Friends of Golden Bay Comments on FLAG draft report
January 2017

Friends of Golden Bay (Inc) (FoGBay) promotes optimum environmental outcomes in Golden Bay. A major effort in recent years has been to study freshwater quality in the Takaka Valley so that the benefits it provides are maintained and preferably improved. We have been particularly concerned with Te Waikoropupū Springs and the associated aquifers as our research showed that nitrate levels had been increasing due to land management practices. We have been so concerned with this deterioration that we sponsored weekly sampling for nitrate and phosphate in the Springs' complex and associated Fish Creek.

Introduction:
FoGBay have not been directly involved in the Takaka FLAG process although we made direct input in the early stages. We are pleased to see that FLAG has been taking the process seriously and welcome the invitation to submit on their interim decisions. The document FLAG produced is not easy to assess and so we have been forced to go back to the discussions and presentations (partly on the TDC website) to see how the decisions were arrived at and their justifications.

We noted that early on there was general agreement on objectives for water quality etc but from the middle of last year TDC staff and its consultants have been pushing for greater water takes from the rivers and aquifers and have been giving great weight to what irrigators are asking for. The Dairy NZ sponsored "expert group" in water quality illustrates this. We note that this has led to a split within FLAG, so that there is not a general consensus over some important aspects within the draft report. Further, local Iwi have still to be properly consulted.

Our approach to this review of the FLAG draft report is to assess how the proposals or options in the discussion document will ensure that freshwater quality is maintained or improved.

Key factors:
The National Policy Statement for Freshwater states that water quality must be maintained or improved. Thus any practices that lead to deterioration need to avoided and practices that lead to improvement are to be encouraged. Objective B4 in MoE (2015) covers the protection of significant values of wetland and *outstanding freshwater bodies* (our emphasis) and suggests further guidance can be obtained from Beca (2008).

There are three key factors that must control water management in the Takaka catchment:
1. Water quality management objectives and Iwi values
2. Limiting factors e.g. pollution or stressors
3. Management e.g. water allocation

The Arthur Marble Aquifer (AMA) and associated Te Waikoropupū springs have extremely high conservation values. First, limitations on toxic nutrients and other stressors must be considered and applied as they are the main limiting factor for this system. Then allocation and other management options may be considered. The current FLAG report looks at allocation before limitations; this needs addressing.

For connected systems such as the AMA the most sensitive and significant values should drive decisions (Beca 2008).

Management objectives:
We agree with the objectives for water bodies that FLAG identified in the May 2015 document and noted that they related these to Iwi values. However, we also understand that the consultation process with Iwi is incomplete.

In particular, we were pleased and **strongly support** the maintenance of the Natural Form & Character of the water bodies, especially within the karst landscapes, National Parks and Spring systems within the Takaka Catchments. FLAG emphasised that *water flows and quality* from spring systems, especially Te Waikoropupū Springs, were to be maintained.

The Springs and the AMA which supply it, *have extremely high conservation values* because of their unique properties: high endemic biodiversity (particularly the stygofauna), landscape values, wide acceptance as a major tourist attraction in the region and their great significance to local Iwi.

We strongly support the emphasis on the rivers being suitable for swimming and the need to maintain ecosystem health in all water bodies, including groundwater.

Nutrient and other pollution:
Friends of Golden Bay are primarily interested in the management of the AMA and Te Waikoropupū springs so our comments are primarily around this.

Te Waikoropupū Springs have some of the clearest freshwater in the world. This results from the oxidation of organic matter in the groundwater by biofilms and stygofauna organisms in the karst AMA. Research to date has found that many of the stygofauna are unique to the AMA and hence of great biodiversity value in themselves. However, very little is known about their tolerance to pollutants such as nitrate.

ANZECC (2000) have said, regarding groundwater fauna: "Little is known of the lifecycles and environmental requirements of these quite recently-discovered communities, and given their high conservation value, the groundwater upon which they depend should be given the highest level of protection". Further, they state "For ecosystems requiring the highest level of protection (condition 1), the objective of water quality management is to ensure that there is no detectable change (beyond natural variability) in the levels of the physical and chemical stressors. For such highly-valued ecosystems, the statistical decision criteria for detecting any change should be ecologically conservative and based on sound ecological principles. This position should only be relaxed where there is considerable biological assessment data showing that such changes will not affect biological diversity in the system"

Dr Fenwick at NIWA has advised that: …." **the aquifers and catchments should be managed to ensure that NO_3-N concentrations in spring water do not exceed 0.4 mg NO_3-N/L in order to protect the springs' high conservation values."** (NIWA 2015). **Currently the Main Spring is at this level and sometimes exceeds this concentration** (see Appendices 1 and 2). Because of our concerns FoGBay undertook and paid for weekly sampling from the Springs' in order to better define the current levels of nitrate and phosphate and study how they changed over 12 months. This research is still on-going but a preliminary report is attached (Appendix 2).

We are disappointed that the Dairy NZ 'expert' panel report is still not available for proper consideration. According to the FLAG draft report and Dr Young's presentation to FLAG, the panel may recommend a 'trigger' NO_3-N concentration of 0.5 mg/l. **We reject this suggestion of a 0.5 mg/l 'trigger' level because it is important to take a precautionary approach where we know so little about the organisms and their ecology**. Further, we note that a 'trigger' level is not prescriptive (i.e. it should not be exceeded) but rather suggests that it is a level when we might get concerned and look in greater depth.

Dr Mead disputes the analysis of nitrate trends in the Main Te Waikoropupū Spring that has been undertaken by the 'expert' panel (Appendix 1). The main issues are:

1. Including the pre 1990 records
2. Including data that have been analysed by different techniques. In particular Cawthron and Hill Laboratories have used methods that are known to give positively biased nitrate levels. Including the limited data from Dancing Springs or Fish Springs is also not justified as they have not been regularly measured over the time period.
3. Excluding outliers without having a good reason to do so. They could just as easily be real. Further, there are robust non-parametric methods that are resistant to outliers and if these methods are used there is no need to drop outliers.
4. Not being systematic in their analysis of the long-term data.

The upshot of this is that the analysis in the FLAG report understates the long-term changes in nitrate changes and overstates the recent changes. That analysis cannot be relied on.

Dr Mead's systematic data analysis (Appendix 1) has found, for the data from 1990 to 2016:

1. From 1990 to mid-1995 no linear change was apparent because of high variability. The median NO_3-N was 0.33 mg/l.
2. Between 1996 and 2011 NO_3-N rose at 1.76% per annum.
3. From 2012 to September 2016 nitrate may or may not be decreasing but has probably levelled off. Further long-term sampling will clarify this. The median concentration was 0.41 mg/l.

Dr Mead's preliminary analysis of the FoGBay weekly sampling between February and December 2016 (Appendix 2) shows:

1. The median NO_3-N concentration is 0.40 mg/l in the Main Spring and 0.36 mg/l in the Fish Spring
2. Both Springs showed a seasonal/climate-related variation and nitrate concentrations were generally highest in winter-spring when the Main Spring exceeded 0.40 mg/l and Fish Spring reached that concentration.

We therefore conclude that the **correct approach to managing the water quality of the AMA is to not allocate more irrigation water in the unconfined aquifer until nitrate concentrations drop to well below 0.4 mg/l. We would recommend that the trigger level for allowing more irrigation be set at 0.30 mg/l.** If more allocation is given at this time and nitrate levels continue to rise, it will be very difficult to ask farmers to give up their allocation. Farmers need security before they invest.

The modelling work on the effects of irrigation on nitrate-N concentrations, presented by Dr Fenemor to FLAG on 27 Nov 2015, shows that increasing the Springs' allocation to 766 l/sec as TDC is proposing would increase the Main Springs nitrate concentration to 0.5 mg/l. **This is unacceptable.** It may be an underestimate because it does not fully take into account the increase that is proposed from the Waingaro where the water would be mainly used in the unconfined aquifer. (There is a strange co-incidence between 0.5 mg/l nitrate-N level predicted by Dr Fenemor to result from the proposed allocation for Te Waikoropupū springs and that recommended to FLAG in Dr Young's provisional report of the Dairy NZ 'expert panel' that recommends 0.5 mg/l nitrate-N as the trigger level).

