

**Assessment of Subsurface Attenuation
in the Ruataniwha Basin**



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Assessment of Subsurface Attenuation in the Ruataniwha Basin

A report prepared for Hawke's Bay Regional Council

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1 Executive Summary

The Institute of Environmental Science and Research (ESR) and Lincoln AgriTech Ltd (LAL), formerly known as Lincoln Ventures Ltd, were asked by Hawke's Bay Regional Council to provide expert advice on the likely range of attenuation rates for nitrate that may occur in the vadose zone and groundwater in the context of the Ruataniwha basin, Central Hawke's Bay to support TRIM2 modelling being conducted by NIWA. This advice was provided in the form of a letter report on 6 November 2012. This was followed by two addendums to that report as further data and information became available, which were prepared on 23 November 2012 and February 2013. This ESR Technical Report is a compilation of the letter report (as Part A) and the two addenda (as Parts B and C, respectively).

Groundwater quality data from the Ruataniwha Basin were collated. The manganese, iron, dissolved oxygen and nitrate (for young and/or shallow groundwaters) data were used to assign a redox status for each groundwater sample. Most of the samples from the Waipawa sub-catchment indicated oxidised groundwater and most of the samples from the Tukituki sub-catchment indicated reduced groundwaters. Initially (as summarised in Part A) there were very few samples from shallow groundwater and a survey of shallow bores and springs was carried out in October 2012 to fill this data gap.

Some wells in the Porangahau Catchment had high (> 1 mg/L) levels of dissolved reactive phosphorous (DRP). These wells were fairly deep and had old reduced or anaerobic groundwater. The high levels of DRP in old, anaerobic, generally deep groundwater are naturally occurring and are independent of any land use activity in the Ruataniwha basin. The contribution of DRP from these layers to the surface waters depends on the flux of groundwater from these layers. It is likely to be fairly small and constant.

Once the data from the survey of shallow groundwater bores and springs were available, they were collated and the redox status assigned. These data were used to assign a redox status of "oxidised", "reduced" or "mixed" for each TRIM2 groundwater sub-catchment in the integrated catchment modelling project. It was recommended that attenuation within groundwater should be assumed to be zero for sub-catchments with oxidised groundwater, and 100% for the sub-catchments with reduced groundwater. The attenuation for the sub-catchments with mixed redox status is likely to be between 30 to 70%; a selection of values within this range should be examined in the modelling. The most appropriate rate will depend on the proportion of groundwater that flows through the reducing zones in each sub-catchment. This assessment was the best achievable based on existing data and within the given time frame, but a more in-depth analysis, as outlined in section 4.1, would increase the confidence level.

The redox assignments were updated in February 2013 (Part C of this report) when the modelling sub-catchments were refined in response to groundwater particle track modelling. This modelling increased the number of sub-catchments included in the modelling from 28 to 39.

2 Project Objectives & Scope

Project Objective: To provide expert advice to Hawke's Bay Regional Council (HBRC) on the likely range of attenuation rates for nitrate that may occur in the vadose zone and groundwater in the context of the Ruataniwha basin, Central Hawke's Bay.

Study Scope

1. Provide expert advice on the likely range of nitrate attenuation that may occur in the Ruataniwha basin, based on existing information for:
 - a. Vadose Zone – area between the root zone and water table.
 - b. Groundwater aquifer for range of groundwater depths (shallow < 25 m and deeper groundwater) in the basin.
2. The results of this review are anticipated to provide HBRC a sufficient estimate of the likely range of attenuation rates that are likely to be applicable to the Ruataniwha basin which can then be used as an input parameter to the integrated catchment model that is currently under development by NIWA.
3. Provide recommendations for further investigations and/or analyses that are needed to refine an estimate of attenuation rates in the vadose zone and groundwater to provide defensible attenuation estimates that are specific to the Ruataniwha basin. Provide advice on the array of methods that could be used and provide an estimate of timing and costs required to implement each method, including data collection and analysis.
4. Provide some brief comment on phosphorus attenuation in groundwater and vadose zone, particularly for the Porangahau Stream catchment.

The deliverables were a letter report compiled jointly that provided comment on the four questions outlined in the study scope.

3 Part A: Main Report (dated 6 November 2012)

3.1 Nitrate Attenuation in the Subsurface

It has become evident in recent years that not all nitrate lost from the root zone necessarily contaminates the underlying groundwater and groundwater-fed surface water bodies, because attenuation processes occur in the vadose zone – groundwater – surface water continuum that remove nitrate from groundwater. Traditionally denitrification research has focused on riparian zones (adjacent to streams) - more recently, attention has been given to denitrification processes that occur in the groundwater system and to a lesser degree to the vadose zone (between root zone and groundwater table) and the hyporheic zone (stream bed).

The degree of attenuation is determined by hydrological and biogeochemical processes:

- In groundwater discharge areas in particular, groundwater derived from areas subject to intensive land use and therefore relatively enriched with nitrate (e.g. plains), mixes with “clean” groundwater derived from upland catchment areas (often Department of Conservation estate). This dilution process results in lower nitrate concentrations in groundwater-fed springs and streams than what would be expected, based on the surrounding land use. While this reduces the nitrate concentration, the mass of nitrate in the groundwater system remains the same. The potential for undesirable environmental outcomes (e.g., excessive periphyton growth) still exists in streams receiving enriched groundwater.
- In contrast, denitrification processes permanently remove reactive nitrate from the groundwater system by converting it into gaseous forms of N (predominantly environmentally benign N₂).

For denitrification to occur, four requirements must be met in the aquifer system:

1. Presence of nitrate;
2. Absence of oxygen;
3. Availability of suitable electron donors (e.g., carbon, ferrous iron,);
4. Presence of microbes with the metabolic capacity for denitrification.

Nitrate is commonly present in (oxidised) groundwater recharged from agriculturally used land. Based on data from the National Groundwater Monitoring Programme, Morgenstern and Daughney (2012) identified two nitrate-N (NO₃-N) concentration thresholds:

- 0.25 mg/L - separating natural baseline concentrations (prior to ≈ 1880) from low-intensity land-use water (up to ≈ 1955), and
- 2.5 mg/L - separating low-intensity land-use water from high-intensity land-use water (post 1955).

Oxygen-depleted conditions are essential for denitrification to occur - facultative anaerobes only switch to the energetically less favourable process of denitrification when aerobic respiration becomes limited due to lack of oxygen. Concentrations of dissolved oxygen (DO) in groundwater below 2 mg/L have commonly been found to be conducive to denitrification (Gillham and Cherry, 1978, as cited in Korom, 1992). Accordingly, groundwater with DO < 2 mg/L rarely contains more than 1 mg/L nitrate nitrogen.

Heterotrophic denitrification requires the presence of organic matter as electron donor, while autotrophic denitrification can be fuelled by reduced iron and sulphur compounds (e.g. pyrite). Reduced inorganic compounds are often found in marine sediments. Previously, mobile forms of organic matter (dissolved organic carbon - DOC) derived from the soil zone were considered the

most important organic electron donors. Recent research has highlighted the importance of particulate organic matter residing in the aquifer matrix (e.g. Clague et al, 2012). It has increasingly become evident that more than one electron donor can contribute to denitrification occurring in an aquifer (e.g. Korom et al., 2012).

Microbes with the metabolic capacity for denitrification are considered to be present wherever conditions suitable for denitrification exist.

The degree of nitrate attenuation in a given zone is predominantly determined by biogeochemical factors, such as the availability of electron donors. However, hydrological factors determine the extent to which this localised attenuation process influences catchment-scale nitrogen fluxes. Denitrification occurring in a particular zone at a high rate will be irrelevant at the catchment scale if a minor fraction of water and the nitrate load pass through this zone. A sound understanding of the spatial and temporal variation of groundwater flows, particularly their relative contribution to groundwater discharge into surface water bodies, is therefore crucial when quantifying catchment-scale nitrate attenuation.

3.2 Nitrate attenuation in the Ruataniwha Basin

Four sources of Ruataniwha Basin groundwater quality data were provided by HBRC for this assessment.

1. Hydrochemical and groundwater age data from 24 wells are contained in the GNS Science Report 2012/23 (Morgenstern et al. 2012).
2. HBRC Technical Report EMT10/20 (Dodson, 2010) contains N concentration data for 14 Ruataniwha Basin wells.
3. Time series data from 12 SOE wells, five of which were also sampled for the GNS Science report (2012/23), were provided in form of an Excel spreadsheet.
4. A draft memo containing data for five consent monitoring wells at Plantation Dairies were also provided (D Gordon, 2012, pers comm).

The data set of the GNS Science Report 2012/23 (Morgenstern et al. 2012) is best suited to assess the redox status of the sampled groundwater because the concentrations of reactants (e.g. DO, NO₃) and reaction products (e.g. Mn²⁺, Fe²⁺) associated with the redox reactions that occur sequentially in groundwater systems were provided. The time series data from the SOE wells were also considered, but their DO data were disregarded (as discussed below).

