Tropicana Gold Project

Water Supply Area Investigation

Tropicana Joint Venture

Anglogold Ashanti Australia Ltd &
Independence Group NL

penningtonscott
securing your water future

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EXECUTIVE SUMMARY

The Tropicana Joint Venture, comprising AngloGold Ashanti Australia Limited (70%) and Independence Group NL (30%) is preparing a Public Environmental Review (PER) for its proposed Tropicana Gold Project (TGP) located on the western edge of the Great Victoria Desert in Western Australia. Process water supply is a key factor critical to the success of the TGP, which requires up to 14 ML/day, ideally having salinity less than 100,000 mg/L, primarily for use in the carbon in leach (CIL) processing circuit, the generation of potable water and dust suppression.

In the scoping phase of the TGP, three targets were identified within a 150 km radius of the Operational Area that had the potential to fulfil these requirements, being:

- Cenozoic palaeochannel deposits infilling the Lake Rason drainage valley, located 40 to 80km northwest of the Operational Area;
- possible sandstone aquifers located within the Minigwal Trough area of the Officer Basin, immediately to the south of Lake Rason, 40 to 60km northwest of the Operational Area; and
- dolomitic sandstone aquifers identified in diamond hole N1-1 around Neale Junction, 115km northeast of the Operational Area, believed to be part of the Officer Basin sequence.

Since the cost of water pipelines and power transmission are significant, these targets were prioritised according to their proximity to the Operational Area. The Lake Rason palaeochannel deposits were discounted after preliminary drilling and airborne survey results suggested they lacked the aquifer storage and were too hypersaline to meet the TGP requirements. The exploration program was thus re-focused on defining the potential of the sandstone aquifers in the Minigwal Trough, referred to herein as the Water Supply Area.

Water investigations in the Water Supply Area were conducted between October 2007 and September 2008 and included:

- Acquisition of 2306 line km of airborne TDEM using the RepTEM system;
- Drilling of nine (9) reverse circulation exploratory holes of 230m depth to define the geometry of the sandstone aquifers;
- Drilling and hydraulic testing of eight (8) mud rotary test production water bores and three (3) observation water bores, including a diamond cored stratigraphic hole, to between 250 and 385m depth;
- Hydrochemical analysis of groundwater samples taken from each bore; and
- Numerical simulation of the borefield development and impacts.

The investigations revealed that the stratigraphy in the Water Supply Area comprises Paterson Formation (a Permian fluvial glacial sequence) unconformably overlying a Neo Proterozoic marginal marine sandstone-shale succession of the Officer Basin. The Paterson Formation, while exposed to seasonal rainfall recharge, is relatively permeable and any groundwater recharge drains across the contact with the Officer Basin into Lake Rason, leaving the sediments mostly unsaturated.

Although the underlying Officer Basin sediments receive almost negligible recharge, sandstone horizon within the succession represent a significant stored water resource. In particular, the Officer Basin succession has a 25 km wide sub-regional downwarp structure which occurs beneath Lake Rason and extends 60 km southeast towards the Operational Area. The structure contains a fine grained quartz sandstone with thickness of 120m, which is semi-confined beneath shale. Several test production bores were developed in the sandstone with yields of between 0.3 and 0.5 ML/day.

Although the sandstone has relatively poor transmissivity (measured at between 4 to 14 m^2/day) and low specific storage (estimated between $1x10^{-6}$ to $5x10^{-5}$), it nonetheless represents a considerable stored water resource with a water quality within TGP's requirements, with up to 200m of available drawdown in the deeper parts of the down warp.

A FEFLOW numerical groundwater model of the aquifer was developed to simulate the feasibility of abstracting the TGP water requirements from the sandstone. Model results indicate that:

- The model outcome is most sensitive to the specific storage parameter, for which a field tested value could not readily tested. Nonetheless, sensitivity simulations were conducted with expected and worst case values;
- A borefield with 40 bores in the deeper areas of the sandstone aquifer can sustain the TGP's requirements over a 15 year period;
- 100% of the groundwater abstracted over the life of the TGP will come from aquifer storage in the sandstone; and
- Depressurisation in the sandstone due to pumping will spread up to 5 km from the borefield over the life of the TGP, but will not reach the Lake Rason edge.

An appraisal of the potential environmental and social issues arising from the borefield development and operation indicates that:

- There are no other groundwater users within 80 kilometres of the Water Supply Area. Since borefield depressurisation will not extend beyond 5 km from the borefield, the TGP will not adversely impact other water users;
- The hydrology of Lake Rason is overwhelmingly driven by seasonal rainfall accessions and throughflows in the overlying Paterson Fm. The sandstone is separated from the lake by a shale layer. The model results indicate that depressurisation in the sandstone will not reach the edge of Lake Rason. However, even in the unlikely event that it does, the impact on the hydrology of the lake and any lake ecosystems would be negligible; and
- The deep, confined aquifer is isolated from the surface by a shale aquitard, is hypersaline groundwater quality (more than 40,000 mg/L), has tight interstitial pore spaces (less than 45 micron) and is not conducive to stygofauna. Sampling of a number of test bores has not identified the presence of any stygofauna.

Water investigations to date indicate that, while the permeability of the sandstone in the Water Supply Area may be poor relative to other basin aquifers in Western Australia, the aquifer is sufficient to meet the TGP's water requirements without causing unacceptable environmental or social impacts. Indicative borefield design would include 40 production bores drilled to 350m, located 40 to 60km northwest of the Operational Area.

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1. BACKGROUND

The Tropicana Joint Venture, comprising AngloGold Ashanti Australia Limited (70%) and Independence Group NL (30%), has interests in the Tropicana / Havana deposits located on the western edge of the Great Victoria Desert in Western Australia (**Figure 1-1**). In 2007 the joint venture commenced a Prefeasibility Study investigating the potential establishment of the Tropicana Gold Project (TGP) and in 2008 commenced working through the Western Australian and Federal Government assessment processes.

The TGP is comprised of:

- an Operational Area - This area contains the mine; a CIL processing plant with a throughput of up to 7 mtpa; an aerodrome; a village and other associated infrastructure;
- a Water Supply Area – a sandstone aquifer the Minigwal Trough of the Officer Basin 40 to 60 km northwest of the Operational Area; and
- an Infrastructure Corridors - Two options are under consideration (Pinjin and Tropicana - Transline options).

The TGP will require water for a variety of uses, including potable, road and plant construction, raw process water and dust suppression. **Table 1.1** summarises the potential water resources available to meet TGP water requirements.

Table 1.1 Potential TGP Water Resources

Groundwater Source	Volume ML/day	Quality (mg/L TDS)	Intended Use
Fractured rock aquifer at Tropicana	2	<40,000	Construction water
Officer Basin sandstone (Minigwal Trough)	<14	<100,000	Primary process water source
Officer Basin sandstone (Neale Junction)	<14	<100,000	Contingency target for process water
Fractured rock aquifer at Tropicana	1	<40,000	Primary Camp & Elution Circuit (RO)
Officer Basin (Minigwal Trough at TWB023)	1	<45,000	Alternate Camp & Elution Circuit (RO)

Pennington Scott (water consultants) was appointed to project manager for the water supply investigations for the TJV.

This report summarises the technical and environmental feasibility of developing the TGP process water from the Water Supply Area in the Minigwal Trough area of the Officer Basin.

The construction water supply will be derived from dewatering bores that are to be developed for the advanced dewatering of the Tropicana and Havana Pits. These supplies are described in a separate Groundwater Assessment of the Operational Area.

It is also envisaged that water for processing, and domestic supply will, if available, be obtained from fractured rock bores in the Operational Area and treated through a reverse osmosis plant. Otherwise lower salinity groundwater in the Minigwal Trough at TWB023 will be piped back separately for treatment through a reverse osmosis plant.

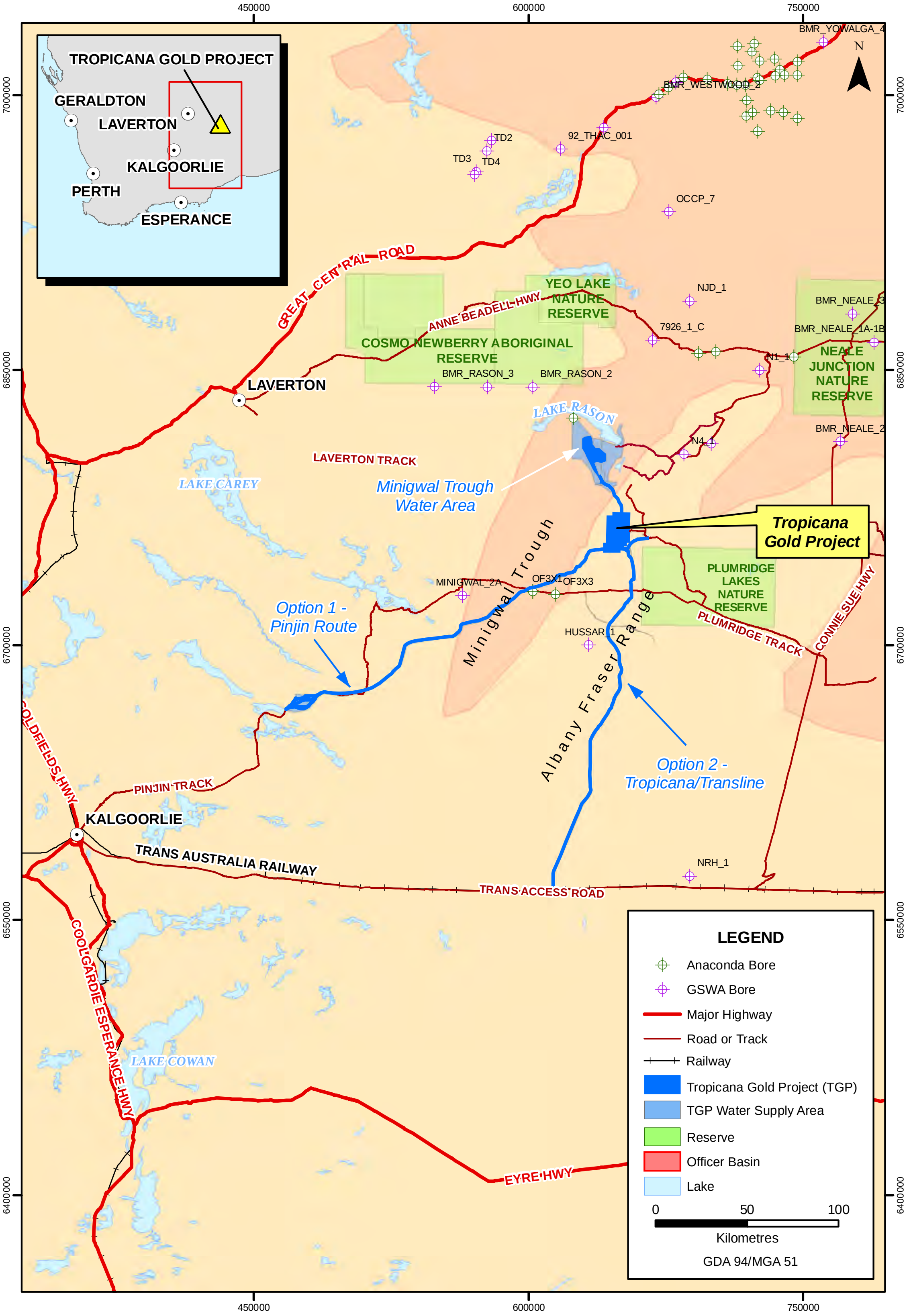


Figure 1-1 Locality plan

1.1 Alternative Process Water Sources

The TGP requires up to 14 ML/d of process water having salinity ideally less than 100,000 mg/L TDS. Higher salinities up to 250,000 mg/L TDS could be acceptable, although plant operating costs significantly increase with higher salinities due to higher reagent requirements.

The arid desert climate in the region is not suitable for development of reliable surface water resources and therefore the groundwater is considered to be the only viable water resource for the TGP's process water requirements. The initial scoping study for the TGP indentified three potential water resource targets within a 150 km radius of the Operational Area as being:

- Cenozoic palaeochannel deposits infilling the Lake Rason drainage valley, located 40 to 80km northwest of the Operational Area;
- Potential sandstone aquifers located within the Minigwal Trough area of the Officer Basin, immediately to the south of Lake Rason, 40 to 60km northwest of the Operational Area; and
- A dolomitic sandstone aquifer identified in diamond hole N1-1 around Neale Junction, 115km northeast of the Operational Area, believed to be part of the Officer Basin sequence.

The unit cost per kilometre for water pipelines and power transmission are significant and over several tens of kilometres can become the highest capital expense in the entire water supply infrastructure. For this reason the water investigations were prioritised to explore the nearest targets to the Operational Area first, these being the Minigwal Trough and the Lake Rason palaeochannel deposits. The Neale Junction area was only to be explored in the event that the first two targets proved to be economically unviable.

In terms of water resource potential, palaeochannel aquifers can have a significant disadvantage over sedimentary basin type aquifers because the amount of groundwater they can hold is limited by their narrow channel geometry. After conducting preliminary RC drilling and a regional airborne geophysical survey, it was apparent that the Rason palaeochannel deposits were unlikely to be a viable water resource because:

- The channel deposits are relatively shallow compared with other goldfields palaeochannels, being less than 70 m thick, thereby limiting their aquifer storage potential;
- The channel stratigraphy appears to lack evidence of a permeable basal sand and gravel that could be targeted to underdrain the low permeability silty valley infill deposits; and
- The groundwater in the Rason palaeochannel deposits is mostly hypersaline, with salinities up to 270,000 mg/L TDS.

The water investigations accordingly focused on the potential of a sandstone aquifer in the Minigwal Trough of the Officer Basin, referred to hereinafter as the **Water Supply Area**. The target continued to develop into a regionally expansive and thick resource with suitable water quality less than 100,000 mg/L TDS, albeit that the bore yields are relatively modest at around 0.35 to 0.5 ML/day per bore.

Given the favourable results from the Water Supply Area, investigation of the contingency target in the Neale Junction area was not necessary.

2. HYDROGEOLOGY

2.1 Achaean Basement

Archaean granite-greenstone rock (~3,000 to 2,500 Ma) forms the basement to the basins and the Frazer Range, which in turn hosts the Tropicana and Havana deposits. Although the crystalline basement contains virtually non-existent primary aquifer permeability and storage characteristics, groundwater exists in secondary fracture defects such as faults, shears and joints.

Jointed aquifers are also known as “saprolite” aquifers; a term that is loosely applied to describe the zone of joint oxidation in a weathering profile. The most productive zone of the saprolite typically tends to be struck immediately below the zone of strong oxidation (soft clayey weathering) in the fresh rock. Fractures in the fresh rock below 90m depth tend to be very tight and hold virtually no water.

Yields from saprolite aquifers tend to be highly variable, but are generally between 20 and 100 KL/day. Bores located along fault and shear zones can occasionally produce very high instantaneous yields of up to 1,000 KL/day. However, these yield estimates can be misleading as the bores would be rapidly dewatered if pumped at these rates due to the limited aquifer storage.

Notwithstanding the yield constraints, saprolite aquifers tend to hold the best groundwater quality due to their exposure to rainfall accessions. However, as the groundwater quality tends to be stratified with poorer quality brackish to saline water at depth, over abstraction can cause the water quality in a saprolite aquifer to deteriorate over time.

In terms of the TGP, the saprolite on the Frazer Range may be a useful target for exploration water, camp potable water and/ or construction water supplies, but it could not provide or sustain the TGP’s process and raw water requirements.

2.2 Officer Basin

The Officer Basin comprises an inter-cratonic downwarp structure that extends 1500 km from the south-eastern flank of the Pilbara Craton to the central west of South Australia, covering an area of over 350 000km^2. The structure contains up to 12 000m of Proterozoic and Palaeozoic sedimentary and volcanic rocks. The Basin is bounded to the northeast by the Musgrave and Rudall Igneous Complexes and to the southwest by the granite-greenstone terrain of the Yilgarn Craton. The Earaheedy and Bangemall Basins bound the western limits and the overlying Eucla Basin defines the southern margin.

Deposition of the Officer Basin sedimentary sequence commenced in the Early Proterozoic (Meso- or Paleoproterozoic) (~1500 Ma) on the edge of the Achaean West Australian Shield, incorporating the Pilbara and Yilgarn Craton, within the Nabberu and Bangemall basins. These older basin sequences were deposited contemporaneously with granitic and layered basic plutonism, effusive acid and basic volcanism, and granulite metamorphism that formed the Musgrave complex and the Albany-Fraser Province of the Yilgarn. By the Middle to Late Proterozoic the eastern edge of the West Australian Shield had become submerged beneath the Centralian Superbasin, a stable epicontinental sea about one fifth the size of the present Australian landmass. Over time the Superbasin developed into a series of large fault bounded troughs, the remnants of which are preserved as the Officer, Savoy, Amadeus, Ngalia, and Georgina basins.

Through the Middle to Late Proterozoic (NeoProterozoic) sedimentation in the Officer Basin comprised a mixture of sub-littoral and shallow marine deposits including sandstones, evaporites and oolitic stromatilitic carbonates. Mild tectonism associated with the Peterman Ranges orogeny in the Early Cambrian Period (550 Ma) resulted in the emergence and gentle folding of the Proterozoic basin sequence followed by faulting and erosion.

Sedimentation resumed during the Delamarian orogeny (500 Ma) with the extrusion of syn-tectonic sub-areal tholeiitic flood basalt flows (Table Hill Volcanics) and deposition within the Gunbarrel Basin. Sedimentation included shallow marine Devonian/Carboniferous grey to red coarse-grained cross-bedded sandstone with minor mudstone and conglomerate (Lennis Sandstone) overlying the basalt, which is in turn conformably overlain by sub-tidal deposits (Wanna Formation) similar to the Lennis Sandstone but with a greater abundance of arkose (quartzo-felspathic sand) and characterised by long amplitude wavy cross stratification.

This sequence is in turn overlain by a mixed glacial, fluvial-glacial and glacial-lacustrine sequence (Paterson Formation) deposited during several advances and retreats of the Gondwana continental ice sheet during the Late Carboniferous to Early Permian ice age (300 Ma) and outcrops extensively throughout the Officer basin.

Early Cretaceous shallow marine sediments were deposited in a short-lived marine transgression and regression over the southern portion of the Officer Basin comprising the Eucla Basin.

By the early Cenozoic Era, the warm and temperate climate was conducive to deep weathering, which resulted in the developed of an iron laterite duricrust over pallid and porcelainised (silicified) clay. High rainfall and runoff conditions eroded broad meandering river valleys which removed much of the Early Cretaceous rocks and redeposited the detritus in the Eucla Basin in the south and the Indian Ocean in the northwest.

By about 36 Ma a continental rift had developed between Australia and Antarctica and the two continents separated. As Antarctica drifted over the southern pole, the earth drifted into the latest glacial period. Although this latest Miocene glaciation has lasted 30 Ma, the two poles have only had permanent ice cover for the past 5 Ma. As Australia drifted north it has been shielded from the direct impacts of glaciation, however the Australian climate continues to be driven by Antarctic conditions. Whenever Antarctica reaches a glacial maxima the Southern Ocean cools, which reduces the atmospheric moisture that otherwise feeds the climate over southern Australia, creating arid conditions. As a result of current Antarctic glaciation the climate has become so arid that drainage systems have become filled with detritus derived from deflation of the surrounding exposed surfaces. The more recent sedimentary deposits include lacustrine and gypsum evaporite strata in playa and salinas, plus development of valley calcrete deposits.

Through the Cenozoic a veneer of residual surficial sand dunes derived from aeolian erosion and redeposition of the duricrust during the Pleistocene glacial maxima (22 Ka) has created the present day sandland terrain of the Great Victorian Desert. This sandland is characterised by spaced east-west longitudinal dunes, which may be tens of kilometres long by 2 to 20 m high. The dunes are interspersed with gently undulating laterite plains bounded by low mesas, buttes and pediments of resistive duricrust. Evidence of surface drainage patterns is largely absent, except close to the flanks of the duricrust escarpments where small ephemeral streams shed into the desert and disappear in the dunes. Major buried palaeodrainage systems are apparent as regional depressions in satellite images and drain south toward the Eucla basin.

2.3 Minigwal Trough

The Operational Area is situated on the south-western margin of the Gunbarrel and Officer Basins and overlies crystalline basement rocks of the Yilgarn Craton and Albany-Fraser Orogen that have a SW – NE boundary running through the region. The extent of the Officer Basin and Gunbarrel Basin (Paterson Formation) in the south-western portion of the basins is shown in **Figure 2-2**. The TGP's exploration drilling for groundwater has been within the Minigwal Trough, which is an informal name given herein to describe a 300km long by 50km wide north-south sedimentary trough abutting the western margin of the Archean basement on the Fraser Range.

The Minigwal Trough corresponds to the Rason Regional Gravity Low described by Shevchenko (2002). It was formed and subsequently modified during several periods of tectonic faulting. The earliest tectonic activity possibly pre-dating formation of the Minigwal Trough was associated with formation of the Proterozoic Albany-Fraser Orogen, and although it did not directly lead to the development of the trough, zones of weakness from earlier tectonic features were later reactivated as faults/fractures or have been preferentially eroded – such as the Lake Rason drainage where it crosses the Fraser Range north of the Operational Area.

Development of the trough as a graben type structure probably commenced during the Mesoproterozoic and continued through to the Neoproterozoic. Faulting occurred predominantly along north-easterly oriented faults resulting from extensional forces, where faults would have been down-thrown to the east, and consequently the trough tends to deepen toward the eastern margin. A prominent fault down-thrown to the west marks the boundary of the trough against the Fraser Range, and is clearly seen on the magnetic image. This fault is also evident on TEM profiles (e.g. Line 3100), but is hidden where there is a thick cover of Paterson Formation.

Subsequent to formation and sedimentation within the Minigwal Trough, or possibly concurrent with the later stages of its development, was a period of tectonic compression from the south-east that resulted in faulting of both the Proterozoic sedimentary section and the underlying Yilgarn Craton (Shevchenko, 2002). East of Lake Yeo, gravity anomalies upon the Bouguer gravity image (**Figure 2-1**) trending northwest and up to 150 km long and 25 km wide are interpreted as strike-slip faults, and north-east elongated, narrow gravity anomalies are interpreted as thrust faults. This tectonic activity potentially caused the formation of a series of 'pull-apart' basins with intervening areas where the succession has been elevated.

Within the Water Supply Area, the eastern contact of the Minigwal Trough with the Archean rocks on the Fraser Range is evident on magnetic images, while the western margin of the trough is uncertain. Gravity data suggests a faulted NE-SW contact coincident with the western end of Lake Rason, which may form the western limit of the trough. **Figure 2-3** shows the Bouguer Gravity image in the Lake Rason area with the boundary of the Minigwal Trough, and including faults interpreted from gravity, magnetic and drilling data.

Gravity data in the Lake Rason area suggests that the Water Supply Area is bordered by NW-SE trending faults, with one located just north of Lake Rason and a southern fault extending SE from the western limit of Lake Rason. These faults are similar to those observed about NJD 1 (Shevchenko, 2002) and probably represent strike-slip faults with the northern block striking westward. An elongate northerly trending 'pull-apart' basin is developed between the strike-slip faults, which is evident on the gravity image and supported by drilling results.

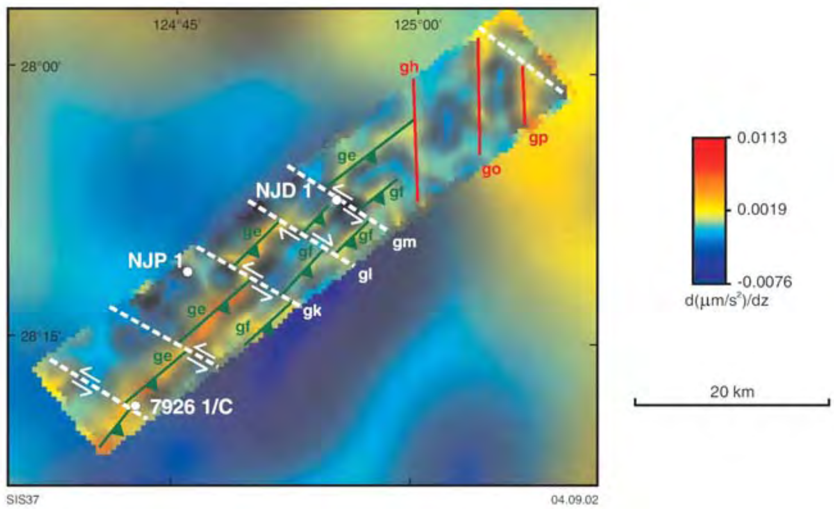


Figure 2-1: Gravity lineaments evident on first vertical derivative of Bouguer gravity image, south-western Officer Basin (after Shevchenko, 2002)

Northeast to northerly oriented thrust faults associated with the strike-slip faulting are probably present in the Lake Rason area. The sense of throw is east-side up. A significant fault is evident approximately 4 to 5 km west of the Fraser Range, and is evident from drilling data and subtle changes on gravity and magnetic images (the magnetic image becomes increasingly fuzzy with greater cover of sedimentary material, and can aid in the identification of faults cutting the basin). This fault separates Officer Basin sediments in the west from Mesoproterozoic sediments below the Paterson Formation on the eastern side. The magnetic image suggests that a couple of northerly oriented faults with east-side down throw are present within the western portion of the trough near Lake Rason. Within the trough other faults will be present that are not apparent with the existing gravity and magnetic imagery. Drilling data suggests that a fault occurs between TWB015 and TWB018, and between TWB017 and TWB023, and may represent the same northerly trending fault that is up-thrown on the eastern side. Extensive lineaments are apparent on topographic hill-shade images, although it is uncertain if these represent faults and what type of displacement they may have.

The thickness of the sedimentary succession within the Minigwal Trough has been evaluated from geophysical surveys and Western Mining Corporation (WMC) drill holes NJP1 and NJD1 to be 1200 to 1500 m (Shevchenko, 2002) at a distance of about 130 km N-NE of the Operational Area. Based on comparison of gravity data between the Lake Rason area and NJD 1, it is likely that at least 1000 m of sediments are present within the trough about Lake Rason. Much of the sedimentary succession will comprise Mesoproterozoic sediments, with a lesser cover of younger Officer Basin and Paterson Formation. Sediments within the southern portion of trough are separated from the main portion of the basins to the east by intervening outcrops of crystalline rocks belonging to the Yilgarn Craton and Albany-Fraser Orogen.

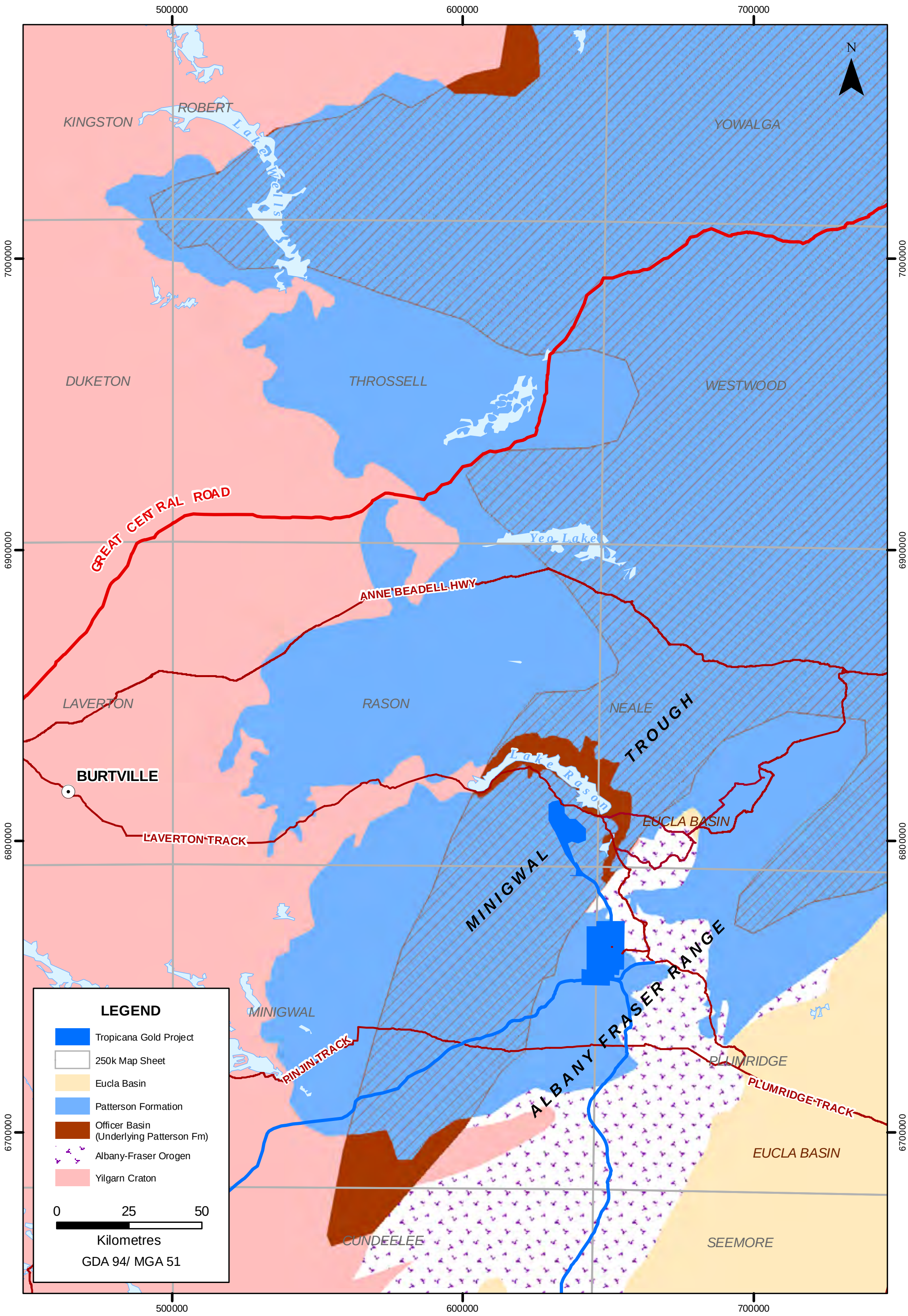


Figure 2-2 Pre-Cenozoic geology of the south-west Gunbarrel and Officer Basins

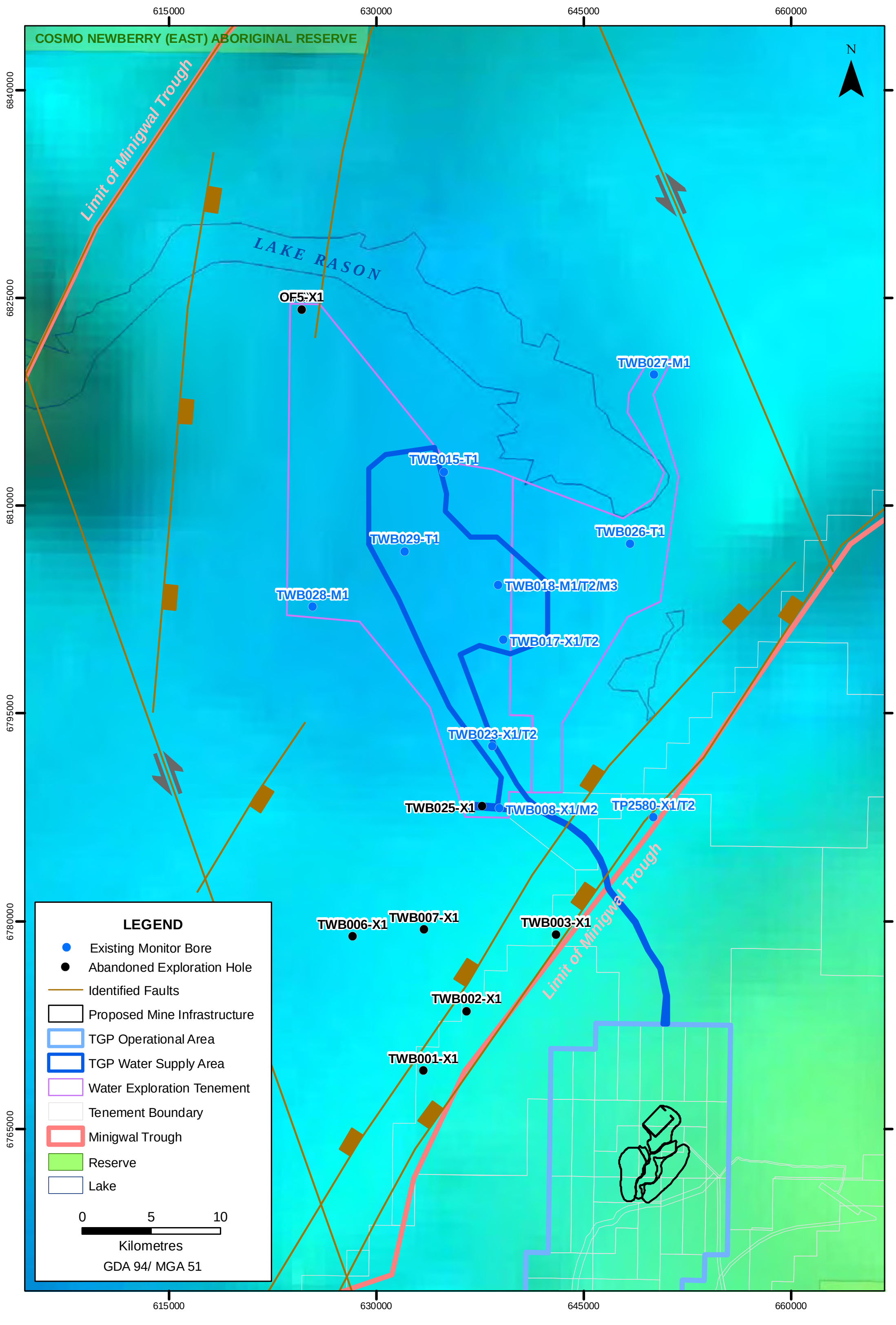


Figure 2-3 Bouguer Gravity image of Lake Rason area

2.4 Regional Stratigraphy

The sedimentary succession within the south-western portion of the Gunbarrel and Officer Basins intersected within the Water Supply Area comprises at least four sedimentary groups, namely:

- Cenozoic deposits comprising palaeochannel and aeolian deposits, and weathering/digenetic alteration products;
- Permian to Ordovician Period deposits of the Gunbarrel Basin;
- Neoproterozoic Officer Basin formations of the Balya Group:
- Mesoproterozoic sediments

The stratigraphic succession is summarised in **Table 2.1**. Each sedimentary succession overlies an older, deeper sequence, or crystalline rocks of the Yilgarn Craton and Albany-Fraser Orogen.

2.4.1 Cenozoic Deposits

Cenozoic deposits (65 Ma to present) form an extensive but relatively thin cover over the majority of the region, and include palaeochannel and lake deposits, authigenic alteration of surface material, and aeolian sand deposits. Until recently the Cenozoic era was divided into the Tertiary (65 to 1.8 Ma) and Quaternary periods (1.8 Ma to present), but in accordance with the International Commission on Stratigraphy, the Australian Government Survey Organisation (AGSO) is promoting adoption of the Neogene (1.8 to 23 Ma) and Palaeogene (23 to 65.5 Ma) periods to replace the "Tertiary", which will no longer be used.

The oldest Cenozoic deposits are early to middle Cenozoic that infill pre-existing palaeochannel systems and can exceed 100 m in thickness. Palaeochannels were incised as river valleys over the Yilgarn Craton during periods of high rainfall and runoff that existed through the hot wet Jurassic and Cretaceous Periods and into the Eocene Epoch of the Cenozoic era (50 Ma). These rivers drained predominantly south-eastward to the Eucla Basin, and consequently many of these channels cross the Officer and Gunbarrel Basins. Arid climatic conditions developed over much of Australia during the Eocene with the onset of the current ice age period, resulting in waning of river flows and sedimentation that choked the river valleys. Sediments infilling the valleys comprise sand, silt, and clay with gypsiferous and saline deposits, and frequently contain basal sand. The Roy Valais palaeochannel near Leonora is an example of a main channel palaeochannel deposit that is filled with 70 to 90 m of sediments extending over a distance of at least 40 km (**Figure 2.3**). Major relict drainage systems now present over much of the palaeochannels contain extensive areas of salt lakes with white halite salt cover over the flat surface. Lunette dunes are often present on the eastern side of salt lakes, and have formed by deflation of the intermittently dry beds, a process that is still continuing. The dunes are of similar composition as the adjacent lake beds, with some gypsiferous and saline dunes, including the south-eastern margin of Lake Rason.

Table 2.1 Stratigraphic succession within south-western Officer Basin and Gunbarrel Basin.

Era/ Period			Formation	Lithology
CENOZOIC	Quaternary		Eolian deposits	Sandplain and dune sand.
CENOZOIC	Miocene to Eocene		palaeochannel deposits	Clay, silt and sand
PALAEOZOIC	Early Permian	*Gunbarrel Basin*	Paterson Formation	clayey sandstone and sandstone, siltstone, claystone and tillite
PALAEOZOIC	Caboniferous to Devonian	*Gunbarrel Basin*	Lennis Sandstone	Sandstone, minor modstone and conglomerate
PALAEOZOIC	early Ordovician	*Gunbarrel Basin*	Table Hill Volcanics	Basalt
NEOPROTEROZOIC		*Officer Basin (Bulya Group)*	Steptoe Formation	Siltstone with dolomite, minor sandstone
NEOPROTEROZOIC		*Officer Basin (Bulya Group)*	Kanpa Formation	Interbedded dolomite (stromatolitic), mudstone, shale and sandstone, some evaporites and chert
NEOPROTEROZOIC		*Officer Basin (Bulya Group)*	Hussar Formation	Sandstone (F-c) interbedded with grey-brown red shale, siltstone and dolomite, over red brown to dark grey siltstone, mudstone, shale and dolomite
NEOPROTEROZOIC		*Officer Basin (Bulya Group)*	Browne Formation	Dolomite, anhydrite, gypsum, halite, siltstone and calcareous shale
NEOPROTEROZOIC		*Officer Basin (Bulya Group)*	Lefroy Formation	Siltstone, white-purple, grey-marron shaly, laminated, micaceous with medium thick bedded sandstone intercalations
NEOPROTEROZOIC		*Officer Basin (Bulya Group)*	Townsend Quartzite	Sandstone (m-c), pebbly in part, significant cementation
MESOPROTEROZOIC		*Pre-Officer Basin Successions*		low grade metamorphic sediments including sandstone, fissile shale and basalt

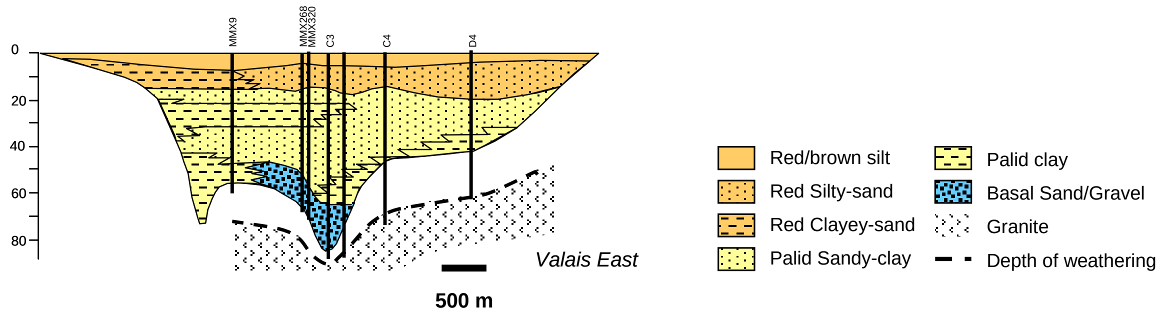


Figure 2.3: Typical infill deposits in a palaeotributary channel

The surface formations have undergone significant weathering and digenetic alteration throughout the Cenozoic Era, developing a deep lateritic soil profile. Rock minerals within the weathering zone break-down to a pallid clay with residual quartz. Silcrete is often developed within the pallid clay at the catchment boundaries. Silcrete is a duricrust formed by the cementation and replacement of quartz and clay particles with micro-crystalline silica. It commonly passes upward into laterite comprising iron-oxide concretions and laminations typically of magnetite and goethite. Calcrete is another type of duricrust that forms by cementation and replacement of soil material with carbonate precipitated from groundwater. The calcrete forming process takes place around the water table in areas where there is a net discharge of groundwater, typically in the lower lying parts of the landscape.

2.4.2 Paterson Formation (Gunbarrel Basin)

Formations comprising the Gunbarrel Basin are, in order from the base upward, the Table Hill Volcanics, Lennis Sandstone, Wanna Formation and Paterson Formation. The Gunbarrel Basin succession is a continuous southward extension of the Canning Basin, with the Paterson Formation concordant with the Grant Group of the Canning Basin. The thickness of the succession is up to 1500 m (Hocking, 1994), but it is considerably thinner over the south-western portion of the basin. Within the Minigwal Trough only the Paterson Formation is known to occur.

The Paterson Formation present through most of the Gunbarrel Basin is a mixed glacial, fluvial-glacial, and glacial-lacustrine sequence with a maximum thickness of about 100 m deposited during several advances and retreats of the Gondwana continental ice sheet during the Late Carboniferous to Early Permian ice age (~300 – 250 Ma) (Lowry et al., 1972). It is overlain by aeolian sand over most of its extent, or Cretaceous deposits of the Eucla Basin in the south, and often outcrops at break-always. The formation unconformably overlies both the Officer Basin and older formations, or crystalline rocks where it on-laps the Yilgarn Craton and Albany-Fraser Orogen.

Three units are recognised within the Paterson Formation (Van de Graaff and Bunting, 1975, 1977), namely:

- Glacial tillite deposits;
- Lacustrine deposits; and
- Fluvial deposits

Tillite deposits often are present at the base of the Paterson Formation, and comprise poorly sorted conglomerate and pebbly mudstone locally containing boulders up to 4 m diameter (Van de Graaff and

Bunting, 1977). The presence of faceted and striated clasts and the general lack of bedding are indicative of tillite deposits. Lacustrine and glacio-lacustrine deposits overlie the tillite and comprise well-bedded to indistinctly-bedded siltstone and claystone with minor sandstone containing rare scattered pebbles and cobbles. Isolated clasts are interpreted as dropstones from melting ice floes, and varved claystones are locally present. Fluvial deposits, possibly associated with outwash fans in front of melting glaciers and braided river systems, overlie and laterally grade into the lacustrine deposits. They comprise coarse-grained sandstones characterised by moderate sorting, often pebbly, and with distinct but irregular bedding and various cross-bedding.

2.4.3 Officer Basin sediments

Officer Basin sediments include Neoproterozoic and Lower Cambrian rocks in the region east of the Yilgarn and Pilbara Cratons, and south of the Canning Basin, and overlie either Meso- or Paleoproterozoic sediments, or crystalline rocks. Sediments of the Gunbarrel Basin, including the Paterson Formation, cover the majority of the Officer Basin and obscure the western boundary of the basin. Elsewhere the basin is overlain by Cenozoic aeolian sand or locally deposited colluvium and alluvium, while in the south Cretaceous rocks of the Eucla Basin on-lap the basin.

The sedimentary succession within the south-western Officer Basin is included in the Buldya Group (Grey, et al., 2005), which has a full thickness of at least 4500 m and comprises siltstone, mudstone, sandstone (in part quartzite), dolomite (commonly stromatolitic), and minor halite and other evaporate minerals. Deposition is considered to have began before about 827 Ma, possibly as early as 850 Ma, and continued beyond 725 Ma (Grey *et al.*, 2005), and is therefore Neoproterozoic in age. The group was principally defined to include the succession previously referred to as ‘Supersequence 1’ (Walter *et al.*, 1995), and constitutes the following formations in ascending order and summarised in **Table 2.1**: Townsend Quartzite, and the Lefroy, Browne, Hussar, Kanpa, and Steptoe Formations.

Sediments of the Officer Basin extend into the Minigwal Trough, where it has been intersected by the WMC hole NJD1 (Hocking, 2002), and in subsequent drilling by Anaconda and the TJV. The succession is considerably thinner within the trough than is encountered in the main portion of the Officer Basin to the northeast, and the lowest formation immediately above the basal contact appears to become progressively younger towards the basin margin (Hocking, 2002). Sediment lithology intersected in exploration drilling within the Minigwal Trough suggests that Officer Basin formations below the Browne Formation are absent, while the Steptoe Formation at the top of the succession is largely not preserved below the unconformity contact with overlying Paterson Formation.

Detailed descriptions of the formations are given by Grey *et al.*, (2005), and are summarised here in descending order for the formations possibly present within the Minigwal Trough.

> *Steptoe Formation*: The Steptoe Formation comprises sandstone with massive dolomite, siltstone, mudstone and claystone. It is recognised within Kanpa 1A (829-1341m) and Empress 1A (483-617m) (Grey, et al.). The siltstone and mudstone is typically coloured light to dark grey, and is dolomitic, while the sandstone is light grey, very fine to medium grained quartzose and is dolomitic (Stevens and Apak, 1999). A dark grey claystone is the main lithology within the lower portion of the formation in Empress 1A (Stevens and Apak, 1999). The formation is seen as a similar but sandier unit to the underlying siltstone and dolomite dominated Kanpa Formation (Townson, 1985).

Kanpa Formation: The Kanpa Formation is a mixed carbonate-siliciclastic sequence of interbedded dolomite (predominantly stromatolitic), mudstone, shale, siltstone, and sandstone with some evaporates and chert. A basal shale is recognised (Townson, 1985) comprising grey claystone with sparse graded siltstone interbeds and fine to medium grained sandstone toward the very base (Haines et al., 2004). The shale is overlain by a number of sandstone intervals grading upward into grey mudstone or claystone. The sandstone is typically light brown or grey, medium grained, and is well sorted and well rounded, while the mudstone is oxidised to reddish brown within the lower-most portion of the formation in Empress 1A (Stevens and Apak, 1999). Abundant soft-sediment deformation structures within the lower mudstone to cm scale are noted (Stevens and Apak, 1999).

Hussar Formation: The Hussar Formation is described as an interbedded sandstone, dolomite, limestone, siltstone and shale (Phillips et al., 1985) containing minor evaporates. It comprises a basal red-grey silty shale with thin dolomite beds overlain by grey to red-brown siltstone and shale with dolomite beds, and show soft-sediment deformation structures. The upper portion contains sandstone that is medium to coarse grained, sub-rounded and usually well sorted, with minor interbeds of grey-brown-red shale, siltstone and argillaceous dolomite (Townson, 1985).

Browne Formation: The Browne Formation is a mixed sequence of fine grained dolomite, anhydrite, gypsum, halite, siltstone and shale. It is dominantly coloured reddish brown. At some locations the Lancer Member is present within the top of the Browne Formation and consists of fine to medium grained, well-sorted orange-brown quartz sandstone with minor silty beds; about 96 m of the member was intersected in Lancer 1 (Haines *et al.*, 2004).

The deepest hole drilled within the Minigwal Trough for which detailed lithological information is available is WMC exploration hole NJD 1, which was cored to 517 m depth. It is located about 80 km northeast of Lake Rason. Un-metamorphosed and mostly sub-horizontal Officer Basin sediments of the Buldya Group were intersected between 108 and 376.8 m depth below the Paterson Formation, and included biodegraded bituminous hydrocarbons from 338 to 342 m, and 502 to 517 m depth. The sequence overlies a low-grade metamorphism sedimentary succession possibly of Mesoproterozoic age (Hocking, 2002).

A summary of the lithology within NJD 1 and the interpreted formations present are shown by **Figure 2-4**. Several alternative correlations with Officer Basin formations have been made. The preferred correlation by Hocking (2002) was with the Kanpa Formation for the succession between 108 and 330 m depth, with the sandstone unit from 330 to 376.8 m belonging to the upper portion of the Hussar Formation. This interpretation is consistent with the Kanpa Formation and Hussar Formation succession described within Empress 1A (Stevens and Apak, 1999). Alternative interpretations require a condensed succession of formations. As an alternative, Hocking (2002) suggested that the full sequence of Bulya Group formations from Kanpa Formation to Townsend Formation were present (**Table 2.1**), while Grey *et al.* (2005) proposed that the Kanpa Formation occurred above 203.5 m, overlying Hussar Formation to 330 m, with the very fine to medium grained sandstone present to the base of the sequence at 376.8 m considered to possibly belong to the Lancer Member of the Browne Formation.

Another deep exploration hole (diamond core) is N1/1 lying east of the Minigwal Trough about 90 km E-NE of Lake Rason (115 km NE of the Operational Area), east of the Fraser Range, was drilled to a depth of 635 m (Geissler, 1981). The hole intersected dark greenish-grey siltstone, fine grained sandstone with dolomite to 255.3 m depth, over dark reddish-brown siltstone with thinner beds of light greenish-grey siltstone and dolomite with gypsum veins and evaporates within the lower portion of the hole between 427.5 to 612 m. Crystalline gabbro basement was intersected from 612 m to total depth. The sedimentary sequence may represent the Kanpa Formation to 427.5 m depth overlying the Hussar Formation. A sequence of fine grained sandstone with dolomite and siltstone intersected above 196 m depth was originally assigned to the Lennis Sandstone of the Gunbarrel Basin (Perincek, D., 1998), but is more consistent with the Kanpa or Steptoe Formation of the Officer Basin.

Anaconda groundwater exploration holes OF2T1 and OF2T2 that are located almost mid-way between NJD 1 and N1/1 are also situated close to the eastern margin of the Minigwal Trough, and were drilled 135 m and 243 m respectively. The holes intersected red brown and greenish-grey coloured mudstone, and black shale with silcrete and calcrete below the Paterson Formation, similar to the sequence between about 180 m and 330 m in NJD 1. OF2T1 encountered red-brown to pale pink brown mudstone, dolomite and medium to very coarse grained sandstone below 119 m depth. The sedimentary sequence intersected probably belongs to the Kanpa Formation or Hussar Formation.

2.4.4 Mesoproterozoic Sedimentary Rocks

Pre-Officer Basin sedimentary rocks occur beneath much of the south-western Officer Basin, and are considered to be of Mesoproterozoic or possibly Paleoproterozoic age. WMC hole NJD1 intersected the sequence within the Minigwal Trough below 376.9 m depth (Hocking, 2002), where it consists of interbedded shale with fissile partings and sandstone dipping up to 70°, and has undergone low grade metamorphism producing crenulations with a slight sheen. The sedimentary sequence is estimated to be 1200 m to 1500 m thick at the site from gravity data (Shevchenko, 2002), which implies that approximately 1000 m of Mesoproterozoic age sediments underlie the Officer Basin sequence. The sediments possibly correlate with other Mesoproterozoic units in central Australia such as the Mission and Tollu Groups (Glikson et al., 1996) and the Wankari – Bloods Range succession (Scrimgeour et al., 1999).

Drilling by CRA Exploration 27 km W-SW of the Operational Area on Temporary Reserve 7483H intersected probable Mesoproterozoic rocks within hole MRM1D below the Paterson Formation at 130 m depth upon the eastern margin of the trough. Within this hole the sediments were described as predominantly angular fragments of very hard, fine grained, grey cherty rock with minor very hard light grey carbonate fragments and black shale.