We note that Young and Hay (2016) confirmed that marble does not provide significant amounts of nitrogen to the water in the AMA. However, their interpretation that the Spittle Creek nitrate-N represents the natural concentration in the deep aquifer is suspect.

Phosphate:
There is an incomplete long-term record on dissolved reactive P for Te Waikoropupū Springs. We agree that P does not seem to be an issue as the concentrations are low. Similarly, the Friends of Golden Bay 2016 weekly sampling found DRP in the Main and Fish Springs had a median of 0.006 mg/l (range 0.003 to 0.008 mg/l). However, DRP in Fish Creek was often higher during the winter storms because of runoff from the farms up-stream.

Dissolved oxygen:
NIWA (2015) notes that critical levels for stygofauna are poorly understood but it will become a problem when concentrations get low. Dissolved oxygen (DO) has not been regularly measured in the Main spring (median 5.7 mg/l; range 1.1 to 9.5 mg/l; N = 27 from 1970). Two extremely low levels were recorded in 1999 and 2000 and the very high concentration was in 2004.

NIWA (2015) emphasised "dissolved oxygen appears to become a critical factor at low aquifer levels when the hydraulic gradient is reduced and the rate of water replacement (containing more dissolved oxygen) is slowed. Thus, managing water levels to ensure near natural velocities/flows through the aquifer matrix, in tandem with managing organic carbon concentrations within groundwater, seems likely to sustain higher dissolved oxygen concentrations…". **Therefore, it is important to stop water take at MALF.** Flatling (i.e. keeping the flow at or below MALF for long periods) might be something FLAG should consider when considering water allocation rules.

The FLAG report has recommended a trigger level of 45% saturation for DO which is 80% of the few data recorded as percentages. We consider using the 80% level as inappropriate for a system with very high conservation values (ANZECC 2000). NIWA (2015) suggested that 6.0 mg/l should be used as a guideline. **NIWA's precautionary approach should be accepted** in the meantime.

Organic carbon concentrations are not being measured in the Springs' water.

Other Pollutants:
The FLAG report does not cover or discuss other pollutants and this is **a major omission** as they could affect the stygofauna. Some guidance is provided by NIWA (2015).

Water clarity:
The FLAG draft report briefly discusses water clarity and recognises that this has not been measured recently. Clarity needs to be re-measured and FoGBay initial discussions with Dr Davis Colley indicated it could be done without divers. **Action required**.

The Dairy NZ 'expert' panel suggested that the trigger level be 50 m which is 21% below what it was when measured in 1993. While an 80% level of protection is reasonable for many rivers, ANZECC (2000) recommend that for high conservation sites, such as Te Waikoropupū , no change should be allowed for (i.e. it should be 63 m). If a number of readings over a period of a year or more were available other statistical methods could be applied (see ANZECC 2000).

Positive management changes:

Friends of Golden Bay applauds that in the last 10-15 years farmers have generally moved to keep stock out of major waterways and planted, albeit narrow, riparian strips. These practices reduce direct pollution of the waterways and reduce sedimentation but have smaller impacts on the movement of nitrate into the rivers and the AMA. Keeping animals out of waterways needs to be extended to all farm animals in the Takaka Catchment. Smaller watercourses or swales may sometimes need to be fenced off.

Dairy farmers have also improved their dairy waste disposal systems particularly as there had been old reports of farmers dumping this and other waste down tomos. Some irrigators have also implemented improved irrigation systems. It is possible that the levelling-off in Main Spring nitrate-N since 2012 may be a result of improved farm management (Appendix 1). However, Dr Mead's analysis identified that these changes may have partly resulted from changes in water flow rate.

We would argue that both water and nutrient management plans be made compulsory, particularly in the unconfined aquifer area, that these be actively monitored by TDC and the results become part of the public record in the interests of transparency. Auditing systems should be a condition of future consents. Further, those being allocated water should be required to contribute towards the monitoring and auditing costs.

FoGBay look forward to seeing more explicit proposals from FLAG.

Adaptive Management:

The only realistic use of this management technique for the AMA is when the aim is to reduce the current pollution – in the case of nitrate-N this would be to ensure the concentration goes down. One problem lies in the long transit time for groundwater and the size of the AMA, which will delay the detection of any changes. If further water allocation is allowed and the pollution gets worse, it will be difficult to change back because of the long-term nature of water consents.

Water allocation:

FoGBay support the FLAG decision that water allocation should stop at MALF. In the FLAG Meeting Notes for 24/7/2015, FLAG members agreed that water allocation to major users, such as irrigators, would be prevented from drawing down river flows to below MALF. Dr Young on page 17 of his 2006 report to TDC emphasised this point also (see Young, R. 2006. Available from

http://www.cawthron.org.nz/publication/science-reports/framework-flow-management-takaka-river-catchment/). A presentation on actual data from Harwood and Lindsay Bridge showed that for many species, optimum habitat was above MALF (see FLAG 2015-07-24 – Presentation and Notes – Setting Ecological Values).

Subsequently, in 2015 Dr Young stated that, in his opinion, it was OK to allocate below MALF; it seems that this is based on MoE (2015) and the 2008 MoE draft guidelines for water allocation (Beca 2008) and not on further research in the Takaka Catchment. In FLAG discussions it was stated TDC had rejected the use of hydraulic-habitat modelling (and presumably the better drift-NREI model) because of costs, so the advice of Dr Young had been sought. Recently a report was released that recommended using the historic flow method, partly because it was used elsewhere in the country (Young and Hay 2016). This report does not consider the ecology of the AMA, which is critical for the management of this interconnected system, but concentrates on the rivers. In May 2015 Dairy NZ suggested that for rivers and for the Springs a 20% allocation would be reasonable. **We strongly reject this as it does not take into account the high conservation values of the area**. Dr Young has been careful to point out that his recommendations were just a starting point for further decisions by FLAG.

In FoGBay's opinion, if proper research cannot be done, then there should be no further allocation of water in the unconfined AMA zone. Clearly to do so would be risky. **The current 500 l/sec limit in the unconfined aquifer should be maintained in the meantime.**

The current allocation of 500 l/sec would represent about 6% of the Main Spring MALF but as the FLAG discussions indicate this an overestimate, the actual effect on the Springs may be only about 2%. The proposal to increase this to 10% of MALF is unacceptable where we have an aquifer system with such high conservation values.

The FLAG interim proposals suggest that the unconfined aquifer should be divided into three zones. **We disagree with this approach**. Water used for irrigation is often applied to areas where leaching of nitrate will be high – sites with high rainfall, stony soils, prevalence of sinkholes etc. The FLAG report and Young and Hay (2016) suggested approach ignores this and focuses on the river's ecology. The protection of the AMA should be the priority and this is influenced by all irrigation in the unconfined zone.

The Waingaro zone clearly illustrates this problem. The TDC proposal is to allocate 550 l/sec in this zone instead of the current permitted 111 l/sec, but there is to be a stop-take when MALF would be reached at the confluence of the Waingaro and Takaka Rivers. The report calculates that there is an additional 184 l/sec that could be allocated (it is unclear how this figure was derived). Significantly it ignores that this water would largely be used in the unconfined zone.

However, **we agree that there should be a stop-take at MALF and recommend that this be applied to all current permits when they come up for renewal in 2019.** This would protect the flow of the Waingaro and should have a positive effect by reducing nitrate ending up in Te Waikoropupū. It will also ensure that very low dissolved oxygen does not become a stressor on the stygofauna. Similar stop-takes at MALF should be applied to all permit holders in the unconfined aquifer zone. The 2008 MoE draft water allocation guidelines stress that 'for connected systems…. the most sensitive or significant value will drive the selection of methods for all resources'.

