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Water Quality Status and Trends: Mangere River (Northland)

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Executive Summary

The Mangere River (Northland) catchment is one of three catchments prioritised for implementation of the National Policy Statement for Freshwater Management (NPSFM) by the Northland Regional Council (NRC). DairyNZ and NRC are working together to assess and improve the water quality of the small (82 km^2) predominantly pastoral catchment. This report determines baseline water quality for the compulsory values of "ecosystem health" and "human health" that are stipulated for protection by the National Objectives Framework (NOF) of the NPSFM.

Data from a high resolution sampling exercise (2007-2010) at six monitoring stations within the Mangere catchment, complemented by a longer-term state of the environment monitoring record at Knight's Bridge (2000-2012) have been collated and analysed to determine:

- Spatial patterns of physico-chemistry;
- Seasonal patterns of physico-chemistry;
- Long-term trends in physico-chemical attributes;
- Grading of proposed NOF numeric attributes for "ecosystem health" and "human health", including additional numeric attributes for pH, temperature and turbidity derived to protect indigenous fauna local to the Mangere.
- Which actions to prioritise in DairyNZ Sustainable Milk Programme plans for each of the catchment's 19 dairy farms.

Examination of the NZ Freshwater Fish Database revealed four records from the Mangere catchment (1986-2010) which have been supplemented by an intensive fish sampling exercise in March and November 2013 (Freshwater Solutions) and investigation of records for the Pukenui Forest (a DOC-managed reserve at the headwaters of the Mangere River). Significant barriers to fish passage (12 m Mangere and 20 m Wairua falls) limits native fish to a community of shortfin and longfin eels (*Anguilla australis*, *A. dieffenbachi*), Crans and common bully (*Gobiomorphus basalis*, *G. cotidianus*) and banded kokopu (*Galaxias fasciatus*). Of this, banded kokopu are the most sensitive taxon to changes in turbidity and temperature, with protective limits proposed at <20 NTU (August-December) and <21.2°C respectively.

Analysis of NRC monitoring data demonstrated a typical pattern of accumulated catchment nutrient, suspended sediment and bacterial loading from headwaters downstream. Unusually, the headwater monitoring site (109166) was exposed to unusually high nutrient and sediment loads that decreased directly downstream. This suggests localised land use upstream of site 109166 (upstream of dairying) is markedly reducing water quality for "ecosystem health". There is therefore a need to take an inclusive, whole-of-catchment approach to managing water quality in the Mangere catchment.

Seasonal patterns were largely typical of Austral locations with a lack of seasonality in ammoniacal-nitrogen, total Kjeldahl nitrogen (TKN), total phosphorus, dissolved reactive phosphorus and E.coli concentrations suggesting their loading is relatively high. Reassuringly, long-term trends indicate that the latter attributes have all reduced at statistically significant ($p<0.05$) and ecologically meaningful (≥1% per annum) rates in the catchment since 2000 (bar TKN which was stable). Latter rates of reduction are large, varying from -13.7% (*E.coli*) to -26.8% (NH_4-N) per annum since 2007 (flow-corrected equivalents range from -13.9% to -32.1% respectively). This appears associated with significant upgrades to 18 of the 19 farm dairy effluent systems in the Mangere catchment. A principal components analysis of physico-chemistry amongst sites and over years (using annual medians) also demonstrated that the Mangere catchment has undergone marked reductions in nutrient and faecal bacterial loading since 2007 with the principal axis (λ_1) a gradient of higher to lesser nitrogen and phosphorus availability. All other attributes tested for long-term trends (temperature, dissolved oxygen, turbidity, pH, total nitrogen and nitrate-nitrogen) were also stable (i.e., all attributes tested were stable or improving across the catchment).

In terms of grading under the proposed NOF, the catchment has shifted from a lower grade C/upper grade D (unacceptable) to a lower grade B/upper grade C for “human health” and consistently scored grades A and B for “ecosystem health” toxicants (NO_3-N, NH_4-N). However, there is clear indication that reductions in minimum oxygenation are increasingly threatening “ecosystem health” with that catchment shifting from lower grade B/upper grade C (2007) to lower grade C/upper grade D (2012) which would place the catchment below the national bottom-line for 1-day DO. A caveat applies, in that the latter numeric attribute applies to point-source discharges under the proposed NOF, whereas it is applied catchment-wide in this report (i.e., a more conservative approach was adopted). The reason being, any point-source discharge is diluted by stream-flow. Hence, a failure to exceed 4.0 mg/L DO (1-day) or 5.0 mg/L (7-day) in river-water offers little ability to dilute discharges to the latter of oxygen-low water or oxygen-consuming detrital matter (effluent). Managing “ecosystem health” in the Mangere catchment should therefore aim to redress a trend to lower DO minima by increasing oxygenation during low-flow and warmer temperatures, which limit oxygen dissolution and increase rates of respiration by indigenous fauna.

A modern banded kokopu population was not noted in the catchment, either by the NZ Freshwater Fish Database nor modern surveys. However, numerous migrating juveniles have been noted navigating the Wairua falls in 2012 (20 km downstream of the confluence with the Mangere River). Given the greater size of the latter falls relative to those on the Mangere (20m and 12 m respectively), and the widespread distribution of banded kokopu across New Zealand, it is likely that local pressures restrict their migration. Insufficient minimum oxygenation in summer could be a pressure, though given young migrate during higher flows and greater oxygenation in the Mangere River (August-December) and that adults could rest in the shaded, well-oxygenated pools of the Pukenui Forest, a more likely pressure appears to be excess suspended sediment entering the waterways during their migratory journey. Migratory behaviours are impaired in young banded kokopu at turbidity >20 NTU, which has been regularly exceeded at Knights Bridge (2002, 2003, 2006, 2010, 2011) and headwaters at site 109166 (2010). An additional priority for management of “ecosystem health” (tailored to the indigenous fauna expected in the Mangere River), is to therefore reduce suspended sediment losses from the catchment through effective riparian management (i.e., livestock exclusion and planting of low-growing, flood-tolerant vegetation well able to trap sediment, including sedges [*Carex* spp.], flax [*Phormium tenax*] and cabbage trees [*Cordyline australis*]). The catchment already possesses extensive mature but under-grazed riparian vegetation which would stand to be complemented by this approach (i.e., improve sediment control whilst maintaining additional benefits of taller shrubs and trees including provision of woody debris, shade and habitat to indigenous fauna).

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1.0 Introduction

Northland Regional Council (NRC) are in the process of implementing the National Policy Statement on Freshwater Management (NPSFM) (2011) aimed at improving management of water resources in the region. This will involve implementation of the National Objectives Framework (NOF), which is currently under revision. The NOF includes a suite of national freshwater values and associated attributes for which states can be determined. The NOF permits freshwater objectives to be set within a framework of nationally consistent environmental bottom-lines (Table 1.1) (MfE, 2013a).

NRC and DairyNZ are developing a collaborative implementation approach for the NOF, around compulsory protection of two national values for water, namely (MfE, 2013b):

1. *"Ecosystem health" – that a resilient ecosystem specific to that freshwater body is supported, including protection from chronic effects on sensitive flora and fauna such as high temperatures, low oxygen, changes in freshwater chemistry, high sediment levels or algal blooms.*
2. *"Human health" (secondary contact recreation) – that unacceptable risks to human health when a waterway is used for wading or boating are avoided (i.e., for secondary rather than primary contact recreation).*

NRC and DairyNZ Ltd. recognise that ongoing stakeholder analysis and feedback is needed to determine a comprehensive understanding of water resource values in Northland. In the interim, this report offers a description of the state and trends of water quality attributes for "ecosystem health" and "human heath" in a priority catchment (the Mangere River).

Note: *This report is limited to analysis of recent state and trends for numeric attributes of two compulsory values in the NOF, using data collected by NRC and DairyNZ in the Mangere catchment (Northland, New Zealand). It does not consider integration of Mangere catchment objectives with higher order waterways downstream, nor too additional freshwater values that ongoing stakeholder deliberation is attempting to define.*

1.1 Regional and National Policy

1.1.1 The National Policy Statement on Freshwater Management (2011) and National Objectives Framework (2013)

The Government set out 'once in a generation' reforms to better management of freshwater resources in New Zealand, through the NPSFM which came into effect in July 2011.

The NPSFM set out objectives and policies to manage water in an integrated and sustainable manner while providing for economic growth, and maintaining or improving 'water quality' within a region (we define 'water quality' in relation to the condition of water for its intended purpose or value).

NRC is obliged by the NPSFM (2011) to determine freshwater objectives and to set limits on indicators for these that mesh with the National Objectives Framework (NOF). The NOF was established in response to recommendations of the second Land and Water Forum (LAWF) report for a national instrument to set bottom lines on numeric state objectives for a limited range of indicators and values (Table 1.1). The NOF should ensure greater consistency in both freshwater objective setting and reporting (recommendation 4 [LAWF, 2012a]).

The NOF aims to implement more effective policy by permitting meaningful consideration of all potential competing values for water amongst the community.

MfE (2013a:28) define “freshwater objectives” as ‘intended outcomes for a water body that will provide for the values the community considers important’, underscoring the importance of local catchment stakeholder groups in water resource decision-making.

Local expectations are expected to be meshed with national minima to protect or improve the current condition of waterways for local use above national bottom-lines (MfE, 2013a). To do so, “attributes” must be identified for objectives and “limits” set on these attributes or indicators that will ensure sufficient protection of water quality (see Table 1.1). For each attribute, the Government recommends categorisation of attribute scores into 4 bands of quality (e.g., A, B, C and D).

Table 1.1 The National Objective Framework – values and related attributes for rivers (summarised from MfE, 2013b).

Value	Attributes	Numeric Attribute Band			
		A	B	C (Bottom-line)	D
Ecosystem health and general protection for indigenous species*	• Nitrate (toxicity) • Ammonia (toxicity) • Dissolved oxygen (DO) • Periphyton • Temperature** • pH** • Sediment** • Invertebrates** • Fish**	99% protection from toxicants (nitrate, ammoniacal-nitrogen) No stress due to hypoxia (DO) Rare blooms indicative of limited nutrient enrichment or modification of flows and habitat (periphyton)	95% protection from toxicants (nitrate, ammoniacal-nitrogen) Occasional minor stress from hypoxia Occasional blooms of plants reflecting minor alteration of flow or nutrient availability (periphyton)	80% protection from toxicants (nitrate, ammoniacal-nitrogen) Moderate stress on sensitive fish and macroinvertebrate taxa Periodic short-duration nuisance blooms reflecting moderate nutrient enrichment and/or alteration of flow regime or habitat (periphyton)	Impacts on the growth of multiple species that approach acute toxicity levels for sensitive species (nitrate, ammoniacal-nitrogen) Significant, persistent stress on a range of aquatic fauna with loss of ecological integrity (DO) Regular and/or extended-duration nuisance blooms reflecting significant nutrient enrichment and/or flow alteration (periphyton)
Human health for secondary* contact	• *Escherichia coli* (*E.coli*) • Planktonic cyanobacteria • Benthic cyanobacteria**	Very low risk of gastroenteritis (<0.1%) from secondary exposure (*E.coli*)	Low risk of gastroenteritis (0.1-1.0%) from secondary exposure (*E.coli*)	Moderate risk of gastroenteritis (1.0-5.0%) from secondary exposure (*E.coli*)	High risk of gastroenteritis (>5.0%) from secondary exposure (*E.coli*)

*These two 'objectives' are enshrined as national values under the NOF; **These numeric attributes are not compulsory in the NOF (MfE, 2013b) but are under consideration for inclusion for 2016-2019.

1.1.2 Northland Regional Water and Soil Plan (2004)

Table 1.2 Northland Regional Plan Statement guidelines on water quality values and objectives.

Value	Attributes	Interpretation
Aquatic ecosystem purposes	• pH	• Range 6.5-9.0
	• Temperature	• Deviation from natural state <3°C
	• Dissolved Oxygen (DO)	• Concentration remains >6 mg/L
	• Toxic metal concentration	• As, Cd, Cr, Cu, Pb, Zn and Hg*
	• Ammonia	• Remain within thermodynamic relationship stipulated in RPS
	• Clarity	• Remain within 20-40% of standard
Primary contact recreation	• Clarity	• Remain >1.6 m
	• *E.coli*	• Median from bathing season (1st December-31st March) <126 per 100 mL and upper limit to remain below 235-576 (designated bathing area to infrequent use).
Fishery purposes	• Temperature	• Deviation from natural state <3°C and <25°C overall.
	• DO	• Concentration remains >6 mg/L
	• Nutrients	• Remain in range: DRP 50-30 mg/m^3 DIN (NO_3 + NH^4) 0-100 mg/m^3
Water supply purposes	• pH	• Range 6.5-9.0
	• DO	• Saturation remain >5 mg/L
	• Taste	• Remains palatable
Stock water and irrigation purposes	• Toxic metals	• As, Cd, Cr, Cu, Pb, Zn*
	• Nutrients	• NO_3 < 500 mg/m^3
	• Faecal coliform	• <5 samples in 30 days exceed: Median of 600/100 ml 80th % <2,400/100 ml

*As per RPS (1999:52-55)

Northland is a water-scarce region whose water resources are managed sustainably for future and current users by Northland Regional Council (NRC, 2011). Under the Resource Management Act (1991), NRC has published a Regional Policy Statement (RPS, 1999 – undergoing revision in the Provisional RPS [2012]), identifying issues related to water resource management, and the Regional

Water and Soil Plan for Northland which specifies water quality standards to protect the life-supporting capacity of natural water bodies (Table 1.2). There is a high degree of overlap between NRC policy/plans and the NPSFM (2011). For instance, the Northland RPS (1999, 48) specifies an objective of 'the maintenance or enhancement of the water quality of natural water bodies in the Northland region to be suitable for aquatic ecosystems, contact recreation…' - equivalent to the fundamental values of the NOF.

The existing RPS outlines several attributes and thresholds to permit freshwater use for provision of aquatic ecosystem, primary contact recreation, fishery, water supply, and stock water & irrigation purposes (Table 1.2). In all purposes, guideline values exist until such time as a water body is classified otherwise by the Council, and are subject to revision in accordance with the NOF in the NRC Provisional RPS (2012).

To report on the state and trends of Northland water bodies, NRC have undertaken regular water quality monitoring exercises since 1996, through a region-wide River Water Quality Monitoring Network (RWQMN). The RWQMN monitors 35 locations in Northland (4 within NIWA's NRWQN), reporting on a range of parameters and referencing these to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality in lowland rivers (ANZECC, 2000) and Microbial Water Quality Guidelines for Marine and Freshwater Recreational Areas (MfE, MoH, 2003).

This enables NRC to monitor the region's performance in meeting conditions of the RPS, namely to reduce the quantity of contaminants that impact on water quality (NRC, 1999).

1.1.3 Waiora Northland Water Programme (2012)

NRC is implementing the NPSFM (2011) and the need to maintain or improve water quality in the region through the *Waiora Northland Water* programme (NRC, 2012). In 2012, through review of LAWF's second report, NRC instigated formation of collaborative stakeholder groups (CSG) in three priority catchments (i.e., as per recommendations 15-27 of LAWF, 2012a):

- Mangere Catchment
- Doubtless Bay Working Group
- Waitangi River Catchment Group

Each CSG aims to engage a number of stakeholders in a governance group that set community objectives for freshwater management, tailoring water standards and monitoring to these goals (e.g., Woolcock and Brown, 2005; Lees et al., 2012).

Whilst catchment groups deliberate on objectives and thresholds, NRC will retain the right to prepare resource management plans that give effect to the NPSFM (2011) (i.e., plan changes to the Regional Water and Soil Plan). The Waiora programme has stipulated this will operate at catchment level and is expected to continue until at least 2022 (i.e., as per recommendation 9 of LAWF, 2012a).

The Waiora programme of NPS implementation is anticipated to be iterative, defining and redefining objectives and limits. Following engagement, stakeholders are expected to revise their decisions in light of more, evolving knowledge (recommendation 6 of LAWF, 2012b).

NRC are aligning closely with the Government's recommendations in their publication, 'Freshwater Reform 2013 and beyond' (MfE, 2013a), for collaborative, community-led policy development akin to the recommendations of LAWF's second report (LAWF, 2012a).

Within this policy context, the Mangere catchment is a proof of concept trial for industry collaboration to implement the NOF (NRC, 2012). Solutions are being sought to improve water quality through industry good management practice (NRC, 2012). These are expected to also contribute to the objectives of the Kaipara Harbour programme, provisionally by 2018 (NRC, 2012).

Note: *This report is the first of two, the second recommending on-farm good practices to ensure that water quality is maintained or improved above national bottom-lines for all attributes of "ecosystem health" and "human health" on dairy farms in the Mangere catchment.*

1.1.4 Sustainable Dairying: Water Accord (2013)

There are 19 dairy farms in the Mangere catchment meaning dairying is a stakeholder in catchment water management. DairyNZ is the industry good body whose role includes developing practices for local stakeholders that will enable the objectives of the NPSFM (2011) to be met.

Examples of responses to the NSPFM (2011) include the Sustainable Dairying: Water Accord – A Commitment to New Zealand by the Dairying Sector ("Water Accord") released by the Dairy Environment Leadership Group (DELG). The Water Accord builds on the 2003 Dairying and Clean Stream Accord (DCSA, 2003). The Water Accord proposes to enhance freshwater performance of the dairying sector by:

- Committing to GMP and regulatory compliance for all dairy farmers in New Zealand;

- Monitoring and reporting on progress to adoption of good management practices.

The Water Accord, like the Government's 'Freshwater reform 2013 and beyond', promotes partnerships with stakeholders to develop a collaborative understanding of challenges/actions required to better manage water resources in New Zealand. All dairying companies, including DairyNZ are accountable to its goals (refer to SDWA, 2013).

Output from the Water Accord includes preparation (in partnership with regional councils) of tailored riparian management guidelines 'to promote stream health and water quality' (SDWA, 2013:5). The Mangere catchment presents an ideal testbed for development of this resource, by tailoring riparian management actions to the pressures identified to limit "ecosystem health" and "human health".

Note: *The Water Accord and Waiora Northland Water programme are complimentary (NRC, 2013). For instance the Water Accord is not a water quality objective setting tool, but rather an agreement to adhere to or exceed those generated by the NPSFM (2011). Like the Waiora Northland Water programme, the Water Accord emphasises the need to operate at catchment scale with local partnerships to reduce the environmental footprint of dairying (SDWA, 2013).*

1.2 Why the Mangere River?

1.2.1 Waiora Northland Priority Catchment

Monitoring data in Northland's State of the Environment RWQMN has repeatedly highlighted the greatest availability of nutrients, sediment and bacterial indicators within the Mangere catchment (i.e., in 2006 and 2007) (NRC, 2008). The reasons for this are complex, including the history of catchment development compounded by natural background effects of precipitation, hydrological and geomorphological processes in the catchment (i.e., flashy, sudden discharges associated with channel scour and overland flow [NRC, 2011]).

The catchment is now one of three priority catchments for improvement of water quality by the NRC (NRC, 2013).

To better understand water quality in the catchment, NRC mounted a high-resolution (fortnightly) investigation from April 2007 to December 2010 across a suite of physicochemical indicators (NRC, 2011).

The Mangere catchment offers an ideal location to demonstrate how industry good management practices can link to the National Objectives Framework to improve ecosystem health and human secondary contact values in Northland, due to:

- high-resolution water quality monitoring data on the Mangere River;
- the catchment's small extent (i.e., limited number of land users); and
- the combination of DairyNZ's obligations under the SDWA (2013), NRC's requirement to improve water quality under the existing RPS, as well as future expectations to improve or maintain water quality under revisions to the Regional Soil and Water Plan (required by the NPSFM [2011]),

1.2.2 NRC and DairyNZ Good Management Practice (GMP)

In its Annual Plan 2012-13, NRC adopted a policy to promote sustainable farming around water quality throughout Northland, using Farm Water Quality Improvement Plans (FWQIPs).

Initial priority catchments were identified for development of FWQIPs, including Whangerei Harbour, Mangere Stream and Waitangi River (NRC, 2013). Dairy farmers have been targeted first in each catchment, partly in response to their obligations under the Clean Streams Water Accord (CSWA, 2003) and forthcoming requirements of the Sustainable Dairying: Water Accord (SDWA, 2013).

NRC and DairyNZ expect FWQIPs to align closely with the industry good practice Sustainable Milk Plans (SMPs) that are being extended from regional trials in the Upper Waikato and Southland to the Mangere catchment.

A DairyNZ SMP is a brief, farm-specific action plan for improvement of environmental performance against catchment-scale objectives. Having an SMP will make on-farm environmental management easier and more effective. Each targets four key areas:

- Nutrient management;
- Waterway management;

- Land management;
- Water use efficiency.

SMPs/FWQIPs are expected to inform dairy farmers of effective management practices that will reduce contamination of water by sediment, nutrients and bacteria, tailored to natural catchment and farm-system constraints. SMPs will be nested within FWQIPs in the Mangere catchment, given the focus of both on good practice measures and greater extent of recommendations made by SMPs (i.e., the latter will apply to the whole farm system, not simply land use practices).

This report will aid development of technical guidance for SMPs that align with FWQIPs, again emphasising the importance of selecting the Mangere catchment as a precedent-setting location for region-wide commitments under the SDWA (2013).

Note: *FWQIPs and SMPs are advisory non-binding documents only. Each identifies works/measures based on their cost-effectiveness and priority. By combining the two, dairy farmers are better placed for support from NRC's Environment Fund or from industry advisors (e.g., Fonterra Sustainable Dairying Advisors)*

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1.3 Aim and scope of the report

The aim of this study is to analyse water quality data (excluding biomonitoring) collected by NRC at a single monitoring location in the Mangere catchment from January 2000 until December 2012 for state and trends in attributes of concern to “ecosystem health” and “human health”.

Spatiotemporal analysis of state and trends amongst attributes for “ecosystem health” and “human health” is also conducted for a further five monitoring stations in the Mangere catchment, using data collected by NRC from January 2007 to December 2010.

This report makes recommendations for future water quality monitoring and management in the Mangere catchment.

A later report will present tailored on-farm actions to improve “ecosystem health” and “human health” through sustainable milk plans (SMP), which are DairyNZ whole-of-farm management plans. SMPs are a tool for better environmental and economic performance on dairy farms, which are key commitments of DairyNZ to the Mangere Stakeholder Group.

2.0 Catchment description

The Mangere catchment lies 12km west of Whangerei with an area varying between 76 km^2 (River Environment Classification) and 82 km^2 [NRC, 2011]) (Table 2.1). The Mangere River originates in the bush of the Pukenui forest, where cobble and bedrock tributaries form a low-gradient (LG) river* (e.g., slope <0.02 [Snelder et al., 2010]). The Mangere River drains east to the Wairua River that feeds the Wairoa River and ultimately, discharges to the Kaipara Harbour (Figure 2.1, 2.2).

Table 2.1. Land cover type as classified in the Land Cover Database 3 (Source: NRC, 2013).

Land cover type (LCDB3)	Area (km^2)	Area (% catchment)
High Producing Exotic Grassland	57.22	75.29
Indigenous Forest	13.79	18.15
Broadleaved Indigenous Hardwoods	2.11	2.78
Exotic Forest	0.99	1.3
Orchard Vineyard & Other Perennial Crops	0.50	0.66
Manuka and/or Kanuka	0.49	0.65
Low Producing Grassland	0.28	0.37
Gorse and/or broom	0.24	0.31
Surface Mines and Dumps	0.11	0.15
Built-up Area	0.11	0.14
Lake and Pond	0.09	0.12
Short-rotation Cropland	0.04	0.05
Deciduous Hardwoods	0.02	0.03

*Mangere catchment includes NZ reach numbers: 1017791, 1017934, 1017685, 1017904, 1018030, 1017801, 1017656, 1017459, 1017460, 1017302, 1017784, 1017692, 1017809, 1017853, 1018074, 1018080, 1018222, 1018223,1017845,1017846, 1017810, 1017854, 1017882, 1017995, 1017988, 1017944, 1017964, 1017980, 1018036, 1018071, 1018150, 1018168, 1018381, 1018397, 1018169, 1018295, 1018296, 1018359, 1018503, 1018504, 1018360, 1018416, 1018432, 1018482, 1018483, 1018537, 1018560, 1018561, 1018657, 1018665, 1018717, 1018736, 1017877, 1017847, 1017802,1017686, 1017582, 1017552, 1017588, 1017303, 1017304, 1017327, 1017295, 1017190, 1017835, 1017859, 1017965, 1018037, 1017785, 1017771, 1917716, 1017772, 1017773, 1017727, 1017746, 1017981, 1017935, 1017972, 1018128, 1018156, 1018224, 1018217, 1018268, 1018562, 1018601, 1018276, 1018368, 1018369, 1018581, 1018582, 1018129, 1018318, 1018299, 101,8332, 1018285, 1018286, 1018361, 1018351, 1018218, 1018165, 1018174, 1017955, 1017905, 1017895, 1017821, 1017728, 1017811, 1017894, 1017893, 1017658, 1017918, 1017936, 1017868, 1018180, 1018117, 1018157, 1018181, 1018242, 1018243, 1018264, 1018271, 1018382, 1018383, 1018410, 1018454, 1018490, 1018541, 1018554, 1018491, 1018530, 1018495, 1017768, 1017867, 1017770, 1017726, 1017648, 1017631, 1017493,1017638, 1017493, 1017504, 1017430, 1017365, 1017242, 1017443, 1017392, 1017366, 1017305, 1017328, 1017227, 1017260, 1017209, 1017191, 1017168, 1017122, 1017075, 1017121, 1016899, 1017082, 1017123, 1017092, 1017046, 1017084, 1017110, 1017233, 1017232, 1017070, 1016959, 1017083, 1017045, 1016815, 1016722.