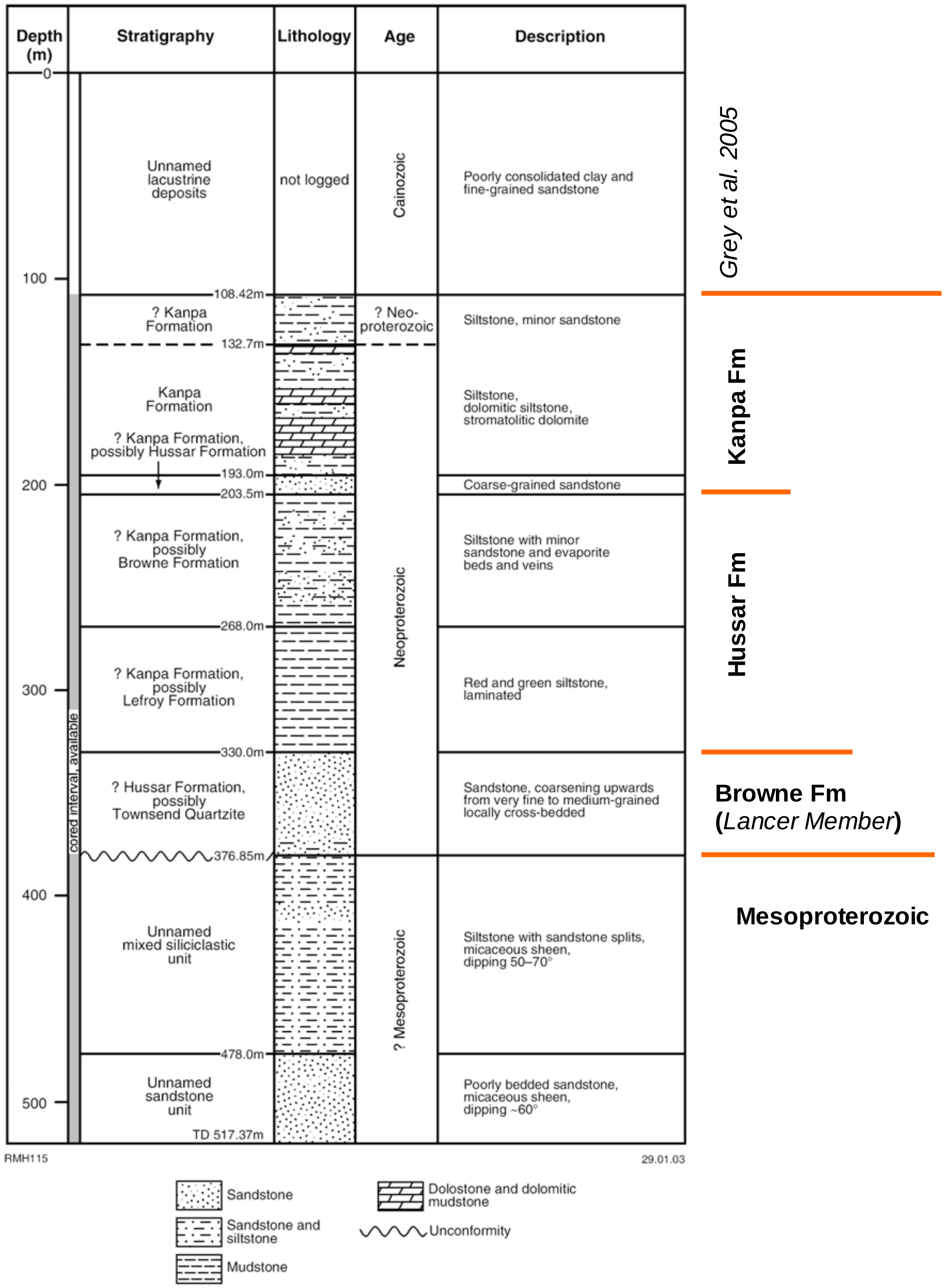


Figure 2-4 Summary section of NJD1 (after Hocking 2002)

2.5 Stratigraphy in the Water Supply Area

Drilling by the Water Supply Area intersected Cenozoic deposits, Paterson Formation, Officer Basin and Mesoproterozoic sediments.

2.5.1 Cenozoic deposits

The Water Supply Area is located within the Sandland Province described by Jennings and Mabbutt (1977), comprising aeolian sand deposits that are draped over all other geological units. They are wind blown sands, and comprise red brown, fine to medium grained quartz sand and silt which form sand plain deposits and an extensive dune system forming elongate ridges up to 20m high with a general east-west orientation.

Soils within the region are dominated by red sands, with sandy earths common on sandplains and deep sands on the dunes. Shallow pisolithic and gibber gravels with deep sandy gravels are found on lateritic plains and tablelands, while stony soil, loamy earth, shallow loam, shallow sand and sandy earth are developed upon hills and ranges. Shallow gravels with deep sandy red-brown hardpan and shallow loams are found on wash plains, stony plains and the slopes of some hills. Calcareous loamy earths occur on calcrete plains while salt lake soils are also present. **Figure 2-11** shows the Cenozoic regolith (surface geology) over the Water Supply Area.

The Rason palaeodrainage crosses the Minigwal Trough from the Yilgarn Craton in the west and passes over the Frazer Range on its way to the Eucla Basin. Unlike many palaeochannels in the region, the Rason palaeochannel conspicuously does not contain significant basal sand or gravel in vicinity of the Frazer Range. Proponent transect drilling (TPA2298 to TPA2584) across the drainage at the eastern margin of the Minigwal Trough found that the entire sedimentary valley infill, which is 20m to 70m thick, comprises mainly gypsiferous clay and silt with authigenic salt. Coarse grained sands were however described in the upper 29 m of water exploration bore TP2580-T situated along the transect, and possibly represents Cenozoic infill deposits of the Lake Rason paleovalley that may be younger than typical palaeochannel deposits. The Rason drainage valley is much broader to the west of the Frazer Range, starting 40 kilometres from the Operational Area, and appears to be best developed beneath Lake Rason. It is possible that the palaeovalley will also become deeper further west and may contain basal sands and gravels.

2.5.2 Paterson Formation

The Paterson Formation is present through most of the Water Supply Area beneath Cenozoic deposits, with outcrops around the flanks of the Lake Rason valley. Most holes drilled by the TJV intersected sediments of the Paterson Formation that predominantly comprise poorly sorted medium and coarse grained sand and gravel, which is clayey within the lower portion at some locations. They are normally oxidised and coloured moderate red, pale greyish pink and pale grey. The sediments probably represent fluvial deposits, and while lacustrine deposits are not identified in the drill holes a few outcrops of the lacustrine unit are mapped on the Minigwal and Rason 1:250 000 scale geological maps (Bunting and Boegli, 1977; Gower and Boegli, 1977). Thin tillite deposits may be present at some locations, but have not been distinguished from the fluvial sediments. The thickest intersection of the Paterson Formation within holes drilled by the TJV was 108 m within TWB002-X1, which is located 21.7 km NW of the Operational Area. Below the Lake Rason valley the Paterson Formation is fully eroded. It is also absent beneath some to the more prominent valleys south of the lake.

Figure 2-12 presents the extent and interpreted base elevation for the Paterson Formation within the Water Supply Area – Operational Area based on drilling data. The highest base elevation for the formation is almost 400 m AHD, intersected in TWB028-T1 at the western limit of the investigation area. Elevations decrease eastward in the Lake Rason area and deepen south along the eastern margin of the Minigwal Trough. The deepest intersection by TJV holes was 295 m AHD in TWB002-X1, while further south in CRA exploration hole MRM1D (located about 27 km W-SW of the Operational Area) the base elevation is recorded at around 273 m AHD. Glaciation probably created considerable topography at the base of the formation with the underlying formations.

2.5.3 Kanpa Formation (Officer Basin)

Exploration groundwater drilling in the Water Supply Area intersected sediments considered to be part of the Officer Basin within most holes, including 255.45 m of core from drill-hole TWB018-M3. The sediments comprise light to medium brownish grey fine grained sand and siltstone with common dolomite beds and medium dark grey plastic clay. There is no apparent metamorphism of the sediments, and evaporite minerals (halite and gypsum) were not identified within the sequence in the Water Supply Area. These sediments are consistent with the Kanpa Formation described in Empress 1A (483 to 617 m) (Stevens and Apak, 1999), Lancer 1 (466.5 to 707.5 m) situated within the north-western portion of the Officer Basin (about 490 km N-NW of the Operational Area) (Haines *et al.*, 2004), and within the upper portion (108.4 to 193 m) of NJD1 (Hocking, 2002), although the unit intersected in the Water Supply Area lacks the medium and coarser grained sands and minor evaporites described elsewhere. Alternatively, the Officer Basin sediments in the Water Supply Area may correlate with the Steptoe Formation that overlies the Kanpa Formation, which was also given as an alternative interpretation within NJD1 above 193 m depth (Hocking, 2002). The greater portion of sand/sandstone and its finer grained character about Lake Rason is consistent with the Steptoe Formation. The lower portion of Officer Basin sediments intersected within NJD1 (193 to 376.8 m), including coarse grained sandstone and evaporite minerals, appear to be absent about Lake Rason. This agrees with the suggestion by Hocking (2002) that the basal formation becomes younger toward the basin margin.

The sequence intersected within the Water Supply Area is best represented within TWB015-T1, for which the gamma-ray geophysical log is shown by **Figure 2-5**, although the hole did not reach the base. A maximum intersected thickness of 293 m was encountered in the cored drill-hole TWB018-M3 from which detailed lithology was obtained and is given in Attachment B with core tray photos contained within Attachment C. These sediments are tentatively assigned to the Kanpa Formation on the basis of the preferred interpretation for the upper portion of Officer Basin sediments within NJD1 (Hocking, 2002).

Three member units are identified within the Kanpa Formation sequence in the Water Supply Area, and their relationship is shown on the geological cross-sections in **Figure 2-13** and **Figure 2-14**. The members are referred to in ascending order as:

1. Lower Sandstone;
2. Shale; and
3. Upper Sandstone

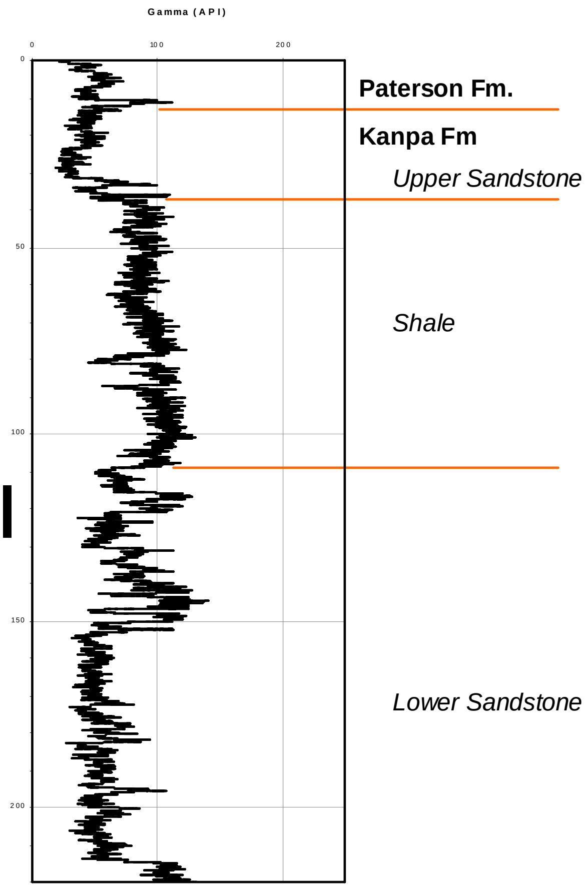


Figure 2-5: Gamma-ray geophysical log for TWB015-T1

The Lower Sandstone member encountered by TJV-drilled holes comprises fine grained sand/sandstone containing common dolomite beds in some holes, with interbedded siltstone and shale. It rests unconformably upon Mesoproterozoic sediments of predominantly shale and siltstone. The sand/sandstone is coloured brownish grey, grey green and grey. Sand tends to dominate the member in the north-west of the investigation area where the thickest intervals were intersected in TWB018-M3, TWB029-T1 and TWB015-T1, while siltstone is dominant in the southern holes as encountered in TWB008-T2, TWB023-T2, and TWB017-T2. A maximum Lower Sandstone thickness of 238 m was intersected in TWB018-M3.

Cored drill-hole TWB018-M3 fully penetrated the Lower Sandstone member between 62.6 and 300.5 m depth. In this hole, sandstone comprises approximately 70% of the interval, where it is dominantly pale yellowish brown, fine grained, well sorted, sub-angular to sub-rounded quartz sand that is weakly consolidated, massive and porous. Sand grains are mostly between 0.08 and 0.15 mm in size. A minor portion of the sandstone is well lithified with low porosity, and intervals of calcareous (presumably dolomite) cemented sandstone are present at 158.1 m (0.7 m thick) and 258.3 m (2 m thick) depth and occur within thicker sandstone intervals. **Figure 2-6** shows core of typical sandstone, and binocular microscopic views of the sandstone from 70.5 m and 249.5 m depth are shown by

Figure 2-7. These microscopic views show matrix clay present in the sandstone from 70.5 m, while the 249.5 m sandstone sample appears clay free.

Layers of siltstone and shale are present within the Lower Sandstone member intersected within cored drill-hole TWB018-M3. They are medium dark grey, hard, with intervals containing fine laminations of shale, siltstone and fine grained sandstone. The layers are generally less than 1 m thick, but reach up to 8.15 m, although the thicker intervals include some fine grained sandstone. A possible stromatolite is present at around 140.8 m bounded by shale beds. Some shale beds are ruptured and infilled with sandstone, suggesting that the sequence has experienced soft-sediment deformation. **Figure 2-8** shows one of the thicker shale/siltstone intervals within TWB018-M3.

Figure 2-6: Core photo TWB018-M3; sandstone 226.7 to 231.5 m

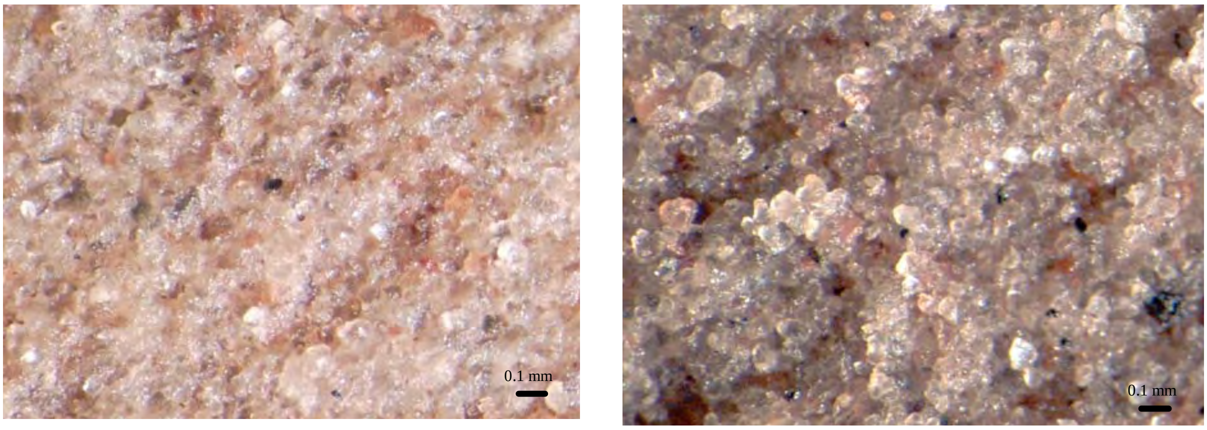


Figure 2-7: Binocular microscope view of sandstone core from TWB018-M3 70.5m (left) and 249.5m (right) (25x)

Figure 2-8: Core photo TWB018-M3; sandstone 198.3 to 202.7 m

Figure 2-15 presents the interpreted extent and base elevation for the Lower Sand member mapped from the exploratory data. The sandstone deepens and thickens to the north where the deepest basal elevation of 86.5 m AHD was found in TWB018-M3, although it may extend deeper within TWB015T which terminated at 96 m AHD but is now interpreted not have reached the base of the Lower Sandstone member. This pattern is consistent with the 'pull-apart' basin model, where the basin deepens northward. The basal elevation of the sandstone rises to around 300 m AHD along the eastern margin, and is interpreted to sub-crop the Paterson Formation at its southern and eastern margins. Elsewhere, it is overlain mostly by the Shale member. It is uncertain how far west and northward the sandstone extends, although gravity data suggests that the basin may extend 20 km north of Lake Rason. Anaconda exploration water bore OF5X1 is interpreted to have intersected the top of the unit near the western margin of the Minigwal Trough.

The Shale member overlies the Lower Sandstone, and comprises firm siltstone and medium plastic clay coloured dark brownish-grey, dark greyish-blue, grey and dark grey, with a trace of fine grained sand. It is often oxidised within approximately 50 m of the surface, where it is typically coloured yellow brown, pale orange and dark yellowish orange. Drill-hole TWB018-M3 cored the lower 17.5 m of the Shale member, where it consisted of various portions of clay, silt and fine grained sand. Where fully preserved (not truncated by the Paterson Formation, Cenozoic sediments or ground surface) the Shale member is approximately 55 to 59 m thick in the southern portion of the investigation area (TWB008-T2, TWB023-T2), and thickens to the north-west where the maximum thickness for the unit of 110 m was intersected in TWB029-T1. **Figure 2-16** shows the interpreted extent and base elevation for the Shale member, which deepens to the north similar to the underlying Lower Sandstone. It lies at about 330 m AHD at the eastern margin, reaches 229 m AHD in TWB028-T1 in the north-west, and possibly extends deeper further north. It is interpreted to have a base elevation of 217 m AHD within Anaconda hole OF5X1.

A second higher sand unit, referred to as the Upper Sandstone member, was identified in several holes. It comprises sandy siltstone, with the sand portion increasing to the north where coarse and medium grained sand was encountered within the upper portion of the unit in TWB028-T1. The unit is coloured dark brown and dark grey, but is often oxidised to white, pale to moderate red and pale grey. A maximum thickness of almost 50 m intersected in TWB023-T2 and TWB028-T1. The full thickness is not preserved at any of the sites as it is truncated by the unconformably overlying Paterson Formation.

The base of Upper Sandstone member was intersected at between 289 and 349 m AHD, and the interpreted distribution and base elevation is shown by **Figure 2-17**.

2.5.4 Mesoproterozoic Sedimentary Rocks

Most exploration drilling by the TJV intersected sediments probably belonging to the Mesoproterozoic sequence. Two distinctive styles of sedimentary rocks were intersected distinguished by the degree of metamorphism, deformation and colour. TGP drill-holes TPA2580 and TWB002-X1 adjacent to the Fraser Range south of the Water Supply Area intersected highly fissile black shale with quartz veining underlying the Paterson Formation or Cenozoic deposits. The sequence has evidently undergone low level metamorphism and deformation, and probably belongs to the Mesoproterozoic sequence or possibly older Paleoproterozoic (Hocking, 2002). Samples from drill-hole TPA2580 submitted for paleontological analysis produced 'oily' samples without palynomorphs (Milne, 2007). This sequence is situated upon what is likely an uplifted terrace along the eastern margin of the Minigwal Trough.

TJV holes drilled further west within the Minigwal Trough encountered below the Kanpa Formation hard shale and siltstone with a trace of fine grained sandstone in part, and variously coloured pale grey brown, grey, dark greyish-blue and dark grey. Bands of dolomite are common in sections. A maximum thickness of 196 m was intersected within TWB017-T2, although the full thickness is unknown as no holes were drilled sufficiently deep to fully penetrate the unit. About 80 m of the unit was cored in drill-hole TWB018-M3 below 300.4 m depth, from which a section of representative core is shown in **Figure 2-9.**

The core of Mesoproterozoic sediments from TWB018-M3 comprises hard, competent beds of shale, siltstone and sandstone coloured pale yellowish brown and greyish brown. Sandstone is fine grained, similar to the overlying Officer Basin sediments, but is hard and well consolidated. Intervals of shale contain fine laminations of siltstone and sandstone. Deformation of the sediments is apparent from bedding planes dipping up to about 70° and small scale displacement structures evident within the sediments, as shown at 306.8 m depth by **Figure 2-10**. Heavy bedded fissility of shale beds and some slicken-sideded joints imply that the sediments have experienced low grade metamorphism in addition to deformation, but the grade of metamorphism appears to be lower than the sequence intersected adjacent to the Frazer Range. Based on the consolidated nature and apparent metamorphism of the sequence it is assigned to the Mesoproterozoic, although this interpretation is not conclusive.

Figure 2-9: Core photo TWB018-M3; Mesoproterozoic shale, siltstone and sandstone 315.8 to 320.2m

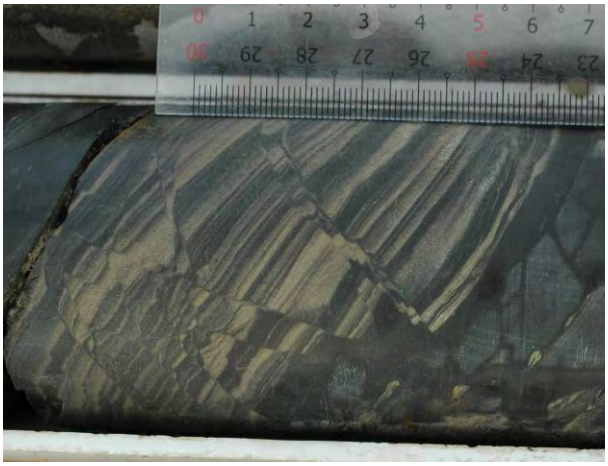


Figure 2-10: Small scale displacement features – TWB018-M3 306.8m.

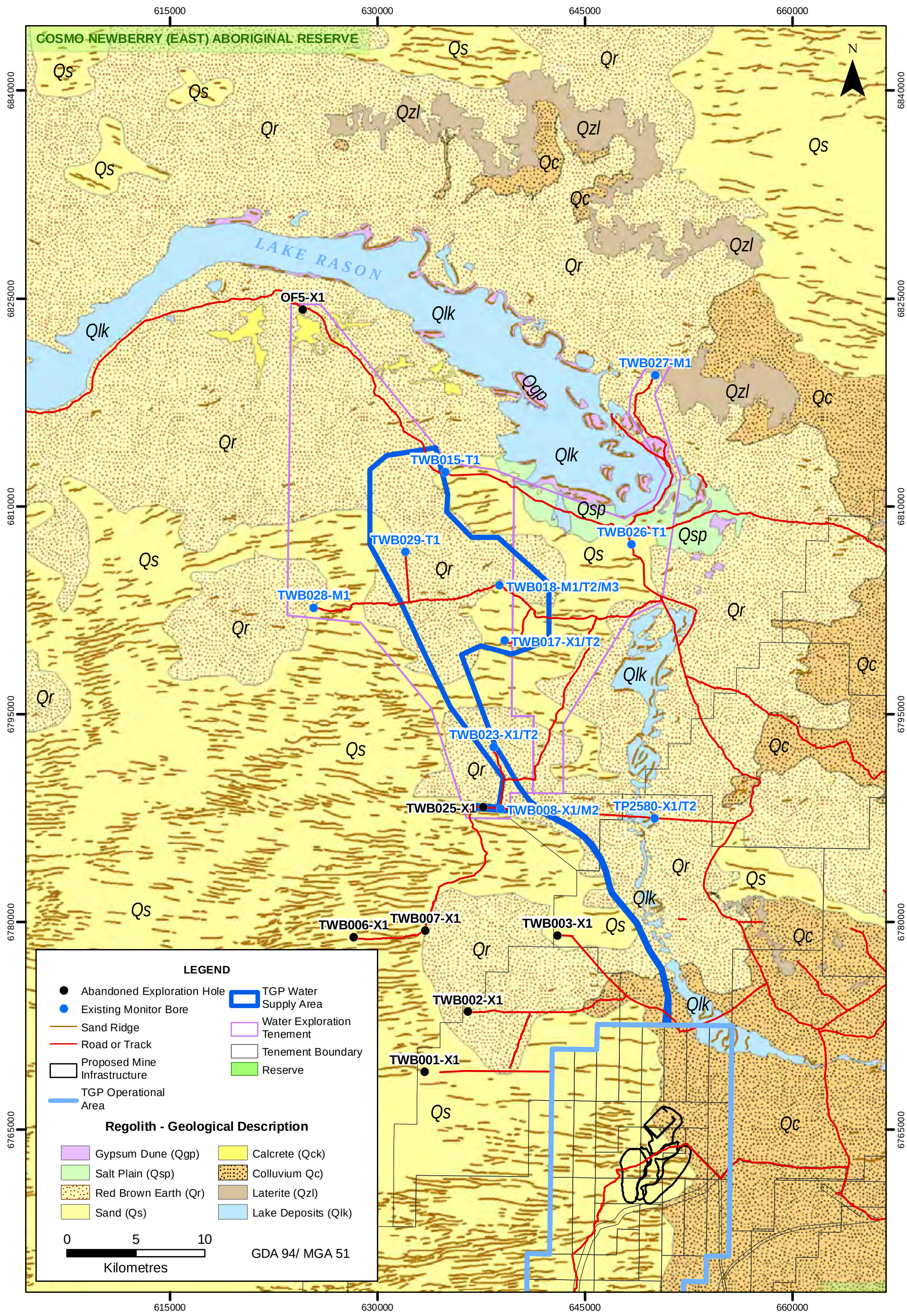


Figure 2-11 Cenozoic geology in the Minigwal Trough area

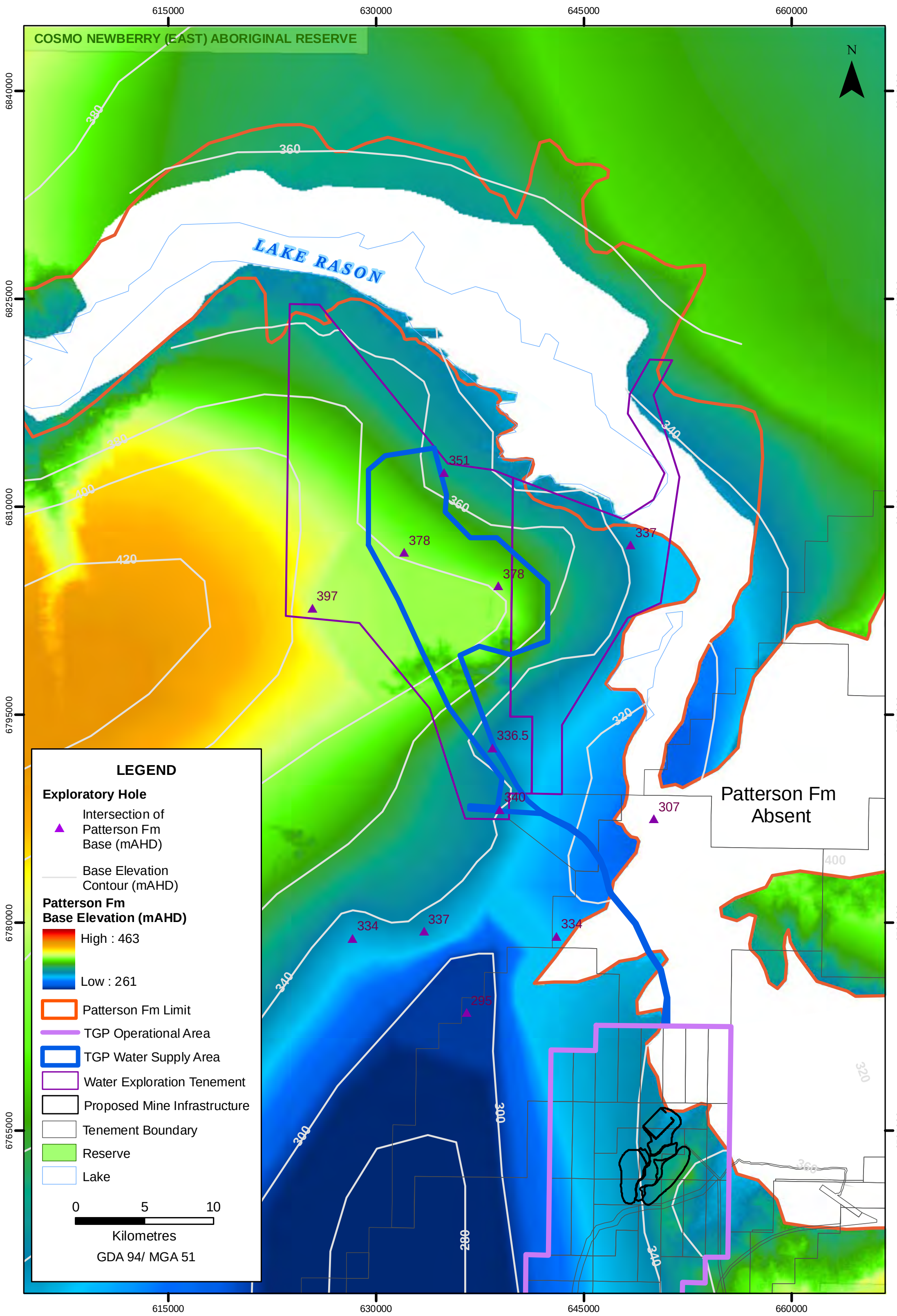


Figure 2-12 Paterson Formation extent and base elevation (m AHD)

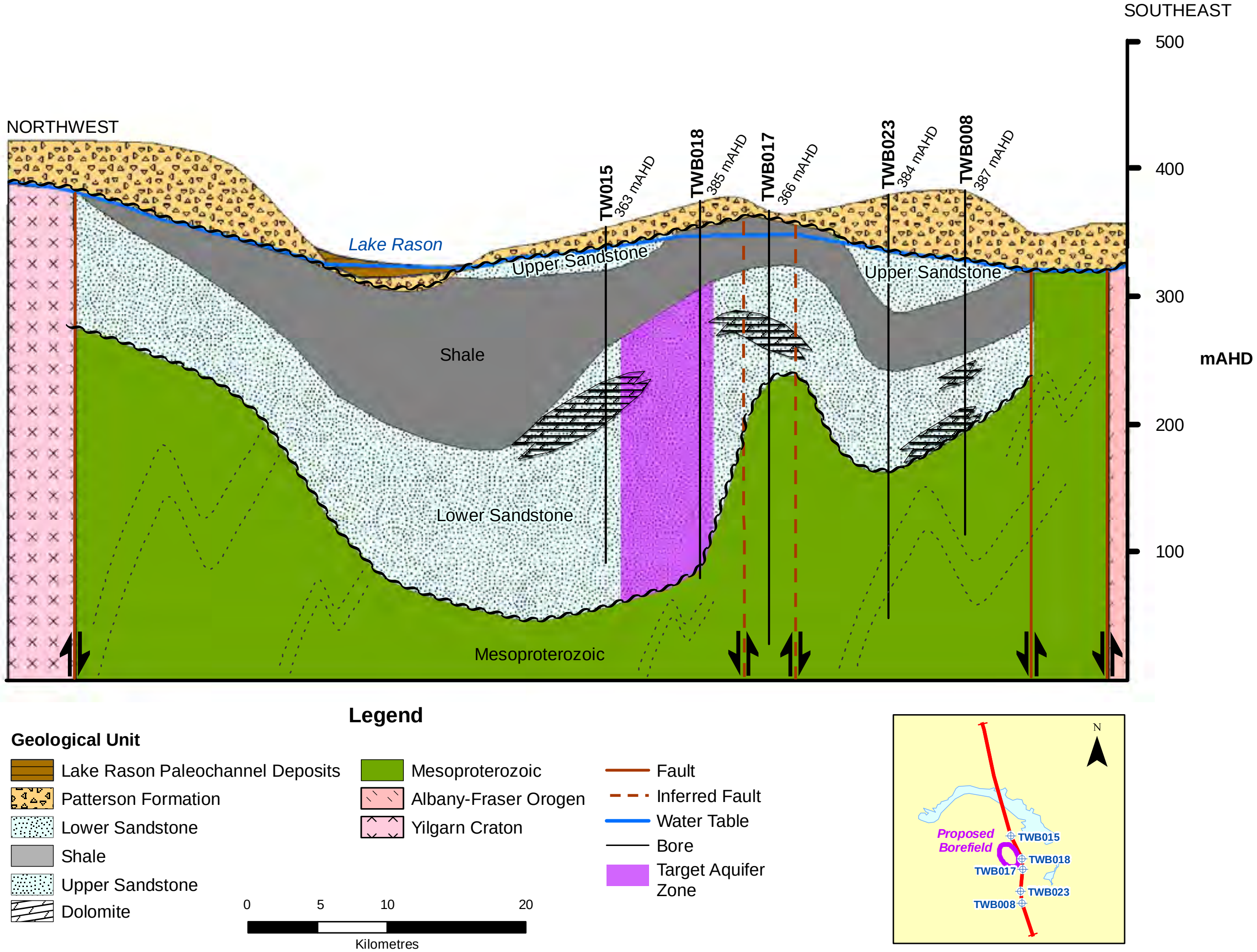


Figure 2-13 Geological cross-section of the Minigwal Trough; NW – SE.

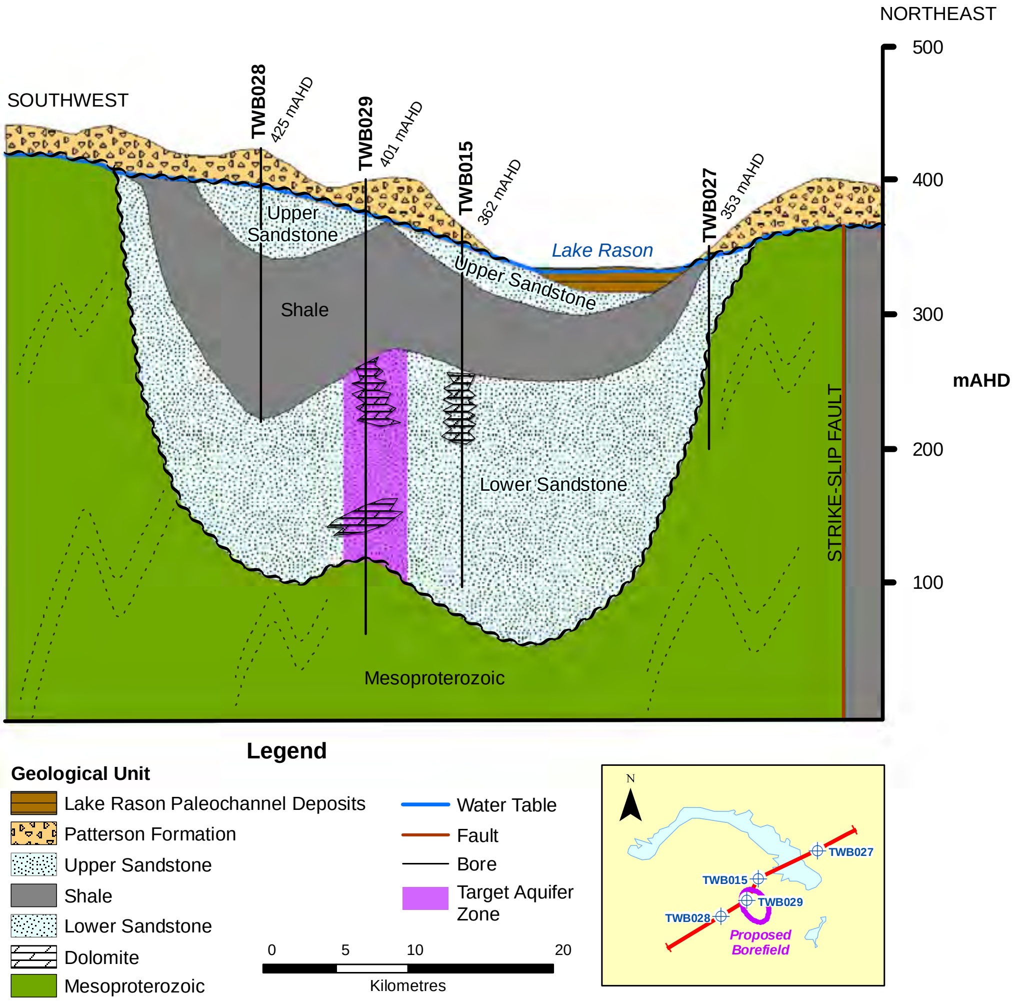


Figure 2-14 Geological cross-section of the Minigwal Trough; SW – NE.

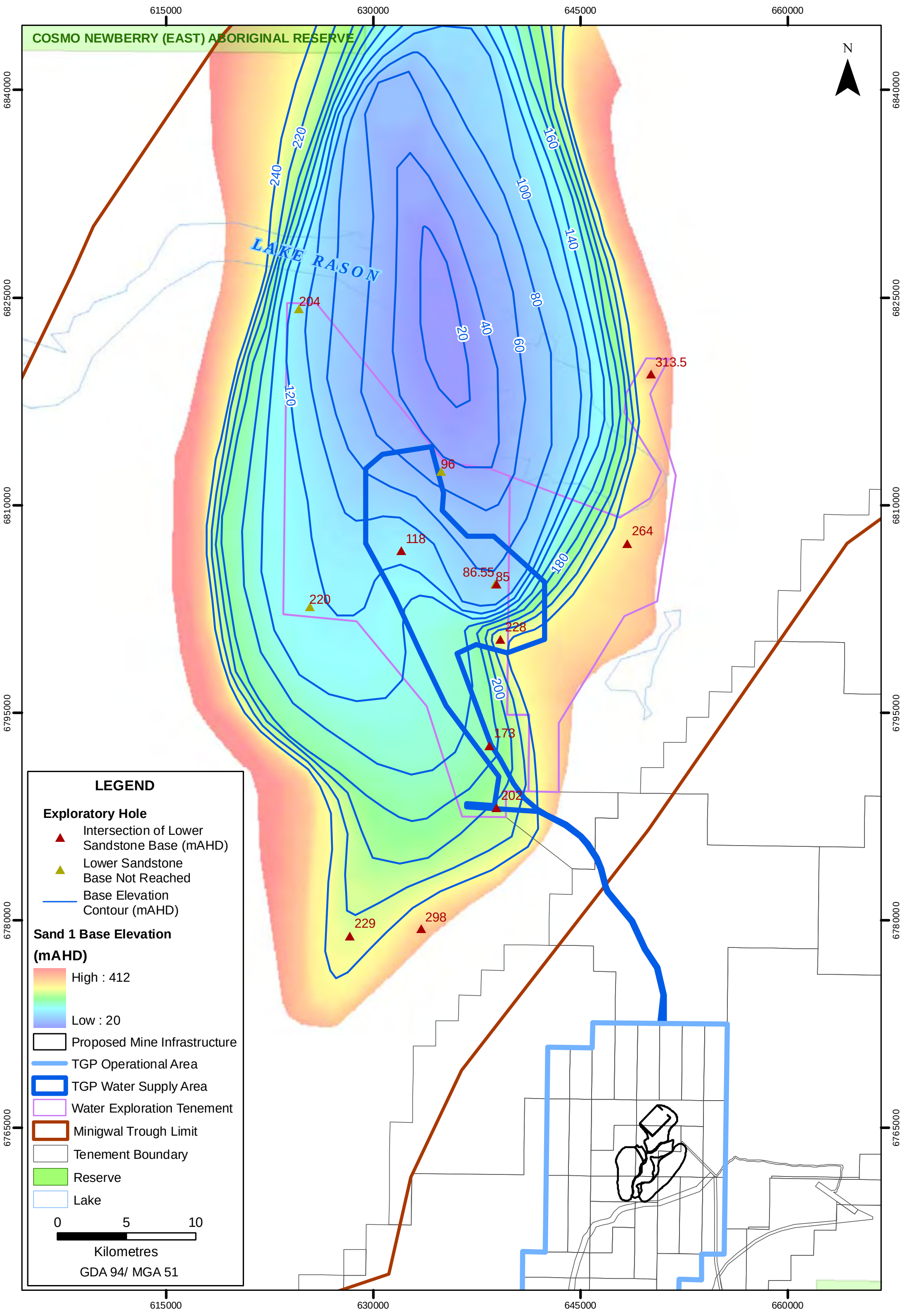


Figure 2-15 Lower Sandstone member extent and base elevation (m AHD)

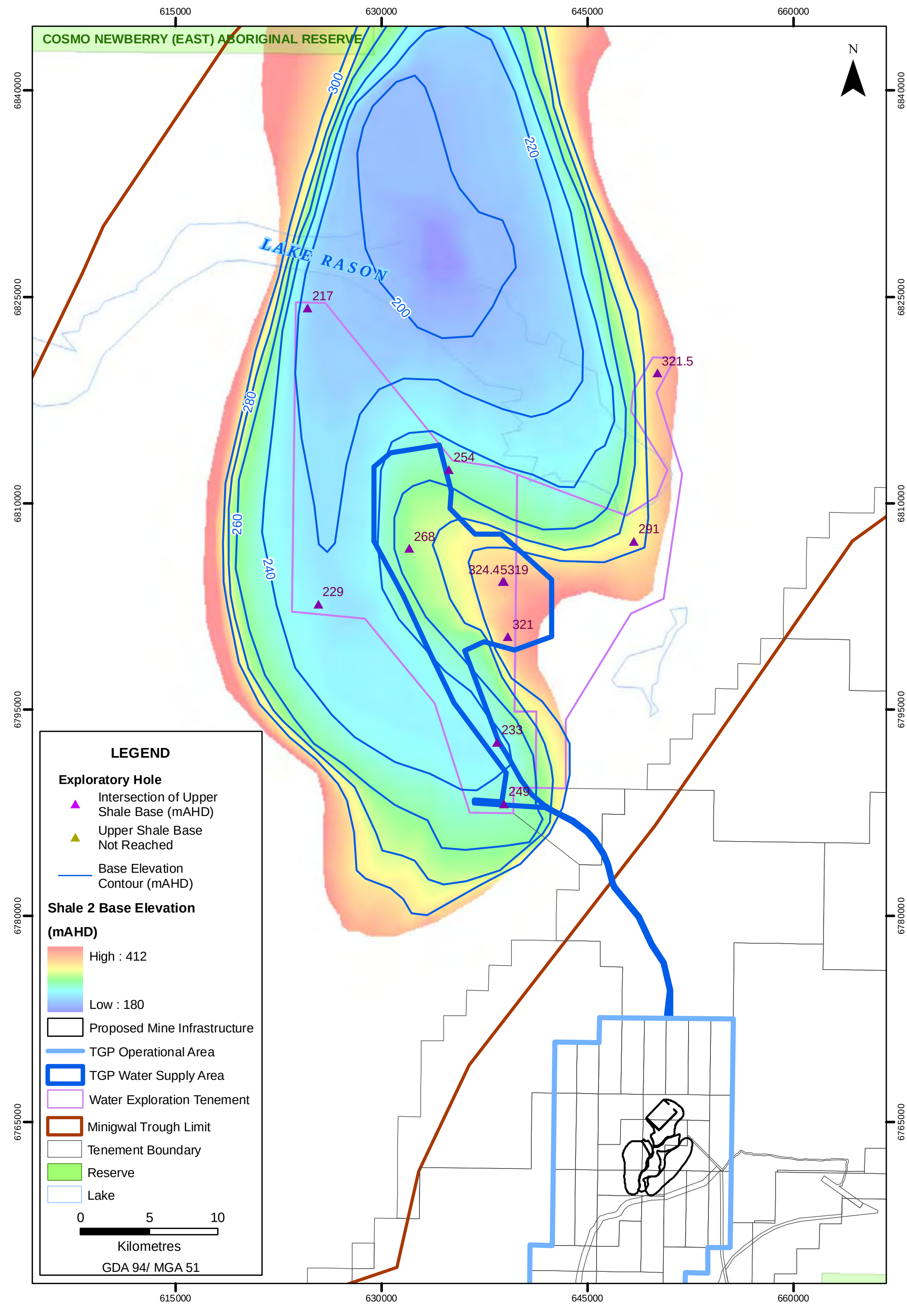


Figure 2-16 Shale member extent and base elevation (m AHD)

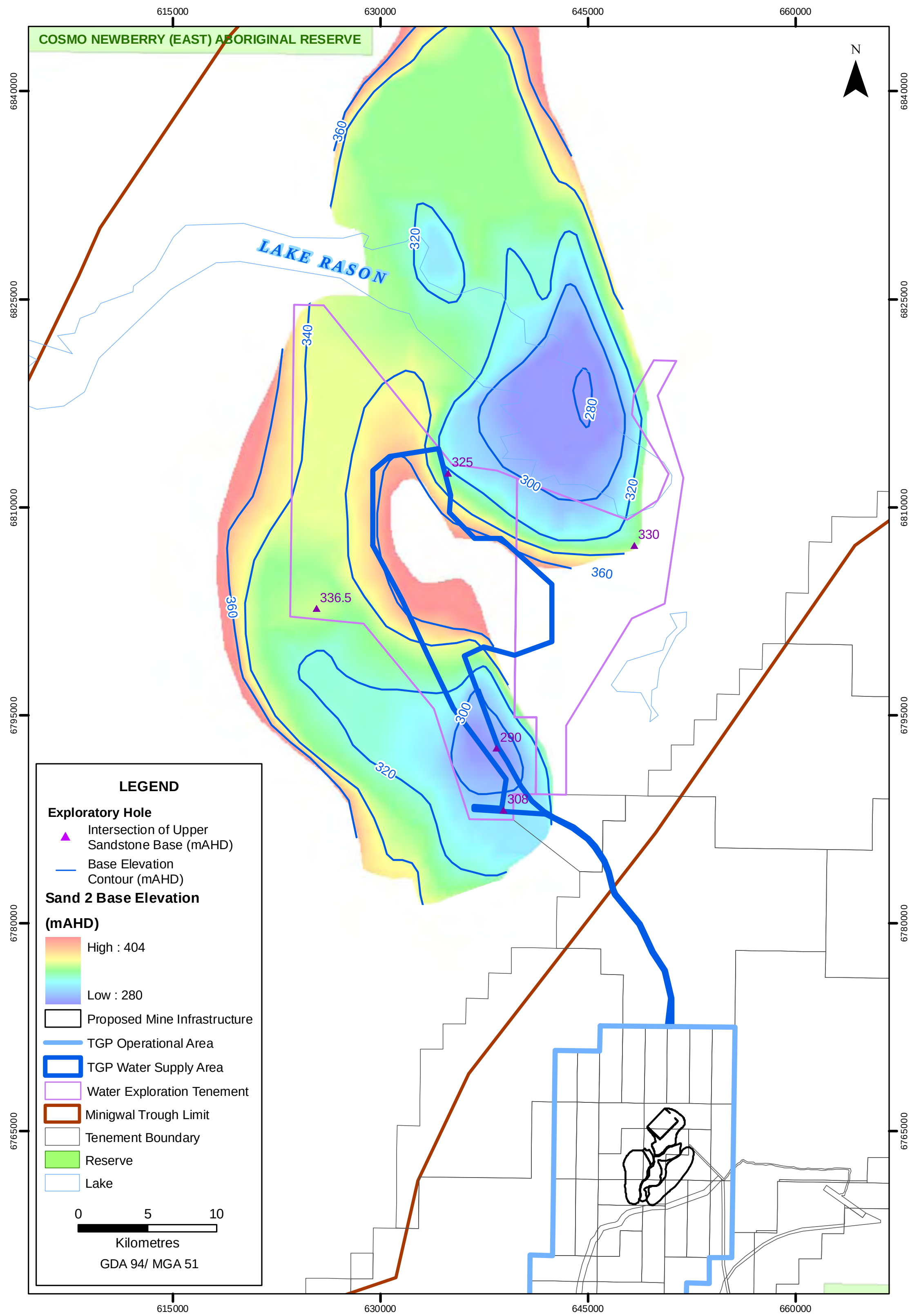


Figure 2-17 Upper Sandstone member extent and base elevation (m AHD)

2.6 Groundwater Occurrence

Within the Water Supply Area of the Minigwal Trough, groundwater occurs in the primary interstitial pore spaces in the sandy units that form aquifers. Two main sand aquifers are identified within the trough:

- Tillite/fluvial member of the Paterson Formation with local Cenozoic sands associated with the Lake Rason valley; and
- The Kanpa Formation Lower Sandstone member.

The Paterson Formation is unsaturated over most of the Water Supply Area, but may form a locally important phreatic aquifer (unconfined) where it extends deeper and the watertable is within formation. This possibly occurs beneath the eastern portion of the trough. Glacially carved palaeovalleys may also be important in the distribution of saturated portions of the unit, but these are difficult to locate in the subsurface. Where the permeable fluvial sands are saturated significant bore yields can be obtained, although the saturated thickness is usually thin which limits the transmissivity of the aquifer. The only known water bore constructed within the Paterson Formation near the Water Supply Area was the CRA Exploration hole MRM1C, located about 27 km W-SW of the Operational Area, which obtained a yield of approximately 500 kL/day, although the bore was not properly tested. Where the Kanpa Formation Upper Sandstone member is present beneath the Paterson Formation, it is likely to be hydraulically connected and form a single aquifer unit with the overlying units. Although the Lacustrine Member of the Paterson Formation is not identified in the Water Supply Area, where present elsewhere in the basin the shale and mudstone units act as an extensive aquitard (a layer of hydraulic impedance) separating the deeper tillite from the upper aquifer within fluvial deposits of the formation.

Colluvial and alluvial Cenozoic sands within the Lake Rason valley form local aquifer systems that may be hydraulically connected with the Paterson Formation in places. Approximately 22 m of saturated coarse grained sands were intersected in TP2580-T within the Lake Rason valley adjacent to the Frazer Range, and may be a productive aquifer in this area. Elsewhere, beneath the Rason palaeodrainage unconsolidated clayey and silty sediments that infill the valley are considered to have predominantly aquitard properties.

An aerially extensive aquifer is formed by the Lower Sandstone member of the Kanpa Formation. It is a low permeability aquifer that has a large extent covering approximately 1500 km^2 (25 x 60 km) with an average thickness of approximately 100 m. It is mostly confined below the Shale member with a sub-artesian piezometric pressure head above the top of the aquifer, but subcrops the Paterson Formation about its southern and eastern margins. The Paterson Formation is likely to be saturated over some of the subcrop area, so that the two aquifers will be hydraulically connected in these areas, possibly including beneath the very eastern limit of Lake Rason.

2.7 Aquifer Recharge and Discharge

Groundwater recharge over the Minigwal Trough is likely to be extremely low due to the low rainfall rates over the Great Victoria Desert, and probably averages just a few millimetres per year. Recharge, when it does occur, is likely to follow rare extreme rainfall and flood events associated with tropical depressions (usually ex-cyclones) that pass over the region. Most groundwater recharge is to the Paterson Formation, with the Lower Sandstone aquifer receiving recharge in the area that subcrops the Paterson Formation. Under natural conditions the rate of recharge via downward leakage through the Shale member aquitard will be very low.

Discharge of groundwater is mostly through evapotranspiration by plants in areas of shallow watertable and via direct evaporation from the lake surface. **Figure 2-20** is a schematic hydrogeological cross-section for Lake Rason showing the relationship between groundwater recharge, flow and discharge. Most interaction between Lake Rason and groundwater is associated with groundwater flow within the Paterson Formation fluvial aquifer and colluvium fringing Lake Rason. During past periods of higher water levels, groundwater discharge may have occurred higher along the valley margins and been responsible for formation of outwash fans observed along portions of the valley. There is poor hydraulic connection between the Lower Sandstone aquifer and watertable which is due to the intervening shale aquitard.

Seepage discharge of groundwater is apparent from the base of the Paterson Formation at several locations along the margins of the Lake Rason palaeovalley. **Figure 2-18** shows a series of seeps emanating from the Paterson Formation with associated salt accumulations along the southern margin of the valley at the eastern end of Lake Rason, about 5 km west of TWB026-T2.

