NIWA
Taihoro Nukurangi

Rai catchment management plan

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Version 1

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Photo credit here as follows: Mist over the Rai Valley. [Photograph provided by Marlborough District Council]

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1. Executive summary

River water and habitat quality in the Rai River catchment, Marlborough, has become degraded as a result of inputs from farming in the catchment. Marlborough District Council (MDC) retained the services of NIWA via the Envirolink fund to:

- Review the current water quality situation in the Rai catchment and the effectiveness of mitigation action to date.
- Provide analysis and guidance about what future actions would be most practical and effective to continue to assist in mitigating the water quality issues in the catchment.

Following a field visit to the Rai catchment an assessment has been made of key ways in which adverse effects due to farming might be mitigated, as follows.

1.1.1 Effluent management

- There are no direct discharges of pond effluent; land irrigation is the method of disposal used by Rai catchment dairy farmers.
- Effluent application must be not less than 20 m from surface water bodies and carried out so that surface runoff to rivers and streams and rapid drainage to groundwater does not occur.
- Storage ponds for Farm Dairy Effluent (FDE) irrigation must be properly sized to enable deferral of irrigation in wet weather until soil water holding capacity is sufficient for surface runoff and drainage not to occur. This has the advantage of giving farmers maximum benefit from the nutrient value of the FDE as well as minimising potential eutrophication of receiving waters.
- Advice on optimal sizes for FDE storage ponds may be obtained from Massey University and their “FDE Storage Calculator”, or by referring to the dairy industry’s “DEC Manual - Managing Farm Dairy Effluent”, which recommends a pond size of 340 m^3 per 100 cows.
- Effluent storage ponds must be sited no closer than 20 m from waterways. Where there are serious impediments to complying with this MDC regulation, farmers may wish to design ponds so that spillage into waterways does not occur and that ponds are protected from river flooding. This might be achieved with bunds.
- Spray rates for irrigated FDE should be matched to local soil characteristics (infiltration rates etc.) and conditions (soil moisture, slope etc.). The DairyNZ “Farm Dairy Effluent (FDE) Design Code of Practice” is the best source of information about this and advice on using it should be sought from appropriate experts. Guidance on FDE application rates for different soils is available in DairyNZ Farmfact 6.9 “How much effluent am I applying to land?”
- The Area used for land irrigation of FDE should be at least 5 ha per 100 cows.

Farmers may need to obtain detailed information about soil types and infiltration rates in order to achieve optimal irrigation of FDE.

1.1.2 Stock exclusion/fences

- Farms on the Rai, Ronga, Brown and Opouri Rivers should exclude stock permanently from access to the rivers with fences that are at least 3-4 m from stream edges. However, it may be better to have temporary, electric fences in low-lying flood-prone areas, with controlled grazing in summer to manage pasture growth. Fonterra dairy farmers should strive to meet the Dairying and Cleans Streams Accord objective of having 90% of dairy cattle excluded from streams, rivers and lakes by 2012.

- Smaller tributaries should also be fenced to exclude livestock where this is feasible. The major pollutant inputs should be identified by (for example) conducting longitudinal surveys down the main river stems and measuring flows and concentrations of water quality variables. Alternatively, some tributary sites could be included in the routine monitoring but made optional, depending on flow conditions, and flows estimated by hydrological area scaling – if the catchment areas are known.

- Monitoring has the advantage of detecting effective land use changes, e.g., adoption of Beneficial Management Practices (BMPs, also called Best Management Practices), and showing farmers the environmental benefits of their actions.

- Stream-banks that are permanently fenced should be planted with shade trees and shrubs to maintain cool water temperatures and minimise unwanted plant growth (viz. periphyton). This has the added advantage of providing a buffer between land and river for trapping pollutants that are transported predominantly in surface runoff, such as phosphorus (P), sediment and faecal matter. Protected wetland/seepage areas will promote nitrogen (N) loss via denitrification.

1.1.3 Stock crossings

Significant progress has been made by MDC and the Rai catchment farmers in constructing bridges and culverts crossing sensitive stream sites. There should now be an initiative to have the remaining 9 high priority (and some of the 30 low priority) streams crossed with bridges or culverts.

1.1.4 Other mitigation methods, farm plans and modelling

A number of methods for mitigating surface and subsurface runoff are mentioned in the report but may be regarded as being possibly of lesser importance than riparian management, cattle crossings and FDE irrigation management. There may be circumstances, however, where they should be investigated by farmers as ways of mitigating pollutant inputs to waterways. The Dairy NZ “Farm Enviro Walk” package is recommended for all dairy farmers.

- Reducing soil Olsen P levels to the agronomic optimum, or using slow-release P fertiliser, to prevent rapid loss of P from land to rivers.

- Reduce soil compaction by good stock management to avoid entry of pollutants (N, P, sediment and faecal matter) in surface runoff. Lighter grazing promotes better soil infiltration rates.
- Effluent from standoff pads and feed pads, or laneways used for that purpose, should be managed to minimise direct runoff to nearby waterways. Feed and standoff pads may require bunds to contain effluent on-site.
- Farm plans are a useful means of getting information about farms and their likely impacts on waterways and are recommended here. Information about FDE storage ponds, irrigation areas, location of fences and open drains, soil characteristics and fertiliser use can be used to target and prioritise actions to mitigate undesirable runoff.
- Farm plans have been trialled by Waikato Regional Council for the Toenepi dairy catchment, in the form of a dynamic map showing targeted areas and actions that have been completed. A similar approach was adopted by the NZ Landcare Trust for farms in the Lake Brunner catchment.
- Detailed information provided in farm plans might be used to examine relative contributions of N and P to runoff losses (e.g., fertiliser versus soil losses for P, or FDE irrigation runoff versus diffuse losses from urine patches for N) using the Overseer™ model. Overseer will soon incorporate the "mitigation toolbox", enabling farmers to see which BMPs will achieve the greatest environmental outcome. This may be best achieved with joint inputs from AgResearch (farm systems modelling) and NIWA (stream rehabilitation and water quality). Farm maps would note "hotspots", such as standoff and feed pads, as well as laneways and bridge approaches where concentrations of effluent occur near waterways. They would also show where fences are (and are not), wet areas that may be contributing source areas for P runoff and may need to be fenced, milking sheds, effluent holding ponds and irrigation areas. Existing farm maps used for recording soil fertility and fertiliser use may be a useful starting point for this.

2. Introduction

The Rai Valley located in the Pelorus Ecological District has valley floors that are mostly gently sloping, with fertile terraces and flats. The flanks are generally steep and rise to strong ridges. The lowland valleys are locally wet and cool, with the strong influence of a diurnal ponding of cold air, creating valley fogs and frosts (MDC 2009). The hill country, with the exception of the mountains, has a milder climate. Summers are warm and rainfall (1600-2000 mm annually) is reliable. The Rai Valley was densely forested in the 19th century but returning servicemen took up many local farms in 1919 and there are now 18 dairy farms and several drystock (sheep, beef and deer) farms within the catchment.

Although water quality in the Rai River and its tributaries is generally quite good - on an average annual basis - there are times of the year when this is not the case (notably during summer low-flows) when inputs from pastoral agriculture adversely affect the river system. The rivers have been affected by numerous cattle crossings, runoff of farm dairy effluent (FDE) from land irrigation sites and from wastewater storage ponds near the river network, and cattle grazing along unfenced stream margins. There are some areas within the catchment where sheep and beef cattle have unrestrained access to the river and its tributaries. Consequences of these actions include high concentrations of faecal indicator bacteria (*E. coli*) during summer when the river is used for recreational activities, and occasional high concentrations of nitrate-N (NO_3-N) and dissolved reactive P (DRP).

Water quality in agriculturally developed catchments in New Zealand is generally poor. Concentrations of nutrients (nitrogen, N, and phosphorus, P), sediment and faecal organisms often exceed guidelines for contact recreation, fish spawning and natural ecosystem values (Larned et al. 2004). Dairy farming is a major cause of degraded stream habitat and water quality because of the intensity of land use and the hydrological connectivity that results from having rainfall (plus irrigation in arid areas) in excess of evapotranspiration (Wilcock et al. 2007a; 2011). A number of management practices have been derived for mitigating the effects of pastoral agriculture on natural waters and fall into two broad groups:

- those dealing with land loading at source (e.g., stocking rates, fences, fertiliser application rates and timing, optimal application of effluent to land), and
- those intercepting runoff along hydrological pathways connecting land and water (e.g., constructed and natural wetlands, riparian planting, denitrification barrier walls, cattle bridges).

Not all are suited to every location and some prudence is needed in selecting the right ‘horses for courses’. The “Dairying and Clean Streams Accord” between Fonterra Co-operative Group, regional councils, Ministry for the Environment and Ministry of Agriculture and Forestry stresses the importance of riparian fencing (stock exclusion), nutrient budgeting and fertiliser management, and having waste treatment systems that comply with local regulations.

The community has made a request to Council for assistance with funding for fencing and riparian planting and, while this may be effective in dealing with some of the issues (i.e., faecal bacteria, phosphorus and sediment), other methods may be needed to deal with nitrate where it presents a water quality problem. Before proceeding to a major investment in fencing and the creation of riparian buffer zones, MDC have indicated that they would like to carry out a more detailed analysis of where these zones would be most effective and what other mitigation measures might also be worth considering. This is so that any investment can be targeted where it will be most effective.

To address the issue of riparian management in the Rai catchment MDC have retained the services of NIWA via the Envirolink fund to perform the following tasks:

- Review the current water quality in streams and rivers in the Rai catchment and the effectiveness of mitigation action to date.
- Provide analysis and guidance about what future actions would be most practical and effective to continue to assist in mitigating the water quality issues in the catchment. This may be a general desktop analysis of current water quality data and site conditions (e.g., topography, soils, rainfall etc.) along with some practical field assessment to identify general areas where stock exclusion or other measures, would be most effective.
- Provide a report and catchment scale plan identifying areas or sections of the various waterways that would be best targeted for fencing, along with advice on other management mechanisms that may also be effective in mitigating water quality problems.

2.1 Overview of current monitoring and research information for the Rai Catchment

Marlborough District Council (MDC) has conducted water quality monitoring of the Rai River and its tributaries since 1997. The current programme entails monthly sampling at 14 sites, with fortnightly summer sampling at some of these during summer, and additional weekly sampling for *E. coli* in summer bathing water surveys (Fleur Tiernan, MDC, pers. comm.). The monitoring data has clearly identified that farming in the Rai catchment is having a deleterious effect on water quality. Elevated concentrations of nitrogen (N) and phosphorus (P) forms and faecal bacteria occur and may require different mitigation methods in different parts of the catchment to minimise their impacts on the aquatic environment. Major outcomes of this pollution are extensive periphyton mats (notably in the Ronga and Rai Rivers, but also in parts of the Opouri River) caused by nutrient enrichment, and a potential public health risk to recreationalists in the Rai River from faecal pathogens.

Considerable work has been carried out with the Rai catchment farming community. MDC have conducted surveys of environmental ‘hotspots’ within the catchment, focusing on and prioritising cattle crossings of streams, in particular. A concerted effort by MDC and the farmers has resulted in the worst of these being eliminated by having bridges and culverts crossing sensitive stream sites. The majority of this work is now complete, such that as of 2010 about 80% of high priority and 57% of low priority stream crossings now have bridges or culverts for cattle (Smart 2003; Smart & Hughes 2007; Hughes 2011). That is, 9 high priority and 30 low priority stream crossings were remaining in the Rai Valley in 2009/10 (Hughes 2011). In addition, the NZ Landcare Trust have a current project funded by the Sustainable Farming Fund to work with dairy farmers on developing ways of farming that have less of an environmental impact.

2.1.1 Water quality

Monitoring of the Rai River and its tributaries has been carried by MDC at the sites listed in Table 1 with their MDC codes (also shown in Fig. 1) at different frequencies (monthly, quarterly and annually) over several years. In the last 3 years, water sampling has been at monthly intervals but with fortnightly samples taken during summer (apart from *E. coli* at RAR-1 and RAR-2, which are sampled weekly over the summer period Nov-Mar). A list of the water quality variables monitored and units used, as well as box plots summarising data at sites, is given in Appendix 1. Phosphorus concentrations are elevated throughout the catchment, even at the upstream pseudo-reference sites, but generally increase in a downstream direction (Appendix 1).

Table 1: MDC Water quality monitoring sites and site codes for the Rai River. Upstream sites are shaded (grey).

