BEFORE A HEARINGS PANEL OF THE GREATER WELLINGTON REGIONAL COUNCIL AND MASTERTON DISTRICT COUNCIL

IN THE MATTER	of resource consent applications to Greater Wellington Regional Council pursuant to section 88 of the Resource Management Act 1991
AND	
IN THE MATTER	of a Notice of Requirement to Masterton District Council pursuant to section 168, 168A and 181 of the Resource Management Act 1991
BY	Masterton District Council
FOR	the proposed upgrade of the Masterton Wastewater Treatment Plant

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STATEMENT OF EVIDENCE OF STEVE GREEN
ON BEHALF OF MASTERTON DISTRICT COUNCIL

Subject Area: Land Treatment Aspects and Storage Model

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1. INTRODUCTION

1.1 My name is Steven Robert Green. I hold the degrees of B.Sc. (Physics and Mathematics) and M.Sc. (Physics, 1st Class Honours) from Auckland University, Auckland, New Zealand, and a Ph.D. degree (Departments of Physics and Forestry and Natural Resources) from Edinburgh University, Edinburgh, United Kingdom. I am a current member of the New Zealand Society of Soil Science, the New Zealand Grasslands Society, and the New Zealand Hydrological Society.

1.2 I have been employed as a research scientist since 1984. My employment has spanned five government research organisations (DSIR Plant Physiology Division, Macaulay Land Use Research Institute (UK), DSIR Fruit and Trees, Horticulture and Food Research Institute of New Zealand Ltd, and Plant and Food Research Institute of New Zealand Ltd). My scientific role has involved a wide range of research disciplines including: water relations and nitrogen nutrition of tree crops; irrigation and nitrogen cycling in orchards, vineyards, forestry and dairy; air flow and turbulent transport processes in agroforestry; instrument design and construction; development of computer models to assess physical, hydraulic and chemical transport properties of soils; and bioremediation of contaminated sites.

1.3 I have managed and participated in numerous research projects dealing with the impacts of land use activity on the receiving environment. My specific research focus has been on irrigation and nutrient (nitrogen) cycling under horticultural and agricultural land. I have worked on experiments to measure nitrate leaching under squash (an NZ Aid project in the Kingdom of Tonga), and dairy, as well as forestry irrigated with effluent wastewater. I am currently participating in long term field experiments measuring water use, irrigation needs and nitrate leaching under potato, kiwifruit, grape, summer fruit and blueberry crops in New Zealand.

1.4 I have a strong background in physics and mathematics. My expertise is in computer modelling. My research has lead to the development of a detailed computer model called SPASMO (Soil Plant Atmosphere System Model). This model has been, and is currently being, used in a wide range of consultancy projects commissioned by Regional Councils and industry to assess the risk of land use activity on irrigation demand and the environmental fate of pesticides and nitrate leaching under productive land.

1.5 I have represented HortResearch as an invited scientist to work with number of organisations overseas including: the National Institute of Agro-Environmental

Sciences, Tsukuba, Japan (1992); the Division of Tropical Horticulture and Agriculture, Kyoto University, Japan (1997 & 1998); the Department of Soil Science, University of Melbourne, Australia (1997 & 1998); the Institute of Natural Resources and Agrobiology, University of Seville, Seville, Spain (1997, 1998, 1999 and 2008); the Department Horticulture and Landscape Architecture, CSU, Colorado, USA (2005); the Horticulture Physiology Section, Department of Primary Industries, Tatura Australia (2005); the Shaanxi Fruit Research Center, Xi'an, China (2001, 2006 & 2008); and Station de Recherches Fruitières de Pocquereux, La Foa, New Caledonia (2008)

1.6 I have published over 100 peer-reviewed scientific papers, and authored more than 140 research reports for industry and Regional Councils.

1.7 In this matter, I have been engaged by Masterton District Council to carry out a desktop modelling exercise to assess the key environmental outcomes arising from the disposal of effluent by a combination of land treatment (irrigation) and direct discharge to the Ruamahanga River. These key outcomes are:

(a) To calculate the impact of effluent disposal on the leaching and runoff losses of water, nutrients (i.e. nitrogen (N) and phosphorus (P)) and contaminants (i.e. Escherichia. coli bacteria) from land at the Homebush site.

(b) To determine the volume of storage that accumulates in the oxidation ponds in response to a set of discharge rules that dictate when a direct discharge to the Ruamahanga River is permitted, and also taking into account that the priority method of disposal for effluent is by irrigation whenever soil conditions allow this to occur during summer and winter.

1.8 I have read the Code of Conduct for Expert Witnesses issued as part of the Environment Court Practice Notes. I agree to comply with the code and am satisfied the matters I address in my evidence are within my expertise. I am not aware of any material facts that I have omitted that might alter or detract from the opinions I express in my evidence.

1.9 My evidence is structured as follows:

(a) introduction;
(b) scope of evidence;
(c) executive summary;
(d) land based treatment and disposal;
(e) the site and surrounding environment;
(f) modelling;
(g) results of modelling;
(h) submitters' concerns; and
(i) conclusion.

2. SCOPE OF EVIDENCE

2.1 My evidence will address the scientific basis for the proposed land based irrigation system for the Masterton Wastewater Treatment Plant (MWTP). I will describe the work carried out by Landcare and HortResearch to characterise the transport properties of the soils, and present details of computer modelling used to predict the movement of water and nutrients through the unsaturated soils of the irrigation area (HortResearch, 2007). My evidence will focus on model predictions for the concentrations of key contaminants in drainage water that exits beyond the depth of the root zone.

2.2 The irrigation system and potential effects on the soil will be discussed in the evidence of Neal Borrie. The evidence of Graham Proffitt will address the impacts of drainage water on the quality of the receiving groundwater.

3. EXECUTIVE SUMMARY

3.1 For the proposed Masterton wastewater scheme I carried out a desktop modelling exercise to assess the environmental outcomes from the discharge of treated effluent to land and the direct discharge to the Ruamahanga River. These key outcomes were:

(a) To calculate the leaching losses of water, nutrients (i.e. nitrogen (N) and phosphorus (P)) and contaminants (i.e. Escherichia. coli bacteria) from effluent irrigated land at the Homebush site.

(b) To determine the volume of storage needed in the oxidation ponds in response to a set of discharge rules that dictate when a direct discharge to the Ruamahanga River is permitted, and also taking into account that the priority method of disposal for effluent is by irrigation whenever soil conditions allow this to occur during summer and winter.

3.2 The model calculations were run on a daily time step using historical wastewater inflows, river flows, climate data including rainfall, evaporation, solar radiation and mean air temperature. Soil descriptions and model soil parameters were derived from observations and laboratory testing of samples taken from the Homebush site.

3.3 A water balance for the storage ponds was calculated by considering the volumes of water going into (i.e. as wastewater influent, rainfall and return flow) and out of the ponds (i.e. as evaporation, leakage losses through the base of the ponds, irrigation to land and direct discharge to the river). A water balance for each irrigation zone was calculated by considering inputs (rainfall and irrigation) and losses (plant uptake, evaporation, runoff and drainage) of water from the soil profile. A set of disposal rules dictated when and to where the effluent was discharged.