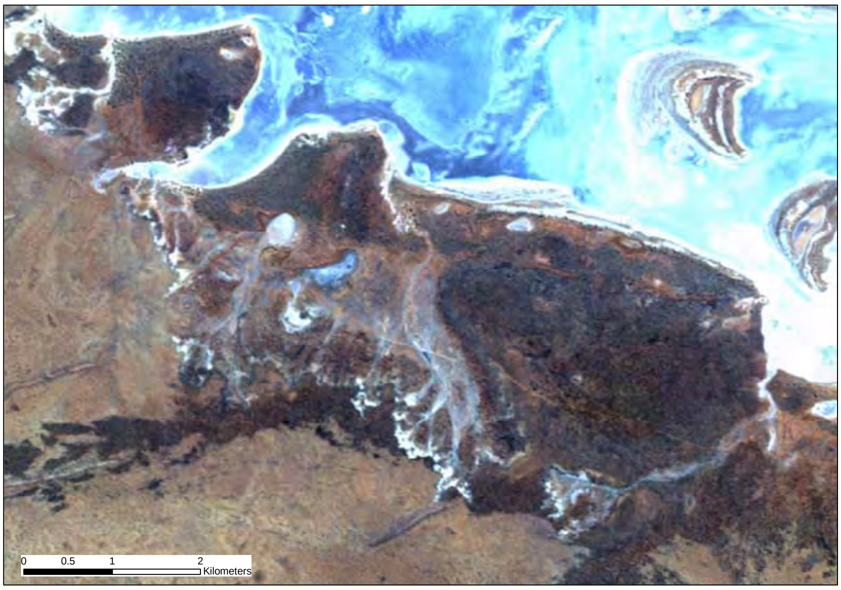


Figure 2-18: Groundwater seepage discharge from base of Paterson Formation aquifer, south-east Lake Rason

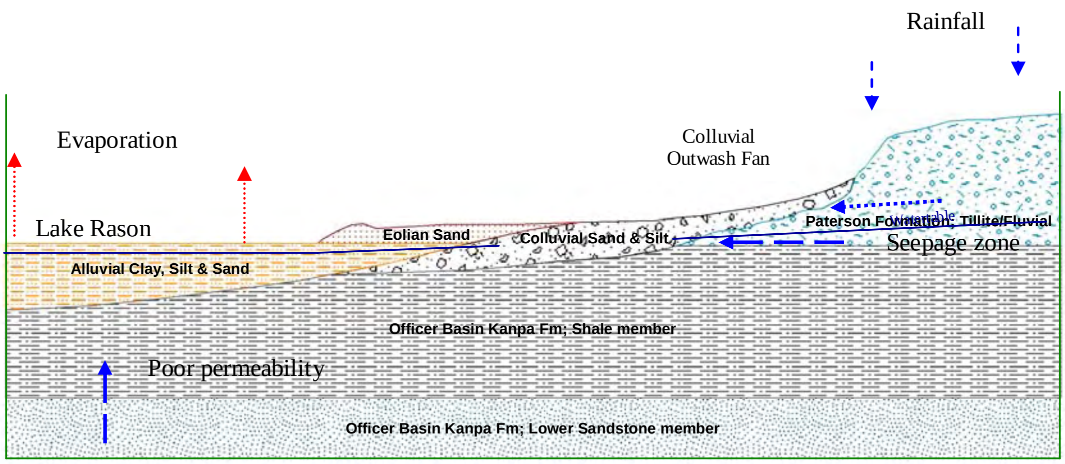


Figure 2-19 Schematic hydrogeological cross-section through Lake Rason

2.8 Groundwater Flow and Salinity

Regional groundwater flow is to the southeast toward the Eucla Basin, but deviates to the Lake Rason valley, which is a groundwater discharge feature. The watertable elevation in the Lake Rason valley floor is approximately 330 m AHD (Australian Height Datum), and rises to the south-west and north of the Lake. The watertable morphology is influenced by the Paterson Formation base elevation topography, which limits the water level to the base of the formation over much of its extent due to its significantly greater permeability compared to the underlying Officer Basin sediments. Interpreted water levels and groundwater flow directions in the Water Supply Area Trough are shown by **Figure 2-21**. South of the Rason palaeodrainage system, groundwater flow is toward the valley from a flow divide interpreted to be slightly little south of the Operational Area. South of the divide, groundwater flow is to the southeast.

The watertable can vary from just a few metres below ground at the lake down to 100 m below ground in the higher elevations of the Water Supply Area.

Groundwater in the Water Supply Area is saline to hypersaline, mostly with salinity between 10 000 mg/L and 270 000 mg/L. Evaporative concentration of salts within the Rason valley result in groundwater brine coincident with the valley, and a pattern of groundwater salinity decreasing away from the valley, shown by **Figure 2-22**. Groundwater salinity decreases south-west from Lake Rason, reaching a minimum of less than 35 000 mg/L within bores TWB017-T2 and TWB028-T1. Within the Lower Sandstone aquifer groundwater salinity tends to be greater where the aquifer subcrops Lake Rason, while it is less influenced by the lake where a thick cover of the Shale aquitard is present, such as is observed at OF5X1 in the western portion of the trough.

Relatively low salinity groundwater occurs within the Paterson Formation where it is saturated and situated away from Lake Rason. A field measured salinity of 12 300 mg/L was obtained from hole TWB025-X1, and probably represents water from the very base of the Paterson Formation. At more distant locations, groundwater from the Paterson Formation was found to have a salinity of 5 700 mg/L in Anaconda hole OF2T1, 63 km north-east of Lake Rason, and 4520 mg/L from OF3X3, 88 km south of the lake. At both locations the water came from basal tillile overlain by thick confining lacustrine clay of the Paterson Formation.

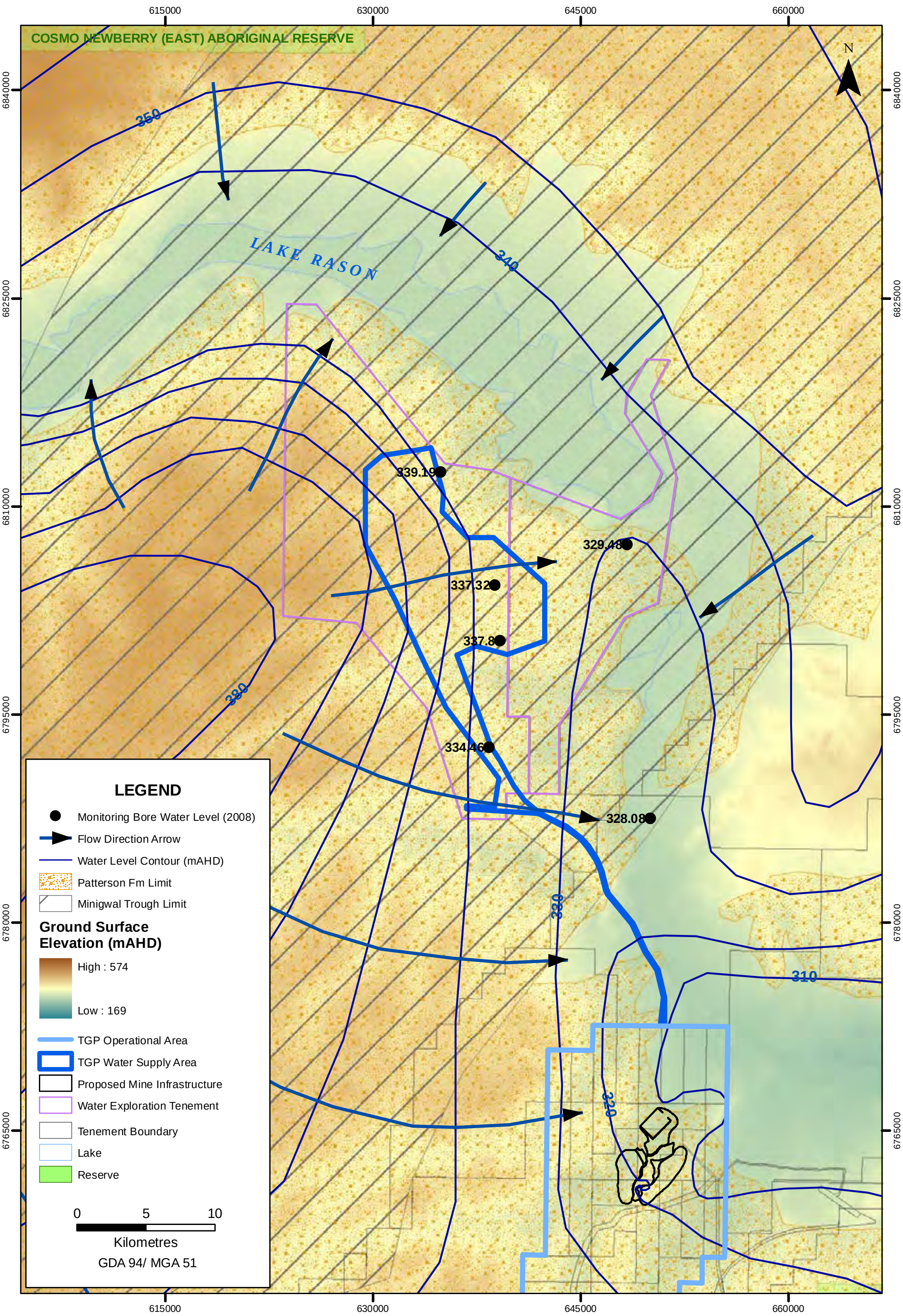


Figure 2-20 Groundwater levels and flow directions within the Minigwal Trough

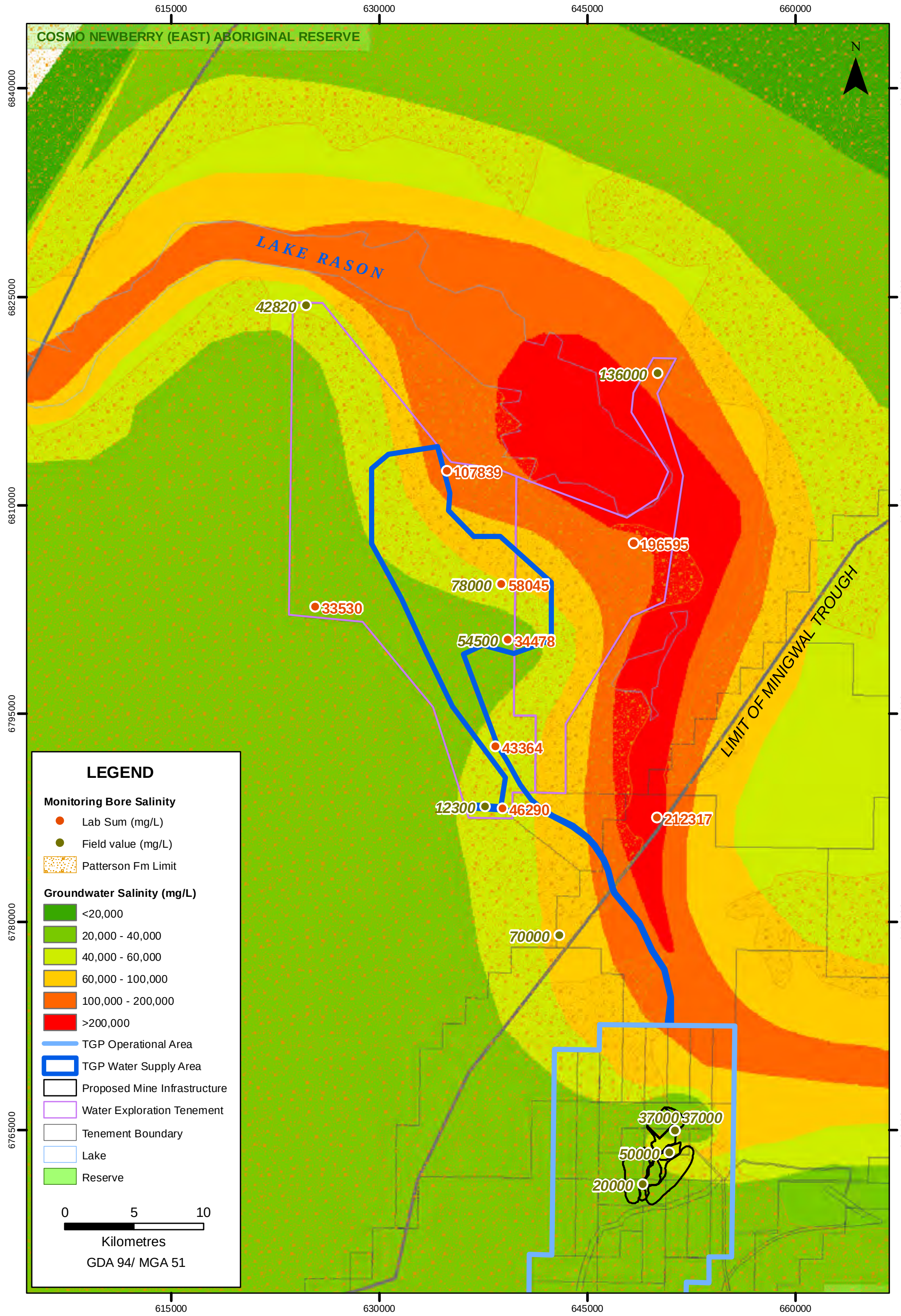


Figure 2-21 Groundwater salinity within the Minigwal Trough

2.9 Permeability and Storage

2.9.1 Cenozoic/Paterson Aquifer

The permeability of aquifer units within the Cenozoic deposits and Paterson Formation tillite and fluvial sediments have not been tested, but are evidently significantly greater than the Kanpa Formation sandstone. Dominantly medium and coarse grained sands within these formations potentially have a high permeability, with values of hydraulic conductivity potentially exceeding 20 m/day.

Due to their limited area and thickness of saturation the Cenozoic deposits and Paterson Formation do not form a substantial aquifer within the region. However, locally important aquifers are likely within the Lake Rason palaeovalley, for instance around the eastern margin of the Minigwal Trough within the Paterson Formation and about test-bore TP2580-T where Cenozoic deposits with 22 m of saturated coarse grained sands were intersected. These aquifers are predominantly unconfined, but portions of palaeochannel sands may be confined if present below the silt and clay deposits infilling the valley. The specific yield is likely to be up to 20% (0.2), although portions with substantial clay matrix will have lower values.

2.9.2 Kanpa Formation Lower Sandstone Aquifer

Hydraulic properties of aquifers within Officer Basin formations are available from laboratory analysis of samples, bore pumping tests and by comparison with similar aquifers elsewhere. In the Water Supply Area the Kanpa Formation Lower Sandstone member is a low permeability aquifer, where values for hydraulic conductivity of between 0.022 and 0.3 m/day have been determined for the sandstone.

Regional data on laboratory determined sediment permeability and porosity are available from several exploratory petroleum wells drilled in the Officer Basin. A fine to medium grained sandstone sample from Lancer 1 (597.1 m depth) belonging to the Kanpa Formation yielded a hydraulic conductivity of 0.057 m/day (68.5 milli-Darcy) and porosity of 23.7% (Haines, et al., 2004), while a similar sample from Empress 1 and 1A (567.5 m depth) produced a hydraulic conductivity value of 0.027 m/day (31.8 mD) and 23% porosity (Stevens and Apak, 1999) (note: 1 darcy = 9.66 X 10^{-6} m/s, or 0.834624 m/day hydraulic conductivity (Freeze and Cherry, 1979)). Higher values for hydraulic conductivity of 0.334 to 0.577 m/day (400 – 691 mD) were obtained for medium to coarse grained sandstone from the Kanpa Formation in Lancer 1(Haines, et al., 2004), and up to 0.31 m/day (371 mD) from Empress 1 and 1A (Stevens and Apak, 1999), although in this well most samples had a very low permeability probably due to interbedded mudstone and dolomite. Dolomite cemented sandstone intervals from Lancer 1 were found to have very low porosity and permeability (Haines, et al., 2004).

Two sandstone core samples from drill-hole TWB018-M3 yielded laboratory derived values of hydraulic conductivity of 0.022 m/day (2.6E-07 m/s) and 0.034 m/day (3.8E-07 m/s) using the falling head method on remoulded core samples (Attachment E). These values are consistent with those obtained from analysis of fine to medium grained sandstone samples from petroleum wells in the Officer Basin.

Pumping tests were performed on six bores slotted within the Lower Sandstone member of the Kanpa Formation, with another test undertaken on TP2580-T1 which was slotted within Mesoproterozoic sediments. All aquifers exhibited confined responses to pumping, except TWB017-T2 which appears to have entered unconfined conditions after 480 minutes once the water level draw down to about 79 m.

A summary of hydraulic data and analysis from the pumping tests are given in Section 3.4, and **Table 2.2** presents pumping test derived hydraulic parameters, including hydraulic conductivity calculated over the slotted interval and for the smaller sandstone section within the slotted interval. The portion of sandstone contained over the slotted interval has been estimated from gamma-ray logs for the holes. Values of hydraulic conductivity calculated over the sandstone portion are remarkably consistent, with the exception of the higher value from TWB017-T2, and suggests that hydraulic properties for the sandstone are relatively uniform through the investigation area. An average value for hydraulic conductivity of 0.1 m/day is derived for the slotted interval (transmissivity divided by slotted interval length), while a value of 0.15 m/day (excluding the outlying value from TWB026-T1) is determined over the sandstone portion. Hydraulic conductivity values determined over the sandstone portion are likely to over-estimate permeability of sandstone due to some minor contribution of water from dominantly clay and siltstone portions of the screened interval, while values calculated using the full slotted interval will under-estimate the permeability of sandstone. It is considered that sandstone contained within the Lower Sandstone member thus has an average value for horizontal hydraulic conductivity of about 0.14 m/day.

Table 2.2 Kanpa Formation Lower Sandstone pumping test derived hydraulic conductivity values

Bore	Test Rate (m3/day)	∆S (m/log cycle)	T (m3/d/m)	Slotted interval K (m/day)	Sandstone thickness	Sandstone K (m/day)
TWB015-T2	411	7.5	9.8	0.1	72	0.14
TWB017-T2	467	12.2	7.2	0.06	51	0.14
TWB018-T2	508	6.7	14.3	0.17	78	0.18
TWB023-T2	270	8.9	5.0	0.05	42	0.12
TWB026-T1	247	9.8	4.8	0.05	16	0.3
TWB029-T1	482	6.3	14.1	0.14	84	0.17

Permeability of approximately 0.14 m/day for sandstone of the Kanpa Formation Lower Sandstone member is consistent with friable sandstone aquifers elsewhere (**Figure 2-22**). Nonetheless, the Officer Basin deposits have a relatively low permeability when compared with other sand aquifers around Western Australia, such as:

- The Basal sand and gravel aquifers in the palaeochannel deposits on the Yilgarn Craton, where permeabilities are two orders of magnitude higher than the Officer Basin, and ranges from 10 to more than 20 m/day;
- The Yarragadee Formation sand aquifer in the Perth Basin, recognised as one of the most productive basin aquifers in Western Australia, where the permeability is about two orders of magnitude higher than the Officer Basin, and ranges from 5 to 20 m/day; and
- The Lennis Sandstone in the Gunbarrel Basin, 300 km north of the Operational Area, which has permeabilities that are one order of magnitude higher than the Officer Basin, ranging from 0.5 to 1.7 m/day.

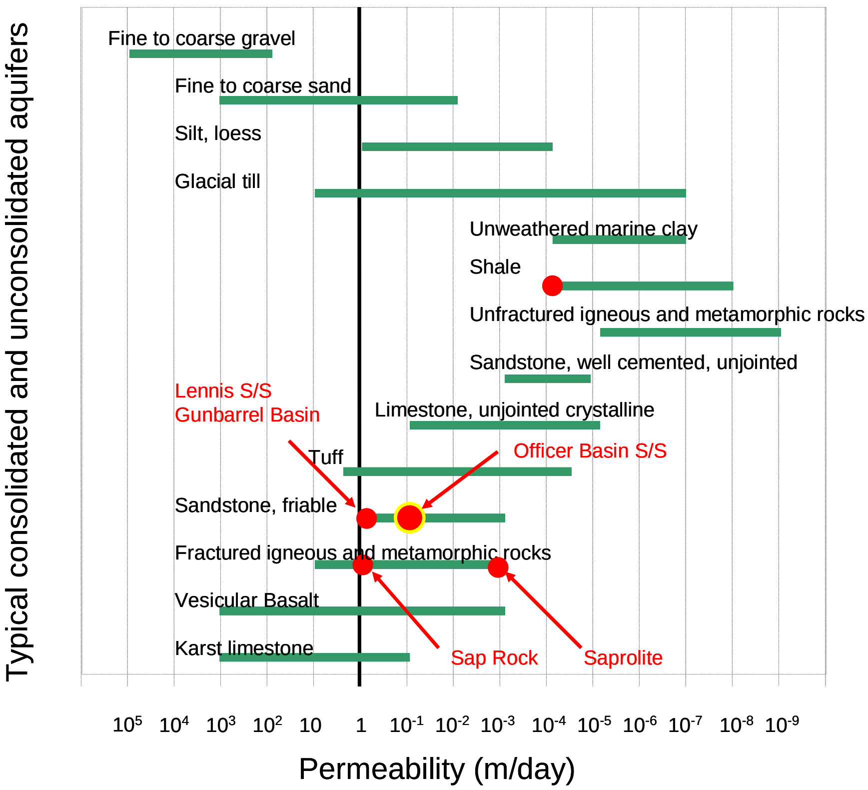


Figure 2-22 Comparison of hydraulic test (after Driscoll 1987)

The apparent discrepancy between laboratory and pumping test derived values of hydraulic conductivity are a reflection of the tests and what was being measured. The laboratory analyses have introduced some error by remoulding of the sample, but the main difference between the tests is that the laboratory values represent vertical permeability of the core, while pumping test vales are a measure of horizontal permeability. An average value for hydraulic conductivity of almost 0.03 m/day derived from the laboratory analysis and 0.14 m/day from pumping tests implies a vertical to horizontal relationship of about 1 : 5, which is consistent with what would be expected for a moderately anisotropic sandstone aquifer.

Although the permeability of the Officer Basin sand may be lower than other comparable aquifers, the aquifer has the advantage that it is relatively thick (50 to 200 m) which provides a useful transmissivity of between 5 and over 20 m^2/day. Transmissivity of the Lower Sandstone aquifer increases to the north-west, which is related mostly to the greater thickness of sandstone present. North of TWB017-T2 the aquifer transmissivity is between 10 and about 25 m^2/day, while to the south it is mostly less than 10 m^2/day. The Lower Sandstone aquifer intersected within TWB018-M3 contains 181.5 m of sandstone and is estimated to have a transmissivity of 25.4 m^2/day, which is considerably higher than the value of 14.3 m^2/day determined from the pumping test on TWB018-T2 as this bore did not fully screen the aquifer.

Specific storage for a confined aquifer is a difficult parameter to evaluate, and is a measure of the amount of water per unit volume of a saturated formation that is yielded from storage owing to compressibility of the mineral skeleton and the pore water per unit change in head. Values for specific storage are very small and have the dimensions of 1/L. Considering the tight and compact nature of the Lower Sandstone aquifer, a value for specific storage of approximately 10^{-6} /m is possible. This will yield a storativity value for the confined aquifer of about 10^{-4} /m, being the product of the specific storage and the aquifer thickness of 100 m.

The Specific Yield is important in the unconfined portion of the aquifer. It is a measure of the volume of water released per unit decline in the water level and is several orders of magnitude greater than storativity. Specific Yield for the Lower Sandstone is expected to be at the lower end for aquifers, probably in the order of 5% (i.e. 0.05).

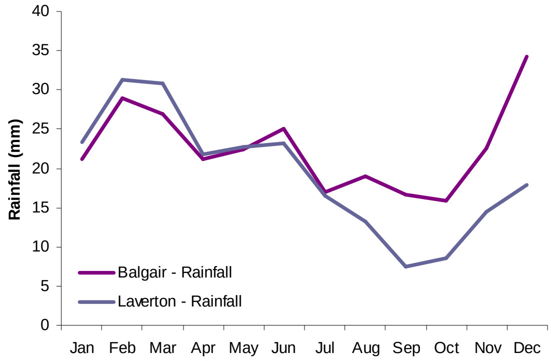
2.9.3 Mesoproterozoic

There are no apparent aquifer zones within the Mesoproterozoic sediments, which is a very low permeability unit. A pumping test performed on bore TP2580-T at a rate of 254 m^3/day yielded a transmissivity of 2.7 m^2/day, which is equivalent to a hydraulic conductivity of 0.03 m/day over the slotted interval. Water produced from the bore was probably yielded from small-scale fracturing associated with deformation of the unit and fissile partings within the shale. It is likely that the unit tightens further with depth.

2.10 Climate

The Great Victoria Desert is characterised by an arid climate, with hot summers and cool winters. Summer maximum temperatures average about 35 °C, while winter minima are around 5 °C. Annual rainfall around the Tropicana Gold Project is 200-230mm. Rainfall is related both to locally generated thunderstorms and to dissipating tropical cyclones tracking southeast. Thunderstorm activity tends to be greatest between October and December when cool airflows from the south wedges beneath humid northwesterly winds. Cyclonic activity is greatest between January and May reflecting the tropical wet season in the north of the state.

These two mechanisms of rainfall generation in opposing seasons lead to a more evenly distributed annual rainfall distribution than in most of the state. Rainfall is highest in the cyclone season (**Figure 2-23**). While relatively evenly distributed, rainfall is very infrequent with only about 30 rain days per year. Most of the annual rainfall is often received in one or two significant events, and many years have close to zero rainfall.



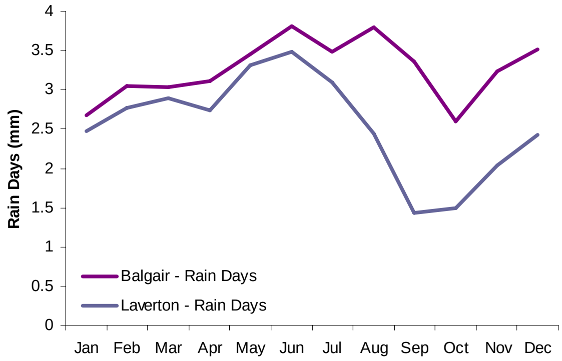


Figure 2-23: Monthly rainfall distribution at Balgair (1983-2008) and Laverton (1910-2008) about 300km to the south and west of the Operational Area respectively

3. GROUNDWATER INVESTIGATIONS

From the initial research, sandstones in the Minigwal Trough and Neale Junction areas of the Officer Basin were identified as the most prospective targets for obtaining the TGP's process water requirements within a 150km radius of the Operational Area. Several hydrogeological investigations were undertaken in the two areas between December 2007 and September 2008 to obtain the necessary hydraulic parameters and to develop an understanding of the system from which to build a representative numerical groundwater simulation model. This section describes the investigations undertaken, which have included:

- Interpretation of thematic remote sensing data including digital air photography, Ikonos, ALOS and Landsat 7 satellite imagery;
- Acquisition of 2306 line kilometres of airborne time domain electromagnetic (TDEM) geophysical traverses conducted orthogonal to the present day drainage in both areas;
- Construction of nine (9) reverse circulation exploratory holes drilled to define the extents and shape of the sandstone in the Minigwal Trough;
- Construction of eight (8) mud rotary test production water bores and two (2) observation water bores in the Minigwal Trough;
- Hydraulic pump test and recovery analyses on eight (8) test production bores to determine intrinsic properties of the aquifer such as permeability, storage and boundary conditions;
- Down hole geophysical logging of ten (10) test production and observation bores using long and short normal resistivity, together with natural gamma to define the lithological stratification within the sediments;
- Hydrochemical analysis of groundwater samples taken from each bore. All samples submitted to a NATA registered laboratory for major component analysis; and
- A regional water level survey of TGP and historic third party investigation bores to define a regional water table surface.

The following sections summarise the investigation program.

3.1 Thematic Remote Sensing

Thematic remote sensing encompasses the use of any remote satellite or areal imaging technique. Thematic imagery not only provides an additional source of correlation between published and unpublished geology, cadastral and topographic maps; it can also provide indications of the relative thickness of deposition, the likely provenance of sedimentary detritus, and the relative health and density of vegetation. **Figure 3-1** shows a regional mosaic thematic image over the Water Supply Area using the best available Ikonos, ALOS and Landsat 7 satellite imagery, and airborne orthophotography. The relative strengths and weaknesses of each imaging method are as follows:

- Digital ortho-air photography produces high quality images in terms of spatial resolution and contrast. However, air photo data acquisition is logistically difficult, costly and more time consuming than off-the-shelf satellite imaging techniques. TGP has surveyed or acquired public domain data much of the Fraser Range, with some overlap into the Minigwal Trough. Where available, air-photo images are used in preference to satellite imagery;
- Ikonos has the highest resolution of any commercially available earth observation satellite system, having one metre panchromatic (PAN) and four metre multispectral (MS) resolution, together with one metre pan sharpened spatial imagery resolution. Although not as high resolution as air-photos, Ikonos is less costly than air photo surveys and easier to design, with a choice of re-flights occurring every 3 to 5 days. Ikonos imagery were collected over most of the Water Supply Area;
- ALOS (Advanced Land Observing Satellite) is a Japanese satellite launched in 2006 which provides reasonably high quality (2.5 m resolution) and relatively low cost Earth observation data for topographical mapping, with new images taken every 46 days. The data costs are attractive for broad scale water exploration. Data was purchased from recent archival data as infill over much of the Water Supply Area and Neale Junction area;
- Landsat 7 is an inexpensive dataset, albeit that the data can have relatively poor resolution and significant data quality issues. Having been launched in 1999, Landsat 7 is now a relatively dated imaging technology with poor 30m pixel resolution. Since 2003, the satellite's Scan Line Correction (SLC) system has been corrupted with an irreparable mechanical fault which causes data drop out in almost 40% of each image. NASA rectifies this problem by infilling the gap areas with historic image data. Despite the poor imagery issues, Landsat 7 costs are nominal and therefore it provides an invaluable infill in the absence of any other image data.

This composite thematic remote sensing image was the basis for the interpreted Cenozoic regolith mapping over the Water Supply Area shown earlier in **Figure 2-11**.

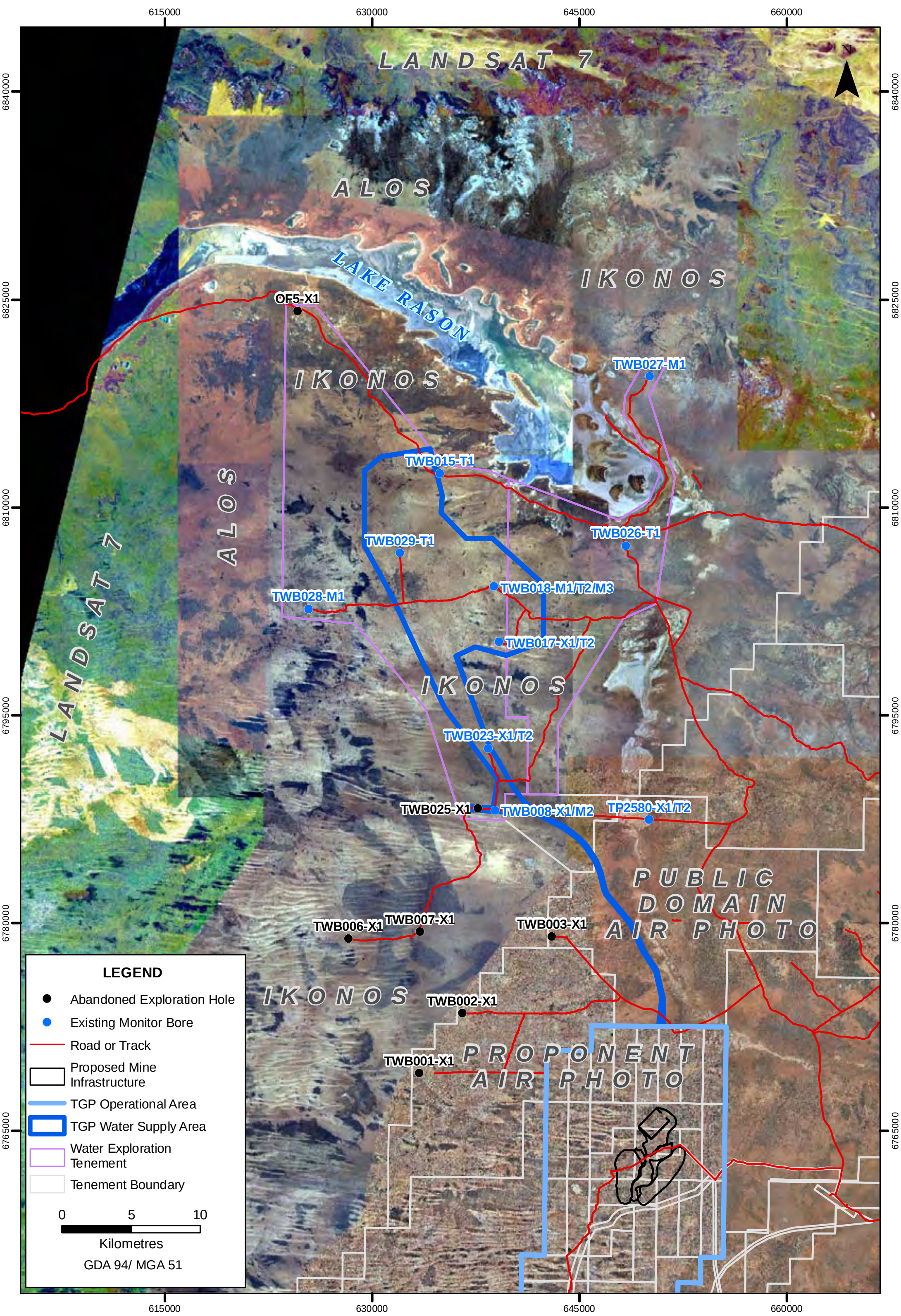


Figure 3-1 Composite thematic remote sensing image of the Water Supply Area

3.2 Airborne Geophysical TDEM Survey

Airborne geophysical techniques are often used as a rapid and cost effective method for delineating subsurface water resources over vast areas. Geophysical methods map contrasts in the intrinsic properties of the rock mass such as density, seismic velocity, magnetism or electrical resistance/conductivity. Of these, time domain electromagnetic methods (TDEM) have proven especially useful in groundwater investigations because of the relationships between conductivity, salinity and rock type. As part of the investigations 2306 line kilometres of airborne TDEM data were acquired over the Neale Junction and Water Supply Area, together with the proposed cable haul road, using the RepTEM system flown by GPX Airborne. The locations of all TDEM lines are shown in **Figure 3-2**.

The TDEM approach involves inducing an electromagnetic field via current flowing through a loop of wire. The electromagnetic field that is generated in the transmitter loop in turn induces secondary electrical currents to flow within the conductive ground. When the electric current in the transmitter loop is turned off, the secondary current continue to flow in the earth for several milliseconds, decaying outwards and downwards at a rate determined by the electrical properties of the ground. The decay of this secondary current in turn generates magnetic fields which can then be monitored by a receiver loop located in the centre of the transmitter loop. The current's decay over time can be converted to an apparent conductivity verses depth in the ground.

The innovation of placing the TDEM system in aircraft has revolutionised the speed and cost of data acquisition, allowing several hundred line kilometres of data to be captured in a day compared with just a few line kilometres using a ground TDEM system. The airborne TDEM approach is essentially the same as ground based TEM, except that the transmitter and receiver loops are stretched between a carbon fibre framework suspended 30m beneath a helicopter and 30m above the ground surface (**Figure 3-3**).

Raw TDEM data collected in the field undergoes several levels of processing and interpretation to derive parameters such as the channel structure and groundwater salinity along each transect. These layers of data processing include:

- Conversion of raw voltage data and its rate of decay in the receiving loop into apparent resistivities at given delay times for each reading;
- Conversion of the apparent resistivity and delay time data into an apparent resistivity and depth section;
- Inversion of the voltage decay data at each station into formation thicknesses and resistivities using computer based layered earth modelling; and
- Calibration of accurate basement depths and groundwater salinities by constraining the layered earth model with information re-entered from drilling logs and down hole geophysical logs.

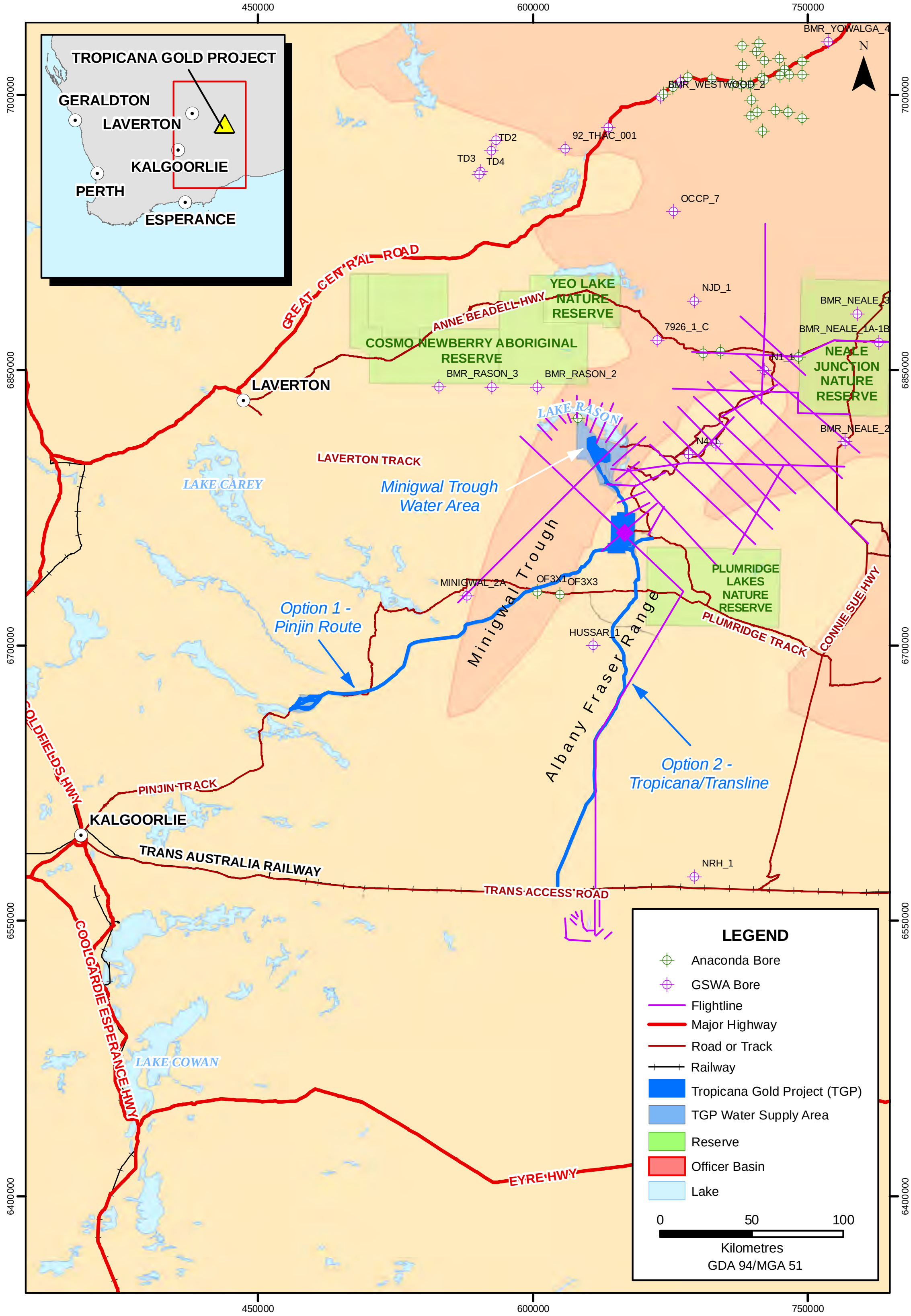


Figure 3-2 Location of RepTEM flight lines

Figure 3-3: RepTEM survey showing magnetometer stinger and transmitter and receiver coils (hoist) slung 30m beneath the aircraft, and flown 30m above the land surface

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Figure 3-4 shows several attempts to correct model raw conductivity data into a layered earth inversion (LEI) along a RC drilling transect at the lower end of Lake Rason. The inversion software has difficulty resolving the base of Cenozoic deposits (shown as green on the drill logs) through the high conductivity hypersaline groundwater, which for the most part resides in a black oil shale, which appears to have become particularly fractured along the faulted margin of the Fraser Range. The TDEM survey clearly distinguishes the water table contact (which appears as the flat surface in all LEI's) and the lateral extents of hypersaline groundwater away from the lake.

The third LEI down in the **Figure 3-3** appears to best resolve the base of Cenozoic deposits, but does not resolve anything below the Cenozoic. Extrapolation of this LEI into the conductivity depth images (CDIs) in the survey suggests that the Cenozoic deposits thicken further north around Lake Rason, but are still no more than 70m thick and appear to contain mostly hypersaline groundwater within the Lake Rason drainage area.

In conclusion, the RepTEM survey can resolve the base of Cenozoic deposits and has been useful in the production of the regional groundwater quality map (Figure 12.13); but it's inability to distinguish between the water bearing sandstone and the low permeability shales has limited its usefulness for water exploration of the Water Supply Area and Neale Junction area of the Officer Basin.

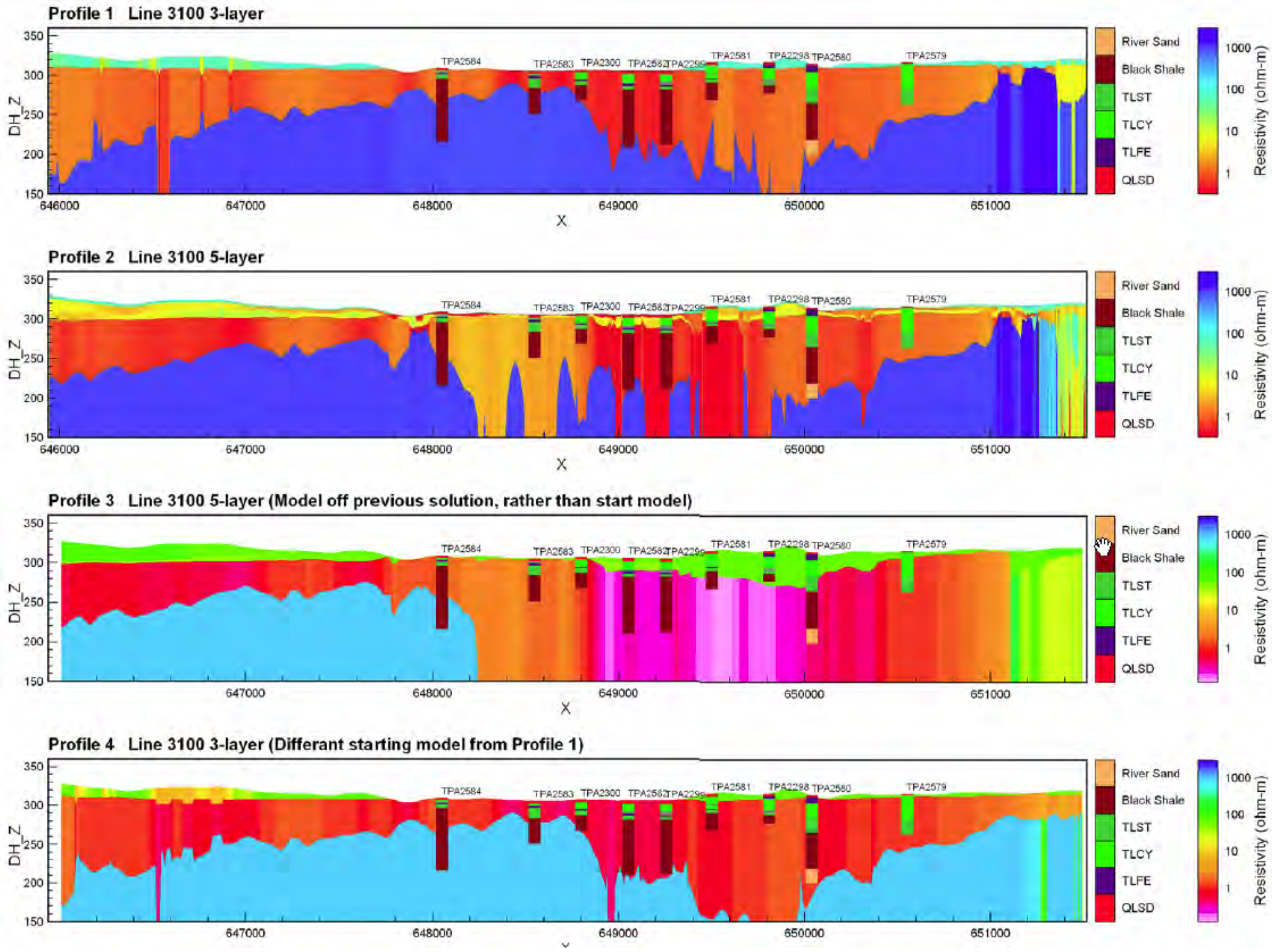

Figure 3-4 Example of a layered earth inversions on a drilling transect south of Lake Rason

3.3 Drilling and Bore Construction

A preliminary exploration drilling program was undertaken in the Lake Rason area between September and November 2007 using a Reverse Circulation (RC), Mud Rotary and Diamond drilling and pump testing program undertaken from December 2007 to September 2008. **Table 3.1** summarises the bore construction details for twenty-one (21) exploratory and test holes completed during the program.

Drilling contractor Ranger Drilling, was engaged to undertake the Reverse Circulation drilling program; Drilling and Grouting Services (DGS) and Scanlon Drilling were engaged to undertake the drilling and casing of all water bore installations; and Drillcorp were engaged to undertake drilling of a stratigraphic diamond hole at TWB018. Construction procedure was in accordance with the following protocols, with all field operations being under the direct supervision by a geoscientist.

- **RC Exploration holes:** Preliminary reverse circulation (RC) air holes were drilled at each location to identify the top of potential sandstone aquifer formations. Each hole was drilled until the hole became unstable, usually at depths ranging from 150m to 230m. The hole was geologically logged by a geologist with chip samples sieved and stored in chip trays every metre. Upon completion, the hole was either opportunistically cased with 100mm or 50mm PVC or capped and abandoned.

- **Mud Rotary Test Production Bores**: At each location a 216mm or 130mm (DGS, Scanlon respectively) pilot hole was first drilled to 400m or until the penetration rate slowed to less than 4m/day using the mud rotary method with a tungsten carbide blade bit. Where competent formations were encountered the blade bit was exchanged for a tricone roller (TCI) bit. On completion of the pilot hole, the hole was lithologically and geophysically logged to full depth using a down hole gamma/calliper or a gamma-long short normal resistivity sonde. Un-sieved chip samples were collected every metre down the hole and stored. DGS holes were then reamed to 300mm cased using a combination of 205mm (i.d.) class 12 PVC in the upper 100m and 150mm (i.d.) class 18 blank and machine slotted liners to the bottom of the hole. Scanlon holes were reamed to 285mm cased to full depth with 195mm (i.d.) class 12 PVC blanks and machine slotted liners to full depth.

  After installation of the casing, the annulus of the hole was backfilled with 1.6 to 3.2 mm graded gravel to 6m above the screens followed by a minimum 4m of bentonite/cement grout. This plug was only necessary where there was a distinctly permeable layer above the screens to prevent any surface water seeping down through the gravel pack. The remaining annulus was then backfilled with gravel pack and cemented at surface. Finally, the bore was developed for at least 6 hours to remove drilling muds. Airlift bore yields were determined during the course of bore development using a V – notch weir (see. **Figure 3-5**)

- **Mud Rotary Monitor Bores:** Two low yield pilot holes were completed as monitor bores for regional Stygofauna and water level observations. The monitor bores were constructed with 100mm class 12 PVC or 150mm (i.d.) class 18 PVC pipe with machine slotted liners set opposite the main water bearing intervals. The annulus of the hole was then backfilled with 1.6 to 3.2 mm graded gravel to 6m above the screens and included a bentonite/cement grout plug as necessary. The remaining annulus was then backfilled with gravel pack and cemented at surface. The bore was then developed with air for a minimum six hours until the discharge ran clear.

- **Diamond Hole:** A 216mm pre collar hole was first drilled to the base of the Upper Shale using rotary air blast. An NQ Diamond hole was then cored from 82 to 385m. Drill core was collected in core trays, photographed and logged and all samples transferred to the TGP core farm. Select core intervals were collected and submitted to CSIRO and SGS Western Geotechnics for further aquifer characterisation. On completion of the diamond hole, the hole was backfilled to 162m and cased using 50mm (i.d.) uPVC casing with machine slotted liners from 82 to 162m. The annulus of the hole was backfilled with clean washed gravel. The hole could not be developed with air due to a lack of appropriate downhole hoses.

Completion drilling logs for all bores are included in **Attachment A**.

The percussion hammer bit employed in the RC program has a fairly rapid penetration through the alternating stiff clay and hard dolomitic sandstone sequence in the Officer Basin, but as the hole penetrates deeper beneath the water table the continuous airlifting causes the friable sandstone to destabilise and collapse into the hole as running sand. Thus while RC drilling can reach to depths of up to 180m below the water table (230m total depth), the hole by this stage is too unstable to be able to install bore or piezometer casing.

The mud rotary method avoids problems with running sands by keeping the hole saturated. However, drilling with mud also limits the choice of drilling tools to two non-percussion drill bits, being either a solid blade or a tricone (TCI) bit. Neither bit can achieve the fast penetration rates achievable with the percussion hammer. The TCI bit is most effective in moderately hard rock, but rapidly clogs up in stiff clay. On the other hand, blade bits are most effective in soft to firm clay, but have a very slow penetration through stiff clay and hard dolomite layers (See **Figure 3-5**). The drilling penetration rates in the mud rotary program in the Minigwal Trough were thus very slow, which contributed to drilling costs.

Figure 3-5: An example of a mud rotary chevron blade bit fouled by stiff grey clay (left); airlift yield in progress in the bore development phase (right).

Table 3.1 Summary of investigation bore completions

Bore	Easting	Northing	Method	Driller	Lithology	Depth (m)	Cased (m)	Casing Dia (mm)	Screen (m)	Airlift (kL/d)	TDS (mg/L)	SWL (m)	RL (mAHD)
TWB002-X1	636491	6773516	RC	Ranger	30 thick sand unit overlying a brown sandstone.	213	Uncased	Backfilled		-	-	-	
TWB003-X1	643010	6779062	RC	Ranger	Siltstone, dolomite and minor sandstone	201	Uncased	Backfilled		<50	~70,000	-	
TWB006-X1	628288	6778873	RC	Ranger	Porcelainised clays above puggy reduced clays	231	Uncased	Backfilled		-	-	>95	
TWB007-X1	633422	6779396	RC	Ranger	Porcelainised clays above puggy reduced clays	232	Uncased	Backfilled		-	-	-	
TWB008-X1	638873	6788229	RC	Ranger	Cenozoic loose sand cover sand	24		Backfilled		-	-	-	
TWB008-M1	638892	6788169	Mud	DGS	Claystone	276	82	205	50 - 80	<50	46,610	61.0	380
TWB015-T1	634879	6812465	Mud	DGS	Siltstone, dolomite and minor sandstone	268	222	205/150	78-90, 108-120, 126-132, 150-216	534	107,850	24.0	362
TWB017-X1	639110	6800381	RC	Ranger	reduced clays above fine sandstone & dolomite beds	165	Uncased	Backfilled		726	~38,500	50.0	
TWB017-T2	639189	6800330	Mud	DGS	Siltstone, dolomite and minor sandstone	334	222	205/150	60-108, 108-138, 180-216	480	34,490	46.0	362
TWB018-M1	638695	6804318	RC	Ranger	reduced clays above fine 'beach' sand	189		Backfilled		594	~62,000	45.0	
TWB018-T2	638818	6804313	Mud	Scanlon	Siltstone, dolomite and minor sandstone	317	210	195	68-152	500	58,060	48.0	381
TWB018-M3	625377	6802652	DDH	Drillcorp	Siltstone, dolomite and minor sandstone	385	162	50	82-162	N/A	N/A	N/A	N/A
TWB023-X1	638387	6792634	RC	Ranger	Siltstone, dolomite and minor sandstone	192		100		-	-	27.5	
TWB023-T2	638379	6792642	Mud	DGS	Siltstone, dolomite and minor sandstone	334	234	205/150	114-222	270	43,380	46.0	380
TWB025-X1	637619	6788316	RC	Ranger	Cenozoic sand above grey claystone	228	Uncased	Backfilled		<50	~12,300	-	
TWB026-T1	648337	6807253	Mud	Scanlon	Siltstone, dolomite and minor sandstone	245	162	195	54-156	270	196,640	22.0	350
TWB027-M1	650061	6819481	Mud	Scanlon	Siltstone, dolomite and minor sandstone	149	144	100	24 - 78	<50	33,630	4.0	352
TWB028-M1	625366	6802691	Mud	DGS	Siltstone, dolomite and minor sandstone	200	200	100		<50	-	-	425
TWB029-T1	632019	6806729	Mud	DGS	Siltstone, dolomite and minor sandstone	200	200	205/150					401
TP2580-T2	650023	6787499	Mud	Scanlon	Hard fissile shale	156	150	195	42-144	306	212,330	-	324

Note: TDS values are derived from laboratory analysis, unless preceded by a ~ sign. In this event the values are estimated from field electrical conductivity.