Site code	Site location	Easting	Northing
BRN-1	Lower Brown River	1648987	5437049
BRN-2	Upper Brown River	1648232	5438140
OPO-1	Opouri above Tunakino confluence	1652486	5437480
OPO-2	Opouri above Tunapai confluence	1658118	5439552
OPO-3	Upper Opouri	1659075	5442029
RAR-1	Rai Falls	1648018	5429266
RAR-2	Rai at Brown River Reserve	1649353	5436649
RAR-3	Rai upstream of Brown confluence	1649547	5437085
RAR-7	Rai upstream of Flat Creek	1648448	5433495
RON-3	Upper Ronga	1651176	5443849
RON-4	Lower Ronga	1649966	5437711
TKO-1	Lower Tunakino	1652187	5437502
TKO-3	Upper Tunakino	1654963	5444398
TNP-1	Lower Tunapai	1658211	5439276

A summary of the water quality data from the 14 monitoring sites (ranges and medians) are contrasted with corresponding ranges of median values from a national monitoring programme for dairy catchments (the Best Practice Dairy Catchments, BPDC, study), as well as trigger values (guidelines) for slightly disturbed lowland river ecosystems (ANZECC 2000) (Table 2). In many cases the Rai catchment site data lie between the two sets of reference data, i.e., the trigger values for slightly disturbed ecosystems and the substantially degraded water quality of streams in catchments with land uses that are close to 100% dairy farming (Wilcock et al. 2007a). It should also be noted that the Rai catchment data is from sites that are both upstream and downstream of dairy farming, with better water quality generally found in the upstream sites.

Units used throughout this report for nutrient forms of N and P, total suspended solids (TSS) and dissolved oxygen (DO) are cited as mg L^{-1} = mg/L = g m^{-3} = g/m^3.

Table 2: Range and median range (bold type) concentrations (mg L^{-1} unless specified otherwise) for water quality variables for the 14 sites monitored in the Rai catchment compared with Best Practice Dairy Catchment study (BPDC) medians (Wilcock et al. 2007a) and trigger values for lowland rivers ANZECC (2000).

Variable	Rai River	BPDCs	ANZECC trigger value [a]
Ammoniacal N NH_4-N	0.005-0.24 (**0.005**)	0.02-0.10	0.021 [b]
Nitrate and nitrite N NO_X-N	0.005-1.06 (**0.005-0.65**)	0.3-2.8	0.444 [b]
Total nitrogen TN	0.05-1.04 (**0.05-0.79**)	0.7-3.3	0.614
Dissolved reactive P DRP	0.0005-0.11 (**0.011-0.014**)	0.02-0.09	0.010
Total P TP	0.005-0.26 (**0.012-0.017**)	0.05-0.17	0.033
Conductivity (µS cm^{-1})	40-226 (**45-145**)	71-271	–
Escherichia coli *E. coli* (MPN/100 ml)	1-12000 (**13-140**)	290-1250	550[c]
pH (dimensionless)	5.5-8.4 (**6.5-7.5**)	7.3-7.9	7.2-7.8
Total suspended solids TSS	1.5-25 (**1.5**)	3.0-21	–
Turbidity (NTU)	0-38.4 (**0.27-1.04**)	2.6-11	5.6
Dissolved oxygen			
DO (mg L^{-1})	5.82-13.5 (**8.5-10.9**)	–	–
DO (% sat.)	68-120 (**82-101**)	81-97	98-105% saturation
Temperature (ºC)	4.1-20.3 (**10.6-14.8**)	10-16	9.8-16.0

[a] See ANZECC (2000) Section 3.3.1.2. This states that: "The default trigger values in the present guidelines were derived from ecosystem data for unmodified or slightly-modified ecosystems supplied by state agencies. However, the choice of these reference systems was not based on any objective biological criteria." The report for New Zealand streams is available at: http://www.mfe.govt.nz/publications/water/trigger-values-rivers-may00/index.html

[b] Note: these are not toxicity trigger values for these contaminants.

[c] Action red level for contact recreation (MfE 2003).

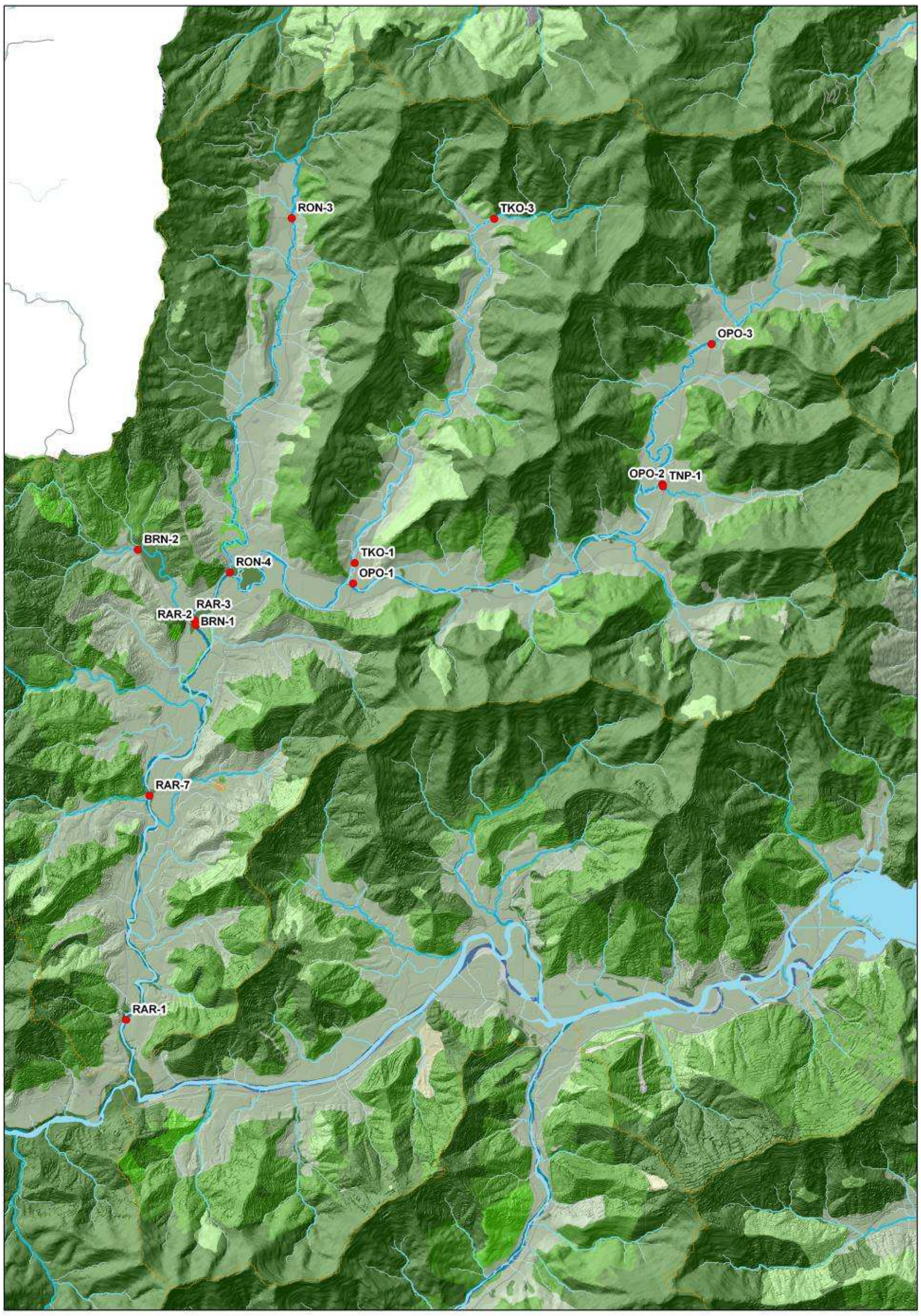

Figure 1: MDC water quality monitoring sites for the Rai River and tributaries.

A simple non-parametric analysis of the summed mean concentration ranks (from lowest to highest mean value) for ammonium N (NH_4-N), nitrate N (NO_3-N), total N (TN), dissolved reactive P (DRP), Total P (TP), *E. coli*, TSS and turbidity shows that sites with the overall poorest water quality are the lower Ronga (RON-4) and Rai Falls (RAR-1), with RAR-7 and BRN-2 the next poorest (Table 3). The sites with the best average water quality are mainly upstream (pseudo reference) sites, viz. TKO-3 and OPO-2.

A consequence of the high nutrient levels is the extensive coverage of periphyton in the Rai and Ronga Rivers. Faecal pollution presents a health risk to people using the rivers for contact recreation and there are anecdotal accounts of kayakers reporting sickness and skin rashes after contact with Rai River water in summer.

Table 3: Ranks of concentration means for selected water quality variables in the MDC Rai catchment monitoring programme in order of worst (highest rank sum) to best (lowest rank sum) water quality. Key: 1=lowest mean, 14=highest mean. See Figure 1 for site locations.

Site code	NH_4-N	NO_3-N	TN	DRP	TP	*E. coli*	SS	Turbidity	Sum of ranks
RON-4	11	14	14	11	14	12	12	10	98
RAR-1	13	13	13	5	13	11	13	14	95
RAR-7	8	12	12	8	11	6	11	11	79
BRN-2	10	2	4	13	12	14	9	12	76
RAR-3	6	11	11	9	9	10	8	6	70
RAR-2	12	8	8	4	7	9	7	13	68
OPO-3	9	7	7	14	4	13	1	3	58
BRN-1	1	5	5	6	8	7	14	9	55
TKO-1	7	6	6	10	10	5	3	5	52
TNP-1	14	3	2	12	2	3	6	8	50
OPO-1	1	9	9	7	6	4	4	4	44
RON-3	1	4	3	1	5	8	10	7	39
OPO-2	1	10	10	2	1	2	5	2	33
TKO-3	1	1	1	3	3	1	2	1	13

Typical NO_3-N concentrations in the Ronga River are shown below (Fig. 2).

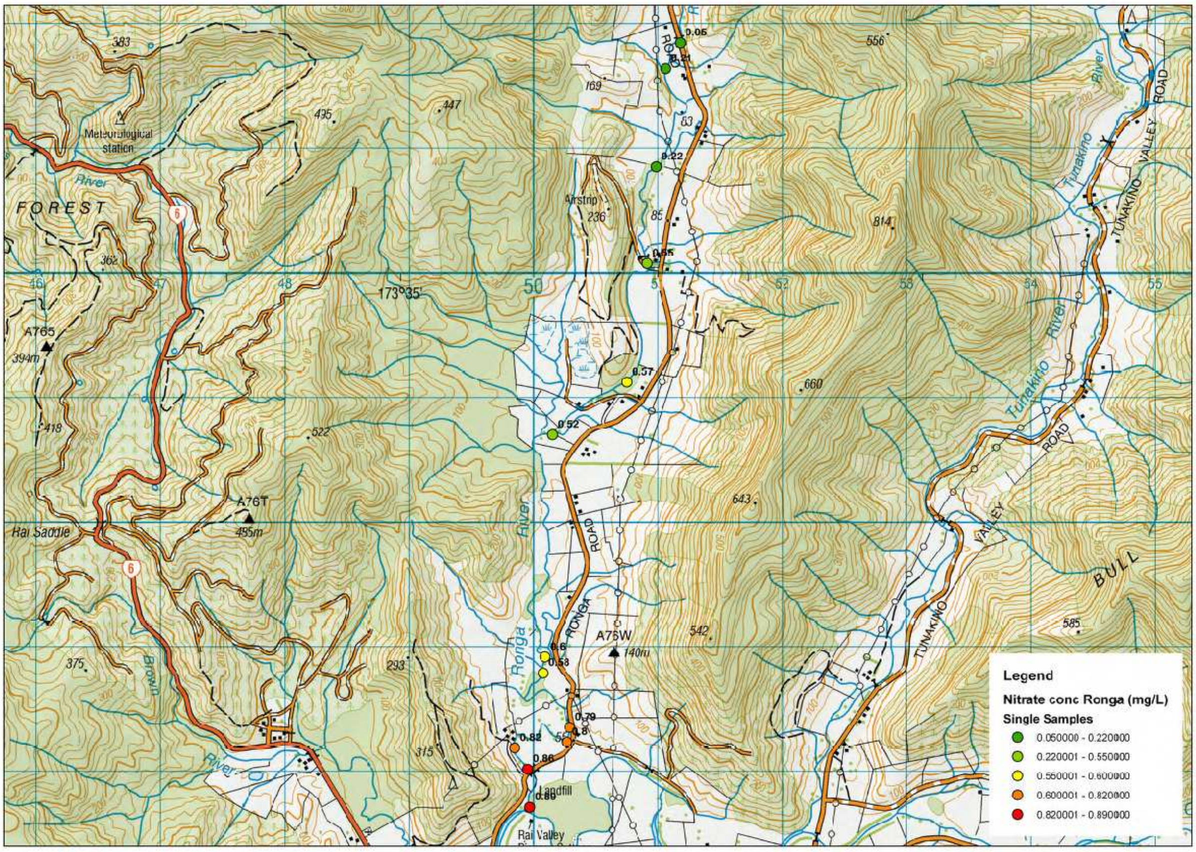

Figure 2: Nitrate-N concentrations along the Ronga River (2010).

