APPENDIX H11

SUMMARY OF PUMPING TRIALS AND DEWATERING ANALYSIS
2006

ANGAS PROCESSING FACILITY

MISCELLANEOUS PURPOSES LICENSE APPLICATION
2019/0826

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Mr Geoff Hodgson
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Dear Geoff,

Re: Angas Development– Summary of Pumping Trials and Dewatering Analysis

1.0 Introduction

AWE Projects Pty Ltd (AWEP) was commissioned by Terramin Australia Limited (Terramin) to conduct pumping trials in selected drillholes and investigation wells as part of the assessment of mine dewatering rates and pump out volumes for the Angas deposit near Strathalbyn. This document summarises the activities carried out and presents the results obtained. It follows on from correspondence sent to Terramin on 28 April 2006, in which tests carried out on drillholes AN 95 and AN 96 were documented, and includes descriptions and results obtained from these previously documented tests.

The Angas Deposit occurs about 2 km east of Strathalbyn in fractured Cambrian age rocks of the Kanmantoo Trough. It is understood that the zone to be mined occurs roughly beneath Callington Road and the DC Alexandrina wastewater treatment lagoons. This area includes the Cambrian age basement rocks hosting the lead zinc mineralization, plus shallower units (sands, silts, gravel, clay, calcrete) of Tertiary and Quaternary age. Investigations to date have indicated that the younger units occur most extensively to the south of Callington Road, forming low hills and tablelands. The majority of holes drilled by AWEP in the vicinity of the orebody indicate that the Tertiary and Quaternary sediments are generally unsaturated. On this basis, the dewatering of younger sediments is unlikely to be required and has not been investigated to date. In contrast, the Cambrian age rocks that host the mineralization occur lower in the landscape and are generally saturated, and hence are the subject of these dewatering investigations. The results of Terramin and AWE drilling programs indicate that the Cambrian rocks at the Angas site are often highly weathered in the uppermost 20 - 40m of the profile. When drilling for mineral exploration, this highly weathered zone is usually cased off to prevent hole collapse. A zone of partially weathered rock also commonly several tens of metres in thickness often occurs below the highly weathered zone. This rock section was observed in drill core to be highly fractured, and has been referred to in this document as the fractured mantle, as it occurs above the competent basement rock.

2.0 Overview of Hole Workover and Drilling Program

This program of pumping trials was carried out in a number of stages. It was initially thought that tests could be carried out in existing Terramin drillholes, and a program of work over, clean out and casing installation was carried out at locations across the mining lease. Drillholes AN 96, AN 134 and AN 143 were worked over in this manner, which involved the setting up of a drilling rig over each hole (using Terramin supplied azimuth and dip angles as references) and running drilling rods to the precollar depth, which was usually to the base of the highly weathered zone and then as much as 20 m into the fractured mantle rock. The highly weathered zone was then cased off using 100mm PVC casing. This workover program was abandoned after the testing of these holes due to difficulties experienced when installing casing in old uncased and inclined drillholes, and also because it was possible that these holes could have been blocked at depth by natural caving and sloughing of the highly weathered zone materials or by the pushing of materials down the hole during work over, all of which could compromise the integrity of the tests.

Tests were also conducted in AWE installed wells, namely AWE 1 and well 116744, both of which were completed at shallow depths into the fresh rock (AWE 1 was installed as a monitoring well and 116744 was installed as part of the investigation of possible leakage from the DC Alexandrina wastewater treatment lagoons). It was subsequently concluded that the testing of these wells was considered to be of limited value as neither well penetrated into or past the ore zone.

This program is described in more detail below.

3.0 Testing of Existing Drillholes and AWE Installed Wells

Pumping trials were conducted in drillholes AN95 and AN96 on 12 April 2006. Additional trials were conducted in drillholes AN134, AWE1, and 116744 between 2 and 5 May 2006. Drillholes AN95, AN96, and AN134 were drilled for mineral investigation purposes using HQ rods across the pre collar interval and then NQ rods to total depth. Prior to testing, the pre collar interval was cased with 100mm PVC casing and grouted in place to preclude the inflow of water from the surface or shallow (Quaternary or Tertiary age) sediments. Drillhole AWE1 was installed and completed for monitoring purposes, while drillhole 116744 was installed as an investigation hole. Construction and completion details of these holes are outlined in Table 1.