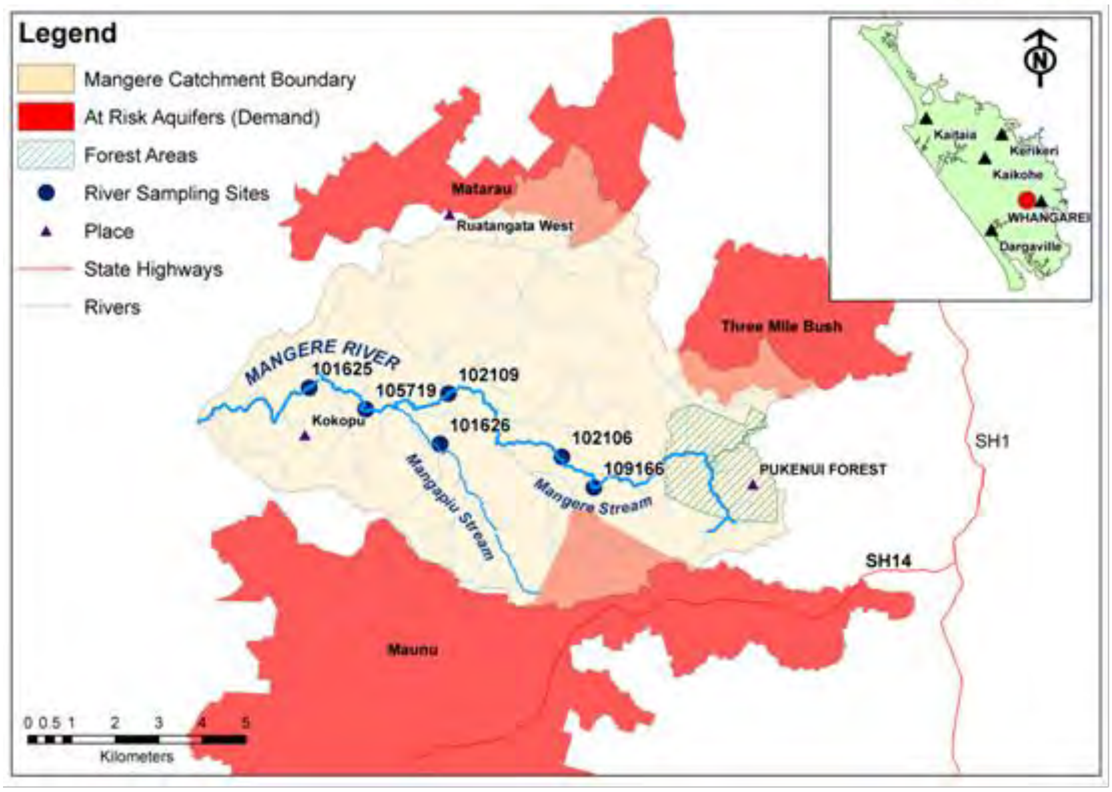

Figure 2.1. Location of Mangere River catchment in Northland, New Zealand (Source: NRC, 2011:8).

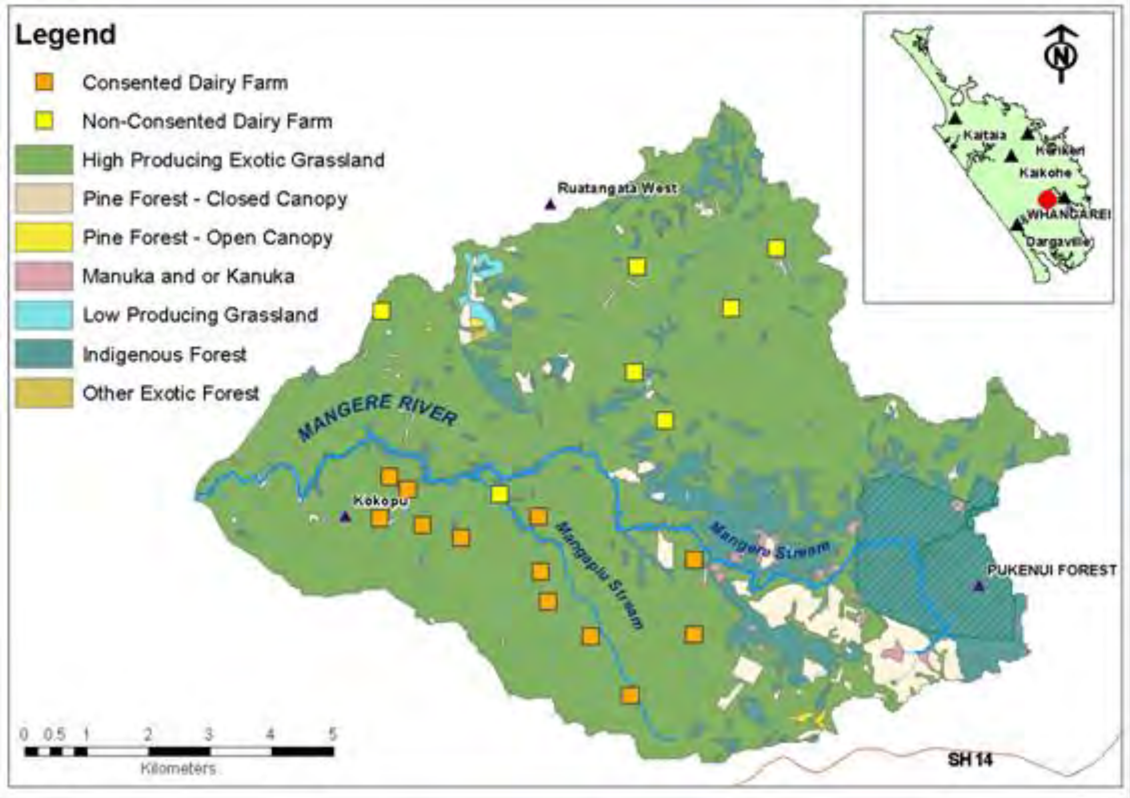

Figure 2.2. Land use and location of dairy farms in the Mangere River catchment (Source: NRC, 2011:9).

2.1 The Mangere River

The River Environment Classification (REC) (Snelder and Biggs, 2002) defines the catchment as warm-wet (WW), low-elevation (L), and comprised of soft sedimentary deposits (SS) with pastoral land use dominant (Table 2.2). Basement geology is mostly greywacke overlain by soft, folded and crushed sandstone, mudstone and shale of the Northern Allochthon. These were later capped by two ages of basalt lava flows from scoria cones along the eastern and northern edges of the catchment. The steeper grewacke (upper Mangere catchment) and sedimentary rock hill country has weathered to produce yellow-brown earths (YBEs) prone to slipping and gully erosion. The easier sedimentary rock land has strongly leached YBEs and podzols (gumland soils), which because of their strongly developed columnar subsoil structure are particularly prone to slipping and gully erosion (Bob Cathcart, pers. comm.).

The older basalt cone at Matarau has deeply weathered and strongly leached red loam soils while the lava flows from these sites have strongly to very strongly-leached brown loams. While the topsoils on the older red and brown loams are friable clays, the subsoils have high concentrations of colloidal clay which yield fine, dispersive sediment when exposed in drains, slips and road cuttings (Bob Catchcart, pers. comm.). Volcanic cones at Maunu and the Three Mile Bush area are less weathered and more free-draining red and brown loams (Bob Cathcart, pers.comm.). These basalt aquifers supply the majority of base-flow to the Mangere River which is naturally rich in iron, aluminium, manganese, nickel, chromium and related igneous minerals. The Maunu aquifer also supplies the Mangapiu Stream, a tributary of the Mangere River, whose basement of sandstone differs from the majority of the catchment.

Low-infiltration rates are expected catchment-wide due to the soft sedimentary status, increasing flood or fresh frequencies and lowering baseflow (e.g., Snelder et al., 2010). Catchment-wide rates of erosion are also likely to be relatively high, enhancing ambient suspended solid concentrations and resulting in greater background phosphorus availability in-stream (e.g., Snelder et al., 2010). This is especially true near the scattered outcrops of phosphorus-rich argillaceous limestone and Aponga clays (AP).

The lack of lakes and reservoirs on the Mangere River coupled to a relatively small extent, suggest rapid hydrological responses are likely from rainfall events (i.e., marked seasonal flow variation as expected in soft sedimentary catchments [Snelder et al., 2010]). Although several basalt aquifers (Matarau, Three Mile Bush and Maunu) retain and slowly release flows to the Mangere River, the presence of weirs near headwaters are likely to further exacerbate the severity of low-flow conditions in downstream reaches.

The artificial weirs and natural barriers like the Mangere Falls (12 m near Kokopu) and the Wairua Falls (20 m - outside catchment) offer substantive barriers to fish passage. In evidence to NRC for consents to take water, Mark Poynter (Evidence In Chief, Northland Fish and Game Council, 1993) identified that the Wairua and Mangere falls are also undercut, further limiting migration of juvenile native diadromous fish.

Note: *Maintaining hydrological flow during periods of maximum potential evapotranspiration is likely to be essential for maintaining ecosystem health in the Mangere catchment due to its geology (i.e., rapid responses to precipitation events) and hydrological management (i.e., artificial storage behind weirs).*

Table 2.2. River Environment Classification data for the Mangere catchment.

REC Parameter	Mangere Catchment	Northland Region*
NZ Reach Number	1017791	-
Catchment area (km^2)	75.92	145.45
Catchment Phosphorus (tonnes/Ha/year)	1.67	2.18
Catchment rainfall variability (coefficient of variation of annual catchment rainfall)	182.18	174.84
Distance to coast (m)	110672.7	45841.56
Mean Flow (m^3/s)	2.4	4.60
Low Flow (L/s)	161.7	596.1
Number of catchment rain days >25 mm	1.15	1.135
Order	5	4
Summer water temperature (°C)	18.9	19.1
Winter water temperature (°C)	5.7	6.4

*Values correspond to averages calculated from REC data for 34 Northland catchments excluding the Mangere River catchment (data supplied by NRC).

Mangere River has intact riparian forest bordering much of its length, including some of the most important riverine forest ecosystem habitat in Northland which is largely under-represented in the Whangerei Ecological District (DoC, 1993). Additional ecological units within the Mangere catchment include raupo-flax wetlands, kauri-totara forest on hillslopes, and totara-kanuka/manuka forest, kahikatea-totara forest and taraire-totara riverine forest on alluvium adjacent to the Mangere River (DoC, 1993).

Note: *Alluvial/riverine forest is a rare and under-represented forest types in Northland (DoC, 1993). This ecological unit contributes to freshwater ecosystem values within the Mangere by providing physical habitat, leaf-litter, woody debris and cover.*

2.2 Water Takes and Discharges

The Mangere catchment is dominated by pastoral users including 19 dairy operations, largely concentrated in the middle-to-lower catchment, and sheep and beef operations extending further upstream to the Pukenui Forest (NRC, 2011).

Dairy farms hold four of 11 consented water takes (all surface) in the Mangere catchment, including the two largest of 1810 m^3/day and 3110 m^3/day for pasture irrigation (NRC, 2011). Remaining surface water takes are each <100 m^3/day emphasising dairying takes. NRC have commissioned

NIWA to study flow limits for ecosystem protection so no further discussion is included on water quantity in this report.

Dairy farms are largely consented for effluent discharge; seven are unconsented but operate to “permitted activity” status. Of the 14 resource consents for animal waste discharge, 3 discharge via ponds to surface water and are of greatest direct concern to “human health”.

2.3 The Pukenui Forest Reserve

The Government has recommended a whole-of-catchment approach to identifying water values and determining protective limits or targets (MfE, 2013a). The Mangere Stream emerges from the Pukenui Forest, a 1700 Ha reserve that is managed through the Pukenui Western Hills Forest Charitable Trust (since ca. 2000 AD). Managing the Mangere catchment to meet the NPSFM (2011) is likely to therefore require consideration of the Pukenui Forest – Ngahere o Pukenui Management Plan (WDC, 2009).

The upper headwaters of the Mangere River are of ‘exceptional value’ to the wider Whangerei Ecological District (a region covering 81,000 Ha and 108 areas of ecological significance) (Manning, 2001) due to their mature unmodified native vegetation distributed in 32 forest types. The Pukenui Forest also contains Northland’s largest remaining long-tailed bat colony and healthy populations of koura (*Paranephrops planifrons*), freshwater limpet (*Latia* sp.) and long-fin eels (*Anguilla dieffenbachia*) (WDC, 2009). Populations of banded kokopu (*Galaxias fasciatus*) and freshwater crab (*Amarinus* sp., formerly *Halicarcinus lacustris*) were noted in 1969 (Walker, 1969; Manning, 2001). Whilst freshwater crabs were noted on a northern tributary of the Mangere (Patuwairoa Stream), no galaxiids were noted in the surveys conducted for DairyNZ by Freshwater Solutions (in summer 2012 and spring 2013) (Richard Montgomerie, pers. comm., 2013).

The NOF objective around “ecosystem health” to maintain or improve the resilience of indigenous flora and fauna aligns well with the objectives of the Pukenui Management Plan to (WDC, 2009):

- ‘protect and maintain the health (waiora) of the natural water systems flowing through the forest’
- ‘conserve and protect indigenous flora and fauna, their natural communities and habitats, indigenous species diversity and nationally threatened or regionally significant indigenous species’.

Given the contemporary presence of native long-finned eels, koura and limpets, managing the Mangere catchment (including the Pukenui Forest) for “ecosystem health” should at least seek to protect latter populations but could seek to go further by providing suitable water quality for freshwater crab and banded kokopu. If so, as both taxa were recorded 50+ years ago, an equivalent time-frame for recovery should be anticipated as a minimum (e.g., decadal scale). Further analysis (including aspect of this report) is needed to shed light on what pressures stress crab and banded kokopu populations, especially as freshwater crabs are not migratory (can thrive in isolated populations), eurytopic (tolerant of widely varying physicochemistry) and well-suited to the soft-bottomed sediments in the Mangere River (Walker, 1969; Wear and Fielder, 1985). By contrast, banded kokopu are diadromous, sensitive to suspended solids in-stream throughout migratory months (along the entirety of their migration from the Kaipara Harbour) and require dense riparian vegetation to prey upon terrestrial insects and undercuts/woody debris for cover (Rowe et al., 2000).

Further objectives of the Pukenui Management Plan relevant to managing the Mangere catchment water quality include reducing flood runoff and sustaining summer low flows.

Note: *Riparian vegetation is crucial to sustaining banded kokopu populations and would benefit any remnant freshwater crab populations by providing woody material and cover from fish (Wear and Fielder, 1985; Rowe et al., 2000).*

3.0 Methodology

3.1 Monitoring dataset

NRC supplied a monitoring dataset for several water quality indicators, recorded at six monitoring locations within the Mangere catchment over the combined interval of January 2000 to December 2012 (Table 3.1). Only one site (Knight's bridge) is part of the State of the Environment (SOE) monitoring network, offering sufficient record length for reliable description of typical seasonal variability and long-term trend testing (notably excluding nitrate-nitrogen which was only monitored from 2007). A further four sites located above Knight's Bridge, were part of an intensive monitoring exercise conducted by NRC from 2007-2010. A sixth monitoring location was added to this exercise in 2008 (Figure 3.1).

All observations were recorded at fortnightly-to-monthly resolution in accordance with the Northland Regional Water Quality Monitoring Network (NRWQMN) guidelines (NRC, 2010) and 'Standard Methods for Examination of Water and Wastewater (APHA, 1998) (i.e., no change to sampling or analytical methodology occurred over record lengths).

Parameters analysed in this report include:

- Temperature (°C)
- Dissolved oxygen (mg/L; %)
- *E.coli* concentration (MPN/100 ml)
- Turbidity (NTU)
- Conductivity (mS cm^{-1})
- Total Kjeldahl Nitrogen (TKN) (mg/L)
- Nitrate nitrogen (NO_3-N) (mg/L)
- Ammoniacal nitrogen (NH_4-N) (mg/L)
- Total nitrogen (TN) (mg/L)
- Dissolved reactive phosphorus (DRP) (mg/L)
- Total phosphorus (TP) (mg/L)

Riparian condition was also assessed at 64 locations within the Mangere catchment in 2013 by a single DairyNZ analyst using the P2 protocol of the *Stream Habitat Assessment Protocols for Wadeable Rivers and Streams of New Zealand* (Harding et al., 2009) (Appendix B). The P2 protocol assesses various aspects of riparian extent and quality of habitat which can modify water quality (i.e., provision of shade, provision of habitat, modification of in-stream geochemistry and hydrology [Naiman and Decamps, 1997; Harding et al., 2009]). The 12 riparian attributes of the P2 protocol were assessed along a 100 m survey reach on both bands, including shade, buffer width, buffer intactness, vegetation composition, bank stability, livestock access, denitrification potential, bank slope, groundcover, soil drainage, rills/channels and sediment sources.

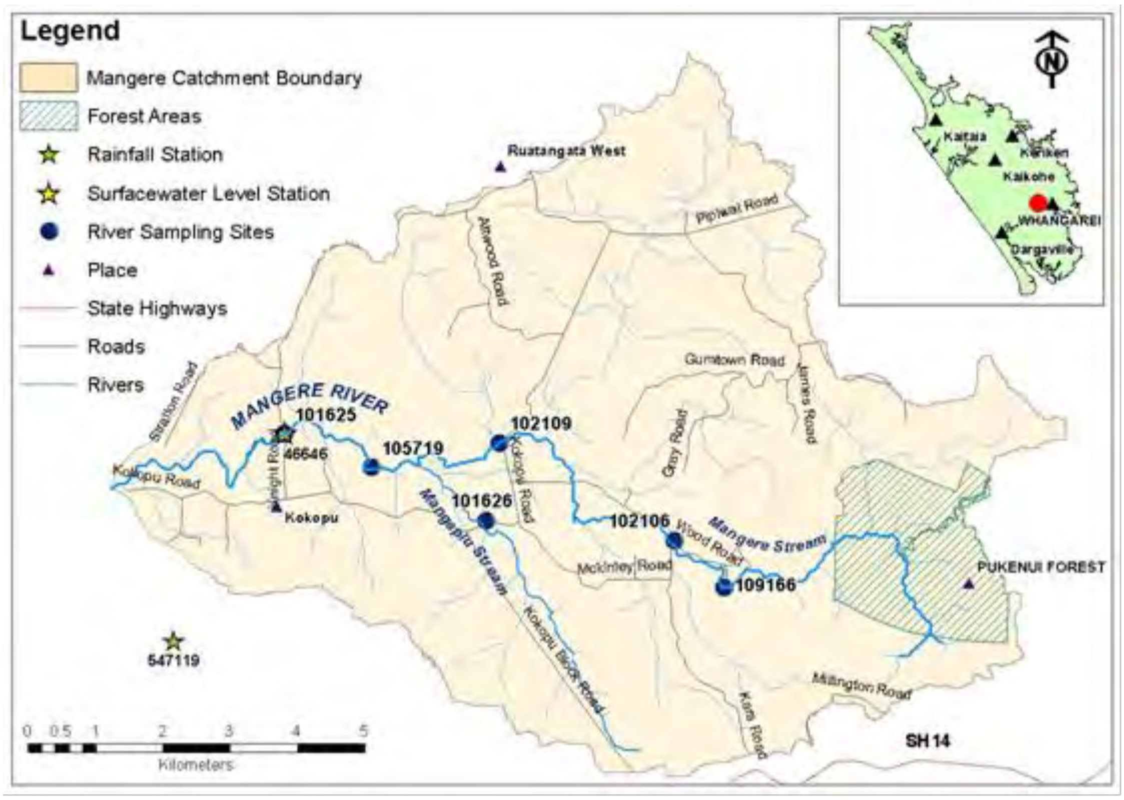

Figure 3.1. Monitoring locations for water chemistry in Mangere River catchment indicating the six reporting stations monitored by NRC in the interval 2000-2012 (Source: NRC, 2011:5).

Table 3.1. Surface water monitoring stations in the Mangere River catchment (listed from headwaters, top to bottom of table).

Station Identifier	Location	Record length analysed	River Environment Classification	Coordinates
109166**	Mangere River (Wood Road)	2008-2010	Hard sedimentary	-35.717889°, 174.217483°
102106	Mangere River (Kara Road)	2007-2010	Hard sedimentary	-35.698830°, 174.180321°
102109	Mangere River (Kokopu Road)	2007-2010	Hard sedimentary	-35.698830°, 174.180321°
101626*	Mangapiu Stream (Kokopu Road)	2007-2010	Soft sedimentary	-35.709281°, 174.178298°
105719	Mangere River (Kokich weir)	2007-2010	Soft sedimentary	-35.702297°, 174.159393°
101625	Mangere River (Knights bridge)	2007-2012	Soft sedimentary	-35.697954°, 174.144951°

*Tributary to Mangere River that flows from Mangapiu Stream; **Upstream of all consented discharges

3.2 Censored data

The NRC Mangere dataset contained several observations below the detection limit which were replaced by a numerical value of half the detection limit (as per Scarsbrook and McBride, 2007). *E.coli* observations also included values in excess of detection, which were included at the lowermost limit of upper detection (i.e., to avoid an artefact or false positive trend from a step-change in analytical sensitivity).

Note: *Censoring data results in artefacts to summary statistics, but their limited number should preclude much bias being introduced to spatiotemporal inferences.*

3.3 Spatial and seasonal variation

Descriptive statistics (mean, percentiles, standard deviation) were generated at five sites over the period 2007-2010 and all sites from 2008-2010, to describe spatial patterns in absolute (censored) parameters monitored by NRC in their SOE programme. Summary flow statistics were generated for site 101625 using daily average flow observations during the period 2007-2010 (data supplied by NRC Hydrology Team) (Tables 3.2 and 3.3). Summary riparian statistics were generated from the 63 sites survyed by DairyNZ in 2013.

Seasonal variation in absolute (censored) SOE parameters were explored by generating Tukey boxplots for Knights Bridge (site 101625) using data for the period 2000-2012 (i.e., boxplots were generated from all observations in any one calendar month at site 101625). Insufficient record lengths (<10 years) at other monitoring stations precluded reliable seasonal analysis elsewhere within the Mangere.

Table 3.2. Flow regime statistics generated for site 101625 from daily average flow observed (2007-2010).

Flow Regime Statistic	Description
Mean and median annual flow	The average and 50th% flow of the calendar year – large variation between both indicates flashy regimes
MALF (7d)	The mean annual low flow (MALF 7d) is the mean of annual seven-day low flows (i.e., n = 4) and describes low flow conditions that potentially constrain fish populations (Wilding and Waldron, 2012), and applies to a water year (July to June) to avoid continuous summer events being classified separately in concurrent years
X3 median	Flows greater than three times the median are described as ‘flood’ flows (Clausen and Biggs, 1997)
MAFF	Mean annual flood flow (MAFF) is the average of the highest instantaneous flows per year (i.e., n = 4) taken in a calendar year
IQR and percentiles	The inter-quartile range is the range of flows occupied by 50% of the data from the 25th% to 75th%

Table 3.3. Biological flow disturbance statistics for site 101625 generated from daily average flow (2007-2010).

Biological Disturbance Statistic	Description
MAFF/MALF (7d) ratio	The ratio of MAFF to MALF is an indicator of the seasonal range of extreme flows (i.e., low ratios indicate limited seasonality, high ratios indicate great range and corresponding ecologic stress)
MAFF/median annual flow ratio	The ratio of MAFF to median annual flow indicates the magnitude of peak annual floods (i.e., low ratios indicate limited range in flows above the median and greater ratios imply greater likely pressure on in-stream organisms (e.g., Henderson and Diettrich, 2007)
FRE3	The number of floods per calendar year is an indicator of the frequency of events sufficiently powerful to limit the periphyton and macro-invertebrate community (Clausen and Biggs, 1997)
SD FRE3	The standard deviation of the annual FRE3 values describes flood behaviour (i.e., whether floods occur in a regular or irregular pattern) (Clausen and Biggs, 1997)
Mean days accrual	The average of periods [days] between floods defines the average period of time available for periphyton growth prior to scouring which can be compared to national periphyton guidelines for corresponding likely periphyton biomass (e.g., Biggs, 2000; Matheson et al., 2012) (minimum and maximum accrual periods can also describe flooding regularity)
SD accrual	The standard deviation of the number of days between flood flows describes flooding regime (i.e., regular or irregular nature of floods)

3.4 Water Quality Status

Water quality status was determined by comparison to proposed NOF guidelines for Bands A-D, amongst attributes listed in the MfE (2013b) discussion document for “human” and “ecosystem health” (*Escherichia coli* [*E.coli*], nitrate-nitrogen [NO_3-N], ammoniacal-nitrogen [NH_4-N], dissolved oxygen [DO]). In addition, limits have been proposed for additional “ecosystem health” parameters based on biodiversity native to the Mangere catchment (including water temperature, pH and turbidity).

NRC did not directly monitor nitrate-nitrogen (NO_3-N) prior to 2007 and instead recorded nitrate and nitrite nitrogen (NNN). The availability of both NO_3-N and NNN observations from 2007-2012, as well as their linearity and normality permitted the relationship between NO_3-N and NNN to be modelled by ordinary least squares regression (i.e., Shapiro-Wilks test for normality $p = 0.0125$ and $p = 0.0098$ for NNN and NO_3-N distributions respectively). The very high degree of fit ($R^2 = 0.9984$) and highly significant relationship between NO_3-N and NNN (ANOVA $p < 0.001$), permitted past NO_3–N concentrations to be hindcast from NNN over the period 2000 to 2006 (Figure 3.2). The relationship to predict NO_3–N (mg/L) from NNN (mg/L) at Knights Bridge is:

$$NO_3\text{-}N = 0.987 * NNN + 0.00015$$

$$(R^2 = 0.9984;\ Adj.\ R^2 = 0.9982;\ p < 0.001)$$

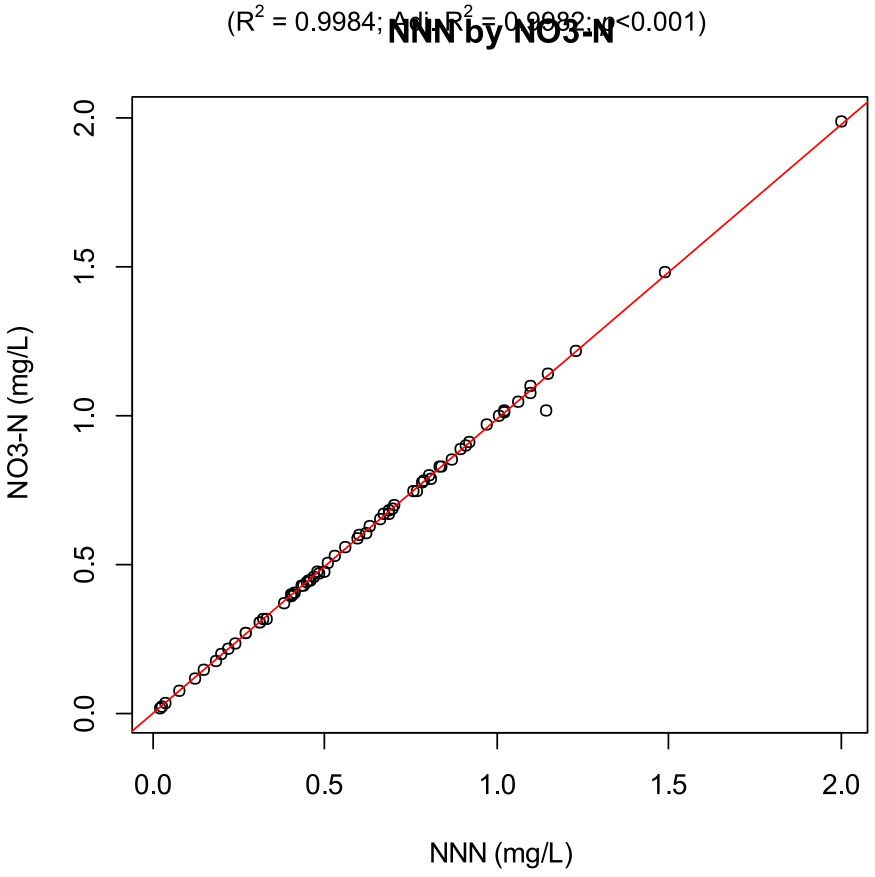

Figure 3.2. Simple linear regression of NO_3–N and NNN observations at Knight’s Bridge from 2007-2012. Both parameters observe a normal, linear distribution with a high degree of fit ($R^2 = 0.9984$) and significance ($p < 0.001$) (Adj. $R^2 = 0.9984$; F-stat = 41165; residual standard error of 0.01463 on 66 df) (note: the residuals although normal suffer from heteroskedasticity – see graphical output in Appendix C).