2.1.2 Invertebrate surveys

Invertebrate surveys have been undertaken at the same 14 sites used for water quality monitoring with results expressed as macroinvertebrate community index (MCI) and semi-quantitative community index (SQMCI) scores (Figs. 3 and 4). MCI scores are used for assessing habitat conditions in a wide range of stream types, such that a score >119 = excellent or very good; 100-119 = good; 80-99 = fair; and <80 = poor (Stark 2000). The SQMCI responds to changes in community dominance, with the following interpretation of measured values: SQMCI >6, water quality status = clean water; 5-6, doubtful quality or possible mild pollution; 4-5, probable moderate pollution; and <4, probable severe pollution (Stark 1998).

The biological surveys of Rai River sites indicate that the ecosystems can be classed as good–excellent with the notable exception of OPO-3, the Upper Opouri site, which is classed as ‘probable severe pollution’. In addition, there has been a significant decrease in the SQMCI score at OPO-2, the mid Opouri site, which has changed in status from ‘clean water quality’ to ‘doubtful water quality’ or ‘mild pollution’. It should be noted that these data are only for two early winter surveys, in June 2002 and May 2009, and that water quality degradation and periphyton growth happens mostly during summer.

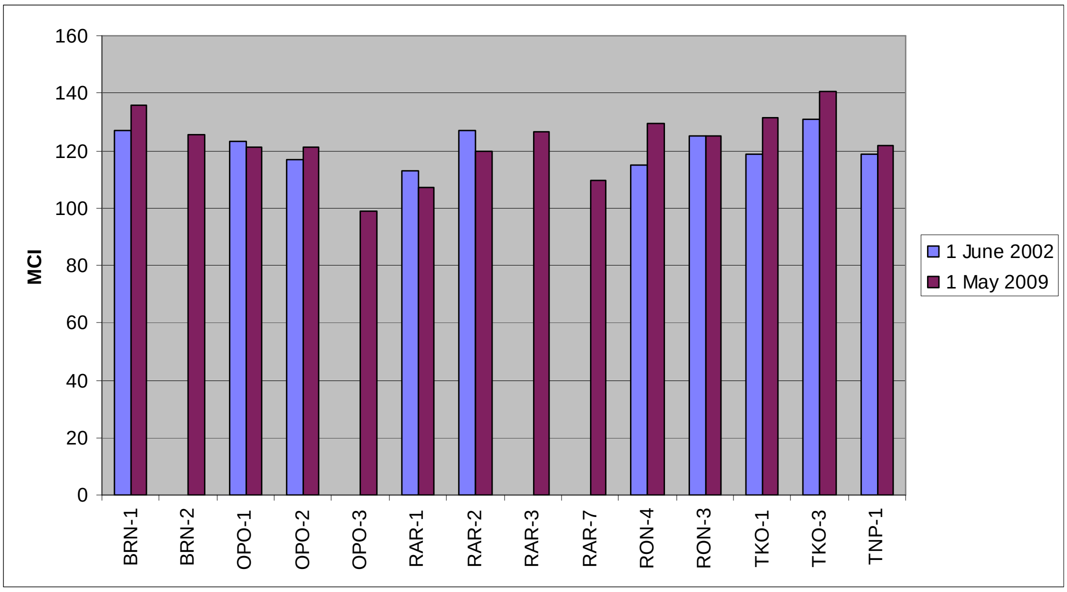

Figure 3: MCI scores for Rai catchment sites.

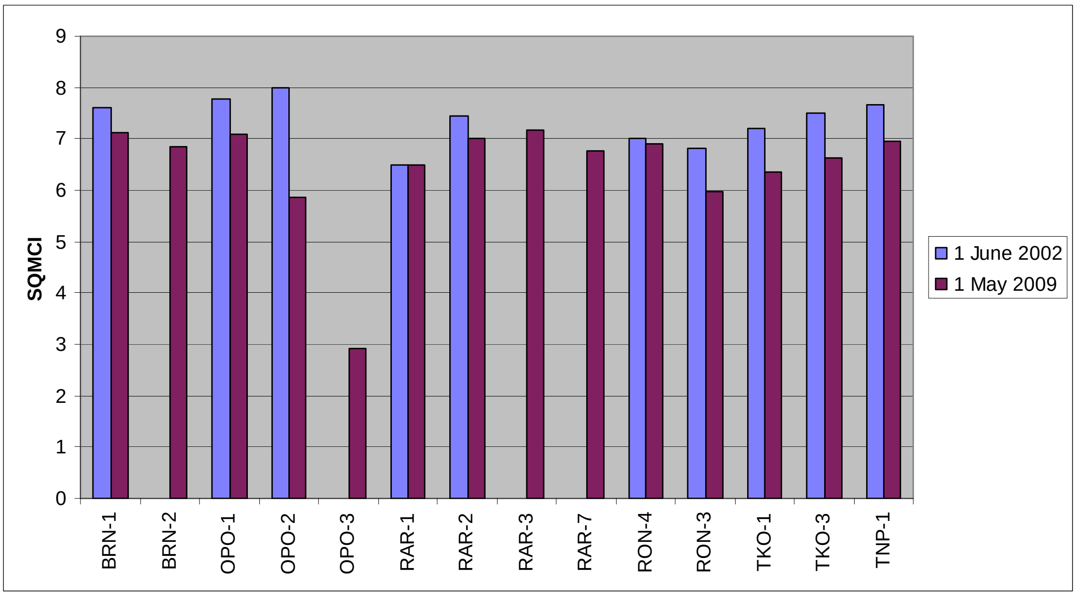

Figure 4: SQMCI scores for Rai catchment sites.

2.1.3 Modelling of N and P concentrations

A NIWA report for MDC (Elliott & Parshotam 2010) used regression models to predict average N and P concentrations in the Rai River as a function of land use. Land uses evaluated were dairy, drystock, forestry and native forest. The total phosphorus (TP) model predicted modest changes in TP concentration such that a 100% pasture land use yielded an average value of 0.031 mg L^{-1}. By comparison, median TP concentrations in the five Best Practice Dairy Catchments were 0.05-0.17 mg L^{-1} (Wilcock et al. 2007a). The total nitrogen (TN) predictions were more notable. Elliott and Parshotam (2010) calculated an average TN concentration of 5.2 mg L^{-1} for 100% pasture, and a yield of 60 kg N^{-1} ha^{-1} yr^{-1}. By comparison the BPDC median TN concentrations were 0.71-3.29 mg L^{-1}, and the TN yields were 25-35 kg N^{-1} ha^{-1} yr^{-1}.

The current land uses in the Rai catchments are: dairy 14%; drystock farming 8%; native forest 60% and plantation 18% (Fig. 5). Future conversion of land use to dairy farming seems limited by the steep topography of the land, but there is scope for modernising and increasing stocking rates on existing farms and perhaps some conversion of drystock farms to dairying. If that were to happen then further increases in TN concentrations might be expected. Nitrate N (NO_3-N) comprises 80-90% of TN in rivers where the dominant land use is dairy farming (Wilcock et al. 2007a).

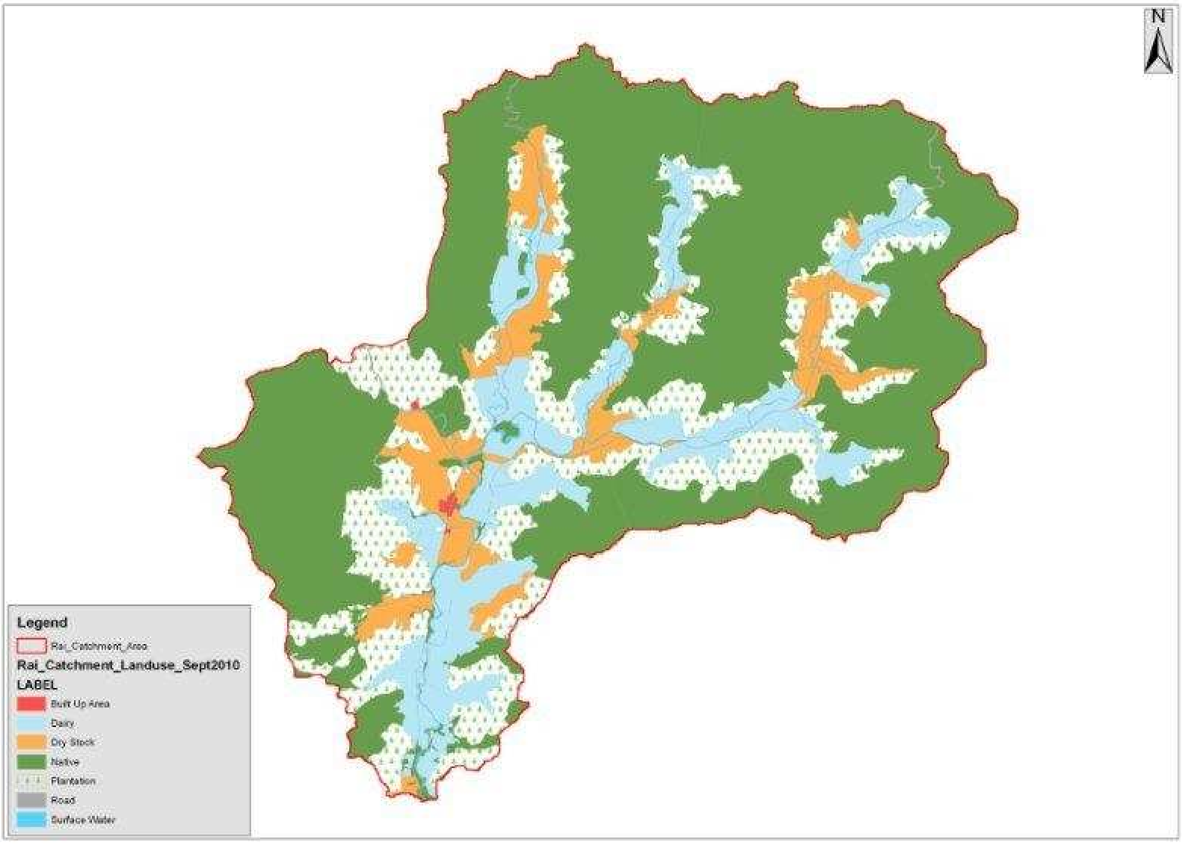

Figure 5: Land uses in the Rai catchment.

3. Field visit and observations – December 2010

A field visit (by the author and MDC officers, notably Nicky Eade, Fleur Tiernan and Justine Hughes) was carried as part of this study out during 8-10 December 2010 with the aims of familiarisation with the key sources of pollution in the Rai River and its tributaries, looking at local farms and identifying key activities that might be changed for the better, and deriving Beneficial Management Practices (BMPs, sometimes called Best Management Practices) that could be adopted to mitigate adverse effects caused by runoff from farms. We noted that the Ronga River in early December had dense mats of filamentous green algae, a kind of periphyton that thrives in open conditions with high nutrient concentrations (Fig. 6), whereas the neighbouring Tunakino River with very little dairying in its catchment had virtually no periphyton at all (Fig. 7). These observations were consistent with the relative nutrient concentrations in these rivers (Table 3).

Figure 6: Periphyton cover of filamentous green algae in the lower Ronga River, 9 December 2010. (Bob Wilcock, NIWA).

Figure 7: Streambed of the Tunakino River, 9 December 2010, with very little periphyton. (Bob Wilcock, NIWA).

Key observations from the site visit:

- Water quality degradation is attributable to both drystock farming (beef and deer) and dairying. Nonetheless, dairy farms have the major impact because of the intensity of land use, the number of dairy farms in the catchment (18) and the relative proportions of land use (14% dairy and 8% drystock).
- There are many family farms in the Rai catchment that have been dairy farming in the district for a long time (fifty years or more). This means that options for improved environmental performance are often limited by the way the farm has come to be organised over time, such as the positioning of milking sheds, effluent holding ponds and (less so) irrigation areas. Many ponds used for land disposal of FDE are too small, are located close to feed pads and other structures so that they can not easily be increased in holding capacity, or are on down-slope areas for easy and inexpensive pumping to irrigation areas (Fig. 8). Relocating effluent holding ponds and increasing their capacity is likely to be expensive for these farmers. The small volumes of many ponds preclude deferring irrigation when soils are saturated and surface runoff losses to nearby watercourses are likely.

Figure 8: An example of a small milking shed effluent holding pond used for spray irrigation to land. (Bob Wilcock, NIWA).