Stenger et al. (2008) identified typical concentrations that have been used in NZ as trigger values to indicate reducing conditions: Mn²⁺ > 0.05 mg/L, Fe²⁺ > 0.10 mg/L and NH₄-N > 0.10 mg/L. Dissolved oxygen (DO) concentration below the O₂ solubility in water (10.1 mg/L at 15°C and 1013 hPa) indicates consumption of oxygen, principally due to aerobic decomposition of organic matter. Once DO concentrations < 2 mg/L are reached, facultative anaerobes switch over to heterotrophic denitrification (Gillham and Cherry, 1978, as cited in Korom, 1992). NH₄-N concentrations greater than approx. 0.10 mg/L, particularly if found together with enhanced dissolved Fe and Mn, can indicate reducing conditions. Such NH₄-N concentrations can result from restricted nitrification (due to O₂ deficiency), or under highly reducing conditions from dissimilatory nitrate reduction.

After evaluating the groundwater quality and redox status of about 3200 wells in the Canterbury and Waikato regions, the following parameters and thresholds are proposed as more appropriate indicators of reducing conditions: Mn²⁺ > 0.05 mg/L, NO₃-N < 0.5 mg/L, DO < 1.0

mg/L (Murray Close, ESR, unpublished data). These values were slightly modified from McMahon and Chapelle, (2008), who also used a threshold of Fe > 0.1 mg/L.

These indicators of reducing conditions should be used collectively to identify reducing conditions, because individual indicators may be affected by factors unrelated to redox status (Chapelle *et al.*, 1995; Appelo and Postma, 2005).

Given the high proportion of groundwater that was recharged prior to commencement of (intensive) agricultural land use, NO₃-N < 0.5 mg/L may not be a good indicator of reducing conditions in the HBRC data set. Accordingly, the following classification system was adopted for this assessment:

1. Fe > 0.1 mg/L and/or Mn > 0.05 mg/L
2. DO < 2 mg/L
3. NH₄-N > 0.1 mg/L
4. NO₃-N concentration was considered for young groundwater only if other parameters yielded ambiguous results.

Groundwater samples that unambiguously indicated oxidised or reduced conditions are labelled in Table A1 as 'ox' or 'red', respectively. If samples had missing data or ambiguous results, their most likely status is shown in Table A1 in brackets. Note that a few analytical results could be artefacts (e.g. Mn in well 1558, DO in well 1430). The Ruataniwha Basin has two major sub-catchments, the Waipawa and the Tukituki, and the location of the sub-catchment boundaries is shown in Figure A1.

Table A1: Selected data reproduced from Tables 2 and 3 in GNS Science Report 2012/23 (Morgenstern *et al.*, 2012). SC – sub-catchment; Tuki = Tukituki; Wai = Waipawa. Parameter values indicating reduced conditions are highlighted in magenta.

Bore No.	SC	Redox status	Bore depth (m)	MRT (y)	NO ₃ -N (mg/L)	Fe (mg/L)	Mn (mg/L)	DO (mg/L)	NH ₄ -N (mg/L)
1376	Tuki	(red)	24.2	>210	0.00	0.09	0.20	n/a	0.25
1381	Tuki	(red)	58.4	>170	0.04	n/a	0.02	0.15	1.80
1402	Tuki	(red)	52	149	0.00	0.04	0.11	0.15	0.04
1430	Tuki	(ox)	46.3	>150	0.68	0.01	0.01	0.15	0.01
1558	Tuki	ox	22.5	34.5	4.60	0.01	0.57	n/a	0.01
1655	Tuki	(red)	12.5	40.5	0.01	0.01	0.01	0.73	0.03
1944	Tuki	red	20.6	57	0.01	1.10	0.70	0.78	0.60
2579	Tuki	red	46.6	102	0.00	0.59	0.21	0.11	0.99
3426	Tuki	red	19	154	0.01	0.01	0.33	0.09	0.06
3702	Tuki	red	123.5	>200	<0.03	1.40	0.30	n/a	0.11
3852	Tuki	red	n/a	130	0.00	0.15	0.33	0.13	0.68
4702	Tuki	red	105	138	0.05	0.45	0.01	n/a	0.62
6716	Tuki		45	114	n/a	n/a	n/a	n/a	n/a
6719	Tuki	red	88.2	149	0.25	0.97	0.54	0.10	0.56
6722	Tuki	red	88.2	129	0.02	0.01	0.08	0.49	4.10
1452	Wai	ox	55.2	25.5	6.10	0.01	0.00	4.73	0.01
1518	Wai	ox	65.8	80	0.95	0.01	0.00	5.98	0.01
2043	Wai	ox	83.5	52	1.10	0.01	0.00	3.89	0.01
2220	Wai	(ox)	110	65	1.30	0.02	0.08	n/a	0.01
2533	Wai		22.3	>190	n/a	n/a	n/a	n/a	n/a
3076	Wai	ox	12	1.5	0.22	0.03	0.02	7.17	0.01
3104	Wai	(ox)	142	>180	0.29	0.01	0.04	0.08	0.62
4694	Wai	ox	43.9	40	0.29	<0.02	0.01	n/a	<0.01
10942	Wai	ox	30	37	1.40	0.01	0.00	6.50	0.02
11005	Wai	red	25.6	136	0.07	0.57	0.42	0.12	0.16

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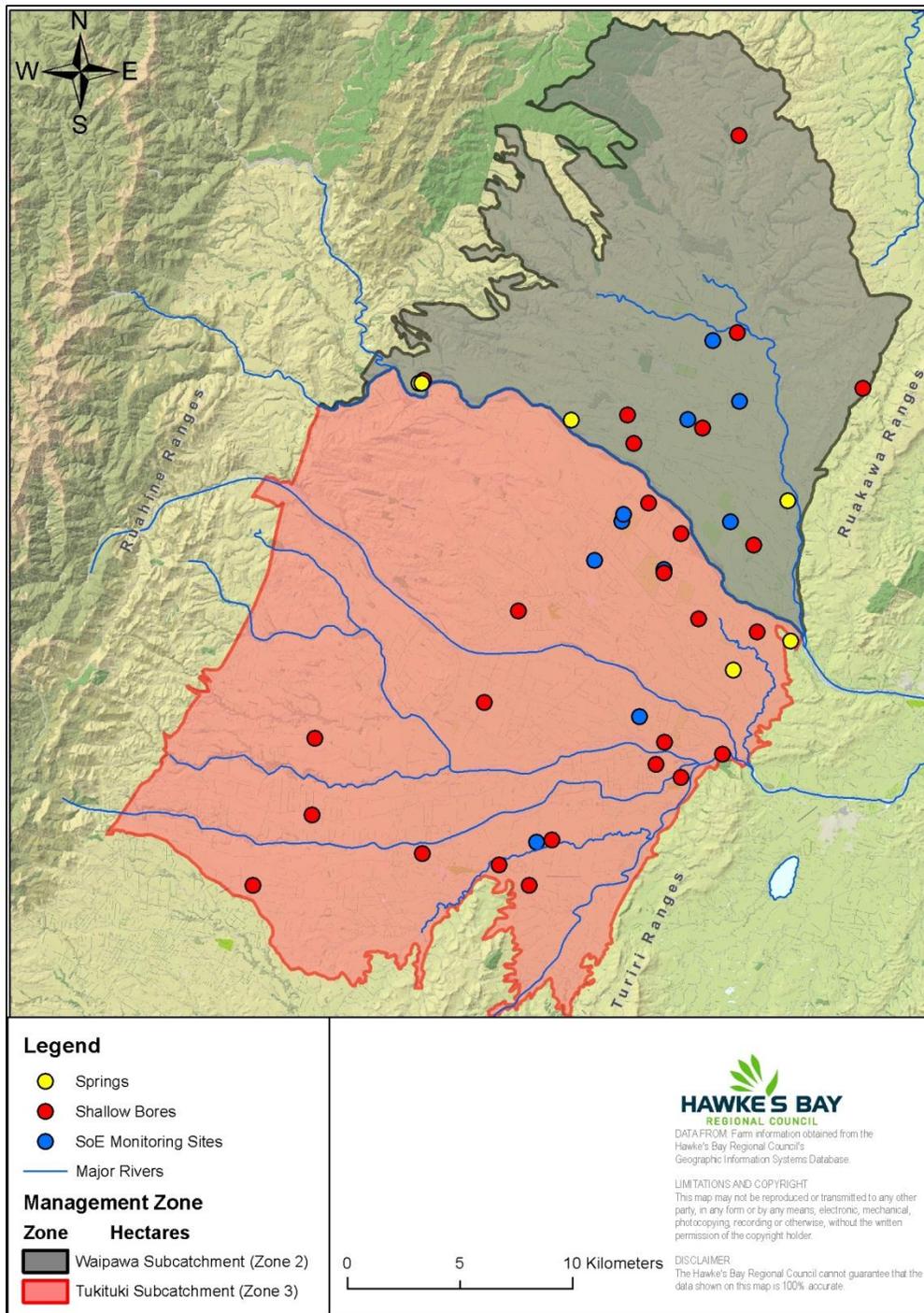


Figure A1: Boundaries for Waipawa and Tukituki sub-catchments.

