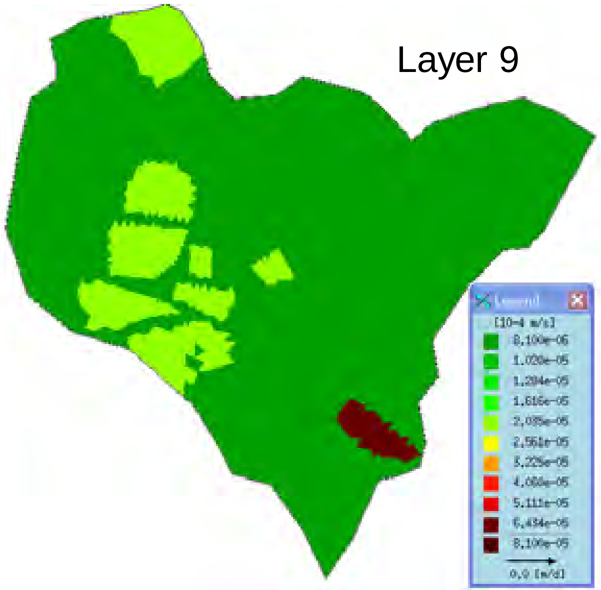

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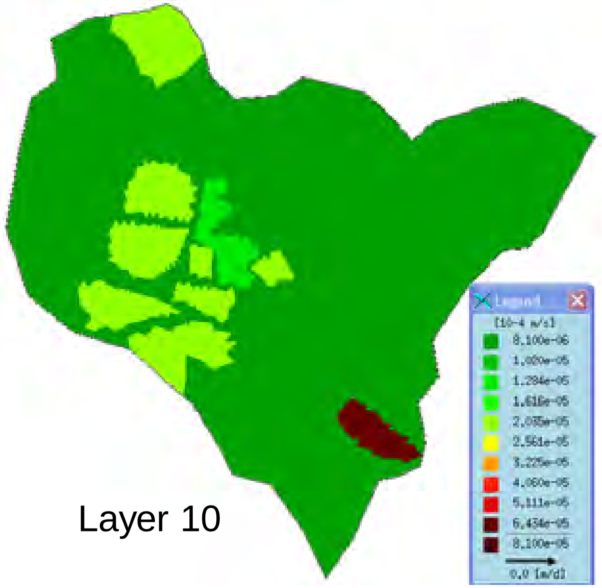

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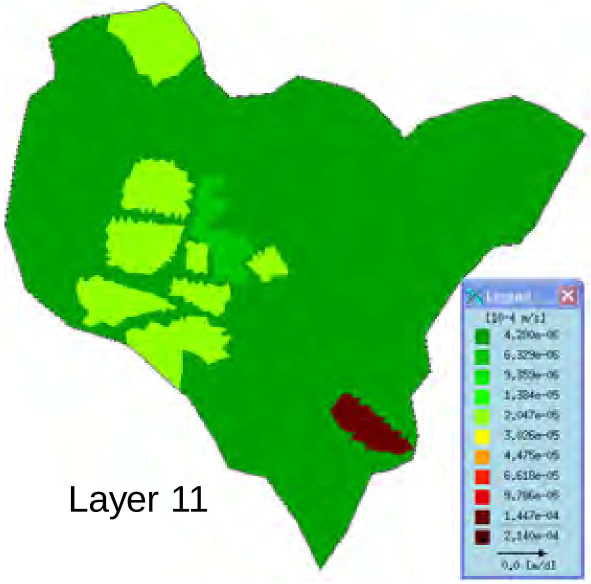

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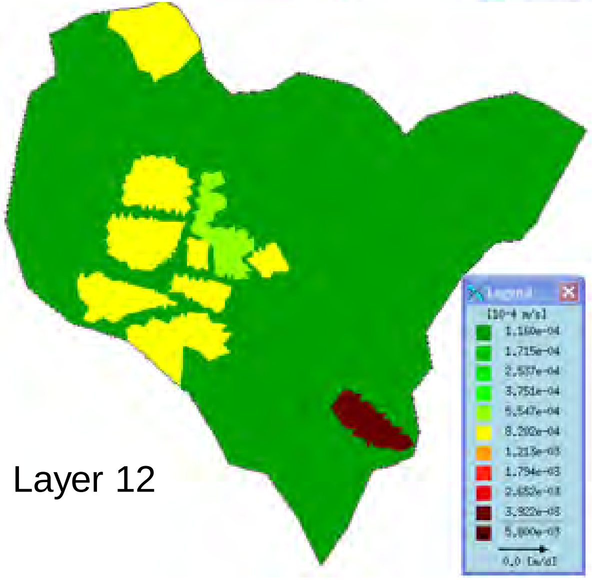

Layer 12

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CLIENT Gujarat		PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011	TITLE **Model Structure Layers 7 to 12**		
CHECKED	DATE			
SCALE Not to Scale		PROJECT No 107636001	FIGURE No **16**	REV No	**A4**

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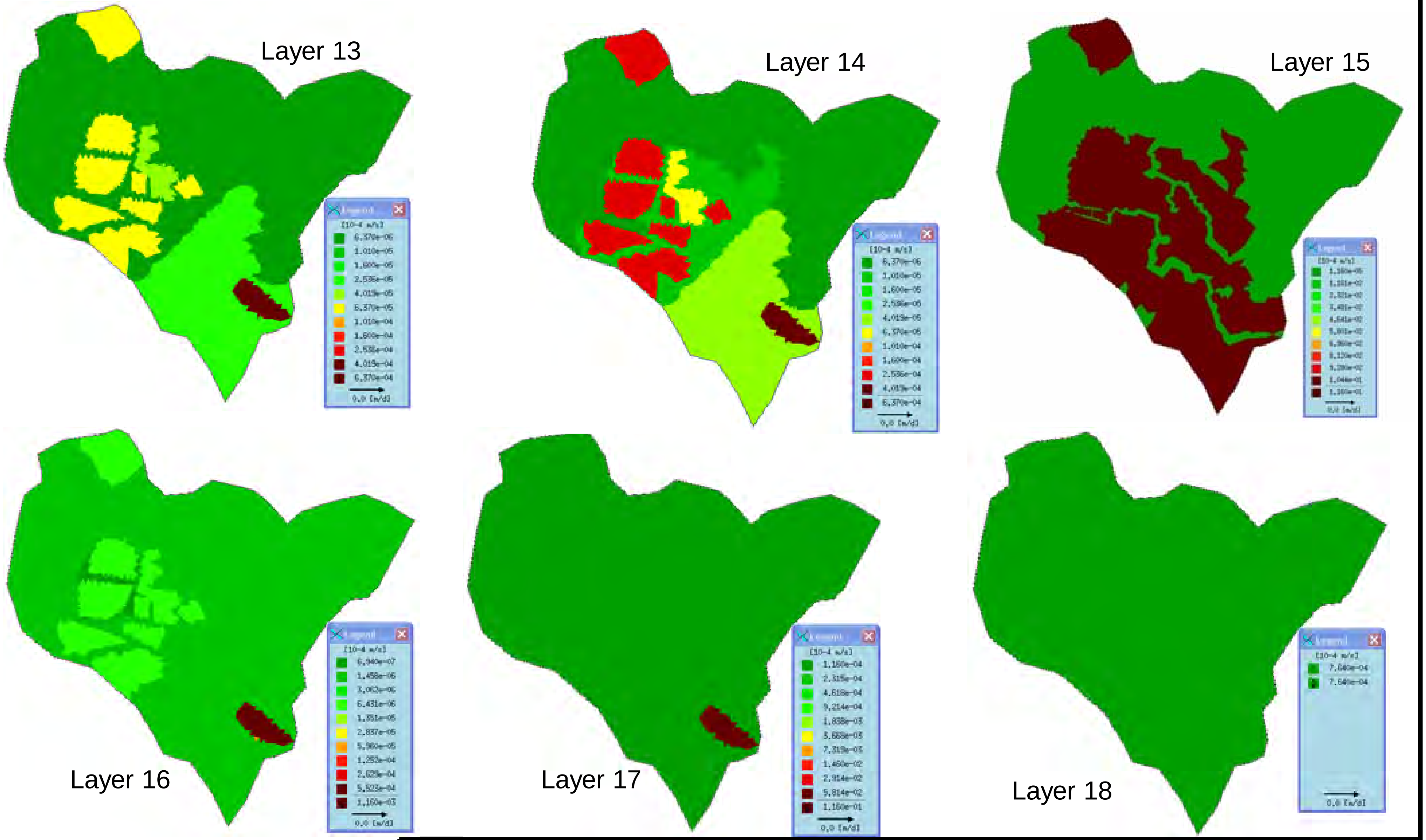

