ENVIRONMENTAL ASSESSMENT

Duralie Extension Project

APPENDIX B

GROUNDWATER ASSESSMENT

GLOUCESTER
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APPENDIX B

DURALIE EXTENSION PROJECT

GROUNDWATER ASSESSMENT

A HYDROGEOLOGICAL ASSESSMENT OF THE DURALIE EXTENSION PROJECT ENVIRONMENTAL ASSESSMENT

FOR

DURALIE COAL PTY LTD

By

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Heritage Computing

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B1.0 INTRODUCTION

This report has been prepared for Duralie Coal Pty Ltd (DCPL), a wholly owned subsidiary of Gloucester Coal Ltd. The report provides a groundwater assessment of the proposed Duralie Extension Project (the Project) (**Figure B-1**).

DCPL owns and operates the mining operations at the Duralie Coal Mine (DCM). The DCM operations are supported by on-site facilities including a main infrastructure area, water management infrastructure/storages and rail infrastructure (**Figure B-2**).

The Project is located approximately 10 km north of the village of Stroud and approximately 20 km south of Stratford in the Gloucester Valley in New South Wales (NSW). The proposed Project would involve the continuation of open pit mining operations at the DCM. The DCM existing/approved surface development areas (including the approximate extent of the open pit and waste rock emplacement) are shown on **Figure B-2**.

Existing facilities at the DCM would be used to service the Project. However, some new facilities and/or upgrades to existing infrastructure would be required to support the ongoing mining activities and the proposed increase in mine production. A description of the Project is provided in Section 2 in the Main Report of the Environmental Assessment (EA).

This report has been compiled with the assistance of Red Earth Geosciences (Dr Boyd Dent) and Coffey Geotechnics (Paul Tammetta).

B1.1 SCOPE OF WORK

The key tasks for this assessment are:

- Characterisation of the existing groundwater environment including identification of potential groundwater dependent ecosystems in consultation with other relevant specialists.
- Collation and review of baseline groundwater data including:
    - existing DCPL exploration programme borehole data;
    - existing mine water management records;
    - relevant groundwater quality data;
    - prior hydrogeological investigations; and
    - additional geological and mapping data.
- Development and refinement of a conceptual groundwater model as a basis for development and calibration of a numerical groundwater model to predict potential impacts of mine development on the groundwater regime.

- Preparation of a Groundwater Assessment report for inclusion in the EA that includes the following:

  - assessment of mine groundwater impacts (e.g. pit inflows, drawdown, groundwater quality and recharge), including assessment of various mining scenarios or stages of mining and cumulative impacts with other existing and approved mines in the area;
  - assessment of post-mining groundwater impacts (e.g. recovery of groundwater levels, groundwater quality); and
  - assessment of any groundwater impacts of surface infrastructure.

- Development of measures to avoid, mitigate and/or remediate potential impacts on groundwater resources and recommended groundwater monitoring to measure potential impacts on groundwater resources.

In accordance with the NSW Department of Planning (DoP) Director-General's Environmental Assessment Requirements (EARs) for the Project, this assessment has been prepared in consideration of the following groundwater-related technical and policy guidelines:

- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (Agriculture and Resource Management Council of Australia and Australian and New Zealand Environment and Conservation Coiuncil [ARMCANZ/ANZECC]);

- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC]);

- NSW State Groundwater Quality Protection Policy (DLWC);

- NSW State Groundwater Quantity Management Policy (DLWC) Draft;

- NSW Groundwater Dependent Ecosystem Policy (DLWC);

- Murray-Darling Basin Groundwater Quality. Sampling Guidelines. Technical Report No 3 (Murray-Darling Basin Commission [MDBC]);

- MDBC. Groundwater Flow Modelling Guideline (Aquaterra Consulting Pty Ltd); and

- Draft Guidelines for the Assessment & Management of Groundwater Contamination (NSW Department of Environment and Climate Change [DECC]).

The specific EARs of relevance to this assessment include:

- ❑ detailed modelling of the potential… ground water impacts of the project;
- ❑ a site water balance, salinity balance, and an assessment of the suitability of minewater for irrigation use;
- ❑ a detailed description of proposed final voids and their management; and
- ❑ a detailed assessment (environmental, hydrogeological, and geomorphic) of the proposed final alignment of Coal Shaft Creek.

The surface water components of the assessment are provided separately in the Surface Water Assessment (Gilbert and Associates, 2009) (Appendix A of the EA).

The proposed final voids and their management are also described in Appendix A of the EA.

As part of the assessment process, an Environmental Risk Assessment was undertaken (SP Solutions, 2009) (Appendix M of the EA). This included a facilitated, risk-based workshop involving experts across a range of disciplines and experienced DCPL personnel. The objective of the assessment was to identify key potential environmental issues for inclusion in the EA. The following key potential groundwater related issue was identified and has been addressed in Appendix A of the EA, but has also been considered in this assessment:

- ❑ Seepage of poor quality water from the final void through the waste rock emplacement to Coal Shaft Creek/Mammy Johnsons River.

B1.2 PROPOSED MINE DEVELOPMENT

The main activities associated with the development of the Project would include (**Figure B-2**):

- continued development of open pit mining operations at the DCM to facilitate a run-of-mine (ROM) coal production rate of up to approximately 3 million tonnes per annum (Mtpa), including:
    - extension of the existing approved open pit in the Weismantel Seam to the north-west (i.e. Weismantel Extension open pit) within Mining Lease (ML) 1427 and Mining Lease Application (MLA) area 1; and
    - open cut mining operations in the Clareval Seam (i.e. Clareval North West open pit) within ML 1427 and MLA 1;
- ongoing exploration activities within existing exploration tenements;
- progressive backfilling of the open pits with waste rock as mining develops, and continued and expanded placement of waste rock in out-of-pit waste rock emplacements;

- increased ROM coal rail transport movements on the North Coast Railway between the DCM and Stratford Coal Mine (SCM) in line with increased ROM coal production;
- continued disposal of excess water through irrigation (including development of new irrigation areas within ML 1427 and MLA 1);
- raising of the existing approved Auxiliary Dam No. 2 from relative level (RL) 81 metres (m) to approximately RL 100 m to provide significant additional on-site storage capacity to manage excess water on-site;
- progressive development of dewatering bores, pumps, dams, irrigation infrastructure and other water management equipment and structures;
- development of new haul roads and internal roads;
- upgrade of existing facilities and supporting infrastructure as required in line with increased ROM coal production;
- continued development of soil stockpiles, laydown areas and gravel/borrow pits;
- establishment of a permanent Coal Shaft Creek alignment adjacent to the existing DCM mining area;
- ongoing monitoring and rehabilitation; and
- other associated minor infrastructure, plant, equipment and activities.

A description of the Project is provided in Section 2 in the Main Report of the EA.

B1.3 DEWATERING AND GROUNDWATER LICENCES

Water reporting to the open pit is currently pumped via in-pit sumps to the Main Water Dam (MWD). DCPL holds an existing Bore Licence (20BL168404) issued by the NSW Department of Environment, Climate Change and Water (DECCW), that allows for up to 300 megalitres (ML) of groundwater to be extracted in any 12 month period.

Bore Licence 20BL168404 was issued under Part V of the *Water Act, 1912* on 23 September 2007. The licence excerpt relevant to this assessment states:

> *"(5) The volume of groundwater extracted from the works authorised by this licence shall not exceed 300 megalitres in any 12 month period commencing 1st July."*

Groundwater monitoring boreholes at the DCM are licensed under the existing Bore Licence 20BL168539 issued by the DECCW, which sets out conditions of use for the monitoring bores.

B2.0 HYDROGEOLOGICAL SETTING

B2.1 RAINFALL AND EVAPORATION

Rainfall experienced in the Project area can be described as moderate to high. Rainfall at Stroud Post Office (PO) and Meroo (Wards River), the closest Commonwealth Bureau of Meteorology (BoM) rainfall gauges, averages between 1,147 millimetres (mm) to 1,241 mm per year. Average potential (pan) evaporation (based on the Paterson [Tocal] station) is some 4.3 mm per day. The average monthly rainfall and potential evaporation statistics from these stations are summarised in **Table B-1** below and indicate that rainfall over the Project area is typically lower during the winter months with maxima generally experienced during the summer months.

Table B-1 Monthly Average Rainfall and Daily Evaporation

Month	Monthly Average Rainfall (mm)		Monthly Average Pan Evaporation (mm)
	Stroud PO[1] (Site 061071)	Meroo (Wards River)[2] (Site 061340)	Paterson (Tocal)[3] (Site 061250)
Jan	115.5	202.6	192.2
Feb	125.2	202.5	148.8
Mar	145.2	150.2	130.2
Apr	101.8	64.2	99.0
May	92	80	74.4
Jun	99	108.7	66.0
Jul	75.1	33.4	77.5
Aug	65.4	30.1	105.4
Sep	63.9	57.3	132.0
Oct	78.5	98.6	161.2
Nov	82.1	108.8	177.0
Dec	102.9	111.7	210.8
Annual Average	**1,146.6**	**1,241.3**	**1,574**

Source: BoM, 2009.

1 Stroud PO Station Record 1889 - 2009.

2 Meroo (Wards River) Station Record 1970 - 1977. The observed annual rainfall at Meroo (Wards River) matches well with the historical measurements at Wards River (Moana) (Appendix A of the EA).

3 Paterson (Tocal) Station Record 1967 - 2009.

Evapotranspiration for the region is up to approximately 750 mm/annum (BoM, 2009)[1].

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[1] Site-specific values for evapotranspiration were not used in this assessment due to the scale of the area modelled. This regional evapotranspiration value is considered to be suitable for the purposes of this assessment.

Rainfall intensity is a particular feature of the area which has a significant bearing on the moisture levels in catchment soils, and on the hydrological response of the local catchments. Extreme weather conditions and unprecedented rainfall were experienced in the region in June 2007 (State Emergency Services [SES], 2007).

Fluctuations in the groundwater table result from temporal changes in rainfall recharge to aquifers. Typically, changes in the groundwater elevation reflect the deviation between the long-term monthly (or yearly) average rainfall, and the actual rainfall, usually described as the Residual Mass Curve (RMC).

The groundwater levels recorded during periods of rising RMC are expected to rise while those recorded during periods of declining RMC are expected to decline. An RMC plot using rainfall data from the Stroud PO since 1889 is shown in **Figure B-3**, and a plot using data recorded at the DCM since 2003 is shown in **Figure B-4**. Despite the above recent unprecedented rainfall events, the latter graph shows that the mining operation to date (i.e. since 2003) has experienced short-term dryer conditions, with wetter interludes from mid-2004 to mid-2005 and mid-2007 to mid-2008.

B2.2 TOPOGRAPHY AND DRAINAGE

The DCM is located within the Karuah River Catchment in an area with significant topographic relief.

The DCM is located within undulating topography. The Mammy Johnsons River valley runs in an approximately north-south direction and forms the main topographic feature to the east of ML 1427 (**Figure B-2**). To the east and south-east of the Mammy Johnsons River, the Buckleys Range is the highest topographical feature in close proximity to the DCM. A parallel ridgeline to the west of ML 1427 effectively screens the DCM from The Bucketts Way (**Figure B-2**). Within ML 1427 the topography is dominated by the valley of Coal Shaft Creek and Tombstone Hill, a locally elevated elongated feature in the north-eastern part of ML 1427 that screens the mining area from the north-east (**Figure B-2**).

Surface elevations in the area vary from approximately 50 m Australian Height Datum (AHD) to 300 mAHD with ridgelines typically rising between 50 and 150 m above the valley floor. Elevations range from around 50 mAHD along the river flats of Mammy Johnsons River to 305 mAHD on Peach Tree Mountain to the east of the Mammy Johnsons River. Tombstone Hill is at approximately 130 mAHD (**Figure B-2**). The ridges that form the western divide between the catchments of Coal Shaft Creek and the Karuah River are typically between 140 m and 170 mAHD.

Surface water hydrology is addressed in detail in Appendix A of the EA.

B2.3 LAND USE

The DCM is located in a rural area characterised by cattle grazing on native and improved pastures, along with some poultry farming and other agricultural production. The majority of the DCM area has been cleared as part of past land use practices. The DCM and the SCM (located some 20 km to the north) are the main mining developments in the area. Other land uses in the district include dairying, timber milling, poultry, cropping and recreation.

DCPL owns the land within ML 1427 and a significant area of surrounding lands. The eastern part of ML 1427 is currently subject to mining development, while the remainder of ML 1427 is managed for agricultural use, including controlled use of stored water for irrigation.

DCPL is a major landholder in the DCM area and manages the majority of its landholdings for agricultural production.

B2.4 GROUNDWATER DEPENDENT ECOSYSTEMS

The NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002) describes the five broad types of groundwater systems in NSW, each with associated dependent ecosystems as follows:

- **Deep Alluvial Groundwater Systems** – occurring under floodplains of major rivers west of the Great Dividing Range (e.g. Namoi, Macquarie, Lachlan, Murrumbidgee and Murray alluvium).
- **Shallow Alluvial Groundwater Systems** – coastal rivers and higher reaches west of the Great Dividing Range (e.g. Hunter, Peel and Cudgegong alluvium, and beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers).
- **Fractured Rock Groundwater Systems** – outcropping and sub-cropping rocks containing a mixture of fractures, joints, bedding planes and faults that contain and submit small and occasionally large amounts of groundwater (e.g. Alstonville Basalt, Molong Limestone and the Young Granite).
- **Coastal Sand Bed Groundwater Systems** – significant sand beds along the coast of NSW (e.g. Botany and Tomago sand beds).
- **Sedimentary Rock Groundwater Systems** – sedimentary rock aquifers including sandstone, shale and coal (e.g. Great Artesian Basin, Sydney Basin and Clarence Moreton Basin).

Groundwater resources in the Project area are located mainly within the sedimentary rock groundwater systems of the Gloucester Basin.

The NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002) also recognises the four Australian groundwater dependent ecosystem types (Hatton and Evans, 1998) that can be found in NSW, namely:

- terrestrial vegetation;
- base flows in streams;
- aquifer and cave ecosystems; and
- wetlands.

The groundwater dependent ecosystems which are known or likely to occur within the Project area as well as the potential impacts of the Project on groundwater dependent ecosystems are described in the Terrestrial Flora and Fauna Assessment (Cenwest Environmental Services and Resource Strategies, 2009a) (Appendix E of the EA) and the Aquatic Ecology Assessment (Cenwest Environmental Services and Resource Strategies, 2009b) (Appendix F of the EA).

B2.5 STRATIGRAPHY AND LITHOLOGY

The Project coal resource is located within the Permian-aged Gloucester Basin in NSW. The DCM is located in the southern closure of the main synclinal structure of the Gloucester Basin and is associated with the coal bearing strata of the Dewrang Group. The Dewrang Group comprises three main stratigraphic units, namely: Mammy Johnsons Formation; Weismantels Formation; and Durallie Road Formation. The main stratigraphic units in **Figure B-5** are shown in a geological cross-section of the Project area in **Figure B-6**[2].

The Dewrang Group subcrops over a major portion of the DCM and consists of coarse and medium grained sandstones with minor siltstone, conglomerate and coal seams including the Weismantel and Clareval Seams associated with the Weismantels Formation and Durallie Road Formation, respectively (**Figure B-5**; **Figure B-6**). The underlying basement rocks are principally volcanics of Early Permian (i.e. Alum Mountain Volcanics) and Carboniferous age that were folded during formation of the Gloucester Basin. The Early Permian and Carboniferous volcanic rocks are typically erosion resistant and form the more prominent ridges to the east and west of the DCM (**Figure B-2**).

Normal and reverse faults are characteristic of the area. The Gloucester Basin is a fault-controlled depositional trough and subsequent compression tectonics have induced folding, which has accentuated the dip of the strata and, in places, resulted in thrust-faulted repetition of the stratigraphic units. The main faulting and fracturing (joints) trend north-south, east-northeast, and west-southwest in the Project area. Generally the joint spacing in the sandstone is approximately 1 m (Kidd, 1997a).

The nominal coal reserve for the Project, based on the planned maximum production rate, is approximately 20.5 million tonnes (Mt) of ROM coal.

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[2] The only formations shown to scale in **Figure B-6** are the coal seams.

Alluvials/Regolith

A thin, narrow and discontinuous deposit of Quaternary to Recent Age alluvial deposits occurs along the river flats of Mammy Johnsons River. The alluvium consists of silty sands and silts with lenses of gravelly sands and sandy, coarse gravel, particularly towards the base of the alluvium. The gravel lenses correspond to former channel deposits of the river and are evident in the present bed and banks of the river. Monitoring bores in the alluvium are drilled to depths of 5.8 to 10.1 m. Other evidence from exploration holes suggests an average thickness of about 9 m for the alluvium, but the maximum thickness is unknown.

Mammy Johnsons Formation

The uppermost layer of the Mammy Johnsons Formation is thick shale. The deeper sections of the Mammy Johnsons Formation comprise coarse grained lithic sandstones. It also hosts minor, poorly developed coal seams.

Weismantels Formation

The Weismantels Formation comprises fine to medium grained sandstones over thick shale covering the Weismantel Seam (below). The Weismantel Seam overburden (comprising Mammy Johnsons Formation and Weismantels Formation) has a median thickness of 34 m.

Weismantel Seam

The Weismantel Seam is currently the only seam being mined at the DCM and would continue to be mined as part of the Project. The Weismantel Seam is generally between 10 and 12 m thick. However, significant reverse faulting causes repetition of the middle and lower sections of the seam resulting in coal thicknesses of up to 20 m. The median thickness is 17 m. The Weismantel Seam is divided into working sections on a coal quality basis. The upper 3 to 4 m is generally thermal coal and the lower 7 to 8 m is a mixture of coking coal and thermal coal.

As the DCM is located at the southern closure of the regional syncline, the pit extent to date has been located at the southern-most outcrops within the axis of the syncline. The Project pit extent would subsequently progress away from the axis and would be located on the western limb of the syncline (**Figure B-5**).

The seam is underlain and overlain by massive medium to coarse grained lithic sandstones, conglomerates and minor siltstones. The immediate roof and floor of the Weismantel Seam have a high pyrite content.

Durallie Road Formation

The Durallie Road Formation forms the base of the Dewrang Group and comprises mostly marine sandstones in the south of the Gloucester Basin. The Durallie Road Formation hosts the Clareval Seam (below). The lower Durallie Road Formation (beneath the Clareval Seam) is 200 to 300 m thick.

Clareval Seam

The Clareval Seam was identified in late 2005 from seismic re-interpretation and was confirmed by an exploration drilling programme. The Clareval Seam is situated at depth typically 60 to 80 m below and parallel to the Weismantel Seam (median depth 62 m).

The Clareval Seam exhibits many of the same features as the Weismantel Seam (e.g. coal quality trends and seam structure). In the Project area, the Clareval Seam is typically 8 to 9 m thick, however sequences of 30 m and up to 50 m thickness are known to exist in the north-west (**Figure B-6**). The median thickness is 15 m.

Alum Mountain Volcanics

The Alum Mountain Volcanics are a ryholitic rock unit, which is underlain by undifferentiated rocks of Carboniferous age.

A number of exploration boreholes have been drilled across the general Project area as shown on **Figure B-7**. Registered bores within the Project area are shown on **Figure B-8**.

B2.6 HYDROGEOLOGY

The deeper aquifer system at the DCM is continuous through the three major geological formations (i.e. Mammy Johnsons, Weismantels and Durallie Road) due mainly to the extent of faulting/fracturing/fissures in the Project area. The various sedimentary rocks at the DCM have low permeability due to their fine-grained nature, the predominance of cemented lithic sandstones and the common occurrence of a clayey matrix in the sandstones and conglomerates. The permeability of the aquifer system is related to the frequency of fissures (i.e. spacing) and the degree of opening of individual fissures. Permeability of the aquifer generally decreases with depth of burial as the fissures tighten and become less frequent, with higher permeabilities encountered in the coal seams.

Golder Associates (1982) established that before mining commenced, natural groundwater flow was generally in a southerly direction (**Figure B-9**). DCPL (1996) extrapolated from this dataset to infer that flow originates in the elevated ground to the west of the open pit (**Figure B-10**). The trend of the groundwater contours under the higher ground is expected to mimic the topographic contours (**Figure B-10**). A topographic divide along easting 387000 (ISG) isolates the Karuah River in the west from the hydrology of the area being mined.

The presence of several free flowing or artesian boreholes on the lower slopes indicates semi-confined conditions due to the presence of siltstone layers, the lower ground elevations along the creek, and the higher elevations of the recharge sources (DCPL, 1996).

The results of predicted maximum groundwater drawdown levels reported in the Duralie Coal EIS (DCPL, 1996) and Expert Panel No. 1 Report (Kidd, 1997b) to the Commission of Inquiry (COI), indicated that groundwater flow would also move toward the pit as mining progresses.

Kidd (1977b) reported that, as a result of mining, it was expected from modelling that:

> *"mine dewatering will have little if any measurable impact on the flow conditions in Mammy Johnsons River".*

Kidd (1977b) also concluded that:

> *"the impacts of mining on the groundwater quality will be minimal due to existing moderately saline groundwater in the coal measures and volcanics under most of the area.".*

Quantification of the impact on flow conditions is undertaken in this assessment.

B2.7 GROUNDWATER BORE CENSUS

As of September 2009, according to the Natural Resources Atlas (http://nratlas.nsw.gov.au) there are 31 registered bores in the vicinity of the Project, three of which are registered production bores located on privately owned land to the north of the Project (i.e. bores GW080288, GW047870 and GW011316) (**Figure B-8**). The licensed use of these bores is stock/irrigation/industrial. The other 28 registered bores shown on **Figure B-8** are located on DCPL-owned land. Bore locations are shown on **Figure B-8** and NSW Office of Water (NOW) registered bore details are summarised in **Attachment BA**.

Some of the bores do not have reported/surveyed surface collar levels; therefore groundwater elevations are estimated from approximate ground levels. The majority of historical data from the NOW registered bores is limited to notes on levels and salinity records taken at the time of installation.

The registered bores have a median depth of approximately 29 m, and median depth to water of approximately 14 m with a range in water depths from approximately 4 to 40 m below ground. For the 14 production bores, the median yield is approximately 0.7 litres per second (L/s). The three private bores lie 6 to 8 km to the north of current mining.

DCPL conducted a bore census of privately held bores surrounding the DCM in October 2009 by visiting local landholders. During the bore census, a local landholder indicated that a spring is located to the west of The Bucketts Way, in a drainage line in or near Black Soil Creek (**Figure B-8**), and west of the catchment divide described by DCPL (1996) (**Figure B-10**). The bore census also confirmed the location of registered groundwater bore GW080288 (**Figure B-8**).

B2.8 GROUNDWATER EMBARGO ZONES

Pursuant to section 113A of the *Water Act, 1912* an embargo on any further applications for sub-surface water licences under Part 5 of the *Water Act, 1912* was declared on 11 April 2008 for the *Coastal Floodplain Alluvial Groundwater Sources and Highly Connected Alluvial Groundwater Sources of Coastal Catchments - Regional NSW* (the alluvial aquifer embargo). This area includes the Project.

The alluvial aquifer embargo relevantly pertains to:

> *"All the groundwater found in alluvial aquifers located upstream of the tidal limit, and within 500 meters of a 3rd order stream or greater…"*

It is noted that there are mapped alluvial sediments along Mammy Johnsons River to the east of the Project, however, there are no mapped alluvial sediments in the proposed Project open pit extension areas (**Figure B-5**).

Consideration of the groundwater embargo at the DCM is addressed in Section 6 in the Main Report of the EA.

B2.9 GROUNDWATER MONITORING

Groundwater quality sampling and water level monitoring in the general Project area has historically been undertaken by DCPL and the NOW in accordance with the National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (ARMCANZ/ANZECC, 1995). Groundwater quality sampling undertaken by DCPL has primarily focused on the Mammy Johnsons River and Coal Shaft Creek, and is associated with areas of proposed or recently completed mining.

Groundwater levels are recorded by DCPL from monitoring bores near the Mammy Johnsons River, Coal Shaft Creek and over the Project area. Groundwater monitoring programmes are currently active at the DCM, with sampling being undertaken in accordance with the DCM Site Water Management Plan (SWMP) (DCPL, 2008a). The groundwater monitoring programme has been updated regularly as mining has progressed, and details of the monitoring programme for the DCM are summarised in **Table B-2**. Groundwater monitoring locations are shown on **Figure B-8.**

Table B-2. Previous and Existing Monitoring Programmes

Parameters	Monitoring Site	Frequency
• Groundwater levels.	• DB1W - DB10W, BH4BW and SI1W – SI3W. • BH1BW, BH2W and BH5W.	• Monthly.
• Electrical Conductivity (EC). • pH. • SO_4. • Ca. Mg. Na. Fe. Al. Mn. Zn. Cl. • Alkalinity as $CaCO_3$, Acidity as $CaCO_3$.	• DB1W - DB10W, BH4BW and SI1W – SI3W. • BH1BW, BH2W and BH5W.	• Monthly.
• Electrical Conductivity (EC). • pH. • SO_4. • Ca. Mg. Na. K. Cl. Fe_{Tot}. • Bicarbonate. • Alkalinity as $CaCO_3$, Hardness as $CaCO_3$.	• WP1 – WP3.	• Results of initial hydrogeological investigation (Golder and Associates, 1981a and b).
• Electrical Conductivity (EC). • pH. • SO_4. • Mn. Fe. • Bicarbonate. • Alkalinity as $CaCO_3$, Total $CaCO_3$, Total Dissolved Solids (TDS).	• T1 – T14.	• Results of hydrogeological investigation by Pells Sullivan Meynink (1995).
• Electrical Conductivity (EC). • pH. • SO_4. • Ca. Mg. Na. Al. Mn. Zn. K. Cl. Fe. • Alkalinity as $CaCO_3$, Total Dissolved Solids (TDS).	• BH1/1A, BH2, BH3, BH4A/4B and BH5 - BH9.	• Results of hydrogeological investigation by DCPL (1996).

Source: (DCPL, 2008a)

Groundwater quality data is presented in **Attachment BB**. An analysis of groundwater levels across the Project area is provided in Section B2.10.

The density, duration and scale of the groundwater monitoring data were considered adequate to inform the development of the numerical groundwater model and to conduct an assessment of potential groundwater impacts. The proposed groundwater monitoring programme is provided in Section B6.3.

B2.10 BASELINE GROUNDWATER LEVEL DATA

B2.10.1 Spatial Groundwater Level Data

Natural groundwater levels are sustained by rainfall infiltration and are controlled by ground surface topography, geology and surface water elevations. Typically, local groundwater would mound beneath hills and would discharge to incised creeks and rivers. During short events of high surface flow, streams would lose water to the host aquifer, but during recession, the aquifer would discharge water slowly back into the stream from bank storage. Groundwater would flow from elevated to lower-lying terrain.

Based on the available groundwater level data and to gain an impression of the regional water table pattern before mining, a contour map of inferred groundwater levels (**Figure B-11**) has been prepared from groundwater levels at the NOW bores or measured from DCM monitoring boreholes (**Figure B-8**). The dataset has been supplemented with surface water levels in no-data areas, assuming equivalence between surface water and groundwater levels along drainage lines, and an assumed depth to groundwater of 20 m along ridgelines.

Apart from small changes in detail where groundwater measurements have been made, the overall patterns are insensitive to the assumption made as to the relative levels of surface water and groundwater where they interact. In all cases, the contour maps indicate the same groundwater flow pattern (**Figures B-9** to **B-11**). As groundwater would flow perpendicular to the contours, in general (except for discrete fracture flow), groundwater would generally move from the ridges to the natural surface drainages. The Mammy Johnsons River is a prominent groundwater discharge feature.

The map in **Figure B-11** is a composite of water levels from different formations. The measurements clustered near the mine are mostly from open holes but would be representative of Weismantel Coal seam heads. The cluster of points to the north-west of the mine are Clareval Seam heads. The three points in the far north are likely to be Weismantels Formation heads.

Despite the uncertainty in the formation sampled, the map in **Figure B-11** is likely to represent the overall potentiometric head pattern across the area, on the assumption that there is some vertical hydraulic connectivity between formations.

Of significance is the direction of groundwater flow due to mining in the nearby DCM open pit. The DCM open pit acts as a groundwater sink, and groundwater nearby maintains a flow direction towards the pit.

B2.10.2 Temporal Groundwater Level Data

Groundwater levels have been monitored at some bores since 1997; monitoring at others commenced in January 2003 prior to the commencement of open pit mining (March 2003).

Figures B-12 to **B-14** show the monitored levels in the Durallie Road Formation, in alluvium, and in the irrigation area.

The bores in alluvium have shown no effect from mining (**Figure B-12a**). Instead, there is a strong correlation between groundwater levels and rainfall.

Two bores (DB2W and DB4W), drilled into the sandstones of the Durallie Road Formation, have shown a noticeable effect on groundwater levels in the earliest period of mining (**Figure B-12b**). Bore DB2W is located to the immediate east of the pit between the Rail Line and Mammy Johnsons River, and bore DB4W is located to the immediate south of the pit adjacent to the Rail Line (**Figure B-8**). To the south-west of the initial mining, Bore DB5W located in the southern tip of the coal structural syncline shows a mild reduction in groundwater level as mining has moved from the eastern areas of the pit to the western areas of the pit. All three of the above bores show partial recovery with the growth of the waste rock emplacement. Bore DB1W (screened in the Upper Durallie Road formation) to the north-east of the current mine shows no effect from current mining, but the water level fluctuations correspond closely with the alluvial responses to rainfall.

Figure B-13 focuses on the alluvial and rock responses in a pair of bores in close proximity at 265 m separation (BH4BW close to Mammy Johnson's River; and DB2W to the immediate east of the North Coast Railway adjacent to initial mining). While there is a clear response in the Durallie Road Formation to the start of mining of the overlying Weismantel seam, there is no evidence of any effect in the alluvium.

Figure B-14 shows hydrographs at more elevated locations, firstly in the Durallie Road Formation to the north-west (DB6W) and south-east (BH2W) of initial mining; and secondly at the DCM irrigation area upgradient of the MWD (SI1W, SI2W, SI3W). All levels are stable with only minor temporal fluctuations, with no definitive correlation with rainfall.

B2.11 BASELINE GROUNDWATER CHEMISTRY DATA

Table B-3 summarises the chemical attributes of all groundwater samples from 1981 to August 2009 taken at monitoring sites and hydrogeological investigation sites by DCPL, Pells Sullivan Meynink and Golder Associates (**Figure B-8**).

Table B-3. Chemical Data Summary at Groundwater Monitoring Sites

Analyte	Unit	Median	Minimum	Maximum	Average
pH	-	6.7	4.4	9.6	6.8
Electrical Conductivity	MicroSiemens per centimetre (µS/cm)	1,874.0	100.0	7,600.0	2,387.1
Sulphate	milligrams per litre (mg/L)	129.0	0.1	813.0	143.3
Calcium	mg/L	83.0	1.0	700.0	138.3
Magnesium	mg/L	53.0	0.4	244.0	62.0
Sodium	mg/L	243.5	15.0	841.0	333.6
Potassium	mg/L	2.35	<0.5	22.0	4.3
Chloride	mg/L	510.0	<5.0	2,400.0	720.7
Iron	mg/L	1.4	0.0	190.0	14.5
Aluminium	mg/L	0.07	<0.01	190.0	6.67
Manganese	mg/L	0.7	<0.001	10.0	0.9
Zinc	mg/L	0.04	<0.005	0.57	0.07
Alkalinity as $CaCO_3$	mg/L	190.0	0.0	710.0	230.5
Total Dissolved Solids	mg/L	1,480.0	156.0	4,110.0	1,416.0

Source: Golder Associates (1981a, 1981b); Pells Sullivan Meynink (1995); DCPL (2009).

The spatial pattern of baseline groundwater salinity is illustrated in **Figure B-15**. The groundwater is considered moderately brackish, as indicated by a median electrical conductivity (EC) of 1,874 µS/cm and a median salinity (TDS) of 1,480 mg/L. Groundwater salinities range from 100 µS/cm to 7,600 µS/cm, even under the river flats (**Figure B-15**). Salinity in the narrow thin alluvium is lower, generally less than 1,000 µS/cm, reflecting the higher rates of recharge and shorter residence times and flow paths compared with the underlying strata.

The average EC from bores in the lower Durallie Road Formation (i.e. DB1W, DB2W and DB5W), which incorporates the Clareval seam, is 2,568 µS/cm.

The pH of groundwater at the DCM is generally within the 6 to 8 range, as shown in **Attachment BB**.

The concentrations of trace metals in the groundwater are generally below ANZECC criteria for irrigation and stock uses although in some locations, aluminium concentrations have exceeded the recommended ANZECC 'low risk' trigger level for stock use. In some locations, dissolved iron concentrations have exceeded the recommended ANZECC agricultural irrigation 'short term trigger values'.

B3.0 CONCEPTUAL MODEL

A conceptual model of the hydrogeological regime has been developed based on the review of existing hydrogeological data as described in Section B2 including:

- Gloucester Basin geology mapping;
- surrounding and regional geological logs (**Figure B-7**);
- relevant data from the NOW register on the Natural Resources Atlas (http://test.nratlas.nsw.gov.au);
- geological and hydrogeological assessments undertaken for the DCM (i.e. Golder and Associates, 1981a, 1981b, 1982; DCPL, 1996);
- piezometric data from monitoring bores; and
- slug and pumping tests undertaken by DCPL in 2009.

In addition, some elements of linkage to the surface flow and groundwater (baseflow) interaction mechanisms described in Appendix A of the EA have been considered.

Based on the above, the data supports two groundwater systems:

- shallow groundwater system – associated with alluvium and regolith; and
- deeper groundwater system, including:
  - the Weismantel and Clareval coal seams; and
  - low permeability/disconnected fractured rock/coal measures of the Mammy Johnsons, Weismantels and Durallie Road Formations (**Figure B-6**).

The two groundwater systems are illustrated in the conceptual model of the region in **Figures B-16a** and **B-16b**.

Recharge to the groundwater system is from rainfall and from lateral groundwater flow at the boundaries of the study area. Although groundwater levels are sustained by rainfall infiltration, they are controlled by topography, geology and surface water levels. A local groundwater mound develops beneath hills with ultimate discharge to incised creeks and water bodies, and loss by evapotranspiration through outcropping sandstone/shales and vegetation where the water table is within a few metres of the ground surface.

During short events of high surface flow, streams can lose water to the aquifers that host the streams (i.e. leakage), but during recession, the aquifer would discharge water slowly back into the stream from bank storage and slow drainage from the surrounding rock strata (i.e. baseflow). Baseflow is caused by slow drainage of groundwater from the surrounding rock strata or alluvium. In places where mining has occurred, groundwater discharge is expected to occur to the mined pit in proportion to local permeabilities.

Recharge and potential shallow interflow systems occur within the weathered zone where the syncline outcrops. The recharge zone is focused into the coal seams where the seams subcrop or outcrop. Both underlying coal seams host aquifers with leaky aquitard fractured rock above and below.

At the DCM, geological strata are roughly uniform in thickness and lithology, although they are still very steeply dipping and subject to faulting, fracturing and slippage. The Weismantel Seam is especially uniform in characteristics, and although it has local thickening it can be regarded as a separate entity. The Clareval Seam is believed to be similar, although it increases in apparent thickness at folds. Hydraulic testing to date has focused on the central rock units (i.e. the overlying units of Weismantels Formation). Very little is known about the rock masses between or below the two seams.

Hydraulic testwork was undertaken in 2009 in both the Weismantel and Clareval seams. A series of pumping and slug testing was carried out in bores DU198R (Weismantel) and DU199R (Clareval) up to a depth of approximately 50 m, while bores WS8, WS18, CS8, CS14 and DU194R to DU197R were used as monitoring bores for the testwork (**Figure B-8** and **Figure B-19**).

The Weismantel Seam aquifer is unconfined in the area where slug and pump tests were undertaken in 2009 (but is confined in other parts of the DCM), and appears to drain quickly. The seam itself responded very quickly during slug testing but only at the point of disturbance, with marginal effects along strike and no effect on underlying rocks.

The Clareval Seam was fully saturated in the slug and pump test area, being mostly confined at the top and leaky to unconfined at the base. It responded rapidly across the whole seam to disturbance with a clear effect along strike - rapidly inducing flow towards the disturbance point. The small slug disturbances in the Clareval Seam had no effect on the overlying rock and a small influence on the underlying rock.

Data from exploration bore logs (i.e. bores DU021R, DU022R, DU023R and WC225C) indicate that below the alluvials adjacent to Mammy Johnsons River to the east of the North Coast Railway, there are clay/claystone layers varying from 2.5 to 6 m in depth. These clay layers effectively act as aquitards, separating the subcropping/outcropping coal and the overlying alluvials of the Mammy Johnsons River. As clay is a low-permeability stratum, the hydrogeological connection between the coal seams and the river is therefore impeded by these clay lenses.

Irrigation operations at the DCM are designed to maintain moisture of the soil at less than field capacity (Appendix A of the EA), in which case there would be no accession of irrigation water to the groundwater table. The DCM Irrigation Management Plan (DCPL, 2008b) describes the general principles of irrigation at the DCM:

> *"The irrigation system is to be managed and operated to ensure… irrigation does not cause the soil to become saturated…"*

Therefore, as the numerical model is focused in the saturated zone, irrigation infiltration has not been included as a source of recharge to the groundwater system.

B3.1 HYDRAULIC PROPERTIES

Seven active layers are conceptualised in **Figure B-17** for the purpose of numerical modelling. The major coal measures/sandstone/conglomerate formations (Weismantels and Durallie Road formations) are split into multiple layers in recognition of their vertical hydraulic gradients and the need to represent the two target coal seams as separate model layers.

Indicative permeabilities for the various stratigraphic units, summarised in **Table B-4**, are informed by DCPL slug and pumping tests, and model calibration by Golder Associates (1982) and DCPL (1996). Golder Associates and DCPL undertook hydrogeological investigations down to the Weismantel Seam. **Figure B-18** shows the adopted hydraulic conductivity profile for the first three layers used by DCPL (1996), with assumed relative permeabilities for unsaturated zone modelling.

Table B-4. Indicative Hydraulic Properties of Stratigraphic Units

Unit	Hydrogeological Description	Local Hydraulic Conductivity K_L [m/day]	Regional Hydraulic Conductivity K_L [m/day]
Alluvium	Unconfined Aquifer	0.1 - 5	0.1 - 5
Coal Measures/Sandstones of the Mammy Johnsons and Weismantel formations	Leaky Confined Aquifer	0.04 - 3	10^{-3} - 0.3 (to 100 m depth)
Weismantel Seam	Confined/Unconfined Aquifer	0.08 – 1.6 0.01 – 0.5 (to 200 m depth)	10^{-4} - 10 (to 200 m depth)
Coal Measures/Sandstones of the Durallie Road formation	Leaky Confined Aquifer	0.04 - 3	10^{-4} – 0.3 (to 200 m depth)
Clareval Seam	Confined Aquifer (top), Unconfined Aquifer (bottom)	0.036 – 0.34 0.01 – 0.5 (to 200 m depth)	10^{-4} - 10 (to 200 m depth)
Coal Measures/Sandstones of the Durallie Road formation	Leaky Confined Aquifer	0.04 - 3	10^{-4} – 0.3 (to 200 m depth)
Alum Mountain Volcanics	Confined Aquifer	-	-

After: Golder Associates (1982); DCPL (1996, 2009).

Slug tests between April and July 2009 revealed that the Weismantel and Clareval coal seams have hydraulic conductivities ranging from 0.073 to 0.15 m/day and 0.044 to 0.062 m/day, respectively. Slug tests in the Mammy Johnsons Formation near Tombstone Hill in the same period revealed that the hydraulic conductivity of this formation ranges from 0.06 to 0.1 m/day.

