MODELLING EFFECTS OF PROPOSED MASTERTON LAND-BASED EFFLUENT DISPOSAL SCHEME ON RECEIVING ENVIRONMENT, MASTERTON, NEW ZEALAND

Parviz Namjou[1] & Graeme Proffitt[2]
Pattle Delamore Partners, Limited, Auckland[1], Wellington[2], New Zealand

ABSTRACT

The Masterton District Council is upgrading its Wastewater Treatment Plant (WWTP) at Homebush. The scheme, which has an estimated cost of $22.8 M, includes irrigation of treated wastewater from six new treatment ponds over an area of up to approximately 150 ha of land to the west of Ruamahanga River, a sensitive receiving environment.

Important issues for the scheme were the amount of groundwater level rise during land disposal and effects on water quality of the receiving environment (groundwater, Ruamahanga River and Makoura Stream). A three dimensional numerical groundwater flow and transport model was developed for the assessments.

The model showed that the groundwater level rise beneath the site during the disposal was estimated to range between 50 mm to 250 mm without causing any breakouts.

The 30 year transient simulations showed that for bacteria, the increase in concentration in groundwater would generally be negligible relative to the existing concentrations over most of the irrigated areas. For nitrate-N, the increase in groundwater concentration was estimated to be of a similar magnitude to the existing concentrations. The modelling showed that phosphorus concentrations in groundwater would likely increase throughout the life of the project, reflecting a depletion of the soil ability to retain phosphorus. The long-term (30-year) increase in phosphorus concentration in groundwater was indicated to range from the background level (0.02 mg/L) to a maximum of 0.5 mg/L adjacent to the river. In all cases the predicted increases were within the current range of natural fluctuations. The model showed a rapid drop-off of contaminant concentrations in groundwater outside of the irrigated area, with minimal effects indicated on nearby private wells.

For the Makoura Stream, which crosses the site, predicted concentration increases for nitrate-N and phosphorus, relative to background concentration for summer low flows, were 7 % and 50 %, respectively. For the river, predicted concentration increases were 6 % for nitrate-N and a long-term 30 % increase for phosphorus (for low flow). In all cases these predicted increases were within the current range of natural fluctuations.

KEYWORDS

Groundwater numerical model, contaminant transport, recharge, wastewater infiltration, mounding, environmental effects.

1 INTRODUCTION

The Masterton District Council (MDC) is upgrading its existing Wastewater Treatment Plant (WWTP) at Homebush. The site is located close to the urban area of Masterton, North Island, New Zealand and is surrounded by pastoral farmland including many small "lifestyle" blocks. Figure 1 shows the general location of the site and Figure 2 the site layout.

The disposal scheme (MDC 2008), which has an estimated cost of $22.8M, includes irrigation of treated wastewater from the six new treatment ponds over an area of up to approximately 150 ha of land to the west of Ruamahanga River, which is recognised as a sensitive receiving environment.

The disposal site is located on the floodplain of the Ruamahanga River. The river has deposited unconsolidated sediments ranging from coarse-grained gravel to fine-grained silt and clay. Groundwater is indicated to discharge principally to the Ruamahanga River, but also to the Makoura Stream (a tributary of the river which crosses the centre of the area).

This paper summarizes the results of a multi-phase study carried out by Pattle Delamore Partners Limited (PDP) for the Masterton District Council from 2000 to 2009 to evaluate transport and fate of contaminants in the groundwater, arising from the proposed irrigation scheme.

Important issues for the scheme were:

- amount of groundwater level rise during land disposal
- effects on groundwater quality adjacent to the Ruamahanga River and Makoura Stream
- effects on groundwater quality in the vicinity of private wells
- effects on surface water quality

