Rockwater
PROPRIETARY LIMITED

**HYDROGEOLOGICAL
INVESTIGATIONS
AT THE PROPOSED
ALKIMOS WWTP SITE**

OCTOBER 2004

**REPORT FOR
WATER CORPORATION**

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Appendices

1   INTRODUCTION

Field investigations were carried out at Alkimos, between Quinns Rocks and Yanchep (Fig.1), planned for a new wastewater treatment plant (WWTP), to assess the infiltration capacity of soils. Seven potential sites for infiltration ponds were investigated, as shown in Figure 2. In addition, a numerical groundwater model was used to predict the impact on groundwater of infiltrating treated wastewater at the site.

This report presents the methods and results of the field investigations and the numerical modelling.

2   HYDROGEOLOGICAL SETTING

The proposed Alkimos WWTP site is about 1 km from the coast, within recent mobile sand dunes known as the Quindalup Dune System (Safety Bay Sand). The Safety Bay Sand consists of fine to medium grained quartz sand and shell fragments, and overlies calcareous sand and limestone of the Tamala Limestone. These formations comprise the Superficial aquifer.

At the Alkimos WWTP site, the Safety Bay Sand is generally unsaturated: the Tamala Limestone crops out in swales in the northern part of the area, particularly near test sites 1 and 2 (Fig. 2). The top of the limestone is usually hard cap-rock, of variable thickness.

The Tamala Limestone is karstic in nature, and has high permeability. The water table is between 5 m (Site 4) and 20 m (Site 5) depth (below ground level). Groundwater in the Tamala Limestone is recharged by rainfall infiltration, and flows westwards to discharge to the ocean. Groundwater flow in the formation is largely controlled by the location, and degree of interconnection, of solution channels within the limestone (Davidson, 1995). A study by Barber et al (1990) in an area 10 km south of Alkimos, indicated groundwater flow velocities of between 85 and 335 m/year.

Groundwater salinity in the Superficial aquifer at the WWTP site is about 500 mg/L TDS, increasing to 1,000 mg/L near the coast. Background nutrient concentrations in the area are low: nitrate concentrations are about 1 mg/L, and phosphorus concentrations are less than 0.03 mg/L (Davidson 1995, Plates 60 and 61).

3   WWTP SITE INVESTIGATIONS

Seven potential areas for the location of infiltration ponds, within swales around the planned WWTP, were selected for investigation. The test sites are shown in Figure 2.

3.1 METHOD

At each site, test pits were excavated to approximately 3 m depth. Material excavated from them was geologically logged, and falling-head ("soak-away") permeability tests were conducted in them. The test results were analysed using a method given in Sommerville (1986). Representative soil samples were taken for sieve analysis to determine grain-size distribution.

Access to the site was difficult: unconsolidated, sandy tracks prevented access of water trucks for the permeability tests. Water was carted to site in a small (1,100 L) tank mounted on the tray of a 4WD utility.

Ring infiltrometer tests were carried out at Sites 3 to 7, using a steel ring of 560 mm diameter. Sites 1 and 2, where limestone cap-rock crops out, were not tested. The rings were pushed into the ground to at least 10 cm depth, and soil was tamped on the outside of them, to ensure there was no lateral leakage. After saturating the soil first to eliminate entrapped air, the ring was filled with water and the rate of water-level decline was recorded. The tests were repeated at each site. Permeability was calculated using a method given in Cedergren (1977).

3.2 RESULTS

The pits intersected bioclastic and/or quartz-dominated sands, and weakly- to well-cemented (caprock) limestone. Geological logs of soil samples from the test pits are included in Appendix I.

3.2.1 Sieve Analyses

Sieve analyses of samples taken from the pits show that the strata consist of moderately- to well-sorted, fine to medium grained sand (Sites 1, 3 (1.0 m), 4 (2.0 m), and 7 (2.5 m)), medium-grained sand (Sites 2, 3 (2.0 m), and 4 (0.6 m)); fine to coarse grained sand (Sites 6 (1.0 m), and 7 (1.0 m)); or medium to coarse-grained sand (Site 5 (1.0 m)).

The data are presented in Appendix II.

3.2.2 Pit Soak-Away Tests

Results of the pit soak-away tests (Table 1, and Appendix III) suggest there is variable permeability in the study area. Moderate permeabilities were recorded at Sites 5 and 6 (6.5 and 3.4 m/day), and there were moderate to high permeabilities (27, 17 and 26 m/day) at Sites 1, 2 and 7. High permeabilities were measured at Sites 3 and 4 (145 and 80 m/day). The measured permeability values represent both horizontal and vertical components.

At sites 1, 2, and 5 there was cemented, hard caprock limestone, which would limit infiltration unless it is excavated in forming infiltration ponds.

Based on the measured permeabilities, the locations most suitable for infiltration of treated wastewater are Sites 3 and 4, followed by Sites 1, 7 and 2. The permeabilities measured at Sites 5 and 6 are also high enough for those sites to be suitable for infiltration ponds.

Table 1 – Pit Soak-Away Test Results

Test Pit	MGA94 Coordinates* (Zone 50J)		Pit Volume (L)	Infiltration Rate (L/min)	Permeability	
	mN	mE			(m/d)	(m/sec)
1	6501920	373798	~1000	66.7	27	3.1×10^{-4}
2	6501724	374178	~1000	16.7	17	1.9×10^{-4}
3	6501487	373818	~1000	127.8	145	1.7×10^{-3}
4	6501413	374016	~1000	100	80	9.3×10^{-4}
5	6501367	374387	~1000	11.6	6.5	7.6×10^{-5}
6	6501094	374434	~1000	7.1	3.4	3.9×10^{-5}
7	6501043	374152	~1000	62.5	26	3.1×10^{-4}

*Approx: measured by GPS.
MGA94 = Geocentric Datum Australia

3.2.3   Ring Infiltrometer Tests

The results of the ring infiltrometer tests (Table 2) indicate variable permeabilities for the surface soils, ranging from 26.5 m/day (Site RIT 3B) to 50.5 m/day (Site RIT 5A). Repeated tests at each site give similar values, except at Site 5 where values of 50.5 m/day and 35.9 m/day were measured. Note that actual values of vertical permeability will be substantially lower than the values calculated from the tests, perhaps one fifth to one tenth of those values, as there is a component of horizontal flow from the rings.

The data are presented in Appendix IV.

3.2.4   Phosphorus Retention Indices

Fourteen sediment samples (two from each test pit) were analysed to determine Phosphorus Retention Indices (PRI). Consolidated samples were crushed to <2 mm prior to analysis. PRI values were variable, ranging between 2.1 mL/g (Site A5, 1.0 m depth) and 130 mL/g (Site A4, 2.8 m depth). Generally, the samples of calcarenite had higher PRI values, ranging between 9.8 and 70 mL/g, whilst PRI values calculated from sand samples ranged between 2.1 and 13 mL/g (except for a sample from pit A4 at 2.8 m, which had a very high PRI value of 130 mL/g).

Results are presented in Table 3 and the original laboratory report is presented in Appendix V.

Table 2 – Ring Infiltrometer Test Results

Test No.	MGA94 Coordinates* (Zone 50J)		Infiltrometer Volume	Infiltration Rate	Calculated Permeability	
	mN	mE	(L)	(L/min)	(m/d)	(m/sec)
RIT 3A	6501487	373818	42.6	3.22	28.8	3.3×10^{-4}
RIT 3B	6501487	373818	43.6	3.23	26.5	3.1×10^{-4}
RIT 4A	6501413	374016	45.6	4.48	41.0	4.7×10^{-4}
RIT 4B	6501413	374016	43.6	4.84	45.5	5.3×10^{-4}
RIT 5A	6501367	374387	35.7	5.1	50.5	5.8×10^{-4}
RIT 5B	6501367	374387	38.2	3.58	35.9	4.2×10^{-4}
RIT 6A	6501094	374434	49.3	4.22	30.3	3.5×10^{-4}
RIT 6B	6501094	374434	49.3	4.08	29.6	3.4×10^{-4}
RIT 7A	6501043	374152	34.5	3.83	41.9	4.8×10^{-4}
RIT 7B	6501043	374152	39.4	3.94	33.1	3.8×10^{-4}

*Approx: measured by GPS.

MGA94 = Geocentric Datum Australia

Table 3 – Phosphorus Retention Indices Results

Pit	Sample Depth (m bgl)	Lithology	Phosphorus Retention Index	Adsorption Capacity (after Allen & Jeffery, 1990)
A1	1.0	Calcarenite	34	Strong
A1	3.0	Sand	12	Moderate
A2	1.0	Calcarenite	70	Strong
A2	2.5	Calcarenite	13	Moderate
A3	1.0	Sand	5.8	Moderate
A3	2.0	Sand	4.5	Weak
A4	0.6	Sand	5.0	Weak
A4	2.8	Sand	130	Very strong
A5	1.0	Sand	2.1	Weak
A5	3.0	Calcarenite	15	Moderate
A6	1.0	Sand	13	moderate
A6	2.5	Calcarenite	9.8	moderate
A7	0.3	Sand	13	moderate
A7	1.0	Sand	10	moderate

3.2.5 Discussion of Results

The cap-rock limestone would greatly restrict the infiltration of treated wastewater, and will need to be stripped in forming infiltration ponds. It was removed in digging the test pits at sites 1 and 2, and there was also some at site 5.

Permeability values calculated from falling-head test data for the test pits, and for the ring infiltrometers, indicate there is variable permeability, related to factors such as variations in grain-size, sorting, and compaction. The ring infiltrometers tested the surface soil, whereas the falling-head tests in the test pits relate to sub-soil sands. The permeability values from both sets of tests are moderate to high and will not be the main factor limiting infiltration rates around the WWTP site. As at other WWTP sites in the Tamala Limestone, wastewater quality (nutrients and suspended solids), the ability to allow ponds to dry, and the maintenance of pond floors will be the main controlling factors of infiltration capacity.

Based on experience at other WWTP's in the Tamala Limestone, infiltration rates of at least 0.4 m/d, and probably more than 0.5 m/d will be achievable with high quality effluent containing total phosphorus and nitrogen concentrations at 10 mg/L, or less. For example, at the Gordon Road WWTP at Mandurah, infiltration rates are at least 0.48 m/d with treated wastewater of good quality. Prior to the plant upgrade, infiltration rates were much lower. At Geraldton, infiltration rates are believed to be about 0.4 m/d where permeabilities of 5.6 to 7.2 m/d were indicated from ring infiltrometer tests; and 12 to 16 m/d from constant-head permeability tests carried out in auger holes (Rockwater, 1993).

4 NUMERICAL MODELLING OF EFFECTS OF WASTEWATER INFILTRATION

4.1 PURPOSE AND SCOPE

Groundwater flow and solute transport modelling was carried out to determine the effects of infiltrating treated wastewater at the site. Calculation of nitrogen loads in groundwater discharging to the ocean, and whether the infiltrated wastewater could flow back to the planned Eglinton production bores, was particularly important.

Also, changes to groundwater levels and the fate of phosphorus in the treated wastewater were to be determined.

4.2   DESCRIPTION OF MODEL

The Alkimos model was "telescoped off" the Perth Regional Aquifer Modelling System (PRAMS) groundwater model being developed by the Water Corporation and the Department Of Environment. That process produced a sub-set of the main model: for this project the model was reduced to an area centred on the WWTP site and covering 17.5 km north–south by 19.5 km east–west, and the top two layers of the PRAMS model that represent the Superficial formations.

The model consists of a rectangular grid of 55 columns and 55 rows, and cell sizes range from 62.5 m by 62.5 m at some of the planned infiltration ponds, to 500 m by 500 m in marginal areas (Fig. 3). It utilises Processing Modflow Pro (Chiang and Kinzelbach, 1991) software that incorporates MODFLOW, finite-difference groundwater modelling software designed by the US Geological Survey (McDonald and Harbaugh, 1988).

Model stress periods were selected to alternate between 212 days of summer (October to April), and 153 days of winter (May to September). All of the recharge is assumed to occur during the winter.

The flow-path model PMPATH (Chiang and Kinzelbach, 1994) was used to calculate flow paths and travel times from infiltration ponds to the ocean.

Solute transport model MT3DMS (Zheng and Wang, 1999) was used to model the transport, dilution and biodegradation of nitrogen, and the adsorption and transport of phosphorus in the groundwater.

4.3   MODEL PARAMETERS, BOUNDARY CONDITIONS

Values of vertical and horizontal hydraulic conductivity, specific yield and storage coefficient were initially as for the PRAMS model. It was necessary to vary values of horizontal hydraulic conductivity for the coastal Tamala Limestone during calibration of the model, as described in Section 4.4, below. The values adopted after calibration are given in Table 4.

The PRAMS model uses two recharge models coupled to the flow model to provide recharge rates. For the Alkimos model (which doesn't include the recharge models), Chengchao Xu (pers. comm.) recommended using recharge rates of 179 mm/a for most of the area, and 6 mm/a for pine plantations. These values were adopted.

PRAMS includes extraction from a large number of public and private bores, and these were simulated with average summer and winter extraction rates in the Alkimos model. The Alkimos model was also run with and without the 11 planned Eglinton Superficial

formations bores, pumping at an average winter rate of 1,274 m^3/d and an average summer rate of 2,410 m^3/d, from 2007.

Boundaries to the model include constant-head boundaries representing the ocean, and on the eastern side of the model to represent groundwater flow into the modelled area. Both are in Layer 1 only. The other boundaries are assumed to be no-flow boundaries, and there is assumed to be no flow into or out of the Superficial formations from the underlying Mesozoic sediments.

Table 4 – Adopted Aquifer Parameters

Parameter	Layer 1		Layer 2	
	Coastal Limestone	Inland Sand And Limestone	Coastal Limestone	Inland Sand And Limestone
Horizontal Hydraulic Conductivity (m/d)	350 to 900	20 to 35	350 to 900	15 to 25
Vertical Hydraulic Conductivity (m/d)	0.1 to 5	0.5 to 5	0.1 to 0.5	0.5
Specific Yield	0.2 to 0.275	0.2 to 0.275	0.1 to 0.2	0.1 to 0.2
Storage Coefficient	N/A	N/A	0.0005 to 0.001	0.0005 to 0.001

4.4   MODEL CALIBRATION

The PRAMS model has been calibrated to regional groundwater levels, but the model-calculated groundwater levels at the WWTP site were too high. It was necessary to increase values of horizontal hydraulic conductivity for the coastal limestone in order to achieve local calibration in the WWTP area.

A comparison of model-calculated and observed groundwater levels for the WWTP area, after calibration, is given in Figure 4. There is a close correspondence, considering that three of the groundwater levels were measured on a different day, and the others were probably measured at a different stage of the ocean tide cycle (groundwater levels in the Tamala Limestone are affected by the ocean tides).

4.5   FLOW AND FLOW-PATH MODELLING

Eight cases were modelled using the flow and flow-path models:

1. Infiltration with a peak of 9.7 (~10) ML/d after 13 years, and no pumping from Eglinton bores;
2. As above, but with pumping from Eglinton bores;
3. Infiltration with a peak of 19.4 (~20) ML/d after 13 years, and no pumping from Eglinton bores;

4. As above, but with pumping from Eglinton bores.

5. As for Case 2, except replacing the bore planned to be north-east of the WWTP with two new bores located north and south of the WWTP. Each of the new bores would be pumped at half the rate of the other Eglinton bores.

6. As for Case 2, but with up to four re-use bores installed down-gradient of the WWTP to extract 8.8 GL/yr from 2008, including 33.6 KL/d in summer and 9.2 KL/d in winter. The bores are to be located to capture as much wastewater flow as possible, and to allow a nominal travel time of two months between infiltration ponds and the bores.

7. As for Case 6, but with re-use bores extracting 15.3 KL/d in summer and 4.2 KL/d in winter in 2008, increasing to 25.9 KL/d in summer and 7.1 KL/d in winter (6.6 GL/yr) in 2020.

8. Similar to Case 7, except wastewater infiltration increasing to 20 ML/d by 2020; and with re-use bores extracting 18.2 KL/d in summer and 5.0 KL/d in winter in 2008, increasing to 33.6 KL/d in summer and 9.2 KL/d in winter (8.8 GL/yr) in 2020.

The models were used to determine changes in groundwater levels resulting from the infiltration, flow paths, and travel times to the coast or to re-use bores.

Infiltration ponds used in the modelling were selected according to proximity to the WWTP, and to spread infiltration across the direction of groundwater flow, i.e. in a north-south direction. A maximum infiltration rate of 0.4 m/d was assumed: a minimum number of infiltration ponds were used/assumed in the modelling, and additional ponds were added in the model once the infiltration capacity of the ponds was approached.

4.5.1 Modelling Results

The flow modelling results are summarised in Table 5, and are shown in Figures 5 to 12.

Table 5 – Results Of Flow and Flow-Path Modelling

Case (Section 4.5)	Max. Water Level Rise (m)	Travel Time To Coast (Months)	Travel Time To Re-Use Bores (Months)
		After 13 Years Infiltration	
1	0.4	8 to 10	Not Applicable (N/A)
2	0.2	8 to 10	N/A
3	0.6	4 to 9	N/A
4	0.5	4 to 10	N/A
5	0.2	8 to 10	N/A
6	0.1	>13 Years for N	2 to 3
7	0.1	>13 Years for N	2 to 3
8	0.4	4 to 7 Years for N	2 to 6

Pumping from the Eglinton bores will reduce the degree and extent of mounding that results from wastewater infiltration, but there is indicated to be little effect of the pumping on the minimum travel time from infiltration ponds to the ocean: that time is more dependent on the rate of wastewater infiltration. Flow-path modelling results indicate there is no possibility of groundwater beneath the infiltration ponds being drawn towards the Eglinton bores. Even if the bores were pumped at their planned peak rates of extraction, and if two bores are located close to the WWTP (Case 5, Fig. 9), all groundwater beneath the ponds would continue to flow towards the ocean.

Extraction from re-use bores (Cases 6 to 8) would capture much of the groundwater containing treated wastewater, and greatly increase travel time to the coast. The results of the solute-transport modelling (Section 4.6) indicate that capture by the re-use bores, and the additional time available for denitrification, would mean that nitrogen in the treated wastewater would not reach the coast within 13 years in Cases 6 and 7; and would first reach the coast after four to seven years in Case 8, the timing depending on bore layout and numbers.

In practice, more than four re-use bores would be needed to extract up to 8.8 GL/yr, to minimise drawdowns and the possibility of up-coning of saline groundwater from beneath the saltwater wedge. The additional bores would also be more efficient at capturing groundwater containing treated wastewater. Also, some of the re-use bores would need to be abandoned and others constructed further to the west, as additional infiltration ponds are commissioned west of the WWTP.

4.6   SOLUTE TRANSPORT MODELLING

Eleven cases were run using the MT3DMS solute-transport model: Cases 1 to 8 were as described above, with nitrogen (or phosphorus) source concentrations assumed to be 10 mg/L (Cases 1 to 4) and 6 mg/L nitrogen for Case 5. The three additional cases were as follows:

9. As for Case 2 (up to 10 ML/d infiltration, and pumping from Eglinton bores in the positions originally planned), but with nitrogen source concentration of 6 mg/L;
10. As for Case 9, but with no denitrification occurring in the aquifer;
11. A run to determine the loadings of nitrogen in groundwater discharging to the ocean, with the background nitrate concentration of 1 mg/L (= 0.2 mg/L nitrogen).

Dispersion was assumed to be zero.

4.6.1   Nitrogen

The first-order reaction rate for denitrification was assumed to be 0.006 day^{-1}, the value determined in calibrating the solute transport model for the Gordon Road WWTP at Mandurah, also in an area underlain by Tamala Limestone.

Cases 1 to 4 (10 mg/L Source Concentration)

The denitrification and dilution by groundwater throughflow and recharge result in decreasing nitrogen concentrations in groundwater towards the coast (Figures 13 to 16). On discharge to the ocean, concentrations are indicated to be up to 1.2 mg/L for the 10 ML/d case, and up to 3 mg/L for the 20 ML/d case.

Plots of variation in nitrogen concentration at a point on the coast (Figures 17 and 18) reflect the gradual increase in wastewater infiltration rates. The curves are irregular because of seasonal changes in recharge, bore pumping, and groundwater throughflow; as well as some (minor) numerical instability. In both the 10 ML/d and 20 ML/d cases, extraction from the Eglinton bores reduces nitrogen concentrations – more so in the 10 ML/d case.

Model-calculated rates of groundwater discharge along the coast, and nitrogen concentrations, were used to determine the <u>additional</u> total nitrogen loads in groundwater discharging to the ocean after 13 years of infiltration. Background nitrogen concentrations were assumed to be negligible. The results are presented in Table 6.

The nitrogen-enriched groundwater would extend over about 1.5 km (10 ML/d case) or 2 km (20 ML/d case) of coastline. The calculated nitrogen loads in groundwater discharging to the ocean will be used by others to assess the potential impact on the coastal ecology.

Table 6 – Nitrogen Loads In Groundwater Discharging To Ocean

Case (Sections 4.5 and 4.6)	N Loading After 13 Years Infiltration (kg/d)
1	10.5
2	8.9
3	38.7
4	33.4
5	5.3
6	0
7	0
8	9.4 (Winter Only)
9	4.8
10	55.7
11	4

Cases 5, 9 and 10 (6 mg/L Source Concentration)

The results indicate that with denitrification (Cases 5 and 9), nitrogen concentrations would be up to 0.6 mg/L above background concentrations in groundwater discharging to the ocean (Fig.19). This would add about 5 kg/d of nitrogen in groundwater discharging to the ocean. Changing the position of Eglinton bores near the WWTP has no significant effect on nitrogen loads: the small difference in the Case 5 and 9 results is due to numerical instability of the MT3DMS model.

Without any denitrification (Case 10), nitrogen concentrations would be up to 4.0 mg/L above background concentrations in groundwater discharging to the ocean (Fig. 20). The additional loading of nitrogen in groundwater discharging to the ocean would be about 56 kg/d.

Case 11 (Background Nitrogen Concentrations)

With background nitrogen concentrations of 0.2 mg/L, there would be about 4 kg/d of nitrogen in groundwater discharging along the length of coast that would be affected by the 10 ML/d wastewater infiltration.

Cases 6 to 8 (With Re-Use Bores)

With the re-use bores pumping at the stipulated rates, nitrogen would not reach the ocean at concentrations above background levels within the 13-year period simulated in Cases 6 and 7 (Figs. 21 and 22).

In Case 8, some nitrogen would reach the coast from the northern part of the plume in winter after four years, and from the rest of the plume after seven years. All of the nitrogen would be captured during the summer throughout the 13-year period simulated, because of higher rates of extraction from the re-use bores, and lower rates of groundwater throughflow. In winter, there would be about 9.4 kg/d of nitrogen discharging to the ocean, over about 1.3 km of coastline (Fig.23).

4.6.2   Phosphorus

The retardation of phosphorus in aquifers can be modelled using adsorption isotherms such as the non-linear Freundlich isotherm, and this method was used in the Alkimos solute-transport model.

Phosphorus retention indices (PRI) measured for sand and limestone at the site can be used to calculate the Freundlich adsorption coefficient (A) for input into the solute transport model, using the following formula (Gerritse, pers. comm.):

$$A = PRI \{1000/(100+5*PRI)\}^{1-b1} \qquad (1)$$

Where b1 is an experimentally derived exponent.

Gerritse (1996) has derived values for A and b1, for various Western Australian soils, using a time-dependent Freundlich adsorption isotherm:

$$\Delta C_s = A (\Delta C)^{b1} t^{b2} \qquad (2)$$

Where ΔC_s = change in the sorbed concentration of phosphorus (mg/kg) with time, ΔC = the change in the concentration of phosphorus in solution (mg/L) with time t and b2 = an empirical exponent. Values of ΔC_s and ΔC are then used to calculate the retardation of phosphorus in the aquifer material.

The MTD3MS solute transport-modelling package includes an option to use an equilibrium Freundlich isotherm to calculate retardation, using the following equation:

$$C_s = A C^{b1} \qquad (3)$$

Gerritse (1996) calculated an adsorption coefficient A = 30 L/kg and a Freundlich exponent b1 = 0.4 from laboratory experiments on a calcareous sand. The bulk density of the sand was 1.45 kg/L. These values were used in the model.

