# Marrying Together Wastewater Application and Land Management in a Nutrient-Sensitive Catchment

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## ABSTRACT

Fonterra are proposing to expand their existing milk powder production processing facility at Pahiatua, in the Manawatu. Existing process wastewater and condensate are applied to farmland when appropriate and condensate to the Mangatainoka River when flows are sufficiently high. The expanded plant will result in treated wastewater and condensate being applied to land only, or being recycled back to the plant.

The discharges to land will occur in the Mangatainoka River catchment, a tributary of the Manawatu River. This catchment has existing nutrient enrichment issues, and the proposed regional plan (One Plan) imposes limits on nutrient leaching from production farming systems within this catchment.

The process involved assessing the soils to establish design loading rates, modelling of wastewater nutrient loading and farming systems' nutrient losses to groundwater and then the interaction between the river and groundwater (to establish nutrient monitoring requirements in groundwater). Modelling indicated that additional nitrogen application (in the form of waste activated sludge) was required.

The paper describes the modelling results and the on-farm actions (change from travelling irrigators to solid set and change to controlled grazing) to achieve nutrient leaching levels compatible with regional plan requirements. The modelling indicated that the wastewater application to land was driven primarily by farming systems rather than wastewater and soil hydraulics.

Keywords: Nitrogen; leaching; modelling; wastewater; groundwater; consenting.

## INTRODUCTION

Fonterra Co-operative Group Ltd propose to increase processing capacity at their Pahiatua processing site. The proposal is to include an additional dryer capable of processing approximately 2.5 million litres of milk per day, an additional boiler, an expanded drystore, new process wastewater treatment plant, additional vehicle movements and expanded rail use.

The key elements of the proposal are the construction of a third dryer with a height of up to 49 metres and associated discharge stacks, a new 25,000 $m^2$ dry goods store, expanded milk reception and Clean In Place (CIP) facilities, an additional 30 MW gas fired boiler, a process wastewater treatment system, a storage pond and expanded treated process wastewater and condensate irrigation system.

The expanded Pahiatua facility will result in increased process wastewater and condensate volumes, which require further management, including biological treatment, recycling and land treatment. The factory and the irrigation farms are located in the Mangatainoka River Catchment, which has been identified as a sensitive sub-catchment of the Upper Manawatu River by Horizons Regional Council in their Proposed One Plan. Therefore, an adaptive farm management strategy is proposed that will significantly reduce the overall nutrient leaching from Fonterra's farms in comparison to the current situation. The application is Discretionary under both Rule 12 of the Manawatu Catchment Water Quality Regional Plan and DL13 of the Land and Water Regional Plan, and Discretionary under Rule 13-27 of the proposed One Plan (POP).

Fonterra currently holds consents to permit various discharges from the plant, including consents to apply process wastewater to land on farms near the plant. Fonterra also hold consent to discharge condensate to a tributary of the Mangatainoka River and a new consent to discharge condensate to land and the Mangatainoka River is currently under appeal. The new consent provides for condensate discharge to the tributary to cease, with discharge then either direct to the Mangatainoka River or to land (river flow and soil moisture dependent).

The location of the existing processing plant and the land treatment farms are shown in Figure 1 below.

