APPENDIX 4

Groundwater Assessment

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Aus-10 Rhyolite Pty Ltd

ASSESSMENT OF POTENTIAL GROUNDWATER IMPACTS ON TINDA CREEK

Proposed Expansion of Tinda Creek Sand Quarry

June 2014

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Proposed Expansion of Tinda Creek Sand Quarry

June 2014

Prepared by
Umwelt (Australia) Pty Limited
on behalf of
Aus-10 Rhyolite Pty Ltd

Project Director: **Peter Jamieson**
Report No. **1731/R25/FINAL**
Date: **June 2014**

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1.0 Introduction

Aus-10 Rhyolite Pty Ltd t/a Hy-Tec Concrete and Aggregates (Hy-Tec) operate Tinda Creek, a sand quarry located approximately 67 kilometres north of Windsor along Putty Road, NSW (**Figure 1.1**). Hy-Tec is seeking approval to increase production levels from Tinda Creek Quarry from approximately 125,000 tonnes per annum (tpa) up to 300,000 tpa by increasing the area subject to sand extraction to include additional identified resource domains. The quarry is currently located within Lot 2 DP 628806.

Umwelt (Australia) Pty Limited (Umwelt) has been engaged by Hy-Tec to investigate the impact of the currently approved quarry and proposed modifications to the extraction plan on the groundwater regime of Tinda Creek.

The quarry expansion is proposed to be undertaken on the site as shown in **Figure 1.2** within parcels of land described in cadastral terms as Lot 1, Lot 2 and Lot 3 in DP 628806, on Putty Road, approximately 23 kilometres north of Colo Heights, NSW. Lot 1, Lot 2, and Lot 3 are 86 hectares, 86.67 hectares and 86 hectares respectively, with a total site area of 258.67 hectares. The proposal area is bounded on the north, east and south by Yengo National Park and on the west by Putty Road, several agricultural land holdings and Wollemi National Park (**Figure 1.2**).

The seven resource domains identified and described by Stitt (2012) as indicated in **Figure 1.2** are summarised below:

- Domain 1 – approximately 11.8 hectare area at the western extent of the site, predominantly located over Lot 2 (with minor extension into Lots 1 and 3) comprising an indicated product-sand resource of 2.1 million tonnes (Mt).
- Domain 2 – approximately 3.6 hectare area to the south-west of the current quarry site, adjacent to the western side of the electricity transmission line on Lot 3, comprising an indicated sand resource of 1.1 Mt.
- Domain 3 – approximately 11.9 hectare area to the north of the current quarry site on Lot 1, comprising an indicated sand resource of 2.3 Mt.
- Domain 4 – approximately 4.3 hectare area to the east of the current quarry site on Lot 2, comprising an indicated sand resource of 0.7 Mt.
- Domain 5 – approximately 5.85 hectare area to the south-east of the current quarry site, adjoins Domain 4 and Domain 7 and is predominantly located on Lot 3 (with a minor extension into Lot 2), comprising an indicated sand resource of 1.7 Mt.
- Domain 6 (referred to in Stitt (2012) as 'NW')) – approximately 12.14 hectare area west of the current quarry site (downstream), adjacent to the electricity transmission line and is predominantly on Lot 2 of DP 628806 consisting of a measured sand resource of 1.17 Mt.
- Domain 7 (referred to in Stitt (2012) as 'SE') – approximately 17.54 hectare area to the south of the current quarry site (upstream), on Lot 3 in DP 628806, consisting of a measured sand resource of 2.64 Mt.

In total, Stitt (2012) identified 11.71 Mt of potentially extractable 'product sand' resource, comprising Joint Ore Reserves Committee (JORC) Code-complaint indicated (7.9 Mt) and measured (3.81 Mt) sand resources.

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Environmental Consultants

Source: Google (2002)

0 0.5 1.0 2km
1:35 000

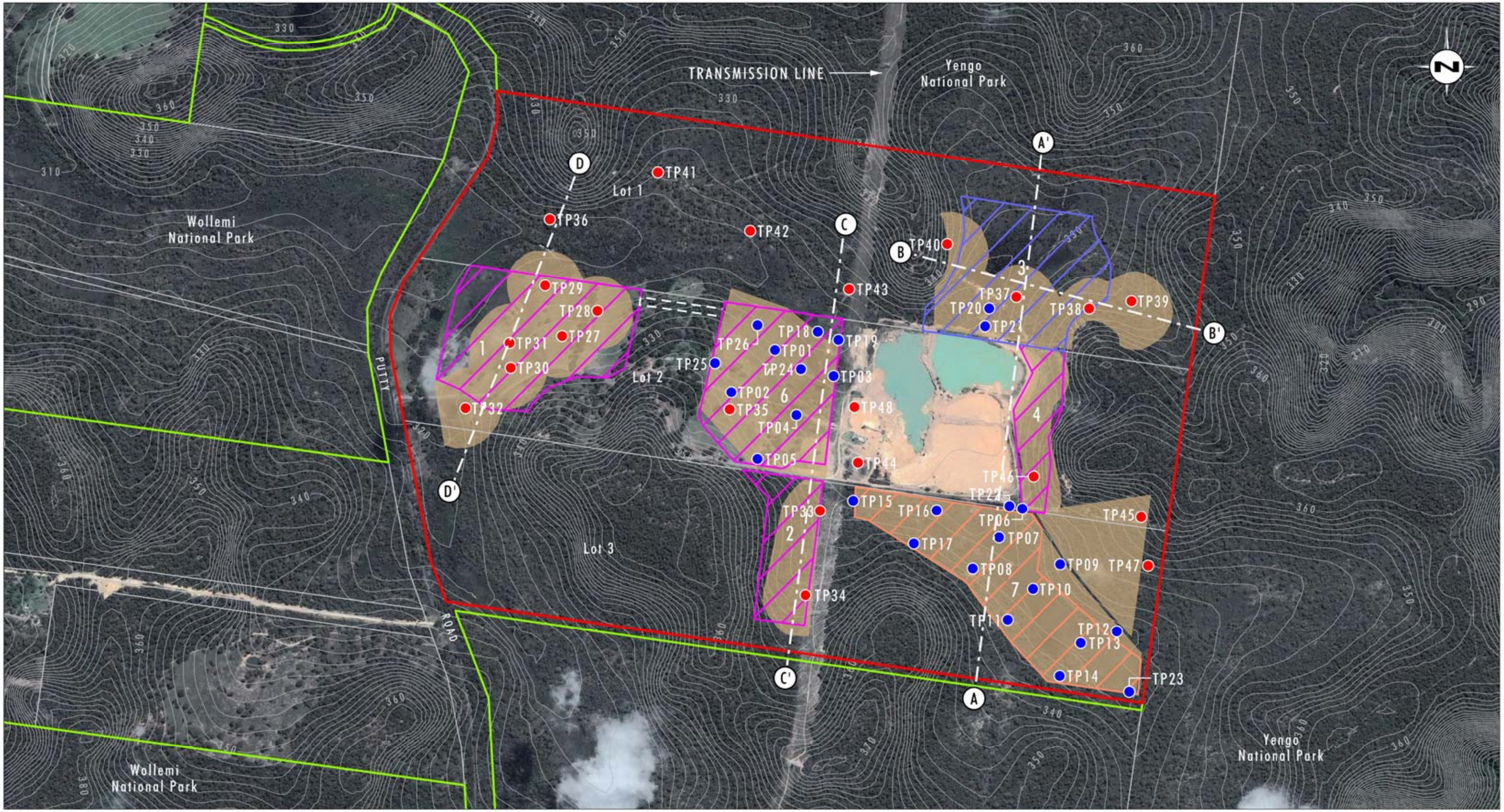
Legend

Project Area

FIGURE 1.1

Locality Map

File Name (A4): R25_V1/1731_409.dgn



Source: Google Earth (2012), LPI NSW (2007)
Note: Contour Interval 2mAHD. For section details refer to Figure 2.4

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1:14 000

Legend

- Project Area
- Proposed Extraction Area
- Domain 3 Extraction Area
- Domain 7 Extraction Area
- National Park Boundary
- Mapped Resource Domains Footprint
- 2010 Drilling Programme
- 2012 Drilling Programme

FIGURE 1.2

Borehole Locations and Mapped Resource Domains

File Name (A4): R25_V1/1731_410.dgn

The outcome of the environmental investigations and refinement of the extraction domains identified by Stitt (2012) has resulted in the selection of the following resource domains for inclusion in the proposed extraction area:

- Domain 1 – approximately 14.17 hectare area comprising an indicated product-sand resource of 1.89 Mt.
- Domain 2 – approximately 5.29 hectare area comprising an indicated product-sand resource of 0.35 Mt.
- Domain 3 – approximately 13.40 hectare area comprising an indicated product-sand resource of 1.95 Mt.
- Domain 4 – approximately 4.14 hectare area comprising an indicated product-sand resource of 0.40 Mt.
- Domain 6 – approximately 13.17 hectare area comprising an indicated product-sand resource of 2.26 Mt.

An alternative biodiversity offset area configuration is also being considered which if adopted would result in quarrying being undertaken within Domain 7 rather than Domain 3. Quarrying within Domain 7 would disturb approximately 14 hectares with an indicated resource of approximately 2 Mt.

The total product-sand resource is estimated at 7 Mt, based on the results of the geotechnical assessment, a maximum extraction depth of 15.24 metres below ground level and internal batters of 3H:1V.

Each extraction stage will involve the removal and stockpiling of topsoil followed by the extraction of available resource via cutter suction dredge. A summary of the extraction sequence is described as follows:

- Following completion of the existing, approved extraction operations (which includes the majority of the Domain 4 area), commence extraction operations in Domain 6. A short trench (approximately 60 metres) will be constructed beneath the overhead powerline to allow movement of the dredge into the Domain 6 starter pond. Following repositioning of the dredge, a pipe will be placed in the trench to provide water to Domain 6 and the trench backfilled.
- While the dredge is located within Domain 6, undertake extraction operations within Domain 2 as a dry extraction operation. Material will be hauled to the edge of Domain 6 and fed to the dredge.
- After completion of extraction operations in Domain 6 and Domain 2, commence in Domain 1. The dredge will be moved into the Domain 1 extraction area via a trench to be constructed on the northern side of Lot 2. This trench will remain open to facilitate movement of water into Domain 1 from Domain 6.
- Once extraction is completed in Domain 1 the dredge will be dissembled and transported back to the existing dredge pond from where the sand resource within Domain 3 will be initially accessed.

If extraction is approved for Domain 7 rather than Domain 3, quarrying would commence in Domain 7 and then progress to Domains 6, 2 and 1 as outlined above. No extraction would occur in Domain 3.

2.0 Statutory and Regulatory Requirements

The Director-General of the Department of Planning and Infrastructure (DP&I), now known as the Department of Planning and Environment (DP&E), has provided requirements for the Project (Director-General's Requirements – DGRs) that identify key issues for consideration in the Environmental Impact Statement (EIS).

The requirements of the DGRs relating to groundwater issues and water resources and where they are addressed in this report are set out in **Table 2.1**.

Table 2.1 – Director-General's Requirements as related to this Assessment

Groundwater Assessment Requirements	Section of Report
Consideration of all relevant environmental planning instruments, including identification and justification of any inconsistencies with these instruments;	**2.0**
Risk assessment of the potential environmental impacts of the development, identifying the key issues for further assessment;	Refer Main EIS
A detailed assessment of the key issues specified below, and any other significant issues identified in this risk assessment, which includes:	**3.0**
• a description of the existing environment, <u>using sufficient baseline data</u>;	**3.0**
• an assessment of the potential impacts of all stages of the development, including any cumulative impacts, taking into consideration relevant guidelines, policies, plans and statutes; and	**4.0**
• a description of the measures that would be implemented to avoid, minimise and if necessary, offset the potential impacts of the development, including proposals for adaptive management and/or contingency plans to manage any significant risks to the environment.	**4.0**
Detailed assessment of potential impacts on the quality and quantity of existing surface and ground water resources in accordance with the NSW *Aquifer Interference Policy*, including:	**3.0**
• detailed modelling of potential groundwater impacts including identification of any highly productive groundwater (as defined by the *Aquifer Interference Policy*) or groundwater dependent ecosystems;	**4.0**
• impacts on affected licensed water users and basic landholder rights; and	**3.0**
• impacts on riparian, ecological, geomorphological and hydrological values of watercourses, including environmental flows.	**4.0**
A detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structures;	**3.2**
An assessment of proposed water discharge quantities and quality/ies against receiving water quality and flow objectives;	**4.0**
Identification or any licensing requirements or other approvals under the *Water Act 1912* and/or *Water Management Act 2000*;	**3.2**
Demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP);	**3.2**
A description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo; and	**2.0**
A detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate surface and groundwater impacts.	This report

2.1 Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources

The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (WSPGWS) was made on 2 March 2011 and commenced on 1 July 2011. The Plan is due for extension/replacement in July 2021.

The Study Area is located in the Sydney Basin North Groundwater Source area.

An analysis of the consistency or otherwise of the proposal with the WSPGWS rules for this groundwater source area is provided in **Table 2.2**. The analysis indicates that the proposal is consistent with the rules. Further details regarding assessment of potential groundwater impacts are provided in **Section 4.2**.

Table 2.2 – Analysis of Proposal Consistency with Water Sharing Plan Rules

Water Sharing Plan Rules		Analysis
Access Rules		
Rules for granting of access licences		
Granting of access licences may be considered for the following	• Local water utility, major water utility, domestic and stock, and town water supply. *These are specific purpose access licences in clause 19 of the Water Management (General) Regulation 2004.*	• Not relevant.
	• Aquifer (Aboriginal cultural), up to 10 ML/yr.	• Not relevant.
	• Commercial access licences under a controlled allocation order made in relation to any unassigned water in this water source.	• Relevant. Hy-Tec currently holds bore licences for its existing operations and these are adequate to supply future needs of the quarry.
Rules for managing water allocation accounts		
Carryover	• Up to 10% entitlement allowed. *Carryover is not allowed for domestic and stock, major utility, local water utility or specific purpose access licences.*	• Not relevant. Commercial access licence sought.
Rules for managing access licences		
Managing surface and groundwater connectivity	• From year 7 of the plan, for areas adjoining unregulated water sources (i.e. rivers and creeks), existing works within 40 m of the top of the high bank of a river or creek, except existing works for, local water utility, town water supply, food safety or essential dairy care purposes, will have conditions which establish: ▪ the flow class of the river established under the water sharing plan for the corresponding unregulated water source, or ▪ in the absence of a flow class, visible flow in the river at the closest point of the water supply works to the river.	• Not relevant. Application for Project Approval pre-dates year 7 of the plan (i.e. 1 July 2017).

Table 2.2 – Analysis of Proposal Consistency with Water Sharing Plan Rules (cont)

Water Sharing Plan Rules		Analysis
	• These distances and rules may be varied for an applicant if the work is drilled into the underlying parent material and the slotted intervals of the works commences deeper than 30 m or no minimal impact on base flows in the stream can be demonstrated. • For major utility and local water utility access licences these rules apply to new water supply works from plan commencement.	
Rules for granting and amending water supply works approvals		
To minimise interference between neighbouring water supply works	No water supply works (bores) to be granted or amended within the following distances of existing bores: • 400 m from an aquifer access licence bore on another landholding, or • 100 m from a basic landholder rights bore on another landholding, or • 50 m from a property boundary (unless written consent from neighbour), or • 1,000 m from a local or major water utility bore, or • 200 m from a NSW Office of Water monitoring bore (unless written consent from NSW Office of Water). *The plan lists circumstances in which these distance rules may be varied and exemptions from these rules.*	• Existing bore licences for the operations are in place and the location of each bore is consistent with the rules.
To protect bores located near contamination	No water supply works (bores) are not (sic) to be granted or amended within: • 250 m of contamination as identified within the plan, or • 250 m to 500 m of contamination as identified within the plan unless no drawdown of water will occur within 250 m of the contamination source, • a distance greater than 500 m of contamination as identified within the plan if necessary to protect the water source, the environment or public health and safety. *The plan lists circumstances in which these distance rules may be varied and exemptions from these rules.*	• The existing water supply bores on the site are located >500 m from the approved septic tank on the site. In addition, modelled drawdown from the bores is approximately 50 m.
To protect water quality	To minimise the impact on water quality from saline interception in the shale aquifers overlying Sydney basin sandstone, the bore being used to take groundwater must be constructed with pressure cement to seal off the shale aquifer as specified by the Minister.	• The site does not draw water from the shale aquifers.

