Masterton Wastewater Upgrade: Revised Groundwater Modelling

Prepared for
Masterton District Council

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Limitations:

The information in this report is based on predictive modelling using the Modflow groundwater modelling code, estimates of the pre-existing groundwater conditions and geology and the output from modelling by others as input. The modelling by others has been taken in good faith and has not been independently verified. While due care has been taken with the modelling, the outputs are predictions and cannot be guaranteed.

The report has been prepared for Masterton District Council, according to their instructions, for the particular objectives described in the report. The information contained in the report should not be used by anyone else or for any other purposes.

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Executive Summary

Pattle Delamore Partners Limited (PDP) previously carried out groundwater modelling on behalf of the Masterton District Council for the Masterton Wastewater Upgrade. That modelling was based on a project concept that has since been substantially revised. This updated report details groundwater modelling for the revised scheme, which includes: 107 ha of new land to the west of the Makoura Stream; the decommissioning of the existing ponds for use as irrigated plots; the construction of new treatment ponds to the north of the existing ponds; and the addition of groundwater drainage systems to lower groundwater levels where it is expected to be near the ground surface. In addition, the revised modelling addresses requests for further information arising during the consent application for the original project and subsequent concerns from various interested parties. This revised modelling should be read in conjunction with the original modelling report.

Additional investigation was carried out over the enlarged area. This included one deeper (20 m) and nine shallower (about 6 m) groundwater monitoring wells installed in the new land to the west of the Makoura Stream. The geology across the western half of the site remains generally as previously described for the eastern portion, however, the confining silt or clay layer is not continuous across the whole site, as was thought during the original investigation. Pump test data for shallow groundwater on the western side of the site has provided a revised hydraulic conductivity value for the whole aquifer of 89.4 m/day (geometric mean) based on all the test results. The original model used a value of 150 m/day.

As in the previous modelling, recharge rates to the aquifer were obtained from modelling of the soil column by HortResearch. A conservative scenario of 15 mm/day summer rate (November to April inclusive) of combined rainfall and irrigation was assumed for the better drained areas while 10 mm/day was assumed for the more poorly drained areas (as identified by Landcare Research soil mapping). Winter rates were 5 mm/day over all areas. Typical rates are actually likely to be lower, meaning the modelling is conservative.

HortResearch provided daily time-series discharge and concentration outputs (for bacteria as represented by E. coli, nitrate-N and phosphorus) for each of the 29 irrigated plots (an increase of 19 plots over the previous model) based on the same input concentrations (on the ground surface) as for the original modelling. The modelling period was 30 years. Input into PDP’s groundwater model was averaged over monthly periods.

Revisions to PDP’s original modelling process include:

- the use of a transient rather than a steady state model;
- downward revision of the hydraulic conductivity value for the whole aquifer as a result of the additional investigations;
- substantial revision of the total irrigated area and irrigated plot numbers;
- upward revision of the irrigation rates for summer and winter months;

- the addition of a drainage system to the west of the stream;
- the addition of notional observation points in the model to evaluate concerns that there could be effects to private groundwater users to the north and west of the site;
- revision of the modelled groundwater discharge ‘zones’ into the stream, river and drainage system;
- diversion of the Makoura Stream around the proposed new ponds; and
- examination of groundwater levels under flood conditions during construction of the new ponds and, post-irrigation, in the location of the existing ponds.

Key results and conclusions to the model output data are as follows:

1. The groundwater flow direction remains southward.
2. Groundwater mounding beneath the site ranges between 50 mm to 250 mm over most of the site, but up to 360 mm on irrigated plots in the location of the existing ponds.
3. The long-term increase in contaminants in the groundwater from the irrigation are, for bacteria generally small relative to the existing groundwater concentrations; for nitrate-N of a similar magnitude to the existing concentrations; and for phosphorus generally of a similar magnitude to the existing concentrations in most cases, but an order of magnitude higher increase for some locations. Phosphorus concentration increase throughout the life of the project.
4. The irrigation and additional drainage from the drainage system results in a predicted increase in the Makoura Stream flow where it leaves the site of 0.15 m^3/s. This will result in a total summer flow of 0.32 m^3/s. Increase in flow to the Ruamahanga River, above the Makoura Stream confluence, is predicted to be 0.04 m^3/s. The river summer low flow below the confluence is therefore predicted to increase by 0.36 m^3/s, resulting in a total flow of 2.89 m^3/s when added to the existing design summer low flow of 2.7 m^3/s.
5. Combining the predicted discharges to the stream and river with predicted contaminant concentrations allows increases in daily mass flux of contaminants to the stream and river to be calculated. The increases in daily mass flux of nitrate-N and phosphorus to the river below the confluence with the stream are 9.3 and 0.82 kg, respectively.
6. Contaminant concentration increase in the stream and river after mixing can be calculated by dividing the daily mass fluxes to the stream and river by the stream and river flows. For the stream, concentration increases relative to background concentration for summer low flows is predicted to be negligible for bacteria, 7 % for nitrate-N (increase from 3.5 to 3.75 mg/L) and 50 % for phosphorus (0.02 to 0.03 mg/L). For the river, predicted concentration increases for the design summer low flow conditions are smaller than for the stream, being negligible for bacteria,

similar to the stream in relative terms (6 %) for nitrate-N but lower in absolute terms (increase from 0.6 to 0.64 mg/L) and a 30 % increase for phosphorus (0.01 to 0.013 mg/L).

7. The modelling predicts no measurable change from the irrigation to groundwater conditions to the north and west of the site, in the vicinity of private properties that use groundwater for domestic supply. This is a direct consequence of the groundwater flow direction remaining north to south and the predicted rapid drop-off of effects away from the irrigated area.
8. Groundwater elevations during a five-year flood event are predicted to come within 100 mm of the base of the proposed new ponds. Temporarily lowering groundwater levels during the passage of the flood is feasible using small dewatering pumps.

The modelling carried out for this study is conservative. In particular, contaminant predictions are conservative as filtration effects for bacteria and attenuation effects for nitrate and phosphorus within the aquifer have not been allowed for in the model. In reality, concentrations are expected to be lower at the site's boundaries than predicted by the model. In addition, the 15 mm/day assumed summer application rate is greater than the expected typical summer rate of 10 mm/day. Thus the modelling will be over-predicting the mass fluxes to the Ruamahanga River and Makoura stream and therefore over-predicting concentration increases in these water bodies.

1.0 Introduction

Pattle Delamore Partners Limited (PDP) reported on modelling of groundwater and contaminant transport for the Masterton Wastewater Upgrade in our report of 18 December 2006. This report was based on a project concept that has since been substantially revised, with a substantially greater area of land now to be irrigated with wastewater.

The Masterton District Council, through its main consultant Beca Carter Hollings and Ferner Limited (Beca), has requested PDP to update the groundwater modelling to reflect the changes. This includes addressing some concerns raised by Greater Wellington Regional Council (GWRC) in a Resource Management Act section 92 request for further information (letter to the Masterton District Council of 24 August 2007) on the consent application for the original scheme. Some of those concerns are still relevant for the new proposal.

This report summarises the results of additional investigations and the model update. It should be read in conjunction with the original groundwater report (PDP, 2006) and the letter report "RMA s92, Update of Groundwater Monitoring" dated 11 October 2007 (PDP, 2007).

The modelling is of a worst case situation of the whole of the available area being irrigated at the maximum rate throughout the design life of the project (taken to be 30 years). This is a conservative scenario because it is not feasible to irrigate continuously at high rates for the duration of the project. High rates representing a short-term event during dry conditions when there is a deficit of soil moisture.

Since the updated numerical modelling was completed in May 2008, adjustments have been made to the size and numbering of some of the proposed irrigated plots. A small increase in area of about 1 ha resulted. The changes are discussed in Section 7.0. The numbering as originally used has been retained in this report, other than where specifically noted. As noted in Section 7.0, the changes have no effect on the conclusions reached in this report.

2.0 Revised Scheme

Originally, land dedicated to wastewater irrigation was limited to an area of approximately 91 ha of land, comprising 11 irrigated plots north of the existing ponds, bounded by the Ruamahanga River to the east and the Makoura Stream to the west. The revised scheme includes 107 ha of new land to the west of the Makoura stream. Changes to the scheme as modelled are in summary:

- Addition of 18 new irrigated plots to the west of the Makoura Stream, with a new total of 29 irrigated plots[1].
- Constructing new ponds to the north of the existing ponds, taking up what were irrigated plots 6, 7 and 11.
- Decommissioning of the existing ponds and using this area for irrigation (new irrigated plots 27, 28 and 29[2]) after removing the sludge and restoring the ponds by levelling the underlying gravels and restoring the surface with silts from elsewhere on the property.
- Construction of a number of drains on the new land, which includes deepening of some existing drains and construction of new drains, to reduce the groundwater level in what otherwise would be areas where the groundwater level was only a few hundred millimetres below the surface.

The layout of the new scheme, as modelled, is shown in Figure 1 and the as-modelled and original irrigated plot numbers and areas are detailed in Table 1.

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[1] Subsequently further divided and renumbered so that there are 20 additional plots for a total of 31 plots, see Section 7.

[2] Subsequently renumbered to 29, 30, 31 when plots 21 and 22 were divided creating plots 21, 22 and new plots 28 and 29.

3.0 Additional Investigations and Revised Geology

In addition to the 21 groundwater monitoring wells installed to investigate groundwater conditions for the original scheme, nine new monitoring wells were installed by Webster Drilling and Exploration Limited under PDP supervision during March 2008, distributed across the 107 ha of new land between the Makoura Stream and the Martinborough-Masterton Road. The new wells include one deep well (HB30b; installed to 23 m), located toward the northwest boundary of the site and eight shallow wells (HB23 to HB30a and HB31) installed to depths between 3.8 and 5 m bgl. One of the shallow wells, HB25, was drilled to 23 m before being backfilled to about 5 m to install the monitoring well.

Shallow monitoring well HB30a and deep monitoring well HB30b are nested within one borehole with the screens installed above and below a confining layer encountered between 16.5 and 18.8 m. A bentonite seal was installed within the confining layer to ensure there was no leakage between the shallower and deeper aquifers.

Locations of all the monitoring wells are shown in Figure 2 and borelogs for the new wells are appended.

During the investigations of the original scheme a 1 to 3 m thick, low permeability, clay or silty confining layer separating a deeper and shallower aquifer was encountered at about 12 to 16.5 m depth. BH30 and HB25 were intended to explore whether such a layer was present under the new land.

HB30 located toward the northwest of the site confirmed such a layer, but HB25, located toward the centre-west of the site did not encounter this layer before the hole was terminated at 23 m. The obvious conclusion is that confining layer is not continuous across the whole site. Previous investigations had shown it is variable in thickness and it is now apparent that it is absent in places, indicating the shallow and deeper aquifers are hydraulically connected, at least beneath the central part of the new land.

In summary, the general geological structure across the western half of the site remains as was described about the eastern portion. Surficial sediments on the western half of the site were found to consist of compact silt ranging in thickness from 1 to 2.2 m, underlain by a permeable, alluvial sandy to silty coarse gravel layer with intermittent clay, silty clay or gravelly clay lenses. The full thickness of this layer (10.5 m) was observed only in HB30 and was underlain by a clay layer approximately 2 m thick. The clay was underlain by silty, permeable gravel, with a thickness extending further than 4 m (past the extent of the borehole). The shallow gravel layer observed during drilling the borehole for well HB25 continued to the maximum drilled depth of 23 m.

After their installation, short pumping tests were conducted by PDP on five of the new wells to determine hydraulic conductivity estimates in the shallow aquifer. These tests were carried out as short constant-rate tests over a few hours using a surface mounted pump and suction line to draw down the water level by a few hundred millimetres. Drawdown and recovery data were measured using electronic transducers.

Hydraulic conductivity estimates for the new wells on the western side ranged between 3.2 to 30.9 m/day. While the previously conducted pump tests for the wells on the eastern side recorded conductivity results between 141 and 1430 m/day. The lower hydraulic conductivities in the eastern zone suggest a higher silt and sand content within the gravels and perhaps indicates a transition from the Te Ore Ore Groundwater Zone to the Masterton Groundwater Zone which is reported to occur in this vicinity (Butcher, 1996).

Groundwater level measurements carried out by the Masterton District Council over the last several years on the eastern portion of the site have expanded to include the newly installed wells on the western side. These measurements have been used to construct a piezometric contour map over the complete irrigated area as a starting point for the groundwater modelling. The piezometric contours for the irrigated area are shown on Figure 3. The groundwater flow direction at any point is perpendicular to the contours.

4.0 Model Revisions

The hydraulic and contaminant transport models have been modified in eight significant ways since the original modelling of early 2006 (PDP, 2006):

1. Major changes to the irrigation areas and revised irrigation plot numbering.
2. Irrigation rates revised upwards, as set out in Table 2 (these are the same rates as used in the October 2007 revision of the original plot areas (PDP, 2007)).
3. The original steady-state contaminant transport model was revised to run as a transient model to address GWRC's concern that the worst case was not being modelled.
4. A drainage system has been incorporated into the model for the western (new) part of the site as a design requirement to ensure groundwater levels are low enough within the surficial silts.
5. The Makoura Stream has been diverted around the western end of the new ponds.
6. Pump test data for the western side of the site has provided a revised hydraulic conductivity value of 89.4 m/day (geometric mean) for the whole aquifer based on all the test results. The original model used a value of 150 to 350 m/day for the whole aquifer based on results from the eastern side only. All of these values are relatively high and the model is not particularly sensitive to this change.
7. Ten contaminant concentration observation points have been included in the model output to evaluate concerns that there could be effects to the north and west of the site (observation points R-1 to R-6 and R-8 to R-11). The locations of these notional points are shown on Figure 4.
8. A number of notional groundwater level observation points have been added to the model to enable groundwater levels to be predicted pre-construction and during construction for a 5-year flood for the new pond locations, and post-construction during normal river flows for the new irrigated plots in the location of the existing ponds, to answer specific questions related to these areas.

Details of the most important of these changes follow:

4.1 Revised areas

The major changes in area since the original groundwater model report (PDP, 2006) are the addition of 18 new irrigated plots to the west of the Makoura Stream, the reallocation of the original plots 11, 6 and 7 (see PDP, 2006) for the construction of new wastewater treatment ponds, excluding the area of bush north of the new ponds from the irrigated area (this change occurred for the October 2007 revisions) and revision of the original plot areas that are still part of the scheme to reflect refinement of the design since the original areas were calculated. The total irrigated area is now approximately 149 ha, versus 75 ha for the original modelling and 80 ha for the 2007 revision.

The old and revised areas are shown in Table 1. The revised areas have been taken from Beca drawing 3202216-560-C601 Rev A. The areas are understood to reasonably accurately reflect the net irrigated areas, taking into account buffer areas. When detailed design is completed these area may be slightly refined[3].

4.2 Recharge rates

The irrigation application rates were revised upwards by Beca as set out in Table 2, appended. These are the likely maximum combined rates of rainfall, and wastewater applied to the ground surface and are the inputs into HortResearch's soil drainage model. The input concentrations of nitrate, phosphorus and bacteria to the HortResearch model were the same as for the original modelling.

HortResearch re-ran their model with the new application rates, land areas and pond volumes to provide an output file for a 30-year period giving the average daily drainage rates for each of the 29 irrigation plots and daily concentrations of bacteria (E. Coli), nitrate and phosphorus for PDP's modelling. The modelled irrigation rate is an extreme situation as such a high rate would not be applied to every plot throughout the scheme's life. The modelled irrigation/rainfall rate was 15 mm/day for free draining soils in the summer. This is the upper rate which would be used in dry conditions. The actual average rate in summer for the free draining soil will typically be 10 mm/day. The modelled rates are shown in Table 2.

The drainage to the aquifer is, on average, significantly less than the irrigation rates shown in Table 2, varying both from plot to plot and seasonally, being dependent on soil properties and seasonal variations of such things as plant-growth, rainfall and evapotranspiration. On average in the summer months the drainage to the aquifer ranges from 1.6 – 8.3 mm/day (mean 4.7 mm/day) or about 7,000 m^3/day for the complete area.

PDP took the HortResearch file and processed it to create input files for each plot of soil drainage flows (i.e. aquifer recharge) and nitrate, phosphorus and bacteria concentrations. The data file from HortResearch was based on ten years of measured input data (1997 – 2007) and 20 years of synthetic input data, the latter based on the partial records (which included temperature and rainfall) for an earlier 20-year period and correlations between these and the various other parameters for the ten years of available full record.

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[3] See Section 7, Table 9 and Figure 10 for post-modelling refinements.

4.3 Transient model

The original contaminant transport model was a steady state model. This was modified to run as a transient (time-varying) model in response to queries from GRWC. The transient model requires a significantly greater computational effort and imposes some other limitations.

In order to overcome model stability problems and excessive computational times, the original 10 x 10 m model grid within the irrigation area was changed to a 40 x 40 m grid, while outside the irrigation area the grid spacing has been modified to gradually increase. The daily drainage data has been averaged over monthly periods as computational effort with daily data would still be too great.

The grid size imposes constraints on the accuracy of modelling the plot boundaries and other physical features. This means that the theoretical plot areas and boundaries as set out in Table 1 and shown in Figure 1 are not exactly represented in the model. For the outer perimeter, the boundaries have been defined to err on the conservative side, while the grid approximation will mean that some plots may be a little smaller than they should be, compensated for by other plots being a little larger. Overall the grid approximation should be sufficiently accurate but slightly conservative.