The modelling method tends to over-estimate phosphorus concentrations in groundwater, because the Freundlich adsorption coefficient (A) and exponent (b1) used in the modelling have been calculated for a time-dependent isotherm, where the total amount of phosphorus adsorbed increases with time. More phosphorus is adsorbed the longer groundwater is in contact with aquifer material. The equilibrium Freundlich isotherm used by MT3DMS assumes that adsorption has gone to completion, limiting the effects of retardation to the continuing adsorption/desorption process.

The impact of using an equilibrium Freundlich isotherm can be seen in modelling results for phosphorus transport from the Esperance WWTP (Rockwater, 2002): the calculated phosphorus concentration after 25 years of infiltration, 100 m down-gradient of the WWTP, was 6 mg/L, an order of magnitude greater than the concentration of 0.6 mg/L measured in a monitoring bore.

The Alkimos solute-transport model was run to simulate a 100-year period with a worst-case infiltration of 20 ML/d from day one for the entire period, without the Eglinton bores pumping. The results suggest that it would take about 28 years for phosphorus to first reach the coast, and after 100 years, phosphorus concentrations in groundwater at the coast would be 7 to 8 mg/L. As stated above, we expect actual travel times to be much greater, and

concentrations much smaller than indicated by the modelling. The model can be calibrated to observed concentrations after, say, 10 years of operation, so that better predictions can be made.

5   EFFECT OF NUTRIENTS ON NEAR-SHORE ENVIRONMENT

The modelling results indicate that without extracting groundwater for re-use, relatively small quantities of nitrogen originating from infiltration ponds will reach the ocean. Much larger quantities discharge with groundwater to the ocean in many parts of the coastal plain where elevated concentrations of nitrate occur naturally in the groundwater. If groundwater is extracted for re-use, most or all of the nitrogen could be captured.

A preliminary report by Oceanica on the potential impact on the near-shore environment of groundwater discharge containing nutrients is included as Appendix VI. It states that:

- There are a number of offshore reefs within 2 km of the beach west of the WWTP.
- The EPA has general requirements to maintain or improve water quality, and to not adversely affect seagrass or other benthic habitat.
- An appropriate response would be to describe the existing marine environment, any increase in nutrient concentrations likely to occur, and the effects of these increases.

Groundwater flows will enter the ocean through the intertidal zone, and will be dispersed by a prevailing northerly current along the coast. The near-shore water will be well mixed vertically by the swell and the wind.

6   CONCLUSIONS

The planned WWTP site is underlain by sand and limestone that are generally of moderate to high permeability, that will enable treated wastewater to be infiltrated to groundwater from ponds in swales, with only minor mounding of the water table. In three swales, hard cap-rock of low permeability outcrops, or occurs at shallow depth. This will need to be excavated in forming infiltration ponds.

Based on rates achieved at other WWTP's in the Tamala Limestone, infiltration rates of at least 0.4 m/d, and probably more than 0.5 m/d, should be sustainable with the planned high quality of the treated wastewater. The infiltration rates will be limited by the wastewater quality, cycling of ponds, and the maintenance of pond bases rather than the intrinsic permeability of soils at the site.

The results of numerical flow and solute transport modelling of the infiltration planned for the first 13 years of operation, and groundwater flows, indicates the following:

- Pumping from the planned Eglinton Superficial formations borefield will not induce flows of groundwater containing treated wastewater to the borefield, but will reduce the degree of mounding beneath infiltration ponds, and the rate and concentrations of nutrients moving towards the coast.

- The travel time from beneath the infiltration ponds to the coast will range from four to ten months, depending on pond location, maximum infiltration rate (10 or 20 ML/d), and whether or not the Eglinton bores are pumping.

- The maximum groundwater-level rise beneath the WWTP will be between 0.2 m and 0.6 m, again depending on the above factors.

- Nitrogen-enriched groundwater will discharge over 1.5 to 2 km of coastline west of the WWTP, with peak total nitrogen concentrations in the groundwater of between 0.6 and 3 mg/L.

- Additional nitrogen loads in groundwater discharging at the coast will be between 5 and 39 kg/d after 13 years of infiltration (depending on the above factors, and nitrogen concentrations of the treated wastewater). At present, about 4 kg/d of naturally occurring nitrogen is discharging along the length of coastline that would be affected with 10 ML/d infiltration.

- Extraction of groundwater down-gradient of the WWTP for re-use, could prevent most or all of the nitrogen entering the groundwater from infiltration ponds from reaching the ocean. The effectiveness of extraction in capturing groundwater elevated in nitrogen will depend on the number of bores and seasonal pumping rates, and the infiltration rate of treated wastewater.

- The transport of phosphorus in groundwater is difficult to predict accurately, because the adsorptive capacity of the sand and limestone is variable and uncertain. Modelling results suggest that at 20 ML/d continuous infiltration and without the Eglinton bores pumping, phosphorus in groundwater would first reach the coast after about 28 years, and after 100 years phosphorus concentrations in groundwater at the coast would be around 7 to 8 mg/L. However, a comparison of modelling results and observed concentrations in a similar hydrogeological environment suggests that the model over-estimates phosphorus concentrations by an order of magnitude. The Tamala Limestone generally has a high adsorptive capacity, and elevated phosphorus concentrations are rarely seen in groundwater from the formation.

- A preliminary report by Oceanica suggests that an investigation should be carried out to characterise the near-shore environment west of the WWTP, and to assess the potential impact of nutrients in groundwater discharging at the coast.

Dated: 11 OCTOBER 2004   Rockwater Pty Ltd

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Principal Hydrogeologist

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FIGURES

FIGURE 1

Alkimos WWTP study area

m N (AMG)

m E (AMG)

0   2000   4000

alkimos.tif/Fig1locmap.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004

Dwg. No: 236.38/04/1-1

LOCATION OF PROPOSED

ALKIMOS WWTP

Rockwater Pty Ltd

FIGURE 2

6502000

Site 1

Site 2

Planned
WWTP

m N (MGA)

6501500

Site 3

Site 4

Site 5

Site 6

Site7

6501000

373500   374000   374500   375000

m E (MGA)

0   500   1000
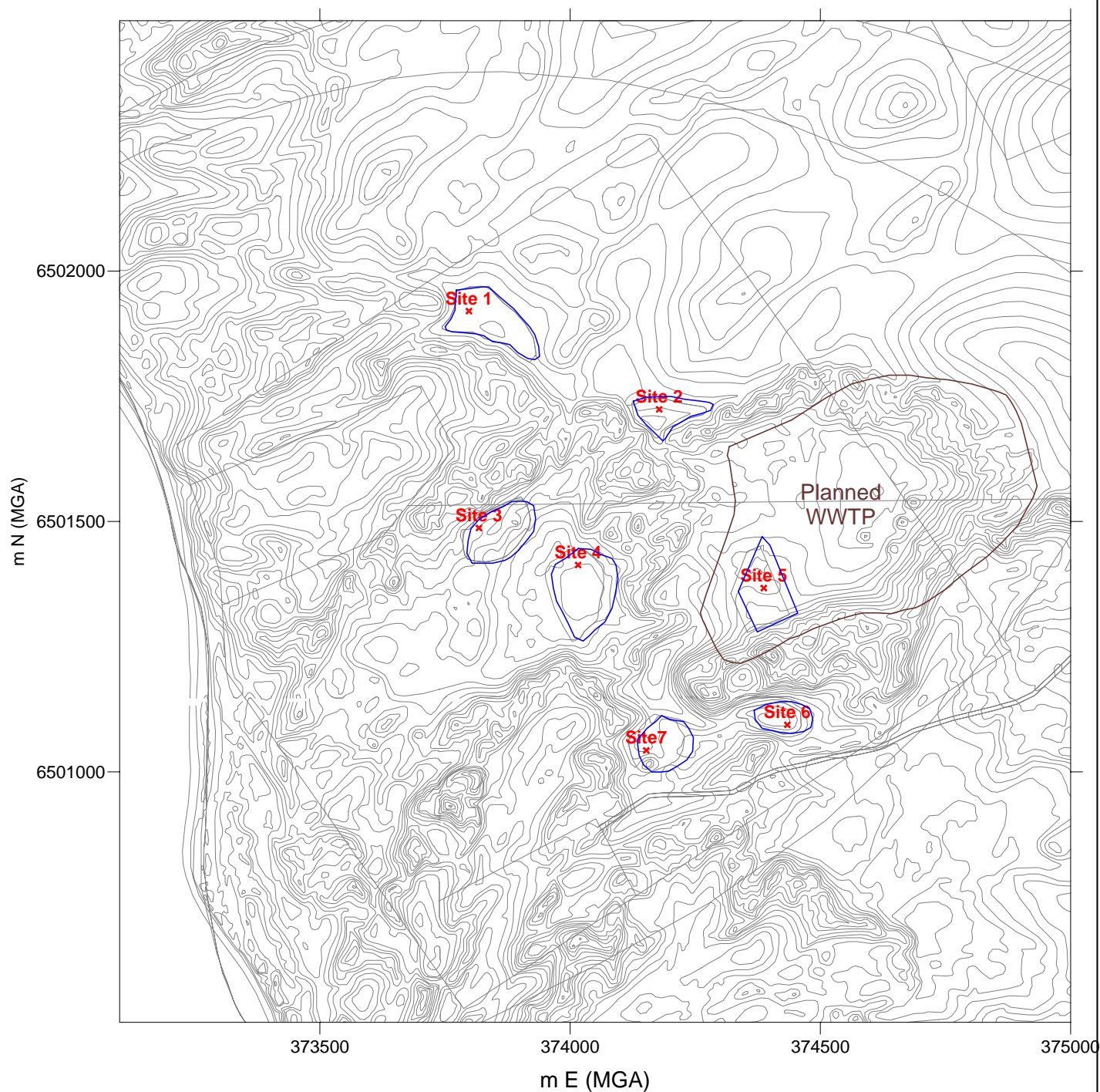
pitlocs.xls/alkimos_1.bln/Fig2locmap.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004

Dwg. No: 236.38/04/1-2

LOCATION OF TEST SITES

AND PLANNED INFILTRATION PONDS

ALKIMOS WWTP

Rockwater Pty Ltd

FIGURE 3

m N (MGA)

m E (MGA)

0   2000   4000
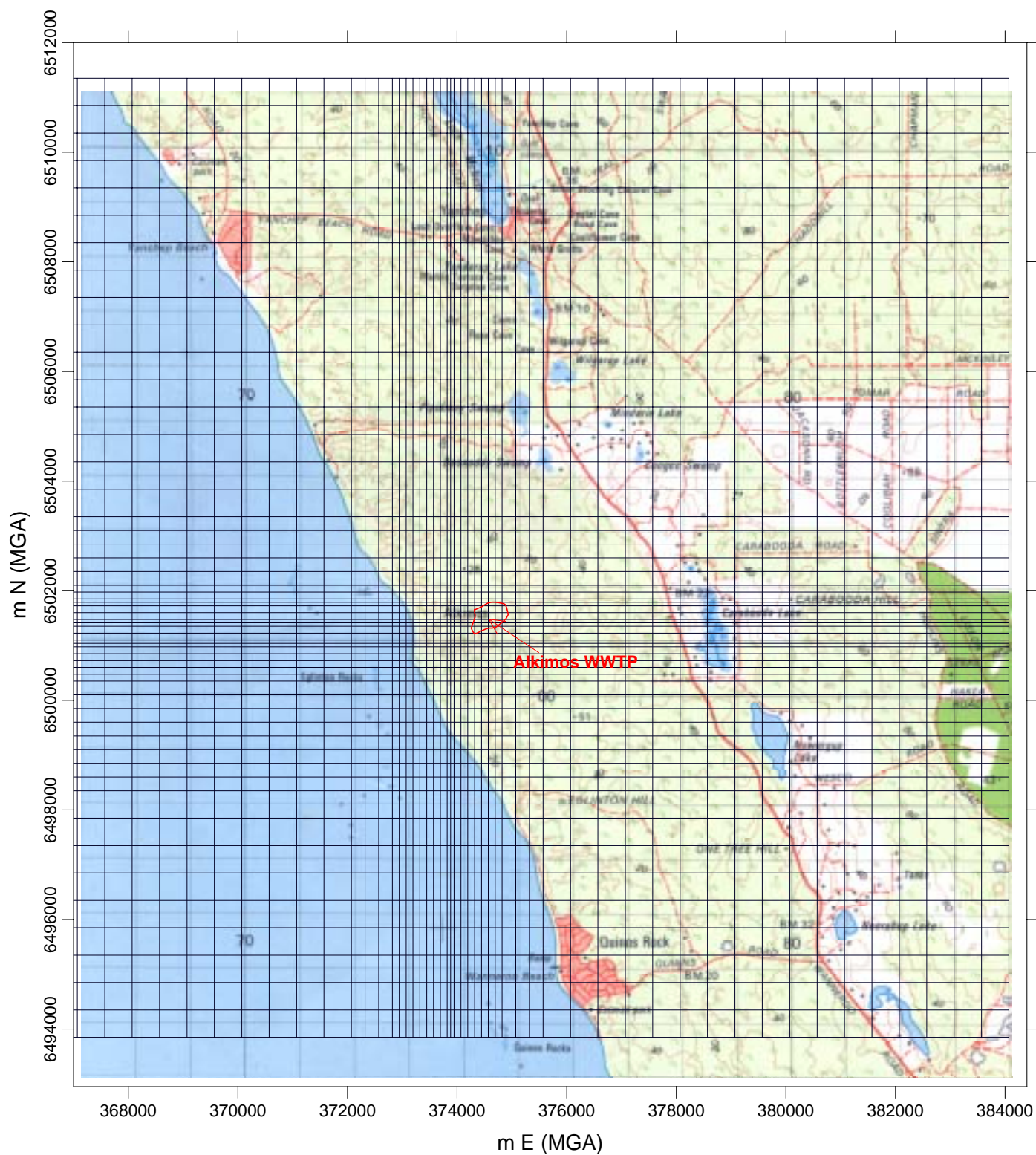
grid.dxf/.srf

CLIENT:	Water Corporation
PROJECT:	Alkimos WWTP
DATE:	August 2004
Dwg. No:	236.38/04/1-3

EXTENT OF MODEL GRID

Rockwater Pty Ltd

FIGURE 4

COMPARISON BETWEEN MODEL-CALCULATED

SUMMER GROUNDWATER LEVELS

(CONTOURS, m AHD) AND LEVELS MEASURED

19 MARCH 1990 (BORE VALUES)

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004
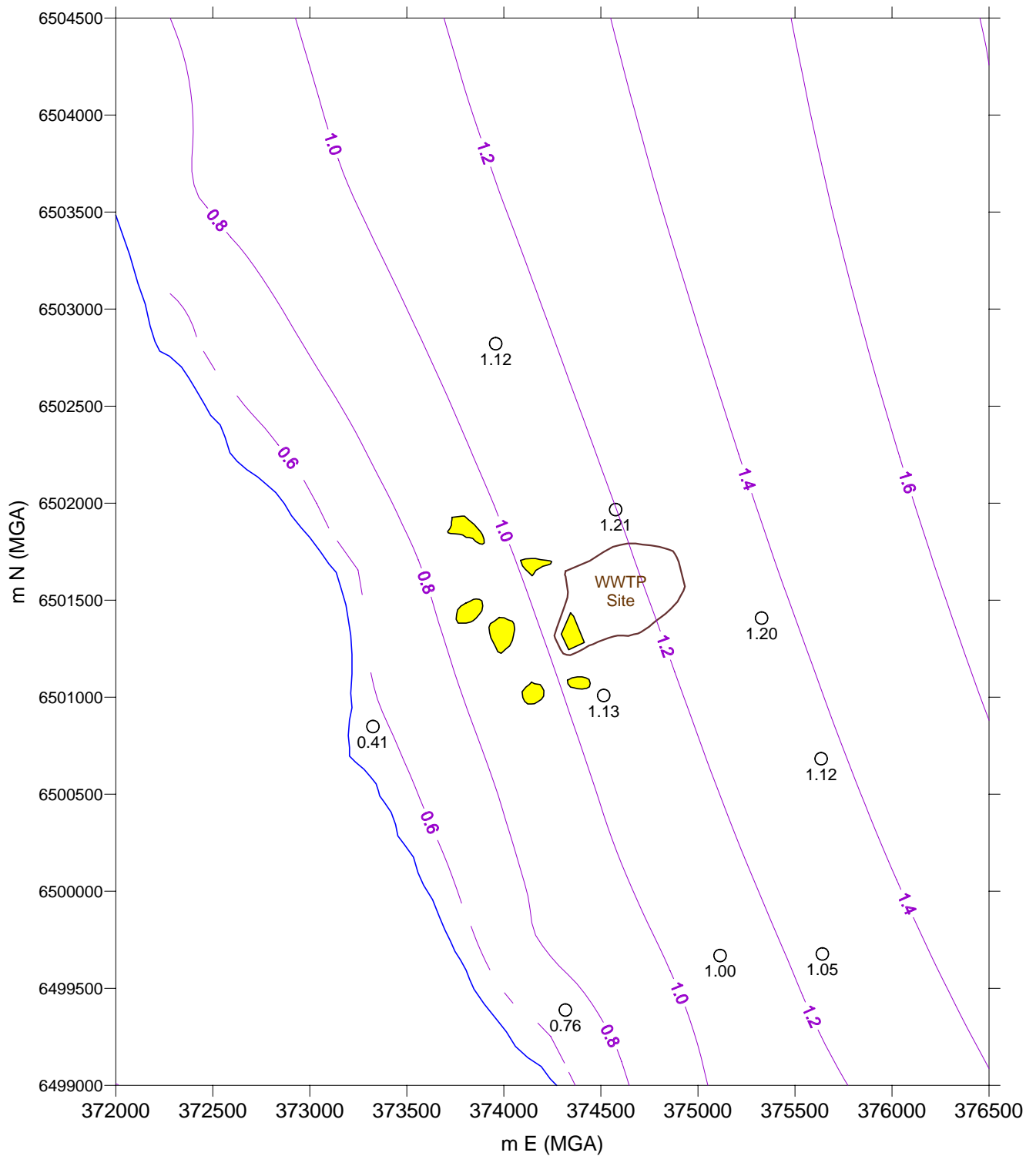
Dwg No: 236.38/04/1-4

rlwls.xls/sssumwl.dat/.grd/.srf

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FIGURE 5
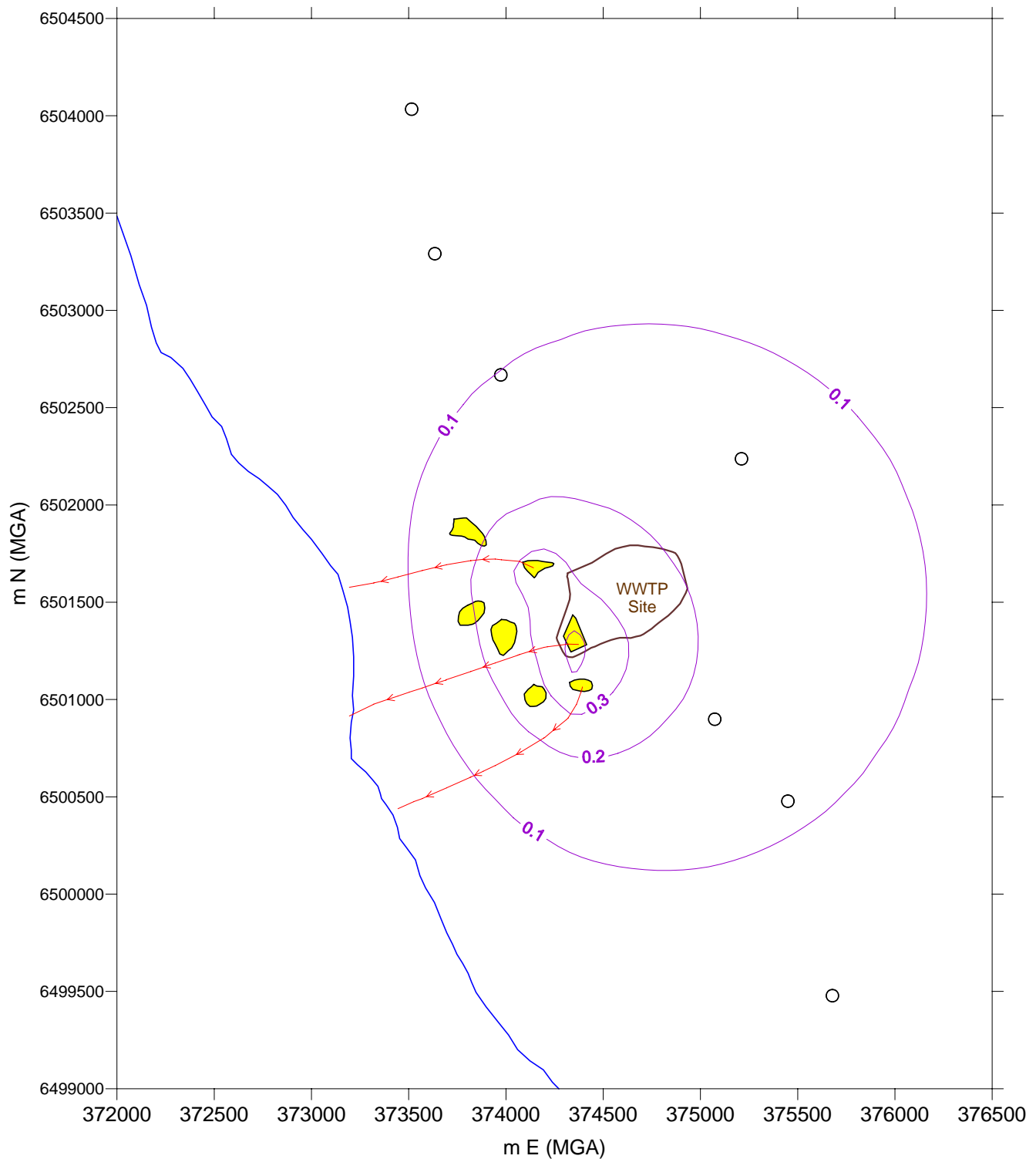
Planned Eglinton Bore