Table 2.2 – Analysis of Proposal Consistency with Water Sharing Plan Rules (cont)

Water Sharing Plan Rules		Analysis
To protect bores located near sensitive environmental areas	No water supply works (bores) to be granted or amended within the following distances of high priority Groundwater Dependent Ecosystems (GDEs) (non-Karst) as identified within the plan: • 100 m for bores used solely for extracting basic landholder rights, or • 200 m for bores used for all other access licences. The above distance restrictions for the location of works from high priority GDEs do not apply where the GDE is a high priority endangered ecological vegetation community and the work is constructed and maintained using an impermeable pressure cement plug from the surface of the land to a minimum depth of 30 m. No water supply works (bores) to be granted or amended within the following distances from these identified features: • 500 m of high priority karst environment GDEs, or • a distance greater than 500 m of a high priority karst environment GDE if the Minister is satisfied that the work is likely to cause drawdown at the perimeter of the high priority karst GDE, or • 40 m of a river or stream or lagoon (3rd order or above), • 40 m of a 1st or 2nd order stream, unless drilled into underlying parent material and slotted intervals commence deeper than 30 m (30 m may be amended if demonstrate minimal impact on base flows in the stream), or • 100 m from the top of an escarpment. *The plan lists circumstances in which these distance rules may be varied and exemptions from these rules.*	• One high priority Groundwater Dependent Ecosystem within the Sydney Basin North Groundwater Source area as identified in the plan is located at Capertree Valley. This GDE is not located within proximity to the project area. • There are existing approved bores located within the Study Area associated with the existing operations. No new bores are proposed.
To protect groundwater dependent culturally significant sites	No water supply works (bores) to be granted or amended within the following distances of groundwater dependent cultural significant sites as identified within the plan: • 100 m for bores used for extracting for basic landholder rights, or • 200 m for bores used for all other aquifer access licences. *The plan lists circumstances in which these distance rules may be varied and exemptions from these rules.*	• The results of the Aboriginal archaeological and cultural heritage assessment indicated that there are no culturally significant sites within the Study Area. Further, the existing licensed bores are located > 200 m from the boundary of the Study Area with the surrounding Yengo and Wollemi National Parks.

Table 2.2 – Analysis of Proposal Consistency with Water Sharing Plan Rules (cont)

Water Sharing Plan Rules		Analysis
Rules for replacement groundwater works	A replacement groundwater work must be constructed to take water from the same water source as the existing bore and to a depth specified by the Minister. A replacement work must be located within: • 20 m of the existing bore; or • If the existing bore is located within 40 m of the high bank of a river the replacement bore must be located within: ▪ 20 m of the existing bore but no closer to the high bank of the river or a distance greater if the Minister is satisfied that it will result in no greater impact. Replacement works may be at a greater distance than 20 m if the Minister is satisfied that doing so will result in no greater impact on the groundwater source and its dependent ecosystem. The replacement work must not have a greater internal diameter or excavation footprint than the existing work unless it is no longer manufactured. If no longer manufactured the internal diameter of the replacement work must be no greater than 110% of the existing work.	• The Project does not propose any replacement groundwater works.
Rules for the use of water supply works approvals		
To manage bores located near contaminated sites	Maximum amount of water that can be taken in any one year from an existing work within 500 m of a contamination source is equal to the sum of the share component of the access licence nominating that work at commencement of the plan.	There are no bores located in the Study Area < 500 m from a contamination source.
To manage the use of bores within restricted distances	The maximum amount of water that can be taken in any one year from an existing work within the restricted distances to minimise interference between works, protect sensitive environmental areas and groundwater dependant culturally significant sites is equal to the sum of the share component of the access licence nominating that work at commencement of the plan.	There are no bores located in the Study Area that are situated within the restricted distances.
To manage the impacts of extraction	The Minister may impose restrictions on the rate and timing of extraction of water from a water supply work to mitigate the impacts of extraction.	There are existing approved bores located within the Study Area associated with the existing operations. No new bores are proposed.

Table 2.2 – Analysis of Proposal Consistency with Water Sharing Plan Rules (cont)

Water Sharing Plan Rules		Analysis
Limits to the availability of water		
Available Water Determinations (AWDs)	• 100% stock and domestic, local and major utilities and specific purpose access licences, • 1 ML/unit of share aquifer access licences. *AWD for aquifer access licences may be reduced in response to a growth in use.*	There are existing approved bores located within the Study Area associated with the existing operations. No new bores are proposed.
Trading Rules		
INTO groundwater source	Not permitted.	Relevant. No trading proposed.
WITHIN groundwater source	Permitted subject to local impact assessment.	Relevant. No trading proposed.
Conversion to another category of access licence	Not permitted.	Relevant. No trading proposed.

2.2 Aquifer Interference Policy

The Aquifer Interference Policy (AIP) provides details of the role and requirements of the Minister administering the *Water Management Act 2000* in the water licensing and assessment processes for aquifer interference activities under *the Water Management Act 2000* and other relevant legislative frameworks.

The AIP applies to all activities that either penetrate, interfere, obstruct, take or dispose with/of water in an aquifer. The existing sand extraction operations at Tinda Creek penetrate the local aquifer, while water is also taken from the aquifer through the pumping of the licensed water supply bores.

2.2.1 Minimal Impact Considerations

The AIP requires that proponents demonstrate that minimal impact considerations specified under the AIP can be met.

The assessment provided here is based on the results of the groundwater modelling reported in **Section 4.0**.

The groundwater source category at Tinda Creek is defined as being 'less productive', given the yield data from production bores is less than 5 L/s. Groundwater sampling has not included data for total dissolved solids.

An assessment of the minimal impact considerations based on the 'less productive' groundwater source category is provided in **Table 2.3**. For the purposes of the assessment, the groundwater source at Tinda Creek is categorised as 'porous rock'.

Table 2.3 – Assessment of Minimal Impact Considerations for Less Productive Porous Rock Groundwater Source at Tinda Creek

Minimal Impact Consideration	Assessment
Water Table	
1. Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. A maximum of a 2 m decline cumulatively at any water supply work.	There is one high priority Groundwater Dependent Ecosystem (GDE) within the Sydney Basin North Groundwater Source area as identified in the plan and it is located at Capertree Valley. This GDE is not located within proximity to the project area. There are no listed high priority culturally significant sites within proximity to the proposed extraction areas. Further, groundwater modelling (**Section 4.9**) indicates that there will be no impacts to any offsite water supply works.
2. If more than 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan if appropriate studies demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than a 2 m decline cumulatively at any water supply work then make good provisions should apply.	There is no listed high priority GDEs or high priority culturally significant sites within proximity to the proposed extraction areas that could be affected by drawdown from the quarry. Groundwater modelling (**Section 4.9**) indicates the variation in water table as a result of the proposed quarry development would be less than 10% at any high priority site.
Water Pressure	
1. A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	Groundwater monitoring and modelling (**Section 4.9**) indicates that the drawdown in the water table will not extend to or impact adversely on any surrounding groundwater supply bores.
2. If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	Predicted pressure head decline is less than requirement 1 (refer above).

Table 2.3 – Assessment of Minimal Impact Considerations for Less Productive Porous Rock Groundwater Source at Tinda Creek (cont)

Minimal Impact Consideration	Assessment
Water Quality	
1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	The use of groundwater on the site is for the purposes of dust control and if required during dry times, to augment water levels in the dredge pond (i.e. to facilitate slurry pumping for transport in dredge pipes). Therefore, its use is highly unlikely to affect groundwater quality or the beneficial use category of the Sydney Basin North Groundwater Source area.
2. If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.	Condition 1 has been met.

In summary, the assessment of the Project against the minimal impact considerations of the AIP indicates that the Project will meet all conditions and as such have a minimal impact on the aquifer at the site, which forms part of the Sydney Basin North Groundwater Source.

3.0 Existing Environment

3.1 Climate

3.1.1 Rainfall

Long term rainfall records are not available for Tinda Creek Quarry. The closest meteorology station to Tinda Creek Quarry is Putty Tea Rooms (Station 061209). Approximately 21 full years of rainfall data are available for Putty Tea Rooms (Station 061209), from 1963 to 1973 and from 2003 to present. Average annual rainfall at Putty Tea Rooms for the 21 years of record is approximately 742.8 millimetres with recorded annual rainfall ranging from 426.5 millimetres in 1965 to 1178.3 millimetres in 1963.

Monthly rainfall recorded at Tinda Creek Quarry since 2007 is provided in **Table 3.1**.

Table 3.1 – Rainfall Records for Tinda Creek Quarry (July 2007 to December 2013)

Month	Year						
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
January	50.5	95.5	29	48.5	66.5	133	138
February	152	146.5	137.5	119.5	47	179	202
March	80.5	43	30	85.5	97	145	103
April	61.5	81.5	117	26	60	64	63.5
May	29	10.5	56.5	59.5	96	-	31
June	210	94	39.5	43	85.5	29	84.5
July	13	24.5	17.5	38.5	25.5	27	18.5
August	107	40.5	4	13.5	90	4	11
September	18.5	58.5	21	18	69	27.5	31.5
October	22	93.5	85.5	85	65.5	17.5	26.5
November	157.5	75	31.5	127.5	159	70.5	106.5
December	76	71	103.5	120.5	72.5	18.5	27
Total (mm)	***977.5***	***834***	***672.5***	***785***	***925***	***715***	***843***

As can be seen from **Table 3.1**, between 2007 and 2013 annual rainfall at Tinda Creek Quarry ranged from 672.5 millimetres in 2009 to 977.5 millimetres in 2007 with 843 millimetres of rainfall received in 2013.

3.1.2 Evaporation

No evaporation data is available at the nearest meteorology station to the site. However, the Australian Bureau of Meteorology (BOM) Average Annual Pan Evaporation map (BOM, 2006) indicates that the average annual pan evaporation in the area is approximately 1500 millimetres. Surface evaporation from dams such as the dredge pond at Tinda Creek Quarry is typically 0.7 times pan evaporation. On this basis the average annual evaporation rate from the surface of water bodies at the quarry would be approximately 1050 millimetres per year.

3.1.3 Evapotranspiration

No evapotranspiration data is available at the nearest meteorology station to the site. However, the Australian BOM Average Areal Actual and Potential Evapotranspiration maps (BOM, 2005) indicate that the average annual actual evapotranspiration in the area is approximately 650 mm/year and that the average annual potential evapotranspiration in the area is approximately 1250 mm/year.

3.2 Topography and Landform

Tinda Creek Quarry is located 67 kilometres north of Windsor, in Tinda Creek Catchment. Tinda Creek is a tributary of Wollemi Creek, which in turn flows into the Colo River. Tinda Creek Quarry is located at the confluence of two small second order intermittent drainage lines in the upper reaches of Tinda Creek Catchment.

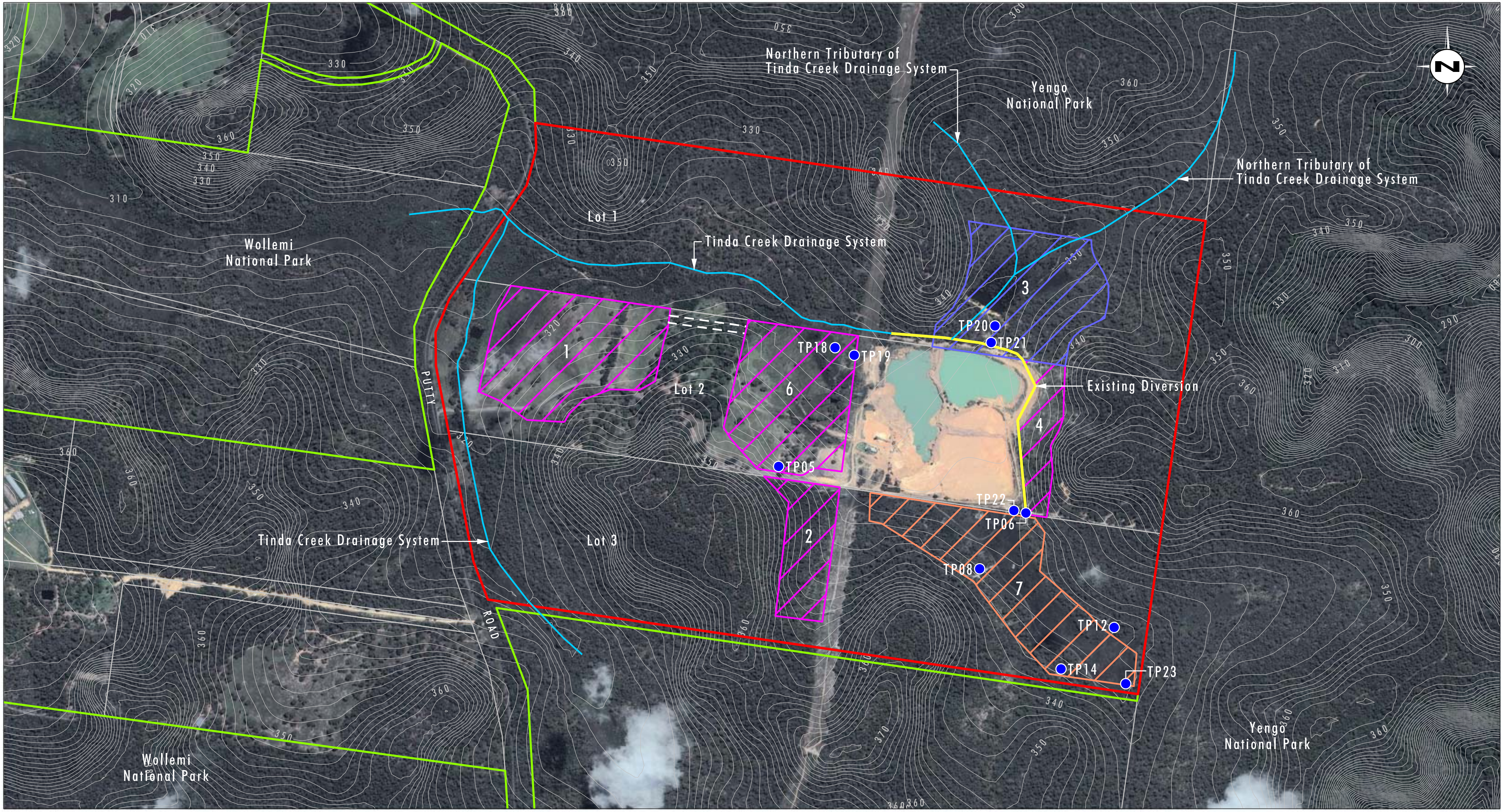
At the location of the quarry, the valley floor is approximately 500 metres wide. The valley is bounded to the east by the Mellong Range, rising to an elevation of approximately 400 metres Australian Height Datum (mAHD). To the north and south, unnamed ridges rise to elevations of approximately 370 mAHD and 380 mAHD respectively. The existing quarry site itself has an elevation of approximately 330 mAHD in the east of the site, grading on a 1% slope to an elevation of approximately 324 mAHD in the north-west of the existing dredge pond. Average ground slope between the quarry and the catchment divide to the east is approximately 14%. Elevation at the western end of the Project area where Tinda Creek flows under Putty Road is approximately 314 mAHD. The topography of the site is shown in **Figure 3.1**.

These landform attributes impact on groundwater levels and the rate of groundwater drainage from various sections of the catchment.

3.2.1 Catchment Drainage

The headwaters of Tinda Creek (see **Figure 3.1**) are located approximately 1 kilometre to the east and south-east of the quarry at the edge of the Mellong Range. The headwaters drain to a sedgeland that has formed on the valley floor immediately to the south-east of the quarry. This area becomes swampy following prolonged wet weather and dries out during longer periods of dry weather.