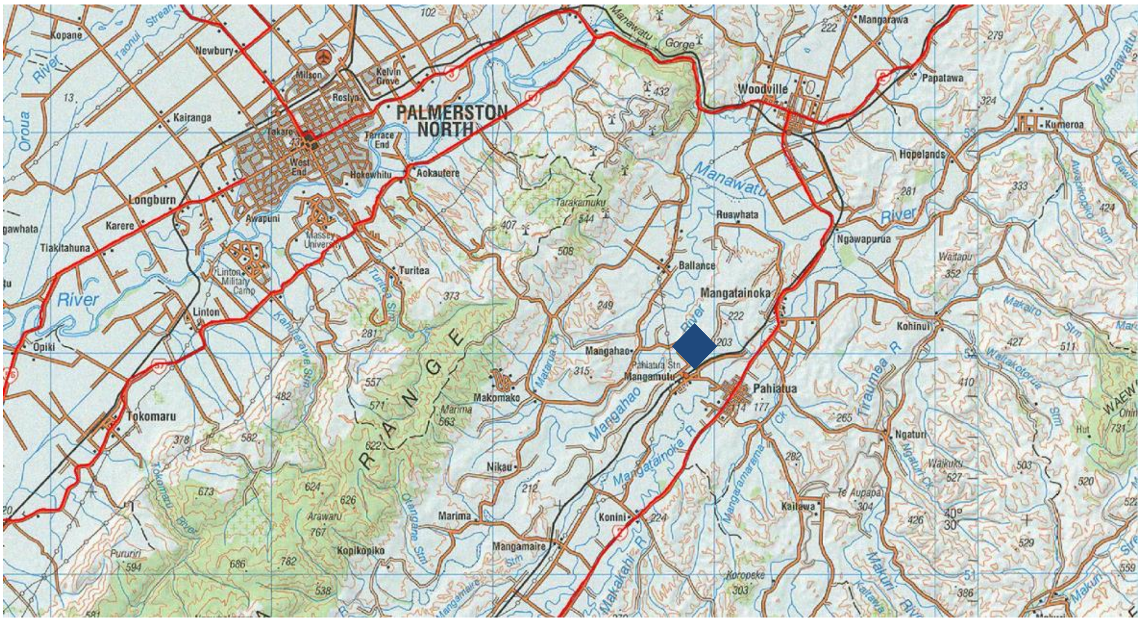

**Figure 1: Overview and Location Map**

## DESCRIPTION OF THE SITE AND ENVIRONMENT

### River

The Mangatainoka River originates from the eastern Tararua Ranges and flows northeast roughly parallel to SH2. The Mangatainoka River flows into the Manawatu River about 6 km downstream from Pahiatua. The median flow at the Pahiatua Bridge is 9.3 $m^3/s$ and the median nitrate-nitrogen concentration at that site is 0.88 $g/m^3$. River flows and nitrate-nitrogen concentrations show strong seasonal dependence and are typically lower in summer and higher in winter.

**Groundwater**
The local shallow groundwater environment in the Mangatainoka valley around Pahiatua consists of an unconsolidated recent alluvial sand, gravel and minor silt aquifer unit of approximately 10 m depth (Phreatos, 2003). Based on a groundwater contour map constructed by Phreatos, it is considered that in winter the groundwater flows parallel to the general flow direction of the upstream reach of the Mangatainoka River as it flows through the valley. The groundwater contours converge towards the river further downstream. Hence, all groundwater will eventually flow into the river prior to its confluence with the Manawatu River, providing it is not abstracted by shallow groundwater bores. The river water quality of the downstream reach of the Mangatainoka River, roughly downstream from the Pahiatua Township, will therefore be strongly influenced by the groundwater quality.

Phreatos (2003) assumed the aquifer transmissivity to be between 1,000 - 2,000 $m^2$/day. Data provided by HRC shows a range of 284 - 3,816 $m^2$/day. There are three aquifer test results available in a radius of 2.5 km around the Fonterra Pahiatua site, and the average transmissivity value of those tests is 1,595 $m^2$/day. This value is assumed to be representative for the aquifer surrounding the Pahiatua site. Depth to groundwater is 3 - 6 m (HRC, 2012) and an average saturated thickness of 7 m is assumed.

Nitrate levels in groundwater bores on both Fonterra's irrigated areas, as well as in the wider valley are typically 1 to 4 g N/$m^3$, with occasional increases to more than 10 g N/$m^3$. Some groundwater monitoring bores are close to the river and pumping from them will result in the abstraction of a substantial amount of river water. Their water quality represents that of a mixture of shallow groundwater and river water.

**Farms and Soils**
Spray irrigation of wastewater has been utilised at the Pahiatua site since 1977. Since then it has been expanded to four farms – Brechin, Tui, O-Brien and a third party farm; Four Mac's, with a total land application area of 260 ha. All the farms are operated as dairy farms, supplying milk to the Pahiatua site. Raw wastewater and farm dairy effluent (FDE) are applied by a mixture of small travelling irrigators and fixed sprinklers.