Each Arrow Head On Flowlines Denotes Two Months Flow

s2610mdd.dat/grd/.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004

Dwg No: 236.38/04/1-5

CALCULATED GROUNDWATER-LEVEL RISE (m) AND

FLOWLINES AFTER 13 YEARS INFILTRATION AT UP

TO 10 ML/d, WITHOUT EGLINTON BORES PUMPING

Rockwater Pty Ltd

FIGURE 6

CALCULATED GROUNDWATER-LEVEL RISE (m) AND

FLOWLINES AFTER 13 YEARS INFILTRATION AT UP

TO 10 ML/d, WITH EGLINTON BORES PUMPING

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004

Dwg No: 236.38/04/1-6

Rockwater Pty Ltd

○ Planned Eglinton Bore

Each Arrow Head On Flowlines Denotes Two Months Flow

s2610medd.dat/grd/.srf

FIGURE 7
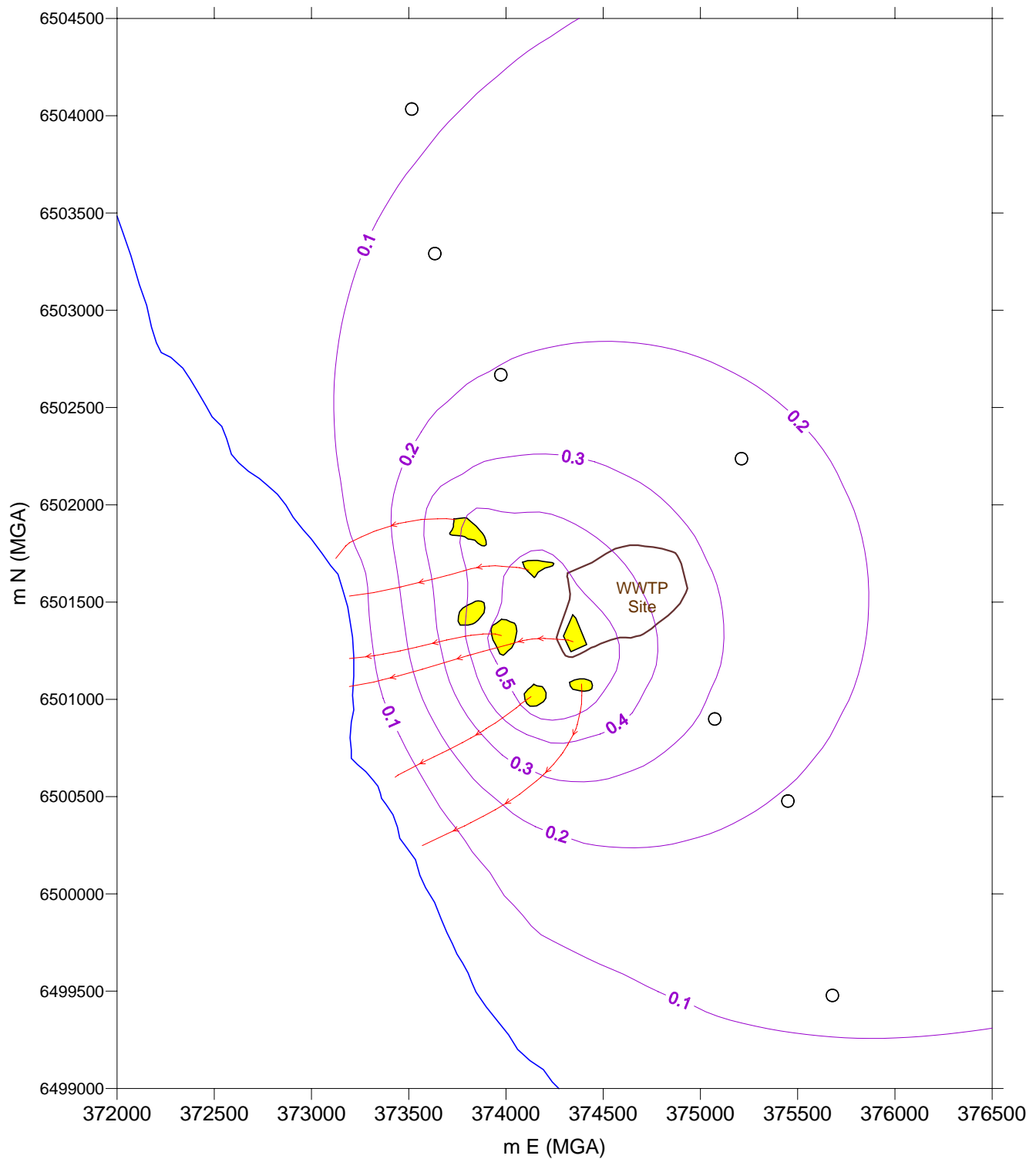
CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004

Dwg No: 236.38/04/1-7

CALCULATED GROUNDWATER-LEVEL RISE (m) AND

FLOWLINES AFTER 13 YEARS INFILTRATION AT UP

TO 20 ML/d, WITHOUT EGLINTON BORES PUMPING

s2620mdd.dat/grd/.srf

○ Planned Eglinton Bore

Each Arrow Head On Flowlines Denotes Two Months Flow

Rockwater Pty Ltd

FIGURE 8

CALCULATED GROUNDWATER-LEVEL RISE (m)
AND FLOWLINES AFTER 13 YEARS INFILTRATION
AT UP TO 20 ML/d, WITH EGLINTON BORES PUMPING

○ Planned Eglinton Bore

Each Arrow Head On Flowlines Denotes Two Months Flow

s2620medd.dat/grd/.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004

Dwg No: 236.38/04/1-8

Rockwater Pty Ltd

FIGURE 9

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: September 2004

Dwg No: 236.38/04/1-9

CALCULATED GROUNDWATER-LEVEL RISE (m)

AND FLOWLINES AFTER 13 YEARS INFILTRATION

AT UP TO 10 ML/d, WITH EGLINTON BORES PUMPING

(REVISED BOREFIELD CONFIGURATION)

Rockwater Pty Ltd

○   Planned Eglinton Bore

Each Arrow Head On Flowlines Denotes Two Months Flow

13y10nbdd.dat/grd/13ynbpth.dxf/.srf

m N (MGA)

m E (MGA)

WWTP
Site

0.2

0.1

FIGURE 10

Planned Eglinton Bore

Modelled Re-Use Bore

Each Arrow Head On Flowlines Denotes One Month Flow
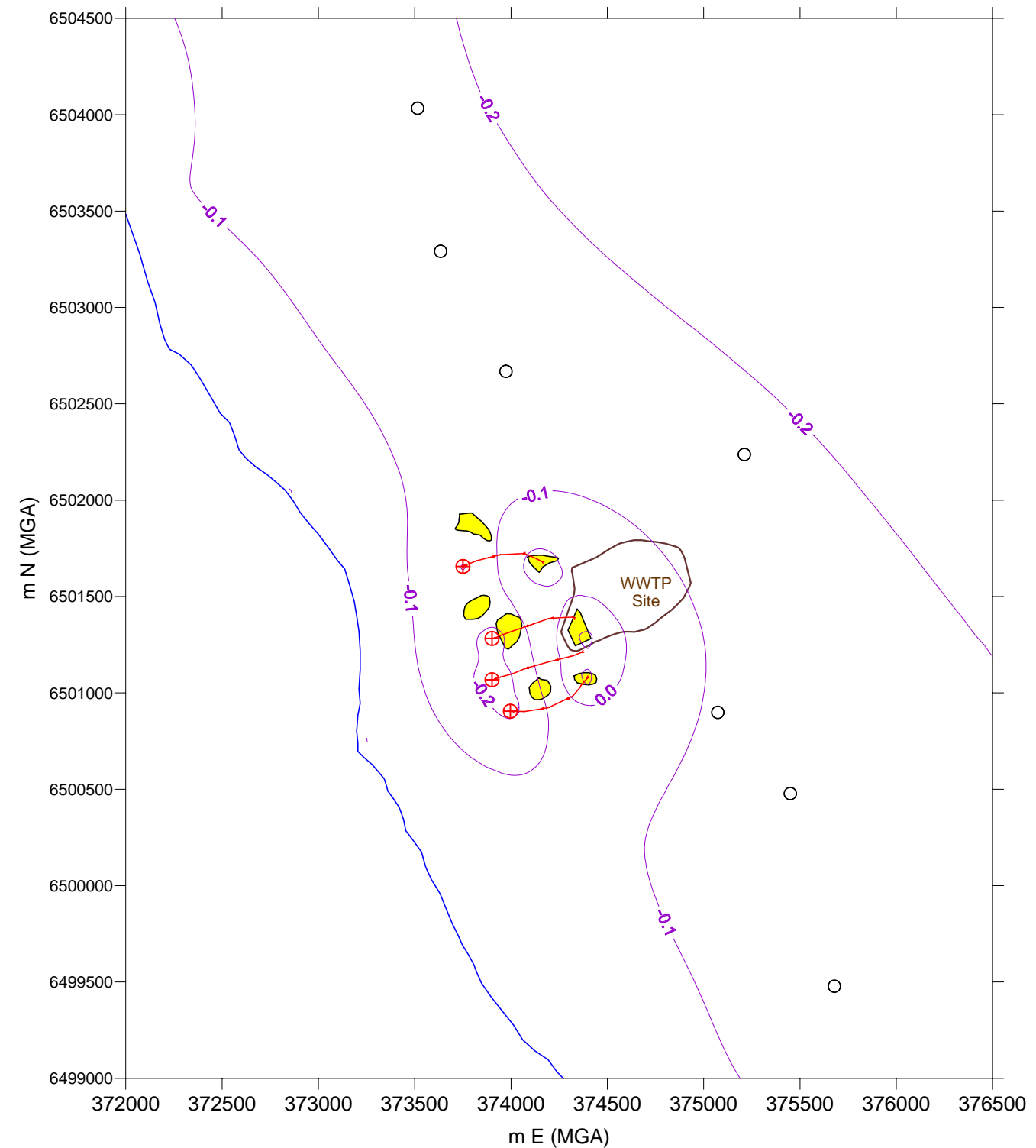
re-use1dds.dat/grd/.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: October 2004

Dwg No: 236.38/04/1-10

CALCULATED GROUNDWATER-LEVEL RISE (m) AND

FLOWLINES AFTER 13 YEARS INFILTRATION AT UP

TO 10 ML/d, WITH EGLINTON BORES

AND RE-USE BORES PUMPING (CASE 6)

Rockwater Pty Ltd

FIGURE 11

CALCULATED GROUNDWATER-LEVEL RISE (m) AND FLOWLINES AFTER 13 YEARS INFILTRATION AT UP TO 10 ML/d, WITH EGLINTON BORES AND RE-USE BORES PUMPING (CASE 7)

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: October 2004

Dwg No: 236.38/04/1-11

○ Planned Eglinton Bore

⊕ Modelled Re-Use Bore

Each Arrow Head On Flowlines Denotes One Month Flow

ru2dds.dat/grd/.srf

Rockwater Pty Ltd

FIGURE 12

FIGURE 13

6504000

6503000

6502000

6501000

6500000

6499000

m N (MGA)

372000   373000   374000   375000   376000
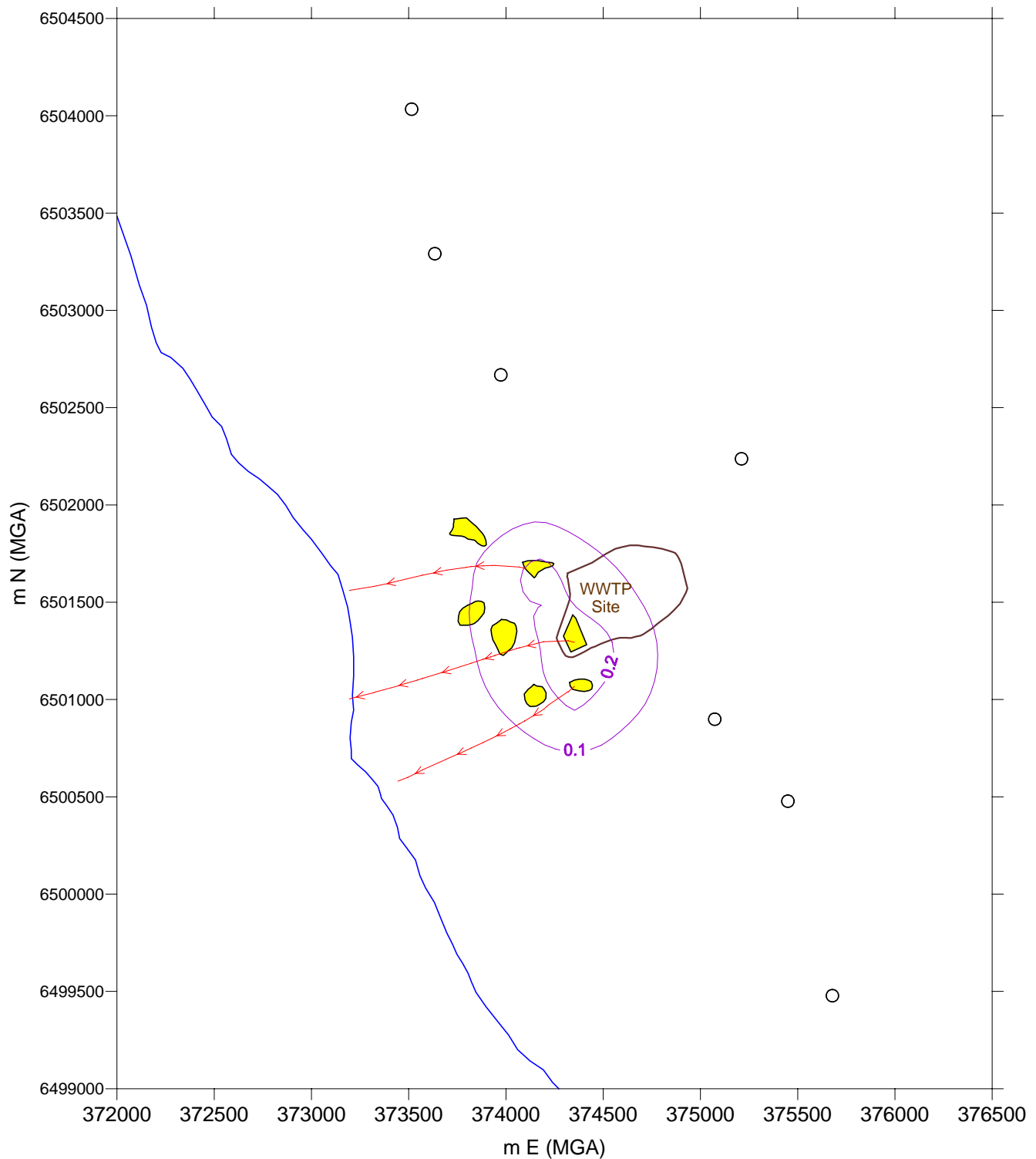
m E (MGA)

2
1
6
8
WWTP
Site
6
2
8
4
1
1
2

O   Planned Eglinton Bore

s2610mn.dat/grd/.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004

Dwg No: 236.38/04/1-13

CALCULATED NITROGEN CONCENTRATIONS (mg/L)

AFTER 13 YEARS INFILTRATION AT UP TO 10 ML/d,

WITHOUT EGLINTON BORES PUMPING

Rockwater Pty Ltd

FIGURE 14

6504000

6503000

6502000

m N (MGA)

6501000

6500000

6499000

372000   373000   374000   375000   376000

m E (MGA)

WWTP
Site

○   Planned Eglinton Bore

s2610men.dat/grd/.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004

Dwg No: 236.38/04/1-14

CALCULATED NITROGEN CONCENTRATIONS (mg/L)

AFTER 13 YEARS INFILTRATION AT UP TO 10 ML/d,

WITH EGLINTON BORES PUMPING

Rockwater Pty Ltd

FIGURE 15

○ Planned Eglinton Bore
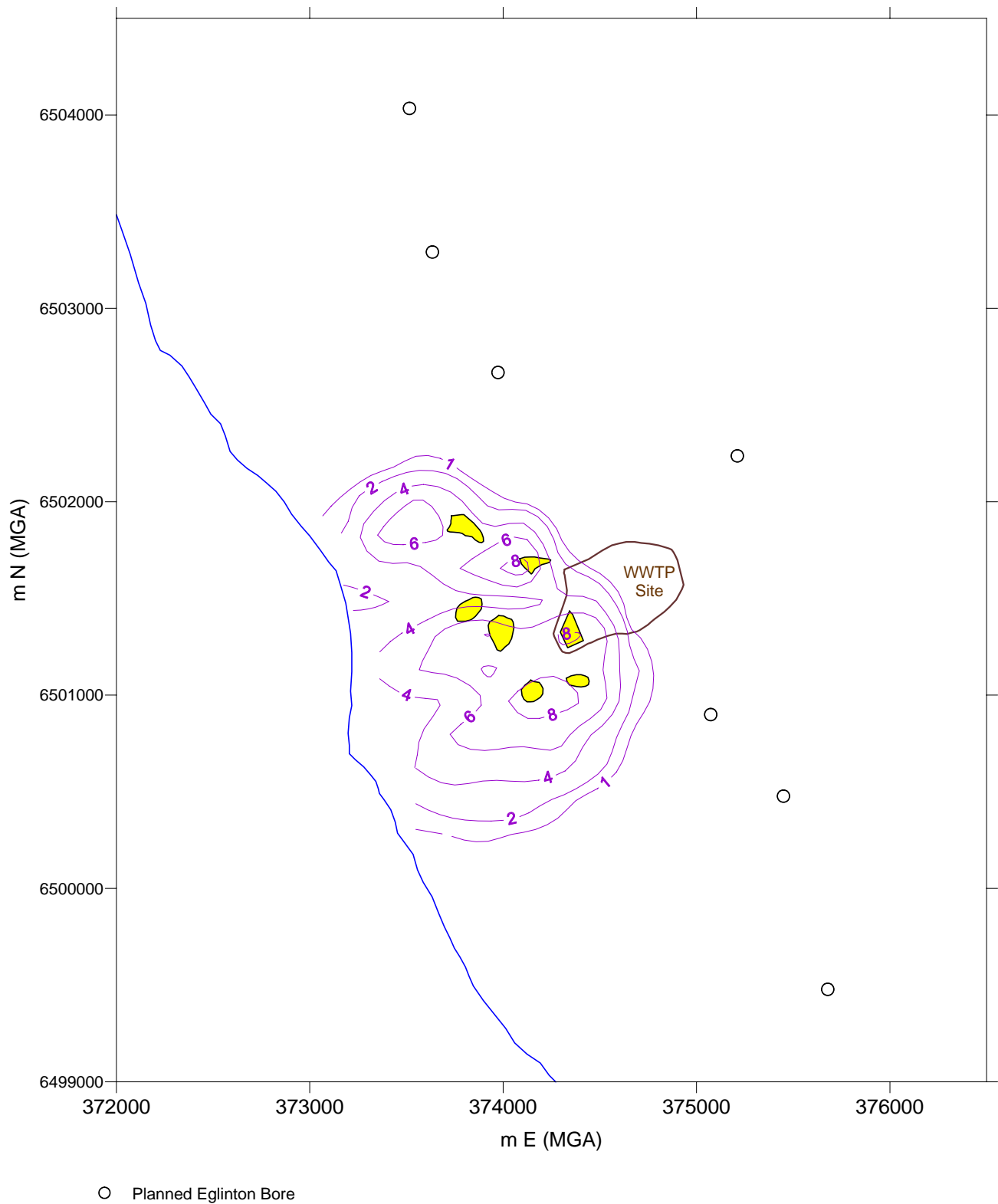
s2620mn.dat/grd/.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: August 2004
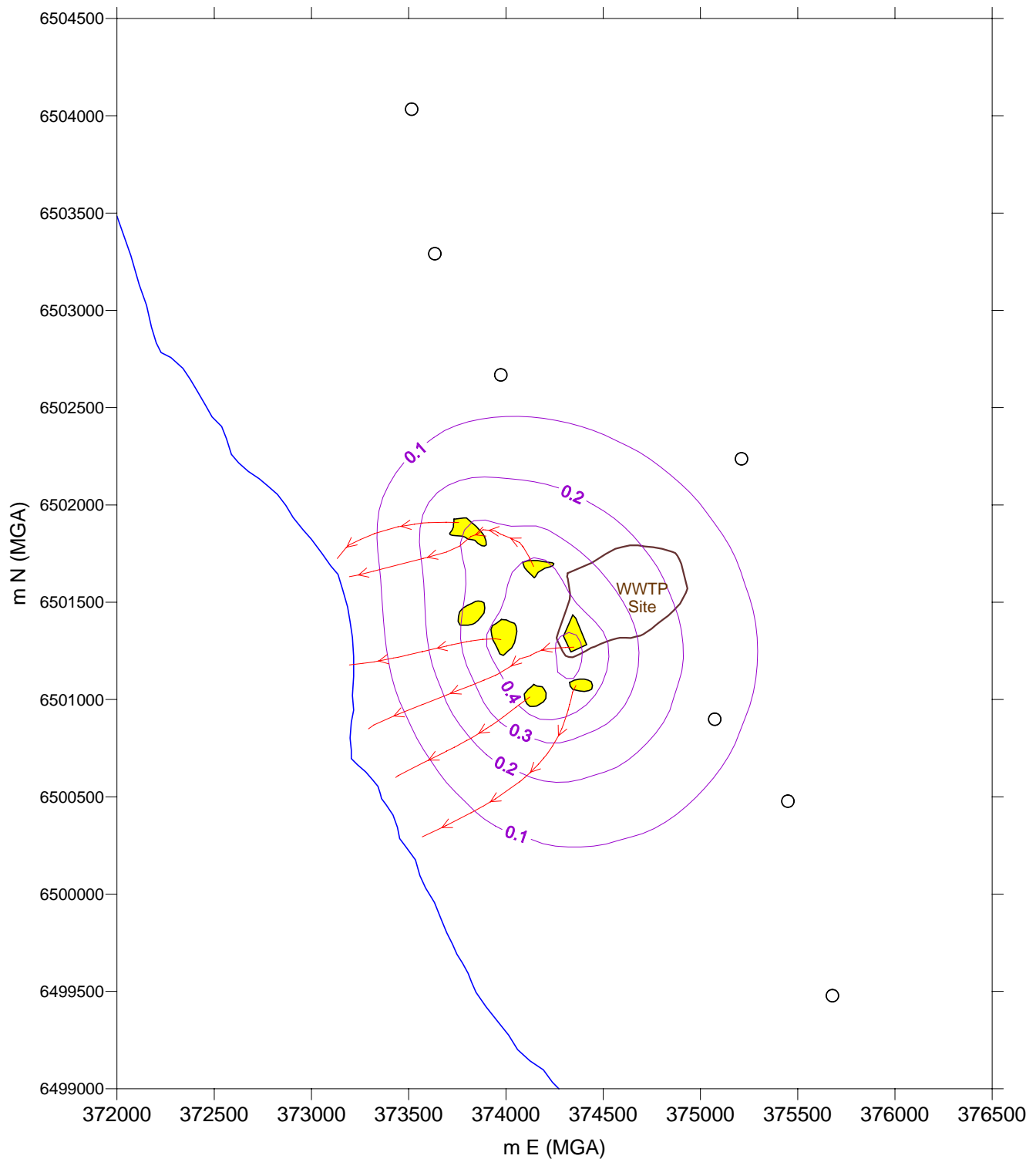
Dwg No: 236.38/04/1-15

CALCULATED NITROGEN CONCENTRATIONS (mg/L)

AFTER 13 YEARS INFILTRATION AT UP TO 20 ML/d,

WITHOUT EGLINTON BORES PUMPING

Rockwater Pty Ltd

FIGURE 16

6504000

6503000

6502000

m N (MGA)

6501000

6500000

6499000

372000　373000　374000　375000　376000
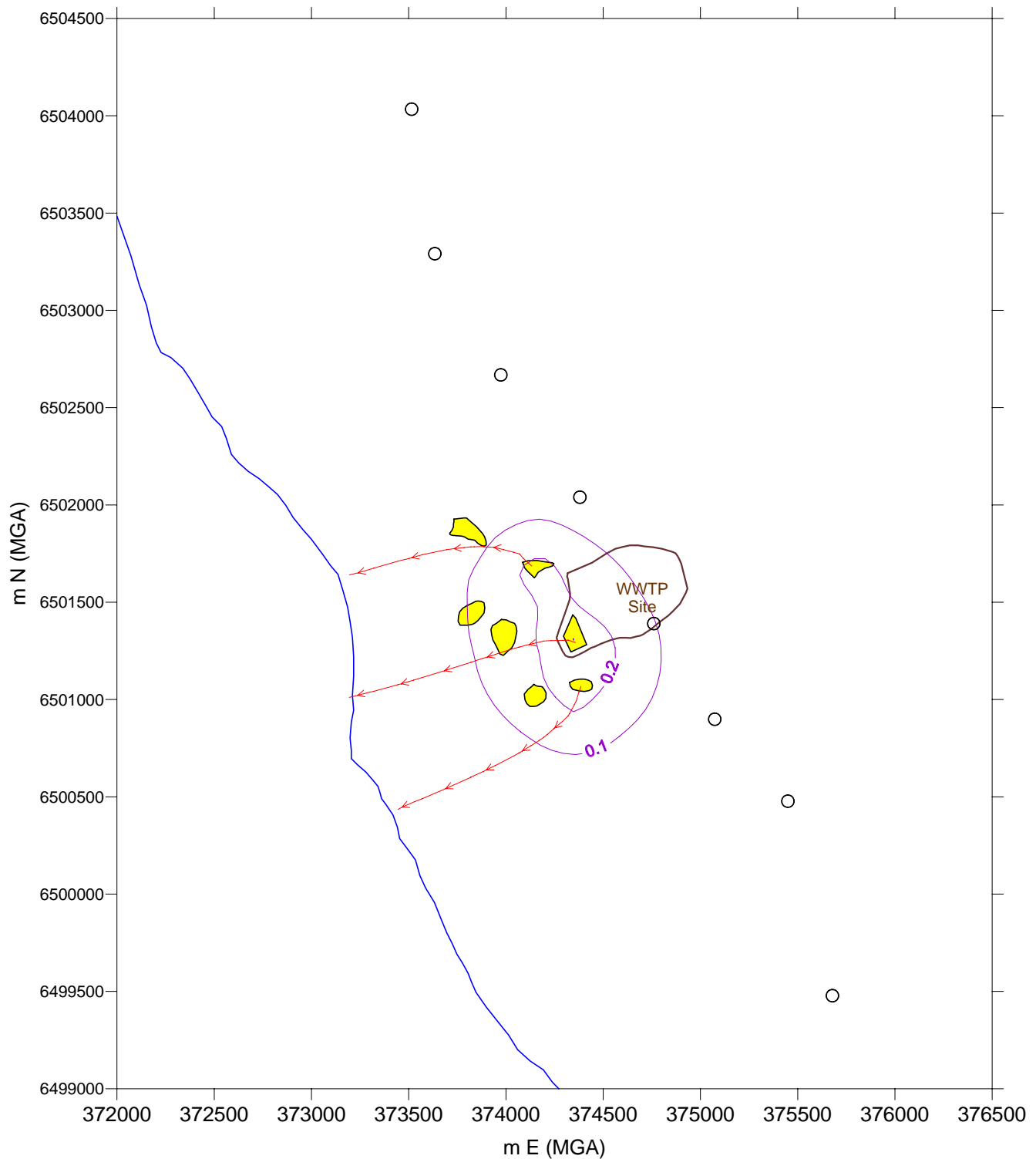
m E (MGA)