A further technical refinement to the model was to modify the way the soil drainage water recharge was applied to the aquifer. Rather than, as in the original model, having the top aquifer layer maintaining the same contaminant concentrations as the drainage water throughout the simulation, the revised model has the drainage water applied to the top of the aquifer in a way that ensures all contaminants reach the groundwater system but without a fixed concentration. This has the effect of allowing initial dilution at the point of recharge, which is a more realistic situation than previously modelled.

4.4 Drainage system

The new land currently has a farm drainage system to help reduce groundwater levels in wet areas. The conceptual design for the new scheme modifies this drainage system, eliminating some drains, but retaining the “backbone” of the current system and adding additional drains to the south-western part of the new land.

The current drainage system drains to the road-side drain beside the Martinborough-Masterton Road. This drain finally drains to the Makoura Stream after passing through farmland downstream (west) of the current ponds. The new drainage system instead discharges more directly to the Makoura Stream, joining the Makoura west of the proposed new ponds. The drain locations are shown (as lines of model cells) in Figure 4.

Levels for the drains were provided by Beca. These have been set up in the model to intercept the gravel aquifer underlying the surface silts. This has the effect of lowering the water level in the silts but also increases the flow within the drains to greater than the existing drain flows irrespective of the applied irrigation. Given that the drains are taking water directly from the gravel aquifer, and that water will be variably contaminated by the wastewater applied on the ground surface, the drains will shorten the transport distance to surface water for some of the irrigated plots. The effect is that the Makoura Stream receives a greater proportion of the contaminant flux than if the drains were not there. On the other hand, without the drains the groundwater level would be higher and the treatment the wastewater would receive in passing through the soil would be less effective and in some plots the groundwater level would be too high given the groundwater will mound slightly with the applied wastewater.

4.5 Contaminant concentrations at the northern and western boundaries

An important consideration for the enlarged scheme is that the new area is northward of a part of the Martinborough-Masterton Road with a number of small holdings. Some of these properties draw their domestic water supply from shallow bores. Given the dominant groundwater flow direction is southward, the possibility exists that these bores could be contaminated by the scheme.

A number of properties immediately to the north of the proposed irrigated area, in the vicinity of Homebush and Pokohiwi roads, also use the shallow groundwater for domestic supply. Residents of these properties have expressed concern that their supplies might be affected.

To examine both of these concerns a number of notional observation points were inserted into the contaminant transport model as notional wells. These are not intended to model actual well locations rather than predict the effect for the general locations.

For the properties along the Martinborough observation points R1, R4 and R5 (Figure 4) are located on the western side of the road. Two additional points were also located in the general vicinity, R3 immediately south of the irrigated area west of the new ponds and R2 further south between the Makoura Stream and the road. These two additional points are intended to gauge the rapid contaminant concentration drop-off upgradient of houses located on the east side of the Martinborough-Masterton Road towards where the road crosses the river on Wardell’s Bridge.

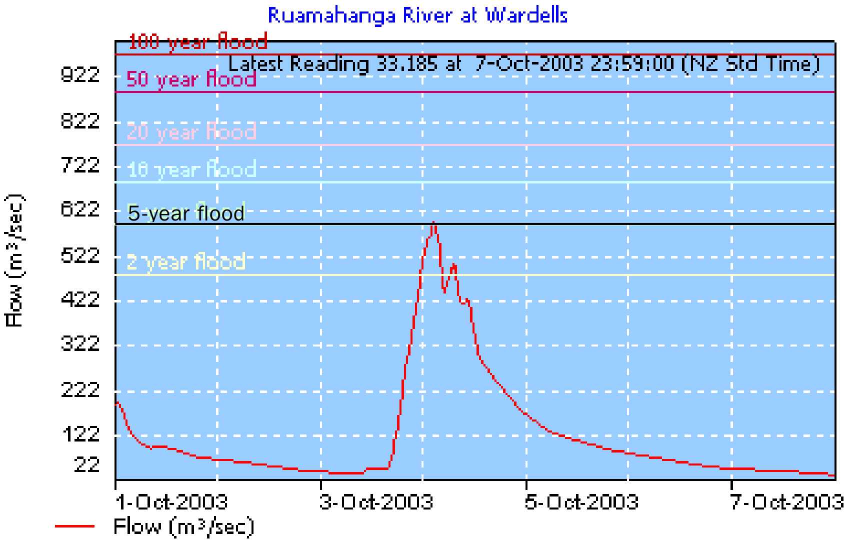
Figure 4 also shows the location of the observation points to the north of the site. Points R8, R9 and R10 are particular relevant for the properties in the vicinity of Homebush and Pokohiwi roads. Given the groundwater flow direction is southward, away from these properties, the general expectation is that domestic wells in this vicinity will suffer no effects. The modelling is intended to confirm this expectation.

4.6 Construction dewatering modelling

Anecdotal accounts suggest that in times of flood the groundwater level rises close to the surface in parts of the proposed irrigation area and upwelling has been observed in the vicinity of the existing treatment plant building. High groundwater levels during floods has implications for the proposed new ponds during excavation for the base liner.

Construction is a short-term event and it is usual to assess risks to construction for only moderate floods. Beca has chosen the 5-year flood, which is equivalent to a flow of about 590 m^3/s (see figure below taken from GWRC's river monitoring).

The passage of a flood of this magnitude was modelled using a transient version of the pre-irrigation groundwater model with the river level varying with time to simulate a flood wave passing down the river over a period of about three days. The shape of the flood wave was obtained from a real flood of that magnitude from river records that GWRC holds for the gauging station at Wardell's Bridge (flood of 3 – 6 October 2003). The flood peak is very short – see figure below – and results in excess groundwater heads for correspondingly short periods of time.



Maximum flood levels in the river for the 5-year flood were obtained from Beca for various river sections adjacent to the site, and were modelled using the GWRC Ruamahanga River flood model.

A number of observation points were set up in the model in the location of the proposed new ponds so that the change in water level as the flood passed could be determined. The groundwater levels during average groundwater conditions, during a five year flood event and pumping during a flood event, were calculated for points along cross sections through the new ponds, provided by Beca. Figure 9 shows the locations of these points along the sections.

It was found that the base of part of the new pond excavations would be close to the flood level for short periods of time. A number of notional dewatering wells were then set up in the model to determine what pumping effort would be required to ensure the water was kept below the base of the excavation. No attempt was made to optimise the location and capacity of the notional pumps. The objective was simply to demonstrate the feasibility of water control and the approximate capacity of pumps required.

5.0 Irrigation Model Outputs and Post-Processing

The revised contaminant transport model produced time-dependent concentrations and flow-field information over the irrigated area, including adjacent to the Ruamahanga River, Makoura Stream and the various drains. In order to calculate contaminant mass fluxes to the Ruamahanga River and Makoura Stream (so that diluted concentrations in the river and stream could be calculated), it is necessary to multiply contaminant concentrations at representative points with the volume flux (discharge) passing through the zones represented by each of these points.

Firstly, the stream and river boundaries of the irrigated area were divided into twelve zones (zones 1 to 11 and zone 17). A further five zones were defined to represent discharge to the drains (zones 12 to 16). Representative points adjacent to the stream, river and drains were then chosen within each zone and defined within the model. The model was then run and concentration time-series obtained for each zone for each of nitrate-N, phosphorus and bacteria. Similarly, a discharge time-series was obtained for each zone. Multiplying the concentration and discharge time series together gives mass flux in g/day, or in the case of bacteria, flux of coliform forming units/day (cfu/day).

Locations of the zone boundaries and representative points (C-1 to C-17) can be seen in Figure 4. The representative points were chosen conservatively after an initial model run and examination of the contaminant concentrations within the model adjacent to the surface water bodies. Firstly, the points represent the maximum concentrations within any particular zone. Secondly, for the southern and eastern boundaries with the Ruamahanga River (zones 1 to 6 and zone 17), and on either side of the Makoura Stream and various drains (zones 7 to 16) the points were chosen to be on the edge of the irrigated area. In reality there will be a buffer zone between the irrigated area and the river, stream or drains in which concentration reduction will occur. Modelling shows a rapid drop-off in concentration outside the irrigated area.

It became apparent that the model output for bacteria and nitrate (and to a lesser extent phosphorus) reflects the seasonal cycle of the input data, with nitrate and bacteria concentrations lowest in summer and highest in winter. Typical concentration plots for four representative points, during the time period between 10 and 20 years of irrigation modelling, are shown in Figure 5.

As the effects on the river of irrigation groundwater discharge are expected to be greatest during the summer when the river flow is lowest, it is most appropriate to calculate mass flux for the summer period. However, taking the lowest summer value is not reasonable, as summer low flow would not necessarily coincide with the mass-flux low point (which is typically in January or February). In consultation with Beca it was decided to calculate the summer-mean mass-flux for the last five years of model output data, summer being defined as November to April inclusive for the purposes of this exercise. The reason for using only the last five years of the time-series is that phosphorus concentration in the groundwater increases throughout the scheme’s life (less is absorbed by the surface soil with time).

A different approach was taken for the Makoura Stream. There is no information on the variability of flows in the Makoura Stream. A small number of stream gaugings were carried out in March 2005. These are believed to be reasonably representative of summer flows, but may not be representative of the lowest flows. To introduce an element of conservatism, the maximum, rather than the mean, mass flux was determined by determining the maximum concentration and discharges over the last five years of data.

Finally, the diluted concentrations in the river and stream were calculated. For the river this was done by taking the total contaminant fluxes summed over the zones discharging to the river (zones 1 to 6 and zone 17) and dividing by the sum of the additional flow to the river and the summer low flow in the river measured at Wardell's Bridge (2.7 m^3/s). The result is the increment in contaminants in the river due to irrigation at a point several hundred metres downstream of the existing wastewater ponds (i.e. the downstream end of Zone 17 on Figure 4). The modelling shows irrigation discharge is negligible below this point.

For the stream, this calculation involved summing the contaminant fluxes over the zones discharging to the stream both directly and via the drains (zones 7 to 16) and dividing by the sum of the flow measured at the downstream section of the Makoura Stream in March 2005 (0.17 m^3/s) and the flow increment from the drains (0.094 m^3/s) and irrigation (0.055 m^3/s). Again, the result is the increase in contaminant concentrations in the stream at the most downstream point of the stream where the irrigation has an effect.

Given the Makoura Stream discharges to the Ruamahanga River the total additional load of contaminants to the river downstream of the Makoura discharge is the sum of the contaminant fluxes to the river and stream. The concentration increase after mixing is this sum divided by the sum of the river and stream flows.

6.0 Modelling Results

6.1 Groundwater flow direction

There is no appreciable change in groundwater flow direction from the irrigation, with the dominant flow direction remaining north to south. When the groundwater contours with irrigation were plotted the plot looked near-identical to the pre-irrigation contours shown in Figure 3. At that scale the contour lines plot on top of each other.

An important conclusion is that there is no appreciable change in groundwater flow direction on the western side of the site towards where a number of private water-supply bores are located.

6.2 Groundwater mounding

The application of additional recharge to the aquifer causes the groundwater level in the aquifer to mound up slightly relative to the pre-irrigation level (noting pre-irrigation does include the lowering effect of the drains). This mounding is shown for a number of the monitoring wells (used as observation points in the groundwater model) in Figure 6. The predicted mounding north of the existing treatment ponds varies from less than 50 mm to a little more than 250 mm. This is similar to the conclusion from the original modelling (PDP; 2006, 2007). Groundwater mounding generally increases from north to south (with the groundwater flow direction) due to the cumulative effect of the irrigation of plots. Mounding is least around the edges of the irrigated area.

The predicted mounding beneath the existing treatment ponds varies from 200 mm to 360 mm.

6.3 Groundwater contamination

The groundwater contamination results and contaminant mass fluxes are presented in Table 3 for each of the flow zones used for the calculations adjacent to the Makoura Stream and Ruamahanga River and as totals for these water bodies. Figure 4 should be referred to for the locations of the flow zones, but in summary, zones 7 to 11 are adjacent to the stream, zones 12 to 16 are adjacent to drains that discharge to the stream and the remainder are adjacent to the river.

Figure 5 shows the variation of concentrations of nitrate-N, bacteria and phosphorus for a ten year period for six observation points distributed across the site. Nitrate and phosphorus are shown on the left hand vertical axis as a logarithmic scale while bacteria is on the right hand axis as a natural scale.

Direct comparisons cannot be made between the October 2007 modelling (PDP, 2007) and the modelling for the revised scheme. This is because of the considerably different arrangement of irrigated plots, the enlarged area and the presence of the drains in the new area affecting model inputs and groundwater behaviour. In addition, the different flow zone and observation point scheme used for the model outputs means the points of comparison are different.

In general terms, the concentrations adjacent to the stream (as summer maximums) show a larger range of nitrate-N (up to 3 mg/L versus 1.4 mg/L previously), similarly long-term phosphorus concentrations (0.036 versus 0.033 mg/L) but bacteria concentrations are several times higher (about 1 cfu/100 ml versus 0.2 cfu/100 ml). However, the bacteria results reflect unexplained spikes in the last ten years of the bacteria input data from HortResearch which may, in turn, reflect errors in generating the synthetic input record for this part of HortResearch's simulation. If these spikes are ignored the bacteria concentrations are similar to the previous modelling. Given the bacteria concentrations results are low (i.e. the increase in concentration is generally much less than the drinking water standard for E. coli) the reason for the spikes has not been pursued.

Concentrations adjacent to the river are similar to the earlier modelling for nitrate and phosphorus, while bacteria concentrations are generally smaller except for the flow zone immediately south of the existing ponds. The latter effect is due to the existing pond area being irrigated in the revised scheme (noting that the modelling does not include the effects of the existing pond leakage). In all cases the bacteria concentration increases are very much lower then the drinking-water standard for E. coli.

A cyclical variation in nitrate and bacteria concentration can be seen in the plots of Figure 5, reflecting the variation in input data. Nitrate concentration is highest in winter and lowest in summer. The pattern for bacteria is generally similar although the cycle is not as consistent. The cyclic nature was taken into account when calculating mass flux by using the summer data for nitrate and bacteria (when river and stream flows are also lowest).

Phosphorus shows less cyclical behaviour. More important for phosphorus is the long-term increase in concentration, which dominates any short-term cyclic response, hence averaging over the last five years of output data for determining concentrations and calculating mass flux.

The plots of Figure 5 are of monthly data because the model used input data as monthly averages for model stability reasons, rather than the daily data from HortResearch. However, the irrigation cycle will actually be one day of loading and up to two weeks of rest before being irrigated again. The monthly cycle of the model adequately represents the actual irrigation cycle when the considerable damping effect within the aquifer and the "smoothing" effect of adjacent plots with irrigation cycles that are not in synchronisation are considered. The validity of using monthly data was checked in the previous modelling (PDP, 2007) when modelling with a few years of daily data was compared with the modelling the same period of monthly data. Similar results were obtained for both datasets.

The increases in groundwater concentrations due to wastewater irrigation may be compared against current groundwater concentrations. Measured concentrations for some monitoring wells upgradient of the existing ponds are presented in Table 4. In general, the increase in bacteria concentration is small relative to the existing concentrations, the increase in nitrate-N is of a similar magnitude to the existing concentrations (i.e. nitrate concentrations will double) and the long-term increase in phosphorus is also of a similar magnitude to the existing concentrations in most cases but an order of magnitude higher for some locations (see Table 3).

6.4 Concentration increases in the river and stream

Summer low flow contaminant concentration increases have been calculated for the Ruamahanga River and the Makoura Stream using the mass flux data of Table 3. The concentration calculations must take into account the increases in flow to the stream and river from the irrigation, and in the case of the stream, from the drains. The flow increases are presented in Table 5 and the concentration increases are presented in Table 6 for the stream, the river above the confluence with the stream and the river below the confluence. The calculations are based on a natural stream flow of 0.17 m^3/s (170 L/s) and a summer low flow at Wardell's of 2.7 m^3/s (i.e. natural summer low flow in the river above the confluence with the stream is assumed to be 2.53 m^3/s).

The concentration increases in the river are minimal (compare Table 6 with background concentrations in Table 4). For bacteria the increase is negligible compared to the background concentrations. For nitrate-N the increase is predicted to be about 6% below the confluence and for phosphorus (measured as dissolved reactive phosphorus, DRP) the increase is predicted to be about 30%.

For the stream, the increase in nitrate-N concentration is larger than the increase in the river in absolute terms (0.25 mg/L versus 0.011 mg/L) but in percentage terms the increase is similarly small (7%). This is because the stream is starting from a higher base (background of 3.5 mg/L) and is despite the larger mass flux of nitrate entering the stream. The increase in phosphorus in the stream is more significant than for the river, however, being about 50%, a direct effect of the proportionately larger discharge to the stream. For bacteria the increase relative to the background is negligible, as the background concentration in the stream is large and the increase from irrigation small.

6.5 Predicted effects on private bores to north and west

Figures 7 and 8 show plots of predicted concentration for nitrate-N, phosphorus and bacteria in the observation points west and north of the site, respectively. The locations of the observation points are shown on Figure 4.

The drinking-water standard for E.coli is 1 cfu/100 ml and for nitrate-N 11.3 mg/L. There is no human-health standard for phosphorus in drinking-water. In all cases, the predicted increases in groundwater concentrations for bacteria and nitrate are only a small fraction of the drinking-water standards. Essentially there will be no effects on private water supply wells to the north of the site or on the other side of the Martinborough-Masterton Road.

More significant effects are predicted for the points immediately south of the south-west corner of the scheme (i.e. observation points R2 and R3 between the road and the existing ponds). However, even here the predicted concentration increases are still well below the drinking-water standard concentrations. It is probable that the current dairying use of the land will have a more significant effect on the groundwater quality in this location.

