APPENDIX D

HYDROLOGY

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HYDROLOGY – WATER BALANCE AND PUMPING REQUIREMENTS

D1. INTRODUCTION

Options for the development of land about the Hornsby Quarry include a lake in the old pit at several levels consistent with both amenity and geotechnical stability. These are about 28.5m, the current lake level, 70m corresponding with a pit bench level and 88m the low point spill level.

This report estimates water balance conditions at each of these levels and calculates filling times. The water balance defines the long term pumping rates required to maintain the prescribed mean levels. Actual pump capacities need to be in excess of these mean rates to ensure that during wet periods lake levels can be contained within prescribed limits. These pump capacities are also evaluated.

D2. ANALYSIS

Inputs into the lake are direct rainfall, runoff from the surrounding catchment and groundwater inflow when lake levels are below the local groundwater table.

Outputs are evaporation and ground water outflow and seepage.

The reliability of estimates of mean pumping rates filling times and pump capacity requirements are directly related to accuracy with which these inputs and outputs can be estimated.

None of the important hydrometeorological quantities have been measured at the quarry site. Rainfall and evaporation have been assessed from an analysis of local meteorological stations.

Groundwater inflow/outflow and local catchment runoff has been assessed using anecdotal data and general measures of catchment response.

Definitioning of each of these inputs and outputs and the physical characteristics of the storage is discussed.

D2.1. Rainfall

Rainfall data was obtained from the Bureau of Meteorology (BOM) for a total of 19 locations. Eighteen locations were found within 10 kilometres of the site. Daily data was also obtained from Observatory Hill, approximately 21km to the south east because the record is long, 46 years, and particularly complete.

Average annual rainfall, and the number of years of complete data for each of the rainfall locations are shown on Figure D1. The indicated average annual rainfall varied considerably with location. The rainfall monitoring station closest to the site is "Pennant

Hills", approximately 4 kilometres to the south, with an average annual rainfall of approximately 1067mm.

A continuous record of rainfall was not available for Pennant Hills or any of the 18 stations within 10km. Daily data from Observatory Hill , with an average annual rainfall of 1213mm was factored to produce a daily record with average annual rainfall matching Pennant Hills.

D2.2. Evaporation

Ten evaporation monitoring stations were found within a 50km radius of the site. The station locations, the average measured pan evaporation and number of years of complete data are shown on Figure D2.

Similarly to rainfall data, there is significant variation between monitoring stations. The closest monitoring location is at Marsfield, approximately 9km to the South West, however there are no complete years of data available. The record of evaporation at Prospect Dam, approximately 21km south west of the site, is the most complete and has been adopted as representative for the Hornsby site. This station is also the closest with more than only a year or two of evaporation data. Pan evaporation values must be reduced to account for the lower evaporation experienced in water bodies with a large surface area. The pan factor, 0.92, established for the Cataract Reservoir (May 1977) was applied to this data.

D2.3. Groundwater Inflow

In the absence of detailed measurements or pumping records, groundwater inflow to the pit has been estimated to be 0.3L per second at the current level, varying linearly with height to zero when the pit water level reaches RL 86m.

D2.4. Catchment Runoff

Catchment areas for the quarry have been measured from 2006 quarry contours, extended by the 1:25,000 Topographic Map where required.

Currently a drain diverts most potential runoff around the pit towards the south west.

Figure D3 shows the resulting catchment area of 134,400m^2. Runoff has been estimated by dividing this area into two parts:

- steep pit slope (some trees) with area 72,700m^2 assumed runoff coefficient of 0.9
- remainder of the catchment with area 46,850m^2 with a runoff coefficient of 0.10 estimated from global 'natural' catchment data.
- water directly falling on the pond with an area of 14,820m^2.

Calibration of the Model

Rainfall in the period September 2003 and September 2006 is estimated to be 2.37m. The total runoff has been calculated to be 201,296m^3.

Evaporation in this period is estimated to be 3.7m based on an average surface area of 16,000m^2 evaporation quantity is calculated to be 54,450m^3.