○　Planned Eglinton Bore

WWTP
Site

1
2
4
6
8
4
8
6
4
6
4
2
1
8

s2620men.dat/grd/.srf

CLIENT:　Water Corporation

PROJECT: Alkimos WWTP

DATE:　August 2004

Dwg No:　236.38/04/1-16

CALCULATED NITROGEN CONCENTRATIONS (mg/L)

AFTER 13 YEARS INFILTRATION AT UP TO 20 ML/d,

WITH EGLINTON BORES PUMPING

Rockwater Pty Ltd

MODEL-CALCULATED N CONCS (mg/L)
AT SHORE WEST OF WWTP
10 ML/d MAXIMUM INFILTRATION
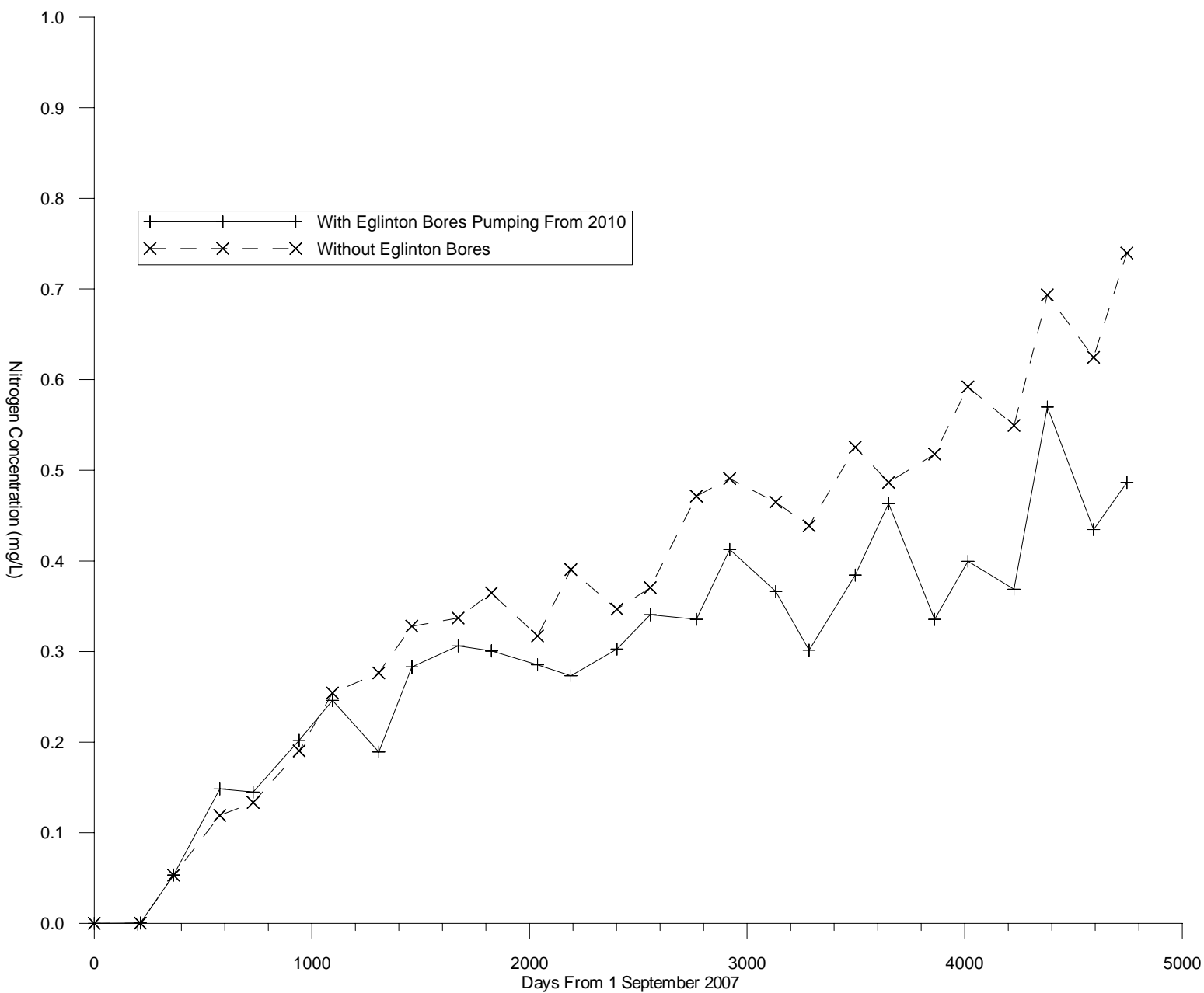
Client: Water Corporation
Project: Alkimos WWTP
Date: August 2004
Dwg. No: 236.38/04/1-17

nconcs.xls/.grf

Rockwater Pty Ltd

FIGURE 17

Nitrogen Concentration (mg/L)

Days From 1 September 2007

With Eglinton Bores Pumping From 2010
Without Eglinton Bores

FIGURE 19

6504000

6503000

6502000

m N (MGA)

6501000

6500000

6499000

WWTP
Site

1 2

4

1

1

4

2

1

372000   373000   374000   375000   376000

m E (MGA)

○   Planned Eglinton Bore

13y6n.dat/grd/.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: September 2004

Dwg No: 236.38/04/1-19

CALCULATED NITROGEN CONCENTRATIONS (mg/L)

AFTER 13 YEARS INFILTRATION AT UP TO 10 ML/d,

WITH ONLY 6 mg/L N, & EGLINTON BORES PUMPING

Rockwater Pty Ltd

FIGURE 20
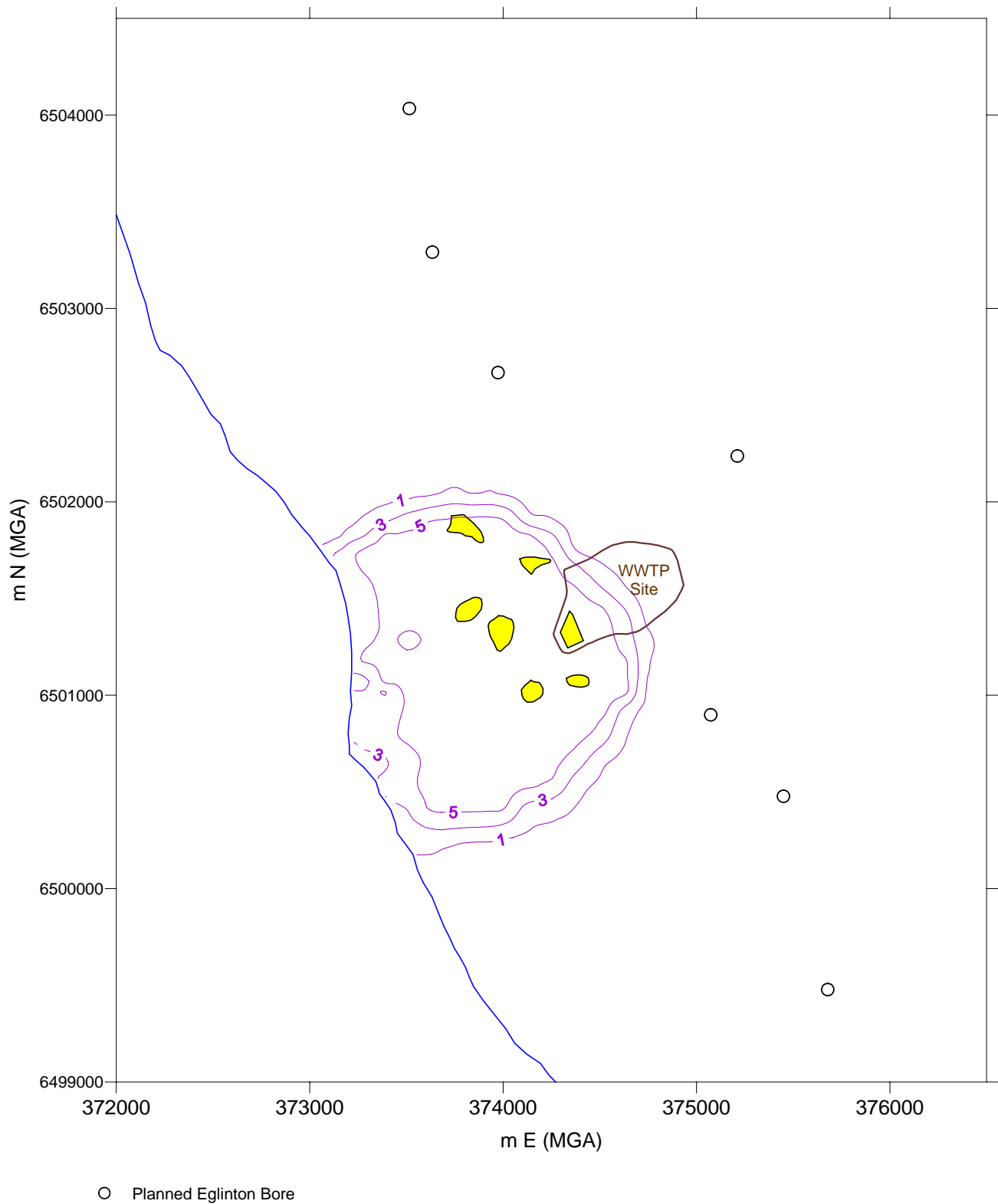
CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: September 2004

Dwg No: 236.38/04/1-20

CALCULATED NITROGEN CONCENTRATIONS (mg/L)

AFTER 13 YEARS INFILTRATION AT UP TO 10 ML/d,

WITH ONLY 6 mg/L N, & EGLINTON BORES PUMPING

WITHOUT DENITRIFICATION

13y6n-dn.dat/grd/.srf

Rockwater Pty Ltd

○ Planned Eglinton Bore

m N (MGA)

m E (MGA)

WWTP
Site

FIGURE 21

Planned Eglinton Bore

Modelled Re-Use Bore
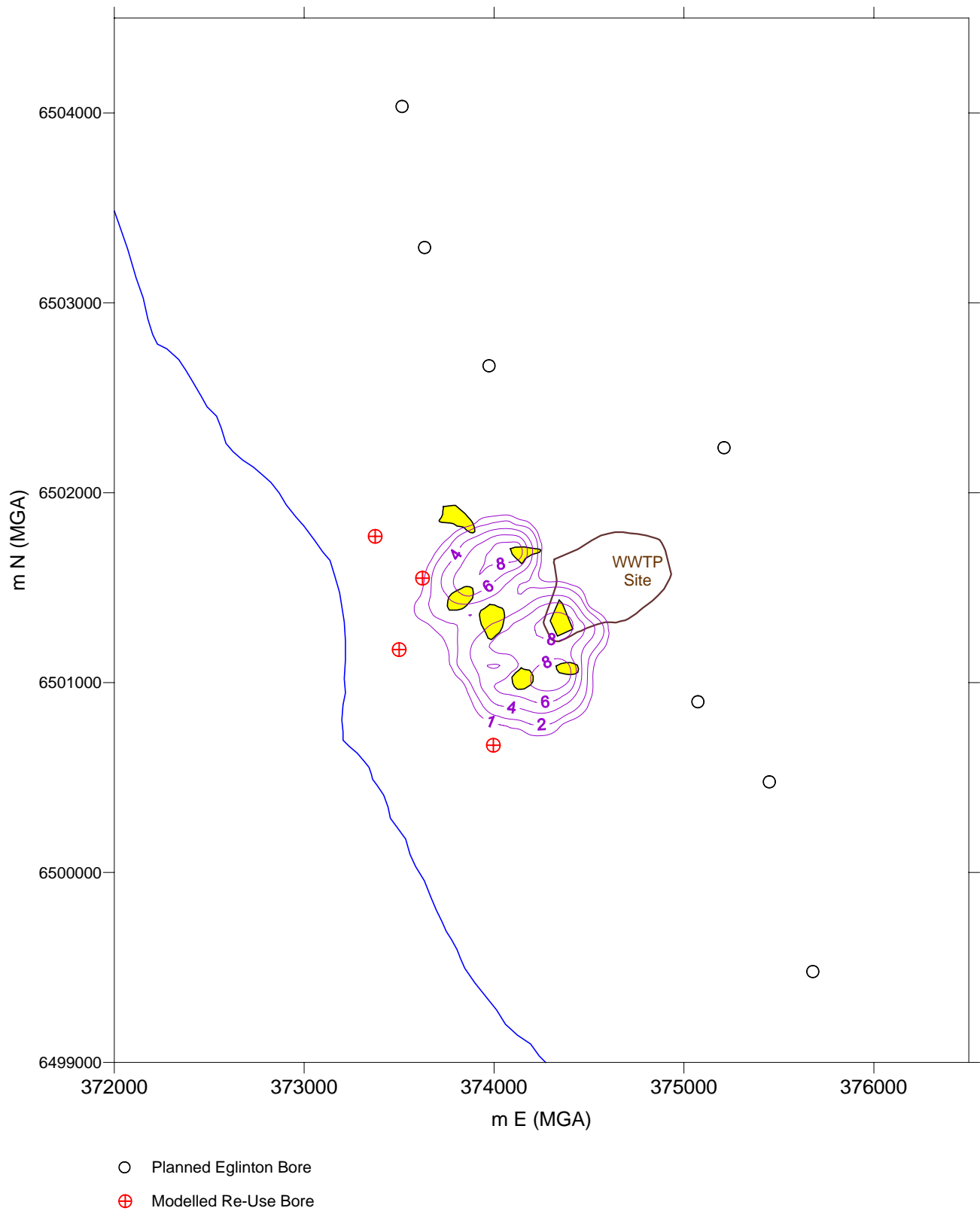
RU1s26n.dat/grd/.srf

CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: October 2004

Dwg No: 236.38/04/1-21

CALCULATED NITROGEN CONCENTRATIONS (mg/L)

AFTER 13 YEARS INFILTRATION AT UP TO 10 ML/d,

WITH EGLINTON AND RE-USE BORES PUMPING

(CASE 6)

Rockwater Pty Ltd

FIGURE 22
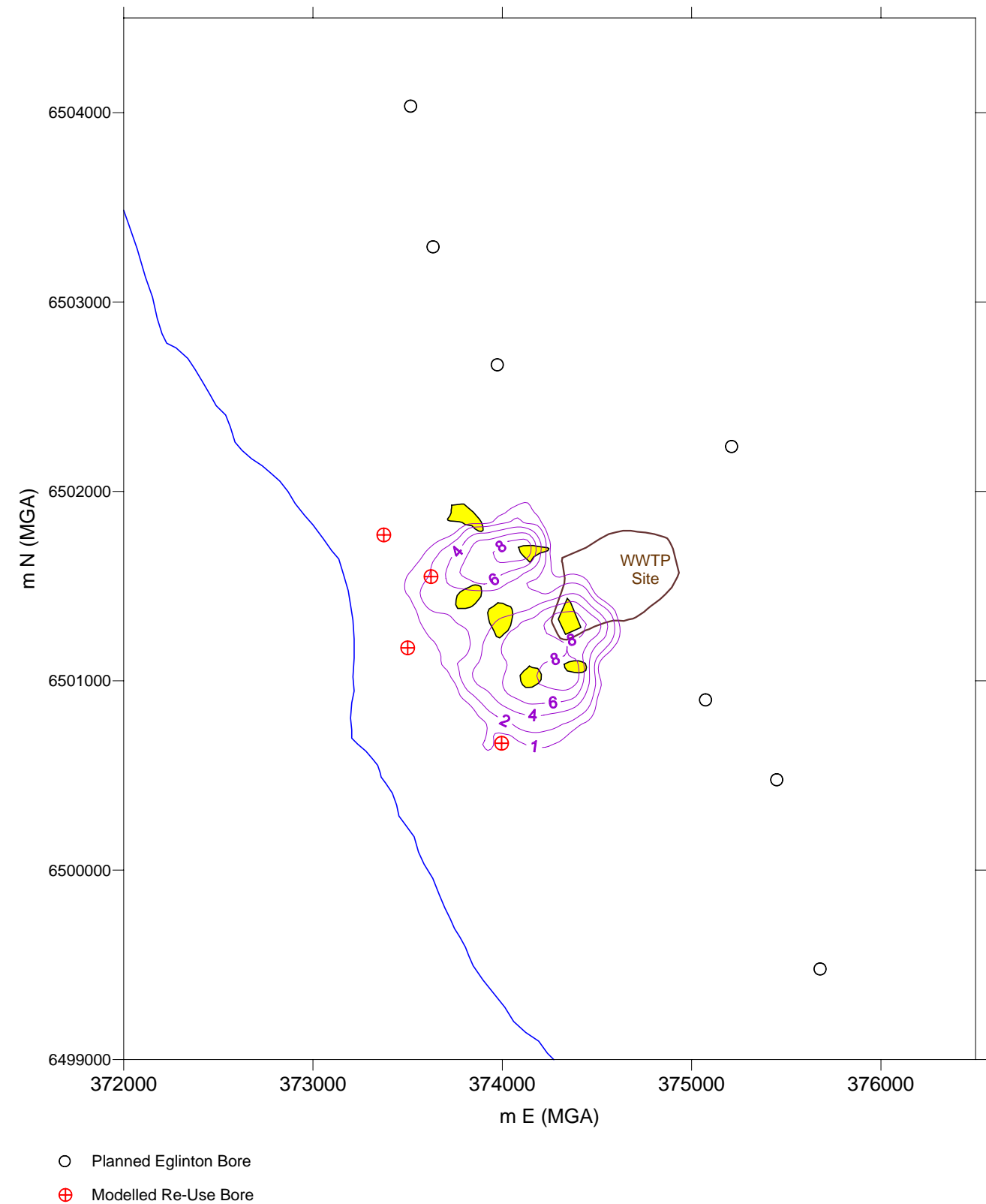
ru2n.dat/grd/.srf

CLIENT: Water Corporation
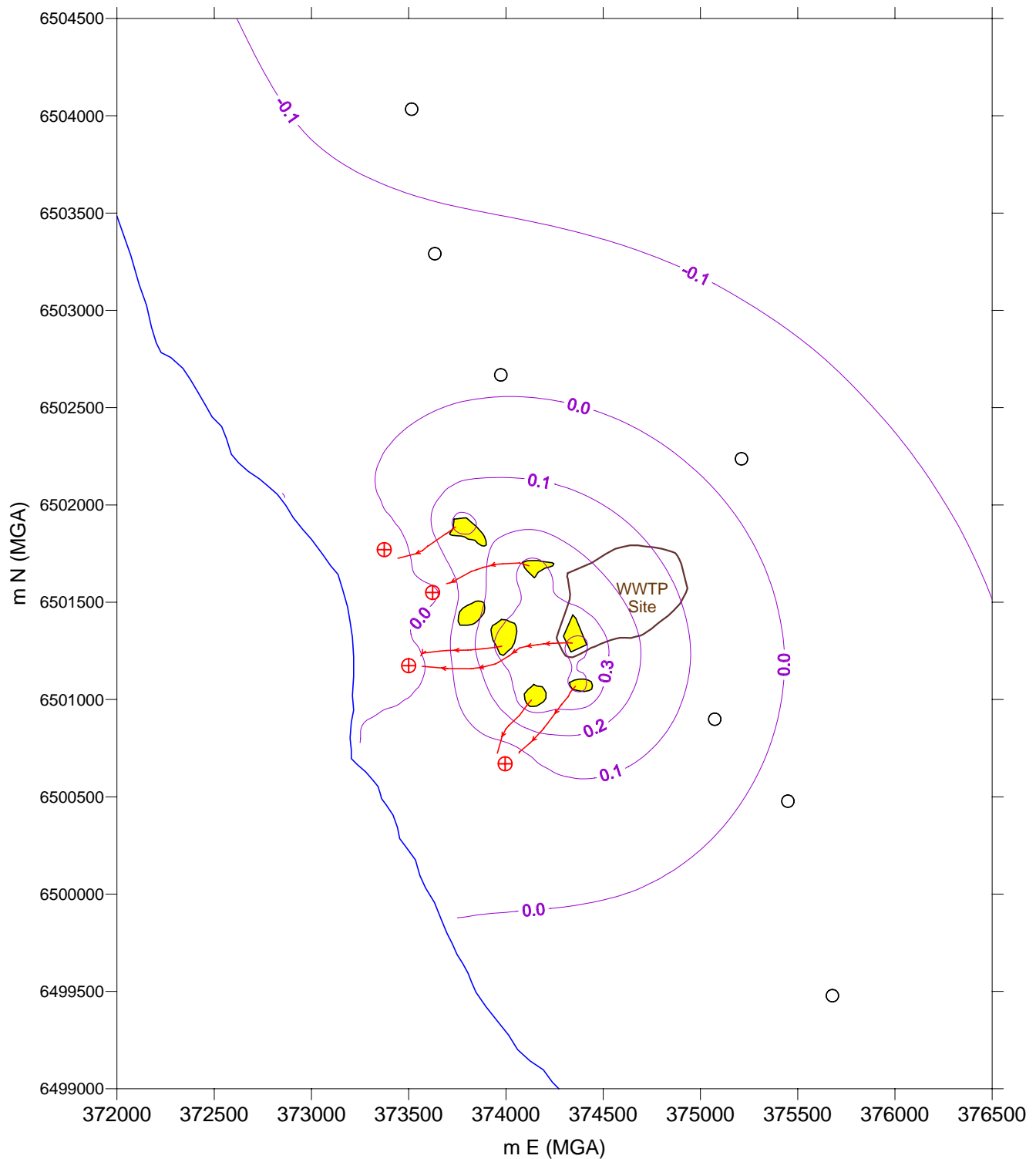
PROJECT: Alkimos WWTP

DATE: October 2004

Dwg No: 236.38/04/1-22

CALCULATED NITROGEN CONCENTRATIONS (mg/L)