6.6 Construction dewatering

Table 7 shows predicted groundwater elevations for various locations requested by Beca for three scenarios: natural groundwater level pre-irrigation, maximum groundwater level during a 5-year flood event (the construction flood scenario), and groundwater level during the flood with the addition of dewatering pumping. The locations of the modelled points are shown on Figure 9.

The modelling shows that groundwater has the potential to come within 100 mm of the base of the new ponds during excavation during a five-year flood event. The amount of pumping required to keep the water level down during a flood event is quite nominal, a total of 4,500 m^3 per day or around 50 litres per second spread across several pumps. Fewer pumps pumping at higher rates would be just as effective. As described in Section 4.6 above, the objective was simply to demonstrate the feasibility of water control and the approximate capacity of pumps required, rather than optimising locations and pumping rates.

6.7 Groundwater levels under existing pond locations when irrigated

Table 8 shows predicted groundwater elevations for the points during irrigation of the decommissioned existing ponds. The locations of these points are shown on Figure 9. This scenario was requested by Beca to answer some queries by interested parties.

The modelling shows irrigated levels will be 200 to 360 mm higher than the pre-irrigation levels (see Section 6.2) due to mounding. The modelling assumes constant river levels. In reality, the groundwater levels in this location (Irrigated plots 27, 28 and 29) will fluctuate with changes in river levels. Mounding will be dominated by changes in groundwater level by relatively moderate floods. This can be seen by the large change in groundwater level for the 5-year flood for points 5, 6 and 7 on each of sections 15A, 16A and 17A, although this is for a pre-irrigation scenario.

7.0 Post-modelling Scheme Adjustments

Since modelling contaminants for the proposed irrigation scheme, irrigation plot areas and numbering have been revised by Beca. A summary of the changes is presented in Table 9. Figure 10 shows the revised plot locations and areas.

Some irrigation plots have increased in size, some have reduced in size while most remain the same. Two plots have been split. In summary, the total proposed irrigation area has increased from 149.4 to 151 ha and the number of irrigated plots has increased from 29 to 31 by splitting plots 21 and 22 into two plots each (21 to 21 and 28 and 22 to 22 and 27). The splitting of plots 21 and 22 resulted in a renumbering of plots 27 to 29 to 29 to 31.

Given the overall area and boundaries are similar, only minor effects on the modelling are anticipated and the effort of revising the model with the new plot boundaries is not warranted, given the conservatism of the current modelling.

The more significant plot boundary changes and the qualitative effects on the modelling are:

Plots 1 and 6

Northern buffer area increased resulted in a southern movement of northern boundary. Reduction in potential effects to the north.

Plot 9

North boundary moved about 40 m northward towards private properties, however current modelling shows no effects on properties to the north and new boundary location not expected to change this.

Plot 4

Plot of trees close to stream removed from area. Small reduction in discharge to stream.

Plot 5

South-western boundary moved northward. Small reduction in local effects.

Plot 8

Small changes to boundaries adjacent to river. Small reduction in effects on river.

Plot 26 and new plots 28 and 29

The western boundary of the irrigated area has been has been extended westward to be close to and parallel with the road. Result will be a westward increase in effects on the groundwater in this area. Effects on wells across road not expected to be significant due to this change, given the absence of effects predicted in the current modelling. Groundwater flow will still be predominantly southward.

Plots 24 and 25

A northward movement of the southern boundary and consequent decrease in area. A small reduction in effects.

8.0 Conclusion

Groundwater modelling has been revised for the proposed upgrade of the Masterton Wastewater Treatment Plant to take into account the acquisition of a 107 ha area of land to the west of the Makoura Stream.

The modelling has found there is no appreciable change in the natural groundwater flow direction as a result of the proposed enlarged irrigation scheme, with the dominant flow direction remaining north to south.

The predicted mounding of groundwater beneath the site due to irrigation varies from less than 50 mm to 360 mm. Groundwater mounding generally tends to increase southward due to the cumulative effect of the irrigation of plots from north to south (with the groundwater flow) Maximum mounding (360 mm) on the site is predicted to be in the vicinity of the decommissioned existing ponds. Otherwise, mounding is generally less than 250 mm.

Modelling of the effects of a passing flood wave on groundwater levels during construction found that during a five-year flood event (chosen as the design flood for the construction period), the ground water level could come within 100 mm of the base of some parts of the new pond excavations. Further modelling showed only modest construction dewatering (cumulatively a few tens of litres per second) would be required to ensure that the groundwater level was kept safely below the pond liner for the short period (less than a day) when the groundwater level was at its peak from the flood wave in the river.

Modification of the current drainage network west of the Makoura Stream and additional groundwater discharge as a result of the irrigation is predicted to result in an increase in the Makoura Stream flow where it leaves the site of 0.15 m^3/s. When added to the assumed pre-scheme summer flow of 0.17 m^3/s this will result in a total flow of 0.32 m^3/s. Increase in flow to the Ruamahanga River past the site including from irrigation, not including the Makoura increase (i.e. the increase above the confluence), is predicted to be 0.04 m^3/s. The river summer low flow below the confluence is therefore predicted to be 2.89 m^3/s, being the current summer low flow of 2.7 m^3/s plus the irrigation drainage and the increase in drain flow.

The increases in groundwater concentrations of bacteria (as represented by E. coli), nitrate-N and phosphorus as a result of the wastewater irrigation have been predicted by the model. The critical locations have been taken as being adjacent to the drains, the Makoura Stream and the Ruamahanga River, where these pass through or border the site, as the model shows that groundwater discharges to these water bodies. The critical time has been taken as summer, when flows in the river and stream are lowest. While there is a cyclic variation in concentrations, tending to be lowest in summer and highest in winter, reflecting the input concentrations, this variation is outweighed by the flow variation, with summer flows providing less dilution after discharge of the groundwater to the water bodies.

For bacteria, the increase in concentration is generally negligible relative to the existing concentrations (measured to be about 1 cfu/100 ml) over most of the irrigated plots. However, concentration increases for bacteria approach that of the existing quality in the centre of the site (modelled discharge zones 9 and 10).

For the nitrate-N, the increase in groundwater concentration is of a similar magnitude to the existing concentrations (0.1 to 3 mg/L relative to 1.2 mg/l). Again, the greatest increases are predicted for the middle of the site, adjacent to the Makoura Stream and some of the drains. The next highest increases are predicted adjacent to the Ruamahanga River where groundwater discharges directly south of the site (south of the existing ponds).

Phosphorus increases in concentration throughout the life of the project, reflecting a depletion of the soil’s ability to retain phosphorus. The long-term (30-year) increase in phosphorus concentration is also of a similar magnitude to the existing concentrations (0.02 mg/L) in many locations but an order of magnitude higher for some locations. The highest concentrations are adjacent to the river directly south of the site.

Combining volume fluxes (discharges) to the drains, stream and river with concentrations adjacent to these water bodies allows mass fluxes of the three contaminants to be calculated. The total daily amounts of nitrate-N and phosphorus discharging to the Ruamahanga River (as a sum of that being discharged directly to the river and via the Makoura Stream) are predicted to be 9.3 and 0.82 kg, respectively.

The mass fluxes to the stream and river may be converted to concentration increases after mixing by combining with the stream and river flows. For the Makoura Stream, concentration increase relative to background concentration for summer low flows is predicted to be negligible for bacteria, 7% for nitrate-N (increase from 3.5 to 3.75 mg/L) and 50% for phosphorus (taking the concentration from 0.02 to 0.03 mg/L).

Concentration increases in the river for summer low flows (2.7 m^3/s before the increase from drainage and irrigation) are generally smaller than for the stream. Increases in the river below the confluence with the stream are predicted to be negligible for bacteria, similar to the stream in relative terms (6%) for nitrate-N but lower in absolute terms (increase from 0.6 to 0.64 mg/L) and moderate for phosphorus (0.01 to 0.013 mg/L – a 30% increase).

The model was also used to predict contaminant effects on the groundwater north of the site, in the vicinity of private properties that use shallow groundwater for domestic supply, and to the west of the Martinborough-Masterton Road, again in the vicinity of properties that use the shallow groundwater. The modelling found negligible effects on groundwater in these areas, an expected result given the groundwater flow direction and the rapid drop-off of contaminant concentrations outside the irrigated area.

The contaminant transport modelling is conservative as filtration effects for bacteria and attenuation effects for nitrate and phosphorus within the aquifer have not been allowed for in the model. In addition, the 15 mm/day assumed summer application rate is greater than the expected typical summer rate of 10 mm/day. Thus the model will be over-predicting the groundwater concentrations, mass fluxes and concentration increases in the stream and river.

9.0 References

PDP (2006). Masterton Wastewater Upgrade – Groundwater Report, Pattle Delamore Partners Ltd, Wellington, December 2006.

PDP (2007). Masterton Wastewater – RMA s92 Request, Update of Groundwater Monitoring, October, 2007.

Butcher G M (1996). Safe Yield Estimates for Identified Aquifers in the Wairarapa Valley Report prepared for the Wellington Regional Council

Appendix A Tables

Table 1: Revised Modelled Irrigation Areas

Modelled Plot Names	Original Irrigated Areas (ha)	October 2007 Revised Irrigated Areas (ha)	June 2008 Revised Irrigated Areas (ha)
Plot 1	6.1	6.9	6.3
Plot 2	4.2	4.9	4.7
Plot 3	4.9	5.6	5.6
Plot 4	5.4	6.4	6.4
Plot 5	5.1	5.4	6.3
Plot 6 (renamed)	Was old plot 8	Was old plot 8	7.6
Plot 7 (renamed)	Was old plot 9	Was old plot 9	4.8
Plot 8 (renamed)	Was old plot 10	Was old plot 10	7.0
Plot 9 (renamed)	New land	New land	3.8
Plot 10 (renamed)	New land	New land	4.4
Plot 11 (renamed)	New Land	New Land	4.9
Plot 12	New Land	New Land	4.9
Plot 13	New Land	New Land	4.0
Plot 14	New Land	New Land	4.2
Plot 15	New Land	New Land	6.7
Plot 16	New Land	New Land	1.6
Plot 17	New Land	New Land	7.5
Plot 18	New Land	New Land	6.5
Plot 19	New Land	New Land	4.8
Plot 20	New Land	New Land	3.7
Plot 21	New Land	New Land	3.3
Plot 22	New Land	New Land	4.1
Plot 23	New Land	New Land	4.0
Plot 24	New Land	New Land	4.2
Plot 25	New Land	New Land	3.2
Plot 26	New Land	New Land	2.5
Plot 27	Old Pond 1	Old Pond 1	8.2
Plot 28	Old Pond 2	Old Pond 2	7.1
Plot 29	Old Pond 3	Old Pond 3	7.1
Old Plot 6	5.1	6.0	New pond
Old Plot 7	5.4	6.7	New pond
Old Plot 8	7.6	9.3	Now new plot 6
Old Plot 9	5.1	5.6	Now new plot 7
Old Plot 10	4.4	5.9	Now new plot 8
Old Plot 11	21.4	17.2	New pond
Total	**74.7**	**79.9**	**149.4**

Table 2: Original and Revised Average Seasonal Irrigation Rates (mm/day) for Nutrient Modelling.

Soil Type:	Original Modelling (PDP, 2006)				Revised June 2008 Modelling	
	Option 6 (Average Rate)		Option 3 (High Rate)		High Rate Option	
	Summer	Winter	Summer	Winter	Summer	Winter
Free Draining	10	5	15	7.5	15	5
Clay Rich	5	0	5	0	10	5

Table 3: Groundwater Concentrations, Discharges and Mass Fluxes into Makoura Stream and Ruamahanga River

	Predicted Groundwater Concentrations Adjacent to Stream and River			**Groundwater Discharge**	**Mass Flux**		
Location	Nitrate-N (mg/L)	Bacteria (cfu/100ml)	Phosphorus (mg/L)	(m^3/day)	Nitrate-N (g/d)	Bacteria (cfu/d)	Phosphorus (g/d)
Makoura Stream – Maximums							
Zone 7	0.99	3.9 x 10^{-10}	0.129	126	124	5.0 x 10^{-4}	16.3
Zone 8	1.44	2.3 x 10^{-9}	0.085	124	178	2.8 x 10^{-3}	10.5
Zone 9	2.84	0.900	0.372	322	916	2,900,747	119.9
Zone 10	2.97	0.684	0.099	344	1,021	2,350,314	34.1
Zone 11	1.77	0.125	0.036	99	175	123,658	3.5
Zone 12	1.19	0.037	0.012	1,218	1,450	453,901	15.0
Zone 13	1.80	0.239	0.040	511	921	1,218,523	20.6
Zone 14	1.03	0.017	0.024	1,106	1,142	188,323	27.0
Zone 15	1.01	0.105	0.027	896	908	937,815	24.1
Zone 16	0.48	3.9 x 10^{-10}	0.018	10	5	3.9 x 10^{-5}	0.2
Means & Totals	**1.44**	**0.172**	**0.057**	**4,755**	**6,840**	**8,173,281**	**271**
Ruamahanga River – Summer Means							
Zone 1	0.23	0.0001	0.009	1,115	254	1,113	9.8
Zone 2	0.13	0.0103	0.055	292	39	30,026	16.0
Zone 3	0.15	0.0001	0.048	399	60	216	19.0
Zone 4	1.78	2.1 x 10^{-4}	0.496	194	347	412	96.4
Zone 5	1.62	1.1 x 10^{-1}	0.453	499	811	535,051	226.3
Zone 6	2.34	2.4 x 10^{-1}	0.434	420	984	1,000,907	182.6
Zone 17	0.00	1.5 x 10^{-31}	0.0003	149	0.5	2.3 x 10^{-25}	0.04
Means & Totals	**0.81**	**0.051**	**0.179**	**3,069**	**2,495**	**1,567,724**	**550**

Table 4: Background Concentrations in Ground and Surface Water 2003/05 [1, 2]

	E. Coli (cfu/100 ml)		**Nitrate-N (mg/L)**		**DRP (mg/L)**	
Location	Mean	Median	Mean	Median	Mean	Median
Groundwater HB5, 6 and 9	1.2	1	1.3	1.3	0.02	0.014
Makoura Stream at Mak1	1,040	420	3.5	3.7	0.02	0.02
Ruamahanga River at Rua1	450	60	0.6	0.7	0.01	0.01

Notes: 1. From consent monitoring reports
2. Reproduced from Table 6 of PDP (2007)

Table 5: Flow Increase in Makoura Stream and Ruamahanga River from Drainage and Irrigation Discharges

	Increase in Flow (m^3/s)Past Site due to:			Increase from Scheme as Percentage of Natural Downstream Flow (m^3/s)			Predicted Downstream Flow During Summer (m^3/s)
	Drainage System	Irrigation	Total Increase	Drainage System	Irrigation	Total Increase	
Makoura Stream	0.094	0.055	0.149	55 %	32 %	87 %	0.32
Ruamahanga above confluence with Makoura	-	0.036	0.036	-	14 %	14 %	2.57
Ruamahanga below confluence with Makoura	0.094	0.091	0.185	3.5%	3.3 %	7 %	2.89

Note: 1. The stream naturally increases by 0.1 m^3/s from approximately 0.07 to 0.17 m^3/s as it passes through the site.
2. The natural river flow measured at Wardell's includes the contribution from the stream.

Table 6: Concentration Change in Ruamahanga River and Makoura Stream from Irrigation

Nitrate-N (mg/L)	Bacteria (cfu/100ml)	Phosphorus (mg/L)
For stream at 0.32 m^3/s		
0.25	0.030	0.0098
For river above confluence at summer low flow of 2.57 m^3/s		
0.011	0.0007	0.0025
For river below confluence at summer low flow of 2.89 m^3/s		
0.035	0.004	0.0031

Table 7: Groundwater Elevations During New Pond Construction

Cross Section	Point Along Cross Section	Average Groundwater (m, RL)	Groundwater during 5-yr Flood Event (m, RL)	Groundwater during 5-yr Flood Event and Pumping (m, RL)
Section 15A (points numbered from north)	1	87	88.1	87.4
	2	86.7	87.5	86.9
	3	86.2	86.9	86.4
	4	85.6	86.5	85.9
	5	85.5	86.4	85.9
	6	84.8	86	85.8
	7	84.3	85.9	85.5
Section 16A (points numbered from north)	1	86.1	86.1	86
	2	85.8	85.9	85.7
	3	85.6	85.7	85.3
	4	85.3	85.6	85.2
	5	84.9	85.3	85
	6	84.7	85.3	85
	7	83.4	85.5	85.5
Section 17A (points numbered from north)	1	85.4	85.4	85.4
	2	85	84.9	84.9
	3	84.8	84.8	84.7
	4	84.2	84.5	84.5
	5	83.7	84.6	84.5
	6	82.8	85	85
Section 18A (points numbered from west)	1	84.2	84.4	84.3
	2	84.5	84.7	84.5
	3	85	85.3	85
	4	85.5	85.8	84.4
	5	86.1	86.5	86
	6	87	87.9	87.6

Note: 1. See Figure 9 for point locations.