Pit water volume change is the runoff minus evaporation, plus ground water inflow. Assuming a groundwater inflow of 30m^3 per day, the estimated volume change is 180,000 m^3.

In chapter 8 of Parsons Brinckerhoff report "2116414A PR_8745 Volume 1 RevC', a pond level of 17.614m is reported for the date 28 September 2003. PSM has estimated a pond water level of about RL 28 metres in September 2006, based on an RL marker provided in the pit. This is calculated to be a change in pit water volume of 168,300m^3.

Therefore the runoff coefficient in the steep pit slopes has been adjusted to calibrate the model, giving a coefficient of 0.83 instead of the previously assumed 0.9.

The full catchment area, assuming that this drain is removed is also shown in figure D3, it has a catchment area of 1,012,000m^2.

D2.5. <u>Relationship between Lake Level, Volume and Area</u>

A 2006 contour plan with 2 metre contours was used to extract a list of surface area versus RL of the quarry. Quarry volume versus RL was calculated from the areas. These have been used in calculating depths versus volumes of water.

D2.6. <u>Long Term Lake Response</u>

A detailed model for the analysis of pit void salt and water dynamics has previously been developed by PSM Australia Pty Ltd. This analysis considered 4 separate physical situations based on the location of the regional groundwater table relative to the pit and water balance. These are depicted in Figure D4.

In the case of the Hornsby quarry salt accumulation is not expected to be significant and therefore evaporation will not be affected by salt content.

Under these conditions the governing differential equation is:

$$\frac{\partial H}{\partial t} = (E - P) - \left(\frac{a.H + R}{A_{ref} - d.H} \right) \tag{1}$$

With the solution

$$T_{ab} = \left[\frac{d.H}{d(E-P)+a} - \left(\frac{d\left(R - A_{ref}(E-P)\right)}{\left(d(E-P)+a\right)^2} + \frac{A_{ref}}{d(E-P)+a} \right) Ln\left(\left(d(E-P)+a\right)H + \left(R - A_{ref}(E-P)\right) \right) \right]_{H_a}^{H_b} \tag{2}$$