Pumping tests in July 2009 revealed that the Weismantel and Clareval seams have hydraulic conductivities ranging from 0.79 to 1.6 m/day and 0.036 to 0.34 m/day, respectively. Typical pumping test responses in the Weismantel and Clareval seams can be found on **Figures B-20a** and **B-20b**.

All investigations to date have provided estimates of longitudinal (“horizontal”) hydraulic conductivity (K_L). There are no known estimates for transverse (“vertical”) hydraulic conductivity (K_T). The relatively high permeabilities in **Table B-4** are indicative of shallow fractured/weathered materials, as measurements were based on tests undertaken at less than 50 m depth. All materials would reduce in permeability with depth. **Figure B-21** displays a published depth dependence for Stratford coal seams in the Gloucester Basin to the north of the DCM (Smith, 2001). There is a distinct exponential decrease with depth as indicated by the line of best fit equation shown in **Figure B-21** with a maximum value near surface of about 500 millidarcies (mD) (<0.5 m/day) and a minimum value of 0.01 mD (~10^{-5} m/day) at 900 m depth.

Figure B-22 places the Gloucester Basin decay function into a broader context by comparing it with Hunter Valley and Sydney Basin lithologies (coal seams, sandstones, sills, interburden) (Tammetta, pers. comm., 2009). There is a distinct decay with depth to 800 m but scatter is substantial at all depths, particularly near ground surface where coal seam hydraulic conductivity can range from 0.001 to 10 m/day.

As the Project open pit would extend to a maximum depth of approximately 180 m below surface, some variation of hydraulic conductivity with depth can be expected in each formation. However, the near-surface hydraulic properties are of most relevance to this investigation.

The hydraulic property measurements have been used to inform the development of the numerical groundwater model and to obtain initial permeability values. The performance of the calibrated numerical model is discussed in Sections B4.5 and B4.6.

B4.0 GROUNDWATER SIMULATION MODEL

B4.1 MODEL SOFTWARE AND COMPLEXITY

Groundwater modelling has been conducted in accordance with the ‚MDBC Groundwater Flow Modelling Guideline (MDBC 2001). Under the modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. The guide (MDBC, 2001) describes this model type as follows:

> *“Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.”*

Numerical modelling has been undertaken using the Groundwater Vistas (Version 5.37) software interface (Environmental Simulations Inc [ESI], 2009) in conjunction with MODFLOW-SURFACT (Version 3) distributed commercially by Hydrogeologic, Inc. (Virginia, USA). MODFLOW-SURFACT is an advanced version of the popular MODFLOW code developed by the United States Geological Survey (McDonald and Harbaugh, 1988). MODFLOW is the most widely used code for groundwater modelling and is presently considered an industry standard.

MODFLOW-SURFACT is a three-dimensional model that is able to simulate variably saturated flow and can handle desaturation and resaturation of multiple aquifers without the “dry cell” problems of Standard-MODFLOW. This is pertinent to the dewatering of layers adjacent to open pit coal mines. Standard-MODFLOW can handle this to some extent, but model cells that are dewatered (reduced below atmospheric pressure) are replaced by “dry cells”.

The model complexity is considered adequate to simulate contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the Project.

B4.2 MODEL GEOMETRY

The model domain is discretised into 212,940 cells arranged into seven layers comprising 260 rows and 117 columns. The dimensions of the model cells are uniformly 50 m in both directions. The model extent as shown in **Figure B-23** is 5.85 km from west to east and 13 km from south to north, covering an area of approximately 76 km^2.

Seven model layers represent the stratigraphic section (**Figure B-17**). Layer 6 represents the Lower Durallie Road Formation and outcropping Alum Mountain Volcanics to allow the allocation of different permeabilities for outcropping and deeper sections of this formation. Layer 7 hosts the deeper portion of the Alum Mountain Volcanics.

The eastern and western limits of the active model area were chosen to coincide with topographic ridgelines and outcropping Alum Mountain Volcanics.

Representative model cross-sections are displayed in **Figure B-24** for northing 6,428,525 (MGA) (model row 130) and northing 6,426,275 (MGA) (row 175) (**Figure B-23**). The cross-sections pass through the proposed Clareval North West open pit (row 130) and the already-mined portion of the Weismantel pit (row 175). The Weismantel and Clareval seams are respectively Layers 3 and 5.

The elevations of the top and base of the Weismantel Seam are well defined in the Project area, and the Clareval Seam is well defined on its western limb. Structure contours have been extrapolated to the north and east to define the stratigraphy throughout the model area, guided by median thicknesses from exploration drilling (as listed in **Figure B-17**).

B4.3 MODEL STRESSES AND BOUNDARY CONDITIONS

The main streams in the area (i.e. Mammy Johnsons River and Wards River) are established as "river" cells in model Layer 1 (denoted by green cells in **Figure B-25**) using the MODFLOW RIV package. This allows water exchange in either direction between the stream and the aquifer. The river conductances are proportional to estimated reach lengths in each river cell. The median conductance is 150 square metres per day (m^2/day) with a range from 10 to 450 m^2/day.

Minor drainage lines were established as "drain" cells in the model using the MODFLOW DRN package (shown in yellow in **Figure B-25**). This allows groundwater to discharge to the drainage lines as baseflow. The drain conductances were set at 50 m^2/day.

The model edges are no-flow by default, with general head boundaries where Mammy Johnsons River enters and leaves the active model area in Layer 1. A wider general head boundary is applied across the alluvial extent of Wards River at the northern boundary. Equivalent general heads are applied through the stratigraphic section at the northern boundary.

"Drain" cells are used to represent mining. Invert levels are generally 1 m above the floor of the coal seam, and equivalent to base levels for layers overlying the mined seam. The drain conductance value (0.2 m^2/day) was determined during calibration.

Rainfall infiltration has been imposed as a percentage of actual rainfall (for transient calibration) or long-term average rainfall (for steady-state calibration and prediction simulations) across four zones (**Figure B-26**):

- regolith;
- hills;
- alluvium; and
- subcropping coal seams.

The recharge rates were determined during model calibration. Additional recharge zones are defined during predictive simulations for the active mining area (zero recharge) and spoil infiltration (initially zero, then 5% after five years).

There is no active groundwater pumping in the model.

Evapotranspiration is applied uniformly using MODFLOW's linear function, with a maximum rate of 750 millimetres per annum (mm/annum) and an extinction depth of 3 m.

B4.4 MODEL VARIANTS

Both steady-state and transient models have been developed:

- ❑ Steady-state model of pre-mining conditions: Calibration against the inferred pre-mining groundwater levels in **Figure B-11**.
- ❑ Transient model of the transition from pre-mining to early mining: Calibration against the groundwater hydrographs in **Figure B-12**.
- ❑ Transient predictive model extending to the end of mining.
- ❑ Post-mining equilibrium model.

B4.5 STEADY-STATE CALIBRATION

The model was set up and initially run in steady-state mode to replicate the broad groundwater elevation and hydraulic gradient spatial patterns shown in **Figure B-11**, inferred from field measurements and drainage controls.

Calibration was performed against 167 head targets measured in various years, concentrated near current mining and the proposed Clareval North West open pit (**Figure B-11**). Head targets were allocated to Layer 1 (10 points), Layer 2 (three points), Layer 3 (86 points), Layer 4 (six points), Layer 5 (56 points), and Layer 6 (six points).

The steady-state calibration was achieved initially with sequential model runs by manually adjusting the longitudinal (K_L) and transverse hydraulic conductivity (K_T) and rainfall recharge values until the best fit between the simulated water levels and field-based water levels was obtained. Then the calibration was finalised automatically using PEST software and zoned regions. Each layer was assumed to be laterally uniform except for two zones in Layer 1 representing alluvium and the regolith. Some variation was also applied in deeper plunging layers to accommodate the expected permeability reduction with depth. However, none of the (relatively shallow) head measurements to date are likely to be sensitive to this variation with depth.

The adopted hydraulic conductivity distributions are illustrated in **Attachment BC**.

Table B-5 summarises the hydraulic properties for the stratigraphic section at the end of steady-state calibration. As automatic calibration tends to drive the values to the lower end of permissible ranges, these values are preliminary only. More reliable values are determined during transient calibration when stresses on the aquifer system (dynamic rainfall and mining) are taken into account.

Table B-5. Steady-State calibrated Longitudinal and Transverse Hydraulic Conductivities

ZONE	LAYER	FORMATION	K_L (m/day)	K_T (m/day)
1	1	Regolith	1	0.016
2	2	Coal Measures/Sandstones of the Mammy Johnsons and Weismantels formations	0.001	0.01
3	3	Weismantel Seam	0.01	1
4	4	Coal Measures/Sandstones of the Upper Durallie Road formation	0.001	1
5	5	Clareval Seam	0.01	0.00018
6	7	Alum Mountain Volcanics	0.001	0.0001
7	1	Alluvium	1	0.01
8	2, 3, 4, 5	Coal Measures/Sandstones of the Lower Durallie Road formation	0.00001	100
9	3	Coal Measures/Sandstones of the Mammy Johnsons and Weismantels formations	0.1	1
10	5	Coal Measures/Sandstones of the Upper Durallie Road formation	0.1	0.00001
11	6	Coal Measures/Sandstones of the Lower Durallie Road formation	0.1	0.001
12	3, 4, 5	Coal Measures/Sandstones of the Mammy Johnsons and Weismantels formations	0.01	0.000001

The PEST-derived values for rainfall infiltration expressed as percentages of long-term average rainfall are:

- regolith: 2.6%
- hills: 12%
- alluvium: 1%
- subcropping coal seams: 1%

B4.5.1 Steady-State Calibration Performance

The simulated steady-state water table for the model area, illustrated in **Figure B-27**, compares favourably with the inferred pattern based on measurements in **Figure B-11**. The model underestimates the heads at the elevated edges of the model domain. However, no field measurements are available to verify the accuracy of the inferred values. The pattern and the absolute water levels are replicated well in the Project area.

Figure B-27 also displays the residual error between simulated and measured head at each calibration site. The residuals range from -16 m to +16 m.

The performance of the calibration is quantified by a number of statistics in **Table B-6**. The key statistic is 4.7% Root Mean Square (RMS), which is well below the target 10% RMS suggested in the MDBC flow model guidelines (MDBC, 2001).

Table B-6. Steady-State Calibration Performance

Calibration Statistics	Value
Number of Data (n)	167
Root Mean Square (RMS) (m)	4.7
Scaled Root Mean Square (SRMS) (%)	7.0
Scaled Residual Standard Deviation (SRSD) (%)	6.6^
Average residual (m)	-1.5
Absolute average residual (m)	3.6

^ This statistic is reported by Groundwater Vistas.

A scattergram of simulated versus measured heads in **Figure B-28** demonstrates good agreement across the whole range of measurements. There is a slight bias towards overestimation at lower elevations and underestimation at higher elevations. The high rainfall recharge of 12% in the hills was required to reduce the underestimation of higher water levels.

B4.5.2 Steady-State Water Balance

The steady-state water balance across the entire model area is summarised in **Table B-7**. The total inflow (recharge) to the aquifer system is approximately 13 ML/day, comprising mainly rainfall recharge (76%), and leakage from the rivers into the aquifer (23%). The stream leakage is simulated to be about 3 ML/day.

Table B-7. Simulated Water Balance for the Steady-State Calibration Model

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	10.0	1.7^
Evapotranspiration	-	8.4
Rivers	3.0	1.6
Creeks	-	1.5
Boundary Flow	0.15	0.03
TOTAL	**13.2**	**13.2**
Discrepancy (%)	**0.01%**	

^ Rejected recharge computed by MODFLOW-SURFACT.

There are multiple opportunities for groundwater discharge. Those implemented in the model are baseflow to rivers (represented by the “river” algorithm in MODFLOW), baseflow to creeks (represented by the “drain” algorithm in MODFLOW), evapotranspiration, and rainfall recharge that is in excess of the ground’s capacity for infiltration (a special feature of MODFLOW-SURFACT).

Evapotranspiration represents the major outflow of about 64%. Baseflow to the rivers accounts for about 12% of the total discharge under steady state conditions, with minor creeks accepting much the same.

Boundary flows are of negligible consequence.

B4.5.3 Steady-State Sensitivity Analysis

A sensitivity analysis has been conducted for rainfall recharge on Zone 1 (regolith) and Zone 2 (hills), as these values affect the degree of bias in matching simulated and measured heads. Although many sensitivity tests on hydraulic conductivity values were undertaken, none are reported here as the distributions are superseded by those found during transient calibration.

Table B-8 shows that the Base-run parameters have the second best performance, but there is not much difference between most of the runs. The best run (#7) suggests that rainfall recharge on the regolith is about 1%.

Table B-8. Sensitivity Analysis for Steady-State Rainfall Recharge

RUN	REGOLITH (Z1) (%)	HILLS (Z2) (%)	%RMS	Average Residual (m)	Absolute Average Residual (m)	RMS (m)
Base^	2.6	12	7.0	-1.5	3.6	4.7
1	2.6	16	7.3	-2.2	3.6	4.9
2	2.6	8	7.1	-0.6	3.7	4.8
3	2.0	12	7.0	-1.3	3.5	4.7
4	2.0	6	7.7	-0.3	4.1	5.2
5	4.0	6	7.5	-0.2	4.0	5.0
6	4.0	8	7.1	-0.8	3.7	4.7
7	1.0	12	6.9	-1.0	3.5	4.6

^ All runs apply 1% to zone 3 and zone 4.

B4.6 TRANSIENT CALIBRATION

Transient calibration was performed from January 2003 to December 2005 in 12 quarterly periods to replicate the transitional behavior of key groundwater hydrographs from pre-mining to early mining. In all, 134 target heads were established for 10 sites: DB1W, DB2W, DB3W, DB4W, DB5W, DB6W, BH4BW, DU151R, DU199R, and DU154R. The last three sites had only one target head each but were included to represent the higher heads in the proposed Clareval North West open pit area. The site locations are shown on **Figure B-25**.

During the calibration period, rainfall recharge was varied according to measured rainfall, but river stages were invariant with time.

Estimated pit inflow from March 2003 to December 2006 served as an important extra target. Although pit inflow is not measured directly, it has been inferred from a surface water balance model (Appendix A of the EA). The inferred values are listed in **Table B-9**.

Table B-9. Inferred Groundwater Inflow Rates

Date	**1/3/2003**	**1/10/2003**	**1/9/2004**	**2/9/2004**	**1/1/2006**	**1/7/2006**	**1/11/2008**
ML/day	0	0.45	0.5	0.06	0.04	0.01	0.15

Source: Gilbert and Associates (2009).

Appendix A of the EA notes that:

> *"groundwater inflow rates are significantly lower than the median 0.68 ML/day predicted as part of Duralie Coal EIS studies"*

Appendix A of the EA also noted:

> *"that the recent groundwater inflow rate could be increased by decreasing the pit area runoff coefficient and still obtain a similarly good match between predicted pit inflow and monitored water pumped from the pit"*

As these estimates do not take account of groundwater inflow evaporated from the pit before water is transferred to the MWD, 0.1 ML/day[3] has been added to the target inflows. A power-law function was fitted to the data to provide a smooth curve as a model target:

$$\text{Flow[ML/d]} = 12.989 \times \text{Time[d]}^{-0.593}$$

The target pit inflow curve is shown in **Figure B-29**.

While automated PEST software was used to get a close match to the pit inflows, the final calibration was fine-tuned manually.

Table B-10 summarises the hydraulic and storage properties for the stratigraphic section at the end of transient calibration. The adopted hydraulic conductivity distributions and the calibrated K_L values are given in **Attachment BC**. The values for K_L are consistent with field estimates listed in **Table B-4**.

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[3] Estimated as 80% of 2 mm/day evaporation over a 300 m x 300 m pit.

Table B-10. Calibrated Longitudinal and Transverse Hydraulic Conductivities, Specific Storage and Specific Yield

ZONE	LAYER	FORMATION	K_L (m/day)	K_T (m/day)	S_S (m^{-1})	Sy (m^{-1})
1	1	Regolith	0.5	0.001	$2x10^{-5}$	0.08
2	2	Coal Measures/Sandstones of the Mammy Johnsons and Weismantels formations	0.05	0.000001	$1x10^{-6}$	0.01
3	3	Weismantel Seam	0.15	1	$1x10^{-6}$	0.02
4	4	Coal Measures/Sandstones of the Upper Durallie Road formation	0.1	1	$1x10^{-6}$	0.01
5	5	Clareval Seam	0.05	0.000001	$1x10^{-6}$	0.02
6	7	Coal Measures/Sandstones of the Lower Durallie Road formation	0.05	0.0005	$1x10^{-6}$	0.01
7	1	Alluvium	1	0.0003	$2x10^{-5}$	0.05
8	2, 3, 4, 5	Coal Measures/Sandstones of the Lower Durallie Road formation	0.000001	100^	$1x10^{-6}$	0.005
9	3	Coal Measures/Sandstones of the Mammy Johnsons and Weismantels formations	0.1	1	$1x10^{-6}$	0.005
10	5	Coal Measures/Sandstones of the Upper Durallie Road formation	0.05	0.000001	$1x10^{-6}$	0.005
11	6	Coal Measures/Sandstones of the Lower Durallie Road formation	0.1	0.0001	$1x10^{-6}$	0.005
12	3, 4, 5	Coal Measures/Sandstones of the Mammy Johnsons and Weismantels formations	0.01	0.000001	-	-

^ Forced vertical linkage between phantom layers.

The adopted values for rainfall infiltration expressed as percentages of long-term average rainfall are similar to those adopted from steady-state calibration:

- Regolith [Zone 1]: 2.0%
- Hills [Zone 2]: 12%
- Alluvium [Zone 3]: 1.0%
- Subcropping coal seams [Zone 4]: 0.5%

Two additional recharge zones were introduced to represent areas of ground to be mined and to be infilled with spoil (**Figure B-26**). Prior to mining, their recharge rates were set as weighted averages of the four natural recharge zones:

- Zone 5: 0.5%
- Zone 6: 0.7%

When mining passed through one of these extra recharge zones, its rate was set to zero. The rate was not reset during the three-year calibration period as spoil was emplaced due to the time required for spoil to resaturate.

A low mine drain conductance of 0.2 m^2/day proved necessary to match low pit inflows for relatively high longitudinal hydraulic conductivity values.

Infilling mined areas with spoil would have a mitigating effect on pit inflow. At one extreme, the spoil could block further pit inflow from the direction of the area already mined. At the other extreme, the base of the spoil could act as a free-flowing rubble drain. From a modelling point of view, a decision must be made as to how long mine “drain” mechanisms remain active after mining has progressed. After experimentation with several durations, the best calibration result was achieved with a one year activation period. In particular, the partial groundwater recovery noted at bore DB2W could not be reproduced with longer activation times. Also, longer exposure of drains led to pit inflow estimates about double those expected.

B4.6.1 Transient Calibration Performance

The simulated pit inflow, illustrated in **Figure B-30**, compares very favourably with the inferred observed inflow curve.

The ability of the model to replicate observed groundwater hydrographs is illustrated in **Figure B-30** to **Figure B-33**. The simulated drawdown in bores DB2W and DB4W in **Figure B-31** and **Figure B-32** respectively are less than observed. Nearby alluvial bores show no mining responses in either the simulated or observed hydrographs. The DB1W hydrograph could not be matched well (**Figure B-33**); this bore is located at the junction of three contrasting permeabilities in the model, and its response is very sensitive to changes in hydraulic parameters. The DB6W hydrograph also shows a rising trend, contrary to what has been observed, but the absolute levels are reasonable.

The overall performance of the transient calibration is quantified by a number of statistics in **Table B-11**. The key statistic is 4.0% RMS, which is well below the target 10% RMS suggested in the MDBC flow model guidelines (MDBC, 2001).

Table B-11 Transient Calibration Performance

Calibration Statistics	Value
Number of Data (n)	134
Root Mean Square (RMS) (m)	4.0
Scaled Root Mean Square (SRMS) (%)	6.4
Scaled Residual Standard Deviation (SRSD) (%)^	5.2
Average residual (m)	-2.3
Absolute average residual (m)	2.7

^ This statistic is reported by Groundwater Vistas.

A scattergram of simulated versus measured heads in **Figure B-34** demonstrates good agreement across the whole range of measurements. There is a slight bias towards overestimation at lower elevations and underestimation at higher elevations.

B4.6.2 Transient Water Balance

The instantaneous transient water balance across the entire model area is summarised in **Table B-12** at the end of the calibration period. The total inflow (recharge) to the aquifer system is approximately 8 ML/day at December 2005, comprising mainly rainfall recharge (70%), and leakage from the rivers into the aquifer (29%). The stream leakage is simulated to be about 2.4 ML/day.

Table B-12. Simulated Water Balance for the Transient Calibration Model

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	5.7	1.6^
Evapotranspiration	-	3.6
Rivers	2.4	1.3
Creeks	-	1.2
Mine	-	0.25
Boundary Flow	0.11	0.16
TOTAL	**8.2**	**8.1**
Storage	**0.15 GAIN**	
Discrepancy (%)	**0.01**	

^ Rejected recharge computed by MODFLOW-SURFACT.

Evapotranspiration represents the major outflow of about 44%. Baseflow to the rivers accounts for about 16% of the total discharge at December 2005, with minor creeks accepting much the same. Of the applied rainfall recharge, 28% is rejected. The computed mine inflow is 3% of the total groundwater discharge over the model area.

Boundary flows and changes in storage are of negligble consequence.

B4.6.3 Transient Sensitivity Analysis

A sensitivity analysis has been conducted for mine drain conductance, mine drain duration and spoil infiltration. The results are listed in **Table B-13**. In addition, many changes in hydraulic conductivity during the calibration process showed extreme sensitivity of pit inflows and hydrographic responses to hydraulic conductivity.

Table B-13 shows that head-based statistics can be similar while pit inflow varies substantially. Reducing mine drain conductance from 0.3 to 0.2 m^2/day led to a 13% reduction in pit inflow. Temporary activation of mine drains resulted in a 25% reduction in pit inflow. Disabling of newly-placed spoil infiltration made no significant difference over the three year calibration period.

Table B-13. Sensitivity Analysis for Transient Calibration

RUN	MINE DRAIN CONDUCTANCE (m^2/day)	ACTIVE MINE DRAINS	SPOIL RAIN	Average Pit Inflow (kilolitres per day [kL/day])	Average Residual (m)	%RSD
Base	0.2	1 year	Off	299	-2.3	5.2
1	0.3	1 year	Off	345	-2.0	4.8
2	0.3	Always	Off	462	-1.9	5.0
3	0.3	Always	On	463	-1.9	5.0

B5.0 SCENARIO ANALYSIS

B5.1 MINE SCHEDULE

Using the hydraulic and storage properties found during transient calibration and a pit activation period of one year, the model was run in transient mode from January 2003 to December 2020. The Project is taken to commence in July 2010 (stress period 24) and finish in June 2019 (stress period 41). Forty-four continuous stress periods have been applied. The first 16 periods (to December 2006) are each three months in length, while the remainder are six months in length. Rainfall recharge is deactivated in cells where mining is currently active, for a period of five years. It has been estimated that spoil would require roughly this length of time to wet up through the unsaturated zone. After five years, 5% recharge is applied to spoil.[4]

Table B-14 summarises the stress period setup in the model and the sequencing of six time-variant recharge zones over the mine footprint. The recharge zones are indicated in **Figure B-26** (as brown polygons). A stress period is the timeframe in the model when all hydrological stresses (e.g. rain recharge, river stage, etc.) remain constant.

The only time-varying stress in the model is rainfall recharge, and then only for the stress periods covered by the transient calibration (periods 1 to 12). From then on, long-term average rainfall is the basis for calculating recharge.

The progression of mining is represented in the model according to the schedule shown in **Figure B-35**. The mining activity is defined in the model using drain cells within the mined coal seams, with drain elevations set to 1 m above the base of a layer. For the Weismantel Seam (Layer 3), drain cells are specified in Layers 1 to 3. For the Clareval Seam (Layer 5), drain cells are specified in Layers 1 to 5.

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[4] Due to MODFLOW’s restriction to time-invariant properties in a continuous simulation, spoil permeability has not been specified.

Table B-14. Model Stress Period Setup

PERIOD	DAYS	START month	START year	END month	END year	PHASE	PROJECT YEAR	RCHz5[1]	RCHz6[1]	RCHz7[1]	RCHz8[1]	RCHz9[1]	RCHz10[1]
1	91.3	January	2003	March	2003			0.5%					
2	91.3	April	2003	June	2003				0.5%				
3	91.3	July	2003	September	2003					1.6%			
4	91.3	October	2003	December	2003						2.0%		
5	91.3	January	2004	March	2004							2.3%	
6	91.3	April	2004	June	2004								4.4%
7	91.3	July	2004	September	2004								
8	91.3	October	2004	December	2004								
9	91.3	January	2005	March	2005								
10	91.3	April	2005	June	2005							**VIRGIN**	**GROUND**
11	91.3	July	2005	September	2005								
12	91.3	October	2005	December	2005	END TRANSIENT CALIBRATION		**OFF**					
13	91.3	January	2006	March	2006								
14	91.3	April	2006	June	2006								
15	91.3	July	2006	September	2006				**OFF**				
16	91.3	October	2006	December	2006								
17	182.6	January	2007	June	2007								
18	182.6	July	2007	December	2007								
19	182.6	January	2008	June	2008								
20	182.6	July	2008	December	2008								
21	182.6	January	2009	June	2009								
22	182.6	July	2009	December	2009					**OFF**			

Table B-14. Model Stress Period Setup (Continued)

PERIOD	DAYS	START month	START year	END month	END year	PHASE	PROJECT YEAR	RCHz5[1]	RCHz6[1]	RCHz7[1]	RCHz8[1]	RCHz9[1]	RCHz10[1]
23	182.6	January	2010	June	2010		YEAR			OPEN PIT			
24	182.6	July	2010	December	2010	START OF PROJECT	1				OFF		
25	182.6	January	2011	June	2011		1					OFF	
26	182.6	July	2011	December	2011		2						
27	182.6	January	2012	June	2012		2						
28	182.6	July	2012	December	2012		3						
29	182.6	January	2013	June	2013		3						
30	182.6	July	2013	December	2013		4						
31	182.6	January	2014	June	2014		4						
32	182.6	July	2014	December	2014		5						OFF
33	182.6	January	2015	June	2015		5						
34	182.6	July	2015	December	2015		6			5% SPOIL			
35	182.6	January	2016	June	2016		6						
36	182.6	July	2016	December	2016		7						
37	182.6	January	2017	June	2017		7						
38	182.6	July	2017	December	2017		8						
39	182.6	January	2018	June	2018		8						
40	182.6	July	2018	December	2018		9						
41	182.6	January	2019	June	2019	END OF PROJECT	9						
42	182.6	July	2019	December	2019		10						
43	182.6	January	2020	June	2020		10						
44	182.6	July	2020	December	2020		11						

[1] Recharge zones (RCHz) are shown on Figure B-26. Rainfall in recharge zones is presented as a percentage of actual rainfall to the end of the transient calibration period, after which percentages of long-term rainfall are applied.

B5.2 WATER BALANCE

Simulated water balances are examined in **Tables B-15** and **B-16** at the start and end of the Project, with and without mining, for the whole model area. At the start of the Project (**Table B-15**), there is no significant difference in component recharge rates but there are minor reductions in groundwater discharge to the rivers (3.4%) and to the creeks (4.2%). There is also a reduction in evapotranspiration by 2.2% to compensate in part for mine inflow of 0.2 ML/day.

At the end of the Project (**Table B-16**), there are minor reductions in groundwater discharge to the rivers (1.3%) and to the creeks (8.9%) when mine inflow is 0.39 ML/day. There is also a reduction in evapotranspiration by 0.8%.

Table B-15. Simulated Water Balance for the Prediction Model at Project Commencement

Component	NO MINING Groundwater Inflow (Recharge) (ML/day)	MINING Groundwater Inflow (Recharge) (ML/day)	NO MINING Groundwater Outflow (Discharge) (ML/day)	MINING Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	8.73	8.76	1.65^	1.65^
Evapotranspiration	-	-	6.24	6.10
Rivers	2.35	2.35	1.49	1.44
Creeks	-	-	1.44	1.38
Mine	-	-	0	0.20
Boundary Flow	0.11	0.11	0.22	0.22
TOTAL	**11.19**	**11.22**	**11.04**	**10.99**

^ Rejected recharge computed by MODFLOW-SURFACT.

Table B-16. Simulated Water Balance for the Prediction Model at Project Completion

Component	**NO MINING** **Groundwater Inflow (Recharge) (ML/day)**	**MINING** **Groundwater Inflow (Recharge) (ML/day)**	**NO MINING** **Groundwater Outflow (Discharge) (ML/day)**	**MINING** **Groundwater Outflow (Discharge) (ML/day)**
Rainfall Recharge	8.73	8.91	1.66^	1.65^
Evapotranspiration	-	-	6.34	6.29
Rivers	2.35	2.35	1.50	1.48
Creeks	-	-	1.45	1.32
Mine	-	-	0	0.39
Boundary Flow	0.11	0.11	0.23	0.22
TOTAL	**11.19**	**11.22**	**11.18**	**11.35**

^ Rejected recharge computed by MODFLOW-SURFACT.

B5.3 PREDICTED PIT INFLOW

The time-varying pit inflow predicted by the model is illustrated in **Figure B-36**. It is expected to vary between 0.2 ML/day and about 1 ML/day during the Project. Note that pit inflow data is presented for both pits (i.e. Weismantel Extension and Clareval North West open pits).

The sharp increase in pit inflow at Project commencement is due to the long strip of the Weismantel seam and overburden assumed to be mined in the first six months of the Project. This is shown in **Figure B-35** (in yellow) for period 24.

B5.4 PREDICTED BASEFLOW CHANGES

Predicted changes in baseflow and natural river leakage have been assessed for relevant Reaches 2 and 3 of the Mammy Johnsons River. **Figure B-25** provides reach definitions. River-aquifer exchanges have been compared for transient simulations with and without mining.

The model results are shown in **Figure B-37**. They reveal that the proposed mining operation has a negligible impact on stream baseflow and natural river leakage of the Mammy Johnsons River. The results show that the maximum predicted reduction in groundwater baseflow and river leakage over nine years of mining operations is 0.00014 megalitres per day per square kilometre (ML/day/km^2) in the Mammy Johnsons River when the size of the catchment is taken into consideration.

Table B-17 expresses the instantaneous river-aquifer flux changes of the Mammy Johnsons River catchment area at the end of mining. The impact is considered negligible.

Table B-17. Predicted Instantaneous River-Aquifer Flux at End of Mining

Stream	Catchment Area (km^2)	Simulated Flux (ML/day)		Flux Change ($ML/day/km^2$)
		No Mining	After Nine Years of Mining	
Mammy Johnsons River	320	1.030	1.018	0.00004

This finding of negligible impact is consistent with the conclusions of separate hydrological studies (Appendix A of the EA) which relevantly conclude that no loss of flow from the Mammy Johnsons River is expected as a result of the proposed future mining.

More detail is shown in **Figure B-38** for Reach 2 (net gaining reach) and in **Figure B-39** for Reach 3 (net losing reach).

B5.5 SENSITIVITY ANALYSIS

Sensitivity analysis for the transient calibration identified mine drain conductance and drain activation duration as the most important factors controlling estimation of pit inflow and groundwater responses. Accordingly, the predictive model has been repeated for lower and higher drain conductances, and for longer activation of mine drains.

The examined sensitivity cases are defined in **Table B-18**.

Table B-18. Sensitivity Analysis Cases for Mine Features

RUN	MINE DRAIN CONDUCTANCE (m^2/d)	ACTIVE MINE DRAINS
Base	0.2	1 year
1	0.1	1 year
2	0.3	1 year
3	0.2	3 years
4	0.3	3 years

Figure B-40 shows the variation in pit inflow. Drain conductance has a mild effect on inflow estimates, while drain activation period has a strong effect. Case 1 (conductance 0.1 m^2/day) matches the inferred water balance data a little better than the base case (conductance 0.2 m^2/day).

Figure B-41 shows the sensitivity in estimates of additional river leakage due to mining, with variation in mine-related parameters. For all considered cases, the reduction in flow ranges from 0.00002 to 0.00027 $ML/day/km^2$. Therefore, for all cases, there would be a negligible impact on river-aquifer interaction.

Additional sensitivity analysis has been conducted on the two parameters that have the most control over aquifer-river interaction: river conductance and the vertical hydraulic conductivity of alluvium. The examined sensitivity cases are defined in **Table B-19**.

Table B-19. Sensitivity Analysis Cases for Aquifer-River Features

RUN	RIVER CONDUCTANCE [Median] [m^2/d]	ALLUVIUM VERTICAL HYDRAULIC CONDUCTIVITY [m/d]
Base	150	3×10^{-4}
5	15	3×10^{-4}
6	1500	3×10^{-4}
7	150	3×10^{-3}

The results, displayed in **Figure B-42**, show that there is negligible difference in extra river leakage between all cases for the duration of the Project. Accordingly, the impact of mining on river leakage is not sensitive to the river-related parameters adopted in the model.

B5.6 POST-MINING EQUILIBRIUM

A final void water balance was prepared by Gilbert & Associates (Appendix A of the EA) using a rainfall-runoff model. Estimates of groundwater inflow over time required as inputs to the model were provided by conducting a series of steady-state groundwater model runs with the open pits at various water levels. Appendix A of the EA estimates equilibrium water levels would be reached (i.e. approximately 80 mAHD in the final void) approximately 120 years after mining ceases.

A steady-state post-mining equilibrium model has been set up using a constant head of 80 mAHD in model Layers 1 to 5 for the Clareval void and 80 mAHD in model Layers 1 to 3 for the Weismantel void. A hydraulic conductivity of 1 m/d (K_L and K_T) has been applied to spoil in Layers 1 to 5 (west) and Layers 1 to 3 (east).

Figure B-43 shows the equilibrium groundwater levels in model Layer 2 and model Layer 3. In Layer 2, the pit lakes act as sources of water for flow away from the lakes into the formation to the north-east, east and south-east. The lakes act as sinks for groundwater entering from the west and north. In Layer 3, the lakes are predominantly groundwater sinks, with groundwater flow from the lake to adjacent spoil only to the south.

B6.0 IMPACTS ON THE GROUNDWATER RESOURCE

B6.1 POTENTIAL IMPACTS ON GROUNDWATER

B6.1.1 Changes in Hydraulic Properties

There would be a change in hydraulic properties over the mine footprint where spoil infills the excavation down to the floor of the mined coal seam. As spoil would have a higher permeability than any natural material in this area, with the possible exception of alluvium, there would be associated reductions in hydraulic gradients in accordance with Darcy's Law. As one increases, the other must decrease to maintain the same flow. The flattening of the hydraulic gradient in the spoil material is evident in the spacing of the contours to the south of the pit lakes in **Figure B-43**.

Rainfall recharge is expected to be higher in the spoil than in any natural local material.

B6.1.2 Changes in Groundwater Flow and Quality

As mining progresses, the void would act as a groundwater sink. This would cause a temporary change in groundwater flow direction, often reversal of direction, until mining is completed and the aquifer system recovers to a new equilibrium. The final void would remain a groundwater sink for some time, and no impacts to groundwater quality are expected during this time as a result of the final void water quality.

The post-mining groundwater level pattern in **Figure B-42** shows that the pit lakes would act as flow-through lake systems. To the east of the mine footprint, natural groundwater flow direction is expected to be restored to a dominant southerly direction. At the mine itself, the spoil infill would encourage preferential flow in a south-southeast direction. Groundwater would be drawn towards the infill from the west and the north-east. There would be no deleterious effect on the groundwater resource or on the quality of the water, because water quality in the surrounding groundwater is in many cases of a poorer quality than what is predicted from the final void; final void salinity is generally predicted to slowly increase with time, reaching 5,000 µS/cm in 310 years (Appendix A of the EA). Therefore, it is expected that groundwater quality would not be impacted by final void water quality after mining.

In addition, Appendix A of the EA reports that the average simulated EC of water in the MWD (i.e. irrigation water) for the median rainfall sequence is 2,144 µS/cm. Therefore water quality in the surrounding groundwater is in many cases of a poorer quality than what is predicted from irrigation and hence the impact on groundwater from irrigation water is expected to be negligible.

This conclusion is supported by monitoring at the DCM. **Attachment BB1** shows the EC of groundwater in bores SI1W, SI2W and SI3W, all of which are in irrigation areas. Only one bore has shown a change in the past five years (SI3W), but EC at this bore has reduced since monitoring began and has returned to its original levels in the past few years. There appears to be no degradation of groundwater quality from irrigation at these three bores.

Predicted impacts on baseflow to Mammy Johnsons River are provided in Section B6.2.

B6.1.3 Geochemistry

Acid rock drainage (ARD) management at the DCM is managed in accordance with the Potential Acid Forming Material Management Plan (PAFMMP). This plan comprises the following components:

- ☐ Potential acid-forming (PAF) material separation procedures;
- ☐ PAF material storage procedures; and
- ☐ monitoring of surface water and groundwater for the control of PAF materials.

Monitoring results from the DCM indicate that the waste rock management methods have been successful in controlling acid release from the open pit floor and waste rock emplacement (Environmental Geochemistry International [EGi], 2009 [Appendix I of the EA]).

Geochemical investigation undertaken in Appendix I of the EA (EGi, 2009) concluded that:

> *"Weismantel Seam overburden appears to be mainly NAF, except for a PAF horizon within 5 m (perpendicular to bedding) immediately above the coal seam. The Weismantel Seam floor rock is likely to be mainly PAF. Results from the EIS Geochemical Assessment testing suggest the PAF zone above the coal seam, the overlying thicker NAF zone, and the PAF floor rock are continuous and predictable, which is supported by more recent testing and operational experience.*
>
> …
>
> *Results indicate that PAF and NAF materials from Weismantel Seam overburden and Clareval Seam overburden are geochemically similar, and hence the existing management approaches used for Weismantel Seam overburden at the current DCM (Section 9) are expected to be applicable to Clareval Seam overburden. However, some modifications would be required to account for the greater complexity in the distribution of PAF and NAF in Clareval Seam overburden"*

Based on these results, it is expected that use of the existing mine waste segregation and handling practices would be sufficient to maintain adequate control over ARD risk on-site. The existing PAFMMP would be revised as part of the Project to account for the greater complexity in the distribution of PAF and non-acid forming material (NAF) in Clareval Seam overburden.

In consideration of the above, there would be negligible impacts to groundwater quality (either directly or via final pit voids) as a result of PAF material.

B6.1.4 Pit Inflows

Up to the end of mining, there would be a continuous loss of water from the aquifer system to the mining void. The predictive simulation in Section B5.3 and the sensitivity analysis in Section B5.5 demonstrated that pit inflow is expected to vary between approximately 0.2 and 1 ML/day during the Project.

B6.1.5 Potential Impacts on Registered Production Bores

The maximum regional drawdowns are expected within model Layer 3 (Weismantel seam) and model Layer 5 (Clareval seam). **Figures B-44** and **B-45** show the drawdown magnitude and pattern for model Layer 3 (Weismantel seam) and Layer 5 (Clareval seam) respectively. Drawdowns are naturally limited to the east, west and south by outcropping volcanics. However, they propagate readily to the north and are in the order of 1 to 2 m in the coal seams at the model boundary.

The drawdowns in the three relatively shallow (<60 m) private production bores at the northern end of the model area would be much less than the drawdowns in the underlying coal seam, which is probably more than 500 m below ground level. The drawdown in Layer 3 varies from 4 to 7 m at the three bores, but the potentiometric level would remain close to ground level. Therefore, the drawdown in the water level in each bore is expected to be negligible.

The one census spring identified during the bore census is located on the other side of the groundwater divide, to the west of the ridgeline that effectively screens the DCM from The Bucketts Way (**Figure B-8**). The census spring is unlikely to be affected by the Project.

No other active registered bores (apart from DCPL bores) are known.