Table 8: Groundwater Elevations During Irrigation of Existing Ponds
(Plots 27, 28 and 29)

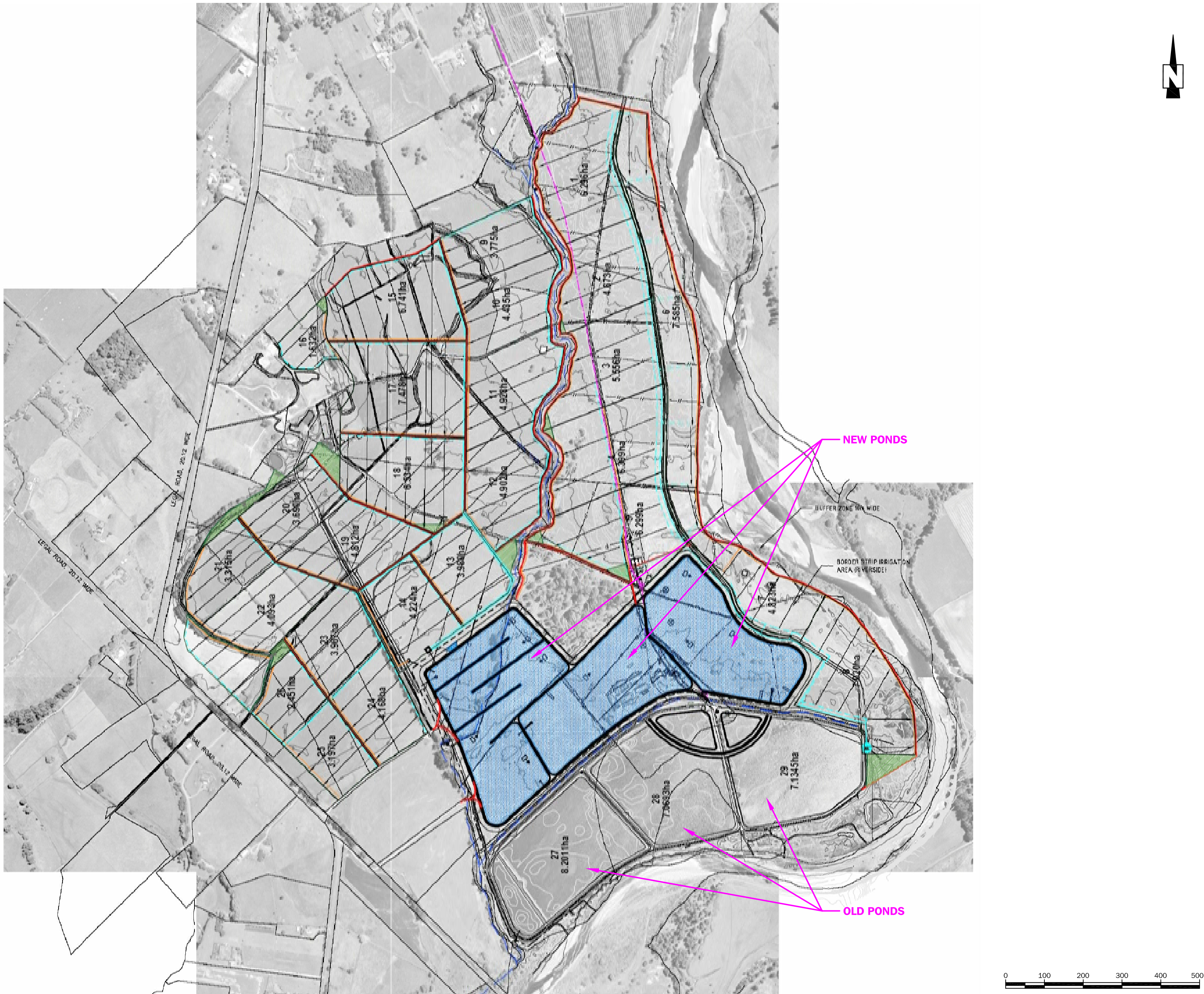
Cross Section	Point Along Cross Section	Average Groundwater (m, RL)	Groundwater during Irrigation (m, RL)
Section 15A (points numbered from north)	5	85.5	85.8
	6	84.8	85.1
	7	84.3	84.5
Section 16A (points numbered from north)	6	84.7	85.1
	7	83.4	83.6
Section 17A (points numbered from north)	5	83.7	84.0
	6	82.8	83.0

Note: 1. See Figure 9 for point locations.

Table 9: Post-modelling Adjusted Irrigation Areas

Modelled Plot Names	Modelled Irrigated Areas (ha)	August 2008 Adjusted Irrigated Areas (ha)	Main Changes
Plot 1	6.3	4.5	North boundary reduced
Plot 2	4.7	4.7	No change
Plot 3	5.6	5.6	No change
Plot 4	6.4	5.6	Tree area removed
Plot 5	6.3	5.6	South boundary reduced
Plot 6	7.6	7.3	North boundary reduced
Plot 7	4.8	4.8	No change
Plot 8	7.0	6.6	West and east boundary reduced
Plot 9	3.8	5.2	North boundary increased
Plot 10	4.4	5.1	Increased area
Plot 11	4.9	5.6	Increased area
Plot 12	4.9	5.5	Increased area
Plot 13	4.0	4.4	Increased area
Plot 14	4.2	4.5	Increased area
Plot 15	6.7	6.7	No change
Plot 16	1.6	1.6	No change
Plot 17	7.5	7.5	No change
Plot 18	6.5	6.5	No change
Plot 19	4.8	4.8	No change
Plot 20	3.7	3.7	No change
Plot 21	3.3	2.5	Plot 21 divided into two and new Plot 28 boundary extended west
New Plot 28	-	1.6	
Plot 22	4.1	2.5	Plot 22 divided into two and new Plot 27 boundary extended west
New Plot 27	-	2.7	
Plot 23	4.0	4.0	No change
Plot 24	4.2	3.4	South boundary reduced
Plot 25	3.2	2.5	South boundary reduced
Plot 26	2.5	3.4	West boundary increased
Plot 29	8.2	8.2	Was old plot 27
Plot 30	7.1	7.1	Was old plot 28
Plot 31	7.1	7.1	Was old plot 29
Total	**149.4**	**151.0**	

Appendix B Figures



Source: Base PDF supplied by Beca, dwg no 3202216-560-C601, Rev A.