Using this classification approach, it was concluded that:

- nine of the twenty-three wells draw reduced groundwater and an additional four most likely draw reduced groundwater.
- seven wells draw oxidised groundwater and three wells most likely draw oxidised groundwater.

Accordingly, the reduced groundwater group accounts for 57% of the wells investigated.

There is a distinct geographical distribution of redox conditions in this data set, with reduced groundwater being dominant in the Tukituki sub-catchment, while oxidised conditions prevail in the Waipawa sub-catchment. Comparison of the well depth distributions and screen lengths used in these two sub-catchments did not reveal any substantial systematic differences that could result in a bias. Consequently, the apparently high attenuation capacity in the Tukituki sub-catchment and the low attenuation capacity in the Waipawa sub-catchment is most likely due to geological (e.g. electron donors) and/or hydrological differences (e.g. mean transit times) between these sub-catchments.

The only unambiguously oxidised groundwater sample from the Tukituki sub-catchment (1558) is from one of the shallowest wells sampled (22.5 m depth), drawing the youngest water (MRT 34.5 y) of all wells sampled in this sub-catchment. In spite of a very low reported DO, well 1430 most likely draws oxidised water, as no other parameter (Mn, Fe, and $\text{NH}_4\text{-N}$) indicates reduced conditions. While the $\text{NO}_3\text{-N}$ concentration (0.68 mg/L) is relatively high for water recharged prior to commencement of agricultural land use (MRT > 150 y), it also indicates oxidised conditions. Reduced groundwater seems to occur at all other wells independent of their well depth, which range from 12.5 m to 123.5 m. The outstanding results of the recently initiated sampling campaign specifically targeting shallow groundwater will reveal whether oxidised conditions are the rare exception as indicated by the currently available data, or more common.

The only unambiguously reduced groundwater sample from the Waipawa sub-catchment is from a well (11005) which is located in the north-west of this sub-catchment, separated from all other wells. The surface geology in this upper catchment area is dominated by Salisbury gravel, rather than the young gravels mapped for all other Waipawa sub-catchment well sites. While the bore depth is shallow (25.6 m), the reported MRT of 136 years demonstrates that this well draws very old water. The other eight wells in this sub-catchment draw oxidised groundwater, even at great depth. A few weak indicators of reduced conditions were observed in the two deepest wells (110 and 142 m, respectively), but even they (2220, 3104) were still classified as most likely oxidised.

Regarding the TRIM1 model calibration, which assumed equilibrium to be reached within 20 years, it is noteworthy that the highest nitrate nitrogen concentrations (6.1 and 4.6 mg/L) were observed in two oxidised groundwater samples with MRTs of 26 and 35 years (1452 and 1558, respectively; see TRIM1 section below).

It is essential to recognise that shallow groundwater, which best reflects recent land use intensity and which may provide a significant portion of the discharge into local streams, is severely under-represented in this data set. Accordingly, only eight samples had MRTs less than 60 years. This means that the low nitrate concentrations in the majority of samples are due to their recharge date occurring prior to commencement of intensive agricultural land use. The widespread occurrence of reduced conditions in these older samples provides confidence that most of the nitrate that may enter these groundwater zones in the future would get denitrified.

The dissolved oxygen (DO) concentrations reported for the 12 SOE well time series data appear inconsistent with the reported Mn, Fe, and $\text{NO}_3\text{-N}$ data. While the DO data indicate oxidised conditions for all wells, on the basis of their average Mn, Fe, and $\text{NO}_3\text{-N}$ concentrations, between six and nine of these wells would be categorized as reduced. Unfortunately, no DO concentrations are available for two (1376, 1558) of the five SOE wells sampled by GNS in 2009. However, the DO concentrations reported by GNS for the other three samples were moderately (1518) or considerably lower (1944, 6719). Accordingly, it would appear that between half and three quarters of the SOE wells draw reduced groundwater.

In summary, the currently available data suggest that reduced groundwater conditions provide a substantial attenuation capacity in the Tukituki sub-catchment, while there is little indication of attenuation capacity in the Waipawa sub-catchment.

3.3 Likely range of attenuation rates

With regard to the likely range of attenuation rates that needs to be considered in the modelling studies, the available data do not allow specific rates to be deduced. The main reason for this shortcoming is that there is a very strong bias in the data set, particularly the reduced groundwater sub-set, towards very old groundwater that never contained significant amounts of NO₃-N because it was recharged more than a century ago.

Only two reduced groundwater samples have MRTs < 60 years (1655, 1944), therefore presumably had NO₃-N concentrations that reflected agricultural land use intensity typical of the second half of the 20th century. These two shallow wells (< 20 m) were identified in the GNS report (Morgenstern et al., 2012) as presumably having excess N₂ resulting from past denitrification. The N₂ and argon (Ar) concentrations reported suggest that denitrification occurring in the groundwater system has reduced the NO₃-N concentration by approximately 2 mg/L, leaving only residual concentrations (~ 0.01 mg/L). These results indicate almost quantitative NO₃-N removal.

This finding is in agreement with information derived from LVL data from the Toenepi catchment near Morrinsville and the Waihora well field in the Lake Taupo catchment (Stenger, unpublished data). Rather than relying on the residual NO₃-N concentration of 0.01 mg/L (determined on the two samples available from the Tukituki sub-catchment) as an indication that denitrification has occurred, it appears more appropriate to use a more conservative value of 0.1 mg/L, supported by more comprehensive LVL data sets (Stenger, unpublished data).

For future modelling work, it would be appropriate to assume that nitrate entering a zone of reduced groundwater is attenuated almost quantitatively, leaving a residual NO₃-N concentration of approximately 0.1 mg/L. This pragmatic approach assumes that the efficacy of nitrate removal is independent of the nitrate concentration entering the reduced zone. This assumption is supported by circumstantial evidence derived from research sites, which suggests that nitrate entering reduced groundwater zones at concentrations typical for agricultural land use can be almost fully attenuated. However, gradual consumption of electron donors means that this attenuation capacity is finite. The time required to deplete the attenuation capacity will be determined by the electron donor consumption rate and the stock of electron donors available. These factors are likely to be site-specific. Time periods ranging from decades to millennia are likely in most circumstances.

This approach requires the following understanding:

1. The spatial distribution of the groundwater redox characteristics.
2. The flux of groundwater through the reduced and oxidised zones, either measured directly or estimated from modelling.

From the currently available information, it appears pragmatic to assume that reduced conditions occur everywhere in the Tukituki sub-catchment below a depth of approximately 50 m. Reduced conditions also appear to be widespread in the shallower groundwater zone (3426, 2579, 1944, 1655, 1376), but oxidised conditions can also exist in this shallower groundwater (1430 and

1558). The current sampling campaign¹ will provide additional data regarding the frequency and spatial distribution of reduced conditions in shallow groundwater.

In contrast, oxidised conditions dominate the entire eastern part of the Waipawa sub-catchment, independent of depth. No conclusion can be drawn for the upper catchment area because it is represented by data for a single well. Accordingly, it is recommended that redox conditions are investigated at a number of wells in the upper catchment area located in Salisbury gravel geology.

Previously, attenuation of NO₃-N to residual concentrations of about 0.1 mg/L is suggested as likely for all groundwater flowing through reducing groundwater zones. Conversely, no attenuation due to denitrification should be assumed for oxidising zones.

Applying this concept to the Tukituki sub-catchment would result in very high overall attenuation, because reducing conditions appear to dominate. The fraction of NO₃-N that will be transferred into the surface waters via groundwater will be determined by the proportion of flow passing through shallow, oxidising groundwater zones. Modelling is required to determine this proportion of flow.

Despite the data gap for the upper catchment, very low overall attenuation is likely in the Waipawa sub-catchment, in particular because the important eastern part is entirely oxidising.

A brief perusal of the results from the just completed survey of shallow groundwater wells and springs suggests that shallow (<25 m) groundwater is more variable than the deep (> 50 m) groundwater for both sub-catchments. There are a number of shallow wells in the Tukituki sub-catchment that have elevated levels of nitrate (between 5.8 and 9.8 mg/L as N) in contrast to the predominantly low values in the deeper groundwater. In the Waipawa sub-catchment, nitrate-N concentrations in the shallow groundwater are also variable and range from 0.1 to 15.1 mg N/L. It would be worthwhile to examine this dataset more closely with regard to redox status, likely groundwater dynamics (upwelling or river influence), and the sub-catchments that are likely to be modelled in TRIM2.