Tinda Creek intermittently flows to the north-west from this point, and has been diverted around the eastern and northern boundaries of the quarry site via a small earthen drainage channel. Tinda Creek joins with another intermittent second order stream on the northern boundary of the quarry site (refer to **Figure 3.1**). These drainage lines contain water during, and immediately following rainfall, but dry out in periods of dry weather. The first significant area of more permanent ponded water in Tinda Creek is located downstream of Putty Road in Gibba Swamp, approximately 1.3 kilometres downstream of the existing dredge pond.



Source: Google Earth (2012), LPI NSW (2007)
Note: Contour Interval 2mAHD

0 250 500 750m
1:15 000

Legend

- Project Area
- Proposed Extraction Area
- Domain 3 Extraction Area
- Domain 7 Extraction Area
- National Park Boundary
- Groundwater Monitoring Bores

FIGURE 3.1

Topography and Drainage

File Name (A4): R25_V1/1731_411.dgn

3.2.2 Quarry Surface Water Management

Tinda Creek Quarry operates a closed water management system which collects and contains all rainfall that falls on the surface of the quarry and groundwater that is intercepted by quarry operations. There are no off-site discharges from the quarry water management system. All process water is managed onsite in sediment dams, tailings dams and the quarry pit, while clean water from the upstream catchment is diverted around the site. The major surface water features of the quarry site are shown on **Figure 3.1** and include:

- quarry pit and dredge pond – varies in size up to approximately 6 hectares in area but is typically approximately 3 hectares in area with the base of the pond up to 15 metres below ground level. The dredge pond that is located within the quarry pit is typically 5 metres deep with the surface water level of the dredge pond being approximately 10 metres below ground surface. The quarry pit has steep sides which display very little seepage of groundwater into the pit;

- silt ponds and tailings dams which cover an area of approximately 4.5 hectares and are now filled to approximately ground level; and

- sediment dams which have a surface area of approximately 1 hectare with a surface water level approximately 1 metre below ground surface.

Sand is extracted from the quarry pit using a cutter-suction dredge that floats on a dredge pond within the quarry pit. Water, sand, silt and clay are pumped from the dredge pond to the processing area as a slurry. The majority of water is delivered back to the sediment dam and tailings ponds following sand separation. A small amount of water is transported off-site in product sand and an additional small amount of water is used in dust suppression on haul roads and access roads. Water also evaporates from the surface of product stockpiles. Some water is also likely to be recharged to the groundwater aquifer at the sand processing plant and via the sediment dams and tailings ponds. It is estimated that total quarry water demand for dust suppression and loss in product is approximately 8 to 10 million litres (ML) per year.

Hy-Tec currently holds groundwater access licences 10 WA 112523 and 10 WA 112531 which permit groundwater extraction of 40 ML/year and 15 ML/year respectively.

Other surface water features in the area include:

- Tinda Creek and its tributaries;

- two small farm dams located approximately 200 metres west of the quarry pit with surface water levels approximately 1 metre below ground surface; and

- a farm dam on the adjoining northern property approximately 150 metres north of the quarry pit with a surface water level approximately 1 metre below ground surface. The wall of this dam has been breached to prevent the dam from holding water.

3.3 Geology

3.3.1 Regional Geology

Tinda Creek Quarry is located in the Sydney Basin, which generally consists of lower rock strata belonging to the Narrabeen Group (sandstone, mudstone, shale) overlain by Hawkesbury Sandstone (sandstone with some shale lenses). Formations of Tertiary basalt occur as mountains (e.g. Yengo and Wareng) and as plugs in the bottom of some valleys. Hawkesbury Sandstone is the predominant sandstone unit outcropping in the region surrounding Sydney. The basement to the sand resources is the unweathered Hawkesbury Sandstone deposited during the Triassic Period (195 to 225 million years ago) (Stitt, 2010; 2012). This unit is overlain by weathered rock, clay and sand.

The Hawkesbury Sandstone in the study area comprises variously coloured sands and clayey sands, white and pale coloured clay, and some grey-dark grey shale. Near the surface it is very soft and intensely weathered, while the sandstone becomes harder and more competent with depth, ranging from approximately 5 metres to 20-30 metres below the surface. Brown and reddish coloured, generally soft, ironstone concretions are observed near the top of the friable sandstone in many locations. Bedding is typical of the Hawkesbury Sandstone as observed elsewhere, variable in thickness, horizontal to sub-horizontal, and cross bedding is common (Stitt, 2010; 2012).

Geological strata from driller's logs (Golders Associates, 2005) for a borehole that was drilled to 90 metres on site for a groundwater supply bore is provided in **Table 3.2**.

Table 3.2 – Driller's Log for Groundwater Bore at Tinda Creek Quarry

Depth Below Ground Level (m)	Material Encountered
0 to 23 m	sandy clay
23 to 51 m	sandstone yellow
51 to 54 m	sandstone white
54 to 63 m	sandstone yellow
63 to 67 m	sandstone white
67 to 68 m	clay grey
69 to 90 m	sandstone, quartzite

As shown in **Table 3.2**, sand clay that is currently being quarried on-site was encountered to a depth of 23 metres. This was underlain by 44 metres of sandstone which in turn was underlain by 1 metre of clay shale at a depth of 67 metres. Below 68 metres sandstone quartzite was encountered to the base of the drill hole at 90 metres below ground level.

3.3.2 Geomorphic Model of Tinda Creek

Tinda Creek drains westward from the sandstone Mellong Range. For part of its course, the present day creek flows over an area of sediments deposited into a shallow lake formed in the palaeo-valley of Tinda Creek during the Tertiary Period (2 to 60 million years ago). In other parts of the study area it flows over the friable Hawkesbury Sandstone into which the palaeo-valley was incised. The Tertiary sediments comprise a sequence of lacustrine and fluvial sands, sandy clays, silty clays, and minor thin peaty clays (Stitt, 2010).

A geological investigation of the site was undertaken by Coffey (1992) who reported that the geological sequence within the study area consists of a colluvial layer of sands and silty sands to a depth of 0.5 metres to 2 metres, underlain by residual clayey sands to a depth of 10 metres to 27 metres. The clayey sands are derived from in-situ weathering of the underlying Hawkesbury Sandstone.

An assessment of sand resources at the site was undertaken (Stitt, 2010; 2012), which included a detailed drilling program. The location of boreholes that informed the resource assessment is shown in **Figure 1.2**, which also details the footprint of the resource domains mapped from the drilling program and the final extraction domains. A conceptual model of the lithology of the study area is shown in **Figure 3.2**, based on the results of the Coffey (1992) and more recent Stitt (2010; 2012) investigations.

Figure 3.3 shows a series of cross sections developed from the results of the drill logs (refer **Figure 3.2** for cross section locations). Where drill holes are not located immediately adjacent to a cross section, the lithology shown on the cross section has been inferred from drill logs of the nearest borehole and surface topography. The depth of clayey sand shown in **Figure 3.3** is limited to the extent of the borehole, however, in all cases shown the borehole was terminated in clayey sand. The depth shown for the clayey sand layer is therefore conservative. The cross sections indicate that the proposed extraction domains are located primarily within the depositional layer of relatively impermeable, lacustrine/colluvial clayey sands.

The extraction domains (and resultant dredge ponds) are therefore effectively contained within the relatively impermeable clayey sand material. As such, extraction operations are not expected to significantly affect groundwater flows or downstream flows in Tinda Creek (via drawdown), which is supported by measured and modelled groundwater levels on site.

The 2010 drilling program included drilling of 26 boreholes across the site to depths ranging from 12 metres to 21 metres. The 2012 drilling program included drilling of an additional 22 boreholes across the site to depths ranging from 10 metres to 27 metres. Boreholes logs from these investigations indicate that the Tinda Creek sand deposits consist of friable sandstone derived from weathered Hawkesbury Sandstone as well as lacustrine sediments in the low-lying areas of the site along Tinda Creek.

Stitt (2010) states that both deposit types comprise of medium-fine sand with varying clay contents and include some interbedded with clay and silt layers. Both Stitt reports (2010 and 2012) indicate that some boreholes in the Hawkesbury Sandstone were intersected by dark grey shale beneath the friable sandstone. Stitt (2010) highlights the significant changes in lithology over short distances as reflected by the changes in ratios of sand to clay and the distribution of clay and silt rich layers throughout the deposit.

These changes are evident in both the friable sandstone and lacustrine sand deposits. Stitt (2010) indicates that the clay content of the clayey sand upstream of the quarry pit ranges from 20% to 38% with the clay content increasing in a south-east to north-westerly direction. The Stitt Report (2010) indicates that the clay content of the clayey sand downstream of the existing quarry pit ranges from 25% to 50% with the clay content increasing in a south-west to north-westerly direction.

Laboratory testing as discussed above indicates that the clay content of the clayey sand ranges from 18% to 47%. Site inspection of the surrounding valley floor indicates that these soils also have significant clay content, evidenced by the steep sides of the quarry excavation (**Plate 3.1**) and test pits that have been excavated around the quarry. However, in the upslope areas, soils have significantly lower clay content (**Plate 3.2**). Unweathered bedrock is also likely to be much closer to the surface in the upslope areas (i.e. 10 metres below ground surface to 20 metres below ground surface in the upslope areas, compared to greater than 60 metres below ground surface in the valley area).

3.4 Aquifer Properties

3.4.1 Conceptual Model

The conceptual model of the aquifers of Tinda Creek catchment comprises the three-layer system shown in **Figure 3.2**, being an upper layer of clayey sand in the valley area to a depth of approximately 20 to 30 metres, underlain by weathered Hawkesbury Sandstone to a

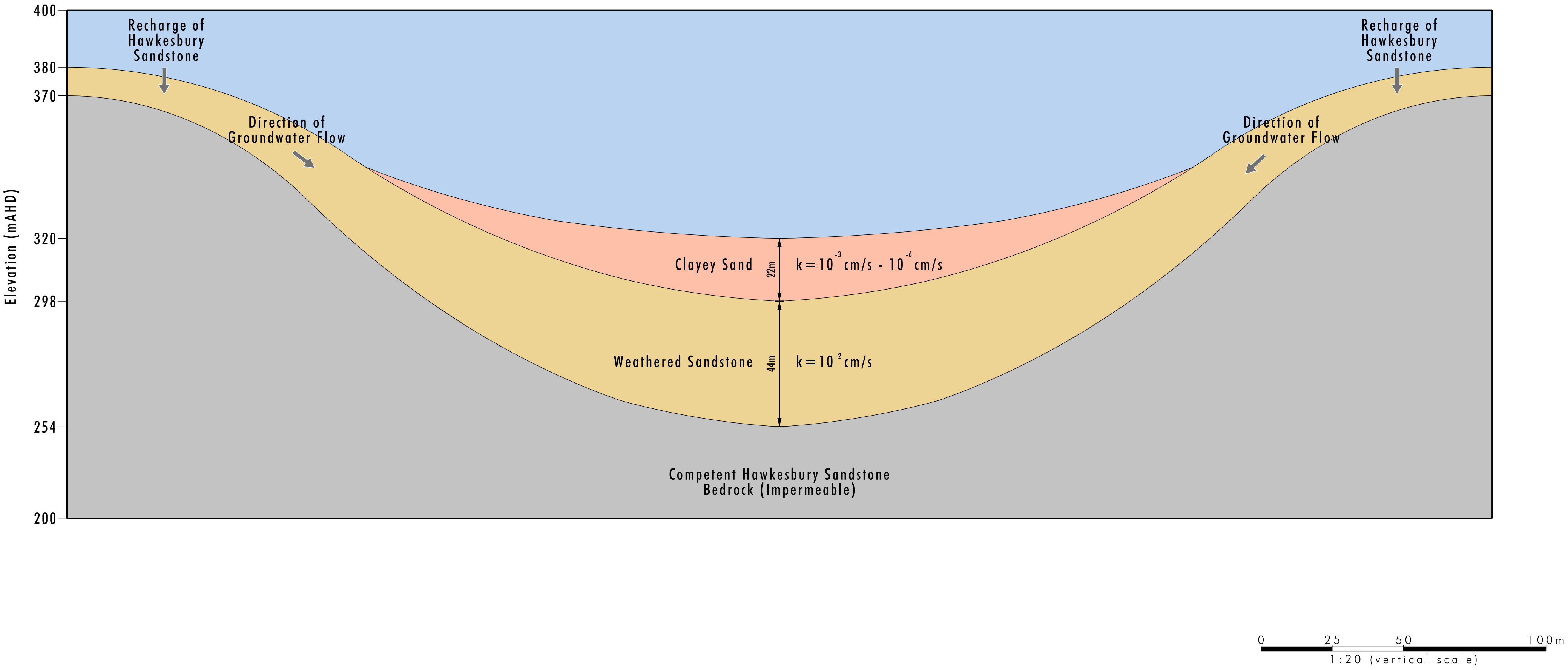


FIGURE 3.2

Conceptual Groundwater Model of Tinda Creek Catchment

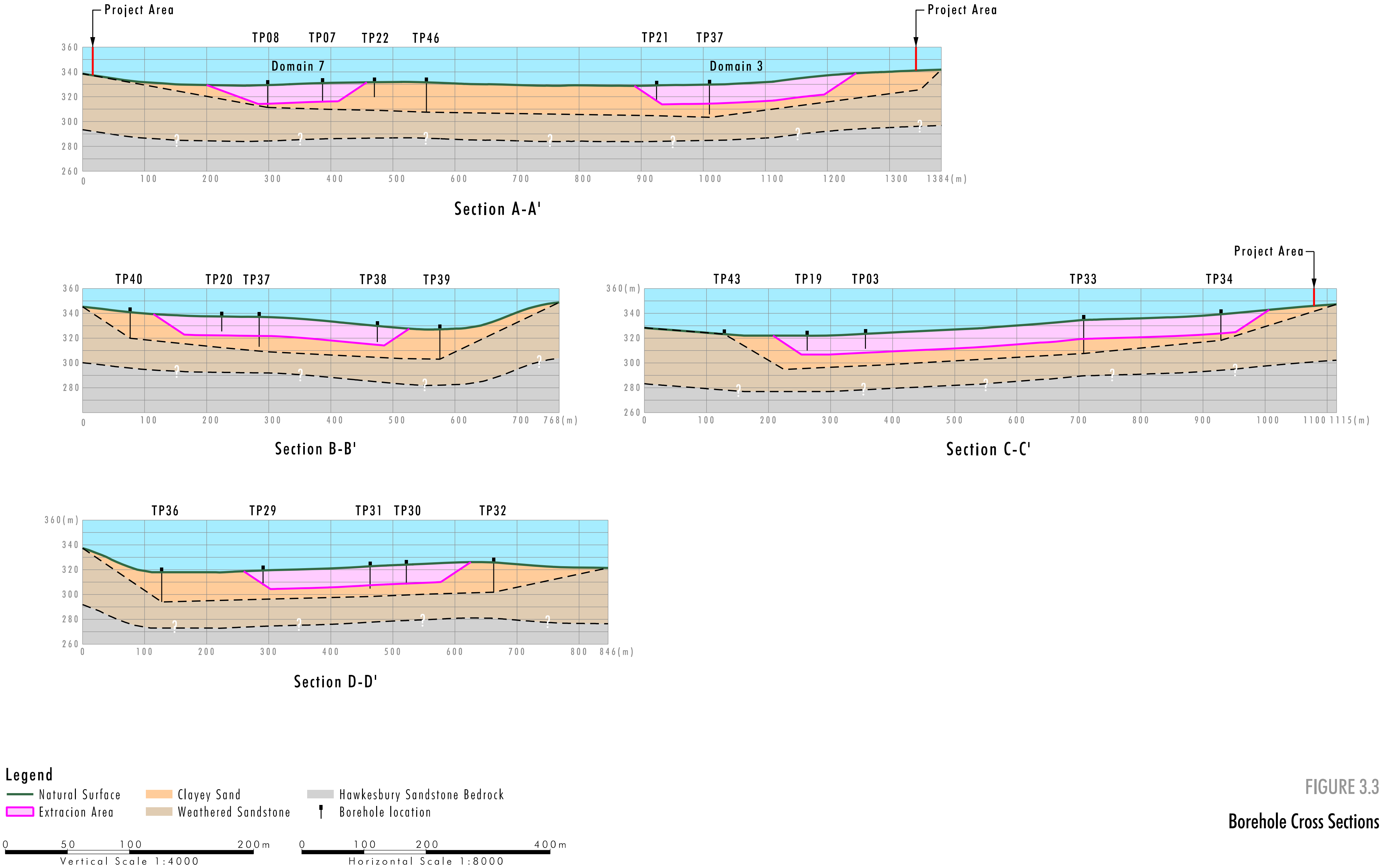


FIGURE 3.3

Borehole Cross Sections

PLATE 3.1
Stage 2 Dredge Pond

PLATE 3.2
Sandy Soils in Upslope Areas

depth of 40 to 60 metres, underlain by competent, low permeability Hawkesbury Sandstone. As discussed in **Section 3.3.1**, a band of shale was detected at the top of the competent Hawkesbury Sandstone bedrock which may act as an aquitard.