3.4 For the water balance modelling, I used the average irrigation rates, which represents a conservative assessment of the required storage of wastewater. Average irrigation rates proposed are 10 mm/day in the summer for free draining and clay rich soils, 5 mm/day in the winter for free draining soils and no irrigation of clay rich soils in the winter. The model used a minimum 10-day stand down period between irrigations. It is important to note that the maximum amount of irrigation applied daily to the land was not allowed to exceed the soil's hydraulic capacity on that day. On those days when rainfall occurred, irrigation was set equal to the lesser of the target irrigation rate or the soil's total storage capacity (calculated as drainage plus refill depth) minus the amount of rainfall on that day.

3.5 The first pond storage modelling scenario was for irrigation zones 1 to 14 excluding irrigation in the existing pond area (zones 29 – 31). Using the proposed rules for the discharge to the Ruamahanga River (median river flow in summer and half-median river flow in winter), resulted in excessive storage volume of 350,000 m^3 due to the lesser area of land available until the decommissioned ponds are converted to border strip irrigation.

3.6 In order to reduce the likely storage demands during the interim period before the decommissioned ponds are converted to border strip irrigation, the discharge rule was changed to half-median all year. This lowered the likely storage demands to 214,000 m^3 which can be accommodated within the 275,000 m^3 of pond storage proposed.

Therefore a discharge rule using a half-median flow trigger is proposed for the interim period.

3.7 Modelling the completed scheme as proposed (zones 1 to 14 and 29 to 31 on the decommissioned pond area) with the proposed long term discharge rules requires a storage volume of 210,000 m^3. The proposed 275,000 m^3 of pond storage provides a contingency for abnormal climate events and operational inefficiencies.

3.8 A number of scenarios were modelled considering the future climate changes and the potential impact on storage requirements. This considered changes in rainfall, river flow, and wastewater influent flow. It is my opinion that climate change will not have an adverse effect on the storage requirements for the ponds, because wastewater inflows are likely to reduce in the event of less rainfall and reduced river flows.

3.9 The fate of nitrogen, phosphorus and bacteria (Escherichia coli) in the upper soil layers was assessed as part of the model development. In order to be conservative in the assessment I modelled the maximum application rates (some 1.5 times that of the anticipated average rates) that represent an extreme situation which might be used in dry conditions and certainly would not apply to every plot throughout the lifetime of the scheme. In addition the modelling for the mass of nutrients and contaminants leached to the groundwater is also conservative in that it included the potential future irrigation area as well as the proposed scheme. I used a period of 28 years that represents the length of available climate and river flow records. Because the modelling assumed maximum application rates (1.5 times average) it is likely that the predictions would equate to a longer period of approximately 42 year if average applications were used.

3.10 A cut-and-carry pasture system is proposed for the border strip irrigation scheme. Cut and carry is an environmentally beneficial option because it removes a greater fraction of nutrients from the site and also avoids additional nitrate leaching that would otherwise occur from urine patches deposited on a grazed pasture.

3.11 For the proposed scheme, nitrate leaching will be of little concern with regard to potential contamination of the groundwater as a result of effluent application. The solution concentration in soil water at 1 m depth is calculated to be 2.7 mg/L. This is about four times lower than the current NZ Drinking Water Standard of 11.3 mg/L for nitrate-nitrogen, even after a period of 28 years of irrigation applied to the land. There is unlikely to be any significant accumulation of nitrate in the soil profile over time. This is because nitrogen uptake by the pasture can easily account for all of the applied nitrogen. Furthermore, the cut-and-carry process for pasture would remove a large fraction of the pasture nitrogen from the site, leaving little excess nitrogen to leach.

3.12 Phosphorus (P) is a relatively immobile element in most New Zealand soils. When applied to land, it would normally be bound to the soil and accumulate within the top 10-20 cm of the root-zone where it can be taken up by plants. The total phosphorus content of the wastewater will be on average 3.2 mg/L. Most of this phosphorus is in the form of dissolved reactive phosphorus (DRP) which is readily taken up by plants, yet strongly adsorbed to the soil's mineral and organic surfaces.

3.13 For the free draining soils, following 28 years of application at the maximum rate of irrigation of 15 mm/day, I calculated that a large fraction (~60-80%) of the applied phosphorus will still reside in the top 1.0 m of the soil profile. While the soil concentration slowly increases over time, it is still a factor of 2-6 times lower than the maximum concentration at saturation. This means the soil has not yet reached the maximum sorption capacity. The corresponding P concentration could slowly rise to 0.15 mg/L on the most free-draining soils that receive the highest nutrient loadings. On those parts of the site, there will be a 94% reduction in the concentration of P relative to the effluent that is applied. It should be noted that additional dilution in the groundwater, combined with strong adsorption by the deeper clay-rich layers, means the off-site impacts on surrounding groundwater are likely to be negligible.

3.14 For the clay rich soils the solution concentration in the drainage water at 1.0 m depth is < 0.01 mg/L, representing a 99.7% reduction in the concentration of P in the effluent.

3.15 It is calculated that between 95-99% of surface-applied E. coli will be removed during transport through the top 1 m of soil. Inactivation (die off) will account for almost all the applied bacteria. The average concentration in the drainage water at a depth of 1 m sometimes exceeds New Zealand Drinking Water Standards of 1 colony forming unit (cfu) per 100 ml by a factor of between 1 and 15. However, additional die off and dilution in the groundwater is expected to reduce these concentrations further. Model results indicate that E. coli in treated effluent added to land is unlikely to have a detrimental impact on the quality of the groundwater under the disposal site.

3.16 In conclusion, the modelling used conservative inputs to predict the environmental fates of pond effluent applied to land, and to calculate the storage requirements of the pond. The modelling has shown that the land area provided for effluent irrigation is able to accommodate the proposed water and nutrient loads being applied and will provide an effective filtering capacity. In my opinion any effects on the quality of the receiving water will be minor and will not pose a risk for human health.

4. LAND TREATMENT

4.1 A schematic of the planned disposal scheme is shown in Figure 1 **[compare with Figures 20 and 21 in AEE]**. A key component of the upgrade is the construction of a land disposal / irrigation scheme north of the current ponds to irrigate effluent to land when soil conditions allow. My role in the AEE was to develop a biophysical, process-based computer model to calculate the site's water and nutrient balance, including evaporation losses and storage volumes of the ponds as well as runoff and drainage losses from the site and volumes disposed to the river. Details of the model are presented in Appendix A (HortResearch 2007). I would like to briefly discuss this system in my evidence.

4.2 Municipal wastewater from the Masterton Township is piped directly to the site where it will be treated in new oxidation ponds constructed to the north of the existing ponds. The total land area will be divided into 17 zones, with each zone representing an area of like soils. Border strip irrigation will be applied to pasture on zones of free-draining soils (labelled as L1 to L14 and 29 to 31 in Figure 1). Neal Borrie will describe the border dyke irrigation in more detail.

4.3 A series of valves will be used to control the flow of effluent, and these will be operated independently. Preference is for land application, although direct disposal to the river is allowed in accordance with the adopted discharge rules (see details later). A wipe-off drain collects any runoff water from each irrigation zone and runoff water will be preferentially discharged to sandy gravel infiltration areas and surplus "first flush" run off will be pumped to the ponds. In extreme wet weather events (greater than 5 year return period) surplus runoff flows directly into the Makoura Stream.

4.4 A water balance for the storage ponds is calculated by considering the volumes of water going into (i.e. as influent, rainfall and return flow) and out of the ponds (i.e. as evaporation, leakage losses through the base of the ponds, irrigation to land and direct discharge to the river). A water balance for each irrigation zone is calculated by considering inputs (rainfall and irrigation) and losses (plant uptake, evaporation, runoff and drainage) of water from the soil profile. A set of disposal rules dictate when and where the effluent is disposed of.