MWH (2003) described general soil conditions on the current irrigation farms as follows:

- Rangitikei sand - well to excessively well drained
- Manawatu fine sandy loam - moderately well to well drained
- Manawatu mottled silt loam - moderately well to well drained
- Kairanga silt loam - poorly drained

These soils are alluvial in origin. While the soils are suitable for irrigation, they are prone to water logging in the spring, which limits the application rate which can be applied during this period.

Soils investigations were undertaken by Lowe Environmental Impact Ltd (LEI, 2012), as part of the consent application preparation process for the expansion. The investigation included an assessment of soil hydraulics on the farms currently irrigated with condensate and process wastewater, and farms proposed for condensate and process wastewater irrigation. Several different sites were chosen across the existing farms reflecting the various soils that receive (or will receive) treated process wastewater and condensate.

Unsaturated hydraulic conductivity was measured in-situ using a disc permeameter. Data was collected to enable the Woodings Equation to be solved for 3 dimensional flow. Unsaturated hydraulic conductivity at a soil matrix potential of -40 mm pressure ($K_{-40\ mm}$) is considered to represent soil water movement through micro and mesopores, i.e. excluding the macropores, and is the focus of results presented in this report as it prevents bypass flow.

Soil physical property details are shown in Tables 1 and 2.

**Table 1: Soil Physical Properties**

| Site ID | Dry bulk density ($g/cm^3$) | Porosity (%) | Macroporosity (%) | Field Capacity (%) | RAWC (%) | AWC (%) |
|---|---|---|---|---|---|---|
| Four Mac's 5 | 1.41 | 47 | 4 | 42 | 10 | 26 |
| Four Mac's 30 | 1.02 | 60 | 11 | 48 | 8 | 21 |
| Tui 37 | 1.33 | 50 | 11 | 38 | 8 | 23 |
| Tui 15 | 1.42 | 47 | 13 | 30 | 12 | 17 |
| Holland 1 | 1.07 | 58 | 10 | 46 | 5 | 18 |
| O'Brien 3 | 1.03 | 60 | 12 | 46 | 5 | 19 |

**Table 2: Soil Hydraulic Properties and Recommended Design Irrigation Rate**

| Sample ID | $K_{sat}$, mm/hour | $K_{-40mm}$, mm/hour | DIR, mm/day |
|---|---|---|---|
| 4M5 | 8 ± 10 | 1.84 ± 0.82 | 13 |
| Tui37 | 22 ± 31 | 1.27 ± 1.56 | 9 |
| Tui2 | 86 ± 34 | 1.83 ± 0.57 | 13 |
| Ho1 | 90 ± 21 | 3.10 ± 0.19 | 22 |
| OB3 | 43 ± 11 | 2.20 ± 1.03 | 16 |

- Some sites surveyed had poor drainage, so soils in these areas need to be managed to avoid compaction which will reduce the soils ability to receive and treat applied wastewater.
- The available depth of application above field capacity prior to saturation being reached is the difference between porosity and field capacity, i.e. between 5 and 17 mm/100 ml. For a 300 mm rooting depth, this equates to 15 – 51 mm of additional water that can be applied without causing ponding, providing the application rate is less than the soils infiltrative capacity.
- The difference between $K_{sat}$ and $K_{-40\ mm}$ results for each site indicate that saturated flow is substantially higher than unsaturated flow. This is an important consideration when designing an irrigation regime where bypass of the soil matrix is to be minimised. The DIR should be based on $K_{-40\ mm}$ rather than Ksat to avoid excessive drainage occurring.
- In consideration of a rate of application suitable for the sites, a conversion needs to be made to allow for the application of "enriched" water which has elevated levels of other constituents (cations, anions, complex organic molecules). A value of 30 % of the $K_{-40mm}$ has been adopted in-line with the recommendations of Crites and Tchobanoglous (1998) to provide a Design Irrigation Rate (DIR). This is considered conservative as historically DIRs were based on 10% of $K_{sat}$ to allow long-term acceptance for an organically loaded wastewater. For these farms, this would have resulted in DIRs ranging from 19 – 216 mm/d.