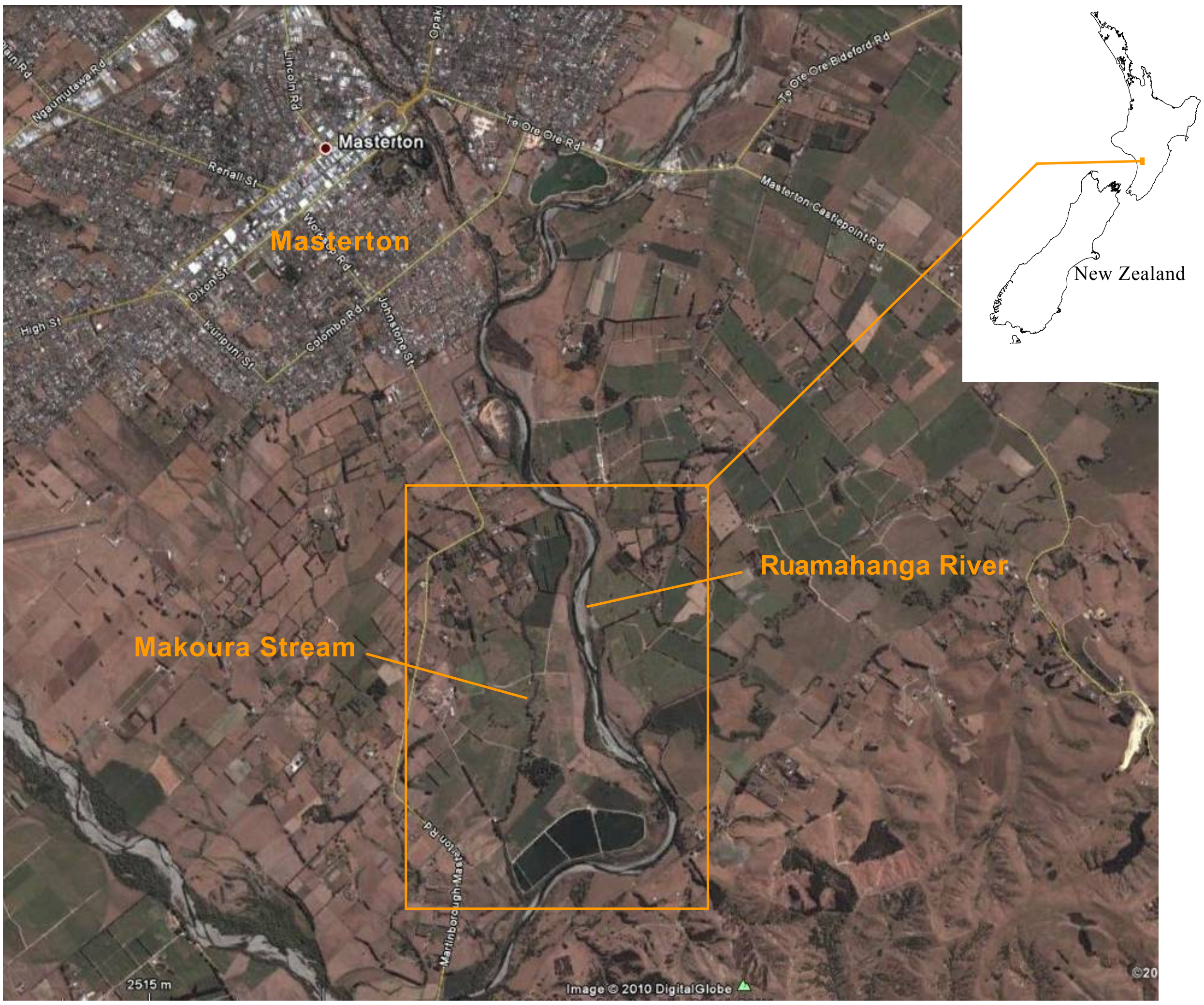


Figure 1: Location Map

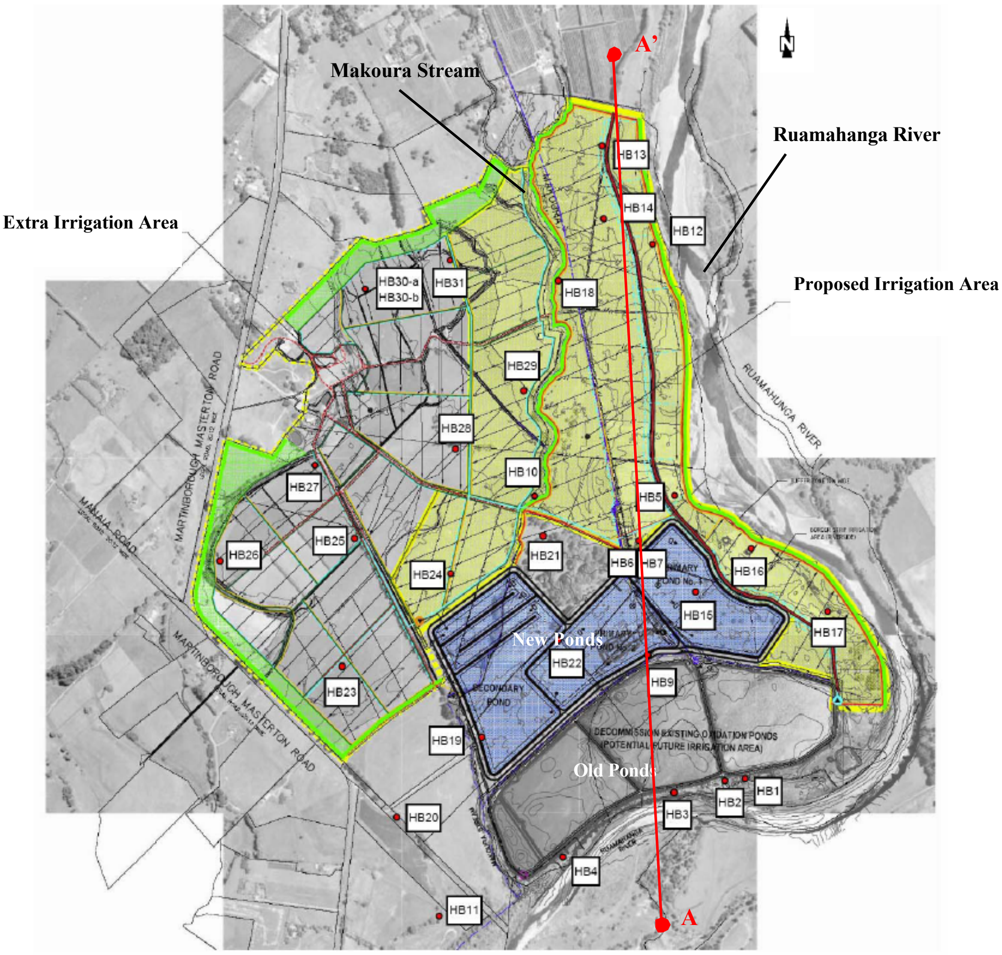


Figure 2: Proposed Irrigation Areas and Groundwater Investigation Boreholes

2 METHODOLOGY

The methodology used in the study consisted of a combination of hydrogeological investigations and groundwater numerical modelling.

The site investigation programme (PDP 2006, 2008) included drilling 30 monitoring boreholes with depths ranging from 5 to 23 m in addition to test pits and hand-augured holes to investigate groundwater conditions underneath the site. Locations of all the monitoring wells are shown in Figure 2.

Some of these wells have been pumped or slug tested to provide estimates of hydraulic conductivity of the aquifer. Regular monitoring by Masterton District Council staff provided information on groundwater levels, with length of records for individual wells varying between one and six years, with the majority of the wells having a two year record. In addition, installation of transducers in several monitoring wells in March 2005 enabled the short-term interaction between the Ruamahanga River and local groundwater levels to be assessed.

A numerical groundwater flow model was developed using the USGS finite-difference code Modflow (McDonald and Harbaugh 1988) and the Waterloo Hydrogeologic pre- and postprocessor Visual Modflow 4.1 to assess mounding and groundwater flow. A contaminant transport model was developed using MT3DMS (Zheng and Wang 1999) which is incorporated as part of Visual Modflow 4.1. The model was used to assess concentration changes of Nitrate-N, phosphorus, viruses and bacteria in groundwater.

A separate water balance modelling exercise was carried out by HortResearch (2008), using their SPASMO model (Soil Plant Atmosphere System Model) to simulate nutrient uptake into the pasture and infiltration and natural treatment of the applied wastewater through the surficial soils. The model description is given by

Green et al. (2003). Outputs from the water balance model were used to assign the infiltration rate and contaminant concentrations of the irrigated water in the groundwater model.

3 HYDROGEOLOGICAL FRAMEWORK

The disposal site is located on the floodplain of the Ruamahanga River (Figure 2). The Ruamahanga River has deposited unconsolidated sediments ranging from gravel to silt and clay. Sand and gravel deposits form a shallow semi-confined aquifer typically 5 to 15 m thick. The aquifer is overlain by silt-dominated strata, which represent overbank floodplain deposits associated with past high water levels. These silt deposits have a variable thickness, typically 0.4 to 4.5 m, but average approximately 2 m thick.

The depth to groundwater within this shallow aquifer varies seasonally between 1 and 4 m. Below the shallow aquifer there are silt and clay-dominated deposits which act at some locations as a semi-confining layer to a deeper gravel-dominated aquifer.

A generalised geological cross-section as interpreted from the available data is shown in Figure 3. The section location is shown in Figure 2. The base of the Makoura Stream is predominantly within the surficial fine-grained sediments along its length with some reaches that have cut through to the underlying gravel deposits.

A number of shallow bores penetrating into this aquifer are used for domestic supply on properties adjacent to the site to the north, to the west on the far side of the Masterton-Martinborough Road and to the southwest.