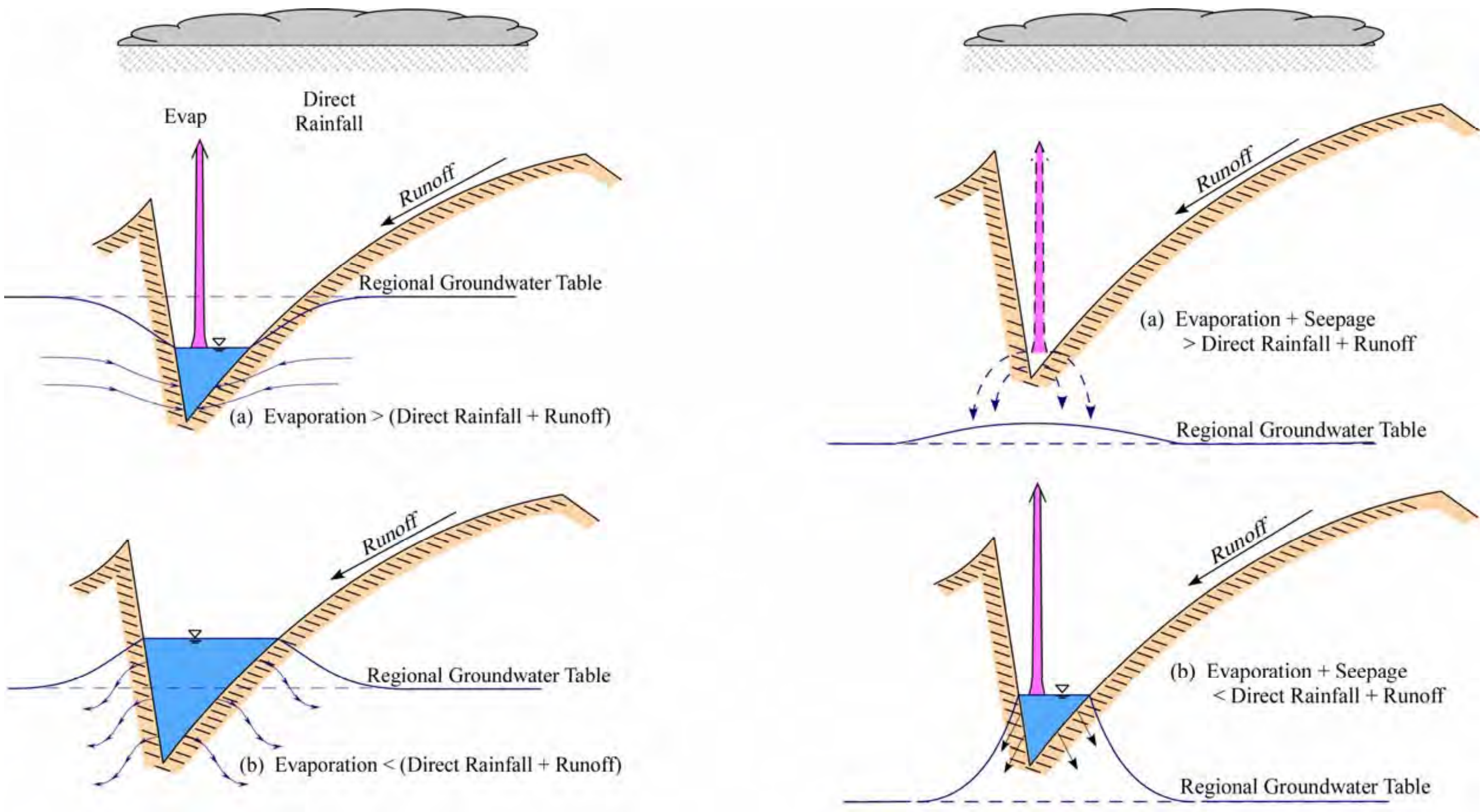

Figure D4: Water Balance and Regional Groundwater Conditions

Where:

- H is the distance from regional groundwater table level to lake level measured positive downward,
- E the evaporation rate,
- P the precipitation rate,
- R the runoff rate,
- A_{ref} the lake surface area at the regional groundwater table level, and
- a and d are coefficients defining variation in groundwater inflow and lake surface area with elevation.

The equilibrium lake level He is defined by

$$H_e = \frac{(E-P)A_{ref} - R}{(a+(E-P).d)} \qquad \textbf{(3)}$$

Lake response is dominated by catchment runoff and all results are presented in terms of best estimate and upper and lower bounds. Table 1 provides these runoff coefficients and the range in mean annual runoff.

TABLE 1
RUNOFF SENSITIVITY

RUN NUMBER	RUNOFF ESTIMATE	COEFFICIENT IN "STEEP SLOPES"	RUNOFF COEFFICIENT IN REMAINING CATCHMENT	SURROUNDING CATCHMENT RUNOFF(m^3/YEAR)
1	"Best estimate"	0.83	0.10	68 930
2	"Lower bound"	0.41	0.05	34 080
3	"Upper bound"	0.91	0.2	75 530

D2.7. <u>Lake response to short wet periods</u>

Equations (1), (2) and (3) define long term response. Over any short period, lake levels will fluctuate about the "smooth" long term curve.

If a prescribed or design level is to be maintained by pumping then the relationship between pump capacity (in excess of the mean rate) and surcharge storage, and level, is required to size the pump. The problem is frequently encountered in open cut mine development and has similarly been analysed in detail by PSM Australia Pty Ltd. The analysis recognises the fact for large lakes with small catchment the critical condition (maximum lake level at a prescribed design frequency) is usually generated by wet periods of days to months duration rather than an individual storm events.

At any prescribed frequency the total rainfall and runoff **volume** increases with increasing "event" duration but the average inflow **rate** declines. The design lake level is reached when inflow (direct rainfall and runoff) is just matched by outflow (evaporation and pumping).