Table 1 Summary of drillhole construction and completion data

Hole Name	Depth (m)	Angle (degrees)	Precollar Depth (m BGL)[1]	Casing Depth (m BGL)	SWL (m BTOC)[2]	Pump setting (m BTOC)
AN95	80	90	15.1	15.6	1.96	10
AN96	374	78	20.7	20.7	10.74	12
AN134	14.2	90	8.2	8.2	8.17	12
AWE1	27	90	16.5	16.5	1.02	12
116744	350	90	33	33	10.17	30

Notes: 1 BGL = Below Ground Level
2 BTOC = Below Top of Casing

Constant rate discharge tests were conducted in each of these holes using an electric submersible pump. Pumping rates were measured using an in line digital flow meter, whilst changes in water level were recorded manually with an electronic dip meter, and automatically with a data logger.

Slug tests were also conducted at drillholes AN95 and AN96. For these tests, water inside the drillhole was displaced by a vessel of known volume that was constructed from 50 mm diameter PVC and filled with sand. Changes in water level with time, both after vessel emplacement (i.e. slug-in) and removal (i.e. slug-out), were measured by a pressure transducer and recorded by data logger.

Data obtained from each test were analysed using the proprietary computer program *AquiferTest v4.0.* Values of hydraulic conductivity were obtained from analysis of slug test data, and values of hydraulic conductivity, storage coefficient and hydraulic resistance were obtained using data from the constant discharge rate tests.

During the constant discharge test conducted in AN96, 4.4 m drawdown occurred due to pumping at 0.01 L/s, which resulted in the water level quickly falling below the pump intake after about 27 minutes of pumping. Data collected during this test have not been analysed due to the limited duration of pumping. Nonetheless, the low pumping rate and rapid drawdown (plus the results of the slug test analyses) indicate that the permeability of the competent basement rocks at this location is very low.

AN95 was pumped at 0.08 L/s and 7.8 m of drawdown was recorded after 100 minutes, at which time a pseudo steady-state had been attained. The specific capacity at 100 minutes is calculated to be approximately 0.013 L/s per m drawdown. Using this specific capacity value, the pumping rate required to dewater the competent basement rocks to a (mine) depth of 250m at this location is estimated to be about 3.2 L/s.

AWE1 was pumped at a rate of 0.03 L/s for 120 minutes. The drawdown after 100 minutes was approximately 0.60 m, which results in the calculation of a specific capacity of 0.05 L/s per m. The pumping rate required to dewater a 250 m thick aquifer at this location is likely to be about 12 L/s and could be more as drawdown was still occurring when the test was halted.

The discharge test conducted at AWE installed investigation well 116744 produced a drawdown of 7.95 m at a pumping rate of 0.066 L/s for 82 minutes, resulting in a specific capacity of 0.008L/s per m drawdown. Using this value, for the dewatering of a 250m thick aquifer at this location, the pumping rate would be about 2 L/s.

AN134 was pumped at a rate of 0.083 L/s for 37 minutes, at which time a drawdown of 7.66 m was recorded. The test was abandoned at this stage as the water level was within 0.5 m of the pump intake. Analysis of the drawdown and recovery data using *AquiferTest v4.0* provided a poor curve match, so the data were not interpreted. The poor curve match is thought to have been due to the hole possibly having been blocked at depth and also due to the presence of high viscosity drilling mud affecting the efficiency of the pump and impeding flow from the formation.

Results of the pumping trials are presented in Table 2.

Table 2: Summary Test Results

Drillhole Name	Test Type	Analysis Method	Hydraulic Conductivity (m/day)	Storage Coefficient (S)	Specific Capacity	Possible Dewatering rate (L/s)*
AN95	Slug In	Bouwer Rice	0.0145	-	-	
		Hvorslev	0.0215	-	-	
	Slug Out	Bouwer Rice	0.012	-	-	
		Hvorslev	0.016	-	-	
	Discharge	Hantush	0.0014	0.21	0.013	3.25
AN96	Slug In	Bouwer Rice	0.0016	-	-	
		Hvorslev	0.0026	-	-	
	Slug Out	Bouwer Rice	0.0036	-	-	
		Hvorslev	0.0053	-	-	
	Discharge	not analysed	-	-	-	
AWE1	Discharge	Hantush	0.185	0.181	0.05	12
116744	Discharge	Hantush	0.006	0.0149	0.008	2

NB: * denotes derived from specific capacity calculation at individual locations
Storage coefficient calculated using drawdown data from production well only and assuming that the ‘r” of an imaginary well = the radius of the production well casing

The results obtained from this phase of testing varied considerably from hole to hole, and it was concluded that the results may therefore be of low reliability. The possibility of the uncased sections of holes having collapsed and hence leading to a reduced or lack of hydraulic connection to fracture sets at depth was of particular concern, as such a scenario would preclude the assessment of hydraulic properties and hence dewatering requirements within the zone of mining.