Hydraulic conductivities for the clayey sand unconsolidated sediments of the type described in **Section 3.2.2** are provided in **Table 3.3**. As shown in **Table 3.3**, the hydraulic conductivity of clayey sand (expected to correlate to the uppermost layer of the conceptual model) generally ranges from approximately 10^{-6} cm/s to 10^{-4} cm/s, while the hydraulic conductivity of silty sands and fine sands (expected to correlate to the middle layer of the conceptual model) ranges from approximately 10^{-5} cm/s to 10^{-3} cm/s.

Table 3.3 – Range of Hydraulic Conductivities for Unconsolidated Sediments

Material	Hydraulic Conductivity (cm/s)
Clay	$10E^{-9}$ – $10E^{-6}$
Silt, sandy silts, clayey sands, till	$10E^{-6}$ – $10E^{-4}$
Silty sands, fine sands	$10E^{-5}$ – $10E^{-3}$
Well-sorted sands, glacial outwash	$10E^{-3}$ – $10E^{-1}$

Source: Fetter (2001)

Clayey Sand Aquifer

The clayey sand aquifer, corresponding to the uppermost layer of the conceptual model in **Figure 3.2,** is a locally occurring deposit associated with the Tinda Creek valley. It is shallow and variable in character, and typically responsive to rainfall and stream flow. These are expected to be the major mechanisms for recharge.

As described in **Section 3.3**, the clayey sand deposit is variable in character and extent. Predicted hydraulic conductivities indicate that it may function as an aquiclude. Based on site observations and the findings of Coffey (1992, cited in CMJA, 2007) and Golder Associates (2005), the sand/clay layer is likely to exhibit areas of perched water. Consequently, wet soak areas and seepage into shallow test pits in the upper catchment may be a result of seepage from areas of perched water rather than as a result of the intersection of the regional groundwater table.

Hawkesbury Sandstone

Hawkesbury Sandstone is the major aquifer across the Sydney region (1:250000 Sydney Basin Geological Map). It is a layered aquifer system, with groundwater occurring in vertically discrete horizons that have little vertical movement between them. In areas of competent rock, groundwater flow is generally dominated by secondary porosity and fracture flow. Observations Coffey (1992) and Golder Associates (2005) identify a band of clay shale at approximately 60 metres to 70 metres depth which may act as an aquitard between the upper weathered sandstone and lower more competent sandstone observed at the site.

According to McKibbon and Smith (2000), groundwater recharge of the Hawkesbury Sandstone on a regional level is typically:

- by direct infiltration of rainfall in outcrop areas;
- from infiltrating run-off in upland areas; and
- by minor inter-aquifer leakage.

The potentiometric surface is typically a muted expression of topography, and this in turn controls groundwater movement, which tends to be towards creeks and rivers.

3.4.2 Groundwater Quality

Groundwater quality at the site (see **Table 3.4**) has been monitored at six monthly intervals since October 2010 with the following parameters recorded at 11 monitoring bores (see **Figure 1.2**):

- pH;
- conductivity;
- nitrate;
- ammonia; and
- TPH.

Table 3.4 – Groundwater Quality for Period October 2010 to November 2013

	pH			Conductivity (µS/cm)		
Bore	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**
TP22	5.4	5.2	4.6	74	60	50
TP06	6.6	5.9	5.3	1320	321	65
TP12	5.5	5.3	5.0	73	63	55
TP23	5.5	5.4	5.2	77	59	50
TP14	5.9	5.2	4.8	170	112	65
TP08	6.7	5.5	5.0	200	120	68
TP05	5.5	5.2	4.9	170	128	80
TP18	5.3	5.2	4.9	130	123	115
TP19	5.6	5.3	4.9	95	88	80
TP20	5.5	5.3	5.0	97	85	75
TP21	5.7	5.5	5.3	73	56	45

As shown in **Table 3.4**, groundwater pH tends to be slightly acid due to the generation of organic acid from the breakdown of plant material with pH levels up to 6.7 being recorded at the start of the monitoring period after a prolonged dry period. Conductivity is generally very low except for monitoring bore TP 06 at the start of the monitoring period which again occurred after a prolonged dry period. By May 2013 after an above average rainfall period, conductivity in TP 06 has reduced to 55 µS/cm.

Available monitoring data indicates that quarry activities are not adversely impacting on groundwater quality which is generally very good and tends to fluctuate in response to changes in rainfall conditions.

3.4.3 Groundwater Table Observations

Groundwater level monitoring has been undertaken at 11 monitoring bores across the site on a monthly basis since October 2010. Monitoring bore locations are shown on **Figure 1.2** and recorded ground levels and monthly rainfall for the period October 2010 to November 2013 are shown on **Figure 3.4**. As shown on **Figure 3.4**, groundwater levels fluctuate reasonably

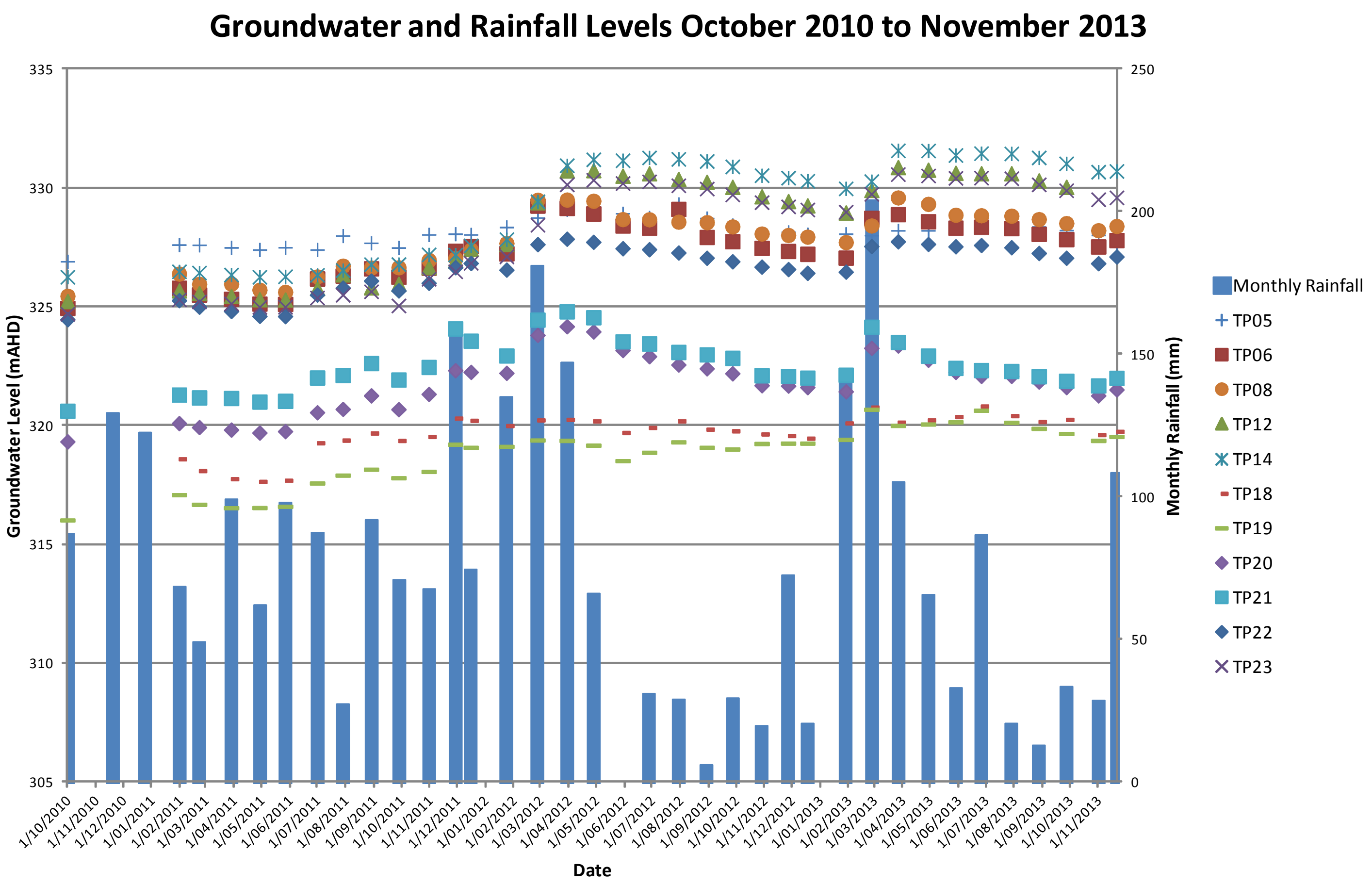


FIGURE 3.4

Groundwater Levels (October 2010 to November 2013) quickly in response to rainfall with variations in groundwater level of up to 6 metres being observed over the October 2010 to November 2013 monitoring period.

The range of groundwater levels recorded for each of the monitoring bores for the period October 2010 to November 2013 is summarised in **Table 3.5**.

Table 3.5 – Recorded Groundwater Levels

Monitoring Bore Location	Ground Level (mAHD)	Minimum Groundwater Level (mAHD)	Maximum Groundwater Level (mAHD)	Range (m)
TP22	328.572	324.5	327.9	3.4
TP06	330.527	324.9	329.2	4.3
TP12	332.026	325.2	330.9	5.6
TP23	331.613	324.7	330.6	5.9
TP14	335.064	326.3	331.6	5.3
TP08	332.071	325.5	329.6	4.1
TP05	334.613	326.9	329.3	2.4
TP18	320.93	317.6	320.8	3.2
TP19	320.965	316.0	320.7	4.7
TP20	325.649	319.3	324.2	4.8
TP21	326.378	320.6	324.8	4.2

As shown in **Table 3.5**, recorded groundwater levels range from approximately 316.0 mAHD at Monitoring Bore TP19 adjacent to the southern boundary of the existing dredge pond to approximately 331.6 mAHD at Monitoring Bore TP14 at the south-eastern corner of the site adjacent to Yengo National Park with variation in groundwater levels over the monitoring period ranging from 2.4 metres at TP05 to 5.9 metres at TP 23. Average rainfall over the period October 2010 to November 2013 was 885 mm/year making the rainfall during the period of groundwater record above average. This followed on from a slightly below average rainfall year in 2009 when 672 millimetres was received.

Groundwater monitoring undertaken for the project (see **Table 3.4**) indicates that groundwater levels are typically 1 to 9 metres below the surface in the area surrounding the existing and proposed quarry operations.

As shown on **Figure 1.2**, a series of three paired monitoring bores each approximately 50 metres apart have been established around the perimeter of the existing quarry operation, those being:

- Monitoring Bores 19 and 18 immediately to the north-west;
- Monitoring Bores 21 and 20 immediately to the north-east; and
- Monitoring Bores 22 and 6 immediately to the south-east.

As can be seen from **Figure 3.4**, groundwater levels in the bores closest to the dredge pond are typically 1 to 2 metres lower than in the adjoining paired bore during dry periods with the difference in water levels reducing during prolonged wet periods. As shown on **Figure 3.4**, groundwater levels rose during the 2010 to 2013 monitoring period which received above average rainfall following on from the below average rainfall received in 2009.

Analysis of the available monitoring data for monitoring bores TP22 (adjacent to the south-eastern corner of the dredging area), TP 6 approximately 50 metres further from the dredge pond to the east of TP 22 and TP 14 approximately 500 metres south-east of TP 14 shows that groundwater levels in all the bores respond similarly to rainfall. Monitoring indicates that groundwater levels in TP 14 are approximately 1 metre higher than those in TP 22 and TP 06 in dry periods (i.e. up to approximately March 2012) with the difference in groundwater level increasing to approximately 4 to 5 metres after prolonged high rainfall events.

4.0 Groundwater Modelling

4.1 Methodology

A steady state groundwater model of Tinda Creek catchment for the existing quarry operation was developed using Visual MODFLOW Pro Version 2011.1. This model was based on the Visual MODFLOW model that was developed for the quarry in February 2008 (Umwelt, 2008) and was updated to take into consideration additional geological information and groundwater level information that has been obtained since that time.

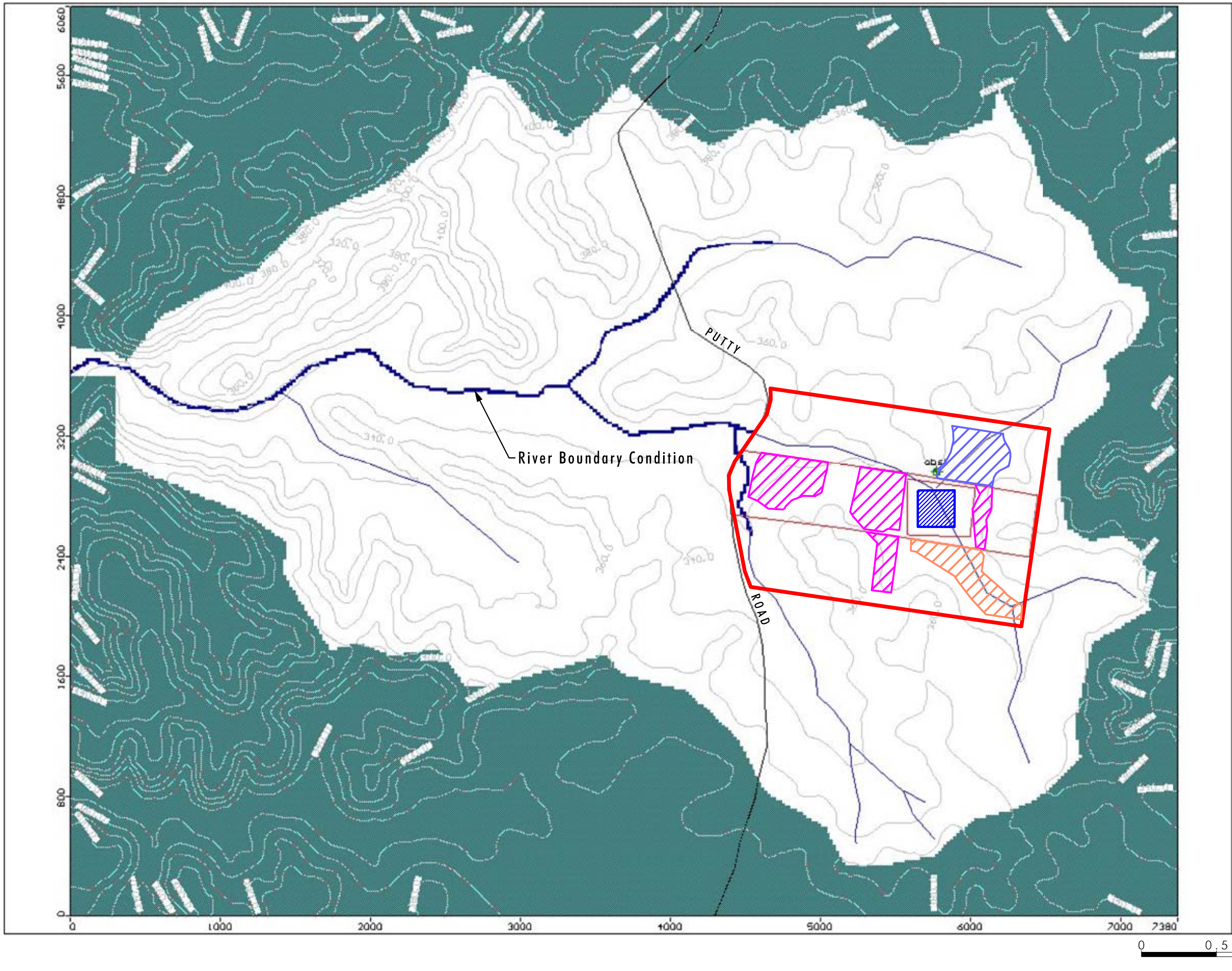
Visual MODFLOW is a computer program that simulates three-dimensional groundwater flow through a porous medium. The model is capable of simulating groundwater flow under the influence of recharge, evapotranspiration, flow to wells, flow to drains and flow through riverbeds. Visual MODFLOW is the most widely used groundwater flow model for applications such as the assessment of the impact of mining and quarrying projects on unconfined groundwater systems. In Visual MODFLOW, catchments are broken up into a grid of blocks known as 'cells', the locations of which are described in terms of rows, columns and layers. A number of layers can be defined in Visual MODFLOW to reflect vertical changes in aquifer properties. The extent of the conceptual groundwater model developed for Tinda Creek catchment and boundary conditions adopted in the model are shown on **Figure 4.1**.