Confined Aquifer Zone of the AMA:

The report proposes allowing an increased take from the AMA in this zone. This also poses some risks. If the bore hits a conduit to the Springs it will have a direct effect on its flow. If it is on the seaward of the springs it may alter the seawater barrier. The idea of a no-take zone around the Spring is a good idea but may be insufficient to protect the Springs. As Professor Williams has emphasised, at low water flows, any take in this zone could have a direct effect on the Springs. Please reconsider.

Justifications for increased water allocation:

The FLAG proposals do not give an economic justification for allocating more water to irrigation water nor do they discuss how, if it is increased, it should be allocated within the wider community. We note that some farmers have not found it necessary to have intensive irrigation and a few have dams to store water for use over summer.

The report bends over backwards to give farmers greater security of supply but this should not be at the expense of the overarching aim of maintaining or improving water quality.

Water Conservation Order:
An application for a WCO for the Springs and AMA is under action and this is noted in the FLAG draft proposals**. FoGBay strongly support this application and believe that FLAG should do so as well**.

Other methods of controlling nitrate inputs:
Piers Maclaren has suggested informally that limiting stock numbers in the unconfined AMA may be a way of a ensuring that nitrate leaching could be limited. Cow numbers by themselves would not be adequate. For example, MAF stock unit (SU) figures show that dairy cow SU vary widely with cow live weight and milksolid yields. Presumably SUs would be related to feed intake and to urine discharge. SU figures are also available for sheep, deer etc. which could be used if they relate directly to nitrate leaching. Because animals are sometimes wintered off farm, SU x grazing days/year would seem a better unit.

Even if this were used as a control tool it would still be necessary to monitor nitrate and other critical limiting factors such as dissolved oxygen and clarity.

Another technique would be to limit N leaching per ha as has been proposed elsewhere in NZ. This would presumably use Overseer® to estimate leaching, as measuring it directly would be expensive.

References:
ANZECC. 2000. Australian and New Zealand guidelines for fresh and marine water quality. Volume 1. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

Beca. 2008. *Draft Guidelines for the Selection of Methods to Determine Ecological Flows and Water Levels*. Report prepared by Beca Infrastructure Ltd for MfE. Wellington: Ministry for the Environment.

NIWA 2015. Sustainability of Te Waikoropupu Springs' aquifer ecosystems. Client report CHC2015-020 by Graham Fenwick. 16 pp.

Young RG, Hay J 2016. A framework for setting water allocation limits and minimum flows for the Takaka Water Management Area, and an assessment of the geological contribution to the nitrogen load to Te Waikoropupū. Prepared for Tasman District Council. Cawthron Report No. 2977. 30 p. plus appendices.

Appendix 1.

Critical analysis of Te Waikoropupū Main Spring long-term nitrate data

Dr D J Mead, Jan 2017

Introduction

The nitrate-N data from Te Waikoropupū is of great importance to on-going discussions on the Springs. There have been several data analyses made and while they all show an increasing trend in nitrate there have been differing interpretations because of various methodologies and assumptions.

The first part of this paper is a detailed look at the data and how it is best analysed and the second part gives the analysis of the long-term data.

Part 1
Review of data sources and appropriate data analysis methods

1.1 Nitrate data sources:

Te Waikoropupū Main Spring's data being used comes from:

1970-71: Four samples were collected by Michaelis (1974, 1976) and analysed by Dr M.E.U. Taylor using the cadmium reduction technique.

1990 on: Quarterly sampling began in 1990; were analysed by the Groundwater Quality Research Laboratory, Christchurch (DSIR) until 1993 when the programme became part of GNS. Prior to September 1996 nitrate was determined by Technicon Auto Analyser II (Rosen 1999, Daughney and Reeves 2005) and since then by ion exchange chromatography. The Auto Analyser II technique for nitrate-N usually used a reduction method but which particular one was used in this programme is not known. Current methods and detection levels are given at http://www.gns.cri.nz/Home/Services/Laboratories-Facilities/New-Zealand-Geothermal-Analytical-Laboratory/Analytical-Methods

Daughney and Reeves (2005) state: "it is important to point out that whenever a change in analytical method have been made, control experiments have been conducted to assess the accuracy of the new technique relative to the old one to ensure the results do not reflect analytical bias".

Tasman District Council (TDC) provided most of the water data used in this study but some is also available on the GNS website at http://www.gns.cri.nz/Home/Our-Science/Environment-and-Materials/Groundwater/Groundwater-Database

1.2 Comment on nitrate analytical techniques:

Hill Laboratories, is currently being used by TDC to analyse nitrate-N (in Fish Spring, for example). This laboratory uses an automated cadmium reduction flow injection analyser to get nitrate + nitrite and then obtains the nitrate value by deducting nitrite from it. This is similar to the procedure used by Taylor in 1970-71. Recent comparisons of this technique for Fish Springs and that used by GNS show that the cadmium reduction technique gives consistently higher values (data available on request). Further, it has been reported that at 0.35 mg/l the automated cadmium

reduction technique has a positive bias of 18%
(https://law.resource.org/pub/us/cfr/ibr/002/apha.**method.4500**-cl.1992.pdf)

1.3 Statistical Analysis methodology:

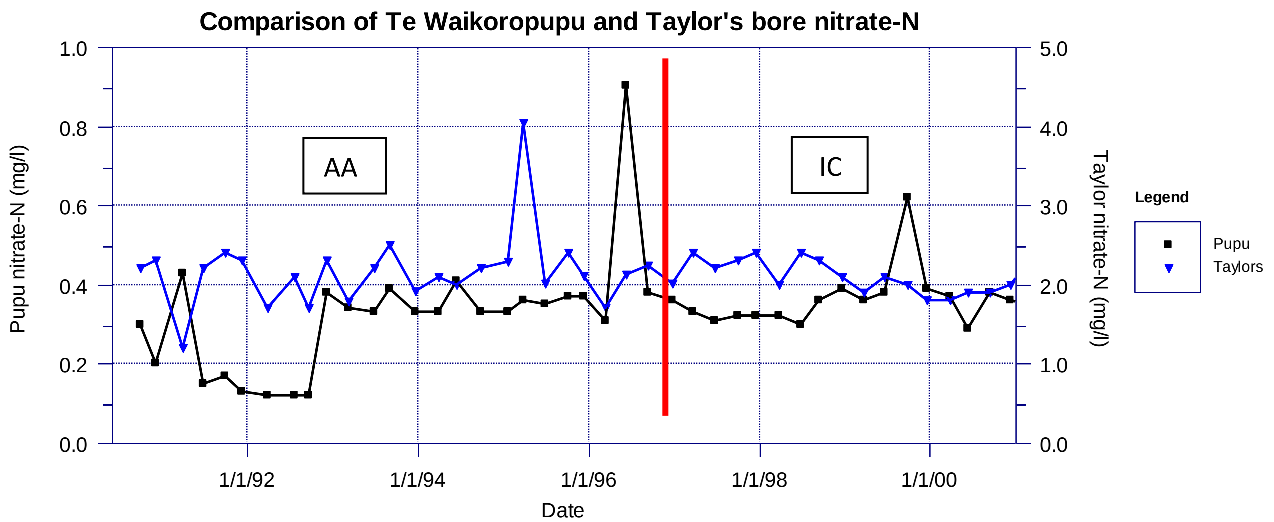
1.3.1 Should the 1970-71 data be included in the study of trends? It is recommended by Helsel and Hirsch (2002, pages 349, 351) that data like the 1970-71 samples should be excluded from statistical trend analysis. They give the following objective procedure: divide the study period into thirds (in this case 1970 – 1985; 1986 - 2000; 2001- 2016). If any third has less than 20% of the total coverage it should be excluded. Obviously the early 1970-70 data should not be included with the analysis of the 1990-2016 data. Further, points such as this 1970-71 data, would have an undue leverage on a linear regression.