Runoff as a fraction of rainfall is higher for design wet period conditions than it is for average or long term response conditions. In assessing pump/surcharge storage requirements the catchment wide instantaneous runoff coefficient, after satisfaction of initial loss, is assumed to increase from zero asymptoting to 1 as the catchment wets up. Modelling this relationship is represented by a $\tanh^2$ function scaled according to the rainfall at which the runoff coefficient reaches 0.9.

D3. RESULTS

Models, numerical and analytical, have been used to assess long term pumping rates at the 28.5 and 70m RL, and filling times with and without diversion to the pit of upstream catchment.

These are presented in the following tables with upper and lower bounds to runoff rates.

TABLE 2
LONG TERM MAINTENANCE PUMPING RATES RL 28.5

RUN NUMBER	RUNOFF ESTIMATE	LONG TERM PUMPING RATE WITH EXISTING DIVERSION
1	"Best estimate"	2.5L/sec
2	"Lower bound"	1.3L/sec
3	"Upper bound"	2.7L/sec

TABLE 3
LONG TERM MAINTENANCE PUMPING RATES AND FILL TIMES

RUN NUMBER	RUNOFF ESTIMATE	LONG TERM PUMPING RATE TO HOLD AT 70.0MRL	TIME TO RL70m WITH EXISTING DRAINAGE	TIME TO RL70m WITH ADDITIONAL CATCHMENT
1	"Best estimate"	2.1L / sec	23 years	11 years
2	"Lower bound"	0.82L/sec	51 years	13 years
3	"Upper bound"	2.1L / sec	22 years	10 years

TABLE 4
LONG TERM SPILL RATE AND FILL TIMES NATURAL OVERFLOW RL 88 M

RUN NUMBER	RUNOFF ESTIMATE	MEAN RATE OF SPILLING	TIME TO RL88M WITH EXISTING DRAINAGE	TIME TO RL70M WITH ADDITIONAL CATCHMENT
1	"Best estimate"	1.9L/s	43 years	19 years
2	"Lower bound"	0.66L/s	107 years	24 years
3	"Upper bound"	1.9L/s	41 years	18 years

D4. CONCLUSIONS

Three operating water levels for the Hornsby Quarry Lake have been considered the current level about RL 28.5m, RL 70m a bench level significant in terms of geotechnical stability and the natural overflow level RL 88m.

With the existing drainage it is estimated RL 70m will be reached in around 23 years and the natural overflow level RL 88m in about 43 years. If the bypass channel were diverted into the pit these levels would be reached in around 11 and 19 years respectively.

Once attained the RL 28.5m and RL 70m levels will need to be maintained by pumping estimated mean discharge rates (existing catchment only) are 2.5 to maintain RL 28.5 and 2.1 to maintain RL 70m.

For a nominal lake level of 28.5m with corresponding surface area of 18,000m^2 under ARI 100a conditions the lake level rise can be maintained at $\leq$2m with 25L/s pump capacity. For <4m rise at ARI 100a the pump capacity required reduces to 8L/s.

For a nominal lake level of RL 70 m with corresponding surface are of 60,000m^2 under ARI 100a conditions the lake level rise can be maintained at <1m with 10L/s pump capacity.