The major aquifer properties required by Visual MODFLOW include:

- surface topography and layer thickness;
- hydraulic conductivity;
- aquifer storage parameters;
- recharge;
- evapotranspiration; and
- flow boundary conditions including no flow boundaries, rivers and areas of constant head.

A series of groundwater models have been developed using Visual MODFLOW to explore the comparative impacts that quarrying could have on groundwater levels and groundwater contributions to flows in the Tinda Creek system. Visual MODFLOW models that have been developed for Tinda Creek model the following landform configurations:

- Tinda Creek catchment with current (2013) quarrying operations;
- Tinda Creek catchment with existing dredge pond and the northern dredge pond (Domain 3) backfilled with silt, clay and excavated neutral material/virgin excavated neutral material (ENM/VENM); and
- Tinda Creek catchment with existing dredge pond, the central dredge pond (Domain 6) and the northern dredge pond (Domain 3) backfilled with silt, clay and ENM/VENM.



Legend

- No Flow Boundary Condition
- Project Area
- Proposed Extraction Area
- Domain 3 Extraction Area
- Domain 7 Extraction Area
- Quarry
- Surface Contours (mAHD)

FIGURE 4.1

Boundary Conditions used in Groundwater Model

4.1.1 Model Layout

Conceptually, the groundwater model of the pre-quarrying catchment was assumed to consist of three layers, namely the surface clayey sand layer (Layer 1), over a weathered sandstone layer (Layer 2), over an impermeable bedrock layer (Layer 3). Layer 3 was assumed to be impermeable on the basis of the presence of a clay shale layer at the top of the competent sandstone bedrock which may act as an aquitard. A conceptualisation of the model is shown in **Figure 3.2**.

The elevation of the ground surface was digitised from the 1:25,000 series topographic map for the broader area, augmented with recent survey data in the vicinity of the quarry and transformed into a digital elevation model for import into Visual MODFLOW. The model covered a catchment area of approximately 2320 hectares (extent shown in **Figure 4.1**). The model was divided into a Visual MODFLOW grid of 337 rows and 450 columns, made up of cells with average side lengths of 20 metres (refer to **Appendix A** for full details of the model layout). The Visual MODFLOW model was divided into three layers as per the conceptual model shown in **Figure 3.2**. Based on bore log data described in **Section 3**, it was assumed that the thickness of Layer 1 ranged from 28 metres in the valley in the vicinity of Tinda Park Quarry to 0 metres on the ridge tops. It was assumed that the thickness of Layer 2 ranged from 44 metres in the valleys to 10 metres on the ridge tops. The elevation of the surface of Layers 2 and 3 was generated by subtracting estimated depth data from the ground surface digital elevation model.

4.1.2 Hydraulic Conductivity

Initial estimates for hydraulic conductivity and storage parameters used in the model (based on the 2008 calibration described in Umwelt (2008)) are shown in **Table 4.1**.

Table 4.1 – Initial Hydraulic Conductivity and Storage Parameters used in Tinda Creek Groundwater Model

	Conductivity (cm/s)	Specific Storage (m^3/m^3)	Specific Yield (%)	Porosity (%)
Layer 1 – clayey sand	5×10^{-6}	1×10^{-5}	8	48
Layer 1 – Sand	1×10^{-2}	1×10^{-5}	28	39
Layer 2 – Sand	1×10^{-2}	1×10^{-5}	28	39
Layer 3 – Bedrock	No flow	No flow	No flow	No flow

The location and layout of the various zones of hydraulic conductivity are shown in **Appendix A**.

4.1.3 Boundary Conditions

Boundary conditions applied in the model include:

- no flow boundaries along the Tinda Creek catchment divide;
- river boundary condition along the main arm of Tinda Creek using elevation data estimated from the 1:25,000 series topographic map and detailed topographic survey of the quarry; and

- river boundary conditions along the southern and northern unnamed tributaries of Tinda Creek in the vicinity of Putty Road and along Rising Fast Gully (see **Figure 3.1**) using elevation data estimated from the 1:25,000 topographic map.

Boundary conditions utilised in the model are shown in **Figure 4.1**.

4.1.4 Recharge and Evapotranspiration

The model was run for the average (700 mm/year) rainfall scenario. Modelling assumed that each of the rainfall scenarios modelled continued for 20 consecutive years which in reality is unlikely to occur and would tend to over-estimate changes in modelled groundwater regime compared to using varying rainfall over a 20 year period.

Recharge and evapotranspiration were applied uniformly over the catchment at rates of 70 mm/year and 600 mm/year respectively for the average rainfall scenario. An extinction depth of 2.5 metres was applied to the model.

4.2 Calibration

4.2.1 Calibration Targets

Preliminary calibration of the model is described in detail in Umwelt (2008). Further calibration of the model was undertaken using groundwater observation data in the groundwater bores shown on **Figure 1.2**. Calibration targets used for the model are provided in **Table 4.2**.

Table 4.2 – Model Calibration Targets

Observation Bore	HEAD (mAHD)
TP05	327.396
TP06	325.11
TP08	325.62
TP12	325.293
TP14	326.253
TP18	317.64
TP19	316.534
TP20	319.696
TP21	321
TP22	324.604
TP23	324.988

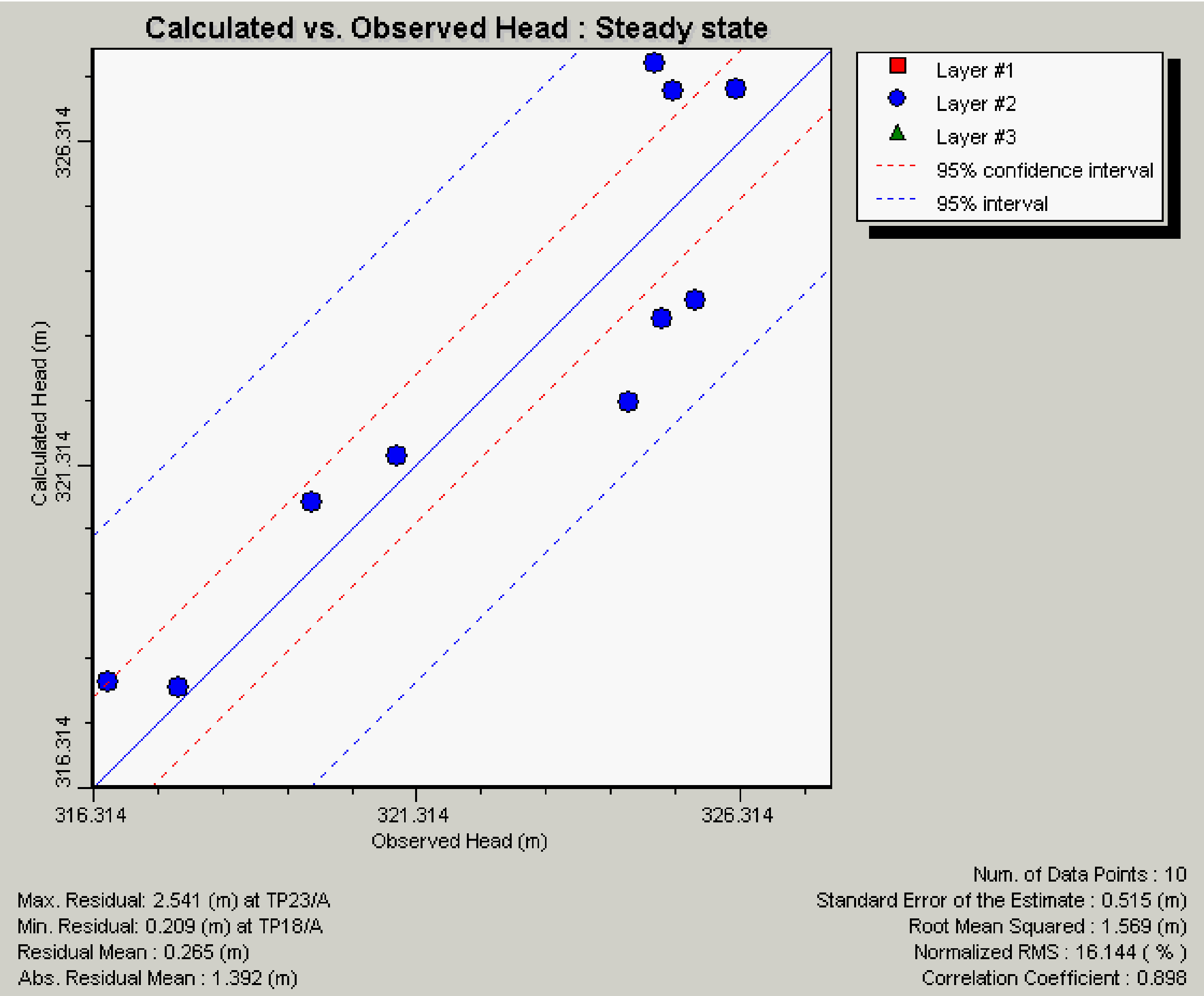
4.2.2 Calibration Results

Calibration of the model was undertaken manually by exploring a range of hydraulic conductivity values. Hydraulic conductivity values that provide closest calibration to observed groundwater levels during the period October 2010 to December 2011 are set out in **Table 4.3**. October 2010 to December 2011 was an average rainfall period.

Table 4.3 – Hydraulic Conductivity and Storage Parameters used in Tinda Creek Groundwater Model

	Conductivity (cm/s)	Specific Storage (m^3/m^3)	Specific Yield (%)	Porosity (%)
Layer 1 – Clayey sand	5×10^{-6}	1×10^{-5}	8	48
Layer 1 – sand	1×10^{-2}	1×10^{-5}	28	39
Layer 2 – sand (lower catchment)	1×10^{-2}	1×10^{-5}	28	39
Layer 2 – sand (upper catchment)*	1.5×10^{-3}	1×10^{-5}	28	39
Layer 3 – Bedrock	No flow	No flow	No flow	No flow

As shown in **Table 4.3,** a closer calibration was achieved through the addition of a slightly lower hydraulic conductivity in Layer 2 of the model upstream of the existing quarry (refer to **Appendix A** for full details of the hydraulic conductivity zones used in the model). Calibration results using the parameters described in **Table 4.3** are shown in **Graph 4.1**.



Graph 4.1 – Calibration Results

Calibration results indicated low groundwater elevation in the ridgeline areas of the model. Across the ridgelines, Layer 1 was dry, with the water table occurring at depth, in Layer 2 of the model. Modelling also predicted dry cells in Layer 2 for some parts of the ridgeline areas.

The extent of dry cells in the model is shown in **Appendix A**. No observation data is available for the areas where dry cells are predicted to occur and consequently, the validity of this result cannot be tested at this time. Further geological investigation of groundwater in the ridgeline areas would be required to refine this result.

4.3 Modelled Scenarios and Predicted Impacts

A series of groundwater models have been developed using Visual MODFLOW to explore the comparative impacts that quarrying could have on groundwater levels and groundwater contributions to flows in the Tinda Creek system. Visual MODFLOW models that have been developed for Tinda Creek model the following landform configurations:

- Tinda Creek catchment with current (2013) quarrying operations;
- Tinda Creek catchment with existing dredge pond and the northern dredge pond (Domain 3) backfilled with silt, clay and ENM/VENM; and
- Tinda Creek catchment with existing dredge pond, the central dredge pond (Domain 6) and the northern dredge pond (Domain 3) backfilled with silt, clay and ENM/VENM.

If the alternate biodiversity offset area is adopted, extraction will occur within Domain 7 rather than Domain 3. This has the potential to cause changes in groundwater levels upslope of Domain 7 however these are expected to be consistent with those modelled for areas adjacent to Domain 3 with quarrying in both areas being confined to lower permeability clayey sand layer, both being approximately 12 hectares in area and both potentially yielding approximately 2 Mt of resource.

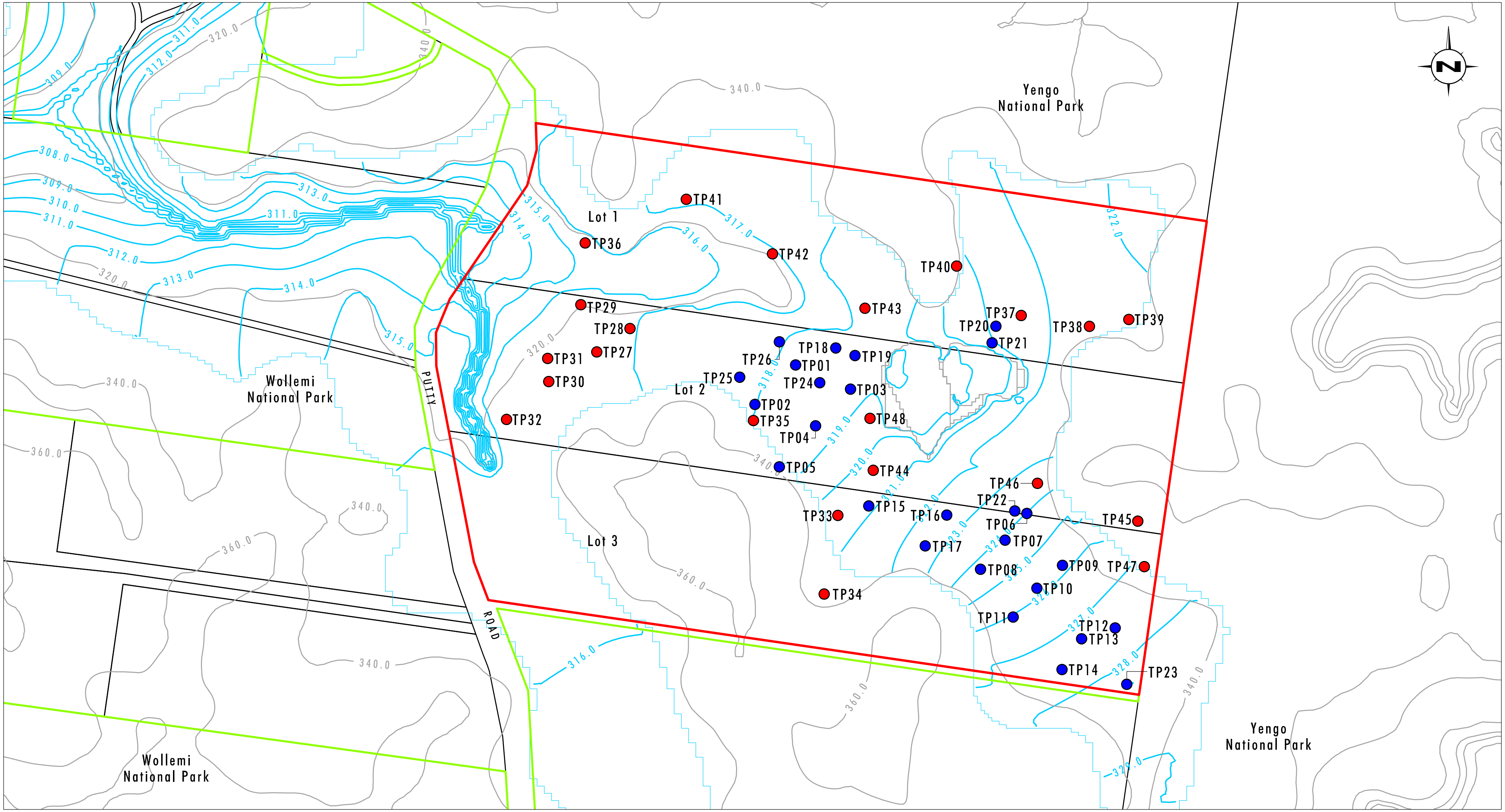
Modelled groundwater head equipotentials for steady state average rainfall conditions for existing quarry operations (2013) are shown on **Figure 4.2**. As can be seen from **Figure 4.2** modelled groundwater levels range from:

- approximately 313 mAHD near the north-western extent of the site where Tinda Creek flows under Putty Road;
- to approximately 316 mAHD at the southern boundary of the site adjacent Putty Road;
- to approximately 328 mAHD at the south-eastern corner of the site adjacent to Yengo National Park; and
- to approximately 322 mAHD at the north-eastern corner of the site adjacent to Yengo National Park.