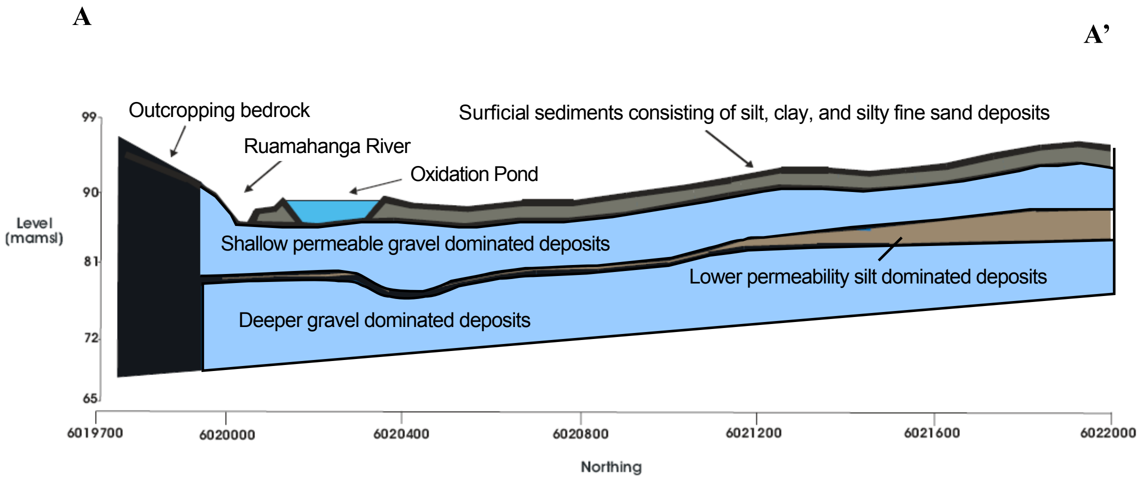


Figure 3: Generalized Geological Cross Section

Groundwater Movement

Figure 4 shows groundwater level contours across the site estimated from measurements in the monitoring wells. The groundwater surface is at shallow depths across the Homebush site and generally lies within the silt deposits or shallow aquifer. Groundwater flow is generally southward through the site. There are some slight variations westward or eastward over various parts of the site reflecting local variations in hydraulic conductivity and possibly discharge to or recharge from the Makoura Stream, Ruamahanga River and various spring-fed farm drains.

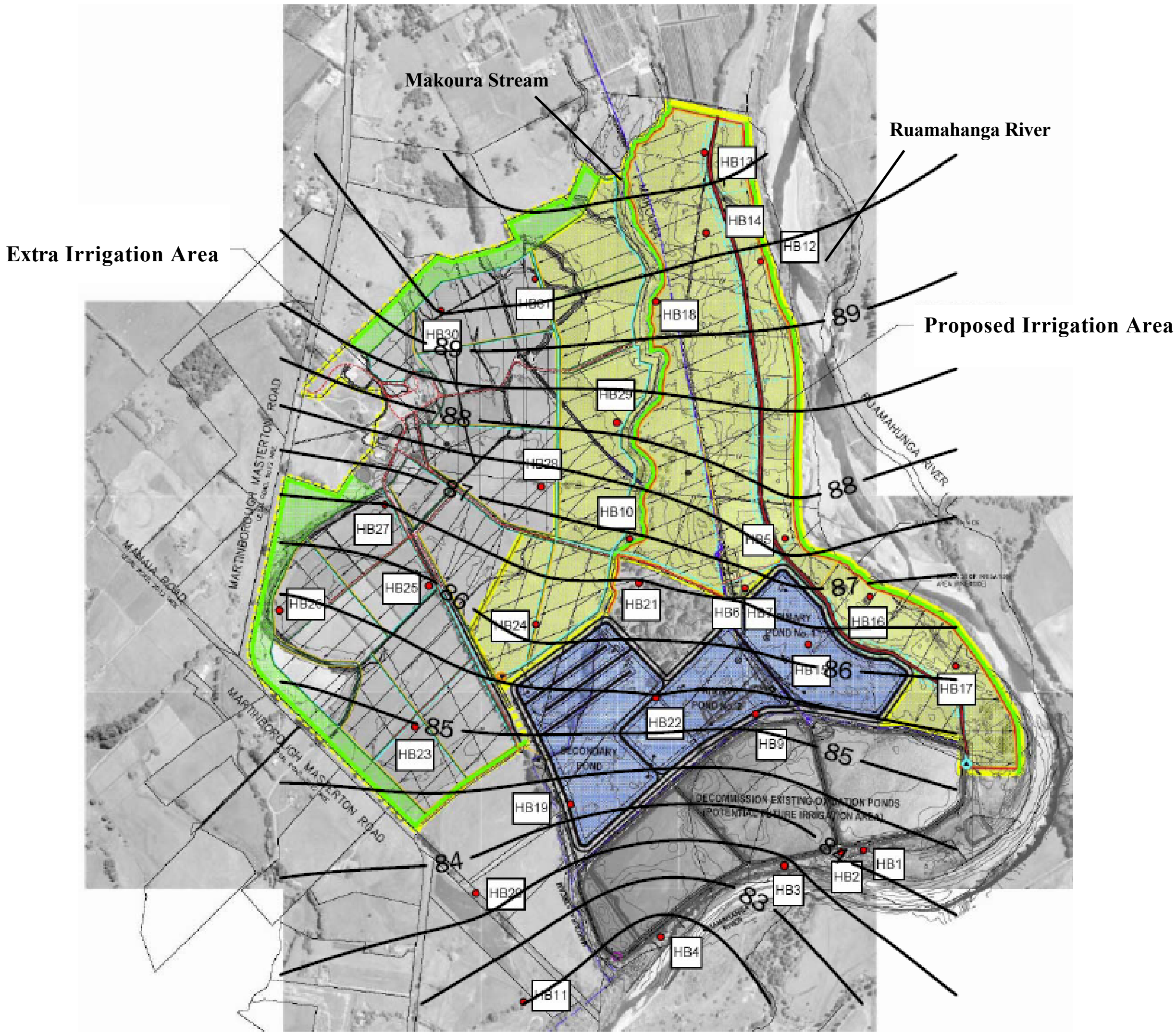


Figure 4: Piezometric Contours (m, RL)

Hydraulic Properties

Pumping tests and slug tests in 11 boreholes were conduced to determine hydraulic conductivity estimates in the shallow aquifer. The results shows the hydraulic conductivity values, east of Makoura Stream ranged between 141 m/day and 1,430 m/day, while the hydraulic conductivity west of the stream was lower and ranged between 3 and 31 m/d. The lower hydraulic conductivities in the western zone suggest a higher silt and sand content within the gravels away from the Ruamahanga River. The specific yield and specific storage of the aquifer was estimated based on pump test results and existing information on soil type. The specific yield ranged between 0.1 and 0.2 and specific storage was 0.0001.

Recharge

The Ruamahanga River is a local major source of recharge to the aquifer due to its hydraulic connection to the shallow gravel layer. Groundwater level and river stage height information indicates that the Ruamahanga River gains from groundwater along the majority of its length south of the Homebush site during average river flows. At other times, depending on the relative heights of river stage and groundwater level, groundwater may either discharge to the river or receive recharge through river bed losses.

The average pre-irrigation recharge to the aquifer from the HortResearch model was about 190mm year or 20% of the annual rainfall.

Groundwater Quality

Groundwater quality has been measured in a number of monitoring wells since 2003 as part of the existing pond discharge consent requirements. The consent monitoring shows groundwater quality up-gradient of the ponds is generally complying with the New Zealand Drinking-water Standards 2005 (MoH 2005) except for E.coli Although the E.coli results show non-compliance with NZ drinking water standards, this is not unusual for a rural area where farming (dairy farming in this case) is the dominant land use. A one-off testing for a suite of metals listed in the drinking-water standards showed a general absence of metals (at the laboratory detection limits) and in all cases compliance with the drinking-water standards.

4 PROPOSED DISPOSAL SYSTEM

Irrigation areas

The proposed development at Homebush (Figure 2) includes up to approximately 150 ha of land to the west of the Ruamahanga River with a total of 29 irrigated plots (MDC, 2008). This includes an area north of the existing ponds which has been granted resource consent for irrigation and a further area to the west which may be consented in future. The scheme includes constructing new ponds to the north of the existing ponds and decommissioning of the existing ponds and using this area for irrigation.