3.4 Hydraulic Testing

To develop a thorough appreciation of the hydrogeological system and its likely long term performance it is important to assess the hydraulic properties of all rock units. In particular, the complex distribution of permeability and storage are the main input parameters used to develop the numerical groundwater model, which will be discussed in Section 4.

Aquifer permeability (hydraulic conductivity) describes the rate that groundwater flows through an aquifer under a uniform hydraulic gradient, per unit thickness of aquifer. Permeability is commonly derived from another closely related parameter, transmissivity, which is calculated from analysis of groundwater level response to controlled pumping of test bores. Permeability is the transmissivity divided by the effective thickness of aquifer screened in the bore.

Aquifer "storage" is a generic term that is sometimes used to describe a number of related, but quite different aquifer parameters. Aquifer porosity is the total percentage (by volume) of water that is held in a saturated medium, whether filling the intergranular pore spaces (primary porosity) or filling structural defects such as joints and fractures (secondary porosity). Porosity is not a useful measure of aquifer resources because not all pore water is commandable by pumping. Some pore water (referred to as the specific retention) is firmly held in the aquifer by capillary action and other forces, and in some cases pores may be poorly interconnected. The Specific Yield (Sy) describes the proportion of a saturated medium that will free drain towards a pumping bore and it is this storage term that is most relevant to water resource investigations in phreatic aquifers. Confined aquifers contain a further storage component known as the compressible storage, which is released by depressurisation of the aquifer. Compressible storage is usually low, being orders of magnitude less than the aquifer's Specific Yield.

A field hydraulic test program was conducted in the Water Supply Area between February 2008 and September 2008, during which time seven (7) bores were tested. In each test a six (6) inch diameter submersible electrical pump was set up and a step test was performed where the bore pumped at five different rates allowing at least 90% recovery in between. The information from the step test allowed the setting of a constant discharge rate for a 48 hour pump test, followed by a period of recovery measurements (see **Figure 3-6**). Water level measurements were recorded manually during both the test pumping and recovery phases, running dip meter down a thin PVC tube slotted at the bottom. A vibrating wire piezometer was also set up in the pumping bore to take automatic readings by means of reading the pressure changes resulting from a change in head of water above the sensor.

All saline discharge from each test was captured in a 25 x 25m turkey's nest constructed near each bore (**Figure 3-6**).

Figure 3-6: Constant rate test pump test being conducted on a test production bore in the Water Supply Area with the saline discharge water captured in a turkey's nest.

Hydraulic response curves for all constant rate pumping tests are presented in **Attachment B**. Reference to these curves show an initial high rate of drawdown in the first several minutes due to well loss effects, usually followed by a period of straight-line logarithmic drawdown. The slope of the straight-line response is a function of the abstraction rate and the near well aquifer transmissivity, which can be readily calculated using a number of empirical equations such as the Cooper and Jacob time-drawdown analysis.

Summaries of near well permeabilities calculated from each test bore are presented in **Table 3.2**. The table indicates that the permeability of the dolomitic sandstone in the Water Supply Area ranges from 0.05 to 0.17 m/day with a median value 0.06 m/day.

Table 3.2 Summary of hydraulic tests

Borehole	Discharge rate (KL/day)	Type of test	SWL (mbtoc)	Max drawdown (m)	Duration (min)	Transmissivity (m2/d)	Permeability (m/d)
TP2580-T2	254	CRT	8.1	60	1440	2.7	0.03
TWB015-T1	411	CRT	23.8	51.6	2880	9.8	0.10
TWB017-T2	467	CRT	28.2	52.6	1969	7.2	0.06
TWB018-T2	508	CRT	47.7	7.2	2993	14.3	0.17
TWB023-T2	206	CRT	45.6	39.4	111	4.2	0.04
TWB026-T1	247	CRT	22.6	65.9	2580	4.8	0.05
TWB029-T1	482	CRT	65.4	24.0	240	14.1	0.14

3.5 Downhole Geophysical Survey

A comprehensive induction and gamma logging program has been used to evaluate the stratigraphy throughout the Water Supply Area. Induction and gamma logging has been conducted on nine (9) holes and two observation bores in the mudded hole.

An induction tool measures horizontal resistance to current flow induced in a volume of earth around the induction tool. The volume of earth energised by the tool is dependent on its operating frequency and the conductivity of the earth. The induction tool used an operating frequency of 28,000 Hz giving a skin depth (signal penetration) of 29m, 9.4m, and 2.9m at conductivities of 10, 100, and 1000 mS/m respectively. By integrating induction log data with lithological logs and water quality samples, it is possible to infer groundwater salinity stratification and differences in the mud penetration between loose and cemented rock units.

All rocks and soils emit gamma radiation in varying amounts. The primary gamma emitting materials are potassium 40, uranium, and thorium. These elements tend to be more abundant in fine-grained sediments. By measuring the amount of emitted gamma radiation as a function of depth it is possible to resolve the degree and thickness of inter bedding between sand and silt beds.

All gamma logs are included on the bore logs in **Attachment A**.

3.6 Water Quality Analyses

During the course of the drilling and testing program, a number of water samples was collected at each bore location and tested in the field for total dissolved solids (TDS), temperature and pH. Samples are usually taken at the completion of airlift development and also at several times during the test pumping of the bore. Representative natural water samples (no preservatives) were submitted to a NATA certified laboratory for major component analysis of sodium, potassium, calcium, magnesium, chloride, bicarbonate, and sulphate and minor species fluoride, aluminium, silica, manganese, iron, strontium, barium, phosphorus, nitrogen, total dissolved solids and pH. Laboratory assay results are provided in **Table 3.3.**

3.7 Scanning Electron Microscopy (SEM) Analysis

Drill core from the Lower Sand in TWB018-M3 was examined using a high resolution optical binocular microscope. While the sand appears relatively uniform throughout its depth extent, its very fine grain size makes it difficult to characterise even at the 25x magnification of optical methods. Thus one representative core sample of Lower Sand from 220m depth was submitted to CSIRO's Electron Beam and X-ray Laboratories in the Australian Resource Research Centre, in Perth for very high resolution scanning electron microscopy analysis.

To preserve the structural integrity of the core, the sample was not washed, and only air dried prior to analysis. This limited preparation runs the risk of sample contamination from drilling additives, such as drilling muds (clay) and salts. The analysis was conducted on a Philips (now FEI) XL40 controlled pressure Scanning Electron Microscope (SEM), fitted with an EDAX energy dispersive X-ray spectrometer. The SEM was operated at an accelerating voltage of 30kV and the chamber pressure was varied between 0.1 and 0.5mBar to prevent charging of the nonconductive samples. X-ray Diffraction (XRD) data was collected using a Philips X'Pert XRD fitted with a Co tube operated at

Table 3.3 Groundwater chemistry results from investigation bores

Parameter	Units	TP2580-T2	TWB008-T2	TWB015-T1	TWB017-T2	TWB018-T2	TWB023-T2	TWB026-T1	TWB028-T1
DATE SAMPLED		26/06/08	8/06/08	3/06/08	5/06/08	8/05/08	6/07/08	30/05/08	8/07/08
Electrical Conductivity	uS/cm	176,000	57,400	116,000	42,000	68,900	51,000	151,000	43,800
TDS	mg/L	212,330	46,610	107,850	34,490	58,060	43,380	196,630	33,630
pH		6.6	7.8	7.1	7.4	7.4	7.4	6.2	7.4
Ion Balance		1.06	0.95	1	0.86	0.9	0.93	0.99	1.03
Sodium - Filterable	mg/L	71,000	13,000	35,500	9,400	17,900	11,400	64,900	10,000
Chloride	mg/L	122,000	27,000	63,000	20,000	35,000	24,000	118,000	17,300
Calcium - Filterable	mg/L	680	1,200	770	770	690	1,340	480	770
Magnesium - Filterable	mg/L	7,890	1,630	3,380	1,060	1,460	1,880	6,910	1,320
Carbonate as CaCO3	mg/L	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate as CaCO3	mg/L	27	1,300	49	65	85	74	25	480
Sulfate	mg/L	9,100	1,900	4,900	3,100	2,800	4,600	5,300	3,500
Fluoride	mg/L	0.3	0.4	0.2	0.4	0.2	0.2	0.3	0.4
Nitrate as NO3	mg/L	120	<1	<1	<1	<1	<1	<1	<1
Potassium - Filterable	mg/L	1,500	260	240	83	110	70	980	160
Aluminum - Total	mg/L	0.028	59	0.18	0.13	0.16	0.044	0.89	36
Barium - Total	mg/L	0.019	0.65	0.027	0.022	0.026	0.05	0.023	0.69
Beryllium - Total	mg/L	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	0.002	<0.001
Boron - Total	mg/L	4.2	3.9	2.4	2.2	2.6	2.3	2.2	4.2
Cadmium - Total	mg/L	0.002	0.004	0.003	0.002	<0.002	<0.002	<0.002	<0.002
Cobalt - Total	mg/L	0.007	0.03	<0.005	<0.005	<0.005	<0.005	<0.005	0.012
Copper - Total	mg/L	0.014	0.19	0.011	0.077	0.008	0.007	0.016	0.022
Iron - Total	mg/L	3.9	250	6.4	9.2	14	6.9	34	46
Lead - Total	mg/L	0.015	0.1	0.031	0.02	0.015	<0.010	0.015	0.033
Manganese - Total	mg/L	1.7	9.2	0.96	1.1	1.2	3.9	1.6	14
Molybdenum - Total	mg/L	0.006	0.025	0.007	<0.005	<0.005	<0.005	0.015	<0.005
Nickel - Total	mg/L	<0.005	0.2	<0.005	<0.005	<0.005	<0.005	0.04	0.036
Selenium - Total	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Silver - Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tin - Total	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Zinc - Total	mg/L	0.13	0.49	0.018	0.021	0.014	0.009	0.081	0.15

40kV, 40mA and an Fe filter; using the following settings: 2-theta range = 5–65°, Step size = 0.03°, Step time = 1s, Divergence slit = 1mm Fixed, Receiving slit = 0.8mm.

Figure 3-7 shows a typical SEM image of the Lower Sand at moderate SEM magnification (at 200x magnification), which reveals the sand to be composed mainly of angular to sub-angular grains with particle sizes that are generally less than 160µm (0.16mm), being classed as SP, a fine poorly graded SAND according to AS1726-1993. The sand is well packed with interstitial pore spaces being typically less than 50µm. The XRD analysis in **Figure 3-8** indicates the sand to be primarily of quartz with smaller quantities of clay minerals, hematite and halite (NaCl); the latter probably remnant from the *in situ* hypersaline groundwater in the bore. **Figure 3-9** shows that at 1600x magnification, there is evidence of weak mineral cementation between many of the grains. In most cases, however, the bridging mineral is potassium chloride (a soluble salt used in the drilling process), which suggests this to be an artefact of the drilling additives.

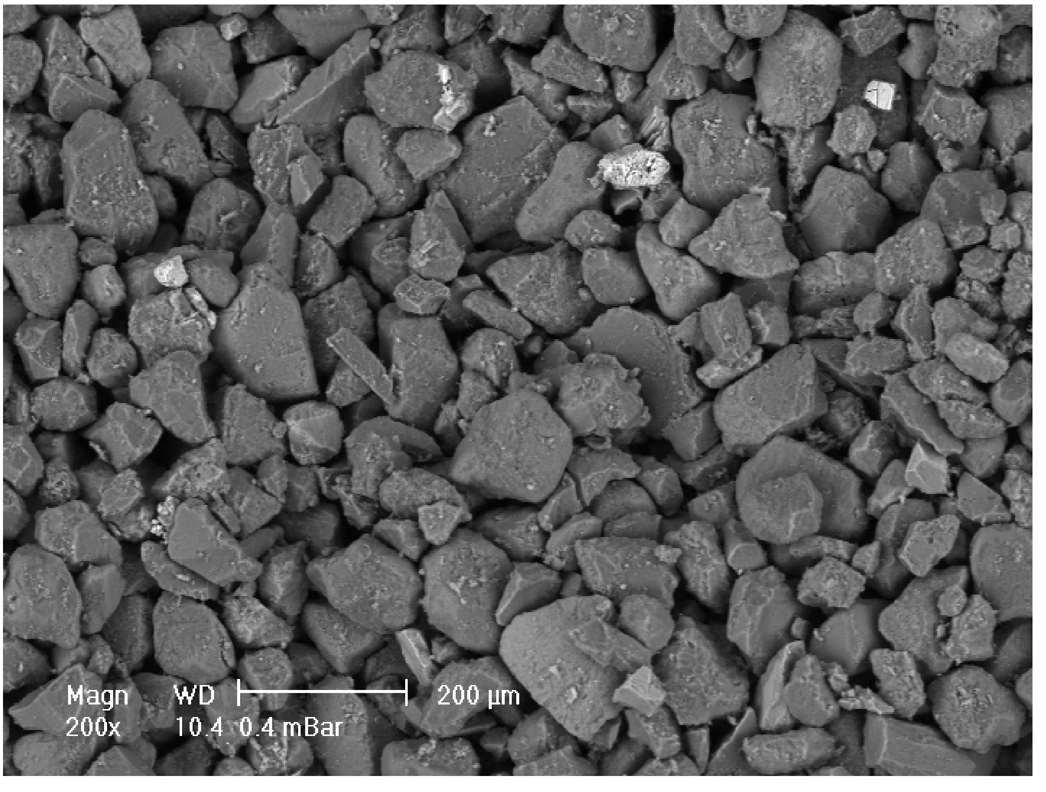

Figure 3-7 Scanning Electron Microscope (SEM) image of Lower Sand drill core sample from TWB018-M3 at low magnification

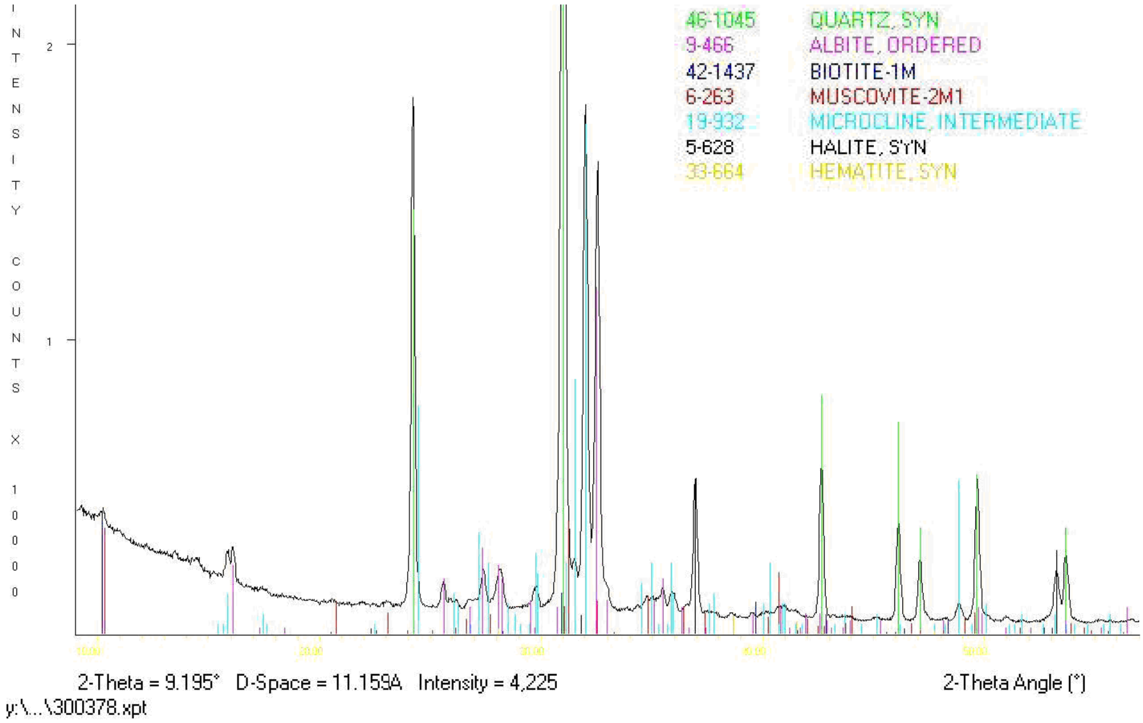

Figure 3-8 XRD analysis of the Lower Sand drill core sample from TWB018-M3

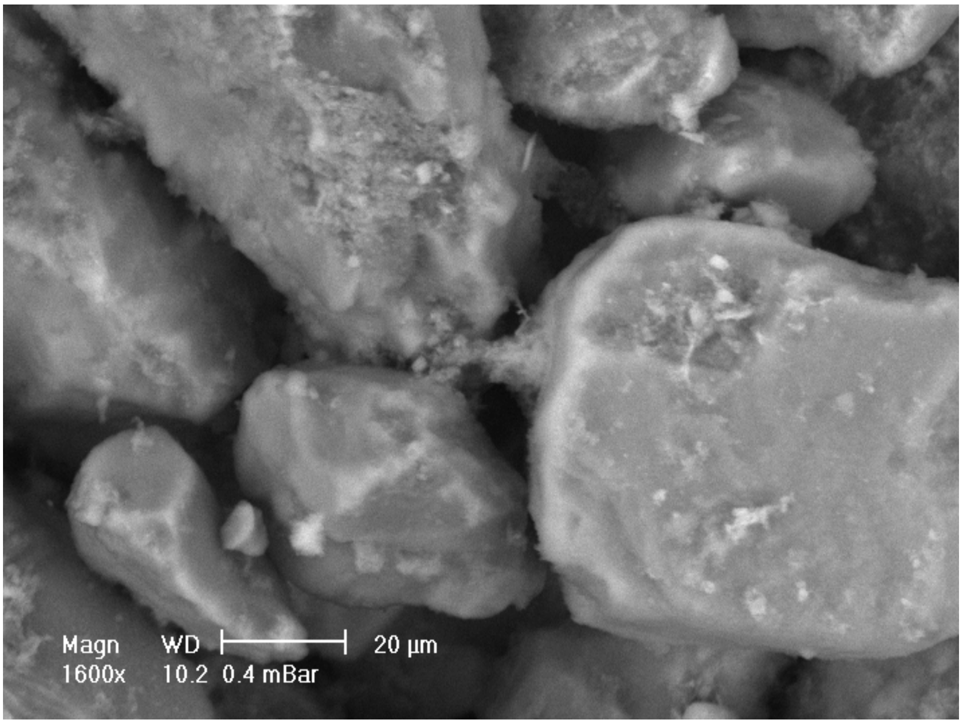

Figure 3-9 Very high magnification SEM image of sediment grains showing potassium chloride bridges between grains at centre of image

3.8 Laboratory Hydraulic Tests

Typical Lower Sand samples were obtained from TWB018-M3 drill core from 70m and 220m depth and were submitted to SGS Western Geotechnics, Engineering Materials Testing & Investigations division. All core samples were cut, remolded and recompacted to fit within a test ring 50mm high by 25mm radius. Each sample was saturated under vacuum and weighed; free drained for 8 hrs and then weighed again; oven dried and then weighed again to determine bulk dry density and saturated moisture contents. The samples were then resaturated and tested in a falling head permeameter with a head of about 1.6m. The results from the laboratory analyses are presented in **Attachment C** and summarised in **Table 3.4**.

Table 3.4 Laboratory measure density, moisture content and permeability

Sample	Depth (m)	Dry Density (t/m3)	Moisture Content (%)	Permeability (m/day)
A	70	1.76	14.0	0.02
B	220	1.73	13.2	0.03

While moisture contents of between 13 to 14% are typical for fine sands, an approximation of specific yield (the drainable component of the moisture content) was not possible in the laboratory.

The laboratory determined permeability values of 0.02 and 0.03 m/day are about an order of magnitude lower than the field measured permeability for TWB018-T2. This difference is likely due to the permeameter test reflecting the vertical permeability, while the pump test provides a measure of horizontal permeability. The anisotropy likely results from micro-layering in the core sample, with a factor ten a typical ratio of vertical to horizontal hydraulic conductivity in a sedimentary aquifer.

4. NUMERICAL MODEL SIMULATION

The use of computer-based numerical models as an aid to problem solving in groundwater investigations provides a powerful tool for the rationalisation of spatial and temporal variability of field conditions (e.g. variations in aquifer transmissivity, pumping, etc.). The development of a numerical model also facilitates sensitivity analyses that assist in understanding the dominant parameters and mechanisms within an aquifer system. The modelling process is a method of simulating groundwater regimes by a system of mathematical equations based on Darcy's Law for groundwater flow. The process requires definition of the following characteristics of an aquifer system:

- The aquifer geometry, including lateral and depth extent;
- The aquifer hydraulic properties - permeability, Specific Yield etc.; and
- The regional head distributions or fluxes - rainfall recharge, throughflows, outflows and borefield abstraction.

The use of computer-based numerical models can overcome the difficulties inherent in assessment of hydrological systems using classical analytical methods, which mostly assume aquifer homogeneity and are more applicable to the interpretation of localised aquifer response.

In this section a numerical aquifer simulation model is developed to evaluate the feasibility of the proposed borefield abstraction in the Water Supply Area and assess the likely regional impact from depressurisation of the Lower Sandstone.

4.1 Groundwater Model Design

Aquifer modelling in this investigation was undertaken using the FEFLOW finite element model code (Diersch 2006). The finite element method employed by FEFLOW requires discretisation of the modelled area into a mesh of triangular elements defined by a series of nodes. Solutions are obtained for potentiometric head at each node point within the model domain and linear interpolation is then employed between nodes.

The Water Supply Area model mesh covers an area of 1,980km^2 and consists of 75,609 nodal points defining 100,074 triangular elements.

The mesh is enhanced by way of increased nodal density around the area of the proposed borefield. A two layer modelling approach has been adopted to accommodate stratigraphic complexity in the hydrogeological model. The model mesh is shown in **Figure 4-1**. Key features of the model include:

- Boundary effects are minimised by placing all model boundaries at least 10km from the proposed borefield. To avoid over-constraining the model solution, most of the model boundaries are assigned as no-flow boundaries, coinciding with either hydraulic boundaries, groundwater divides or groundwater streamlines.
- The model has two layers defined by three slices (contour surfaces). The top layer (layer 1) in part represents a saturated low permeability Upper Shale which overlies and confines the Lower Sandstone aquifer. Elsewhere, Layer 1 represents the saturated part of the Paterson Formation, which overlies both the Upper Shale and the Lower Sandstone. For the most part,

Layer 2 represents the Lower Sandstone, however, where the model has been extended beyond the extents of the sandstone, Layer 2 represents the Mesoproterozoic sediments;

- The top surface of the model (Slice 1) has been derived from the 9 second digital elevation model, whereas Slices 2 and 3 represent the top and base of the Lower Sandstone based on interpretation of the drilling results;
- One way fixed head nodes (which can take water out of the model, but can not recharge the model) have been assigned at 4m below the Lake Rason surface level, being the depth at which evaporation can occur direct from the water table via the capillary fringe. Similar one way fixed heads have been assigned 20m below a drainage line on the southern end of the model to simulate high permeability gravels observed in bore TWB025-X1 and TWB008-T2;
- Very low rainfall accessions spatially distributed over the entire shaly portions of the model mesh. A small zone of enhanced recharge of 1.8mm/yr (equivalent to 0.75% of annual rainfall) has been assigned over the recharge area of the Lower Sandstone on the western boundary of the trough (refer to section 2.5);
- A conservative bulk Specific Yield value of 3% has been adopted as the base case for the Lower Sandstone. Given the degree of uncertainty in the parameter, sensitivity analyses have been conducted using a number of different Specific Yield values to quantify the influence of this parameter has on the simulation outcome;
- Compressible storage is another parameter that could not be accurately defined. A specific compressible storage of 5×10^{-5} has been adopted as a base case for the Lower Sandstone. Again, given the degree of uncertainty in the parameter, sensitivity analyses have been conducted using a number of different compressible storage values to quantify the impact that this parameter has on the simulation outcome;
- A summary of the permeability and storage parameters, determined from hydraulic testing and model calibration, is provided in **Table 4.1**. Permeabilities of the sandstone aquifer were calculated using the Cooper-Jacob pump test analysis from seven (7) bores. The distributions of these permeabilities were interpolated over the model area.

Table 4.1 Summary of model hydraulic parameters

Unit	Bulk Permeability m/day	Vertical Permeability (m)	Specific Yield %	Specific storage (1/m)
Lacustrine Deposits (Layer 1)	7.5×10^{-3}	7.5×10^{-4}	1	-
Paterson Fm (Layer 1)	0.02	2×10^{-3}	3	-
Upper Shale (Layer 1)	7.5×10^{-4}	1×10^{-5}	0.1	-
Lower Sandstone (Layer 2)	0.05 to 0.15	0.015	1	5×10^{-5}
Mesoproterozoic (Layer 2)	1×10^{-4}	1×10^{-5}	1	1×10^{-4}

4.2 Calibration

A model water balance represents equilibrium between spatially distributed inflows from rainfall and outflows to the lake. The areal distribution of these flows and permeabilities shapes the geometry of the regional water table.

Normally an understanding of the magnitude and distribution of rainfall and groundwater outflows would allow the modeller to calibrate the distribution of permeabilities throughout the model. However, in this case, while seasonal stormwater may infiltrate the permeable Paterson Formation, as this percolating groundwater encounters the unconformity over the low permeability Upper Shale it drains across the contact and discharges into Lake Rason as baseflow discharge, leaving the Paterson Formation unsaturated. Limited recharge to the Lower Sandstone does occur, but only along the western margin of the model where the Upper Shale is thin or absent. In this area an aquifer recharge rate of 2% of annual rainfall has been adopted (refer to Section 2.4).

Given that rainfall recharge to the Upper Shale over most of the model is virtually non-existent, it is difficult to meaningfully calibrate the permeability distribution in the Lower Sandstone. **Figure 4-2** shows conservative (tending to worst case) permeability interpolation that has been adopted between the known points at the test bore locations. Notwithstanding limited sensitivity of the calibration process, a gross steady state calibration was undertaken by adjusting the permeabilities in the Paterson deposits, shale and sandstone on a trial and error basis between reasonable expected values to achieve the best empirical matching between the model response and the observed regional water table shown in **Figure 4-3**.

Upon completion of the calibration process, the model was driven to a 300 year transient steady state to assess model numerical stability and robustness. **Table 4.2** shows the end of calibration water balance. The out of balance error of less than 10^{-5} is considered to indicate a very robust numerical model.

Table 4.2 Pre-borefield water balance

Inflow/Outflow	Parameter	Flow Rate (ML/day)
Inflows	Rainfall recharge to lower sandstone aquifer	0.4
Outflows	Discharge from lower sandstone into Lake Rason	0.4
Imbalance	Out of balance error	$< 10^{-5}$

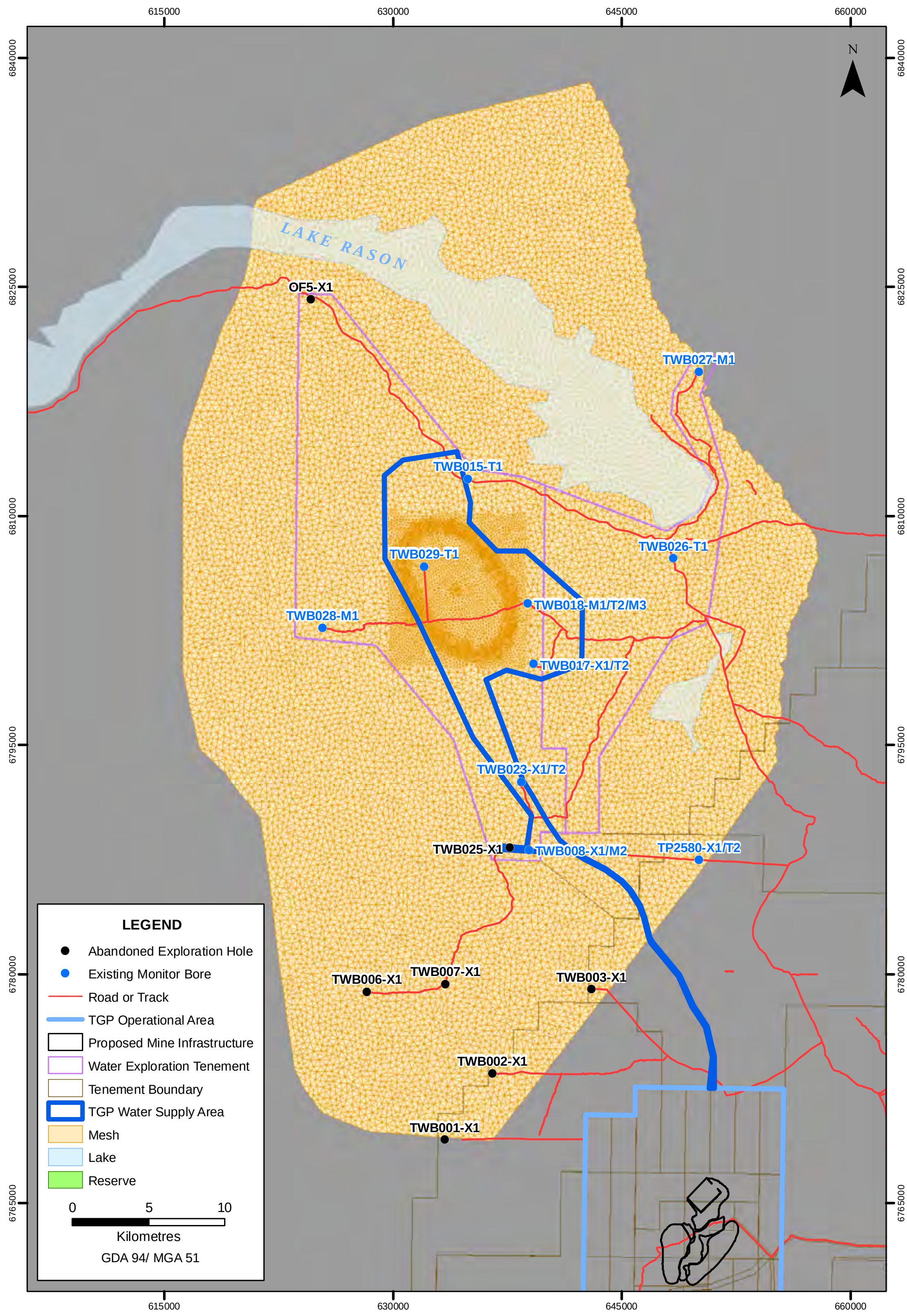

Figure 4-1 Model mesh

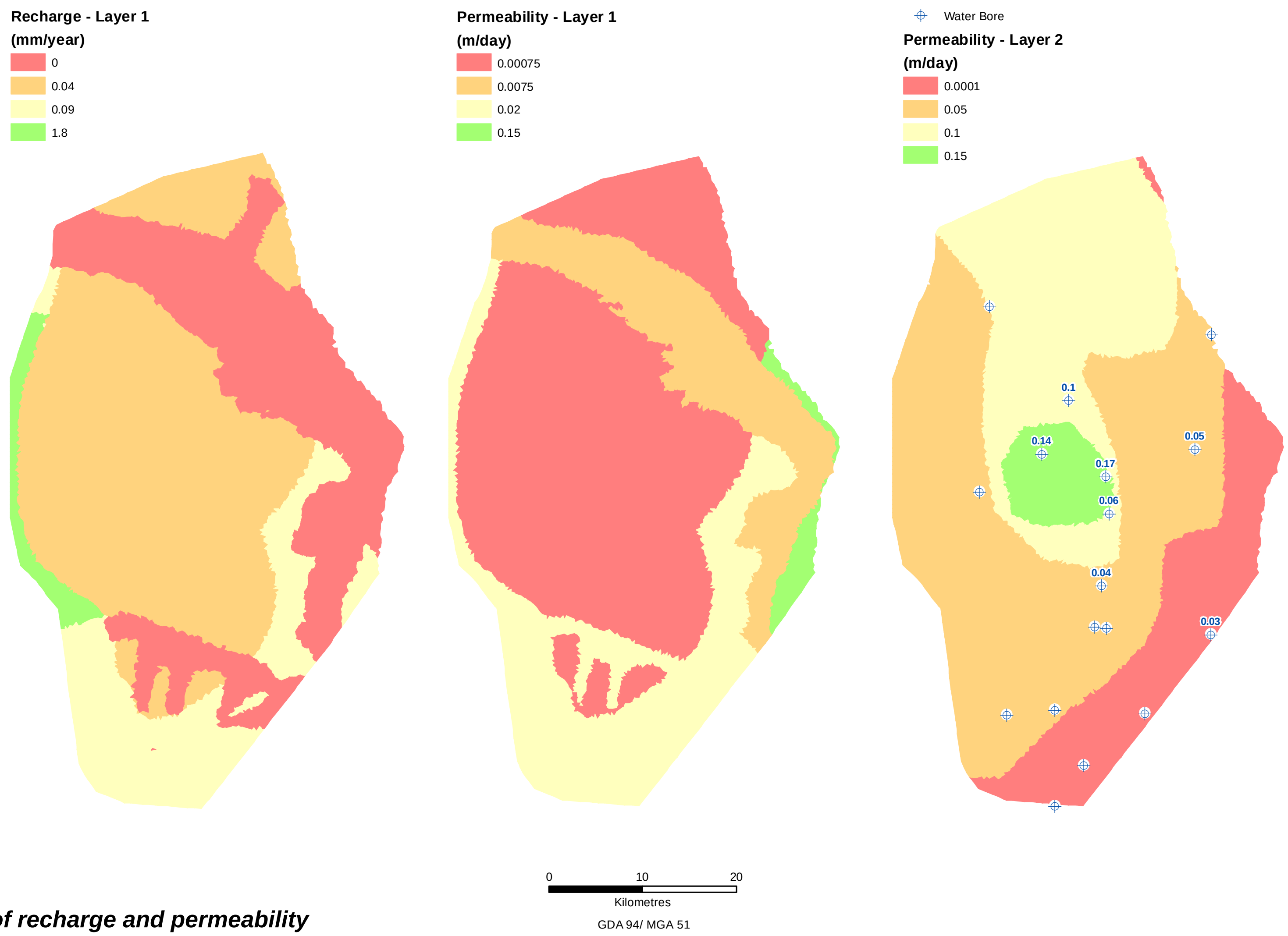

Figure 4-2 Distribution of recharge and permeability

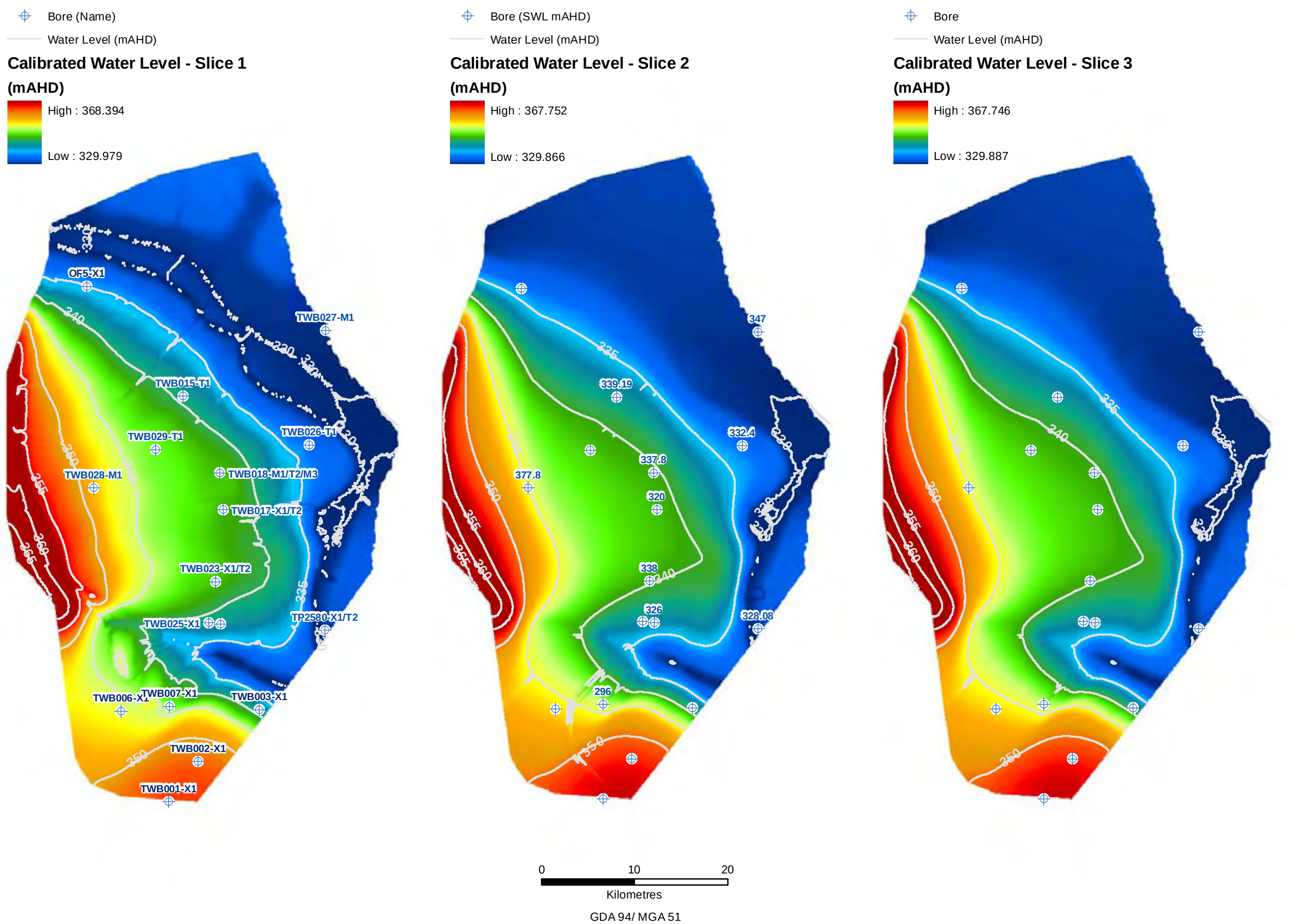

Figure 4-3 Calibrated groundwater heads at all three model surfaces (Slice 2 represents the top of the lower Sandstone aquifer)

4.3 Borefield Simulations

The calibrated model was modified to simulate borefield abstraction from 28 bores, each pumping at 0.5 ML/d for a period of 15 years, followed by 300 years of aquifer recovery.

An indicative circular borefield layout has been initially used in the model as shown in Figure 4-4. The test production drilling results to date indicate that production bore yields are likely to range between 350 and 500 kL/day per bore. The ultimate borefield is likely to require a minimum of 28 bores, with a recommended contingency of a further 12 bores. Using a guideline 400m separation between bores, a circular borefield with 28 bores would have a diameter of 7.5 km.

The circular geometry is the theoretical optimum configuration for homogeneous and isotropic planar aquifers to minimise interference drawdown impacts between bores. The actual borefield layout will be refined in later stages of the TGP to address constraints including access, environmental considerations, power and pipeline alignments as they become more clearly defined. Nevertheless, for feasibility simulation purposes, the circular borefield layout is a reasonable approximation of the ultimate borefield design. In particular, Lake Rason is sufficiently far from the borefield that simulation of depressurisation impacts at the Lake will be insensitive to borefield configuration.

The modelled water table and drawdown in the sandstone aquifer at the end of pumping are shown in **Figure 4-5**, while **Table 4.3** shows the model water balance at the end of abstraction. The model results suggest that the groundwater abstracted by the borefield would be drawn entirely from aquifer storage in the sandstone with no appreciable depressurisation impacts occurring at the Lake.

Table 4.3 Water balance after 15 years of pumping

Inflow/outflow	Parameter	Flow Rate (ML/day)
Inflows	Rainfall recharge to lower sandstone aquifer	0.4
Outflows	Discharge from lower sandstone into Lake Rason	0.4
	Borefield abstraction	14.0
Imbalance	Decrease in aquifer storage	14.0

Figure 4-6 shows the simulated drawdown response that would be expected at each of the production bores. For the first few days the bores would respond with the typical straight line Cooper-Jacob type drawdown. After a few days the rate of drawdown decreases, adapting a characteristic leaky aquifer response due to delayed yield from the Upper Shale. After three years the rate of drawdown starts to increase due to the interference drawdown from the surrounding bores.

After 15 years of pumping the entire borefield abstraction stops and the aquifer is allowed to recover. The model suggests that water levels in the in the borefield will recover 65% of its drawdown within the first three months, and 80% after 10 years of recovery.

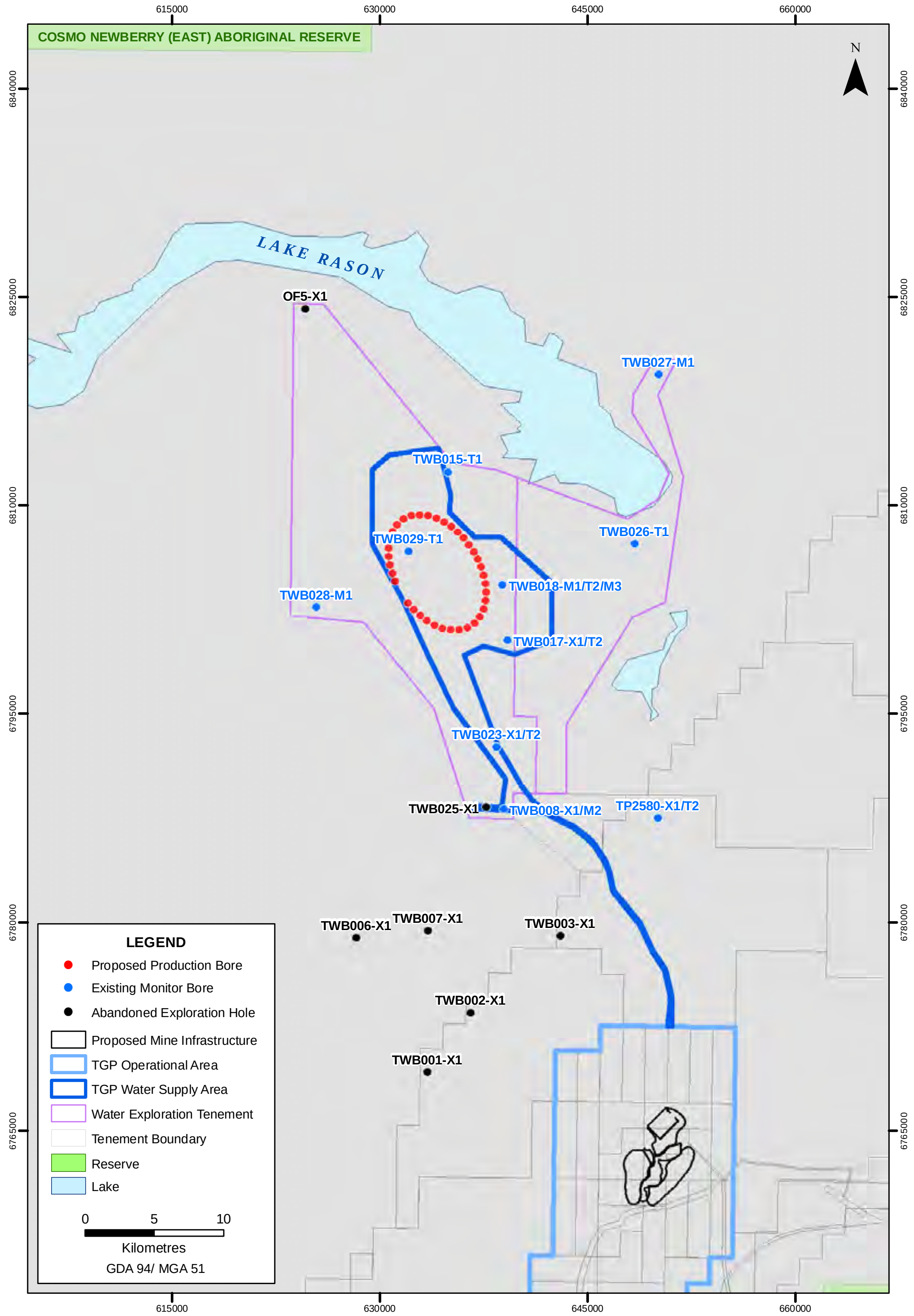

Figure 4-4: Indicative borefield geometry used for model simulation, also showing exploration and proposed monitoring bores

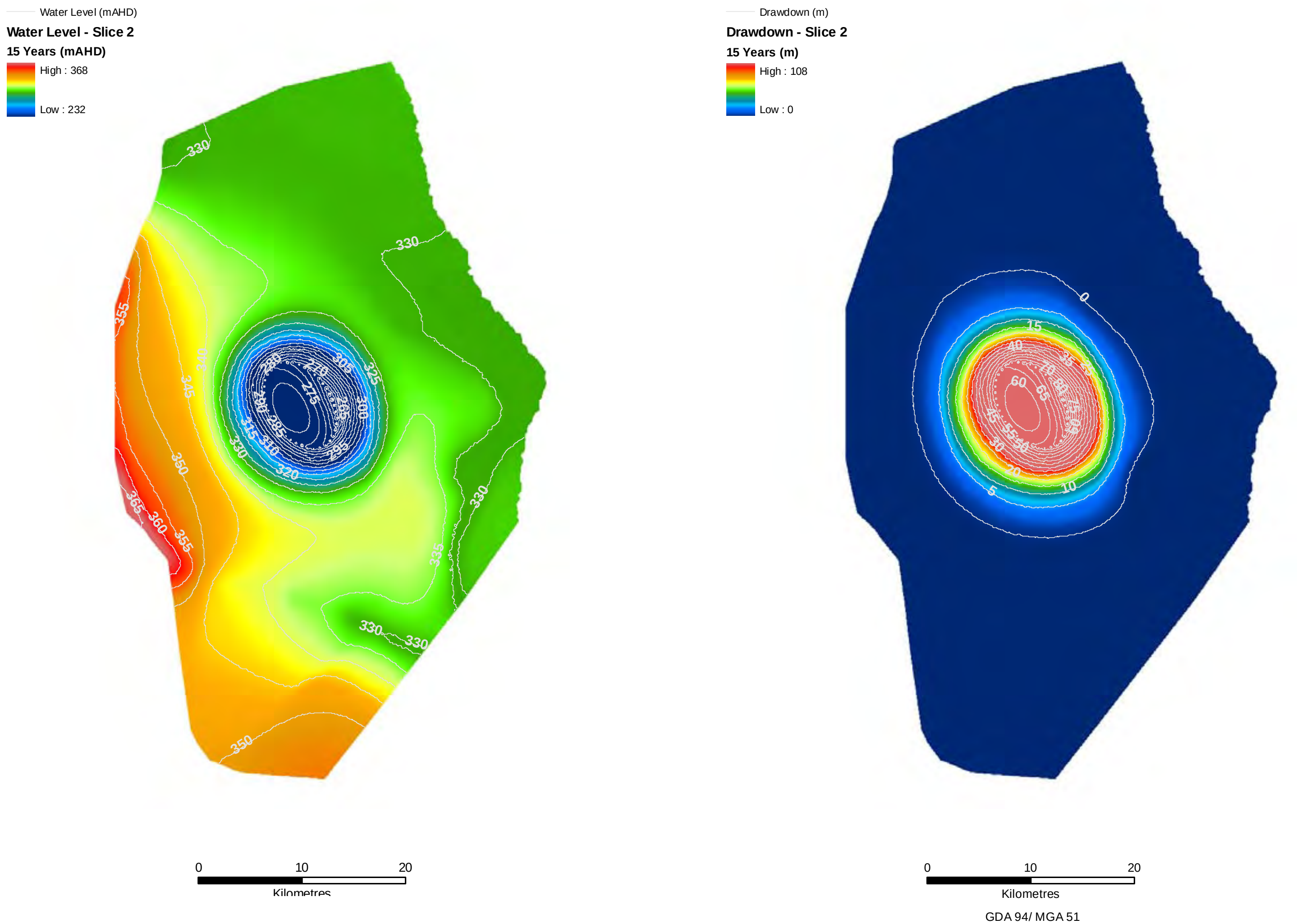

Figure 4-5 Modelled water table and drawdown in the Lower Sandstone after 15 years of pumping (Slice 2)

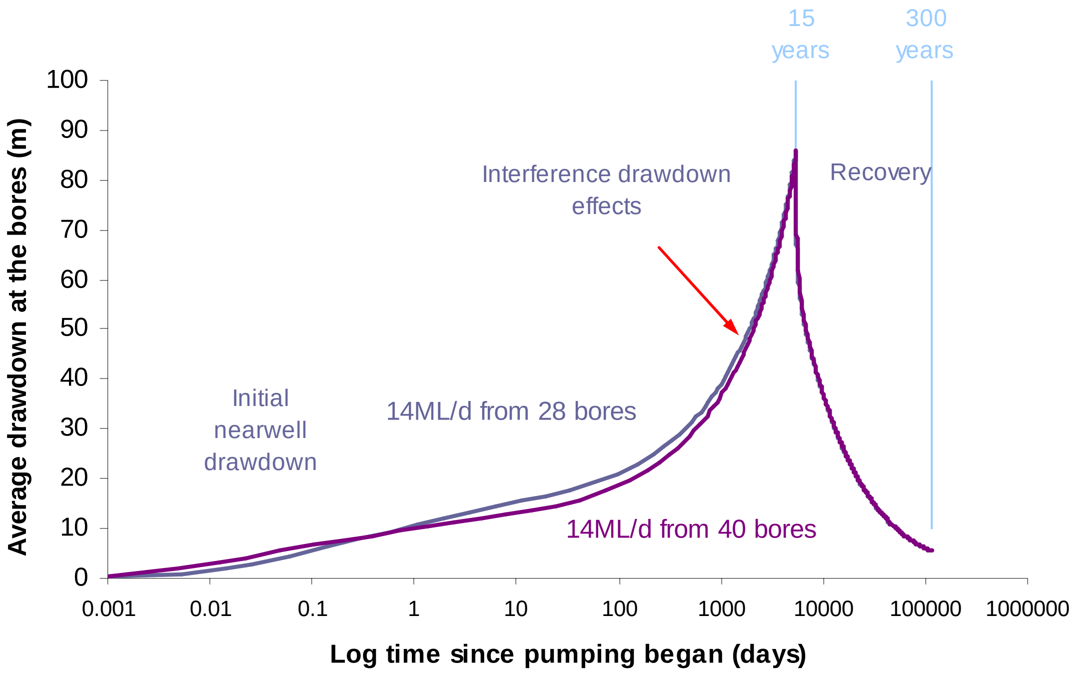

Figure 4-6 Modelled drawdown at a typical production bore

4.4 Analysis of Model Limitations

The development of the numerical model made use of a finite element modelling approach, and the best available, and information and assumptions from the conceptual hydrogeological model. Field measured parameters have been incorporated into the model wherever available. The distributions of certain parameters have lent themselves to further, albeit limited, refinement through the calibration process. There are parameters that may influence the model predictions that can not be readily measured in the field or laboratory, nor lend themselves to being calibrated. In this situation a best estimate has been adopted as a base case, then a range of parameter values has been modelled to determine the sensitivity of the parameter to the model outcome.