Ground level at each of these locations ranges from approximately 3 metres to 12 metres above predicted groundwater levels.

Modelled groundwater head equipotentials for steady state average rainfall conditions for the proposed dredging operation with existing quarry and northern dredge pond (Domain 3) backfilled to approximately 3 metres below existing ground level are shown on **Figure 4.3**. As can be seen from **Figure 4.3** modelled groundwater levels range from:

- approximately 312 mAHD near the north-western extent of the site where Tinda Creek flows under Putty Road;
- to approximately 316 mAHD at the southern boundary of the site adjacent Putty Road;



Source: Google Earth (2012), LPI NSW (2007)

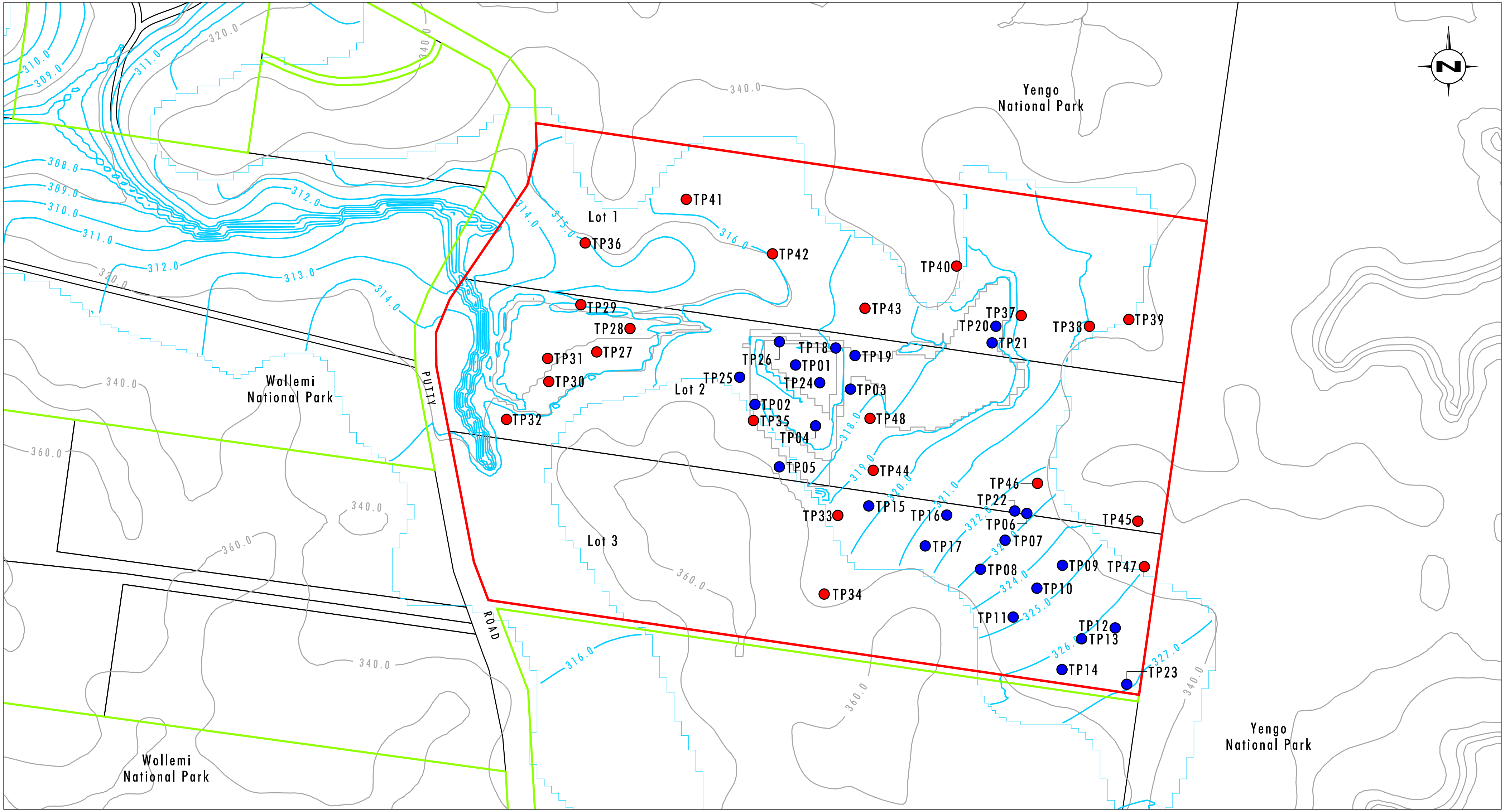
0 250 500 750m
1:15 000

Legend

- Project Area
- National Park Boundary
- 2010 Groundwater Bores
- 2012 Groundwater Bores

FIGURE 4.2

Modelled Groundwater Head Equipotentials (mAHD) - Existing Quarry



Source: Google Earth (2012), LPI NSW (2007)

0 250 500 750m
1:15 000

Legend

- Project Area
- National Park Boundary
- 2010 Groundwater Bores
- 2012 Groundwater Bores

FIGURE 4.3

Modelled Groundwater Head Equipotentials (mAHD) - Final Landform with infilled Existing and Northern Pits

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- to approximately 327 mAHD at the south-eastern corner of the site adjacent to Yengo National Park; and
- to approximately 321 mAHD at the north-eastern corner of the site adjacent to Yengo National Park.

As shown on **Figure 4.3**, predicted groundwater levels under this scenario have dropped by approximately 0 metre and 1 metre when compared to predictions for the existing quarry operation.

Modelled groundwater head equipotentials for steady state average rainfall conditions for the proposed dredging operation with existing quarry, northern dredge pond and central dredge pond (Domain 6) backfilled to approximately 3 metres below existing ground level are shown on **Figure 4.4**. As can be seen from **Figure 4.4** modelled groundwater levels range from:

- approximately 313 mAHD near the north-western extent of the site where Tinda Creek flows under Putty Road;
- to approximately 316 mAHD at the southern boundary of the site adjacent Putty Road;
- to approximately 327 mAHD at the south-eastern corner of the site adjacent to Yengo National Park; and
- to approximately 322 mAHD at the north-eastern corner of the site adjacent to Yengo National Park.

As shown on **Figure 4.4**, predicted groundwater levels under this scenario have dropped by approximately 0 metre and 1 metre when compared to predictions for the existing quarry operation.

Modelling of the proposed dredging operation and final landform as discussed above indicates that groundwater levels in the surrounding National Park estate will not be significantly affected by proposed dredging operation with only small changes predicted in groundwater level.

The calibrated MODFLOW model was used to explore potential changes in base flow to Tinda Creek catchment as a result of the various modelled quarrying scenarios. The results of this analysis are summarised in **Table 4.3**.

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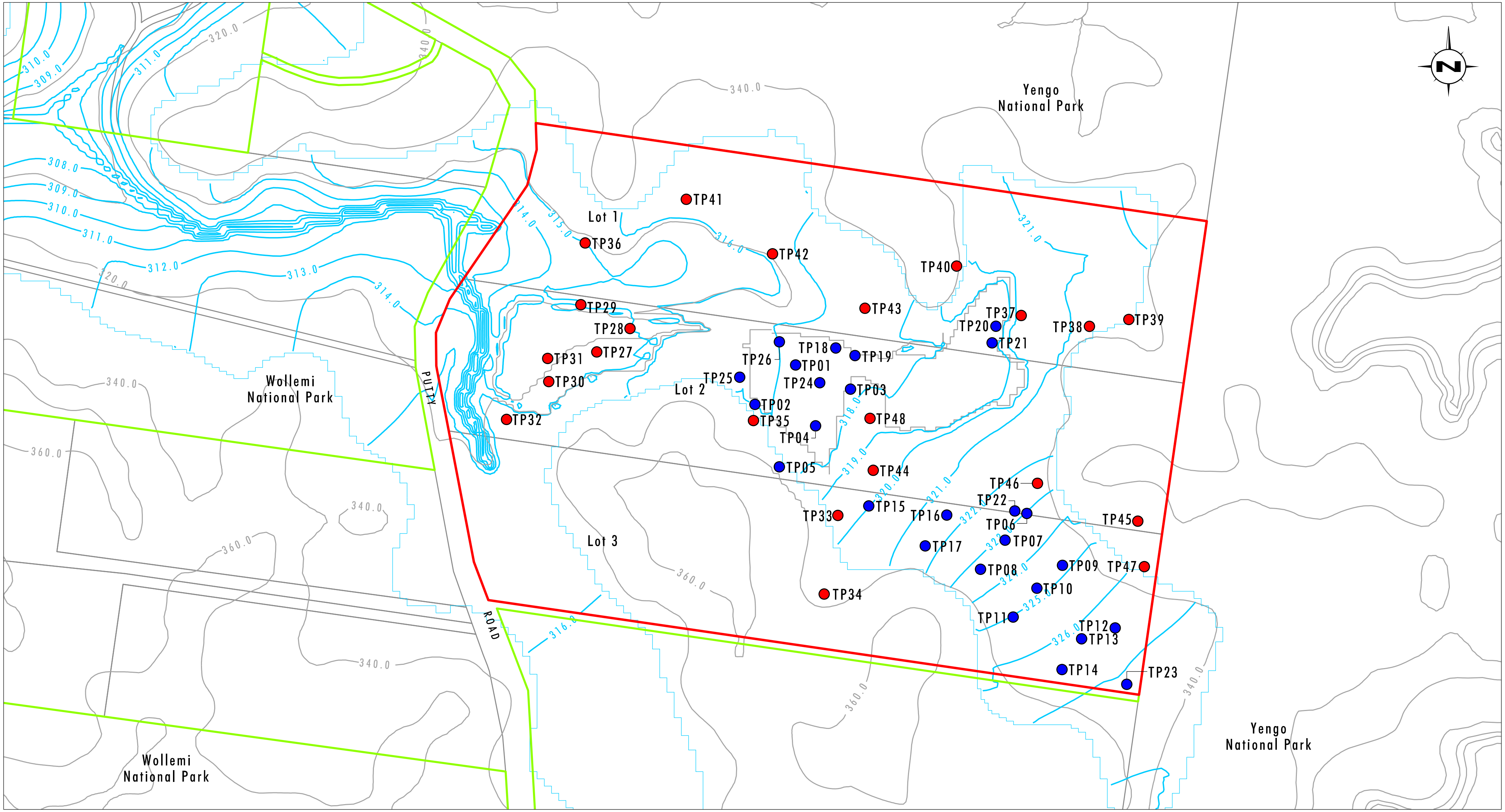

Source: Google Earth (2012), LPI NSW (2007)

0 250 500 750m
1:15 000

Legend

- Project Area
- National Park Boundary
- 2010 Groundwater Bores
- 2012 Groundwater Bores

FIGURE 4.4

Modelled Groundwater Head Equipotentials (mAHD) - Final Landform with infilled Existing, Northern and Central Pits

File Name (A4): R25_V1/1731_417.dgn

Table 4.3 – Predicted Base flow Contributions to Tinda Creek System

	Wet Rainfall Scenario			Average Rainfall Scenario			Dry Rainfall Scenario		
	Upper Catchment Outflow (m^3/day)	**Total Catchment Outflow (m^3/day)**	**Total Catchment Outflow (ML/year)**	**Upper Catchment Outflow (m^3/day)**	**Total Catchment Outflow (m^3/day)**	**Total Catchment Outflow (ML/year)**	**Upper Catchment Outflow (m^3/day)**	**Total Catchment Outflow (m^3/day)**	**Total Catchment Outflow (ML/year)**
Existing Quarry Scenario									
Recharge	-1640.6	-3315.7	-1210.2	-1112.7	-2235.1	-815.8	-597.32	-1208.31	-441.0
Evapotranspiration	733.28	2849.38	1040.0	386.38	1947.88	711.0	152.02	1140.67	416.3
Tinda Creek (inflow)	0	-5.426	-2.0	0	-38.859	-14.2	0	-93.049	-34.0
Tinda Creek (outflow)	90.8	472.31	172.4	70.289	325.889	118.9	35.916	160.816	58.7
Final Landform Infill Existing and North Pits									
Recharge	-1859	-3522.7	-1285.8	-1271	-2382.8	-869.7	-688.51	-1290.5	-471.0
Evapotranspiration	1073.3	3088.5	1127.3	662.83	2130.03	777.5	365.81	1266.42	462.2
Tinda Creek (inflow)	0	-8.1607	-3.0	0	-43.82	-16.0	0	-101.23	-36.9
Tinda Creek (outflow)	83.432	442.392	161.5	61.44	297.3	108.5	24.53	124.92	45.6
Final Landform Infill Existing, North and Central Pits									
Recharge	-1667.2	-3325.6	-1213.8	-1122.1	-2231.8	-814.6	-606.69	-1209.91	-441.6
Evapotranspiration	886.23	2892.63	1055.8	493.94	1974.34	720.6	259.34	1178.42	430.1
Tinda Creek (inflow)	0	-8.699	-3.2	0	-43.308	-15.8	0	-99.384	-36.3
Tinda Creek (outflow)	83.217	440.347	160.7	62.909	301.669	110.1	26.92	132.64	48.4

As show in **Table 4.3**, during average rainfall conditions total catchment outflow at the western edge of the groundwater model which is approximately 2 kilometres downstream from Putty Road is expected to reduce from approximately 118.9 ML/year to approximately 108 ML/year if only the existing and north pits (Domain 3) are backfilled and to 110.1 ML/year if the central pit (Domain 6) is also backfilled. Similar results are expected if Domain 7 is quarried rather than Domain 3. All of these predicted reductions in groundwater yield are less than the 55 ML/year that Hy-Tec is currently licensed to extract from groundwater resources on-site.

4.3.1 Groundwater Management Controls

Groundwater modelling indicates that the proposed quarry operation is unlikely to have a significant adverse impact on surrounding groundwater levels or the availability of groundwater to groundwater dependent ecosystem in the surrounding area.

It is proposed that groundwater level monitoring will continue to be undertaken on a monthly to quarterly basis with additional monitoring bores to be established towards the western boundary of the site and in the north-east corner over the site.

Groundwater level information will be regularly reviewed and reassessed against model predictions with the groundwater model being revised if monitoring results indicate this is required. This section outlines the groundwater modelling of the portion of Tinda Creek catchment shown in **Figure 4.1**.

5.0 Numerical Model and Concept Design Limitations

The model developed in this study, and the predictions made by the model, are subject to various assumptions and limitations as described throughout this report. A summary of the critical assumptions and limitations of the modelling is as follows:

- Modelling has been conducted using steady state simulation and can be considered a conservative assessment of the impacts of quarry expansion on the groundwater system. Transient quarry stage plans have not been modelled.
- The base layer of the model was assumed to be impermeable on the basis that the clay shale band detected at approximately 68 metres depth acts as an aquitard. This is likely to result in a conservative estimate of quarry impacts on groundwater in the catchment as it discounts the influence of regional groundwater movement in the Hawkesbury Sandstone.
- In Layer 2 of the model, a lower hydraulic conductivity was used upstream of the quarry to achieve calibration. The validity of this assumption could be investigated further as a part of any future geological investigations carried out at site.
- The river boundary used in the model was derived from available 1:25,000 topographic data and information derived from site visits. No water level information was available for use in the model.
- No data is available to test the validity of the predicted dry cells in the model. Any future geological investigations carried out at site could include an investigation of groundwater levels on the ridgelines to further refine the model.