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CLIENT
Gujarat

PROJECT
Groundwater Modelling

DRAWN SWW
DATE Nov 2011

CHECKED
DATE

TITLE
Model Structure Layers 13 to 18

SCALE
Not to Scale

PROJECT No 107636001
FIGURE No 17
REV No
A4

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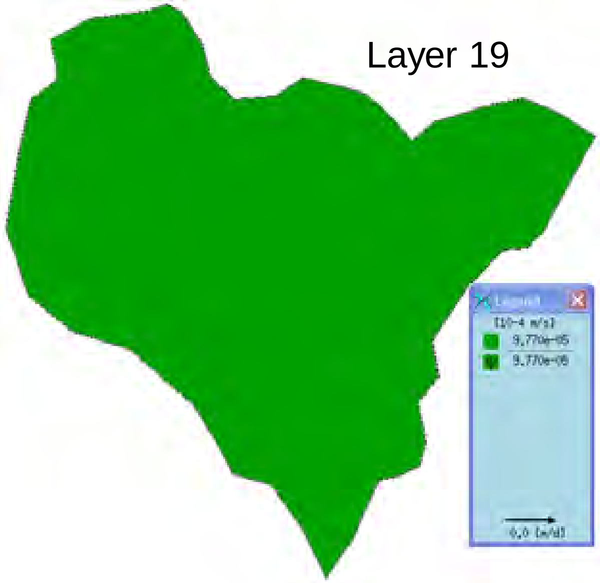

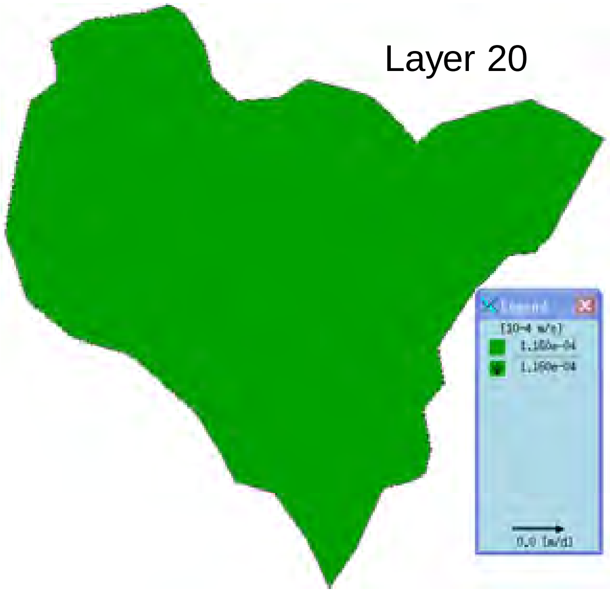

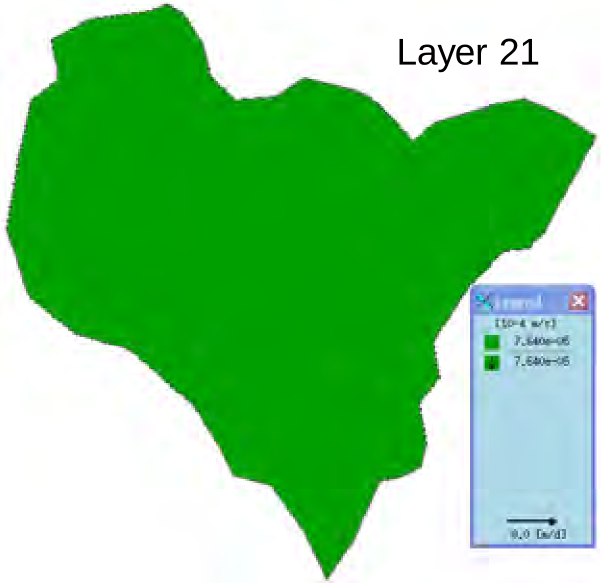

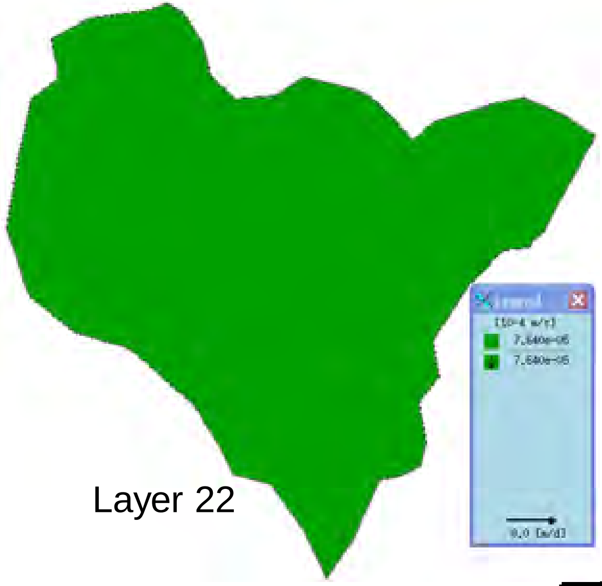

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CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