- The MDC 2009/20 dairy farms compliance report shows that a number of farms do not comply with standards by having discharges and wash water collection, containment and application systems within 20 metres of a surface water body. MDC rules for dairy effluent disposal to land in the Marlborough Sounds plan stipulate that the “discharge shall not be within 20 meters of a surface waterbody or over any unconfined aquifer”. Furthermore, “there shall be no run-off of contaminants into surface water resulting from the discharge of the contaminant onto or into land”.
- Where the Rai River is buffered from farms either by riparian reserves or roads there is a break in the connectivity between farmland and river, and generally less impact on water quality and stream health.
- The Brown River has been identified as an area of occasionally poor water quality. Site BRN-1 had the worst ranked mean TSS concentration, and BRN-2 had the worst ranked mean *E. coli* concentration, as well as relatively high DRP and TP mean concentrations (Table 3). These effects are likely to be caused by beef cattle fording a small (possibly ephemeral) tributary of the Brown River (Davies-Colley et al. 2004).
- The lower reach of the Ronga River had an extensive periphyton bloom (Fig. 6) that extended upstream almost as far as RON-3. The narrow valley of the Ronga River has several farms that are close to the river. Of special note is that the effluent irrigation blocks are adjacent to the river so that there is a high degree of connectivity between land and water. One of the remaining high priority stream crossings is in the lower Ronga River and could be a significant source of (notably faecal) pollution.

- There are some drains on farms in the Ronga Valley that might be treatable with small constructed wetlands, especially at the northern (upper) end. The initial recommendation would be to extend irrigation areas and move them further back from river. Improved riparian fencing is recommended, with riparian plants/shrubs.

- The Tunakino River is a clear river with little periphyton evident (Fig. 7), consistent with low nutrient concentrations, although the lower site, TKO-1, has markedly poorer water quality than upper site, TKO-3 (Table 3). Most of the river has riparian fencing with grassy strips either side except for a small area at the upper end. There are two dairy farms along the Tunakino River valley.

- The Opouri River has water quality that is intermediate between that of the Ronga and Tunakino Rivers. Three farms were visited, two of which had very small effluent holding ponds that had inadequate capacity for deferred irrigation. They were also too close to streams (within 20 m) and one of them had been inundated during recent high river flows. The farms are smallish (c. 150 ha) and options are limited for repositioning sumps. The best outcome for the environment would be to make the ‘ponds’ bigger and leak-proof, and to ensure that contact with nearby streams is minimal. Some minor earthworks may be necessary. Relocating the ponds would entail pumping effluent from the dairy shed and, possibly, the need for standby pumps. The irrigation blocks seemed suitably distant from streams although there are some ephemeral streams and wetland seeps that are obviously connected with the Opouri River. Temporary electric fencing during wet periods would be one way of stopping cattle from grazing near the river bank. Jan Derks (NZ Landcare Trust) has recommended greater use of reticulated water tanks in paddocks to reduce the need for cattle to go into wet areas.

- A number of new farm bridges were examined and although impressive structures, they don’t have a way of preventing runoff from the deck to the streams. This might be simply prevented with wooden battens/planks down either side to contain dung and urine. Likewise there remain flow paths for dung to enter the rivers at the bridge approaches and the old river ford sites. This can be rectified with bunds so that animal wastes are diverted away from the river and onto paddocks.

- Jan Derks of the NZ Landcare Trust is compiling farm plans for some farmers that address aspects of environmental sustainability. This report will entail some coordination with Jan’s plans.

4. Beneficial Management Practices

4.1.1 DairyNZ Code of practice

DairyNZ released the Farm Dairy Effluent (FDE) Design Code of Practice (CoP) in February 2011. The CoP is available online[1] and lists six key design objectives:

- to capture all FDE
- to spread the FDE at a time that allows uptake by plants
- to uniformly spread the FDE to the desired depth, and at the desired intensity
- to control FDE application to within the boundaries of the application area
- to ensure that FDE systems can be operated safely; and
- to comply with all regulatory requirements, including consent conditions.

The CoP stresses the need for good prior information about effluent strength (concentrations of N, P, K and total dissolved solids) and soil properties (notably, infiltration rates and water holding capacities) and site layout and gives a rational basis for calculating the area of land needed for irrigation of FDE based on the limiting nutrient concentration. The limiting nutrient is the nutrient in FDE (e.g., N, P, or K) with the highest concentration relative to the annual demand for that nutrient. As FDE is applied, the limiting nutrient will be the first to reach its annual limit. Land area for irrigation is based on soil type(s) ground slope, drainage, proximity to nearby surface water bodies, minimum separation distances to neighbouring dwellings, and prevailing wind conditions. Other factors (e.g., shelter trees) are also considered.

The CoP recommends appropriate storage of FDE prior to land application so that minimal damage to the environment occurs from runoff to waterways, or ponding on pasture. Advice is also given on sprinkler types, nozzles and pumping rates for uniform application to desired depths.

Because of the highly technical nature of the CoP, it is best to seek advice from a specialist, or seek initial advice from the local DairyNZ Consulting Officer.

4.1.2 Massey University FDE storage calculator

The ‘FDE Storage Calculator’ has been developed to identify the unique storage volume required on a dairy farm. The Calculator uses farm specific information, including a soil risk factor, along with local climate data to determine the necessary storage volume. The Calculator predicts the volume of FDE generated on a daily basis and identifies suitable days for irrigation using a soil water balance. The scheduling of irrigation is also dependent on irrigator type and management (Horne et al. 2010). Further advice on use of the ‘calculator’ can be obtained from Dr David Horne, Massey University, or from Dr Dave Houlbrooke, AgResearch, Ruakura Agricultural Research Centre, Hamilton.

[1] http://www.dairynz.co.nz/page/pageid/2145869375?resourceId=625

It is most likely that several of the storage tanks/ponds used by dairy farmers in the Rai catchment will not meet the recommendations of the Massey University calculator, or the DairyNZ CoP.

The FDE Storage Calculator will need to be calibrated for farms in Marlborough using 30-year climate data from climate stations in the region and the addition of local soil data. Soils are assigned as either low or high risk in terms of their capacity to receive and store effluent within the rooting zone. This is based on a soil/landscape framework and includes factors such as: soil infiltration rate, drainage, presence of artificial drains, soil structure, slope etc. This categorisation work is currently getting done for the Marlborough region by AgResearch via a medium Envirolink advice grant and will be available by the end of May or early June.

4.1.3 Other methods for mitigating pollutant loads

In addition to the preceding references to advice on FDE storage and irrigation, there are a range of beneficial management practices (BMPs, formerly called best management practices) that have been derived for pastoral farmers in New Zealand. These are generally of two kinds: those that affect the sources of pollution and land loadings (e.g., stock grazing intensity, effluent irrigation rate and area of coverage, fertilizer application rates and sites); and those sited along hydrological pathways that intercept surface and subsurface runoff (e.g., vegetated riparian buffer zones, wetlands, stock exclusion and vegetated drains). A summary of some key mitigation strategies (BMPs) and estimated reductions in pollutant loads is given in Table 4 (Quinn et al. 2009).

BMPs most likely to be relevant to the Rai catchment are those addressing effluent management and riparian protection from livestock (deer, beef cattle and dairy cows). Other issues that may be important are fertiliser application rate and soil residual concentrations (Olsen P levels), and field drainage networks entering waterways.

Current thinking about intensive dairying is that surface transported pollutants, viz. sediment faecal matter and particulate P, are amenable to a range of BMPs that will achieve substantial reductions (Table 4). However, the hydrological connectivity of many dairy farm systems to nearby surface waters and groundwaters, high loading rates of N (notably in urine patches) and the mobility of nitrate in runoff, limit our ability to contain reduce inputs of N to waterways.

Effluent from standoff and feed pads, or laneways used for that purpose, should be managed to minimise direct runoff to nearby waterways. Feed and standoff pads may require bunds to contain effluent on-site.

Reduce soil compaction by good stock management to avoid entry of pollutants (N, P, sediment and faecal matter) in surface runoff. Lighter grazing promotes better soil infiltration rates. In one study, soil macroporosity, which controls the rate of water infiltration through saturated soil, took 3-4 months to fully recover at 0-5 cm soil depth after moderate treading damage by dairy cows, in which cows were grazed in wet conditions for four hours (Betteridge et al. 2003).

Phosphorus transport in surface runoff is a result of high concentrations in soils and good connectivity between land and water. The contributing source area model of P runoff identifies key areas in landscapes where these two features may co-occur in order to minimise impacts by, for example, fencing permanently wet areas off from stock access, applying the agronomic optimum amounts of P fertiliser, using slow-release P fertilisers, and avoiding compaction of soils by managing stock grazing rates (Betteridge et al. 2003).

Nitrification inhibitors (e.g., dicyandiamide, DCD) have proven successful in cooler climates in lowering nitrate losses in shallow sub-surface runoff and deeper drainage, as well as lessening atmospheric losses of the greenhouse gas nitrous oxide. Nitrous oxide is an intermediate product of the reduction of nitrate via denitrification in anaerobic or suboxic soil conditions. The inhibitors block the microbial enzyme that converts ammonium (NH_4^+) to nitrate (NO_3^-) - the process of nitrification - so that more NH_4^+ is available for plant uptake and less NO_3^- is lost from the pasture in drainage water. Nitrification inhibitors are particularly attractive to farmers when increased production results from greater capture of N by pasture and thereby offsets the cost of applying the product. Nitrification inhibitors are not cost-effective in warm climates where rapid breakdown of dicyandiamide requires that several applications be made annually to achieve a significant reduction in N losses (de Klein & Monaghan 2005).

Other ways of reducing N losses from dairy farms include the use of wintering pads with appropriate effluent and dung collection, and restricted grazing regimes.

Table 4: Potential effectiveness of some mitigation strategies for managing contaminant sources from different New Zealand grassland industries. Key: PN = particulate N; DP = dissolved P; PP = particulate P; FDE = Farm dairy effluent; FD = Field drainage; AEF = Animal excreta to fields; AEW = Animal excreta direct to water; FSR = Field surface runoff; SE = Streambank erosion. (Quinn et al. 2009).

Targeted industry	Mitigation strategy	Source	Percentage mitigation N	P	Sediment	*E. coli*	References
Dairy	Advanced effluent pond treatment system	FDE	63	29	58	99	Craggs et al. (2004)
	Alternative aggregates for tile drains	FD	-[1]	55	38	-	McDowell et al. (2008)
	Deferred irrigation of dairy shed effluent	FDE	99	99	-	-	Houlbrooke et al. (2004)
	Feed pad for use during wet periods	AEFW	0 - 60				Ledgard and Menneer (2005)
	Low rate land application of dairy shed effluent	FDE	90 - 99[2]	86 - 90	-	70 - 95	Houlbrooke et al. (2006)
	Nil grazing in winter (cows sent outside catchment)	AEF	60 - 70	-	-	-	Ledgard et al. (2000)
	Restricted (3-4 hr) grazing during winter of forage crop	AEF & FSR	35 - 50	77	67	91	de Klein and Ledgard (2001); McDowell et al. (2005)
	Low N feed	AEF	20	-	-	-	Ledgard et al. (2006)
	Restricted autumn/winter pasture grazing times	AEF	41	-	-	-	de Klein and Ledgard (2001); de Klein et al. (2006)
	Permanent fencing with riparian planting Dairy, flat-undulating land	AEF, FSR, AEW	4	27	30	80-90	Collins et al. (2005)
Deer	Alternative wallowing sites	AEW, SE	60 - 85	90	88	90	McDowell (unpublished)
	Fencing and riparian planting	AEW, FSR, SE	78 - 91	86	98	92	McDowell (2008a,b)
	Shelter belt to deter fence-line pacing	FSR	15 - 98	-12 - 5	-20 to -120	93 - 95	McDowell et al. (2006)
All	Constructed wetlands[3]						
	Surface and shallow subsurface runoff	FSR, FD	10-40	50-60 PP	>60	80	McKergow et al. (2007)
	Subsurface mole and tile	FD	10-40	0	30-50	80	
	Stream-flow from 100-500 ha agric. catchment	All	10-40	50-60 PP	>60	80	
	Riparian grass filter strips: Sheep/beef, hill-land	FSR	<67 NO_3 <85 PN	<55 DP <85 PP	<87	60-90	Smith (1989); Collins et al. (2005)
	Low soil Olsen P	FSR	-	10-30	-	-	
	Minimising flood irrigation outwash	FSR	-	80	-	-	Houlbrooke et al. (2008)
	Nitrification inhibitor	FD	0-55	-	-	-	Di and Cameron (2002); Monaghan (Unpublished data)

[1] Not applicable or not measured; [2] Measured as ammoniacal-N; [3] Wetland is 1% of contributing catchment area; greater removals can be achieved with increased wetland size and with the use of filters for P removal in anaerobic conditions

5. Analysis and Recommendations

5.1 General comments

The MDC water quality data (Appendix 1) suggests that the Rai River and tributaries are generally cool (<20ºC), well-oxygenated (>80% saturation), clear (turbidity <2 NTU) waters with low-moderate nutrient concentrations. Nitrate N concentrations in the Rai, Ronga and two Opouri sites (OPO-1 and OPO-2 frequently exceed the ANZECC trigger values for slightly disturbed lowland river ecosystems (ANZECC 2000). Although most *E. coli* concentrations are below the “action red mode” value of 550 per 100 ml for contact recreation (MfE 2003), there are numerous exceedances of this standard (Appendix 1). Furthermore, it is the extreme values and particularly the numbers of outlier values greater than the 75th percentiles that often define water quality problems. Thus, maximum nitrate N in the Rai and Ronga Rivers is about 1 mg L^{-1}, compared with 0.3 and 0.3-0.7 mg L^{-1}, in the Tunakino and Opouri Rivers, respectively. Similarly, 75th percentile values of DRP, and the frequency of *E. coli* concentrations above 5000 per 100 ml, are generally higher in the Rai and Ronga Rivers than in the other two rivers (Appendix 1).