6.0 Conclusions

Groundwater quality monitoring indicates that groundwater quality at the site is high with pH levels being slightly acid and consistent with pH levels to be expected in sedgeland/wetland environments. Conductivity levels are low indicating that quarrying activities are being undertaken in a low salinity environment. Water quality results indicate that quarry operations at the site over the last 30 years have not adversely impacted groundwater quality. No adverse impacts are expected from future operations which will be undertaken in similar hydrogeological conditions to quarry operations over the last 30 years.

Groundwater level monitoring indicates that drawdown as a result of dredging operations is limited in extent due to the low permeability of the sandy clay material being quarried. Modelling of proposed future quarry operations are not expected to adversely impact on groundwater levels in the surrounding area with potential impacts being reduced through proposed backfilling with ENM and VENM to achieve a final void of no greater than 16 hectares in area.

Groundwater modelling indicates that the proposed dredging operations will result in an approximately 8 to 10 ML/year reduction in groundwater contribution to base flows in Tinda Creek. In addition the quarry utilises approximately 8 to 10 ML/year of groundwater for dust suppression making the total annual water demand approximately 16 ML/year to 20 ML/year. Hy-Tec currently has water access licences for 55 ML/year of groundwater which is approximately three times its annual groundwater usage.

It is proposed to leave a final void in the western dredge pond (Domain 1) to assist with future fire-fighting and staging operations for the surrounding area.

7.0 References

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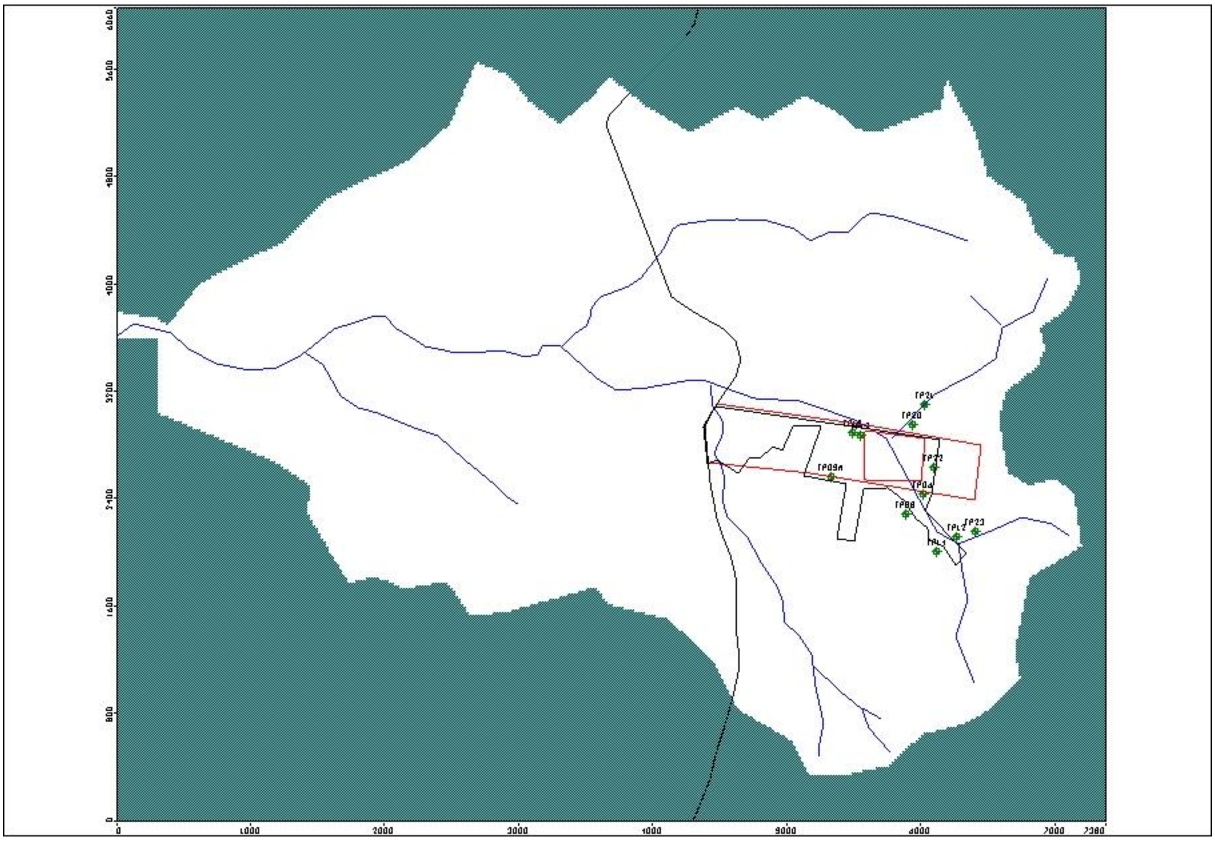
1:250,000 Sydney Basin Geology Map.

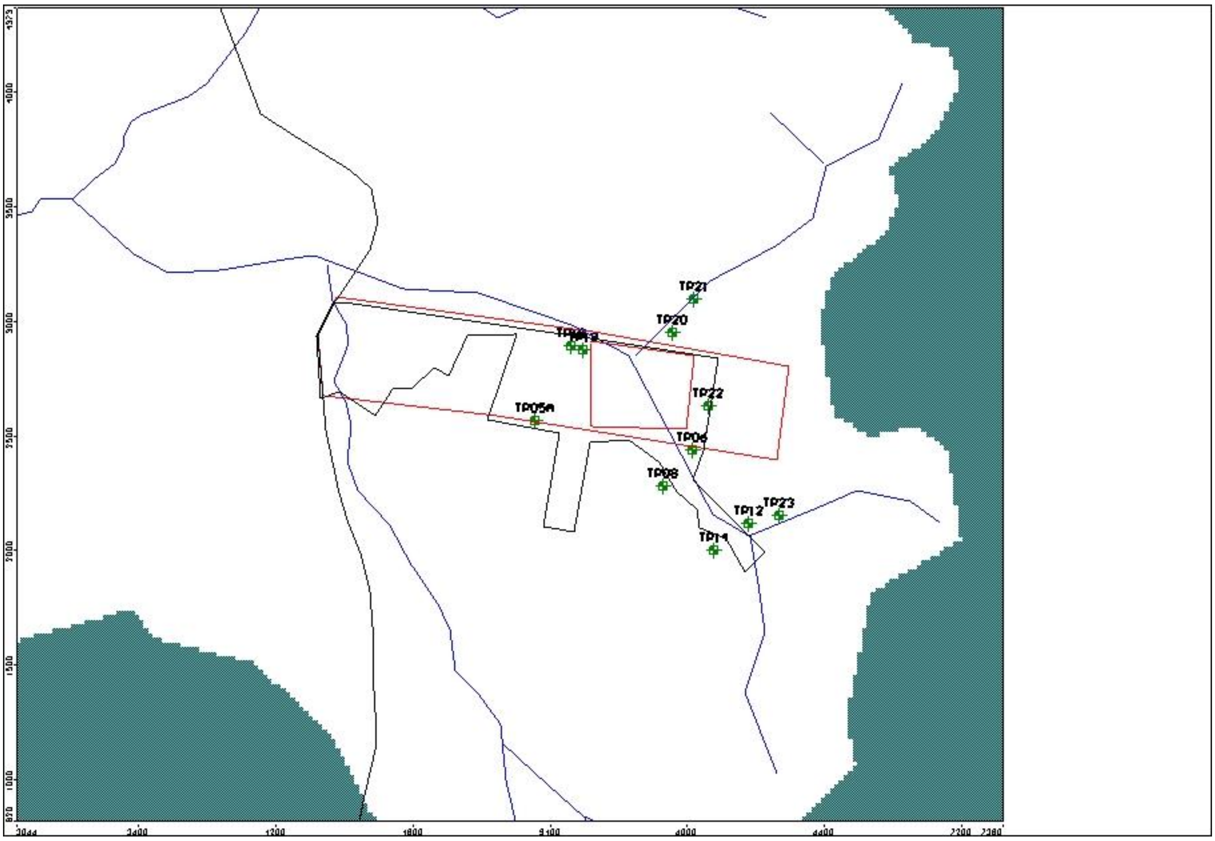
APPENDIX A

Model Layout Screenshots

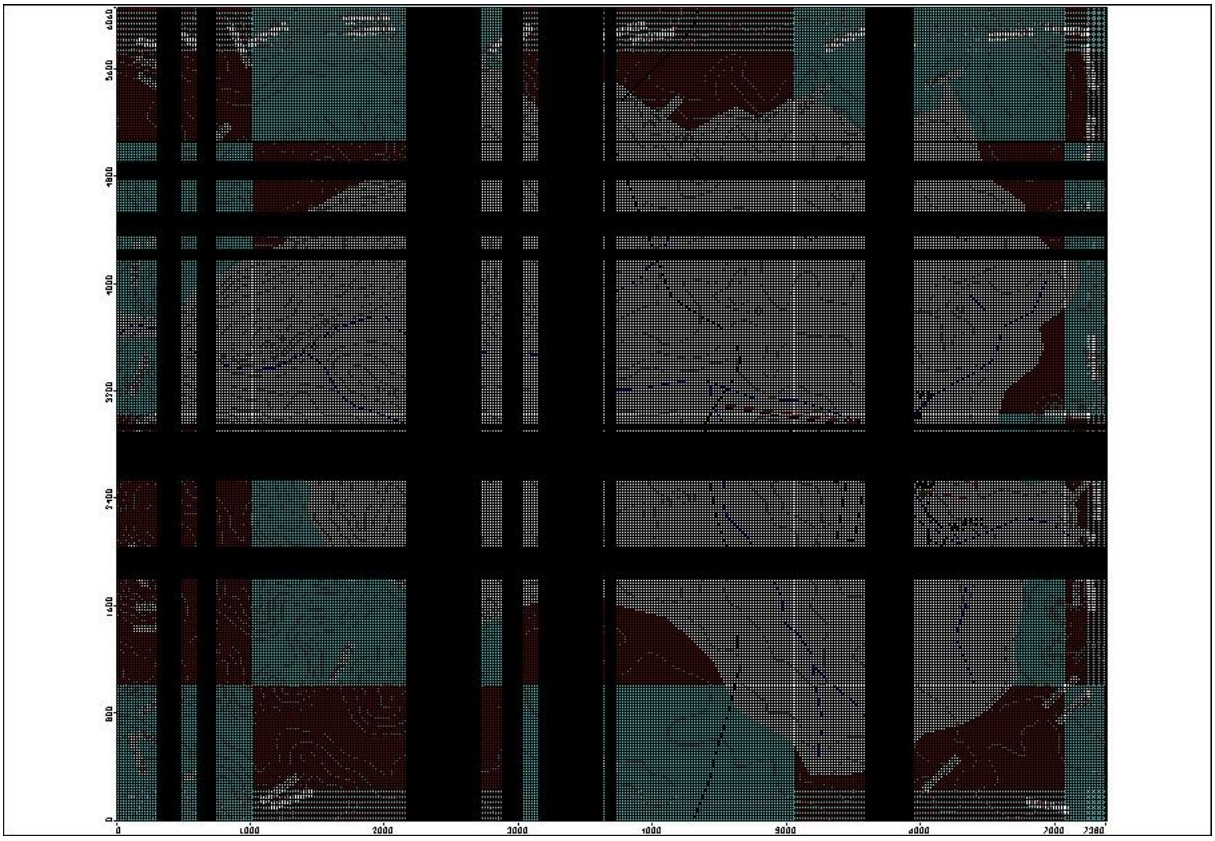
Appendix A – Model Layout Screenshots



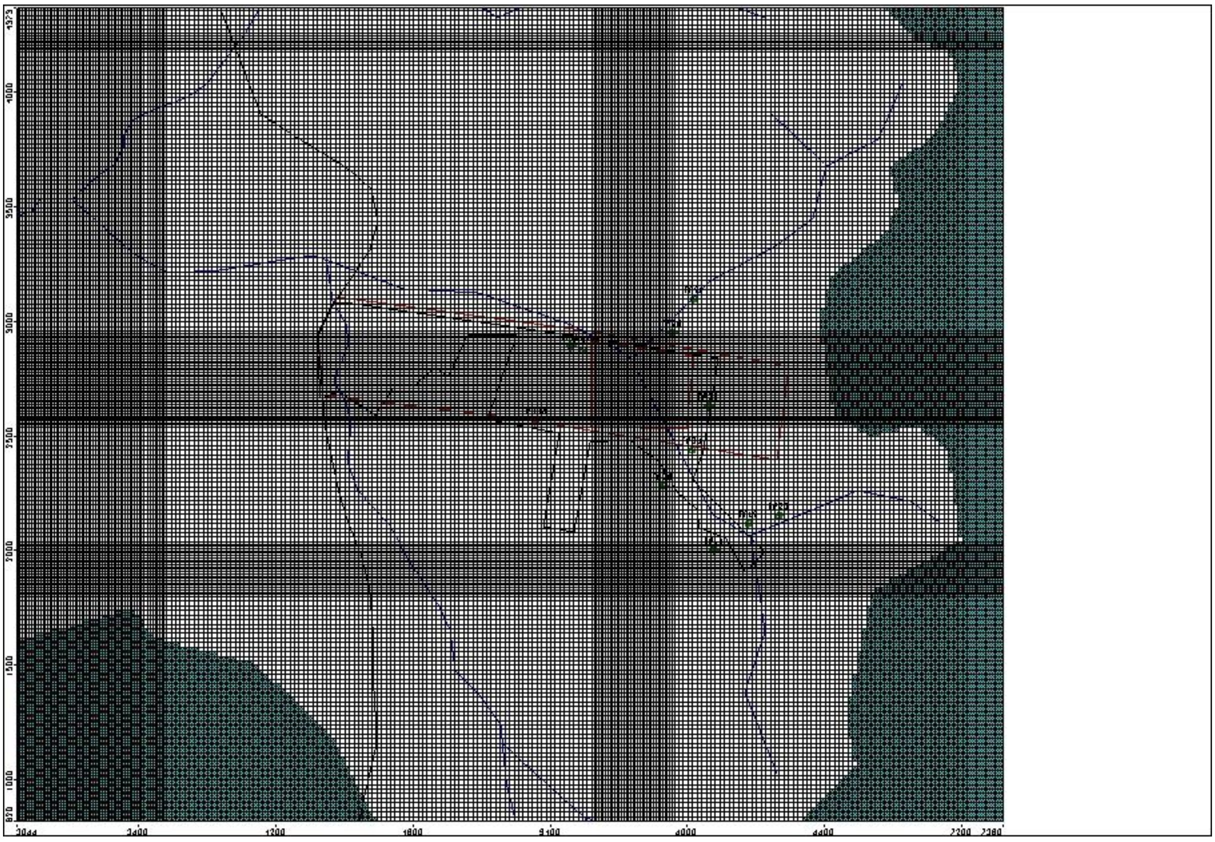
Screenshot 1 – Model Extent and Bore Locations