The new ponds include maturation ponds for disinfection with a combination of discharges to land treatment and the Ruamahanga River when river flows are sufficiently high. The pond system will have the capacity to contain 275,000 m^3. The new ponds will be lined with 400 mm liner of compacted silty clay.

Irrigation rates

The proposed irrigation application rates are given in Table 1. These were used as inputs into the drainage model developed by HortResearch (2008) to provide output files on infiltration for each of the proposed irrigation plots for a 30-year period. A conservative scenario of 15 mm/day summer rate (November to April inclusive) of combined rainfall and irrigation was assumed for the well-drained areas, while 10 mm/day was assumed for the poorly drained areas. Winter rates were 5 mm/day over all areas.

Table 1: Average Seasonal Irrigation Rates (mm/day)

Soil Type	Summer	Winter
Free Draining	15	5
Clay Rich	10	5

HortResearch (2008) also calculated daily time-series concentrations within the drainage water for bacteria as represented by E. coli, nitrate-N and phosphorus for each of the 29 irrigated plots. These were used as source inputs in the transport model.

5 GROUNDWATER MODEL

The numerical model was based on a conceptual model developed using the site-specific geological and hydrogeological investigations (PDP 2006 and 2008). Several years of groundwater level monitoring was used to conceptualize groundwater-surface water interactions.

5.1 MODEL GRID STRUCTURE

The model consisted of four hydrogeological units (Table 2), including six layers, 114 row and 111 columns. It covered an area of 170 km^2 with grid spacing of 40 m over the irrigation area. The model domain and grid structure is shown in Figure 4.

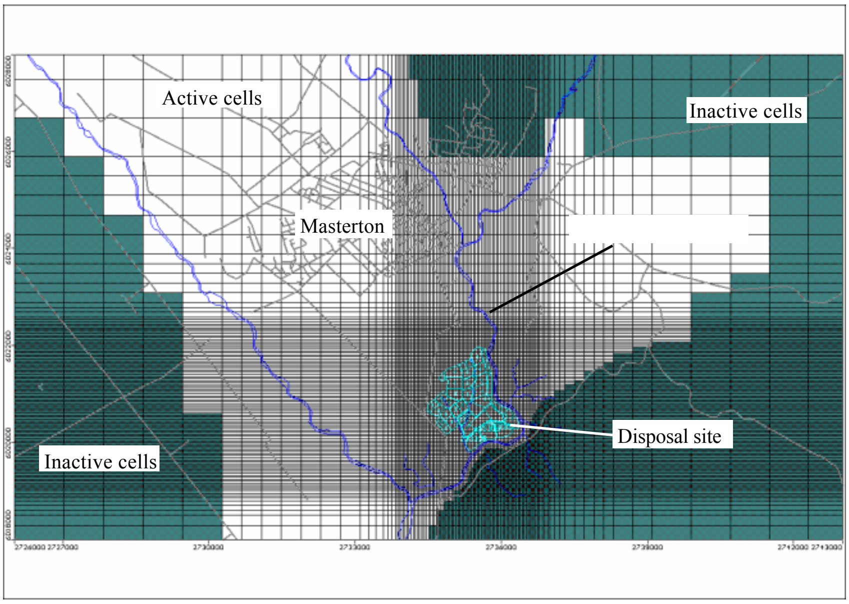


Figure 4: Model Domain and Grid Structure

5.2 BOUNDARY CONDITIONS

Two types of boundary conditions were assigned in the model.

1) Fixed head boundaries (e.g. river and drain boundary conditions) for which the head is known.

2) No-flow boundaries where the flux is zero.

The model boundary conditions are shown in Figure 5. The river boundary conditions simulate the seepage between groundwater and surface water (Ruamahanga River and Makoura Stream) by defining the river/stream stage and streambed conductance (McDonald and Harbaugh 1988).

The no-flow boundary over low permeability mudstones/sandstones of tertiary-age rocks to the south were simulated using inactive cells. Other model cells to the west and north-east that are considered to have no influence on the aquifer system were also designated as inactive cells. The inactive cells are shown as the dark green area in Figure 4.

The current farm drainage system drains to the road-side drain beside the Martinborough - Masterton Road. This drain finally discharges to the Makoura Stream after passing through farmland downstream (west) of the current ponds. A new drainage system is proposed which discharges more directly to the Makoura Stream, west of the proposed new ponds. The existing and proposed drains were simulated using drain cells. The drain intake and stream stage levels were identified from survey data.