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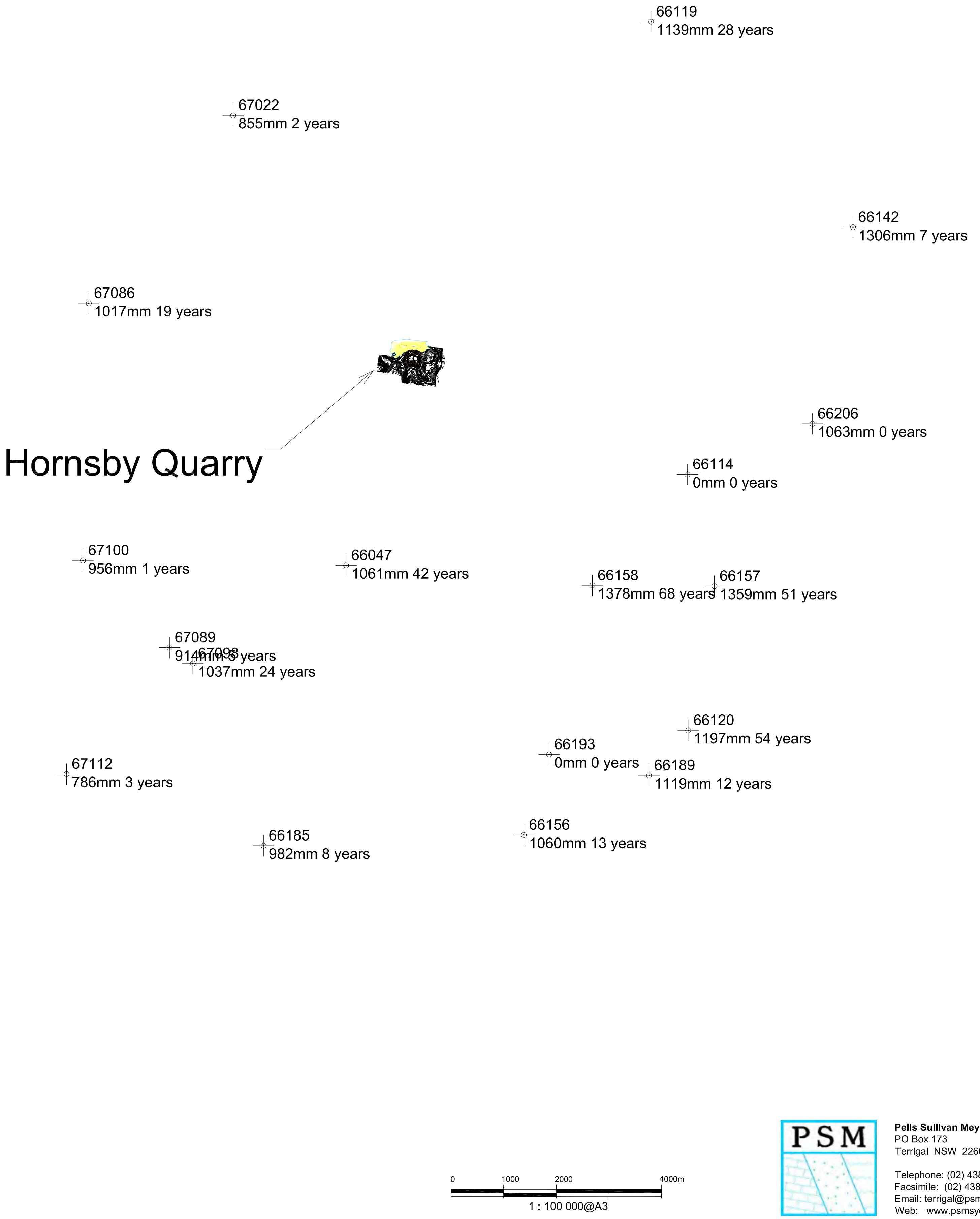

Pells Sullivan Meynink Pty Ltd
PO Box 173
Terrigal NSW 2260

Telephone: (02) 4384 7055
Facsimile: (02) 4384 7066
Email: terrigal@psmtoo.com.au
Web: www.psmsyd.com.au