## PROPOSED CHANGES TO OPERATION AND MANAGEMENT

Fonterra propose to implement the following measures to both reduce the environmental effects of the expanded Pahiatua processing operation and to reduce effects that already exist:

- Recycling of condensate for use in the factory after reverse osmosis treatment;
- Use of an aerated biological wastewater treatment system to greatly reduce process wastewater organic and nutrient concentrations;
- Storage of treated wastewater to avoid irrigation during extremely wet weather;
- Re-use of biomass from the biological wastewater treatment plant as a slow release fertiliser;
- Export to composting of excess volumes of biomass from the biological wastewater treatment plant;
- Expansion of the land treatment area to reduce hydraulic loadings (addition of another third party farm; Holland Farm);
- Replacement of travelling irrigators with low rate fixed in-ground irrigators; and
- Implementation of a Duration Controlled Grazing animal management regime, to reduce nitrogen inputs.

The volumes of treated process wastewater and condensate to be irrigated are shown in Table 3 and the composition in Tables 4 to 6.

**Table 3: Expected Irrigation Volumes**

| **Destination** | **Treated wastewater - Spring & Autumn $m^3$/day** | **Treated wastewater + condensate + storage pond water - Summer $m^3$/day** |
|---|---|---|
| Tui, O'Brien & Four Mac's | 3,060 | 4,520 |
| Additional third party farm (Hollands) | 0 | 1,200 |
| **Total** | **3,060** | **5,720** |

**Table 4: Process Wastewater Composition**

| **Analyte** | **Pre-Treatment** | | **Post Treatment** | |
|---|---|---|---|---|
| | **Average** | **95%ile** | **Average** | **95%ile** |
| Chemical oxygen demand (COD) (g/$m^3$) | 2,500 | 4,435 | 50 | 100 |
| $cBOD_5$ (g/$m^3$) | 1,500 | 2,660 | 25 | 50 |
| Total Kjeldahl – N (g/$m^3$) | 60 | 86 | 15.0 | 20.0 |
| Nitrate – N (g/$m^3$) | 50 | 106 | 5.0 | 10.0 |
| Total N (g/$m^3$) | 110 | 190 | 20.0 | 30.0 |
| Total Phosphorus (g/$m^3$) | 30 | 40 | 23.0 | 27.0 |
| Sodium (g/$m^3$) | 321 | 476 | 300 | 450 |
| Calcium (g/$m^3$) | 30 | 52 | 10 | 20 |
| Potassium (g/$m^3$) | 55 | 83 | 50 | 80 |
| Magnesium (g/$m^3$) | 3 | 5 | 3 | 5 |

*Note: When WAS is mixed in, concentrations will be higher.*

**Table 5: Condensate Composition**

| **Analyte** | **Average** | **95%ile** |
|---|---|---|
| COD (g/$m^3$) | 15 | 50 |
| cBOD (g/$m^3$) | 7.5 | 32 |
| TKN (g/$m^3$) | 1.5 | 5.2 |
| $NO_3$-N (g/$m^3$) | 0.01 | 0.52 |
| TP (g/$m^3$) | 0.03 | 0.46 |
| pH | 6.3 | 8.8 |

**Table 6: WAS Composition**

| Analyte | Average |
|---|---|
| COD ($g/m^3$) | 4,200 |
| TKN ($g/m^3$) | 280 |
| $NO_3$-N ($g/m^3$) | 5 |
| TP ($g/m^3$) | 70 |
| Sodium ($g/m^3$) | 300 |
| Potassium ($g/m^3$) | 50 |
| Magnesium ($g/m^3$) | 3 |

**Proposed Irrigation Management**

The irrigation system will operate as described below:

- The irrigation systems will utilise fixed in-ground sprinklers, or low rate moveable pods (e.g. K-Line) at a rate of <10 mm/hour;
- On the Fonterra and Four-Macs farms an average dose of 25 mm will be irrigated with an average irrigation cycle of 16 days;
- Two doses will be applied within several days to irrigate up to 50 mm per irrigation event between December and March or when soil moisture is suitable at other times of the year;
- On the Holland farm an average dose of 25 mm will be irrigated with 2 doses, or 50 mm per irrigation event every 16 days during January, February, and March. Irrigation may also occur outside this timeframe if conditions are suitable and the farmer requests irrigation;
- Excess treated wastewater that cannot be irrigated on the farms during the autumn and spring will be stored in a pond with a minimum volume of 86,500 $m^3$ for irrigation during the summer; and
- Condensate from the current dryers will be irrigated in January, February and March and in December when the river flow is below the Half Median flow.