1.3.2 How to handle unusual data points (outliers):

Young (2015) in his presentation to FLAG said that outliers should be removed because they *may* be due to sampling or analytical techniques. Helsel and Hirsch (2002 page 11) discuss the outlier problem in depth. They state that you should first verify the data for obvious errors and correct where possible. If there are no obvious errors they say: "outliers should not be discarded based solely on the fact they appear unusual. Outliers are often discarded in order to make the data fit a preconceived theoretical distribution such as normal, there is no reason to suppose they should!" … "Rather than eliminating actual (and possibly very important) data in order to use analytical procedures requiring symmetry or normality, procedure resistant to outliers should instead be used."

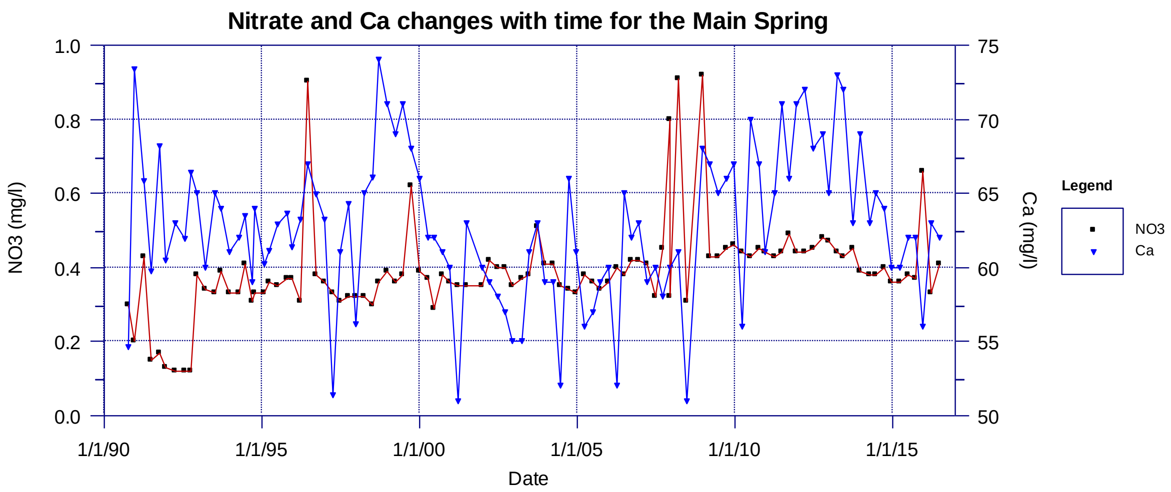
This set of data from 1990 has possibly both low and high outliers. The low outliers (<0.2 mg/l) are between June 1991 and Sept 1992. Rosen (1999), who reported on the 1990 to 1997 nitrate results, did not question the data's validity (or the first high value in 1996) but suggested the low values may be due to changes in flow.

Fortunately samples were collected on the same days for DSIR from both the Main spring and from a bore in the Takaka Valley (Taylors bore WWD6601). As shown below, Taylors bore does not have parallel low levels in the first few years, strongly suggesting the low levels are not an analytical problem. It is likely the samples from these two sites were analyzed in the same batch. Further, there is no suggestion that nitrate levels suddenly changed when the analyses method changed from Technicon Auto Analyser II (AA) to ion exchange chromatography (IC) from June 1996.



Note: the different scales in the above figure.

This does not rule out field sampling errors but we could look at other nutrients to see if they suggest this was a contamination problem. The most useful nutrient is Ca as it will be dominated by solution of the marble and be relatively less affected by saltwater.



The above figure does not suggest there an obvious sampling problem, with high or low values being associated with unusual Ca concentrations. Visual inspection of temperature, conductivity, flow or other nutrients also show no obvious associations that explain the outliers.

Does our knowledge of farming or other practices offer any clues to these outliers? While not definitive they do illustrate that farm practices were altering. Prior to 1978 the Springs were owned by Miss Campbell and there are records that show cows had ready access to the Springs and grazed the watercress (e.g. See Michaelis, 1974 who recorded several instances). The Reserve was fenced off in 1979. Better waste disposal systems and fencing off streams gradually became accepted practice while intensification of dairy farms and pasture irrigation expanded in the 1990s (Mead 2015). There are also reports that tomos have been used for waste disposal which could have led to direct contamination of the AMA (Mueller 1987), including the disposal of scallop-shell waste into a sinkhole 300m from the Springs in the 1970s (Prof. Williams, pers. comm.).

Thus the limited information does not justify rejection of any outliers but to handle these outliers robust non-parametric techniques should be used.

1.3.3 Appropriate statistical methodology:

Several techniques would seem to be most appropriate to analyze the 1990 to 2016 data. I would recommend the following approach.

1. Plot the nitrate data against time and use lowess smoothing to look at the trend over time to see if a linear model is appropriate (Helsel and Hirsch 2002 page 46). This procedure does not pre-suppose what model may be most appropriate but may suggest the next steps. Lowess is a robust, non-parametric procedure.
2. If a linear trend is apparent over all or part of the data, then the use non-parametric Mann-Kendall trend test. Covariates such as water flowrate can be explored as well.
3. Seasonal effects should also be studied to determine whether a seasonal trend test is required. With this data set the samples were collected on a regular basis four times per year.

4. It may be useful to consider using a broken stick analysis – i.e. look for more than one linear trend over time. Alternatively, the lowess smoothing trend may be considered sufficient to explain the pattern.
5. If the data appear to show discrete changes with time the non-parametric Kruskal-Wallis method could be employed.

Helsel and Hirsch (2002 page 339) have stated that care must be used when combining data collected at different intervals of time. This makes it difficult to combine the long-term Springs' data collected quarterly with the weekly sampling being undertaken by Friends of Golden Bay.

1.4 Summary:

It is important when analyzing data of this type to allow the data to speak for itself and to do the study methodically. Only when the statistical analysis is completed should the results be interpreted.

In this first part the emphasis has been on showing how the nitrate-N data should be handled. It was concluded that the 1970-71 data should not be included with the 1990 to 2016 data set and that robust non-parametric tests should be employed. This report has not included the Friends of Golden Bay data set – that is presented in Appendix 2.

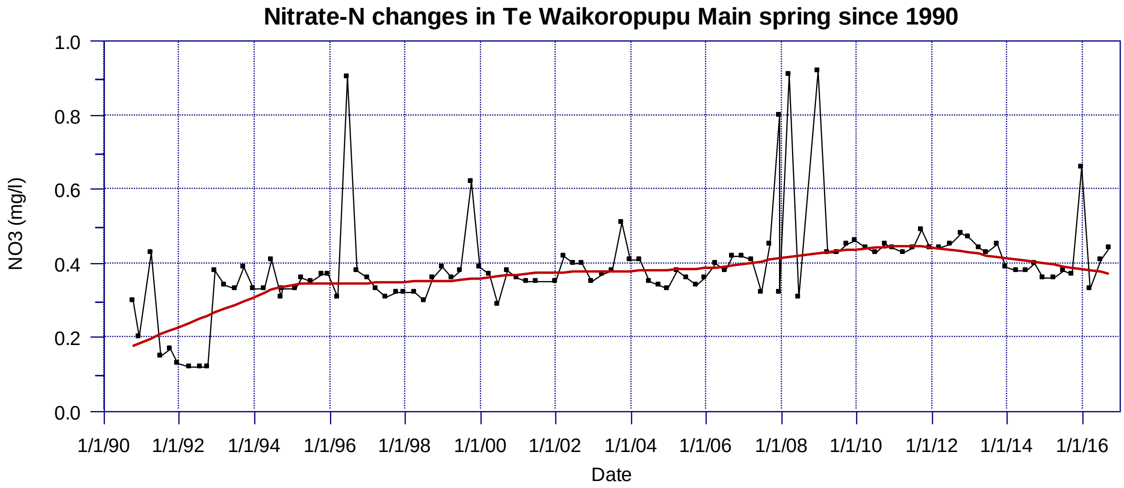
Part 2

Analysis of Te Waikoropupu Spring nitrate-N levels since 1990

2.1. Introduction:

The analysis of this long-term data on nitrate-N changes in the water of the Main Spring has been undertaken systematically as discussed in Part 1. The analysis is explained in depth, step by step.