3.4 Attenuation in TRIM1

The approach taken in TRIM1 was to calibrate three model coefficients so that nitrogen input from the root zone minus attenuation in the groundwater and the streams matched outputs at the catchment outlet (Tukituki and Waipawa Rivers). As a result, the fitted drainage, groundwater attenuation and stream attenuation coefficients are catchment-average, lumped parameters. Groundwater attenuation includes all removal or storage processes within the vadose zone and groundwater, such as: uptake by tree roots, adsorption to mineral surfaces, denitrification in anoxic groundwater and removal at the groundwater/surface water interface (Rutherford, 2012). This approach is very sound provided the inputs and outputs are in equilibrium. The observation that two groundwater samples (wells 1452, 1558) with relatively high nitrate concentrations (6.1 and 4.6 mg/L) had MRTs of 26 and 35 years, respectively, suggests that the assumed 20 year maximum travel time may have been inadequate. Accordingly, any future (re-)calibration should consider a calibration period of at least 35 years. However, an underestimation of the real travel time during the calibration will result in an overestimation of the attenuation coefficients, given current land use has been used with a historical climate dataset to simulate N inputs for previous years. Rutherford (2012, p78) discusses this issue in more detail.

¹ Described in Part B of this report.

3.5 Attenuation in TRIM2

The modelling approach is different for TRIM2. It relies on delineating recharge zones using particle tracking – this enables all recharge from the land surface within the catchment to be linked to discharge to a reach of surface water. The land use history for the Ruataniwha Plains is being derived and will be linked with the transit times to provide an estimate of current and future nutrient concentrations in each river reach. An estimate of groundwater attenuation is required to derive these river nutrient concentrations. Once in the river or stream, stream attenuation coefficients derived from previous modelling or relevant literature values will be applied. The observed river concentration time series at two monitoring sites at the bottom of the catchment, and at two monitoring sites within the catchment, will ensure that the model estimates selected are appropriate.

A distinct difference between the general groundwater redox conditions in the Tukituki and Waipawa sub-catchments was described above. However, it is evident that there is considerable variation within these two large sub-catchments. The current sampling campaign will provide much-needed information regarding the redox status of shallow groundwater, particularly for the Tukituki sub-catchment. However, as the groundwater attenuation in the model is a lumped parameter, and includes removal processes in the vadose zone, adsorption to mineral surfaces, and removal at the groundwater/surface water interface, in addition to denitrification in anoxic groundwater, these other processes also need to be considered. The approach outlined above is focused on denitrification in the groundwater system, which is likely to be the major but not the only contributor to overall attenuation.

An important difference between TRIM1 and TRIM2 is that the high quality concentration time series available for the outflows from major catchments used in TRIM1 are available for only two of the sub-catchments to be modelled in TRIM2. As a consequence, simple matching of the nutrient inputs and outputs for each sub-catchment via calibration of attenuation coefficients is not possible. Attenuation factors will again need to be lumped parameters averaged on a sub-catchment basis.

It is not possible to estimate groundwater attenuation coefficients for specific sub-catchments because suitable data for shallow groundwater do not exist at this stage. The available data indicate significant variability, with certain locations showing oxidised groundwater where little denitrification would occur and other locations showing reduced groundwater even at shallow depths (for example, well 1944; depth = 21 m, age = 57 years). Other shallow wells with reducing groundwater, such as wells 1376, 3426 and 11005, are old and likely to be influenced by upwelling groundwater.

Once the results from the current shallow groundwater survey are available, it may be possible to provide plausible estimates of attenuation coefficients.

If TRIM2 is calibrated to borewater concentrations derived from wells where the age of water exceeds 26 years, then TRIM2 will need to be run for a long time. For TRIM2 it is planned to reconstruct historical land use plus associated recharge rates and N concentrations at decadal intervals since the early 20th century². It would be worthwhile to assess which (if any) shallow bores can be used to help calibrate TRIM2.

² K Rutherford, NIWA; I. Millner, HBRC; D. Wheeler; AgResearch, pers comm.

There is also a requirement for an assessment of the attenuation likely at the groundwater/surface water interface for each of the TRIM2 sub-catchments - this is likely to be a variable, but locally-important process. For example, it is probable that in stream reaches where the recharge is from groundwater flowing through gravel, little removal of nitrate will occur, while in other reaches where more extensive riparian cover or beds with finer sediments occur, more nitrate removal is likely. The importance of this process will be greater in reaches where relatively large mass of nitrate is discharging into streams.

3.6 Recommendations for Further Work

There is a gain of about 4 m³/s from groundwater to the Tukituki and Waipawa Rivers at the eastern boundary of the Ruataniwha basin (Rutherford, 2012). It would be very useful to know the proportions of shallow and deep groundwater (layers 1 and 3) that are recharging the rivers because these groundwaters tend to have very different chemistry and have been subject to different attenuation processes. A zone budget from the groundwater model or a more detailed estimate of water fluxes from each cell at the bottom of the catchment should be available from the groundwater model. These will be very helpful in understanding the relative contributions of deep and shallow groundwater to surface water.

Of the 25 wells where water age has been determined (Morgenstern et al., 2012), seven wells are < 25 m deep and about half are deeper than 50 m. Of the seven shallow wells (<25 m) only one well has water with a very young age (well 3076 = 1.5 years), while water in three wells have ages between 35 and 57 years, and water in the other three is older than 150 years. It would be very useful to determine the age of water in more shallow wells – this information would allow an assessment of shallow groundwater transit times.

Relatively few groundwater quality data exist for the shallow groundwater system, with most of these data derived from monitoring wells associated with the Plantation Dairy (nitrate concentration data only). This is a significant data gap because most of the groundwater with elevated nitrate concentration will travel through the shallow groundwater system. The shallow groundwater survey currently underway will provide single values for each well at this stage. The inclusion of DO, dissolved Mn and dissolved Fe will enable a robust assessment of the redox status of shallow groundwater. These data will allow the attenuation processes within the shallow groundwater system to be better understood

The MODSIM and MT3DMS modelling work being undertaken by HBRC³ should provide some understanding of the role of the shallow groundwater system for NO₃-N transfer from the land to the discharge locations into the various surface water bodies.

There are relatively few wells where data for water age, redox status and DRP concentrations exist (six wells). It would be useful to obtain missing age and DRP data for those wells listed in Table A1 where that information is missing.

Monitoring of surface waters within the Ruataniwha Plains would provide data that could be used to calibrate some of the attenuation coefficients proposed for use in the TRIM2 modelling. The 100 point surface water survey recently carried out provides a useful starting point and a number of sites should be selected to provide ongoing monitoring data to increase confidence in the TRIM2 model outputs.

³ H. Baalousha and D. Gordon, pers comm.

3.7 Phosphorus Attenuation in the Porangahau Catchment

Table A2 summarises information regarding groundwater dissolved reactive phosphorus (DRP) concentrations and associated well depth, age and redox status. The well with the highest DRP concentrations in the Ruataniwha basin is well 6719 in the Porangahau Stream catchment. DRP concentrations were consistently high, with one sample out of 58 taken between 1997 and 2011 not exceeding 1 mg/L. This well is quite deep (88 m) and the groundwater is relatively old, with a MRT of 149 years. The Mn and NO₃ data indicate that the redox status is reducing or anaerobic. These characteristics, as well as the age of the water, are consistent with elevated concentrations of DRP. Other wells with high levels of DRP, for example wells 1376 and 1944, with mean DRP concentrations of 0.13 and 0.56 mg/L, respectively, are also reducing and contain relatively old groundwater. Although no DRP data are available for the other wells in or near the Porangahau Stream catchment in Table A2, water in those wells (1381, 3426, 4702, 6716 and 6722) are all very old, likely to be anaerobic and therefore likely to have similar DRP concentrations.

If wells with NO₃-N concentrations greater than 1 mg/L are regarded as oxidising groundwater, then the DRP concentrations in those wells would range from 0.005 to 0.054 mg/L (Table A2).

Young, aerobic groundwater is likely to have much lower DRP concentration, for example in well 1558, which has the youngest water (35 years), as well as DRP data – the mean DRP concentration is 0.006 mg/L.

There are six wells where data exists for age, redox status and DRP concentration. It would be good to increase this number by obtaining missing age and DRP data for those wells in Table A2 where this information is missing. The survey of shallow wells currently being undertaken will add significantly to the current paucity of DRP groundwater concentration data.

The high concentrations of DRP in old, anaerobic, generally deep groundwater occur naturally and are independent of land use activity in the Ruataniwha basin. The contribution of these layers to the surface water DRP concentration depends on the flux of groundwater from these layers. It is likely to be fairly small and constant⁴.

The extent of DRP attenuation in anaerobic groundwater is likely to be low, but determined by site-specific factors:

- Recent laboratory scale transport experiments carried out in aerobic conditions⁵ indicate that little phosphate removal occurs in clean gravel media, with mass recoveries ranging from 60 to 100% over a distance of 2 m.
- In 0.4 m intact cores of alluvial gravel material containing fines, more phosphate removal occurred, but mass recoveries ranged from 30 to 50% over the 0.4 m distance.
- Mass removal is likely to be significant over longer travel paths (100's or 1000's of metres).