B6.2 POTENTIAL IMPACTS ON SURFACE WATER BODIES

The drawdown patterns in **Figures B-44** and **B-45** show substantial reduction in potentiometric head in the aquifers of the deeper groundwater system due east and to the north of the Project area. However, there is no significant reduction in groundwater levels simulated in the alluvium. This is evidenced by groundwater hydrographs for a notional bore in the alluvium to the east of the final pit voids (see location of L1L7_North in **Figure B-43**). The hydrographs in **Figure B-46** show no variation at Layer 1, in spite of substantial fluctuations in deeper layers as mining progresses. As coal seam heads have about 20 m artesian head at this location, a drawdown of 15 to 20 m will make the deep heads similar to river level. This result supports the description of the alluvium/coal seam disconnection in Section B3.0, where clay lenses below the alluvium where the coal seams outcrop would impede any connection between the Mammy Johnsons River and the coal seam or final void.

The predictive simulation in Section B5.4 and the sensitivity analysis in Section B5.5 demonstrate that the reduction in baseflow and natural river leakage is expected to be negligible.

In addition, the Duralie Coal EIS (DCPL, 1996) proposed to

> *"construct clay cut-off walls along the southern end of the dump toe at Coal Shaft Creek and to line the main drain and its banks with a low permeability liner to reduce (to negligibly low levels) direct seepage out of the dump."*

Once constructed, this clay liner would impede flow of any groundwater from the waste rock emplacement to Mammy Johnsons River and Coal Shaft Creek in this area.

B6.2.1 Changes in Water Quality

There are not expected to be any changes in the quality of groundwater as a consequence of the Project (Section B6.1.2), other than possible freshening over the mine footprint due to higher rainfall infiltration rates through spoil.

As described in Section B6.1.2, no groundwater quality impact is expected from groundwater interactions with the final void water. Therefore, it is unlikely the water quality of any surface water body would be impacted via final void water migration through groundwater.

As described in Section B6.2, the clay cut-off walls along the southern end of the dump toe at Coal Shaft Creek would limit flow of any groundwater from the waste rock emplacement (and associated water quality effects) to Mammy Johnsons River and Coal Shaft Creek.

As described in Section B6.2, there is little evidence of a connection between the coal seam and the alluvium of the Mammy Johnsons River, which would limit seepage of final void water to the surrounding groundwater and surface water body via outcropping. Given no changes to groundwater quality are expected, and the limited connection via outcropping to Mammy Johnsons River or Coal Shaft Creek, it is unlikely that the water quality of any surface water body would be impacted by seepage.

Given the localised disturbance of open pit mining, and the demonstration of inconsequential changes in river leakage, baseflow and groundwater quality, no effects on water quality of the Mammy Johnsons River are anticipated.

B6.2.2 Changes in Water Balance

Numerical modelling has allowed quantification of the relative magnitudes of the major components of the water balance. Pre-mining recharge is dominated by rainfall (70%) and river leakage (29%), while discharge is dominated by evapotranspiration (44%) and baseflow to rivers and creeks (32%). End of Project recharge is expected to be dominated by rainfall (79%) and river leakage (21%), while discharge should be dominated by evapotranspiration (56%) and baseflow to rivers and creeks (25%). Discharge to the mine is estimated to be about 3% of the water budget, both before the Project and at the end of the Project.

These figures suggest that the Project would have a minor effect on the water balance component relativities.

B6.2.3 Effects on Surface Ecosystems

Given the localised disturbance of open pit mining, and the demonstration of inconsequential changes in river leakage or baseflow, no effects on surface ecosystems are anticipated in relation to mining-induced changes to the water system.

B6.3 PROPOSED GROUNDWATER MONITORING PROGRAMME

The proposed groundwater monitoring programme for the Project is summarised in **Table B-20** and described below. The groundwater monitoring programme should augment the existing DCPL groundwater monitoring programme and should expand the existing knowledge of groundwater systems in the Project area. The groundwater monitoring programme should comply with the Murray-Darling Basin Groundwater Quality Sampling Guidelines (MDBC, 1997).

The groundwater monitoring programme should monitor groundwater conditions for changes as a result of mining and should include consideration of aquifer definition and interactions, strata hydraulic properties, expected drawdown extent and groundwater quality.

The results of the groundwater monitoring programme should be used to validate modelling predictions.

B6.3.1 Monitoring Piezometers

The existing DCPL monitoring network should be augmented to include new Project areas as mining progresses (**Table B-20**). Piezometers should be installed at least six months prior to mining. The network of piezometers should be similar to near previously mined areas (**Figure B-8**). The final location of piezometers should include consideration of site characteristics, their location relevant to the mine plan, access and site inspection.

Additional piezometers should also be installed into in-pit spoil, to provide information on the recharge rates and spoil permeabilities and to validate modelling assumptions and predictions.

Water level measurements should be automated with daily or more frequent recordings and should continue for at least two years following mining.

Table B-20. Proposed Groundwater Monitoring Programme

Parameter	Location
Groundwater Levels	- Existing monitoring bores on-site. - New piezometers in waste rock spoil.
Groundwater Quality	- At piezometers above.
Hydraulic Property Measurements (Core Sampling and Testing)	- In exploration bores, as mining exploration progresses.
Mine Water Balance	- Measurement of volumes extracted from voids to MWD, pumped water, coal moisture, etc.

B6.3.2 Groundwater Quality

The groundwater monitoring network should also be sampled for water quality on a regular basis at least six months prior to mining, during mining, and for at least two years following mining. Water quality samples should also be taken during drilling of new piezometers and hydrogeological investigation bores.

Groundwater quality monitoring should include, but not necessarily be limited to, analysis of the following parameters: pH, dissolved oxygen, EC, TDS, iron, aluminium, magnesium, calcium, sodium, chloride and sulphate. Analysis should be undertaken at a National Association of Testing Authorities (NATA) accredited laboratory. Water quality data should be evaluated as part of the Annual Environmental Management Report (AEMR) processes and should aim to identify any potential mining related impacts.

B6.3.3 Hydraulic Property Measurements (Core Sampling and Testing)

Core sampling and testing should be conducted during appropriate DCPL drilling within the Project area, where practicable, to determine aquifer properties within the natural rock strata (e.g. porosity and permeability). DCPL should create a database of testing data throughout the Project area, which should be used to validate model parameters and guide potential future groundwater assessments.

B6.3.4 Mine Water Balance

Water balances should be conducted regularly accounting for all monitored volumes and should be reported in the AEMR.

The water balance should be regularly reviewed to confirm groundwater transmission characteristics and modelling predictions. Monitoring results which indicate anomalous mine water seepage should be investigated. If anomalous seepage is detected, DCPL should notify and consult with the relevant regulator regarding further courses of action.

The Project water management system is discussed further in Appendix A of the EA.

B7.0 CLIMATE CHANGE AND GROUNDWATER

The effects of climate change on groundwater are projected to be negative in some places on earth, but positive in other places. In the Netherlands, for example, beneficial effects are anticipated (Kamps *et al*., 2008). There it is expected that coastal water tables will rise but evapotranspiration will reduce in response to the adaptation of vegetation to higher levels of carbon dioxide. Modelling shows more pronounced seasonal water table fluctuations by accounting for vegetation feedback mechanisms (Kamps *et al*., 2008). Plants are expected to have a lower water demand under higher carbon dioxide levels due to production of more biomass, increased leaf area index, and a shorter time to reach the saturation point for carbon demand (Kamps *et al*., 2008).

In New Hampshire USA, on the other hand, negative effects on the water table are expected due to the onset of spring recharge 2 to 4 weeks earlier (Mack, 2008). This shift will allow a longer period for evapotranspiration prior to summer months, at which time groundwater availability is likely to decrease.

The modelling of climate change effects needs to take into account complex vegetation and hydrologic feedback mechanisms, coupled surface water and groundwater interactions, and inter-annual temporal variations. Very few modelling studies have been conducted so far. Hunt *et al*. (2008) reported on the difficulties to be overcome in doing comprehensive modelling using newly released integrated GSFLOW software (MODFLOW plus PRMS).

Order of magnitude estimates can be found by ignoring feedback mechanisms and changing the currently calibrated rain infiltration percentages. However, more intense rainfall events would be expected to increase fast runoff and lead to a reduction in infiltration. This should be taken into account to allow for short-term temporal variations.

Annual rainfall is expected to change by -10 to +5% by 2030 (Pittock, 2003) in parts of south-eastern Australia. In addition, annual average temperatures are projected to increase by 0.4 to 2.0°C (relative to 1990) at that time.

The approach taken for this assessment is to conduct steady state simulations at the completion of mining (Year 9) for two scenarios:

- rainfall infiltration reduced by 10%; and
- rainfall infiltration reduced by 20%.

The results of the climate change scenario analysis are summarised in **Table B-21** in terms of the percentage changes in pit inflow and percentage changes in net baseflow and natural leakage for the Mammy Johnsons River.

Table B-21. Predicted Changes in Pit and River Fluxes due to Climate Change

SCENARIO	Reduction in Pit Inflow	Increase in Net River Leakage
10% Less Rain	2.3 %	0.9 %
20% Less Rain	7.4 %	3.9 %

There is expected to be about 2% reduction in pit inflow for 10% reduction in rainfall, and about 7% reduction for 20% less recharge from rainfall. The simulated reduction in pit inflow is due to reduced groundwater levels adjacent to the Clareval and Weismantel final voids.

Due to an anticipated reduction in water table levels near the Mammy Johnsons River in the event of climate change, there is expected to be about 1% increase in net river leakage for 10% reduction in rainfall, and about 4% increase for 20% less recharge from rainfall.

B8.0 MANAGEMENT AND MITIGATION MEASURES

DCPL should implement the proposed groundwater monitoring programme outlined in Section B6.3.

The numerical model developed as part of this groundwater assessment should be used as a management tool for the prediction of groundwater impacts throughout the Project life. The results of the groundwater monitoring programme (Section B6.3) should inform progressive development and revision of the numerical model. Revised outputs from the numerical model should be reported in subsequent relevant groundwater assessments over the life of the Project.

B8.1.1 Surface Water Features

The following commitment was made in the original Duralie Coal EIS regarding the construction of clay cut-off walls (DCPL, 1996):

> *"Seepage of groundwater from the overburden dump is likely to be high in gypsum. The movement of this water undiluted to Mammy Johnsons River during the recession of runoff events may have undesirable impacts on the water quality of the river - particularly during periods of low river flow. To control this, it is proposed to construct clay cut-off walls along the southern end of the dump toe at Coal Shaft Creek and to line the main drain and its banks with a low permeability liner to reduce (to negligibly low levels) direct seepage out of the dump."*

Over the Project life, DCPL should:

- ❑ continue with the commitment to construct the clay cut-off walls along the southern end of the dump toe at Coal Shaft Creek following mining in the Weismantel pit to impede potential seepage from the waste rock emplacement to Mammy Johnsons River or Coal Shaft Creek; and
- ❑ develop a comprehensive groundwater monitoring programme (Section B6.3) to measure the actual groundwater effects of the Project (including triggers for investigation).

Other potential management measures (e.g. management of PAF material) are discussed in Appendix I of the EA and the proposed surface water monitoring programme is described in Appendix A of the EA.

B8.1.2 Groundwater Users

Over the Project life, DCPL should develop a comprehensive groundwater monitoring programme (Section B6.3) to measure the actual groundwater effects of the Project (including triggers for investigation).

B9.0 MODEL LIMITATIONS

Although MODFLOW-SURFACT is capable of simulating unsaturated conditions, the focus in this study has been on the saturated part of the groundwater system. Nevertheless, MODFLOW-SURFACT will report groundwater heads (equivalent to negative pore pressures) in dry portions of model layers. Much of model Layer 1 is simulated to be dry.

A deficiency of MODFLOW-SURFACT is that it does not allow time-varying formation properties (e.g. hydraulic conductivity). In this study, predictive simulations are continuous for 44 periods from January 2003 to December 2020. The runs are not interrupted for progressive emplacement of waste rock. However, the rainfall recharge through the spoil and the duration of activation of mine drains are varied in time to account in part for the emplacement of waste rock.

At this stage the model has adopted laterally uniform properties in layers and uniform rainfall recharge across four zones. As more data are gathered, the spatial distributions of aquifer properties can be refined. At this stage, there is no hydrographic evidence for hydraulic conductivity reduction with depth, but this can be expected as mining proceeds to greater depths. Lower pit inflows can be expected as coal seam permeability reduces with depth.

As there is poor knowledge of formation interface elevations and geometry in the northern half of the model area, predictions in this area should be regarded as indicative only.

The model does not include structural features such as faults or dykes, except to the extent that they determine formation thicknesses observed in exploration holes. There is uncertainty as to their size, scale, vertical persistence, locations of smaller structures and whether they are resistive barriers or transmissive conduits. Geological structures are more likely to compartmentalise aquifers and thereby localise drawdown effects and limit pit inflows. By ignoring such structures in the model, predictions of pit inflow would tend to over-estimation, and predicted environmental effects are expected to be conservative. Geological features can be added to subsequent model revisions to refine prediction of effects on the groundwater system.

B10.0 CONCLUSIONS

The data supports two groundwater systems:

- ❑ shallow groundwater system – associated with alluvium and regolith; and
- ❑ deeper groundwater system, including:
    - o the Weismantel and Clareval coal seams; and
    - o low permeability/disconnected fractured rock/coal measures of the Mammy Johnons, Weismantels and Durallie Road Formations (**Figure B-6**).

For mining since 2003, there is strong hydrographic evidence of mining effects on the deeper groundwater system, with no discernible effect on the shallow groundwater system. Based on strong evidence from hydrographic data and field observations, there is expected to be:

- ❑ negligible loss of groundwater yield to/from surface stream systems (i.e. Mammy Johnsons River); and
- ❑ limited potential for reduction of groundwater yield to other groundwater users, for bores located in the shallow groundwater system.

These observations are consistent with the conclusions of the numerical model, described below.

As would be expected, a lateral hydraulic gradient towards the open pit has developed, and groundwater flow would continue to move toward the pit as mining progresses.

Based on groundwater modelling, there is expected to be:

- ❑ negligible drawdown in the aquifers of the shallow groundwater system;
- ❑ negligible impact on access to water in known registered production bores licensed to external parties;
- ❑ substantial reduction in potentiometric head in the aquifers of the deeper groundwater system due east and to the north of the Project area;
- ❑ negligible loss of groundwater yield to surface stream systems (i.e. Mammy Johnsons River);
- ❑ negligible reduction in groundwater contribution to total stream flows, and negligible reduction in natural leakage from streams;
- ❑ a final pit inflow in the order of 0.3 ML/day at the completion of mining, ranging between approximately 0.2 ML/day and 1 ML/day over the nine years of mining;

- negligible deterioration in groundwater quality as a result of mining, including in the long-term; and
- slow recovery of the groundwater system over many decades to a new equilibrium in which the pit lakes would act as flow-through lake systems, with groundwater flow expected to be restored to a dominant southerly direction due to the higher permeability of the waste rock emplacement.

The potential impacts of mining on surface water resources, other than those assessed within this report, are assessed in Appendix A of the EA.

B11.0 REFERENCES

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Website: http://www.ses.nsw.gov.au. Date accessed: 10/09/2009.

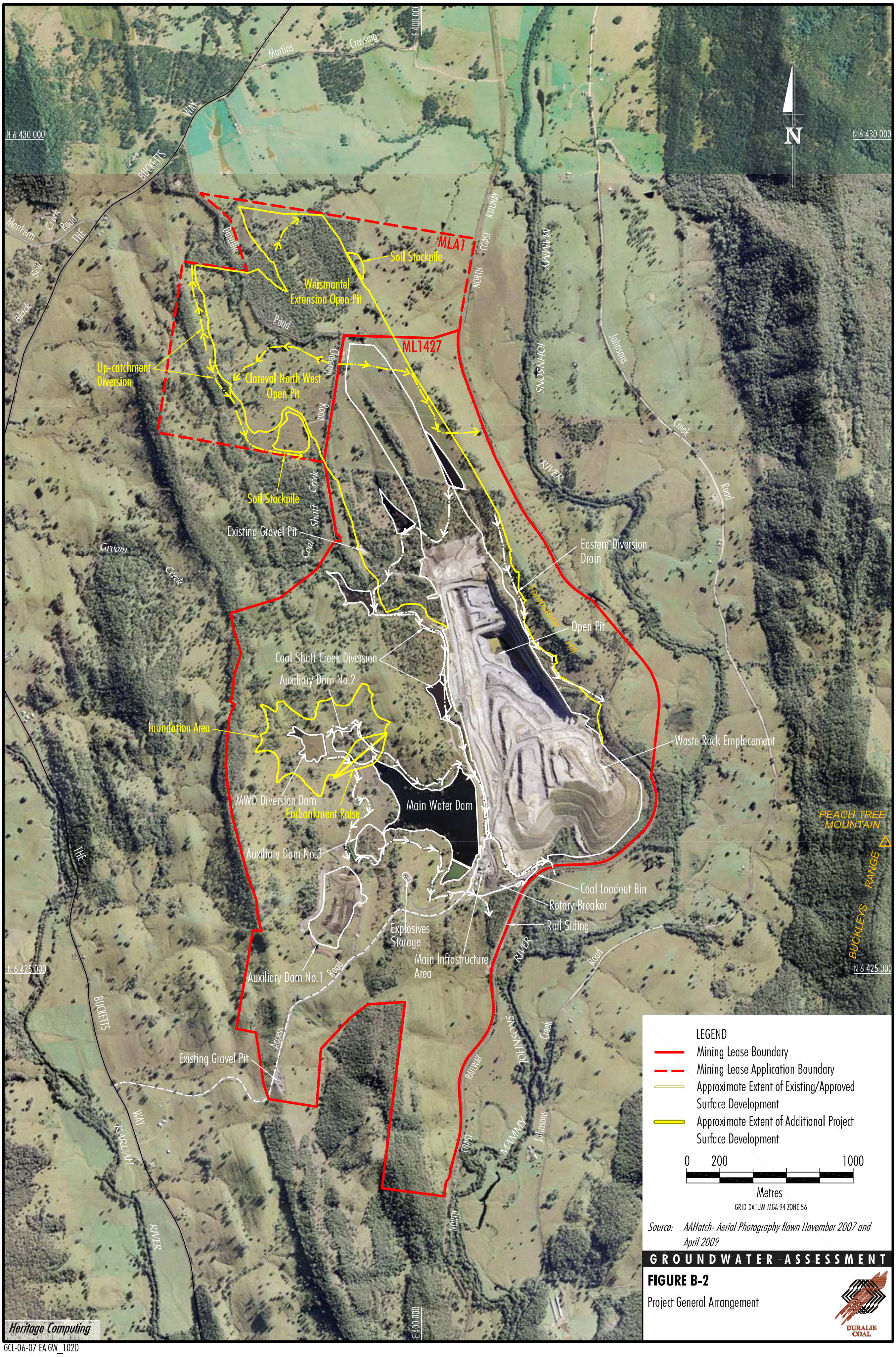
Source: Geoscience Australia (2009); Department of Lands (May 2009); DECC (2009) and DCPL (2009)

GROUNDWATER ASSESSMENT

FIGURE B-1

Regional Location

GCL-06-07 EA GW_101B



Source: AAHatch- Aerial Photography flown November 2007 and April 2009

GROUNDWATER ASSESSMENT

FIGURE B-2

Project General Arrangement

GCL-06-07 EA GW_102D

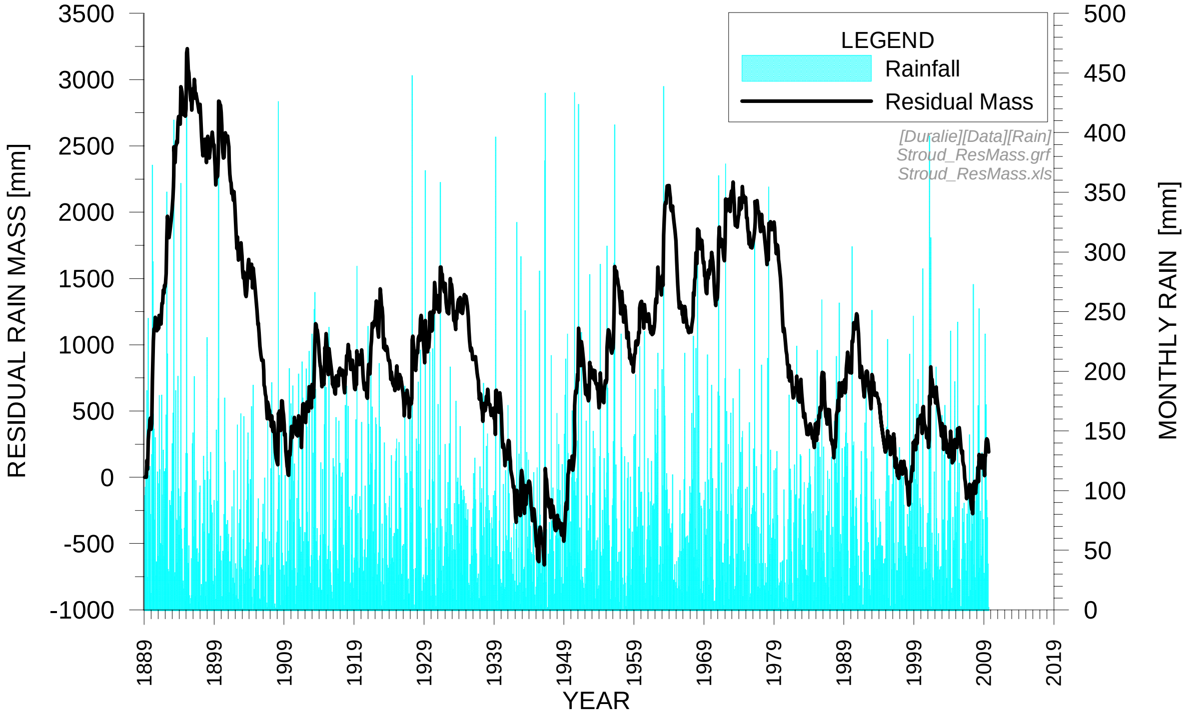


Figure B-3. Rainfall – Residual Mass Curve for Stroud Post Office (since 1889)

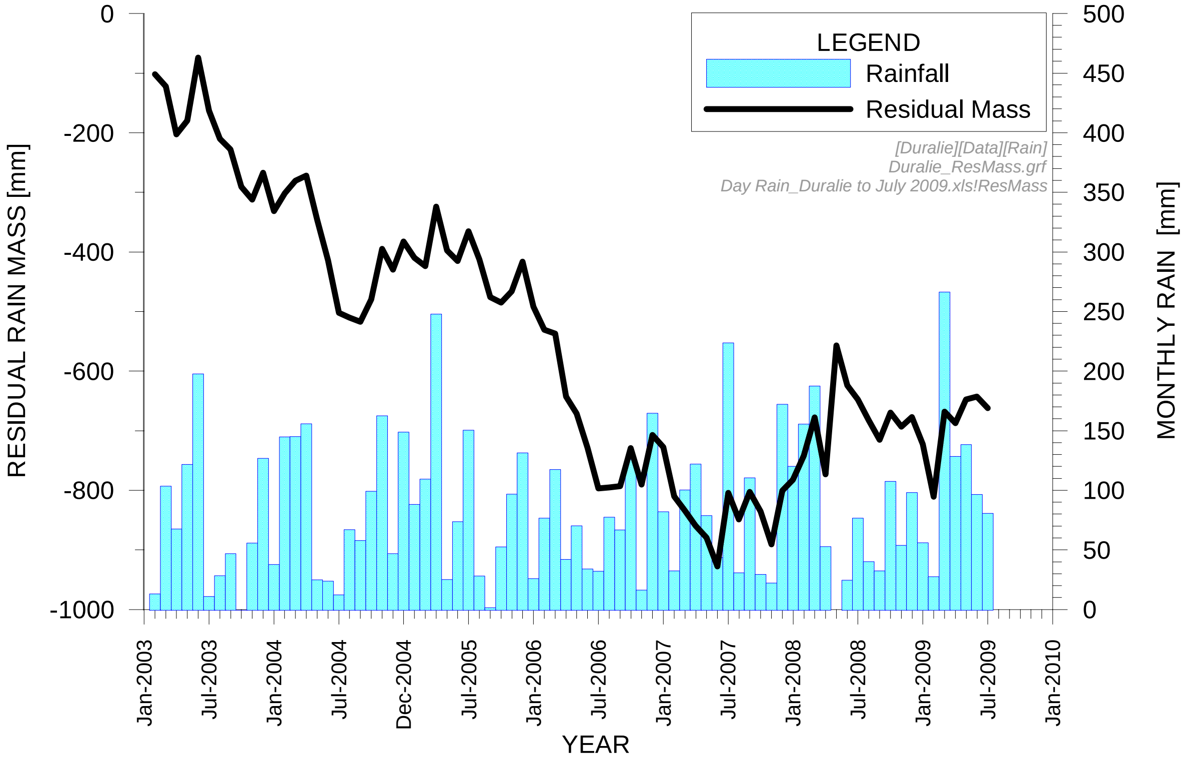
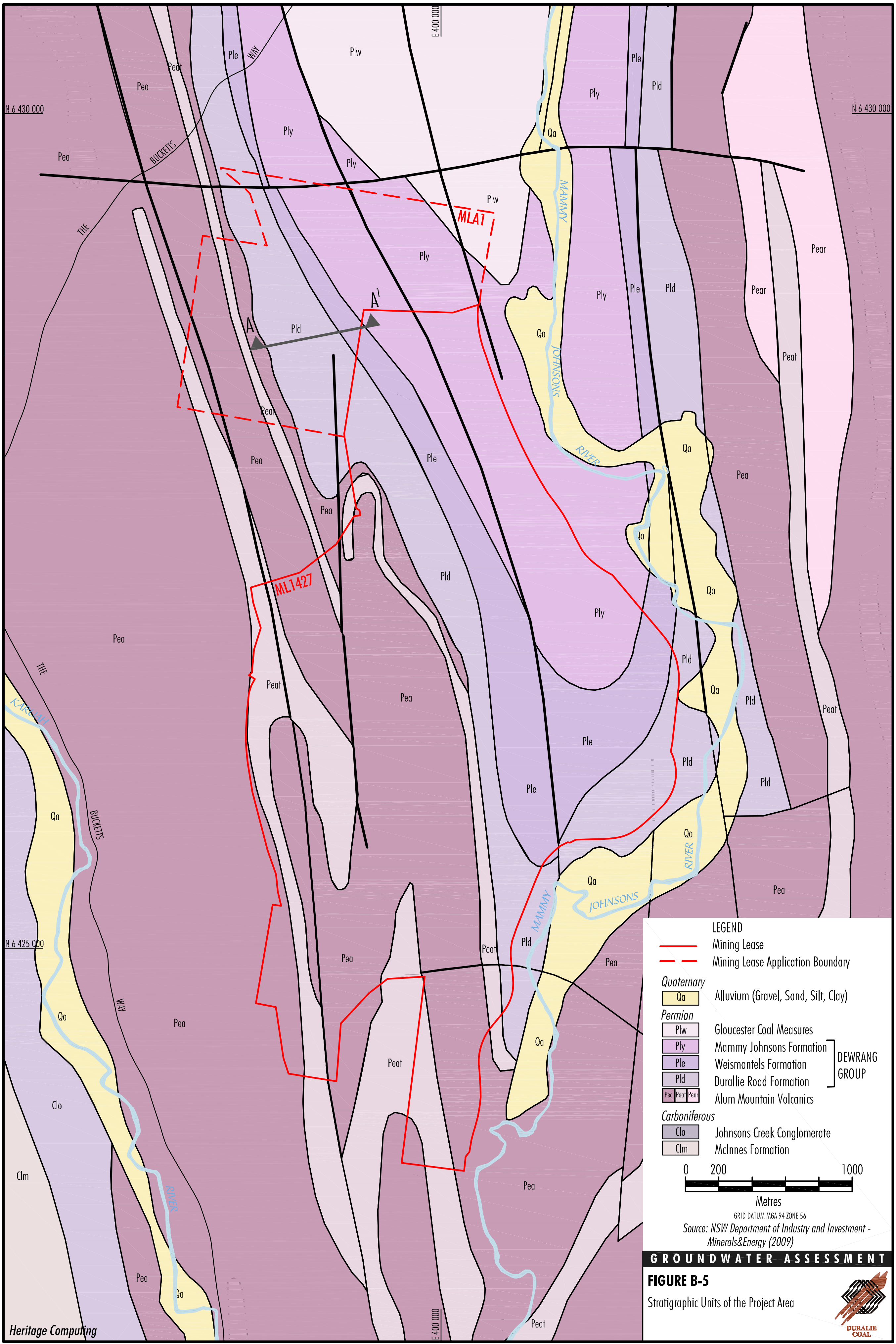


Figure B-4. Rainfall – Residual Mass Curve for the DCM (since 2003)



Source: NSW Department of Industry and Investment - Minerals&Energy (2009)

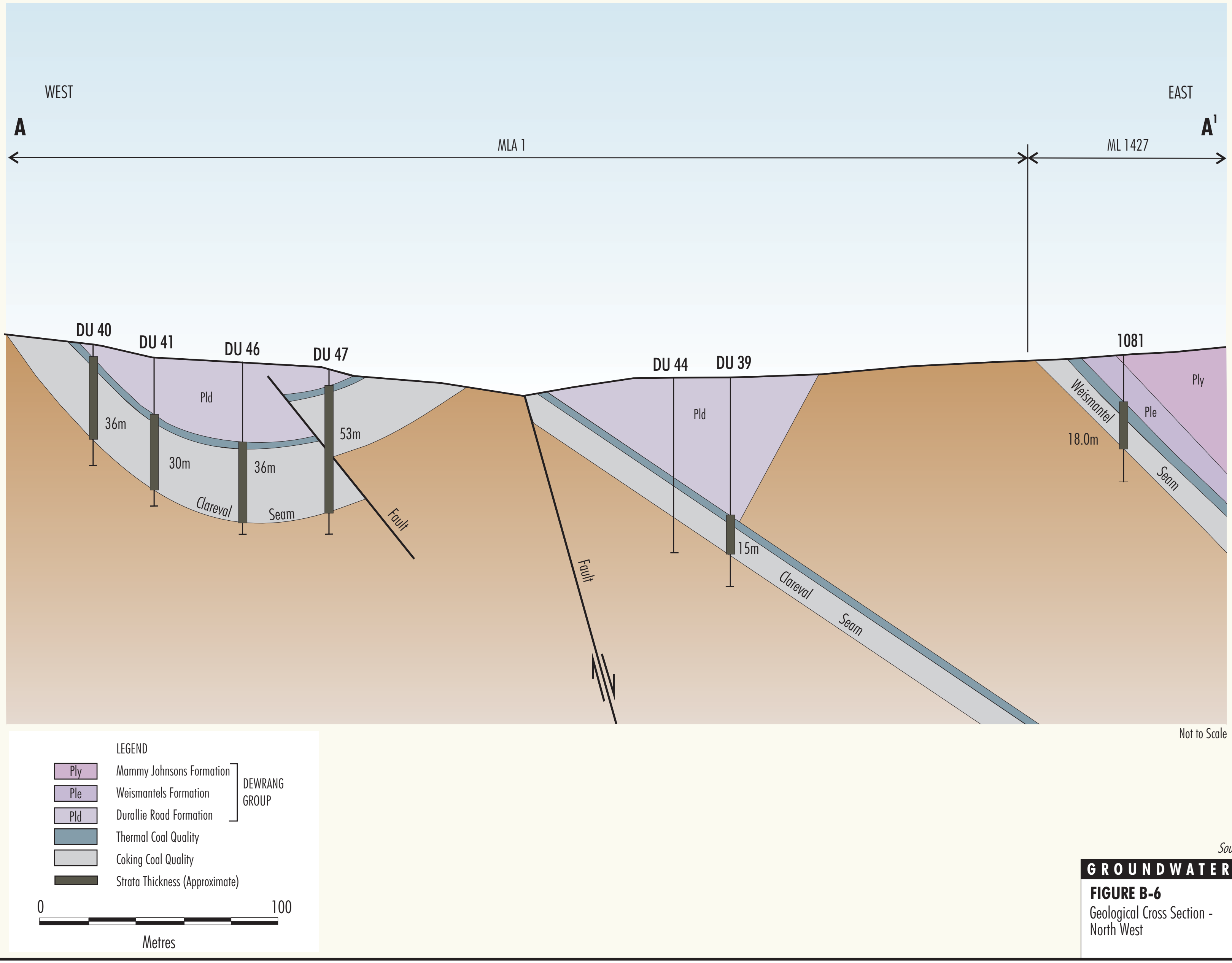
GROUNDWATER ASSESSMENT

FIGURE B-5

Stratigraphic Units of the Project Area

DURALIE COAL

GCL-06-07 EA GW_103B



Source: *Gloucester Coal Ltd (2007)*

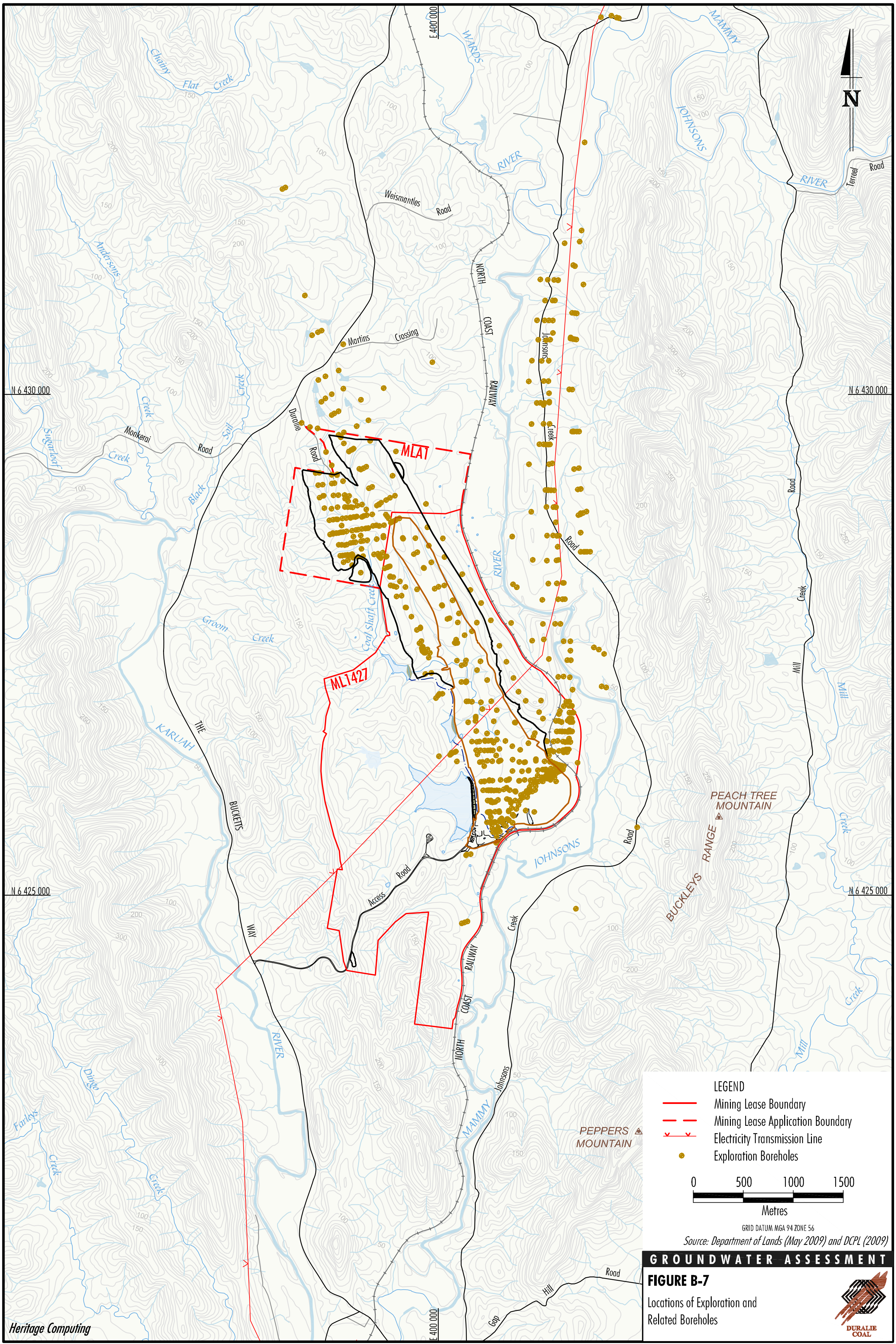
GROUNDWATER ASSESSMENT

FIGURE B-6

Geological Cross Section -
North West

Heritage Computing

GCL-06-07 EA GW_004C



LEGEND

- Mining Lease Boundary
- Mining Lease Application Boundary
- Electricity Transmission Line
- ● Exploration Boreholes

0 500 1000 1500

Metres

GRID DATUM MGA 94 ZONE 56

Source: Department of Lands (May 2009) and DCPL (2009)

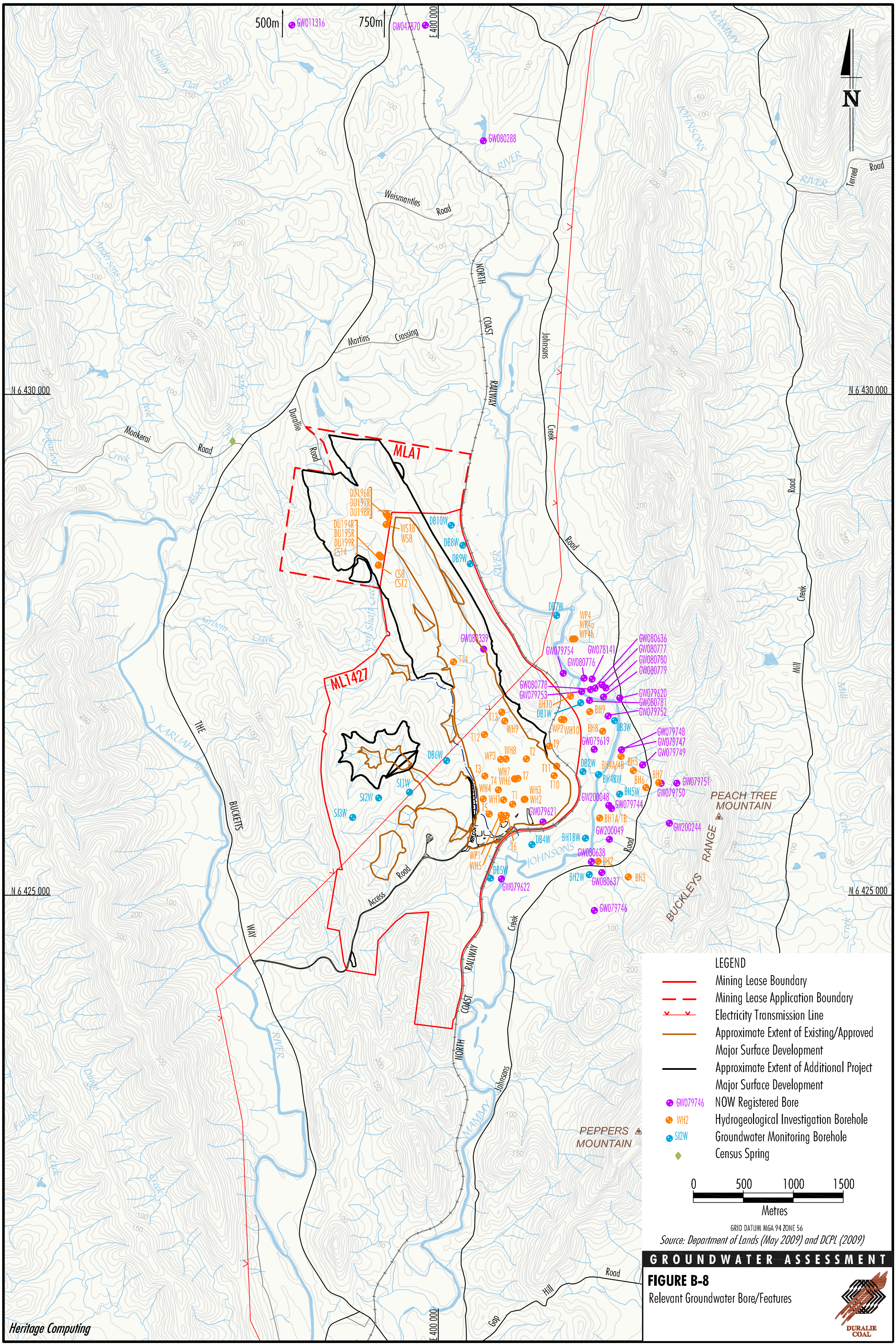
GROUNDWATER ASSESSMENT

FIGURE B-7

Locations of Exploration and Related Boreholes

DURALIE COAL

GCL-06-07 EA GW_105B



Source: Department of Lands (May 2009) and DCPL (2009)