Figure 1 : PROPOSED IRRIGATION PLOTS SHOWING PLOT NUMBERS AND AREAS

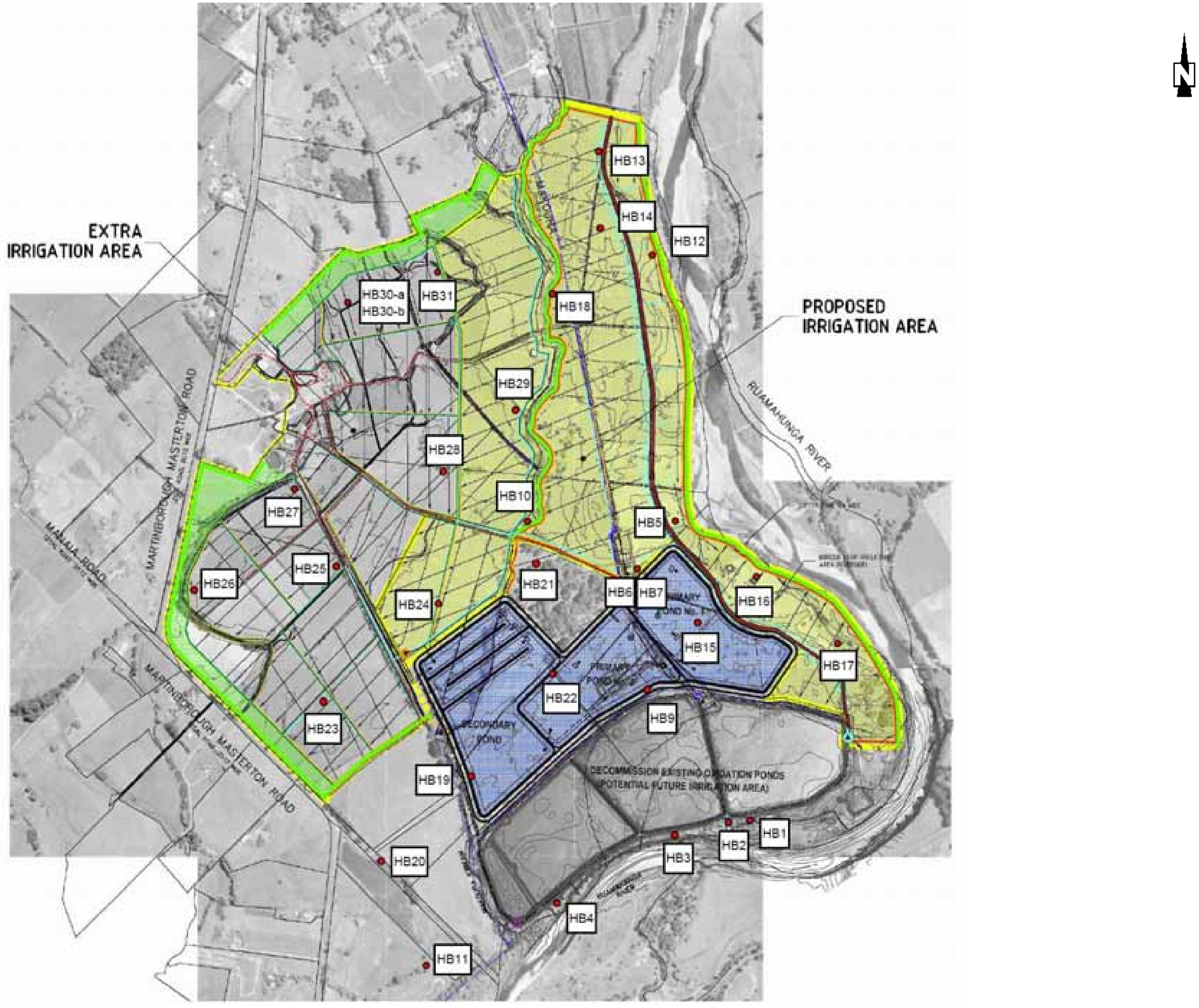


Figure 2: MONITORING WELL LOCATIONS

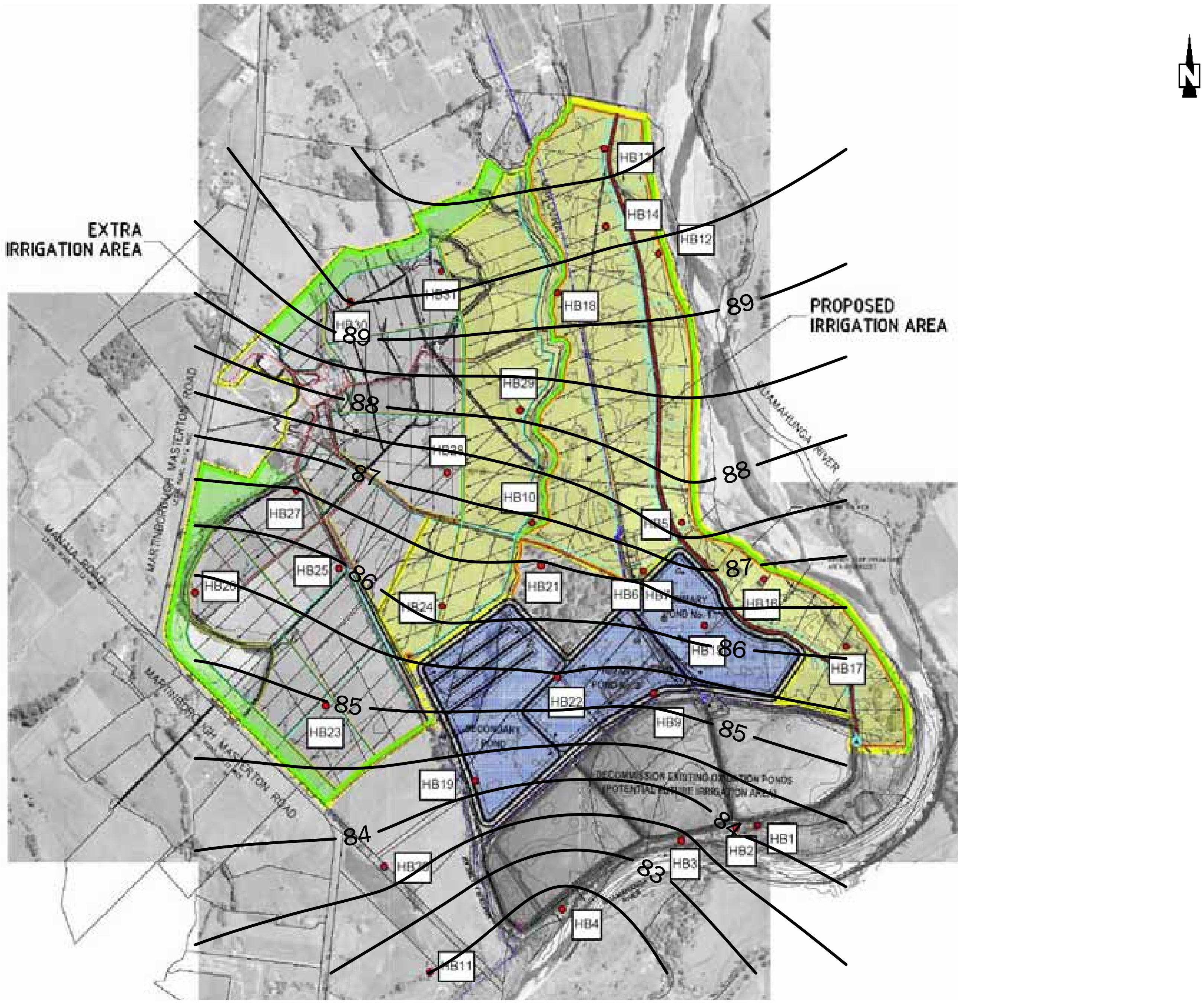


Figure 3: PIEZOMETRIC CONTOURS

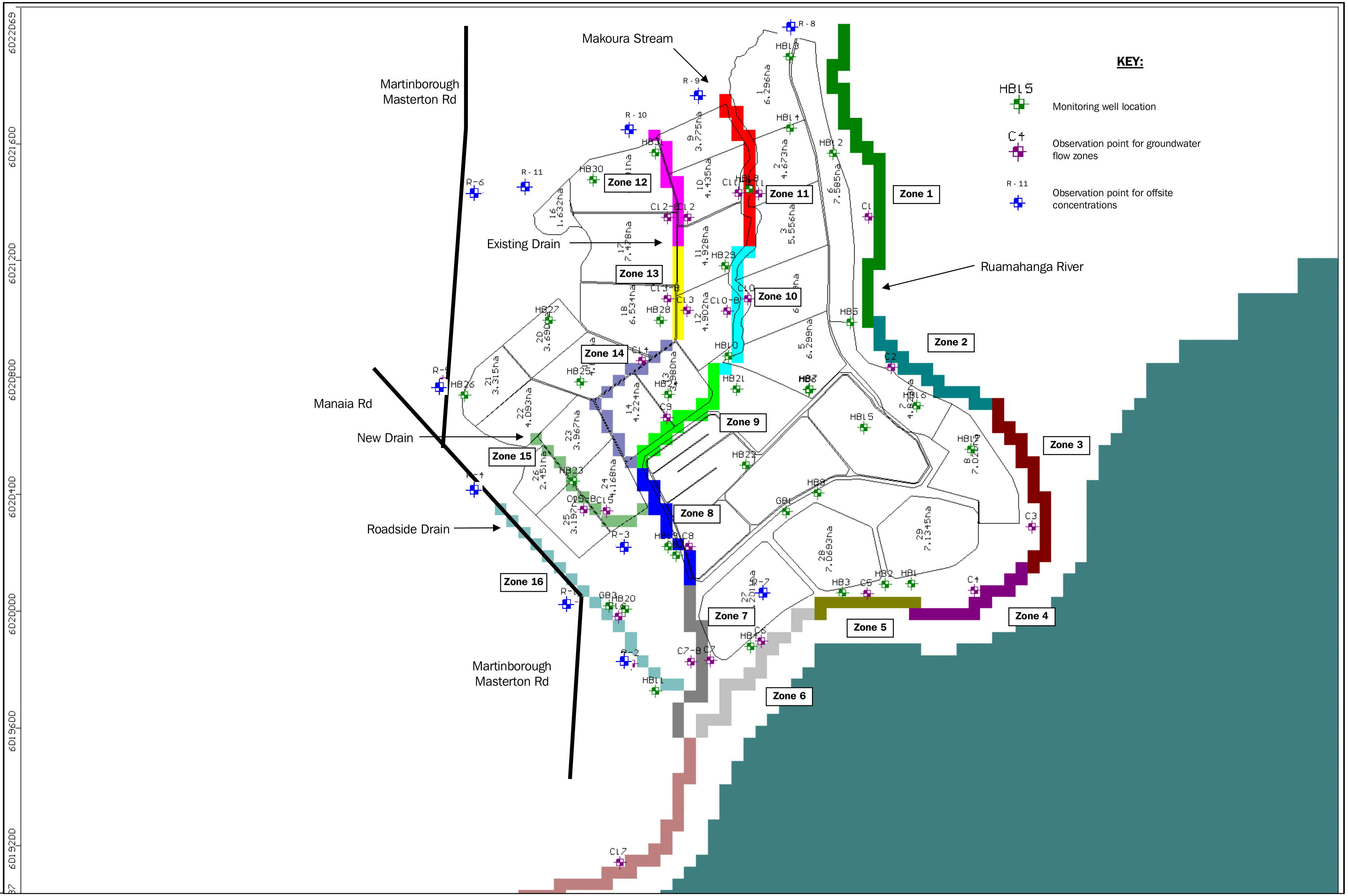


Figure 4: GROUNDWATER FLOW ZONES AND OBSERVATION POINTS FOR CALCULATING CONTAMINANT FLUXES

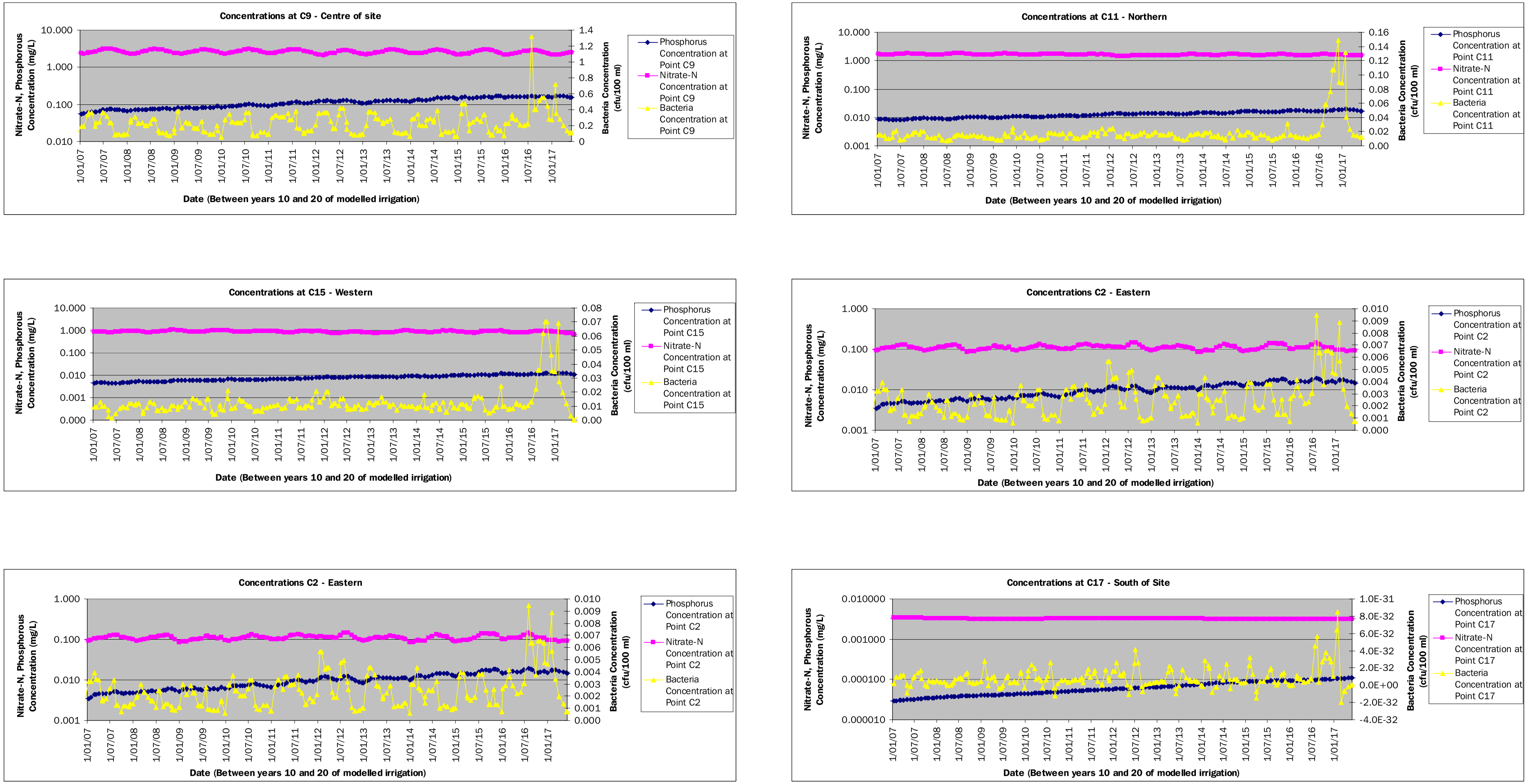


Figure 5: PREDICTED GROUNDWATER CONCENTRATIONS ON SITE

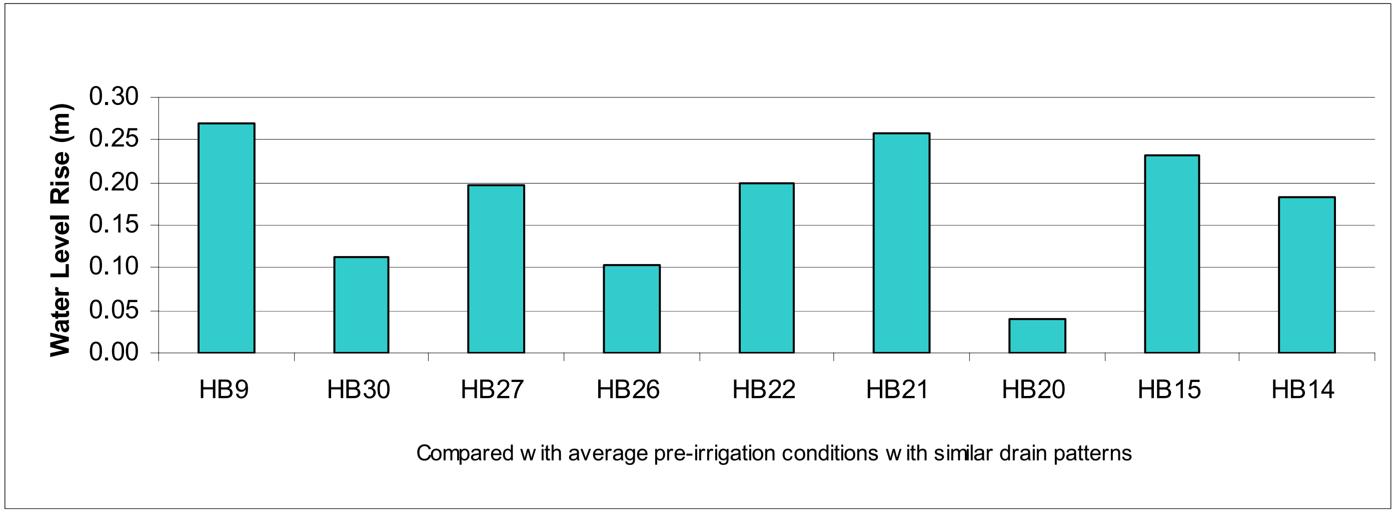


Figure 6: MAXIMUM MOUNDING (assuming only post drainage system for both pre and post irrigation models)

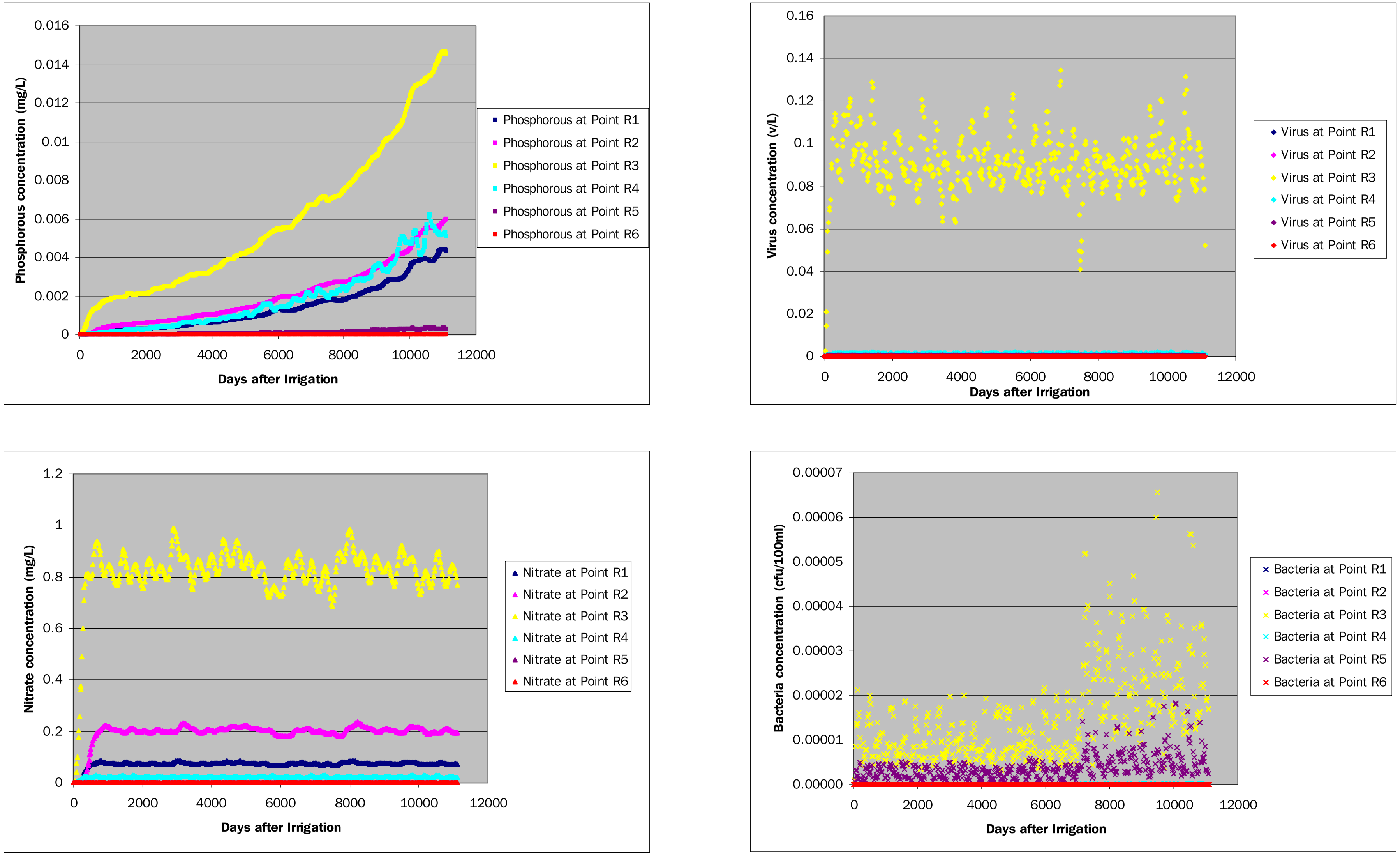


Figure 7: PREDICTED CONCENTRATIONS WEST OF SITE

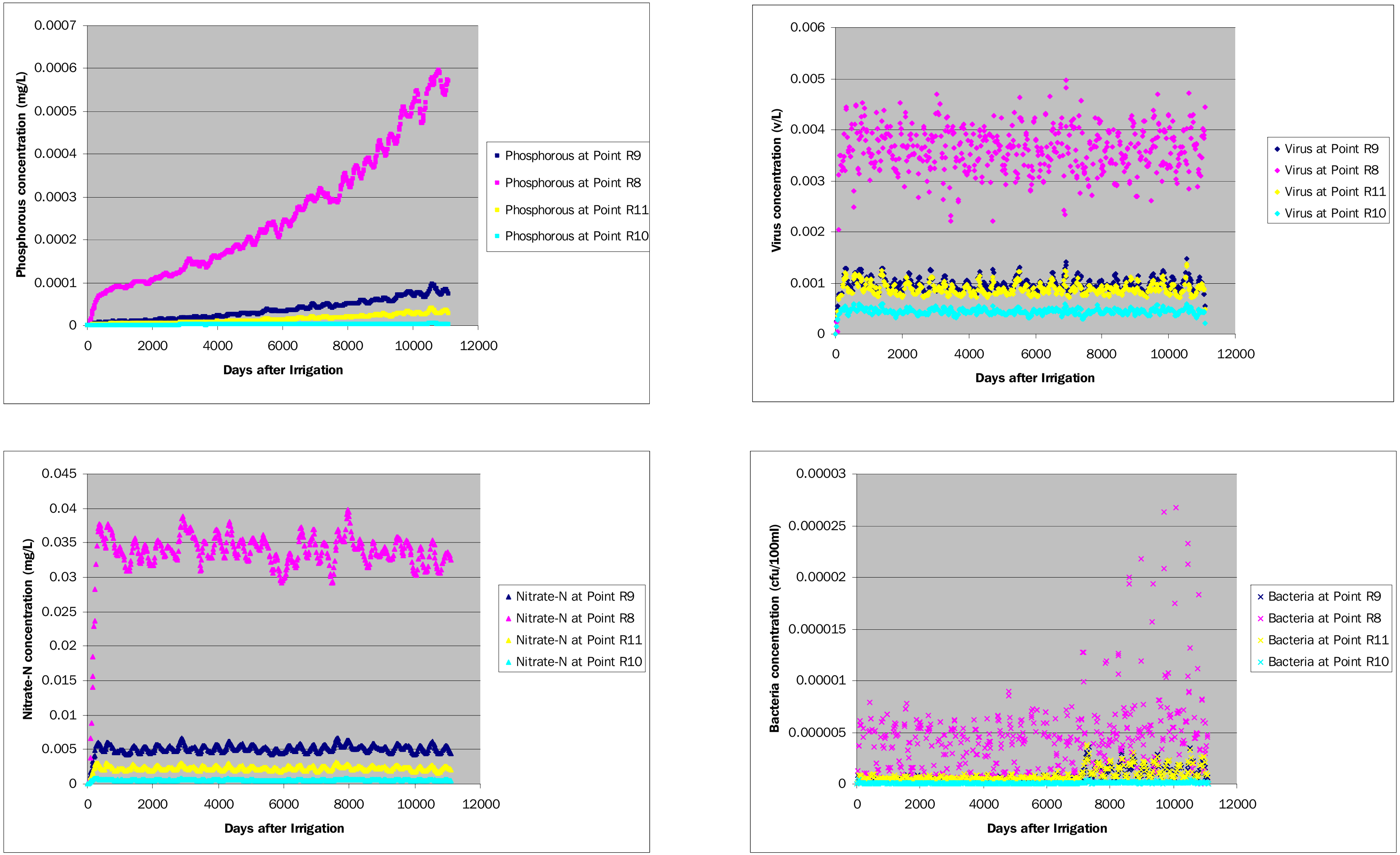
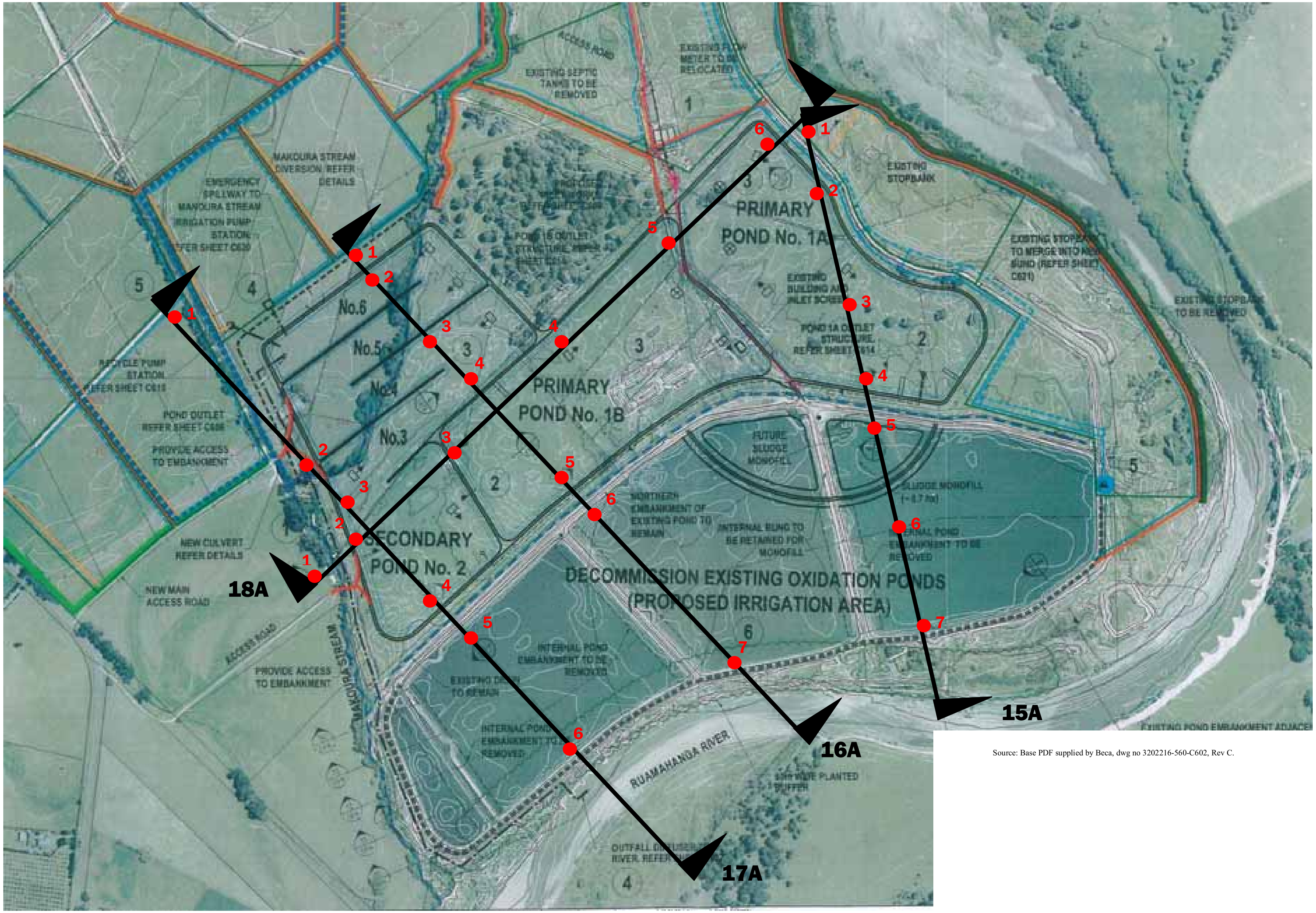


Figure 8: PREDICTED CONCENTRATIONS NORTH OF SITE



Source: Base PDF supplied by Beca, dwg no 3202216-560-C602, Rev C.