TITLE **Model Structure Layers 19 to 22**

CHECKED

DATE

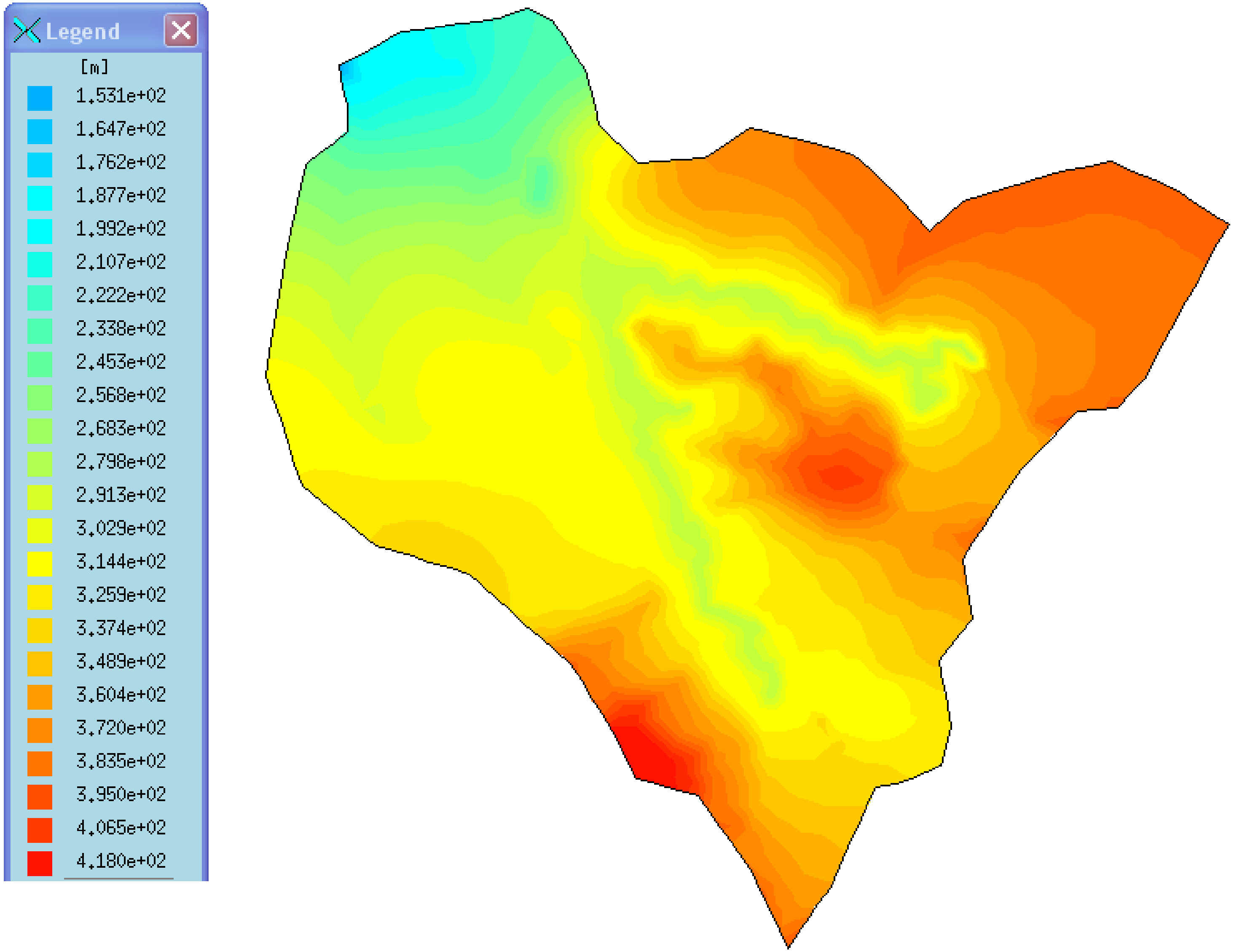
SCALE Not to Scale

PROJECT No 107636001

FIGURE No 18

REV No

A4



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CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