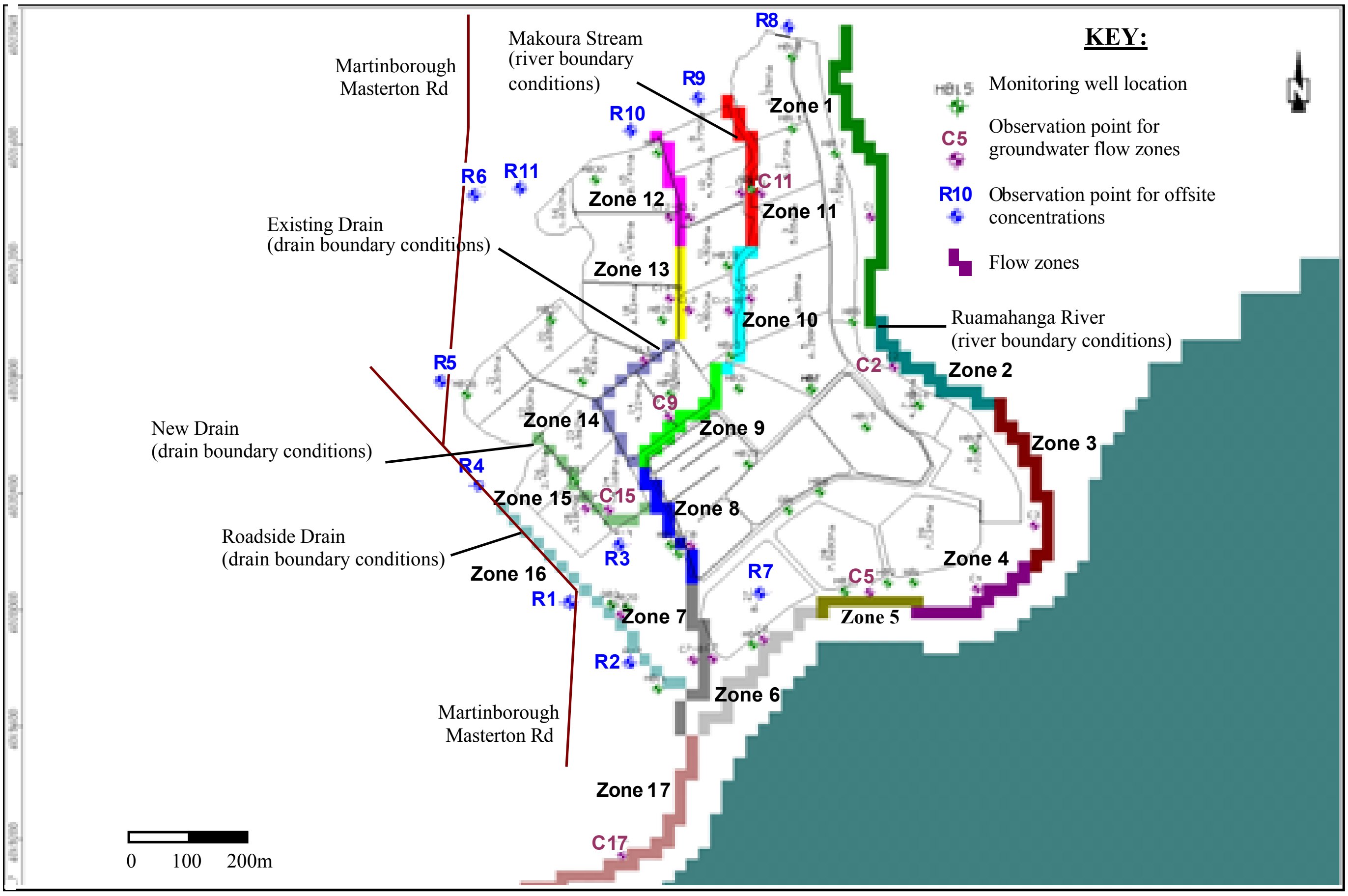


Figure 5: Model Boundary Conditions and Observation Points

5.3 MODEL CALIBRATION

The flow model was calibrated using the water levels measured in 30 boreholes (shown in Figure 2). The geometric mean values of hydraulic conductivity combined with recharge calculated using the HortResearch (2008) water balance model produced satisfactory calibration results with a root mean squared (RMS) error of 0.6 m and normalised RMS of 7%. The sensitivity analyses indicated the model is least sensitive to variations in rainfall recharge within its reasonable range. The model is more sensitive to hydraulic conductivity of the aquifer and the streambed conductance. These control interaction between the surface water and groundwater. The aquifer hydraulic conductivity used in the calibrated model is within the range of field measured values, suggestive of the calibrated model satisfactorily approximating the groundwater system. The calibrated hydraulic properties of the hydrogeological layers are given in Table 2.

Table 2: Aquifer Properties used in the Model

Hydrogeological Units	Hydraulic Conductivity (m/s)	Specific yield	Specific storage
Surficial confining unit	$1 \times 10^{-7} - 1 \times 10^{-5}$	0.1 – 0.2	0.0001
Gravel unit	1×10^{-3}		
Lower silt/sand unit	1×10^{-4}		
Lower gravel unit	1×10^{-3}		

5.4 CONTAMINANT TRANSPORT MODEL

The contaminant transport model was developed using MT3DMS (Zheng and Wang 1999). The concentration of each species accompanying the recharge flux was specified in the flow model using Recharge Concentration Boundary Conditions (Zheng and Wang 1999). The above boundary conditions were assigned to the shallow aquifer underlying the surficial deposits.

The constituents that were modelled were:

- E.Coli
- Adenovirus
- Nitrate (expressed as nitrogen)
- Phosphorus

Input parameters governing the transport equations used in the MT3DMS modelling are summarised in Table 3.

Table 3: Input Parameters used for MT3DMS

Parameter	*k* (First order decay, day^{-1})	Longitudinal Dispersivity (m)
Bacteria	0.41	10
Virus	0.037	10
Nitrate-N	0	10
Phosphorus	0	10

Longitudinal dispersivity is estimated conservatively within the flow field with the ratio of vertical to longitudinal dispersivity equal to 0.01.

For E.Coli a T_{90} value (time for 90% of the coliforms to die-off) of 135 hours (5.6 days) was used, based on information supplied by the Institute for Environmental Science and Research (PDP 2006). The relationship between T_{90} and *k* was defined from the following equation (Kuo 1998):

$T_{90} = -ln(0.1)/k = 2.3/k$

The transport model did not account for bacterial filtration or adsorption, given the uncertainty of appropriate factors for the aquifer. This introduces further conservatism into this aspect of the modelling. For adenovirus a T_{90} value of 62 days was used. This was based on testing carried out in a sample of tap water containing Adenovirus 41 by Enriquez et al. (1995).

6 GROUNDWATER EFFECTS ASSESSMENTS

6.1 AMOUNT OF GROUNDWATER LEVEL RISE DURING LAND DISPOSAL

The application of additional recharge to the aquifer to simulate waste water irrigation caused the groundwater level in the aquifer model to mound relative to the pre-irrigation level (noting pre-irrigation includes the lowering effect of the proposed drains). The steady-state flow model was used to predict the amount of mounding. The 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. Groundwater mounding increases towards the centre of the irrigation due to the cumulative effect of the irrigation on different plots.

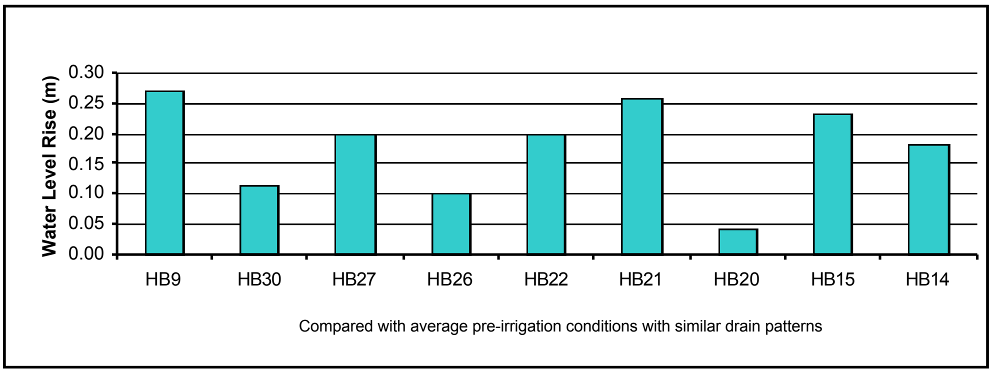


Figure 6: Groundwater Level Rise in Monitoring Bores

6.2 EFFECTS ON GROUNDWATER ADJACENT TO STREAMS

The groundwater contamination results and contaminant mass fluxes from the modelling are presented in Table 4 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. The locations of the flow zones are shown in Figure 5. 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 7 shows the variation of concentrations of nitrate-N, bacteria and phosphorus for a ten year period for six observation points distributed across the site. The locations of the observation points are shown on Figure 5. Nitrate and phosphorus are shown on the left hand vertical axis as a logarithmic scale.

In all cases the simulated bacteria concentration increases are very much lower than the drinking-water standard for E. coli. A cyclical variation in nitrate and bacteria concentration can be seen in the plots of Figure 7, reflecting the variation in the irrigated water concentrations. 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 fluxes by using the summer data for nitrate and bacteria (when river and stream flows are also lowest and therefore the effects of groundwater discharge are greatest).