2.2.1 Plot of nitrate-N against time from Sept 1990 to Sept 2016

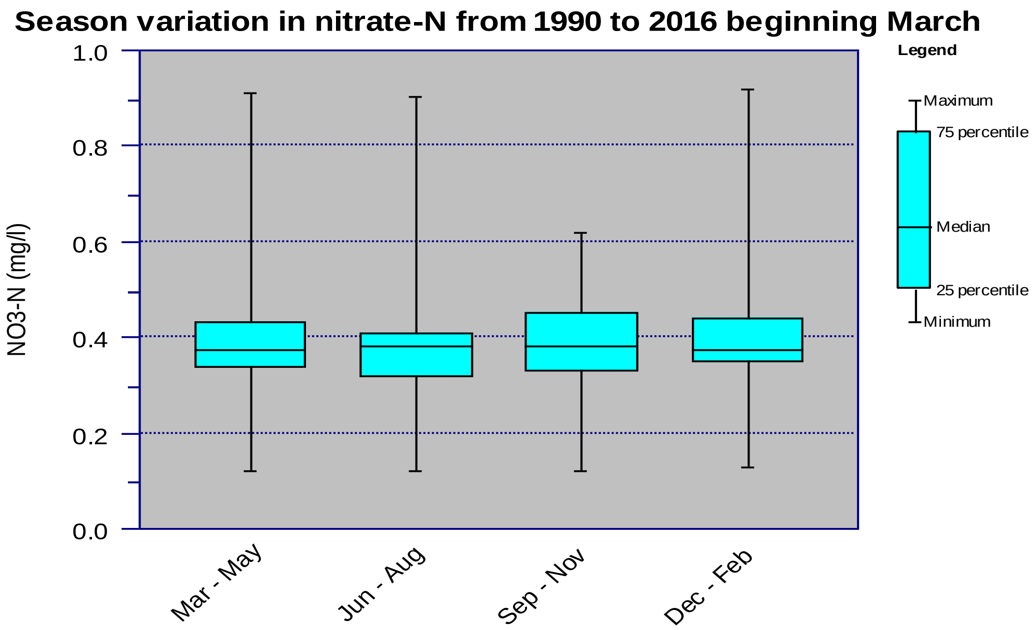


The red Lowess smoothing trend explained 22 % of the variation.

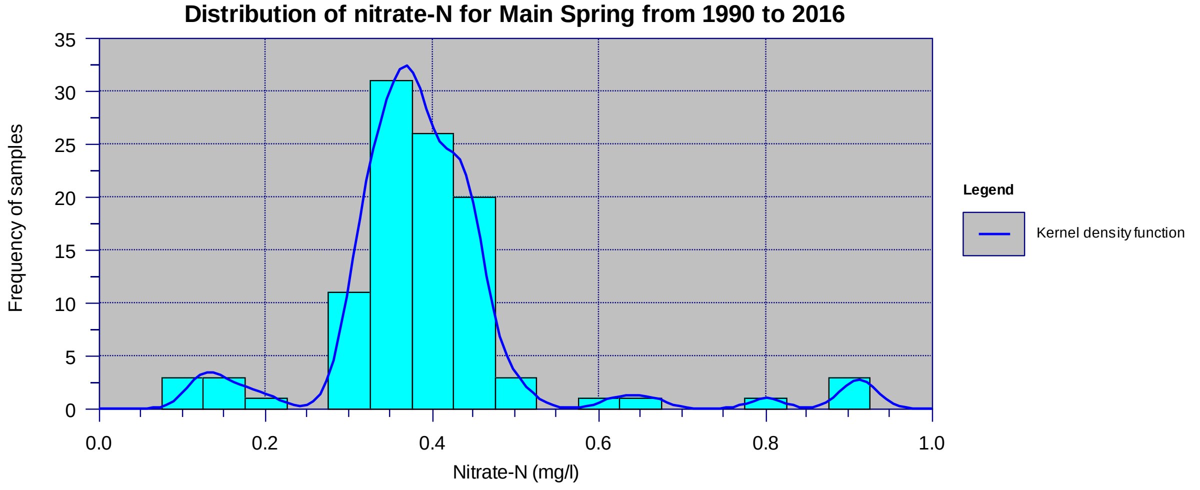
This figure suggests three regions: 1990 to 1995; 1995 to 2011 and 2012 to 2016. These are studied separately (see sections 2.2.3, 2.2.4 and 2.2.5)

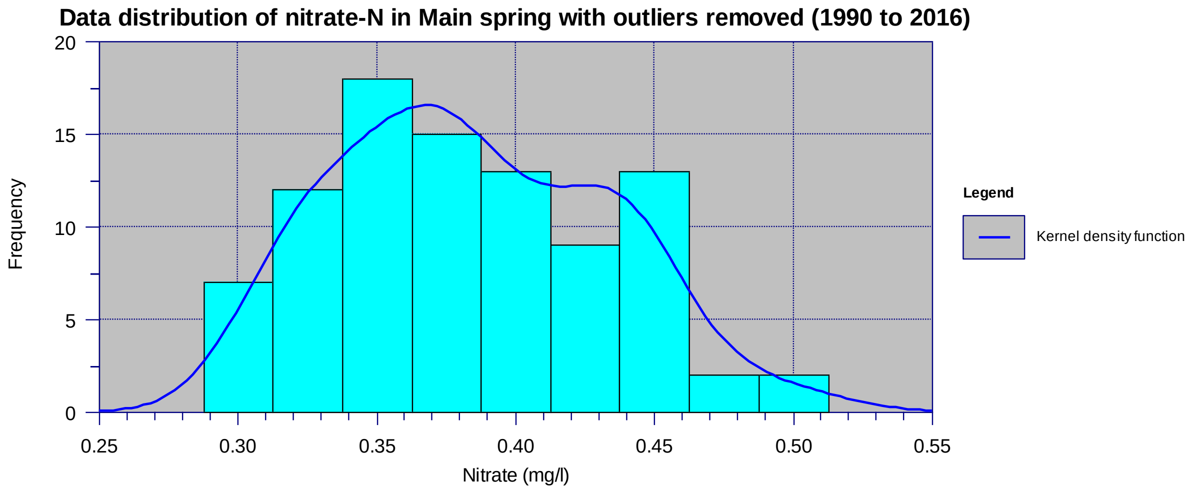
2.2.2 Check for seasonality and normality:

Seasons were found to be not significant (P = 0.635).



The box plot suggested that the data are not normally distributed. This was explored by a frequency plot and this shows, even if outliers are omitted the distribution is still skewed:





When using of non-parametric tests this is not a problem.

2.2.3 Analysis of 1990 to June 1995 data:

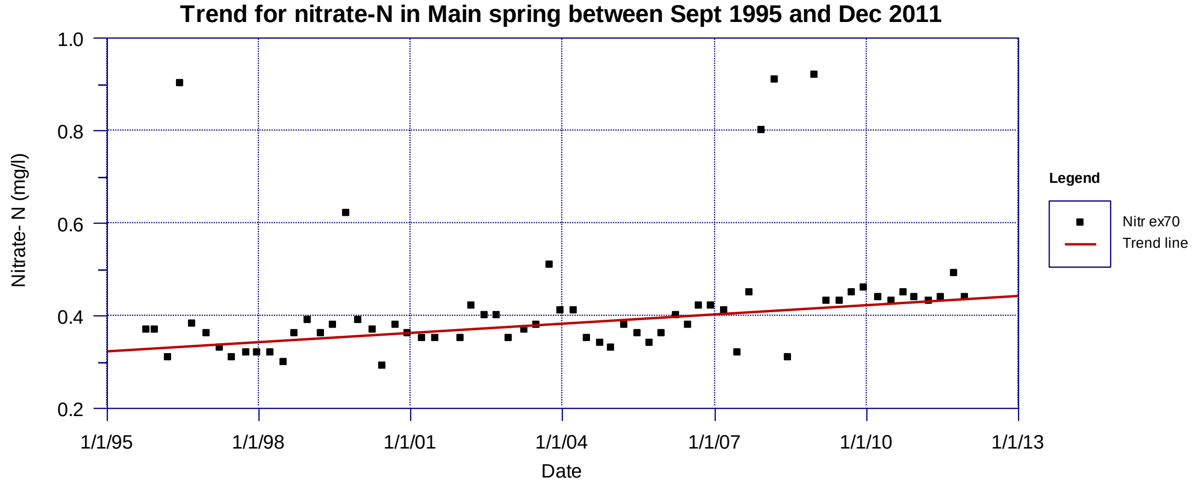
This is the early period suggested by the initial graph. The Mann-Kendall trend test (which is resistant to outliers) found no statistically significant linear trend in this short-term data set although the data itself suggested there was a major short-term drop in nitrate levels in 1991-92. There was no relation of nitrate concentrations to Spring water flow, Cl or Ca levels.