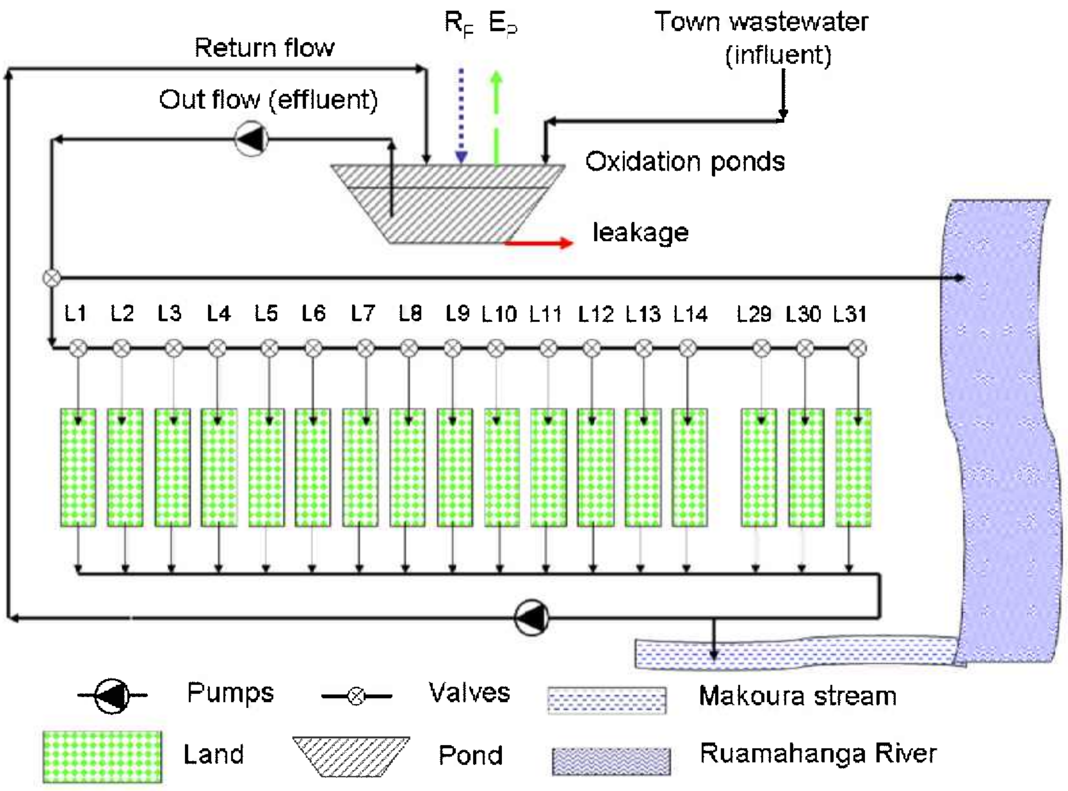

Figure 1. Schematic of the proposed irrigation scheme at the Homebush site. Irrigation is controlled by a series of valves that can be operated independently. Here R_F = rainfall and E_p = evaporation from the ponds. The potential future irrigation areas (L15-L28) are not shown in this figure.

Refer to the attached Drawing C624 for locations of L1 to L31

4.5 Contaminants from the irrigated effluent have the potential to pollute groundwater and therefore affect the quality of abstractions from the aquifer, or the quality of surface waters once it enters the river/stream systems. The predominant transport pathways are considered to be down through the soil and then through the aquifer. Modelling is needed to assess the potential effects, both short-term and long-term, of wastewater disposal on the receiving environment.

4.6 The model calculations run on a daily time step using local soil and climate data. The following model outputs are generated:

(a) Volumes discharged to land. Land application occurs only when soil moisture and irrigation management permits it.

(b) Volumes discharged to the Ruamahanga River. Effluent from the ponds is discharged directly into the river only when river flows are greater than a given trigger flow.

(c) Storage volumes in the oxidation ponds. Effluent is accumulated in the ponds whenever irrigation and discharge to the river, is less than the inflow volume.

(d) The fate of nitrogen, including growth and N-uptake by pasture, and the quantity of nitrogen resident in the soil and leached to groundwater.

(e) The fate of phosphorus, including P-uptake and the quantity of phosphorus resident in the soil and leached to groundwater.

(f) The fate of bacteria (i.e. E. coli), including the filter capacity of the soil and the quantity of bacteria (colony forming units per 100 ml) leached to groundwater.

4.7 A cut-and-carry pasture system is proposed for the border strip irrigation scheme. Cut-and-carry pasture provides the ability to assimilate large quantities of nitrogen and phosphorus from the applied effluent. A 'cut and carry' system will also remove the greatest amount of nutrients (N & P) from the site (c.f. with grazed systems) which is the prime treatment objective (particularly P).

4.8 Inherent in a cut-and-carry wastewater irrigation operation, is the need to exclude grazing animals, although limited use of grazing animals (for example, sheep) will be beneficial at certain times of the year to 'tidy up' those areas unable to be harvested. A pasture system grazed by cattle would typically return 80% of the nitrogen and 66% of the Phosphorus back to the pasture in the form of dung (30%) and urine (70%) (Monahagan et al, 2007). Concentrated urine patches from cattle increase the propensity to leach nitrate, especially on free draining sandy soils. Cut and carry is an environmentally beneficial option because it removes a greater fraction of nutrients from the site and also avoids additional nitrate leaching that would otherwise occur from urine patches deposited on a grazed pasture.

4.9 The nutrient uptake by pasture is expected to vary, depending on the quantities of nitrogen and phosphorus that are applied to the land and the rate that the pasture can assimilate them. With the proposed quality and quantity of effluent, it is likely that pasture growth on this site, under a cut and carry system, will become limited due to a deficiency of nitrogen. This deficiency will be addressed by including some nitrogen fixing species within the pasture mix. It is proposed that a perennial ryegrass pasture mix be used, together with white and/or red clover that fixes nitrogen from the atmosphere. I understand that pasture has a good growth record at this site, which can have relatively high groundwater table conditions at times. The pasture dry matter yield on the irrigated zones is calculated to be in the range of 10,000-12,000 kg/ha/yr, assuming a 15% clover content.

5. THE SITE AND SURROUNDING ENVIRONMENT

The 91 ha site (part of the proposed Land Treatment area)

5.1 Because the soils investigations were done in two stages as MDC procured the land packages, the soils characteristics are reported separately for the 91 ha and 107 ha sites. The soils on the 91 ha site are described in three Landcare Research Ltd reports (H Wilde and J Dando, Report No LC0304/173 July 2004, H Wilde and J Dando, Report No LC0405/090 March 2005 and H Wilde, Report No LC0506/054 March 2006).

5.2 The 91 ha site which is a part of the proposed Land Treatment site is located on a former floodplain of the Ruamahanga River, immediately west of the river and east of Makoura Stream. The soils have been formed from the river alluvium, comprising gravelly sediments overlain by predominantly sandy and silty alluvial sediments.

5.3 Nearer the river, the alluvium is coarser, with a tendency to have sandy textures sometimes interspersed with gravels plus fine sandy loams, sandy loams and gravelly sand textures as well as some loamy silts. These soils are named Greytown sandy loam and gravelly sandy loam in the Soil Survey of the Wairarapa Valley (Heine 1975, as referenced in HortResearch, 2007). Westward of these coarser soils, a finer-textured sediment overlies the gravels, and the soils are silty-textured (silt loam and silty clay loam textures) with intermittent clay-rich layers at depth. These soils are named Greytown silt loam. Refer to Soil Maps attached to my evidence.