Figure 9: CONSTRUCTION DEWATERING – LOCATION OF MODELLED GROUNDWATER LEVEL POINTS ALONG SECTIONS

Figure 10: REVISED IRRIGATION PLOT NUMBERS AND AREAS

Source: Base PDF supplied by Beca, dwg no 3202216-560-C624, Rev C.

Appendix C Borehole Logs

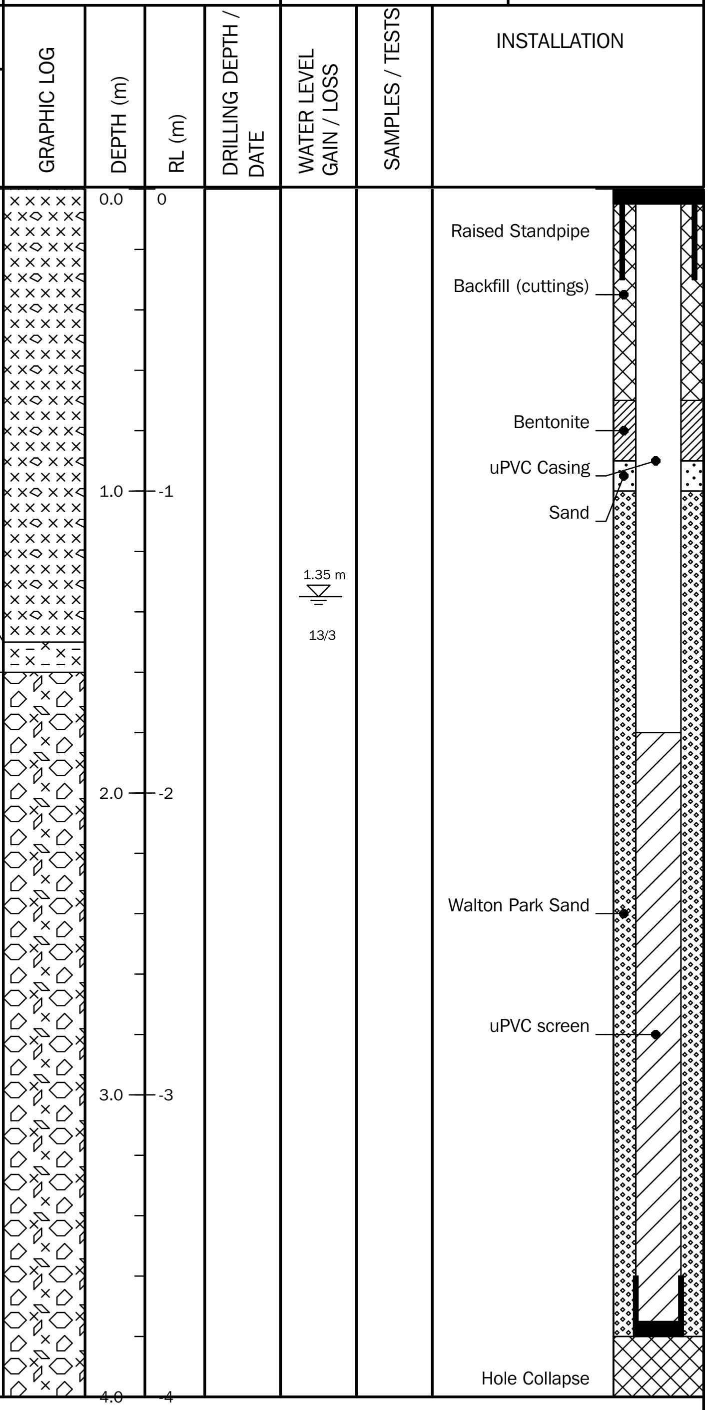
PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB23**
JOB NO: WJ29213

CLIENT:	Beca Carter Limited
LOCATION:	"Yards 3"
START DATE:	10/03/2008
END DATE:	10/03/2008
COORDINATES:	3734844.93 6020444.03
TOTAL DEPTH:	4.0 m
LOGGED BY:	SH
SHEET 1 OF 1	
GROUND LEVEL:	86.42
TOP OF CASING:	86.96

INTERPRETATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)
	Light brown SILT, with a trace of fine rounded gravel. Very compact. Dry.
	Grey-dark brown SILTY CLAY, with minor angular gravel. Moist.
	Grey GRAVEL with minor silt and coarse sand. Gravel sub-rounded to sub-angular, diameter 40 mm up to 100 mm. Dark brown silt. Moist. Wet below 1.8 m.



END OF BOREHOLE AT 4.0m

Notes: Hand excavated to 0.55 m.
Standpipe extends 0.54 m above ground level.
Coordinate system is NZMG.

KEY
▽ Groundwater Level
← Water Gain
→ Water Loss
● Grab sample

Drilled By:	Webster Drilling
Diameter:	200 mm
Method:	Machine auger
Datum:	Mean Sea Level
Filename:	WJ29213 HB23

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

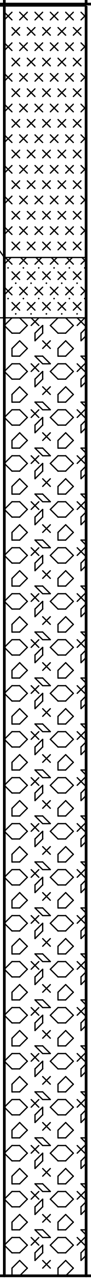
PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

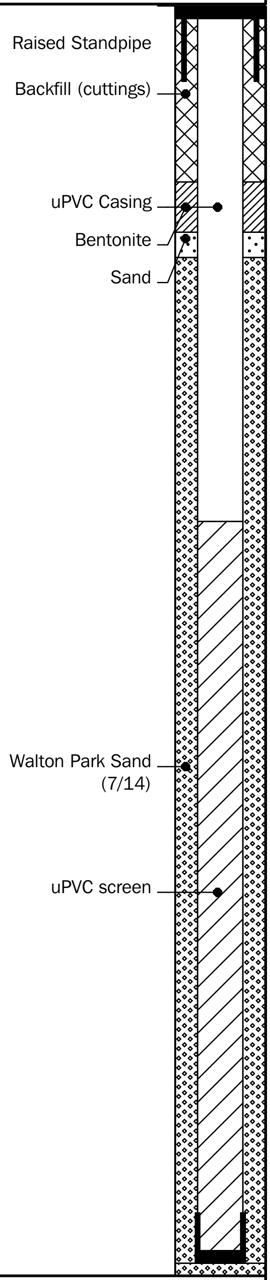
HOLE NO. **HB24**
JOB NO: WJ29213

CLIENT: Beca Carter Limited		LOCATION: "Centre Right 5"	
START DATE: 11/03/2008 END DATE: 11/03/2008	COORDINATES: 2735167.66 6020741.66	TOTAL DEPTH: 5.1 m	LOGGED BY: SH SHEET 1 OF 1
GROUND LEVEL: 87.34 TOP OF CASING: 87.81			

INTERPRETATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)	GRAPHIC LOG	DEPTH (m)	RL (m)	DRILLING DEPTH / DATE	WATER LEVEL GAIN / LOSS	SAMPLES / TESTS
	Brown SILT (topsoil), dry to moist.		0.0	0			
	Brown SILT with some sand. Silt is plastic, moist. Medium sand.		1.0	-1		1.04 m ▽ 13/3	
	Brown-grey GRAVEL with some brown silt and coarse sand. Gravel is sub-angular to sub-rounded, up to 20 mm diameter.		2.0	-2			
			3.0	-3			
			4.0	-4			
			5.0	-5			



INSTALLATION



END OF BOREHOLE AT 5.05m

Notes: Standpipe extends 0.47 m above ground level.
Coordinate system is NZMG.

KEY
▽ Groundwater Level
← Water Gain
→ Water Loss
● Grab sample

Drilled By:	Webster Drilling
Diameter:	140 mm
Method:	Concentrix
Datum:	Mean Sea Level
Filename:	WJ29213 HB24

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

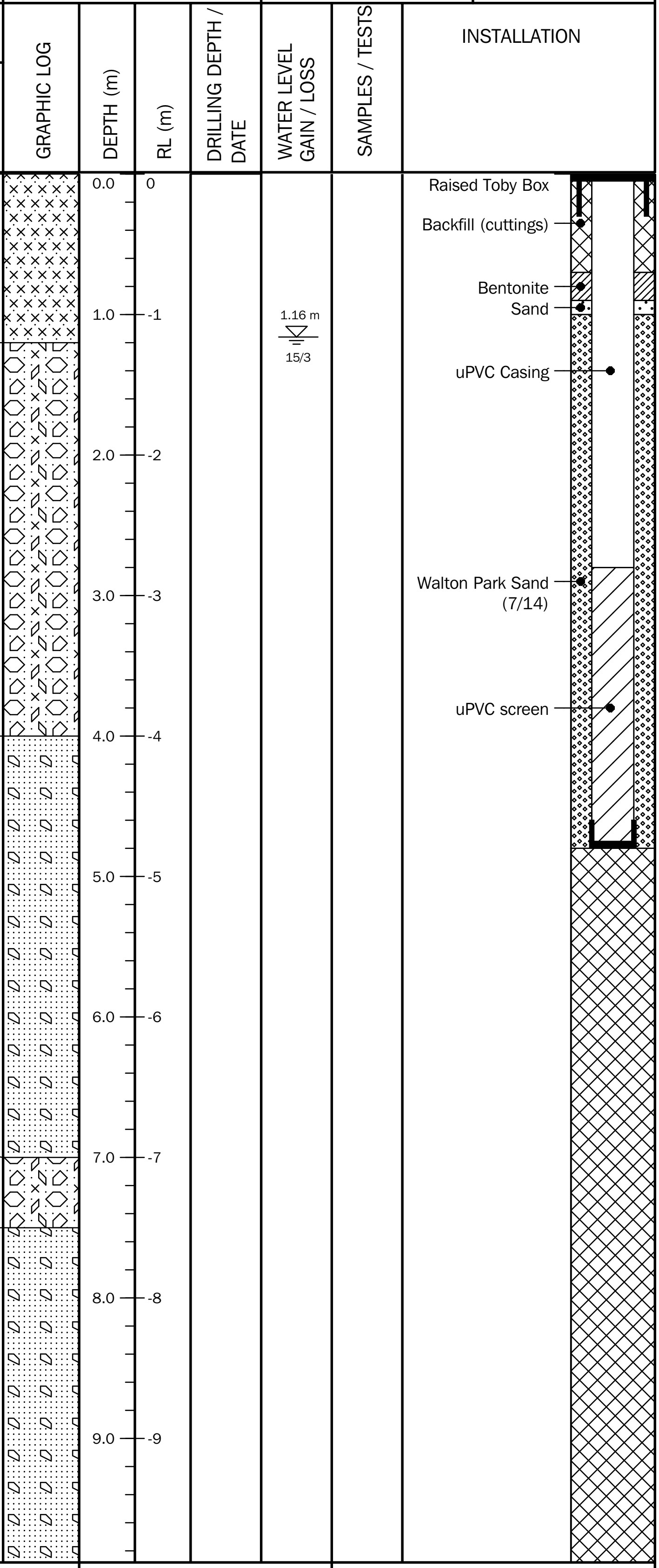
PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB25**
JOB NO: WJ29213

CLIENT: Beca Carter Limited		LOCATION: "Bluegum 6"	
START DATE: 14/03/2008 END DATE: 14/03/2008	COORDINATES: 2734871.68 6020783.65	TOTAL DEPTH: 23.0 m	LOGGED BY: SH · SHEET 1 OF 3
GROUND LEVEL: 86.88 TOP OF CASING: 87.28			

INTERPRETATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)
	Medium brown SILT with minor coarse rounded sand. Dry. Hard. Moist below 1 m
	Light grey rounded GRAVEL with some coarse sand and grey silt. Gravel is sub-angular to sub-rounded, up to 20 mm diameter. Wet.
	Coarse angular dark grey SAND with some rounded gravel up to 10 mm diameter. Wet.
	Reddish brown GRAVEL with some coarse sand and minor silt. Wet.
	Reddish brown coarse to medium angular SAND with some rounded gravel up to 20 mm diameter. Wet.



Notes: Standpipe extends 0.4 m above ground level.
Coordinate system is NZMG.

KEY
▽ Groundwater Level
← Water Gain
→ Water Loss
● Grab sample

Drilled By: Webster Drilling
Diameter: 140 mm
Method: Concentrix
Datum: Mean Sea Level

Filename: WJ29213 HB25

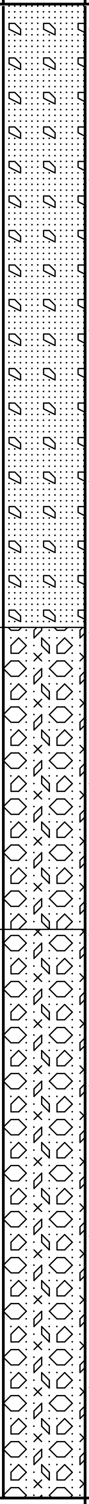
Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

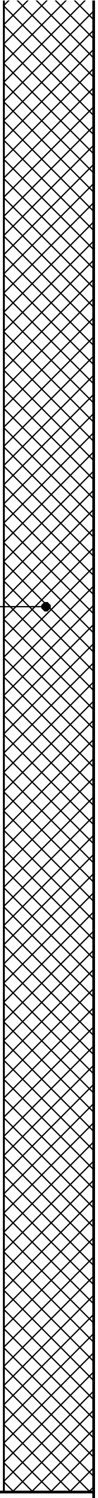
PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB25**
JOB NO: WJ29213

CLIENT: Beca Carter Limited		LOCATION: "Bluegum 6"	
START DATE: 14/03/2008 END DATE: 14/03/2008	COORDINATES: 2734871.68 6020783.65	TOTAL DEPTH: 23.0 m	LOGGED BY: SH
GROUND LEVEL: 86.88 TOP OF CASING: 87.28			SHEET 2 OF 3





INTERPRETATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)	DEPTH (m)	RL (m)	DRILLING DEPTH / DATE	WATER LEVEL GAIN / LOSS	SAMPLES / TESTS	INSTALLATION
		10.0	-10				
		11.0	-11				
		12.0	-12				
		13.0	-13				
	Medium brown GRAVEL with some coarse sand and minor clay clumps (possibly small lenses). Wet.	14.0	-14				Backfill (cuttings)
		15.0	-15				
	Brownish grey GRAVEL with some silt and coarse sand. Gravel is sub-angular up to 20 mm diameter. Larger clasts are broken. Wet.	16.0	-16				
		17.0	-17				
		18.0	-18				
		19.0	-19				

Notes: Standpipe extends 0.4 m above ground level.
Coordinate system is NZMG.

KEY
- ▽ Groundwater Level
- ← Water Gain
- → Water Loss
- ● Grab sample

Drilled By:	Webster Drilling
Diameter:	140 mm
Method:	Concentrix
Datum:	Mean Sea Level
Filename:	WJ29213 HB25

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

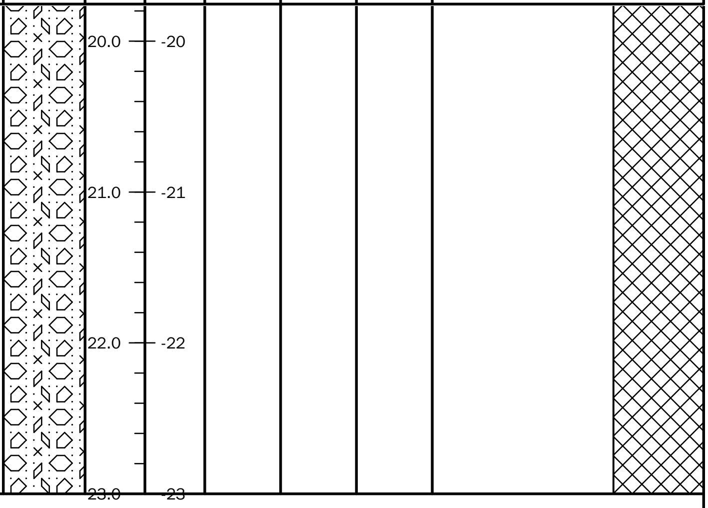
PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB25**
JOB NO: WJ29213

CLIENT: Beca Carter Limited		LOCATION: "Bluegum 6"	
START DATE: 14/03/2008 END DATE: 14/03/2008	COORDINATES: 2734871.68 6020783.65	TOTAL DEPTH: 23.0 m	LOGGED BY: SH SHEET 3 OF 3
GROUND LEVEL: 86.88 TOP OF CASING: 87.28			

INTERPRETATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)	GRAPHIC LOG	DEPTH (m)	RL (m)	DRILLING DEPTH / DATE	WATER LEVEL GAIN / LOSS	SAMPLES / TESTS	INSTALLATION



END OF BOREHOLE AT 23.0m

Notes: Standpipe extends 0.4 m above ground level.
Coordinate system is NZMG.