Hornsby Shire Council
Former CSR Hornsby Quarry & Associated Lands

AVERAGE ANNUAL RAINFALL SUMMARY

PSM1059	Figure D1

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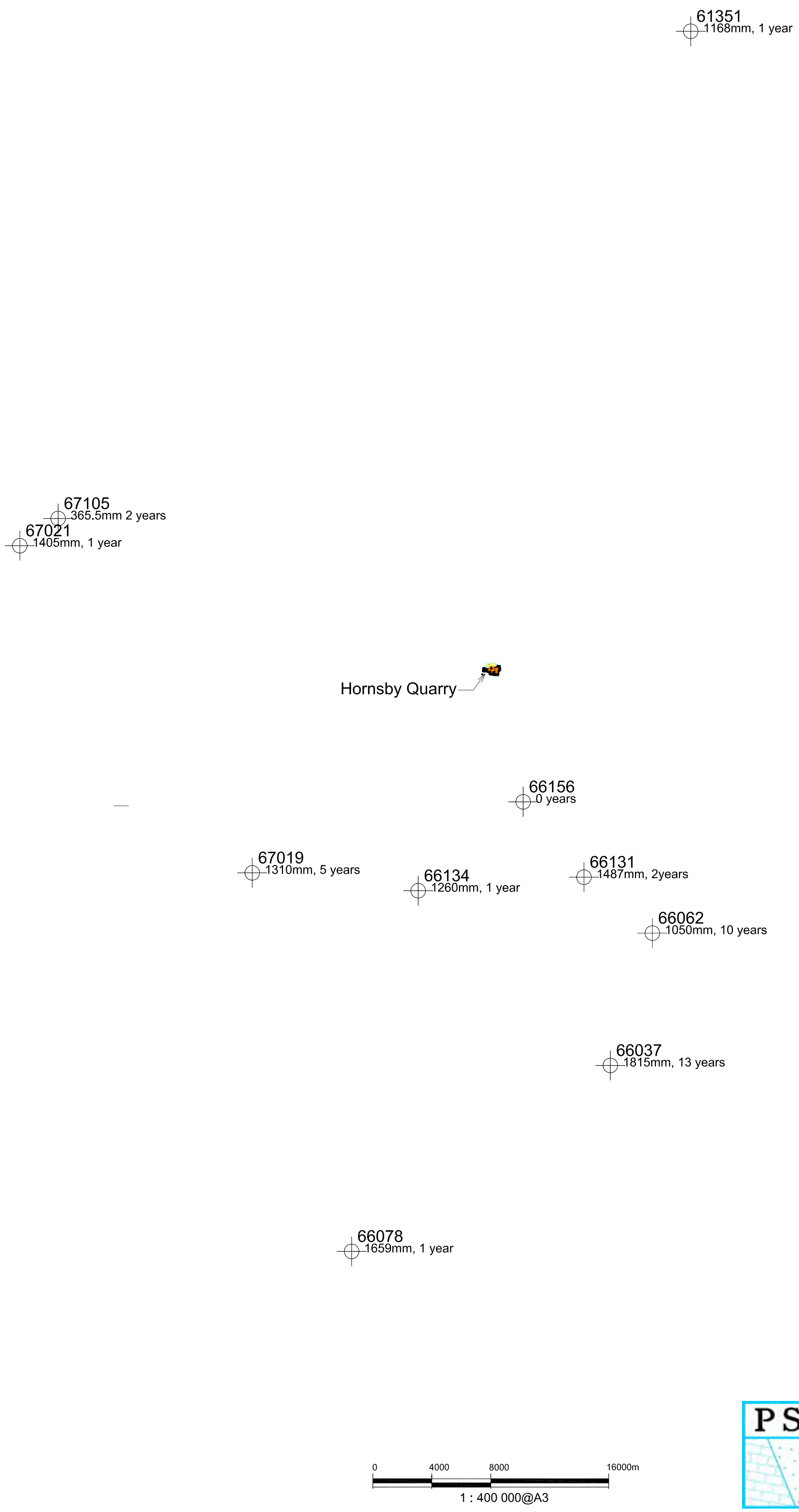

Pells Sullivan Meynink Pty Ltd
PO Box 173
Terrigal NSW 2260

Telephone: (02) 4384 7055
Facsimile: (02) 4384 7066
Email: terrigal@psmtoo.com.au
Web: www.psmsyd.com.au