4.0 Drilling and Testing of AN146

Due to the variability of pumping responses and results obtained from the testing of AN95, AN96, AN134, AWE1 and 116744, it was agreed with Terramin that a new hole be drilled and tested.

Hole AN143 was located near Callington Road adjacent to the Garwood Quarry access road, and was drilled vertically to 48 m using air hammer methods. It was abandoned due to unstable hole conditions.

A replacement hole, AN146, was then drilled nearby. This hole was initially drilled to 25 m using blade/air methods, and 177 mm diameter PVC casing was installed across the highly weathered interval. It was then drilled to 65 m using hammer/air methods into the fractured mantle. Air lift yield in this interval was about 3 L/s, and was considered to be sufficiently significant to warrant testing prior to drilling to full depth. This section of the hole was completed with 100 mm diameter (HQ) steel casing, slotted between 56 and 65 m. The casing was not grouted in place, so groundwater from the full saturated thickness of the fractured mantle could be accessed by the pump.

Two tests were conducted on AN 146 in this depth range using a Grundfos SQ3-105 electric submersible pump set at approximately 40 m below ground level. Pumping rate was measured by an in-line digital flow meter whilst water levels were monitored manually with an electronic dip meter and also automatically using an In-Situ minitroll logger. The aim of tests 1 (preliminary trial) and 2 (main trial) was to measure the response to pumping from the fractured mantle.

The preliminary trial was conducted on 5 June 2006, and consisted of the pumping of AN 146 at 1.3 L/s for 30 minutes. In this test, a drawdown of 14.49 m was recorded, from which it was concluded that a discharge rate of 1.25 L/s could be sustained over two log-cycles of time (i.e. 1000 minutes). Water levels were allowed to recover overnight and the main trial commenced at 9:00 on 6 June 2006. For this test, water was pumped at 1.25 L/s for 1420 minutes, and resulted in a drawdown of 21.32m being recorded. Water pumped from the well was initially disposed to nearby mud pits and periodically carted off-site, and then discharged to the quarry pit during the latter stages of the test. The test was halted at approximately 8:40 am on 7 June 2006. A summary of AN146 pumping test information is presented in Table 3.

Drawdown data were analysed using the software package Aquifer Test Pro version 3.5. Estimates of aquifer parameters are presented in Table 4. The Moench method was used to analyse the data, and is considered to be an appropriate analysis method for groundwater flow in fractured rock aquifers. The Hantush method has been used for comparison, and could be valid if the response to pumping from the (fractured) rocks approximates the response from a homogeneous porous medium.

Table 3: Summary of constant discharge pumping tests conducted at AN146 (7m – 65m)

Test	Interval	Date	Total Depth (m)	Saturated Aquifer thickness (m)	SWL (mbgl)	Yield (L/s)	Duration (mins)
1	fractured mantle	05/06/06	65	58	7	1.25	30
2	fractured mantle	06/06/06	65	58	7	1.25	1420

Table 4: Summary of pumping test results for AN 146 (7m – 65m)

Test	Method of Analysis	Transmissivity (m^2/d)	Hydraulic conductivity	Storage Coefficient
1	Moench	-		-
	Hantush	-		-
2	Moench	1.1	0.019	0.107
	Hantush	3.3	0.057	0.045

NB: Storage coefficient calculated using drawdown data from production well only

This test indicated that the hydraulic conductivity of the fractured mantle is approximately 0.02 – 0.05 m/d. Pseudo steady-state conditions were achieved after pumping for approximately 1400 minutes at a rate of 1.25 L/s. At this pumping rate, the recorded drawdown was 21.8 m and the specific capacity of the shallow fractured rock aquifer is approximately 0.057 L/s per metre. Based on this value, a pumping rate of over 3 L/s would be required to dewater this interval.

5.0 Deepening and Testing of AN146

Following Tests 1 and 2, cement grout was pumped into the hole to seal the annulus and casing slots, and thus limit the potential for ingress of shallow groundwater. The cement plug inside the casing was then drilled out using a 75 mm diameter air-hammer and the hole deepened to 250 m. The hole was left uncased between 65m and 250 m in predominantly competent basement rock to enable the response to pumping across that interval to be assessed.