Aquatic plant growth (i.e., macrophytes and algae) in rivers is controlled by nutrient concentrations and available light. From a consideration of nutrients only, the N:P ratio is sometimes a useful index of the relative importance of nitrogen and phosphorus control for the purpose of managing unwanted plant growth (Wilcock et al. 2007b). An N:P concentration (mg L^{-1}) ratio of about 7:1 is optimal for algal growth so that when the ratio is much less than 7 (e.g., 2:1), N limits plant growth because it is in relatively short supply. Correspondingly, when the ratio is well above 7 (e.g., 20:1), then P is the limiting element. Analysis of the mean concentrations of reactive soluble forms of N and P (i.e., the DIN:DRP ratio, where DIN is the sum of NH_4-N + NO_3-N) and total forms (TN:TP ratio) shows that most Rai catchment sites are generally P limited, with the exceptions being BRN-1, BRN-2, RON-3, TKO-3 and TNP-1. The ratio of soluble N:P is most relevant to algae, including periphyton, whereas ratios of total N:P relate mostly to macrophyte growth. In reality, most agricultural rivers are N-rich (P limited) in winter) and N-poor (N limited) in summer. The key point to be made is that both N and P are important at different times of the year, but some rivers are predominantly P limited. Shading of the stream channel by riparian shrubs and trees by 70% or more will minimise growth of nuisance plants. Filamentous green algae (Fig. 6) have a higher light requirement than diatoms so that reduction of lighting, even by a small amount, may shift the balance towards diatoms (Collier et al. 1995).

Nearly half the cows (2000) in the whole catchment are located in farms beside the main Rai River below the Ronga River confluence. Approximately 1100 dairy cattle are in farms within the Opouri River subcatchment, 700 in the Ronga River subcatchment and fewer than 400 in the Tunakino subcatchment. MCI and SQMCI macroinvertebrate scores indicate that site OPO-3 at the head of the Opouri River had ‘probable severe pollution’ (Figs. 3 and 4). The site was not inspected during the December visit and may be attributable in part to the 19 remaining cattle crossings above OPO-3 identified in the 2009/10 survey (Hughes 2011). Further investigation of this site is warranted.

Priority for BMP implementation should be in the order: Ronga and lower Rai > Opouri > Brown > Tunakino.

The following recommendations apply equally to all subcatchments of the Rai River.

5.2 Effluent systems and irrigation

Amounts of N and P entering rivers from FDE irrigation runoff may be reduced by ensuring that irrigation areas are adequately sized (i.e., at least 3 ha per 100 cows and preferably more) and located far enough back to avoid surface and shallow subsurface runoff entering the river. Given that FDE represents roughly 10% of the total excreta output from cattle (Sukias et al. 2001), then allowing at least 3 ha irrigation area for every 100 cows equates to a normal stocking rate of 3 cow/ha on pasture and an average leaching rate of about 30 kg N ha^{-1} yr^{-1}, for pasture receiving no additional N fertiliser (Monaghan et al. 2007). Most of the N draining below the root zone is nitrate (NO_3-N) and there is generally little attenuation until opportunities for denitrification and biological uptake occur in wet soils near stream margins. Denitrification is the only process that removes N from the aquatic environment and estimates vary as to how effective this is in riparian zones; perhaps no more than 7-10% (Zaman et al. 2008).

Monaghan et al. (2007) give the average N excretion (dung+urine) from lactating dairy cows as 0.29 kg N d^{-1} so that 100 cows excrete 10,600 kg N yr^{-1}. In the Rai catchment about 10% of this, or 1060 kg N, is collected as FDE from the milking shed and irrigated onto pasture as FDE at a rate not to exceed 200 kg N ha^{-1} yr^{-1}. Thus, at least 1060÷200, or 5 ha is needed per 100 cows.

FDE irrigation rates are known for 16 of the 18 dairy farms in the whole Rai catchment and are in the range 3-23 ha per 100 cows but 10 farms irrigation areas are less than 5 ha per 100 cows (MDC Technical Report No: 10-002) and may need to increase the size of their irrigation blocks (Fig. 9).

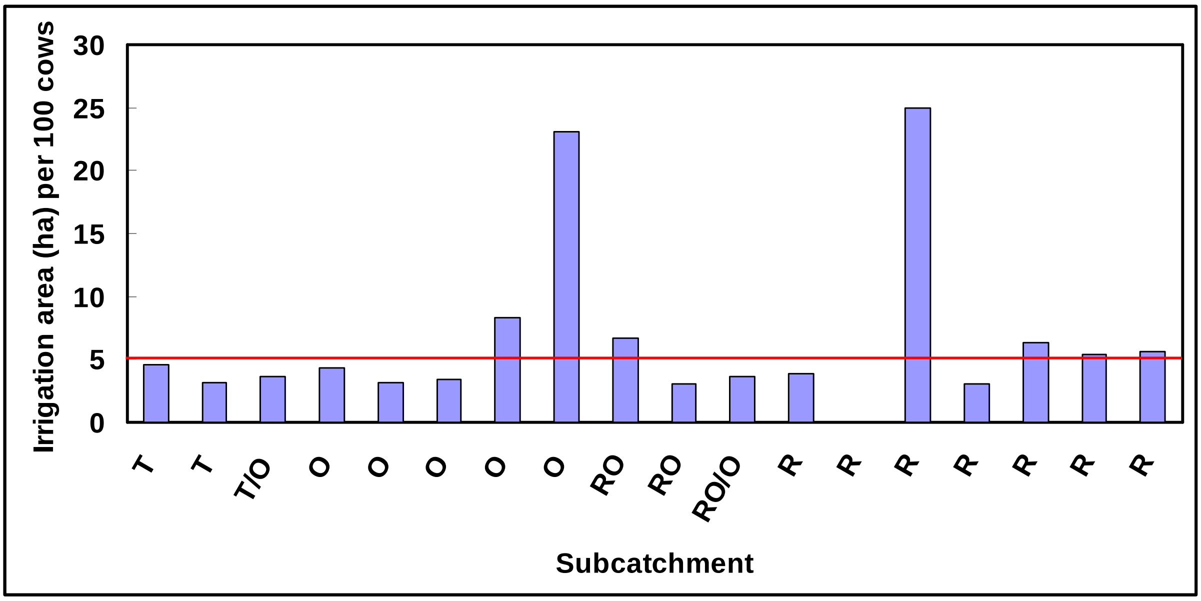

Figure 9: Irrigation loading rate (ha irrigated with FDE per 100 cows) for dairy farms in subcatchments of the Rai catchment. Rates are not known for one farm and have been estimated (based on whole-farm irrigation and a grazing rate of 4 cow ha^{-1}) for another. A recommended loading rate of 5 ha per 100 cows is shown (red line). Key: T=Tunakino; T/O=Tunakino/Opouri confluence; O=Opouri; RO=Ronga; RO/O=Ronga/Opouri confluence; R=Rai .

Leaching rates in freely draining soils for N will be higher than 30 kg N ha^{-1} yr^{-1} and although there are techniques for intercepting groundwater nitrate along hydrological flowpaths, the most cost-effective solutions entail managing land loadings, viz:

- The FDE irrigation area is no smaller than is required by MDC and preferably is at least 5 ha per 100 cows.
- The FDE irrigation area is located at least 20 m from the river to avoid direct entry of surface runoff and provide a reasonable buffer for shallow groundwater to flow through.
- Irrigation should be carried out with well-maintained equipment such that the applied FDE is distributed uniformly and efficiently. Irrigator nozzles may block and the increased pressure cause burst pipes and ponding. Advice is available from the DairyNZ Farm Dairy Effluent (FDE) Design Code of Practice.
- Application rates should be appropriate to soil types, as outlined in Table 5.

Table 5: Maximum application rate and depth for different soil types. (From DairyNZ Farmfact 6.9 “How much effluent am I applying to land?” at www.dairynz.co.nz.)

Soil type	Maximum application depth (mm)	Maximum application rate (mm hr^{-1})
Sand, pumice	15	32
Sand loam	24	20
Silt loam	24	10
Clay loam	18	13
Clay	18	10
Peat	20	17

- Milking shed effluent ponds and sumps should have sufficient storage to defer irrigation of FDE until times when soils are dry, and to provide back-up storage in case of system breakdown, and settling of solids that may otherwise damage the pump. The dairy industry recommends the following requirements for the Marlborough region (section 3.5.8.3 DEC Manual – Managing Farm Dairy Effluent):
  - The best months for irrigation are October-April.
  - Ponds should have a capacity for storing 2 months of FDE.
  - The recommended (guideline) storage volume is 340 m^3 per 100 cows.
- For a typical dairy farm in the Rai catchment with 150-300 cows the recommended storage volume is 510-1020 m^3. The holding pond (sump) in Fig. 8 (located in the Opouri River subcatchment) has a capacity of less than 100 m^3 for a farm of 160 cows. Four of the six lower Rai River farms had FDE holding ponds within 20 m of a boundary or watercourse and some had effluent systems for which improvements were recommended by MDC to improve effluent distribution (MDC Technical Report No. 10-002).

It has been established that if FDE is stored in a suitably sized and lined pond when soil moisture is close to, or at, field capacity, and then applied to land at a time when appropriate soil moisture deficits exist, direct drainage or run-off of applied FDE can virtually be eliminated. Such <u>deferred irrigation</u> of FDE has the potential to retain most of the applied N and P in the soil (Table 4). It should be noted, however that effluent N is mostly in the form of ammonium and that some of this will be nitrified and lost to groundwater via drainage, at an average rate of about 30 kg ha^{-1} yr^{-1}, without additional N fertiliser being applied (Monaghan et al. 2007). Leaching rates calculated for the Best Practice Dairy Catchments, with different amounts of N fertiliser use, are in the range 30-50 kg ha^{-1} yr^{-1} (Monaghan et al. 2008). Because dairy farming is carried out in conditions where there is an excess of rainfall (plus irrigation in arid climates) over evapotranspiration, there is always net runoff (Wilcock 2008). Nitrate is especially mobile in surface and subsurface runoff from pastoral agriculture and is the dominant form of N in pastoral streams (Wilcock et al. 2007a).

Land irrigation of FDE should be deferred when soils are saturated until there is adequate water holding capacity. Deferred irrigation of FDE at a land loading of at least 5 ha per 100 cows has the potential to reduce N and P leaching and runoff losses to the same level as occurs with average losses from pasture (i.e., about 30-50 kg N ha^{-1} yr^{-1} and 1 kg P ha^{-1} yr^{-1}). Such systems utilise low-rate land application of FDE and should be at least 20 m from surface waterbodies.

5.3 Riparian management

The main focus should be on reducing N and P inputs to rivers from dairy farms. Inputs of faecal matter although arguably of lesser importance, do affect the Rai River and its suitability for contact recreation notably near Rai Falls. Reducing sediment inputs, primarily from treading damage done by cattle to stream banks, will improve river habitat quality. It is recognised, however, that sediment loads may be dominated by high rainfall events and flood flows generated in the afforested headwaters of the River system.

The entire length of stream in pasture areas should be fenced both sides to exclude livestock permanently, and the fenced off areas vegetated either naturally or purposefully with appropriate riparian species. Dairy farms should strive to meet the Dairying and Clean Streams Accord objective of having dairy cattle excluded from 90% of streams, rivers and lakes by 2012. However, it may be better to have temporary, electric fences in low-lying flood prone areas, with controlled grazing in summer to manage pasture growth.

Farms should have reticulated water supply tanks in paddocks so that cattle can have access to water without the need to go into wet areas that have a high degree of connectivity with the river network. Critical source areas (CSAs) occur where there is good connectivity with natural waters (e.g., wet soils near seeps and springs) and a high loading rate (heavy grazing and/or fertiliser application rates). Best practice for managing CSAs is to exclude stock and not apply P fertiliser to these areas (McDowell et al. 2004).

Collins et al. (2005) estimate that for flat-undulating slopes and medium soil drainage rates (5-64 mm h^{-1}) vegetated riparian buffer widths of 1, 2 and 4 m may achieve 80, 90 and 95% reductions in faecal bacteria inputs, respectively (Table 4). These reductions in faecal bacteria inputs are based on minimising the risk of direct deposition of dung into stream channels, and wash-off of dung deposited on stream banks (Collins et al. 2005).