Mean nitrate-N = 0.282 mg/l (range 0.12 – 0.43); median = 0.33 mg/l; SD = 0.106 mg/l.

Rosen (1999), who first reported this data, suggested that a change in water flow may have resulted in the low nitrate concentrations but this analysis did not confirm this.

2.2.4 Trend test for Sept 1995 to Dec 2011:

This long period, where there was a steady increase in nitrate, was analysed using the Mann-Kendall trend test.

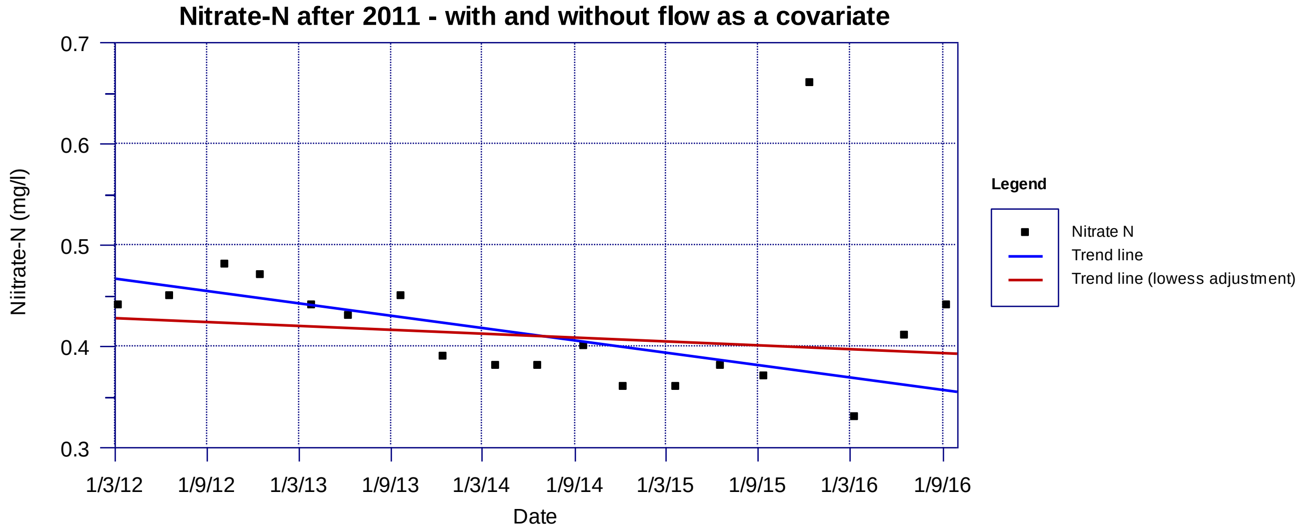


Results:
N = 65; Kendall statistic 770; Z = 4.326; ***P* = <0.000**
Median annual slope = 0.006 mg/l N per year (90% CI 0.005 to 0.009)
Percent annual change = 1.70%

There are a few outliers but they do not affect the conclusion that there was a steady rise in nitrate-N over this period. Removal of values >0.6 mg/l gave the percentage annual slope as 1.65%.

The use of covariates which might explain the upward trend was investigated. Nitrate-N was not correlated with the Spring's flow rate, Cl, Ca, Mg, K or Na but there was a significant Pearson correlation with SO_4. All were tried as covariates but did not change the results appreciably and the upward trend was always highly significant (*P* = >000).

2.2.5: Statistical analysis for period 2012 to Sept 2016:
The Mann-Kendall trend test found a significant decrease in nitrate-N but when the Spring's flow rate was used as a covariate the analysis the slope was not significant.



Mann-Kendall trend test results:
Unadjusted
N = 19; Kendall statistic = -64; Z = 2.223; ***P = 0.026***
Median annual slope = -0.024 mg/l N per year (90% CI -0.007 to -0.032)
Percent annual change = -5.91%

Adjusted using Main Spring flow rate as a covariate
N = 19; Kendall statistic = -34; Z = 1.158; ***P = 0.247*** (not significant)
Median annual slope = -0.008 mg/l N per year (90% CI 0.002 to 0.020)
Percent annual change = -1.88%

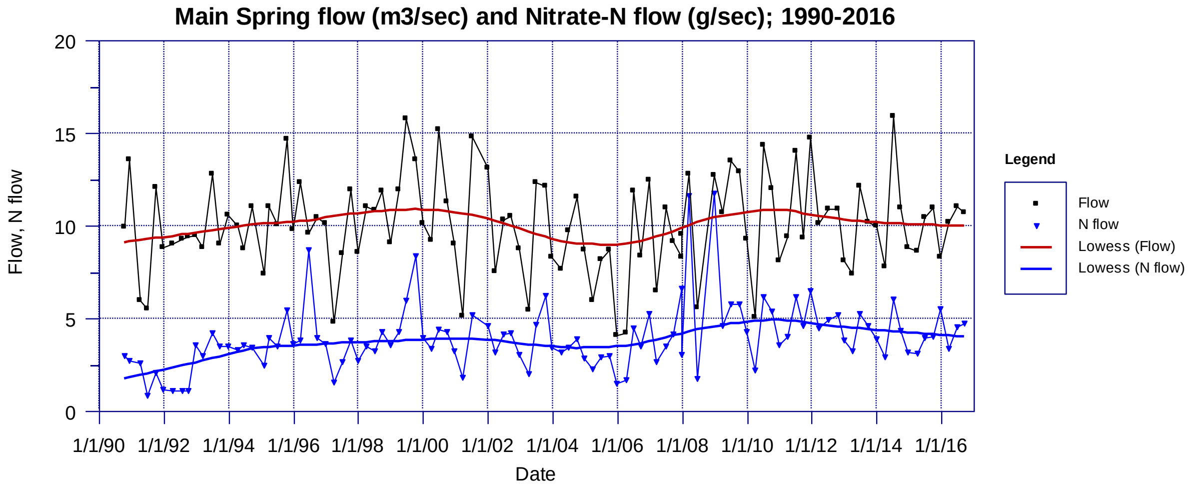
Flow, as a covariate adjustment (by lowess), explained 14 % of the variation.

The median nitrate-N for this period is 0.41 (range 0.33 to 0.66, SD = 0.071).

It is thus still unclear as to whether the nitrate levels are decreasing, but they seem to have plateaued.