GROUNDWATER ASSESSMENT

FIGURE B-8

Relevant Groundwater Bore/Features

Heritage Computing

GCL-06-07 EA GW_107J

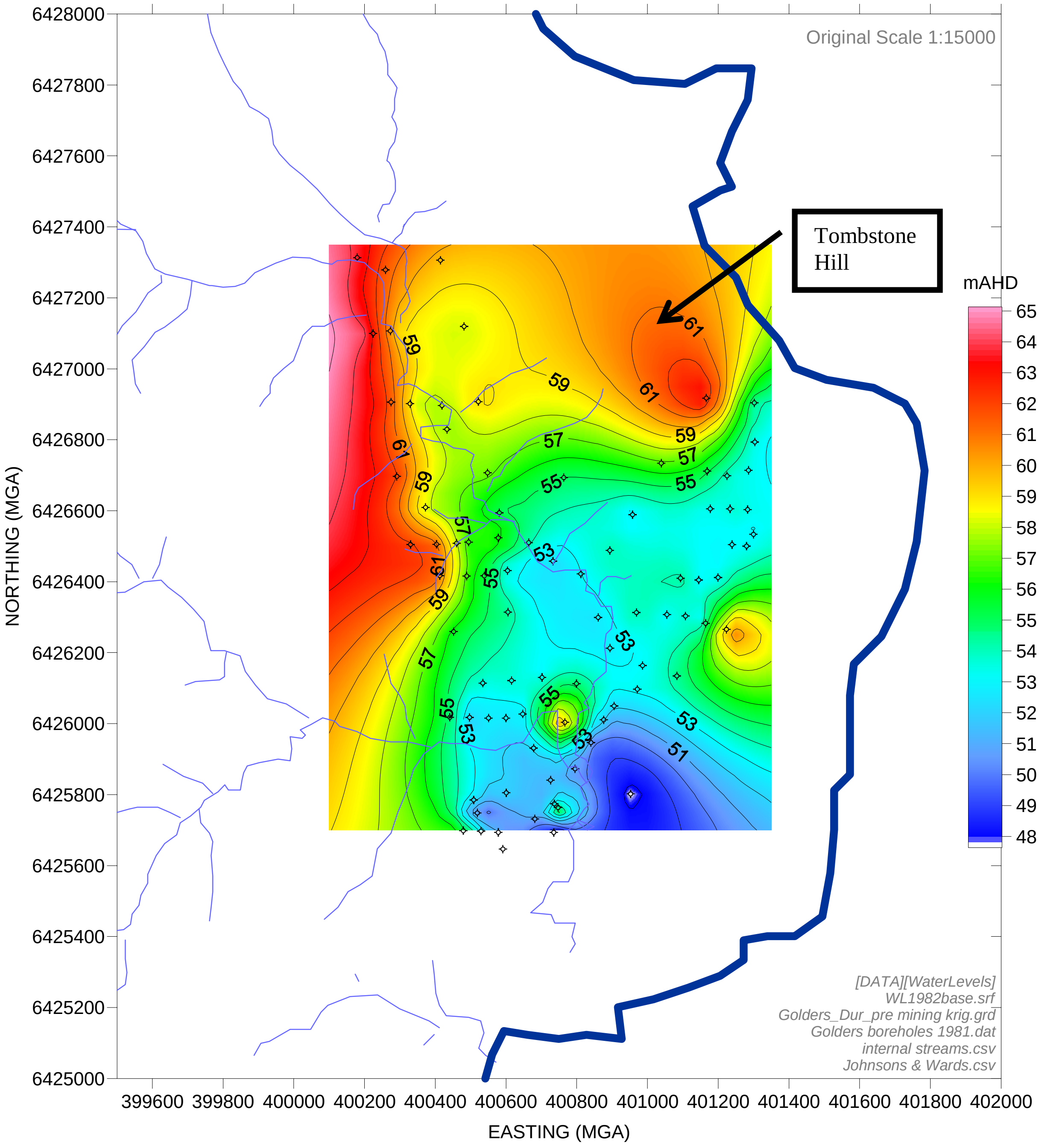
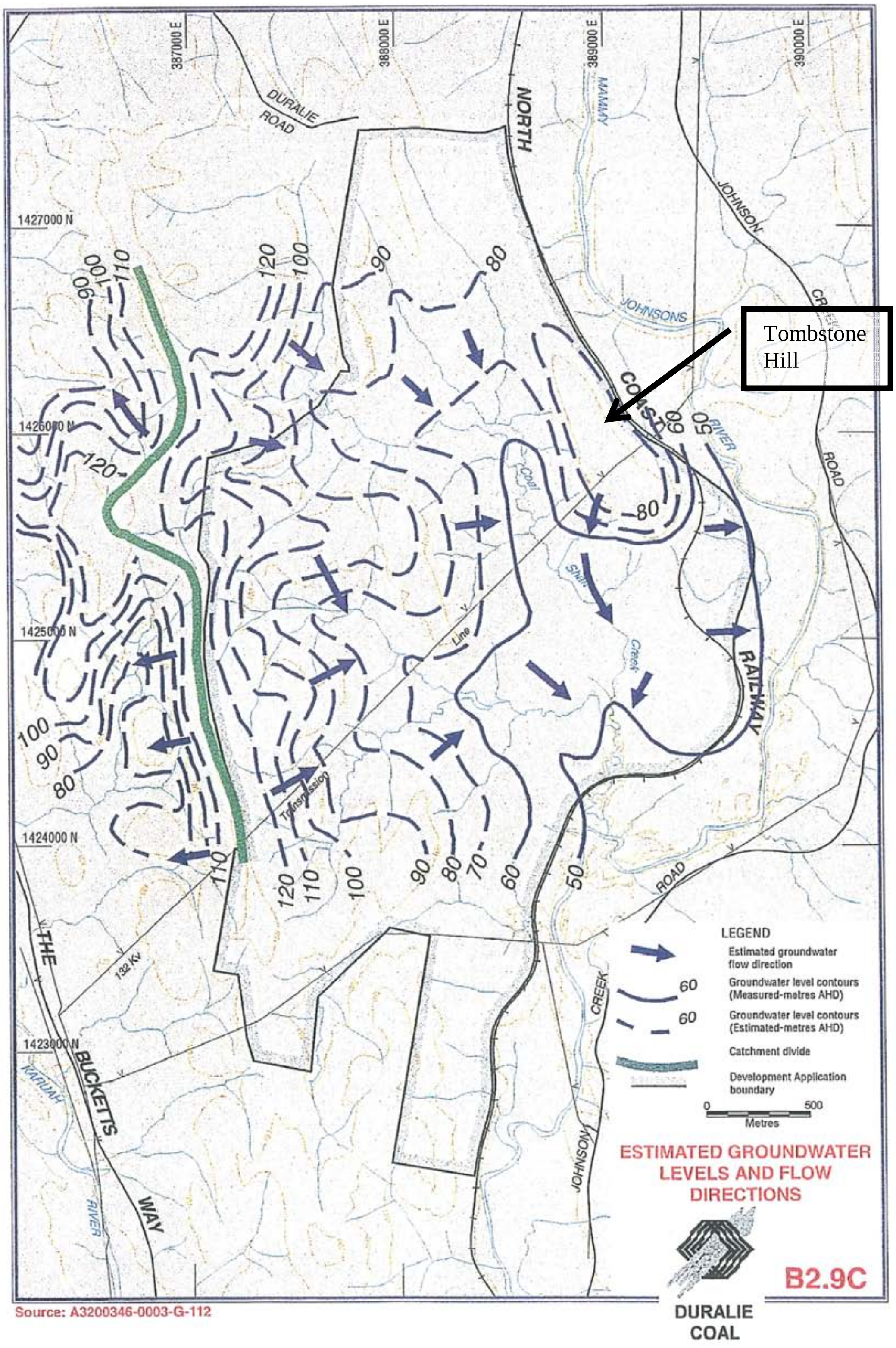


Figure B-9. Pre-mining groundwater level contours (mAHD) [Source: Golder Associates, 1982]



Source: A3200346-0003-G-112

Figure B-10. Inferred pre-mining groundwater level contours (mAHD) and flow directions [Source: DCPL, 1996]

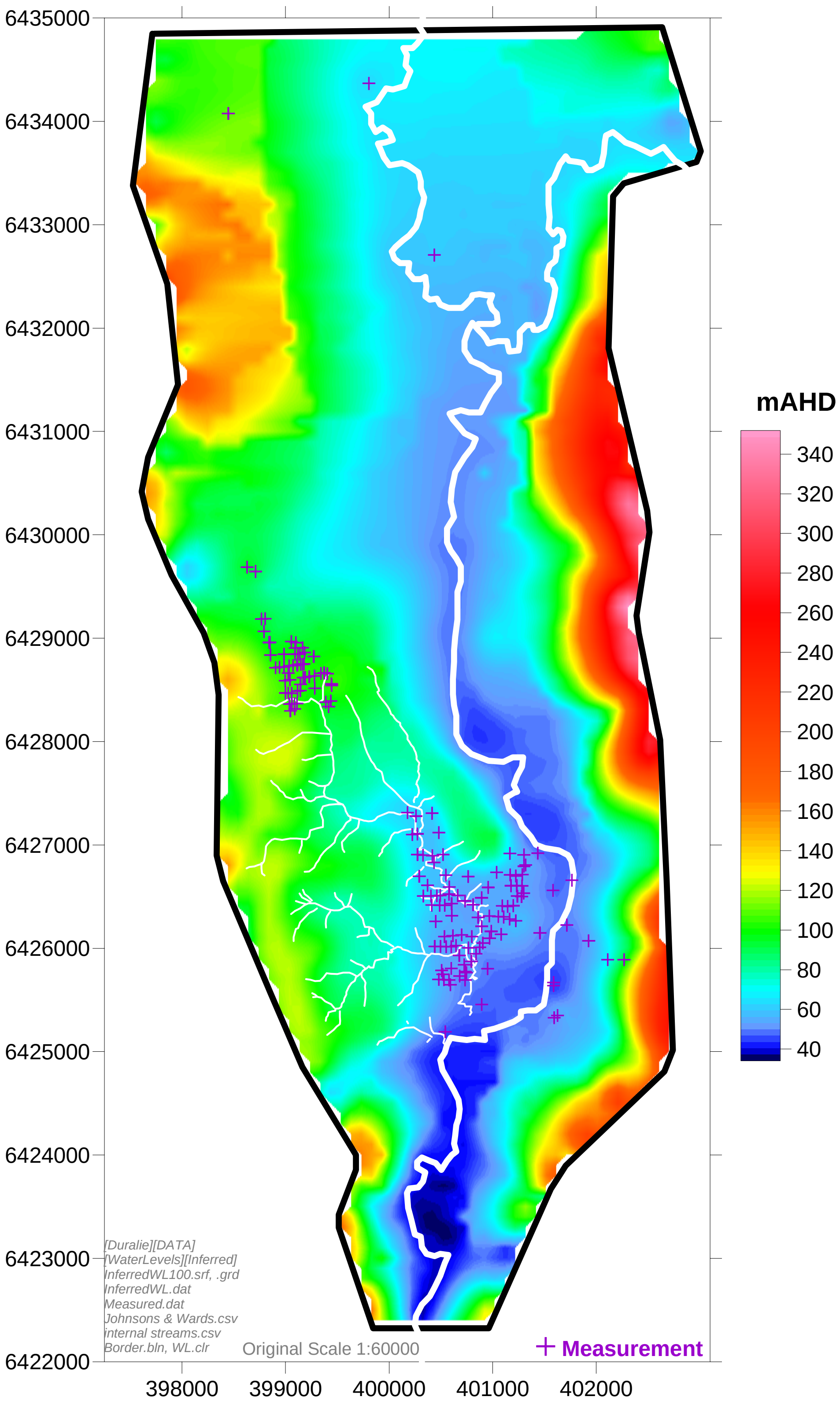


Figure B-11. Inferred pre-mining groundwater level contours (mAHD) for the entire model extent

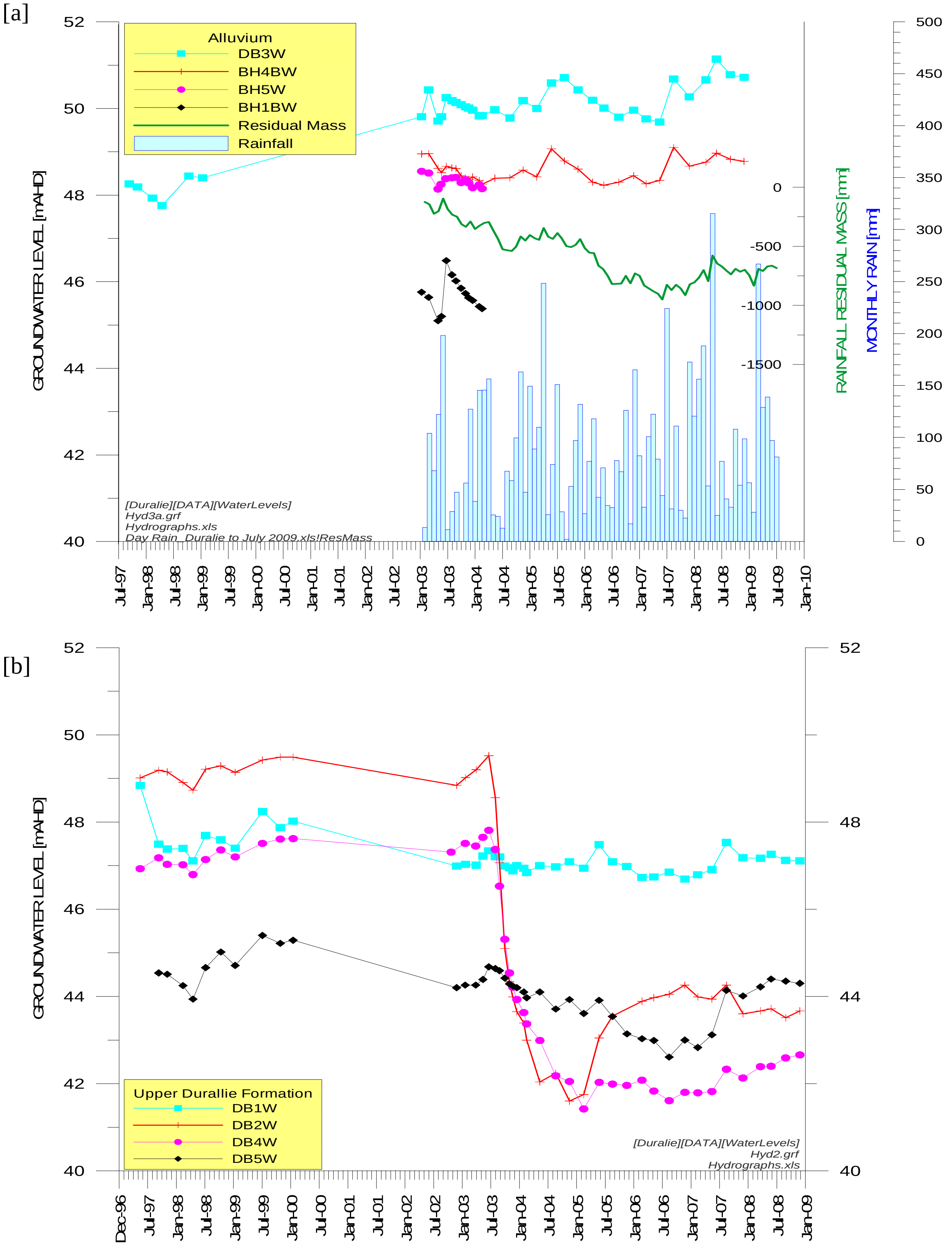


Figure B-12. Groundwater elevation hydrographs (mAHD):
[a] Alluvium; [b] Upper Durallie Road Formation

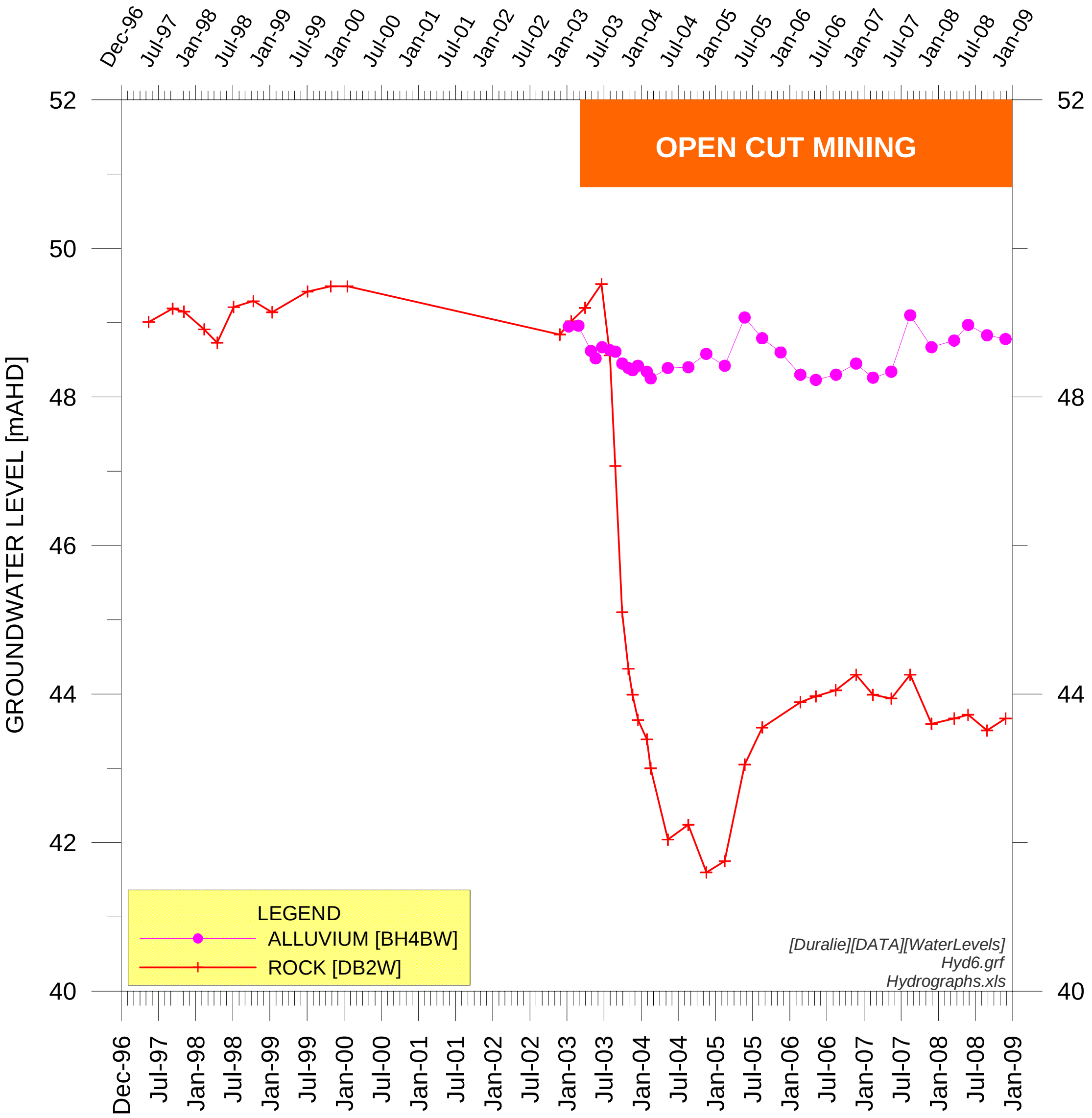


Figure B-13. Groundwater elevation hydrographs (mAHD) for alluvium and rock (Upper Durallie Road Formation) in response to early open pit mining

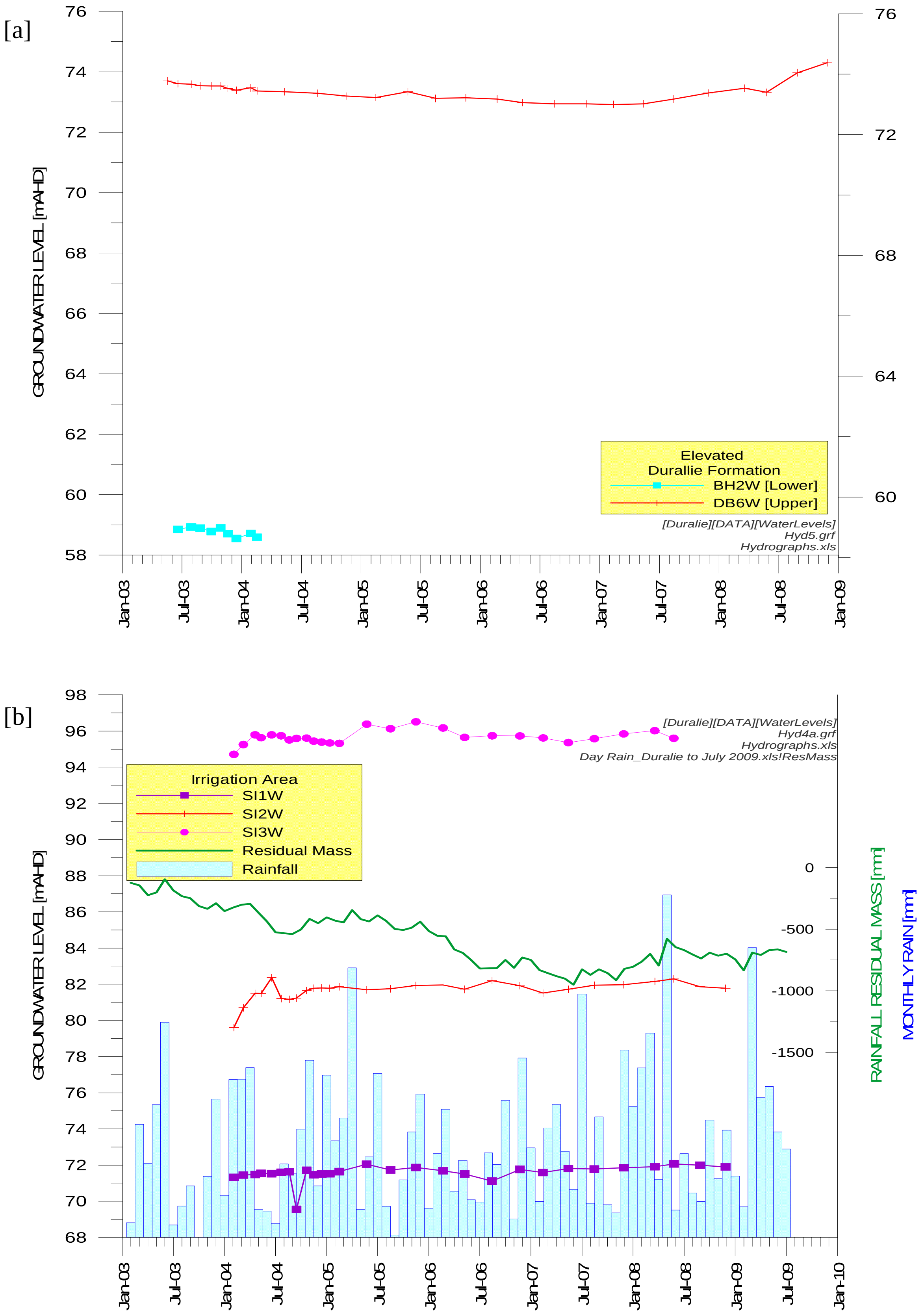
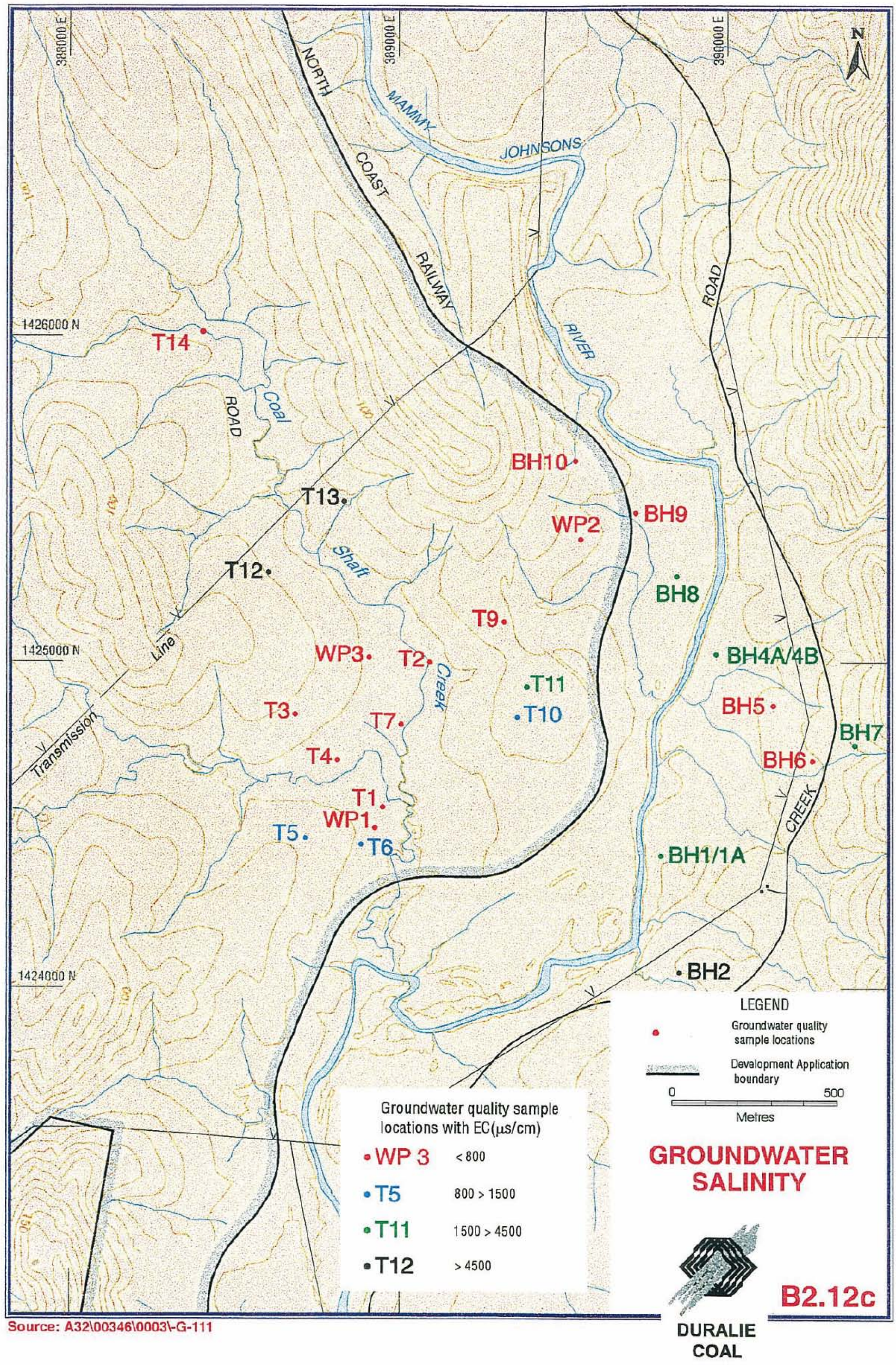
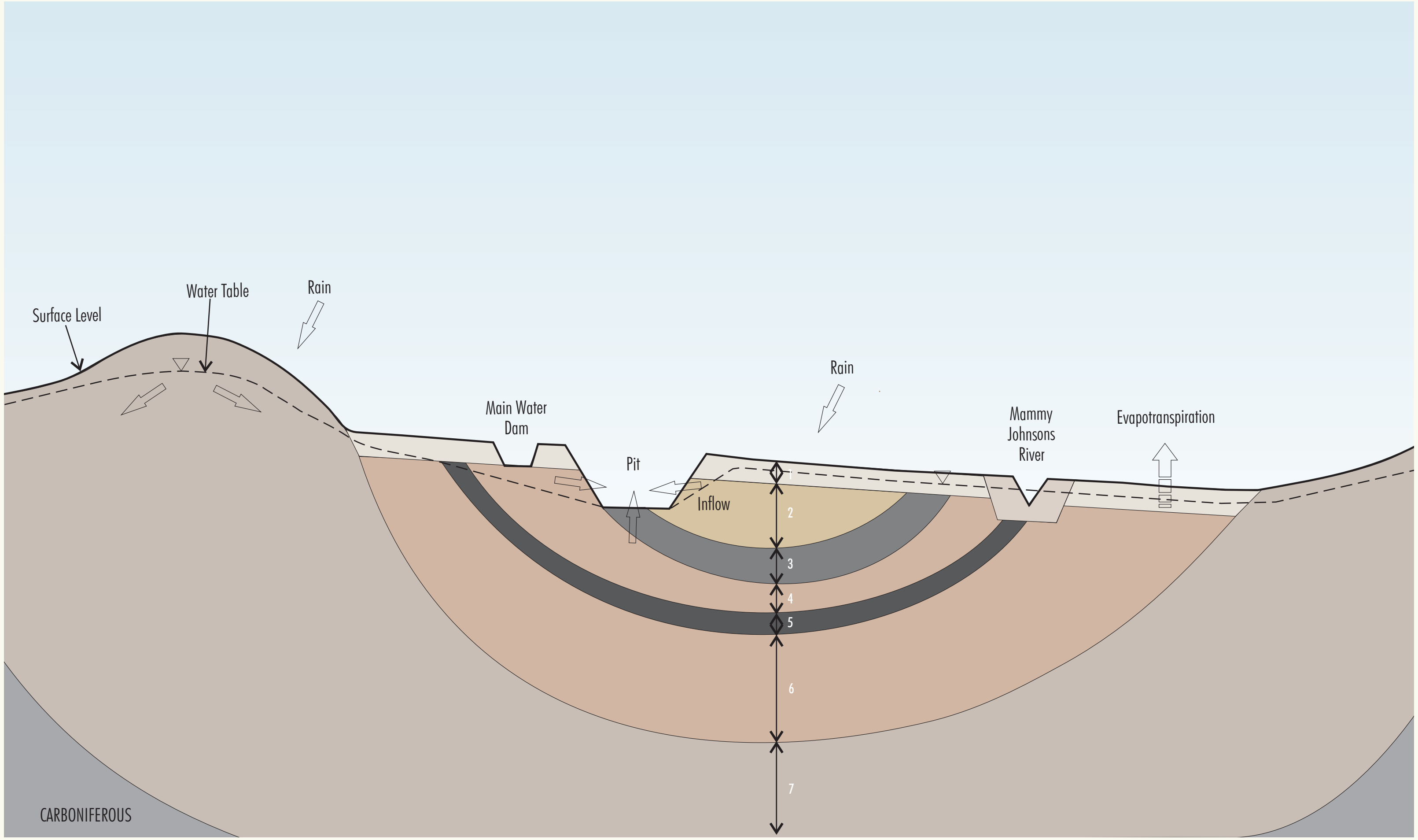


Figure B-14. Groundwater elevation hydrographs (mAHD):
[a] Durallie Road Formation on elevated land; [b] Type II Irrigation Area



Source: A32\00346\0003\-G-111

Figure B-15. Groundwater salinity pattern in the Project area [from Kidd, 1996].



Not to Scale

LEGEND

1 Alluvials 1 Regolith
2 Coal Measures/Sandstones of the Mammy Johnsons and Weismantels Formations
3 Weismantel Seam
4 Coal Measures/Sandstones of the Durallie Road Formation
5 Clareval Seam
6 Coal Measures/Sandstones of the Durallie Road Formation
7 Alum Mountain Volcanics

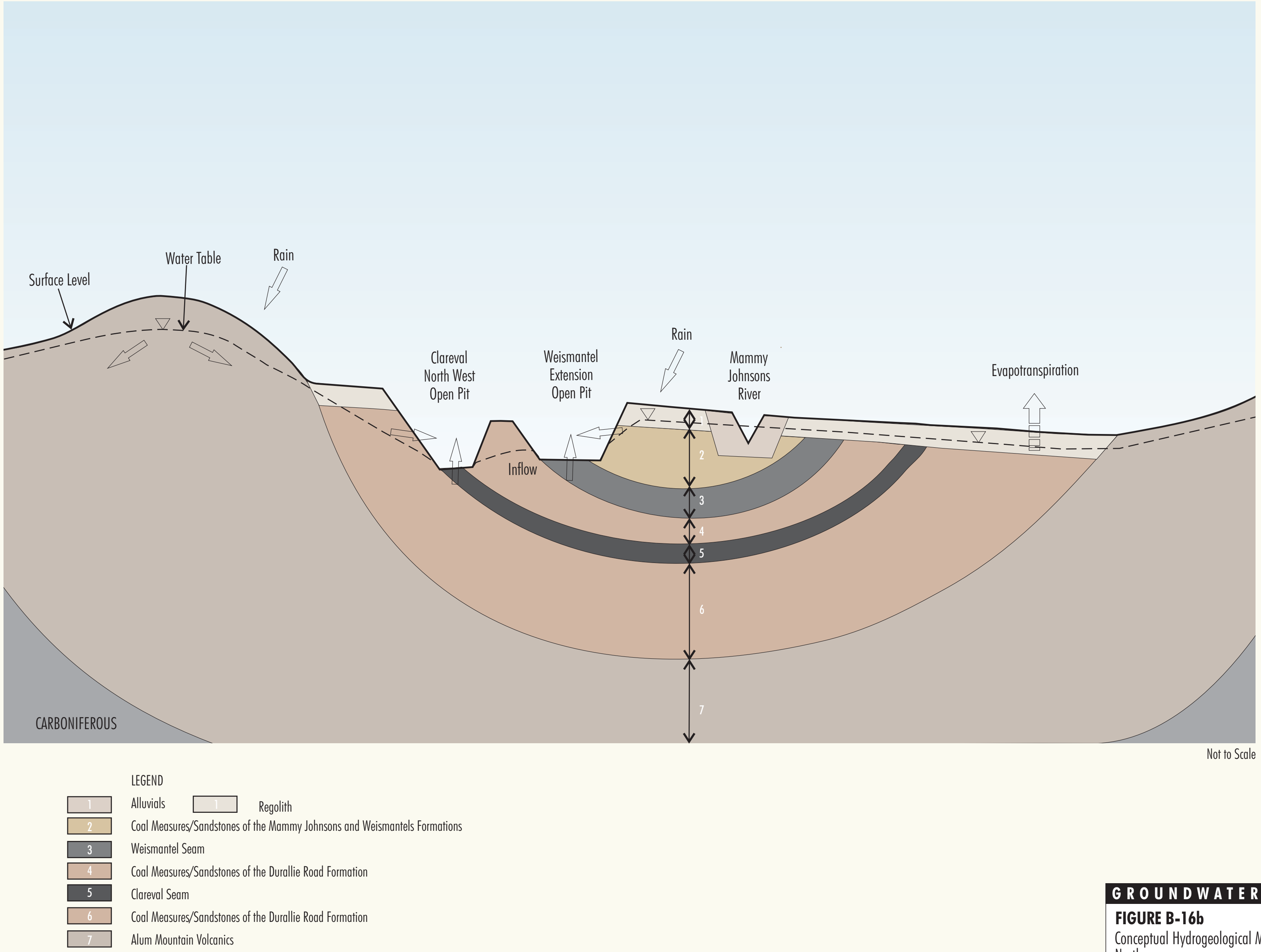
GROUNDWATER ASSESSMENT

FIGURE B-16a

Conceptual Hydrogeological Model - South

Heritage Computing

GCL-06-07 EA GW_007C



GROUNDWATER ASSESSMENT

FIGURE B-16b

Conceptual Hydrogeological Model - North

DURALIE COAL

Heritage Computing

GCL-06-07 EA GW_008C

INDICATIVE THICKNESS (m)	*LAYER*			*LITHOLOGY*
9	**1**	🟧		**ALLUVIALS; REGOLITH**
34	**2**	🟨		**COAL MEASURES / SANDSTONES OF THE MAMMY JOHNSONS AND WEISMANTEL FORMATIONS**
17	**3**	▨		**WEISMANTEL SEAM**
62	**4**	🟨		**COAL MEASURES / SANDSTONES OF THE DURALLIE ROAD FORMATION**
15	**5**	▨		**CLAREVAL SEAM**
~100	**6**	🟨		**COAL MEASURES / SANDSTONES OF THE DURALLIE ROAD FORMATION**
~200	**7**	🟦		**ALUM MOUNTAIN VOLCANICS**

Figure B-17. Numerical model layers

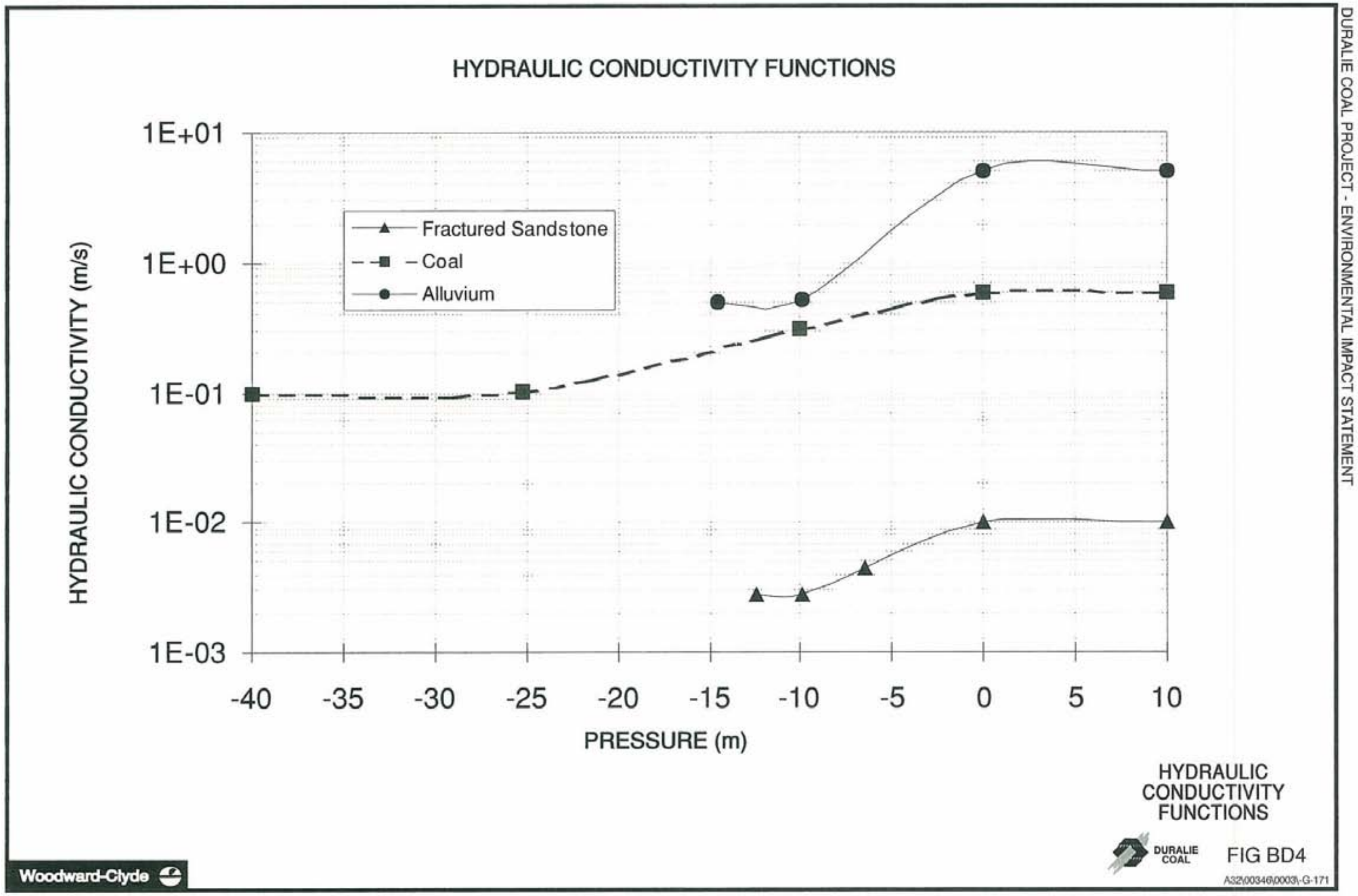


Figure B-18. Hydraulic Conductivities of Fractured Sandstone, Coal and Alluvium [DCPL, 1996]

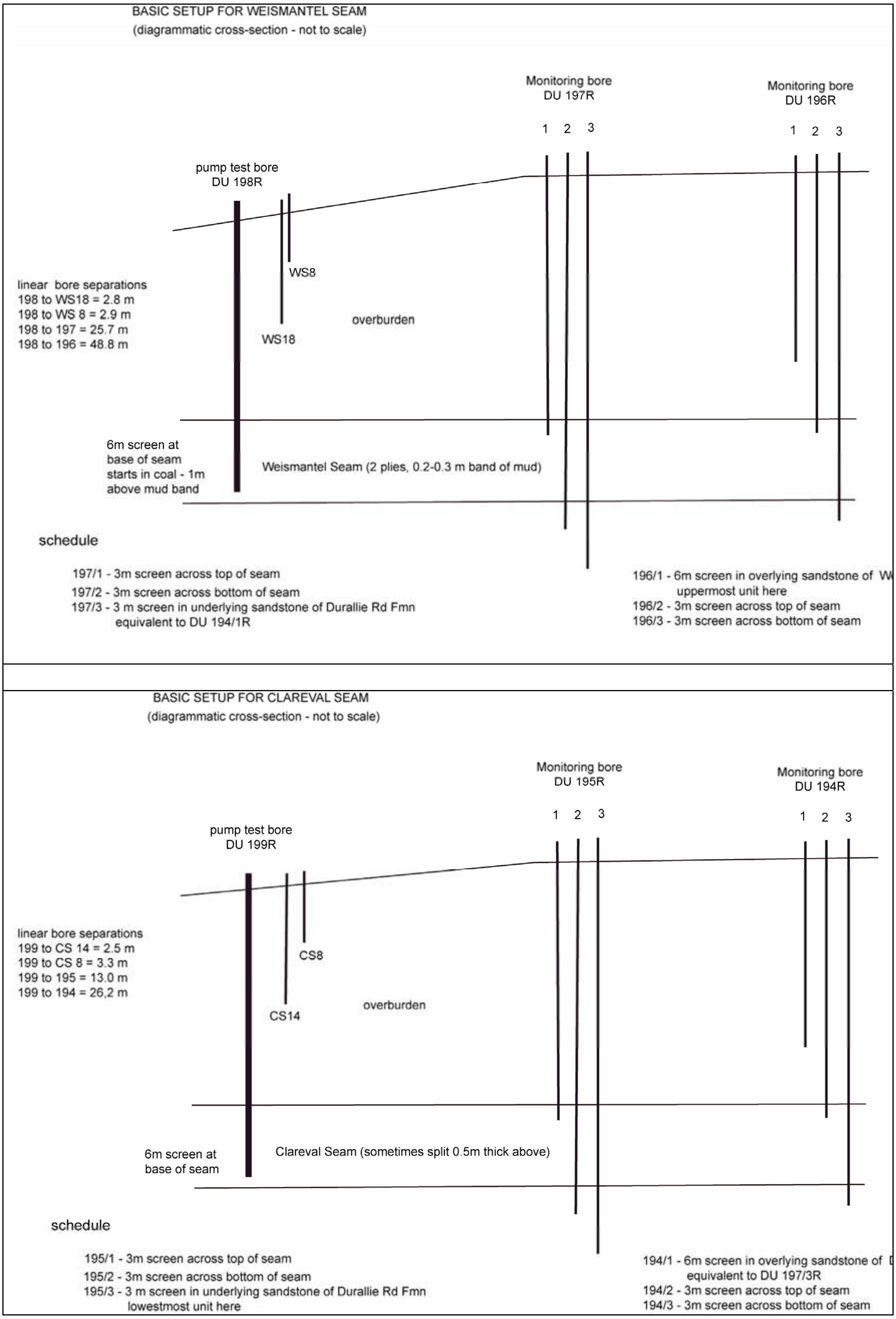


Figure B-19. Hydrogeological Investigation Boreholes (2009 testwork).