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

Table 4: Groundwater Concentrations and Mass Fluxes into Makoura Stream and Ruamahanga River

	Predicted Groundwater Concentrations Adjacent to Stream and River			Groundwater Discharge	Mass Flux		
Location (zones)	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							
7	0.99	3.9×10^{-10}	0.129	126	124	5.0×10^{-4}	16.3
8	1.44	2.3×10^{-9}	0.085	124	178	2.8×10^{-3}	10.5
9	2.84	0.900	0.372	322	916	2,900,747	119.9
10	2.97	0.684	0.099	344	1,021	2,350,314	34.1
11	1.77	0.125	0.036	99	175	123,658	3.5
12	1.19	0.037	0.012	1,218	1,450	453,901	15.0
13	1.80	0.239	0.040	511	921	1,218,523	20.6
14	1.03	0.017	0.024	1,106	1,142	188,323	27.0
15	1.01	0.105	0.027	896	908	937,815	24.1
16	0.48	3.9×10^{-10}	0.018	10	5	3.9×10^{-5}	0.2
Means &	1.44	0.172	0.057	4,755	6,840	8,173,281	271

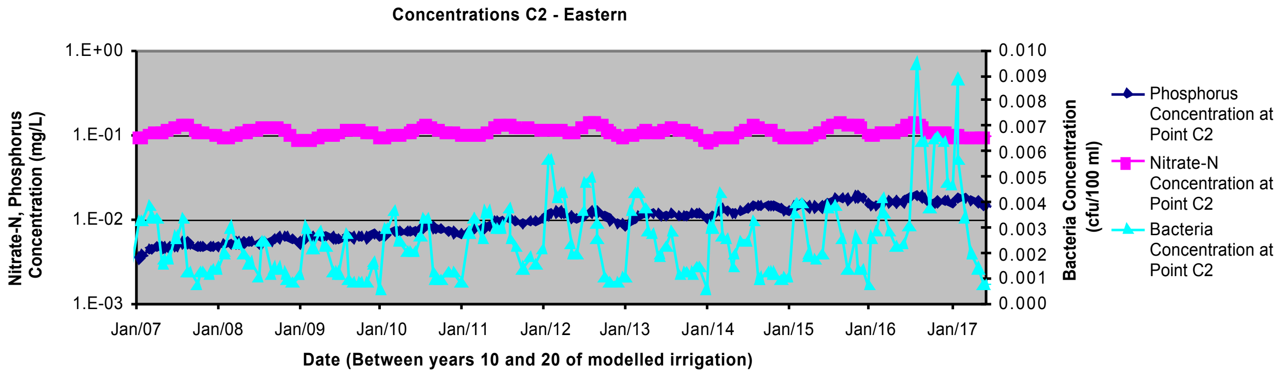
Totals							
Ruamahanga River – Summer Means							
1	0.23	0.0001	0.009	1,115	254	1,113	9.8
2	0.13	0.0103	0.055	292	39	30,026	16.0
3	0.15	0.0001	0.048	399	60	216	19.0
4	1.78	2.1×10^{-4}	0.496	194	347	412	96.4
5	1.62	1.1×10^{-1}	0.453	499	811	535,051	226.3
6	2.34	2.4×10^{-1}	0.434	420	984	1,000,907	182.6
17	0.00	1.5×10^{-31}	0.0003	149	0.5	2.3×10^{-25}	0.04
Means & Totals	0.81	0.051	0.179	3,069	2,495	1,567,724	550

Table5: Background Concentrations in Groundwater and Surface Water

	E. Coli (cfu/100 ml)		**Nitrate-N (mg/L)**		**DRP (Dissolved Reactive Phosphorus) (mg/L)**	
Location[1]	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
Note: 1. Beca (2004, 2005)						

The plots of Figure 7 are of monthly data because the model used input data as monthly averages to reduce model instability, rather than the daily data from HortResearch (2008). However, the irrigation cycle will comprise one day of loading and up to two weeks of rest before repeat loading. It is considered that 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 non-synchronised irrigation cycles are considered. Nevertheless the validity of using monthly data was checked by comparing the results for a five year period based on monthly and daily simulations. Similar results were obtained for both datasets.

The increases in groundwater concentrations due to wastewater irrigation was compared against current groundwater concentrations. Measured concentrations for the selected parameters in some monitoring wells up-gradient of the existing ponds are presented in Table 5. In general, the predicted increase in bacteria concentration is small relative to the existing concentrations, the predicted increase in nitrate-N is of a similar magnitude to the existing concentrations and the predicted 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.



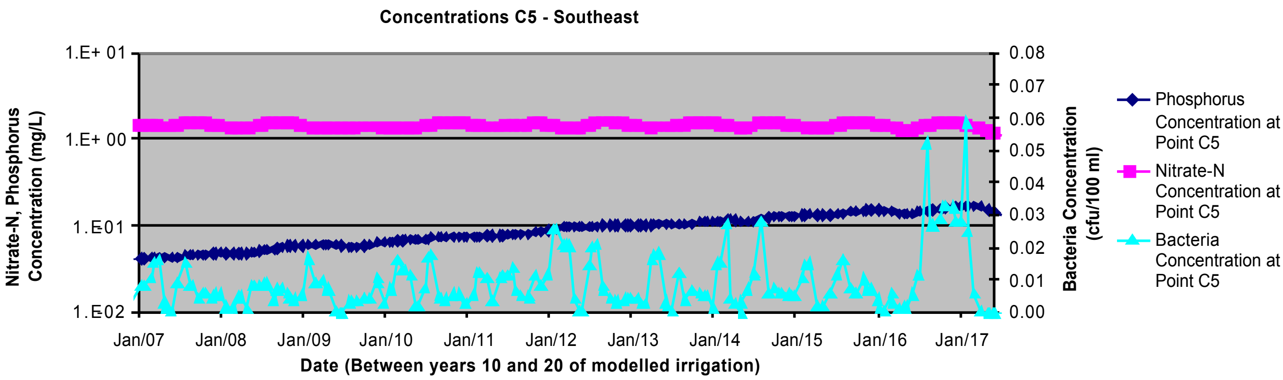
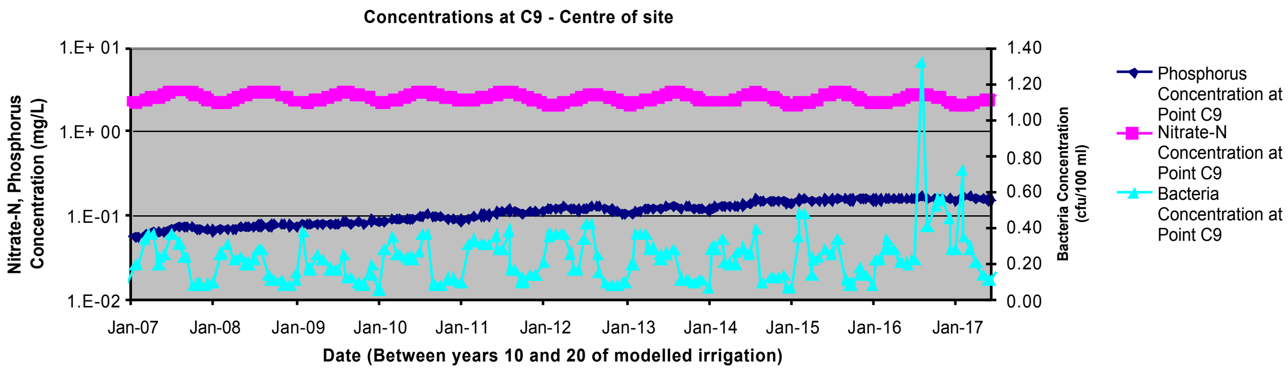
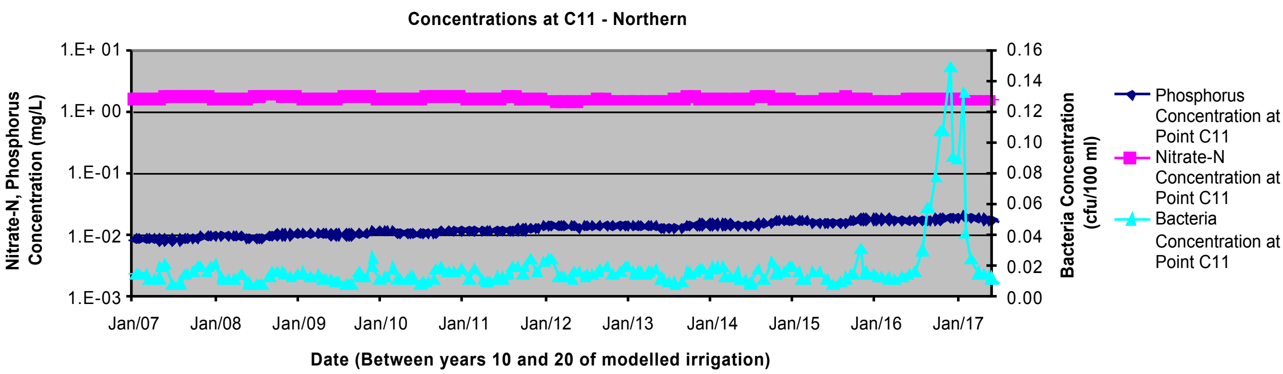
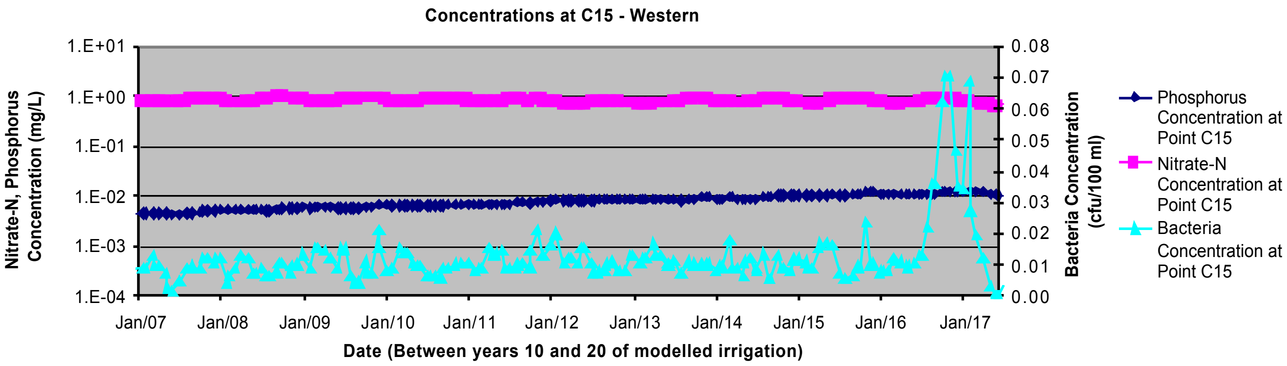