Tributaries and open drains should ideally be fenced to exclude stock and often are where there is a risk of animals falling in or damaging drain walls. Because of their high connectivity with the land these small, 1^{st} order watercourses often have very high concentrations, albeit with low flows. The result is that they generally have a cumulative effect on the main rivers while not all having very large individual impacts. Some tributaries and drains will consistently be a cause of water quality degradation in the Rai River system, especially during summer low flow periods, and better understanding of temporal variations in loads to the main river from these smaller sources might be of use in targeting key inputs for better management.

Fences should be at least 3-4 m from stream edges, but in flood prone areas it may be better to have temporary, electric fences with controlled grazing in summer to manage pasture growth.

Riparian fencing and vegetated buffers will not affect N losses greatly because it is mostly nitrate in shallow groundwater. There will be some reductions in N that will amount to <5% that result from plant uptake and denitrification at the land-water interface. Interception of particulate P is likely to reduce P inputs by about 27% (Table 4).

Management of noxious weeds in vegetated buffers is not regarded as a major problem, usually being controlled by spraying from the farm side of the fence. A better long-term solution is to plant native shrubs and trees that shade out unwanted weeds. Examples of how this might be done are available from the NZ Landcare Trust (viz. a recent publication entitled “Best Management Practices for enhancing water quality in the Waikato”) and the following Taranaki Regional Council websites

http://www.trc.govt.nz/assets/Publications/information-sheets-and-newsletters/land-management-information-sheets/riparian-management-information-sheets/50riparianplantguide.pdf

http://www.trc.govt.nz/assets/Publications/information-sheets-and-newsletters/land-management-information-sheets/riparian-management-information-sheets/25plants-for-riparian-margins09.pdf

Riparian fencing a distance of 3-4 m from the stream edge, with some vegetative barrier, will reduce inputs of N (4%), P (27%), sediment (30%) and *E. coli* (80-90%) (Quinn et al. 2009).

5.4 Managing periphyton growth

If undesirable growth of periphyton is the target for managing farm runoff then the aim should be to keep river water concentrations of DIN and DRP below those specified by guidelines. The ANZECC (2000) default trigger values for DIN and DRP concentrations in slightly disturbed lowland river ecosystems are 0.465 and 0.010 mg L^{-1}, respectively, but are not rigorously aimed at controlling periphyton growth. However, they have been adopted as useful benchmarks for water quality by several regional councils in New Zealand.

The New Zealand Periphyton Guideline (Biggs 2000) recommends that for an accrual period 20 days (i.e., the period between major flood flows due to heavy rainfall) and major in-stream values being angling and trout habitat, the year-round monthly average DIN and DRP concentrations should be no more than 0.295 and 0.026 mg L^{-1} (g m^{-3}), respectively. If the target values are aesthetic appearance and recreation a lower level of plant biomass is sought with correspondingly lower concentrations, viz. 0.02 and 0.001 mg L^{-1} for DIN and DRP, respectively.

Nitrate N concentrations in the parts of the river network affected by periphyton (Ronga, Rai and Opouri Rivers) are always in excess of 0.295 mg L^{-1}, meaning that DIN (nitrate N plus ammonia N) always exceeds the less stringent guideline values for periphyton management.

Ways of reducing nitrogen leaching to groundwater are discussed by Monaghan et al. (2008) and include the use of nitrification inhibitors, restricted autumn or winter grazing, and use of covered wintering pads. The Dairy NZ “Farm Enviro Walk” package gives practical advice on ways of reducing water pollution by managing on-farm effluent. Subjects covered include proper design and management of: sumps and holding ponds, land application of effluent, oxidation ponds, and hotspots that include standoff and feed pads.

Standoff pads and laneways used for that purpose, as well as feed pads, collect large amounts of N in the form of urine and dung. These should be contained with bunds or managed otherwise to prevent effluent from entering waterways in surface or shallow subsurface runoff.

Farmers should be encouraged to examine the feasibility of using nitrification inhibitors, if they have not already done so. Under optimal conditions, nitrification inhibitors (e.g., DCD) increase pasture growth and reduce drainage losses of nitrate and emissions of the greenhouse gas, nitrous oxide (Di & Cameron 2002; de Klein et al. 2006).

Use of the Overseer™ model indicates that 40-60% reductions of N loss in drainage may be achieved. The use of a nitrification inhibitor, such as DCD, may increase pasture production by 4% and reduce N leaching losses by about 30% (Monaghan et al. 2008).

Management of P will also be achieved by sound effluent management but is also accomplished through nutrient budgeting and maintaining soil Olsen P levels at the agronomic optimum level for each type of farming. In some instances, slow-release P fertilisers (i.e., those based on reactive rock phosphate) may be best to avoid rapid runoff losses to surface waters.

5.5 Other BMPs

The Dairying and Clean Streams Accord between Fonterra, Regional Councils, Ministry for the Environment and Ministry of Agriculture and Forestry requires dairy farmers to fence their streams, have bridges and culverts where stock cross watercourses more than twice a week, ensure that FDE is appropriately treated and discharge, and manage nutrients to minimise losses to grounds and surface water. Some of these have been achieved in the Rai catchment already (viz. culverts and stock bridges) while others are already addressed in the report. Compliance with the Accord would be a good starting point for improving water quality, with notable attention to nutrient budgeting and management.

Constructed wetlands can be used to lower levels of N, P and faecal bacteria in farm ponds and drains. Guidelines for constructed wetlands in New Zealand have recently been produced (Tanner et al. 2010) and are available at the following website.

http://www.niwa.co.nz/our-science/freshwater/tools/tile-drain-wetland-guidelines

5.6 Drystock farms

5.6.1 Beef cattle and sheep farms

A particular issue in the Rai catchment is beef cattle fording some small streams and causing high concentrations of *E. coli*, suspended sediment and P forms (sections 2.1.2 and 2.1.3). Beef cattle should be fenced out of watercourses, for the same reasons as dairy cows. That is, to prevent stream bank destabilisation caused by trampling and to minimise inputs of faecal matter. Without an “Accord” to be an incentive for drystock farmers, MDC may have to rely on education and an appeal to reason to get farmers to adhere to sound riparian practice. Ideally, cattle should be excluded from watercourses by permanent fences and use bridges or culverts instead of fording rivers and streams. The Brown River and its tributaries is a particular instance where beef cattle in or near the water the have caused water quality degradation.

Drystock farmers should optimise fertiliser use to provide the agronomic optimum for their farms. Reputable fertiliser company representatives should be able to do that.

5.6.2 Deer farms

The New Zealand Deer Farmers’ Landcare Manual (2004) lists ways of minimising damage to soil and water from deer farming. These include:

- Providing alternative (on-farm) locations for deer wallows.
- Fencing off wet areas temporarily or permanently and planting with trees and wetland grasses and sedges.
- Keeping deer out of paddocks with poor drainage during wet weather.
- Design and manage wallow sites with sediment traps.
- Provide shade trees to keep stock cool.
- Excluding deer from streams and other water bodies such as ponds and lakes.

The Manual was developed from consultation with deer farmers and has a wide acceptance within the industry. It was written to “provide farmers an incentive to farm in an environmentally friendly fashion.”

6. Summary and Conclusions

The main causes of water pollution issues in the Rai River network, including excessive periphyton growth in summer and occasional high faecal bacteria concentrations, are attributable to runoff from dairy farms with little riparian buffering. The primary solutions to these problems entail improved irrigation practices for FDE, and better riparian management – notably, permanent fencing and some sort of vegetated riparian buffer. The absence of cattle around riparian seepage areas will enhance denitrification and further reduce N inputs to the rivers. Elimination of the remaining 9 high priority stock crossings should be accorded a high priority for reducing water pollution in the Rai River system.

The Ronga River has the poorest water quality in the Rai catchment and current mean concentrations of DIN and DRP at RON-4 are 0.80 and 0.015 mg L^{-1}, respectively (Appendix 1). Given that the Ronga River is mostly P limited with respect to periphyton growth, an approximately 30% reduction in low-flow concentrations of P, as a result of vegetated fenced buffer strips, coupled with riparian shading will reduce the incidence of unwanted periphyton blooms in the Ronga River. The resulting mean DRP and TP concentrations are likely to be about 0.010 and 0.016 g m^{-3}, respectively, and are lower than the least stringent recommendations for periphyton control specified in the New Zealand periphyton Guideline (Biggs 2000).

6.1 Summary of recommendations

6.1.1 Effluent management

- Effluent application must be not less than 20 m from surface water bodies and carried out so that surface runoff to rivers and streams and rapid drainage to groundwater does not occur.

- Storage ponds for FDE irrigation must be properly sized to enable deferral of irrigation in wet weather until soil conditions are such that surface runoff and drainage do not occur. This has the advantage of giving farmers maximum benefit from the nutrient value of the FDE as well as minimising potential eutrophication of receiving waters.

- Advice on optimal sizes for FDE storage ponds may be obtained from Massey University and their “FDE Storage Calculator”, or by referring to the dairy industry’s “DEC Manual - Managing Farm Dairy Effluent”, which recommends a pond size of 340 m^3 per 100 cows.

- Effluent storage ponds must be sited no closer than 20 m from waterways. Where there are serious impediments to complying with this MDC regulation, farmers may wish to design ponds so that spillage into waterways does not occur and that ponds are protected from river flooding. This might be achieved with bunds.

- Spray rates for irrigated FDE should be matched to local soil characteristics (infiltration rates etc.) and conditions (soil moisture, slope etc.). The DairyNZ “Farm Dairy Effluent (FDE) Design Code of Practice” is the best source of information about this and advice on using it should be sought from appropriate experts. Guidance on FDE application rates for different soils is available in DairyNZ Farmfact 6.9 “How much effluent am I applying to land?”

- The Area used for land irrigation of FDE should be at least 5 ha per 100 cows.

Farmers may need to obtain detailed information about soil types and infiltration rates in order to achieve optimal irrigation of FDE.

6.1.2 Stock exclusion/fences

- Farms on the Rai, Ronga, Brown and Opouri Rivers should exclude stock permanently from access to the rivers with fences that are at least 3-4 m from stream edges. However, it may be better to have temporary, electric fences in low-lying flood-prone areas, with controlled grazing in summer to manage pasture growth. Fonterra dairy farmers should strive to meet the Dairying and Cleans Streams Accord objective of having 90% of dairy cattle excluded from streams, rivers and lakes by 2012.

- Smaller tributaries should also be fenced to exclude livestock where this is feasible. The major pollutant inputs should be identified by (for example) conducting longitudinal surveys down the main river stems and measuring flows and concentrations of water quality variable. Alternatively, some tributary sites could be included in the routine monitoring but made optional, depending on flow conditions, and flows estimated by hydrological area scaling – if the catchment areas are known.

- Monitoring has the advantage of detecting effective land use changes (e.g., adoption of BMPs) and showing farmers the environmental benefits of their actions.

- Stream-banks that are permanently fenced should be planted with shade trees and shrubs to maintain cool water temperatures and inhibit unwanted plant growth (viz. periphyton). This has the added advantage of providing a buffer between land and river for trapping predominantly surface runoff transported pollutants, such as P, sediment and faecal matter. Protected wetland/seepage areas will promote N loss via denitrification.

6.1.3 Stock crossings

Significant progress has been made by MDC and the Rai catchment farmers in constructing bridges and culverts crossing sensitive stream sites. There should now be a push to have the remaining 9 high priority (and some of the 30 low priority) streams crossed with bridges or culverts.

6.1.4 Other mitigation methods, farm plans and modelling

A number of methods for mitigating surface and subsurface runoff are mentioned in the report but may be regarded as being possibly of lesser importance than riparian management, cattle crossings and FDE irrigation management. There may be circumstances, however, where they should be investigated by farmers as ways of mitigating pollutant inputs to waterways. The Dairy NZ “Farm Enviro Walk” package is recommended for all dairy farmers.

- Reducing soil Olsen P levels to the agronomic optimum, or using slow-release P fertiliser, to prevent rapid loss of P from land to rivers.
- Reduce soil compaction by good stock management to avoid entry of pollutants (N, P, sediment and faecal matter) in surface runoff. Lighter grazing promotes better soil infiltration rates.
- Effluent from standoff pads and feed pads, or laneways used for that purpose, should be managed to minimise direct runoff to nearby waterways. Feed and standoff pads may require bunds to contain effluent on-site.
- Farm plans are a useful means of getting information about farms and their likely impacts on waterways and are recommended here. Information about FDE storage ponds, irrigation areas, location of fences and open drains, soil characteristics and fertiliser use can be used to target and prioritise actions to mitigate undesirable runoff.
- Farm plans have been trialled by Waikato Regional Council for the Toenepi dairy catchment, in the form of a dynamic map showing targeted areas and actions that have been completed. A similar approach was adopted by the NZ Landcare Trust for farms in the Lake Brunner catchment.
- Detailed information provided in farm plans might be used to examine relative contributions of N and P to runoff losses (e.g., fertiliser versus soil losses for P, or FDE irrigation runoff versus diffuse losses from urine patches for N) using the Overseer™ model. Overseer will soon incorporate the “mitigation toolbox” (summarised in Table 4) and will enable farmers to see which BMPs will achieve the greatest environmental outcome. This may be best achieved with joint inputs from AgResearch (farm systems modelling) and NIWA (stream rehabilitation and water quality). Farm maps would note “hotspots”, such as standoff and feed pads, as well as laneways and bridge approaches where concentrations of effluent occur near waterways. They would also show where fences are (and are not), wet areas that may be contributing source areas for P runoff and may need to be fenced, milking sheds, effluent holding ponds and irrigation areas. Existing farm maps used for recording soil fertility and fertiliser use may be a useful starting point for this.