TITLE **Initial Groundwater Heads (mAHD)**

CHECKED

DATE

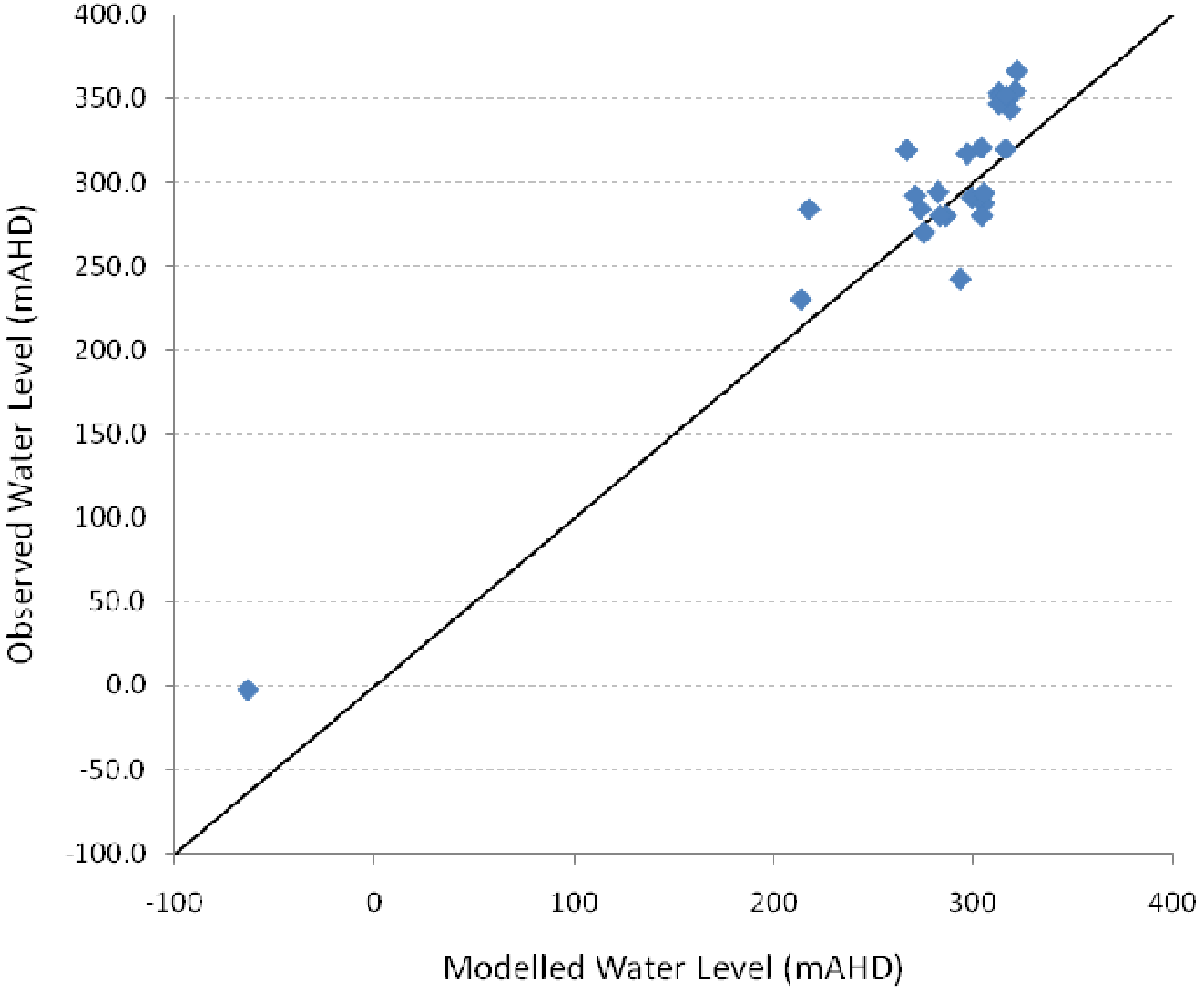
SCALE Not to Scale

PROJECT No 107636001

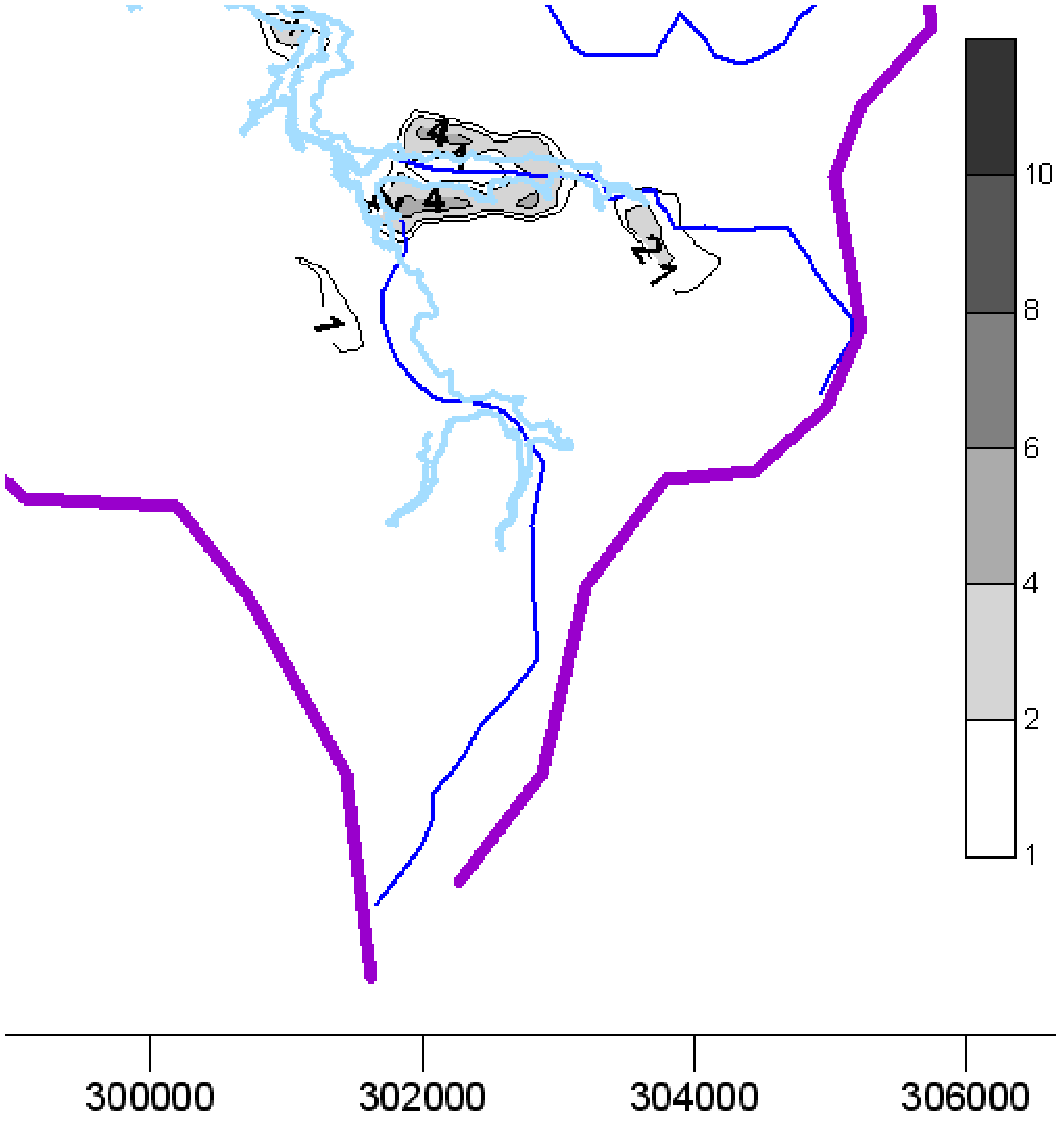
FIGURE No **19**

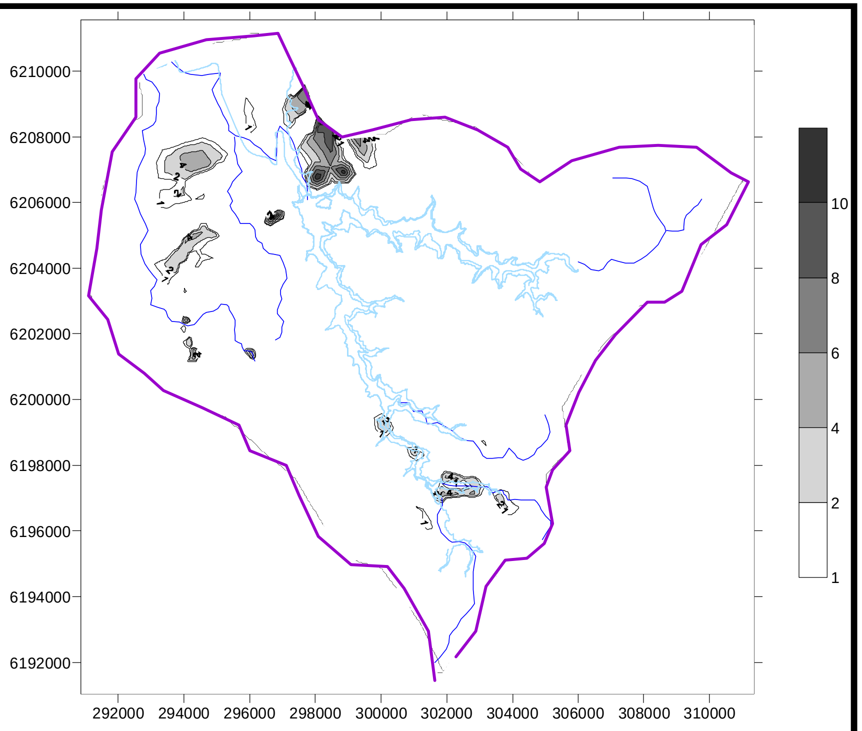
REV No

A4



CLIENT Gujarat		PROJECT Groundwater Modelling			
DRAWN SWW	DATE Nov 2011	TITLE **Calibration Results**			
CHECKED	DATE				
SCALE Not to Scale		PROJECT No 107636001	FIGURE No **20**	REV No	**A4**