Figure 7: Predicted Groundwater Concentrations on Site







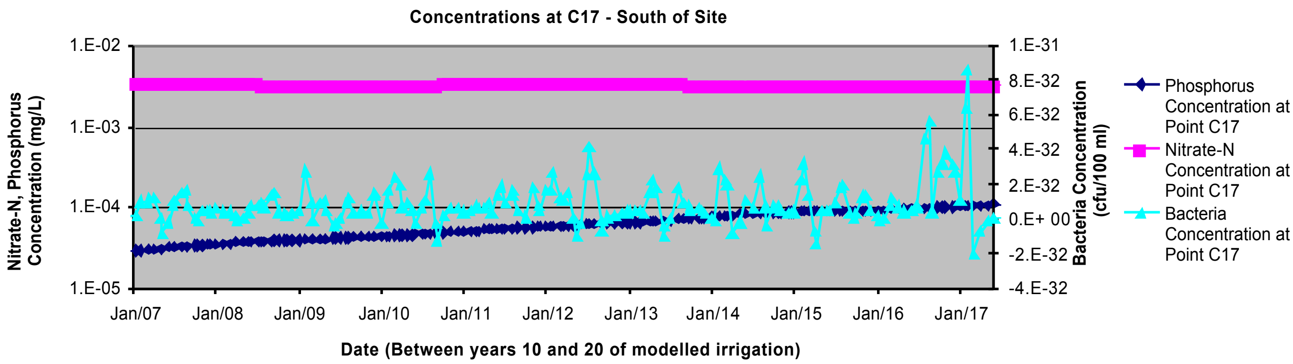


Figure 7 (continued): Predicted Groundwater Concentrations on Site

6.3 EFFECTS ON GROUNDWATER QUALITY IN THE VICINITY OF PRIVATE WELLS

An important consideration for the irrigation scheme is potential effects on a number of shallow bores supplying domestic water. These are located on farms and small holdings to the north, west and southwest of the site. The dominant flow direction being north to south suggested that there was little prospect of contamination of water supplies to the north of the site. However effects on these and the other wells were specifically examined during the modelling.

As expected, the simulations predicted no effects on the wells to the north. Figure 8 shows plots of predicted concentration for nitrate-N, phosphorus and bacteria in the observation points to the west of the site set up in the model. The locations of the observation points are shown on Figure 5.

The drinking-water standard (MoH 2005) 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 (MoH 2005). 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, Figure 5). However, even here the predicted concentration increases are indicated by this assessment to be still well below the drinking-water standards. It is probable that the current dairying use of the land will have a more significant effect on the groundwater quality in these locations.

6.4 EFFECTS ON SURFACE WATER QUALITY

Summer low flow contaminant concentration increases have been calculated for the Ruamahanga River and the Makoura Stream using the mass flux data in Table 4. The concentration calculations took into account the increases in flow to the stream and river from the irrigation, and in the case of the stream, from the farm drains.

The flow increases are presented in Table 6 and the predicted concentration increases are presented in Table 7 for the stream, the river above the confluence with the stream and the river below the confluence with the stream. The calculations were based on a natural stream flow of 0.17 m^3/s and a summer low flow at the nearby gauging station at Wardell's Bridge of 2.7 m^3/s.

The concentration increases in the river are minimal (compare Table 7 with background concentrations in Table 5). 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%.

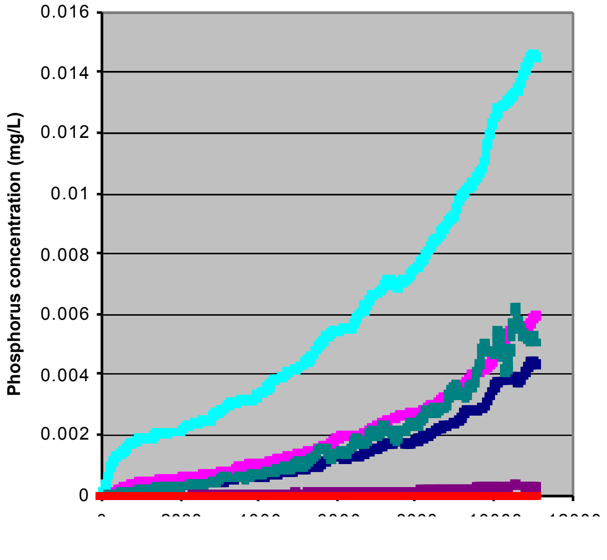
For the stream, the increase in nitrate-N concentration is predicted to be larger than the increase in the river in absolute terms (0.25 mg/L versus 0.011 mg/L) but in percentage terms the increase is similarly small (7%). This is because the stream is starting from a higher base (background of 3.5 mg/L) 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%. This is considered to be a direct effect of the proportionately larger discharge to the stream. For bacteria the predicted increase relative to the background is negligible (even though not accounting for bacterial filtration or adsorption), as the background concentration in the stream is large and the increase from irrigation small.