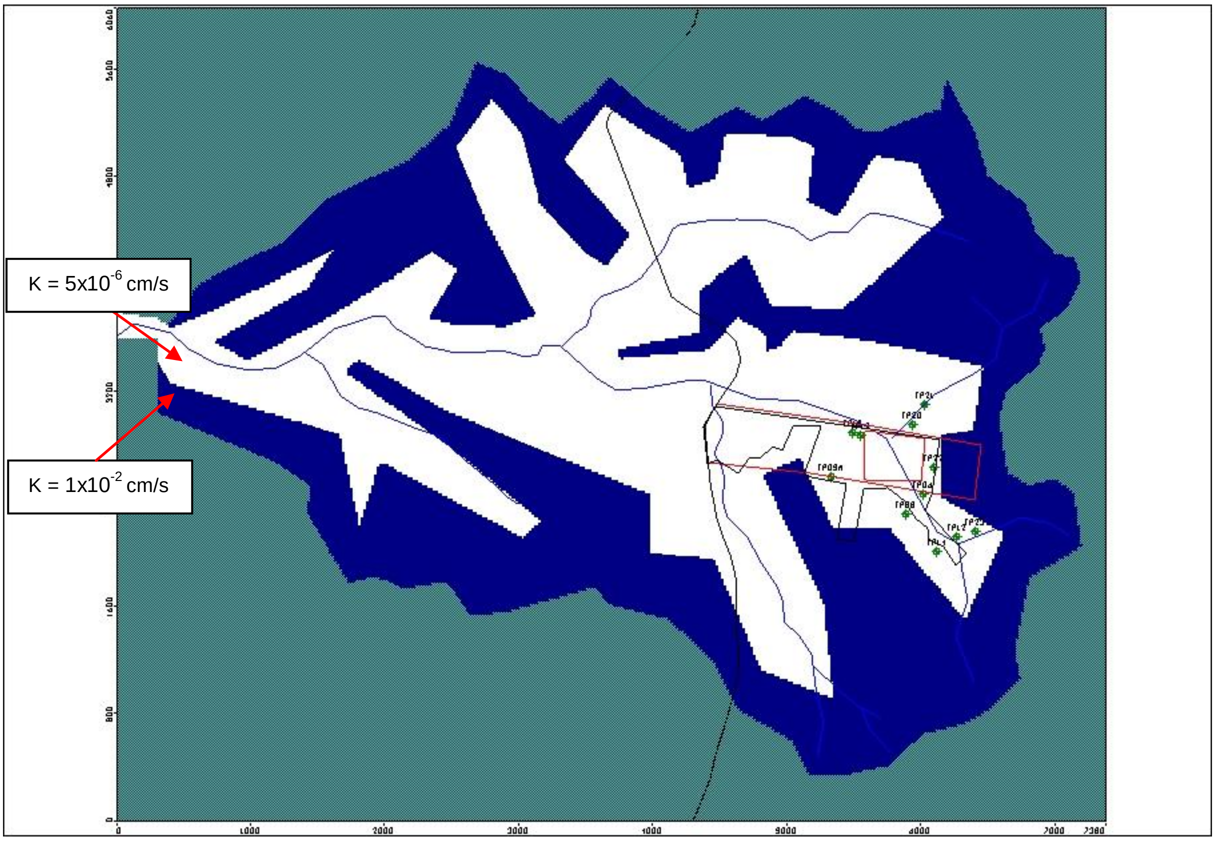
Screenshot 2 – Head Observation Points



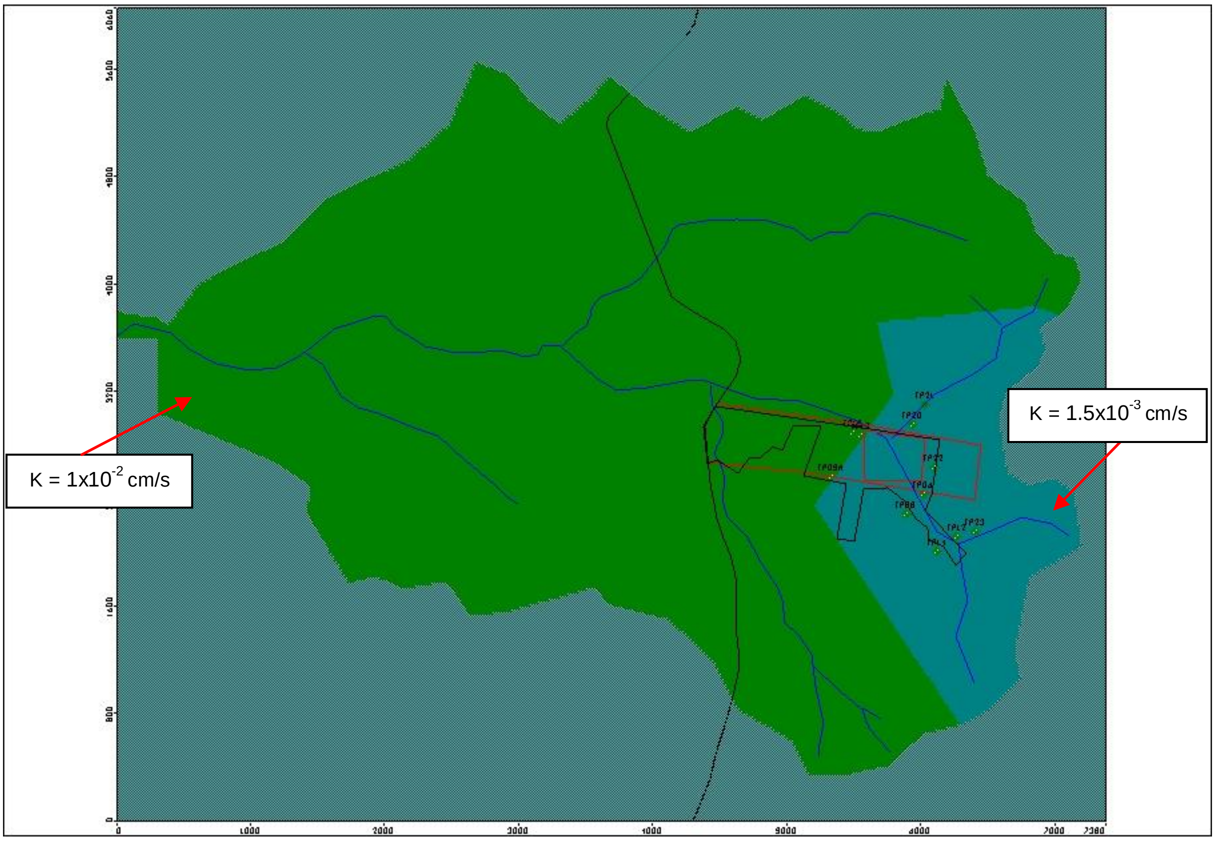
Screenshot 3 – Grid Cells: Model Extent



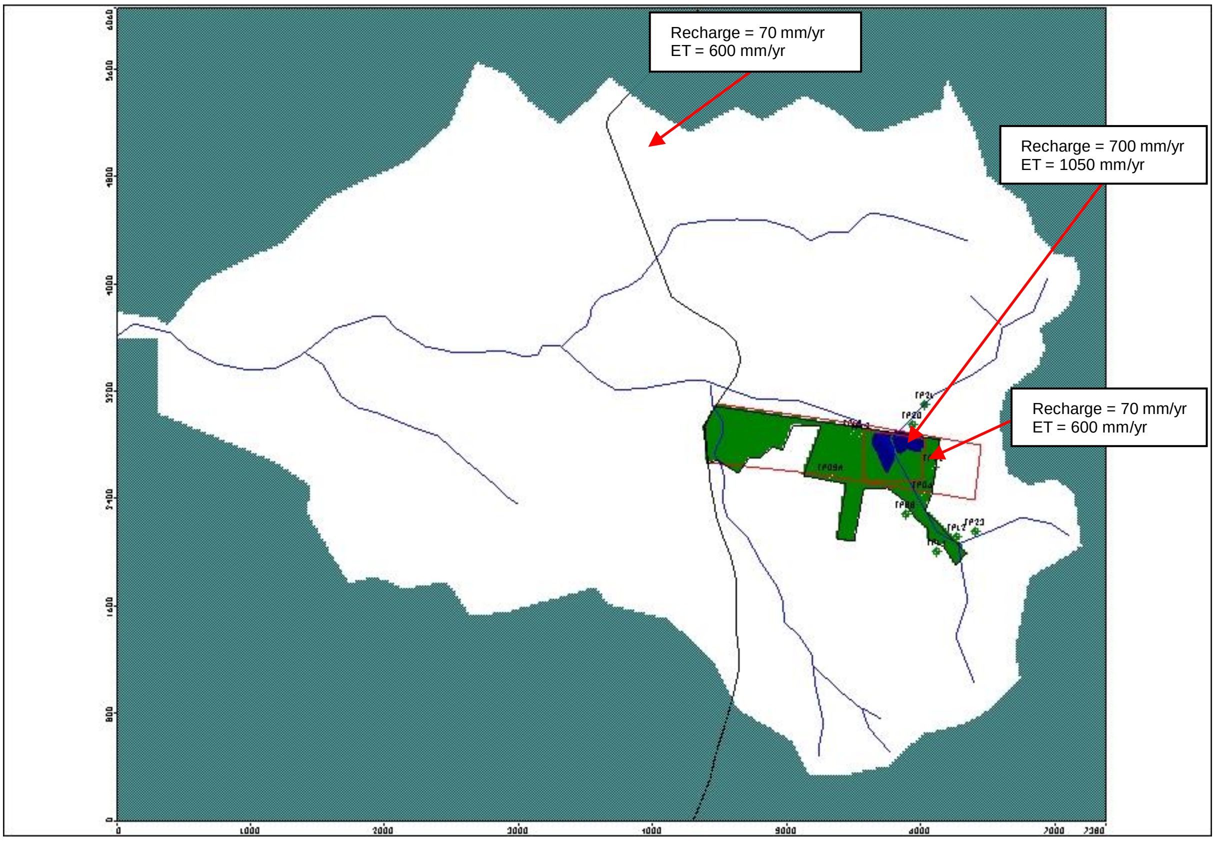
Screenshot 4: Grid Cells in the Quarry Area



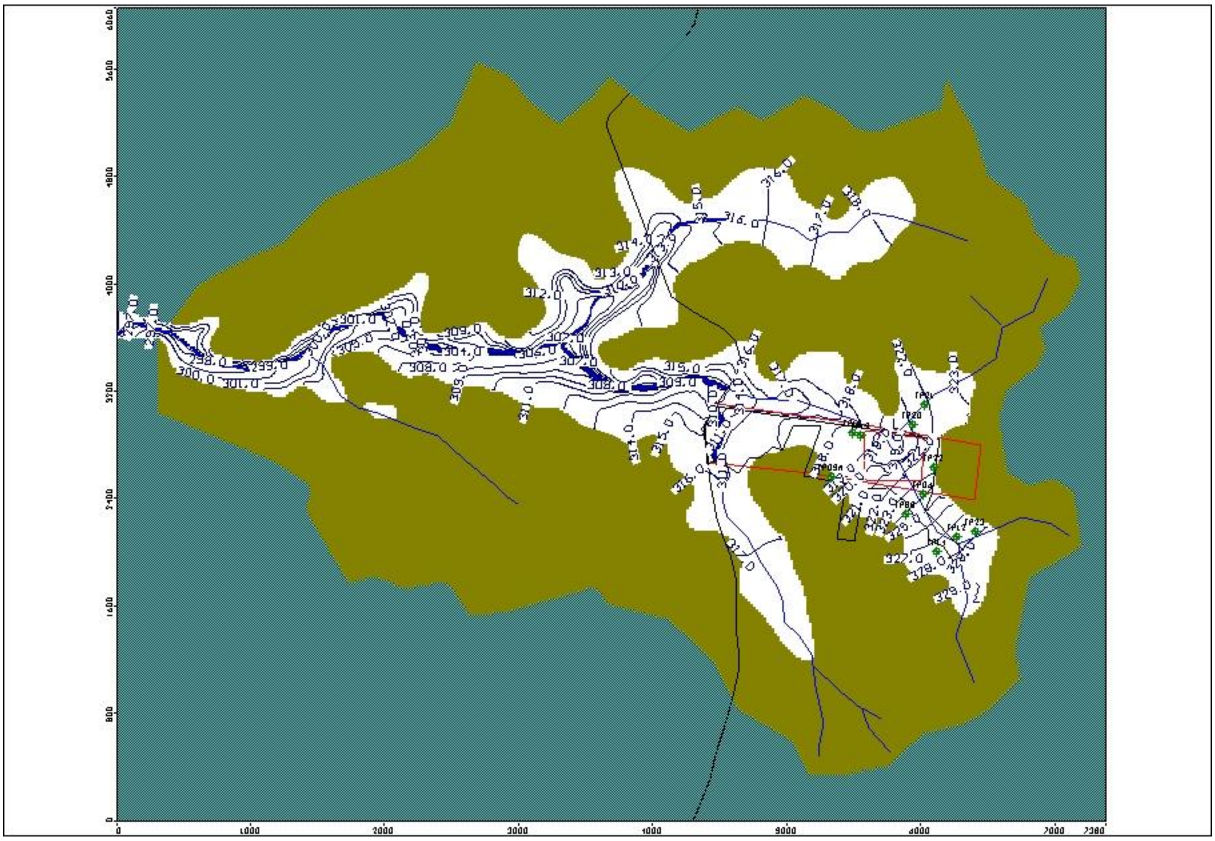
Screenshot 5 – Hydraulic Conductivity Zones: Layer 1



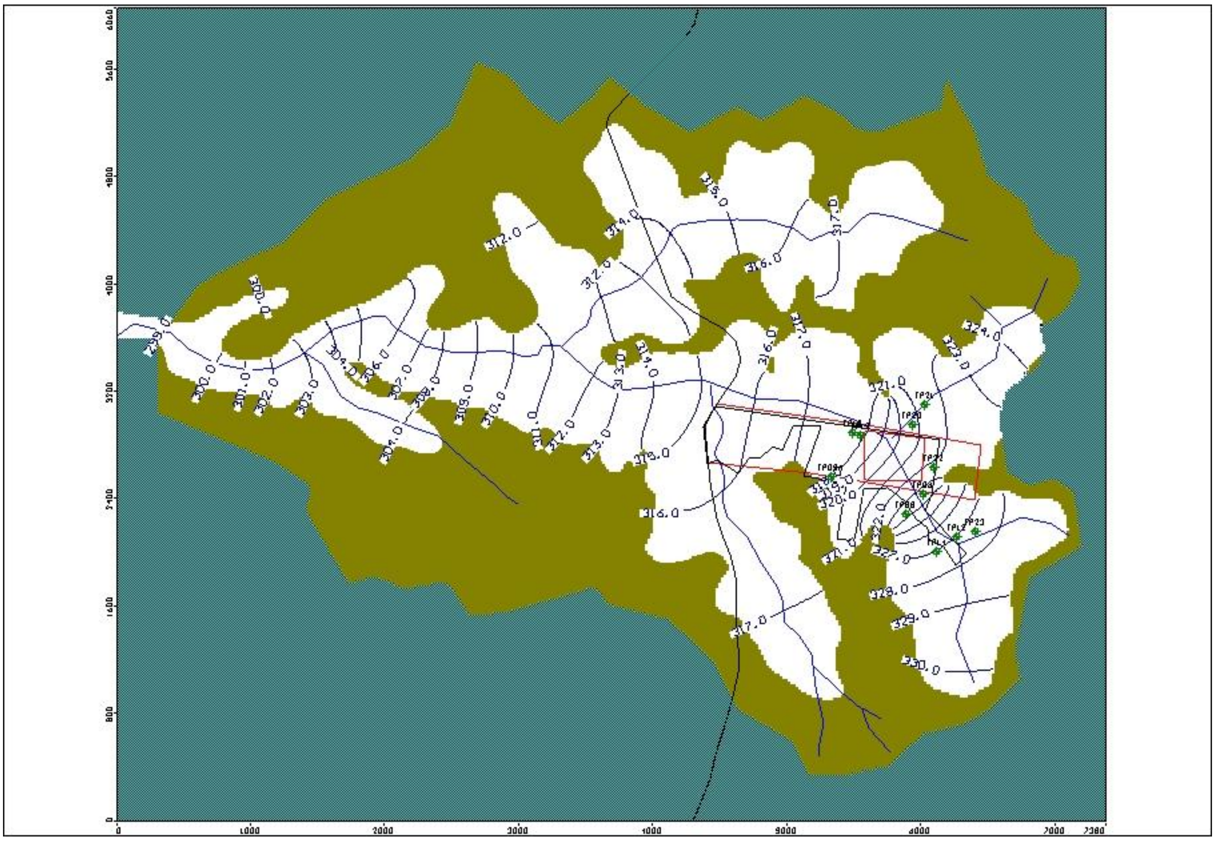
Screenshot 6 – Hydraulic Conductivity Zones: Layer 2



Screenshot 7 – Recharge and Evapotranspiration Zones: Layer 1



Screenshot 8 – Dry Cells: Layer 1



Screenshot 9 – Dry Cells: Layer 2

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