AFTER 13 YEARS INFILTRATION AT UP TO 10 ML/d,

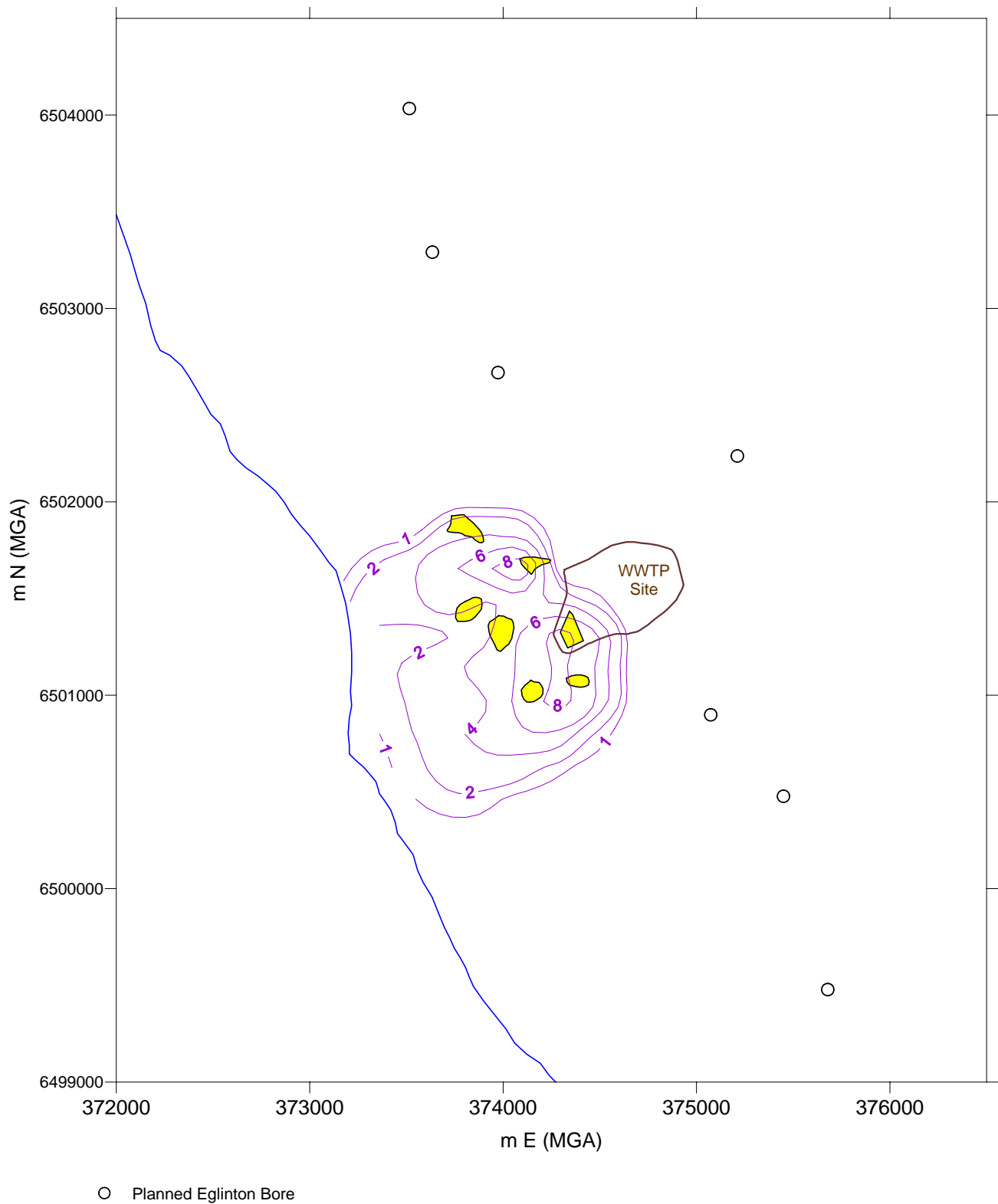WITH EGLINTON AND RE-USE BORES PUMPING

(CASE 7)

Rockwater Pty Ltd

FIGURE 23
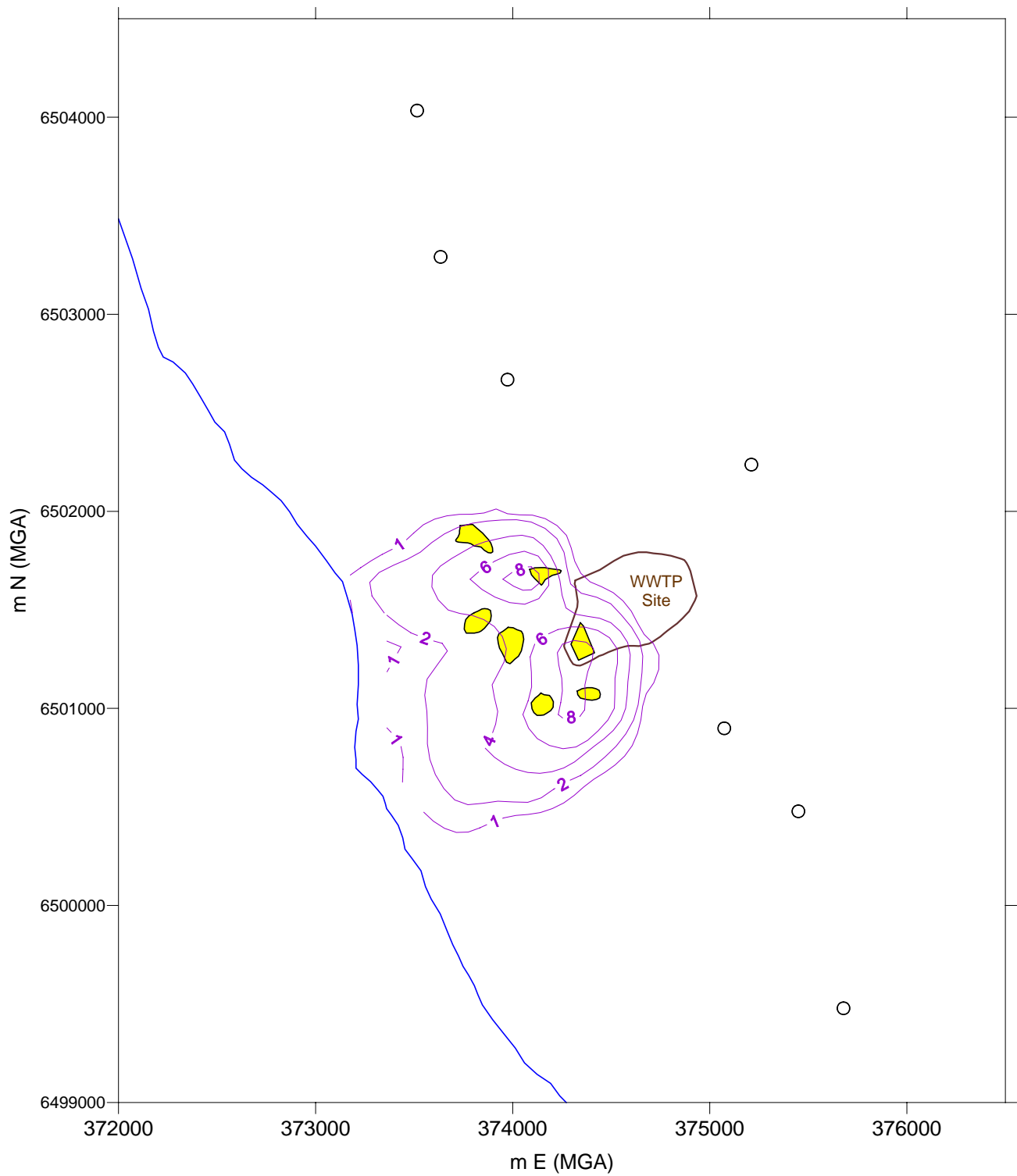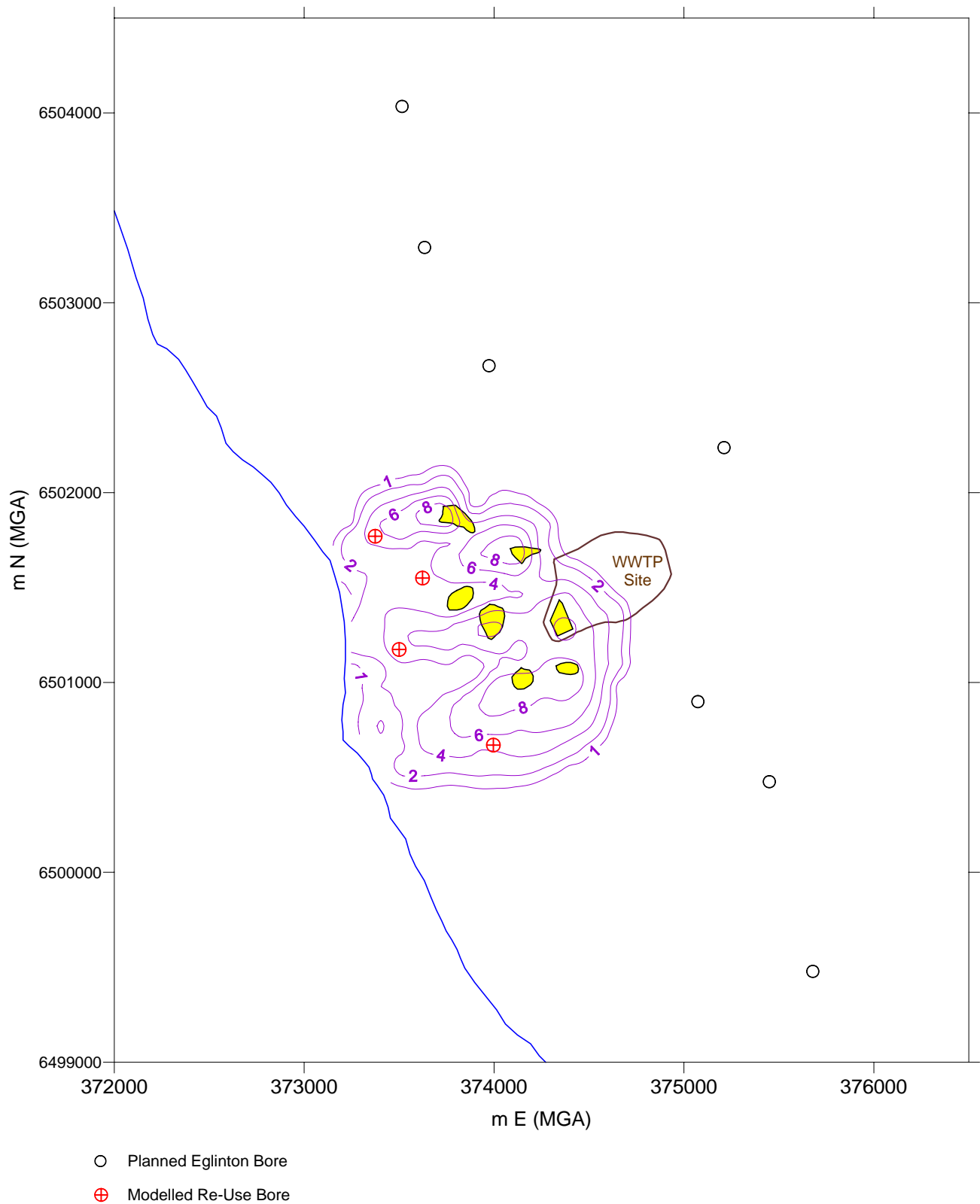
CLIENT: Water Corporation

PROJECT: Alkimos WWTP

DATE: October 2004

Dwg No: 236.38/04/1-23

CALCULATED NITROGEN CONCENTRATIONS (mg/L)

AFTER 13 YEARS INFILTRATION AT UP TO 20 ML/d,
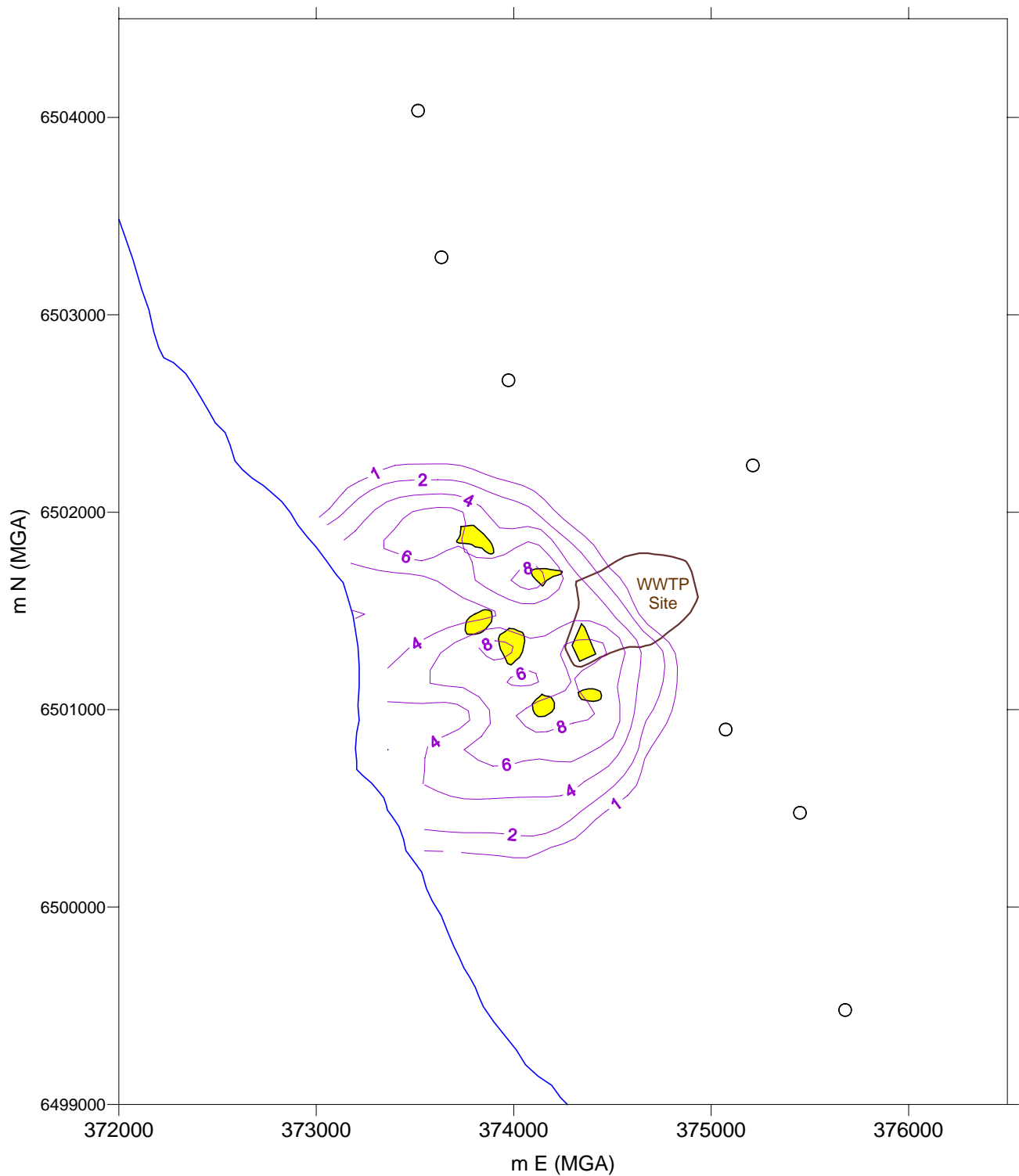
WITH EGLINTON AND RE-USE BORES PUMPING

(CASE 8)

Rockwater Pty Ltd

APPENDICES

APPENDIX I

**LITHOLOGICAL DESCRIPTIONS
OF PIT SAMPLES, ALKIMOS**

APPENDIX I
Lithological Descriptions of Pit Samples,
Alkimos

SITE 1

Depth (m)	Lithology	Description
0 to 0.5 m	Sand with calcarenite rubble	Greyish brown, moderately sorted, medium grained, subangular to subrounded, quartz sand. Some iron staining, minor organic matter. Unconsolidated, with calcarenite rubble (as below).
0.5 to 2.0 m	Calcarenite	Greyish cream, moderately sorted, fine to medium grained, subangular to subrounded, quartz with calcite cement, minor heavy minerals, hard, some fractures.
2.0 to 3.3 m	Sand	Cream, moderately sorted, fine to medium grained, subangular to subrounded, quartz and carbonate (skeletal) grains, weakly cemented.

SITE 2

Depth (m)	Lithology	Description
0 to 0.1 m	Sand	Greyish brown, moderately sorted, medium grained, subangular to subrounded, quartz sand. Some iron staining, minor organic matter, unconsolidated.
0.1 to 1.6 m	Calcarenite	Cream, moderately sorted, fine to medium grained, subrounded, quartz and carbonate (skeletal) grains, calcite cement, hard.
1.6 to 3.0 m	Calcarenite	Creamy orange, moderately- to well-sorted, medium grained, subangular to subrounded, quartz sand. Iron stained, calcite cement, moderately hard.

SITE 3

Depth (m)	Lithology	Description
0 to 0.6 m	Sand	Dark grey, moderately sorted, fine to medium grained, subangular to rounded, quartz and carbonate (skeletal) grains. Some iron staining, minor organic matter, unconsolidated.
0.6 to 2.3 m	Sand	Cream, moderately- to well-sorted, fine to medium grained, subrounded to rounded, quartz and carbonate (skeletal) grains. Some iron staining, unconsolidated.

SITE 4

Depth (m)	Lithology	Description
0 to 0.3 m	Sand	Greyish brown, moderately sorted, fine to medium grained, subangular to rounded, quartz and carbonate (skeletal) grains. Minor organic matter, unconsolidated.
0.3 to 1.0 m	Sand	Cream, moderately sorted, medium grained, subrounded to rounded, quartz and carbonate (skeletal) grains. Some iron staining, unconsolidated.
1.0 to 1.2 m	Sand	Greyish cream, moderately- to well-sorted, medium grained, subrounded to rounded, quartz and minor carbonate (skeletal) grains. Iron stained, unconsolidated.
1.2 to 1.5 m	Sand	Cream, moderately sorted, medium grained, subrounded to rounded, quartz and carbonate (skeletal) grains. Some iron staining, unconsolidated.
1.5 to 2.1 m	Sand	Grey, moderately sorted, fine to medium grained, subangular to subrounded, quartz and minor carbonate (skeletal) grains. Some iron staining, unconsolidated.
2.1 to 3.2 m	Sand	Cream, moderately sorted, fine to medium grained, subangular to subrounded, quartz and carbonate (skeletal) grains, weakly cemented.

SITE 5

Depth (m)	Lithology	Description
0 to 0.3 m	Sand	Greyish brown, moderately to well sorted, medium to coarse grained, subangular to rounded, quartz sand. Some iron staining, minor organic matter, unconsolidated.
0.3 to 1.2 m	Sand	Yellow, moderately sorted, medium to coarse grained, subangular to rounded, quartz sand. Some iron staining, unconsolidated.
1.2 to 3.6 m	Calcarenite	Yellowish cream, moderately sorted, medium grained, subangular to subrounded, quartz with calcite cement. Minor heavy minerals, hard.

SITE 6

Depth (m)	Lithology	Description
0 to 1.7 m	Sand	Dark grey, moderately sorted, fine to coarse grained, subrounded to well-rounded, quartz and carbonate (skeletal) grains. Minor organic matter, unconsolidated.
1.7 to 2.9 m	Calcarenite	Pale creamy orange, moderately sorted, medium grained, subangular to subrounded, quartz sand. Iron stained, calcite cement, moderately hard.

SITE 7

Depth (m)	Lithology	Description
0 to 0.6	Sand	Black, moderately-poorly sorted, fine to medium grained, silty, quartz and carbonate (skeletal) grains. Carbonaceous, unconsolidated.
0.6 to 1.5	Sand	Greyish black, moderately sorted, fine to coarse grained, quartz and carbonate (skeletal) grains. Carbonaceous, unconsolidated.
1.5 to 3.0	Sand	Cream, moderately sorted, fine to medium grained, subrounded to rounded, quartz and carbonate (skeletal) grains. Some iron staining, unconsolidated.

APPENDIX II

SIEVE ANALYSIS, PIT SAMPLES, ALKIMOS

Appendix II: Sieve Analysis, Pit Samples, Alkimos
CLIENT - Water Corporation: Alkimos WWTP   CLIENT No.   236-38

Site 1: 3.0 m

μm	Mass(g)	%	cum %
>1700	0.2	0.1	0.1
1000-1700	0.4	0.3	0.4
500-1000	17	11.0	11.4
250-500	63	40.8	52.1
125-250	71	45.9	98.1
<125	3	1.9	100.0
TOTAL	154.6	90%	
		50%	
		40%	

Site 2: 2.5 m

μm	Mass(g)	%	cum %
>1700	0	0.0	0.0
1000-1700	0.5	0.3	0.3
500-1000	26	14.6	14.9
250-500	116	65.4	80.3
125-250	26	14.6	94.9
<125	9	5.1	100.0
TOTAL	177.5	90%	
		50%	
		40%	

Site 3: 1.0 m

μm	Mass(g)	%	cum %
>1700	0	0.0	0.0
1000-1700	0	0.0	0.0
500-1000	10	3.5	3.5
250-500	145	50.5	54.0
125-250	129	44.9	99.0
<125	3	1.0	100.0
TOTAL	287	90%	
		50%	
		40%	

Site 3: 2.0 m

μm	Mass(g)	%	cum %
>1700	0	0.0	0.0
1000-1700	0.1	0.0	0.0
500-1000	11	3.5	3.5
250-500	193	60.9	64.4
125-250	110	34.7	99.1
<125	3	0.9	100.0
TOTAL	317.1	90%	
		50%	
		40%	

Site 4: 0.6 m

μm	Mass(g)	%	cum %
>1700	0	0.0	0.0
1000-1700	0.2	0.1	0.1
500-1000	17	7.0	7.1
250-500	161	66.5	73.6
125-250	62	25.6	99.2
<125	2	0.8	100.0
TOTAL	242.2	90%	
		50%	
		40%	

Site 4: 2.0 m

μm	Mass(g)	%	cum %
>1700	0	0.0	0.0
1000-1700	0.5	0.2	0.2
500-1000	25	10.7	10.9
250-500	125	53.3	64.2
125-250	74	31.6	95.7
<125	10	4.3	100.0
TOTAL	234.5	90%	
		50%	
		40%	

Appendix II: Sieve Analysis, Pit Samples, Alkimos

CLIENT - Water Corporation: Alkimos WWTP   CLIENT No.   236-38

Site 5: 1.0 m

μm	Mass(g)	%	cum %
>1700	0.1	0.0	0.0
1000-1700	3	0.9	0.9
500-1000	116	33.2	34.1
250-500	204	58.4	92.6
125-250	23	6.6	99.1
<125	3	0.9	100.0
TOTAL	349.1	90%	
		50%	
		40%	

Site 6: 1.0 m

μm	Mass(g)	%	cum %
>1700	0	0.0	0.0
1000-1700	0.5	0.2	0.2
500-1000	60	25.9	26.1
250-500	126	54.4	80.6
125-250	38	16.4	97.0
<125	7	3.0	100.0
TOTAL	231.5	90%	
		50%	
		40%	

Site 7: 1.0 m

μm	Mass(g)	%	cum %
>1700	0.2	0.1	0.1
1000-1700	0.8	0.3	0.4
500-1000	56	22.4	22.8
250-500	111	44.4	67.2
125-250	66	26.4	93.6
<125	16	6.4	100.0
TOTAL	250	90%	
		50%	
		40%	

Site 7: 2.5 m

μm	Mass(g)	%	cum %
>1700	0	0.0	0.0
1000-1700	0.5	0.2	0.2
500-1000	45	15.2	15.3
250-500	152	51.3	66.6
125-250	93	31.4	98.0
<125	6	2.0	100.0
TOTAL	296.5	90%	
		50%	
		40%	

Figure A1

Site 2 (2.5 m)

Grain Size (µm)

Cumulative % Retained

Site 1 (3.0 m)

Grain Size (µm)