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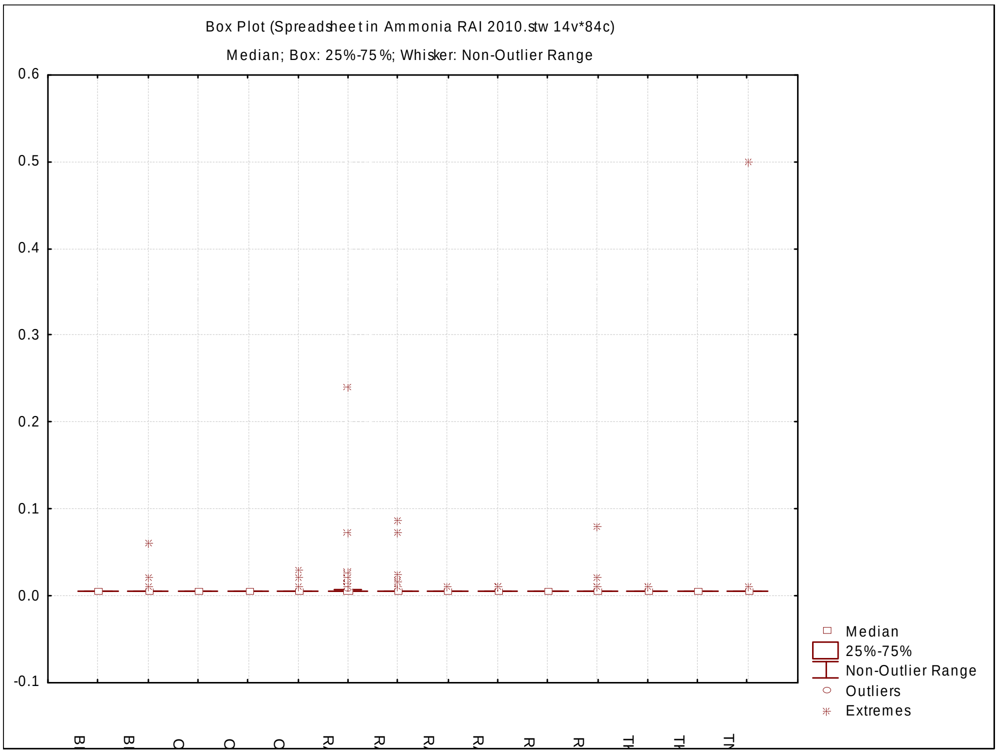
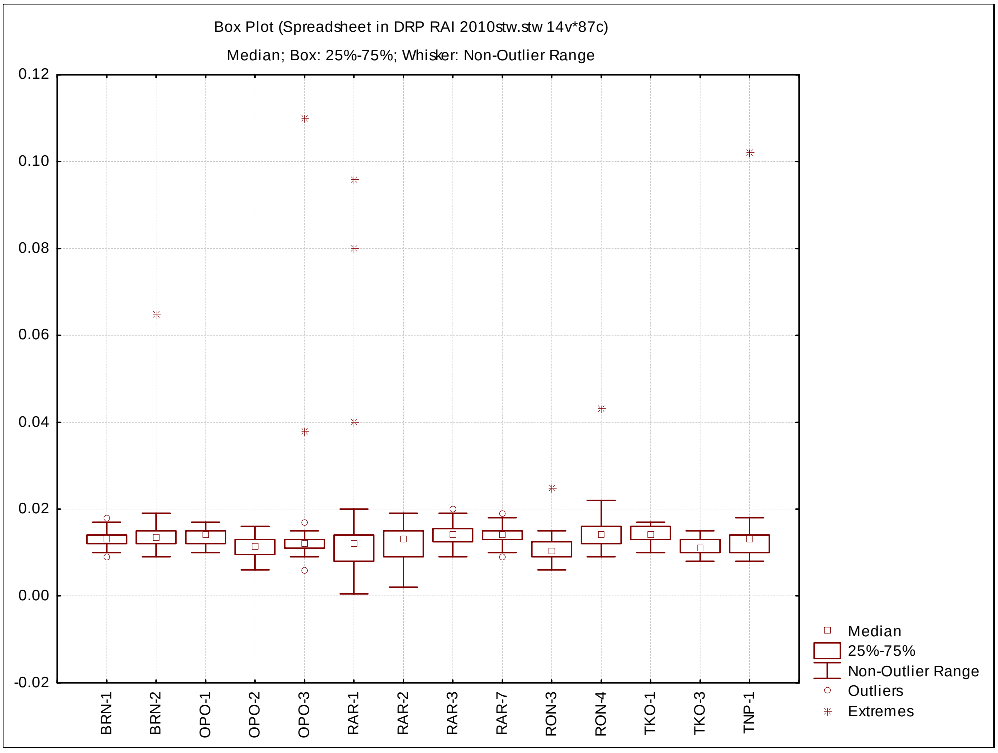
Appendix 1. Summary water quality data

Box plots of MDC data provided by Fleur Tiernan. Water quality variables monitored and units used are: ammoniacal nitrogen (NH_4-N, mg L^{-1}); dissolved reactive phosphorus (DRP, mg L^{-1}); *Eschercihia coli* (*E. coli*, MPN/100 ml); Nitrate plus nitrite nitrogen (NO_X-N, often simplified as nitrate N where nitrite is a negligible component, mg L^{-1}); total nitrogen (TN, mg L^{-1}); total phosphorus (TP, mg L^{-1}); turbidity (NTU), dissolved oxygen (DO, % saturation) and temperature (℃). Units: mg L^{-1} = mg/L = g m^{-3} = g/m^3.