7 CONSTRUCTION DEWATERING

Additional transient simulations were carried out recently to assess the effect of annual and five-year construction floods on groundwater inflow during the excavation of the new ponds. This involved modelling effects of cut-off drains to be constructed around the ponds. For the assessment the following modifications were made in the model:

- Reducing the model grid size to 10 m in the vicinity of the proposed ponds to more accurately represent the cut-off drains.
- Refining the calibration to reproduce long-term groundwater levels in summer (the expected construction period). The groundwater levels for summer were derived based on the longer period of record available since the earlier modelling.
- Assigning drain cells along the proposed cut-off drains.
- Using average summer groundwater levels and river stage as initial conditions for the transient simulations.
- Defining flood waves using flood hydrographs for 1 and 5 year floods measured at Wardell's Bridge gauging station, scaled to match predicted river flood stages at the site.

The drainage modelling predicted the need for dewatering of less than 130 l/s during annual flood conditions and less than 200 l/s during the five-year, 24-hour peak storm event.



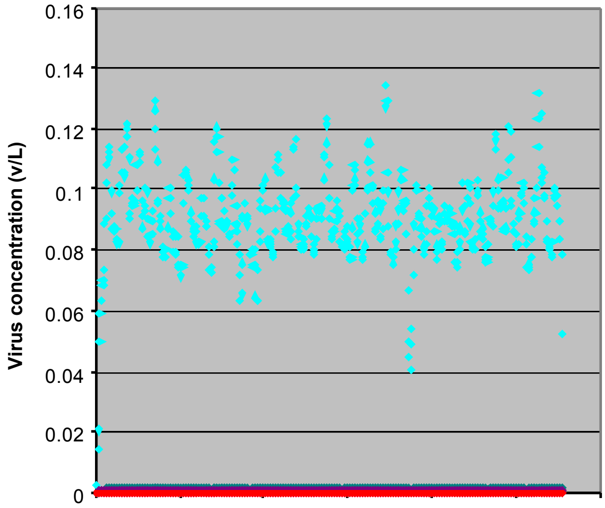


Figure 8: Predicted Concentrations West of Site

Table 6: Flow Increase in Makoura Stream and Ruamahanga River from Drainage and Irrigation							
Location	Increase in Flow (m^3/s) Downstream from Site			Increase from Scheme as % of Natural Downstream Flow			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 7: 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

8 CONCLUSIONS

Groundwater modelling was carried out to simulate land disposal of treated wastewater at the Masterton District Council's Homebush wastewater treatment plant site. The modelling was used to predict groundwater mounding from the irrigation and to gauge effects on groundwater and surface water quality within the adjacent Ruamahanga River and Makoura Stream.

The model showed that the groundwater level rise beneath the site during the disposal would likely range between 50 mm to 250 mm and would be unlikely to cause any breakouts.

The 30 year transient contaminant transport simulations showed that for bacteria, the likely increase in concentration in groundwater was generally negligible relative to the existing concentrations over most of the irrigated areas. For nitrate-N, the increase in groundwater concentration was of a similar magnitude to the existing concentrations. The simulation suggested an increase in phosphorus concentrations in groundwater throughout the life of the project. This was considered to reflect a depletion of the soil's ability to retain phosphorus. The predicted long-term (30-year) increase in phosphorus concentration ranged from the background level (0.02 mg/L) to a maximum of 0.5 mg/L adjacent to the river. In all cases these predicted increases were within the current range of natural fluctuations. The model showed a rapid drop-off of contaminant concentrations in groundwater outside the irrigated area, with minimal effects on nearby private wells.

The predicted increases of bacteria concentrations in the river and stream were negligible. For the stream, predicted concentration increases for nitrate-N and phosphorus, relative to background concentration for summer low flows, were 7 % and 50 %, respectively. For the river, predicted concentration increases were 6 % for nitrate-N and a long-term 30 % increase for phosphorus. In all cases these predicted increases were within the current range of natural fluctuations. The modelling results showed that the proposed irrigation would have only minimal environmental effects on groundwater and surface water beneath and adjacent to the site.

ACKNOWLEDGEMENTS

This study was funded by the Masterton District Council and managed by Beca Carter Hollings and Ferner Limited. We wish to acknowledge and thank David Hopman from the council and Ron Haverland and Humphrey Archer from Beca for their support. We also wish to acknowledge Steve Green of HortResearch, who provided irrigation input data. We are grateful to Wayne Russell and Zeljko Viljevac for their review of the draft paper and valuable comments.

REFERENCES

Beca (2004 and 2005) *Masterton Wastewater Treatment Plant at Homebush (WAR020074)*, Annual Monitoring Reports, Report prepared for Greater Wellington Regional, Council by Beca Carter Hollings & Ferner Ltd on behalf of Masterton District Council, May 2004-2005.

Enriquez C.E., Hurst C.J. and Gerba C.P. (1995) 'Survival of the Enteric Adenoviruses 40 And 41 in Tap, Sea, and Waste Water' *Water Research,* v. 29, Issue 11, November 1995, 2548-2553.

Green S.R., Snow V.O. and Clothier B.E. (2003) *Modelling the Nitrogen Dynamics under Pasture Irrigated with Dairy Factory Effluent.* Hortresearch Client Report no. 2003/6115, HortResearch, Palmerston North, New Zealand.

HortResearch (2008) *Modelling the Environmental Effects of Wastewater Disposal at the Masterton Land-based Sewage Effluent Disposal Scheme,* Report prepared for Beca Carter Hollings & Ferner.

Kuo J. (1998) *Practical Design Calculations for Groundwater and Soil Remediation,* Publisher: CRC Press; 1 edition (September 17, 1998).

McDonald M.G. and Harbaugh A.W. (1988) *A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model,* Techniques of Water-Resources Investigations, Book 6. U.S. Geological Survey.

MDC (2008) *Masterton Wastewater Treatment Plant and Disposal System Long-Term Upgrade: Notice of Requirement, Resource Consent Applications and Assessment of Effects on the Environment*, Masterton District Council, September 2008.

Ministry of Health, MoH (2005) *Drinking-water Standards for New Zealand 2005,* Wellington: Ministry of Health.

PDP (2008) *Masterton Wastewater Upgrade: Revised Groundwater Modelling*, Report prepared for the Masterton District Council, Pattle Delamore Partners Limited, Wellington, September 2008.

PDP (2006) *Masterton Wastewater Upgrade - Groundwater Report,* Report prepared for Beca Carter Hollings & Ferner Limited, Pattle Delamore Partners Ltd, Wellington, December 2006.

Zheng C. and Wang P.P. (1999) *A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion and Chemical Reactions of Contaminants in Groundwater Systems,* Prepared for U.S. Army Corps of Engineers, Washington, DC 20314-1000.