Note: *A lack of information on periphyton precludes inclusion of estimated abundance; invertebrate data is too infrequent for trend analysis and currently absent from the NOF; riparian and fish habitat scores are being collected [see below]; flows and connectivity are being reported separately by NIWA.*

3.4.1 Human health: *E.coli*

The NOF has proposed numeric attribute limits on the microbial content of water, which limits its use for contact recreation, especially primary forms during which ingestion of water is markedly greater than the lesser risks attached to secondary forms (MfE and MoH, 2003; Ryder, 2004). The NOF proposes to protect secondary contact recreation nationwide, year-round. Secondary contact recreation includes shallow wading and boating, for which the risks of ingesting water and therefore water-borne pathogens, are markedly lower (Sinton and Weaver, 2008).

McBride (2012) provided recommendations on the NOF E.coli numeric attribute states, adopting the Quantitative Risk Assessment Model (QMRA) approach utilised in the MfE and MoH (2003) *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*. Essentially, this established the thresholds in E.coli abundance associated with a 0.1, 1.0 and 5.0% risk of Campylobacter infection, because campylobacteriosis has New Zealand's highest reported rate of illness (200 per 100,000 persons per annum), is a waterborne disease found in New Zealand's recreational freshwaters, and its dose-responses characteristics are well understood (Dufour, 1984 in MfE and MoH, 2003).

McBride (2012) confirmed that secondary contact recreationists ingested considerably less water volume than primary contact recreationists (i.e., mode of 1.9-7.5 mL/hr for secondary recreationists in Chicago [Rijal et al., 2011 in McBride, 2012], compared to the mode of 50 mL/hr used to describe primary recreationists in MfE and MoH, 2003). McBride (2012) acknowledged that although lesser, there is high variability in reported water ingestion rates of secondary contact recreationists (i.e., both Rijal et al., 2011 and Dorevitch et al., 2011 suggest secondary exposure ingestion rates are 1/10th that of primary contact recreation). Therefore, McBride (2012) modelled the *E.coli* thresholds associated with a 0.1%, 1.0% and 5.0% risk of campylobacteriosis, assuming a range of exposures from 1/10 to 1/1 that of primary contact recreation, before settling on an exposure risk of ¼ that of primary contact. For a national bottom-line 5% risk of campylobacteriosis, assuming an ingestion rate of ¼ that of primary contact recreation, McBride (2012) recommends an *E.coli* concentration of 1000 MPN/100 ml.

The recommended national bottom-line for *E.coli* to protect human health is also commensurate with the recommended limit by Sinton and Weaver (2008) for Environment Canterbury, of 900 MPN/100 ml, which is derived from the ANZECC (2000) recommended faecal coliform limit for secondary contact recreation of <1000 MPN/100 ml (over 5 samples) multiplied by a factor of 0.9 as in New Zealand, only 90% of faecal coliforms are expected to be *E.coli*. Sinton and Weaver (2008) noted that Ryder Consulting (2004) made similar recommendations. Neither ANZECC (2000), nor Sinton and Weaver (2008) recommended a compliance reporting statistic (i.e., whether the limit of 900 MPN/100 ml *E.coli* should be defined for annual median, maximum or nth%). McBride (2012) raises this very issue and as the proposed "human health" *E.coli* attribute state is open for submission, this report will take a precautionary approach of reporting against the proposed NOF *E.coli* bottom-line of a median ≤1000 MPN/100ml **and** two alternatives:

1. Median ≤550 MPN/100 ml at flows three or less times the median. (The latter is modified from the threshold for a 5% risk of campylobacteriosis from primary contact recreation, which is typically reported against the 95th% of weekly observations taken over a 20-week period, excluding observations taken at flows three or more time the annual median (MfE and MoH, 2003). The ≤550 MPN/100 ml *E.coli* threshold used in this report has been modified to be reported as the annual median rather than 95th%, though retaining the caveat that observations are acquired at flows three times or less that of the median).

2. Maximum ≤1000 MPN/100 ml at all flows with no more than two permitted exceedances at monthly resolution per year.

***Note:** The NOF numeric attribute states for "human health" and E.coli are highly contentious and will shortly be revised based on feedback to the MfE (2013b) discussion document, so utilizing the national bottom-line of ≤1000 MPN/100 ml E.coli at all flows and ≤550 MPN/100 ml E.coli at flows three times or less that of the median, should offer some protection from a conservative revision of the proposed national bottom-line.*

3.4.2 Ecosystem health: Nitrate-Nitrogen (NO_3-N)

Nitrate occurs naturally in aquatic environments although at sufficiently high concentrations, can be toxic to aquatic biota at high concentrations (Hickey and Martin, 2009). Nitrate concentrations are therefore an important indicator for ecosystem health (Hickey, 2013).

In 2013, NIWA undertook a review of nitrate toxicity research for protection of "ecosystem health" through the NOF, based on the methodology contained in ANZECC guidelines (i.e., define a threshold level for the nitrate peaks based on a threshold effect concentration [TEC] for a specific level of % species protection). The TEC is the geometric mean of the no observable effect concentration (NOEC) and lowest observable effect concentration (LOEC) (i.e., a conservative guideline value for managing nitrate toxicity risk associated with seasonal concentration peaks). The review of Hickey (2013) is notable for its better representivity of indigenous fauna than Hickey and Martin (2009), including chronic responses to NO_3-N amongst juvenile inanga (*Galaxias maculatus*) and a mayfly (*Deleatidium* sp.) amongst 22 species (7 species are resident in New Zealand).

The two TECs for nitrate toxicity are described under "grading" and "surveillance" terms, which represent median and 95th% observation of NO_3-N. These are suitable to the Mangere catchment given the focus on native fauna and lack of viable salmonid fishery (salmonids are markedly more sensitive to NO_3-N). Also note that Hickey (2013:24) describes the TEC results as likely 'conservative' given the most sensitive species (lake trout) were tested in low-hardness water (greater hardness reduces NO_3-N toxicity to freshwater species), albeit the exclusion of groundwater fauna and inclusion of only two native taxa requires further revision.

The national NO_3-N bottom-line (80% community protection) TECs are:

1. Annual median ≤6.9 mg/L (NO_3-N)
2. Annual 95th% ≤9.8 mg/L (NO_3-N)

***Note:** acute (hourly to daily) toxicity guidelines are inappropriate for use given the resolution of the data used in this study (i.e., monthly medians).Limits on nitrite tend to not be proposed as the latter is rapidly oxidised to nitrate or reduced to ammonia in river systems. For reference, acute NO3-N TECs are 20 mg/L (annual median) and 30 mg/L (95th%).*

3.4.3 Ecosystem health: Ammoniacal-Nitrogen (NH_4-N)

Ammonia is a natural product of decaying organic matter in soils and waterways, including two chemical species collectively referred to as ammoniacal-nitrogen (NH_4-N): highly toxic un-ionised ammonia (NH_3) and the less toxic ionised ammonium ion (NH_4^+). Ammoniacal nitrogen (equivalent to total ammonia nitrogen in ANZECC) can like nitrate nitrogen, be toxic to aquatic organisms at high concentrations (Hamill and Porter, 2008). The concentration of the more toxic ammonia (NH_3) species varies with physico-chemical conditions, primarily pH and temperature. At higher pH and temperature, ammoniacal nitrogen is increasing toxic because an increasing proportion of unionised ammonia (NH_3) remains in solution (ANZECC, 2000).

There is no supporting report for the proposed NOF ammoniacal-nitrogen attribute limits. The national NH_4-N bottom-line (80% community protection) TECs are (at pH 8.0 and temperature of 20°C):

1. Annual median ≤1.30 mg/L
2. Annual 95th% ≤2.20 mg/L

The proposed NOF surveillance (95th%) guideline for 80% community protection differs from the equivalent in ANZECC (2000) of 2.30 mg/L NH_4-N (at pH 8.0 and temperature of 20°C). Likewise the proposed NOF 95% community protection surveillance (95th%) guideline of 0.40 mg/L NH_4-N differs markedly from the equivalent in ANZECC (2000) of 0.90 mg/L (at pH 8.0 and temperature of 20°C). The proposed NOF 99% community protection surveillance (99th%) guideline of <0.03 mg/L NH_4-N is however, consistent with the ANZECC (2000) surveillance guideline of 0.320 mg/L). There is no supporting report for the proposed NOF NH_4-N guidelines so the reasons behind this discrepancy are unknown. Nonetheless, both NOF and ANZECC (2000) NH_4-N guidelines are likely to be “conservative” for the Mangere River because both are derived from highly sensitive salmonids that are not native to the catchment and which would be unwise to introduce given their near total displacement of native fish in trophic food webs (i.e. reduce ecosystem health by competing for habitat, prey and predating upon native fish and invertebrates) (McDowall, 2003). Likewise, the absence of the native freshwater fingernail clam (*Sphaerium novaezealandiae*) from the Mangere further precludes the necessity for a 99% community protection NH_4-N guideline. For instance, Hickey et al. (1999) demonstrated that *Deleatidium* sp. and *Coloburiscus humeralis* were most sensitive amongst native macro-invertebrates to NH_4-N toxicity (with the exception of *Sphaerium novaezealandiae*), with no observed effects from chronic exposure as high as 0.95 mg/L and 2.33 mg/L, respectively.

To account for varying toxicity with changes in pH and temperature, the proposed NOF guidelines demand that NH_4-N be adjusted to report to a pH of 8.0 and temperature of 20°C (MfE, 2013:71). However, as the pH of Mangere stream is typically below 8.0 and the temperature seldom exceeds 20°C, such condition-specific chronic trigger values are likely to be in excess of the NH_4-N numeric attribute states. Although no conversion for pH and temperature has been attempted here, the report will therefore present a conservative impression of NH_4-N toxicity.

***Note:** acute (hourly to daily) toxicity guidelines are inappropriate for use given the resolution of the data used in this study (i.e., monthly medians).*

3.4.4 Ecosystem health: Dissolved Oxygen

Dissolved oxygen (DO) is required for aquatic organisms to respire aerobically. DO levels affects energy budgets because if insufficient, fish must dedicate increasing energy reserves to gill ventilation and aquatic surface respiration (ASR) which results in greater predation risk, lesser energy to migrate or pursue other behaviour like hunting for prey (Dean and Richardson, 1999). Hence, ensuring sufficient oxygen is available to prevent changes in fish behaviour is crucial to their long-term growth, reproduction and population (i.e., resilience of an aquatic ecosystem). Notably, the opposite of hypoxia, supersaturation (>100% DO) is not believed to result in adverse effects or abnormal behaviour on freshwater fish (Dong et al., 2011; Davies-Colley et al., 2013).

Amongst native organisms in New Zealand waterways, fish are most sensitive to levels of dissolved oxygen (Davies-Colley et al., 2013). An absolute minimum standard typically applied to protect the health of fish populations in New Zealand and abroad, is 5 g/m^3 (BCME, 1999) which can also be compared to a relativistic limit of 80% of saturation (Hay et al., 2006). Accordingly, the proposed NOF DO bottom-line numeric attribute states (below point sources) are:

1. 7-day mean minimum ≥5.0 mg/L (1 November to 30 April)
2. 1-day minimum ≥4.0 mg/L (1 November to 30 April)

Instantaneous measurements taken as part of the SOE monitoring programme might be of limited value because DO concentration varies diurnally, with maximum values generally late afternoon and minimum values at dawn (Wilcock et al., 1998; Goodwin et al., 2008). Thus, measurements at dawn or continuously, are required to meaningfully assess daily minimum DO concentration actually occurring. Accordingly, DairyNZ has contracted Freshwater Solutions Ltd. to continuously monitor diurnal DO concentration at multiple locations in the Mangere catchment. In the interim, this report utilizes the proposed NOF 7-day minimum national bottom-line of ≥5.0 mg/L DO to balance the likelihood SOE monitoring is not conducted at dawn minima (i.e., unconservative) and the need to exceed a national 1-day bottom-line of 4.0 mg/L DO. Indeed, Davies-Colley et al., (2013) describe the 4 mg/L national bottom-line recommendation as an acute threshold unintended for monthly SOE monitoring.

A 7-day minimum DO of 5 mg/L is described by Alabaster and Lloyd (1982 in Davies-Colley et al., 2013:53) as providing 'general protection from any greater than moderate chronic effects in most fish communities'. It is also the equivalent threshold for moderate impairment proposed by USEPA (1986a in Davies-Colley et al., 2013). It is however, unclear whether this is effective to protect native galaxiids given that data on early life-stages of native fish in New Zealand is scarce. Dean and Richardson

Note: *if management objectives are protection of banded kokopu smelt, a higher DO attribute state might be advisable as a long-term target because the LOEC for inanga was observed at acute (1-day) exposures ≤7.0 mg/L DO (Davies-Colley et al., 2013). The Class B 7-day mean minimum of 8 mg/L DO and 1-day minimum of 5 mg/L is expected to also protect the most sensitive macroinvertebrate species from hypoxic behavioural change (Davies-Colley et al., 2013).*

3.5 Additional "ecosystem health" attributes

Given the importance of native fish to the Pukenui Forest Management Plan (WDC, 2009) and that fish incorporate long-term and widespread changes to the health of lower trophic tiers (McDowall, 1990), limits on further water quality attributes that protect for native fish should offer wider "ecosystem health" protection to the Mangere River.

To determine which fish are native to the Mangere River, a review of local observations in the NZ Freshwater Fish database was conducted (accessed 19/04/2013). This highlighted a limited community comprised of 4 species (noted from 1992 to 2010 on 3 surveys): *Anguilla australis* (shortfin eel), *Anguilla dieffenbachia* (Longfin eel), *Gobiomorphus basalis* (Crans bully) and *Gobiomorphus cotidianus* (common bully) (Figure 3.3). This confirms evidence given to the NRC in consent hearings by Northland Fish and Game (Poynter, 1993) that the undercut natural waterfalls downstream and in the Mangere catchment proper, are significant barriers to fish passage. As banded kokopu juveniles are renowned climbing fish (Rowe et al., 2000) noted as previously present in the Pukenui Forest

(WDC, 2009) and more recently as present at the Wairua Falls (20 km downstream of Knights Bridge – 121 juveniles noted by NIWA during an elver population sub-sampling assessment from 29 Sept-24 Oct 2012 [Williams et al., 2013]), it seems prudent to add their presence to the short-list of native fish suited to the Mangere catchment and expected to be protected under the NOF (i.e., indicative of "the range of healthy indigenous fauna and flora that would naturally live there" which defines "ecosystem health" [MfE, 2013:65]). Hence, additional "ecosystem health" attributes to the NOF can be derived for a limited native community of: shortfin and longfin eels, common bullies and banded kokopu.

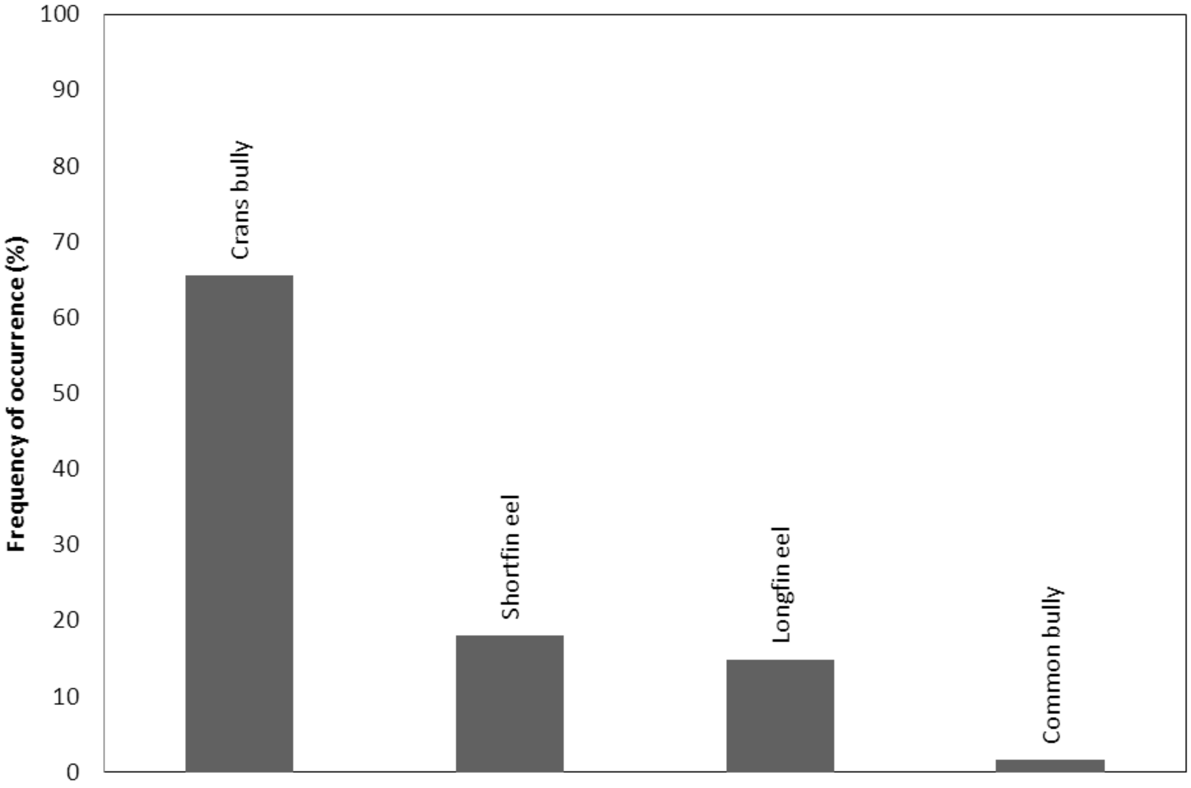

Figure 3.3. Relative abundance of fish species in the Mangere River based on 7 records in the NZ Freshwater Fish Database (1982-2010) (note: *Paranephrops* sp. [Koura] were reportedly 'abundant' in 2010) (Crans Bully = 65%; Shortfin eel = 18%; Longfin eel = 15%; Common bully = 2%) (Appendix H).

***Note:** to improve understandings of the native fish community of Mangere River further, DairyNZ has contracted Freshwater Solutions Ltd. to conduct a seasonal spot-lighting, electrofishing and netting exercise (using draft national NZ Freshwater Fish Samping Protocols, 2013). Preliminary results from April and November 2013 support previous NZ Freshwater Fish surveys, highlighting the presence of native (shortfin eels, longfin eels and common bullies) and exotic taxa (mosquito fish, brown trout) as well as suitable habitat for banded kokopu (Richard Montgomerie, pers.comm.).*

3.5.1 Water temperature

Fish growth, metabolism, reproduction, mobility and migration patterns can change in response to ambient water temperature (ANZECC, 2000). Frosts are largely absent in Northland and instead thermal stress is a consequence of exceeding upper incipient lethal temperatures.

The preferred ambient temperature and tolerance limits of several native New Zealand fish are reported in Quinn and Hickey (1990) and Richardson et al (1994). Of those native to the Mangere

River, banded kokopu offer the most sensitive taxon, which require a long-term maximum temperature target below 21.2°C (Richardson et al., 1994).

The thermal bottom-line (maximum) of ≤21.2°C utilised in this report to protect banded kokopu in the Mangere catchment, is likely to be conservative given this is markedly less than the upper incipient lethal temperature (LC50) for banded kokopu, which varies from 28.5-34.0°C (Main, 1988; Simons, 1986, Richardson et al., 1994). For instance, in a wide-ranging review of thermal tolerances, Olsen et al (2012:64) recommend that for lowland systems like the Mangere River (i.e., low gradient), "the most sensitive native taxa in **lowland** streams should be protected as long as maximum temperatures are less than 25°C". (The recommended maximum temperature for protection of the most sensitive native taxa in upland streams is <20°C). Olsen et al. (2012) derived their lowland recommendation after thoroughly exploring thermal responses for native fish (as per Todd et al., 2008) and demonstrating that short-fin eels, Cran's bully, common bully, inanga, banded kokopu and common smelt in lowland waterways all possess chronic upper incipient thermal limits >26°C. A limit of ≤21.2°C is also likely to protect thermally-sensitive macroinvertebrate communities (i.e., Quinn and Hickey, 1990, recommended annual maxima of 19°C and 21.5°C to protect stoneflies [Plecoptera] and mayflies [Ephemeroptera], respectively).

As per DO, instantaneous measurements might be of limited value because temperature varies diurnally, with maximum values generally late afternoon and minimum values at dawn (Wilcock et al., 1998). Future revisions of the NOF are likely to include measures of temperature variability including the Cox-Rutherford Index (CRI = $[T_{max}+T_{mean}]/2$) (Cox and Rutherford, 2000b). The absence of continuous temperature data for the Mangere catchment limits inferences about thermal stress induced by variability, on native biodiversity. However, continuous temperature measurements have been made by Freshwater Solutions which are incorporated within this report for subsequent comparison to CRI values determined for (but ultimately excluded from) the NOF (e.g., Davies-Colley et al., 2013). Davies-Colley et al. (2013) recommended a national bottom-line CRI for "maritime" regions (including the entirety of Northland) of ≤24°C. Davies-Colley et al. (2013) recommended that the CRI be determined from the 5 hottest days whereas Freshwater Solutions sampled temperature continuously from 25-28 March 2013. So, CRI values reported here are likely to underestimate the true CRI for the Mangere during the hottest summer months of January-February.

***Note:** a temperature limit of 21.2°C provides a more sensitive limit than the 25°C maximum permissible temperature under Schedule 3 of the Resource Management Act. Also note that Quinn and Hickey (1990) found no strong relationship between temperature and macroinvertebrate families, other than Plecoptera and Ephemeroptera with Plecoptera will be limited in their natural distribution within the Mangere catchment by its soft sedimentary channel.*

3.5.2 pH

The variable pH is a measure of the concentration of hydrogen ions (H+) in water (where p stands for $-\log_{10}$). The geology and provenance of surface water typically determine background pH upon which diurnal and seasonal changes are introduced by in-stream plant photosynthesis and respiration. In New Zealand, pH maxima and minima typically occur in the late afternoon and dawn through the consumption of CO_2 and HCO_3^- by photosynthesis during the day and their production by respiration during the night (Wilcock and Chapra, 2005). Davies-Colley et al (2013) cite concerns about diel pH variation related directly to interactions on physiology but indirectly on the speciation of toxic metals (e.g., As, Al, Mn).

The response of nine native fish species were tested by West et al (1997) who demonstrated that all bar inanga (*Galaxias maculatus*) avoided pH >9.5 (most avoiding pH >9.0). Adult fish were also less tolerant than juveniles, with all species bar short-finned elvers avoiding pH <6.5. For a fish community comprised of short and long-finned eels, common and Cran's bullies and banded kokopu, the combined minimum and maximum pH preferences are pH 6.5 and 9.5, respectively (West et al., 1997). Accordingly, this report adopts both as additional bottom-line numeric attribute states for pH for the protection of ecosystem health.

3.5.3 Turbidity

Increased loadings and concentrations of suspended particulate and colloidal matter can reduce ecosystem health by limiting the transmission of light, smothering benthic organisms and habitats, abrasive impairment of the gills of fish, crustaceans and molluscs, and restricting feeding rate or behaviour in fish (Lloyd, 1987; Campbell and Doeg, 1989; Rowe et al., 2002).

Turbidity is a measure of the concentration of suspended particulate and colloidal matter in water (e.g., clay, silt, phytoplankton and detritus) (Grayson et al., 1996). Changes in turbidity can occur from a change in the size, shape, composition and amount of suspended particles (Grayson et al., 1996). In most instances, turbidity in rivers is highly related in a positive manner with flow. Monitoring at high flows is therefore essential to accurately describe exposure to turbidity associated risks, albeit without biasing sampling frequency away from lower flow conditions that typify the majority of flow conditions.

NIWA have produced a decision support system to set suitable TSS thresholds for native fish (Figure 3.4-3.5). From this, banded kokopu (*Galaxius fasciatus*) are the most sensitive native fish to changes in turbidity within New Zealand fluvial systems (Boubee et al., 1997; Rowe and Dean, 1998; Ausseil and Clark, 2007). As before for temperature, their national distribution (McDowall, 1990), historic (if not contemporary) presence in the headwaters of the Mangere (WDC, 2009) and excellent climbing ability (Rowe et al., 2000) predicate their use as the most sensitive taxon for setting local turbidity limits.

Given the absence of smelt or inanga within the Mangere catchment, the DSS for TSS suggests a maximum limit of 40,000 NTU at peak flow (per 24hr period) (Figure 3.5). To ensure reliable comparisons are drawn, this maximum NTU limit will be applied to all NRC observations rather than monthly medians.

Base flow limits during August-December will need input from the CSG to determine an acceptable 'effects level' (see Figure 3.6). Further higher resolution sampling is also required to more accurately determine the frequency (%) of time during August-December that TSS >20 NTU (i.e., rather than from twice monthly observations). This report is limited to assessing the likely occurrence of banded kokopu by site and year, expected from August-December observations of turbidity (calculated from Rowe et al., 2000).

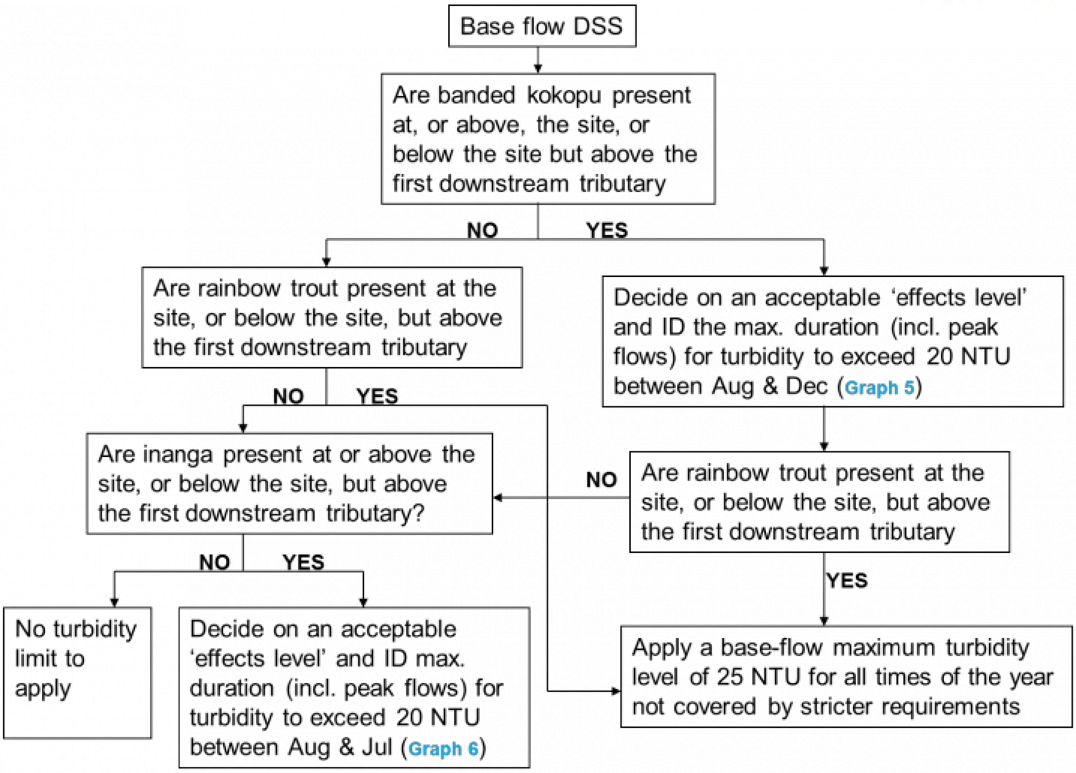

Figure 3.4. Decision support system for setting turbidity limits at base flows (Accessed online: https://www.niwa.co.nz/our-science/freshwater/tools/turbidity [17/02/2014]).