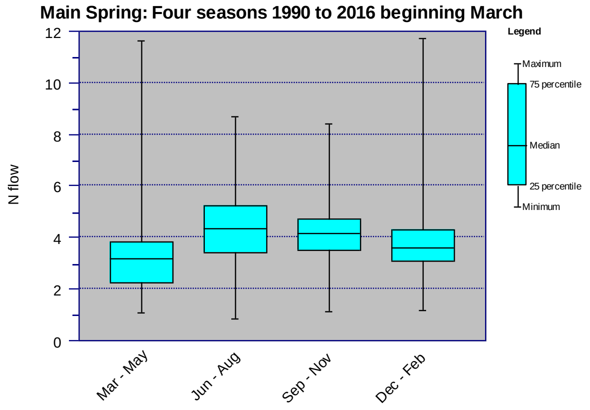
2.2.6 Study of nitrate-N discharge in the Main Spring:

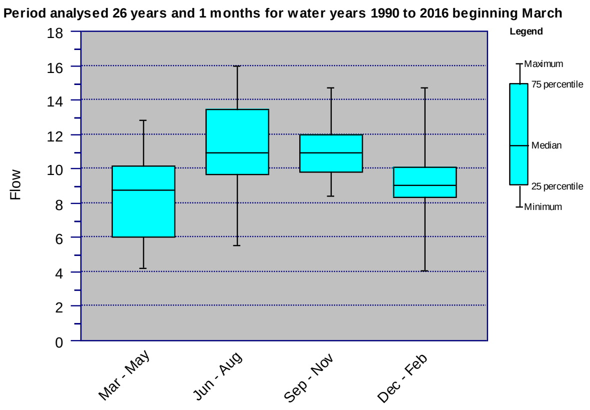
The actual flow of nitrate-N in grams/second was obtained using the concentration and spring flow data. The graphs of water flow and nitrate-N flow between 1990 and 2016 do not show the same three distinct time periods as the nitrate-N concentrations showed. Rather both have two periods when these flows were higher, presumably owing to long-term climate fluctuations.



Lowess for water flow explained 9% of the variation
Lowess for N flow explained 20% of the variation

For both parameters there was a strong seasonal effect:





	Mean				Median				Probability
Month	*MAM*	*JJA*	*SON*	*DJF*	*MAM*	*JJA*	*SON*	*DJF*	
N flow (g/sec)	3.34	4.28	4.22	4.01	3.16	4.32	4.17	3.59	**0.00607**
Flow (m^3/sec)	8.41	11.26	11.01	9.48	8.72	10.94	11.00	9.06	**0.00005**

The non-parametric Seasonal Kendall test gave the following results:
Flow (m^3/sec)
N = 104; Kendall statistic = 2; Z = 0.044; ***P* = 0.965** (not significant)
Median annual slope = 0.031 m^3/sec per year (90% CI -0.042 to 0.048)
Percent annual change = 0.03%

Nitrate-N flow (g/sec)
N = 102; Kendall statistic = 340; Z = 7.783; ***P* = <0.000**
Median annual slope = 0.064 mg/l N per year (90% CI 0.036 to 0.089)
Percent annual change = 1.72%

Over this 26-year time period there was no change in the water flow from the spring but there was a definite increase in nitrate-N discharging from the Main spring. This confirms the conclusion from the analysis of nitrate-N concentrations. With further study of the nitrate-N discharge rates it may be possible to explain the long-term fluctuations shown on the graph.

2.6 Summary:
There has been an increasing trend in nitrate-N in the Main Spring since 1990. There is a suggestion that nitrate may be decreasing in recent years but this is not yet clear because this may be related water flow.

The significance of these findings are that nitrate-N has risen for many years in the Main Spring and are now at a concentration that is of concern in that they may threaten the health of the aquifers' ecosystems.

3 References:

Daughney C J, Reeves RR 2005. Definition of hydrochemical facies in the New Zealand National Groundwater Monitoring Programme. Journal of Hydrology (NZ) 44: 105–130.

Helsel DR, Hirsch RM 2002. Statistical methods in water resources. Chapter A3 of Book 4, Hydrologic analysis and interpretation. Techniques of water-resources investigations of the United States Geological Survey. United Sates Geological Survey, U.S. Department of the Interior. 510 p. Available at:
http://water.usgs.gov/pubs/twri/twri4a3/

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Michaelis FB 1974. The ecology of Waikoropupū springs. PhD thesis, University of Canterbury, Christchurch. 158 p plus appendicies.

Michaelis FB 1976. Physico-chemical features of Pupu Springs. New Zealand Journal of Marine and Freshwater Research 10: 613–628.

Mueller M 1987. Takaka valley hydrology (preliminary assessment). Nelson Catchment and Regional Water Board internal report (available TDC, Takaka Library)

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Appendix 2.

Results of Friends of Golden Bay weekly sampling at Te Waikoropupū in 2016

Dr D J Mead, Jan 2017

1.1 Introduction:

Friends of Golden Bay (Inc) have been undertaking weekly sampling of the Springs and Fish Creek from 2 February 2016 and this report gives the preliminary results. A full report will be undertaken after there is a full year's data.

1.2 Methods:

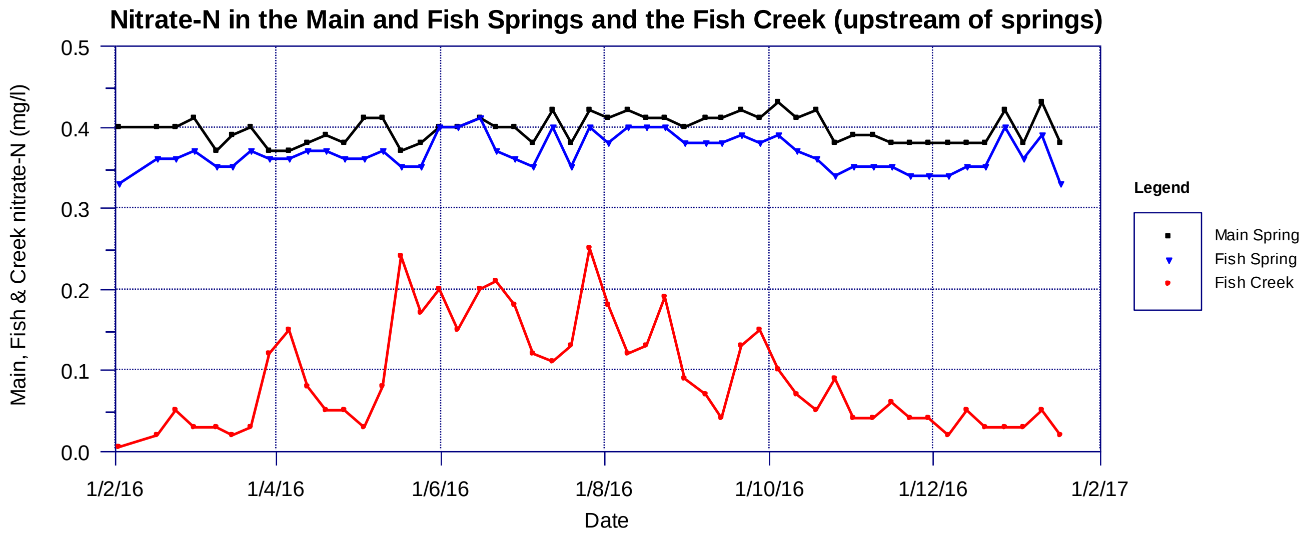
Samples were collected weekly, usually at noon on Tuesday, by Andrew Yuill and Greg Anderson. Filtered water samples were taken from the Main Spring, Fish Spring and from Fish Creek where it enters Te Waikoropupū reserve. The Fish Spring site samples were taken from a different vent from that sampled by TDC. This vent was chosen because it this vent still flows during droughts. The Fish Creek site is upstream of Fish Springs. Fish Creek starts in a bush-clad catchment and flows through a couple of dairy farms.

Samples were sent overnight to Geological and Nuclear Sciences where all were analysed for nitrate-N and dissolved reactive phosphate (DRP). Some samples were also analysed for Cl concentrations. At the same time as the water samples were collected water temperature and water conductivity were measured with an YSI 30 multimeter (kindly provided by TDC). Temperature and conductivity were also measured at the TDC Fish Spring site and at Fish Creek downstream of the Fish Springs (since 28/6/2016).

Data have been analysed using Time Trends Version 6.01, build 11.