KEY
Groundwater Level
Water Gain
Water Loss
● Grab sample

Drilled By: Webster Drilling
Diameter: 140 mm
Method: Concentrix
Datum: Mean Sea Level

Filename: WJ29213 HB25

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

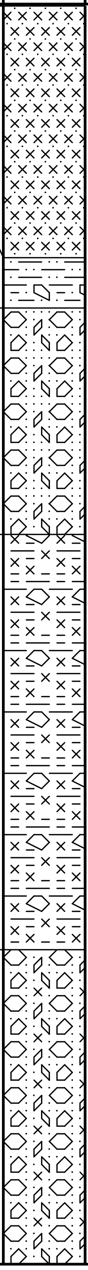
PATTLE DELAMORE PARTNERS LTD

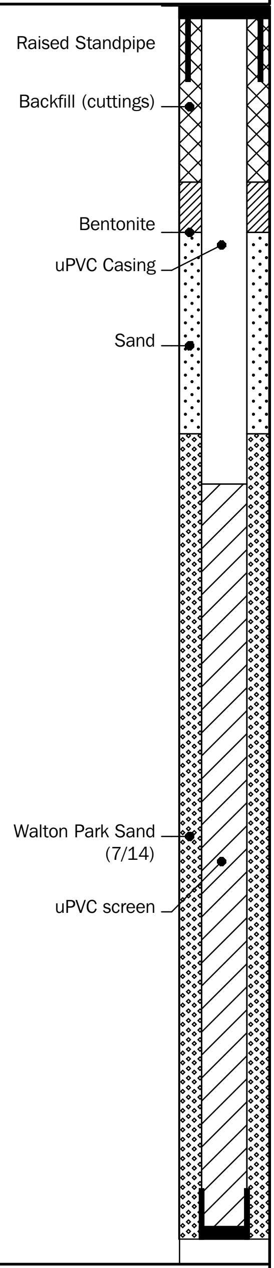
LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB26**
JOB NO: WJ29213

CLIENT: Beca Carter Limited	LOCATION: "Bluegum 3"
START DATE: 10/03/2008 END DATE: 11/03/2008	COORDINATES: 2734479.81 6020738.57
TOTAL DEPTH: 5.0 m	LOGGED BY: SH
SHEET 1 OF 1	
GROUND LEVEL: 86.02 TOP OF CASING: 86.48	

INTERPRETATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)	GRAPHIC LOG	DEPTH (m)	RL (m)	DRILLING DEPTH / DATE	WATER LEVEL GAIN / LOSS	SAMPLES / TESTS	INSTALLATION
	Medium brown SILT. Dry.		0.0	0		0.72 m 13/03		
	Grey coarse SANDY CLAY with some fine to medium rounded gravel. Wet.		1.0	-1				
	Grey coarse angular to rounded SANDY GRAVEL. Unknown clast size due to air hammer drilling. Wet.		2.0	-2				
	Grey SILTY CLAY with some fine rounded gravel. Moist.		3.0	-3				
	Fine rounded GRAVEL, up to 20 mm diameter, with some coarse sand and reddish brown silt. Wet.		4.0	-4	11 Mar			
			5.0	-5				





END OF BOREHOLE AT 5.0m

Notes: Standpipe extend 0.46 m above ground level.
Coordinate system is NZMG.

KEY
▽ Groundwater Level
← Water Gain
→ Water Loss
● Grab sample

Drilled By:	Webster Drilling
Diameter:	140 mm
Method:	Concentrix
Datum:	Mean Sea Level
Filename:	WJ29213 HB26

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB27**
JOB NO: WJ29213

CLIENT: Beca Carter Limited	LOCATION: "Bluegum 1"
START DATE: 11/03/2008 END DATE: 11/03/2008	COORDINATES: 2734763.56 6020995.49
TOTAL DEPTH: 5.0 m	LOGGED BY: SH
SHEET 1 OF 1	

GROUND LEVEL: 87.09
TOP OF CASING: 87.52

INTERPRE-TATION

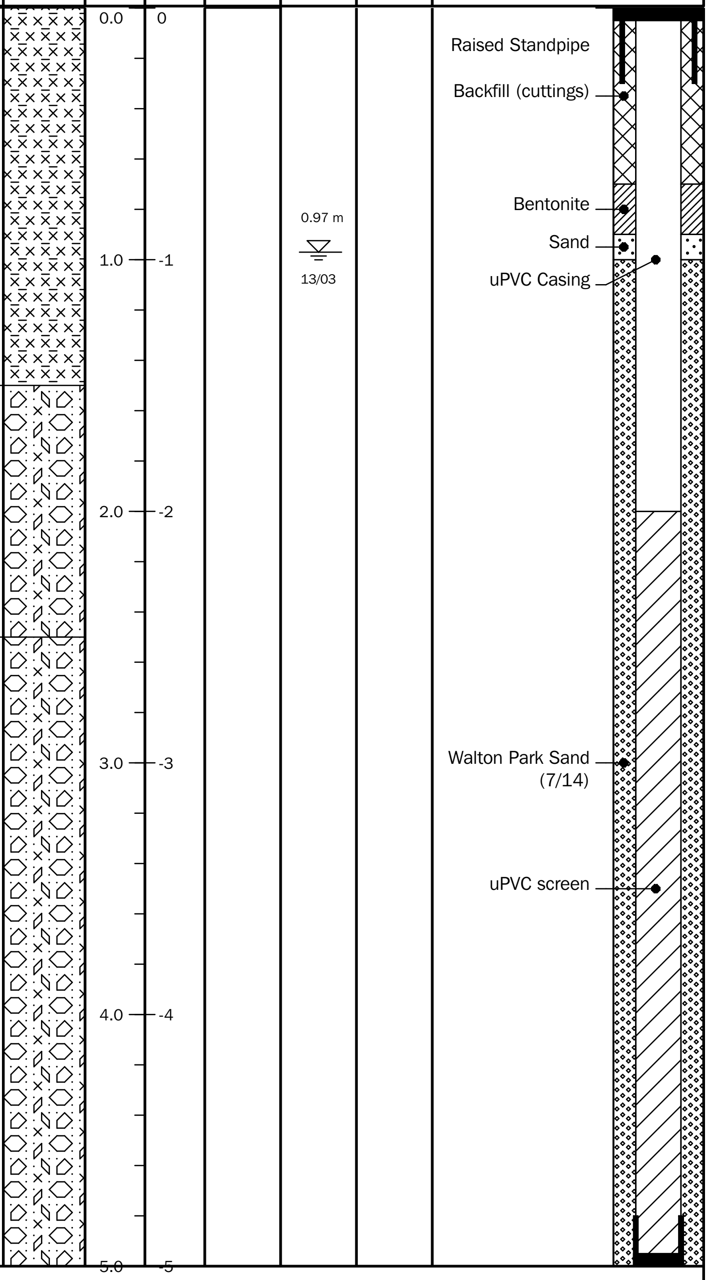
DESCRIPTION OF SOIL / ROCK
(based on cuttings etc.)

GRAPHIC LOG | DEPTH (m) | RL (m) | DRILLING DEPTH / DATE | WATER LEVEL GAIN / LOSS | SAMPLES / TESTS | INSTALLATION

Medium brown SILT (topsoil) with some clay and minor medium gravel. Plastic.

Angular to sub-rounded GRAVEL with dark grey silt and sand. Wet.

Medium angular to sub-rounded GRAVEL up to 20 mm, with brown sandy silt. Sand is medium to coarse. Wet. Fast recovery.



END OF BOREHOLE AT 5.0m

Notes: Standpipe extends 0.4 m above ground level.
Fast water recovery.
Coordinate system is NZMG.

KEY
$\underline{\nabla}$ Groundwater Level
← Water Gain
→ Water Loss
● Grab sample

Drilled By: Webster Drilling
Diameter: 140 mm
Method: Concentrix
Datum: Mean Sea Level
Filename: WJ29213 HB27

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

PATTLE DELAMORE PARTNERS LTD

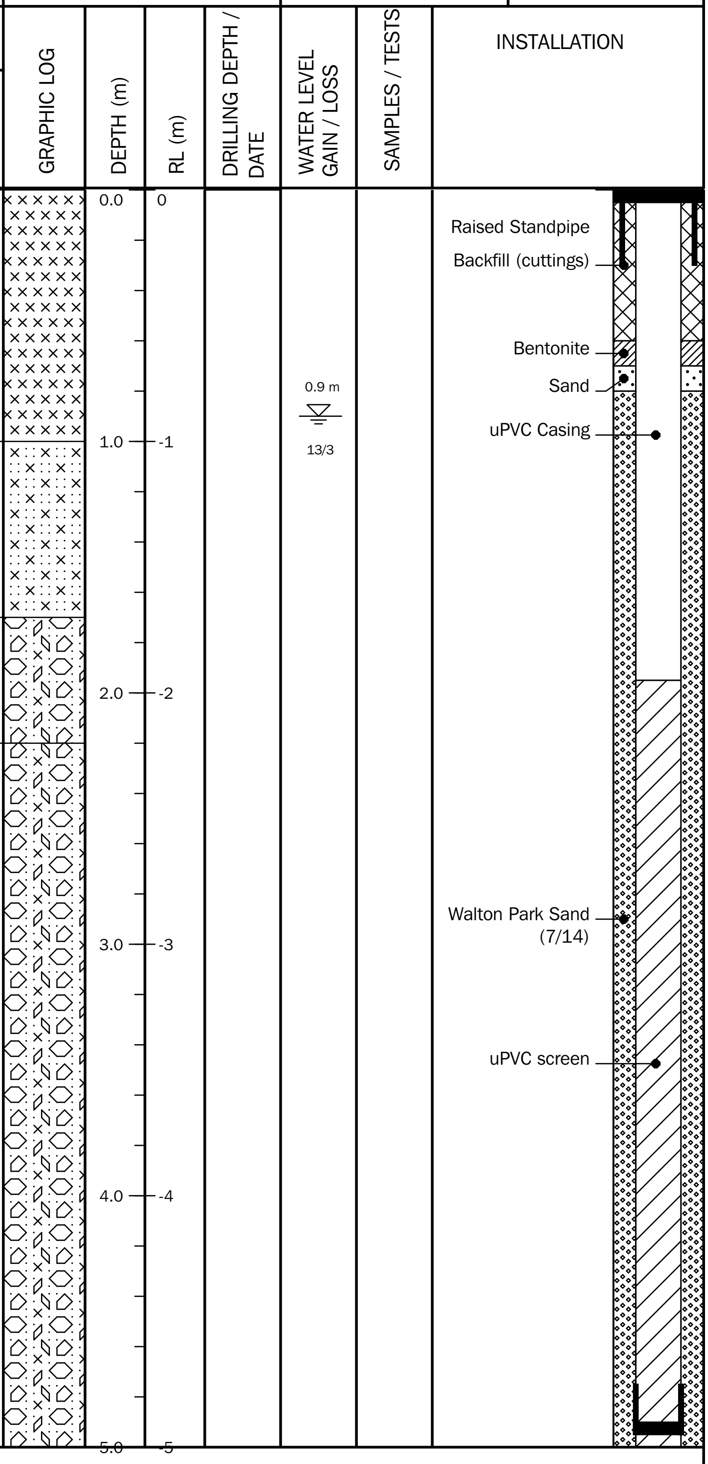
LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB28**
JOB NO: WJ29213

CLIENT: Beca Carter Limited		LOCATION: "Centre Left 3"	
START DATE: 11/03/2008 END DATE: 11/03/2008	COORDINATES: 2735140.98 6020995.27	TOTAL DEPTH: 5.0 m	LOGGED BY: SH — SHEET 1 OF 1

GROUND LEVEL: 87.66
TOP OF CASING: 88.10

INTERPRETATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)
	Medium brown SILT (topsoil). Very compact. Dry. Moist below 0.5m
	Dark grey SILTY SAND. Fine to medium sand. Moist.
	Grey GRAVEL with some silt and medium sand. Wet.
	Light brown SANDY GRAVEL with some silt. Very wet. Very fast recovery.



END OF BOREHOLE AT 5.0m

Notes: Standpipe extends 0.44 m above ground level.
Coordinate system is NZMG.

KEY
- Groundwater Level
- Water Gain
- Water Loss
- ● Grab sample

Drilled By:	Webster Drilling
Diameter:	140 mm
Method:	Concentrix
Datum:	Mean Sea Level
Filename:	WJ29213 HB28

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

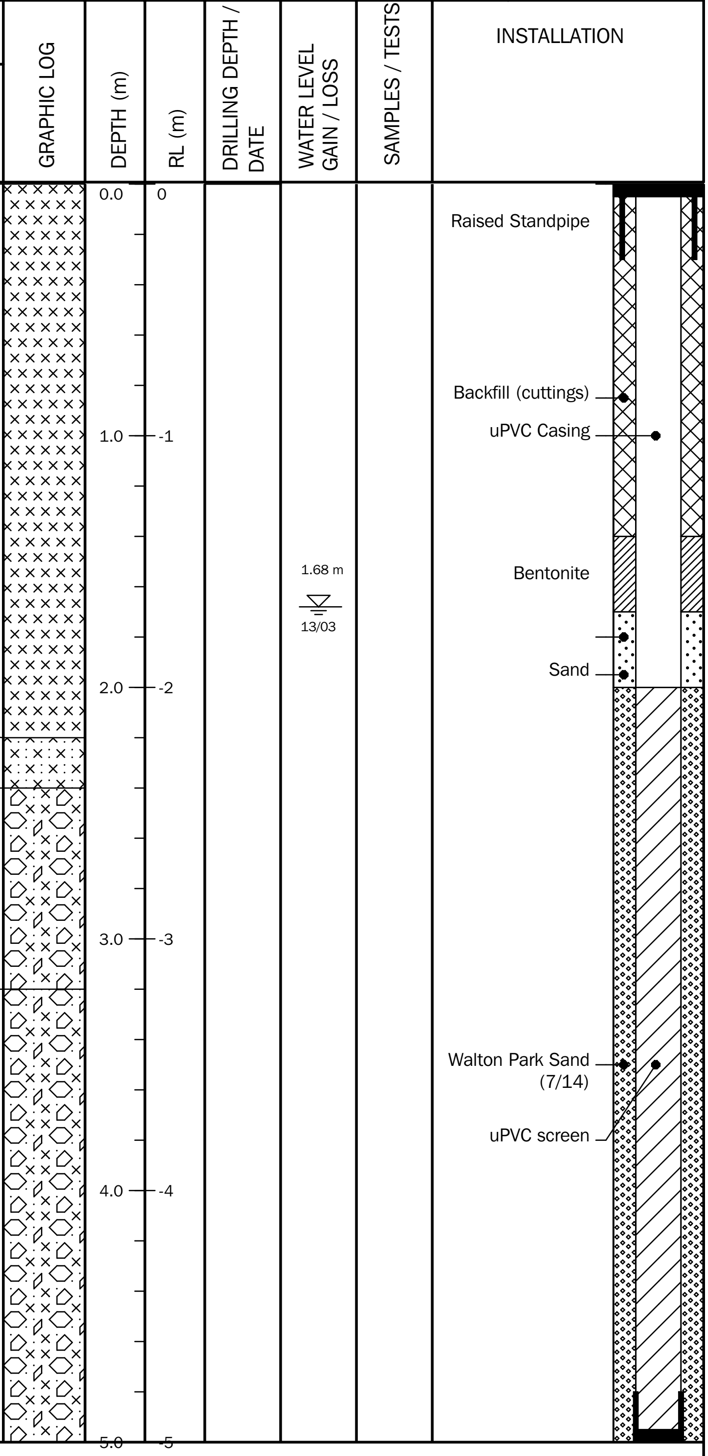
PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB29**
JOB NO: WJ29213

CLIENT: Beca Carter Limited	LOCATION: "Gnome"
START DATE: 11/03/2008 END DATE: 11/03/2008	COORDINATES: 2735359.08 6021183.69
TOTAL DEPTH: 5.0 m	LOGGED BY: SH
SHEET 1 OF 1	
GROUND LEVEL: 89.41 TOP OF CASING: 89.81	

INTERPRETATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)
	Medium brown SILT. Compact and plastic/stiff. Dry. Moist below 1m
	Grey coarse SANDY SILT with some fine rounded gravel. Wet.
	Grey SILTY GRAVEL with some coarse sand. Wet.
	Medium brown SILTY GRAVEL with some coarse sand. Very wet. Very fast recovery.



END OF BOREHOLE AT 5.0m

Notes: Standpipe extends 0.4 m above ground level.
Coordinate system is in NZMG.