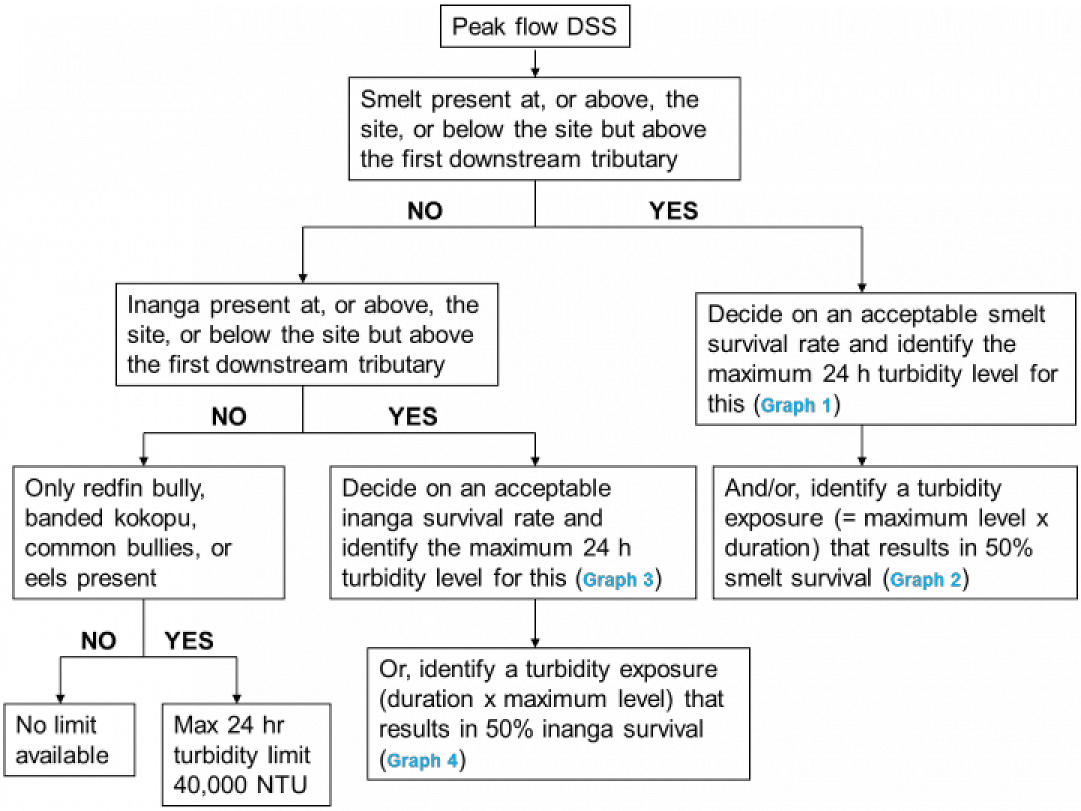

Figure 3.5. Decision support system for setting turbidity limits at peak flows (Accessed online: https://www.niwa.co.nz/our-science/freshwater/tools/turbidity [17/02/2014]).

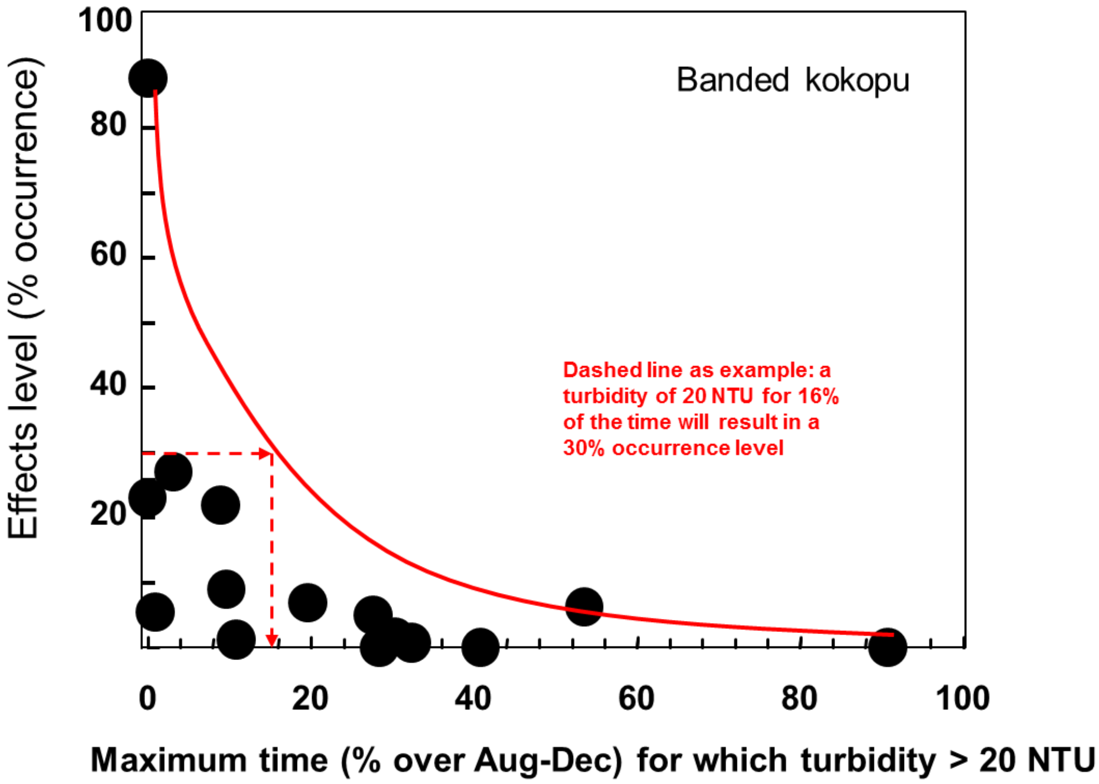

Figure 3.6. Effects level (% occurrence) of banded kokopu by maximum time TSS >20 NTU (August-December) (Accessed online: https://www.niwa.co.nz/our-science/freshwater/tools/turbidity [17/02/2014]).

3.5.4 Trend analysis

Long-term trends in water quality indicators were analysed, as follows:

1. Seasonal Kendall slope estimator and trend tests, to determine the direction, significance and relative magnitude of long-term changes at all sites, in the statistical package 'TimeTrends' version 3.2 (produced by NIWA in conjunction with Northland and Hawkes Bay Regional Councils for the analysis of hydrological time-series data [Jowett, 2011]);
2. Time-series decomposition into seasonal (average), trend (loess smoother) and random/unexplained components of instantaneous observations (Cleveland et al., 1990) in the statistical programme 'R' using the 'stl' function of the 'stats' package. Analysis was limited to site 101625 by reason of its record length and resolution, examining the period 2000-2012.

In steps 1 and 2, data remain in corresponding units of measurement and interval (daily observation). Step 1 is robust to the effects of outliers or anomalous samples, precluding the need to remove outliers from the dataset (Cleveland et al., 1990; Gilbert, 1987). Step 2 is sensitive to outliers and so all observations >±3 standard deviation of the series mean were excluded.

Step 1 generated precise estimates of the direction, magnitude and statistical significance of changes observed in water quality indicators at all sites during the interval 2007-2010 (2008-2010 at site 109166). Longer-term data at site 101625 permitted examination of trends amongst indicators for a longer period, from 2000-2010. Lengthier records offer greater chances of describing underlying trends above background noise, so caution should be exerted on trends reported for all sites bar 101625.

Non-parametric seasonal Kendall trend analyses were conducted on in-stream concentrations due to the non-linearity of seasonal observations, yielding two statistical measures (Gilbert, 1987):

- Seasonal Kendall slope estimator (SKSE) – measures the magnitude of the non-seasonal trend (SEN slope) and can yield the relative change (% per annum on a series median; RSKSE);
- Seasonal Kendall trend test – measures the statistical significance of the non-seasonal trend.

The SEN slope estimator computes the direction and magnitude of trends in the data by determining the slopes for all pairs of observations (constrained by temporal order) and generating the median of these slopes as an estimate of the long-term trend (Helsel and Hirsch, 1992). Positive and negative SEN estimates indicate a positive and negative long-term trend, respectively. Division of the SEN by the series median, offers the RSKSE, the relative Seasonal Kendall Slope Estimator.

The distinction between a trend's statistical significance and magnitude is important. Statistical significance describes the likelihood of a trend arising from random variability in a time-series, with 'significant' trends denoted by a *p*-value <0.05 (i.e., less than 1 in 20 occurrence due to chance). Magnitude refers to the precise estimate of change in an attribute over time (i.e., the slope of a trend). Trends of sufficient magnitude to induce an ecological change to water quality are denoted by an RSKSE of ±1% or more (Vant and Wilson, 1998).

Flow-adjustment of trend testing in rivers and streams is often required to account for changes in discharge that can dilute or concentrate contaminants, regardless of changes in catchment load (Smith et al., 1996). The availability of average daily flow data at site 101625 permitted flow-corrected seasonal Kendall trend testing of NRWQMN indicators for the period 2007-2012, using a locally weighted scatterplot smoother (LOWESS) with 30% span (as per Ballantine and Davies-Colley, 2009).

Average daily flow estimates from the furthest downstream site 101625 were utilised also, to flow-correct all other sites during the period 2007-2010 (i.e., under the assumption that relative changes in flow at the downstream site would approximate relative changes in flow upstream; Vant, 2013 adopted a similar approach, limiting this approach to sites within 20 km of a flow-gauge).

Flow-adjustment identifies a relationship between flow and contaminant concentration, with which to derive estimates of concentration at any observed flows, deduct this from the observed concentrations to yield residuals, and tests these flow-dependent residuals for their magnitude and statistical significance with the seasonal Kendall trend test (Vant, 2013). By accounting for inter-annual changes in flow, flow-adjusted trends are better able to identify changes in catchment loading (i.e., accounting for dilution or concentration of loads by changes in flow).

A NIWA software package was used to perform seasonal trend testing, adjusting records for daily average flow, calculating SKSE and RSKSE and associated *p*-values (TimeTrends, version 3.10).

Step 2 decomposes a time-series into three cumulative data-series: (1) a replicated seasonal pattern determined from the data using a specified 12-month repetitive window; (2) a long-term loess-smoothed trend determined from observations that have had seasonal variation removed; and (3) a remainder or residual estimate of variance, unexplained by the loess smoother in (2) or the seasonal variation in (1). Output is graphical, meaning use of time-series deconstructions here, is limited to diagnosing points in the recent past that contributed most heavily to statistically significant and ecologically meaningful, flow-corrected trends. The approach assumes equidistant sample observations in time, so:

- when several observations were available for a parameter in a given month, the result closest to the monthly average was included for time-series deconstruction;
- on rare occasions, some sites had two samples in 1 month, but none in the preceding or following month. A sample was binned into an alternate month when taken close to the beginning of the end of a month without a sample, to obtain a more consistent dataset.

3.5.5 Multivariate analysis

Table 3.4. NRWQMN water quality indicators included for principal components analysis (for all six monitoring sites in the Mangere, over varying timespans, but covering the period 2007-2012).

Indicator	Unit	Description
NO_3-N	g/m^3	A highly soluble form of Nitrogen available for plant uptake, which can indicate groundwater supply (dissolution and transport of agricultural fertilizer and effluent) and/or point source discharges (e.g., stock crossings).
NH_4-N	g/m^3	Ammoniacal-nitrogen records the sum of dissolved ammonia (NH_3) and ammonium (NH_4) present. Ammonia readily ionises to ammonium ions at greater temperature and lower alkalinity (i.e., there is lower risk of ammonia toxicity at greater temperature and lower alkalinity).
TKN	g/m^3	Total Kjeldahl nitrogen is the sum of organic and ammoniacal nitrogen.
TN	g/m^3	Total nitrogen is a measure of the total abundance of nitrogen in bioavailable and mineral forms (NNN + TKN).
DRP	g/m^3	Dissolved reactive phosphorus measures the abundance of a biologically-active form (freely-available) of phosphorus that can stimulate nuisance algal growth.
TP	g/m^3	Total phosphorus is a measure of the total abundance of phosphorus in biologically-active and mineral forms.
TN/TP	Unit-less	The mass ratio of TN/TP is an indicator of nutrient limitation.
Turbidity	NTU	Turbidity is a measure of water clarity recorded through total suspended solids (TSS).
DO	% Saturation	Dissolved oxygen concentrations vary by temperature and pH, with corresponding changes to in-stream organisms and geochemical processes.
Cond.	µS/cm	Conductivity measures the availability of dissolved solutes, recording changes in geochemistry that can influence biota.
E.coli	MPN / 100ml	*Escherichia coli* abundance is recorded through the maximum probable number (MPN), indicating the suitability of water for stock drinking and contact recreation.

Water quality indicators often exhibit complex patterns in time and across a catchment. Ordination is a form of dimension-reducing analyses that reduce this complexity (Legendre and Legendre, 1998).

Ordinations isolate the underlying gradients (or factors) in a dataset, by generating *compound gradients* that maximise the variation between samples along generated gradients (i.e., a new linear axis comprised in part by one or all parameters, is generated which maximises the variance between site scores [see Legendre and Legendre, 1998]).

Ordination analysis is useful to express the dominant gradients of change across a suite of indicators (i.e., within-site as a measure of seasonal changes at a site; and between sites as a measure of the spatial changes in water quality).

A measure of the variance explained by each ordination axis was generated by comparison to that generated by a random or null ‘broken stick’ distribution (Bennett, 1996). Comparing variance explained by chance to that of the PCA, ensures only statistically significant axes are retained for data exploration.

Prior to ordination all indicators must be standardised to equivalent units of measurement (i.e., neutralise the effect of an indicator recorded in units of greater variance, skewing any compound axes to changes in that indicator [Legendre and Legendre, 1998]). Accordingly, linear indirect ordination (principal components analysis [PCA]) was performed on the SOE water quality variables reported by NRC (Table 3.4), standardising each to zero mean, unit variance prior to PCA.

Ordinations were performed in the statistical programme ‘*R*’ using the DECORANA function of the ‘Vegan’ package (Oksanen, 2013).

4.0 Water Quality of the Mangere River

The water quality of the Mangere River is reported below from a whole-of-catchment perspective, beginning with spatial patterns between the six monitoring locations (from 2007-2010), followed by investigation of the seasonal profile of NRWQMN indicators at Knight's Bridge (site 101625; from 2000-2012) and finally by inspection of data at the six monitoring stations for exceedance of limits proposed to protect "ecosystem" or "human health". This is followed by results of long-term statistical trend tests and indirect PCA between NRWQMN indicators at all sites.

4.1 Spatial patterns

Median site concentrations of NRWQMN indicators derived for the period 2007-2010 vary markedly between monitoring stations in the Mangere catchment (Appendix D). For instance, a near three-fold increase in median TN and seventeen-fold increase in median TP occurs between the furthest upstream site 109166 and the Mangapiu at site 101626. Similar changes occur in median *E.coli* concentrations (two-fold between the headwaters [109166] and the confluence of the Mangapiu with the Mangere [105719]). Turbidity undergoes a less marked but similar change from a median of 5 NTU at site 109166, to 6.9 NTU by at the furthest downstream station at Knights Bridge (site 101625). Notably, the Mangapiu Stream at site 101626 recorded the greatest median and average concentration of nutrients (NO_3-N, NNN, NH_4-N, TN, DRP, TP) and suspended solids, as well as lowest dissolved oxygen (%), of all monitoring stations. The combined picture from these observations is one of increasing downstream nutrient, solute, suspended solid and *E.coli* availability (Appendix D), a likely response to the accumulation of increasing pastoral land use effects (e.g., Ballantine et al., 2010). Montgomerie (2014) also noted a similar pattern in physico-chemistry, with increasing contaminant maxima and seasonal-diurnal variability in DO downstream.

An exception to the general pattern of downstream accumulated effects is the greater median NH_4-N, TKN, DRP and lesser DO (%) occurring in headwaters (site 109166) relative to observations immediately downstream at site 102106. (Examination of series averages also highlights greater concentrations of NO_3-N, NH_4-N, TKN, TN, DRP, TP, and lesser DO (%) at site 109166 relative to site 102106). The average DO (%) at site 109166 also sits below an 80% threshold for the protection of fish (Hay et al., 2006) and recovers by 15.3% once waters reach site 102106 directly downstream. An equivalent pattern is evident in median DO% which, recovers by 10.2% between the two sites. Although even the 5^{th}% of site 102106 doesn't drop below 80%, nearly half of all observations upstream at site 109166 failed to meet the 80% threshold for protection of fish between 2007 and 2010. Indeed, with the exception of the Mangapiu Stream all other sites on the Mangere River typically exceeded a DO of 80% over the period 2007-2010 (Figures 4.1-4.2). It is worth noting that despite relativistic DO % being beneath protective levels of 80% at site 109166, the absolute DO concentration (mg/L) is seldom less than the national 7-day bottom-line of 5 mg/L. For instance, median and mean absolute DO therein is 8.7 and 8.0 mg/L (i.e., <80% although concerning is not necessarily a stressor on in-stream fauna). Nonetheless, the absence of nearby or upstream dairying operations at site 109166 and its relatively short distance (<2 km) from presumably pristine, highly oxygenated headwaters in the Pukenui Forest, suggest a substantial effect of upstream local land use on in-stream nutrient and DO availability (i.e., absolute DO concentrations at the headwaters are equivalent to those of the furthest downstream site at Knight's Bridge despite its limited upstream land-use – see Appendix C). This is important as any changes introduced by site 109166 can alter baseline water chemistry downstream for all other sites on the Mangere River. A single, extensive drystock operation is located upstream of 109166 (Tess Dacre, pers. comm.). Given that DO is a numeric attribute state for "ecosystem health" (MfE, 2013b) it is crucial that the cause(s) for depleted oxygen levels at site 109166 are determined and addressed by the Mangere CSG to meet the NPSFM. This therefore will require a whole-of-catchment rather than simply a dairying approach to water quality management in the Mangere River.

Action: *Determine the cause of nutrient enrichment and oxygen depletion as the Mangere Stream emerges from its headwaters, upstream of site 109166, and ensure greater minimum oxygenation.*

As noted, the Mangapiu Stream (site 101626) also experienced highly variable oxygen levels from 2007 to 2010 with a mean and median well below 80% (63.4% and 68.3% respectively). Indeed, only 6% of DO observations on the Mangapiu Stream exceeded 80% between 2007 and 2010. A similar pattern is evident in absolute DO concentrations with the 20^{th}% of observations just exceeding the proposed long-term bottom-line of 5 mg/L (20^{th}% = 5.04 mg/L). This pattern was also observed in 2013 during a summer survey (24% DO). The Mangapiu Stream is believed to be intermittent which would contribute to lower DO% in summer months when water temperatures might also rise markedly, contributing to lower relative saturation. If so, then management of "ecosystem health" year-round would not be appropriate. However, if continuously flowing then "ecosystem health" is likely to be severely limited by the lack of sufficient oxygenation for fish and macroinvertebrate respiration.

The relatively high TKN (organic nitrogen and ammoniacal-nitrogen) concentration of the Mangapiu Stream, being more than three times that of the second highest concentration at the furthest downstream Knights Bridge (median 1.300 g/m^3 and 0.420 g/m^3 respectively) hints at very high in-stream productivity and/or very high discharge of organic matter and ammoniacal-nitrogen to the stream – bear in mind that despite locally enriched NH_4-N concentrations, median and mean TKN concentrations are both ten times those of NH_4-N (i.e., the vast majority of TKN is contributed by organic nitrogen, which would result in greater biological oxygen demand (BOD) by subsequent microbe-mediated aerobic decay). Notably, the Mangapiu Stream also exhibited greatest DRP and TP availability of all sites (median 0.270 and 0.468 g/m^3 respectively), again being approximately three times that of the furthest downstream site 101625 (median 0.068 and 0.124 g/m^3 respectively) over the period 2007-2010. This in turn appears linked to the density of dairy farming on the Mangapiu Stream (4 of the 14 dairy farms border the Mangapiu Stream [Tess Dacre, pers. comm.]). Despite its relatively high phosphorus concentrations, it is unlikely the Mangapiu Stream contributes substantially to DRP or TP loads within the Mangere River proper as median DRP and TP concentrations are both approximately five times less at the confluence of both the Mangapiu and Mangere Streams (i.e., site 105719 has DRP and TP concentrations five times less than site 101626). Hence, the effects of nutrient enrichment and limited DO appear localised in the Mangapiu Stream, rather than driving changes to "ecosystem health" in the Mangere River downstream.

Action: *Determine if the Mangapiu Stream is intermittently flowing or continuously flowing and adjust how water quality guidelines are applied accordingly. Assess the cause of limited DO availability in the Mangapiu Stream by examining whether inputs of organic matter or in-stream nuisance weeds are the likely cause. Possible remedial actions will include better effluent and/or riparian management accordingly. Also, note that inspection of long-term trends suggests marked reductions in ammoniacal-nitrogen, DRP and TP concentrations associated with rising DO (%) since 2007 (i.e., actions already taken since 2007 are beginning to address the causes of limited oxygenation in the Mangapiu Stream – see Section 4.4. Long-term Trends).*

Median *E.coli* concentrations rise steadily downstream from sites 109166 through 102106 to 102109 (554 to 613 to 650 MPN/100 ml respectively), before approximately doubling downstream of the confluence with the Mangapiu Stream at site 105719 (median *E.coli* 1178 MPN/100 ml). Substantive bacterial loading of the Mangere River therefore occurs in the middle reaches, which might be linked to a higher density of dairy operations nearby (i.e., 7 of 14 consents to discharge animal waste to land or water are held by dairy farms discharging downstream of site 102109). As before, the Mangapiu Stream itself is unlikely to be a major contributor to total bacterial loads as the instream median concentration over the period 2007 to 2010 was <600 MPN/100 ml, and the stream is believed intermittently flowing (i.e., discharges a limited volume to the Mangere River).

The spatial pattern in turbidity also demonstrates a cumulative effect from upstream to downstream with the median turbidity rising steadily without interruption from the headwaters at site 109166 (5.0 NTU) to Knights Bridge at site 101625 (8.8 NTU) (over the period 2007-2010). Again, the Mangapiu Stream observes the most elevated turbidity with a median of 9.1 NTU over the period 2007-2010.

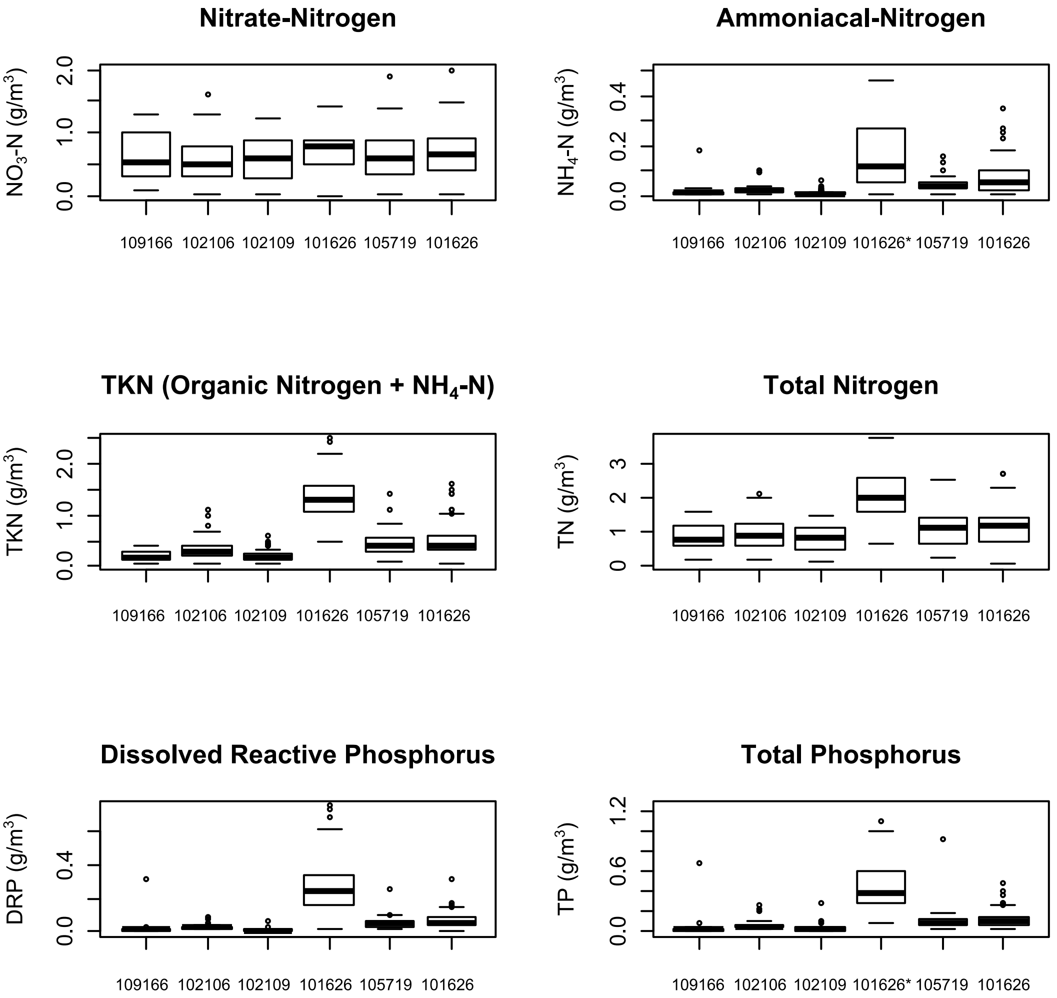

Figure 4.1. Tukey boxplots of censored absolute data for water quality indicators, by site at six monitoring locations in the Mangere catchment, over the period 2007-2010 (with the exception of site

109166 whose record is limited to 2008-2010) (boxes bound the inter-quartile range [IQR] and whiskers the upper and lower bounds of 1.5*IQR). *indicates outliers in excess of y-max.