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CLIENT
Gujarat

DRAWN SWW
DATE Nov 2011
CHECKED
DATE

SCALE
As shown

PROJECT
Groundwater Modelling

TITLE
End Of Stage 1 Drawdown (m)
in Upper Hawkesbury Sandstone

PROJECT No 107636001
FIGURE No 21
REV No
A4

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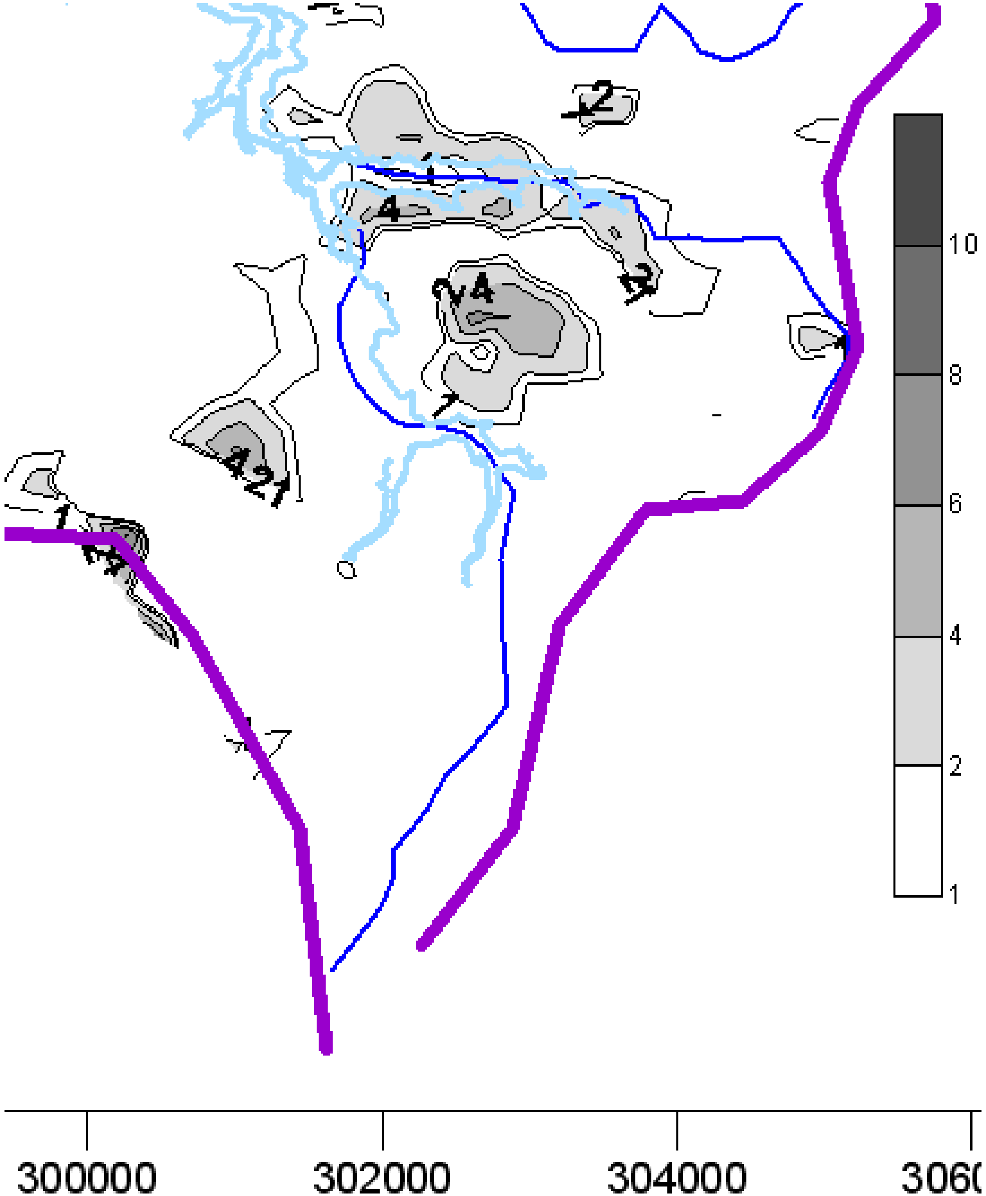