5.4 The northern land area is generally free draining, while the southwest area is generally poorly draining (this part of the site and the area directly to the north west of the existing oxidation ponds will be used for the construction of the new oxidation ponds). The soils for the proposed irrigation site were extensively investigated as part of the upgrade work (Figure B2.1 in Appendix B2 shows the extent of on-site investigations for the soil's physical and transport properties; HortResearch, 2007). These investigations analysed soil texture, the soils' capacity to store and transport nutrients, as well as the soils' hydraulic properties (i.e. how fast the water moves though the soil, and how much water the soil holds). Table 1 summarises basic soil textural information for each of the irrigation zones, while Table 2 presents data describing the soils' capacities to store and transport nutrients.

Table 1. Profile of 'average' soil texture, as determined from a visual assessment of soils across the 14 sites at the Homebush, Masterton site (data from H. Wilde, Landcare Research). Refer to AEE Drawings C624 for the locations of sites.

Depth [cm]	site													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0-10	loamy silt	silt loam	silty clay loam	loamy silt	silt loam	silt loam	silt loam	silt loam	silty loam	silty loam	silty loam	silty loam	silty loam	silty loam
10-20	loamy silt	silty clay loam	silt loam	loamy silt	silt loam	silt loam	silt loam	silt loam	silty loam	silty loam	silty loam	silty loam	silty loam	silty loam
20-30	loamy silt	silty clay loam	silt loam	loamy silt	sandy loam	silt loam	silt loam	silt loam	silty loam	silty loam	silty loam	silty loam	silty loam	silty loam
30-40	silt loam	silty clay loam	silt loam	silt loam	sandy loam	sand	sand	sand	silty loam	silty loam	silty loam	silty loam	silty loam	silty loam
40-50	silty clay loam	silty clay loam	silty clay loam	silt loam	sandy loam	loamy silt	sand	sand	silty loam	silty loam	silty loam	silty loam	silty loam	silty loam
50-60	silty clay loam	silt loam	silty clay loam	silt loam	silt loam	loamy silt	sand	sand	silty loam	silty loam	silty loam	silty loam	silty loam	silty loam
60-70	silty clay	sandy loam	silty clay	loamy silt	loamy silt	silt loam	sand	sand	silty loam	silty loam	silty loam	silty loam	silty loam	sandy clayey loam
70-80	clay loam	sandy loam	silty clay	loamy silt	loamy silt	silt loam	silty sand	silty sand	silty clay	silty clay	silty clay	silty loam	silty loam	gravels
80-90	sandy clay loam	sand	silt loam	loamy silt	silty clay loam	silt loam	sand	sand	silty clay	silty clay	silty clay	silty loam	silty loam	gravels
90-100	sandy loam	sand	loamy silt	clay loam	silty clay loam	silt loam	sand	sand	silty clay	silty loam	silty loam	silty loam	silty loam	gravels

Table 2. Model parameters used to relate soil texture to the soil's hydraulic properties. Data were sourced from Landcare Research (LCR) reports (Wilde & Dando 2004, 2005) and the New Zealand Soils Database (NZSDB, Landcare Research). Here SAT, FC and WP refer to the soil's water content at saturation, field capacity and wilting point; RAW and TAW are the corresponding values of readily available and total-available soil water; and K_{SAT} is the saturated hydraulic conductivity.

Texture	Data source	Bulk density [kg / L]	SAT [L/L]	FC [L / L]	WP [L / L]	RAW [L / L]	TAW [L / L]	K_{SAT} [mm / d]
clay / silty clay	from NZSDB	1.03	61.6	59.3	48.3	3.7	11.0	14
silty clay loam	Average (LCR)	1.39	47.9	35.6	16.6	9.5	19.0	30
clay loam	Bush (LCR)	1.16	57.0	35.3	15.2	11.3	20.1	43
loamy silt	Northeast Bore (LCR)	1.36	49.4	28.9	8.7	11.5	20.1	81
silt loam	Average (LCR)	1.48	44.2	37.4	20.0	7.8	17.4	86
sandy clay loam	from NZSDB	1.27	53.3	39.7	19.5	10.1	20.2	96
sandy loam	Enclosure (LCR)	1.37	49.0	26.1	9.2	9.6	16.9	540
loamy sand	Pumphouse (LCR)	1.38	48.8	24.1	5.1	16.7	19.0	1410
sand	from NZSDB	1.42	47.4	15.3	1.1	10.5	14.2	2870
gravel	from NZSDB	1.53	43.7	28.2	17.4	5.5	10.8	5400

5.5 In terms of the hydraulic properties of the site's soils, the analysis indicates that where clay-rich soil materials occur at shallow depth, interpedal cracks and macropores, most of which are invisible to the naked eye, conduct water at significant rates (>77 mm/hr). However, the deeper clay-rich layers tend to conduct water at much slower rates of 0.5-4.0 mm/hr, mainly because there are fewer macropores. Locations having silty clays at depth are classified as poorly drained, and they will transport less water and nutrients at much slower rates.

5.6 In terms of the soils' nutrient characteristics, soil pH ranges from moderately acid on the wetter soils in the south of the property to near neutral in the north. Mineralizable nitrogen, which results from activities of the soil's microbial biomass, varies quite markedly across the property, but is generally quite low. Total organic carbon is also very low on all soils, although the carbon to nitrogen ratio is typical of soils under pasture. Soil phosphate values in the top 100 mm of the soil profile also vary across the site, being generally adequate to low. Pasture growth is expected to be nitrogen limited on the Homebush soils.

The 107 ha site (part of the Proposed Land Treatment area and the Potential Future Land Treatment area)

5.7 The 107 ha site generally lies west of Makoura Stream, and further from the Ruamahanga River. Extensive soil sampling was completed to identify soil textures, depths and drainage characteristics. The data were then used to map the overall distribution of soil properties (i.e. drainage, texture, particle-size classes, depth to gravel, and depths to the underlying clay-rich layer). Soil mapping allowed for the identification of zones of similar soils across the 107 ha site (Figure B2.2 in Appendix B2 of the AEE shows the extent of the soil investigations).

5.8 The soils on the 107 ha site are described in a Landcare Research Ltd report (H Wilde and J Dando, Report No LC0708/139, June 2008). The soils on the 107 ha site are divided into four drainage classes. The Tauherenikau soils on the high terrace on the western side of the site are well to excessively drained, the Greytown soils on the eastern side of the site include areas that are well drained, moderately well drained and imperfectly drained and the Ahikouka soils that occur in a strip running north-south in the centre of the site, are poorly drained. Refer to Soil Maps attached to my evidence.

5.9 On the 107 ha site, the soils are generally finer textured than those on the 91 ha site adjacent to the river, where the coarser-textured alluvium was deposited. There is also a slight trend of the soils on the 107 ha site becoming finer textured from the margin towards the centre.

5.10 In addition, the clay-enriched layers under the 107 ha site, tend to occur at shallower depths nearer the centre of the property. They also occur in a strip running north–south, although their distribution is sporadic. There are "gaps" in these clayey layers, similar to that on the 91 ha site that may provide improved soil drainage yet offer less filtering of bacteria and nutrients.