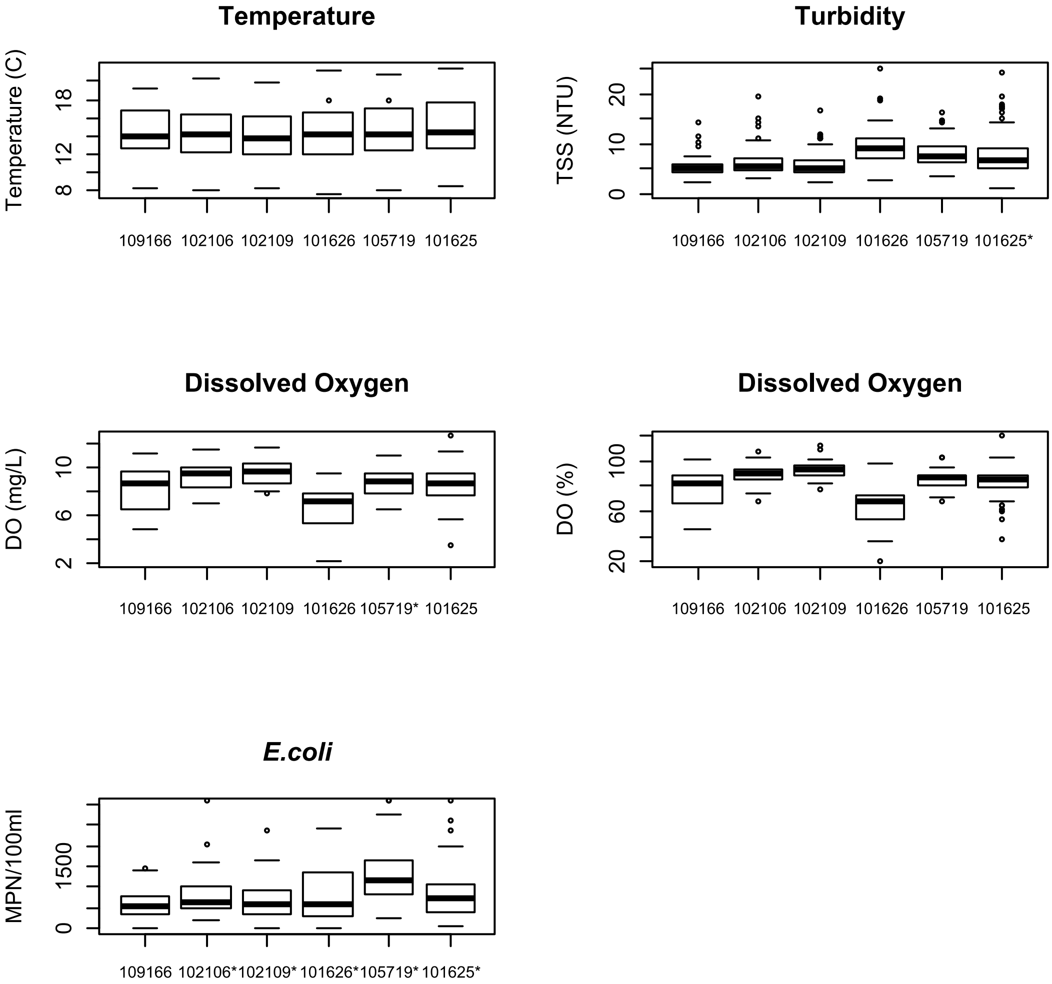

Figure 4.2. Tukey boxplots of censored absolute data for water quality indicators, by site at six monitoring locations in the Mangere catchment, over the period 2007-2010 (with the exception of site 109166 whose record is limited to 2008-2010) (boxes bound the inter-quartile range [IQR] and whiskers the upper and lower bounds of 1.5*IQR). *indicates outliers in excess of y-max.

Riparian conditions have been surveyed at 64 locations, on the main stem of the Mangere River, Mangapiu Stream and northern tributary of the Mangere Stream (Figure 4.3) (summary statistics provided in Appendix E). Riparian shading appears extensive with median scores suggesting 50-80% coverage of the water's surface by canopy cover – 11 of the 63 sites possessed <25% shade. High proportions of shade and the underlying soft substrate of channels limits potential for nuisance in-stream plant growth as shading >60% is associated with marked reductions in proliferation of aquatic weeds (Quinn et al., 1997; Rutherford et al., 1997). Nonetheless, just under 50% of sites currently lack sufficient shade to directly limit in-stream nuisance weeds – bear in mind that other controls, including the lack of sufficient hard substrate or duration of low flows might limit nuisance weeds (e.g., Parkyn, 2004).

Median riparian zone widths were 8 m (on each bank), with the 75% of riparian sites offering at least 5 m of buffering land managed separately from surrounding land use. In keeping with the complex catchment geology, buffer widths varied 0 to 30 m. In a review of riparian buffer effectiveness, Parkyn (2004) notes that at least 5 m of vegetated riparian buffer is required to filter the majority of >40 µm diameter particles (and at least 10 m to filter finer colloidal clays). The precise width required to strip surface-borne contaminants varies with the contaminant, clay content of soil, slope, hillslope length and vegetation type or age (Collier et al., 1995). In New Zealand for instance, Cooper (1990, 1994) demonstrated that a buffer width of 3-4 m could filter 0-97% of nitrate whereas buffers of 10-13 m are required to filter >85% of total suspended solids (Smith, 1989). As little as 5 m of native vegetation can markedly reduce summer air temperatures (by 3.25°C [Meleason and Quinn, 2004]) with buffers of 8 m able to support macroinvertebrate communities equivalent to those of "clean water" or native forest status in the Coromandel (Quinn et al., 2004). Although the science to describe the effects of riparian buffers is therefore quite equivocal, riparian margins in the Mangere catchment appear sufficiently wide for significant benefits to be provided for "ecosystem health" from shade, inputs of woody debris, nutrient attenuation and sediment infiltration.

Buffer intactness (a measure of gaps in vegetation ground cover) of the 64 riparian survey sites was typically good with a third of sites (*n* = 22) offering <20% gaps in coverage and nearly two thirds (*n* = 44) offering at least 50% coverage. That said, this also means that one third of sites offer less than 50% coverage of ground by vegetation. Whilst canopy vegetation is important to the uptake of subsurface nutrients through extensive root networks and provision of root exudates to support denitrifying bacteria (Cooper, 1990; Fennessy and Cronk, 1997), surface cover vegetation is crucial to infiltration and sedimentation of particulate contaminants suspended in surface runoff (Collier et al., 1995). In addition, a fifth of sites permitted direct livestock access from one or both banks (*n* = 12) and nearly half (*n* = 27) scored "very low" to "low" on bank stability, further emphasising that groundcover in the Mangere catchment is ineffective in many locations, to significantly mitigate surrounding land use. This is further underscored by the fact that only 4 (6%) survey sites possessed a slope <20° on one or both banks, with 52 sites (83%) possessing a slope >35° on both banks, meaning the Mangere River and its tributaries occupy heavily incised "U" shaped channels that favour higher rates of erosion on riparian buffers (Parkyn, 2004).

Consequently, despite their width many riparian margins in the Mangere catchment would benefit from greater groundcover to protect banks and reduce sediment loss. This is notable, because earlier analysis has revealed the likely presence of banded kokopu (*Galaxias fasciatus*) in the Mangere River, whose migrating young are highly sensitive to water clarity or suspended solid concentrations from August to December (Rowe et al., 2000). Adult banded kokopu also require dense surrounding riparian vegetation to provide a screen for winds and permit detection of invertebrate prey landing on the surface of pools (David Rowe, pers. comm.). In order to prioritise future riparian management for banded kokopu (as a measure of "ecosystem health"), five attributes of riparian condition (water shading, buffer width, intactness, bank stability and groundcover) have been ranked and sites scored by a traffic-light system in Figure 4.3:

- Red = scoring less than the mode for more than three attributes (19% sites, *n* = 12)
- Amber = scoring less than the mode for three attributes (26% sites, *n* = 17)
- Green = scoring less than the mode for less than three attributes (55% sites, *n* = 35)

"Red" riparian conditions predominate in the middle Mangere River and northern Mangapiu Stream, meaning the area around the confluence of the Mangapiu and Mangere Streams is a likely hotspot for bank instability, limited infiltration of surface runoff, higher suspended solid concentrations and limited shade or density of canopy vegetation. Note however, that the proximity of “green” sites within a kilometre of “red” sites suggests marked heterogeneity of riparian condition over short distances. Underlying causes for poor riparian condition are therefore likely to be spatially complex (i.e., not linked simply to land use – dairy farms occupy “red”, “amber” and “green” scoring sites).

Action: *More comprehensively survey the Mangere catchment for riparian health, particularly nearer the Pukenui Forest, and reassess priorities for management remediation. Focus on preventing live-stock access to restrict treading damage and associated erosion of riparian sediment (Collier et al., 1995), particularly as pastoral streams typically retain substantial sediment loads through channel narrowing (Davies-Colley, 1997 and Collier et al., 2001 in Parkyn, 2004). Focus on establishing groundcover vegetation by the removal of weed/pest species and livestock, followed by riparian planting. Remember that grass filter strips are essential between fences and plantings as up to 90% of suspended sediment can be deposited in a 1 m grass filter strip (Neibling and Alberts, 1979 in Parkyn, 2004). Grass filter strips should be designed to treat sheet flow and establishing sufficient groundcover will enable this by preventing channelized flow (Collier et al., 1995). The general rule of thumb governing riparian zone design is for larger buffers of grass strip and shrub/tree vegetation on heavier soils, longer paddocks and steeper slopes.*

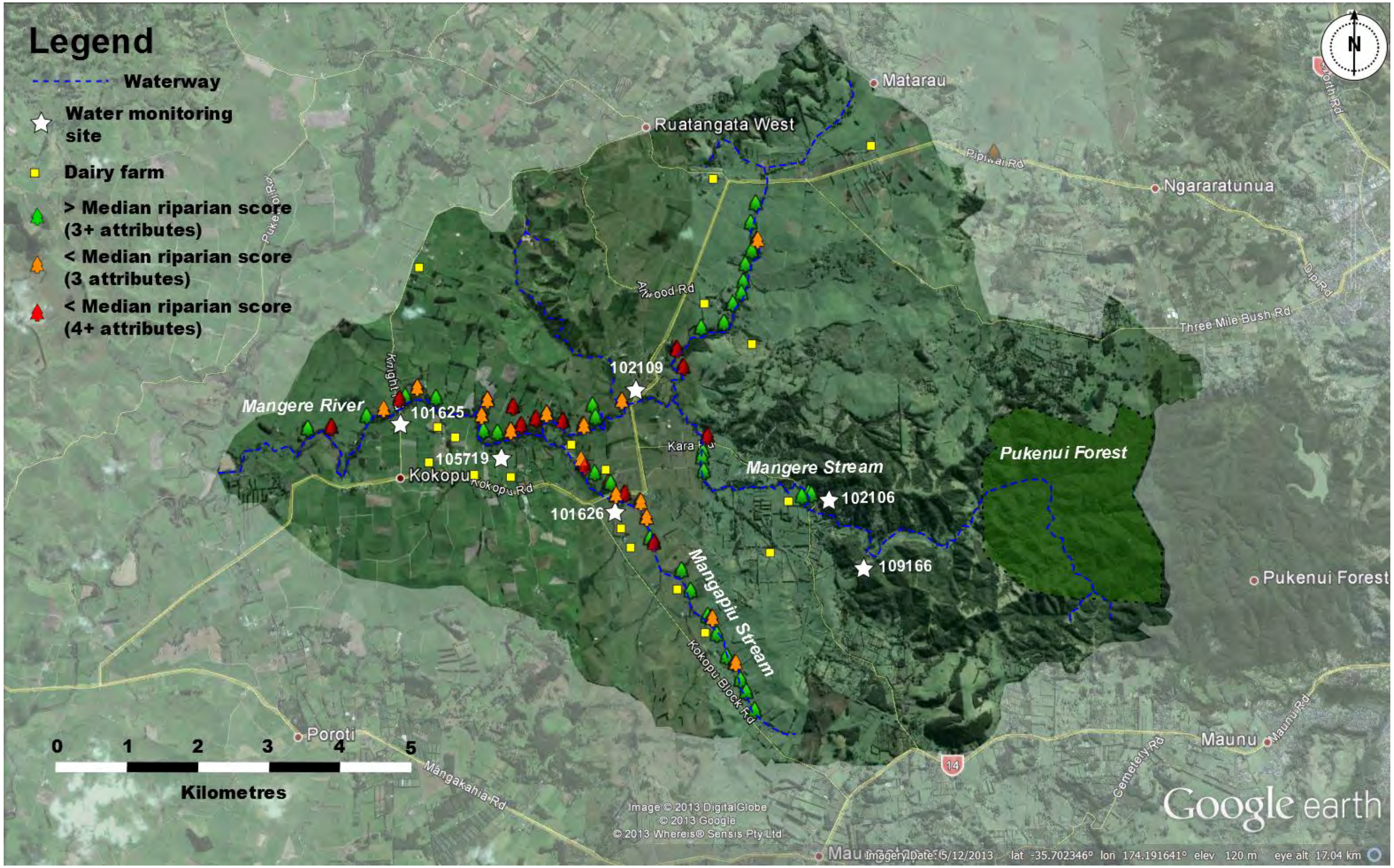

Figure 4.3. Riparian condition survey sites and scoring according to a traffic light system to diagnose areas most prone to loss of suspended solids and limited in-stream “ecosystem health”. Red sites scored less than the mode for 3+ attributes, amber scored less than the mode for 3 attributes and green scored less than the mode for 2 or less attributes.

4.2 Seasonal patterns

Median monthly variation in NRWQMN indicators for Knights Bridge (site 101625) over the period 2000-2012 is displayed by Tukey boxplots in Figures 4.4-4.5 (see Appendix D for a table of series medians by attribute for site 101625).

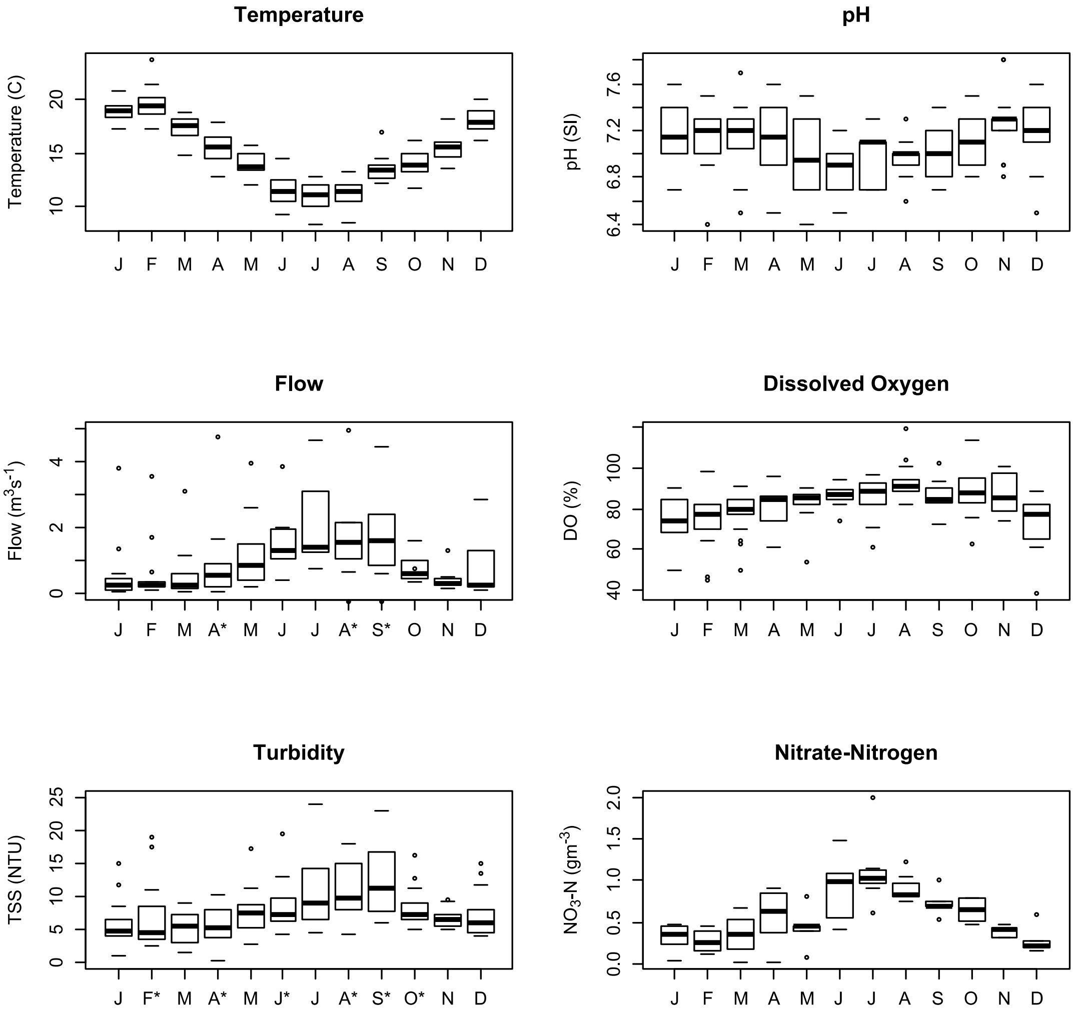

Figure 4.4. Tukey boxplots of censored data for water quality indicators, at Knights Bridge (site 101625), over the period 2000-2012 (boxes bound the inter-quartile range [IQR] and whiskers the upper and lower bounds of 1.5*IQR). *indicates outliers in excess of y-max.

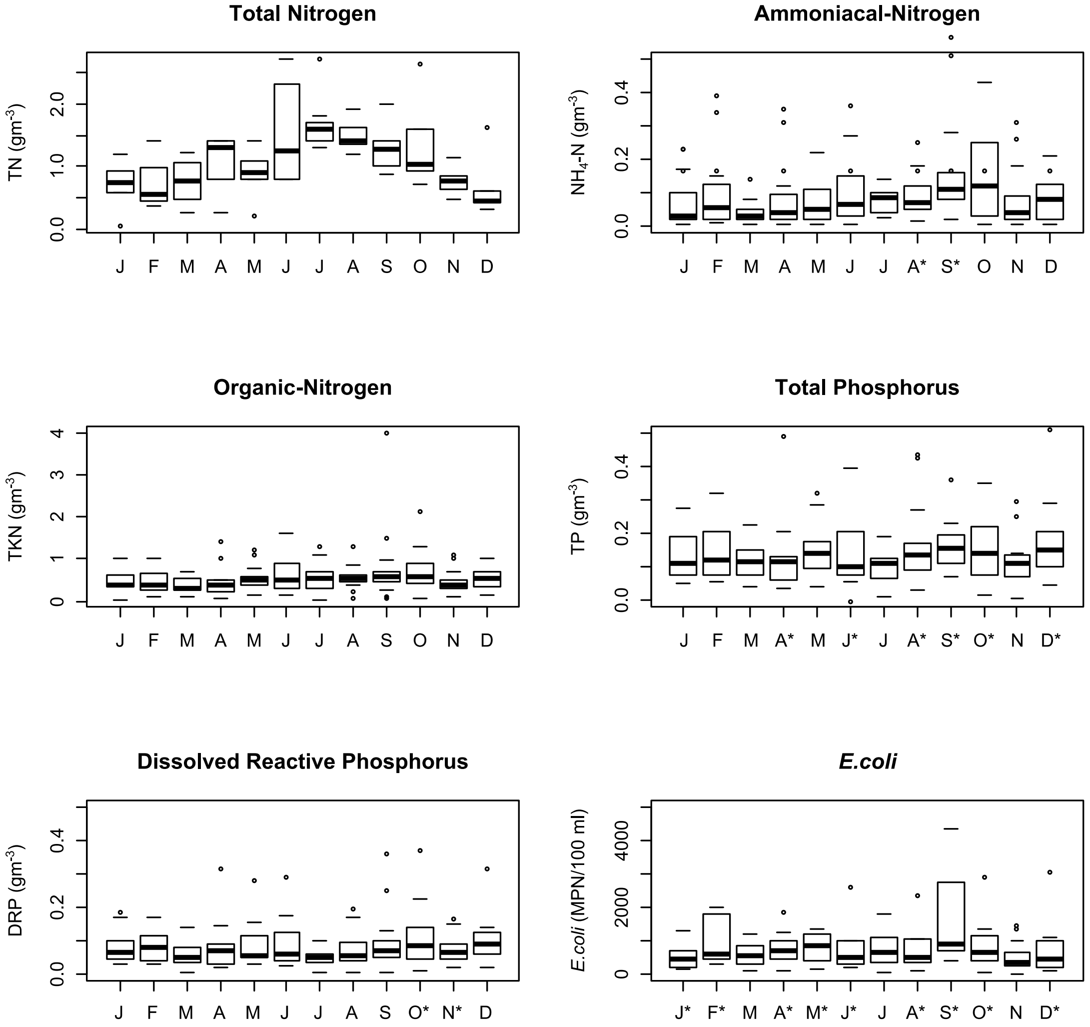

Figure 4.5. Tukey boxplots of censored data for water quality indicators, at Knights Bridge (site 101625), over the period 2000-2012 (boxes bound the inter-quartile range [IQR] and whiskers the upper and lower bounds of 1.5*IQR). *indicates outliers in excess of y-max.

Water temperature exhibits a typical Austral pattern of summer maxima and winter minima, as do changes in median monthly pH in which summer months exhibits greatest variability and absolute pH (i.e., when autotrophic productivity is greatest and consuming/replacing in-stream dissolved inorganic carbon [Davies-Colley et al., 2013]). The seasonal range in median monthly water temperature is 8.25°C, from 19.40 to 11.15°C, beneath the threshold of 21.2°C for protection of banded kokopu. However, several January and February observations from 2000-2012 did exceed 21.2°C, but remained beneath the RMA permitted maximum of 25°C which is also the limit proposed for “lowland” streams by Olsen et al. (2012). Continuous monitoring of water temperatures at 5 locations in the Mangere catchment by Freshwater Solutions in March 2013, also generated an average CRI of 15.6°C (varying from a 14.1°C minimum CRI to a 17.4°C maximum CRI – Table 4.1). As the hottest instream temperatures of New Zealand streams are typically experienced in January-February (Davies-Colley et al., 2013), and because datasondes were deployed for just short of 24 hours (biased to lower temperatures at night), CRI’s are likely to be under-estimates. Nonetheless, all five

CRI's are well below the CRI of ≤24°C which was proposed (but not adopted) to protect "ecosystem health:" in "maritime" catchments under the NOF (e.g., Davies-Colley et al., 2013).

Table 4.1. Cox-Rutherford Index (CRI) for temperature at five locations in the Mangere catchment monitored over an approximately 24-hr period by Freshwater Solutions (March 2013). Data sondes sampled continuously at 15 minute intervals. T_{max} = thermal max; T_{mean} = thermal mean; CRI = $(T_{max}+T_{mean})/2$ (Cox and Rutherford, 2000b). (Note: if *n* < 96, data sonde was not deployed for full 24-hr period). For location of sites, refer to Appendix A (Figure A1).

Site	Date	N obs.	T_{max} (°C)	T_{mean} (°C)	CRI (°C)
1*	25/03/13-26/03/13	86	18.06	16.74	17.40
3*	25/03/13-26/03/13	79	16.06	14.99	15.53
4	26/03/13-27/03/13	96	15.29	14.87	15.08
5*	26/03/13-27/03/13	88	16.13	15.50	15.81
6*	27/03/13-28/03/13	84	14.25	13.88	14.07

*Denotes data sonde deployed for full 24 hour period (i.e., *n*<96) and observations skewed to overnight temperatures – data sondes were deployed primarily to record DO minima overnight/dawn.

Table 4.2. Flow regime statistics for site 101625 (using mean daily observations from January 01 2007 to December 31 2010 [n = 1460]).

Flow Regime Statistic	Value at 101625 (2007-2010, daily observations)
Mean	1.609 m^3s^{-1}
Median	0.614 m^3s^{-1}
MALF (7d)	0.108 m^3s^{-1}
X3 median	1.842 m^3s^{-1}
MAFF*	49.569 m^3s^{-1}
25th% (75th%)	0.250 m^3s^{-1} (1.571 m^3s^{-1})

*Derived from 4 maximum annual flood flows (i.e., 2007, 2008, 2009, 2010).

Table 4.3. Biological disturbance flow statistics for site101625 (using mean daily observations from January 01 2007 to December 31 2010 [n = 1460]).

Biological Disturbance Statistic	Value at 101625 (2007-2010, daily observations)
MAFF/MALF (7d)	459.7
MAFF/annual median	80.7
FRE3	14.75
SD FRE3	1.71
Mean days accrual	21 (20.92)
SD accrual	37 (37.09)

Seasonal changes in median monthly pH appear limited varying from 6.9 to 7.3 pH. This is indicative of limited in-stream algae or aquatic macrophyte biomass at site 101625 (i.e., the latter would alter the availability of dissolved carbon and drive marked summer rises in pH). With the exception of outliers and a small percentage of observations in April and May, few samples exceed the Soil and Water Plan recommendations of pH 6.5-9.0, which are also the limits proposed from this report's review of Davies-Colley et al. (2013).

Marked variation occurs in median monthly discharge including greater and more variable flows in autumn and winter, although with considerable variation in flow during early summer low flows as expected from the relative impermeable catchment soils (Figure 4.4). There are numerous outliers in all months (circle outliers greater than 1.5*IQR) demonstrating frequent and wide variation in discharge during each calendar month (i.e., frequent flood pulses or flow greater than three times the annual median [>1.842 m^3s^{-1}]). Summary flow statistics for the Mangere River confirm the wide variation in hydrology at site 101625 (Tables 4.2-4.3). For instance, the FRE3 statistic which is a measure of the frequency of flood disturbance, expressed as the number of events per year (Clausen and Biggs, 1997) is approximately 15 when calculated without any filter period (as per Matheson et al., 2012). The average accrual time between flood events is therefore, 21 days with a large standard deviation of accrual (SD accrual) of 37 days meaning a highly variable number of floods occur in any given year at Knights Bridge. For instance, examination of monthly flow boxplots at site 101625 over 2000-2012 highlight flood events occurred in all months, bar October and November (i.e., boxes, whiskers or outliers of 1.5*IQR exceed 1.842 m^3s^{-1} in ten of twelve months). Combined, the high frequency, irregular and widespread distribution of flood events throughout a typical year, indicate the Mangere River is a highly dynamic hydrologic environment in which changes to flow conditions are likely to restrict the growth of periphyton and nuisance macrophytes by limiting accrual periods (e.g., Biggs and Smith, 2002; Tockner et al., 2000). Further evidence of the key role of hydrology on instream ecology is given by the high MAFF/MALF (459) and MAFF/median values (81) which are described as 'harsh' in Henderson and Diettrich (2007). Matheson et al. (2012) also note in their review of national in-stream plant and nutrient guidelines, "limited potential" for nuisance macrophyte or periphyton growth under recent nutrient and flow conditions (Tables H1 and H2 therein).