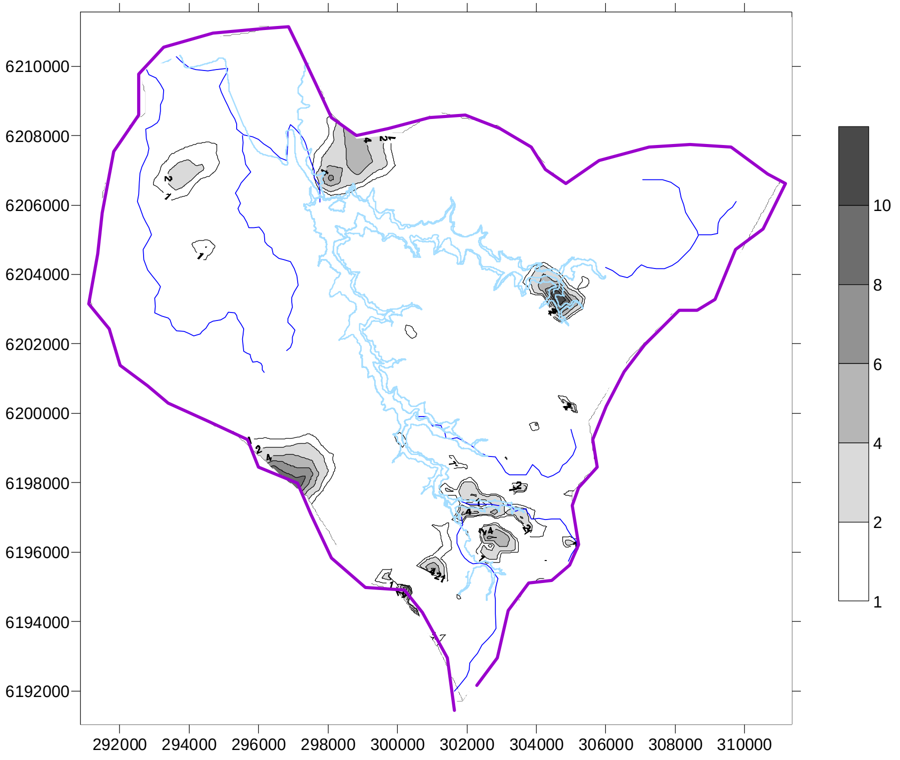

CLIENT
Gujarat

DRAWN
SWW

DATE
Nov 2011

CHECKED

DATE

SCALE
As shown

PROJECT
Groundwater Modelling

TITLE
End Of Stage 1 Drawdown (m)
In Lower Hawkesbury Sandstone

PROJECT No
107636001

FIGURE No
22

REV No

A4

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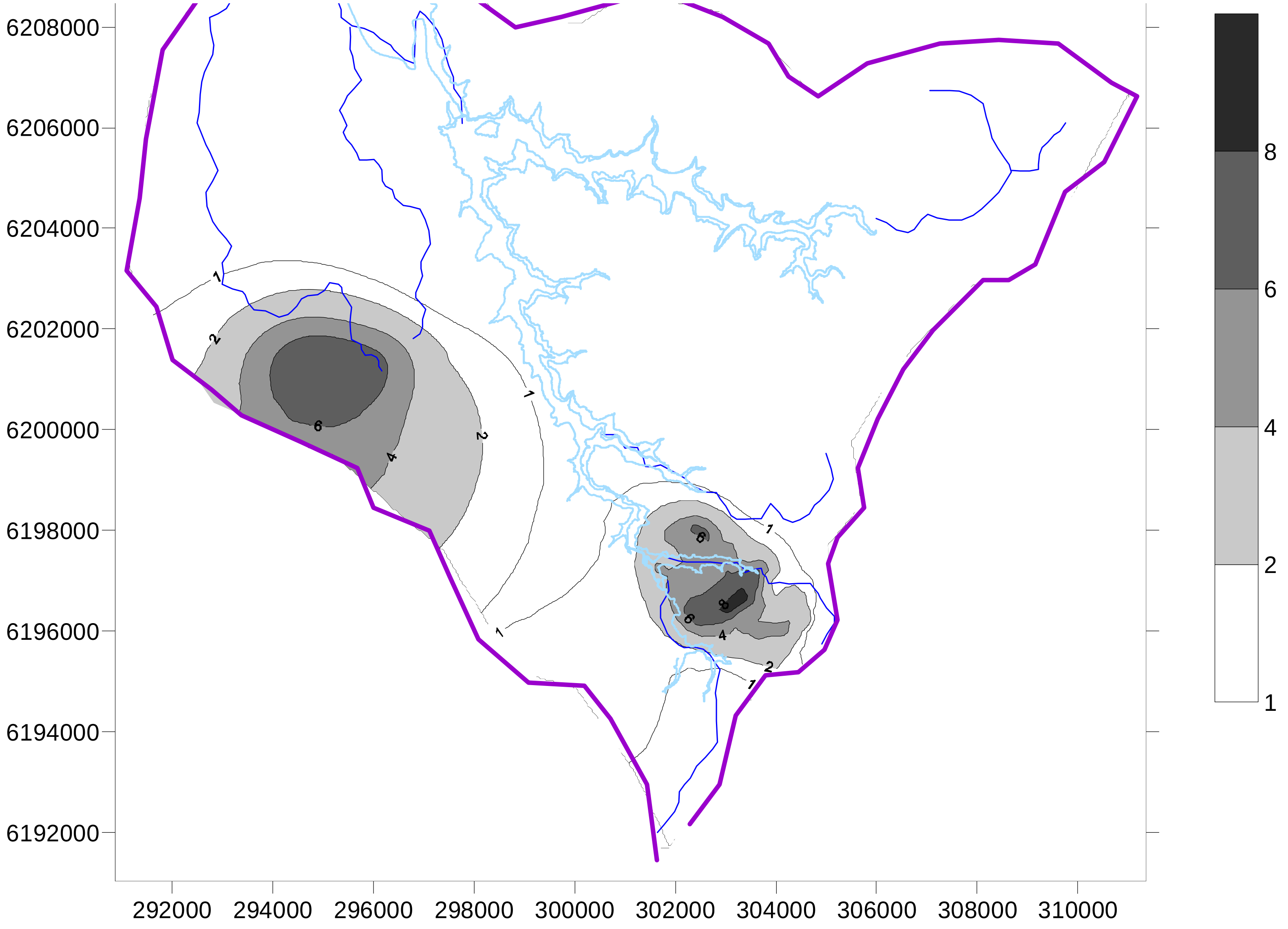

CLIENT Gujarat			PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011		TITLE End Of Stage 1 Drawdown (m) in Upper Bulgo Sandstone	
CHECKED	DATE			
SCALE As shown			PROJECT No 107636001	FIGURE No 23	REV No	A4

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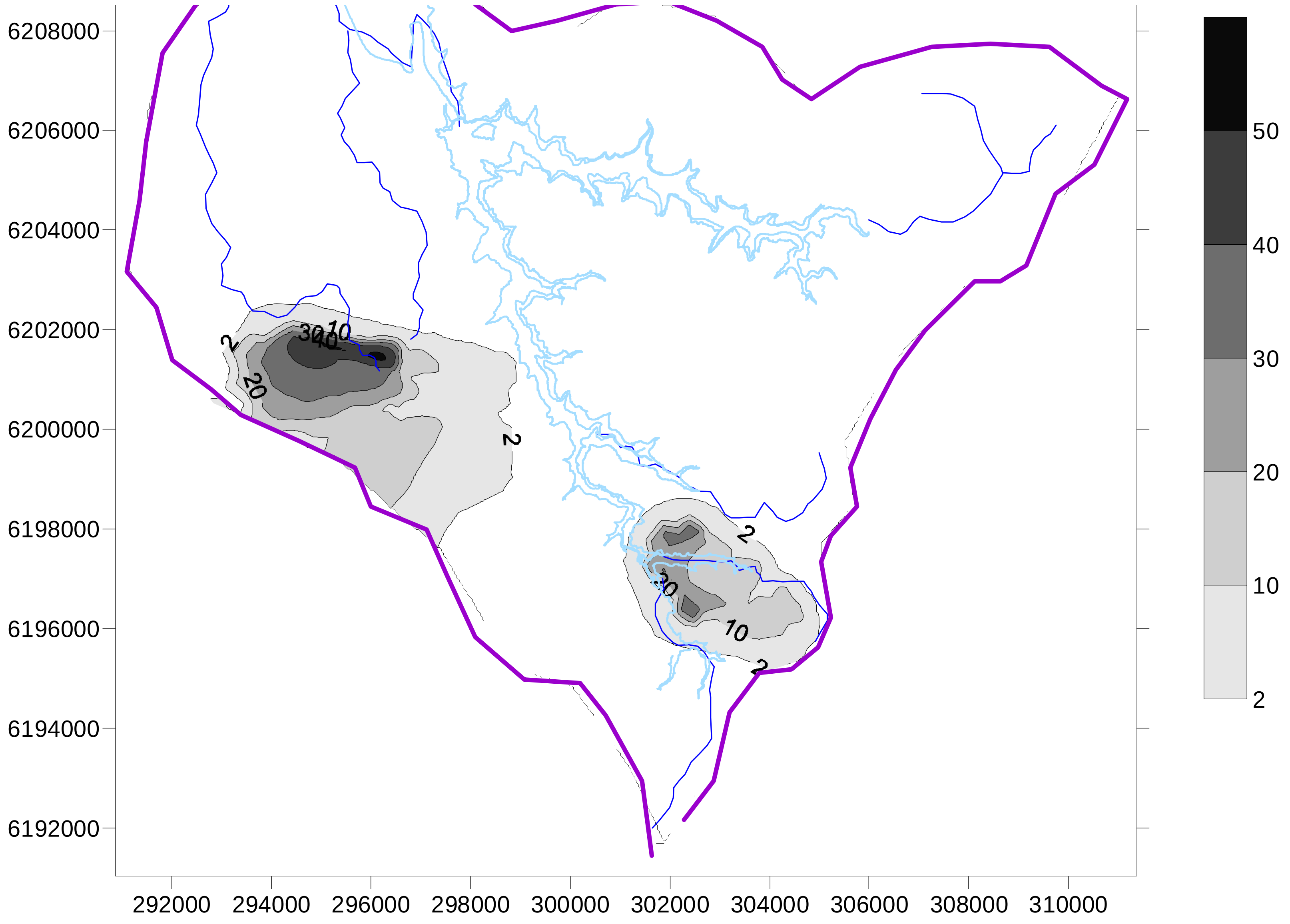