5.11 Soils on the western part of the 107 ha site are poorly drained (Ahikouka soils) with the underlying clay-rich materials at shallow depth (less than 50 cm depth). The generally poorer draining parts of the 107 ha site are a greater distance from the Ruamahanga River where the finer-textured alluvium was deposited, possibly in a former back swamp abutting the older and higher terrace (Tauherenikau soils).

5.12 For the above reasons, the western portion of the 107 ha site has been reserved as a potential "Future Land Treatment Area" because it will be relatively more expensive to develop this area for effluent irrigation, using such techniques as sand slit drains and deep drains to lower the groundwater levels – refer to Humphrey Archer's evidence.

6. MODELLING

6.1 Computer modelling is needed to assess the environmental effects arising from treated wastewater application to land, and to predict the amount of nutrients and contaminants that will be removed or retained on site, and the amounts entering groundwater and then the river.

6.2 The water and nutrient balance of the site was calculated using an extended version of HortResearch's SPASMO model (Green et al. 2003b). This model uses appropriate science to link the mechanisms of water and nutrient flow through soil with the complex transformations that result from both natural processes that occur in soils and plants, as well as those processes consequent upon the surface application of effluent to soil. The SPASMO model is described in more detail in HortResearch (2007; Appendix A).

6.3 Field validations of SPASMO include nitrate leaching under pasture (Green et al. 2005; Rosen et al. 2003) and fruit crops (Green et al. 2006), and pesticide movement (Sharma et al. 2005; Sharma et al. 2006) under a range of New Zealand soils and climatic conditions. SPASMO is gaining acceptance by the wider scientific community e.g. being incorporated within the larger framework of catchment models (CLUES) and being used in similar environmental applications e.g. being incorporated within the OVERSEER® nutrient budgeting tool as part of the Sustainable Farming Fund project entitled 'Nitrogen Management for Environmental Accountability'.

6.4 The SPASMO model accommodates the simultaneous disposal of effluent across multiple land areas using a range of options for disposal onto the land and into the river. The variables modelled were water, E.coli, mineral nitrogen (as ammonium and nitrate in solution) and phosphorus. E.coli was used as an indicator to assess the potential transport of micro-organisms of concern for human health. Nitrate and phosphorus were modelled to assess the potential effects on human health (nitrate) and on the quality of the receiving waters of the Ruamahanga River and the Makoura Stream (nitrate and phosphorus) as well as the groundwater under the site.

6.5 Plant growth and nutrient (N and P) uptake was calculated using daily values of solar radiation and mean air temperature, with growth being reduced whenever soil water or nutrients were limiting. The water-borne transport of bacteria through the soil profile was modelled as a colloidal-filtration process that depends on soil texture and an inactivation (die-off) rate that is determined by a characteristic half-life (residence time). These abiotic processes are modified by the temperature and water content of the soil. Details of the modelling approach are described in more detail in HortResearch (2007; Appendix A).

6.6 Model inputs include a time series of daily climate, river flows and the volume and composition of effluent coming to the site. Under the current design rules for operation, different amounts of treated pond effluent will be disposed onto each land area (irrigation zone) at a rate that depends on the soils' hydraulic capacity to store and/or drain water. The water balance of the oxidation pond is guided by a set of decision rules for disposal options. The operational rules for land and river disposal are described later.

6.7 All simulations are based on daily climate records from Te Ore Ore (NIWA climate station No. 7578; 1977-2008). Mr Ron Haverland of Beca provided existing records of daily influent volumes and composition coming to the site, and Greater Wellington Regional Council's daily records of river-flow from Wardells Bridge. Soil properties were derived using observations from auger hole sampling and soil pits excavated from across the site (refer to Figures B2.1 & 2.2 of Appendix B of the AEE).

6.8 Modelling was carried out to determine both the storage requirements of the oxidation ponds and the environmental fate of nutrients (i.e N & P) and contaminants (i.e. E coli.)

contained in the wastewater applied to land. Initially a base-case model was established. Then a range of different options were tested in order to assess the impact of altering various operational parameters. The outcome of the option testing was the selection of a preferred scheme. A key focus of the development of the discharge rules was to recognise the importance of the Ruamahanga River for its recreational value, particularly during summer at times of low river flow when there is a strong community desire to use the river for contact recreation.

Discharge rules

6.9 The following rules were established in the model relating to irrigation of effluent on to land:

(a) Preference was given to effluent irrigation. If a site could be irrigated, then the maximum volume possible, under the rules, was applied to the land. For the purpose of calculation, the year was divided into two periods: winter was from May to October, and summer was from November to April.

(b) To determine the wastewater storage requirements in the ponds, irrigation to the border strips for the proposed irrigation scheme (Zones 1 to 14 and 29 to 31) was set at a maximum rate of 10 mm/day in the summer and 5 mm/day in the winter for the free draining soils. For the clay rich soils, the winter irrigation rate was set to zero (this being a conservative assessment when determining the amount of wastewater to be stored). The model used a minimum 10-day stand down period between irrigations. These irrigation rates were adopted as the basis for the design following recommendations from a number of experts in the fields of soil science and irrigation (including specific expertise with irrigation of effluent from wastewater treatment plants) who were engaged to provide input to the project. Furthermore, the model accommodated an additional stand-down period of 10 days prior to harvest of the pasture.

(c) The maximum amount of irrigation applied daily to the land was not allowed to exceed the soil's hydraulic capacity on that day. On those days when rainfall occurred, irrigation was set equal to the lesser of the target irrigation rate or the soil's total storage capacity (calculated as drainage plus refill depth) minus the amount of rainfall on that day.

(d) On those days when the rainfall exceeded 20 mm, all pastures were given an additional two-day stand down period before the next irrigation resumed.

(e) Stormwater was separated from effluent runoff. When a rainfall event occurred, any runoff from the land area being irrigated on a given day was always directed back to the storage pond. The first 2 mm of rainfall from the other paddocks not being irrigated, was also directed back to the ponds. This approach is conservative as it overestimates the storage required. In practice it is proposed to discharge wipe off drains to infiltration areas and discharge to Makoura Stream will only occur during major events greater than five year return period. Refer also to Humphrey Archer's evidence.

6.10 Discharge direct to the river will comply with these rules:

(a) In summer, only when the river flow is greater than the median (12.3 $m^3 s^{-1}$).
(b) In winter only when the river flow is greater than half the median (6.15 $m^3 s^{-1}$).
(c) Whenever there is a direct discharge to the river, the ratio of river flow to effluent flow will be at least 30 to one, up to the maximum effluent flow.
(d) The maximum effluent flow for a direct discharge is 104,000 $m^3 d^{-1}$ (1200 $L s^{-1}$).

Treatment Capacity of Soils

6.11 The soil acts as a reservoir to filter, retain or remove particular constituents from the effluent. The degree of effluent renovation will depend on the interaction between soil processes and water movement. To be effective, the effluent needs both a sufficient residence time and adequate travel distance in the soil to adsorb and attenuate. The main potential for adverse outcomes to occur relate to nutrients (phosphorus and nitrogen) and pathogens (bacteria) leaching from the base of the root-zone into the receiving ground and surface waters.

6.12 Drainage trials were carried out on the site to determine the soil's hydraulic properties (as detailed in section 6.4.2 of the AEE). The results determined that the whole area can be irrigated using border strip irrigation. The adopted application rates for the free draining and clay rich soils during summer and winter are specified in 6.4.3 of the AEE.