The current model is essentially a “bucket model” with water being drawn from storage. The size of the storage is a function of the aquifer geometry and aquifer storage parameters. While the aquifer geometry has been reliably interpolated from drilling data, the Specific Yield (Sy) and compressible aquifer storage parameters have thus far not been reliably measured, and the sensivity of the model of these parameters is tested herein.

4.4.1 Sensitivity to Mesh Discretisation

Modelled drawdowns at pumping bores in layer models inevitably contain a level of rounding error dependent upon how fine the model mesh is discretised around the bores. The FEFLOW finite element model includes a mesh refinement function that can incrementally increase the mesh discretisation around a point. This function has been used to incrementally refine the mesh around the bores until such a point that the modelled drawdown at the bores after 15 years of pumping showed no further discernible improvement between refinements. While this feature helps to reduce rounding problems compared with finite difference model, it may not eliminate the problem entirely and therefore modelled drawdowns at the bores should be considered as being indicative and likely to be under-estimates.

4.4.2 Sensitivity to the Specific Yield of the Lower sandstone

Using a base case Sy value of 3% for the Lower Sandstone, **Figure 4-7** shows the modelled average drawdown at the bores and in the centre of the 28 bore circular borefield after 15 years of pumping. Reference to this figure suggests that the model outcome is not sensitive to the value of sandstone Sy adopted in the model because the productive aquifer is confined, not phreatic.

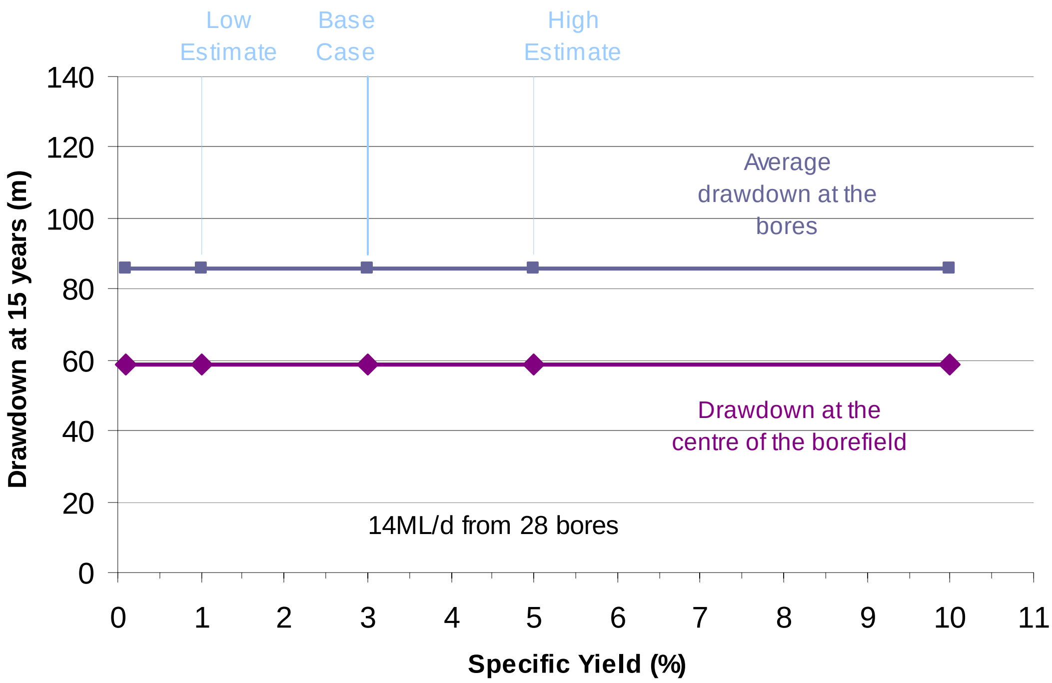

Figure 4-7 Sensitivity of the model to Sy in the Lower Sandstone

4.4.3 Sensitivity to the Specific Storage in Lower Sandstone

Figure 4-8 and **Figure 4-9** show the modelled average drawdown at the bores at the end of 15 years and as hydrographs throughout the 15 years of pumping, using a range of specific storage values. References to these figures illustrate how the specific storage parameter influences the timing of that interference drawdowns reaches the neighbouring bores. The lower the specific storage, the earlier the onset of interference effects at the neighbouring bore and therefore, the greater the drawdown at each bore at the end of 15 years. .

In the event that the lowest anticipated specific storage value of $5x10^{-6}$ occurs, a borefield of 28 bores would experience excessive interference drawdown after 15 years that several bores would be dewatered toward the end of 2008 project. **Figure 4-6** shows that increasing the number of bores in the borefield to 40, or by spreading the bores wider apart, it would be possible to reduce the interference impacts and thereby reduce the drawdowns at bore.

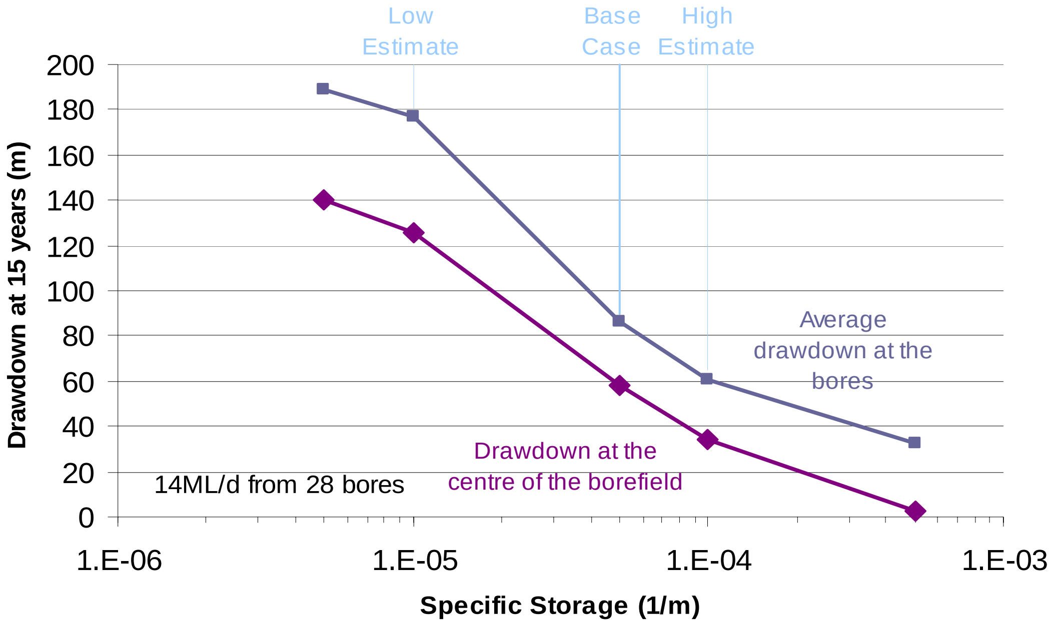

Figure 4-8 Sensitivity of the model to specific storage in the Lower Sandstone at 15 years

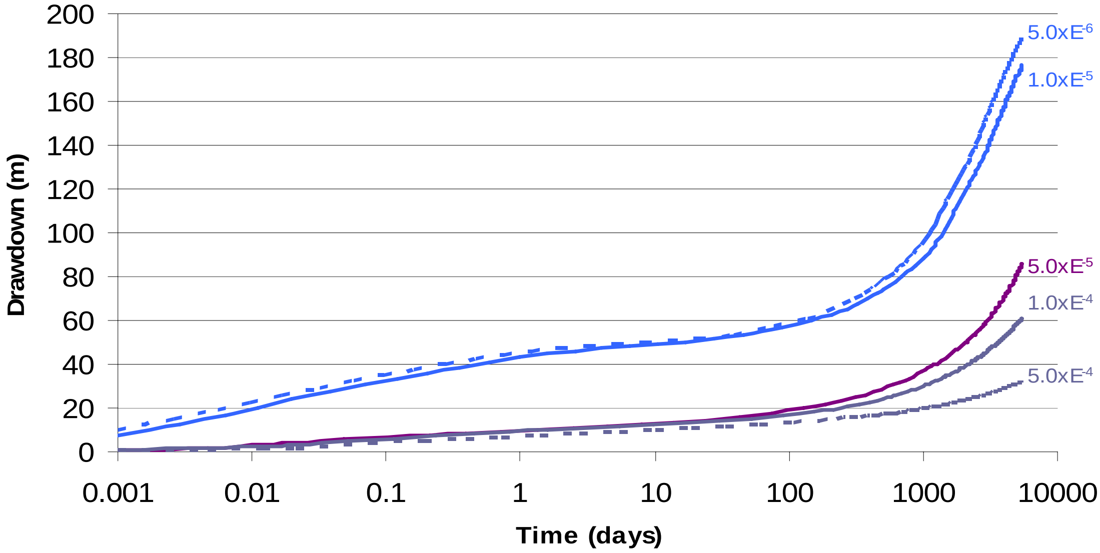

Figure 4-9 Sensitivity of model to specific storage in Lower Sandstone over time

5. IMPACT ASSESSMENT

The proposed borefield in the Water Supply Area will be screened in the Lower Sandstone beneath the Paterson Formation. The borefield will abstract up to 14 ML/day of water with a salinity of less than 100,000 mg/L over the TGP life of 15 years, after which time pumping will cease and the aquifer will be allowed to recover. An appraisal of the environmental and social issues arising from development and operation of the Water Supply Area has identified the following issues:

- The TGP abstraction is unlikely to impact halophytic vegetation on the edge of Lake Rason. The hydrology of the lake is overwhelmingly driven by seasonal rainfall accessions and throughflows in the Paterson Formation. The volume of these flows is orders of magnitude greater than the seepage to the lake from the Lower Sandstone through the Upper Shale. Hence, the depressurisation in the Lower Sandstone due to borefield abstraction is not likely to impact on the lake hydrology, and therefore will not influence the groundwater dependent ecosystems surrounding the Lake. Nonetheless, the pressure heads in the Paterson Formation and Cenozoic deposits around the lake should be monitored over the life of the Project.
- The borefield abstraction will not adversely impact the diversity and viability of stygofauna. Thus far surveys of the area have not identified any stygofauna in any TGP or existing third party bores in the Water Supply Area or the Operational Area. The result is supported by the deeper, confined nature of the aquifer, the tight interstitial pore spaces and high salinity which are not a conductive habitat for stygofauna;
- The abstraction from the proposed Water Supply Area will not impact other groundwater users. The nearest private bores to the Water Supply Area borefield are the abandoned Yamana Homestead and the Cosmo aboriginal community; both are located well outside the boundaries of the Lower Sandstone 80 and 130 km NNE of the borefield respectively. The borefield depressisation after 15 years will not extend beyond the extents of the Lower Sandstone and therefore the TGP abstraction is not likely to impact on other third party groundwater users;
- There is negligible risk of the abstraction water quality deteriorating significantly over the life of the TGP due to hypersaline groundwater migration from Lake Rason to the borefield. A borefield simulation, using particle tracking, shows that the groundwater catchment area for the borefield does not extend into Lake Rason.

A summary of these impacts is given below.

5.1 Groundwater dependent ecosystems

Both the 1994 COAG water reforms and the more recent National Water Initiative explicitly recognise the environment as a legitimate water user possessing an entitlement to water.

The hydrology of Lake Rason is overwhelmingly driven by rainfall recharge-discharge in the Paterson Formation. During periods of high seasonal rainfall, relatively fresh to brackish groundwater throughflow discharges to the Lake over the base of the Paterson Formation and emerges as an outwash on the margins of the lake (refer to Section 2.4). Up to 70m of low permeability shale, that confine the Lower Sandstone, ensures that the rate and volume of saline upward groundwater discharge from the Lower Sandstone aquifer to the Lake is very low. Potentiometric water levels in the Lower Sandstone are mostly too deep to be accessible to the overlying vegetation except around the Lake Rason drainage, where the groundwater quality in the aquifer is invariably saline, being more than 40,000 mg/L TDS and up to 212,000 mg/L TDS.

Halophytic vegetation around the margins of the lake rely on this fresher run-on surface flow and throughflows in the Paterson Formation for part of their water requirements. However, there is a possibility that this vegetation may also be able to use the saline moisture from the Upper Shale during periods of drought, transpiring the water and depositing the salt in their foliage.

The groundwater simulation modelling shows that discernible groundwater depressurisation impacts in the Upper Shale over the life of the TGP are not expected to extend to the lake. In the unlikely event that pressure heads that drive upward seepage are lowered, the reduced discharge through the shale is unlikely to have a discernible impact on the Lake hydrology.

Pressure heads should be monitored in the Lower Sandstone at the Lake over the life of the TGP.

5.2 Stygofauna

Over the past decade or so researchers in the field have come to recognise the existence of aquatic sub terrain life forms that inhabit the voids and other interstitial pore spaces in sand and calcrete aquifers. These life forms can vary from fish and crustaceans to arachnids and nematodes.

The threat of the TGP to stygofauna populations was assessed by Subterranean Ecology (2009), who undertook extensive literature search and stygofauna sampling in and around the proposed Water Supply Area.

Their study concluded that the Lower Sand aquifer is unlikely to be a stygofauna habitat because:

- Occurring at generally 100m or more, the Lower Sand aquifer is much deeper than known occurrences of stygofauna recorded in Western Australia, which mostly inhabit shallow aquifer systems;
- The aquifer is compact with tight interstitial pore spaces less than 50µm; meaning that there no living space for most stygofauna groups except possibly burrowing forms;
- Being a deep confined aquifer, there is little possibility for exchange of oxygen and nutrients required to sustain stygofauna life; and

- The hypersaline groundwater salinity excludes most species and is at the upper limit of halo-tolerant species.

To confirm these conclusions, the desk study was followed up with a pilot field survey of all of the water exploration bores according to EPA Guidance No. 54 (EPA 2003). The survey failed to identify any stygofauna, and it was concluded that no further sampling was required. The borefield abstraction is therefore very unlikely to impact on any stygofauna.

5.3 Other Water Users

Being located in a remote region of the Great Victoria Desert, there are only a few third party projects, dwellings or stock and domestic bores within a 150km radius of the Water Supply Area. There are no other existing or foreseeable water users in the Lower Sandstone depressurisation area. The nearest dwellings are the abandoned Yamana Homestead and Cosmo Aboriginal Community, both screened in Paterson Formation well outside the extents of the Lower Sandstone, 80 and 130 km NNE of the borefield respectively.

The discernible depressurisation impacts over the life of the TGP will not extend more than 5 km from the borefield, and will not extend outside the boundaries of the Lower Sandstone aquifer. There should therefore be no potential for the TGP to adversely impact other human water users.

5.4 Saline Groundwater Encroachment

The proposed borefield has a current near-well groundwater salinity ranging from 40,000 to less than 100,000 mg/L TDS. The borefield is located about 5 kilometres from known hypersaline groundwater associated with the Lake Rason drainage valley. There is concern that abstraction from the borefield could cause the hypersaline groundwater from the lake to migrate to the deeper Sandstone aquifer.

High salinity groundwater tends not to be as mobile or behave as other solutes. The mass of salt contained in hypersaline groundwater is denser and heavier than fresh water and its distribution in the groundwater regime is described by the Gyben-Hyberg principle. **Figure 5-1** shows the results of a particle tracking model at the end of 15 years, which follows the flow lines from the borefield back to its source. Reference to this figure suggests that the majority of water abstracted by the borefield is derived from groundwater storage, with no groundwater is drawn from beneath the lake.

There will be some movement of higher salinity water in the direction of the borefield caused by the changes to the groundwater gradient caused by pumping. Given the depth and the salinity of the groundwater which precludes vegetation dependence, and the believed absence of stygofauna (Subterranean Ecology 2009), this minor change in the salinity distribution should have no environmental impact. Also, given the groundwater's hypersaline quality, it falls in the lowest beneficial use category, suitable only for limited industrial uses with no potential agricultural or domestic uses. Changes in salinity distribution as a result of the TGP will therefore not change the groundwater's beneficial use category or have any impact on the groundwater's potential beneficial use.

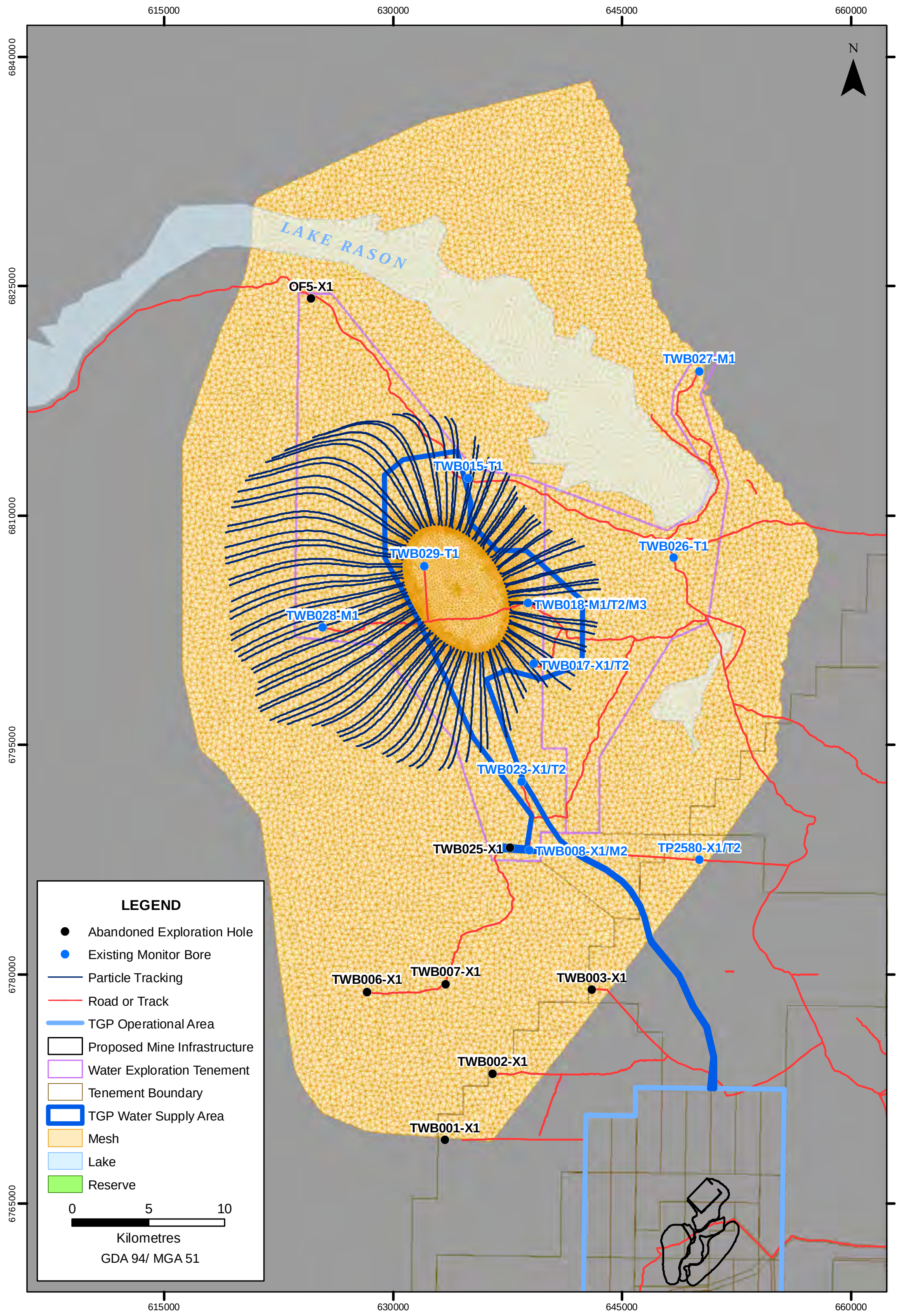

Figure 5-1 Particle tracking showing the flow lines to borefield after 15 years pumping

5.5 Water Level Rebound After Closure

Upon completion of the TGP all abstraction from the borefield in the Water Supply Area will cease and the aquifer will recover.

Given that recharge to the Lower Sand aquifer is very low and only occurs on the western margins the aquifer; full recovery within measurable human time scales is unlikely to occur. Water levels in the Water Supply Area, however, will rebound over time as the regional groundwater storage readjusts. In other words, water levels in the furthest parts of the aquifer will appear to continue to decline after closure as regional groundwater continues to migrate into the borefield area to recover the cone of depressurisation left by historic abstraction.

This apparent rebound will occur most rapidly the years after closure, but slow down asymptotically over several hundred years. Thus, water levels in the borefield area will recover 30% of drawdown within the first year after closure; 50% within the first decade; and 65% within the second decade. Modelling suggests that 95% recovery would not occur for 300 years after closure.

5.6 Climate Change

Climate change has the potential to affect the availability of groundwater for abstraction through changes in the rate of rainfall recharge. The Minigwal Trough lies within the Great Victoria Desert which already experiences very low rainfall conditions. Consequently in the modelling assessment, only a very low volume of recharge was assumed to occur, mainly concentrated in a narrow band of exposed Lower Sand about 20 km upgradient of the abstraction (refer Figure 4-2). This recharge was incorporated into the steady state model to replicate the very low flow gradient toward Lake Rason. As detailed in the steady state water balance in Table 4.2, recharge is 0.4 ML/day and balanced by equivalent discharge to Lake Rason.

The modelled water balance at the end of the Project life, detailed in Table 4.3, highlights that 100% of the abstraction comes from a reduction in storage in the aquifer, with no change in the discharge flux. This shows that 100% of the water abstracted for the TGP comes from existing storage of groundwater, and that there is therefore no dependence on recharge whatsoever. A reduction in rainfall caused by climate change will therefore have no impact on the feasibility of the proposed groundwater abstraction, nor on the discharge of flow to Lake Rason over the life of the TGP. It is possible that a reduction in rainfall caused by climate change my affect the post closure recovery of the aquifer, which has been estimated at 300 years.

6. BOREFIELD DEVELOPMENT

Development and licensing of the Water Supply Area borefield will require the development of a detailed operating strategy including borefield construction plan, borefield management, monitoring, contingencies and performance review. These elements are described below.

6.1 Borefield Construction

The Water Supply Area will be developed as the principal water source for the TGP. A detailed gravity survey will be undertaken to target prospective bore locations. The final Water Supply Area Borefield layout will be designed to optimise a series of factors including borefield geometry, hydrogeological prospectivity, environmental considerations, access, power and pipeline layouts.

The Water Supply Area borefield will comprise up to 40 fully-equipped production bores drawing groundwater from a screened thickness of about 100 to 120 metres of Lower Sandstone. Individual production bore yields will range from 0.3 ML/day to 0.5 ML/day with a total borefield output of 14ML/day. Bores will be evenly distributed at 400 to 500 m intervals with an average depth of around 350m and static water levels between 40 and 60m below ground. Groundwater salinity from individual production bores will vary between 40,000 and 120,000 mg/L with an overall blend from the borefield of 60,000 mg/L to 100,000 mg/L. A number of observation bores will also be constructed at strategic locations within the catchment to monitor water levels and confirm the modelled spread of drawdown.

All bores will be installed by a certified groundwater drilling contractor to the ANZECC (2003) standard, in accordance with the conditions of the well construction licence issued by the Department of Water (DoW).

Upon completion of the drilling program, each production bore will be equipped with electric submersible pumps and connected to a main borefield pipeline via a 65 mm HDPE rising main. Water from the bores will be transmitted through HDPE pipe, increasing in diameter from 100 mm at each bore to 1,000 mm for the mainline carrying the total borefield flow. A telemetric pressure monitoring system will be installed in the pipeline system to ensure that any leaks can be rapidly detected and pinpointed. The pipeline will either be placed in an earthen bund or buried to reduce the environmental damage in the event the pipeline fails.

A light vehicle access and maintenance track will follow alongside the pipeline. The borefield will likely be powered by a stand alone diesel power generation at the borefield; however, the TGP is evaluating renewable power sources.

The borefield would be pumped for a minimum life of 15 years, after which time, the borefield will be decommissioned

6.2 Pumping Regime

The maximum required draw for the entire borefield per year is 5,000 ML. The draw of groundwater for individual bores will be optimised on a bore by bore basis depending on their individual hydraulic characteristics. It is anticipated the maximum draw per bore will be in the order of 0.5 ML/day. Bores will be operated continuously as required with low level cut-off switches installed to deactivate the pump in the event that water levels in the bore become too low for effective pumping. Borefield operation will be optimised on a set-point basis that dictates which bores are to be operated and at what rate to produce a desired total draw from the borefield, e.g. for pumping volumes of 7 ML/day, 10 ML/day, 12 ML/day and 14 ML/day.

Following final borefield design and construction, specific operating rules will be developed for individual bores to ensure interference impacts and risks are minimised and operating efficiency is optimised.

6.3 Monitoring Program

The TGP's approach to sustainable water abstraction will be achieved through the establishment of detailed groundwater monitoring program. Elements of the monitoring program will include:

- Comprehensive monitoring of water levels, individual bore pumping rates and water chemistry;
- Monitoring program for the halophytic vegetation on the southern boundary of Lake Rason, including modelling of potential impacts;
- Monitoring program for the Cenozoic aquifer adjacent to Lake Rason, to monitor its response to the operation of the borefield and how quickly it recovers following rainfall events;
- Annual reporting of all data and its interpretation by a qualified hydrogeologist;
- Implementation of a detailed aquifer management plan involving monitoring, contingencies and rehabilitation in the event of aquifer or environmental problems;

The volume of water drawn from all production bores will be recorded continuously via a telemetered system with daily abstraction data available. Water levels in production bores will be monitored on a weekly basis, with groundwater pH and salinity (TDS & EC) to be measured monthly, and a major component analysis either bi-annually or annually. Water levels in observation bores will be measured monthly, with groundwater pH and salinity (TDS & EC) measured six monthly.

The TGP will regularly review all of the monitoring data to ensure that the borefield is operating as expected. This work will involve the use of the numerical groundwater model to refine its predictions (based on the actual monitoring data) and to forward predict the behaviour of the aquifers to enable early identification of any significant issues.

The results of the groundwater and vegetation monitoring programs and the back and forward numerical modelling will be presented in the TGP's Annual Environmental Report.

6.4 Contingency Measures

Detailed contingency measures will be developed based on triggers defined in the monitoring program to ensure that should any issues arise, they will be addressed immediately to ensure protection of the environment and security of water supply.

Given the long time lag for drawdowns to spread from the borefield, triggers will be designed around the monitoring bores close to the borefield so that drawdowns that are greater than modelled or that expand quicker or further than modelled can be detected early, before unacceptable interference impacts on other bores or environmental impacts occur. A typical trigger would be an observed drawdown of more than 10% higher than modelled.

Exceedance of the triggers would require re-modelling and re-optimisation of the abstraction distribution. This analysis may lead to modifications to the timing or distribution of abstraction from the borefield or, at a worst case, reduction in volumes abstracted and/or switching to alternative water sources.

In the event of any emergency arising in the borefield such as burst or damaged water mains, leaking or flooding, power will be turned off and the affected area of the borefield shut down until the situation is brought under control and measures to prevent a reoccurrence implemented.

6.5 Borefield Performance Review

The proposed borefield strategy would be in place from the time of commissioning of the borefield for a period of twelve months, at which point both borefield management and performance will be reviewed. Reporting of borefield performance and aquifer response to groundwater abstraction is to be undertaken annually starting from the time the borefield is commissioned. Reporting will include both individual bore performance including hydrographs, pumping rates and variation in water quality. Reporting will also include water level and water quality data from monitoring bores.

Aquifer performance and water level observations will be re-entered into a numerical model to assess both actual aquifer response compared with predicted response and to further predict the future behaviour of the aquifer.

In the event of any breach of the operating strategy appropriate steps will be taken to rectify the situation or a contingency plan will be put into operation, depending on the severity of the breach.

For the purposes of monitoring and reporting of the proposed borefield, the TGP's water year will be deemed to start from the time of commissioning.

6.6 Decommissioning and Rehabilitation

Following completion of the TGP, all abstraction from the borefield will cease and aquifer recovery wull be monitored for a period of 15 years or until it recovers to more than 80% of its capacity or until another user takes control of the borefield. Water levels in all production bores will be monitored at monthly intervals during the first year of recovery, then at quarterly intervals until year 3, then annually until year 10. The aquifer would then be returned to the State.

TGP will cap and lock all production bores and remove and rehabilitate all other associated borefield infrastructure and ground disturbance to the satisfaction of the Western Australian Dept of Environment and Conservation (DEC) and the Dept of Mines and Petroleum (DMP).

7. ECOLOGICALLY SUSTAINABLE DEVELOPMENT

Water resources in Western Australia are in continual demand for mining, agricultural and environmental use (e.g. sustaining vegetation). Therefore, it is important to manage the cumulative withdrawal of each new water project in a sustainable manner to ensure that it does not:

- Adversely impact the beneficial use of the resource by other existing or future users in terms of water quality and quantity;
- Cause serious or irreversible environmental, social or economic impacts; or
- Cause detrimental changes to the aquifer system itself.

Currently there is no universal understanding or definition of sustainable development with respect to groundwater resources that embraces the range of technical, social, environmental, timeframe and economic factors. The Council of Australian Governments (COAG) (1996) recognised that one of the key requirements for sustainable development is the definition of acceptable and achievable environmental impacts as part of the water allocation process. In 2000, Australian and New Zealand Environmental Conservation Council (ANZECC) considered the following definition regarding sustainable management of the groundwater resources:

"The groundwater extraction regime, measured over a specified planning timeframe that allows acceptable levels of stress and protects the higher values that have a dependency on the water."

The TJV is committed to sustainable development and will undertake all water development activities associated with the TGP within this definition. The ecologically sustainable development principles discussed in the Intergovernmental Agreement on the Environment (1992), and the subsequent guidelines suggested by COAG and the WA EPA Principle of Environmental Protection will also be applied by the TGP. The Four core key principles established these documents are:

- The precautionary principle;
- The principle of intergenerational equity;
- The principle of conservation of biological diversity; and
- The principle of improved evaluation, pricing and incentive mechanisms.

Of the four principles listed above the first three are relevant to the development and management of water resources in the Water Supply Area and the impacts arising there from.

7.1 The Precautionary Principle

The precautionary principle states that if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

It is never possible to guarantee zero risk to the environmental, social and economic values. However, the TJV has demonstrated a thorough and comprehensive analysis of the existing environment and has sought to identify and evaluate all potential detrimental impacts and concerns regarding the development of the borefield in an impartial, conservative (tending towards worst-case), manner. Where risks or concerns have been identified, no matter how remote their occurrence may appear, the TJV has committed to and developed practical and auditable monitoring programs.

The TJV is capable and prepared to manage, monitor, and control the impacts of the development in a sustainable manner. It achieves this through its borefield management and contingency plans. Monitoring will be established in consultation with the DoW to assess real time aquifer performance against model simulation predictions. Some specific precautionary measures include:

- During the pumping period, the TGP will monitor water levels, pumping rates and groundwater chemistry on a monthly basis to verify that the system is acting as predicted by forward modelling; and
- As a precaution against possible saline water discharges to the environment, the entire borefield pipeline will be buried beneath the ground.

7.2 Conservation of Biodiversity

The principal of conservation of biological diversity is that the conservation of biological diversity and ecological integrity should be a fundamental consideration.

The proposed development of the Water Supply Area has considered the results of the flora and vegetation surveys undertaken by Botanica Consulting and the stygofauna survey completed by Subterranean Ecology. In particular the borefield has been developed at least 5km from the Lake boundary to avoid potentially groundwater dependent halophytic vegetation.

In the unlikely event that vegetative stress due to the TGP's activity does become evident, remedial measures will be implemented in consultation with the DoW, DEC and the DMP. Immediate management options may include modifying the distribution of abstraction in the borefield.

7.3 Intergenerational Equity

The principle of intergenerational equity requires that the health, diversity and productivity of the environment is maintained or enhanced for future generations.

In terms of intergenerational equity, the TGP is committed to developing mechanisms to ensure that the beneficial use of its water resources is maintained and, where possible, enhanced in terms of quantity and quality for other water users during and after the life of the Project. In terms of the intergenerational equity; water levels in the Lower Sandstone aquifer may decline by up to 120m during borefield operation. Water levels in the borefield area will recover 30% of drawdown within the first year after closure; 50% within the first decade; and 95% within 300 years.

The TGP is committed to continuous improvement in the manner it manages its water resources and is accordingly evaluating a number of sustainable water management initiatives aimed at reducing intergenerational impacts by reducing water use, and identifying opportunities for water re-use. Examples of the TGP's sustainable water management initiatives include:

- Studies are in progress into ways of re-using water from certain areas of the processing cycle for other ancillary purposes within the plant and also for dust suppression in and around the plant; and
- The use of thickened tailings discharge

7.4 Summary

In summary, the TJV has committed to the sustainable use and management of the Minigwal Trough aquifer using the following criteria:

- Definition of groundwater system in terms of aquifer storage and yield;
- Delineation of how borefield development would proceed;
- Determination of time period over which the water can be economically and practically abstracted from the borefield;
- Formulation of detailed aquifer management plans, including local and regional monitoring programs, as well as commitments to other aquifer uses which may be adversely impacted by the Proponent operations;
- Contingency measures which can be adopted to cater for both short term or long term unforseen or unplanned aquifer problems;
- Possible impact of aquifer use in vegetation or other dependent ecosystems, within the regional context;
- Maintaining acceptable aquifer water quality;
- Water conservation and reuse strategies; and
- Aquifer recovery and monitoring.

The above criteria and the manner in which the TJV has approached adherence to the sustainable use of groundwater have been described in the report.

Further development and continuous improvement will be implemented during the course of borefield development and production management.

8. REFERENCES

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Attachment A

Bore Completion Logs

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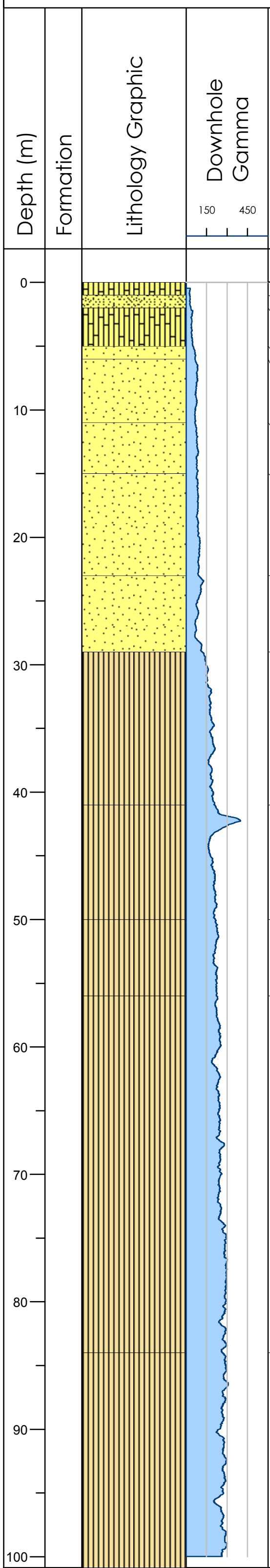
1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

Borehole: TP2580-T2

Project: Tropicana Water Study	Client: Anglogold Ashanti	Location: Lake Rason
Easting: 650023 Elevation: 324 (mAHD)	SWL: 4 m (toc) on 22/04/2008	Logged By: Ian Anderson/Will White
Northing: 6787499 Total Depth: 198 m	Salinity: 212330 mg/L on 22/04/2008	Checked By: B Gallen

SUBSURFACE PROFILE

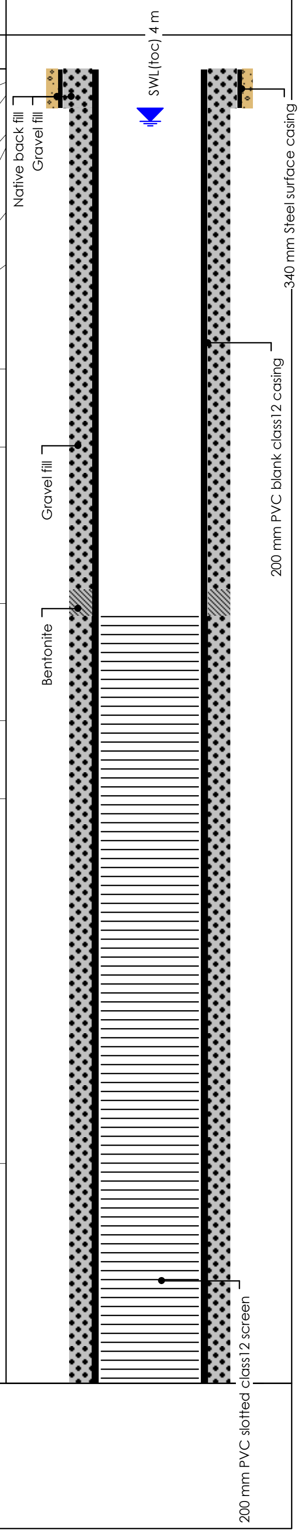


Lithology

Ground Surface

- SM silty med SAND well graded, loose, SR orange pink
- SP-SM med SAND with trace silt poorly graded, loose, SR, pale brown with speckled red gypsum / halite
- SM silty med SAND poorly graded, very loose, SR, pale brown with mottled grey
- SW-SM med SAND with trace silt well graded, dense, SR white with speckled white Fe and Si overprint
- SW-SM coarse SAND with trace silt well graded, very loose, SR, pale yellow
- SW-SM coarse SAND with trace silt well graded, very loose, SR, pale brown
- SW-SM coarse SAND with trace silt well graded, medium dense, SR greyish orange
- SW-SM coarse SAND with trace silt well graded, dense, SR, dark red brown with mottled brown Fe and Si overprint
- ML SILT, very soft, low plasticity, pale grey Striated fragments
- ML SILT, soft, low plasticity black Striated fragments. Pyrite grains <0.1-1mm
- ML SILT, soft, low plasticity black with mottled white Striated fragments. Pyrite grains <0.1-1mm
- ML SILT, soft, low plasticity black Striated fragments. Pyrite grains <0.1-1mm
- ML SILT, stiff, low plasticity black with mottled white Striated fragments. Pyrite grains <0.1-1mm

Bore Construction



Drilling Company: Scanlon
Drilling Equipment: Kelly Bar Rig
Drilling Method: Mud

Started: 4/04/2008
Completed: 22/04/2008
Compiled: 7/09/2008

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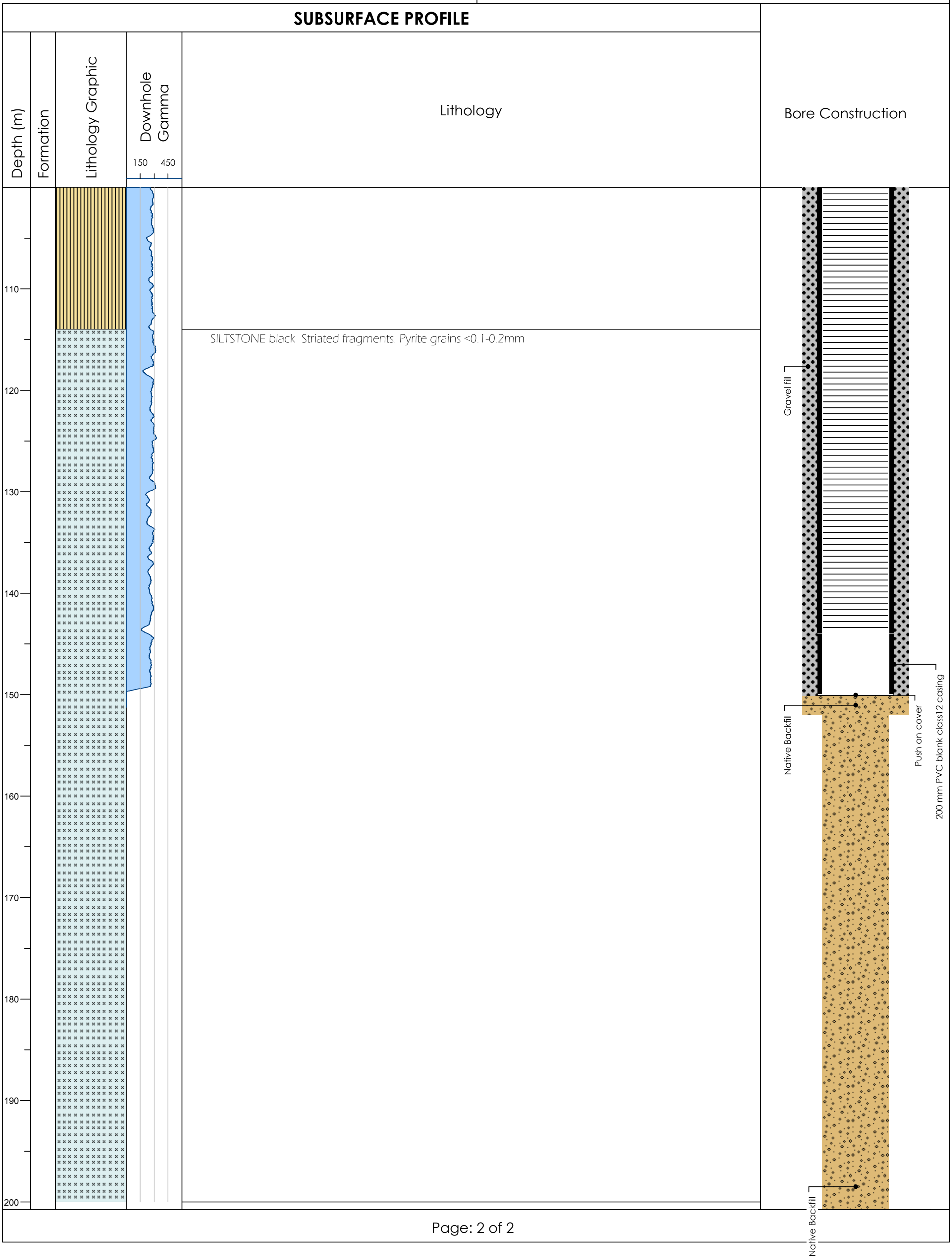
T: +618 94410999 F: +618 92041595

Borehole: TP2580-T2



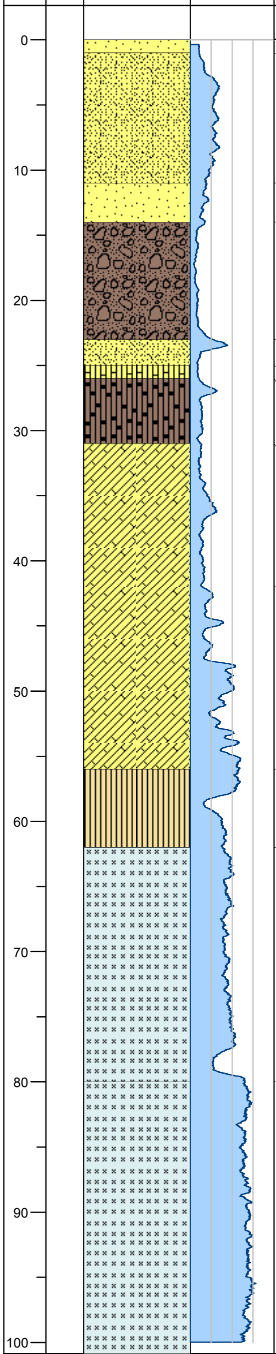
1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

Borehole: TWB008-M1

Project: Tropicana Water Study		Client: Anglogold Ashanti	Location: Lake Rason
Easting: 638892	Elevation: 380 (mAHD)	SWL: 61 m (toc) on 8/07/2008	Logged By: Ian Anderson
Northing: 6788169	Total Depth: 276 m	Salinity: 46610 mg/L on 8/07/2008	Checked By: B Gallen

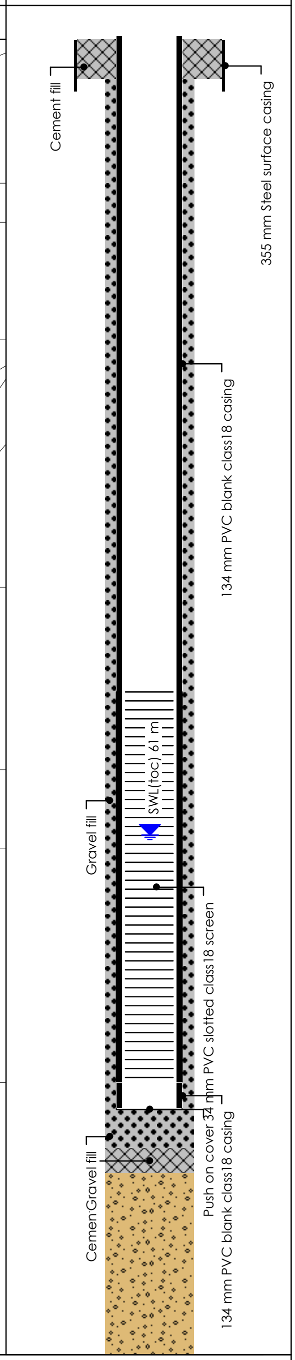
SUBSURFACE PROFILE

Depth (m) | Formation | Lithology Graphic | Downhole Gamma | Lithology | Bore Construction



Ground Surface

- SW-SM med SAND with trace silt, medium dense, SA, pale brown, Aolian Deposits
- SP med SAND with trace silt poorly graded, loose, SA, pale brown with speckled white, Colluvium 2-4m = Gypsum bands; Intermittant Silicified horizons <30cm thick
- SW med SAND with trace silt well graded, loose, SR with speckled red
- GP fine GRAVEL poorly graded, loose, SR, pale orange with mottled, very pale greyish pink
- SP-SM coarse SAND with trace silt poorly graded, medium dense, SR, pale orange with speckled red brown Slicified white bands 10-30cm thick; hard drilling
- SM silty med SAND poorly graded, medium dense, SR, qtz, pale grey Slicified white bands 10cm thick?
- GM silty fine GRAVEL poorly graded, very loose, SR, pale orange with speckled white Slicified white bands approx 10cm thick
- SC clayey coarse SAND poorly graded, very loose, rounded, pale grey with speckled white
- SC clayey coarse SAND well graded, very loose, rounded, pale grey
- ML sandy SILT with trace fine sand, very soft, low plasticity, moderate red with speckled white Ferruginised bands <1cm? @ 58-59m
- SILTSTONE, dark brown with speckled white Mica, also purple mottling
- SILTSTONE, dark brown with speckled white Mica, pyrite grains <1mm)



Drilling Company: DGS	Started: 14/01/2008
Drilling Equipment: Edson 4000	Completed: 28/01/2008
Drilling Method: Mud	Compiled: 7/09/2008

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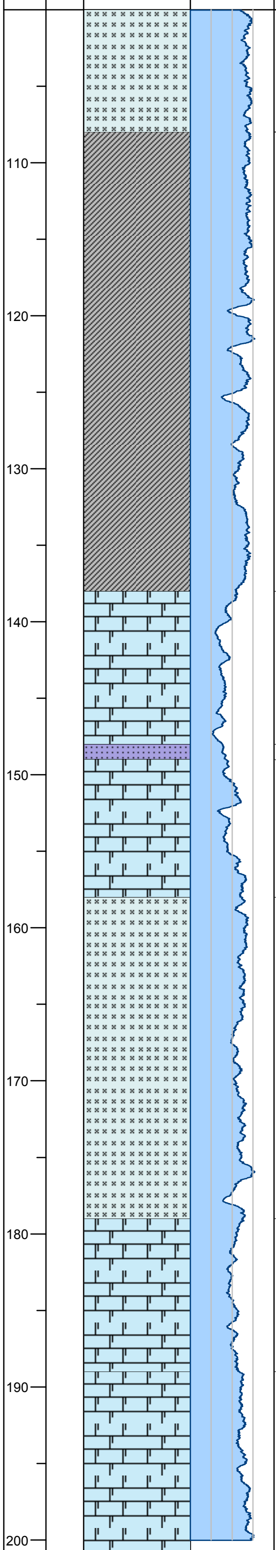
Borehole: TWB008-M1

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (50 – 150)	Lithology	Bore Construction



SHALE, dark greyish blue Mica

DOLOMITE vuggy, sugary qtz; mica flakes

SANDSTONE, qtz, dark brown

DOLOMITE brown Pyrite grains <0.2mm

SILTSTONE, dark greyish blue with mottled brown Pyrite grains <0.2mm

DOLOMITE

DOLOMITE

1/298 Selby St, Osborne Park WA 6017
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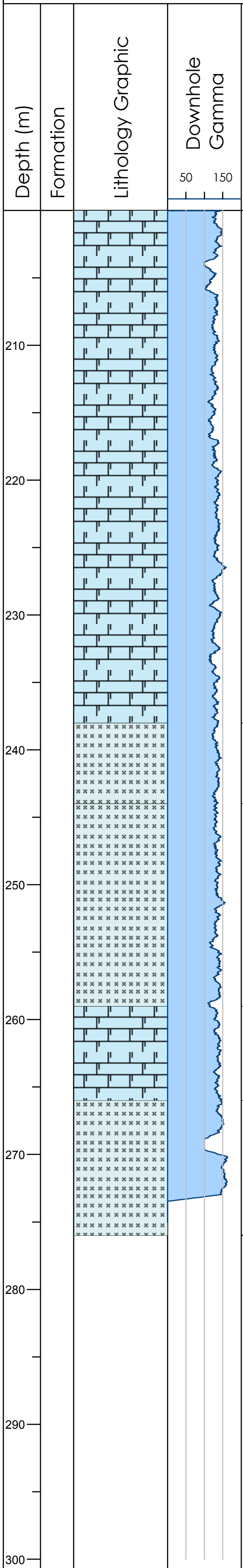
Borehole: TWB008-M1

SUBSURFACE PROFILE

Depth (m) / Formation / Lithology Graphic / Downhole Gamma	Lithology	Bore Construction
	SILTSTONE, dark greyish blue with mottled brown	
	SILTSTONE, dark greyish blue with mottled yellowish brown Pyrite grains very slow drilling.	
	DOLOMITE, dark greyish blue	
	SILTSTONE, dark greyish blue with mottled brown pyrite grains <0.2mm	



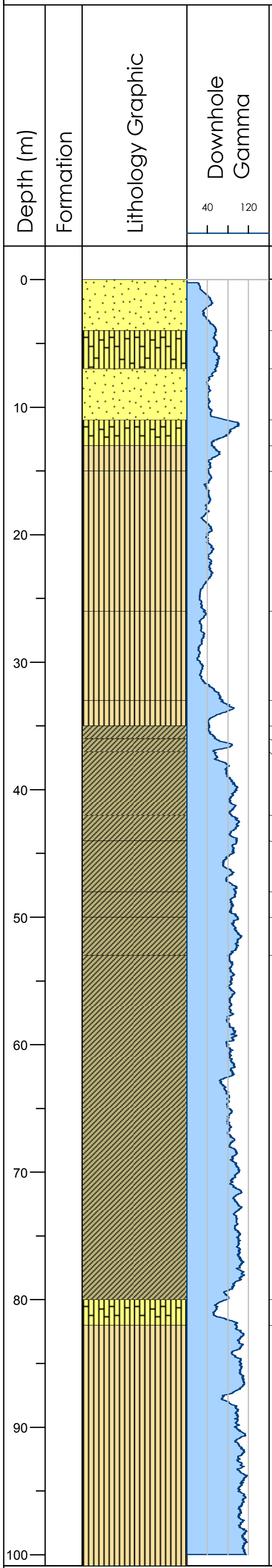
1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