Changes in dissolved oxygen (DO) availability are governed by in-stream temperature, photosynthesis, respiration, salinity, turbulent mixing and biochemical oxygen demand (ANZECC, 2000). Within-month variation in DO% is large in spring and summer months (i.e., wider IQR and boxes in Figure 4.4), which exceed ANZECC (2000) recommendations of 7% (98-105%). Continuous diurnal monitoring of DO in March 2013 by Freshwater Solutions reported daily variability of 16.6% (91.1-107.0%) typify lower reaches of the Mangere and greater still, 21.7% (76.6-98.3%) in middle reaches (Montgomerie, 2013). Although the latter are large, none of the 5 monitoring sites in Montgomerie (2013) observed a DO below 5 g/m^3, an absolute minimum to avoid loss of sensitive fish (i.e., to be exceeded at all times [BCME, 1999] and recommended as the national 7-day bottom-line in the NOF [Davies-Colley et al., 2013]).

The large within-month variation for summer and spring months could be the consequence of variable in-stream temperature, photosynthesis, organic matter (BOD), flow and/or photosynthetic production. The absence of BOD data limits any inference on whether excessive inputs of organic matter drive summer and spring DO variability, but a weak and insignificant Spearman's rank correlation between monthly median DO (mg/L) and monthly median *E.coli* (p=0.318; ρ = 0.32) or monthly median TKN (p=0.056; ρ = 0.56) – both proxies for BOD – suggest instead that instream respiration or temperature are likely to be more important controls on absolute oxygenation (note: latter correlations are also positive, whereas if dominant drivers of DO, influxes of greater organic detritus would result in reductions of DO). Periphyton and macrophyte abundance data is lacking for the Mangere. However, a highly significant and strong negative correlation between monthly median DO (mg) and in-stream temperature at Knights Bridge (site 101625; $p<0.001$, $\rho = -0.95$ [Figure 4.6]) highlights the latter's strong effect on the absolute solubility of oxygen (e.g., Davies-Colley et al., 2013). A significant negative association remains even in % DO saturation ($p<0.001$, $\rho = -0.86$ [Figure 4.7]), which is a measure of oxygenation factored for changes in temperature, meaning another factor of similar seasonal variability to temperature is likely to be responsible for changes in relative oxygenation at Knights Bridge. Again, instream demands for nuisance weeds or BOD cannot be excluded (i.e., summer insolation drives changes in stream temperature, that might also result in greater plant productivity and respiration driving summer diurnal minima), but the presence of a highly significant strong positive correlation between monthly median DO (%) and flow ($p<0.005$; $\rho = 0.77$), suggests troughs in DO (%) are associated with low-flow (Figure 4.8). Hence, management of DO to avoid minima might prioritise increased flow, reductions in BOD and/or greater shade to limit plant biomass (e.g., Davies-Colley et al., 2013).

Action: *Conduct fine-resolution (continuous) DO, flow, BOD and plant biomass surveys at Knights Bridge to determine the principal control on DO (%) during troughs in oxygenation (during warmer months). Attempt to record gross primary productivity and ecosystem respiration (Wilcock et al., 2011).*

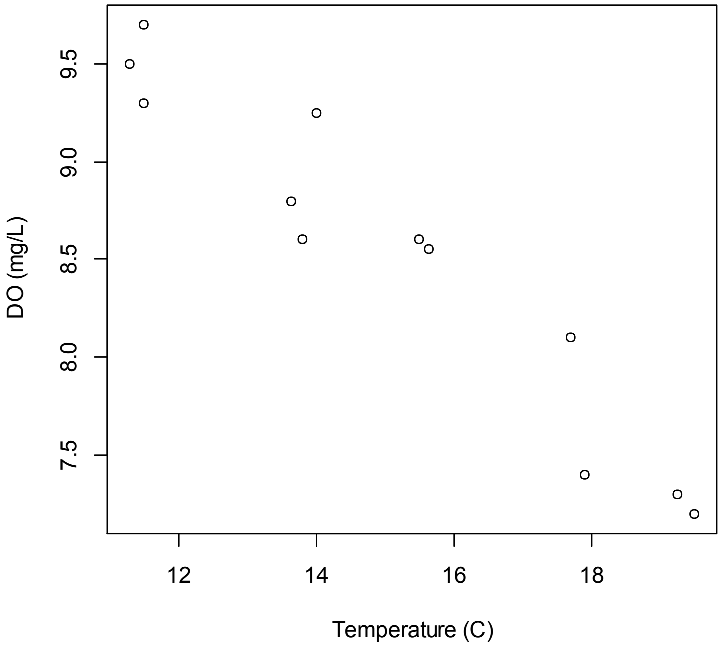

Figure 4.6. Scatterplot of monthly median DO (mg/L) by monthly median water temperature (°C) for Knights Bridge (2007-2010). (Temperature limits the absolute solubility of oxygen in an inverse, highly significant manner [$p<0.001$; $\rho = -0.95$]).

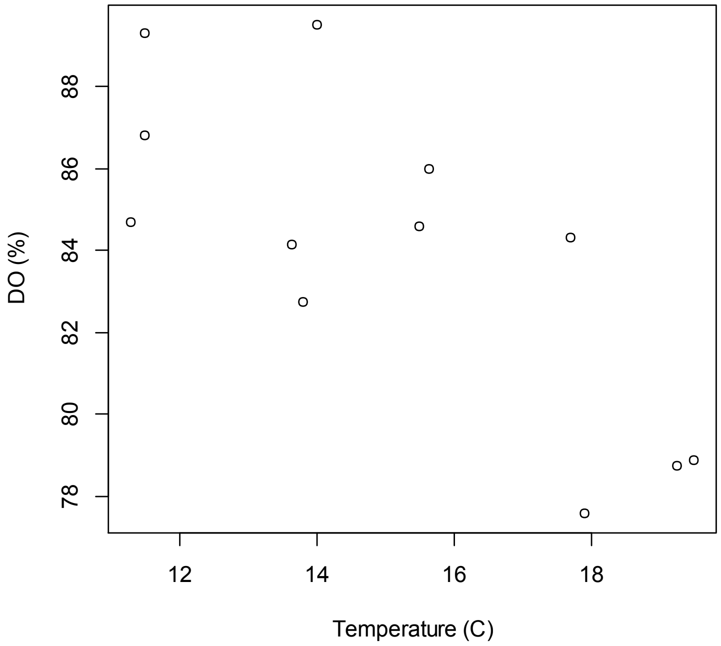

Figure 4.7. Scatterplot of monthly median DO (%) by monthly median water temperature (°C) for Knights Bridge (2007-2010). The presence of a significant negative correlation (p<0.001; ρ = -0.86) between water temperature and DO (%) suggests minima in oxygen saturation are associated with a process linked or varying in a similar fashion to water temperature.

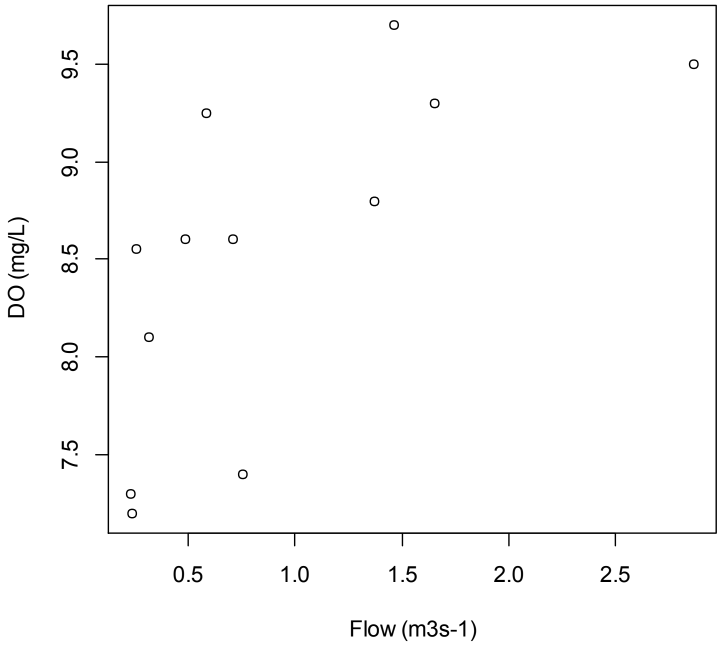

Figure 4.8. Scatterplot of monthly median DO (mg/L) by monthly median flow (m^3s^{-1}) for Knights Bridge (2007-2010). (A highly significant, positive correlation exists [p<0.005; ρ = 0.77]).

Note: *an attempt to model the predictive power of normalised flow, temperature and TKN upon DO was made using the monthly median dataset (above – 2007-2010; n = 12) and a modified dataset of DO observations <7.0 mg/L at site 101625 (2000-2012; n = 28). Model output is included in Appendix G.*

Seasonal variation in turbidity (TSS) includes a winter/spring peak from July to September (Figure 4.4). Given the lack of evidence for significant in-stream photosynthesis and the lower insolation rates of winter, this peak is likely driven by the input of suspended particles from surface runoff. A strong, significant positive correlation between average monthly flow and turbidity supports this inference ($p<0.005$; $\rho = 0.91$). Importantly, the 75th% of September observations at site 101625 (16.9 NTU) approaches the threshold limit governing the abundance of banded kokopu, set to <20 NTU (e.g., Rowe et al., 2000). The 75th% of July (14.2 NTU) and August (14.3 NTU) are also close to the chronic limit for protection of banded kokopu from turbidity effects. During the period 2000-2013, approximately 5.6%, 11.1% and 17.7% of observations in July, August and September exceeded 20 NTU, reinforcing that from July to September there is a frequent risk of exceeding the turbidity threshold for protection of banded kokopu (note: outliers >20 NTU also occur February, March, June and October). This underscores the potential for turbidity to be a limiting factor on "ecosystem health" in the Mangere River.

Seasonal changes in nitrogen-availability undergo a typical Austral pattern (Figure 4.5), with a winter peak and summer minimum driven in large part by the concentration of dissolved nitrate (i.e., the concentration of NO_3-N approximates that of TN). A winter peak in NO_3-N likely reflects both climatic and land management processes (i.e., peak rainfall and continued grazing or winter cropping contributing to greater soil throughflow). Greater variability in TN and NO_3-N concentrations during winter months also records the greater likelihood of coeval extremes in soil saturation and N-excess, over more stable base-flow contributions from groundwater and greater N-uptake by pasture/instream vegetation during summer and spring.

There is limited seasonality in DRP, TP, TKN, NH_4-N or *E.coli* concentrations observed at Knights Bridge (site 101625) from 2000 to 2012 (Figure 4.5). This suggests little effect of seasonal changes in climate and hydrology on latter in-stream concentrations, although as median DRP concentrations are approximately half those of TP there is a considerable load of particulate phosphorus supplied to the Mangere River, including the likelihood of inorganic clay-bound phosphorus in runoff or bankside erosion. The spatial patterns suggest marked DRP and *E.coli* loading in the middle catchment, meaning the lack of seasonality in the latter might be attributed to the effects of dairying, whose operations are centred largely on middle catchment sites (see Figure 2.2; sites 102109, 105719, 101625 and 101626).

4.3 Numeric attribute status and exceedance of proposed limits

4.3.1 Human Health

Compliance with proposed *E.coli* limits for protection of "human health" above national bottom-lines are presented in Table 4.4 (i.e., annual median ≤1000 MPN/100 ml at all flows [NOF bottom-line in MfE, 2013b]; annual median ≤550 MPN/100 ml, excluding flood flows; annual maximum ≤1000 MPN/100 ml with two exceedances permitted at monthly resolution). Caution should be practiced with these statistics as the *E.coli* attribute guidance is likely to undergo changes from submissions on the NOF, given there has been no previous guideline nor defensible limits on *E.coli* concentration for secondary contact recreation in New Zealand (e.g., Sinton and Weaver, 2008).

An unusual pattern noted earlier, of greater *E.coli* concentration in headwaters relative to mid-catchment, is evident in annual median concentrations during 2008 and 2009 and would likely have been reproduced were it not for a near trebling of *E.coli* concentration at site 102106 in 2010. The greater faecal contamination in 2010 recorded at site 102106 is noteworthy because this was the only site that experienced a marked rise in *E.coli* concentration in 2010, relative to 2007. For instance, annual median *E.coli* concentrations declined markedly at Knights Bridge, halving from 2007 to 2010 and remaining stable at approximately 500 MPN/100 ml thereafter. Immediately upstream at site 105719, annual median *E.coli* concentrations also approximately halved (from 1315 to 758 MPN/100 ml) from 2007-2010. Further upstream at site 102109, annual median *E.coli* concentrations also fell by a third from 2007-2010 (from 990 to 611 MPN/100 ml). As noted, immediately upstream at site 102106, annual median *E.coli* concentrations rose by 50% from 2007 to 2010 (645 to 918 MPN/100 ml). Finally, by the headwater site of 109166, annual median *E.coli* concentrations also fell by a quarter from 2008-2010 (767 to 594 MPN/100 ml). The most marked decrease in *E.coli* concentrations occurred on the Mangapiu Stream (site 101626) which declined by nearly 400% (from 798 to 238 MPN/100 ml 2007-2010). Hence, the increase in faecal bacterial concentrations at site 102106 in 2010 is highly unusual and detrimental to water quality for "human health".

Action: *Repeat the wider catchment monitoring adopted in 2007-2010 to determine whether E.coli concentrations have stabilised or continued to trend, and if so, determine if the rise in E.coli contamination at site 102106 has been arrested since 2010.*

Greatest annual median *E.coli* concentrations were recorded at site 105719 (immediately downstream of the confluence with the Mangapiu Stream) although by 2010 the greatest faecal bacterial concentrations were localised upstream of site 102106. It is worth reiterating that *E.coli* concentrations at site 105719 also continuously decreased (halved) over the period 2007-2010.

Compliance with the proposed national bottom-line for the NOF *E.coli* attribute of "human health" is demonstrated in Table 4.4. The choice of *E.coli* reporting statistic substantively alters compliance. For instance, there were a handful of exceptions to the proposed NOF bottom-line with only sites 101625 (2007) and 105719 (2007-2009) failing to meet the bottom-line. All sites met the NOF bottom-line in 2010. However, if the reporting statistic excludes flood flows (>FRE3) as per the primary contact recreation guidelines (MfE and MoH, 2003), numerous exceedances of an annual median of 550 MPN/100 ml *E.coli* are noted (Table 4.4). Knights Bridge (site 101625) would exceed this modified bottom-line in 2007, 2008 and 2011 whereas immediately upstream at site 105719, all years from 2007-2010 would exceed the guideline (as would site 102109). This modified *E.coli* bottom-line would also be met in 2009 at sites 102106 and 109166. The Mangapiu Stream would only meet the flood-flow modified *E.coli* statistic in 2010 courtesy of the quartering of instream faecal bacterial concentrations.

In examining Table 4.4, the reader should note that excluding or including flood-flows (>FRE3) from the *E.coli* reporting statistic, makes little difference to the absolute annual median at all sites – it is the drop from the proposed NOF bottom-line of 1000 MPN/100 ml to 550 MPN/100 ml that results in greater breaches (550 MPN/100 ml *E.coli* is the minimum permissible primary contact grade, albeit this is at a 95th% rather than median). Hence, the flood-flow modified statistic is far more conservative than the proposed NOF bottom-line (i.e., is exceeded more than the latter in the Mangere catchment [2007-2010]).

Alternatively, if the *E.coli* reporting statistic is inclusive of >FRE3 events and the bottom-line is revised to an annual maximum concentration ≤1000 MPN/100 ml (with 2 permitted exceedances at monthly resolution, within any 12 month period) the greatest number of breaches occur (Table 4.4). For instance, many sites record exceptionally high *E.coli* concentrations during flood events (i.e., beyond the upper limit of detection of 24912 MPN/100 ml), when presumably surface runoff transports greater faecal bacteria into waterways. For instance, during the period 2007-2010, breaches of a maximum

E.coli concentration of 1000 MPN/100 ml with more than 2 monthly exceedances occurred at all sites (Table 4.4). However with the exception of site 102106, the number of monthly observations >1000 MPN/100 ml decreased from 2007-2010. The choice of reporting statistic therefore does not affect the pattern of reducing faecal bacterial loads observed in annual medians throughout all sites since 2007, bar site 102106. Further, continued lower observed *E.coli* concentrations at Knights Bridge (furthest downstream) since 2010 suggest that this pattern of reduced faecal contamination of the Mangere River has been sustained more recently. However, the choice of reporting statistic, that is whether to report at all flows and/or to a maximum or median, markedly alters compliance for “human health”.

In explaining the observed pattern of reduced faecal bacterial concentrations, the reader should note that extensive effluent upgrades have occurred on dairying operations in the Mangere catchment since 2007, and the Mangapiu Stream has 4 consented dairy farms along its relatively short length (i.e., 18 of the 19 dairy farms in the Mangere catchment have upgraded effluent systems at least once in the last 6 years with all bar two systems discharging to land as good practice [Tess Dacre, pers. comm.]). Hence, success at mitigating *E.coli* contamination of both the mid-lower Mangere River and the Mangapiu stream might well be explained by adoption of on-farm good practices around effluent treatment and application to land.

Table 4.4. Summary statistics for human health, for three reporting statistics of *E.coli* concentration. The NOF bottom-line is provisionally an annual median of ≤1000 MPN/100 ml. ND = > detection limit. Cells highlighted red exceed the respective *E.coli* bottom-line (see text).

Site	**Year**	**E.coli (MPN/100 ml) reporting statistic**			
		Median (NOF)	**Median (flows <x3 median)**	**Maximum**	**Months >1000 MPN/100 ml**
101625	2000	183	193	1600	2
	2001	465	519	1153	1
	2002	654	505	24912 (ND)	3
	2003	618	512	15531	3
	2004	505	505	921	0
	2005	738	613	11199	4
	2006	821	782	2755	5
	2007	1027	1014	24192 (ND)	7
	2008	875	661	24192 (ND)	4
	2009	496	496	6131	2
	2010	496	504	24192 (ND)	3
	2011	567	567	24192 (ND)	3
	2012	447	447	19863	3
Site	**Year**	**Median (NOF)**	**Median (flows <x3 median)**	**Maximum**	**Months >1000 MPN/100 ml**
105719	2007[†]	1315	1396	19863	8
	2008	1250	1187	3076	11
	2009	1187	1187	3076	8
	2010	758	677	12997	5
Site	**Year**	**Median (NOF)**	**Median (flows <x3 median)**	**Maximum**	**Months >1000 MPN/100 ml**
102109	2007[‡]	990	1035	7270	6
	2008	805	959	1467	4
	2009	554	554	1616	2
	2010	611	624	1354	1

Site	Year	Median (NOF)	Median (flows <x3 median)	Maximum	Months >1000 MPN/100 ml
102106	2007[‡]	645	645	10462	3
	2008	624	657	1274	1
	2009	441	441	1118	1
	2010	918	918	3873	6
Site	**Year**	**Median (NOF)**	**Median (flows <x3 median)**	**Maximum**	**Months >1000 MPN/100 ml**
109166	2008	767	836	1414	4
	2009	512	512	1259	1
	2010	594	594	1467	1
Site	**Year**	**Median (NOF)**	**Median (flows <x3 median)**	**Maximum**	**Months >1000 MPN/100 ml**
101626	2007[†]	798	933	24192 (ND)	5
	2008	782	748	3255	5
	2009	728	728	3448	6
	2010	238	189	6488	3

4.3.2 Ecosystem Health

The NOF does not prescribe explicitly how to protect ecosystem health but rather presents four tiers of water quality for "ecosystem health". Ensuring the Mangere catchment performs above the national bottom-lines for toxicants (NO_3-N, NH_4-N) and dissolved oxygen is crucial as defensible bottom-lines have been described for latter attributes. The NOF does not however, preclude recommending additional attributes for ecosystem health that target sensitive indigenous fauna and flora. In addition to the bottom-lines of NO_3-N (median ≤6.9 mg/L; 95th% ≤9.8 mg/L), NH_4-N (median ≤1.30 mg/L; 95th% ≤2.20 mg/L) and DO (7-day mean ≥5 mg/L), additional bottom-lines have therefore been set for turbidity (<20 NTU August-December), temperature (<21.2°C) and pH (6.5≤n≤9.0) that protect the native fish community expected in the Mangere catchment. By protecting against excess suspended solids entering catchment waterways during winter when runoff associated erosion peaks, and by adoption of a temperature limit more conservative than that recommended for protection of lowland fauna (<25°C [Olsen et al., 2012), the additional attributes offer further protection of wider ecosystem components beyond fish alone, including macroinvertebrates.

With this in mind, it is reassuring that from 2007-2010 none of the six monitoring sites within the Mangere catchment exceeded recommended bottom-lines for protection from NO_3-N or NH_4-N toxicity (Table 4.5). For instance, neither grading nor surveillance NO_3-N and NH4-N concentrations in the Mangere during 2007-2010 exceeded guidelines recommended for the boundary of Bands C and D in the NOF (e.g., MfE, 2013b). Likewise, since 2010 the latter bottom-lines have continued to be met by water quality at Knights Bridge (site 101625). In fact, whereas the NOF NO_3-N bottom-line is for 80% community protection, all sites adhered to at least 99% protection from 2007-2010 (NOF Band A), including until 2012 at Knights Bridge (i.e., do not exceed a grading and surveillance limit of <1.0 and <1.5 mg/L NO_3-N respectively [Hickey, 2013]). Nitrate concentrations within the Mangere catchment are therefore highly unlikely to be *directly* stressing native biodiversity through toxicity, nor *indirectly*, by promoting excessive periphyton growth as hydrologic constraints and shading are likely to prevent the proliferation of nuisance plants (i.e., FRE3 of 14 and median shading of 50-80%). Importantly too, annual median NO_3-N concentrations have declined markedly at all sites within the Mangere since 2007, halving at nearly all sites by 2010 and since, remaining at equivalent reduced concentrations at Knights Bridge until 2012 (Table 4.5). Less marked reductions have occurred to 95^{th}% NO_3-N concentrations. For instance, whereas annual median NO_3-N concentration declined from 0.740 to 0.315 mg/L at Knights Bridge, a decline from 1.101 to 0.710 mg/L occurred to 95^{th}% NO_3-N. At two sites (105719 and 102109, downstream and upstream respectively of the confluence with the Mangapiu Stream), 95^{th}% NO_3-N concentrations actually rose in 2010 relative to 2007. Hence, although grading and surveillance NO_3-N concentrations met 99% (Band A) and 95% (Band B) limits for protection from toxicity, further investigation might be warranted to determine if 95^{th}% concentrations continued to rise since 2010 at several sites.

Action: *Investigate whether 95^{th}% NO_3-N concentrations continued to rise at several sites by a future survey of in-stream NO_3-N, at monthly resolution over a 12 month period (i.e., in accordance with the NOF protocol).*

Ammoniacal nitrogen concentrations at all sites in the Mangere met the national grading and surveillance bottom-lines throughout 2007-2010, actually meeting the 95% community protection guidelines of NOF Band B. Further, by employing the NH_4-N guidelines derived for pH 8.0 and temperature of 20°C, when instream temperatures seldom exceeded 20°C and pH never exceed 8.0, the degree of protection from NH_4-N toxicity is higher than 95% (i.e., at lower temperature and pH, less of the unionised and more toxic NH_3 species exists in freshwater [Hickey, 2013]). The Mangapiu Stream (site 101626) observed the greatest annual median concentration of NH_4-N amongst all sites (throughout the interval of 2007 to 2010) with the latter being approximately three times that of the Mangere River proper at Knights Bridge (site 101625) (Table 4.5). Whilst this emphasises the geochemical environment of the Mangapiu Stream differs markedly from that of the Mangere River, it emphasises that NH_4-N loading from the Mangapiu is limited overall and that it is likely sourced locally (i.e., as evidenced by considerably lower concentrations in downstream Mangere River sites 105719 and 101625). Likely causes for local enrichment of NH_4-N in the Mangapiu include dairy effluent, fertilizer and decaying in-stream vegetation, whose effects are likely concentrated due to the permitted take for water from the Mangapiu Stream (approximately 1810 m^3day^{-1} or 0.021 m^3s^{-1} over an evenly distributed 24hr take [Tess Dacre, pers. Comm., 2013]). However, it is worth reiterating that concentrations in the Mangapiu Stream have markedly reduced since 2007 (by a factor of three) and are well below the national bottom-line. Indeed, all sites observed a marked reduction in both annual median and 95^{th}% NH_4-N concentrations, by a factor of approximately 2-3 since 2007 (Table 4.5).

The fortnightly-to-monthly resolution of DO limits insights of associated pressure on “ecosystem health” because short-lived diurnal minima might fail to be observed. Assuming the dataset is representative however, only the Knights Bridge (site 101625) and Mangapiu Stream (site 101626) failed to meet the 1-day national bottom-line of ≥4.0 mg/L DO over the summer period (1 November-30 April). For instance, the Mangapiu Stream consistently failed to meet the national 1-day bottom-line for DO in 2008, 2009 and 2010 (DO minima of 3.2, 3.9 and 2.1 mg/L respectively). Knights Bridge failed to meet the national DO 1-day bottom-line only in 2010 (minimum of 3.5 mg/L DO). Although subsequent summer minima in 2011 (4.5 mg/L DO) and 2012 (4.3 mg/L DO) met the national bottom-line, continuous DO levels <5.0 mg/L from February to March 2012 suggests the site would fail to meet the 7-day national bottom-line of 5.0 mg/L DO. Although sensitive organisms could migrate from the entrance to the Mangere River at Knights Bridge, the fact that this site receives the combined outflow from the 82km^2 catchment upstream and is not ephemeral, further emphasises that DO should be managed to at least exceed that 7-day national bottom-line of 5.0 mg/L. Changes to oxygenation at the headwater site (109166) are also alarming because although meeting the 1-day and 7-day national bottom-lines in 2008 and 2009, by 2010 the summer minimum in DO declined markedly and would have breached a 7-day minimum of 5.0 mg/L (January minimum = 4.8 mg/L). Given the Pukenui Forest is located near the site, this further reiterates that a marked detrimental effect of local land use occurs on "ecosystem health" upstream of dairying operations.

By contrast, mid-catchment sites (105719, 102109 and 102106) all exceeded the national 1-day and 7-day DO bottom-lines for the period 2007-2010, ultimately meeting the >5.0 mg/L 1-day minimum of Band B which equates to occasional minor stress on sensitive organisms during short periods (few hours a day) (MfE, 2013b). Furthermore, despite breaches of DO minima at the headwater and mouth of the Mangere River, as well as the Mangapiu Stream, continuous daily monitoring of instream DO by Freshwater Solutions highlighted 1-day minima in DO ranging from 7.8-9.2 mg/L. Notably, these sampling exercises were conducted in March whereas seasonal DO (mg/L) minima occur in January and February (Appendix E). Hence although diurnal sampling is reassuring, the fact that increasing breaches of the 1-day DO national bottom-line occurred in 2010, 2011 and 2012 suggests a trend to reduced "ecosystem health" that should be prioritised for better management (and that localised effects of land use are likely on the Mangapiu Stream, headwaters and mouth of the Mangere River).