Cumulative % Retained
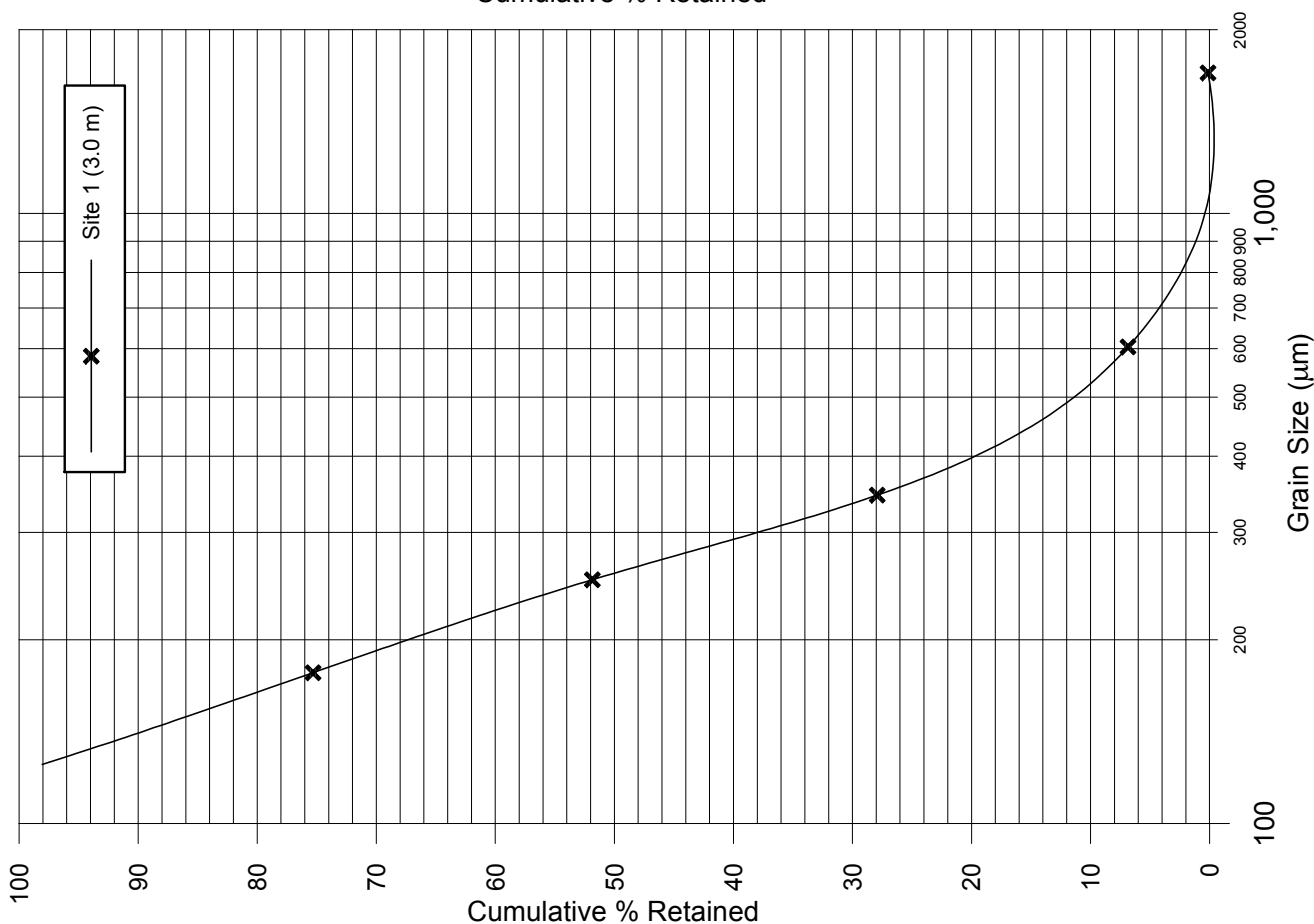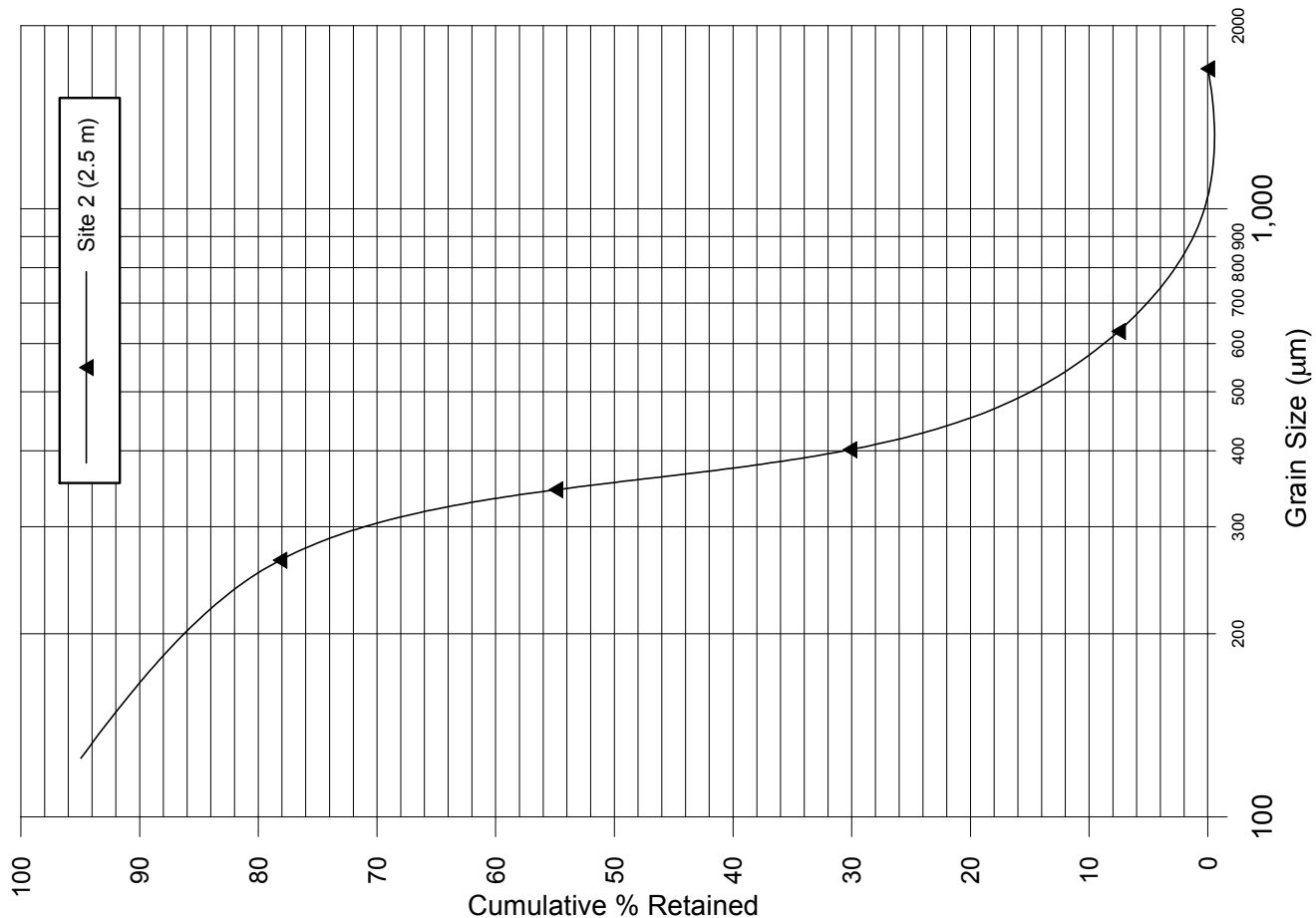
236-38/Grapher/Data/Sieve Tests.xls/Sieves Site 1 and 2.grf

Client: Water Corporation

Project :   Alkimos WWTP Site

Date   :   July 2004

Dwg. No: 236.38/04/1-A1

Grain Size Curves For Pits at Sites 1 and 2
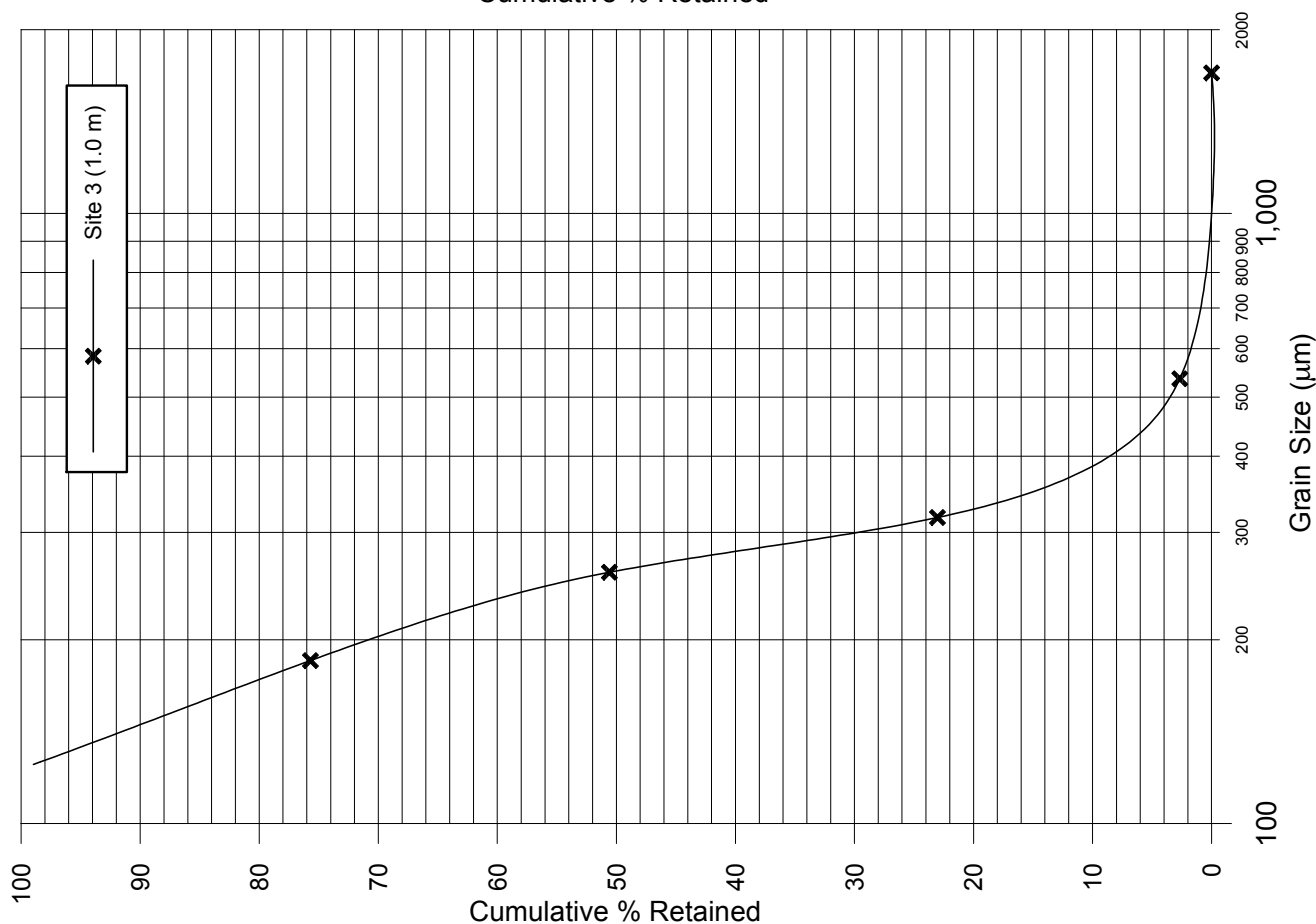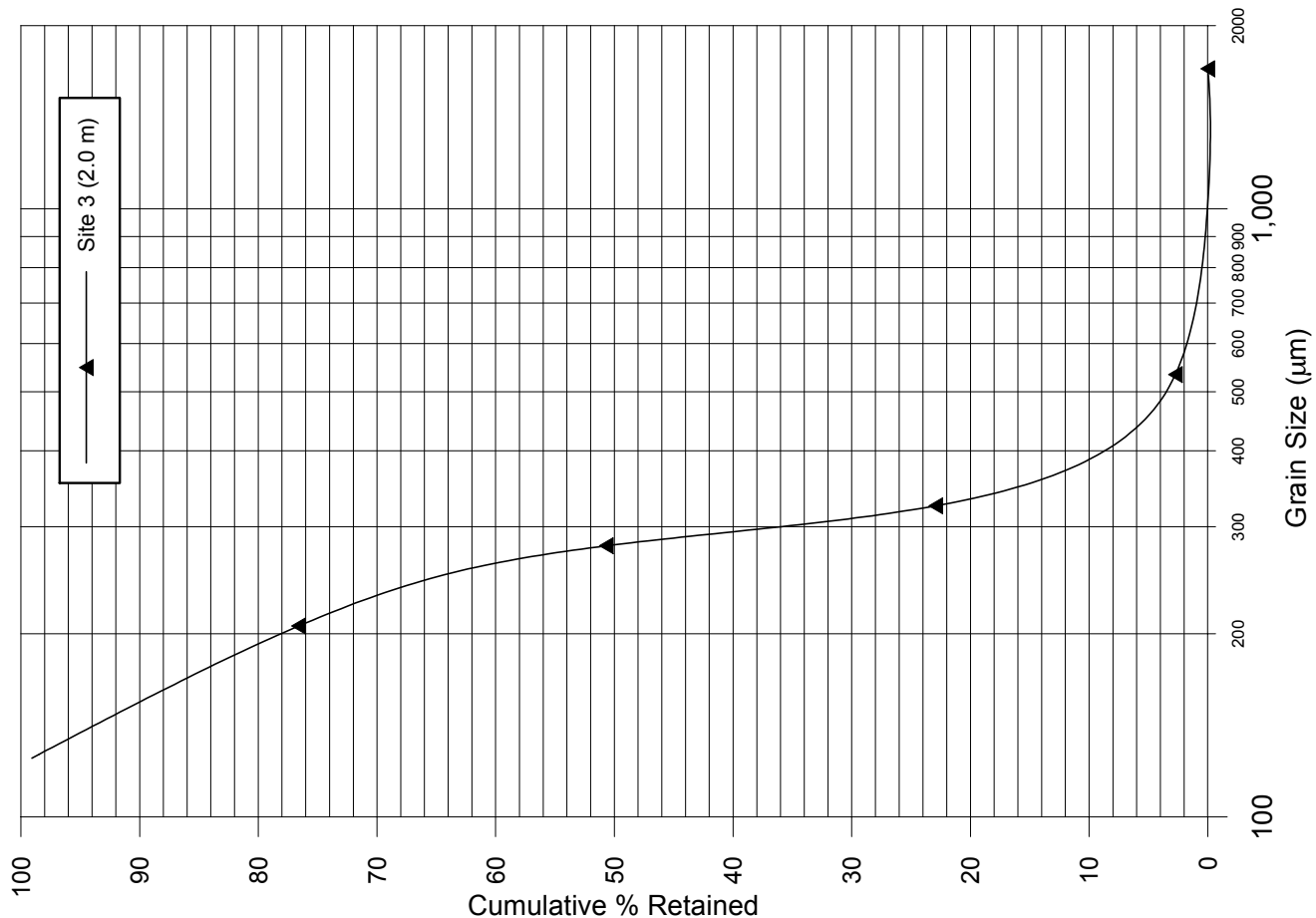
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Figure A2

Grain Size Curves For Pit at Site 3

Client: Water Corporation

Project : Alkimos WWTP Site

Date : July 2004

Dwg. No: 236.38/04/1-A2

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236-38/Grapher/Data/Sieve Tests.xls/Sieves Site 3.grf

Figure A3

Site 4 (2.0 m)

Cumulative % Retained

Grain Size (µm)

Site 4 (0.6 m)

Cumulative % Retained
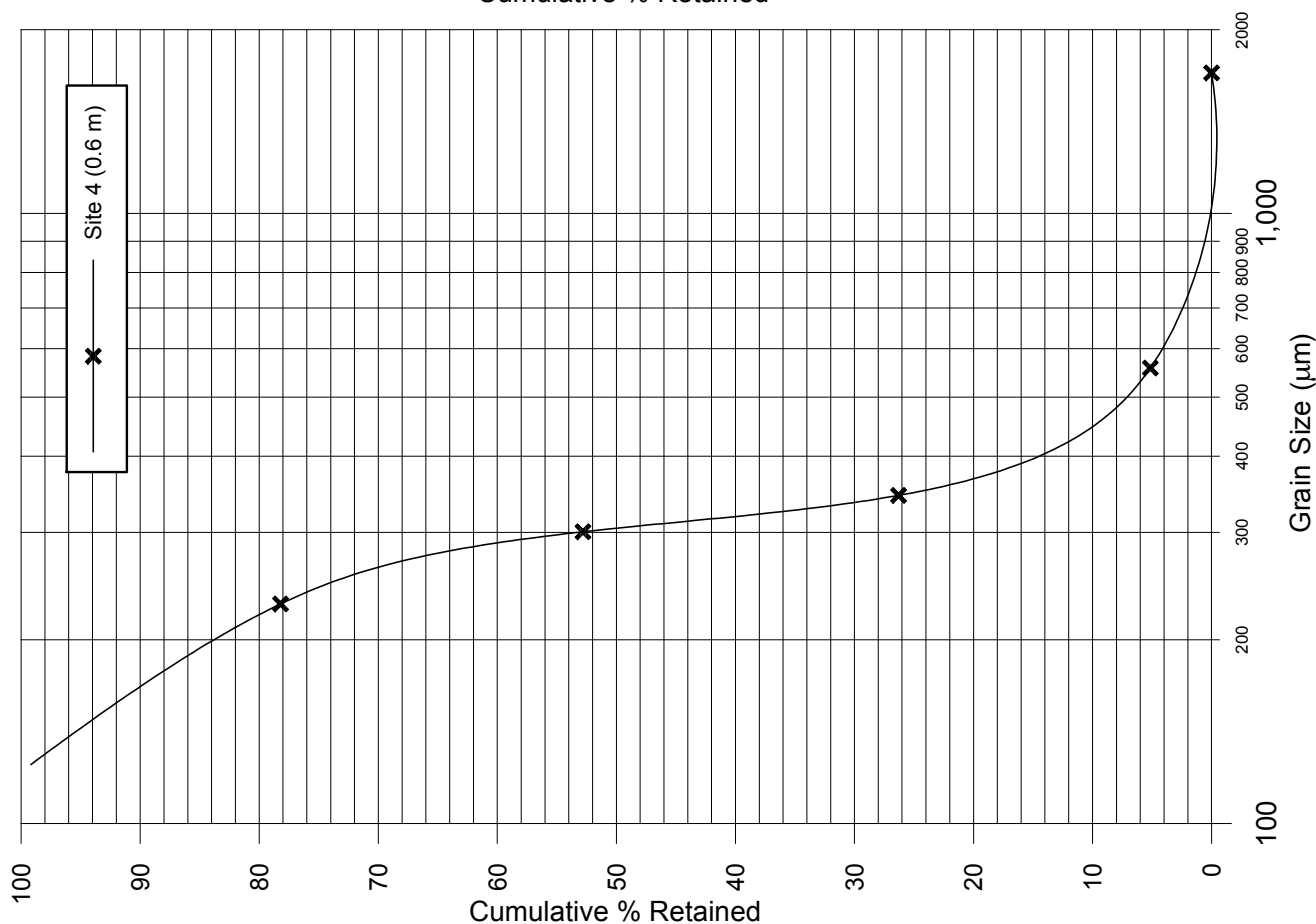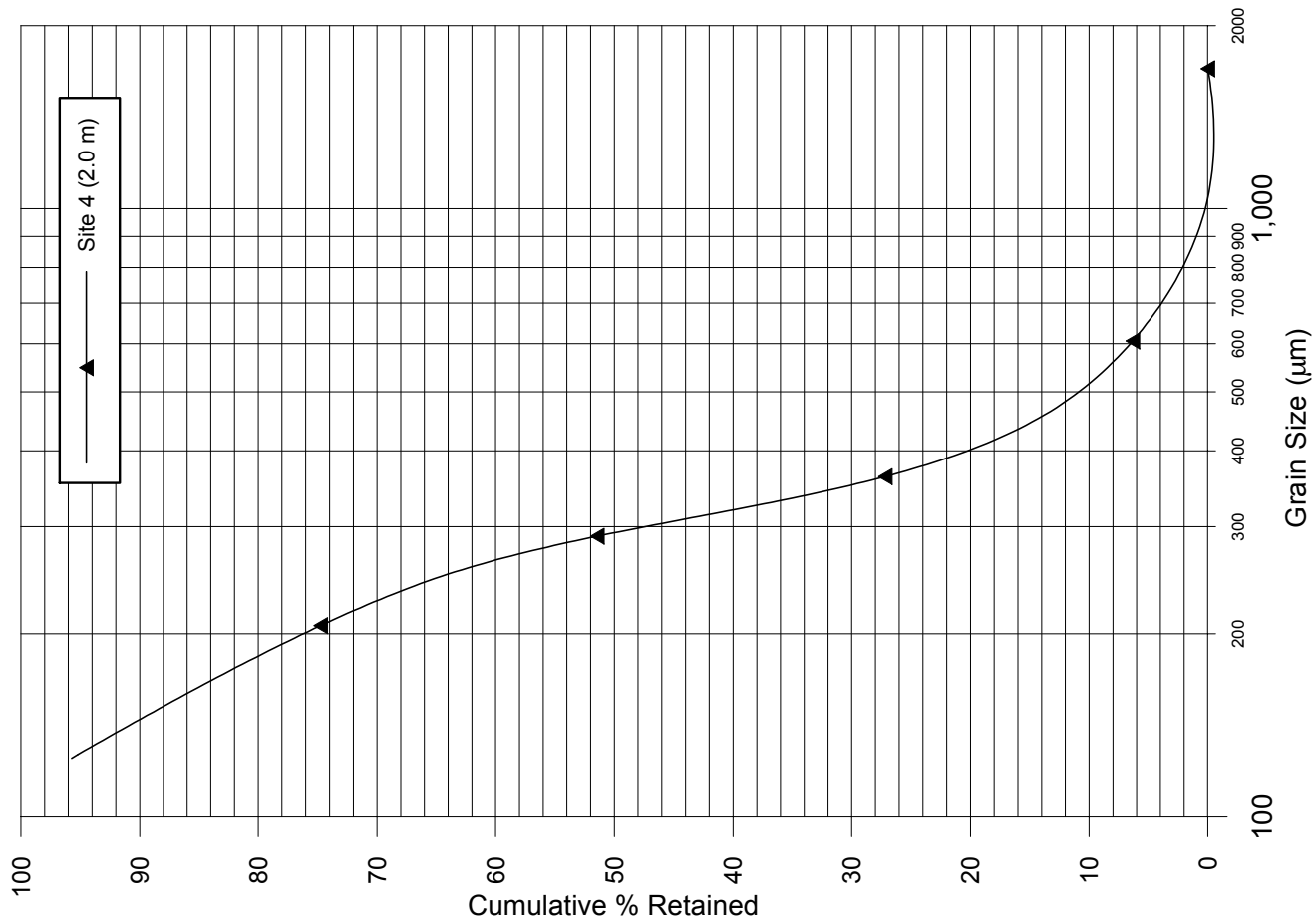
Grain Size (µm)

236-38/Grapher/Data/Sieve Tests.xls/Sieves Site 4.grf

Client: Water Corporation

Project :   Alkimos WWTP Site

Date   :   July 2004

Dwg. No: 236.38/04/1-A3

Grain Size Curves For Pit at Site 4

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Figure A4

Grain Size (μm) — Site 6 (1.0 m)

Cumulative % Retained

Grain Size (μm) — Site 5 (1.0 m)