## NUTRIENT MODELLING

Modelling of nutrient leaching was undertaken by Dr Jeff Brown (2012) of Fonterra for three alternative loading and farm management options using the AgResearch Overseer® v6 nutrient modelling program: The current situation (Base Case), which forms the existing environment; and two alternative farm management scenarios were considered in the nitrate leaching assessment.

The scenarios assessed were:

- ***Scenario A: Base Case (current situation)***
  This represents an average of the past two seasons (2010/11 and 2011/12) in terms of wastewater irrigation and farming system inputs and outputs for the Fonterra and third party farms. Results for the Holland farm are included as a dryland farm as it is not currently irrigated with wastewater from the Pahiatua site.

- ***Scenario B: Full Treatment & Standard Grazing (SG)***
  This scenario has the process wastewater being treated via a biological treatment process, with waste activated sludge (WAS) being added into the irrigation water. The average nitrogen loading rate has been set at 250 kg N/ha/year (current consent limit is 500 kg N/ha/year), similar to that being applied around New Zealand to new

industrial wastewater land treatment systems. Under this scenario, standard dairy grazing practices would be used on all the farms.

- ***Scenario C: Full Treatment + Duration Controlled Grazing (DC)***
  This scenario involves the application of treated process wastewater with WAS at a loading rate of 250 kg N/ha/year (current consent limit is 500 kg N/ha/yr), similar to that being applied around New Zealand to new industrial wastewater land treatment systems. It involves the application of treated process wastewater and WAS together, to the Tui, O'Brien and Four Mac's farms. The Holland farm will receive treated process wastewater and condensate (i.e. no WAS) only during the summer months.

  Under this scenario, a Duration Controlled (DC) dairy grazing regime will be implemented on the two Fonterra farms (O'Brien, Tui). Standard dairy grazing practices will continue to be used on the privately owned Four Mac's and Holland farms. Using covered cow-houses, the cows pasture grazing is limited to one 4 to 5 hour morning session and a further 4 to 5 hour afternoon session. Actual time spent on the pasture reduces from 17 to 20 hours (standard) down to 8 to 10 hours for DC grazing. During the remaining time, the cows are either being milked or located in the covered cow-house, where they receive some supplementary feeding.

## RESULTS

Figure 2 gives the Overseer results for Nitrogen leaching for the four farms and comparison to the Horizons One Plan limits.

Based on average farm inputs and outputs, the Overseer nutrient budgeting software predicts a combined total nitrogen leached from all four farms of 25,000 kilograms per year for the current system.

For the expanded factory scenario, with its upgraded wastewater treatment and a nitrogen loading of 250 kg N/ha/yr, the combined total nitrogen leached decreases by 25% to 19,000 kg N/yr (Scenario B).

Implementing a duration controlled grazing regime on the Fonterra owned Tui and O'Brien farms results in dramatic reductions in nitrogen leached, originating from the cows spending less time on pasture and an associated reduction in urine patch contribution to nitrogen leaching. Under this preferred scenario (C = Full Treatment and Duration Controlled Grazing) total nitrogen leached from all 4 farms drops to 13,100 kg N/yr, an improvement of 48% on the present day losses.

The four farm average nitrogen leached of 28 kg N/ha/yr is in line with the Year One limits required by the One Plan.