KEY
⊽ Groundwater Level
← Water Gain
→ Water Loss
● Grab sample

Drilled By:	Webster Drilling
Diameter:	140 mm
Method:	Concentrix
Datum:	Mean Sea Level
Filename:	WJ29213 HB29

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

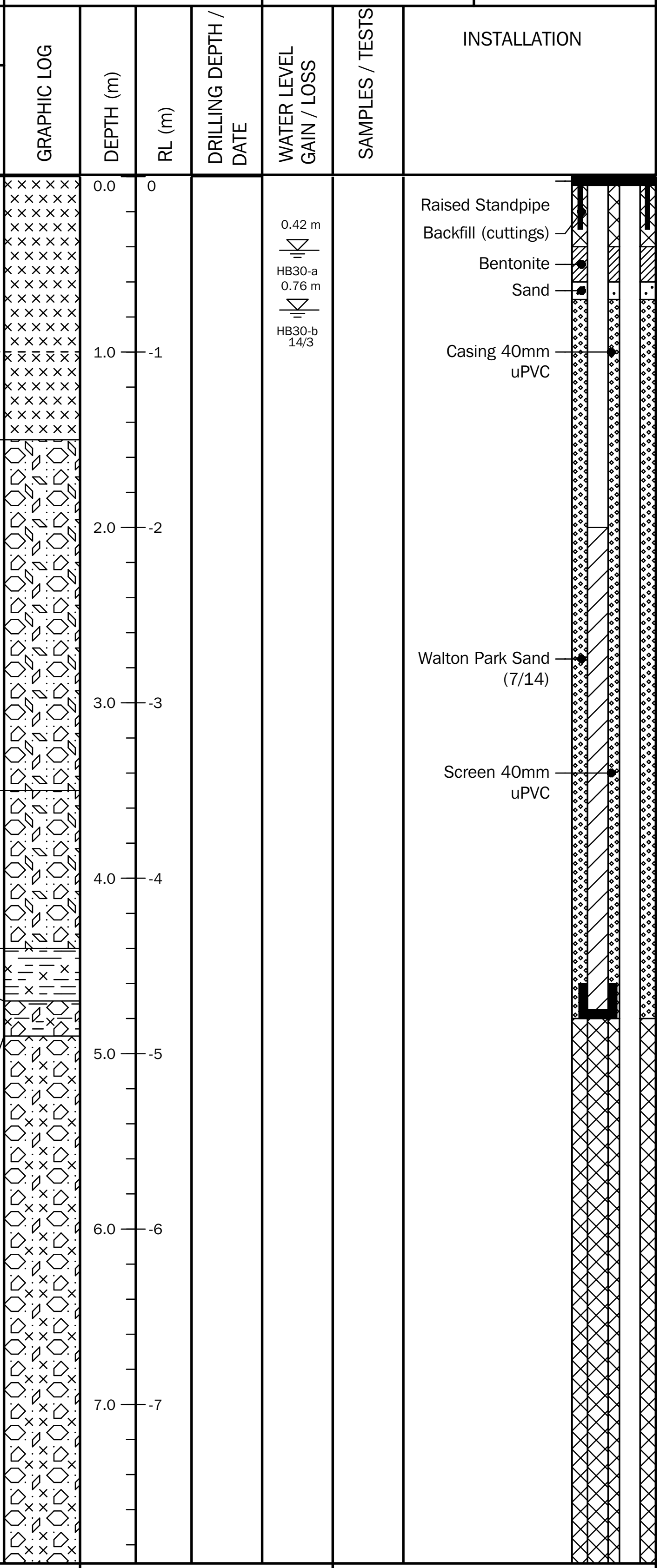
PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB30**
JOB NO: WJ29213

CLIENT: Beca Carter Limited
LOCATION: "Maize 1"
START DATE: 12/03/2008
END DATE: 14/03/2008
COORDINATES: 2734913.57 6021476.31
TOTAL DEPTH: 23.0m
LOGGED BY: SH
SHEET 1 OF 3
GROUND LEVEL: 89.69
TOP OF CASING: 89.98 (HB30-a) 90.02 (HB30-b)

INTERPRE-TATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)
	Medium brown SILT
	Moist below 1m
	Grey GRAVEL with some grey silt and coarse grey sand. Wet.
	Grey GRAVEL with some brown silt and coarse grey sand. Wet.
	Light brown SILTY CLAY.
	Light brown to grey fine rounded GRAVEL in silty clay matrix. Wet.
	Reddish brown SILTY GRAVEL with some coarse sand. Wet.



Notes: Standpipes HB30-a (4.8 m deep) and HB30-b (23 m deep) extend 0.29 m and 0.33 m above ground level respectively.
Coordinate system is NZMG.

KEY
▽ Groundwater Level
← Water Gain
→ Water Loss
● Grab sample

Drilled By: Webster Drilling
Diameter: 140mm
Method: Concentrix
Datum: Mean Sea Level
Filename: WJ29213 HB30

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

PATTLE DELAMORE PARTNERS LTD

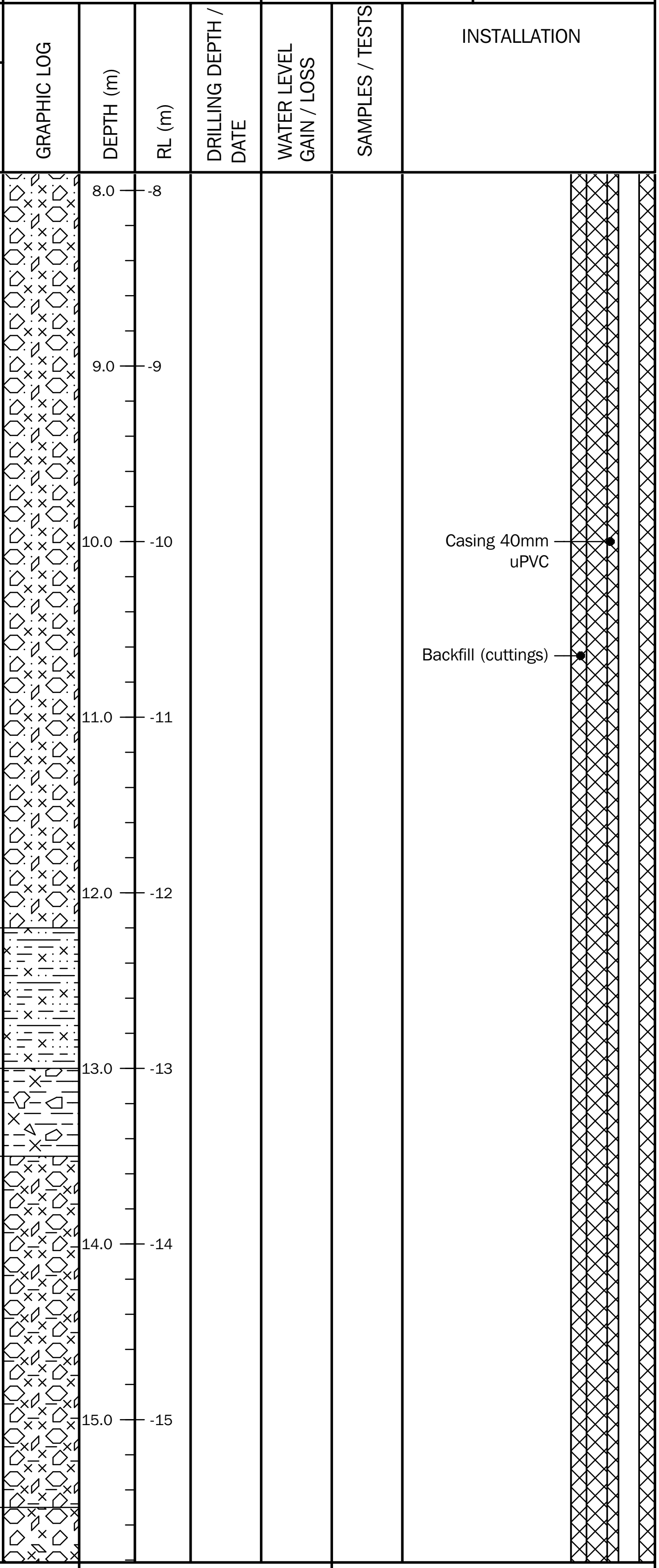
LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB30**
JOB NO: WJ29213

CLIENT: Beca Carter Limited		LOCATION: "Maize 1"	
START DATE: 12/03/2008 END DATE: 14/03/2008	COORDINATES: 2734913.57 6021476.31	TOTAL DEPTH: 23.0m	LOGGED BY: SH — SHEET 2 OF 3

GROUND LEVEL: 89.69
TOP OF CASING: 89.98 (HB30-a) 90.02 (HB30-b)

INTERPRETATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)
	Dark grey SILTY CLAY . Moist, plastic. Some minor sand. Stiff in places. Wet.
	Grey GRAVELLY CLAY with some silt and medium sand. Wet.
	Reddish brown SILTY GRAVEL with some clay. Very wet.
	Light Brown GRAVEL with minor silt. Gravel rounded to sub-angular. Wet, very fast recovery.



Notes: Standpipes HB30-a (4.8 m deep) and HB30-b (23 m deep) extend 0.29 m and 0.33 m above ground level respectively.
Coordinate system is NZMG.

KEY
- Groundwater Level
- ← Water Gain
- → Water Loss
- ● Grab sample

Drilled By:	Webster Drilling
Diameter:	140mm
Method:	Concentrix
Datum:	Mean Sea Level
Filename:	WJ29213 HB30

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB30**
JOB NO: WJ29213

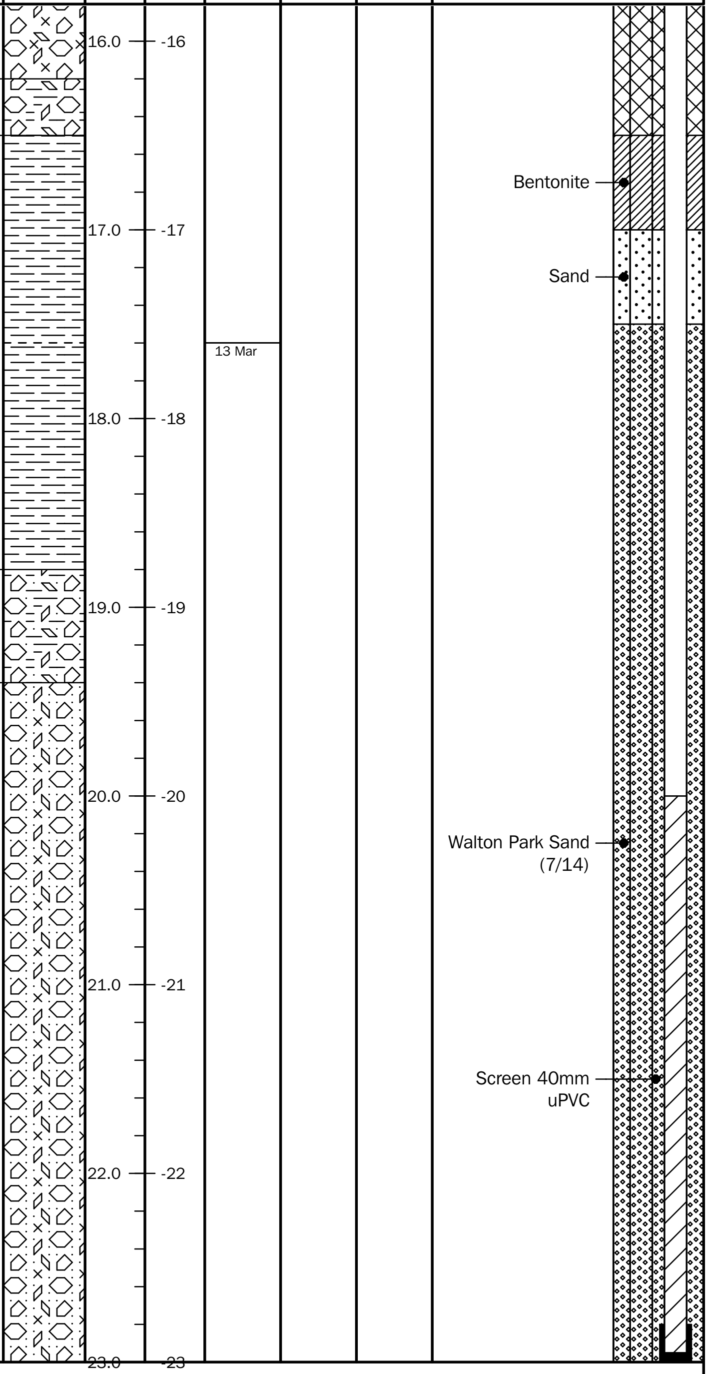
CLIENT: Beca Carter Limited
LOCATION: "Maize 1"

START DATE: 12/03/2008
END DATE: 14/03/2008
COORDINATES: 2734913.57 6021476.31
TOTAL DEPTH: 23.0m
LOGGED BY: SH
SHEET 3 OF 3

GROUND LEVEL: 89.69
TOP OF CASING: 89.98 (HB30-a) 90.02 (HB30-b)

INTERPRE-TATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)
	Grey CLAYEY GRAVEL. Wet.
	Grey CLAY. Plastic.
	becoming brownish grey below 17.6m
	Grey CLAYEY GRAVEL with some coarse sand. Wet.
	Reddish brown coarse SANDY GRAVEL with some silt. Gravel is rounded to sub-angular, clast sizes from 10mm. Wet, very fast recovery.

GRAPHIC LOG | DEPTH (m) | RL (m) | DRILLING DEPTH / DATE | WATER LEVEL GAIN / LOSS | SAMPLES / TESTS | INSTALLATION



END OF BOREHOLE AT 23.0m

Notes: Standpipes HB30-a (4.8 m deep) and HB30-b (23 m deep) extend 0.29 m and 0.33 m above ground level respectively.
Coordinate system is NZMG.

KEY
- Groundwater Level
- Water Gain
- Water Loss
- ● Grab sample

Drilled By:	Webster Drilling
Diameter:	140mm
Method:	Concentrix
Datum:	Mean Sea Level
Filename:	WJ29213 HB30

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

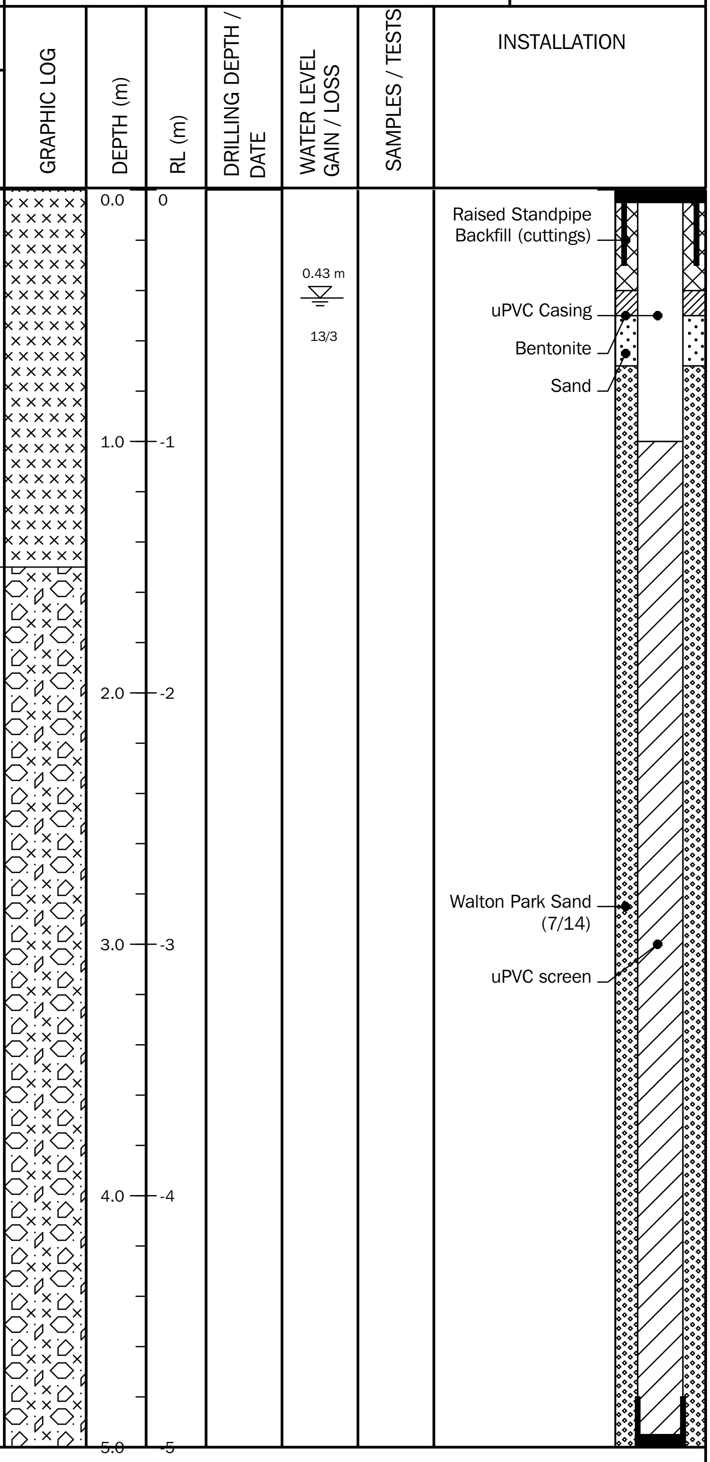
PATTLE DELAMORE PARTNERS LTD

LOG OF BOREHOLE
Masterton Wastewater Investigation

HOLE NO. **HB31**
JOB NO: WJ29213

CLIENT: Beca Carter Limited	LOCATION: "Duck Hide"
START DATE: 11/03/2008 END DATE: 11/03/2008	COORDINATES: 2735124.38 6021569.40
TOTAL DEPTH: 5.0 m	LOGGED BY: SH
SHEET 1 OF 1	
GROUND LEVEL: 89.68 TOP OF CASING: 90.14	

INTERPRE-TATION	DESCRIPTION OF SOIL / ROCK (based on cuttings etc.)
	Medium brown SILT. Very compact and hard. Dry. Moist below 0.7m
	Medium brown SILTY GRAVEL with some medium to coarse sand. Gravel is rounded to angular. Wet.



END OF BOREHOLE AT 5.0m

Notes: Standpipe extends 0.46 m above ground level.
Coordinate system is NZMG.

KEY
- ⊻ Groundwater Level
- ← Water Gain
- → Water Loss
- ● Grab sample

Drilled By: Webster Drilling
Diameter: 140 mm
Method: Concentrix
Datum: Mean Sea Level

Filename: WJ29213 HB31

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)