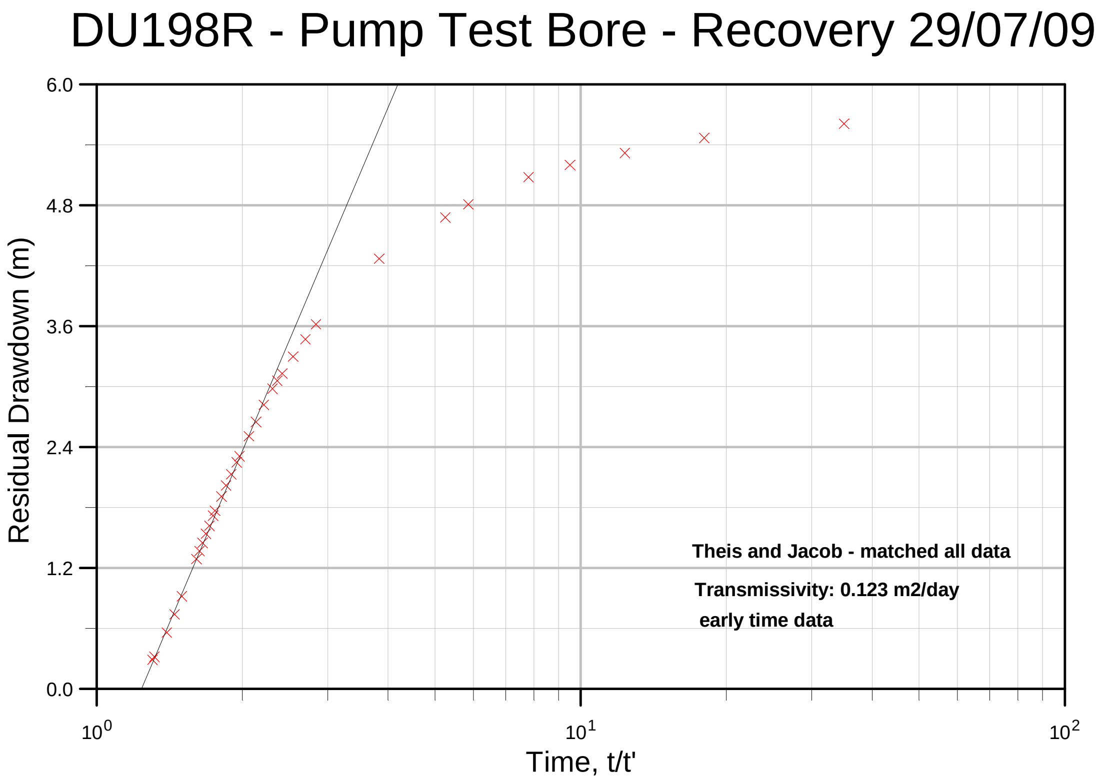


Figure B-20. [a] Indicative pumping test recovery for the Weismantel coal seam.

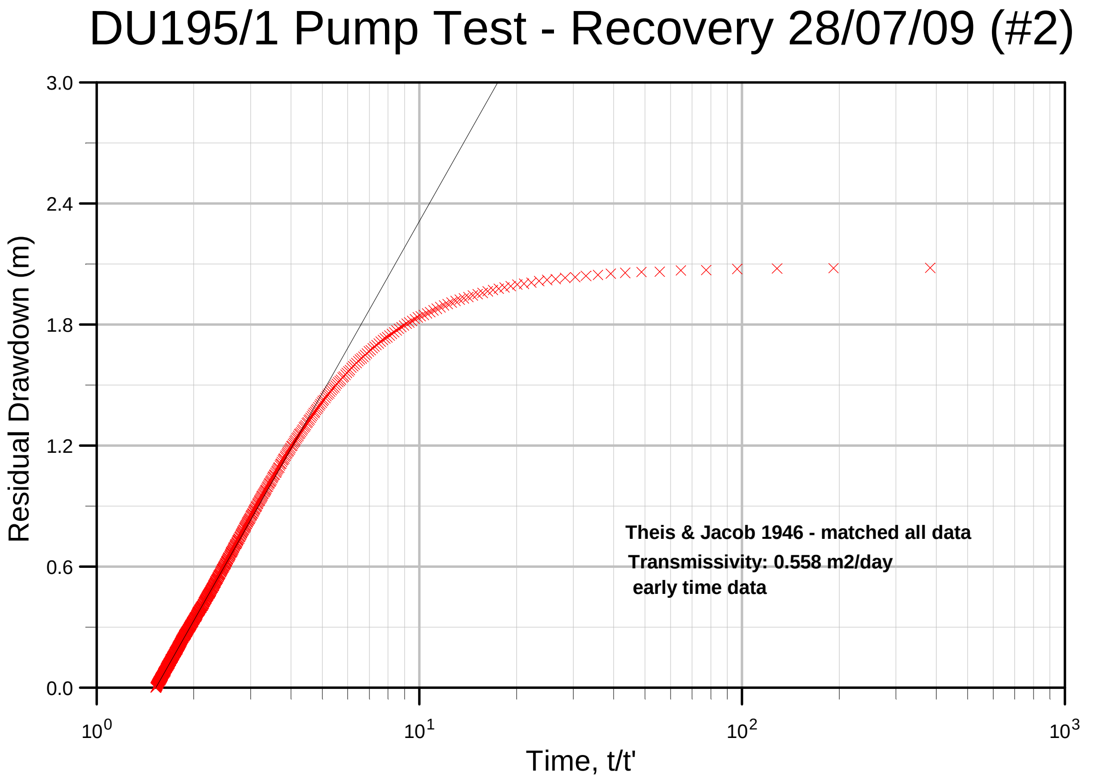
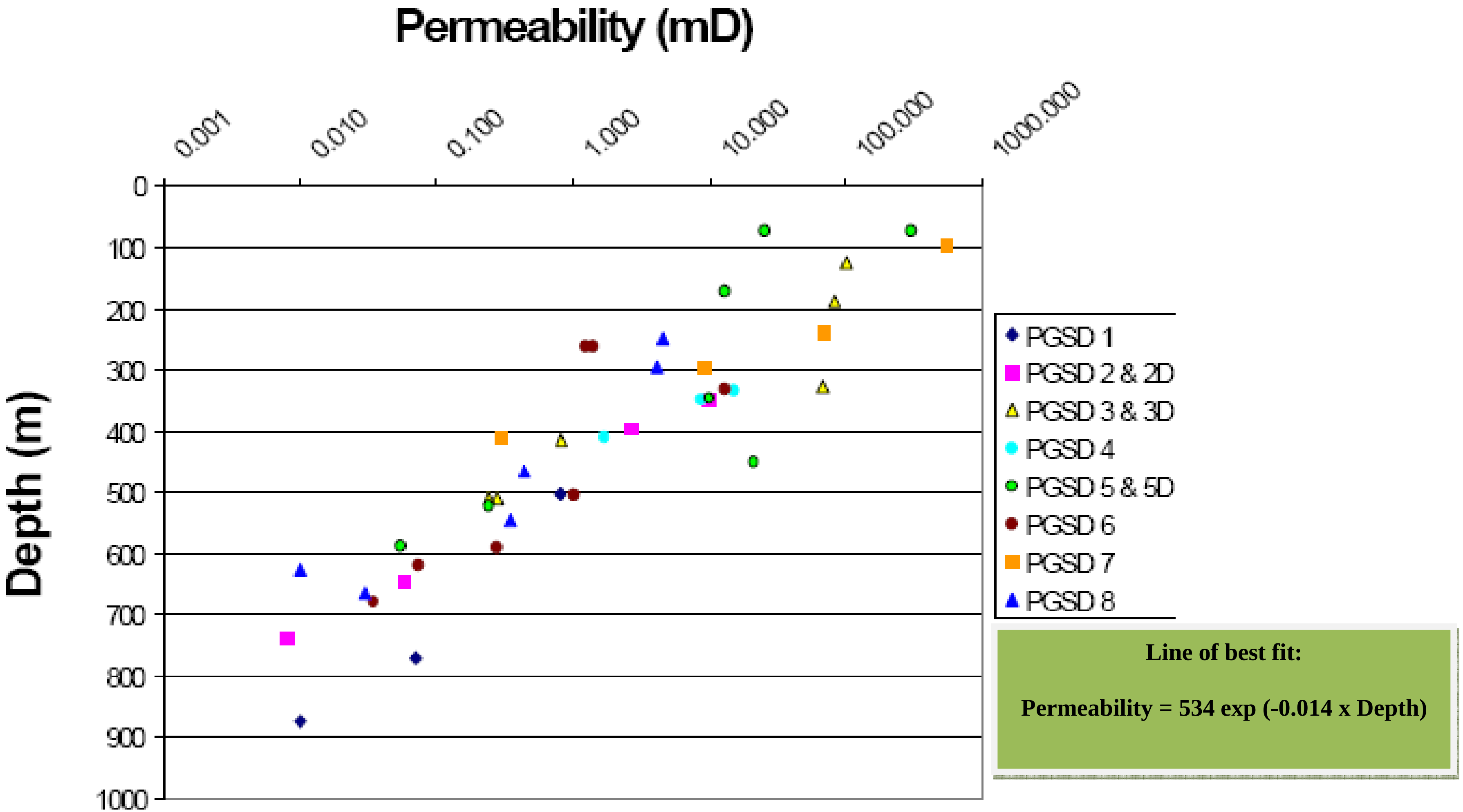


Figure B-20. [b] Indicative pumping test recovery for the Clareval coal seam.



Line of best fit:

Permeability = 534 exp (-0.014 x Depth)

Figure B-21. Intrinsic permeability measurements of coal seams at Stratford in the Gloucester Basin [Source: Smith, 2001]

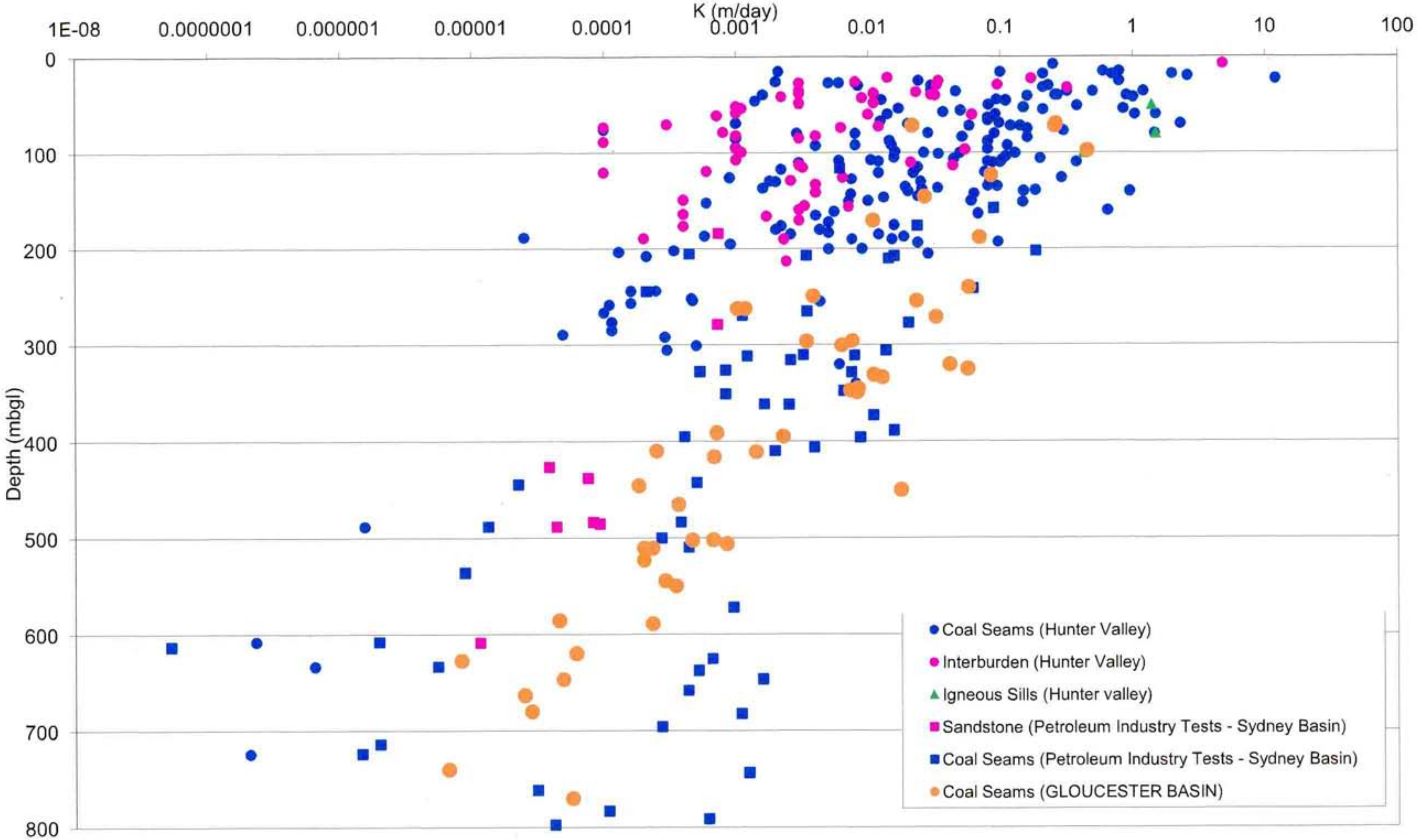


Figure B-22. Comparative hydraulic conductivity measurements in the Gloucester Basin, Sydney Basin and Hunter Valley

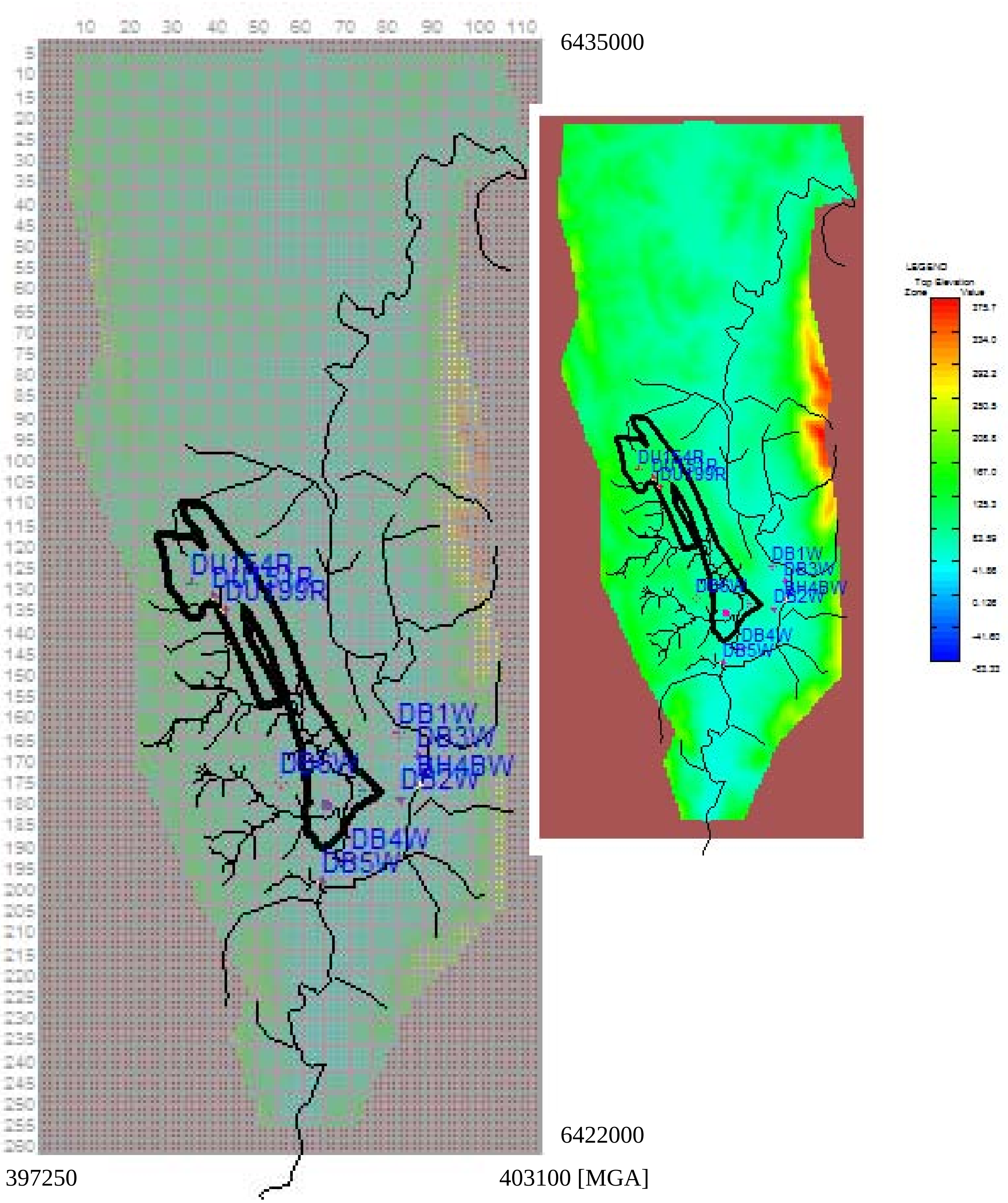


Figure B-23. Model extent, surface topography, drainage network and mine outline

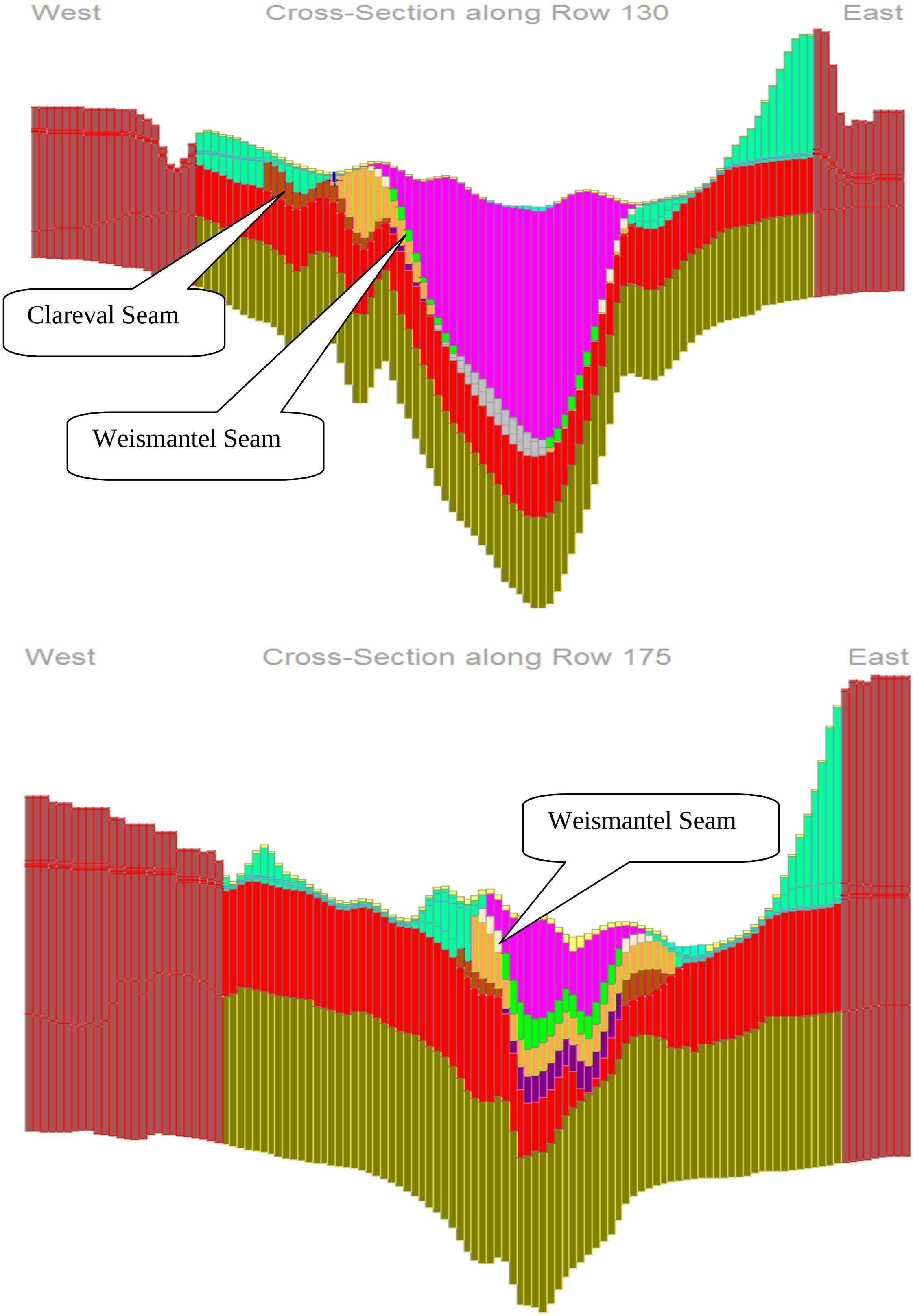


Figure B-24. Representative model cross-sections along Row 130 (Clareval pit) and Row 175 (early Weismantel pit)

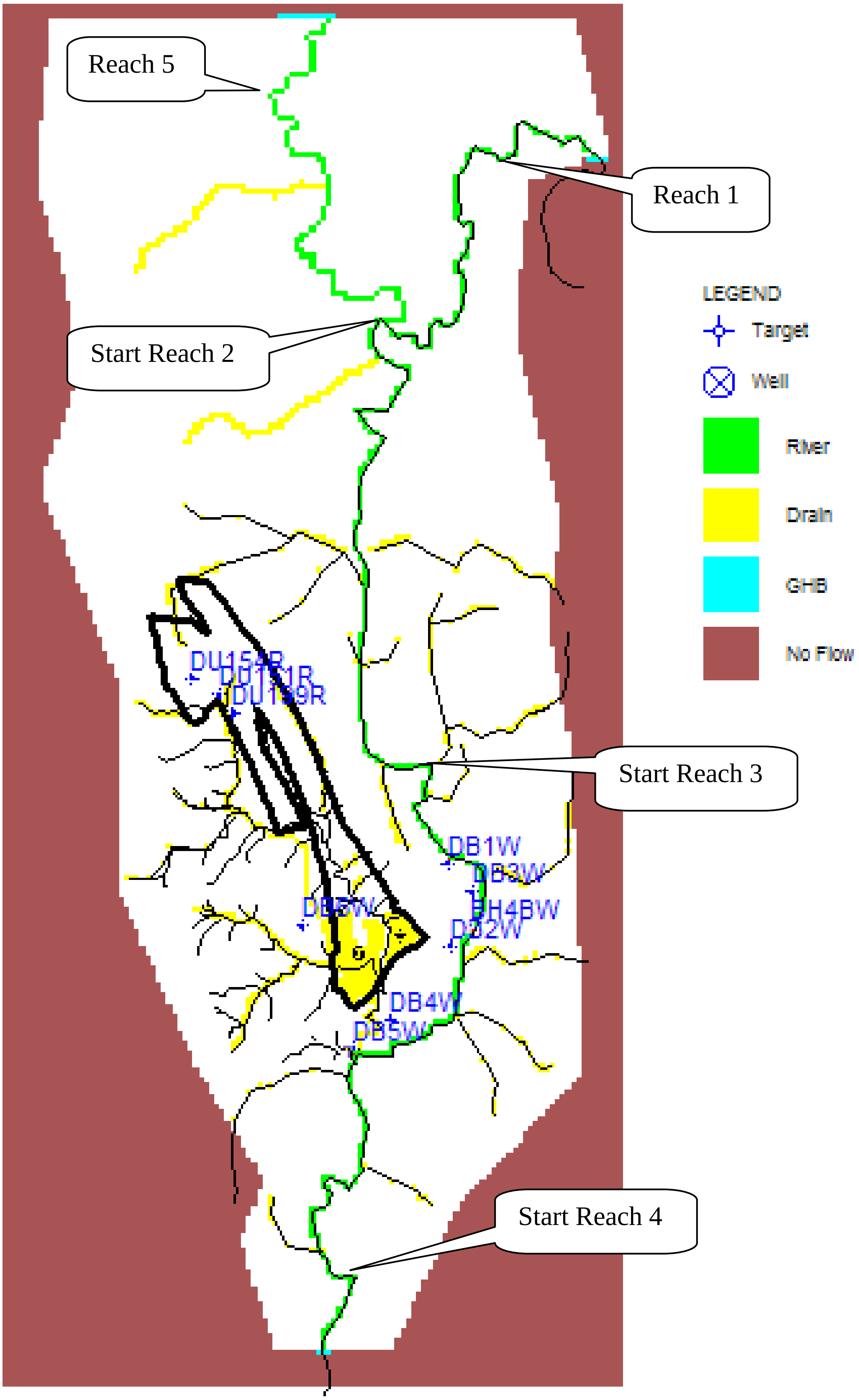


Figure B-25. Boundary conditions applied to model layer 1

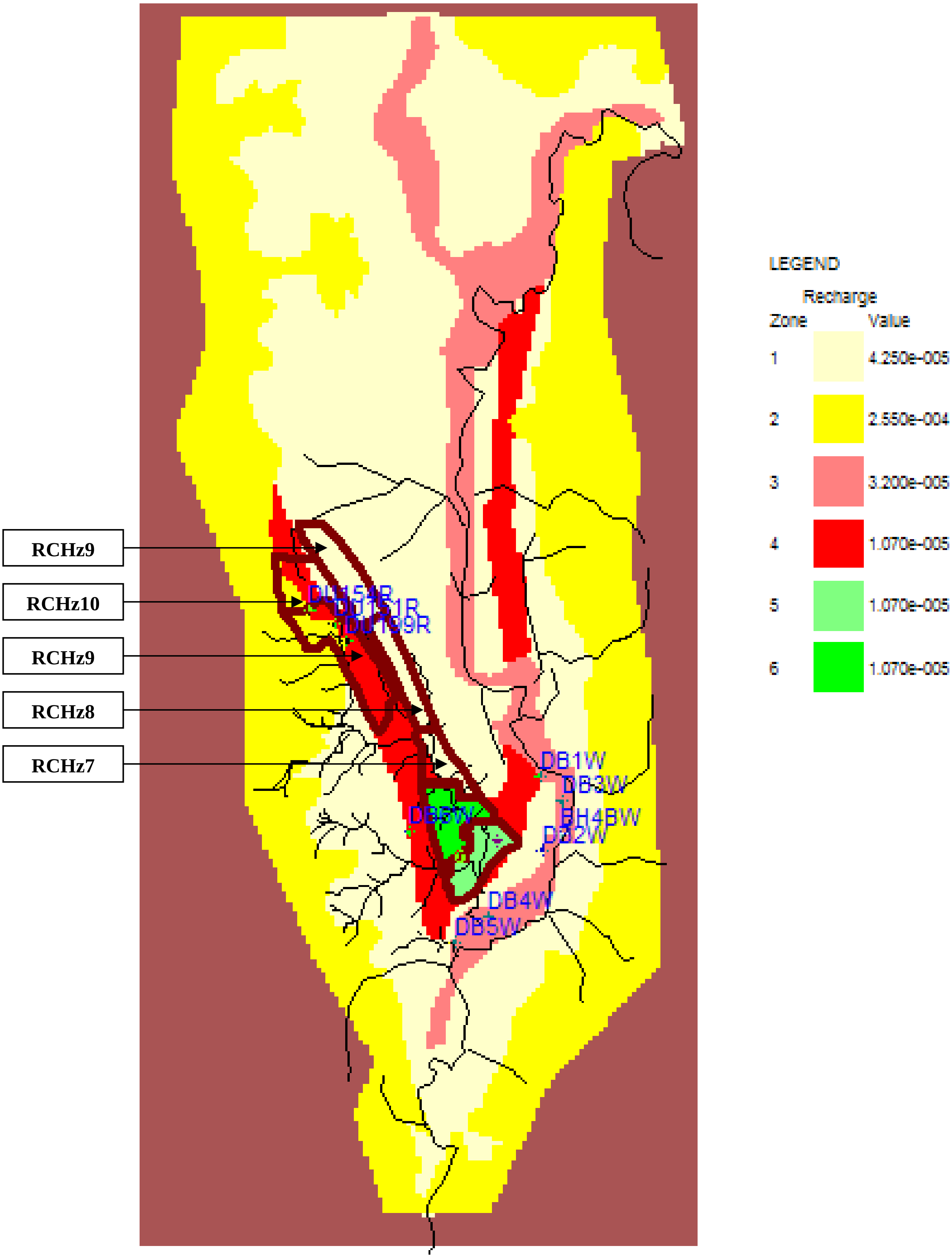


Figure B-26. Rainfall recharge zones [m/day]
[Brown polygons are time-varying recharge zones during predictive simulation]

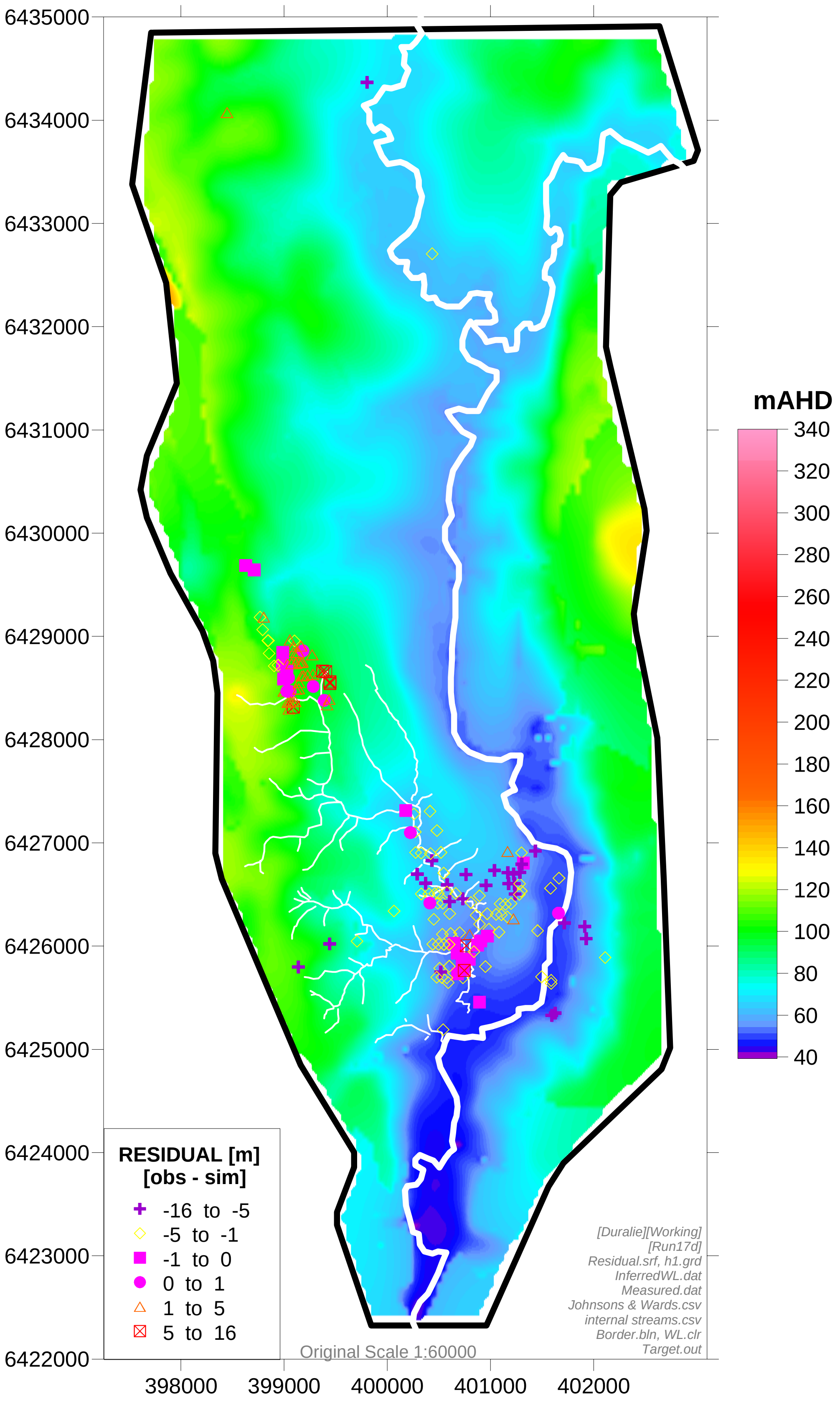


Figure B-27. Simulated steady-state water table elevations [mAHD] and the distribution of residuals [m] at calibration sites

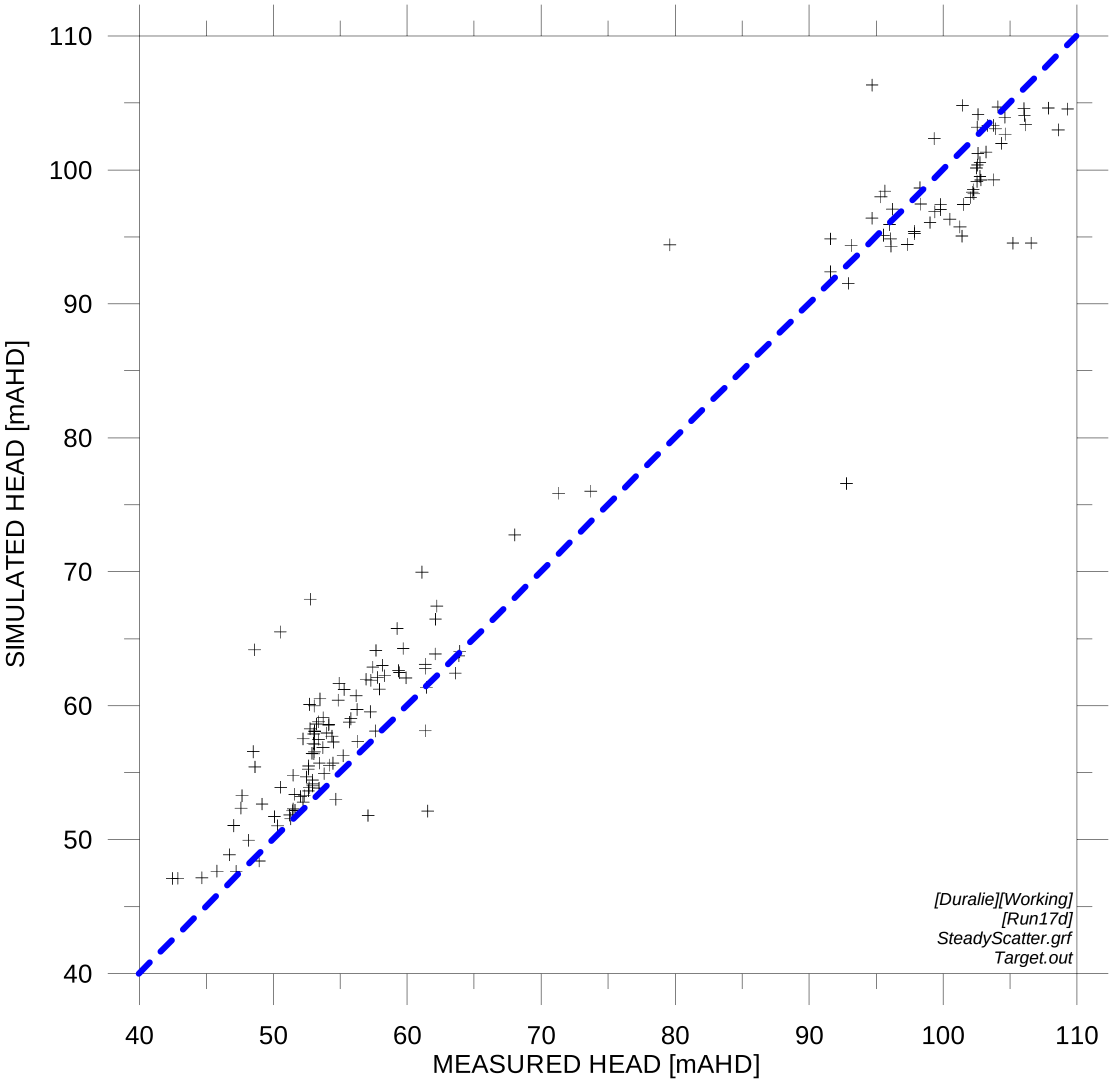


Figure B-28. Scattergram of simulated and measured heads for steady-state calibration

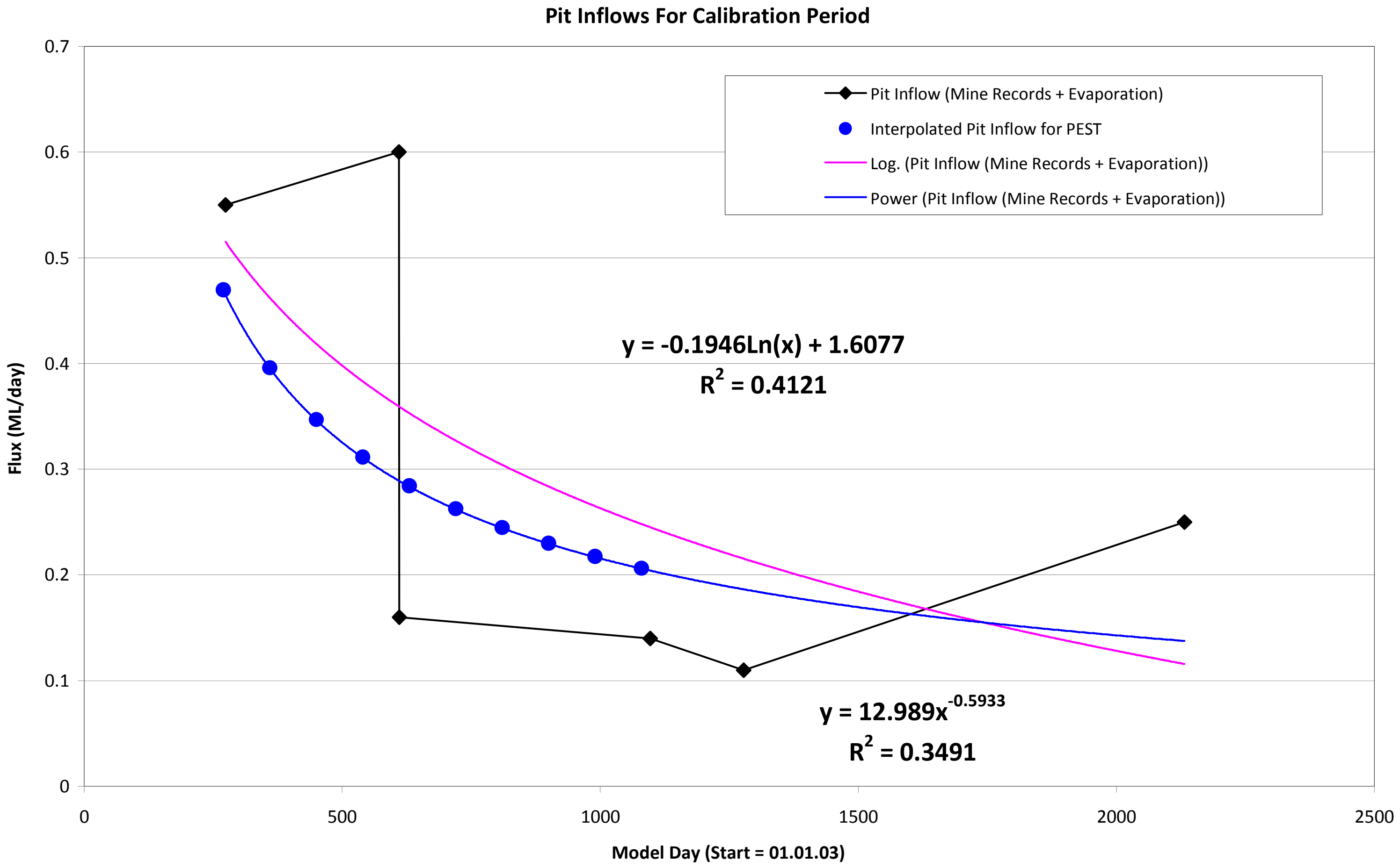


Figure B-29. Target pit inflow curve.