Action: *Determine the cause of reduced DO at Knights Bridge (site 101625) and the headwaters of the Mangere River (site 109166) (i.e., whether through instream photoautotrophic and/or heterotrophic production, and/or insufficient turbulent flow entraining more atmospheric oxygen (see Davies-Colley et al., 2013). Also inspect the causes of low DO in the Mangapiu Stream (i.e., whether the stream is intermittently flowing, receives excessive organic matter and/or has excessive instream vegetation). Determine corresponding mitigation tool to adopt (i.e., greater shade, reduced inputs of organic matter and/or greater scouring flows).*

Observations of pH were limited to Knight's Bridge (site 101625) where all observations fell within the limits proposed for native fish to the Mangere (i.e., pH 6.5-9.0) in all years bar 2002 and 2011 when a single observation of 6.4 occurred respectively. Given West et al. (1997) demonstrated that amongst native fish most avoided a pH >9.0 and <6.5, changes in pH do not appear to threaten "ecosystem health" for fish native to the Mangere catchment.

Owing to their heightened thermal sensitivity (relative to other native fish), a temperature limit of ≤21.2°C is protective of other native fish and are also more conservative than those recommended by Olsen et al (2012) for the wider protection of native lowland biota in New Zealand waterways (i.e., including lowland macroinvertebrates). The latter was met at all sites bar Knights Bridge, from 2007 to 2010, with 91% and 96% of fortnightly observations ≤21.2°C respectively (i.e., only 3 of 223 observations taken from 2000-2012 at site 101625 exceeded 21.2°C). Earlier inspection of diurnal temperature variations at 5 sites in the Mangere during March 2013, recorded CRI values of 17.4-14.1°C, both well below the proposed threshold for a national bottom-line in "maritime" rivers of ≤24.0°C in Davies-Colley et al. (2013) (note: the latter is not a compulsory attribute in the NOF [MfE, 2013b]). Hence, water temperatures including maxima and diurnal variation, do not appear to threaten in-stream native biota - a likely consequence of widespread riparian shade in the catchment (i.e., median shading of 50-80% was observed in 2013).

Again due to their heightened sensitivity, bottom-lines on turbidity have been applied to protect juvenile banded kokopu from deleterious effects of reduced water clarity (<20 NTU, August-December [e.g., Richardson et al., 2001]). As juvenile banded kokopu are the most sensitive of New Zealand's native fish species to suspended solid concentrations (Boubee et al., 1997), the protective limit of <20 NTU is also likely to protect wider native fauna in the Mangere. However, the monthly resolution of turbidity sampling limits the ability to accurately capture short-lived, high-turbidity events and reliably define % >20 NTU between August and December (in some cases less than 1 sample per month was recorded from August-December in any year). Nonetheless, assuming the data is representative, only two sites observed turbidity >20 NTU from August-December (Table 4.5). For instance, in 2009 the Mangapiu Stream (site 101626) exceeded 20 NTU for 20% of observations which might have potentially excluded approximately 75% of juvenile banded kokopu – though the Mangapiu Stream is likely to be intermittently flowing and unsuited to recruitment. More important are the exceedances of 20 NTU (August-December) recorded furthest downstream at Knights Bridge (site 101625) in 2002, 2003, 2006, 2010 and 2011, indicating a consistent pressure on "ecosystem health" from excess suspended sediment (i.e., erosion, in-stream production). For instance, excess turbidity in 2010 and 2011 is likely to have excluded approximately 55% and 85% of juvenile banded kokopu from the Mangere River. As the Knights Bridge site sits at the mouth of the Mangere River, excess turbidity even when localised (as all further stations upstream on the Mangere River did not observe >20 NTU August-December) is sufficient to markedly prevent recruitment to any adult banded kokopu population in the Pukenui Forest. The accuracy of latter inferences is however, limited by both the resolution of the data (which in 2011 involved only 3 monthly samples over the 5 monthly period), and the precise nature of the relationship between turbidity and recruitment presented in Figure (i.e., whose fit is poor). Regardless, no single measure of turbidity observed at any site in the Mangere over the period 2000-2012 approached the recommended acute threshold of 40,000 NTU (for a 24hr period [Rowe et al., 2000]).

***Action:** Conduct higher resolution turbidity sampling in the Mangere at Knight's Bridge during migratory months for juvenile banded kokopu (August-December) to better define the threat to recruitment of juvenile migrants.*

Table 4.5. Annual reporting by site for provisional ecosystem health attributes. Cells shaded red do not meet proposed national bottom-lines in the NOF for NO_3-N (median ≤6.90 mg/L; 95th% ≤9.80 mg/L), NH_4-N (median ≤1.3 mg/L; 95th% ≤2.20 mg/L) and DO (7-day mean ≥5.0 mg/L). Additional attributes added as reported in text. Turbidity corresponds to period of August-December only. Cells shaded red do not meet conditional limits proposed by this report for turbidity (<20 NTU Aug-Dec), temperature (<21.2°C) and/or or pH (6.5≤n≤9.0). Note: NO_3-N observations at Knights Bridge have been inferred from an OLS regression of NO_3-N and NNN derived for paired observations from 2007-2012 (R^2=0.9984).

Site	**Year**	**NO_3-N (mg/L)**		**NH_4-N (mg/L)**		**DO (mg/L) 1-day min (%≥5.0)**	**Turbidity %<20NTU**	**Temperature (°C)**			**pH (SI) 6.5≤%≤9.5**
		Median	**95th%**	**Median**	**95th%**			**%<21.2°C**	**Max**	**Median**	
101625	2000	0.893	1.569	0.110	0.367	6.5 (100%)	100%	100%	19.8	15.3	100%
	2001	1.016	1.372	0.095	0.264	6.5 (100%)	100%	91%	23.7	16.0	92%
	2002	0.590	1.061	0.110	1.259	5.9 (100%)	60%	100%	19.6	14.3	100%
	2003	0.627	0.859	0.095	0.234	7.6 (100%)	75%*	100%	19.1	14.9	100%
	2004	0.642	0.783	0.115	0.269	6.4 (100%)	100%	100%	20.8	15.5	100%
	2005	0.569	1.300	0.085	0.197	5.7 (100%)	100%	100%	20.0	15.7	100%
	2006	0.583	0.948	0.050	0.244	5.9 (100%)	80%	100%	20.0	15.7	100%
	2007	0.740	1.101	0.095	0.208	5.6 (100%)	100%	100%	19.4	14.1	100%
	2008	0.680	1.037	0.050	0.247	6.0 (100%)	100%	100%	20.9	15.1	100%
	2009	0.530	1.040	0.030	0.118	7.1 (100%)	100%	100%	20.0	14.3	100%
	2010	0.315	0.710	0.026	0.148	3.5 (96%)	90%*	96%	21.4	14.9	100%
	2011	0.580	0.961	0.023	0.182	4.5 (92%)	67%*	100%	20.8	15.8	92%
	2012	0.495	0.786	0.028	0.095	4.3 (83%)	100%	100%	18.7	13.8	100%

Site	Year	NO_3-N (mg/L)		NH_4-N (mg/L)		DO (mg/L) 1-day min (%≥5.0)	Turbidity %<20NTU	Temperature (°C)			pH (SI) 6.5≤%≤9.5
		Median	95th%	Median	95th%			%<21.2°C	Max	Median	
105719	2007	0.786	0.978	0.060	0.120	7.2 (100%)	100%*	100%	18.7	12.4	No data
	2008	0.610	0.990	0.040	0.076	6.5 (100%)	100%*	100%	20.7	14.3	
	2009	0.530	0.976	0.030	0.094	7.2 (100%)	100%	100%	18.7	14.4	
	2010	0.280	1.614	0.035	0.075	6.9 (100%)	100%	100%	19.1	14.0	

Site	Year	NO_3-N (mg/L)		NH_4-N (mg/L)		DO (mg/L) 1-day min (%≥5.0)	Turbidity %<20NTU	Temperature (°C)			pH (SI) 6.5≤%≤9.5
		Median	95th%	Median	95th%			%<21.2°C	Max	Median	
102109	2007‡	0.640	0.871	0.025	0.094	7.9 (100%)	100%*	100%	18.8	12.7	No data
	2008	0.540	0.926	0.020	0.040	7.0 (100%)	100%*	100%	20.2	14.1	
	2009	0.500	0.914	0.010	0.024	7.7 (100%)	100%	100%	18.4	14.3	
	2010	0.250	1.424	0.013	0.036	7.0 (100%)	100%	100%	18.9	13.9	

Site	Year	NO_3-N (mg/L)		NH_4-N (mg/L)		DO (mg/L) 1-day min (%≥5.0)	Turbidity %<20NTU	Temperature (°C)			pH (SI) 6.5≤%≤9.5
		Median	95th%	Median	95th%			%<21.2°C	Max	Median	
102106	2007‡	0.670	1.007	0.010	0.041	8.6 (100%)	100%*	100%	18.0	12.5	No data
	2008	0.650	1.132	0.010	0.036	7.9 (100%)	100%*	100%	19.8	14.2	

	2009	0.660	1.116	0.005	0.010	8.2 (100%)	100%	100%	17.9	14.3	
	2010	0.307	0.975	0.005	0.018	8.0 (100%)	100%	100%	18,7	13.7	
Site	**Year**	**NO_3-N (mg/L)**		**NH_4-N (mg/L)**		**DO (mg/L) 1-day min (%≥5.0)**	**Turbidity %<20NTU**	**Temperature (°C)**			**pH (SI) 6.5≤%≤9.5**
		Median	**95th%**	**Median**	**95th%**			**%<21.2°C**	**Max**	**Median**	
109166	2008	0.665	1.216	0.020	0.113	6.2 (100%)	100%*	100%	19.1	13.7	No data
	2009	0.680	1.156	0.010	0.020	6.1 (100%)	100%	100%	18.6	14.0	
	2010	0.355	1.005	0.025	0.025	4.8 (67%)	100%	100%	18,5	13.5	
Site	**Year**	**NO_3-N (mg/L)**		**NH_4-N (mg/L)**		**DO (mg/L) 1-day min (%≥5.0)**	**Turbidity %<20NTU**	**Temperature (°C)**			**pH (SI) 6.5≤%≤9.5**
		Median	**95th%**	**Median**	**95th%**			**%<21.2°C**	**Max**	**Median**	
101626	2007†	0.810	1.239	0.355	0.971	4.5 (75%)	100%*	100%	19.5	12.3	No data
	2008	0.840	1.276	0.155	0.647	3.2 (80%)	100%	100%	21.2	14.7	
	2009	0.760	1.088	0.082	0.358	3.9 (85%)	80%	100%	18.8	14.7	
	2010	0.540	1.169	0.069	0.304	2.1 (83%)	100%	100%	19.2	13.9	

†indicates monitoring commenced in July; ‡indicates monitoring commenced in April; *indicates less than 5 samples over the five month period (Aug-Dec).

4.4 Long-term Trends

The variable lengths of monitoring records between sites, affords Knights Bridge (site 101625) the greatest reliability for time-series analysis. Trends are therefore described for this site in preference to others (Table 4.6). Nonetheless, Tables 4.7 and 4.8 demonstrate that many of the trends evident at Knights Bridge are repeated at other monitoring stations in the Mangere catchment, albeit at resolution and reliability.

At site 101625, from January 2007 to December 2012, all geochemical and bacterial indicators for 'ecosystem health' and 'secondary contact recreation' exhibit either **stable** or **improving** trends (observed and flow-corrected). For instance, no statistically significant ($p<0.05$) trend could be detected for observed or flow-corrected temperature, dissolved oxygen, turbidity, pH, TN or NO_3-N observations, implying stable concentrations and loads (note the distinction between observed and flow-corrected concentrations that record changes to in-stream concentration and catchment loading respectively [e.g., Vant and Wilson, 1998]).

Ecologically meaningful changes of ≥1% per annum and statistically significant ($p<0.05$) improvements in observed and flow-corrected concentrations of NH_4-N, TP, DRP and *E.coli* were detected at Knights Bridge (2007-2012) (Table 4.6). As noted, a change of ≥1% per annum is considered as having a meaningful effect on river ecology (Vant, 2013). Hence, the 32.1% decline per annum in flow-corrected NH_4-N concentration is likely to have reduced already low risks of toxicity from ammoniacal-nitrogen further, at site 101625. As this estimate has been flow-corrected it implies marked reductions in total catchment NH_4-N loading for the period 2007-2012.

At site 101625, flow-corrected DRP reductions of 16.7% per year appear to have driven in large part, flow-corrected reductions in TP of 9.1% per year (2007-2012), because DRP comprises approximately 50% of TP at all six monitoring stations in the Mangere catchment (see Appendix C).

Reductions in flow-corrected *E.coli* concentrations from 2007-2012 are also encouraging as they imply a 13.9% per annum decline in faecal bacterial loads upstream of site 101625.

Reductions in catchment loading of *E.coli*, NH_4-N, DRP and TP concentrations likely correspond to the extensive upgrades of farm dairy effluent systems in the Mangere but could equally include upgrades to human effluent and livestock access to waterways. For instance, 17 of the 19 dairy farms have upgraded effluent systems since 2007, 11 more than once (Tess Dacre, NRC pers. comm., 2013). Upgrades include to larger storage, land application and/or greater land application area. Similar effects of farm dairy effluent upgrades have been reported elsewhere upon faecal and nutrient loading to New Zealand waterways (Wilcock et al., 2007).

Importantly however, the lack of a trend in observed turbidity is important to future management of "ecosystem health" as turbidity repeatedly exceeded 20 NTU from August-December during the past six years, reducing the health of any local banded kokopu population. Trend testing of the period 1996-2013 reiterates this point as no significant trend could be demonstrated for flow-corrected or observed turbidity (p = 0.131and 0.173 respectively).

As before, the limited representivity of temperature and dissolved oxygen data (i.e., absence of diurnal data), precludes much certainty in the absence of trends in observations of either (p = 0.339 and 0.271 respectively). Raw rather than flow-corrected observations should be interpreted for trends in temperature and dissolved oxygen, due to the latter's direct effect on physiology.

Table 4.6. Observed and flow-corrected change in water quality attributes (RSKE; % change per annum on series median) for the period 2007-2012 at site 101625 (statistical significance is presented in brackets). Only trends highlighted in bold are statistically significant ($p<0.05$) and ecologically meaningful (RSKE ≥1% per annum). Blue denotes improvement, red worsening and stable trends lack any colour.

Site 101625	**Temperature (°C)**	**DO (%)**	**Turbidity (NTU)**	**pH (SI)***	**TN (g/m^3)**	**NO_3-N (g/m^3)**	**TKN (g/m^3)**	**NH_4-N (g/m^3)**	**TP (g/m^3)**	**DRP (g/m^3)**	***E.coli* (MPN/100ml)**
Uncorrected (“observed”)	-0.7% (0.339)	+0.5% (0.271)	-3.2% (0.284)	+0.4% (0.089)	-5.3% (0.087)	-5.3% (0.052)	-3.6% (0.125)	**-26.8% (0.000)**	**-14.0% (0.000)**	**-17.6% (0.000)**	**-13.7% (0.002)**
Flow-corrected	-0.1% (0.826)	+0.2% (0.642)	+0.0% (0.977)	+0.5% (0.064)	-4.9% (0.078)	-4.9% (0.099)	-2.7% (0.548)	**-32.1% (0.000)**	**-11.0% (0.000)**	**-14.0% (0.000)**	**-13.9% (0.008)**

Table 4.7. Flow-corrected change in water quality attributes (RSKE; % change per annum on series median) for the period 2007-2010 (statistical significance is presented in brackets). Only trends highlighted in bold are statistically significant (*p*<0.05) and ecologically meaningful (RSKE>1.0%). Blue denotes improvement, red worsening and stable trends lack any colour.

Site		**Temperature (°C)**	**DO (%)**	**Turbidity (NTU)**	**pH (SI)***	**TN (g/m^3)**	**NO_3-N (g/m^3)**	**TKN (g/m^3)**	**NH_4-N (g/m^3)**	**TP (g/m^3)**	**DRP (g/m^3)**	***E.coli* (MPN/100ml)**
Downstream	**101625**	-1.5% (0.210)	1.0% (0.210)	-0.7% (0.630)	0.3% (0.380)	-1.6% (0.720)	4.7% (0.470)	-2.8% (0.342)	**-25.0% (0.010)**	**-9.1% (0.000)**	**-16.7% (0.000)**	**-12.5% (0.050)**
	105719	**-3.1% (0.016)**	**1.6% (0.016)**	-10.2% (0.178)	N/a	-1.1% (0.669)	5.7% (0.521)	6.8% (0.199)	-10.0% (0.134)	-6.1% (0.392)	-6.3% (0.831)	3.9% (1.000)
	101626	-3.2% (0.054)	3.6% (0.199)	-1.3% (1.000)	N/a	-8.5% (0.054)	1.1% (0.831)	-16.7% (0.087)	-61.5% (0.054)	-13.4% (0.054)	-7.5% (0.392)	18.1% (0.831)
Headwater	**102109**	-3.3% (0.102)	1.2% (0.102)	**-13.8% (0.009)**	N/a	-0.7% (0.716)	4.9% (0.363)	-2.1% (0.856)	**-21.1% (0.000)**	**-17.0% (0.004)**	-8.3% (0.102)	**-22.6% (0.004)**
	102106	-4.2% (0.069)	1.3% (0.146)	-12.2% (0.178)	N/a	-2.4% (0.716)	0.2% (1.000)	-14.0% (0.203)	-25.0% (0.275)	**-19.2% (0.006)**	0% (0.856)	-7.6% (0.585)
	109166**	-1.2% (1.000)	2.3% (0.545)	-4.5% (0.545)	N/a	-6.5% (0.545)	-7.3% (0.130)	-15.7% (0.762)	11.1% (0.545)	-13.6% (0.069)	0% (0.364)	-8.1% (0.130)
Improving		2	1	1	0	1	0	0	4	4	0	2
Stable		4	5	5	1	5	6	6	3	2	4	4
Worsening		0	0	0	0	0	0	0	0	0	0	0

*N/a denotes no data available; **Limited record (2008-2010).

Table 4.8. Non flow-corrected relative change in water quality attributes (RSKE; % change per annum on series median) for the period 2007-2010 (brackets correspond to observation number).

Site		**Temperature (°C)**	**DO (%)**	**Turbidity (NTU)**	**pH (SI)***	**TN (g/m^3)**	**NO_3-N (g/m^3)**	**TKN (g/m^3)**	**NH_4-N (g/m^3)**	**TP (g/m^3)**	**DRP (g/m^3)**	***E.coli* (MPN/100ml)**
Downstream	**101625**	-0.7% (0.660)	1.0% (0.080)	**-10.2% (0.000)**	0.7% (0.100)	-5.9% (0.171)	-4.8% (0.585)	-3.6% (0.125)	**-20.0% (0.000)**	**-18.2% (0.000)**	**-16.7% (0.000)**	**-20.6% (0.000)**
	105719	-1.6% (0.560)	0.5% (0.288)	**-7.2% (0.037)**	N/a	-7.6% (0.134)	-4.9% (0.831)	-10.5% (0.199)	-20.0% (0.102)	-18.9% (0.067)	-12.7% (0.333)	-16.5% (0.162)
	101626	-3.6% (0.521)	**5.0% (0.013)**	-9.0% (0.270)	N/a	**-13.8% (0.003)**	-8.0% (0.669)	-26.3% (0.134)	**-59.0% (0.032)**	**-28.7% (0.010)**	**-21.3% (0.032)**	-32.3% (0.333)
Headwater	**102109**	-1.5% (0.363)	0.3% (0.856)	**-13.8% (0.009)**	N/a	-1.3% (0.194)	-2.2% (0.716)	0.0% (1.00)	**-20.5% (0.011)**	**-21.7% (0.000)**	-9.6% (0.139)	**-26.0% (0.018)**
	102106	-1.7% (0.271)	-0.4% (0.463)	**-20.6% (0.020)**	N/a	-9.1% (0.121)	-12.5% (0.235)	-18.2% (0.118)	0.0% (0.044)	**-24.2% (0.000)**	0.0% (0.850)	2.1% (0.856)
	109166**	-2.2% (0.545)	-4.8% (0.545)	**-15.1% (0.034)**	N/a	**-15.3% (0.022)**	**-16.8% (0.034)**	-11.1% (0.278)	-48.0% (0.108)	**-30.0% (0.016)**	-12.5% (0.063)	-22.4% (0.545)
Improving		0	1	5	0	2	1	0	3	5	2	2
Stable		6	5	1	1	4	5	6	3	1	4	4
Worsening		0	0	0	0	0	0	0	0	0	0	0

*N/a denotes no data available; **Limited record (2008-2010).

Time-series deconstructions are presented for those parameters demonstrating a statistically significant and ecologically meaningful trend at site 101625, for the period 2000-2012 in Figures 4.9-4.12. Observed concentration is displayed uppermost, cyclical variation over a 12-month period (“seasonality”) beneath this, followed by the long-term trend and residuals unexplained by the seasonal or long-term components, lowermost.

The abrupt, noisy pattern of seasonal changes in *E.coli*, NH_4-N, DRP and TP concentrations suggest little of total variance over the interval 2000-2012 can be explained by seasonal changes. Likewise, residuals in all four indicators are relatively large (accounting for nearly as much variance as that explained by the long-term trend [loess smother]), suggesting continued episodic discharges substantively affect each time-series. This is especially so for changes in *E.coli* concentration from 2000-2012, for which the loess smoother has inappropriately attempted to smooth changes between large, episodic peaks that result artefacts within long-term trends (i.e., peaks identified by long-term trends are artefacts of the smoothing process, as denoted by high residuals for peaks in 2003 and 2012).

Residuals in the 2000-2012 NH_4-N time-series are less pronounced, accruing seasonal and long-term trends better explanatory power. As vertical bars on each graph represent the same absolute variance, seasonal changes are relatively minor compared to long-term changes, and long-term changes support earlier inferences of marked reductions since 2007 (-26.8% per annum, uncorrected RSKE). Long-term reductions in DRP and TP are also evident since 2007, interrupted by a brief reversal to greater concentration in 2012 (-17.6% and -14.0% per annum, uncorrected RSKE respectively). The annual median of daily flow at site 101625 for 2012 was considerably higher than the series median for 2007-2010 (0.869 m^3s^{-1} and 0.614 m^3s^{-1} respectively), indicating that greater rainfall characterised 2012 than earlier years. The brief rise in DRP and TP could therefore, be a result of greater runoff contributing more phosphorus.

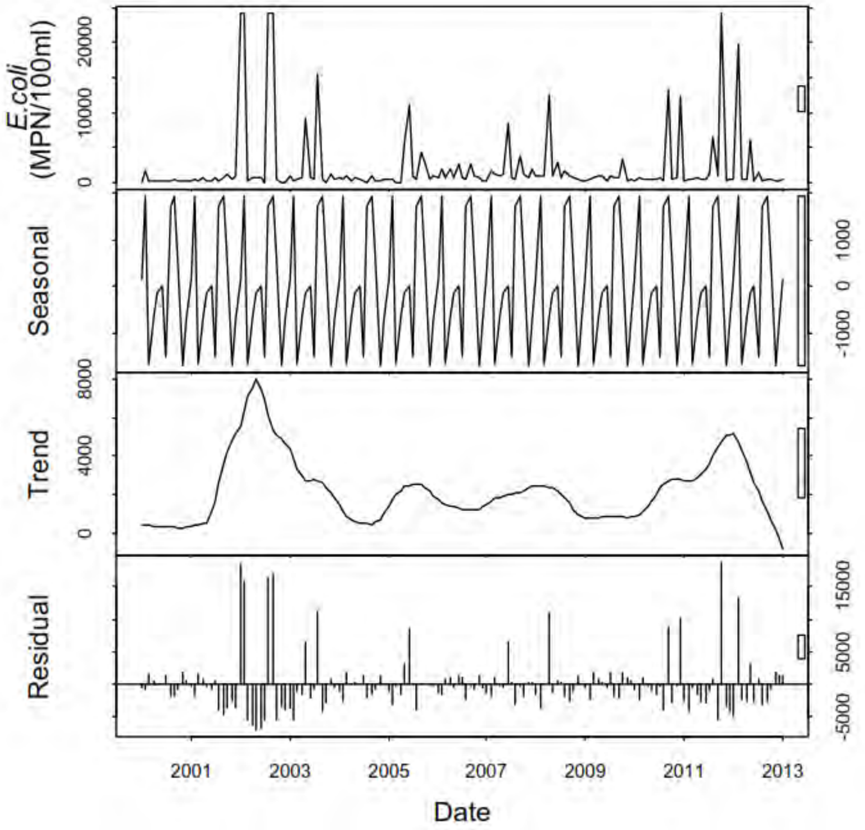

Figure 4.9. Seasonal trend loess time-series deconstructions of *E.coli* concentration at Knights Bridge (site 101625) from 2000-2012.

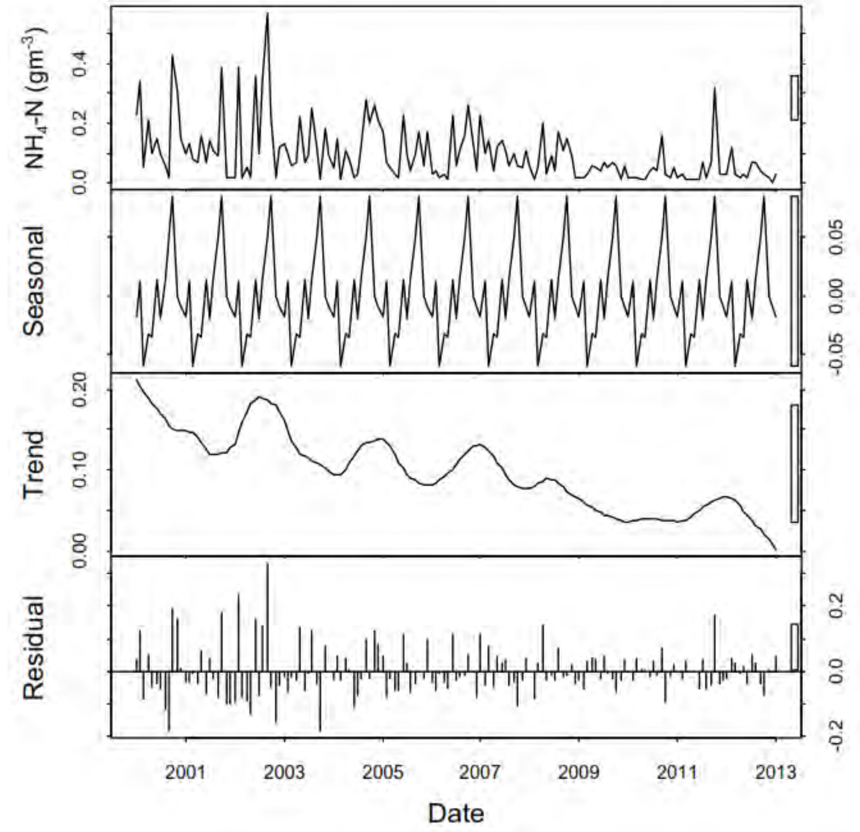

Figure 4.10. Seasonal trend loess time-series deconstructions of NH4-N concentration at Knights Bridge (site 101625) from 2000-2012.