Borehole: TWB015-T1

Project: Tropicana Water Study		Client: Anglogold Ashanti	Location: Lake Rason
Easting: 634879	Elevation: 362 (mAHD)	SWL: 24 m (toc) on 19/05/2008	Logged By: Will White / Gary Bownds
Northing: 6812465	Total Depth: 268 m	Salinity: 107850 mg/L on 19/05/2008	Checked By: B Gallen

SUBSURFACE PROFILE

Depth (m) | Formation | Lithology Graphic | Downhole Gamma (40–120) | Lithology | Bore Construction



Ground Surface

SW med SAND with trace silt well graded, very loose, SR red brown with speckled orange Aeolian deposit

SM silty med SAND well graded, very loose, SR red brown Minor cementation of sands

SW coarse SAND with trace fine gravel well graded, very loose, SR yellow Chips of silcrete / calcrete

SM silty med SAND well graded, very loose, SA white Cemented sand

MH SILT with trace fine sand, soft, medium plasticity white with mottled white Minor fine sand

MH SILT, soft, high plasticity white

MH SILT, soft, medium plasticity, pale white grey

MH SILT, soft, high plasticity white

CH CLAY, soft, high plasticity white

CH silty CLAY with trace silt, soft, high plasticity white

CH silty CLAY with silt, soft, high plasticity white, very pale pink

CH silty CLAY with silt, soft, high plasticity yellowish brown, very pale pink stains likely organics

CH silty CLAY with trace silt, soft, high plasticity yelllowish brown, very pale pink stains likely organics

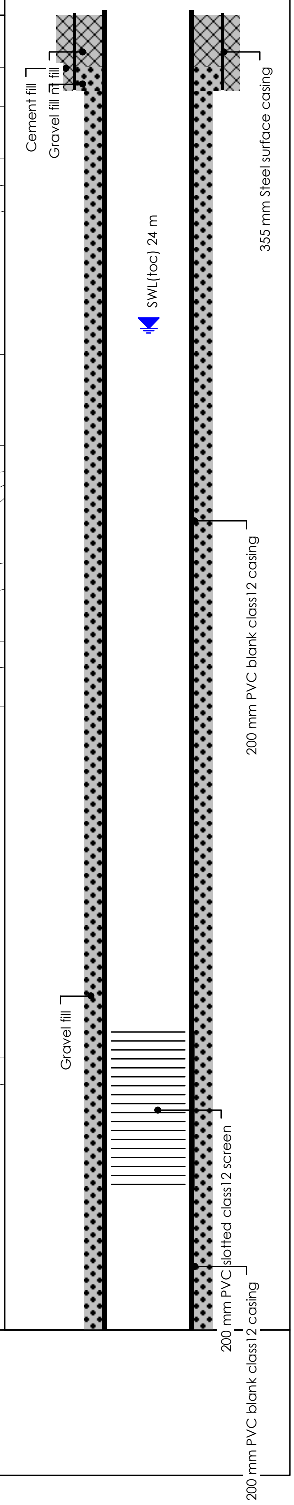
CH silty CLAY silt, soft, high plasticity grey

CH CLAY, soft, high plasticity yelllowish brown

CH CLAY, soft, high plasticity grey with speckled grey

SM silty med SAND poorly graded, very loose, SR grey Slow to very slow dilatancey

MH SILT with trace fine sand, soft, medium plasticity, pale grey



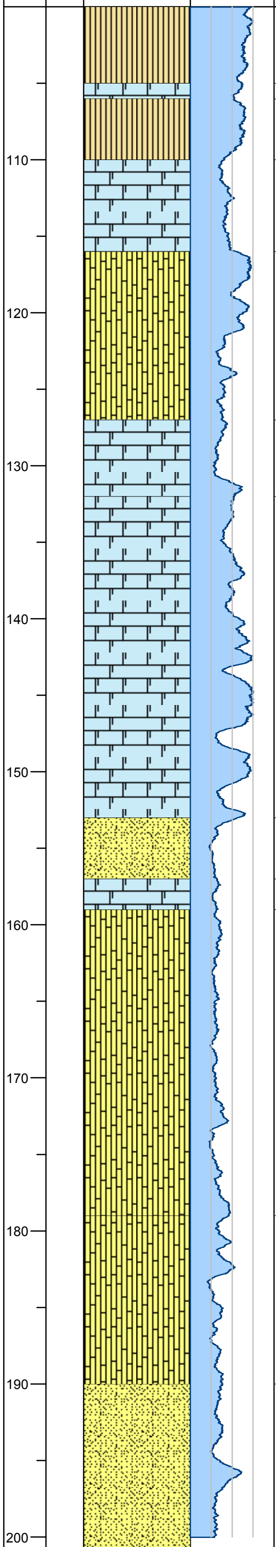
Drilling Company: DGS	Started: 3/05/2008
Drilling Equipment: Edson 4000	Completed: 19/05/2008
Drilling Method: Mud	Compiled: 7/09/2008

1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

Borehole: TWB015-T1

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (40–120)	Lithology	Bore Construction



DOLOMITE, pale grey

MH SILT, soft, medium plasticity grey white

DOLOMITE, pale grey white

SM silty fine SAND poorly graded, very loose, rounded grey, pale grey

DOLOMITE, pale grey

DOLOMITE white, pale grey

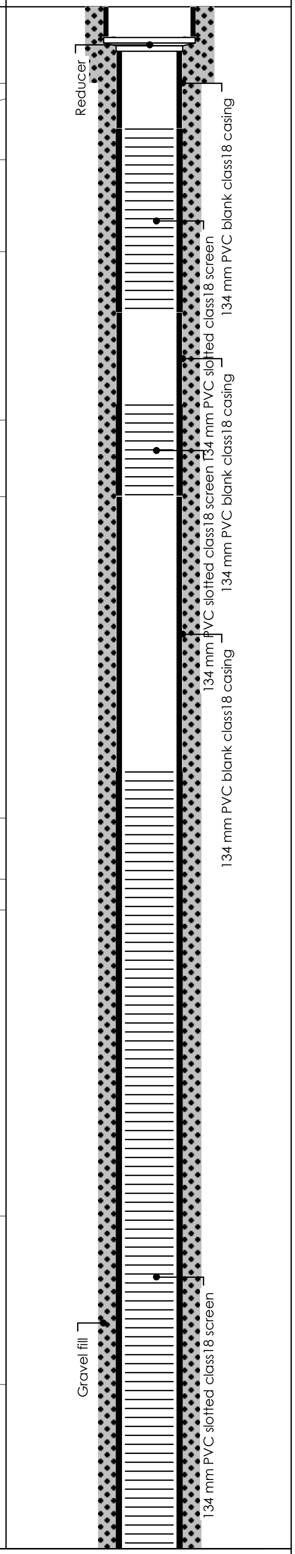
SP fine SAND with trace silt poorly graded, very loose, rounded grey

DOLOMITE, pale grey

SM silty fine SAND poorly graded, very loose, rounded grey Minor pockets of brown matrix; Dolomite at 161m and 170m

SM silty fine SAND poorly graded, very loose, rounded, pale grey Pellets of dense clay; minor dolomite

SP fine SAND with trace silt poorly graded, very loose, rounded, pale grey with speckled orange



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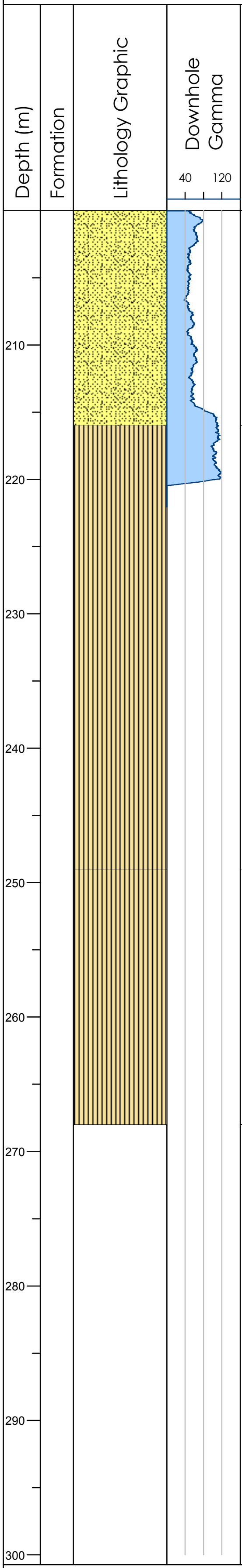
Borehole: TWB015-T1

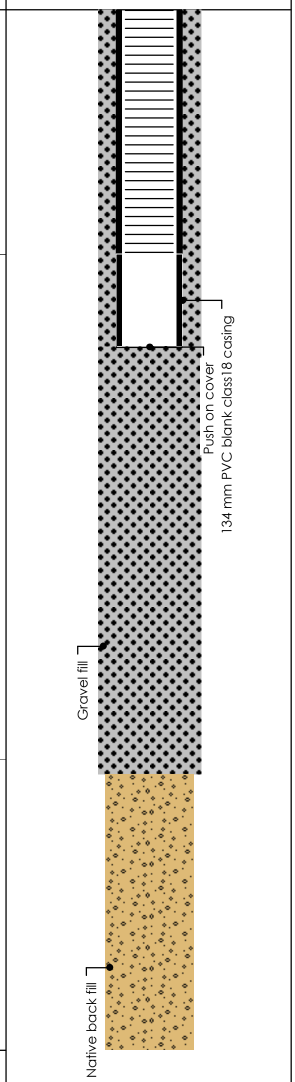
SUBSURFACE PROFILE

Depth (m) / Formation / Lithology Graphic / Downhole Gamma	Lithology	Bore Construction



MH SILT with trace fine sand, soft, medium plasticity, pale brown with mottled orange

MH SILT, soft, medium plasticity, pale greyish brown with mottled brown



1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

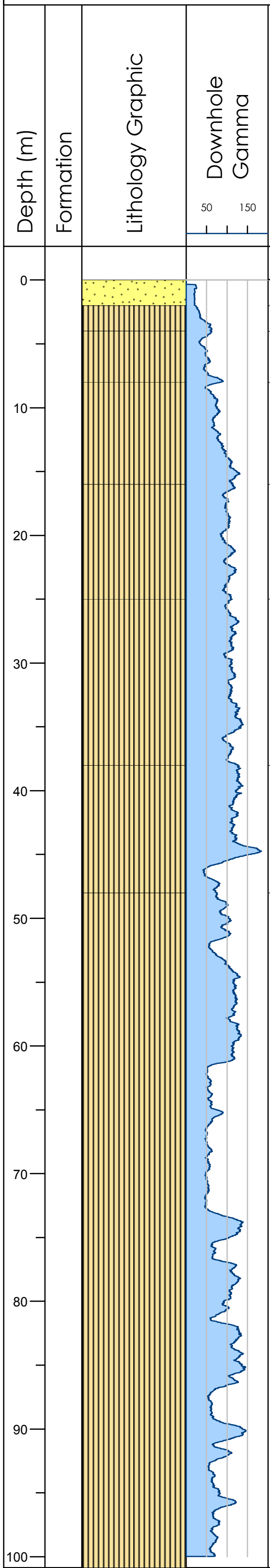
Borehole: TWB017-T2

Project: Tropicana Water Study | Client: Anglogold Ashanti | Location: Lake Rason

Easting: 639189 | Elevation: 362 (mAHD) | SWL: 28 m (toc) on 19/06/2008 | Logged By: Ian Anderson
Northing: 6800330 | Total Depth: 334 m | Salinity: 34490 mg/L on 19/06/2008 | Checked By: B Gallen

SUBSURFACE PROFILE

Depth (m) | Formation | Lithology Graphic | Downhole Gamma | Lithology | Bore Construction



Ground Surface

SW med SAND with trace silt, loose, SR, pale brown with mottled orange, Aolian Deposits

ML SILT, firm, low plasticity, dark orange with mottled grey green Silcrete; chemical weathering

ML SILT, very stiff, low plasticity, pale orange with speckled grey green, Colluvium Silcrete; chemical waethering

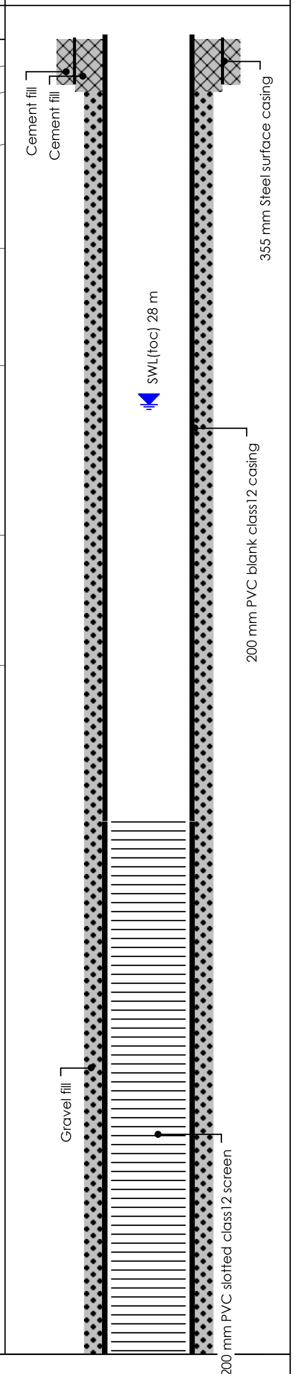
ML sandy SILT with fine sand, soft, low plasticity white with speckled yellow brown Silcrete bands <1cm from 8 to 12m

ML sandy SILT with trace fine sand, firm, low plasticity, pale orange Silcrete bands <1cm from 17 to 18m

ML SILT, stiff, low plasticity grey brown Slow drilling

MH sandy SILT with trace fine sand, firm, medium plasticity, mottled grey

MH sandy SILT with trace fine sand, firm, medium plasticity, mottled grey with speckled yellow



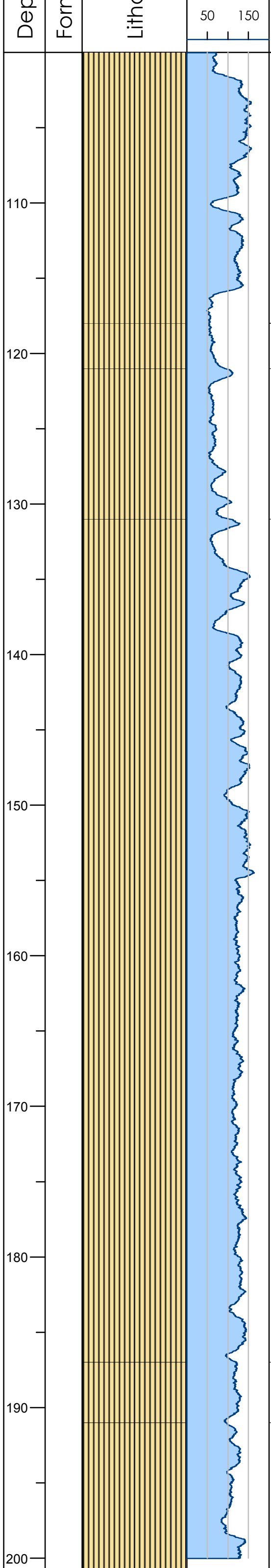
Drilling Company: DGS | Started: 30/03/2008
Drilling Equipment: Edson 4000 | Completed: 15/04/2008
Drilling Method: Mud | Compiled: 7/09/2008

1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

Borehole: TWB017-T2

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma	Lithology	Bore Construction



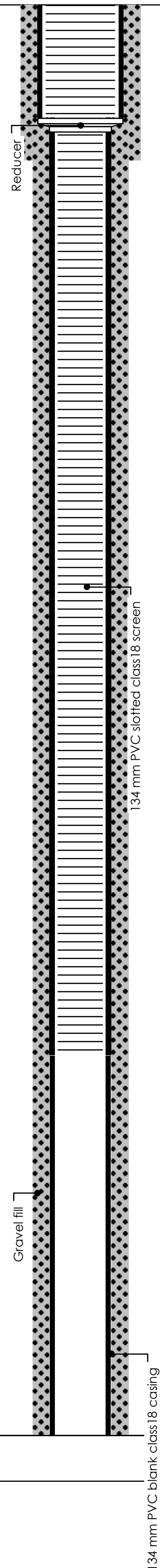
MH SILT, firm, medium plasticity with mottled, pale brown dolomite

MH SILT, firm, medium plasticity with mottled Some dolomite

MH SILT, firm, medium plasticity

MH SILT, firm, medium plasticity with mottled, pale dolomite

MH SILT with trace med sand, firm, medium plasticity grey with speckled yellow



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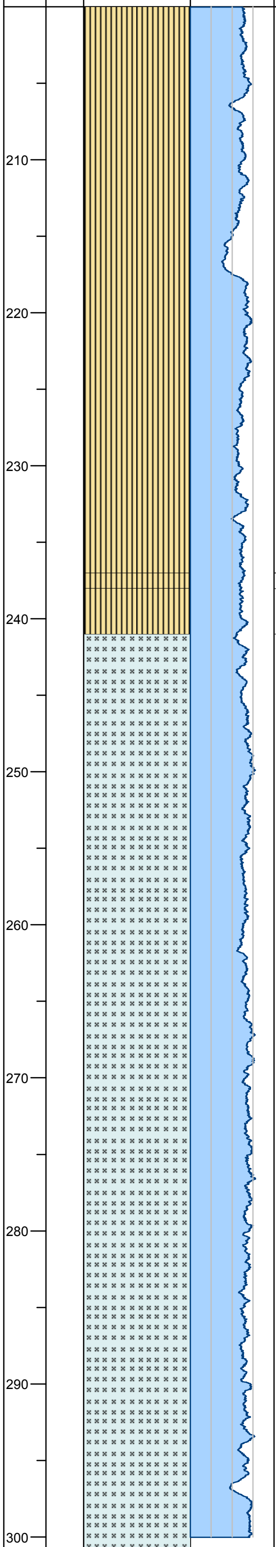
Borehole: TWB017-T2

SUBSURFACE PROFILE

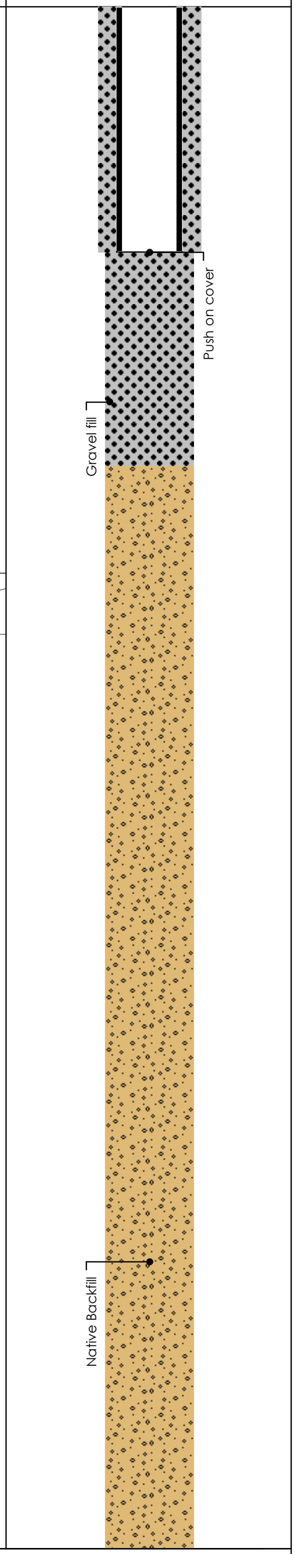
Depth (m)	Formation	Lithology Graphic	Downhole Gamma (50 – 150)	Lithology	Bore Construction



M SILT MH SILT, firm, medium plasticity   with dolomite

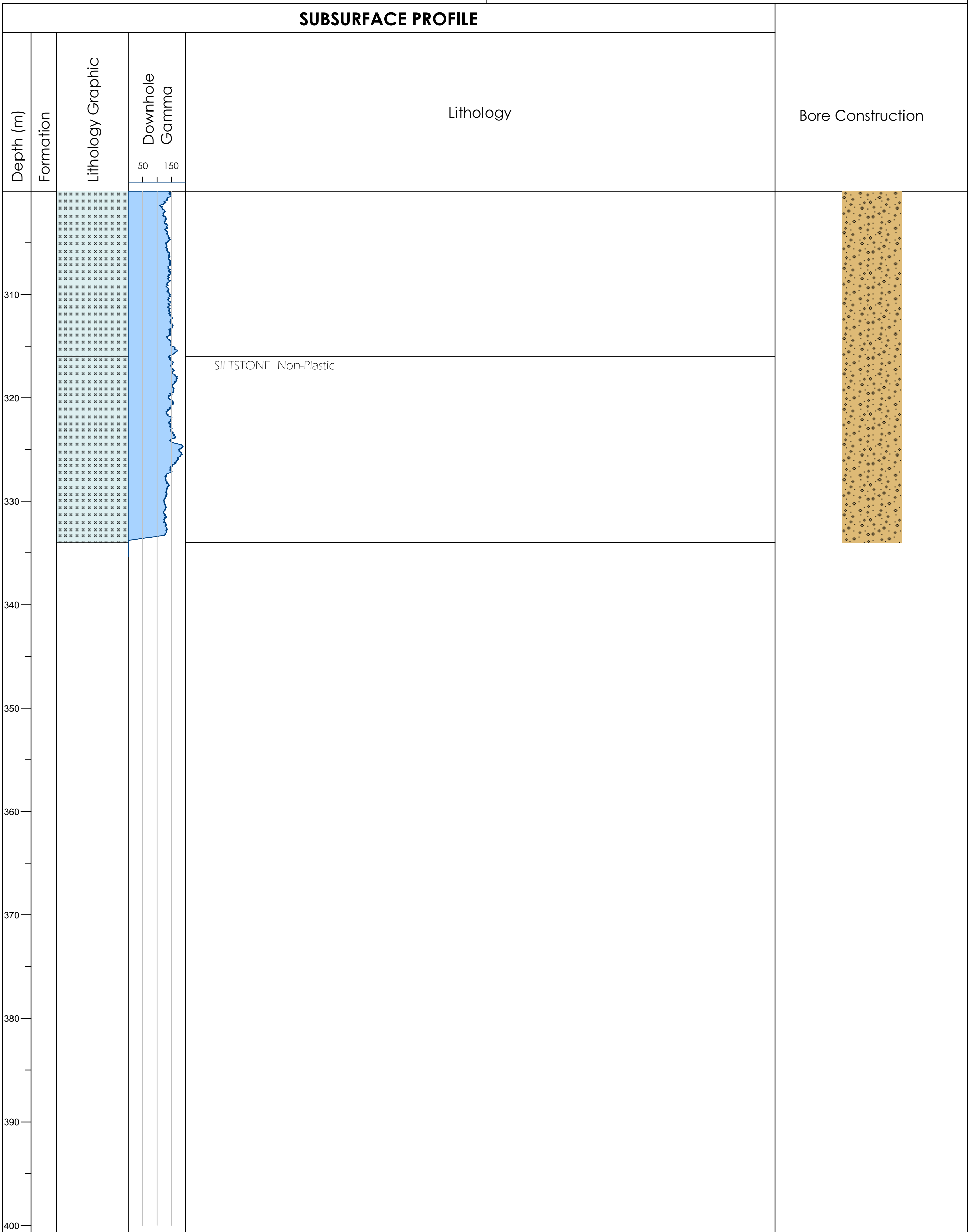
MH SILT with trace fine sand, firm, medium plasticity with mottled grey

SILTSTONE, mottled grey with speckled orange ; with some dolomite at intervals 241m, 280m, 290m-299m and 306m



1/298 Selby St, Osborne Park WA 6017
T: +618 94410999   F: +618 92041595

Borehole: TWB017-T2



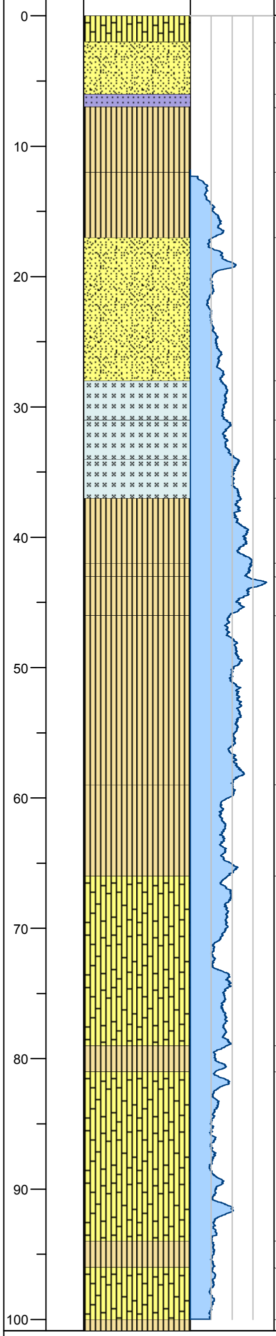
1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

Borehole: TWB018-T2

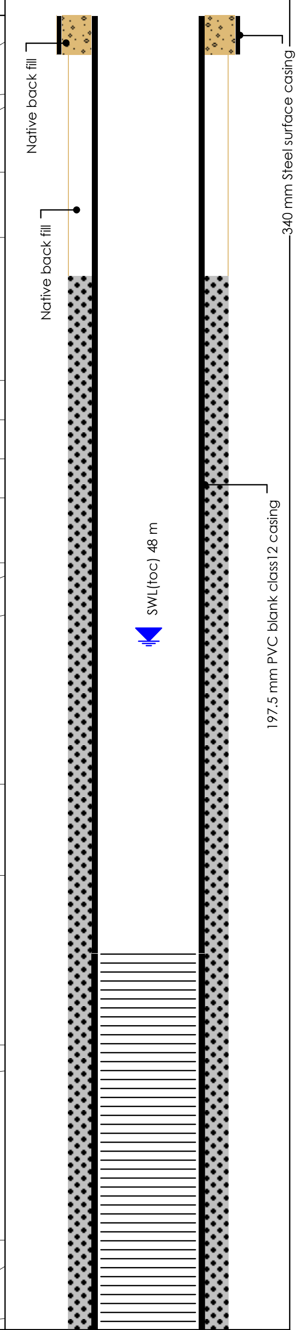
Project: Tropicana Water Study	Client: Anglogold Ashanti	Location: Lake Rason
Easting: 638818 / Northing: 6804313	Elevation: 381 (mAHD) / Total Depth: 317 m	SWL: 48 m (toc) on 30/03/2008 / Salinity: 58060 mg/L on 30/03/2008
Logged By: Will White / Ian Anderson	Checked By: B Gallen	

SUBSURFACE PROFILE

Depth (m) | Formation | Lithology Graphic | Downhole Gamma (50 – 150) | Lithology | Bore Construction



Lithology
Ground Surface
SM silty med SAND gap graded, loose, SR, moderate red brown with speckled red brown, Aolian Deposits
SP-SM med SAND with trace silt gap graded, medium dense, SA, pale brown, pale brown
SANDSTONE, very pale orange Very strongly silified.
ML sandy SILT with fine sand, firm, low plasticity, very pale orange Strongly silified.
ML sandy SILT with trace fine sand, stiff, low plasticity, very pale orange with speckled grey Silified.
SP-SM fine SAND with trace silt poorly graded, very loose, SR, very pale orange Minor silified bands. Iron staining.
SILTSTONE, very pale orange Pale pink bands
SILTSTONE, very pale orange with mottled, pale brown, Alluvial Deposit
SILTSTONE, dark yellowish orangewith banded, pale pink
MH SILT, soft, medium plasticity, dark yelllowish orange
MH SILT, soft, medium plasticity, dark yelllowish orange Organic present
MH SILT, soft, medium plasticity, pale brown
MH sandy SILT with trace fine sand, soft, medium plasticity, dark yellowish brown
MH sandy SILT with trace fine sand, soft, medium plasticity olive grey
SM silty med SAND poorly graded, very loose, SR, pale olive grey with speckled grey
ML sandy SILT with trace fine sand, soft, low plasticity greyish green olive grey
SM silty med SAND poorly graded, very loose, SR, pale greyish green olive grey
ML sandy SILT with trace fine sand, soft, low plasticity olive grey with speckled grey Moderate dilatency. No toughness
SM silty med SAND poorly graded, very loose, SR olive grey with speckled grey



Drilling Company: Scanlon
Drilling Equipment: Kelly Bar Rig
Drilling Method: Mud

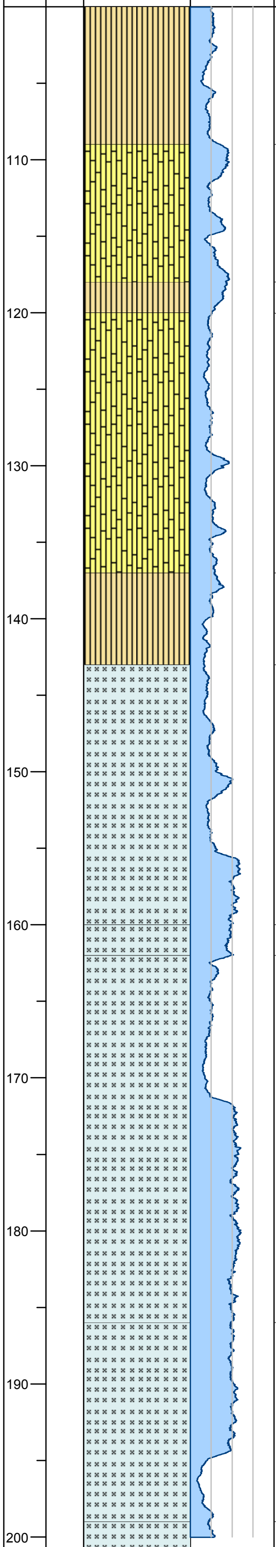
Started: 11/12/2007
Completed: 30/03/2008
Compiled: 7/09/2008

1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

Borehole: TWB018-T2

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (50 – 150)	Lithology	Bore Construction



ML sandy SILT with fine sand, soft, low plasticity olive grey with speckled grey Low dilatency. No toughness

SM silty med SAND poorly graded, very loose, SR olive grey with speckled grey

ML sandy SILT with trace fine sand, soft, low plasticity olive grey with speckled grey Low dilatency. Low toughness

SM silty med SAND poorly graded, very loose, SR olive grey with speckled grey

MH SILT with trace fine sand, soft, medium plasticity olive grey with speckled orange Meduim toughness

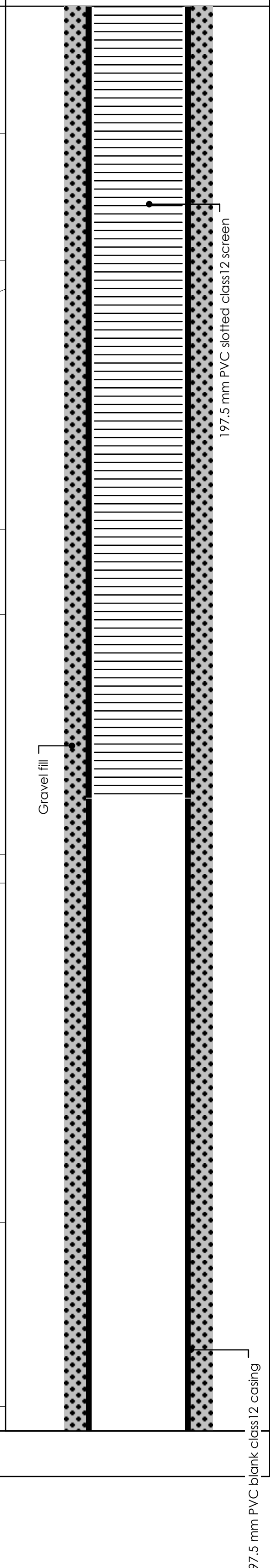
SILTSTONE grey

SILTSTONE, dark yelllowish brown hard band, slow drilling, partly silicified

SILTSTONE grey

SILTSTONE, dark bluish grey with pyrite grains

SILTSTONE grey with pyrite grains



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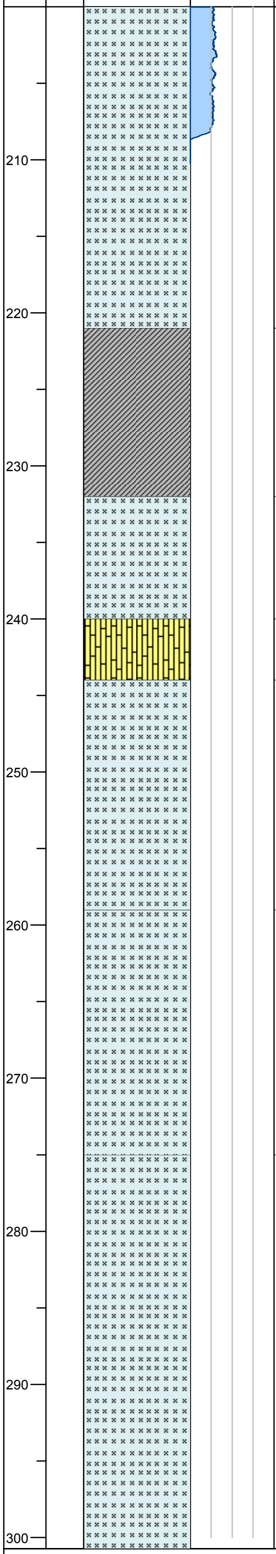
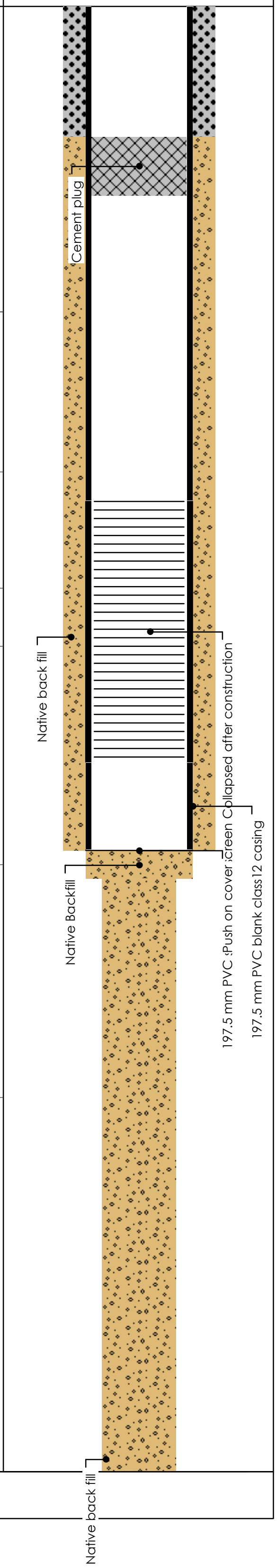
Borehole: TWB018-T2

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (50 – 150)	Lithology
				SHALE, dark bluish grey with pyrite grains
				SILTSTONE bluish grey with pyrite grains
				SM silty med SAND poorly graded, loose, SR grey
				SILTSTONE grey with pyrite grains
				SILTSTONE, dark bluish grey with pyrite grains
				SILTSTONE, dark grey



Bore Construction



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Borehole: TWB018-T2

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (50 – 150)	Lithology	Bore Construction
310					
320					
330					
340					
350					
360					
370					
380					
390					
400					

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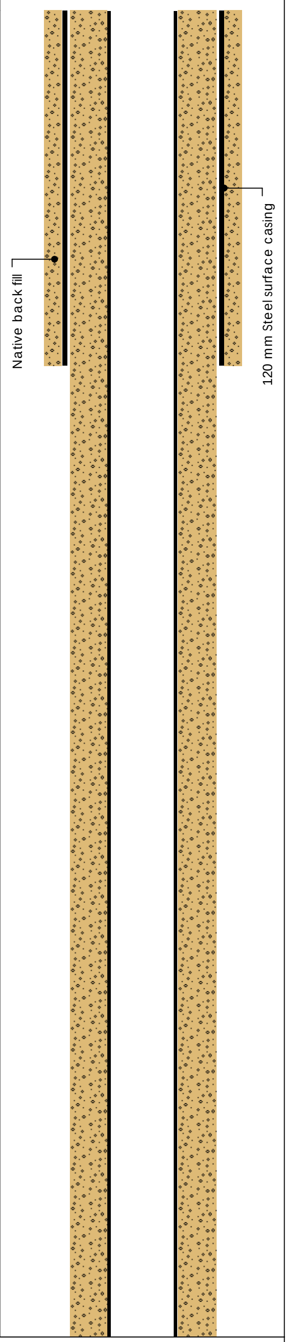
Borehole: TWB018-M3

Project: Tropicana Water Study		Client: Anglogold Ashanti	Location: Lake Rason
Easting: 638922	Elevation: 381 (mAHD)	SWL: 45 m (toc) on 6/09/2008	Logged By: Len Baddock
Northing: 6804256	Total Depth: 385 m	Salinity:	Checked By:

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology	Bore Construction
			Ground Surface	
0				
5				
10				
15				
20				
25				



Drilling Company: Boart Longyear	Started: 30/08/2008
Drilling Equipment:	Completed: 6/09/2008
Drilling Method: Diamond	Compiled: 19/02/2009

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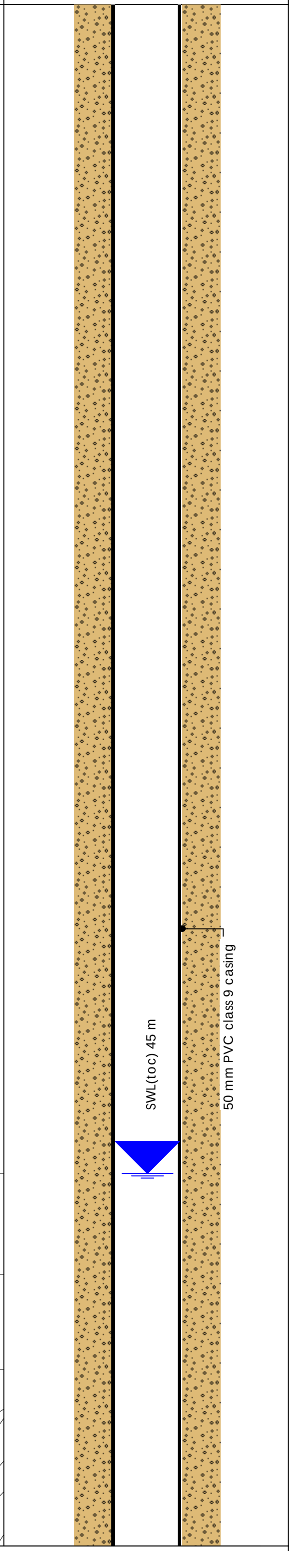
Borehole: TWB018-M3

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology
30			
35			
40			
45			CLAYSTONE. Moderate brown claystone with sand (20%), fine to medium grained, SA-SR, quartz; massive, very low strength.
			CLAYEY SANDSTONE. Greyish orange, fine grained (0.08mm), SR, well sorted, with clay matrix (10 - 30%), trace medium grained, SR sand; massive, very stiff.
			SANDSTONE. Dark yellowish orange, fine grained, well sorted, SR quartz sand, grains with goethite coating, trace heavy minerals; Secondary CLAYEY SANDSTONE. pale yellowish brown, fine grained sand with clay matrix (20-30%), as narrow bands; ferruginous band @ 48.8m.
			SANDY SILTSTONE. Dark yellowish orange siltstone with fine grained (30-40%), SR-SA quartz sand; massive, very firm
50			SILTY SANDSTONE. Moderate brown, fine grained, SR-SA, well sorted quartz sand with silt matrix (40%).
			SANDY CLAYSTONE. Dark yellowish orange claystone with fine grained (30-40%), SR-SA quartz sand; very firm.

Bore Construction



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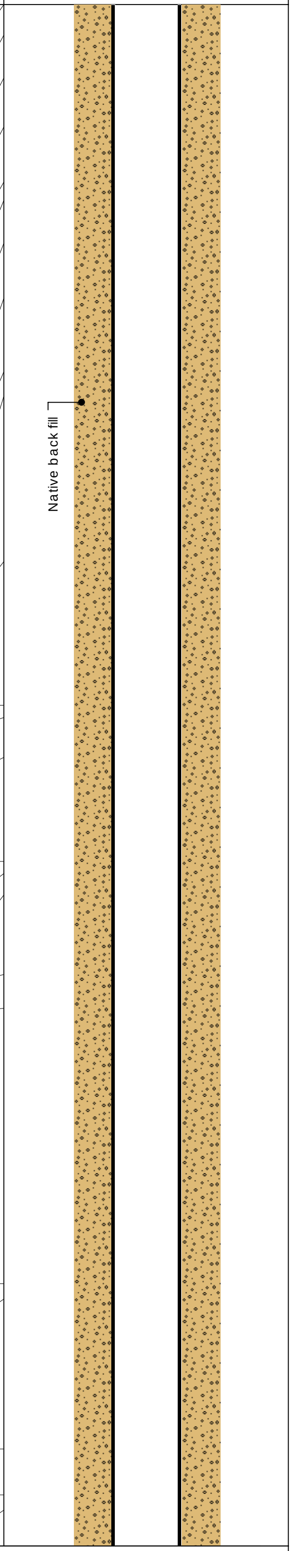
Borehole: TWB018-M3

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology
			SANDSTONE. Dark yellowish orange, fine grained (0.1mm), well sorted, SA quartz sand, trace heavy minerals; Secondary CLAYEY SANDSTONE – pale yellowish brown, fine grained sand with clay (20-30%); soft sediment deformation – clayey sandstone ruptured and filled with sandstone, very firm.
			SANDSTONE. Dark yellowish orange, fine grained (0.1mm), well sorted, SA quartz sand, trace heavy minerals; very firm.
			CLAYEY SANDSTONE. Dark yellowish orange, fine grained (~0.07mm) quartz sand with clay matrix (~20%); massive, very stiff.
			SANDY CLAYSTONE. Pale yellowish brown claystone with fine grained quartz sand (~30-40%); massive, very stiff.
55			CLAYEY SANDSTONE. Dark yellowish orange, fine grained (0.07mm), well sorted, SA quartz sand, with clay matrix (~20%); 53.6-53.7m – moderate brown, ferruginous; massive, very firm.
			SANDSTONE. Dark yellowish orange, fine grained (0.1mm), well sorted, SR quartz sand; ferruginous @54.1m; Secondary CLAYEY SANDSTONE as above; firm, soft sediment deformation – ruptured clayey sandstone.
			SANDSTONE. Pale yellowish brown, fine grained (0.15 – 0.1mm), moderately well sorted quartz sand, minor clay matrix.
			SANDY CLAYSTONE. Pale yellowish brown claystone with fine grained sand; Secondary SANDSTONE – dark yellowish orange, fine grained (0.1mm), well sorted, SR quartz sand; very firm, soft sediment rupture of claystone with sandstone filling.
			SANDSTONE. Light brown, fine grained (0.1mm), well sorted, SA-SR quartz sand, trace heavy minerals and garnet, minor clay; some clayey sandstone to 56.3m; medium dense.
			CLAYEY SANDSTONE. Dark yellowish orange, fine grained (0.1mm), quartz sand, with clay matrix (~20%); loose to medium dense; ferruginous goethite cemented band @ 57.3m, moderate brown, dense (Base of oxidised zone).
60			SANDSTONE. Medium dark grey, fine grained (0.07-0.15mm), moderately well sorted, partial siliceous cementation, minor clay matrix; medium dense; Sandstone filled fractures, dark yellowish orange, @ 58, 58.6 and 58.7m; Clayey Sandstone clasts present.
			SANDSTONE. Medium grey, fine grained (0.07mm), well sorted, SA-SR, quartz sand, trace heavy minerals, garnet; Secondary CLAYEY SANDSTONE – ruptured beds and clasts present
			SANDY SILTSTONE. Medium dark grey siltstone with abundant fine grained sandstone; medium dense.
			SANDSTONE. Light brownish grey, fine grained (0.1-0.12mm), well sorted, SA-SR quartz sand, trace heavy minerals; massive, medium dense; clay band @ 62.75m.
			SILTSTONE. Medium grey siltstone with fine grained sand; medium dense; fine grained (0.07mm) sandstone intervals.
65			SANDSTONE. Light brownish grey, fine grained (0.1-0.15mm), well sorted, SA-SR quartz sand, minor heavy minerals and garnet; medium dense.
			SANDY SILTSTONE. Brownish grey siltstone with abundant fine grained sand; SANDSTONE – as above; disturbed bedding.
			SANDSTONE. Light brownish grey, fine grained (0.1mm), well sorted, SA quartz sand; medium dense.
			SHALE. Dark grey shale, hard, dense, bedding broken and ruptured, infilled with SANDSTONE – as above
			SANDSTONE. Light brownish grey, fine grained (0.2mm), well sorted, SA-SR quartz sand, trace heavy minerals and garnet; loose – medium dense, porous.
70			
			SHALE. Medium dark grey shale, minor interbedded fine grained sandstone layers to 2cm thick; low angle bedding.
			SANDSTONE. Light brownish grey, fine grained (0.1-0.12mm), well sorted, SA-SR quartz sand, common red brown stained grains, some shale flakes in beds; low strength, porous.
75			SHALE. Medium dark grey shale, some thin sandstone beds; medium strength.
			SILTY SANDSTONE. Light brownish grey, fine grained (0.1mm), quartz sand with silt matrix; some shale clasts at base; low – medium strength.

Bore Construction



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SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology	Bore Construction
			SANDSTONE. Light brownish grey, fine grained (0.13-0.2mm), well sorted, SA-SR quartz sand, common red brown stained grains; thin clay band @ 76.05 and 76.4m; siltstone clast @ 83.9m; low strength, porous.	
80				
85				
			SANDSTONE. Light brownish grey, fine grained, well sorted, SA-SR quartz sand, common red brown stained grains; common ruptured SANDY SILTSTONE beds up to 1cm thick.	
			SHALE. Medium dark grey shale.	
			SANDSTONE and SHALE. Light brownish grey, fine grained, well sorted, SA-SR quartz sand, common red brown stained grains, with common shale lamination; 5cm clay bed @ 89.3m.	
90			SANDSTONE. Light brownish grey, fine grained (~0.1-0.15mm), well sorted, SA-SR quartz sand, trace heavy minerals and garnet; minor shale clasts.	
			SHALE. Medium dark grey shale; medium strength, very stiff; some SANDSTONE filled fractures toward base.	
95			SANDSTONE. Light brownish grey, fine grained (0.15mm), well sorted, SA-SR quartz sand, minor heavy minerals and trace garnet, common red brown stained grains; low strength, porous.	
			SHALE. Medium dark grey shale; ruptured beds filled with SANDSTONE as above.	
			SANDSTONE. Light brownish grey, fine grained (0.15mm), well sorted, SA-SR quartz sand, minor heavy minerals and trace garnet, common red brown stained grains; low strength, porous.	
100			SHALE. Medium dark grey shale; ruptured beds filled with SANDSTONE as above.	
			SANDSTONE. Light brownish grey, fine grained (0.15mm), well sorted, SA-SR quartz sand, minor heavy	

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SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology
			SHALE. Medium dark grey shale; some thin sandstone layers; predominantly horizontal bedding, small scale displacement of beds ~101.8m.
			SANDSTONE. Light brownish grey, fine grained (0.15mm), well sorted, SA-SR quartz sand, minor heavy minerals and trace garnet, common red brown stained grains; low strength, porous; 103.6-103.7m silty sandstone; small scale displacement of beds.
105			
			SHALE. Medium dark grey shale with SANDY SILTSTONE.
			SANDSTONE. Light brownish grey, fine grained (0.15mm), well sorted, SA-SR quartz sand, minor heavy minerals and trace garnet, common red brown stained grains; low strength, porous; SHALE beds at 108.3 (5cm), 108.77 (2cm) and 109.05m (4cm); silty sandstone 'flame' at base.
110			SANDSTONE. Light brownish grey, fine grained (0.15mm), well sorted, SA-SR quartz sand, minor heavy minerals and trace garnet, common red brown stained grains; low strength, porous; SHALE beds at 108.3 (5cm), 108.77 (2cm) and 109.05m (4cm); silty sandstone 'flame' at base.
			SANDSTONE. Light brownish grey, fine grained (0.15mm), well sorted, SA-SR quartz sand, minor heavy minerals and trace garnet, common red brown stained grains; low strength, porous; interlayered with silty sandstone in lower 10cm.
			SHALE. Medium dark grey shale; ruptures filled with fine grained sandstone.
			SANDSTONE. Light brownish grey, fine grained (~0.15-0.18mm), well sorted, SA quartz sand, with common red brown stained grains, minor heavy minerals; very low strength, loose to medium dense.
			SHALE. Medium dark grey shale with laminations (few mm thick) of fine grained sandstone.
			SANDSTONE. Light brownish grey, fine grained (~0.15-0.18mm), well sorted, SA quartz sand, with common red brown stained grains, minor heavy minerals; very low strength, loose to medium dense.
			SHALE. Medium dark grey shale, with siltstone laminations; medium dense, medium strength.
115			SANDSTONE. Light brownish grey, fine grained (0.1mm), well sorted, SA quartz sand, minor heavy minerals, common red brown stained grains; medium dense, low strength.
			SANDSTONE. Light brownish grey, fine grained (0.1mm), well sorted, SA quartz sand, minor heavy minerals, common red brown stained grains, well lithified, hard; dense, very high strength.
			SANDSTONE. Light brownish grey, fine grained, well sorted, SA quartz sand, with common red brown stained grains, minor heavy minerals; very low strength, loose to medium dense; clayey sandstone and siltstone bands 119.2-119.5m.
120			
			SHALE. Medium dark grey shale; ruptured and filled with SANDSTONE (50% of interval).
			SANDSTONE. Light brownish grey, fine grained (0.15mm), well sorted, SA-SR quartz sand, common red brown stained grains, minor heavy minerals; medium dense, low strength, porous.
125			

Bore Construction

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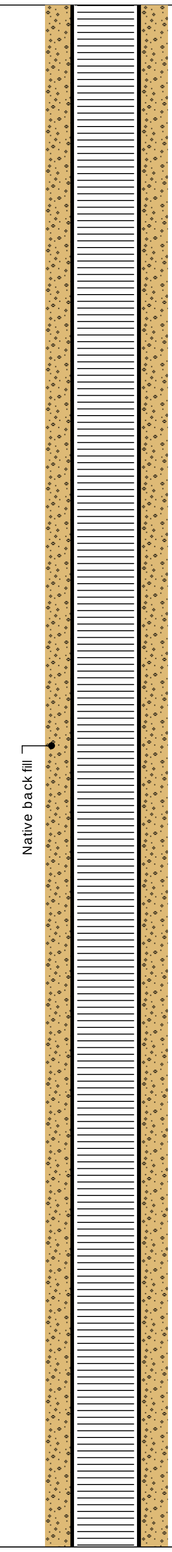
SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology
130			SANDSTONE. Light brownish grey, fine grained, well sorted, SA-SR quartz sand, common red brown stained grains, minor heavy minerals; common SHALE rupture clasts; medium dense, low-medium strength.
			SANDSTONE. Light brownish grey, fine grained (0.15mm), well sorted, SA-SR quartz sand, common red brown stained grains, minor heavy minerals; medium dense, low strength, porous; 132.8-132.95m SILTSTONE.
			SANDSTONE. Light brownish grey, fine grained sandstone with SHALE and SILTSTONE beds; medium dense, medium strength
135			SILTY SANDSTONE. Light brownish grey, fine grained (0.1mm) sandstone with minor silt matrix, moderately lithified; medium dense – dense, high strength.
140			SHALE. Medium dark grey shale, with silty sandstone layers, deformed; medium strength, dense.
			LIMESTONE/DOLOMITE. Pale yellowish brown (fizzes with 2M HCl) (?possible Stromatolite).
			SHALE. Medium dark grey; sandy siltstone @ 142 and 142.2m.
145			SILTSTONE. Pale yellowish brown siltstone; hard, dense; SANDSTONE – fine grained swirls and veins, minor in part; 145.85-146.3 shale layers and clasts.
			SHALE. Medium dark grey shale; hard, dense; common thin, fine grained sandstone and siltstone layers, thicker beds to 15cm.
150			SANDSTONE. Light brownish grey, fine grained (0.1mm) sand; moderately porous; medium strength, medium dense; 150.85-151.1m calcareous cemented band, pale yellowish brown; siliceous cemented sandstone band 152.7 (6cm) and 152.84 (5cm).