1.3 Results:

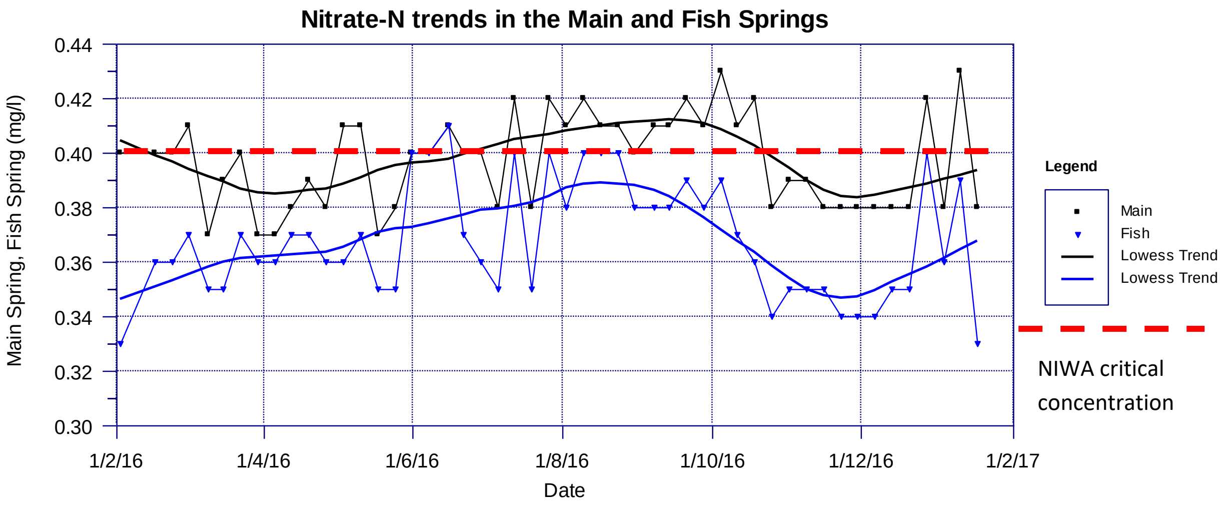
1.3.1 Nitrate-N changes:



The nitrate-N in the Main Spring is almost always consistently higher than Fish Spring and sometimes slightly above the critical concentration of 0.4 mg/l recommended by NIWA (2015) for protection of the stygofauna. Fish Creek nitrate-N concentrations were higher after the summer drought broke with peaks occurring at high rainfall events owing to the effects of the farming operations upstream. Note the catchment is dominated by forest.

1.3.2 Seasonal nitrate trends in the Spring:

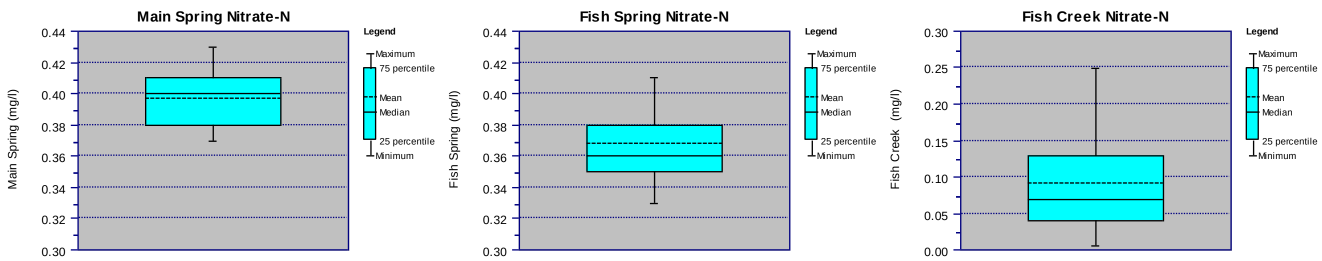
There were significant seasonal/climate-related trends in the Springs nitrate-N concentrations. They were stronger in Fish Spring, presumably because of its higher proportion of shallow aquifer water. This is the first time such a trend has been detected. The reasons behind these trends are still to be studied in depth.



Knowing there is a seasonal/climate related trend may help in designing a monitoring system for managing these aquifers.

1.3.3 Nitrate-N statistics:

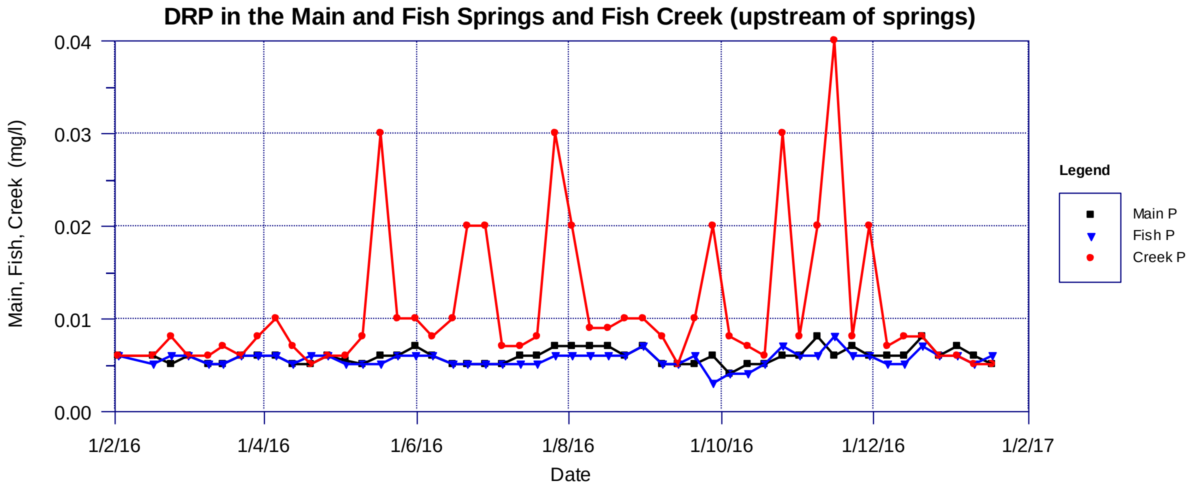
The basic statistics from 2 February 2016 to 17 Jan 2017 are shown below by box plots:



The median nitrate-N concentrations (with SD in brackets) in the Main and Fish Springs were 0.40 (0.017) and 0.36 (0.021) mg/l.

1.3.4 Dissolved reactive phosphate (DRP):

DRP was low and with only small variations in the Main and Fish Springs, but in Fish Creek the phosphate levels were higher during the winter/spring.



The ANZEC (2000) 'trigger' concentration for lowland streams is 0.01mg/l and Fish Creek was at or above this concentration a third of the time because of farm run-off.

The median DRP in both the Main and Fish Springs was 0.006 (SD = 0.001) mg/l.

1.3.5. Other results:

Nitrate-N was lower in Fish Springs than in the Main Spring. Other TDC sampling has consistently found the reverse. The difference is due to the different analytical methods as the automated cadmium reduction technique gives higher values (see Appendix 1). This result has implications for understanding the AM aquifers.

Chloride concentrations were measured less frequently with the median concentrations being 104.5, 24 and 4.3 mg/l in the Main Spring, Fish Spring and Fish creek, respectively. Main Spring to Fish Spring Cl concentrations varied with water flow but their ratio was usually constant. Water conductivity was closely related to Cl concentrations in the Springs.

Water conductivities were also used to estimate the proportion of water that comes from Fish Springs lower down Fish Creek. Some 95-96% of the water comes from these Springs unless the creek is in flood.

1.4 Conclusions:

Nitrate-N is lower in Fish Springs than the Main Spring, but both are close to or at the 0.4 mg/l critical concentration recommended by NIWA (2015). There is also a significant seasonal/climate-related trend that could be useful in designing reliable monitoring techniques.

DRP is low in the Springs but is frequently high in Fish Creek. Together with elevated nitrate-N concentrations and very high *E coli* levels (not reported here) in Fish Creek, they illustrate the run-off from upstream farms. Similar run-off can be seen in data from elsewhere in the Takaka catchment, although often nitrate-N is higher than in Fish Creek.

2 Reference:

NIWA 2015. Sustainability of Te Waikoropupu Springs' aquifer ecosystems. Client report CHC2015-020 by Graham Fenwick. 16 pp.