An approach that could be adopted in the TRIM2 modelling would involve assigning a bulk attenuation coefficient to OVERSEER estimates of P drainage in young water from farms, plus a

⁴ The water flux calculations discussed with Kit Rutherford on 10 October 2012 (detailed in the previous section recommendations), should provide some guidance on the relative contribution.

⁵ ESR, unpublished data, 2012

Assessment of Subsurface Attenuation in the Ruataniwha Basin

negative attenuation coefficient (to mimic dissolution) in old water from deep up-welling groundwater⁶.

Table A2: Summary of selected water quality data for wells in the Ruataniwha Basin.

Bore No	Catchment	Depth	Age	Mean DRP	Min DRP	Max DRP	Mean Mn	Mean NO ₃ -N	Min NO ₃ -N	Max NO ₃ -N
		m	yr	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SOE bores - Current & Archive										
1376		24	210	0.129	0.046	0.176	0.214	0.065	0.001	0.775
1485		46		0.081	0.007	0.11	0.015	0.282	0.001	1.800
1518		66	80	0.026	0.001	0.063	0.115	0.534	0.001	4.100
1558		23	35	0.006	0.001	0.026	0.56#	4.781	2.400	8.900
1861		21		0.072	0.004	0.094	0.001	0.159	0.015	0.720
1944	Makaretu	21	57	0.561	0.266	1.084	0.735	0.154	0.008	2.680
2219		98		0.054	0.046	0.058	0.003	1.257	1.090	1.500
2220		110	65	0.003	0.001	0.03	0.090	0.095	0.001	1.300
2749		51		0.029	0.001	0.13	0.012	4.094	2.100	6.900
2979		12		0.005	0.001	0.014	0.011	1.040	0.185	6.200
6719	Porangahau	88	149	1.330	0.643	1.6	0.513	0.057*	0.001	0.60*
15015		50		0.088	0.001	0.25	0.001	0.431	0.001	6.410
Other bores in or near the Porangahau Catchment										
1381	Porangahau	58.4	170					0.035		
3426	Makaretu	19	154					0.007		
4702		105	138					0.050		
6716	Porangahau	45	114							
6722	Porangahau	88	129					0.016		

* Note that there is an outlier for nitrate in well 6719; it is given as 12 mg/L but should probably 0.012 mg/L. This outlier was omitted for the calculation of the mean.

The high values for Mn are surprising as the well also has high NO₃-N levels and low Fe levels (0.04 mg/L – data not shown in table)

3.8 References

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4 Part B: Addendum to Report on Attenuation in Ruataniwha Basin (dated 23 November 2012)

4.1 Introduction

A letter report providing an assessment of attenuation in the Ruataniwha Basin subsurface was completed in November 2012 (Part A of this Technical Report). At that stage few groundwater quality data existed for shallow wells. To improve this limitation a survey of shallow wells was undertaken in October 2012 to supplement the existing data. The results of that survey became available just as the first report was finalised. We were requested by Hawke's Bay Regional Council (HBRC) to update that report by including the new data and providing an assessment for the sub-catchments proposed for the TRIM2 modelling. This addendum is the response to that request and is Part B of this Technical Report.

The nitrate data from the new survey of shallow groundwater and springs are displayed spatially in Figure B1. Sub-catchments have been defined using a particle tracking approach in the groundwater modelling. These sub-catchments will be used in the TRIM2 modelling – they are shown in Figure B2.

The following approach was taken in this addendum:

- the data were collated and assessed to determine the redox status of each well and spring
- each well and spring was assigned to a TRIM2 sub-catchment
- following assessment, a redox status was assigned to the Waipawa and Tukituki catchments and then a redox status was assigned to the TRIM2 sub-catchments.

In the previous report it was assumed that if the groundwater was oxidised then little subsurface attenuation could take place. Conversely, if the groundwater was reducing, the nitrate entering a zone of reduced groundwater was regarded as being effectively fully attenuated, leaving only a residual NO₃-N concentration of about 0.1 mg/L. This pragmatic approach is independent of the nitrate concentration entering the reducing zone.

The pragmatic approach recommended in Part A of this report and this section are considered the best outcome achievable within the time available and with the groundwater data provided by HBRC. The inferences and conclusions given in this report are based on the data available - no attempt was made to relate groundwater quality data to the geology.

Should the HBRC project schedule allow for a more in-depth analysis of the nitrate attenuation potential in the Ruataniwha Basin, the approach outlined below is recommended.

It should be ascertained whether the groundwater chemistry data (including groundwater MRT) can be related to geological and hydrogeological information available for the depth of the well screens from borelogs and geological reports (e.g. Francis, 2001). Should it prove feasible to establish such relationships, then the data gaps identified in the previous report could be filled with greater confidence. This is because the redox status of twelve of the TRIM2 sub-catchments was assigned on the basis of a single sample from each of these sub-catchments and no data were available for a further eight sub-catchments.

Additional hydrogeological information would allow the extent of connection between the aquifer sampled and the monitored surface water bodies to be determined. Many of the wells which

Assessment of Subsurface Attenuation in the Ruataniwha Basin

have age dating information have very high mean residence times. The groundwater represented by these samples may have originated from confined aquifers that may discharge very little to surface water. The overall effect that denitrification has on the nitrate discharged into surface waters is determined by the proportion of groundwater contributing to streamflow that has flowed through reduced zones and undergone nitrate removal.

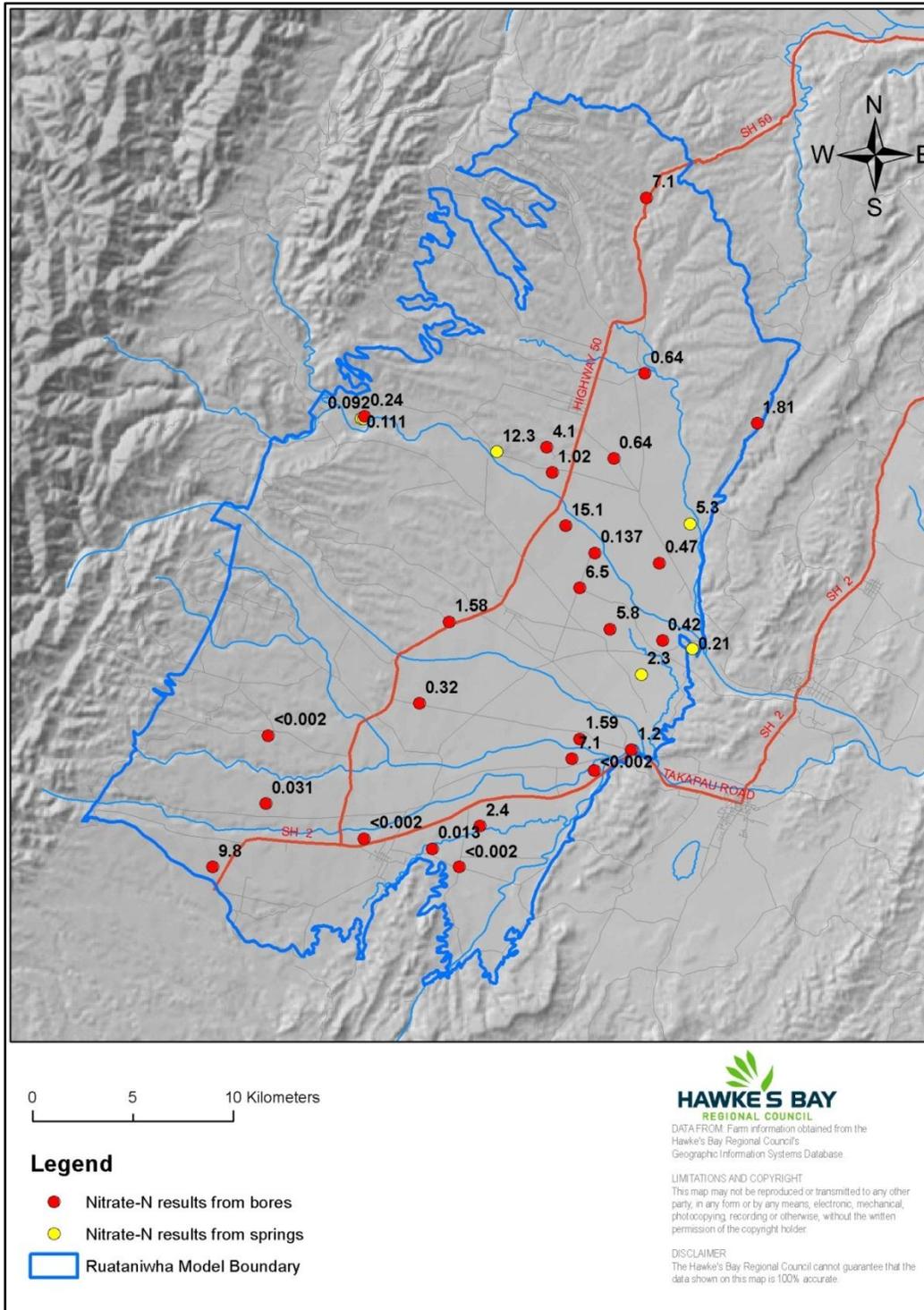


Figure B1: Nitrate-N data from October 2012 survey of shallow wells and springs.