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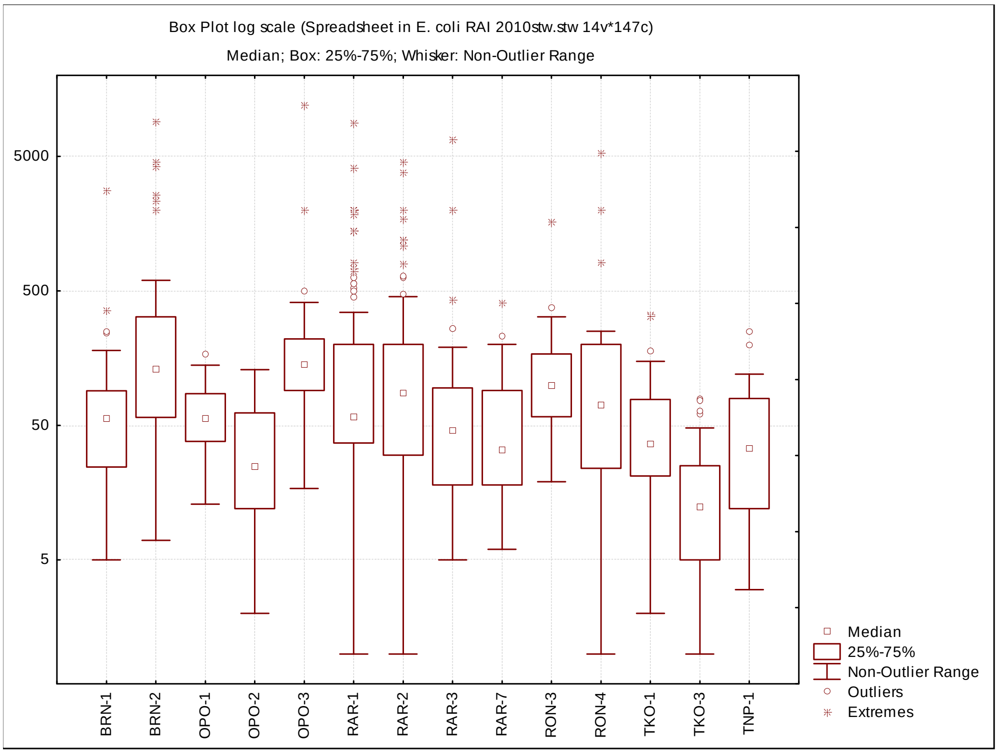
0.08
0.06
0.04
0.02
0.00
-0.02
BRN-1
BRN-2
OPO-1
OPO-2
OPO-3
RAR-1
RAR-2
RAR-3
RAR-7
RON-3
RON-4
TKO-1
TKO-3
TNP-1
Median
25%-75%
Non-Outlier Range
Outliers
Extremes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Median; Box: 25%-75%; Whisker: Non-Outlier Range
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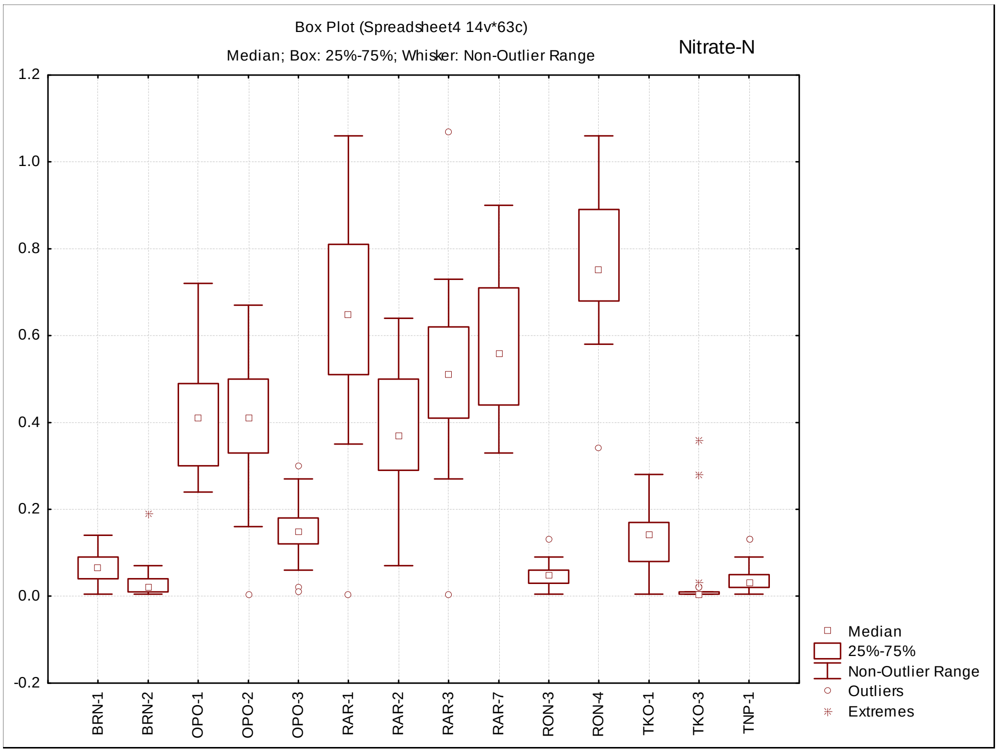
500
50
5
BRN-1
BRN-2
OPO-1
OPO-2
OPO-3
RAR-1
RAR-2
RAR-3
RAR-7
RON-3
RON-4
TKO-1
TKO-3
TNP-1
Median
25%-75%
Non-Outlier Range
Outliers
Extremes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Nitrate-N
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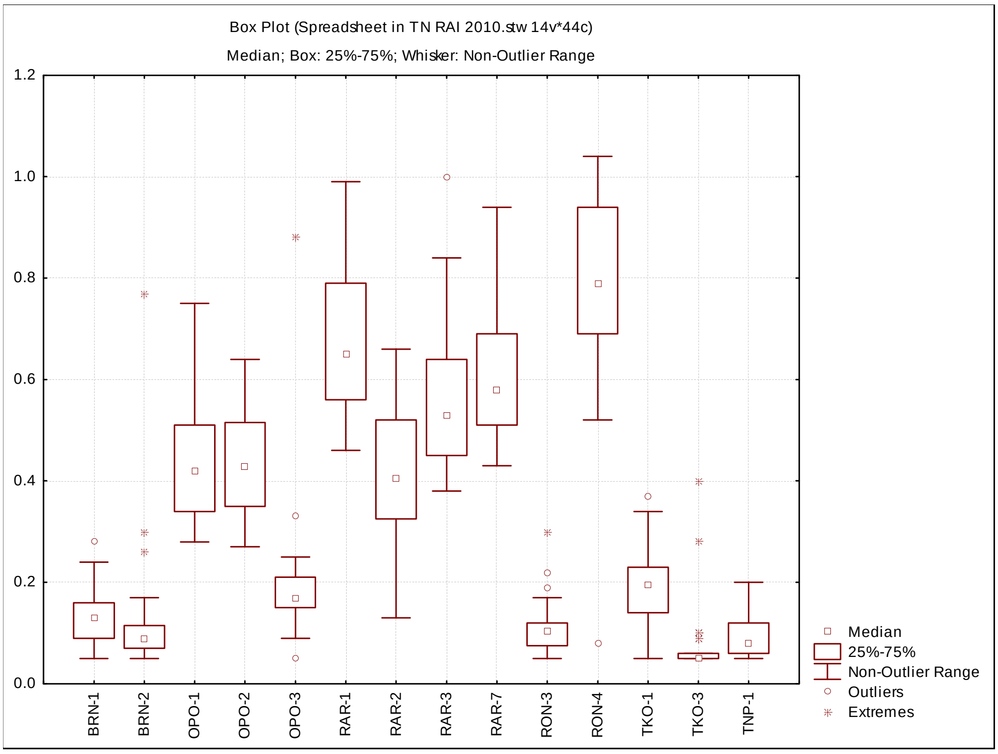
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
BRN-1
BRN-2
OPO-1
OPO-2
OPO-3
RAR-1
RAR-2
RAR-3
RAR-7
RON-3
RON-4
TKO-1
TKO-3
TNP-1
Median
25%-75%
Non-Outlier Range
Outliers
Extremes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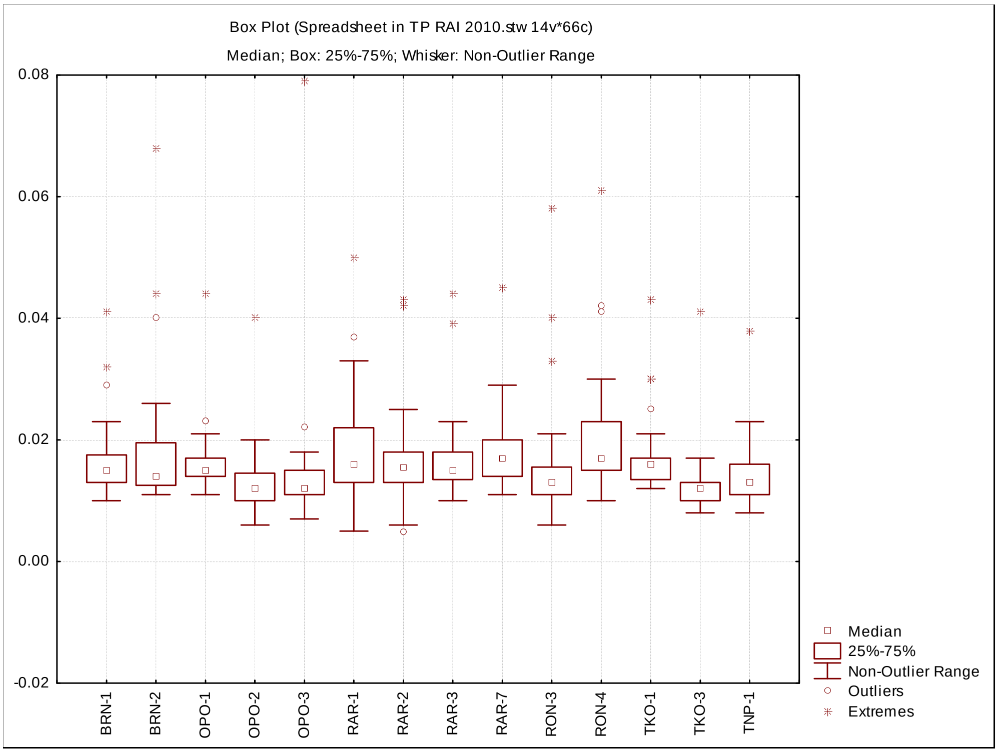
1.0
0.8
0.6
0.4
0.2
0.0
BRN-1
BRN-2
OPO-1
OPO-2
OPO-3
RAR-1
RAR-2
RAR-3
RAR-7
RON-3
RON-4
TKO-1
TKO-3
TNP-1
Median
25%-75%
Non-Outlier Range
Outliers
Extremes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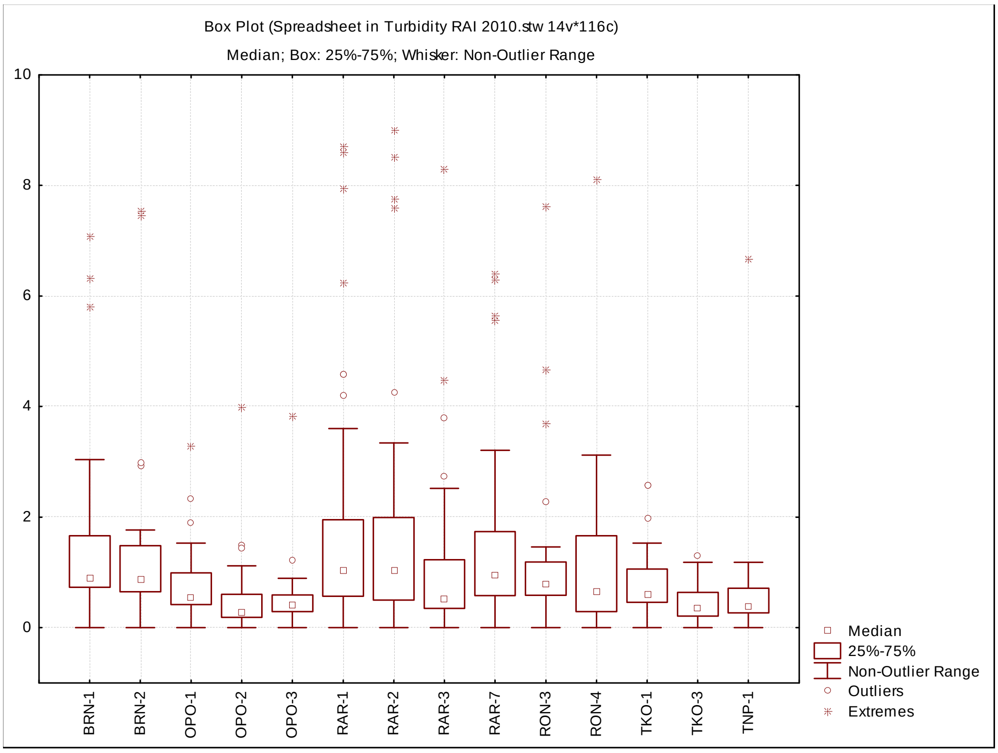
0.06
0.04
0.02
0.00
-0.02
BRN-1
BRN-2
OPO-1
OPO-2
OPO-3
RAR-1
RAR-2
RAR-3
RAR-7
RON-3
RON-4
TKO-1
TKO-3
TNP-1
Median
25%-75%
Non-Outlier Range
Outliers
Extremes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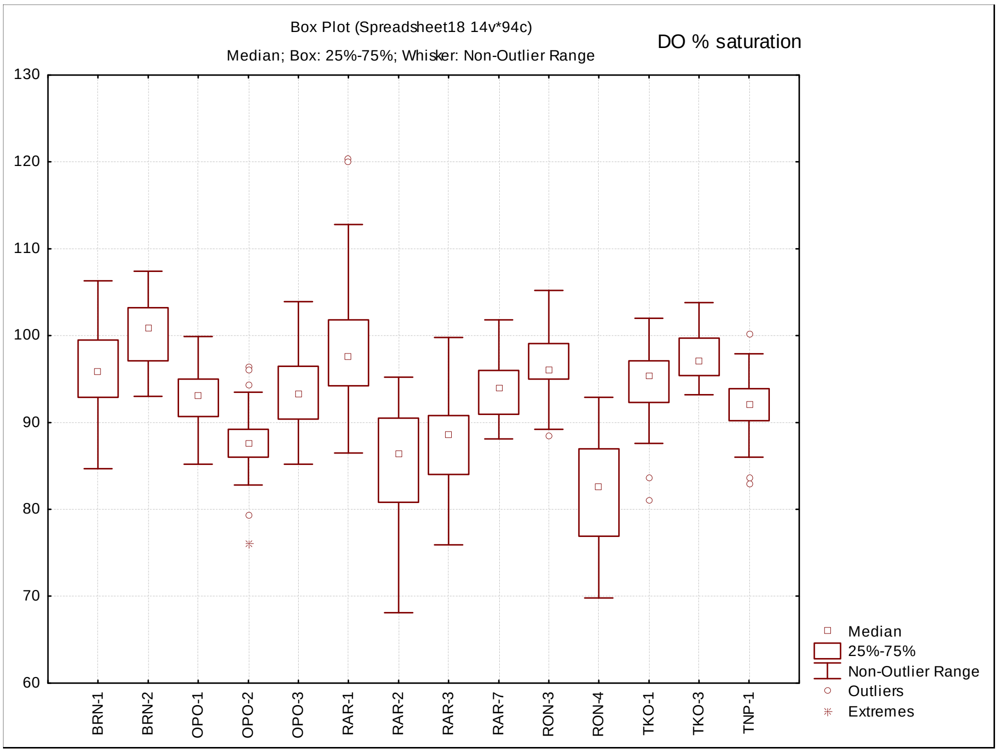
Median; Box: 25%-75%; Whisker: Non-Outlier Range
10
8
6
4
2
0
BRN-1
BRN-2
OPO-1
OPO-2
OPO-3
RAR-1
RAR-2
RAR-3
RAR-7
RON-3
RON-4
TKO-1
TKO-3
TNP-1
Median
25%-75%
Non-Outlier Range
Outliers
Extremes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DO % saturation
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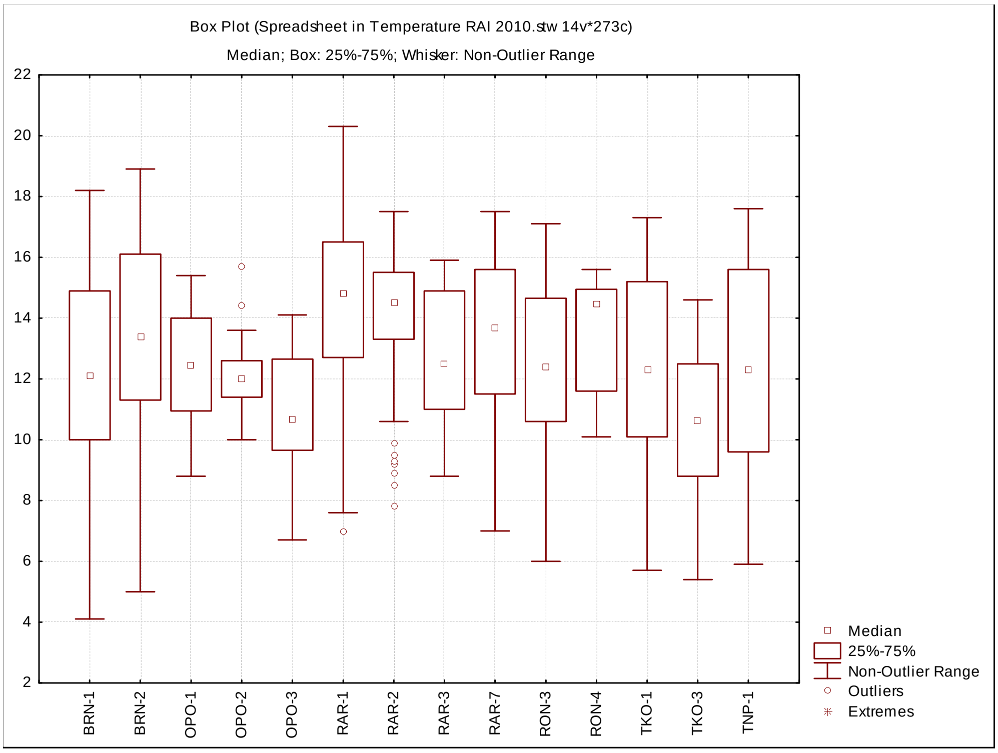
120
110
100
90
80
70
60
BRN-1
BRN-2
OPO-1
OPO-2
OPO-3
RAR-1
RAR-2
RAR-3
RAR-7
RON-3
RON-4
TKO-1
TKO-3
TNP-1
Median
25%-75%
Non-Outlier Range
Outliers
Extremes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Median; Box: 25%-75%; Whisker: Non-Outlier Range
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20
18
16
14
12
10
8
6
4
2
BRN-1
BRN-2
OPO-1
OPO-2
OPO-3
RAR-1
RAR-2
RAR-3
RAR-7
RON-3
RON-4
TKO-1
TKO-3
TNP-1
Median
25%-75%
Non-Outlier Range
Outliers
Extremes