Bore Construction



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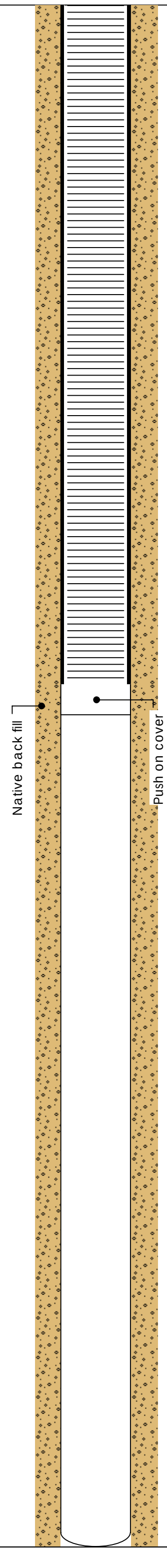
SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology
			SILTSTONE and SHALE. Greyish brown shale and siltstone; ruptured beds filled with SANDSTONE – pale brown, fine grained (<0.1mm); hard, medium dense, high strength.
155			SANDSTONE. Pale yellowish brown, fine grained (0.1mm), well sorted, SA-SR quartz with trace heavy minerals, common red brown stained grains; SHALE and SILTSTONE bands, contorted, 155.4, 155.8, 156.5, 156.65, 156.85 and 157.25m.
			CALCAREOUS SANDSTONE. Pale yellowish brown, fine grained sandstone, calcareous cemented (fizzes with 2M HCl); very hard, very dense, very high strength.
160			SANDSTONE. Pale yellowish brown, fine grained (0.15mm), well sorted, SA-SR quartz sand, trace heavy minerals, common red brown stained grains; loose – medium dense, low strength, porous (good mud-cake); 161.05-161.4m SANDSTONE – (<0.1mm), moderate cementation, dense, high strength, silty over lower 10cm.
165			
			SILTSTONE and SHALE. Greyish brown shale and siltstone; ruptured beds filled with SANDSTONE – pale brown, fine grained (<0.1mm); hard, medium dense, high strength, contorted shale and siltstone beds within sandstone.
			SANDSTONE. Pale yellowish brown, fine grained (0.12-0.15mm), well sorted, SA-SR quartz sand, trace heavy minerals, common red brown stained grains; loose – medium dense, low strength, porous (good mud-cake).
			SHALE. Greyish brown shale; predominantly horizontal bedding, some sandstone filled fractures and swirls; high strength, dense.
170			SANDSTONE. Pale yellowish brown, fine grained (0.15mm), well sorted, SA-SR quartz sand, trace heavy minerals, common red brown stained grains; loose, low strength, porous (good mud-cake); occasional small shale clasts.
175			

Bore Construction



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SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology	Bore Construction
180				
			SANDSTONE. Pale yellowish brown, fine grained, well sorted, SA-SR quartz sand, trace heavy minerals, common red brown stained grains; medium dense, medium strength, low porosity (no mud-cake).	
			SANDSTONE. Pale yellowish brown, fine grained (0.1-0.2mm), well sorted, SA-SR quartz sand, trace heavy minerals, common red brown stained grains, rare green stained grains; low-medium strength, medium dense, porous (moderate-good mud cake).	
185				
190				
			SANDSTONE. Pale yellowish brown, fine grained (0.1mm), well sorted, SA-SR quartz sand, trace heavy minerals, common red brown stained grains; medium strength, medium dense, low porosity (little-no mud cake).	
			SANDSTONE. Pale yellowish brown, fine grained, well sorted, SA-SR quartz sand, trace heavy minerals, common red brown stained grains; low-medium strength, medium dense, porous (moderate-good mud cake); 194.65m shale/siltstone clast (4cm).	
195				
			SANDSTONE. Pale yellowish brown, fine grained (0.07-0.1mm) sandstone; SHALE and SILTSTONE – greyish brown, broken and contorted clasts within sandstone fill; medium strength, hard, low porosity.	
			SHALE. Brownish grey shale with thin layers and laminations of SILTSTONE and SANDSTONE, pale yellowish brown, fine grained; layers dipping up to ~60°, some small scale displacement features; hard, medium-high strength.	
200				

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Borehole: TWB018-M3

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology	Bore Construction
205			SANDSTONE. Pale yellowish brown, fine grained (0.09-0.13mm), well sorted, SA quartz sand, trace heavy minerals, common red brown stained grains; common shale-siltstone clasts (1mm-4cm), mostly within upper portion, 205.1m shale clast (15cm); layering horizontal to ~40°; medium strength, low porosity (little-no mud cake).	
210			SANDSTONE. Pale yellowish brown, fine grained (0.08-0.13mm) well sorted, SA quartz sand, trace heavy minerals, common red brown stained grains; low-medium strength, moderate porosity (moderate-good mud cake); 210.5-210.9 silty sandstone; shale clasts at 211.3 (7cm) and 212.4m (4cm).	
215			SANDSTONE. Pale yellowish brown, fine grained, well sorted, SA quartz sand, trace heavy minerals, common red brown stained grains; loose, very low strength, porous (good mud cake); irregular clasts – shale @ 217.5 (12cm), siltstone @ 218m (10cm).	
			SANDSTONE. Pale yellowish brown, fine grained (0.1mm) sandstone, and SILTSTONE – medium dark grey; moderately consolidated, medium dense, medium strength.	
220			SANDSTONE. Pale yellowish brown, fine grained (0.09-0.13mm), well sorted, A-SA, quartz sand, trace heavy minerals, common red brown stained grains; moderately consolidated, low-medium strength, medium dense, porous (good mud cake); broken/ruptured shale and siltstone clasts 220.3-220.5m and 221.55-221.62 m.	
225				

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Borehole: TWB018-M3

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology	Bore Construction
230				
235				
			SILTSTONE. Pale yellowish brown siltstone, ruptured and broken; filled with SANDSTONE - fine grained, well sorted, A-SA, quartz sand; hard, dense, high strength.	
240			SANDSTONE. Pale yellowish brown, fine grained (0.08-0.13mm), quartz sand, trace heavy minerals, common red brown stained grains; moderately consolidated, medium strength, medium dense, moderately porous (medium mud cake); common small shale fragments.	
			SHALE and SILTSTONE. Brownish grey shale and siltstone, hard; ruptured and broken, filled with SANDSTONE – fine grained.	
			SANDSTONE. Pale yellowish brown, fine grained, quartz sand, trace heavy minerals, common red brown stained grains; moderately consolidated, medium strength, medium dense, moderately porous (medium mud cake); siltstone lens @ 244.6m (5cm)	
245			SHALE. Brownish grey shale; well consolidated, hard, medium-high strength; rupture fractures filled with sandstone in upper 30cm; 45° angle bedding at base.	
			SANDSTONE. Pale yellowish brown, fine grained, well sorted, A-SA, quartz sand, trace heavy minerals, common red brown stained grains; moderately consolidated, low-medium strength, medium dense, porous (good mud cake); occasional small shale shards.	
250				

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SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology	Bore Construction
255				
			CALCAREOUS SANDSTONE. Pale yellowish brown, fine grained, well sorted sandstone, well cemented; very hard, very high strength.	
260				
			SANDSTONE. Pale yellowish brown, fine grained, well sorted, A-SA, quartz sand, trace heavy minerals, common red brown stained grains; moderately consolidated, low-medium strength, medium dense, porous (good mud cake); silty @ 261.75m (10cm), shale and siltstone clasts @ 262.7m (15cm),	
265				
			SILTSTONE and SHALE. Brownish grey shale and siltstone; 268.3-268.45m rupture zone filled with SANDSTONE – fine grained; hard, medium-hard strength.	
			SANDSTONE. Pale yellowish brown, fine grained (0.08-.1mm), well sorted, SR quartz sand, trace heavy minerals, common red brown stained grains; consolidated, medium dense – dense, medium-high strength, low porosity; 296.0-296.3m common shale clasts to 5cm, and common small shale shards below.	
270				
			SHALE. Brownish grey shale, hard; layers and ruptures filled with SANDSTONE – fine grained, well sorted, SR quartz sand, trace heavy minerals, common red brown stained grains; medium-hard strength, low porosity.	Open Hole
275				
			SANDSTONE. Pale yellowish brown, fine grained, well sorted, A-SA, quartz sand, trace heavy minerals, common red brown stained grains; moderately consolidated, low-medium strength, medium dense, porous	

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SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology	Bore Construction
280				
			SHALE. Brownish grey shale; hard, high strength, bedding planes dip up to ~45°; 284.06-284.35, 285.75-286.7m rupture zones filled with fine grained sandstone.	
285				
			SANDSTONE. Pale yellowish brown, fine grained (0.09-0.12m), well sorted, A-SA quartz sand, trace heavy minerals, common red brown stained grains; moderately consolidated, medium strength, medium dense, porous (good mud cake); 294.7-294.85m silty carbonaceous, 295.3-295.45m silty, 295.7-295.85m silty, 298.45-298.55m broken shale, 299.75-300m silty.(UNCONFORMITY)	
290				
295				
300				
			SHALE. Light brownish grey shale with SILTSTONE and fine grained SANDSTONE thin layers and filled	

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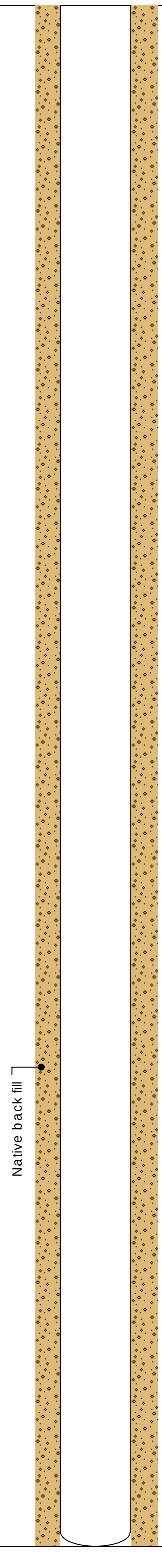
SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology
			SHALE and SANDSTONE. Light brownish grey shale, steeply dipping, with fine grained sandstone layers; hard, very high strength.
305			SANDSTONE. Pale yellowish brown, fine grained sandstone, well consolidated; dense – very dense, very high strength.
			SHALE and SILTSTONE. Light brownish grey shale and siltstone; thinly bedded, some small scale displacement features, hard, very high strength.
			SANDSTONE. Pale yellowish brown, fine grained sandstone, some siltstone; well consolidated, dense – very dense, very high strength.
			SHALE. Light brownish grey shale with thin beds of SILTSTONE and SANDSTONE – fine grained; some small scale displacement features, well consolidated, dense – very dense, very high strength, some slickensided joints.
310			SILTSTONE and SANDSTONE. Light brownish grey siltstone and fine grained sandstone; massive, well consolidated, dense – very dense, very high strength.
			SILTY SANDSTONE. Light brownish grey fine grained sandstone with silt; bedding deformation (rupture and swirls), well consolidated, dense – very dense, very high strength.
			SILTSTONE. Light brownish grey siltstone with fine grained SANDSTONE beds; well consolidated, dense – very dense, very high strength.
315			SHALE. Light brownish grey shale, with interbedded SILTSTONE and SANDSTONE – fine grained (0.05mm); bedding plans dip up to ~30°, heavy bedded (fissility scale).
320 325			SILTSTONE. Greyish brown siltstone; well consolidated, massive, very dense, very high strength.

Bore Construction



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Borehole: TWB018-M3

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology	Bore Construction
			SILTSTONE. Greyish brown siltstone with SHALE layers; dipping up to ~30°.	
			SILTSTONE. Greyish brown siltstone; well consolidated, massive, very dense, very high strength.	
330			SILTSTONE. Greyish brown siltstone interbedded with SHALE and SANDSTONE; dipping and faulted beds, heavy bedded (rough breakage along beds), hard, high strength.	
			SILTSTONE. Greyish brown siltstone with minor fine grained sandstone layers; massive, hard, very dense, very high strength.	
335			SILTSTONE. Greyish brown siltstone with common thin layers of SHALE and SANDSTONE – fine grained; dipping bedding up to ~30°, heavy bedded, hard, high strength.	
			SILTSTONE. Greyish brown siltstone with minor fine grained sandstone layers; massive, hard, very dense, very high strength.	
340			SILTSTONE. Greyish brown siltstone with common thin layers of SHALE and SANDSTONE – fine grained; dipping bedding up to ~30°, heavy bedded, hard, high strength.	
			SILTSTONE. Greyish brown siltstone with minor fine grained sandstone layers; massive, hard, very dense, very high strength.	
			SILTSTONE. Greyish brown siltstone with common thin layers of SHALE and SANDSTONE – fine grained; dipping bedding up to ~30°, small scale bed displacement, some pinch and swell structures, heavy bedded, hard, high strength.	
345				
350				

Borehole: TWB023-T2

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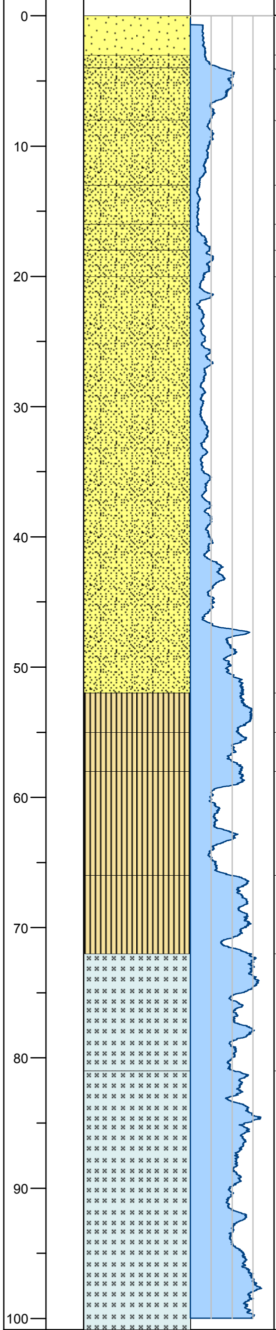
Project: Tropicana Water Study		Client: Anglogold Ashanti	Location: Lake Rason
Easting: 638379	Elevation: 381 (mAHD)	SWL: 46 m (toc) on 6/07/2008	Logged By: Ian Anderson/Will White/Len Baddock
Northing: 6792642	Total Depth: 335 m	Salinity: 43380 mg/L on 6/07/2008	Checked By: B Gallen

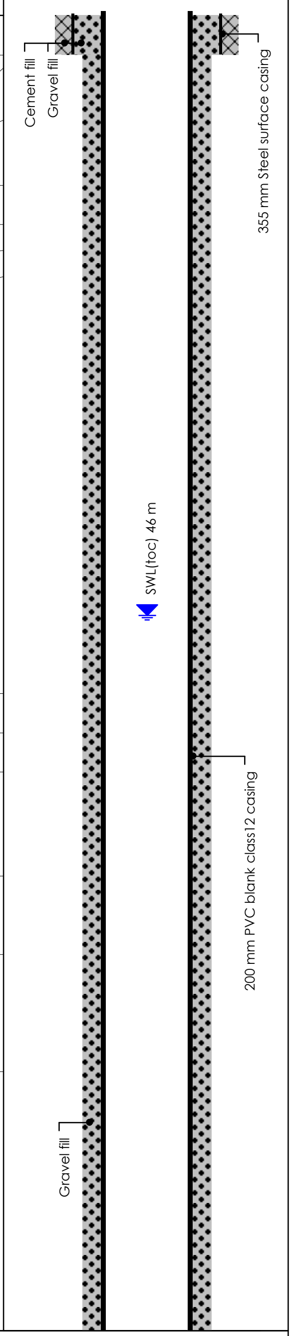
SUBSURFACE PROFILE

Depth (m) | Formation | Lithology Graphic | Downhole Gamma (40 – 120) | Lithology | Bore Construction



Ground Surface

- SW med SAND with trace silt well graded, loose, SR, pale brown, Colluvium
- SP coarse SAND with trace silt poorly graded, loose, SA, pale red brown with speckled white, Colluvium
- SP med SAND with trace silt poorly graded, loose, SR, pale brownish grey
- SP med SAND with trace silt poorly graded, loose, SR greyish brown
- SP coarse SAND poorly graded, loose, SR, very pale orange, pale grey, Colluvium Dark quartz
- SP med SAND with trace silt poorly graded, loose, SR, pale orange and pale grey, Colluvium
- SP-SM med SAND with trace silt poorly graded, loose, SR, pale orange with mottled grey
- SP coarse SAND with trace silt poorly graded, loose, SR, pale orange with mottled grey
- ML sandy SILT with med sand, very soft, low plasticity, pale red Weathered shale
- ML sandy SILT with trace med sand, very soft, low plasticity, moderate grey Weathered shale
- ML SILT, soft, low plasticity grey Pyrite grains <0.2mm
- MH SILT, soft, medium plasticity, dark grey with mottled white Pyrite grains <0.2mm
- SILTSTONE, dark grey Pyrite grains <0.2mm
- SILTSTONE, dark grey with mottled yellow brown Pyrite grains <0.2mm; hard zones @ 147-151m, 161-163m (sugary qtz), 156-158m



Drilling Company: DGS
Drilling Equipment: Edson 4000
Drilling Method: Mud

Started: 28/01/2008
Completed: 5/03/2008
Compiled: 7/09/2008

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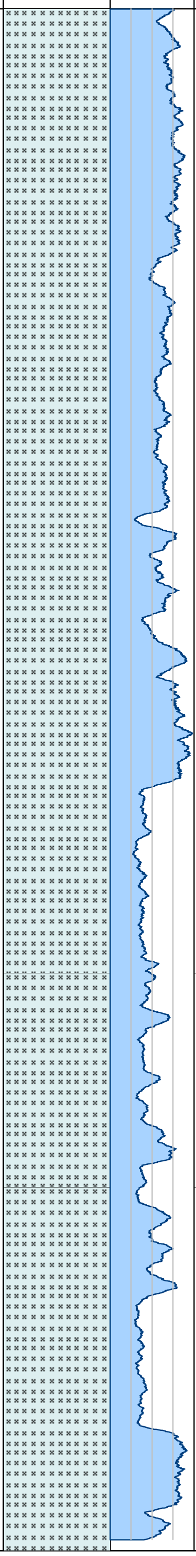
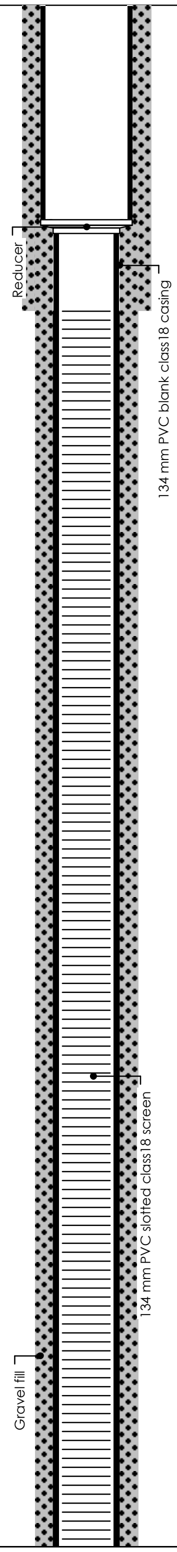
Borehole: TWB023-T2

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (40 – 120)	Lithology	Bore Construction
110, 120, 130, 140, 150, 160					
170				SILTSTONE, dark grey yelllowish brown Pyrite grains <0.2mm	
180, 190, 200				SILTSTONE, dark grey Pyrite grains <0.2mm; 190-197m thin (<2mm) white bands	





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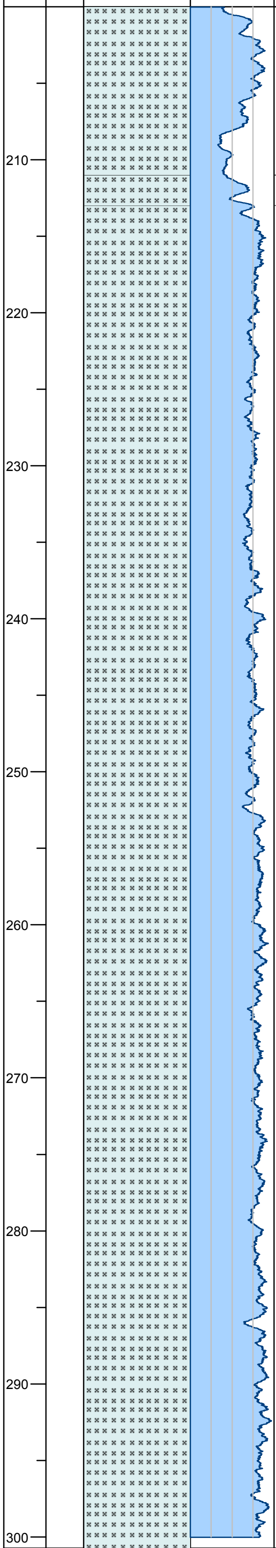
Borehole: TWB023-T2

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (40 – 120)	Lithology	Bore Construction



SILTSTONE, dark grey with some dolomite

SILTSTONEwith banded, pale grey Pyrite grains <0.2mm; 232-239m thin (<2mm)

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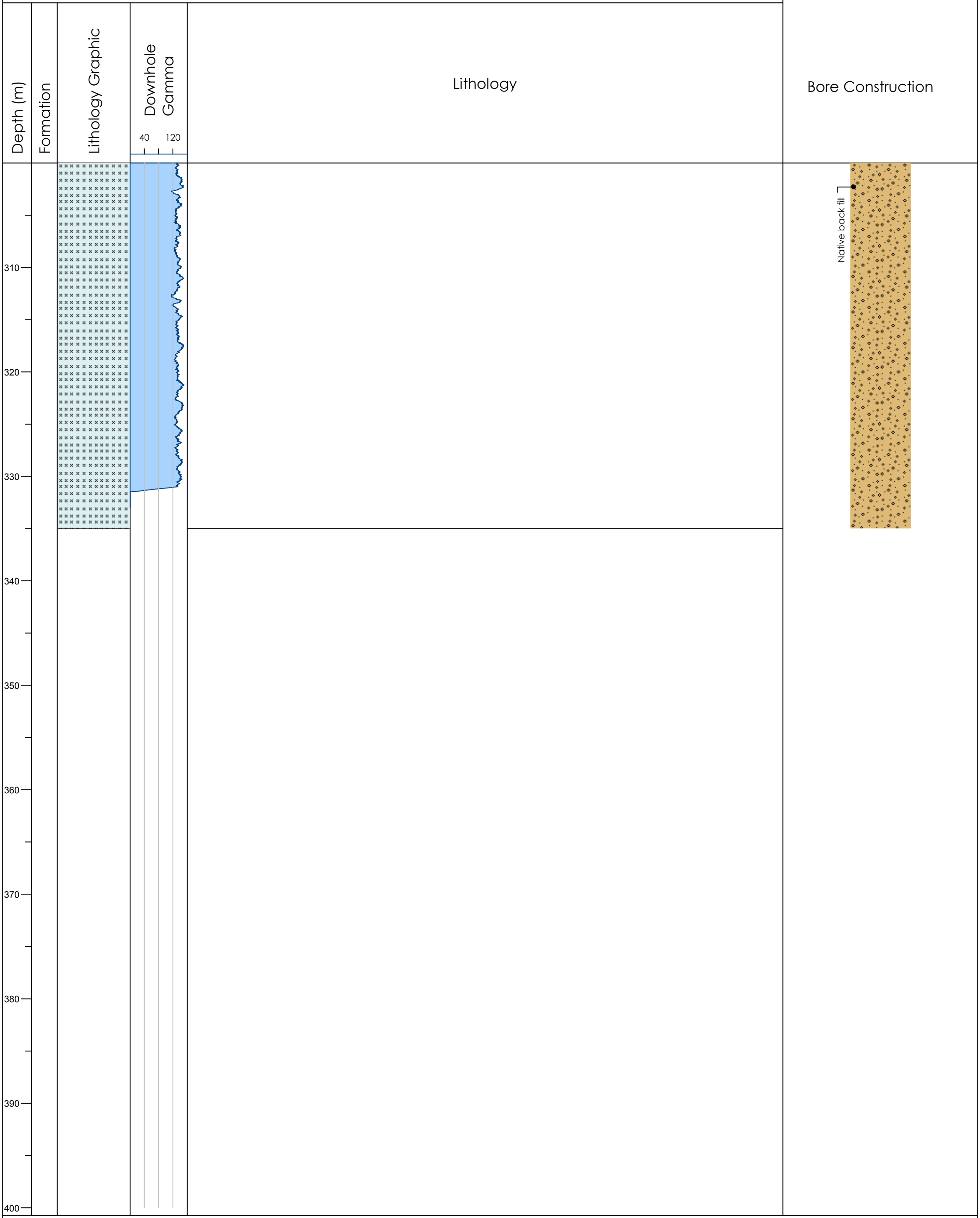
Borehole: TWB023-T2

SUBSURFACE PROFILE



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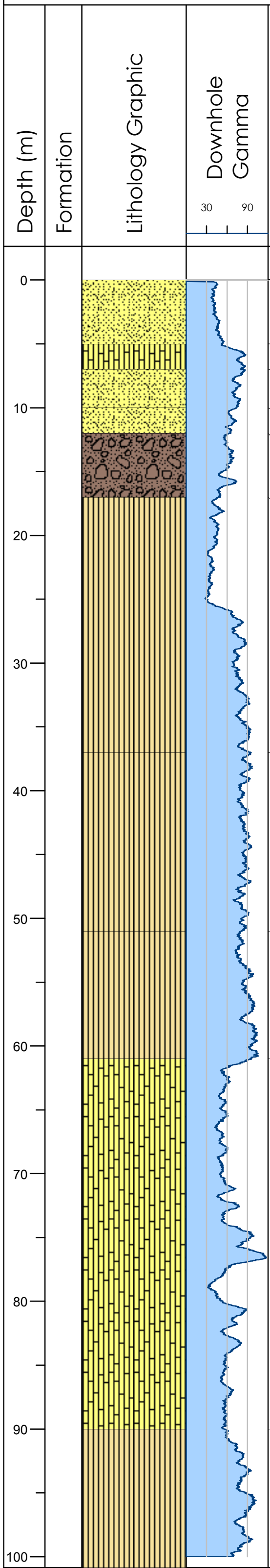
Borehole: TWB026-T1

Project: Tropicana Water Study		Client: Anglogold Ashanti	Location: Lake Rason
Easting: 648337	Elevation: 350 (mAHD)	SWL: 22 m (toc) on 27/05/2008	Logged By: Ian Anderson
Northing: 6807253	Total Depth: 245 m	Salinity: 163900 mg/L on 27/05/2008	Checked By: B Gallen

SUBSURFACE PROFILE



Lithology

Ground Surface

SP-SM med SAND with trace silt poorly graded, loose, SR, pale brown greyish green, Aolian Deposits

SM silty coarse SAND poorly graded, medium dense, SR, pale brown Iron and Silica induration

SP-SM med SAND with trace silt poorly graded, dense, SR, pale brown with mottled orange ferricrete and silcrete

SP med SAND with trace silt poorly graded, very loose, SR, pale orange with mottled orange Pisoliths <30mm present

GP fine GRAVEL with trace silt poorly graded, very loose, SR, very pale yellow with mottled orange, Alluvial Deposit

ML sandy SILT with fine sand, soft, low plasticity, pale orange with mottled white 20mm gravels, rounded, quartz 17-18m Silcrete bands @16-17m;

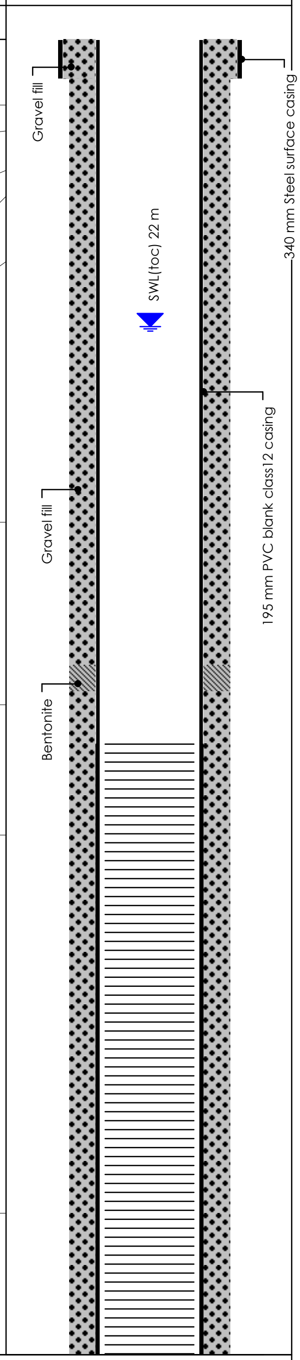
ML sandy SILT with fine sand, soft, low plasticity, very pale orange 30mm quartz cobbles @ 41-42m - contamination?

MH sandy SILT fine sand, soft, medium plasticity, pale orange

SM silty fine SAND well graded, loose, SR, moderate grey Pyrite grains? <0.1mm

ML sandy SILT fine sand, soft, low plasticity, dark grey, Alluvial Deposit Pyrite grains? <0.1mm

Bore Construction



Drilling Company: Scanlon	Started: 23/04/2008
Drilling Equipment: Kelly Bar Rig	Completed: 10/05/2008
Drilling Method: Mud	Compiled: 7/09/2008

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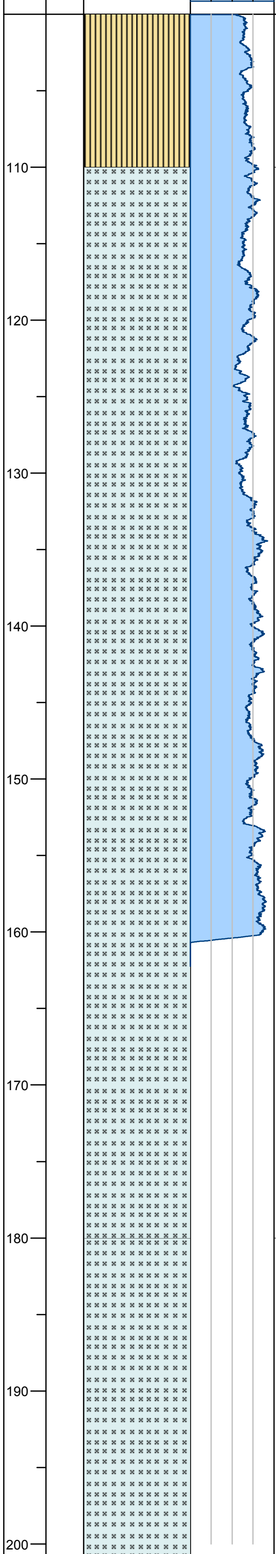
Borehole: TWB026-T1

SUBSURFACE PROFILE

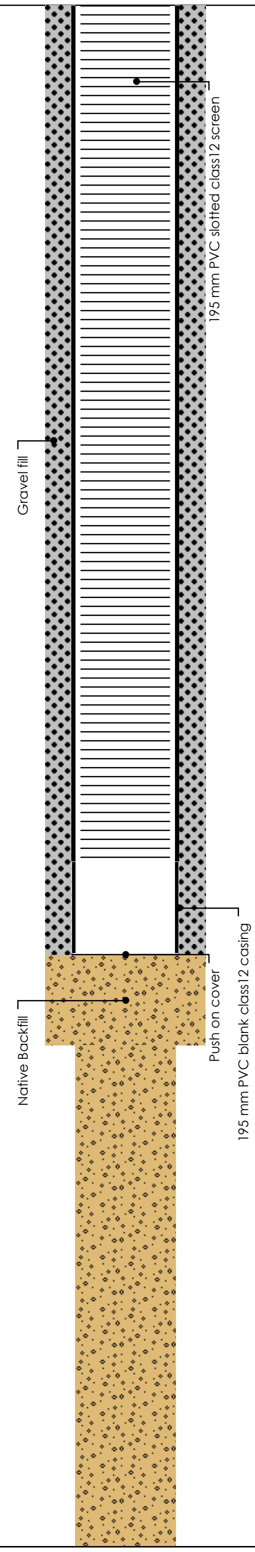
Depth (m)	Formation	Lithology Graphic	Downhole Gamma (30–90)	Lithology	Bore Construction



Lithology:

110 m — SILTSTONE, dark grey Pyrite grains? <0.1mm

180 m — SILTSTONE, dark grey with speckled grey Pyrite grains? <0.1mm



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Borehole: TWB026-T1

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (30–90)	Lithology	Bore Construction
to 245				SILTSTONE, dark grey Pyrite grains? <0.1mm; possible trace of fine organics	Native Backfill

Depth scale: 210, 220, 230, 240, 250, 260, 270, 280, 290, 300

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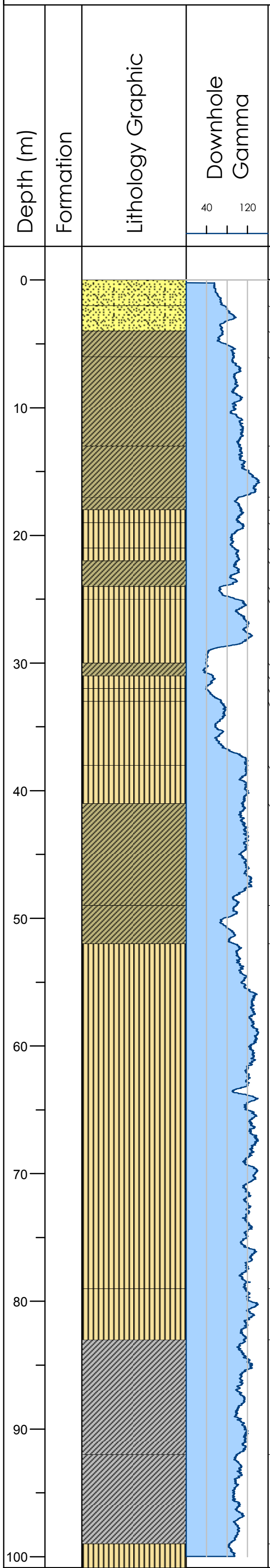
Borehole: TWB027-M1

Project: Tropicana Water Study		Client: Anglogold Ashanti	Location: Lake Rason
Easting: 650061	Elevation: 352 (mAHD)	SWL: 4 m (toc) on 28/05/2008	Logged By: Will White / Gary Bownds
Northing: 6819481	Total Depth: 149 m	Salinity: 33630 mg/L on 28/05/2008	Checked By: B Gallen

SUBSURFACE PROFILE

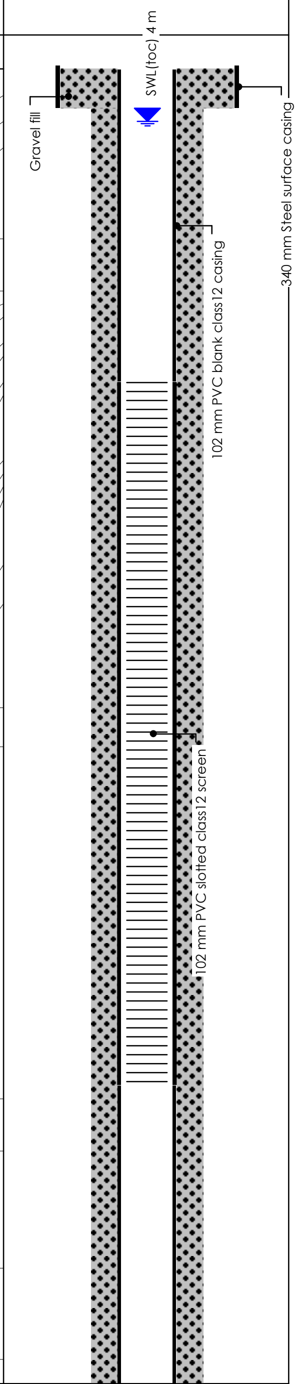


Lithology

Ground Surface

- SP-SM coarse SAND with trace silt poorly graded, very loose, SR, qtz lithic, dark reddish brown, Aolian Deposits
- SP fine SAND poorly graded, dense, SR, qtz feld, pale brown
- C CLAY, stiff white with mottled, pale brown
- CH CLAY, soft, medium plasticity, pale brown
- CH CLAY, soft, medium plasticity brown
- CH sandy CLAY with trace fine sand, soft, medium plasticity brown
- MH sandy SILT with fine sand, soft, medium plasticity greyish brown
- MH sandy SILT with med sand, firm, medium plasticity grey
- MH SILT with trace fine sand, firm, medium plasticity brown
- CH sandy CLAY with fine sand, soft, medium plasticity, dark grey
- MH sandy SILT with fine sand, soft, medium plasticity, dark grey
- MH SILT, soft, medium plasticity grey
- CH sandy CLAY with fine sand, soft, medium plasticity, dark brown
- MH SILT, soft, medium plasticity, dark grey
- MH sandy SILT with fine sand, soft, medium plasticity, dark grey
- MH sandy SILT with fine sand, firm, medium plasticity grey
- M sandy SILT with trace fine sand, dark grey
- CH sandy CLAY with trace fine sand, firm, medium plasticity, dark brownish grey
- CH sandy CLAY with trace fine sand, soft, medium plasticity, dark greyish brown
- MH SILT with trace fine sand, soft, medium plasticity, dark brownish grey
- MH sandy SILT with trace fine sand, soft, medium plasticity, dark brownish grey
- SHALE brownish grey
- SHALE brownish grey
- ML SILT, soft, low plasticity, pale grey

Bore Construction



Drilling Company: Scanlon	Started: 10/05/2008
Drilling Equipment: Kelly Bar Rig	Completed: 16/05/2008
Drilling Method: Mud	Compiled: 7/09/2008

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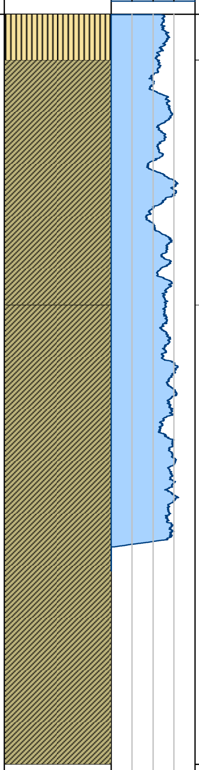
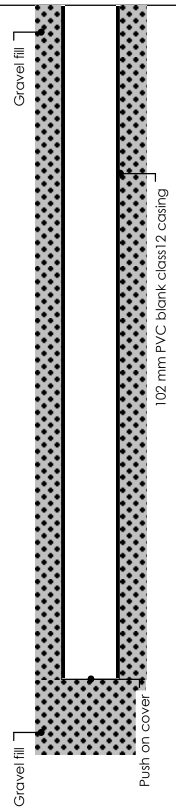
Borehole: TWB027-M1

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (40 – 120)	Lithology	Bore Construction
~103–105					
~105–119				CH CLAY, very soft, medium plasticity grey	
~119–149				CH CLAY, soft, medium plasticity grey	

Depth scale: 110, 120, 130, 140, 150, 160, 170, 180, 190, 200





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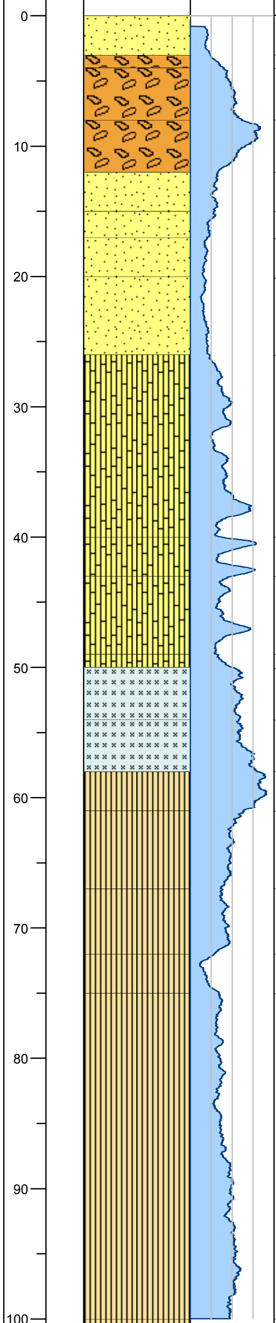
Borehole: TWB028-M1

Project: Tropicana Water Study		Client: Anglogold Ashanti	Location: Lake Rason
Easting: 625366	Elevation: 425 (mAHD)	SWL: 61 m (toc) on 7/07/2008	Logged By: Will White
Northing: 6802691	Total Depth: 204 m	Salinity: 79500 mg/L on 7/07/2008	Checked By: B Gallen

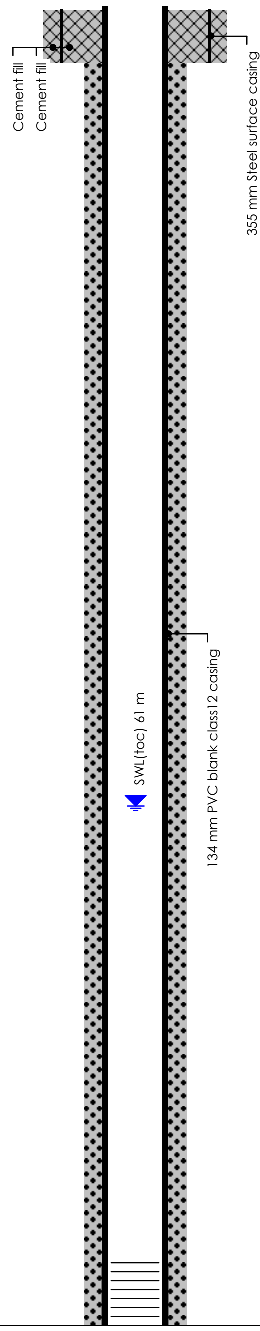
SUBSURFACE PROFILE

Depth (m) | Formation | Lithology Graphic | Downhole Gamma (50, 150) | Lithology | Bore Construction



Ground Surface

- SW med SAND well graded, loose, rounded, moderate reddish brown, Aolian Deposits
- pisolithic LATERITE, moderate reddish brown
- LATERITE, pale brown weakly cemented
- LATERITE, pale brown moderately graded.
- SW med SAND well graded, very loose, SR, moderate red Primary: Red / orange speckled light brown and very pale orange
- SW med SAND well graded, very loose, SA, moderate orange with speckled, pale brown Higher proportion of quartz frags
- SW med SAND well graded, very loose, SA, moderate red with speckled orange Highly cemented chunks of very pale orange sand.
- SW-SM med SAND with trace silt well graded, very loose, SA, very pale orange Secondary: very pale orange
- SM silty med SAND, very loose, SA, pale grey, very pale orange Quartz of various colours.
- SM silty coarse SAND, very loose, SR, pale grey with speckled yellowish orange Quartz fragments vary from rounded to angular. Up to 10mm.
- SM silty med SAND, very loose, SR, pale grey Secondary: very pale orange with pink
- SM silty med SAND, very loose, SR, pale grey Some large quartz chunks. Secondary: very pale orange with yellow
- SILTSTONE, moderate red with speckled grey green Primary: Munsells 5R/5/4
- SILTSTONE, moderate red with speckled grey green Primary: Munsells 5R/4/6
- MH sandy SILT with trace med sand, soft, medium plasticity, pale red brown A mixture of layers above and below
- MH sandy SILT with med sand, soft, medium plasticity, pale red brown with speckled grey green Secondary: smaller quartz sand
- MH sandy SILT med sand, soft, medium plasticity, pale red brown with mottled grey green Hard cemented sand layer
- MH SILT with trace med sand, soft, medium plasticity, pale red brown with speckled grey green A mixture of layers above and below
- ML SILT with trace med sand, soft, low plasticity grey brown with mottled grey green Primary: Munsells 5YR/4/1



Drilling Company: DGS	Started: 19/05/2008
Drilling Equipment: Edson 4000	Completed:
Drilling Method: Mud	Compiled: 7/09/2008

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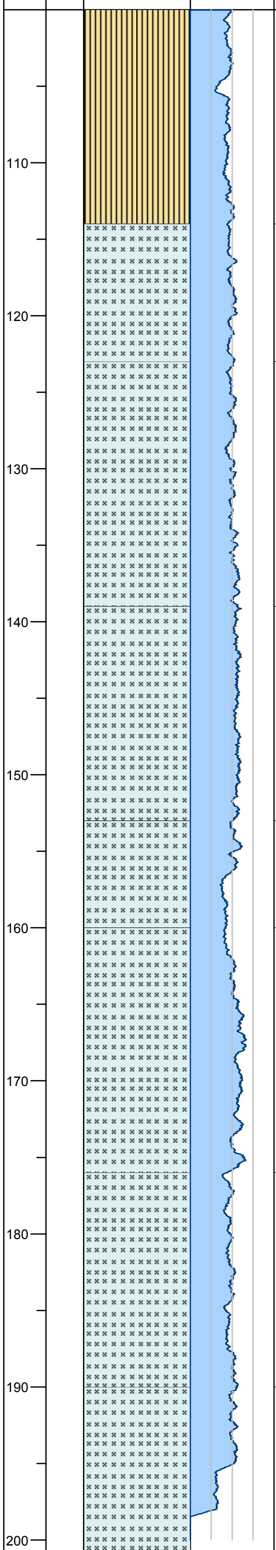
Borehole: TWB028-M1

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (50 – 150)	Lithology	Bore Construction



MH sandy SILT with coarse sand, soft, medium plasticity grey with speckled grey green Sample consists of large soft pieces up to 4cm

SILTSTONE, dark grey Sample consists of angular chips up to 2mm

SILTSTONE, dark grey Sample consists of angular chips up to 5mm

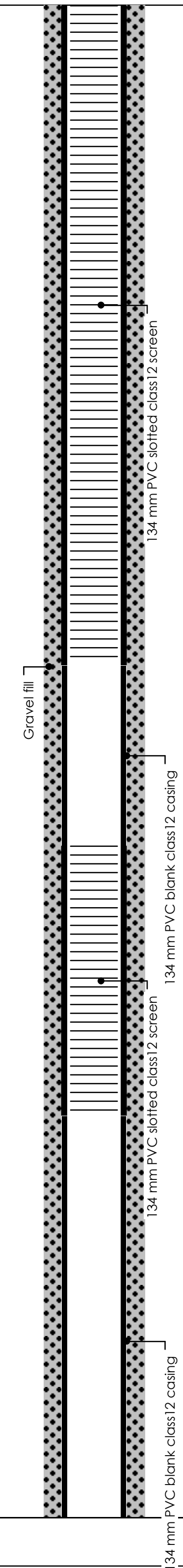
SILTSTONE, dark grey Sample consists of angular chips up to 2-3mm

SILTSTONE, dark grey Sample consists of angular chips up to 7mm

SILTSTONE, dark grey Sample consists of angular chips up to 7mm

SILTSTONE, dark grey Sample consists of angular chips up to 2-3mm

SILTSTONE, dark grey Sample consists of angular chips up to 5mm



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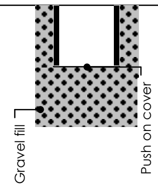
Borehole: TWB028-M1

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (50–150)	Lithology	Bore Construction
210					
220					
230					
240					
250					
260					
270					
280					
290					
300					



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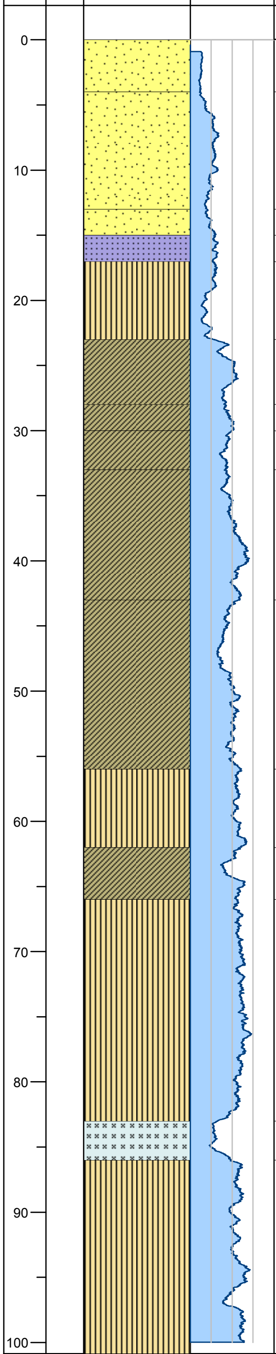
Borehole: TWB029-T2

Project: Tropicana Water Study	Client: Anglogold Ashanti	Location: Lake Rason

Easting: 632019	Elevation: 401 (mAHD)	SWL: 65.44 m (toc) on 29/07/2008	Logged By: Will White / Gary Bownds
Northing: 6806729	Total Depth: 340 m	Salinity:	Checked By: B Gallen

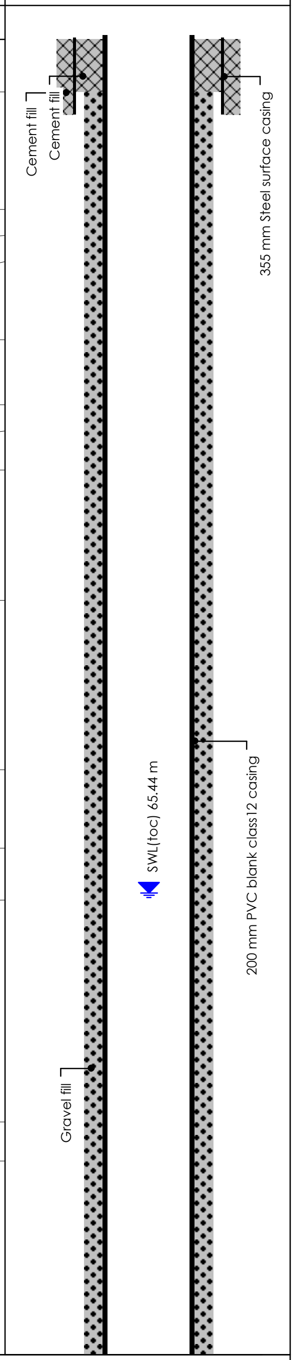
SUBSURFACE PROFILE

Depth (m) | Formation | Lithology Graphic | Downhole Gamma (40–120) | Lithology | Bore Construction



Ground Surface

- SW med SAND well graded, loose, rounded red brown reddish brown
- SW gravelly coarse SAND well graded, loose, SA red brown reddish brown fragmented, some 10mm chunks
- SW fine SAND well graded, loose, SR red brown reddish brown some hard chips
- SANDSTONE white
- M sandy SILT med sand, very soft white Speckled Reddish Brown
- CH CLAY with trace med sand, soft, medium plasticity white
- CH CLAY with trace med sand, soft, high plasticity
- CH CLAY, soft, high plasticity, pale yellowish brown
- CH CLAY, soft, high plasticity, dark yelllowish orange
- CH CLAY, soft, high plasticity, dark yelllowish orange small black fragments
- MH clayey SILT clay, very soft, medium plasticity, pale yellowish brown yellowish brown small black fragments
- CL CLAY, firm, low plasticity, pale yellowish brown reddish brown secondary: reflective particles (mica?)
- MH clayey SILT with trace clay, very soft, medium plasticity, pale yellowish brown, pale yellowish brown
- SILTSTONE, pale yellow brown
- MH clayey SILT with clay, very soft, medium plasticity yellowish brown, pale yelllowish brown