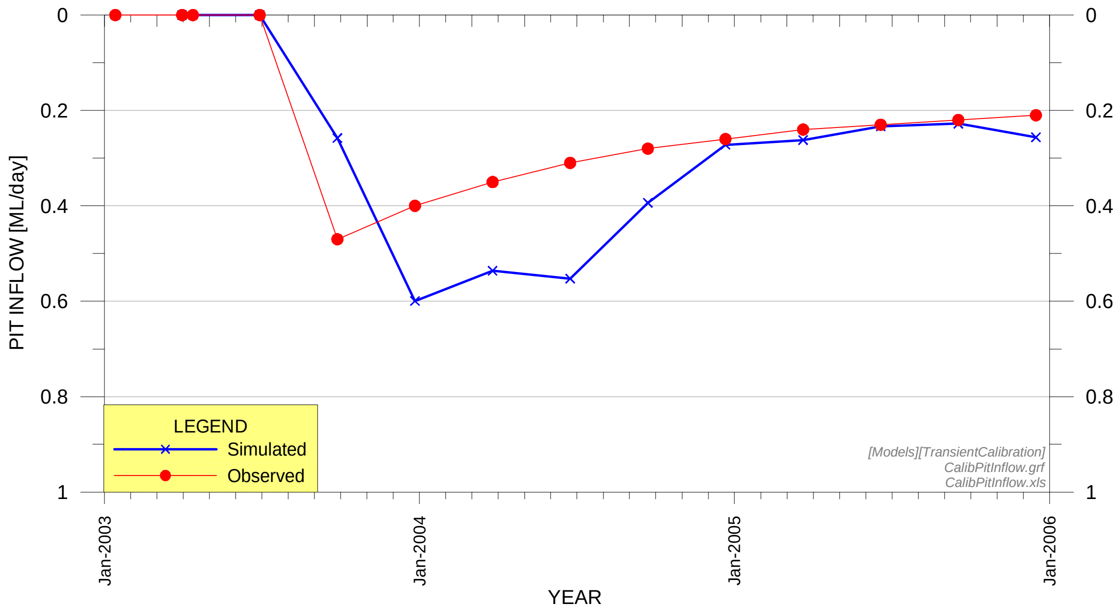


Figure B-30. Comparison of simulated and measured pit inflows during the transient calibration period

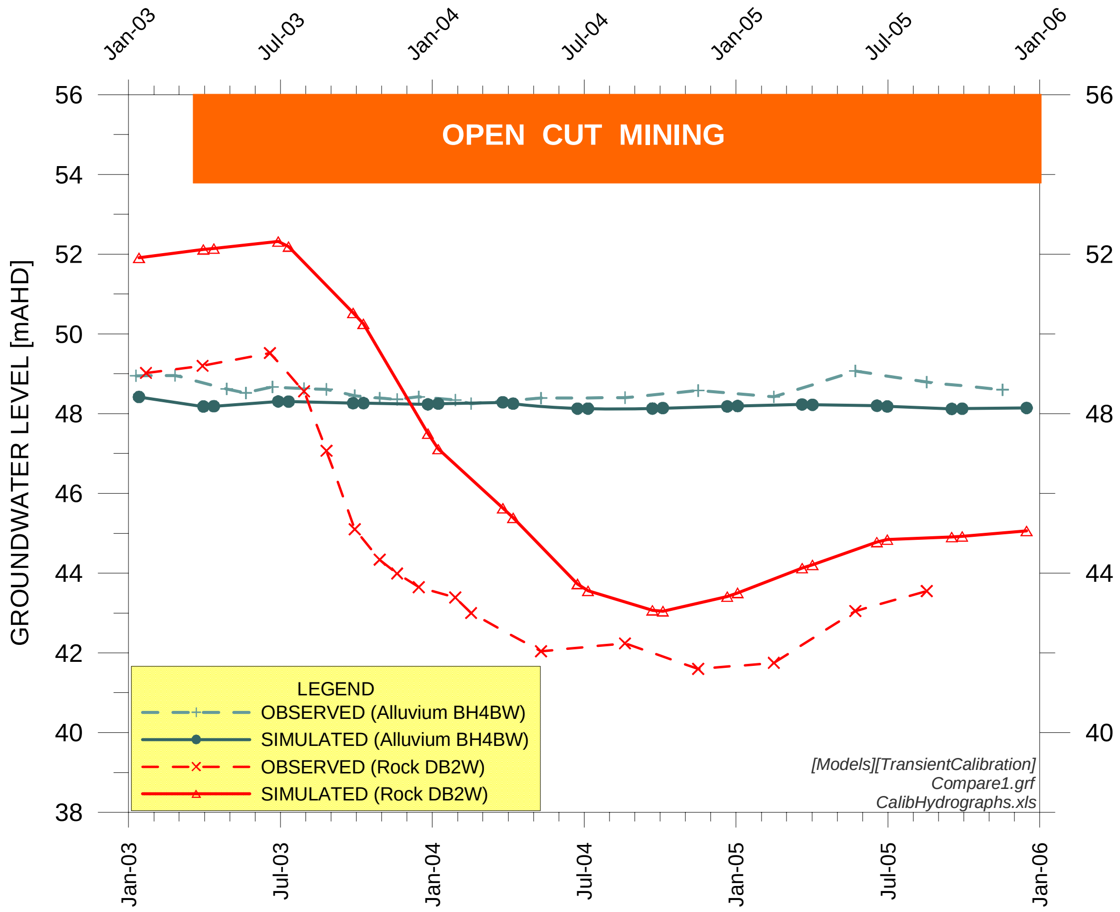


Figure B-31. Comparison of simulated and observed groundwater hydrographs in alluvium (BH4BW) and Upper Durallie Road Formation (DB2W)

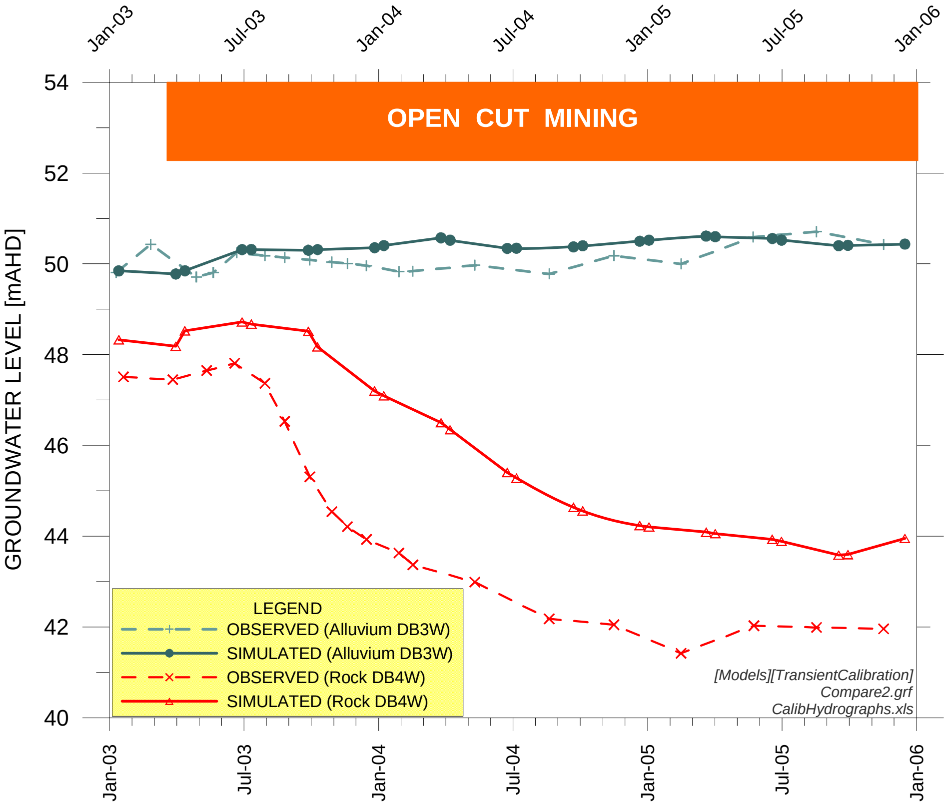


Figure B-32. Comparison of simulated and observed groundwater hydrographs in alluvium (DB3W) and Upper Durallie Road Formation (DB4W)

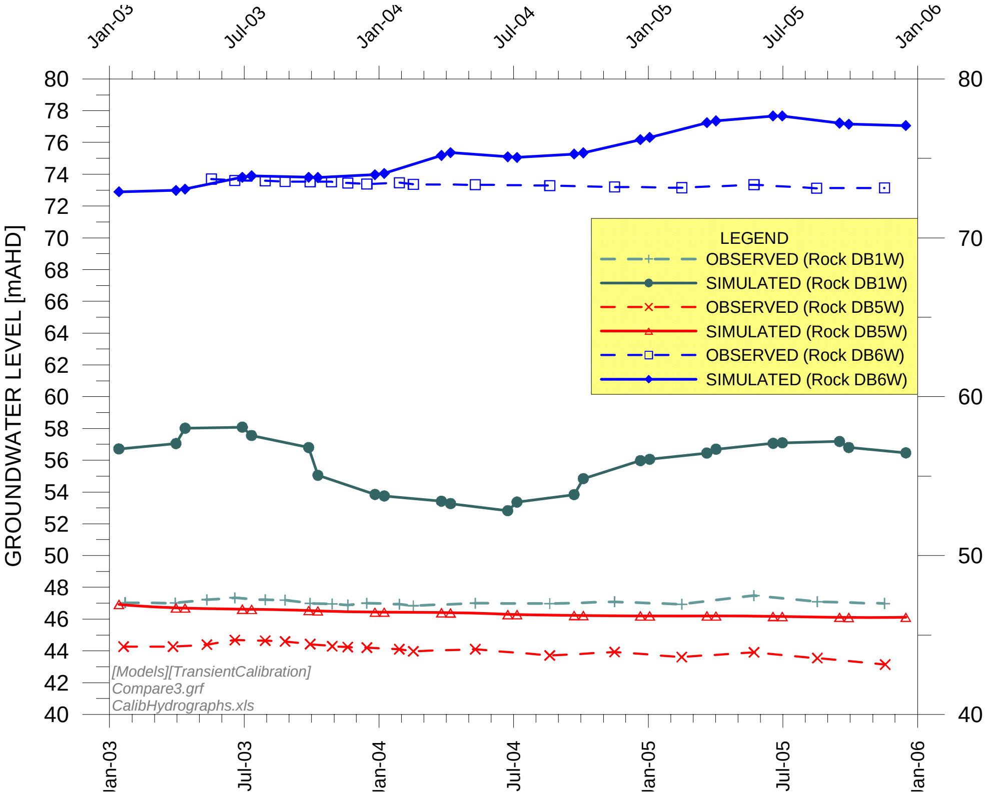


Figure B-33. Comparison of simulated and observed groundwater hydrographs in Upper Durallie Road Formation (DB1W, DB5W, DB6W)

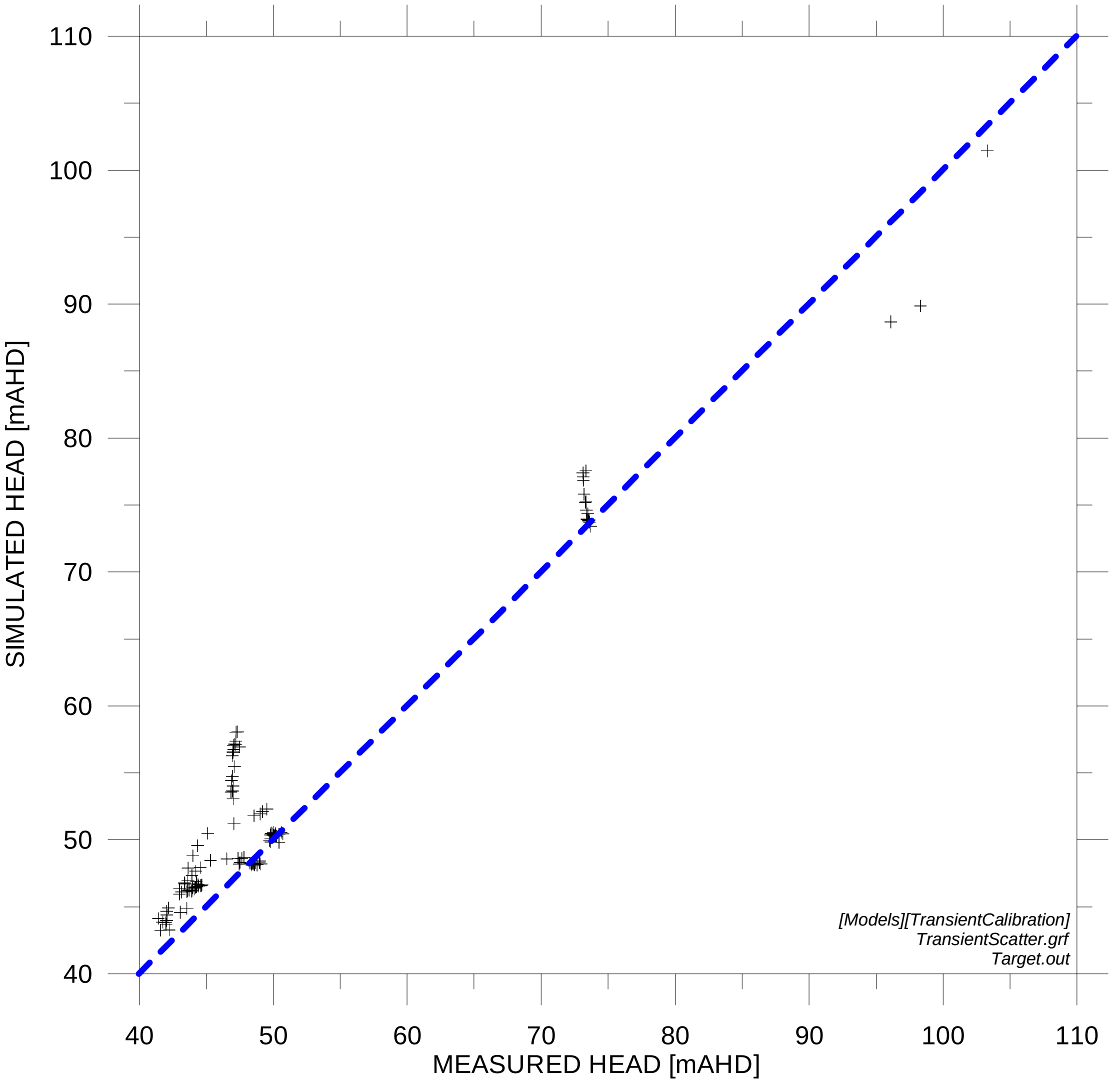


Figure B-34. Scattergram of simulated and measured heads for transient calibration

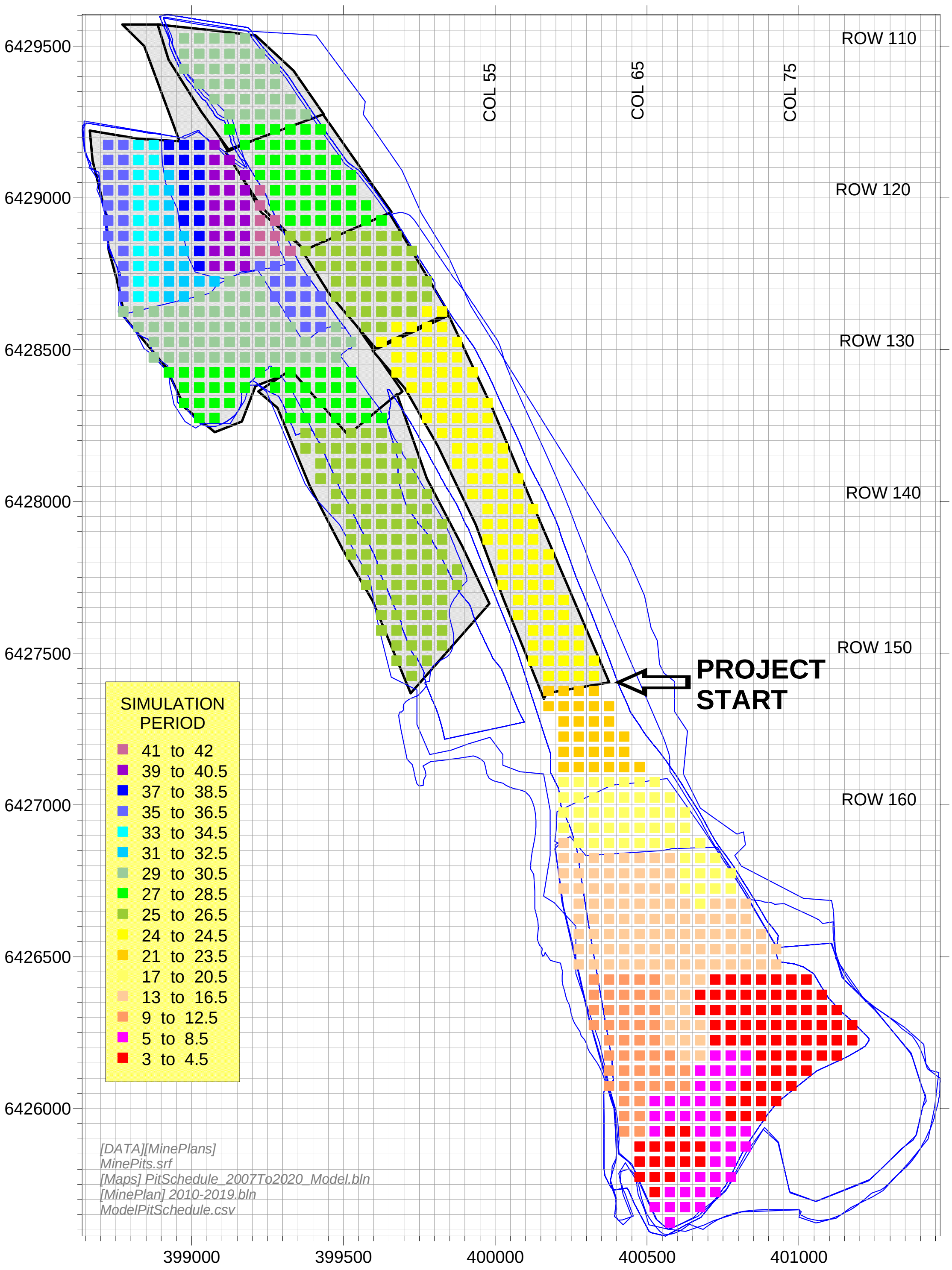


Figure B-35. Simulated pit excavation schedule

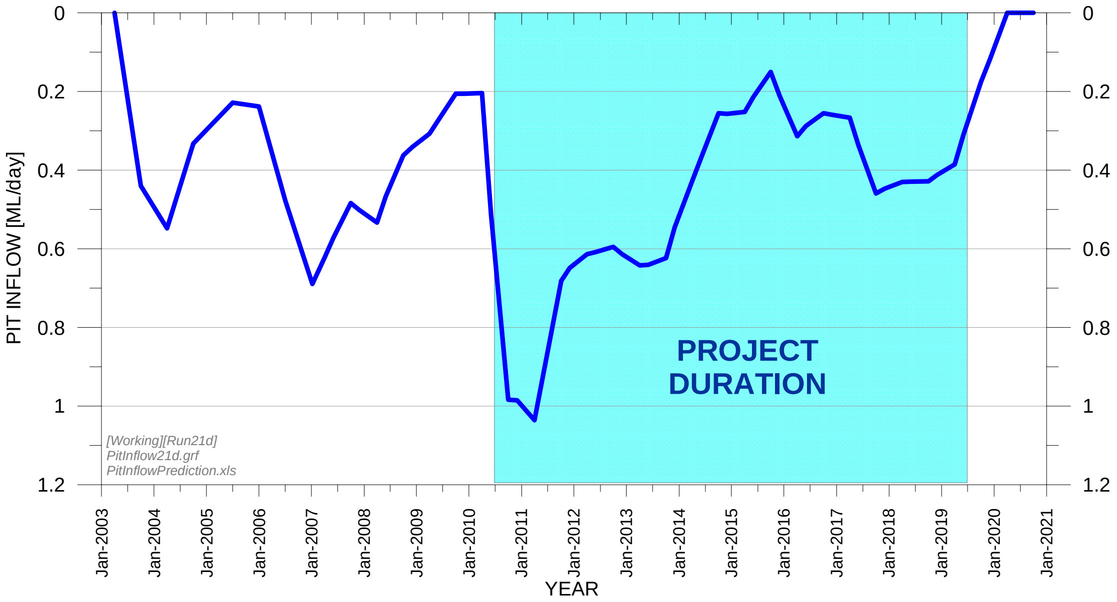


Figure B-36. Simulated pit inflow [ML/day]

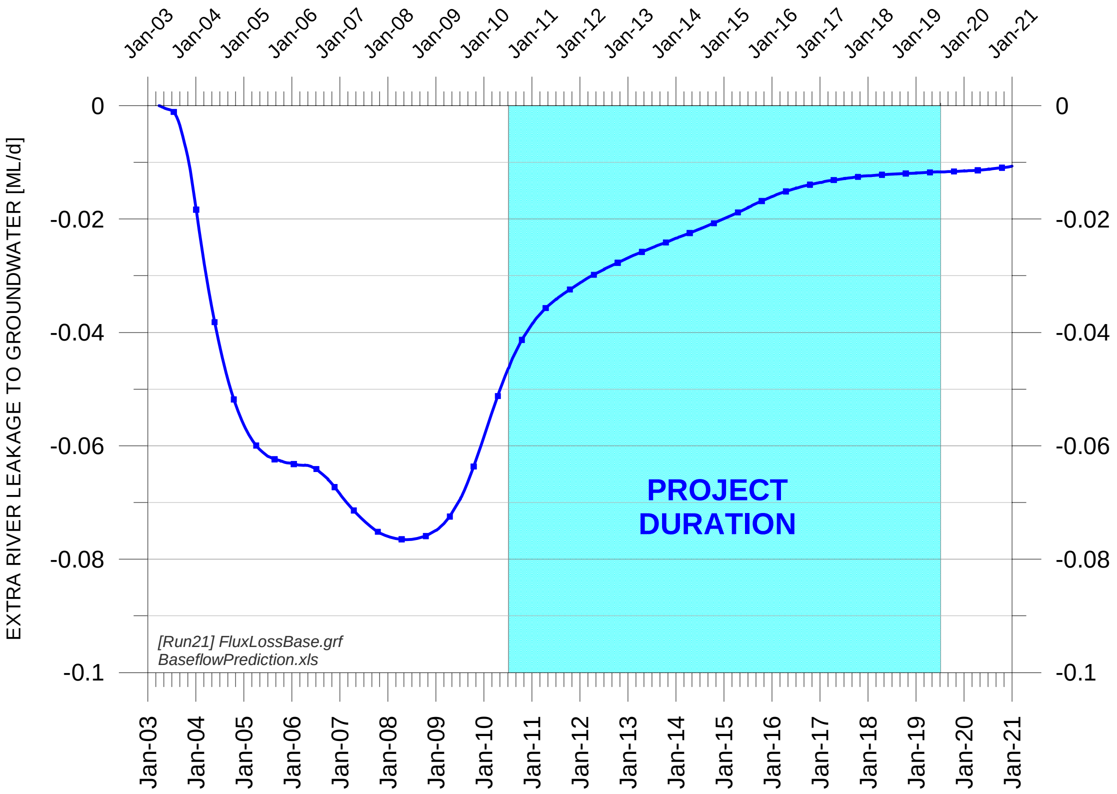


Figure B-37. Additional simulated leakage from Mammy Johnsons River due to mining [ML/day]

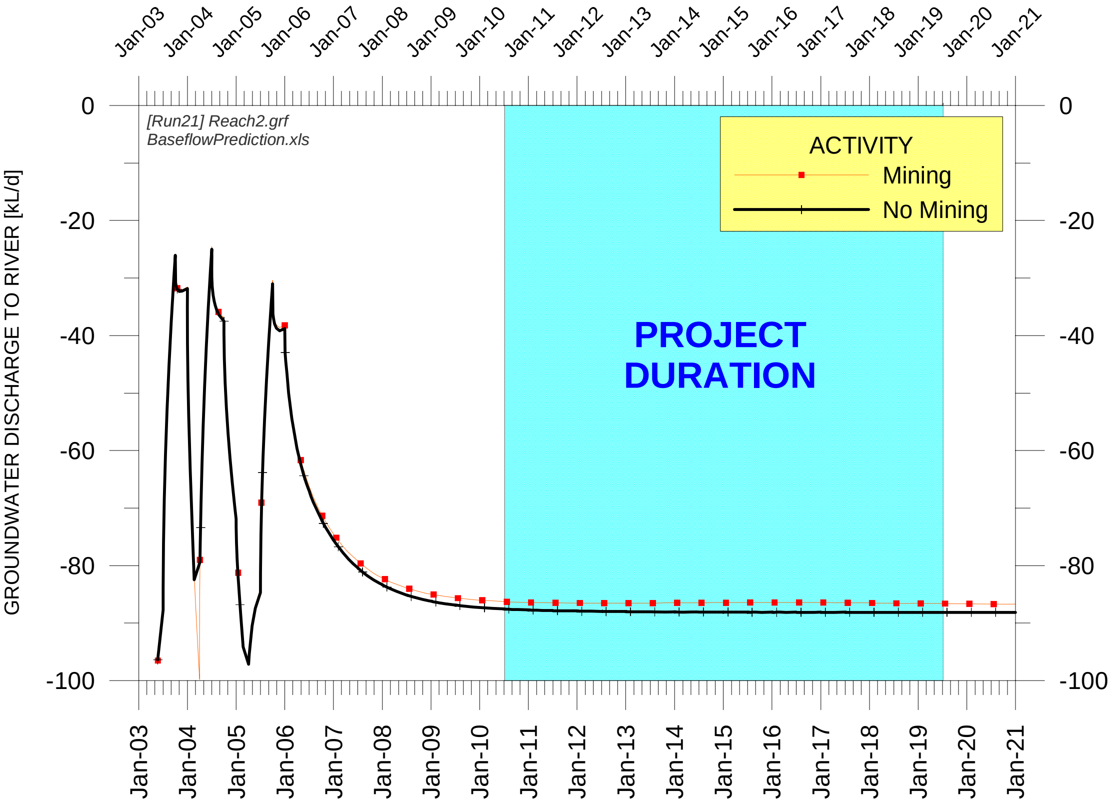


Figure B-38. Simulated baseflow to Mammy Johnsons River Reach 2 [kL/day]

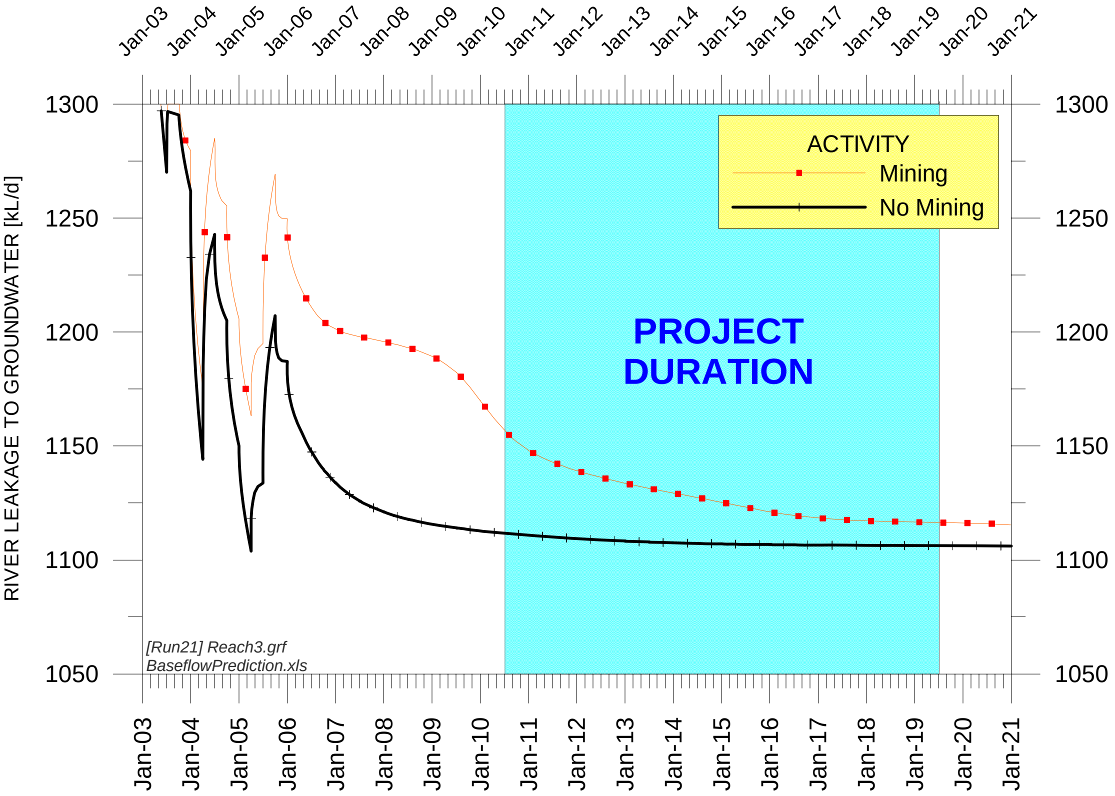


Figure B-39. Simulated leakage from Mammy Johnsons River Reach 3 [kL/day]

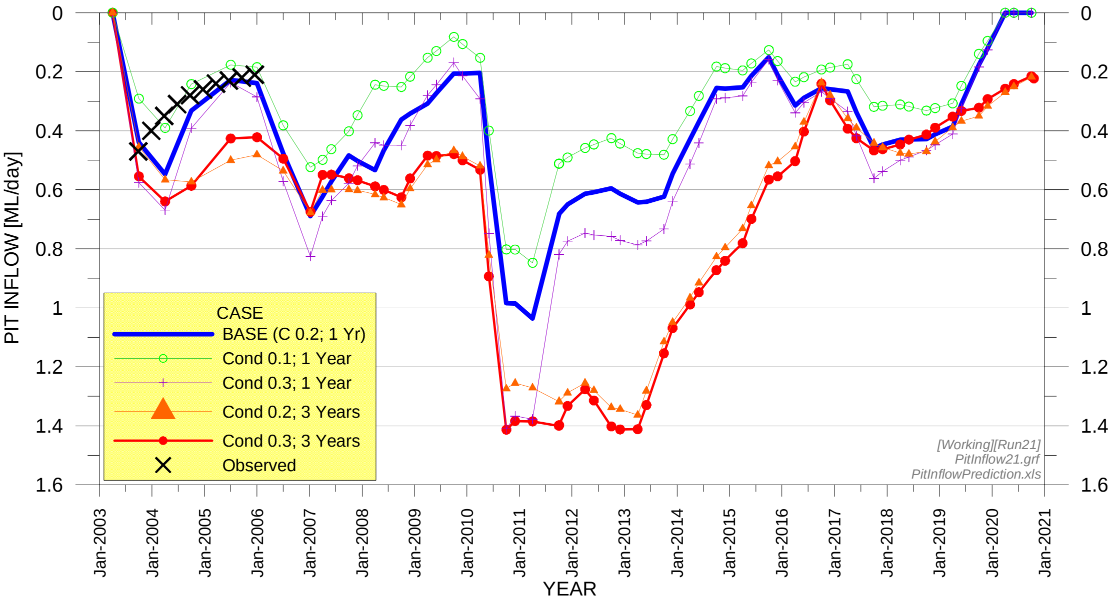


Figure B-40. Sensitivity analysis for simulated pit inflow [ML/day]

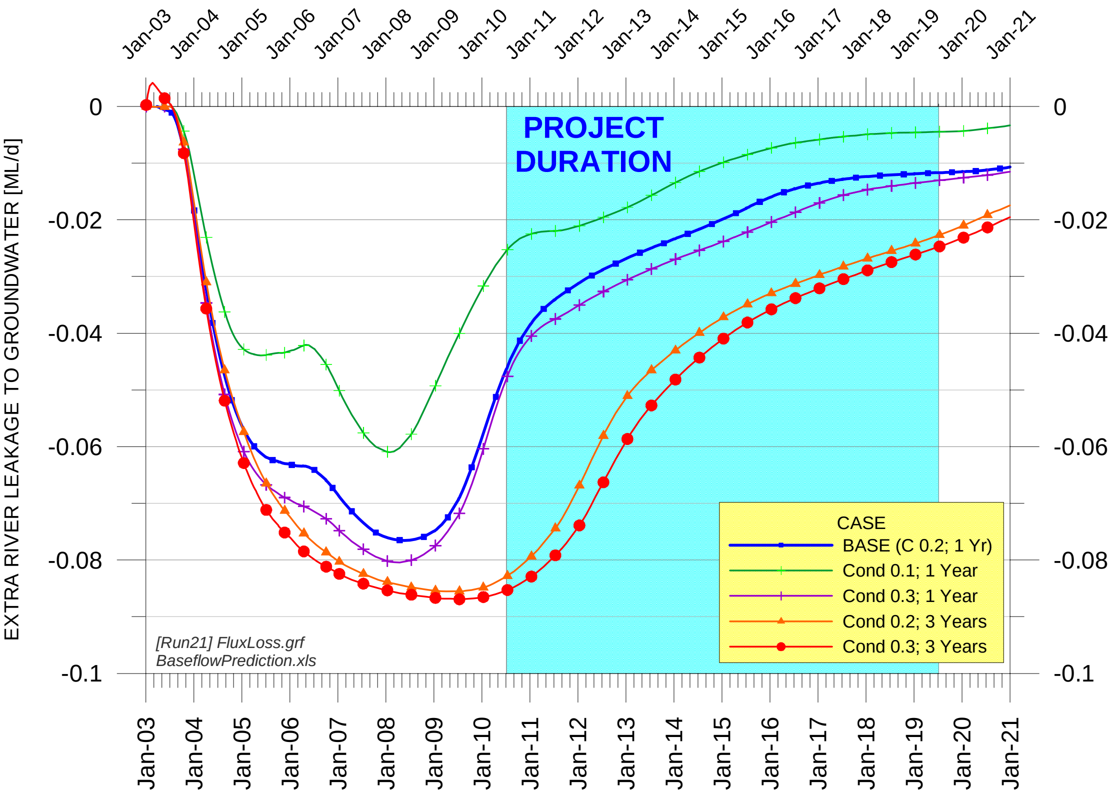


Figure B-41. Sensitivity analysis for additional simulated leakage from Mammy Johnsons River due to mining, for mine-related model parameters [ML/day]