6.13 The following model outputs relate to the proposed scheme that comprises border strip irrigation to pasture only:

- Maximum storage volume in the ponds

- Tabulated summaries of volumes disposed to land and river (as detailed in section 6.7.4 of the AEE)

6.14 It is important to recognise that the predicted effects of nutrients applied to soils and the groundwater effects at the perimeter of the site, are based on specific estimated application rates. It is a fundamental concept of the scheme that the applicant seeks to have the flexibility to vary application rates as site conditions allow, consistent with maintaining 'good practice' with respect to irrigation, soil health and avoidance of nutrient breakthrough to groundwater and the river.

6.15 In order to be conservative in our assessment of the fate of nutrients, the larger potential future irrigation scheme was modelled and the calculations used the maximum irrigation rates (AEE Table 23) rather than the average rates which represent the likely long term application rates. The modelled upper application rates represent an extreme situation which might be used in dry conditions and certainly would not apply to every plot throughout the lifetime of the scheme.

6.16 Table 3 gives an overview for the purpose of the main model runs.

Table 3 The irrigation zones and river flow triggers used to determine storage requirements and nutrient leaching losses for both the proposed irrigation area and the potential future irrigation area.

Purpose of model run	Interim storage requirements	Storage requirements (for the completed proposed irrigation scheme	For nutrient leaching across the proposed and future schemes
Irrigation Zones	1 to 14 (Proposed Irrigation area excluding decommissioned ponds)	1 to 14 and 29 to 31 (Proposed irrigation area including decommissioned oxidation ponds)	1 to 31 (Proposed and Potential Future irrigation areas)
Application rates	Average application rates; 10 mm/day in summer 5 mm/day in winter (and zero in clay rich areas)	Average application rates; 10 mm/day in summer 5 mm/day in winter (and zero in clay rich areas)	Maximum applications; 15 mm/day in summer on free draining soils 10 mm/day in summer on clay rich soils 5mm/day in winter on free draining and clay rich soils
River flow trigger	Half median in summer and winter	Median in summer Half-median in winter	Median in summer Half-median in winter

7. MODELLING RESULTS

Storage in the Ponds

7.1 Modelling for pond storage was on the basis of average irrigation rates and therefore represents a conservative assessment of the required storage of wastewater. Figure 22 of the AEE illustrates the pond storage required over the period of the modelling from 1996 to March 2008. This represents the maximum period of available data for daily pond influent volumes. The peak storage volume is calculated to be 200,100 m^3. The new oxidation ponds will actually provide a storage volume of 275,000 m^3 which will provide a contingency for abnormal climate events and operational inefficiencies.

7.2 The storage volume calculations for the proposed irrigation scheme included irrigation zones 1 to 14 as well as zones 29 to 31 which are the areas that will be redeveloped on the site of the existing ponds (22 ha total). Prior to these irrigation areas being established, on the site of the existing oxidation ponds, there will be a period of 2 to 3 years when only 75 ha of land can be irrigated. Modelling of this situation using the proposed trigger flows of median in the summer and half median in the winter determined that 350,000 m^3 of storage would be required. This large storage volume is neither practical nor cost effective for an interim period until the existing ponds are decommissioned and the additional irrigation areas are constructed. Therefore during this interim period a year-round half median flow trigger is proposed. Modelling with the revised summer trigger of half median showed that 214,000 m^3 of storage would be required during this interim period. This volume is manageable and can be accommodated under the proposed storage of the new oxidation ponds.

7.3 In considering future climate changes and their potential impacts on the storage requirements for the ponds, a scenario approach was taken to examine the sensitivity of model outputs to changes in rainfall and river flow. Under a “medium-high” climate change scenario, that brackets the 75% temperature change projection range, NIWA scientists estimate a 0.9 C increase in mean annual air temperature, a 5-10% decrease in mean annual rainfall and a four fold increase in the occurrence of severe droughts across much of the Wairarapa ([1]Mullan et al., 2005). Less rainfall in Wairarapa as a result of climate change would allow a greater quantity of the effluent to be irrigated to land. While the application rates would remain the same, total volumes disposed to land would increase as there would be greater opportunities for irrigation to land, and therefore less effluent would be discharged to the river.

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[1] Mullan, A.B.; Porteous, A.; Wratt, D.S.; Hollis, M. (2005). Changes in Drought Risk with Climate Change. NIWA Client Report WLG2005-23, prepared for the Climate Change Office, Ministry for the Environment, and the Ministry of Agriculture and Forestry. 56p.

7.4 Under the "medium-high" climate change scenario, NIWA scientists also predict slightly higher rainfalls (+5%) in the Tararua's. That would generate increased flows in the Ruamahanga River and thereby lower the storage requirements for effluent because greater volumes could be discharged to the river. Nonetheless, it also is realistic to expect that river flows during critical periods (i.e. summer drought when daily flows are very low) will be reduced, perhaps in proportion to regional rainfall (a 5-10% reduction) because the base flow of the river will be closely linked to groundwater recharge from rainfall. A reduced flow in the river, as would occur under a reduced rainfall scenario, would increase storage requirements for effluent because lower volumes would be discharged to the river. To future proof the operation, it is prudent to examine the case of lower river flows in more detail.

7.5 Here we consider the case of a 90% rainfall and a 90% river flow (i.e. this represents a future climate having 10% less rain and 10% less river flow). The maximum storage requirement is calculated to be 343,100 m^3. This means that if the rainfall and river flow both dropped by 10%, then the capacity of the proposed storage would be exceeded for 1 day per year, on average, if all other factors were unchanged. However, the volumes of wastewater entering the treatment plant at Masterton are characterised by large volumes of stormwater and groundwater flow entering the system. It is likely that the contribution from stormwater and groundwater will also reduce under a lower rainfall scenario.

7.6 A more realistic future climate scenario might be a 5% reduction in the influent flow, along with a 10% reduction in rainfall and river flow. In this scenario the storage requirement would be 209,926 m^3 which is manageable and can be accommodated under the proposed storage, with a reasonable safety margin. The assumption of a 5% reduction in influent flow is reasonable in the light of the existing summertime minimum flow of 7,980 m^3/day compared to the annual average of 15,750 m^3/day as shown in Table 2 of the AEE. On balance it is my opinion that climate change during the lifetime of the irrigation scheme will not have any major adverse effects on the storage requirement of the ponds.

Environmental fate of nutrients and contaminants

7.7 The fate of nitrogen, phosphorus and bacteria (Escherichia coli) in the upper soil layers was assessed as part of the model development. An estimate was made of the quantity and quality of the water that would leach to the underlying groundwater. In order to be conservative in our assessment we modelled the upper application rates that represent an extreme situation which might be used in dry conditions and certainly would not apply to every plot throughout the lifetime of the scheme. We used a period of 28 years that represents the maximum length of available climate and river flow records.

7.8 Thereafter, the assessment of the impact on groundwater quality was undertaken and reported separately by Pattle Delamore Partners (see evidence of Graeme Proffitt). Key conclusions with respect to the fate of nutrients and contaminants in the top 1.0 m of the soil profile are summarised below.

Nitrogen

7.9 Modelling was carried out to assess the environmental fate of the surface-applied nitrogen. The results were reported in the HortResearch (2007) report which forms part of the AEE. Total nitrogen content of the effluent proposed for land application is about 12 mg/L, on average. About two-thirds of applied nitrogen is in the form of ammonium (90%) and nitrate (10%) in solution while the remainder is organic-N. Ammonium adsorbs to the soil's mineral and organic matter and is also rapidly oxidised to nitrate by microbial processes in the soil. Nitrate is highly mobile and would travel freely though the soil, being transported downwards along with the percolating drainage water.