Assessment of Subsurface Attenuation in the Ruataniwha Basin

Table B1: Combined data set derived from Morgenstern et al. (2012) and October 2012 survey of shallow groundwater (bold bore numbers). The data have been sorted according to TRIM2 sub-catchments from NE to SW. Bores 1376, 1944, and 3426 occur in both data sets.

Bore No.	TRIM2 subcatchment	Sub-Catch	Redox status	Bore depth (m)	MRT (y)	NO ₃ -N (mg/L)	Fe (mg/L)	Mn (mg/L)	DO (mg/L)	NH ₄ -N (mg/L)
2372	6	Wai	ox	6.7	n/a	7.10	<0.02	<0.0005	7.1	<0.010
2533	7	Wai	ox	22.3	>190	0.64	<0.02	<0.0005	1.8	<0.010
1357	9	Wai	ox	5.2	n/a	1.81	0.03	0.036	6.8	<0.010
1380	9	Wai	ox	15.2	n/a	0.47	0.05	0.0008	9.7	<0.010
3496	9	Wai	ox	22.5	n/a	0.64	<0.02	<0.0005	4.1	<0.010
Spring 38	9	Wai	ox	n/a	n/a	5.30	<0.02	0.0007	6.2	<0.010
3076	5	Wai	ox	12.0	1.5	0.22	0.03	0.02	7.17	0.01
4694	5	Wai	ox	43.9	40	0.29	<0.02	0.01	n/a	<0.01
4163	5	Wai	(ox)	24.7	n/a	0.42	0.03	0.033	11.0	0.142
Spring 10	5	Wai	ox	n/a	n/a	0.21	<0.02	<0.0005	7.1	<0.01
2220	3	Wai	(ox)	110.0	65	1.30	0.02	0.08	n/a	0.01
10942	3	Wai	ox	30.0	37	1.40	0.01	0.00	6.50	0.02
4744	3	Wai	ox	8.2	n/a	15.10	<0.02	0.0005	7.2	<0.010
10948	3	Wai	ox	22.6	n/a	4.10	0.09	0.0046	4.7	<0.010
15024	3	Wai	ox	4.6	n/a	0.14	<0.02	0.0013	9.3	<0.010
WSP	3	Wai	ox	4.9	n/a	1.02	<0.02	<0.0005	3.8	<0.010
Spring WSP	2	Wai	ox	n/a	n/a	12.30	<0.02	0.0035	8.7	<0.010
11005	1	Wai	red	25.6	136	0.07	0.57	0.42	0.12	0.16
1879	1	Wai	ox	6.1	n/a	0.24	0.10	0.0092	3.1	<0.010
Spring WL1	1	Wai	ox	n/a	n/a	0.11	<0.02	0.0009	1.6	0.015
Spring WL2	1	Wai	(ox)	n/a	n/a	0.09	0.17	0.03	2.6	0.012
1655	17	Wai	(red)	12.5	40.5	0.01	0.01	0.01	0.73	0.03
1452	17	Wai	ox	55.2	25.5	6.10	0.01	0.00	4.73	0.01
2043	17	Wai	ox	83.5	52	1.10	0.01	0.00	3.89	0.01
3104	17	Wai	(ox)	142.0	>180	0.29	0.01	0.04	0.08	0.62
4781	17	Wai	ox	8.7	n/a	6.50	<0.02	<0.0005	7.9	<0.010
15029	17	Wai	ox	8.7	n/a	5.80	<0.02	<0.0005	7.5	<0.010
Spring 43	17	Wai	ox	n/a	n/a	2.30	<0.02	<0.0005	2.8	<0.010
4477	13	Tuki	(ox)	10.2	n/a	1.58	<0.02	0.0017	0.3	<0.010
4695	25	Tuki	ox	6.8	n/a	1.20	0.02	0.0082	5.1	0.054
1402	24	Tuki	(red)	52.0	149	0.00	0.04	0.11	0.15	0.04
1430	24	Tuki	(ox)	46.3	>150	0.68	0.01	0.01	0.15	0.01
1518	24	Tuki	ox	65.8	80	0.95	0.01	0.00	5.98	0.01
1558	24	Tuki	ox	22.5	34.5	4.60	0.01	0.57	n/a	0.01
3852	24	Tuki	red	94.0	>130	0.00	0.15	0.33	0.13	0.68
1656	24	Tuki	(red)	19.8	n/a	1.59	<0.02	0.32	0.1	<0.010
5369	24	Tuki	(ox)	19.3	n/a	0.32	<0.02	0.026	0.5	<0.010
1376	28	Tuki	(red)	24.2	>210	0.00	0.09	0.20	n/a	0.25
1376	28	Tuki	red	24.2	n/a	<0.002	0.06	0.25	0.3	0.28
1666	28	Tuki	(ox)	12.3	n/a	7.10	<0.02	<0.0005	0.2	<0.010
2579	10	Tuki	red	46.6	102	0.00	0.59	0.21	0.11	0.99
3702	12	Tuki	red	123.5	>200	<0.03	1.40	0.30	n/a	0.11
3426	16	Tuki	red	19.0	154	0.01	0.01	0.33	0.09	0.06
3426	16	Tuki	red	19.0	n/a	<0.002	0.06	0.38	0.3	0.059
3421	19	Tuki	red	12.6	n/a	<0.002	1.83	0.21	0.2	0.06
1944	23	Tuki	red	20.6	57	0.01	1.10	0.70	0.78	0.60
1944	23	Tuki	red	20.6	n/a	0.031	1.03	0.77	0.9	0.61
1381	26	Tuki	red	58.4	>170	0.04	n/a	0.02	0.15	1.80
6716	26	Tuki	n/a	45.0	114	n/a	n/a	n/a	n/a	n/a
6719	26	Tuki	red	88.2	149	0.25	0.97	0.54	0.10	0.56
6722	26	Tuki	red	88.2	129	0.02	0.01	0.08	0.49	4.10
15962	26	Tuki	ox	6.3	n/a	2.40	0.06	0.12	6.10	<0.010
15963	26	Tuki	red	14.2	n/a	<0.002	<0.02	0.10	0.20	0.03
4254	26	Tuki	red	22.1	n/a	0.013	0.03	0.122	0.1	0.118
4702	27	Tuki	red	105.0	138	0.05	0.45	0.01	n/a	0.62
10986	15	Tuki	ox	5.8	n/a	9.80	<0.02	<0.0005	7.4	<0.010

Notes: Symbols were defined in Part A of this Technical Report.

Table B2: Notes on assignment of redox status

Well	Comments
4163	Enhanced NH ₄ -N only reason for (ox), otherwise ox
2220	(ox) due to enhanced Mn, alternatively ox
1879	Rust was noted during sampling
1655	(red) due to low DO and NO ₃ -N low for young water; alternatively (ox)
3104	(ox) due to relatively high NO ₃ -N and low Mn and Fe
4477	DO artefact?
1402	(red) as Fe low, Mn enhanced, DO low but NH ₄ -N also low
1430	DO artefact?
1558	Mn artefact?
1656	DO artefact?
5369	DO artefact?
1376	(red) as DO missing and MRT very high
1666	DO artefact?
1381	(red) as Fe missing, Mn low, but DO also low and NH ₄ -N high

4.2 Waipawa sub-catchment

Of the 24 sampled bores located within the Waipawa sub-catchment (see Table B1), only one (11005) drew clearly reduced groundwater, and a second one groundwater with some indications of reduced conditions (1655, Figure B3). Although only 25.6 m deep, the mean residence time (MRT) of the groundwater sampled at bore 11005 (136 yrs) was the third-highest determined in the Waipawa sub-catchment (Table B1). Old groundwater occurring at relatively shallow depth could either indicate upwelling groundwater or a zone with low hydraulic conductivity. The low DO concentration measured at bore 1655 is in disagreement with low Mn, Fe, and NH₄-N concentrations. This bore was nevertheless classified as most likely reduced, as the NO₃-N concentration is very low for groundwater with a MRT of 40.5 years.

No groundwater data are available for the TRIM2 sub-catchments 4, 8, and 14.

In summary, the additional data from the October 2012 survey confirm that there is little potential for denitrification in those TRIM2 sub-catchments that lie within the Waipawa sub-catchment.