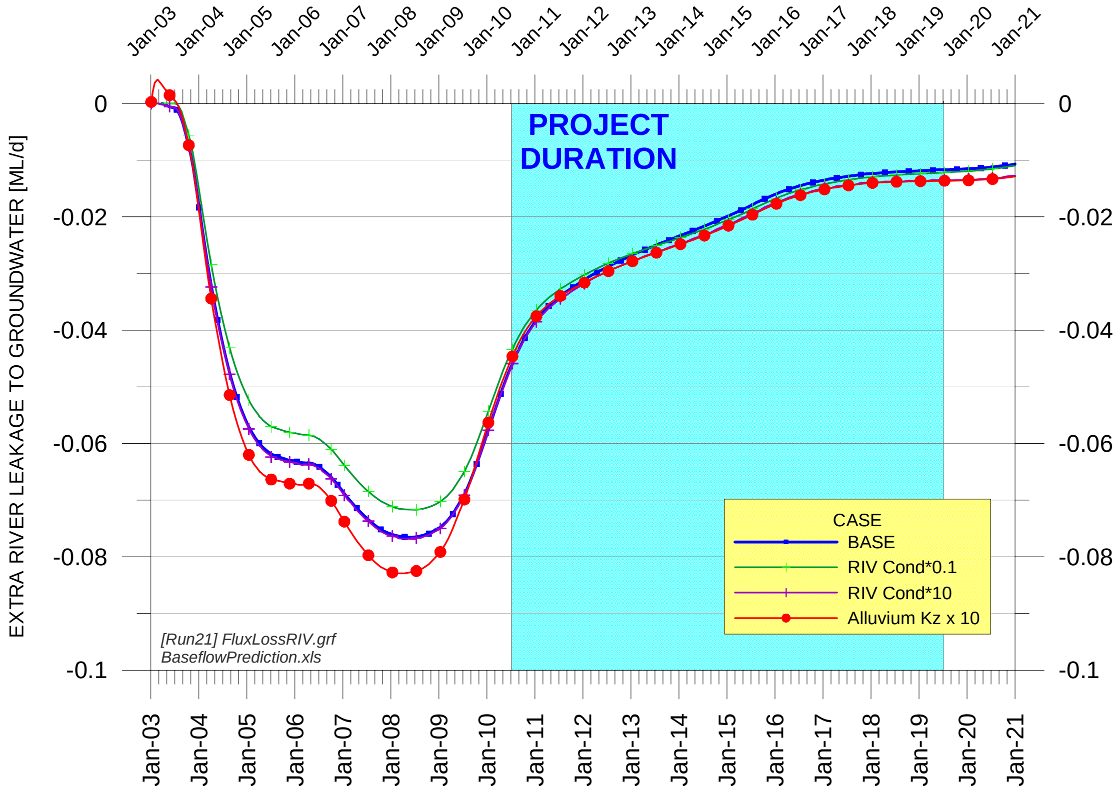


Figure B-42. Sensitivity analysis for additional simulated leakage from Mammy Johnsons River due to mining, for river-related model parameters [ML/day]

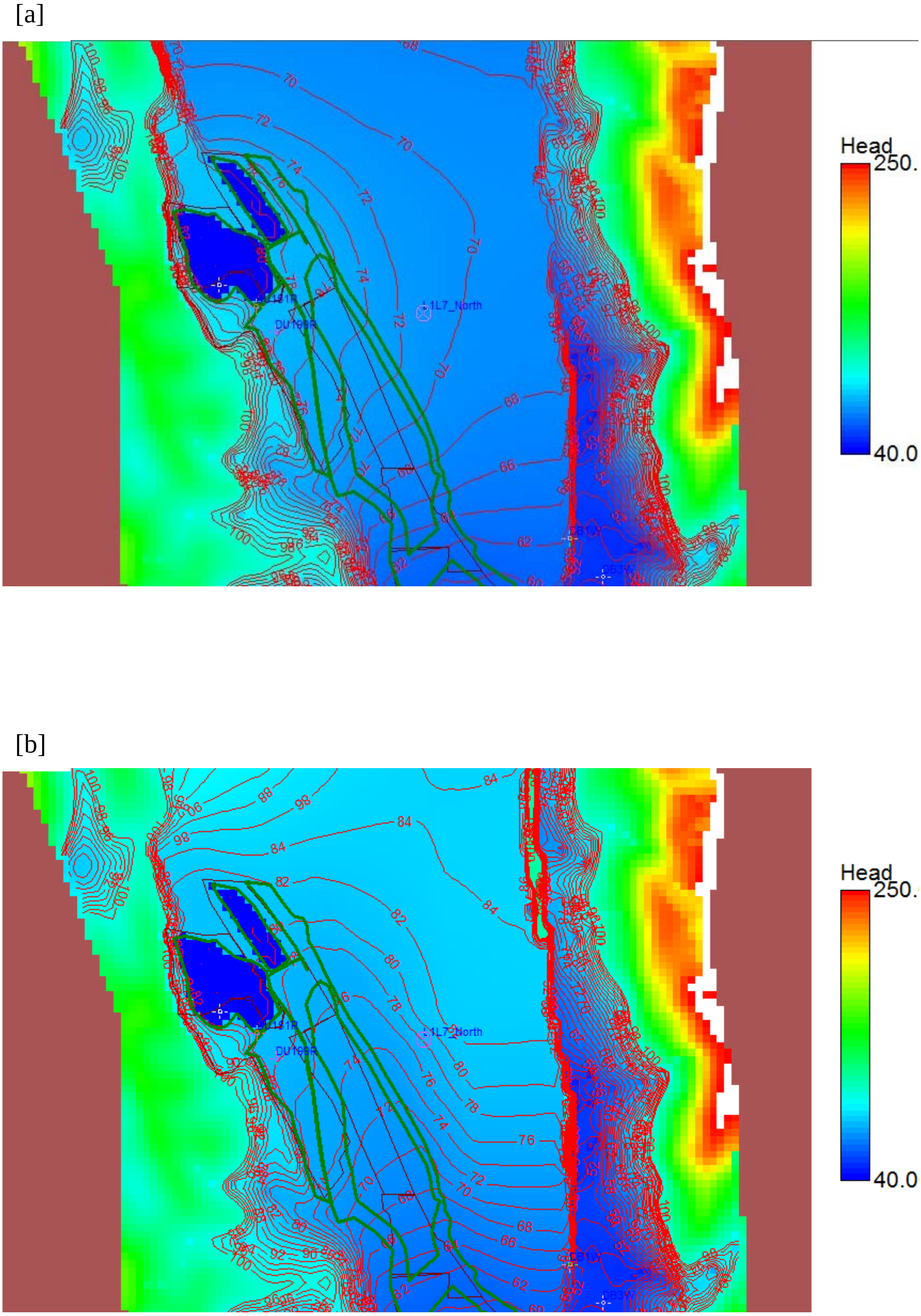


Figure B-43. Simulated post-mining equilibrium groundwater levels [mAHD]
[a] Layer 2; [b] Layer 3

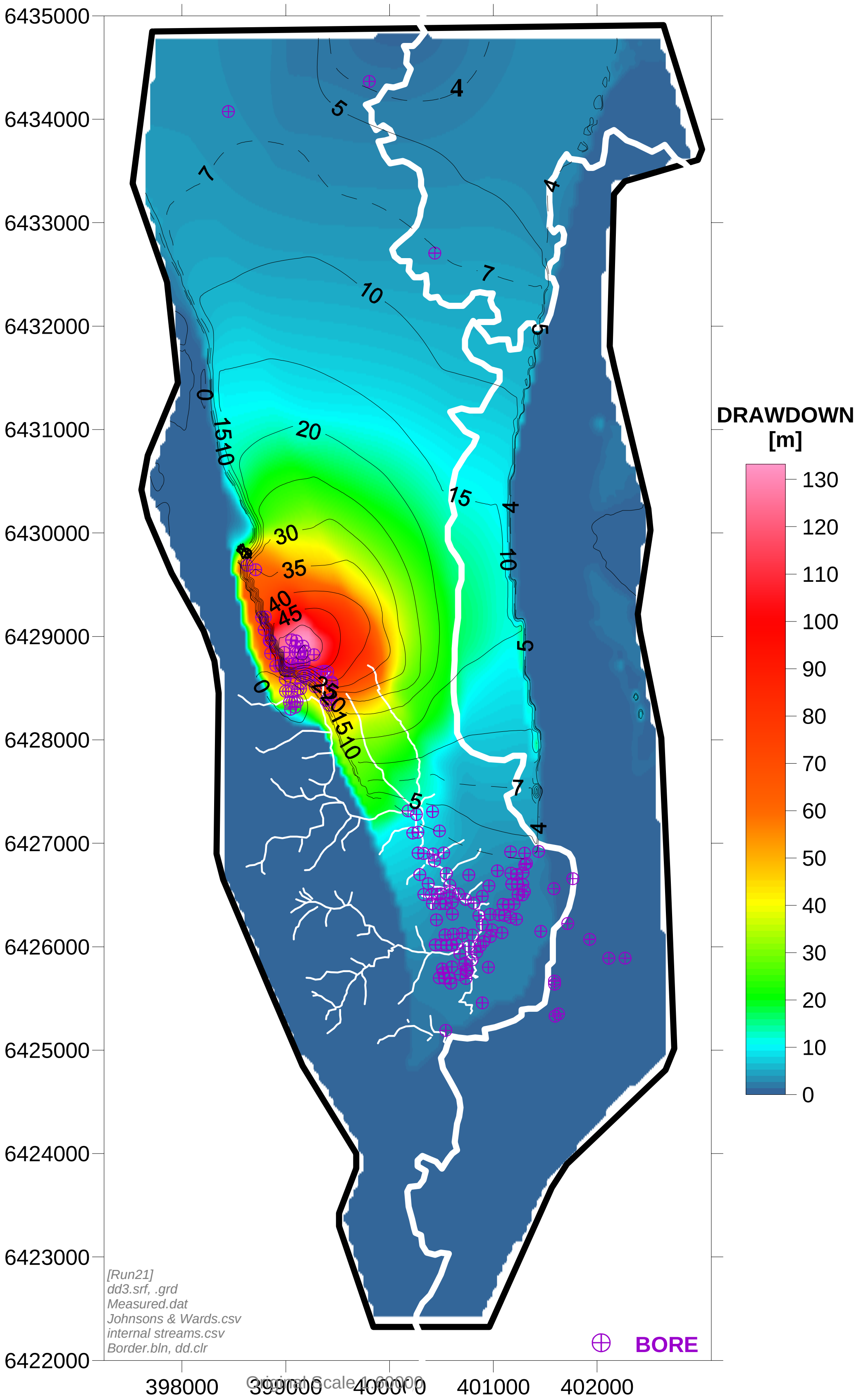


Figure B-44. Simulated drawdown in groundwater levels at the end of mining in model Layer 3 (Weismantel coal seam)

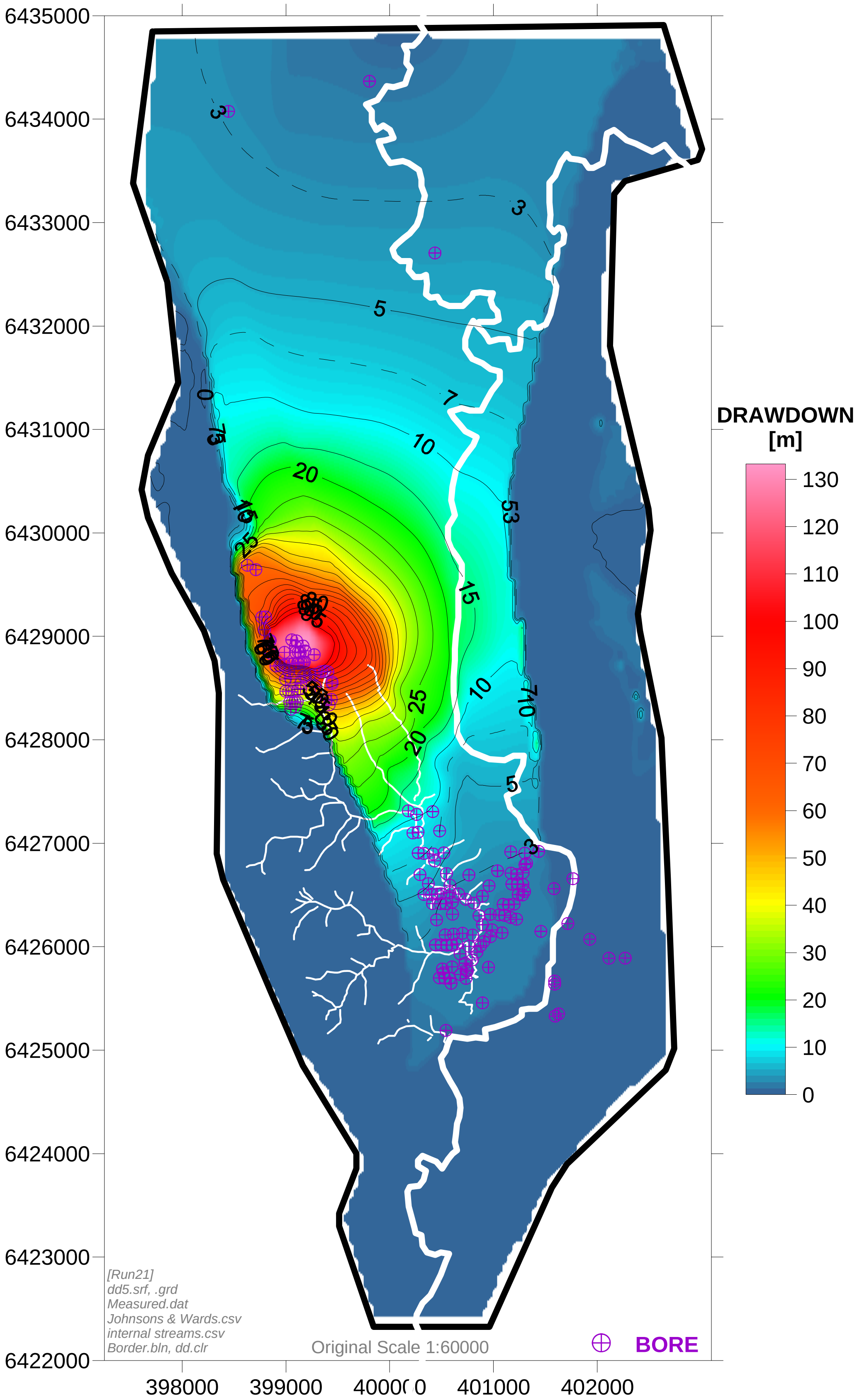


Figure B-45. Simulated drawdown in groundwater levels at the end of mining in model Layer 5 (Clareval coal seam)

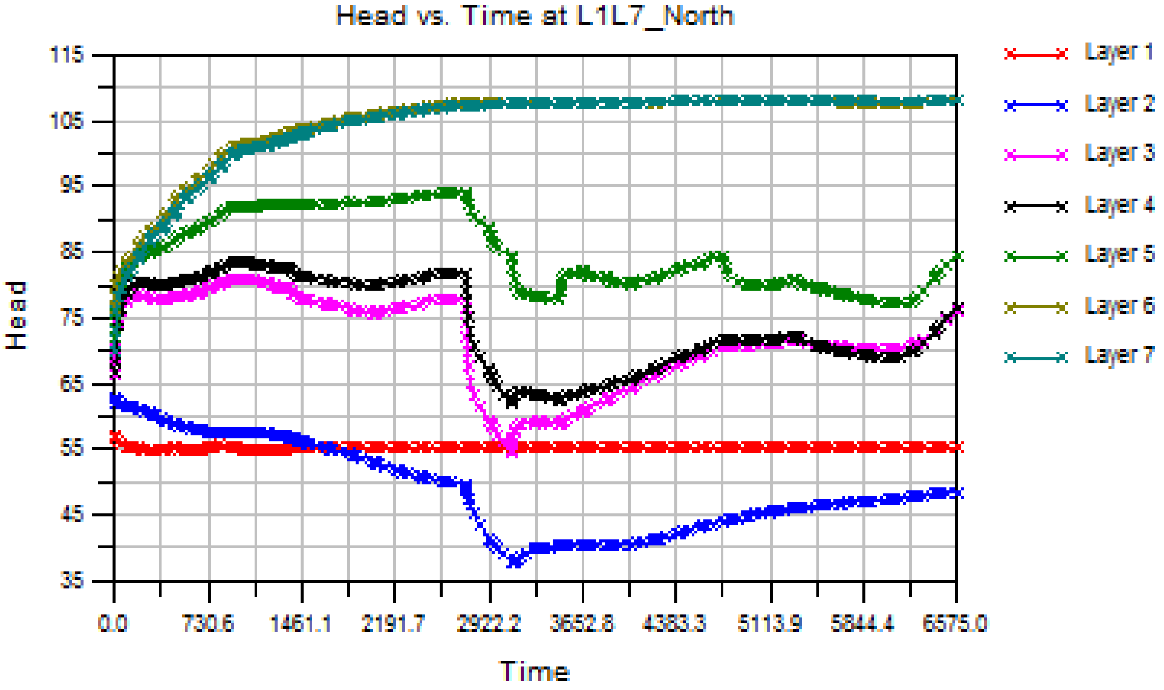


Figure B-46. Simulated groundwater hydrographs for each layer up to 18 months beyond the end of mining at a site in alluvium east of the final pit voids [see Figure B-43 for location]

ATTACHMENT BA

Known Registered Bores in the Vicinity of the Duralie Coal Mine

Table BA1. Known registered bores in the vicinity of the Project

Bore ID	Easting (AMG 56)	Northing (AMG 56)	Year of Construction	Hole Depth (m)	Elevation (mAHD)	Depth to Water (m)	Water Level (mAHD)	Max Yield (L/s)	Lithology
GW047870	399805	6434366	1981	30.00	-	12.00	-	0.76	Soil to 2 m; Clay to 4 m; Shale Water Supply to end.
GW080288	400436	6432706	2002	58.20	-	4.20	-	0.30	Top Soil to 0.3 m; Brown Clay to 1 m; Hard conglomerate rock pre case, hole to 5m - cave in; Hard basalt to 9m; Water cut at 9.2 m; Hard basalt to 33 m; Water cut at 33.3 m; Hard granite to end.
GW011316	398447	6434078	1955	18.30	-	17.10	-	-	Water bearing nominal rock to 18.29 m; Nominal clay to end.
GW078141	401423	6426930	1997	36.50	62.25	14.09	48.16	0.80	Grey, brown soil/sand loam to 2 m; Cream/orange, fine grained, weathered litchi sandstone to 9 m; Dark to mid grey, fine grained litchi sandstone to end.
GW079620	401700	6426741	1997	60.00	55.11	14.78	40.33	5.00	Cream/grey soil, sandy loam to 1 m; Cream/orange fine grained, weathered litchi sandstone to 5 m; Mid grey, fine grained, litchi sandstone to end.
GW079621	400932	6425503	1997	40.00	53.6	7.26	46.34	1.81	Cream brown/orange, sandy silt, soil to 1 m; Cream/brown, fine grained, weathered litchi sandstone to 4 m; Mid grey, fine grained, partly weathered litchi sandstone to 6.5 m; Mid grey, fine grained, litchi sandstone to end.
GW079622	400517	6424167	1997	40.00	55.97	-	-	0.60	Dark brown/black soil, silty clay to 1 m; Red brown mottled silty clay to 2 m; Cream/brown fine grained, weathered litchi sandstone to 11 m; Mid grey fine grained, litchi sandstone to end.
GW079744	401618	6425637	1996	9.50	-	5.81	-	-	Dark brown sandy loam to 1 m; Brown sandy loam to 2 m; Brown sandy silt with traces of clay to 4 m; Brown loam to 5 m, Brown sandy silt with traces of clay to 7 m; Brown sandy gravel/cobble to end.
GW079746	401445	6424619	1997	11.00	-	-	-	-	Dark brown clay to 0.1 m; Dark brown clay with trace sand to 1.5 m; Volcanics/pyroclastics to 3 m; Basalt to end.
GW079747	401717	6426224	1996	7.00	-	-	-	-	Brown, clayey loam to 1 m; Brown clay to 2 m; Grey/Brown silty clay with traces of sand to 3 m; Grey/brown (15% fine sand) silty clay to 4 m, Grey/brown (5% fine sand) silty clay to 5 m; Silty clay as above, with highly weathered volcanic gravel to 6 m; Light brown fine grained sand to end.

Table BA1. Known registered bores in the vicinity of the Project (Continued)

Bore ID	Easting (AMG 56)	Northing (AMG 56)	Year of Construction	Hole Depth (m)	Elevation (mAHD)	Depth to Water (m)	Water Level (mAHD)	Max Yield (L/s)	Lithology
GW079748	401717	6426224	1996	10.00	-	-	-	-	Brown clayey loam to silty clay to 1 m; Brown silty clay/clay to 2 m; Grey brown, silty clay with traces of sand to 3 m; Silty clay, as above (15% fine sand) to 4 m; Silty clay, as above (5% fine sand) to 5 m; Silty clay, as above, with highly weathered volcanic gravel to 6 m; Light brown sand with traces of highly weathered volcanics to 7.2 m; Light brown volcanics (rhyolite) to end.
GW079749	401928	6426072	1996	10.00	-	-	-	-	Brown loam with some gravel to 1 m; Volcanics (rhyolite tuff) to 3 m; Light/orange volcanics to 8 m; Hark rock, rhyolite to end.
GW079750	402113	6425889	1996	10.50	-	-	-	-	Brown loam to 0.1 m; Volcanics (rhyolite/docite/tuff) to 1 m; Light grey chert (rhyolite?) to 2 m; Highly weathered tuff to 3 m; Volcanics, light to moderately weathered to end.
GW079751	402269	6425890	1996	9.50	-	-	-	-	Brown clay to 0.2 m; Brown gravelly clay to 1.0 m; Highly weathered basalt to end.
GW079752	401583	6426561	1996	9.50	-	-	-	-	Brown clayey loam to 1 m; Brown silty clay (15% fine sand) to 2 m; Brown sandy silt with traces of clay to 3 m; Brown sandy silt (5-10% clay) to 4 m; Brown sandy silt with traces of clay to end.
GW079753	401319	6426805	1996	7.50	-	-	-	-	Brown clayey loam to 1 m; Brown, grey sandstone to 3 m; Mottled brown, grey sandstone to 5 m; Slightly weathered sandstone to 6 m; Fresh grey, fossiliferous sandstone to end.
GW079754	401134	6426988	1996	12.00	-	-	-	-	Brown silty loam to 0.8 m; Dark brown, highly weathered sandstone to 3 m; Moderately weathered sandstone to 7 m; Grey, slightly weathered sandstone to 8 m; Fresh sandstone to end.
GW080339	400339	6427228	2002	-	-	-	-	-	-
GW080636	401453	6426839	2004	35.70	-	33.70	-	0.25	Top soil to 0.5 m; Brown weathered rock to 5 m; Grey weathered rock to 15 m; Rock to end.
GW080637	401520	6424997	2004	16.40	-	14.00	-	-	Top soil to 1 m; Silt stone to end.
GW080638	401416	6425106	2004	28.20	-	-	-	-	Top soil to 1 m; Siltstone with iron stone layers to end.

Table BA1. Known registered bores in the vicinity of the Project (Continued)

Bore ID	Easting (AMG 56)	Northing (AMG 56)	Year of Construction	Hole Depth (m)	Elevation (mAHD)	Depth to Water (m)	Water Level (mAHD)	Max Yield (L/s)	Lithology
GW080776	401342	6426938	2002	40.00	-	9.00	-	0.25	Top soil to 0.1 m; Tan sandy clay to 0.5 m; Tan weathered sandstone to 3 m; Creamy grey sandstone to 6 m; Soft grey sandstone to 13 m; Hard grey sandstone to 27 m; Water cut at 27.5 m; Hard grey sandstone to 38 m; Coal seam at 38.5 m; Hard grey sandstone to end.
GW080777	401522	6426872	2002	40.00	-	22.00	-	1.00	Top soil to 0.1 m; Tan sandy clay to 0.5 m; Tan weathered sandstone to 3 m; Creamy grey sandstone to 6 m; Soft grey sandstone to 23 m; Hard grey sandstone to 33.8 m; Water cut at 34.2 m; Hard grey sandstone to end.
GW080778	401407	6426825	2002	36.50	-	18.00	-	0.75	Top soil to 0.1 m; Weathered brown and grey sandstone to 9 m; Creamy grey sandstone to 13 m; Dark grey sandstone to 14 m; Coal seam to 14.5 m; Grey sandstone to 18 m; Light great sandstone to 23.6 m; Water cut at 24.6 m; Hard grey sandstone to end.
GW080779	401537	6426751	2002	60.00	-	40.00	-	4.00	Top soil to 0.05 m; Sandy brown clay to 5 m; Weathered orange sandstone to 6 m; Hard grey sandstone to 15 m; Moist grey sandstone to 17 m; Hard grey sandstone to 53.6 m; Water cut at 54.3 m; Hard grey sandstone to end.
GW080780	401559	6426842	2002	40.00	-	22.00	-	0.30	Top soil to 0.1 m; Brown sandy clay to 0.3 m; Weathered sandstone to 15 m; Hard grey sandstone to 30 m; Water cut at 30.3 m; Hard grey sandstone to end.
GW080781	401396	6426717	2002	58.00	-	25.00	-	0.35	Top soil to 0.05 m; Brown clay to 1 m; Mud stone to 7 m; Orange sandstone to 8 m; Shale to 14 m; Hard grey shale to 17 m; Coal seam to 17.5 m; Shale to 19 m; Grey sandstone to 36 m; Coal seam to 36.8 m; Soft grey shale to 50 m; Hard grey sandstone to 53 m; Water cut at 53.5 m; Hard grey sandstone to end.
GW200048	401589	6425668	1996	6.50	-	5.72	-	-	Dark brown sandy loam to 1 m; Brown sandy loam to 2 m; Brown sandy silt, trace of clay (5%) to 4 m; Brown, moist loam to 5 m; Brown sandy silty, trace of clay (5%) to end.
GW200049	401595	6425329	1996	7.00	-	4.90	-	-	Brown loam (10% rock gravel) to 0.1 m; Volcanics to 1 m; Moderate-slightly weathered volcanics to 2 m; Slightly weathered hard rock to 5 m; High weathered rock (tuff) to end.

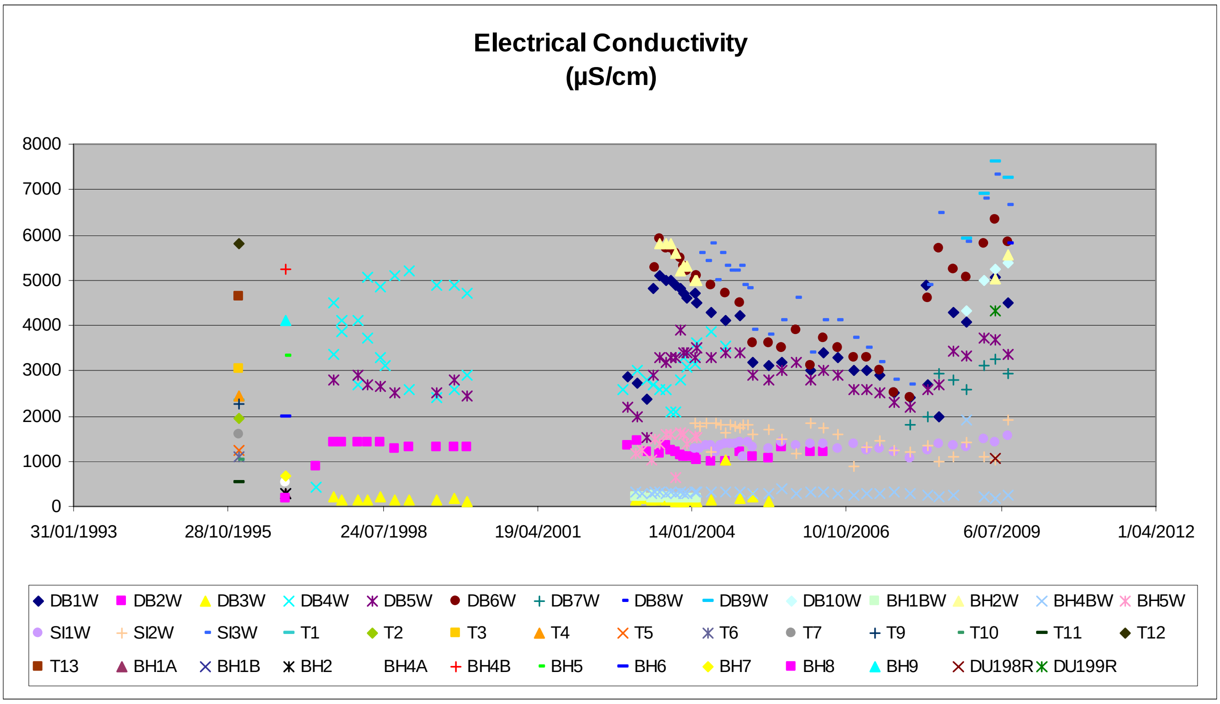
Table BA1. Known registered bores in the vicinity of the Project (Continued)

Bore ID	Easting (AMG 56)	Northing (AMG 56)	Year of Construction	Hole Depth (m)	Elevation (mAHD)	Depth to Water (m)	Water Level (mAHD)	Max Yield (L/s)	Lithology
GW200244	402195	6425490	2002	40.00	-	9.00	-	0.25	Topsoil to 0.1 m; Clay (sandy tan) to 0.5 m; Sandstone (weathered tan) to 3 m; Sandstone (creamy grey) to 6 m; Sandstone (soft grey) to 13 m; Sandstone (hard grey) to 27 m; Water cut at 27.5 m; Sandstone (hard grey) to 38 m; Coal seam to 38.5 m; Sandstone (hard grey) to end.
GW079619	401444	6426228	-	60.00	-	-	-	-	-

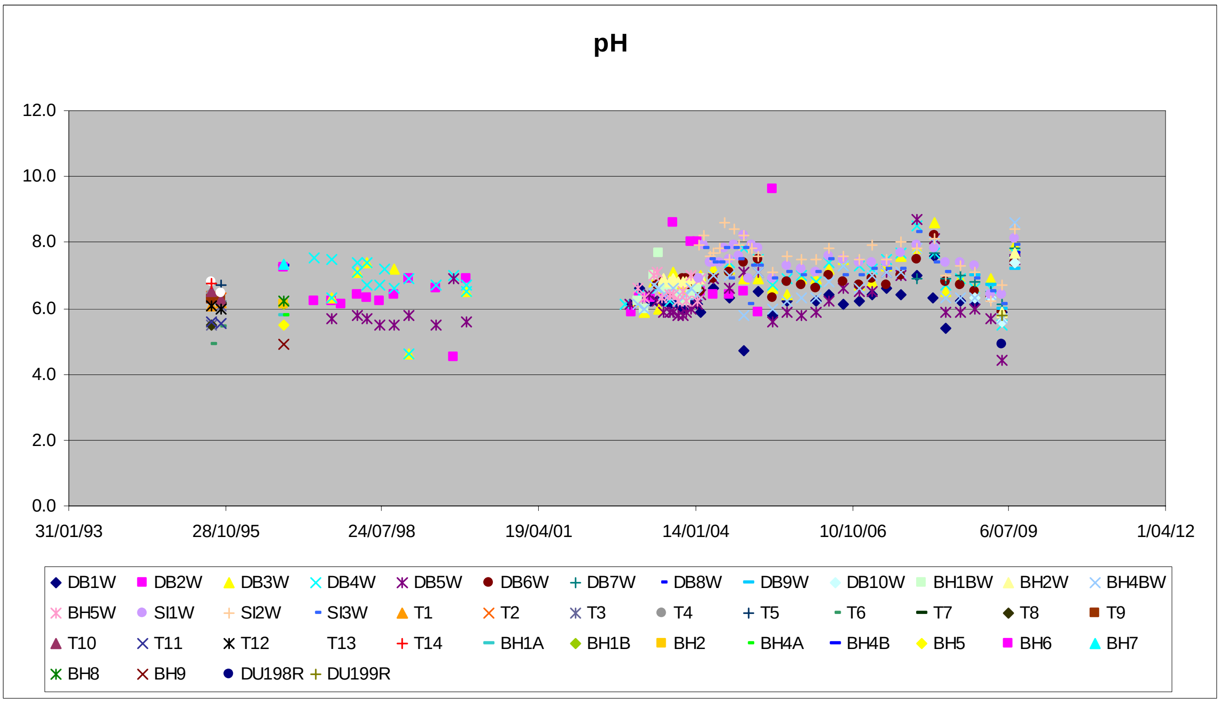
m = metres.
mAHD = metres Australian Height Datum.
L/s = litres per second.

ATTACHMENT BB

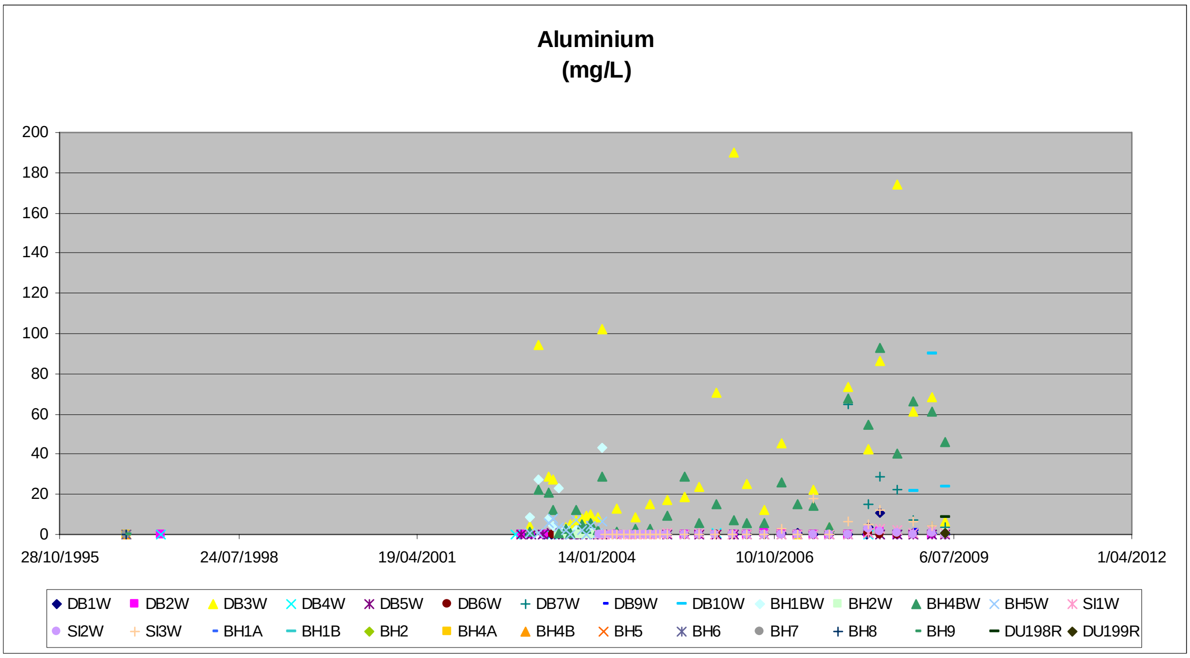
Groundwater Quality Monitoring Results



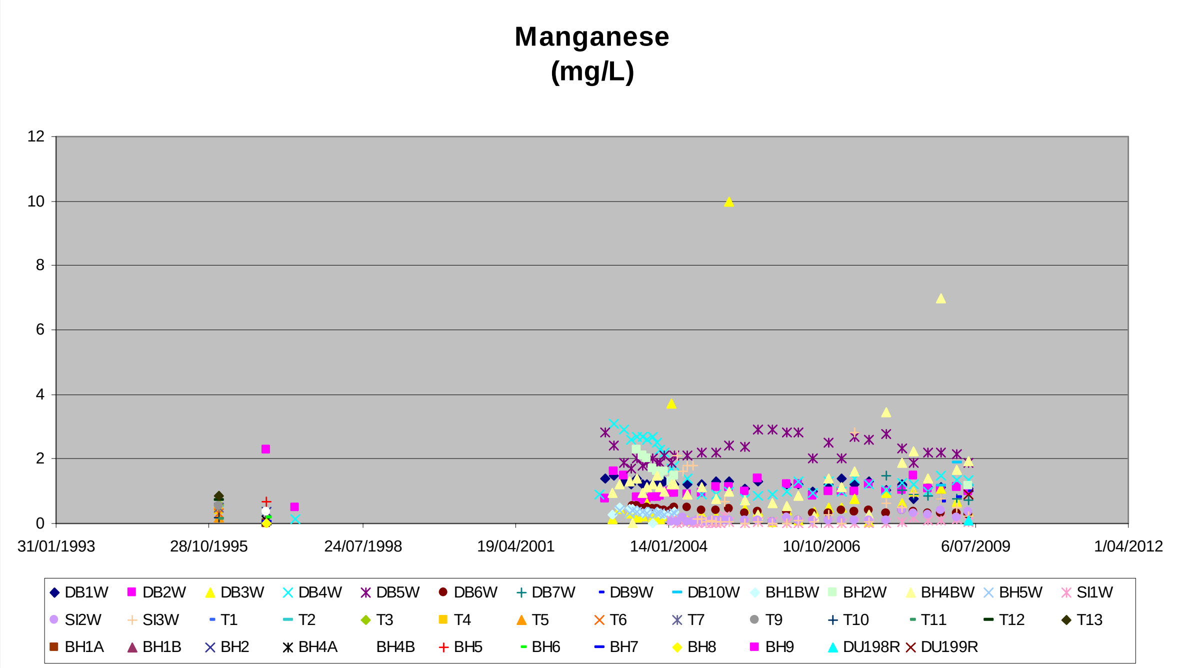
Attachment BB1 Observed Electrical Conductivity – Duralie Coal Mine.



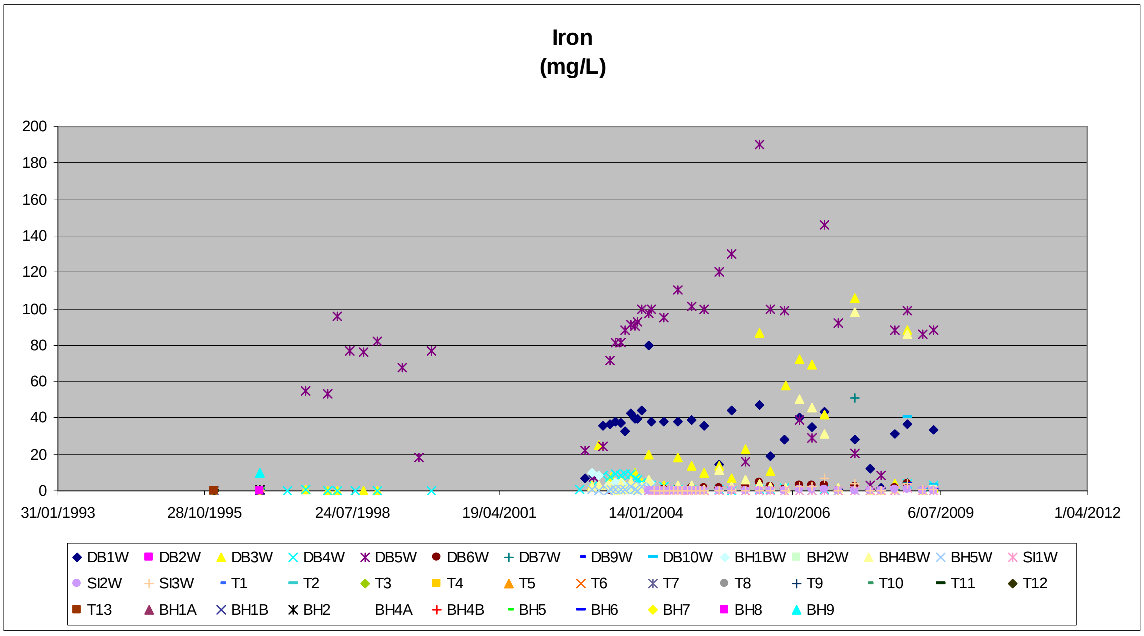
Attachment BB2 Observed pH – Duralie Coal Mine.