7.10 For the proposed scheme, nitrate leaching will be of little concern with regard to potential contamination of the groundwater as a result of effluent application. Figure 2 below shows the profile of nitrate-nitrogen in the soil water for site 3 (a clay-rich soil) and site 7 (a sandy soil). The solution concentration in soil water at 1 m depth will remain well below the NZ Drinking Water Standard of 11.3 mg/L for nitrate-nitrogen, even after a period of 28 years of effluent irrigation applied to the land (as shown in Figure 2).

7.11 There is unlikely to be any significant accumulation of nitrate in the soil profile over time. This is because nitrogen uptake by the pasture can easily account for all of the applied nitrogen. Furthermore, the cut-and-carry process for pasture would remove a large fraction of the pasture nitrogen from the site leaving little excess nitrogen to leach.

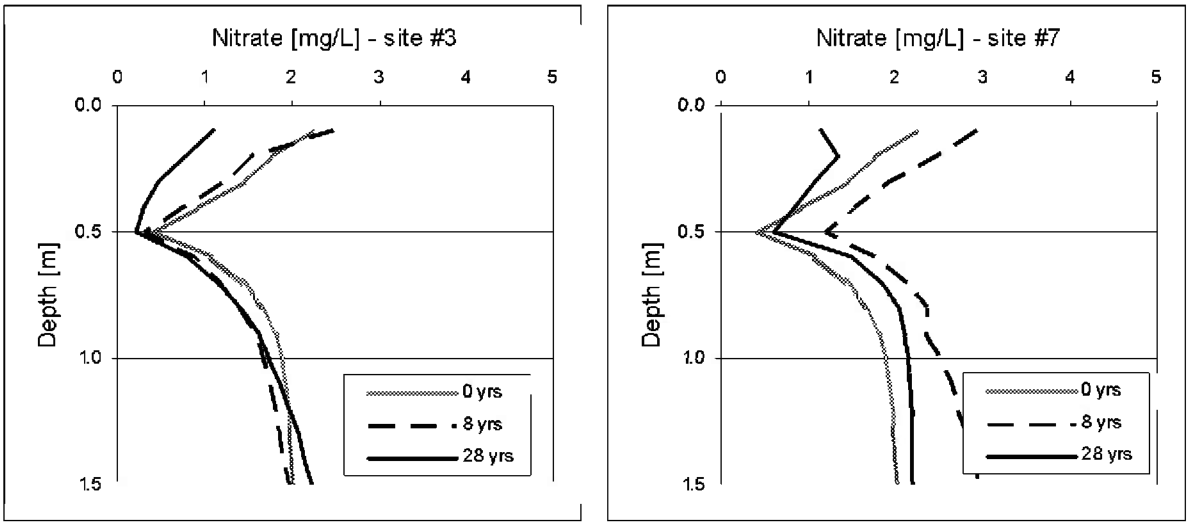

Figure 2 (Figure 24 in the AEE) **Profile of Nitrate-Nitrogen**[2]

Note: Site 3 is a clay rich soil, and site 7 is a free draining soil.

Phosphorus

7.12 Phosphorus (P) is a relatively immobile element in most New Zealand soils. When applied to land, it would normally be bound to the soil and accumulate within the top 10-20 cm of the root-zone where it can be taken up by plants. Modelling was carried out here to assess the environmental fate of the surface-applied phosphorus. Preliminary results were reported in the HortResearch (2007) report which forms part of the AEE. Subsequent to that report, model parameters that describe phosphorus uptake by pasture have been revised to to ensure that the N:P ratio of herbage lies in the normal range of 8-12. This is necessary in order for the pasture herbage to accumulate the correct amount of phosphorus. Hereafter all P results are based on revised parameter values for phosphorus uptake by the pasture.

7.13 The total phosphorus content of the wastewater will be on average 3.2 mg/L. Most of this phosphorus is in the form of dissolved reactive phosphorus (DRP) which is readily taken up by plants, yet strongly adsorbed to the soil's mineral and organic surfaces. Because the ability of soils to adsorb DRP varies greatly, equilibrium sorption isotherms were constructed for the range of soils at the site (HortResearch, 2007). These isotherms are needed to determine how the dissolved phosphorus will be partitioned in the soil domain, between solution (mobile) and solid (immobile) phases.

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[2] In-soil water solution draining through soil, site 3 with an annual loading of 130 kg N/ha at site 3 (a clay rich soil), and 290 kg N/ha at site 7 (a free draining soil) – the NZ Drinking Water Standard for nitrate-nitrogen is 11.3 mg/L.

7.14 Phosphorus partitioning was described using a Langmuir adsorption-isotherm that relates the equilibrium solution concentration [C, mg/L] to the amount of P adsorbed onto the soil matrix [q, mg/kg]. Figure 3 presents one isotherm for soil from the Bw horizon (clay loam at 50 cm) where the P retention is 19%. The maximum sorption capacity of these clay rich layers is typically between 410-615 mg/kg.

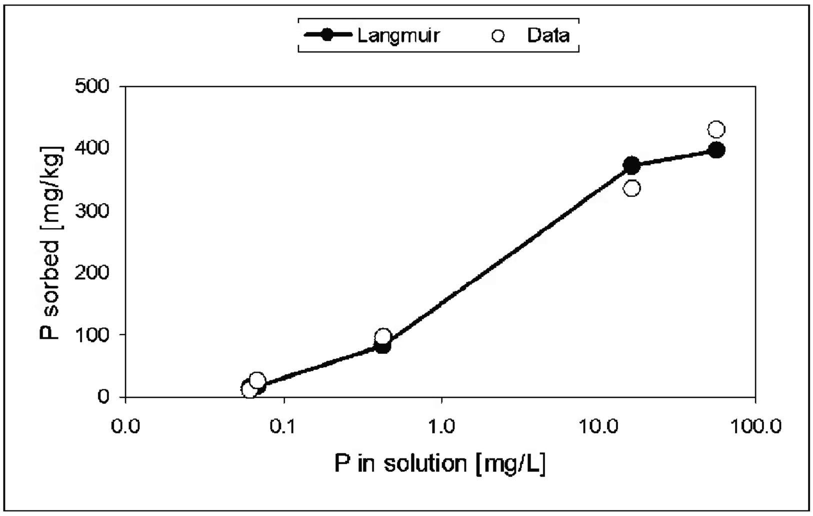

Figure 3: Langmuir isotherm for P retention in soil from the Bw horizon (a clay rich soil at 50-53 cm depth) at the Homebush site (source: HortResearch, 2007; Figure B2)

7.15 Site investigations showed the P retention capacity of all soils is very low: 8-19% (HortResearch, 2007: Table B4). This retention capacity means the surface soil could become "saturated" with phosphorus, under a heavy load, thereby possibly enabling some leaching of P to occur. Long-term (28 yr) simulations were carried out to assess P build up in the soil, and P movement through the profile. In order to simulate a worst case scenario, the maximum irrigation rate was set equal to 15 mm/day, or some 1.5 times higher loading than the likely average applications. Thus predictions for 28 years at 15 mm/day would equate to 42 years at 10 mm/day which is likely to be the long-term average.