Test 3 commenced on 29 June 2006 at a pumping rate of 1.3 L/s. After 9 minutes of pumping, a drawdown of 30 m was recorded and the test was terminated as the water level in the bore fell below the intake of the pump. Due to the rapid drawdown and limited results obtained, data from this test were not anlaysed.

When the water level had fully recovered, Test 4 was carried out at a pumping rate of 0.3 L/s, with the aim of obtaining a drawdown response over several hundred minutes of pumping. The test commenced at 1:30 PM on 29 June 2006 and was terminated approximately 5 hours later before steady state conditions had been achieved. During this time the maximum measured drawdown was 18 m. Drawdown data were used to calculate transmissivity and storage coefficient using the software package Aquifer Test Pro version 3.5. Water levels in drillholes AN96 and AN136 were also monitored but no response to pumping was observed.

To assess the validity of the aquifer parameters obtained from data acquired during the fourth test, an additional test (Test 5) was conducted on 30 of June 2006 at a pumping rate of 0.5 L/s. After 90 minutes of pumping, drawdown had reached the pump intake and the test was terminated. During this test, water levels in nearby drillholes (AN96 and AN136) were also monitored but no change was observed.

Tables 5 and 6 present test pumping data and results for the testing of this deeper interval of AN 146.

Table 5: Summary of constant discharge pumping tests conducted at AN146 (65m – 250m)

Test	Interval	Date	Total Depth (m)	Open Interval (m)	SWL (mbgl)	Saturated thickness (m)	Yield (L/s)	Duration (mins)
3	competent basement	29/06/06	250	65-250	7	185	1.3	9
4	competent basement	29/06/06	250	65-250	7	185	0.3	260
5	competent basement	30/06/06	250	65-250	7	185	0.5	90

Table 6: Summary of pumping test results for AN 146 (65m – 250m)

Test	Method of Analysis	Transmissivity (m^2/d)	Hydraulic conductivity	Storage Coefficient
3	Moench	NA	NA	NA
	Hantush	NA	NA	NA
4	Moench	0.31	0.0017	0.058
	Hantush	0.33	0.0018	0.142
5	Moench	0.25	0.0014	0.048
	Hantush	0.33	0.0018	0.147

NB: NA denotes not analysed

These tests indicate that the specific capacity of the deeper fractured rock aquifer is about 0.018 L/s per metre. On this basis, it would require a pumping rate of about 3L/s to dewater the competent basement rocks to 250m (in addition to the dewatering of the fractured mantle as described above).

6.0 Summary and Conclusions

The testing program documented above indicates that groundwater occurs in competent basement rock at depths below about 60m. It also occurs in what appears to be a fractured mantle of partially weathered basement rocks that occur between the compenent rock at depth and the highly weathered interval nearer the surface. The sedimentary profile (Quaternary and Tertiary age sediments) was not tested because these sediments are generally unsaturated in the vicinity of the mining zone, although significant aquifers may occur to the east of the mining lease.

The analysis of test pumping data indicates that the shallow mantle rocks have an hydraulic conductivity of about 0.02 m/d whereas the hydraulic conductivity of the competent basement is about 0.002 m/d. Storage coefficient for both sets of rocks is about 0.05 to 0.1, whilst specific capacity for the shallow mantle interval was calculated to approximately 0.057 L/s per metre. Specific capacity for the competent basement is about 0.018 L/s/metre drawdown.

On the basis of the test data obtained, dewatering rates for the deeper competent basement rock and the shallower mantle are both likely to be about 3L/s. However, due to the lack of observed drawdown in the observation drillholes, the extent of dewatering and the shape of the cone of depression caused by pumping is not known. Additional long term testing of AN 146 is recommended to identify the extent of dewatering if suitable observation drillholes are available. If additional testing is not conducted, it may be a necessary operational precaution to install additional dewatering wells if the mining zone is areally extensive. The analysis of rock defect distribution and orientation may be a useful means of identifying fractures that could transmit significant volumes of water. The defining of fracture orientation or the construction of a 3 dimensional fracture model would enable dewatering sites to be identified and wells installed at target depths to intersect water in fractures and hence control pore pressures during the mining operation.

Additional drilling, testing and hydraulic modeling could also be useful in refining estimates of dewatering rates, particularly as fracture properties may vary significantly across the site.

Whilst we have considered the fractured mantle separately from the deeper competent basement rocks, it could be possible to dewater both sections of the profile using the same wells, although the cost benefit relationship between the two options has not been evaluated.

Yours sincerely,

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