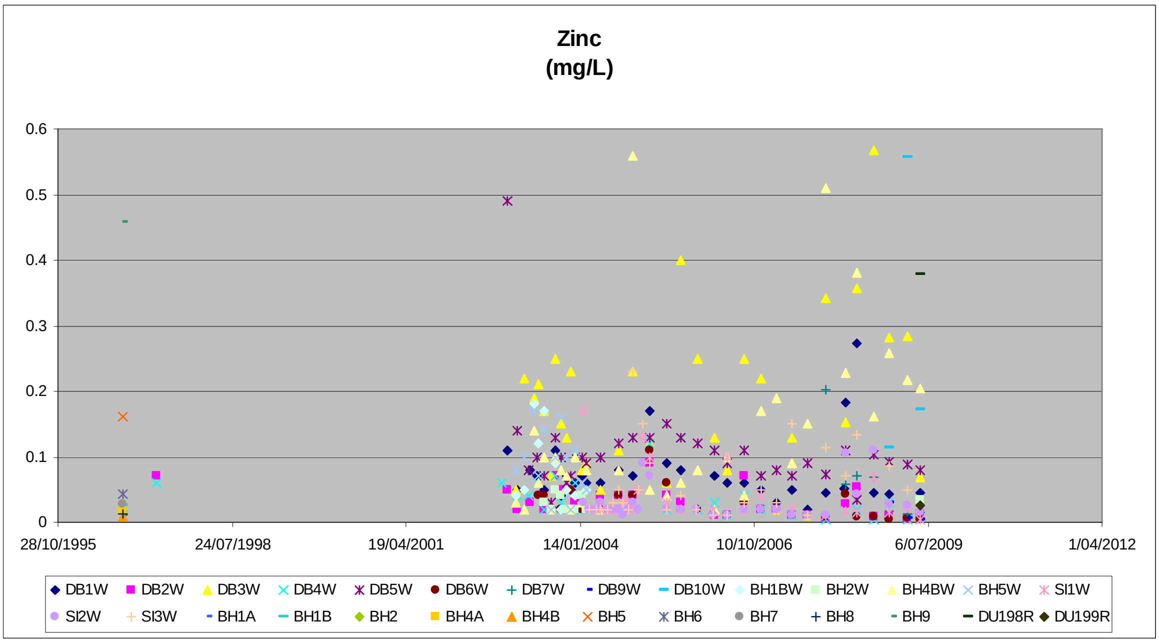
Attachment BB3 **Observed Aluminium Concentrations – Duralie Coal Mine.**



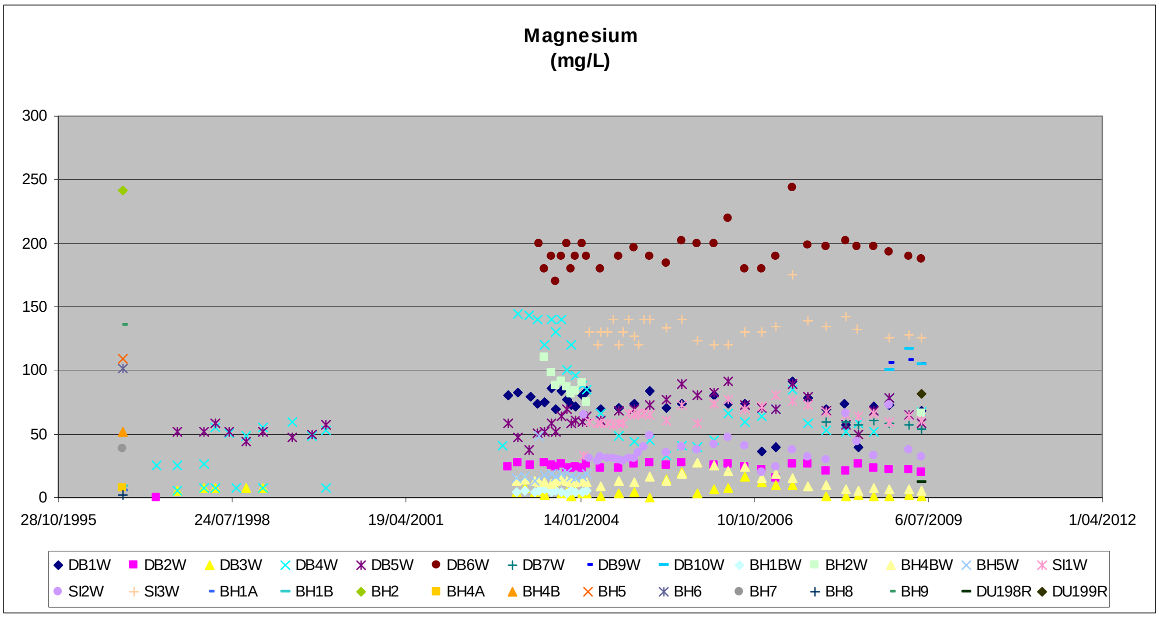
Attachment BB4 **Observed Manganese Concentrations – Duralie Coal Mine.**



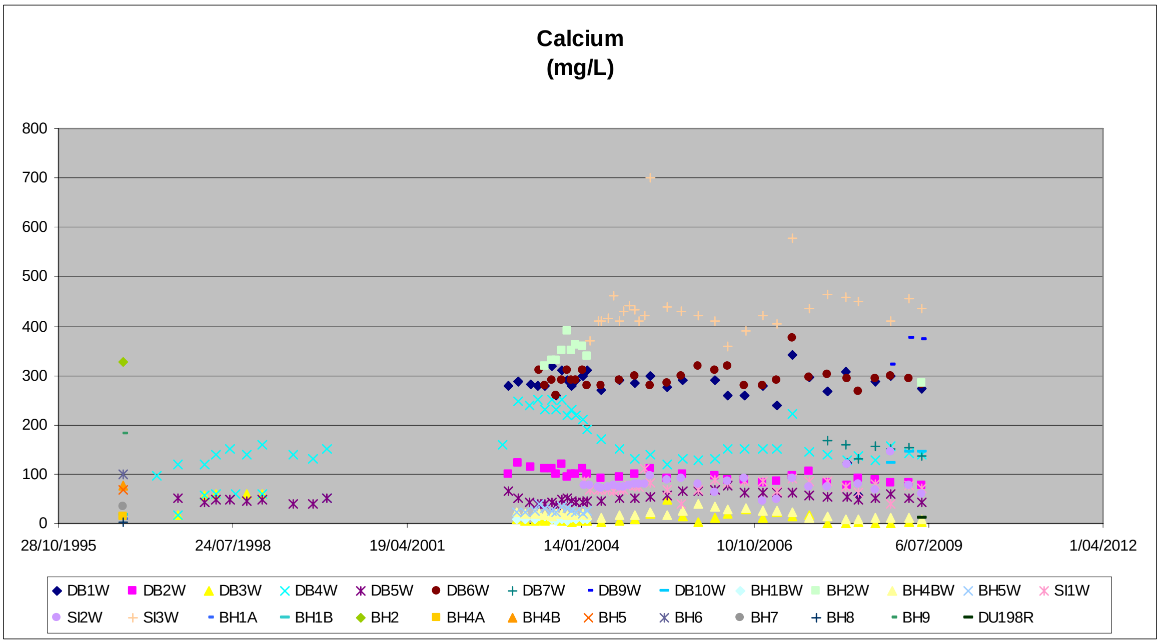
Attachment BB5 Observed Dissolved Iron Concentrations – Duralie Coal Mine.



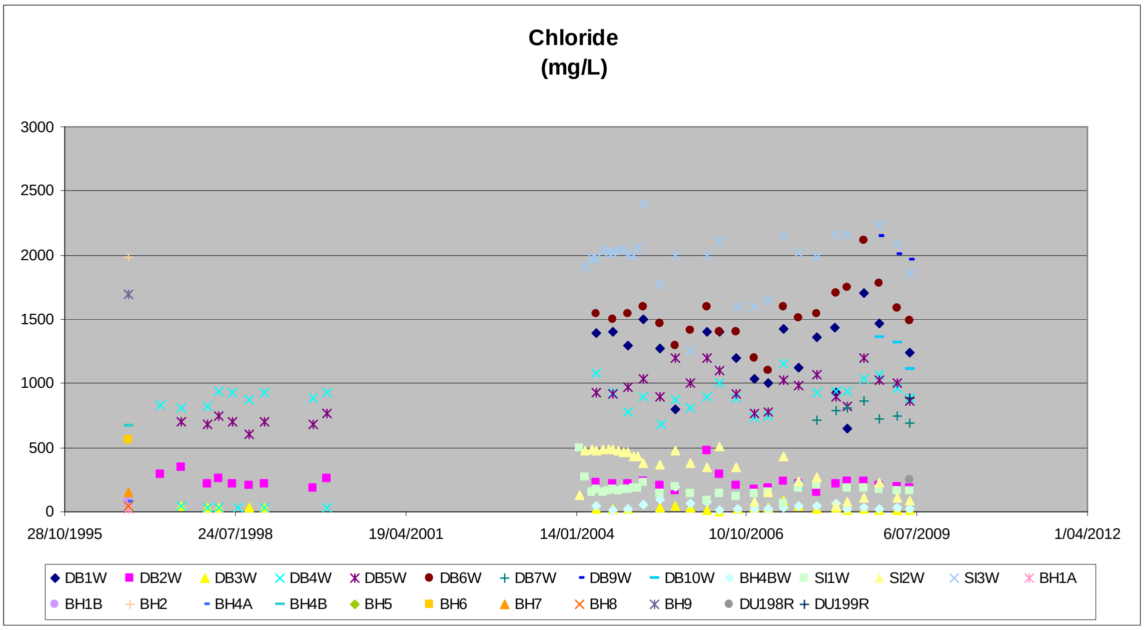
Attachment BB6 Observed Zinc Concentrations – Duralie Coal Mine.



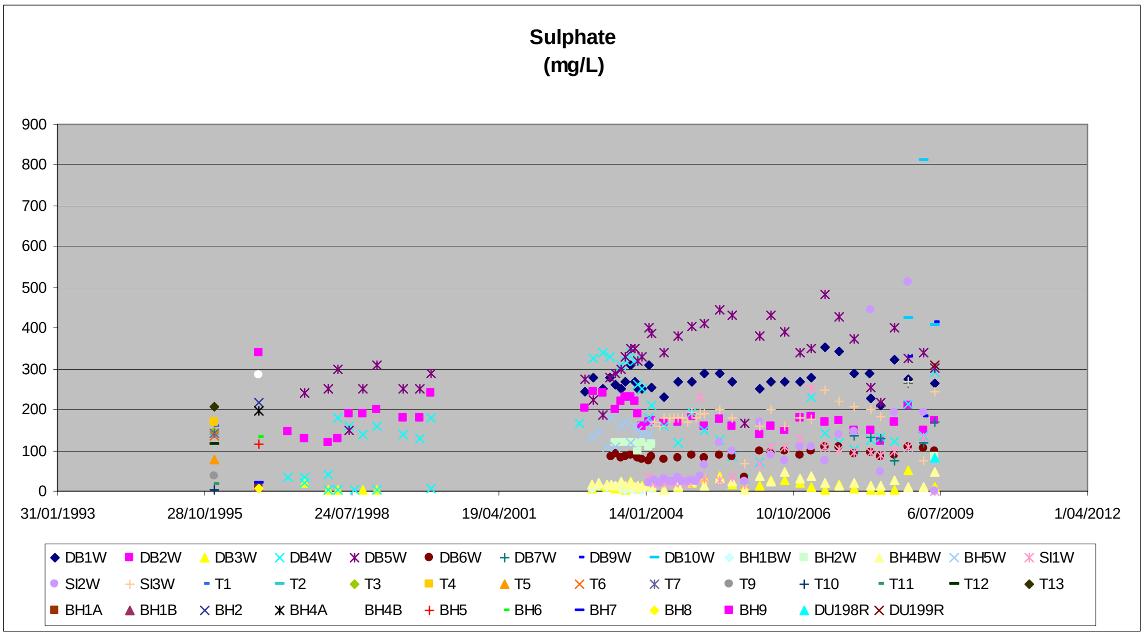
Attachment BB7 Observed Magnesium Concentrations – Duralie Coal Mine.



Attachment BB8 Observed Calcium Concentrations – Duralie Coal Mine.



Attachment BB9 Observed Chloride Concentrations – Duralie Coal Mine.



Attachment BB10 Observed Sulphate Concentrations – Duralie Coal Mine.

ATTACHMENT BC

Calibrated Hydraulic Conductivity Distributions

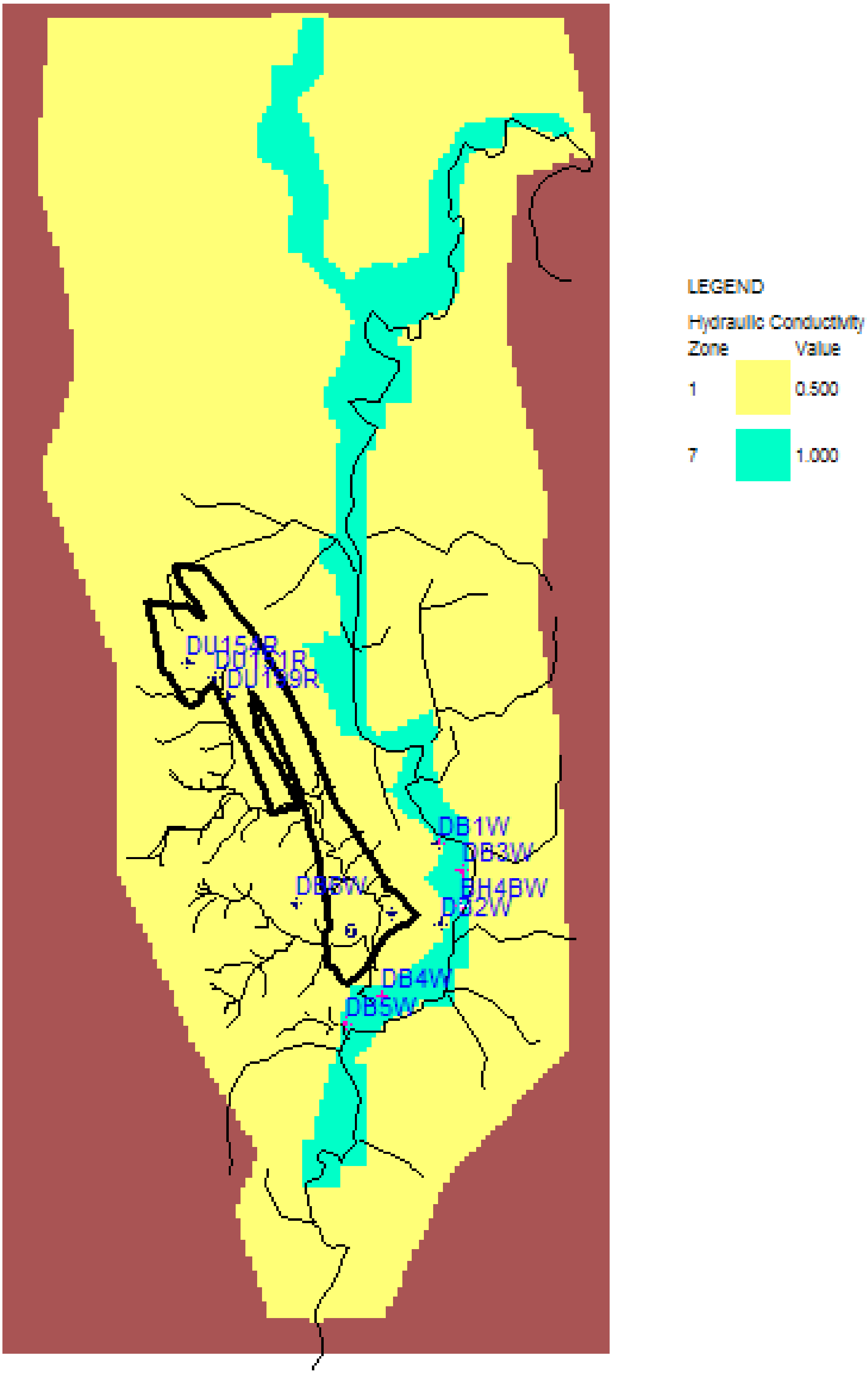


Figure BC-1. Hydraulic conductivity zones for model layer 1 [m/day]

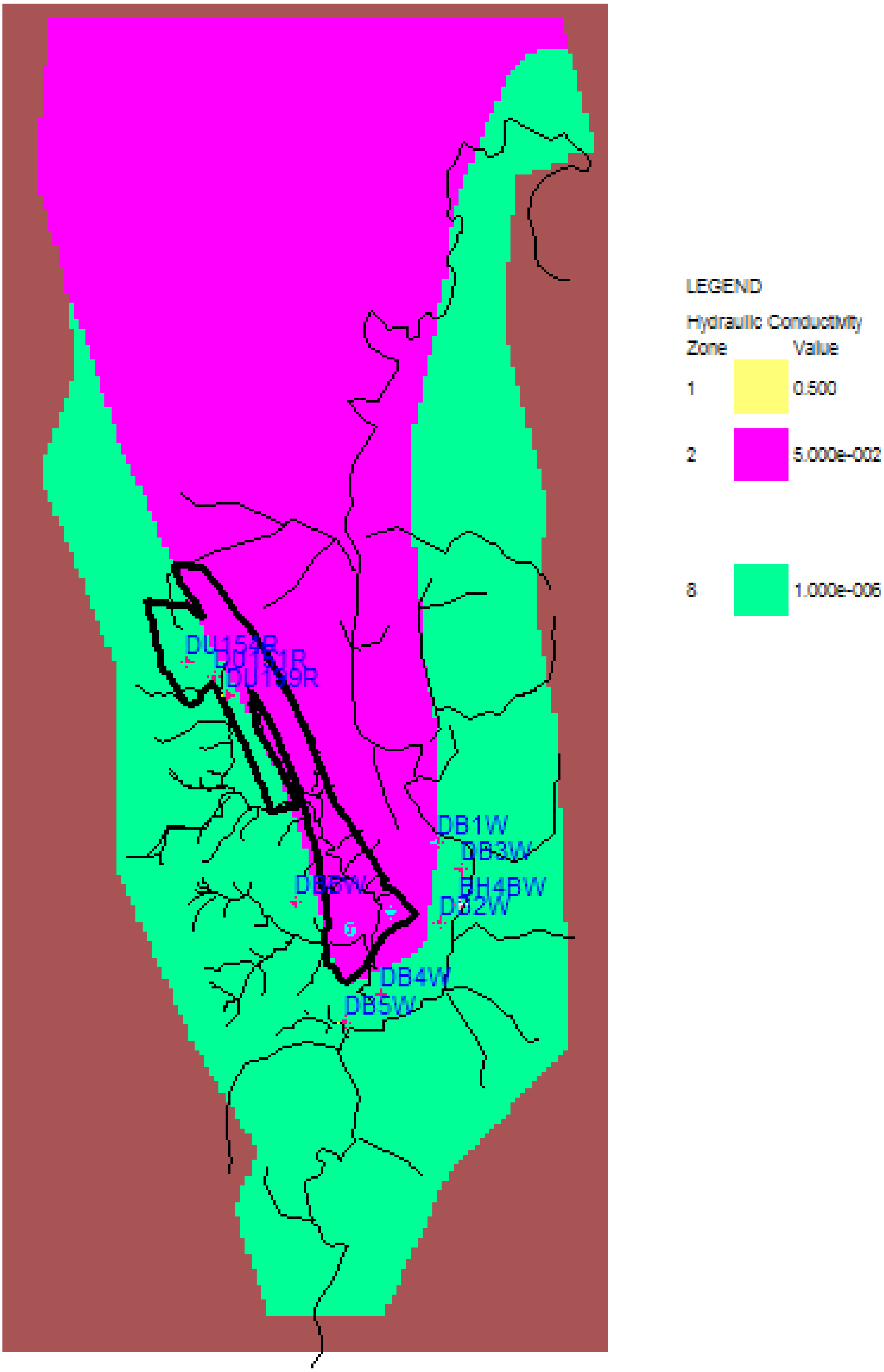


Figure BC-2. Hydraulic conductivity zones for model layer 2 [m/day]

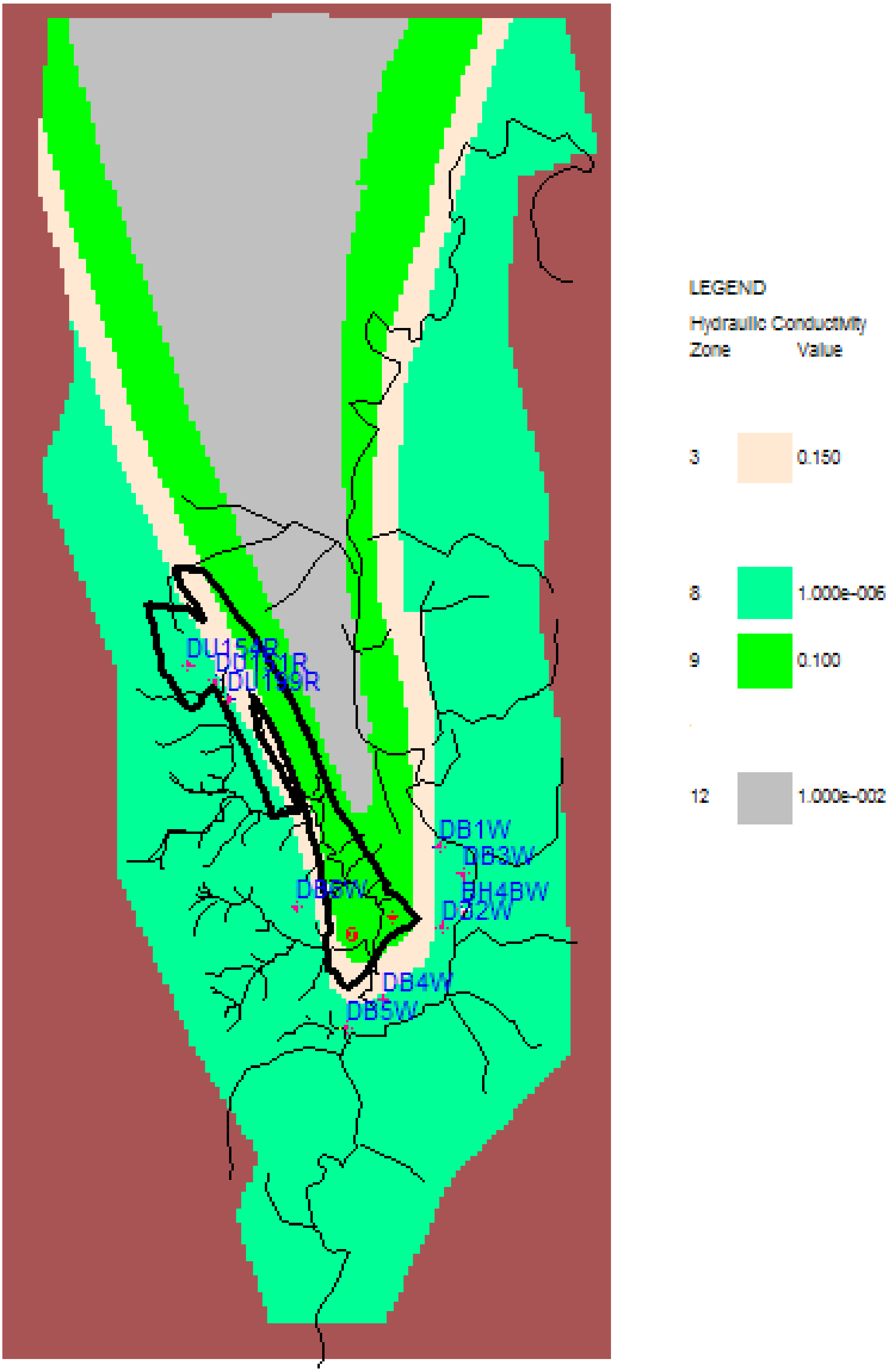


Figure BC-3. Hydraulic conductivity zones for model layer 3 [m/day]

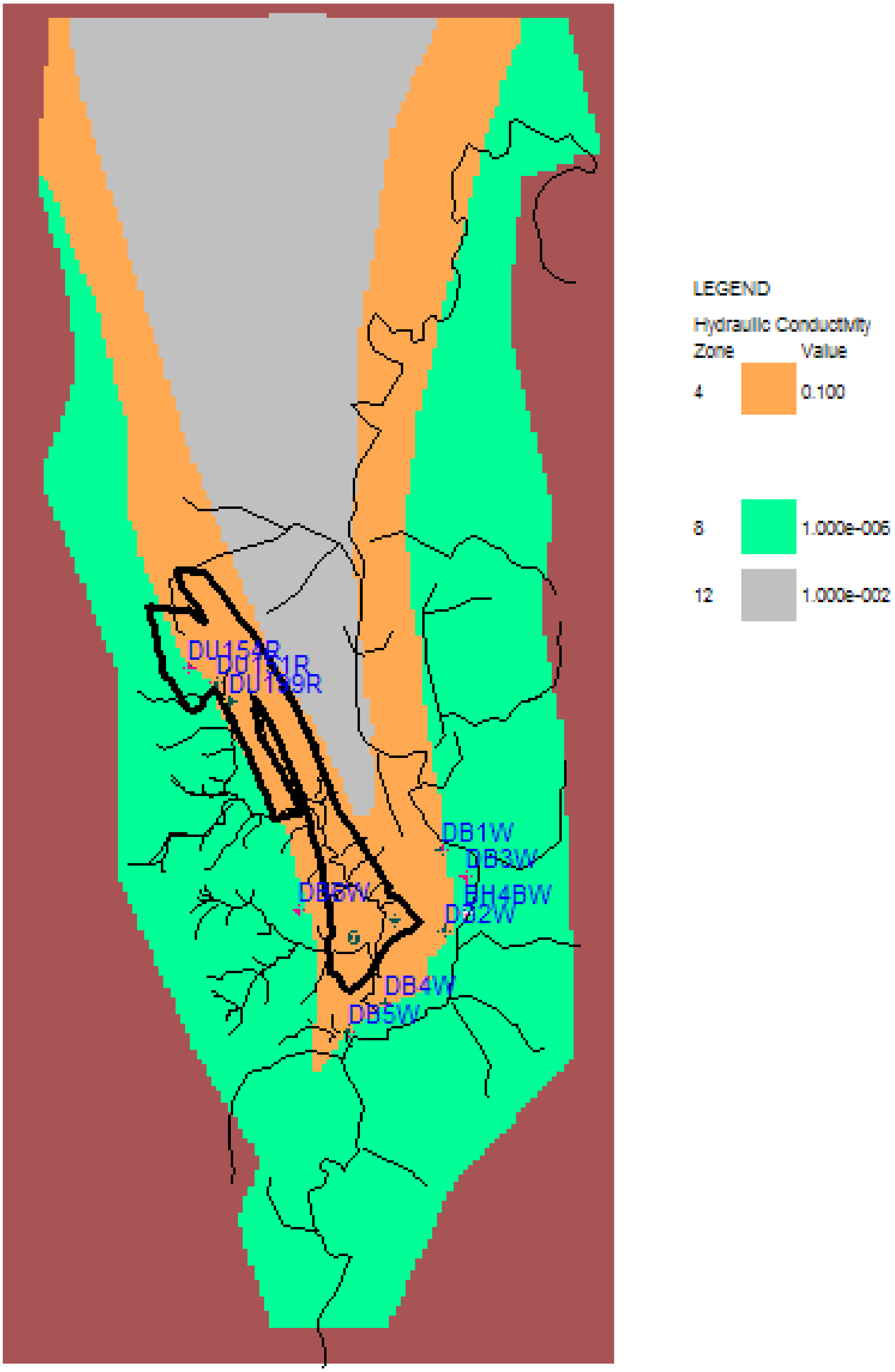


Figure BC-4. Hydraulic conductivity zones for model layer 4 [m/day]

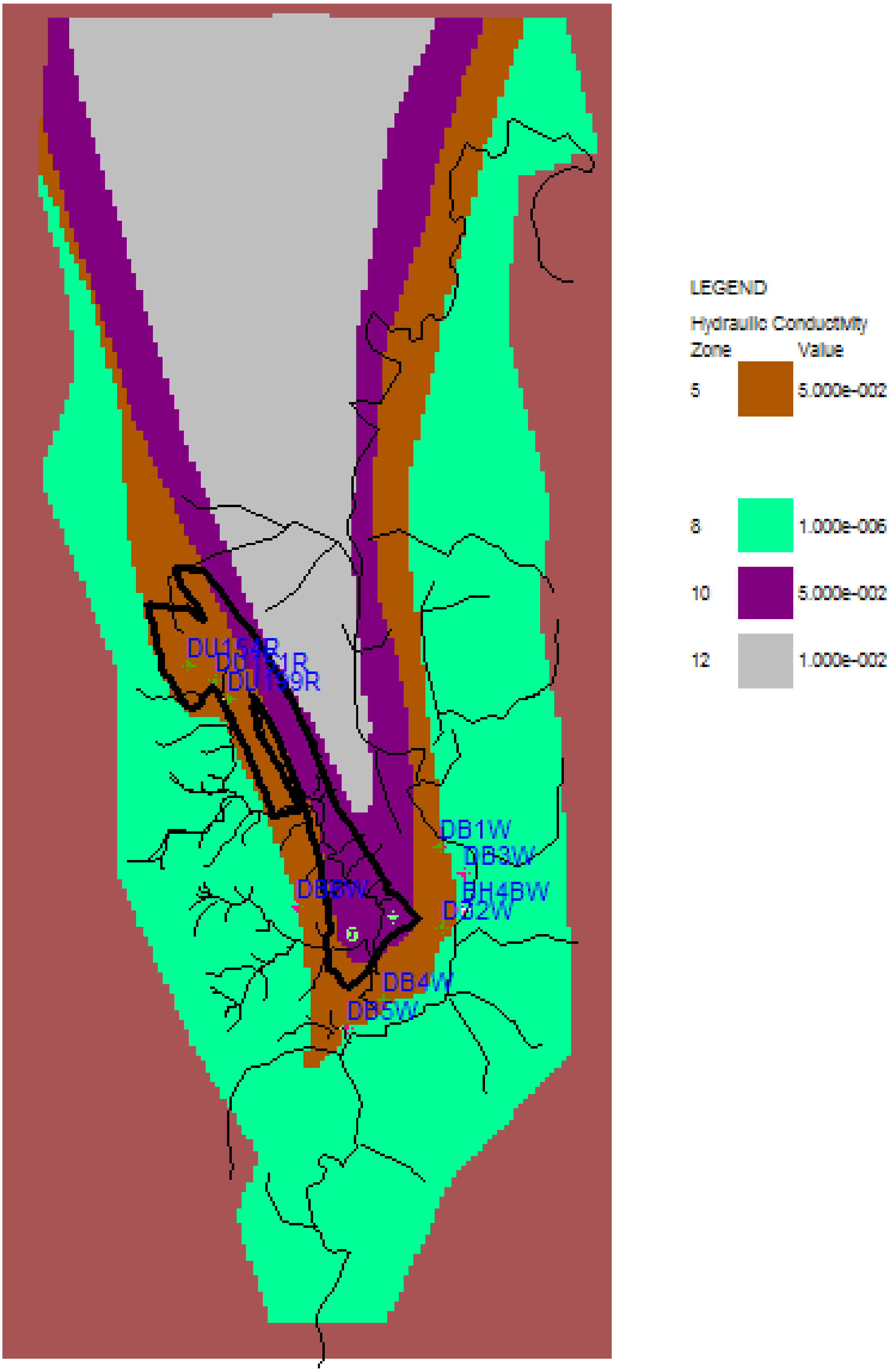


Figure BC-5. Hydraulic conductivity zones for model layer 5 [m/day]

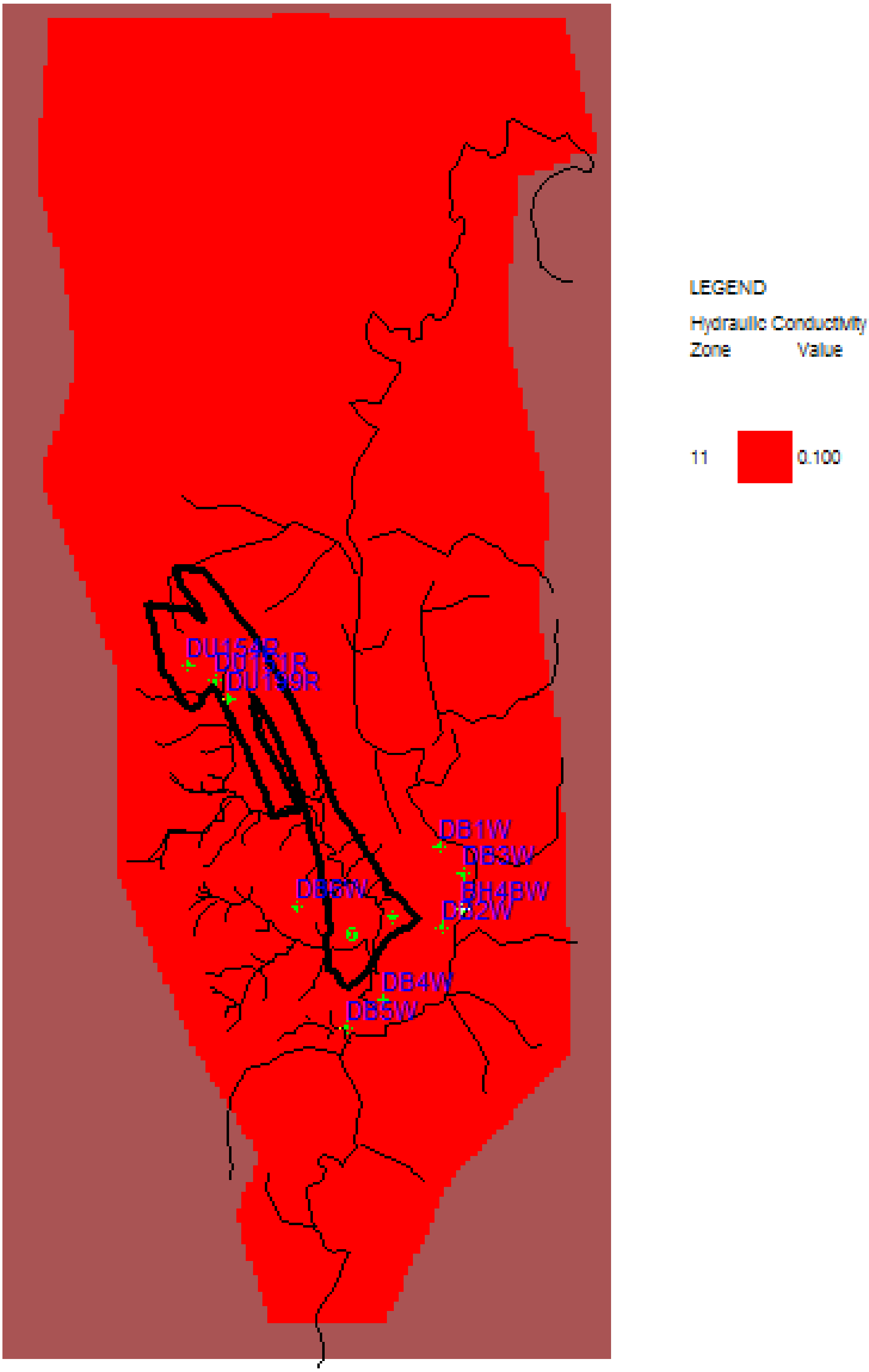


Figure BC-6. Hydraulic conductivity zones for model layer 6 [m/day]

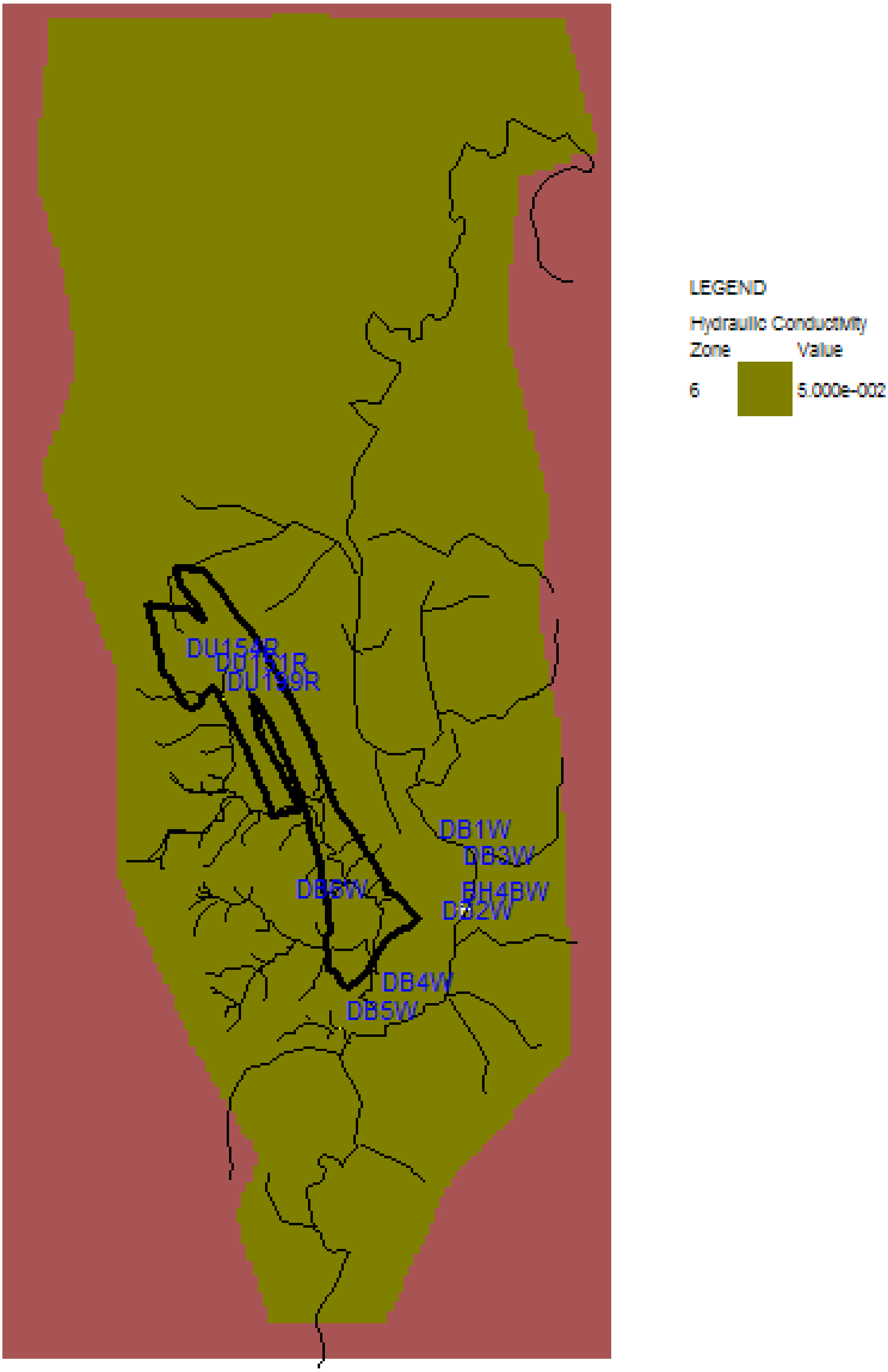


Figure BC-7. Hydraulic conductivity zones for model layer 7 [m/day]