CLIENT
Gujarat

PROJECT
Groundwater Modelling

DRAWN SWW
DATE Nov 2011
CHECKED
DATE

TITLE
End Of Stage 1 Drawdown (m)
in Lower Bulgo Sandstone

SCALE
As shown

PROJECT No
107636001

FIGURE No
24

REV No

A4

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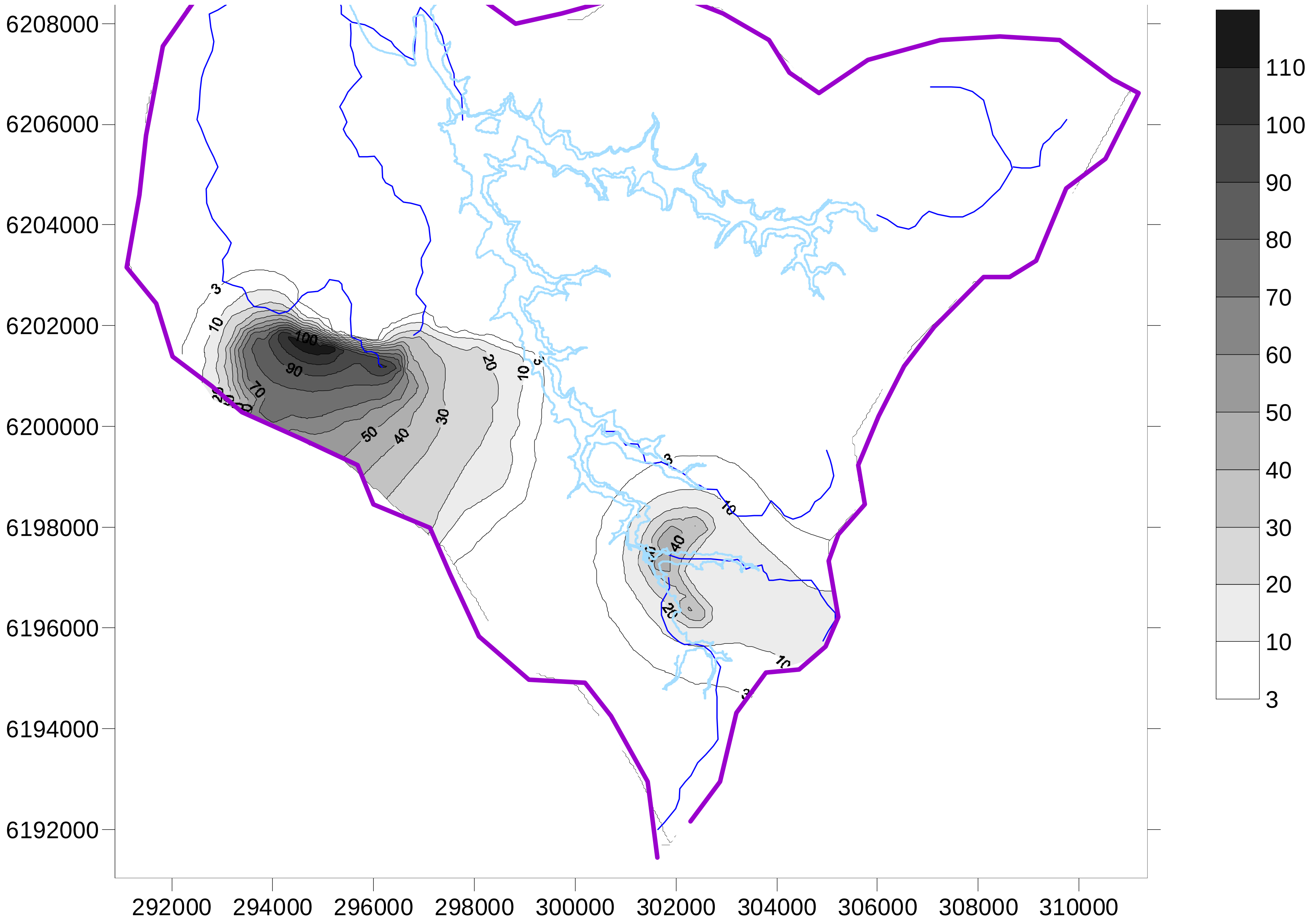
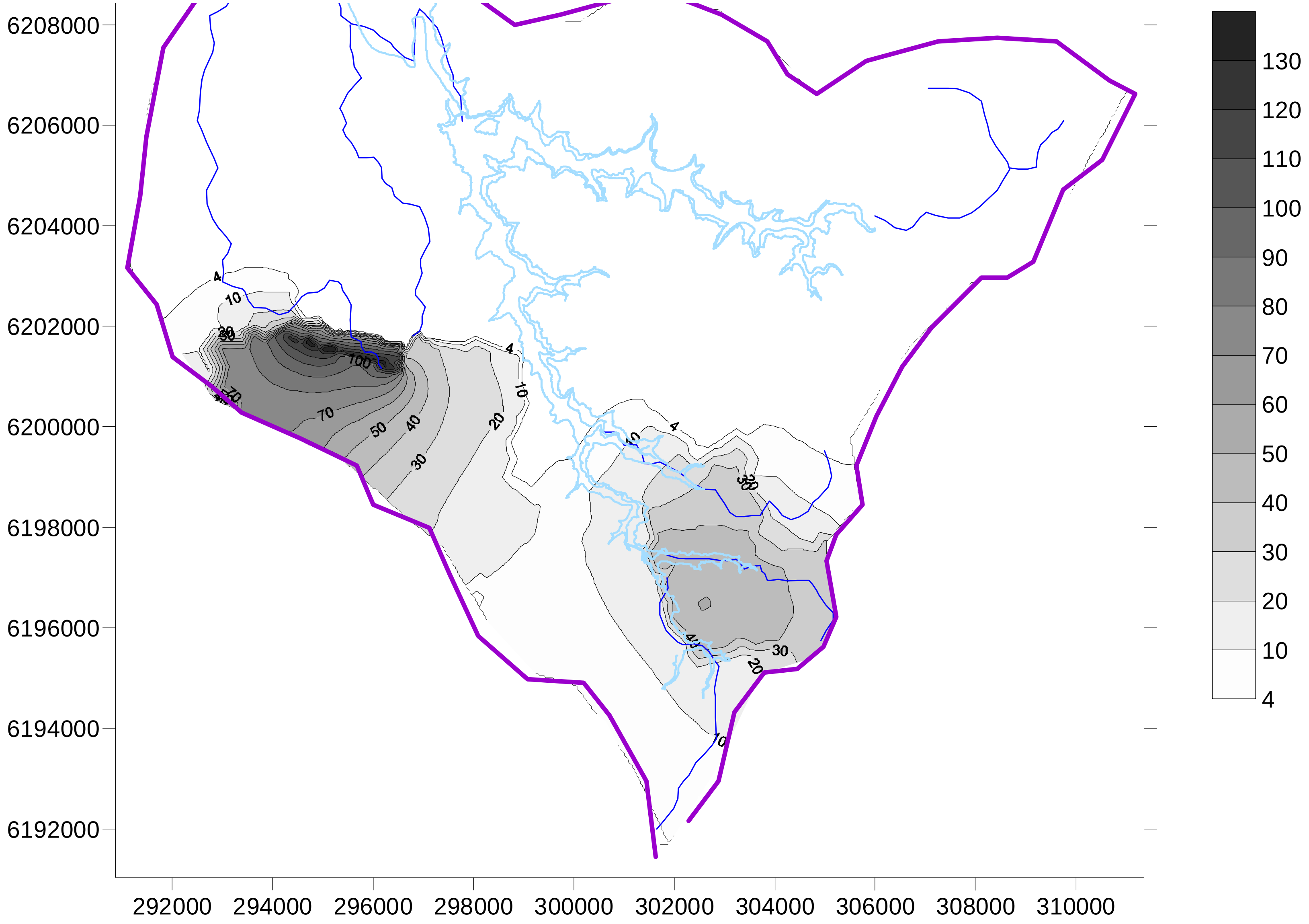
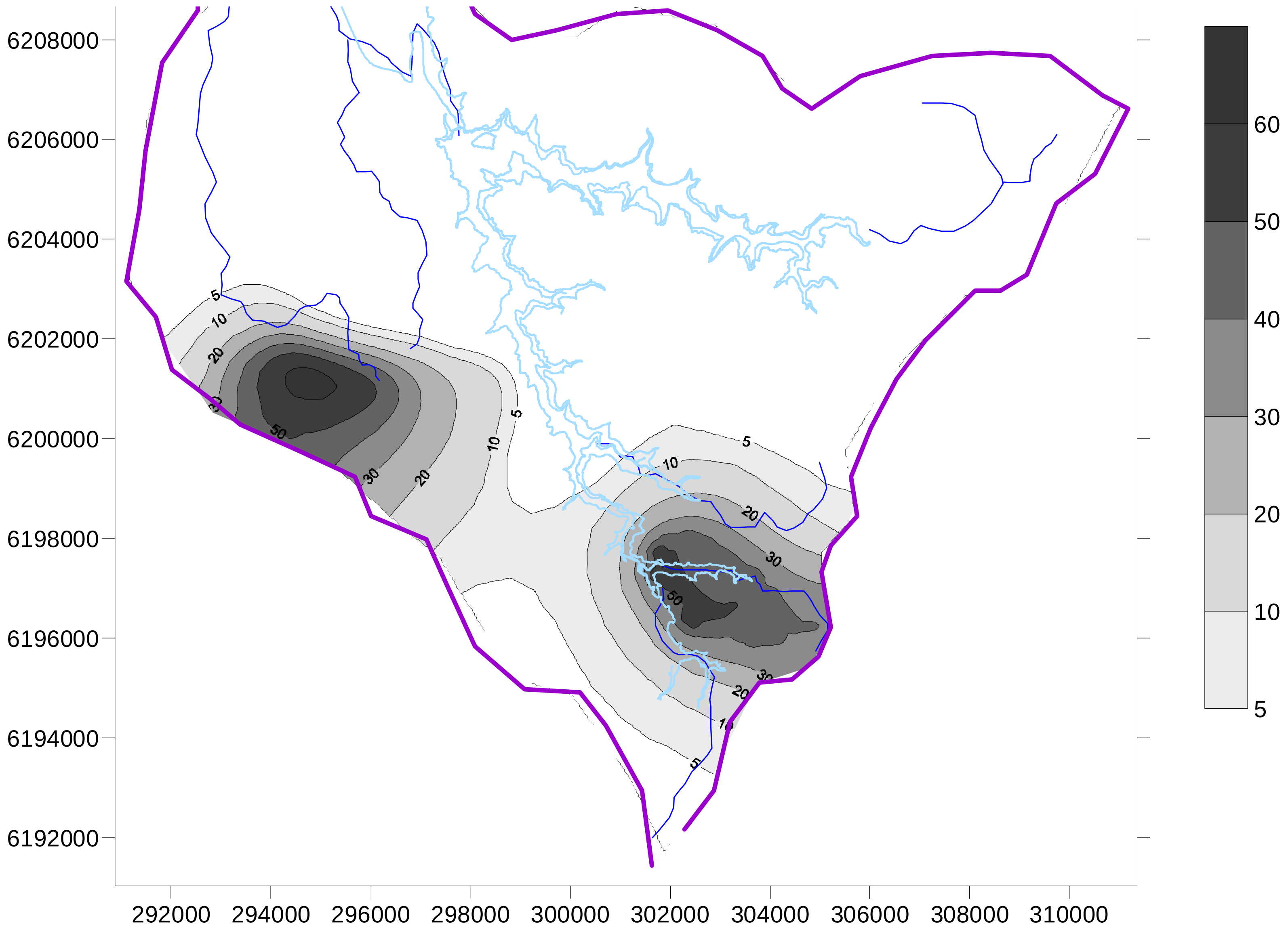


CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE End Of Stage 1 Drawdown (m) In Scarborough Sandstone	
CHECKED	DATE		
SCALE As shown		PROJECT No 107636001	FIGURE No 25 · REV No · A4



CLIENT Gujarat		PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011	TITLE End Of Stage 1 Drawdown (m) In Bulli Coal Seam		
CHECKED	DATE			
SCALE As shown		PROJECT No 107636001	FIGURE No 26	REV No

A4



CLIENT	Gujarat	PROJECT	Groundwater Modelling
DRAWN	SWW	DATE	Nov 2011
CHECKED		DATE	
TITLE	End Of Stage 1 Drawdown (m) In Wongawilli Coal Seam		
SCALE	As shown	PROJECT No	107636001
FIGURE No	27	REV No	
	A4		

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