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Summary of Evaporation Data

PSM1059	Figure D2

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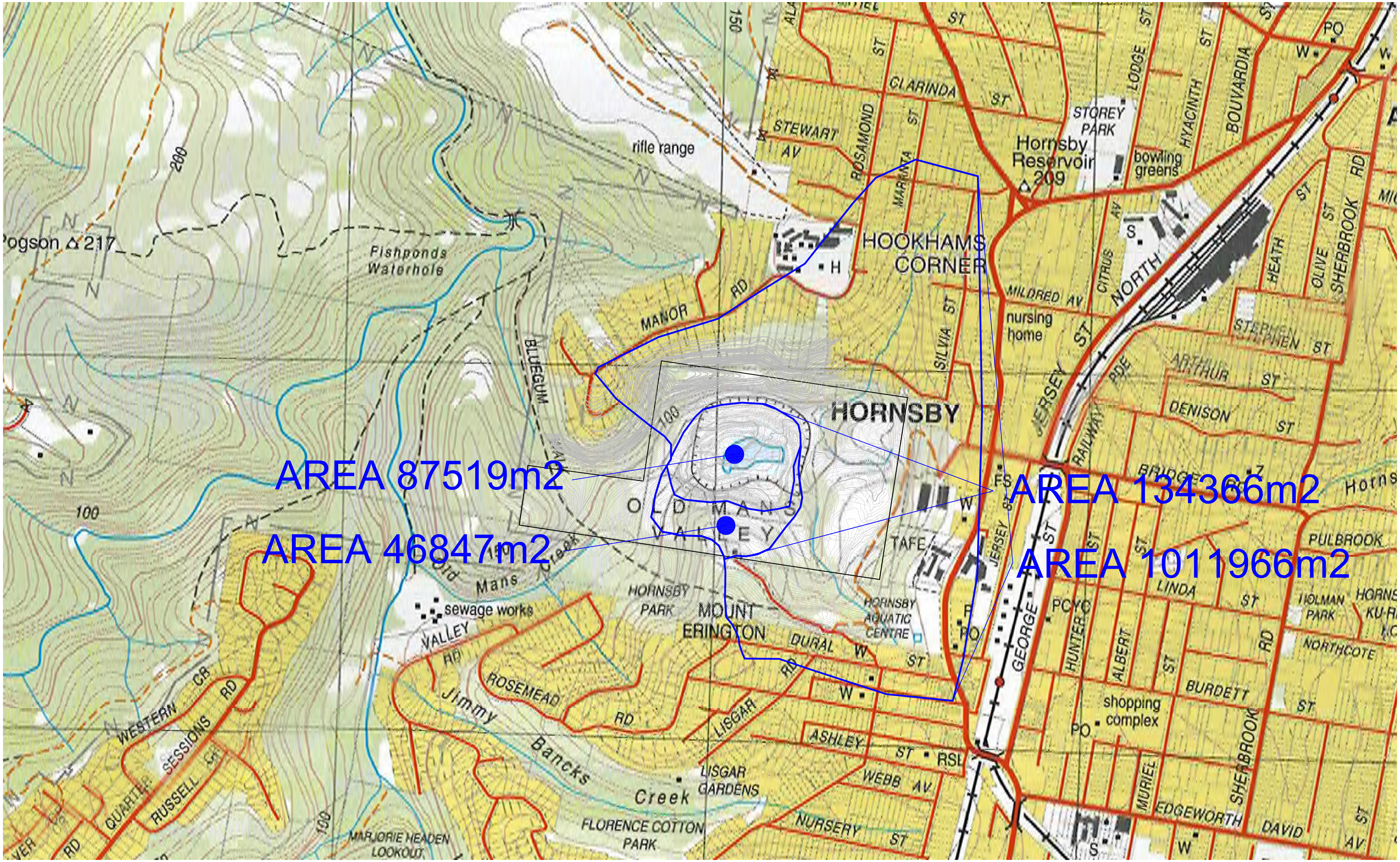

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Pells Sullivan Meynink Pty Ltd
PO Box 173
Terrigal NSW 2260

Telephone: (02) 4384 7055
Facsimile: (02) 4384 7066
Email: terrigal@psmtoo.com.au
Web: www.psmsyd.com.au

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Catchment Boundaries

PSM1059	Figure D3