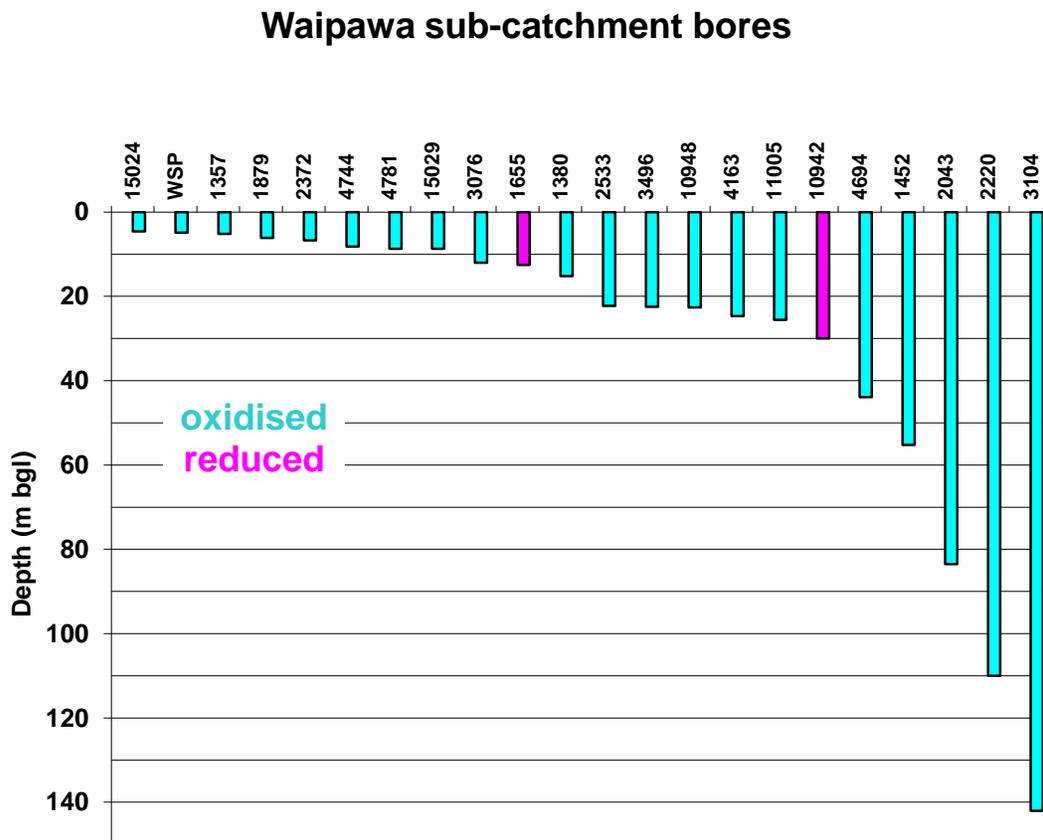


Figure B3: Bores sampled in the Waipawa sub-catchment graphed against bore depth below ground level. Oxidised groundwater indicated by turquoise colour, reduced groundwater by pink colour.

4.3 Tukituki sub-catchment

Although reducing groundwater conditions were observed at most bores in the Tukituki sub-catchment (Figure B4), oxidising conditions are not uncommon in those TRIM2 sub-catchments (13, 25, and 24) that border the Waipawa sub-catchment (bores 4477, 4695, 1430, 1518, 1558, 5369; see Table B1 and Figure B2).

The data from sub-catchment 24 demonstrate that oxidised groundwater is not confined to shallow depth – it has been found down to 65.8 m (1518, Figure B4). Elsewhere in this sub-catchment, reduced groundwater occurred at the shallow depth of 19.8 m (1656), indicating that redox status may vary considerably with depth throughout this sub-catchment (Table B1).

Elsewhere in the Tukituki sub-catchment, oxidised groundwater was found only in three particularly shallow bores (1666: 12.3 m; 15962: 6.3 m; and 10986: 5.8 m). All other bores sampled in the Tukituki sub-catchment (depths 12.6 – 105 m) drew reduced groundwater.

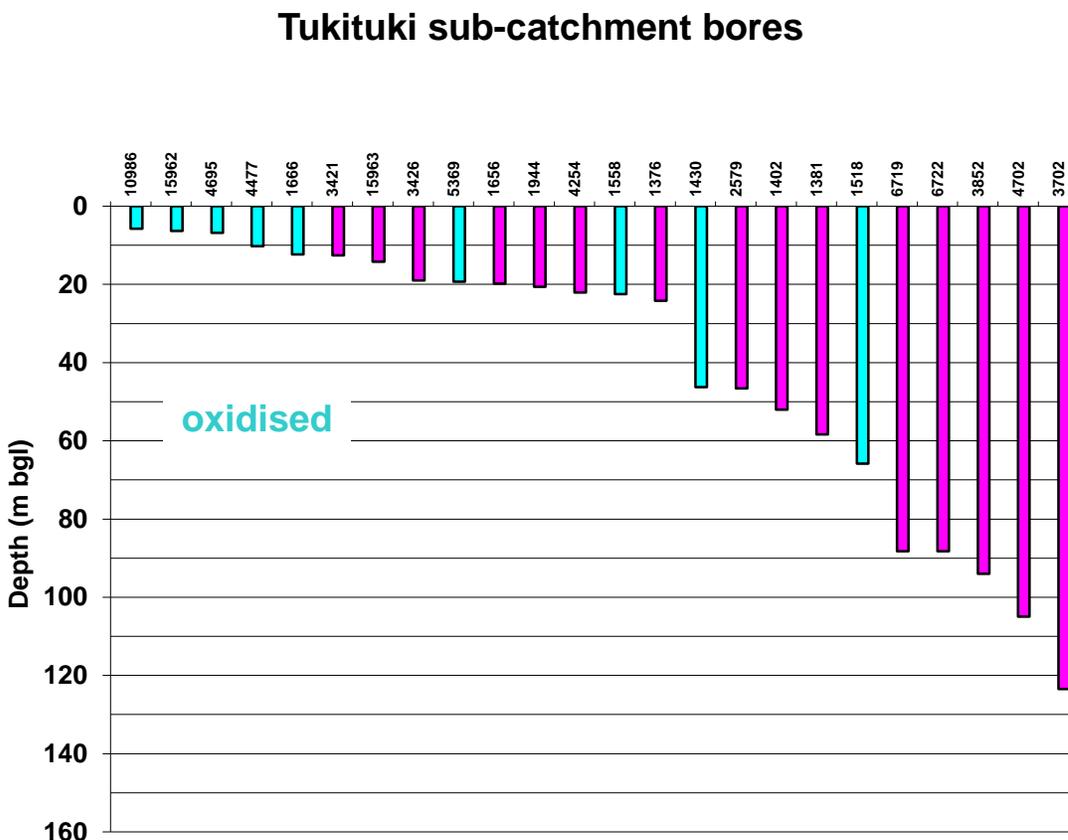


Figure B4: Bores sampled in the Tukituki sub-catchment graphed against bore depth below ground level. Oxidised groundwater indicated by turquoise colour, reduced groundwater by pink colour.

The available data suggest that there is considerably greater attenuation potential (due to denitrification) in the Tukituki sub-catchment than in the Waipawa sub-catchment. Within the Tukituki sub-catchment, the attenuation potential appears to be lower in those TRIM2 sub-catchments (13, 25, and 24) that are bordering the Waipawa sub-catchment. In all other sub-catchments where data are available, oxidised groundwater appears to be confined to very shallow depths (<12 m). Note that no data are available for the TRIM2 sub-catchments 11, 18, 20, 21, and 22.

4.4 Attenuation rates for TRIM2 sub-catchments

The summary of redox status for the TRIM2 sub-catchments is given in Table A3. Where no wells or springs were available for the sub-catchments, a probable redox status was assigned following consideration of the redox status of the surrounding sub-catchments and whether the sub-catchment was in the Waipawa or Tukituki catchments. It should be noted that because of the relatively large number of TRIM2 sub-catchments being modelled, there are a number of sub-catchments where data for only one well exists. This increases the uncertainty of the inferences made and conclusions reached. The well data are not distributed homogeneously across the catchment spatially or by depth and no attempt has been made to relate groundwater data to geology.

The attenuation of nitrate within groundwater should be assumed to be:

- zero for the sub-catchments with oxidised groundwater, and
- 100% for the sub-catchments with reduced groundwater.
- 30 to 70% for the sub-catchments with mixed redox status.

Application of a range of values should be considered in the modelling of sub-catchments with mixed redox status. The most appropriate rate will depend on the proportion of groundwater that flows through the reducing zones in each sub-catchment.

The groundwater attenuation rate used in the model will be a lumped parameter. Nitrate attenuation includes removal processes in the vadose zone, adsorption to mineral surfaces, and removal at the groundwater/surface water interface, in addition to denitrification in anoxic groundwater (Rutherford, 2012). These other processes also need to be considered, because the attenuation rates suggested above consider only the denitrification capacity in the groundwater system. Adsorption of nitrate to mineral surfaces is not likely to be a major process because nitrate is negatively charged and therefore highly mobile. Although removal in the vadose zone could be important, it is likely to vary spatially in a similar manner to denitrification within the groundwater system.