Drilling Company: DGS
Drilling Equipment: Edson 4000
Drilling Method: Mud

Started: 16/06/2008
Completed:
Compiled: 7/09/2008

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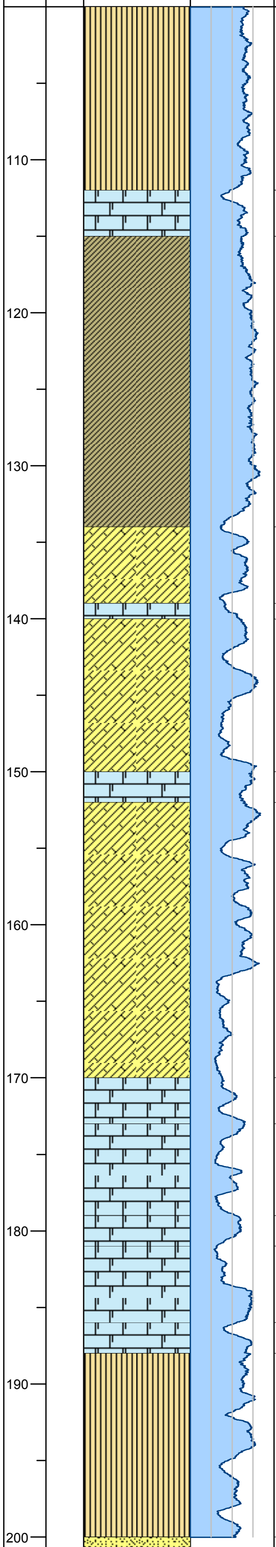
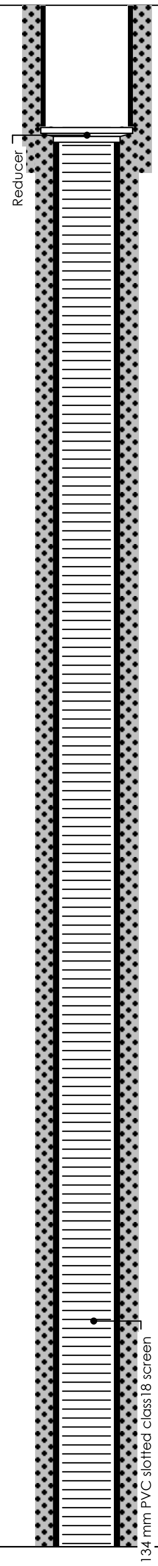
Borehole: TWB029-T2

SUBSURFACE PROFILE

Depth (m) | Formation | Lithology Graphic | Downhole Gamma (40 – 120) | Lithology | Bore Construction



Lithology
DOLOMITE yellowish brown with Clay (possibly contamination)
CH CLAY, soft, medium plasticity brownish grey, pale yellowish brown
SC clayey fine SAND poorly graded, loose, SR brownish grey
DOLOMITE
SC clayey med SAND poorly graded, SR brownish grey
DOLOMITE
SC clayey fine SAND poorly graded, loose, SR brownish grey
DOLOMITE, pale yellowish brown
DOLOMITE brownish grey
DOLOMITE, pale yellowish brown with sand/silt/clay contamination?
DOLOMITE, pale yelllowish brown
DOLOMITE with sand/silt/clay contamination?
ML sandy SILT with trace fine sand, soft, low plasticity, dark grey
SP fine SAND uniformly graded, loose, rounded, qtz



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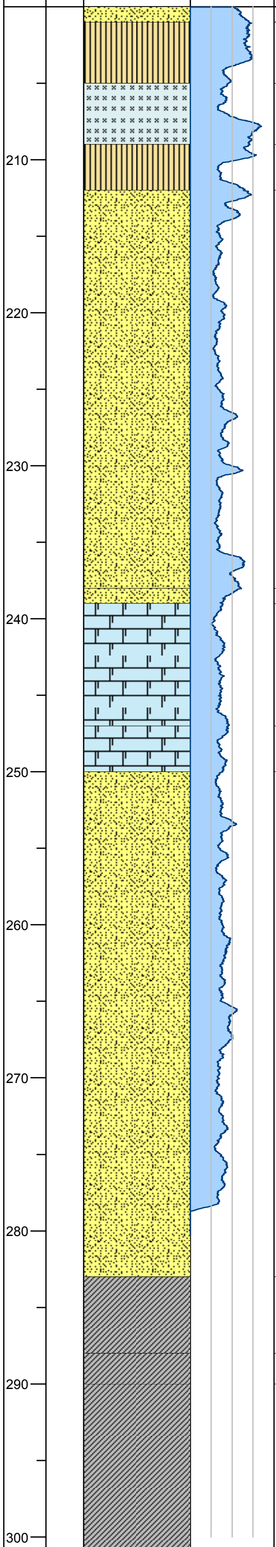
Borehole: TWB029-T2

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (40 – 120)	Lithology	Bore Construction



ML sandy SILT with fine sand, soft, low plasticity grey Contains chips of siltstone

SILTSTONE, dark grey Hard slow drilling 205 - 205.3m

ML clayey SILT clay, firm, low plasticity, dark grey

SP fine SAND uniformly graded, loose, rounded, qtz grey

SP fine SAND uniformly graded, loose, rounded, qtz grey

DOLOMITE, qtz feld, pale grey Much contamination. Very hard drilling 239 - 241.5m

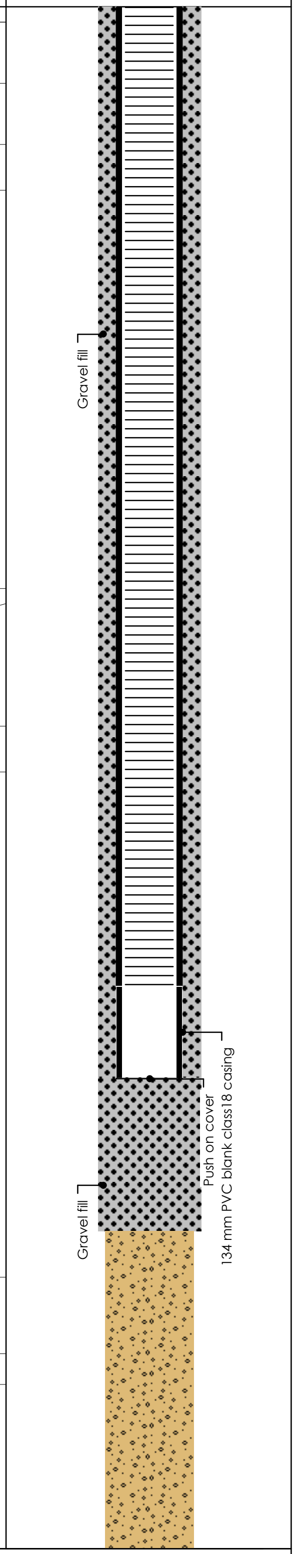
DOLOMITE, pale grey very low strength, fresh

SP fine SAND uniformly graded, loose, rounded, qtz, dark grey SANDSTONE & SILTSTONE chips abundant. Some dolomite

SHALE, dark grey, pale brown

SHALE, pale brown, pale brown

SHALE, pale brown



1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

Borehole: TWB029-T2

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Downhole Gamma (40–120)	Lithology	Bore Construction
310				SHALE, pale brown	Native back fill
320					
				SHALE, pale brown SHALE, dark grey and pale brown, very low strength, fresh. Silt, grey, medium plasticity (ground Shale?)	
330					
				SHALE, dark brown	
				SHALE, dark brown	
340					
350					
360					
370					
380					
390					
400					

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1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

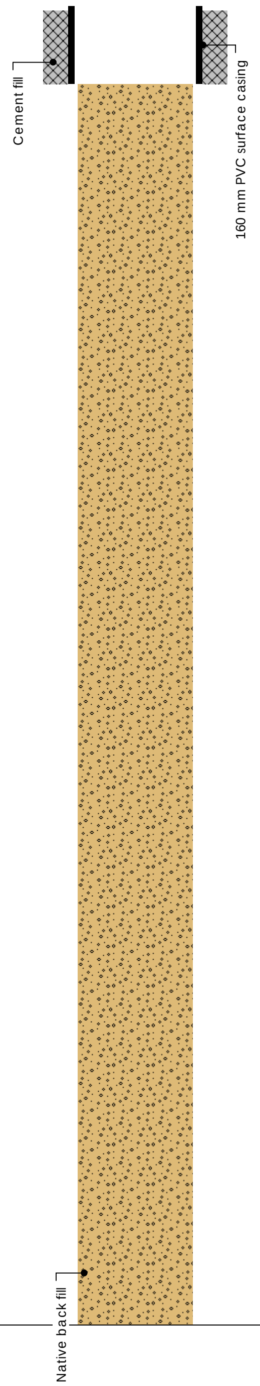
Borehole: OF5X1

Project: Tropicana Water Study		Client: Anglogold Ashanti	Location: Rason Lake
Easting: 624610	Elevation: 346 (mAHD)	SWL: 0 m (toc) on 21/08/2000	Logged By: G Sheppard
Northing: 6824207	Total Depth: 136 m	Salinity: 42820 mg/L on 21/08/2000	Checked By: B Harris

SUBSURFACE PROFILE

Depth (m)	Formation	Lithology Graphic	Lithology	Field Notes
0			Ground Surface	
			SM silty med SAND well graded, medium dense, SA, qtz reddish brown , sa to sr, chert and quartzite class to 30mm	
			CL CLAY, firm, low plasticity, pale grey reddish brown with some ferricrete	
10			CL sandy CLAY with trace fine sand, firm, low plasticity greenish grey	
20			CL CLAY, firm, low plasticity greenish grey remnant textures	
			dolomitic SHALE grey rare fragments of homblend/garnet gneiss(ie one chip 10mm across) in sample at 120m, slightly laminated, minor pyrite	
30				
40				
50				
60				
70				
80				
90				
100				

Bore Construction



Drilling Company: Thompson Drilling
Drilling Equipment: Rig 2
Drilling Method: RAB

Started: 21/08/2000
Completed: 21/08/2000
Compiled: 9/09/2008

1/298 Selby St, Osborne Park WA 6017
T: +618 94410999 F: +618 92041595

Borehole: OF5X1

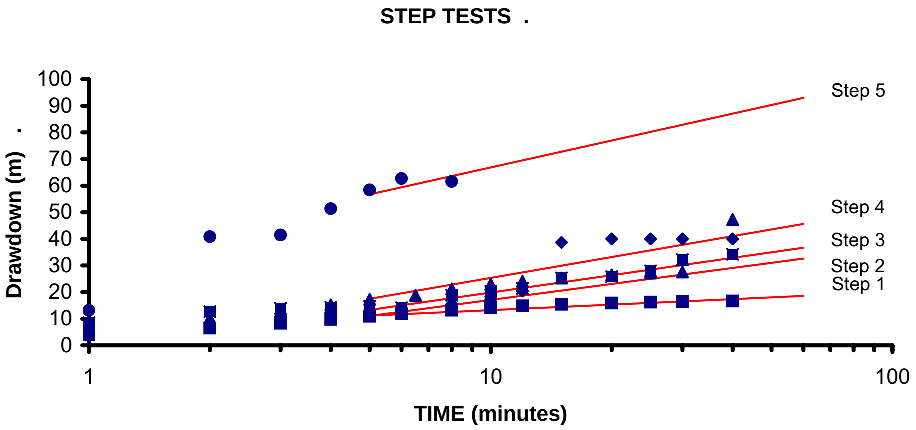
SUBSURFACE PROFILE

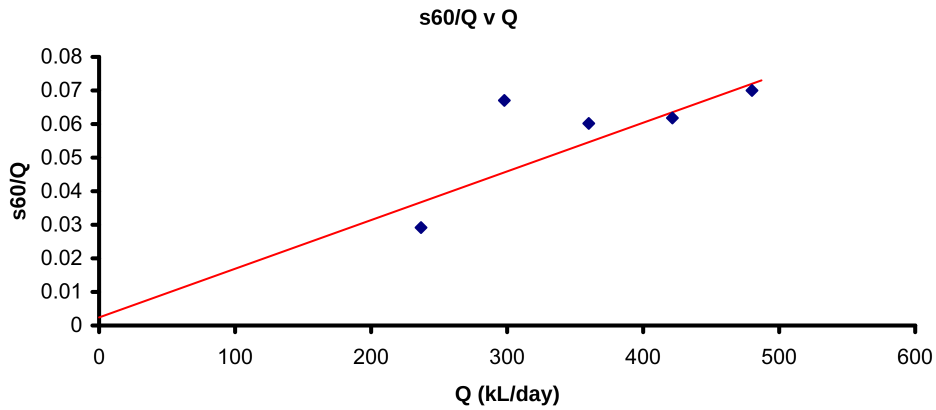
Depth (m)	Formation	Lithology Graphic	Lithology	Field Notes	Bore Construction
110					
120					
130			SANDSTONE weakly cemented grey , minor interbedded mudstone		
			SHALE		
			SANDSTONE weakly cemented grey	Airlift Yield 218kL/day	
			SHALE		
140					
150					
160					
170					
180					
190					
200					

Attachment B

Hydraulic Test Results

STEP TEST ANALYSIS
TP2580-T2





s60 = projected step drawdown at 60 minutes
Q = bore discharge measured in kL/day
s(ln) = incremental drawdown per log time cycle (i.e. from 10 to 100mins)
App Ew = apparent well efficiency

Calculation of well efficiency using Roraaugh's Equation

$S = BQ + CQ^2$

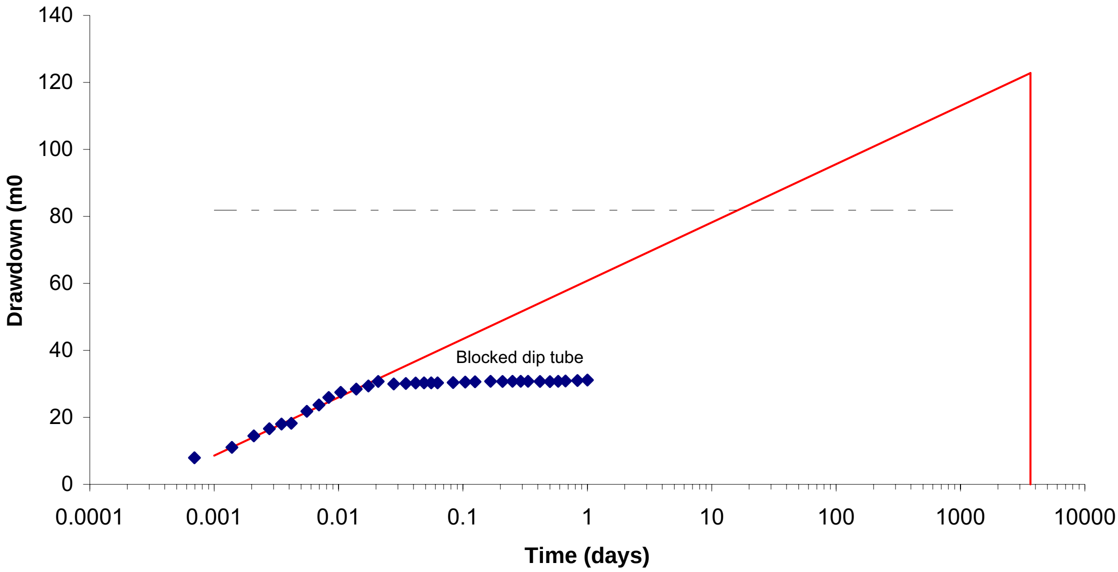
B = y intercept = 0.0024
C = Gradient = 0.00014497
S = drawdown in the bore

$Ew = BQ / (BQ + CQ^2) \times 100$

Step	Q (kl/day)	s(ln)	s/Q	App Ew
1	237	6.91	0.029	7%
2	298	19.98	0.067	5%
3	360	21.66	0.060	4%
4	421	26.05	0.062	4%
5	480	33.6	0.070	3%

CONSTANT RATE TEST
TP2580-T2

DRAWDOWN PROJECTED TO 10 YEARS



Date of Test	25-Jun-08	
SWL at start	8.1	mBTOC
Pump Setting	90.0	mBTOC
L = Length of Screen =	98	m
Availible drawdown above pump setting	81.9	m
Max availible drawdown in pump well		m

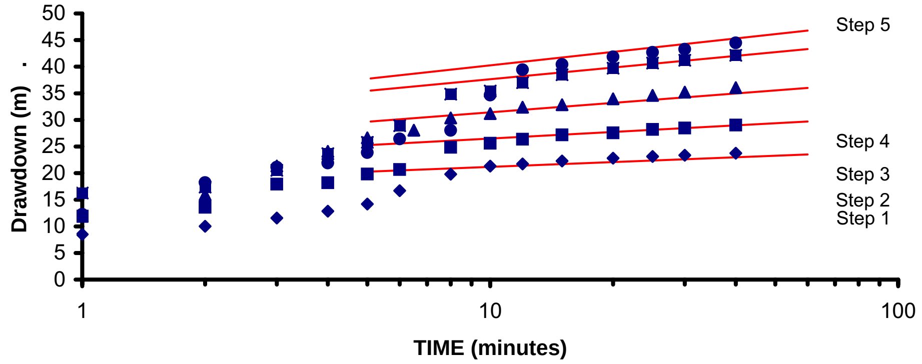
T = 2.3Q/(4πΔ(h0-h))

Q = Test Discharge =	254	Kl/day
Δ(h0-h) = Drawdown per log cycle =	17.40	m
T= Transmisivity =	2.7	m2/day
K = Hydraulic Conductivity = T/L =	**0.03**	**m/day**

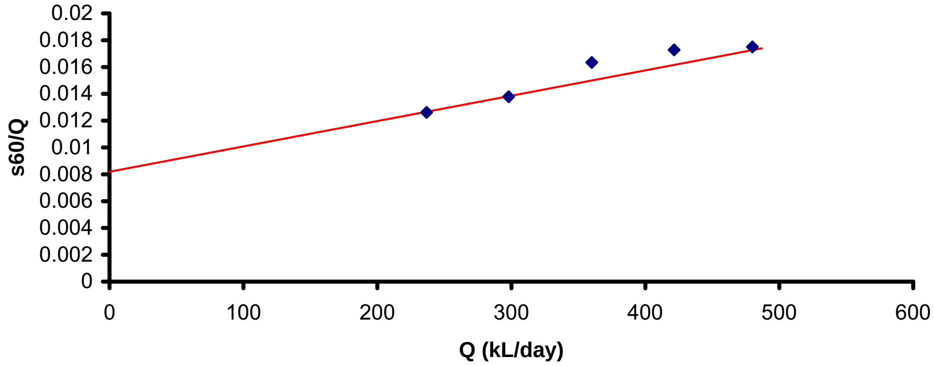
STEP TEST ANALYSIS

TWB015-T1

STEP TESTS .



s60/Q v Q



s60 = projected step drawdown at 60 minutes
Q = bore discharge measured in kL/day
s(log) = incremental drawdown per log time cycle (i.e. from 10 to 100mins)
App Ew = apparent well efficiency

Calculation of well efficiency using Roraaugh's Equation

$S = BQ + CQ^2$

B = y intercept = 0.0082
C = Gradient = 1.8891E-05
S = drawdown in the bore

$Ew = BQ / (BQ + CQ^2) \times 100$

Step	Q (kl/day)	s(log)	s/Q	App Ew
1	237	2.99	0.013	65%
2	298	4.11	0.014	59%
3	360	5.88	0.016	55%
4	421	7.28	0.017	51%
5	480	8.4	0.018	47%

CONSTANT RATE TEST
TWB015-T1

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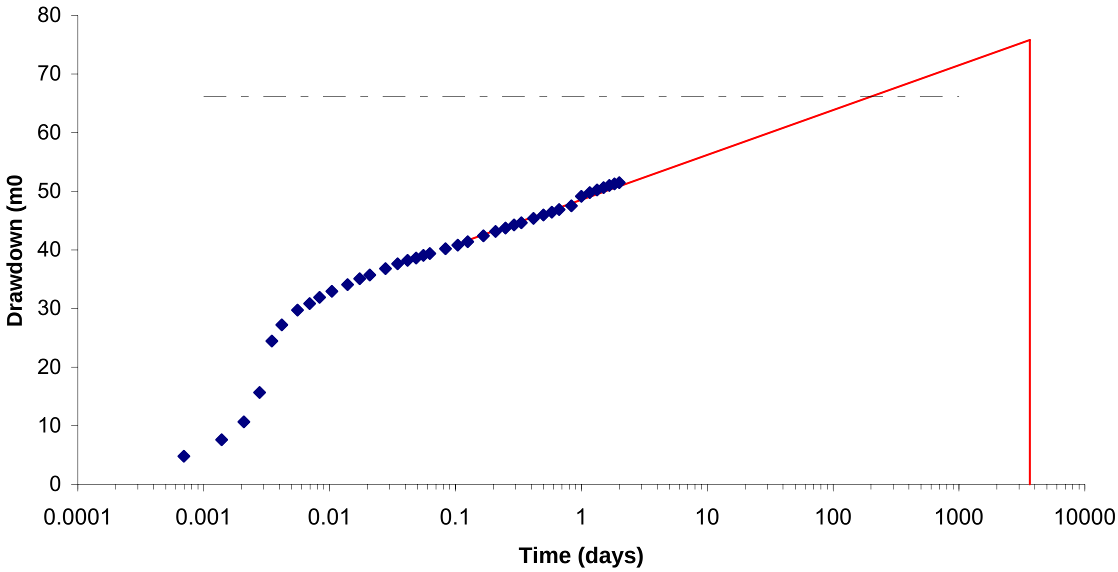
DRAWDOWN PROJECTED TO 10 YEARS



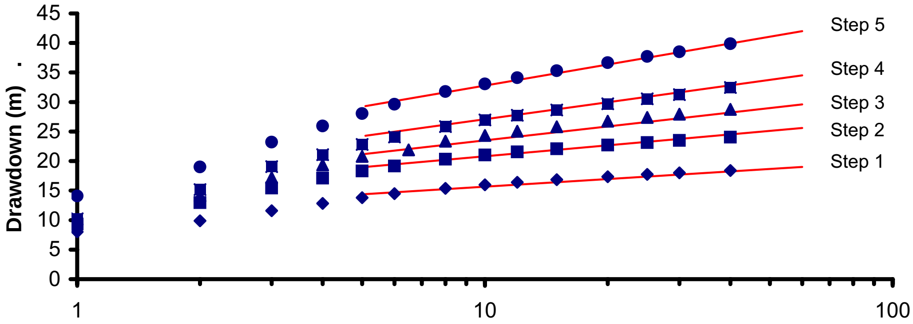
Date of Test	03-Jun-08	
SWL at start	23.8	mBTOC
Pump Setting	90.0	mBTOC
L = Length of Screen =	102	m
Availible drawdown above pump setting	66.2	m
Max availible drawdown in pump well		m

T = 2.3Q/(4πΔ(h0-h))

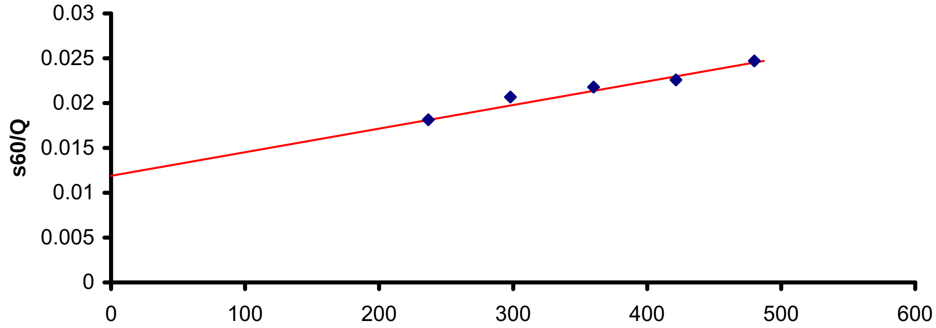
Q = Test Discharge =	411	Kl/day
Δ(h0-h) = Drawdown per log cycle =	7.65	m
T= Transmisivity =	9.8	m2/day
K = Hydraulic Conductivity = T/L =	**0.10**	**m/day**

STEP TEST ANALYSIS
TWB017-T2

STEP TESTS .



s60/Q v Q



s60 = projected step drawdown at 60 minutes
Q = bore discharge measured in kL/day
s(log) = incremental drawdown per log time cycle (i.e. from 10 to 100mins)
App Ew = apparent well efficiency

Calculation of well efficiency using Roraaugh's Equation

$S = BQ + CQ^2$

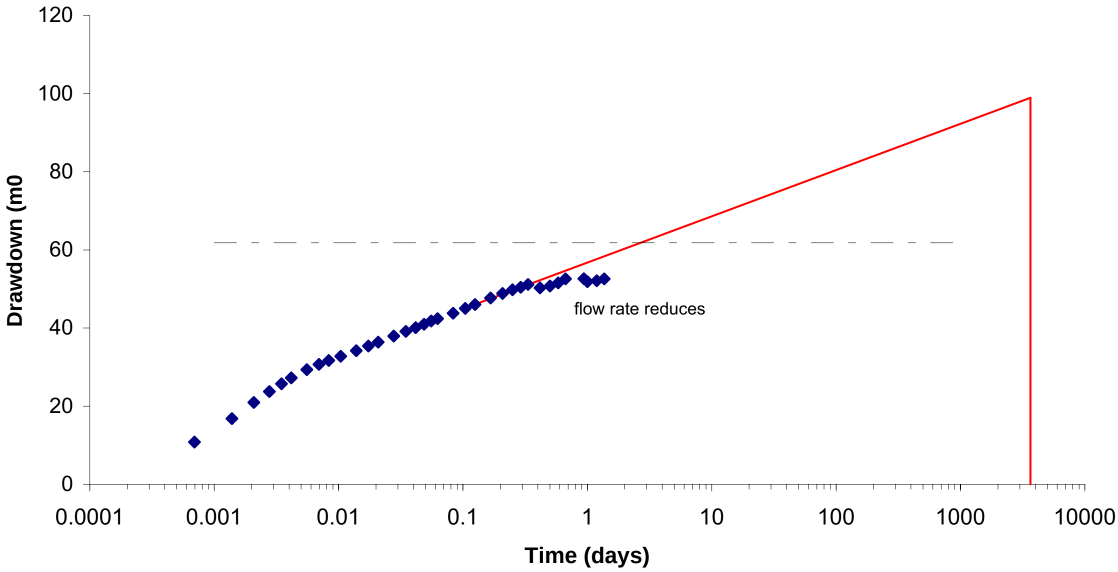
B = y intercept = 0.0119
C = Gradient = 2.6283E-05
S = drawdown in the bore

$Ew = BQ / (BQ + CQ^2) \times 100$

Step	Q (kl/day)	s(ln)	s/Q	App Ew
1	237	4.29	0.018	66%
2	298	6.16	0.021	60%
3	360	7.84	0.022	56%
4	421	9.52	0.023	52%
5	480	11.9	0.025	49%

CONSTANT RATE TEST
TWB017-T2

DRAWDOWN PROJECTED TO 10 YEARS



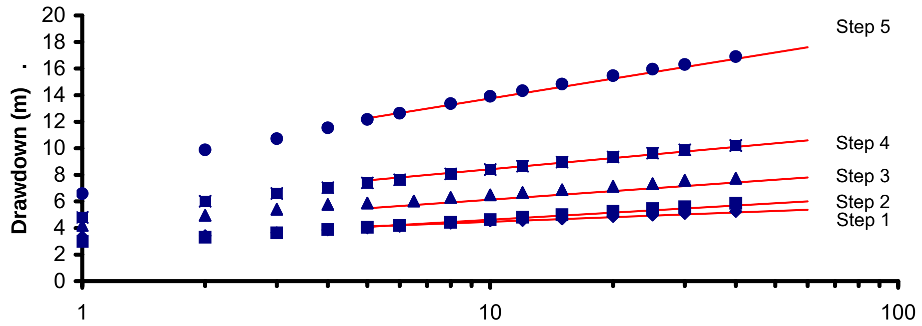
Date of Test	10-Jun-08	
SWL at start	28.2	mBTOC
Pump Setting	90.0	mBTOC
L = Length of Screen =	114	m
Availible drawdown above pump setting	61.8	m
Max availible drawdown in pump well		m

T = 2.3Q/(4πΔ(h0-h))

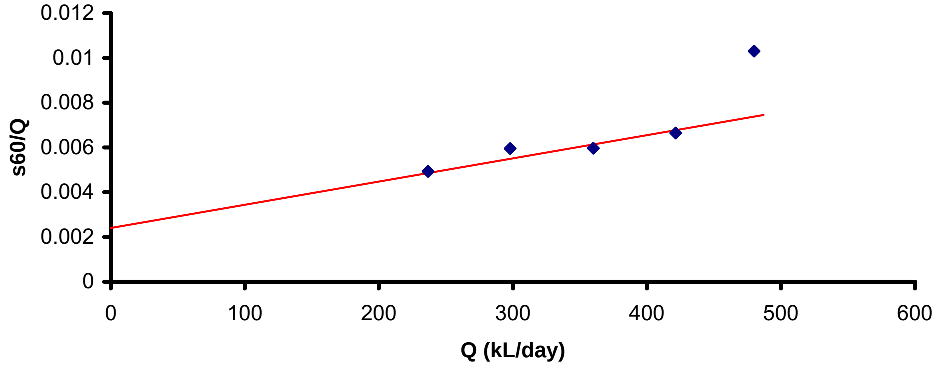
Q = Test Discharge =	467	Kl/day
Δ(h0-h) = Drawdown per log cycle =	11.84	m
T= Transmisivity =	7.2	m2/day
K = Hydraulic Conductivity = T/L =	**0.06**	**m/day**

STEP TEST ANALYSIS
TWB018-T2

STEP TESTS .



s60/Q v Q



s60 = projected step drawdown at 60 minutes
Q = bore discharge measured in kL/day
s(ln) = incremental drawdown per log time cycle (i.e. from 10 to 100mins)
App Ew = apparent well efficiency

Calculation of well efficiency using Roraaugh's Equation

$S = BQ + CQ^2$

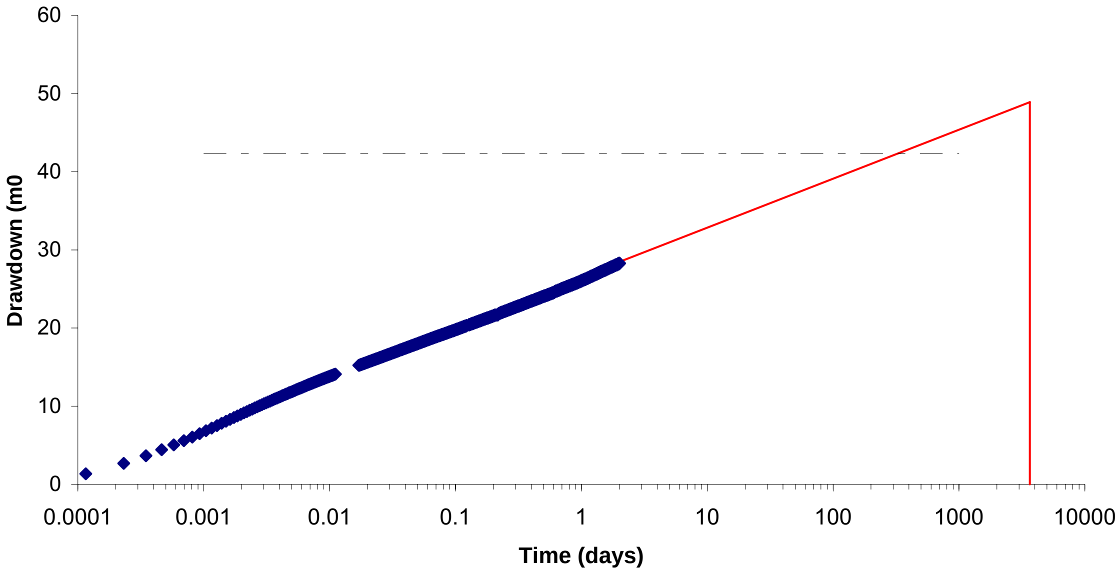
B = y intercept = 0.0024
C = Gradient = 1.037E-05
S = drawdown in the bore

$Ew = BQ / (BQ + CQ^2) \times 100$

Step	Q (kl/day)	s(ln)	s/Q	App Ew
1	237	1.17	0.005	49%
2	298	1.77	0.006	44%
3	360	2.15	0.006	39%
4	421	2.80	0.007	35%
5	480	4.9	0.010	33%

CONSTANT RATE TEST
TWB018-T2

DRAWDOWN PROJECTED TO 10 YEARS



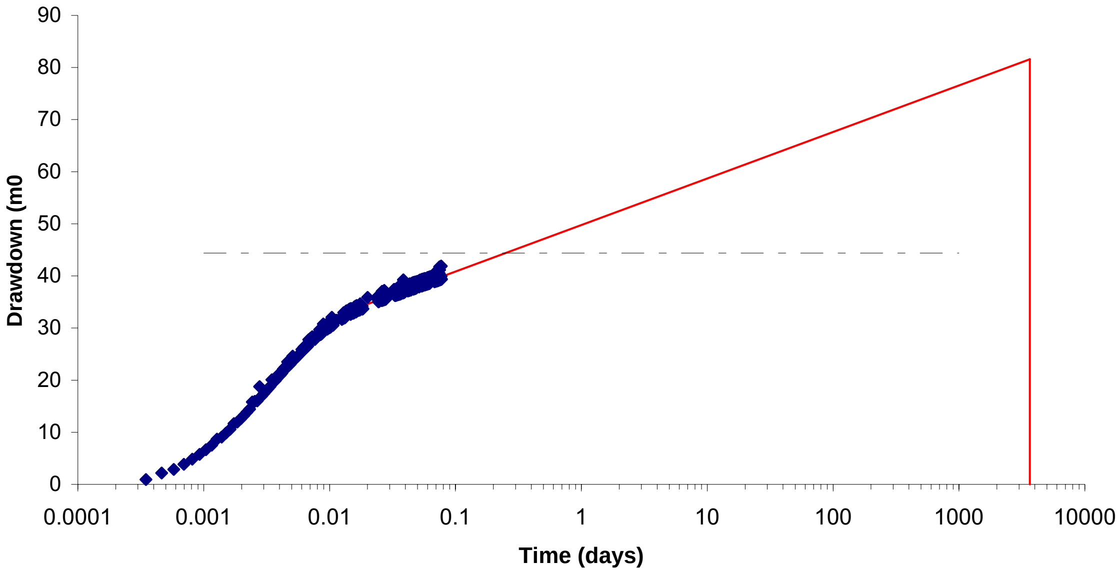
Date of Test	02-May-08	
SWL at start	47.7	mBTOC
Pump Setting	90.0	mBTOC
L = Length of Screen =	84	m
Availible drawdown above pump setting	42.3	m
Max availible drawdown in pump well		m

T = 2.3Q/(4πΔ(h0-h))

Q = Test Discharge =	508	Kl/day
Δ(h0-h) = Drawdown per log cycle =	6.27	m
T= Transmisivity =	14.8	m2/day
K = Hydraulic Conductivity = T/L =	**0.18**	**m/day**

CONSTANT RATE TEST
TWB023-T2

DRAWDOWN PROJECTED TO 10 YEARS

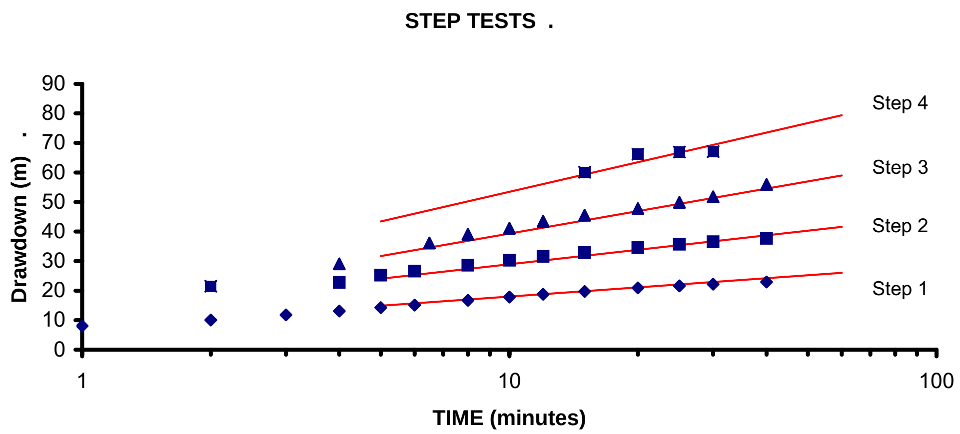


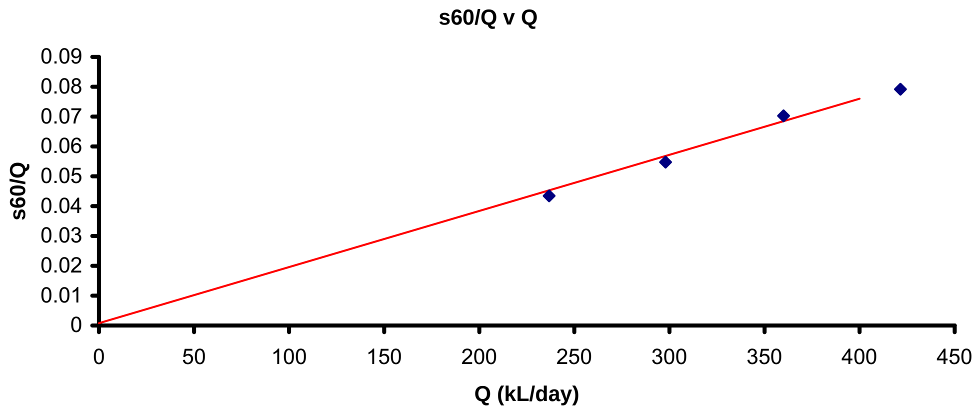
Date of Test	31-Mar-08	
SWL at start	45.6	mBTOC
Pump Setting	90.0	mBTOC
L = Length of Screen =	108	m
Availible drawdown above pump setting	44.4	m
Max availible drawdown in pump well		m

T = 2.3Q/(4πΔ(h0-h))

Q = Test Discharge =	206	Kl/day
Δ(h0-h) = Drawdown per log cycle =	8.93	m
T= Transmisivity =	4.2	m2/day
K = Hydraulic Conductivity = T/L =	**0.04**	**m/day**

STEP TEST ANALYSIS
TWB026-T1





s60 = projected step drawdown at 60 minutes
Q = bore discharge measured in kL/day
s(ln) = incremental drawdown per log time cycle (i.e. from 10 to 100mins)
App Ew = apparent well efficiency

Calculation of well efficiency using Roraaugh's Equation

$S = BQ + CQ^2$

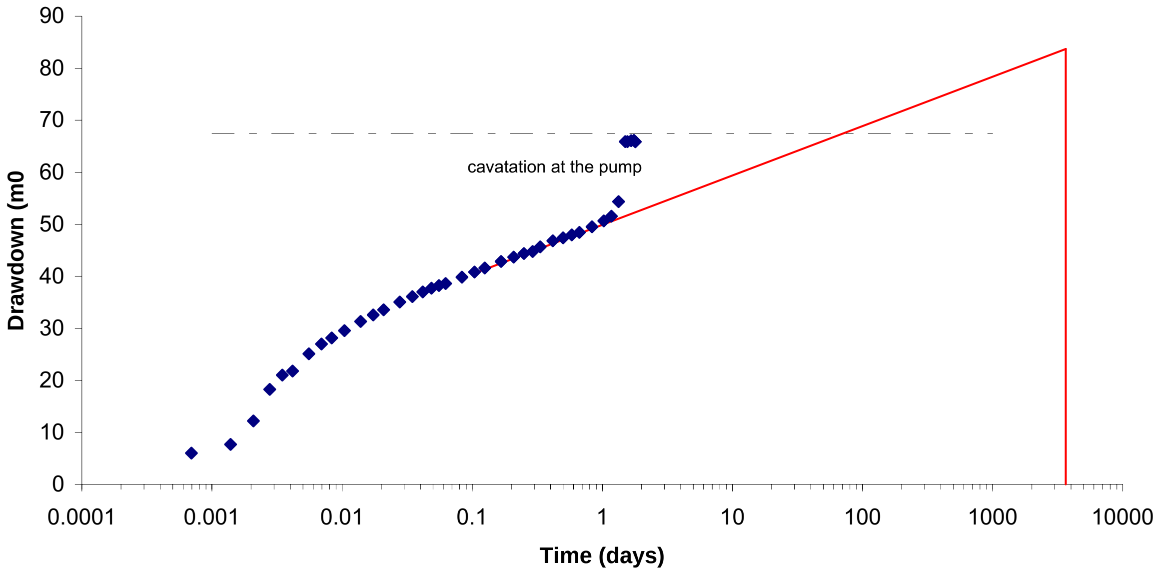
B = y intercept = 0.0008
C = Gradient = 0.000188
S = drawdown in the bore

$Ew = BQ / (BQ + CQ^2) \times 100$

Step	Q (kl/day)	s(log)	s/Q	App Ew
1	237	10.29	0.043	2%
2	298	16.31	0.055	1%
3	360	25.30	0.070	1%
4	421	33.36	0.079	1%
5	480	34.1	0.1	0%

CONSTANT RATE TEST
TWB026-T1

DRAWDOWN PROJECTED TO 10 YEARS



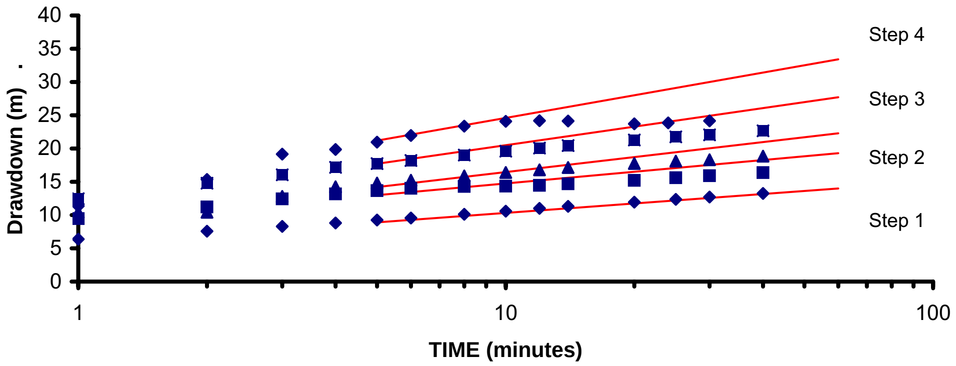
Date of Test	29-May-08	
SWL at start	22.6	mBTOC
Pump Setting	90.0	mBTOC
L = Length of Screen =	102	m
Availible drawdown above pump setting	67.4	m
Max availible drawdown in pump well		m

T = 2.3Q/(4πΔ(h0-h))

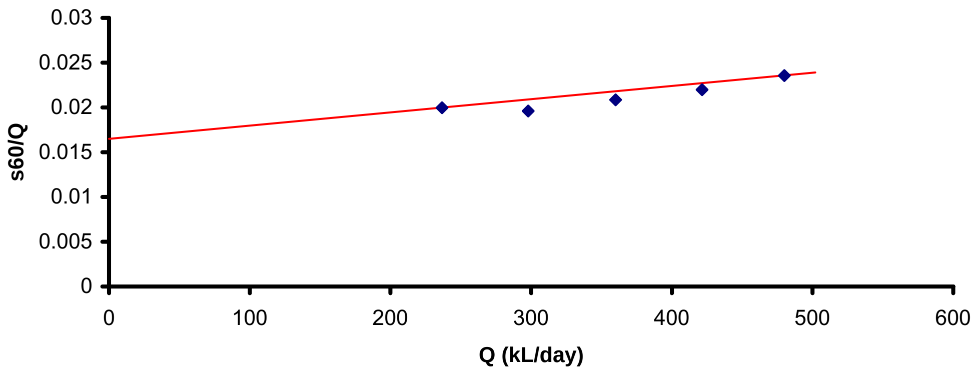
Q = Test Discharge =	247	Kl/day
Δ(h0-h) = Drawdown per log cycle =	9.49	m
T= Transmisivity =	4.8	m2/day
K = Hydraulic Conductivity = T/L =	**0.05**	**m/day**

STEP TEST ANALYSIS
TWB029-T1

STEP TESTS .



s60/Q v Q



s60 = projected step drawdown at 60 minutes
Q = bore discharge measured in kL/day
s(ln) = incremental drawdown per log time cycle (i.e. from 10 to 100mins)
App Ew = apparent well efficiency

Calculation of well efficiency using Roraaugh's Equation

$S = BQ + CQ^2$

B = y intercept = 0.0165
C = Gradient = 1.4741E-05
S = drawdown in the bore

$Ew = BQ / (BQ + CQ^2) \times 100$

Step	Q (kl/day)	s(log)	s/Q	App Ew
1	237	4.73	0.020	83%
2	298	5.84	0.020	79%
3	360	7.51	0.021	76%
4	421	9.27	0.022	73%
5	480	11.3	0.024	70%

CONSTANT RATE TEST
TWB029-T1

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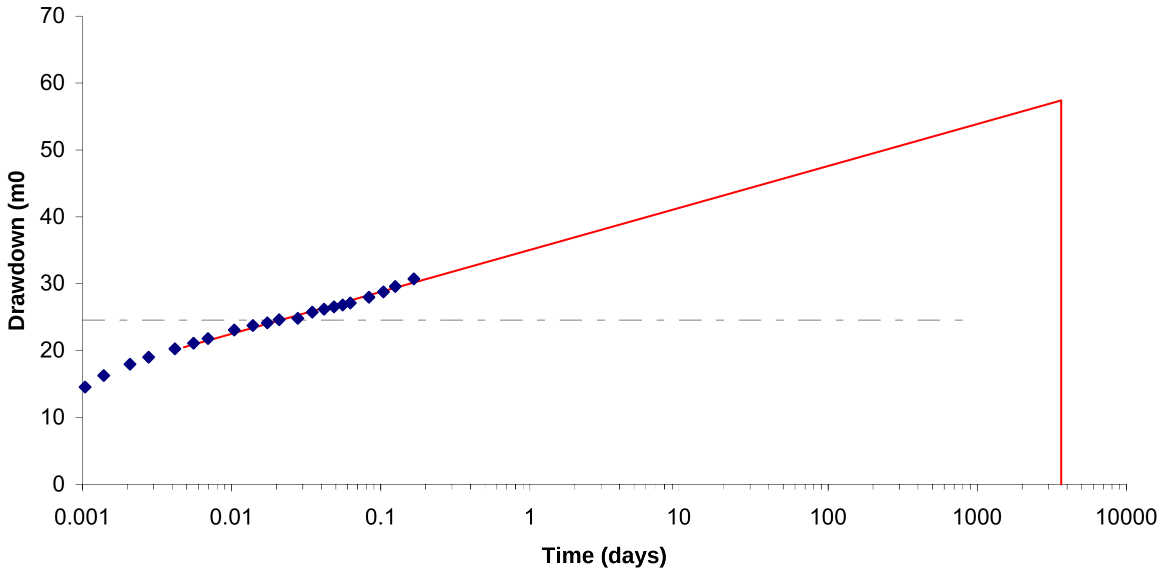
DRAWDOWN PROJECTED TO 10 YEARS



Date of Test	29-Jul-08	
SWL at start	65.4	mBTOC
Pump Setting	90.0	mBTOC
L = Length of Screen =	102	m
Availible drawdown above pump setting	24.6	m
Max availible drawdown in pump well		m

T = 2.3Q/(4πΔ(h0-h))

Q = Test Discharge =	482	Kl/day
Δ(h0-h) = Drawdown per log cycle =	6.27	m
T= Transmisivity =	14.1	m2/day
K = Hydraulic Conductivity = T/L =	**0.14**	**m/day**

Attachment C

Laboratory Parameter Analyses

Western Geotechnics Group
PO Box 219 Bentley WA 6982
36 Railway Parade
Welshpool WA 6106

TEST CERTIFICATE

perth@westerngeo.com.au
ABN: 91105324436
ph: 1300 781744
fx: (08) 9458 3700

Client:	Pennington Scott	Client Job No:	
Project:	Submitted Samples	Order No:	
Location:	Unknown	Tested Date:	7/10/2008
Sample No:	08-WG-13211	WG Job Number:	08-01-2465
Sample ID:	Sample A	Lab:	Welshpool

DENSITY & MOISTURE

Calliper method

Moisture & Density Determination

Moisture Content (%):	14.0
Dry Density (t/m3)	**1.76**

Note: Sample supplied by client.

Approved Signatory: (Mark .Matthews) Date: 10/10/2008

Western Geotechnics Group
PO Box 219 Bentley WA 6982
36 Railway Parade
Welshpool WA 6106

TEST CERTIFICATE

perth@westerngeo.com.au
ABN: 91105324436
ph: 1300 781744
fx: (08) 9458 3700

Client:	Pennington Scott	Client Job No:	
Project:	Submitted Samples	Order No:	
Location:	Unknown	Tested Date:	7/10/2008
Sample No:	08-WG-13211	WG Job Number:	08-01-2465
Sample ID:	Sample A	Lab:	Welshpool

PERMEABILITY: FALLING HEAD

AS1289.6.7.2 Remoulded sample

Sieve Size (mm):	4.75
Moisture Ratio (%)	100.0
Max. Dry Density (t/m3)	1.76
Optimum Moisture Content (%)	14.0
Dry Density (t/m3)	1.76
Dry Density Ratio (%)	99.9
Moisture Content (%)	14.0
Surcharge (kPa)	0.0
Hydraulic Gradient (mm)	1,612

COEFFICIENT OF PERMEABILITY

m/sec at 20 ° C	**2.6E-07**
Percentage Retained:	0

Insitu Dry Density (t/m³):

Note: Sample supplied by client.

Approved Signatory: (Mark .Matthews) Date: 10/10/2008

Western Geotechnics Group
PO Box 219 Bentley WA 6982
36 Railway Parade
Welshpool WA 6106

TEST CERTIFICATE

perth@westerngeo.com.au
ABN: 91105324436
ph: 1300 781744
fx: (08) 9458 3700

Client:	Pennington Scott	Client Job No:	
Project:	Submitted Samples	Order No:	
Location:	Unknown	Tested Date:	7/10/2008
Sample No:	08-WG-13212	WG Job Number:	08-01-2465
Sample ID:	Sample B	Lab:	Welshpool

DENSITY & MOISTURE

Calliper method

Moisture & Density Determination

Moisture Content (%):	13.2
Dry Density (t/m3)	**1.74**

Note: Sample supplied by client.

Approved Signatory: (Mark .Matthews) Date: 10/10/2008

Western Geotechnics Group
PO Box 219 Bentley WA 6982
36 Railway Parade
Welshpool WA 6106

TEST CERTIFICATE

perth@westerngeo.com.au
ABN: 91105324436
ph: 1300 781744
fx: (08) 9458 3700

Client:	Pennington Scott	Client Job No:	
Project:	Submitted Samples	Order No:	
Location:	Unknown	Tested Date:	7/10/2008
Sample No:	08-WG-13212	WG Job Number:	08-01-2465
Sample ID:	Sample B	Lab:	Welshpool

PERMEABILITY: FALLING HEAD

AS1289.6.7.2 Remoulded sample

Sieve Size (mm):	4.75
Moisture Ratio (%)	100.0
Max. Dry Density (t/m3)	1.74
Optimum Moisture Content (%)	13.2
Dry Density (t/m3)	1.73
Dry Density Ratio (%)	99.9
Moisture Content (%)	13.2
Surcharge (kPa)	0.0
Hydraulic Gradient (mm)	1,595
COEFFICIENT OF PERMEABILITY	
m/sec at 20 ° C	**3.8E-07**
Percentage Retained:	0

Insitu Dry Density (t/m³):

Note: Sample supplied by client.

Approved Signatory: (Mark .Matthews) Date: 10/10/2008