Cumulative % Retained
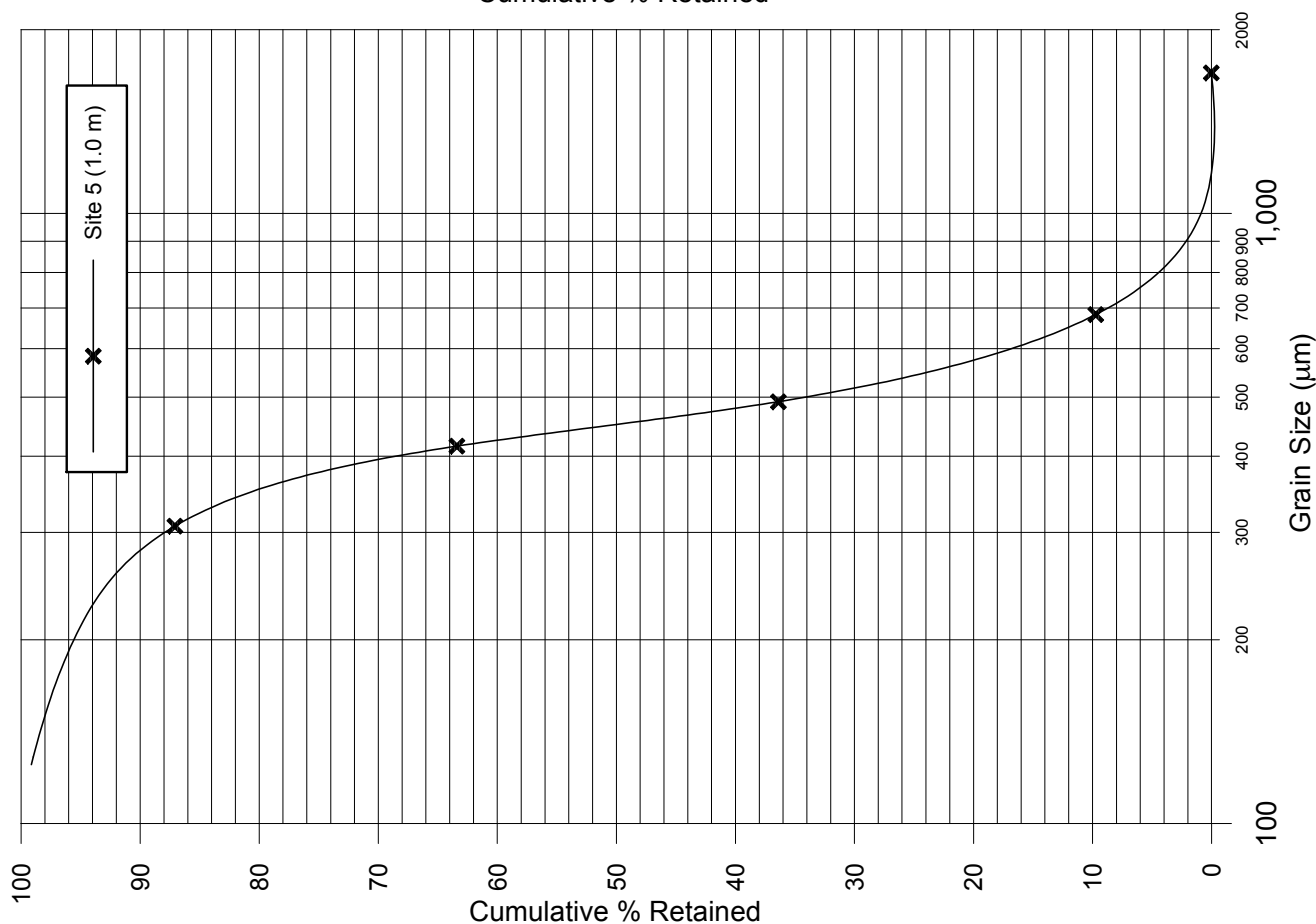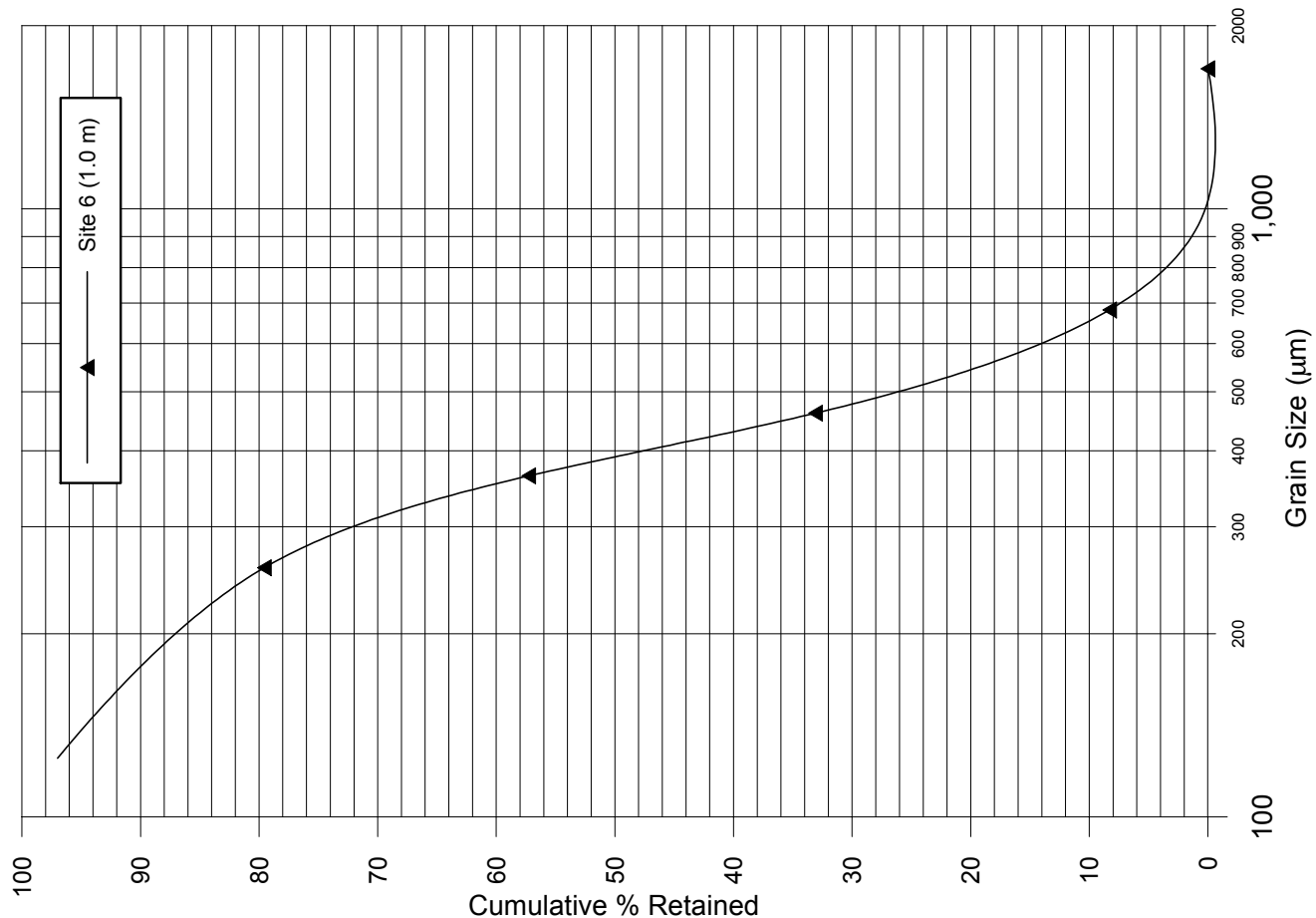
236-38/Grapher/Data/Sieve Tests.xls/Sieves Sites5 and 6.grf

Client: Water Corporation

Project :   Alkimos WWTP Site

Date   :   July 2004

Dwg. No: 236.38/04/1-A4

Grain Size Curves For Pits at Sites 5 and 6

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Figure A5

Site 7 (2.5 m)

Cumulative % Retained

Grain Size (μm)

Site 7 (1.0 m)

Cumulative % Retained
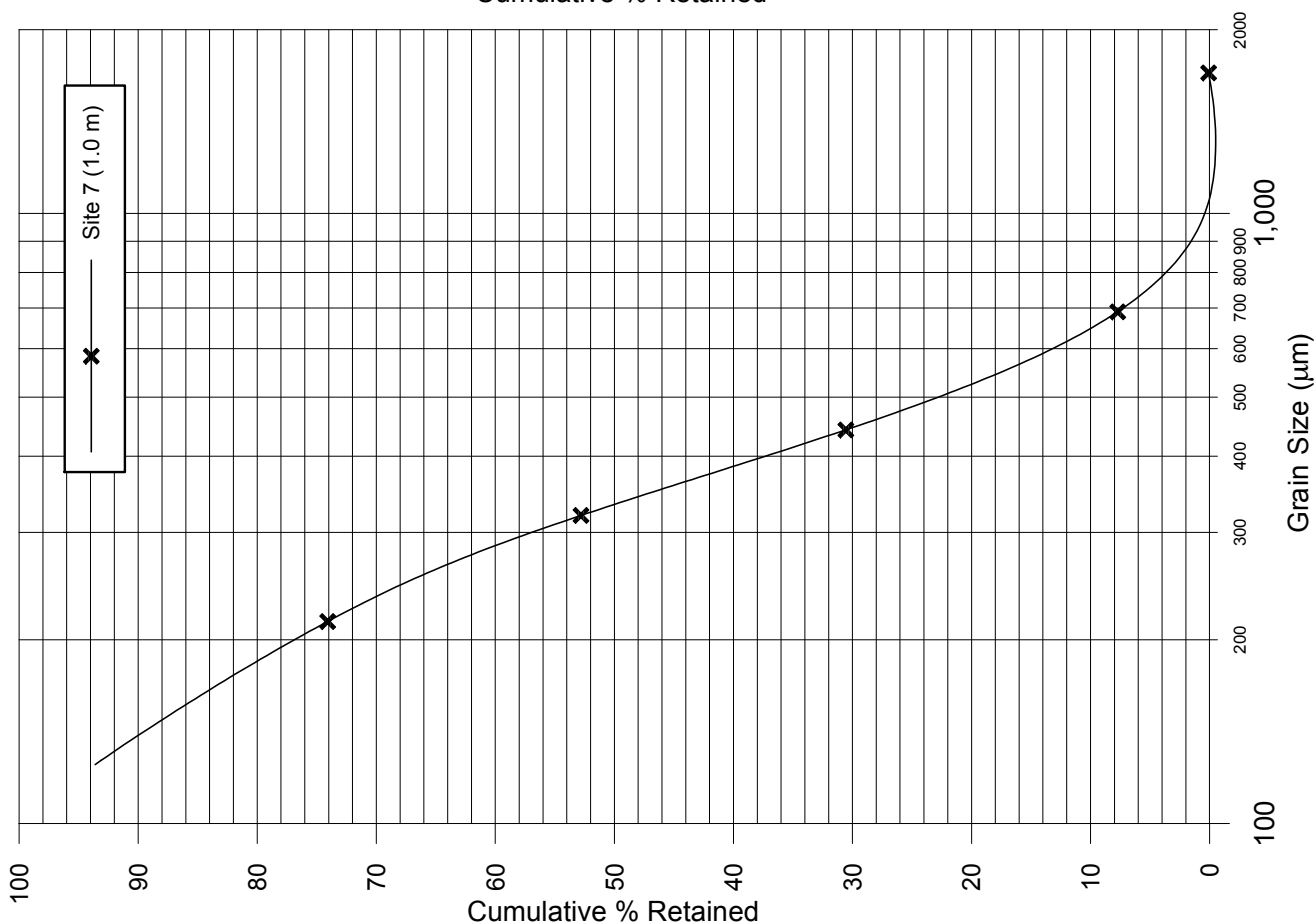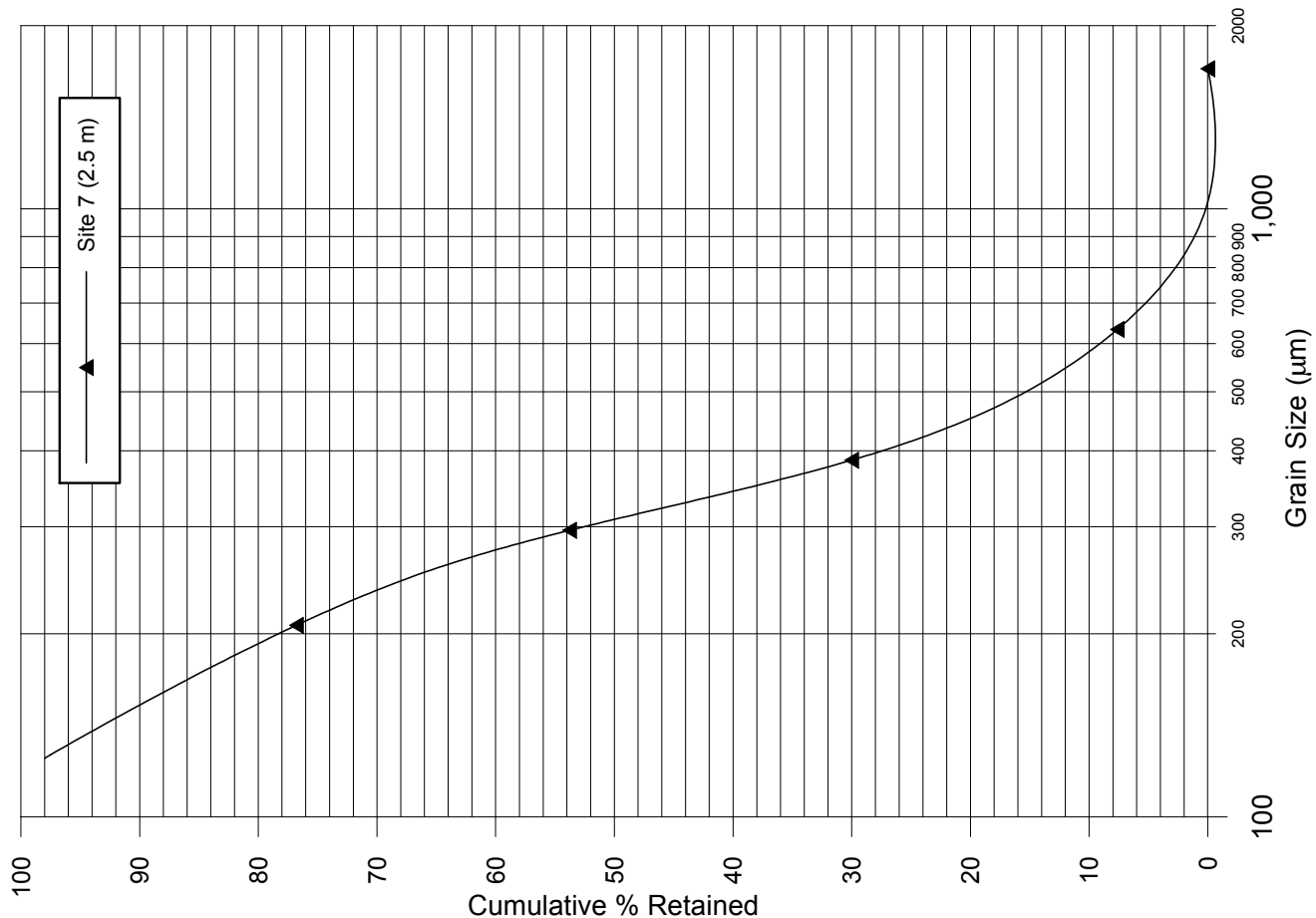
Grain Size (μm)

236-38/Grapher/Data/Sieve Tests.xls/Sieves Site 7.grf

Client: Water Corporation

Project :   Alkimos WWTP Site

Date   :   July 2004

Dwg. No: 236.38/04/1-A5

Grain Size Curves For Pit at Site 7

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APPENDIX III

PIT SOAKAWAY TEST RESULTS

Appendix III: Pit Soakaway Test Results
SITE # 1

(Using Somervilles' Method For Test-pits)

Formula:

$k\ i\ (t_2-t_1) = \log(h1/h2)\quad - \log(\alpha h_1+1/\alpha h_2+2)$

where: $\alpha = P/2A$

(P = mean perimeter, A = area)

(Assumes hydraulic gradient is unity)

a =	2.72	(Area, m^2)
p =	6.60	(Pit perimeter, m)
h_1 =	0.36	(Head at $t_{1,\ m}$)
h_2 =	0.30	(Head at $t_{2,m}$)
t_1 =	1.0	(Time at h_1 in mins)
t_2 =	4	(Time at h_2 in mins)
$t_2 - t_1$ =	3.0	

$\alpha = 1.213$

k   3.0=   0.0792   -   0.0226 (Interim Calculation)

k=   1.89E-02 m/min

=   3.14E-04 m/sec   ⊢ Hydraulic Conductivity

=   27.17 m/day

(i:\blanks\permsom.xls)

Time (min)	Time (sec)	Head (mm)	H (m)
0	0	400	0.4
0.5	30	370	0.37
1	60	360	0.36
2	120	340	0.34
3	180	320	0.32
4	240	300	0.3
5	300	280	0.28
6	360	260	0.26
7	420	240	0.24
8	480	190	0.19
9	540	110	0.11
11	660	50	0.05
15	900	0	0

Appendix III: Pit Soakaway Test Results

SITE # 2

(Using Somervilles' Method For Test-pits)

Formula:

$$k \, i \, (t_2 - t_1) = \log(h1/h2) \quad - \log(\alpha h_1 + 1/\alpha h_2 + 2)$$

where: $\alpha = P/2A$

(P = mean perimeter, A = area)

(Assumes hydraulic gradient is unity)

a =	2.85	(Area, m^2)
p =	6.80	(Pit perimeter, m)
h_1 =	0.36	(Head at $t_{1, m}$)
h_2 =	0.26	(Head at $t_{2,m}$)
t_1 =	1.0	(Time at h_1 in mins)
t_2 =	10	(Time at h_2 in mins)
$t_2 - t_1$ =	9.0	

$\alpha = 1.193$

.   .

k   9.0=   0.1413   -   0.0378 (Interim Calculation)

k=   1.15E-02 m/min

=   1.92E-04 m/sec   ⊢ Hydraulic Conductivity

=   16.56 m/day

(i:\blanks\permsom.xls)

Time (min)	Time (sec)	Head (mm)	H (m)
0	0	370	0.37
0.5	30	360	0.36
1	60	360	0.36
2	120	340	0.34
3	180	330	0.33
4	240	320	0.32
5	300	310	0.31
6	360	310	0.31
7	420	300	0.3
8	480	290	0.29
9	540	270	0.27
10	600	260	0.26
15	900	230	0.23
20	1200	190	0.19
25	1500	160	0.16
30	1800	130	0.13
35	2100	110	0.11
40	2400	80	0.08
45	2700	60	0.06
50	3000	40	0.04
55	3300	20	0.02
60	3600	0	0

Appendix III: Pit Soakaway Test Results

SITE # 3

(Using Somervilles' Method For Test-pits)

Formula:

$$k \, i \, (t_2-t_1) = \log(h1/h2) \quad - \log(\alpha h_1 + 1/\alpha h_2 + 2)$$

where: $\alpha = P/2A$

(P = mean perimeter, A = area)

(Assumes hydraulic gradient is unity)

a =	1.6	(Area, m^2)
p =	5.200	(Pit perimeter, m)
h_1 =	0.16	(Head at $t_{1, m}$)
h_2 =	0.07	(Head at $t_{2,m}$)
t_1 =	1.0	(Time at h_1 in mins)
t_2 =	4	(Time at h_2 in mins)
$t_2 - t_1$ =	3.0	

$\alpha = 1.625$

k	3.0=	0.3556 -	0.0535 (Interim Calculation)

k = 1.01E-01 m/min

= 1.68E-03 m/sec   Hydraulic Conductivity

= 144.99 m/day

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Time (min)	Time (sec)	Head (mm)	H (m)
0	0	195	0.195
0.5	30	177	0.177
1	60	161	0.161
2	120	128	0.128
3	180	100	0.1
4	240	71	0.071
5	300	48	0.048
6	360	25	0.025
7	420	10	0.01
7.83	470	0	0

Appendix III: Pit Soakaway Test Results

SITE # 4

(Using Somervilles' Method For Test-pits)

Formula:

$$k \, i \, (t_2 - t_1) = \log(h1/h2) \quad - \log(\alpha h_1 + 1/\alpha h_2 + 2)$$

where: $\alpha = P/2A$

(P = mean perimeter, A = area)

(Assumes hydraulic gradient is unity)

a =	2.56	(Area, m^2)
p =	6.4	(Pit perimeter, m)
h_1 =	0.156	(Head at $t_{1, m}$)
h_2 =	0.10	(Head at $t_{2,m}$)
t_1 =	1.0	(Time at h_1 in mins)
t_2 =	4	(Time at h_2 in mins)
$t_2 - t_1$ =	3.0	

$\alpha = 1.250$

k   3.0 =   0.1931   -   0.0262   (Interim Calculation)

k =   5.56E-02 m/min

=   9.27E-04 m/sec ⎤
                          ├ Hydraulic Conductivity
=   80.12 m/day ⎦

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Time (min)	Time (sec)	Head (mm)	H (m)
0	0	180	0.18
0.5	30	168	0.168
1	60	156	0.156
2	120	135	0.135
3	180	118	0.118
4	240	100	0.1
5	300	83	0.083
6	360	68	0.068
7	420	50	0.05
8	480	30	0.03
9	540	10	0.01
10	600	0	0

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APPIII: Pit Soakaway Test Results

SITE # 5

(Using Somervilles' Method For Test-pits)

Formula:

$k \, i \, (t_2 - t_1) = \log(h1/h2) \quad - \log(\alpha h_1 + 1/\alpha h_2 + 2)$

where: $\alpha = P/2A$

(P = mean perimeter, A = area)

(Assumes hydraulic gradient is unity)

$a =$	2.1	(Area, m^2)
$p =$	5.8	(Pit perimeter, m)
$h_1 =$	0.45	(Head at $t_{1, m}$)
$h_2 =$	0.39	(Head at $t_{2,m}$)
$t_1 =$	1.0	(Time at h_1 in mins)
$t_2 =$	10	(Time at h_2 in mins)
$t_2 - t_1 =$	9.0	

$\alpha = 1.381$

k   9.0=   0.0644   -   0.0236   (Interim Calculation)

k=   4.54E-03 m/min

=   7.56E-05 m/sec   ⊢ Hydraulic Conductivity

=   6.53 m/day

(i:\blanks\permsom.xls)

Time (min)	Time (sec)	Head (mm)	H (m)
0	0	460	0.46
0.5	30	455	0.455
1	60	450	0.45
2	120	440	0.44
3	180	435	0.435
4	240	425	0.425
5	300	420	0.42
6	360	410	0.41
7	420	408	0.408
8	480	402	0.402
9	540	395	0.395
10	600	388	0.388
15	900	360	0.36
20	1200	335	0.335
25	1500	310	0.31
30	1800	290	0.29
35	2100	265	0.265
40	2400	240	0.24
45	2700	222	0.222
50	3000	200	0.2
55	3300	180	0.18
60	3600	160	0.16
65	3900	140	0.14
70	4200	120	0.12

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SITE # 6

Formula:

$k \, i \, (t_2-t_1) = \log(h1/h2) - \log(\alpha h_1 + 1/\alpha h_2 + 2)$

where: $\alpha = P/2A$

(P = mean perimeter, A = area)

    (Assumes hydraulic gradient is unity)

a =	1.96	(Area, m^2)
p =	5.6	(Pit perimeter, m)
h_1 =	0.54	(Head at $t_{1,\,m}$)
h_2 =	0.50	(Head at $t_{2,m}$)
t_1 =	1.0	(Time at h_1 in mins)
t_2 =	10	(Time at h_2 in mins)
$t_2 - t_1$ =	9.0	

$\alpha = 1.429$

.   .

k   9.0 =   0.0369   -   0.0157   (Interim Calculation)

k =   2.36E-03 m/min

=   3.93E-05 m/sec   ⌐ Hydraulic Conductivity

=   3.40 m/day

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Time (min)	Time (sec)	Head (mm)	H (m)
0	0	550	0.55
0.5	30	545	0.545
1	60	540	0.54
2	120	535	0.535
3	180	530	0.53
4	240	524	0.524
5	300	518	0.518
6	360	514	0.514
7	420	508	0.508
8	480	504	0.504
9	540	500	0.5
10	600	496	0.496
15	900	478	0.478
20	1200	460	0.46
25	1500	440	0.44
30	1800	427	0.427
35	2100	412	0.412
40	2400	400	0.4
45	2700	387	0.387
50	3000	375	0.375
55	3300	360	0.36
60	3600	349	0.349

SITE # 7

(Using Somervilles' Method For Test-pits)

Formula:

$k \, i \, (t_2 - t_1) = \log(h1/h2) \quad - \log(\alpha h_1 + 1/\alpha h_2 + 2)$

where: $\alpha = P/2A$

(P = mean perimeter, A = area)

(Assumes hydraulic gradient is unity)

a =	3.24	(Area, m^2)
p =	7.2	(Pit perimeter, m)
h_1 =	0.21	(Head at $t_{1, m}$)
h_2 =	0.18	(Head at $t_{2, m}$)
t_1 =	1.0	(Time at h_1 in mins)
t_2 =	4	(Time at h_2 in mins)
$t_2 - t_1$ =	3.0	