Removal at the groundwater/surface water interface for each of the TRIM2 sub-catchments also needs to be considered because this is likely to be an important but variable attenuation process. For example, in stream reaches where the recharge from groundwater occurs through gravel, limited attenuation is likely, whereas in reaches where more extensive riparian cover and beds of finer sediments occur, removal of nitrate is more likely. The removal of nitrate at the groundwater/surface water interface will be more significant where groundwater discharging to streams has elevated nitrate concentrations. Nitrate attenuation within the TRIM2 modelling could be refined by applying attenuation coefficients at the groundwater/ surface interface.

4.5 Summary

Each TRIM2 sub-catchment has been assigned a redox status of “oxidised”, “reduced” or “mixed”. Attenuation within groundwater should be assumed to be zero for sub-catchments with oxidised groundwater, and 100% for the sub-catchments with reduced groundwater. The attenuation for the sub-catchments with mixed redox status is likely to be between 30 to 70%; a selection of values within this range should be examined in the modelling. The most appropriate rate will depend on the proportion of groundwater that flows through the reducing zones in each sub-catchment.

Nitrate removal at the groundwater/surface water interface for each of the TRIM2 sub-catchments should be considered because this is likely to be an important, site-specific attenuation process.

The TRIM2 modelling could be expanded to include attenuation coefficients for nitrate removal at the groundwater/ surface interface.

Table B3: Summary of redox status for TRIM2 sub-catchments and assignment of sub-catchments with no wells or springs present.

Redox status	TRIM2 Sub-catchment	Number of wells or springs		Comments
		Oxidised	Reduced	
100% Oxidised	2	1		
	3	6		
	5	4		
	6	1		
	7	1		
	9	4		
	13	1		Low DO but low Fe, Mn & mod NO ₃
	15	1		
	25	1		
Mixed Redox	1	3	1	
	17	6	1	
	24	4	3	
	26	1	5	
	28	1	1	
100% Reduced	10		1	
	12		1	
	16		1	
	19		1	
	23		1	
	27		1	
No wells or springs present	4			Oxidised; between SC 3 & 5
	8			Oxidised; between SC 6, 7 & 9
	11			Probably reduced; between 10 & 12; adjacent to mixed 24
	14			Probably oxidised; adjacent to 17, 13 & 25
	18			Reduced
	20			Reduced
	21			Reduced
	22			Reduced

5 Part C: Second Addendum to Report on Attenuation in Ruataniwha Basin (dated February 2013)

5.1 Introduction

A letter report that assessed nitrate attenuation in the Ruataniwha Basin was completed in November 2012 (Part A of this Technical Report). Following inclusion of additional data from an extensive survey of shallow wells and springs (undertaken in October 2012), an addendum to the first report was requested by Hawke's Bay Regional Council (HBRC). This updated the report and included an assessment of the attenuation potential for the sub-catchments proposed for the TRIM2 modelling exercise (Part B of this Technical Report). Subsequent to that addendum, the sub-catchments for the TRIM2 modelling were modified in response to groundwater particle track modelling. This modelling increased the number of sub-catchments included in the TRIM2 modelling from 28 to 39. This second addendum updates the assignment of redox status to the enlarged set of sub-catchments, now designated as GRID2 to distinguish them from the previous sub-catchment notation and is Part C of this Technical Report.

5.2 Methods and Updated Results

The location of each well and spring was assigned to a GRID2 sub-catchment (Figure C1). The redox status previously assigned to each well and spring was retained.

As a consequence of increasing the number of sub-catchments, there are now more sub-catchments overall and there are now 19 sub-catchments without groundwater quality data, compared to eight sub-catchments previously.

The same procedure used previously was followed to assign a redox status to the GRID2 sub-catchments:

- Where groundwater data existed, these data were used to make the redox assignment
- Where groundwater data were not available, a likely redox status was assigned, taking into account the where the sub-catchment was located and the status of neighbouring sub-catchments. The assigned redox status is shown in Table C1.

There are no GRID2 sub-catchments numbered either 3 or 30. Number 3 relates to a losing reach of the river and number 30 was omitted from the numbering system.

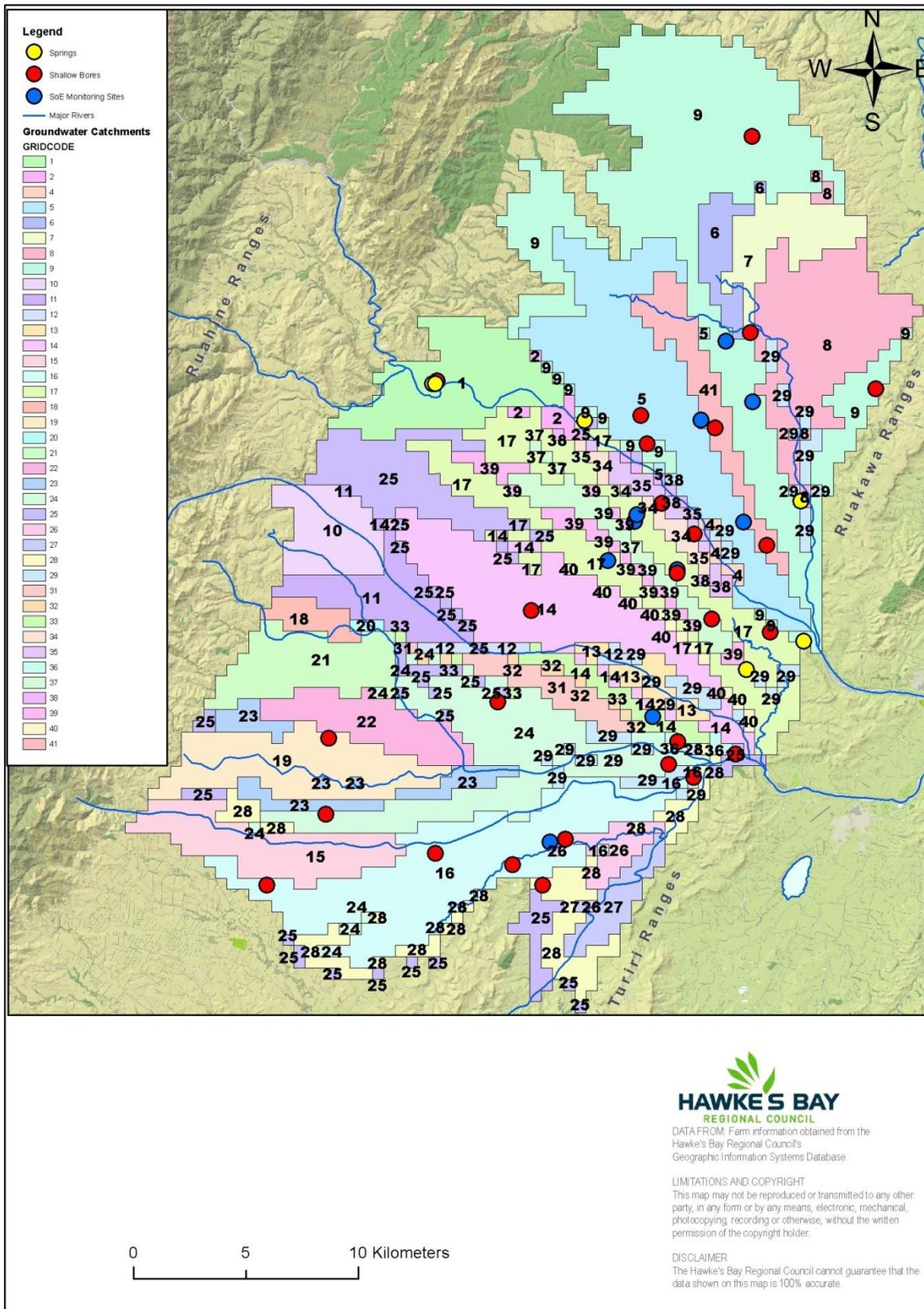


Figure C1: Bore and spring locations shown for GRID2 sub-catchments.

Table C1: Summary of redox status for GRID2 sub-catchments and assignment of sub-catchments with no wells or springs present.

Redox status	GRID2 Sub-catchment	Number of wells or springs		Comments
		Oxidised	Reduced	
100% Oxidised	5	5		
	6	1		
	8	1		
	9	5		
	14	2		
	25	2		
	35	2		
	37	1		
	41	2		
Mixed Redox	1	3	1	
	16	1	7	
	17	6	1	
	24	1	1	
	26	1	1	
	33	2	1	
100% Reduced	10		1	
	19		1	
	23		1	
	28		1	
	32		2	
No wells or springs present	2			Probably oxidised
	4			Oxidised
	7			Oxidised
	11			Probably reduced
	12			Probably mixed
	13			Probably mixed
	15			Probably mixed
	18			Probably reduced
	20			Probably reduced
	21			Probably reduced
	22			Reduced
	27			Reduced
	29			Oxidised
	32			Mixed
	34			Oxidised
	36			Mixed
38			Oxidised	
39			Oxidised	
40			Oxidised	



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