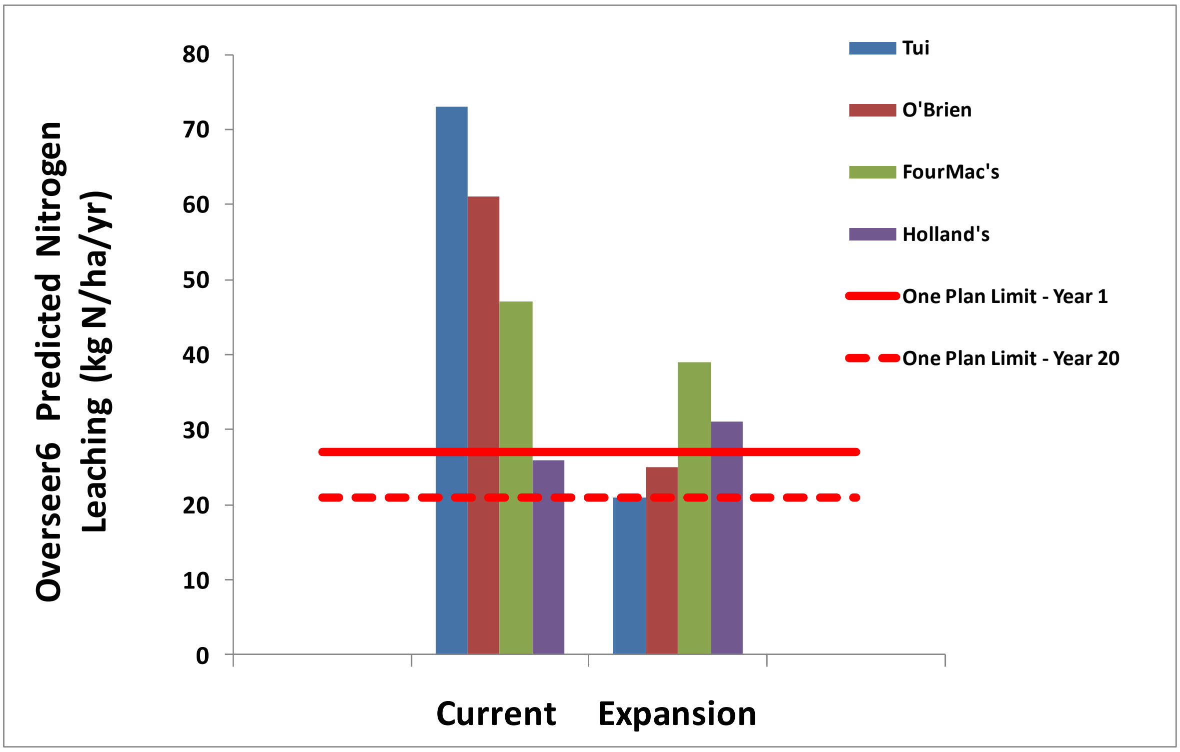


**Figure 2: Whole Farm Nitrogen Leaching both Current and Proposed**

The decrease in nutrient leaching from the proposed changes to Fonterra's activities will cause an improvement in groundwater quality as well as river water quality downstream.

Nitrogen concentrations measured in the Mangatainoka River near the Fonterra plant are consistently higher than the POP target of 0.44 g N/m$^3$ both upstream and downstream from Fonterra's current activities and proposed developments. Therefore, the POP targets for the river water quality cannot be used to assess the impact of the proposed activities. Instead it is considered to benchmark the impact on river and groundwater quality from the leaching associated with the proposed developments against a situation in which the farms fully comply with the POP leaching rates is the best form of assessment.

## GROUNDWATER MODELLING

To assess how concentrations in groundwater downstream from the proposed developments will be affected, it is important to understand how solutes migrate in groundwater. Nitrogen in mobile form (e.g. nitrate and nitrite) will follow the same path as the groundwater in which it is dissolved. Infiltrating rainwater or irrigation water will travel vertically trough the unsaturated soil and replenish groundwater. From that point the groundwater flows downstream along imaginary flow lines. Solutes dissolved in the groundwater will form plumes as depicted in Figure 3 below. This picture is a schematic representation of a southwest-northeast cross-section across the river. It is based on the groundwater contour map from Phreatos (2003). The solute plumes will disperse increasingly downstream. However, full mixing may not occur until the groundwater flows into an abstraction well or into the river.