7.16 Figures 4 and 5 below **[similar to Figures 26 and 27 in the AEE, but with revised parameters for P-uptake]** illustrate the situation for two areas within the site that would receive different amounts of effluent. Site 3 (a heavier clay-rich soil type) receives the lowest effluent input equivalent to about 28kg P/ha each year (see Table at paragraph 6.20). Following 28 years of effluent application to this clay-rich soil, we calculate that 61% of the applied phosphorus would remain in the top 1 m of the profile, and the concentration of P entering the groundwater would remain below 0.01mg/L.

7.17 In contrast, site 7 (a free draining soil) would receive the highest wastewater input, with some 63 kg/ha of phosphorus being added each year (see Table at paragraph 6.20). The topsoil here has a lower P retention capacity because of lower clay content, which means that a greater amount of the surface-applied P moves downward through the soil profile. Over a 28-year period, 66% of the applied phosphorus to the free draining soil would still remain in the top 1 m of the profile, and the concentration of P entering the groundwater would remain below 0.15 mg/L.

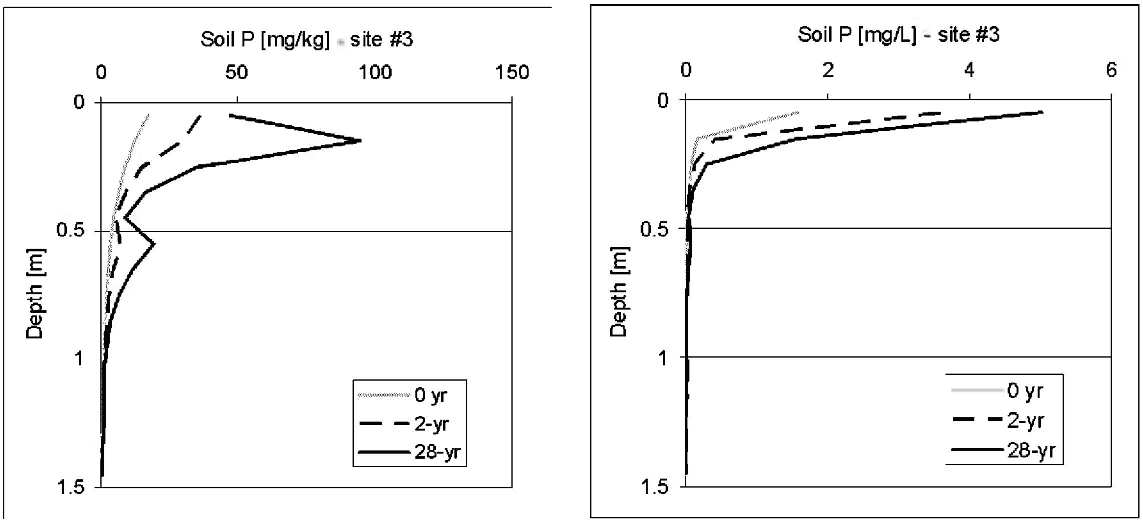

Figure 4 (Figure 26 in the AEE) **Predicted Concentration of Soil Phosphorus and Soil Solution Concentration at Site 3 (a heavier, clay-rich soil)**

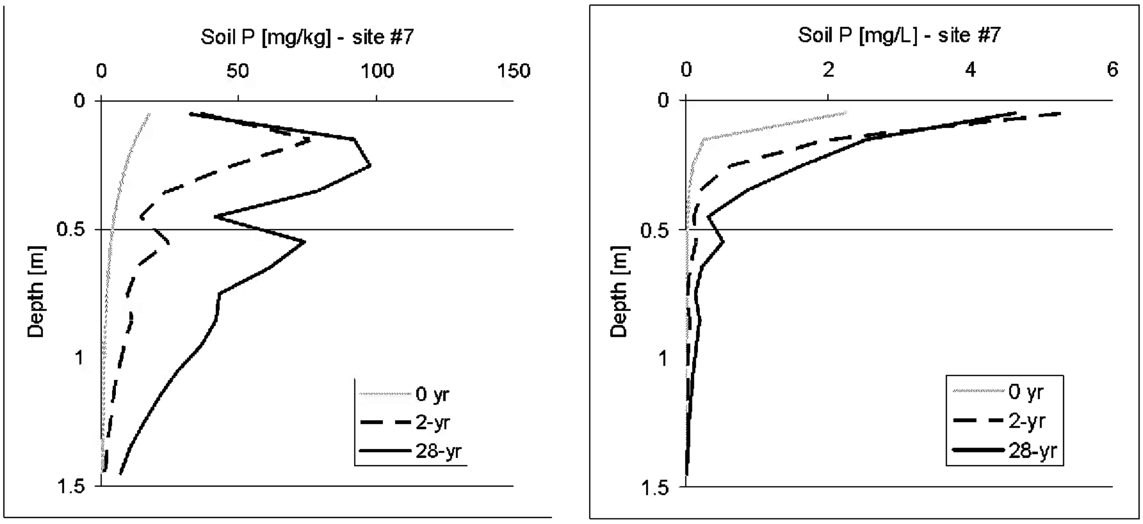

Figure 5 (Figure 27 in the AEE) **Predicted Concentration of Soil Phosphorus and Soil Solution Concentration at Site 7 (a lighter, free draining soil)**

7.18 The proposed irrigation scheme would add between 28 and 63 kg P/ha each year to the pasture sites. Some 30-48 kg/ha of this P would be assimilated by pasture that is subsequently harvested and removed from the site under the cut-and-carry operation.

Irrigation of treated effluent adds more phosphorus to the soil than can be utilized by the pasture, so there is opportunity for some leaching to occur. However, a large fraction of the remaining P is largely retained, or filtered, by the soil profile. The degree of renovation will depend on the interaction between soil processes and water movement.

7.19 Following 28 years of a high application of phosphorus to pasture, we calculate a large fraction (~60-80%) of the applied P will still reside in the top 1.0 m of the soil profile (Figures 4 & 5). While the soil concentration slowly increases over time, it is still a factor of 2-6 times lower than the maximum concentration at saturation (Figure 5 cf. asymptote of Figure 3). This means the soil has not yet reached the maximum sorption capacity.

7.20 On site 3 (a heavier, clay rich soil), the solution concentration in the drainage water at 1.0 m depth is < 0.01 mg/L, representing a 99.7% reduction in the concentration of P in the effluent. The corresponding P concentration on site 7 (a free draining soil) could slowly rise to 0.15 mg L^{-1}, which is much higher than on the clay-rich soils firstly because there is less sorption due to the lower clay content and secondly because there is a higher nutrient loading and increased drainage losses. On the free-draining parts of the site, there will still be a 94% reduction in the concentration of P relative to the effluent that is applied.

7.21 It should be noted that additional dilution in the groundwater, combined with strong adsorption by the deeper clay-rich layers, means the off-site impacts on surrounding groundwater are likely to be negligible, (as described in the evidence statement from Graeme Proffitt).

Bacteria

7.22 The effluent contains a variety of pathogens, including bacteria and viruses. Land application of effluent may increase the risk of groundwater contamination by these pathogenic micro-organisms, which can cause disease in humans and livestock.

7.23 The NZ Drinking Water Standard for bacteria is currently set at <1 colony forming unit (cfu) per 100 mL. Groundwater concentrations that exceed this guideline value are indicative that faecal matter and possibly other disease-causing organisms may be present. *E.* coli was used as an indicator to assess, via modelling, the potential transport of micro-organisms of concern for human health. For the purposes of