$\alpha = 1.111$

.   .

k   3.0 =   0.0669   -   0.0119 (Interim Calculation)

k =   1.83E-02 m/min

=   3.06E-04 m/sec   ⎤

=   26.42 m/day   ⎦   ─ Hydraulic Conductivity

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Time (min)	Time (sec)	Head (mm)	H (m)
0	0	310	0.31
0.5	30	260	0.26
1	60	210	0.21
2	120	200	0.2
3	180	190	0.19
4	240	180	0.18
5	300	180	0.18
6	360	160	0.16
7	420	130	0.13
8	480	110	0.11
9	540	100	0.1
10	600	90	0.09
15	900	10	0.01
16	960	0	0

APPENDIX IV

RING INFILTROMETER TEST RESULTS

Appendix IV: Ring Infiltrometer Test Results

CLIENT -   Water Corporation: Alkimos WWTP   **CLIENT No.   236-38**

Site 3, Test 1

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)
0	0	173	0.173	**Incremental permeabilities**	
0.5	30	165	0.165	2.52E-04	21.8
1	60	159	0.159	1.97E-04	17.1
2	120	140	0.14	3.39E-04	29.3
3	180	128	0.128	2.39E-04	20.6
4	240	115	0.115	2.85E-04	24.7
5	300	105	0.105	2.42E-04	21.0
6	360	97	0.097	2.11E-04	18.3
7	420	84	0.084	3.84E-04	33.1
8	480	73	0.073	3.74E-04	32.3
9	540	64	0.064	3.51E-04	30.3
10	600	53	0.053	5.03E-04	43.4
11	660	42	0.042	6.20E-04	53.6
13.25	795	0	0		
			Average k (m/d) =	3.33E-04	28.8

Std Deviation
10.89
Variance
118.63

Site 3, Test 2

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)
0	0	177	0.177	**Incremental permeabilities**	
0.5	30	164	0.164	4.07E-04	35.1
1	60	156	0.156	2.67E-04	23.0
2	120	145	0.145	1.95E-04	16.8
3	180	130	0.13	2.91E-04	25.1
4	240	118	0.118	2.58E-04	22.3
5	300	108	0.108	2.36E-04	20.4
6	360	98	0.098	2.59E-04	22.4
7	420	87	0.087	3.17E-04	27.4
8	480	76	0.076	3.60E-04	31.1
10	600	53	0.053	4.80E-04	41.5
13.5	810	0	0		
			Average k (m/d) =	3.07E-04	26.5

Std Deviation
7.46
Variance
55.68

Appendix IV: Ring Infiltrometer Test Results

CLIENT -   Water Corporation: Alkimos WWTP   **CLIENT No.   236-38**

Site 4, Test 1

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)		
0	0	185	0.185	**Incremental permeabilities**			
0.5	30	175	0.175	2.96E-04	25.6		
1	60	165	0.165	3.14E-04	27.1		
2	120	145	0.145	3.44E-04	29.8		
3	180	129	0.129	3.12E-04	26.9		
4	240	110	0.11	4.25E-04	36.7		
5	300	95	0.095	3.91E-04	33.8		
6	360	78	0.078	5.26E-04	45.4		
7	420	64	0.064	5.27E-04	45.6		
8	480	49	0.049	7.12E-04	61.5		
9	540	35	0.035	8.97E-04	77.5		**Std Deviation**
10	600	17	0.017	1.92E-03	166.3	*	17.06
10.17	610.2	0	0				**Variance**
			Average k (m/d) =	4.74E-04	41.0		290.90

Site 4, Test 2

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)		
0	0	177	0.177	**Incremental permeabilities**			
0.5	30	160	0.16	5.38E-04	46.5		
1	60	150	0.15	3.44E-04	29.7		
2	120	133	0.133	3.21E-04	27.7		
3	180	113	0.113	4.34E-04	37.5		
4	240	94	0.094	4.91E-04	42.4		
5	300	76	0.076	5.67E-04	49.0		
6	360	59	0.059	6.75E-04	58.3		
7	420	43	0.043	8.43E-04	72.9		**Std Deviation**
8	480	24	0.024	1.55E-03	134.3	*	14.95
9	540	0	0				**Variance**
			Average k (m/d) =	5.27E-04	45.5		223.44

* Anomalous values eliminated in calculating averages, Std deviation and variance

Appendix IV: Ring Infiltrometer Test Results

CLIENT - Water Corporation: Alkimos WWTP   **CLIENT No.   236-38**

Site 5, Test 1

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)		
0	0	170	0.17	**Incremental permeabilities**			
0.5	30	145	0.145	8.48E-04	73.3		
1	60	138	0.138	2.64E-04	22.8		
2	120	115	0.115	4.86E-04	42.0		
3	180	90	0.09	6.53E-04	56.5		
4	240	70	0.07	6.70E-04	57.9		
5	300	40	0.04	1.49E-03	128.9	*	**Std Deviation**
6	360	10	0.01	3.70E-03	319.3	*	19.03
7	420	0	0				**Variance**
			Average k (m/d) =	5.84E-04	50.5		362.11

Site 5, Test 2

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)		
0	0	170	0.17	**Incremental permeabilities**			
0.5	30	155	0.155	4.92E-04	42.5		
1	60	148	0.148	2.46E-04	21.3		
2	120	133	0.133	2.85E-04	24.6		
3	180	120	0.12	2.74E-04	23.7		
4	240	103	0.103	4.07E-04	35.2		
5	300	90	0.09	3.60E-04	31.1		
6	360	78	0.078	3.81E-04	33.0		
7	420	63	0.063	5.69E-04	49.2		
8	480	48	0.048	7.25E-04	62.6		
9	540	30	0.03	1.25E-03	108.2	*	**Std Deviation**
10	600	15	0.015	1.85E-03	159.6	*	13.50
10.67	640.2	0	0				**Variance**
			Average k (m/d) =	4.16E-04	35.9		182.22

* Anomalous values eliminated in calculating averages, Std deviation and variance

Appendix IV: Ring Infiltrometer Test Results

CLIENT - Water Corporation: Alkimos WWTP   CLIENT No.   236-38

Site 6, Test 1

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)		
0	0	200	0.2	**Incremental permeabilities**			
0.5	30	190	0.19	2.73E-04	23.6		
1	60	180	0.18	2.88E-04	24.9		
2	120	160	0.16	3.14E-04	27.1		
3	180	145	0.145	2.62E-04	22.7		
4	240	125	0.125	3.96E-04	34.2		
5	300	110	0.11	3.41E-04	29.4		
6	360	93	0.093	4.48E-04	38.7		
7	420	78	0.078	4.69E-04	40.5		
8	480	68	0.068	3.66E-04	31.6		
9	540	50	0.05	8.20E-04	70.8	*	**Std Deviation**
10	600	35	0.035	9.51E-04	82.1	*	6.46
11.67	700.2	0	0				**Variance**
			Average k (m/d) =	3.51E-04	30.3		41.70

Site 6, Test 2

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)		
0	0	200	0.2	**Incremental permeabilities**			
0.5	30	195	0.195	1.35E-04	11.7		
1	60	180	0.18	4.27E-04	36.9		
2	120	165	0.165	2.32E-04	20.0		
3	180	148	0.148	2.90E-04	25.0		
4	240	130	0.13	3.46E-04	29.9		
5	300	115	0.115	3.27E-04	28.2		
6	360	97	0.097	4.54E-04	39.2		
7	420	81	0.081	4.81E-04	41.5		
8	480	70	0.07	3.89E-04	33.6		
9	540	54	0.054	6.92E-04	59.8	*	**Std Deviation**
10	600	38	0.038	9.37E-04	80.9	*	9.61
12.08	724.8	0	0				**Variance**
			Average k (m/d) =	3.42E-04	29.6		92.38

* Anomalous values eliminated in calculating averages, Std deviation and variance

Appendix IV: Ring Infiltrometer Test Results

CLIENT -   Water Corporation: Alkimos WWTP   **CLIENT No.   236-38**

Site 7, Test 1

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)		
0	0	140	0.14	**Incremental permeabilities**			
0.5	30	130	0.13	3.95E-04	34.1		
1	60	122	0.122	3.39E-04	29.3		
2	120	115	0.115	1.58E-04	13.6		
3	180	95	0.095	5.09E-04	44.0		
4	240	75	0.075	6.30E-04	54.4		
5	300	60	0.06	5.95E-04	51.4		
6	360	45	0.045	7.67E-04	66.3		
7	420	30	0.03	1.08E-03	93.4	*	**Std Deviation**
8	480	20	0.02	1.08E-03	93.4	*	17.63
9	540	0	0				**Variance**
			Average k (m/d) =	4.85E-04	41.9		310.93

Site 7, Test 2

Time (min)	Time (sec)	Head (mm)	H (m)	k (m/s)	k (m/d)		
0	0	160	0.16	**Incremental permeabilities**			
0.5	30	150	0.15	3.44E-04	29.7		
1	60	140	0.14	3.68E-04	31.8		
2	120	120	0.12	4.11E-04	35.5		
3	180	110	0.11	2.32E-04	20.0		
4	240	95	0.095	3.91E-04	33.8		
5	300	80	0.08	4.58E-04	39.6		
6	360	68	0.068	4.33E-04	37.4		
7	420	58	0.058	4.24E-04	36.6		
8	480	40	0.04	9.90E-04	85.6	*	**Std Deviation**
9	540	25	0.025	1.25E-03	108.2	*	6.13
10	600	0	0				**Variance**
			Average k (m/d) =	3.83E-04	33.1		37.58

* Anomalous values eliminated in calculating averages, Std deviation and variance

APPENDIX V

PHOSPHORUS RETENTION INDICES (PRI) RESULTS

C. New
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PO Box 201
WEMBLEY   WA   6913

Report on 14 samples of limestone from Alkimos WWTP
received on 12-AUG-2004   31-AUG-2004

LAB NO	SAMPLE	P (PRI) mL/g
04A		
100_001	A1 1.0m	34
100_002	A1 3.0m	12
100_003	A2 1.0m	70
100_004	A2 2.5m	13
100_005	A3 1.0m	5.8
100_006	A3 2.0m	4.5
100_007	A4 0.6m	5.0
100_008	A4 2.8m	130
100_009	A5 1.0m	2.1
100_010	A5 3.0m	15
100_011	A6 1.0m	13
100_012	A6 2.5m	9.8
100_013	A7 0.3m	13
100_014	A7 1.0m	10

P   (PRI)   = Phosphorus Retention Index by method S15
mL/g   = millilitres per gram

The samples were crushed to <2 mm prior to analysis.

The results apply only to samples as received.

D.G. ALLEN
Principal Chemist
LAND RESOURCES CHEMISTRY SECTION
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Appendix VI: Commentary On Impacts From Nitrogen Loading To The Shoreline Resulting From Short-Term Infiltration To Groundwater (Oceanica Consulting Report)

Alkimos Wastewater Treatment Plant

Commentary on impacts from nitrogen loading to the shoreline resulting from short-term infiltration to groundwater

Prepared for:

Rockwater

Prepared by:

Oceanica Consulting Pty Ltd

October 2004

Report No. 426/1

Revisions history

Report	Version	Prepared by	Reviewed by	Submitted to client	
				Copies	**Date**
FINAL	1	M Bailey	P Wharton/ K Congdon	1 digital	11/10/04

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1. Introduction

Rockwater have been engaged by the Water Corporation to examine the impacts of infiltration from the Alkimos WWTP (Figure 1.1) on groundwater levels and quality downstream of infiltration basins. Rockwater have in turn requested that Oceanica provide preliminary comment on the potential magnitude of any impacts of nitrogen rich groundwater on the marine environment and the method by which any future assessment of potential impacts on the marine environment would be undertaken.

Figure 1.1   Project location

2.   Background

The Water Corporation (2004) submitted a Referral Document to the EPA for the project which contains the following relevant section concerning groundwater infiltration:

"*It is intended to defer the large capital expenditure required for the construction of the ocean outfall system for approximately 10 years. This will also allow sufficient flows to build up for satisfactory operation of the ocean outlet system at lower flows and velocities.*

Up to a capacity of 10-15ML/d, it is proposed to recharge the surface aquifer. Following treatment, the wastewater will be discharged to between five and ten infiltration lagoons on Lot 101. These lagoons will generally be sited at lower locations across the site approximately 500m from the shoreline. As far as practical they will be spread in a north-south direction to minimise groundwater mounding. The treated wastewater will be pumped to the basins on rotation, to allow for basin resting and maintenance. .....

This proposal can also be compared to the recently decommissioned system at the Bunbury, where approximately 7ML/d was infiltrated into lagoons located much closer to the shoreline.

At Bunbury measurements showed faecal coliform levels along the adjacent shoreline well within the National guidelines for primary contact recreation. At Bunbury the nitrogen and phosphorus (nutrient) levels in the treated wastewater were higher than those found in the natural environment and this resulted in elevated nutrient levels in the nearshore area adjacent to the Bunbury WWTP. At Alkimos, natural groundwater nitrogen concentrations are expected to be higher and the treated wastewater concentrations lower than at Bunbury."

The following information was provided by Phil Wharton of Rockwater:

"*Evaluating Acceptability of Marine Nitrogen Loading:*
An evaluation of the acceptability of modelled nitrogen loads to the nearshore environment is required. This needs to consider:

- *The fact that Lot 101 is adjacent to a fairly enclosed environment, due to reefs and reef platforms; how much flushing/dilution would be occurring;*
- *The likely DoE position on what would be deemed an 'acceptable' load, i.e. maximum allowable nitrogen load;*
- *That modelled scenarios 5 and 6 are the most likely scenarios; and*
- *That natural groundwater nitrogen concentrations further north are higher than at the Alkimos site (e.g. Yanchep ~3-6 mg/L TN); could loadings discharged from infiltration be within this natural variation?*

This information will be used in evaluating whether infiltration is the best short term disposal option for Alkimos.

We are not concerned with an exact, modelled solution, but an assessment on the acceptability of proposed nitrogen loadings. If the answer is not clear, modelling may be undertaken in the future.

Attached (Tables 1 and 2) is a summary of nitrogen loadings (I have removed the no denitrification scenario)"

Table 2.1   Modelled scenarios

Scenario	Infiltration in 2020 (ML/day)	Eglinton bores pumping?	Effluent N concentration (mg/L)	Other
1	10	No	10	
2	10	Yes		
3	20	No		
4	20	Yes	10	
5	10	Yes	10	NE bore replaced with 2 bores, each pumping at half the rate of original bore
6	10	Yes	6	
8	0	No	0.2	Background GW N loading

Table 2.2   Discharged nitrogen concentrations and loadings after 13 years of infiltration. Values for scenarios 1-6 represent loadings above background level (scenario 8)

Scenario	Max GW level rise (m)	Travel time to coast (months)	N loading at coast (kg/day)	N loading (t/yr)	Length of discharge front (km)	N loading (kg/day/km)
1	0.4	8-10	10.5	3.8	1.5	7
2	0.5	8-10	8.9	3.2	1.5	5.9
3	0.6	4-9	38.7	14.1	2.0	19.4
4	0.5	4-10	33.4	12.2	2.0	16.7
5	0.2	8-10	5.3	1.9	1.5	3.5
6	0.2	8-10	4.8	1.8	1.5	3.2
8	0	n/a	4.0	1.5	1.5	2.7

3. EPA Policy

The EPA does not have a policy on "Acceptable Nitrogen Loading" as such, rather, there is a general requirement to maintain or improve water quality and then there are criteria for chlorophyll_a (a measure of phytoplankton biomass) which is in turn is usually a measure in response to nitrogen loadings. There is also a general requirement not to adversely affect seagrass or other benthic habitat. The following documents provide guidance on these issues:

- Revised Environmental Quality Criteria Reference Document (Cockburn Sound) (November 2002); and
- EPA Guidance Statement 29: Benthic Primary Producer Habitat Protection for Western Australia's Marine Environment (June 2004).

4. Existing Environment

There is limited information at hand to describe the existing marine environment in detail at Alkimos. A brief reconnaissance study was undertaken by DA Lord & Associates (1997). Key findings from this study were:

- The study area was characterised by reasonably wide beaches which varied in width from approximately 100 m (due south of the southern breakwater of the Mindarie Keys Marina) to as little as 20 m in the pocket beach zone immediately north of the breakwater/marina entrance. The average beach width in the study area was in the order of 60 m;

- The beach condition directly opposite Lot 101 was moderately steep. The beach profile was about 1:15 and the materials involved comprised of thick, loosely packed sand;

- There was no exposed reef platform on the beach immediately opposite Lot 101;

- No clear impression was gained of the distribution of seagrass meadows in the nearshore environment. However, from the seagrass mapping that was undertaken by Alan Tingay and Associates (1991) it was assumed that, in common with the rest of Perth's metropolitan coastal waters, a mosaic of seagrass meadows occurs throughout the study area;

- Throughout the study area, opportunities exist for a wide variety of recreational pursuits, ranging from active sports such as swimming, surfing, diving and angling to more passive forms of recreation such as sunbathing and beachcombing. Due to the shelter offered by fringing reefs, relatively calm and safe bathing conditions occur throughout the study area; and

- There were a number of localities in the study area where emergent reefs occur offshore. It was considered significant from the point of view of the study that about half of these offshore emergent reefs (these being centred upon Pamela Shoal, Eglington Rocks and Alkimos Reef), lay within 2 km of Lot 101. The seven main reefs (from south to north) were:
  - Burns Rocks—1 km offshore;
  - Quinns Rocks—1.5 km offshore;
  - Pamela Shoal—1 km offshore;
  - Eglington Rocks—750 m offshore;
  - Alkimos Reef—1.5 km offshore;
  - Pipidinny Reef—1.3 km offshore;
  - El Reef—700 m offshore; and
  - Laurance Reef—450 m offshore.

If this area is typical of the limestone/sand coast elsewhere in the region, then the groundwater flows will enter the ocean through the intertidal zone, possibly with preferred flow pathways through tunnels in karst formations and possibly enhanced flows to the ocean near limestone headlands. Seawater levels will have some affect on flows, with the overall peak flow to the sea likely to be in late winter and spring, primarily due to the effect of winter recharge combined with reducing sea levels as high pressure systems start to dominate the local weather conditions (e.g. Jervoise Bay Groundwater Recovery Scheme, Parsons Brinckerhoff 2003).

In relation to the dispersion of groundwater, the waters will be clear, low in nutrients and currents will generally be wind driven, with a prevailing northerly current along

the coast driven by the predominant south-westerly winds. Swell and wind will generally mean that the waters nearshore will be well mixed vertically with longshore currents likely to be in the range of 5 to 15 cm/s.

5. Potential impacts of groundwater infiltration

5.1 Water quality

The Water Corporation referral document makes a useful comparison to the Bunbury WWTP, where infiltration of ~7 ML/d occurred to a series of seven ponds between 50 m and 200 m of the beach. Monitoring of the near-shore waters immediately adjacent to the beach found elevated concentrations of bioavailable forms of nitrogen and phosphorus at the sites closest to the Bunbury WWTP and there appeared to be a corresponding response to in phytoplankton growth. Figure 5.1 provides an example of the results. A more detailed investigation of the findings from the three pre-construction surveys for Bunbury may be a useful part of any assessment for Alkimos.
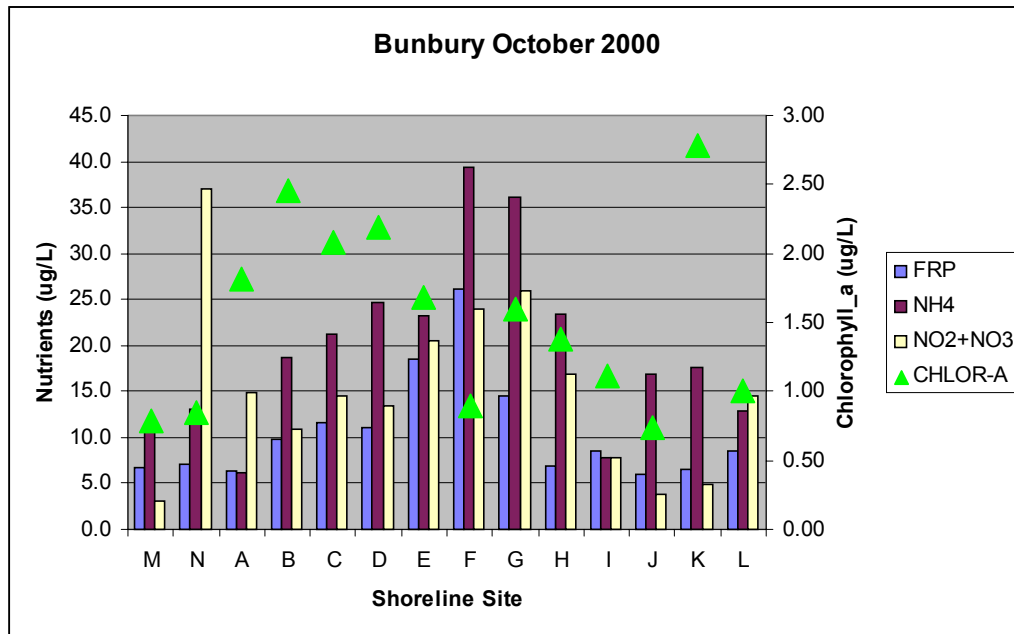

Figure 5.1   Example of shoreline water quality monitoring data adjacent to Bunbury WWTP

As stated in the EPA referral document, nitrogen concentrations in treated wastewater are expected to be lower, and the natural groundwater concentrations higher, than at Bunbury. The Rockwater modelling results suggest a relatively small increase in nitrogen concentrations in groundwater discharging at the coast that may be within the range of natural variation in nitrogen concentrations along some sections of the coast.

The strength of the long-shore currents, lack of exposed reef platform immediately west of the WWTP site and the high degree of vertical mixing mean that groundwater discharging to the ocean is likely rapidly diluted and dispersed.

5.2 Odour

In addition there were effects on local amenity at Bunbury due to odour. Local professional beach fishermen commented on the smell of fish caught in nets immediately offshore the WWTP, while excavation of the beach downstream of Bunbury WWTP would reveal water which had a smell that reflected the higher ammonium concentrations. The additional distance between the Alkimos plant

(600 m to 1,100 m) and the coast is expected to allow all the nitrogen to be oxidised to nitrate and so the are unlikely to be any odour issues. However, this possible concern can be addressed in the approvals documentation.

5.3   Ponding

Ponding of water on the beach was one of the key impacts at Bunbury. Apart from odour and community perception of potential health concerns, the elevated groundwater levels were thought to reduce the capacity of the beach to resist erosion at a time when strong storms may still occur (late winter early spring). The greater distance of the Alkimos WTTP from the plant from the ocean means that groundwater levels are not expected to be significantly raised at the coast (Rockwater modelling suggests ~5 cm above background) and so there should be no ponding or instability of the beach at Alkimos.

5.4   Suggested strategy for assessment

An appropriate response would be to describe the existing marine environment in terms of nutrient related water quality, residence times, groundwater loadings and benthic habitat and then describe any increase in nutrient concentrations likely to occur and the effects of these increases relative to existing conditions.

Given that;
- the flows will be similar or larger than those at Bunbury;
- the Rockwater model results seem to suggest an increase in nitrogen concentrations at the coast;
- there is reasonable evidence from Bunbury to show the likely nature of any impacts; and
- Then it is recommended that, if the option of infiltration is to be pursued, a detailed study to address the impacts of nutrients.

The potential for ponding and odours on the beach are unlikely to be issues, but should be considered.

The tasks would include:

- Model likely increases in groundwater levels and changes in nutrient concentrations;
- Review results from Bunbury and Jervoise Bay and any other relevant studies to develop a likely range of water quality impacts due to groundwater nutrient loads;
- Obtain good background water quality data for the Alkimos shoreline;
- Assess the likely residence times of the waters along the shore and the risk of localised nutrient enrichment;
- Assess the any possible impacts on recreational amenity and beach stability; and
- Assess the potential compliance with EPA's nutrient related water quality guidelines.

6.   References

Alan Tingay & Associates Pty Ltd, 1991. Eglington Beach Resort Public Environmental Review.

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