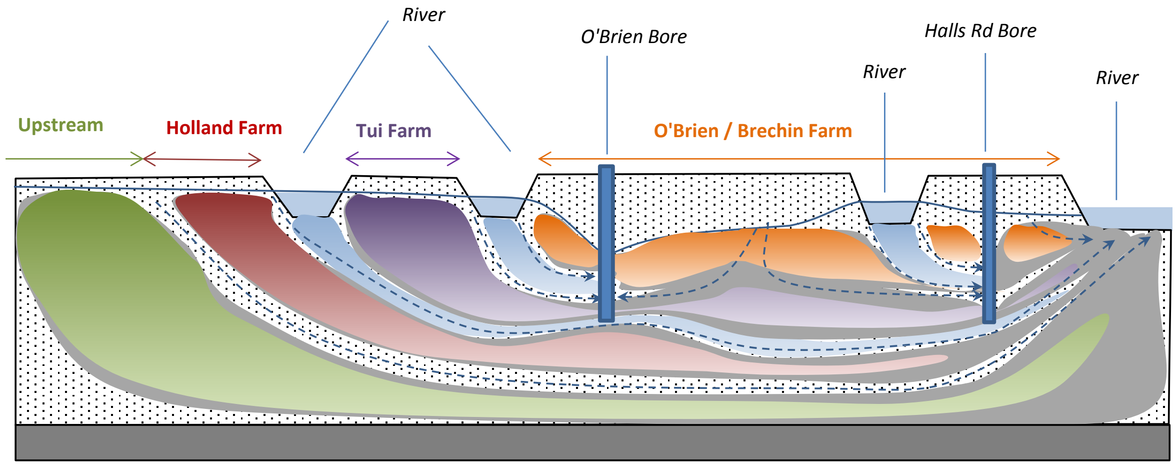


**Figure 3: Schematic Representation of Migrating Groundwater Solute Plumes**

Water quality measurements from groundwater samples taken from bores close to the river will always reveal the water quality of a mixture. This can be understood from Figure 3 above. Both the O'Brien and the Halls Rd bores receive a mixture of groundwater from different sources as well as river water. It is equally so that all groundwater in the shallow aquifer underneath Fonterra's proposed developments and existing farms, will eventually flow out into the Mangatainoka River in which it will fully mix with the river water.

Based on the groundwater flow lines from Phreatos (2003), it is considered that all groundwater below the farms will first flow past the Pahiatua Bridge downstream of Fonterra Pahiatua's current activities and proposed developments and then discharge into the river. As all groundwater will be mixed with river water beyond the Bridge, a mass-mixing approach can be used to establish how the concentration will change at that point. The average concentration and the total amount of groundwater flow that passes the Bridge will be used to assess the downstream river water quality change.

The resulting concentration in groundwater downstream from Fonterra's farms for the Base Case (e.g. current situation) and scenarios B and C are presented in Table 7 below.

**Table 7: Calculated Groundwater Quality at Pahiatua Bridge**

| Scenario | Nitrate-Nitrogen (g N/m$^3$) |
|---|---|
| BASE CASE | 4.32 |
| SCENARIO B | 3.41 |
| SCENARIO C | 2.60 |
| ONE PLAN LEACHING LIMIT [a] - Year 1 | 2.46 |
| ONE PLAN LEACHING LIMIT [a] - Year 20 | 2.13 |

a. This row is the modelled concentration of Nitrate-N in groundwater if all the Fonterra and Third Party Farms were managed to meet the leaching limits based on their LUC in the One Plan.

In the current situation, the groundwater quality downstream from Fonterra's current activities is calculated to be between 4 and 5 g N/m$^3$ on average. The subsequent change in river concentration depends on both the background (or upstream) concentration in the river as well as the river flow.

In both Scenarios B and C the nitrate-nitrogen concentration in groundwater will drop below 4 g N/m$^3$ but only Scenario C will come close to the One Plan guideline for dairy farming to be considered a controlled activity. Due to other inputs in the Mangatainoka Catchment, the average river water concentrations will remain above the One Plan target of 0.44 g $N/m^3$ even if Fonterra's operations meet the leaching limits for the Land Use Capability classes.

## CONCLUSIONS

Detailed site investigations have resulted in significant changes to the management of wastewater and of the farms. The wastewater is to be treated to reduce organic loading and stored at times of wet weather. Irrigation application rates have been adopted based on mesoporosity flow through the soil and the depths applied reduced when the soils are near field capacity. In order to control application rates, all irrigation will now be fixed sprinklers.

Farm management has altered to incorporate controlled grazing to reduce the average of the four farms leaching to sustainable levels long-term.

Modelling has shown that both Scenarios' B and C will cause groundwater and river water quality to improve significantly in comparison to the current situation, although the One Plan targets are not met. It has shown that it is possible to marry together wastewater application systems with land management to reduce potential effects in a nutrient-sensitive catchment.

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