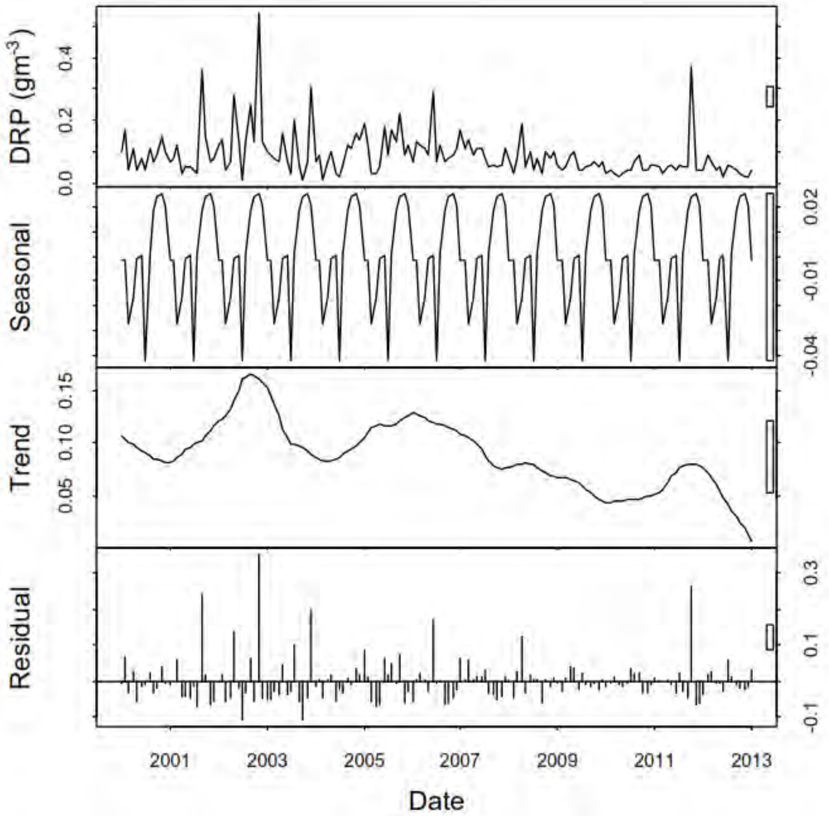

Figure 4.11. Seasonal trend loess time-series deconstructions of DRP concentration at Knights Bridge (site 101625) from 2000-2012.

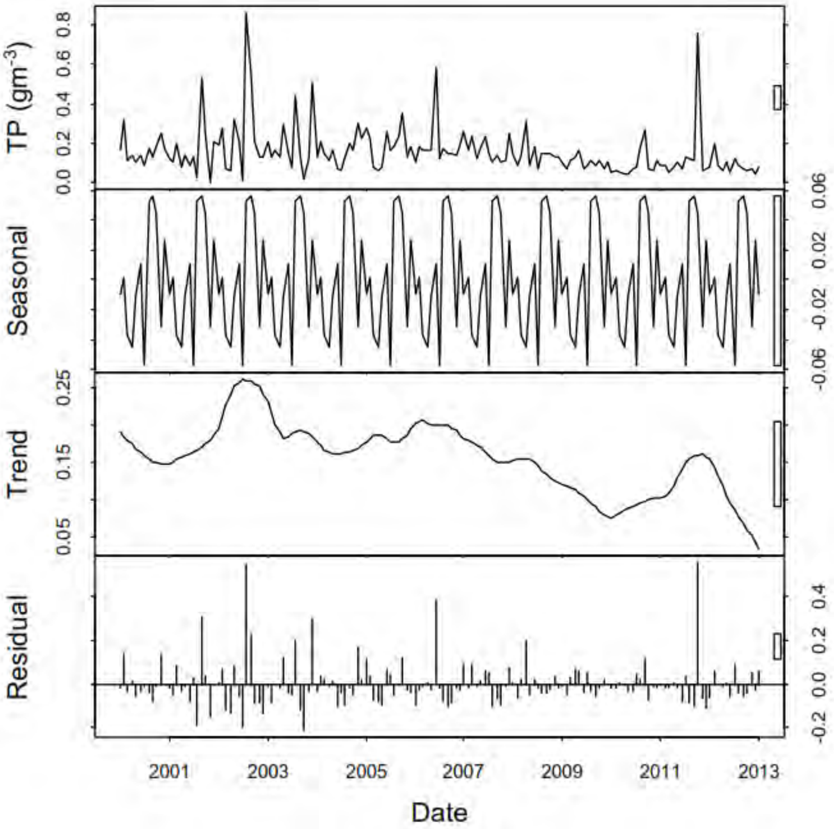

Figure 4.12. Seasonal trend loess time-series deconstructions of TP concentration at Knights Bridge (site 101625) from 2000-2012.

4.5 Relationships between water quality attributes

The PCA of centred and standardised (zero unit mean variance) annual medians for geochemical and bacterial concentrations at all monitoring sites are presented in Figure 4.13 (note the varying temporal spans of data with all sites bar 109166 having at least 4 years of data).

PCA axes 1 and 2 explain 55.63% and 13.1% of the total variance respectively between samples (Table 4.9). From inspection of Figure 4.13 it is clear that that first axis is a compound of changes to nutrient availability (i.e., composed of changes in TN, NH_4-N, NO_3-N, TKN, DRP and TP). Although the second PCA axis is a response to bacterial and sediment loads (*E.coli* and turbidity), it explains less variance than expected due to chance so is not included for further analysis – the variance explained or “inertia” of the axis is less than that attributed to a broken stick or null model ($p<0.05$; see Figure 4.13). Therefore, changes to sample scores on Axis 1 underscore that significant changes in nutrient availability have likely occurred within the Mangere catchment since 2007.

The position of annual median scores along Axis 1 confirms that many sites have undergone a marked change in sample geochemistry, from higher to lower nutrient availability, more recently (i.e., Axis 1 is a gradient of nutrients with high negative scores associated with greater TN and TP whilst high positive scores are associated with the inverse, lesser TN and TP). For instance, most site scores since 2007 shift from highly negative to positive Axis 1 scores. This is particularly evident on the Mangapiu Stream (site 101626). Other site scores like those of 101625 are more varied, including an apparent increase of annual median *E.coli* concentration but this is an artefact of including flood flows as opposed to limit-setting guidelines that exclude flood flows. In 2011 and 2012 several flood pulses occurred at site 101625 that resulted in higher coeval faecal bacterial concentrations but reading these site scores orthogonal to the vector for DRP and TP demonstrates, despite flood pulses, DRP and TP loading continued to decline more recently.

The PCA biplot does not offer as precise a level of information as trend tests but are useful diagnostic plots to demonstrate patterns between water quality indicators. For instance, vectors that plot in the same direction indicate similar changes over time amongst indicators, such that changes to annual medians of *E.coli* and turbidity are highly similar, which indicates the likelihood of a shared source or pathway. Likewise as would be expected, changes to TN are associated with similar changes to NH_4-N, TKN and NNN, whilst changes in DRP and TP closely correspond. This offers faith in the likely veracity of the NRC monitoring dataset and affords greater strength to inferences derived from this data.

Table 4.9. Summary of PCA for centred and standardised annual medians of water quality indicators from six monitoring sites, generated over varying intervals by site (overall, from 2007 and 2012).

PCA Axis	**1**	**2**	**3**	**4**
Eigenvalue (λ)	6.116	1.4367	1.3404	0.88082
Percentage variance explained	55.6%	13.1%	12.2%	8.0%
Cumulative percentage variance explained	55.6%	68.7%	80.9%	88.9%
Significant ($p<0.05$; inertia explained > broken stick)	Yes	No	No	No

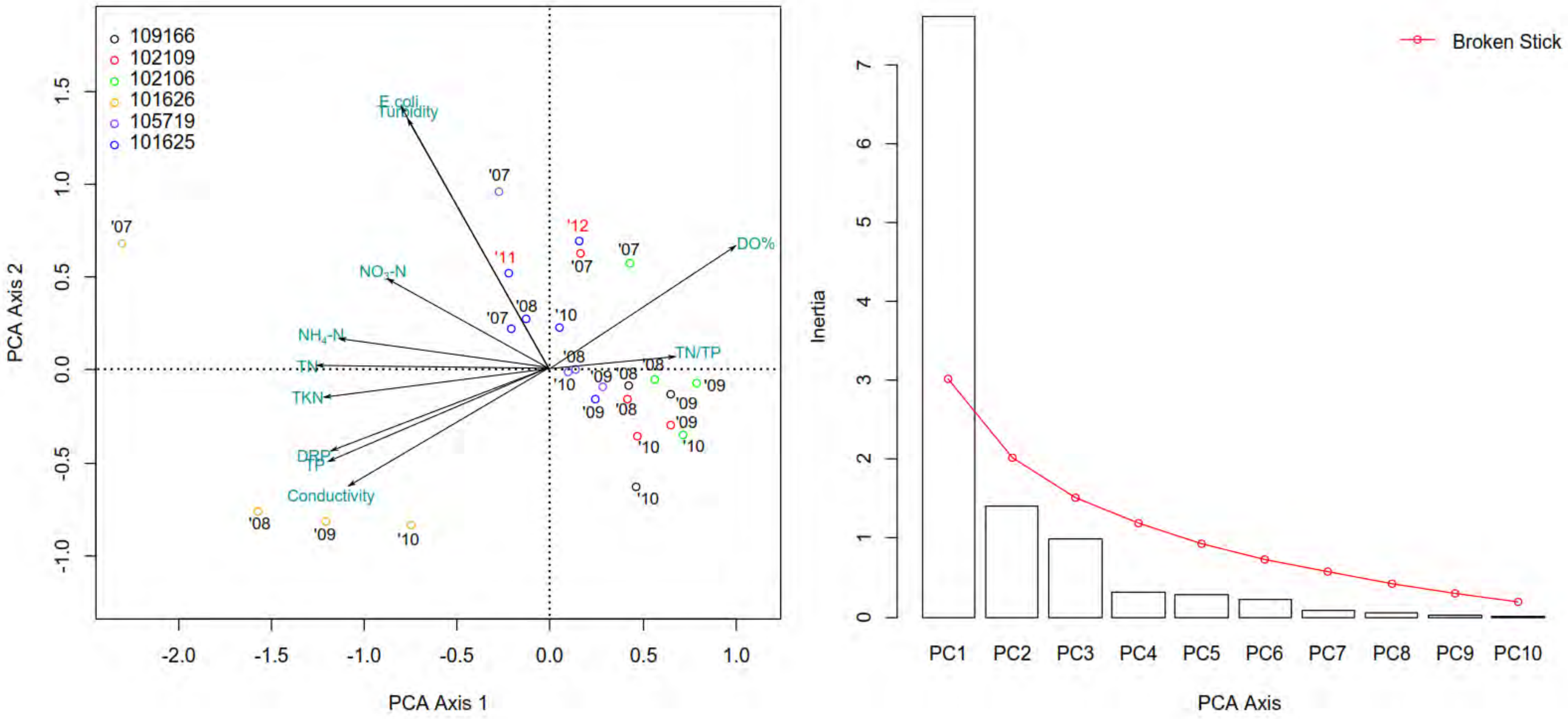

Figure 4.13. PCA biplot of centred and standardised annual median observations of NRWQMN indicators for multiple monitoring stations over the period 2007-2012. Annual medians for Knights Bridge in 2011 and 2012 have been highlighted in red font to indicate a slight worsening in E.coli contamination and turbidity during latter years (i.e., sample scores have travelled nearer to the apex of the E.coli and turbidity vectors).

5.0 Summary and Recommendations

Spatial pattern of water quality:

- A general profile for increasing nutrient, solute, suspended solid and *E.coli* concentration is evident in the Mangere catchment from headwaters downstream. However, this pattern is interrupted at site 109166, immediately downstream of native bush, by greater average nutrient and sediment concentrations than the nearest downstream site (NO_3-N, NH_4-N, TKN, TN, DRP, TP, turbidity). There are no dairy operations upstream of site 109166, indicating that land uses other than dairying result in marked effects to water quality within the Mangere River. An integrated management approach should therefore be adopted to manage water quality in the Mangere, targeting all substantive load contributors.
- Greatest nutrient, faecal bacterial, turbidity and least dissolved oxygen (DO) concentrations were recorded in a southern intermittently flowing stream, the Mangapiu Stream at site 101626.
- Median and average DO levels for 2007-2010 in the Mangapiu Stream fell below a protective 80% limit for fish (68.3% and 63.4% respectively). Recent sampling in March 2013 demonstrated DO minima of 26% that would severely threaten in-stream biodiversity (Montgomerie, 2013). However, the intermittently flowing nature of the Mangapiu Stream limits its potential contribution to "ecosystem health" and low DO might be consequence of limited flow during summer. Further investigation is required to determine diurnal DO during periods of flow and hydrological connectivity with the Mangere River, which has been contracted to Freshwater Solutions by DairyNZ.
- *E.coli* concentrations doubled from the upper catchment at site 109166, relative to mid-catchment at site 105719 (downstream of the confluence with the Mangapiu Stream). Greatest risk to "human health" occurs within the middle to lower catchment (downstream of site 102109) where the cumulative effects of pastoral land use are concentrated. Concomitant increases to DRP and TKN concentrations, and greater concentration of dairy farm downstream of site 102109, suggest an origin in farm dairy effluent for much of the faecal bacterial loading.

Seasonal pattern of water quality:

- Seasonal changes in discharge at Knights Bridge (site 101625) suggest frequent flood events year-round but concentrated in autumn and winter (annual FRE3 = 14.75; x3 median flow = 1.842 m^3s^{-1}). The hydrological regime is therefore likely to limit the potential for nuisance periphyton or macrophytes to develop in the catchment by limiting accrual periods between flood events to on average, approximately 25 days.
- Typical Austral seasonality is evident in pH, DO (%), temperature and turbidity observations at Knights Bridge (2000-2012). Marked seasonality occurs in NO3-N and TN concentrations, with peaks in availability during winter and troughs in summer.
- An absence of seasonality in phosphorus (DRP, TP) and *E.coli* concentrations at Knights Bridge from 2000-2012, despite marked seasonality in flow, suggests loading of the latter is

sufficiently high as to dampen any natural variability attributed to seasonal hydrological or climatic regime.

- Given the lack of seasonality in phosphorus and *E.coli* attributes at Knights Bridge (2000-2012), each load is preferentially transported during peak flow conditions. Hence, despite a lack of seasonality in latter concentrations, greatest loading overall still occurs in winter (i.e., akin to the greater loading of nitrogen and suspended sediments at higher concentrations and greater discharge of winter).

Compliance with NOF and additional bottom-lines for "human health" and "ecosystem health" (see Table 5.1):

- Any direct toxic effect of nutrients (NO_3-N and NH_4-N) to native biodiversity is limited, with both chronic and acute 95% community protection thresholds not exceeded at all sites (2007-2010) and until 2012 at Knights Bridge (furthest downstream).
- The indirect effects of nutrients driving nuisance algal and macrophyte growth appear limited by a largely soft clay substrate, highly variable hydrological regime and extensive riparian shading. For instance, the majority of surveyed locations possessed 50-80% shading, which would effectively limit insolation and in-stream primary production (e.g., Colley and Quinn, 1998; Matheson et al., 2012).
- However, the NPSFM (2011) requires that limits be set to account for cumulative effects, and so the Mangere CSG should bear in mind that downstream nuisance plant growth or toxicity affects, particularly in the Kaipara Harbour, might determine upstream nutrient load limits.
- Instead, the greatest pressure on "ecosystem health" is likely to arise from DO minima which have been worsening furthest downstream at Knights Bridge (site 101625) since 2000 and resulting in 2012 in a breach of the 1-day national bottom-line of ≥4.0 mg/L. All other sites, bar the Mangapiu Stream, exceeded the DO 1-day national bottom-line from 2007-2010.
- The Mangapiu Stream, repeatedly and markedly failed to meet the DO 1-day national bottom-line (<4.0 mg/L from 2008-2010). The latter should be monitored to determine the cause (i.e., intermittent flow, excess in-stream vegetation, inputs of organic matter) and appropriate management taken (if not linked to natural periodic lack of flow).
- An additional important feature of spatial changes in DO availability is that lesser DO (% and mg/L) is noted at the headwater site (109166) than immediate downstream sites which are subject to dairying. The absence of dairying upstream of site 109166 and its proximity to pristine waterways in the Pukenui Forest, suggest a marked localised effect on "ecosystem health" immediately east of the forest that should also be investigated and action taken to improve oxygenation. Note that if the 7-day DO national bottom-line (≥5.0 mg/L) is applied to the NRC dataset, the Mangapiu Stream would fail in all years, the headwater site 109166 would fail in 2010 and the Mangere River at Knights Bridge (site 101625) would fail consistently in 2010, 2011 and 2012.
- Changes to pH appear limited in the Mangere and it is likely that should a pH attribute be included, the catchment would meet national bottom-lines for the protection of fish (6.0-9.5 proposed in Davies-Colley et al [2013]).
- Amongst fish fauna native to the Mangere, banded kokopu (*Galaxias fasciatus*) are likely to be most sensitive fish to temperature changes, requiring an upper limit of 21.2°C to avoid

behavioural effects (Richardson et al., 1994). Only 3 of 223 observations at site 101625 (2000-2013) exceeded 21.2°C. No exceedance of 21.2°C was observed at the five additional monitoring sites from 2007-2010. Although continuous monitoring is recommended to better capture diurnal temperature changes (i.e., daily maxima from 1 November-31 April), riparian surveys suggest a high degree of shade throughout the Mangere catchment, limits the likelihood of thermal stress on native biota.

- Banded kokopu are also the most sensitive native fish in the country to suspended sediment concentrations. Negative behavioural changes can occur during migratory periods (August-December) if turbidity exceeds 20 NTU (Rowe et al., 2000). Analysis of turbidity measurements revealed that a 20 NTU limit was exceeded during August-December, in the Mangapiu Stream at site 101626 in 2009 and, in the Mangere River at site 101625 during 2010 and 2011. Current sediment loads to the Mangere River during winter-spring appear to limit the potential for migration of banded kokopu into the catchment, which might also be a descriptor of "ecosystem health".
- The Mangere catchment continues to receive extremely high faecal bacterial pulses with maxima in *E.coli* concentrations beyond the upper limit of detection (>24,192 MPN/100 ml) in 2002, 2007, 2008, 2010 and 2011 at Knights Bridge (site 101625), and in 2007 on the Mangapiu Stream (site 101626). However, there is clear evidence of marked declines (near halving) in *E.coli* concentrations at all sites since 2007, bar the middle-catchment site 102106 which underwent a marked (near doubling) of *E.coli* concentration in 2010 – the cause might well lie in the year's lower flows, concentrating faecal discharges to water upstream. A survey of E.coli concentrations at site 102106 is recommended to determine if the abrupt local deterioration in "human health" was a one-off.
- In terms of the current NOF national bottom-line (median *E.coli* ≤1000 MPN/100 ml) for "human health", as before there is a clear improvement in water quality since 2007 at all sites bar 102106. Several sites consistently met the national bottom-line in all years (sites 102109, 102106, 109166 and 101626) whilst the lower catchment (sites 105719 and 101625) only met the national bottom-line in 2010 and 2008 respectively, following considerable declines to in-stream *E.coli* concentrations. Nonetheless, changing the statistic against which the *E.coli* bottom-line is reported can markedly affect compliance. The general pattern of faecal bacterial loading (and risks for compliance with a "human health" bottom-line) is:
    - The upper catchment (109166, 102106 and 102109) is likely to have resulted in <5% risk of Campylobacteriosis from 2007-2010 (i.e., the minimum permissible risk under the NOF). The absence of changes in *E.coli* concentration at the headwater site 109166 (upstream of dairying) from 2007-2010 coupled to a near doubling of *E.coli* concentration immediately downstream at site 102106 in 2010 is cause for concern. Although increased upstream *E.coli* concentrations appear to have driven an equivalent 10% increase at site 102109 in 2010, the lesser magnitude of this rise suggests the cause was localised upstream of 102106 (and downstream of 109166).
    - The lower catchment (105719 and 101625) would likely have resulted in >5% risk of Campylobacteriosis throughout 2007 at both sites and until 2009 at site 105719 (downstream of the Mangapiu Stream). Despite the relatively poor performance until recently, both sites have undergone marked reductions overall in faecal bacterial

concentrations in 2010, which continued through until 2012 (the furthest downstream site rating in Band B, between 0.1-1.0% risk of Campylobacteriosis in 2012).

  - The Mangapiu Stream might well have contributed to breaches in the national bottom-line for E.coli downstream of its confluence with the Mangere River at site 105719. For instance, E.coli concentrations were typically second or third highest in the catchment, until 2010. Thereafter, a marked decline (75%) in E.coli concentrations occurred. As before, further sampling is recommended to determine whether the latter has continued until present or was a one-off.

Long-term trends in sediment, nutrient and bacterial numeric attributes for water quality

- Flow-corrected trends at site 101625 (2007-2012) offer greatest reliability of all sites tested, due to their greater length of monitoring data (i.e., >60 observations; 5 years monthly resolution [Jowett, 2011]).
- All standard NRWQMN water quality indicators were either stable or improving at site 101625 for the period 2007-2012. Flow-corrected trends improved at a statistically-significant ($p<0.05$) and ecologically-meaningful rate for NH_4-N (-26.8% per yr), DRP (-17.6% per yr), TP (-14.0% per yr), *E.coli* (-13.7% per yr) and NO_3-N (-5.3% per yr).
- Similar flow-corrected trends were noted elsewhere for the remaining five monitoring sites, albeit at shorter record lengths and statistical reliability. Nonetheless, this is indicative of above trends being representative of the wider Mangere catchment.
- Standardised and centred PCA of NRWQMN indicators for water quality confirmed that changes in nutrient concentrations were most marked across the six monitoring sites within the Mangere catchment for the period 2007-2010 (2008-2010 at site 109166 and 2007-2012 at site 101625), also highlighting that the Mangapiu Stream has undergone most marked change in nutrient loading overall.

Table 5.1. NOF bands by attribute and value for the period 2007-2012 across the six monitoring stations in the Mangere catchment (for compulsory values and attributes of the NOF). Red cells fail the national bottom-line (D) and blue cells indicate the best grade (A).

Value	**Attribute**	**Year**	**Monitoring Site**					
			101625	**105719**	**102109**	**102106**	**109166**	**101626**
Human health	*E.coli*	2007	D	D	C	C		C
		2008	C	D	C	C	C	C
		2009	B	D	C	B	B	C
		2010	B	C	C	C*	C	A
		2011	C					
		2012	B					
Ecosystem health	NO_3-N (Median/95th%)	2007	A/A	A/A	A/A	A/A		A/A
		2008	A/A	A/A	A/A	A/A	A/A	A/A
		2009	A/A	A/A	A/A	A/A	A/A	A/A
		2010	A/B**	A/B**	A/A**	A/A	A/A	A/A
		2011	A/A					
		2012	A/A					
	NH_4-N (Median/95th%)	2007	B/B	B/B	A/B	A/A		C/C
		2008	B/B	B/B	A/A	A/A	A/B	B/C
		2009	B/B	B/B	A/A	A/A	A/A	B/B
		2010	A/B	B/B	A/A	A/A	A/A	B/B
		2011	A/B					
		2012	A/B					
	DO (1-day/7-day)	2007	B/C	B/B	A/B	A/A		C/D
		2008	B/C	B/C	B/B	A/B	B/C	D/D
		2009	B/B	B/B	A/B	A/A	B/C	D/D
		2010	D/D	B/C	B/B	A/A	C/D	D/D
		2011	C/D					
		2012	C/D					

*Indicates marked (x2) increase or worsening of water quality for human health; **indicates marked rise or worsening in 95th% NO_3-N (x1.5).

Conclusions:

- Hydrological and geochemical monitoring data suggest limited potential in-catchment deleterious effect from current nutrient concentrations (i.e., limited direct effect through nitrate or ammonia toxicity and limited indirect effect driving nuisance periphyton or macrophyte growth due to hydrological and riparian constraints). Trends observed furthest downstream at Knights Bridge (site 101625), also suggest current inorganic nitrogen and total phosphorus levels are declining at a statistically significant, ecologically meaningful rate.
- Geochemical data suggests the supply of particulate matter to the Mangere River is impacting on the health of potential native biodiversity by limiting the migration of juvenile banded kokopu. The absence of significant meaningful trends in turbidity at site 101625 from 2007-2012, and all bar one further site for the brief period of 2007-2010 suggest a need for greater management of suspended solids, to improve “ecosystem health”.
- A survey of riparian habitat condition demonstrated the potential to reduce sediment loads by targeting middle-to-lower catchment of the Mangere River, including the lower Mangapiu Stream, with effective riparian management. Note that turbidity estimates for 2007-2010 also suggest livestock exclusion and riparian management should be practiced upstream of site 109166 to ensure the cumulative effects from upstream land users do not impair downstream “ecosystem health” (and permit migration of banded kokopu to the Pukenui Forest).
- All monitoring sites met at least national bottom-lines for “human health” in 2010 although the lower catchment (sites 105719 and 101625) would not have met this minimum in earlier years. However, a statistically significant and ecologically meaningful trend for decreasing (improving) *E.coli* concentrations at Knights Bridge (-13.9% per yr), observed from 2007-2012, is encouraging. This trend is also evidence of large declines in faecal bacterial loading throughout the middle-to-lower catchment, where dairy operations are concentrated, and potentially of the effects of significant upgrades in 18 or 19 farm dairy effluent systems since 2007.
- A doubling of *E.coli* concentrations in the upper catchment at site 102106 from 2007-2010 is cause for concern and warrants further investigation to determine the origin and if this forms part of a worsening trend (i.e., 2010 was a drought year with lower annual median flow than the series median for 2007-2010 which could have concentrated effluent discharges).

Note: *These conclusions are based on data collected by NRC from 2000-2012, with inferences on all sites bar Knights Bridge (101625) limited to 2010. Hence, changes since 2010 at sites other than Knights Bridge may have occurred that are omitted from this report. An attempt to limit this uncertainty has been made by examining trends at furthest downstream until 2012, at Knights Bridge (site 101625).*

Note: *No attempt to report on periphyton (due to an absence of data), cyanobacteria (due to an absence of data) nor macroinvertebrate health has been made (due to a paucity of information in the Mangere and regionally, in Northland for controls on MCI score). Both are important attributes for “ecosystem health” and should be targeted for management by the Mangere CSG using regional or national information as required.*

Recommendations:

- Adopt a "whole of catchment" approach to managing "ecosystem health", focussing principally on sediment control and riparian condition as a means of improving water quality for the latter. Likewise continue a "whole of catchment" focus on faecal bacterial loading, particularly upstream of dairy influences at site 109166 (i.e., to ensure connectivity of healthy water with the Pukenui Forest and reverse any increase in 2010 to poorer water quality for "human health"). Note that the choice of reporting statistic for E.coli concentrations, relative to guideline recommendations in McBride (2012) will have significant implications on whether the catchment achieves the national bottom-line.
- Prioritise management of dissolved oxygen and suspended sediment attributes for "ecosystem health" throughout the Mangere catchment, but especially in the Mangapiu Stream (site 101626) and Knights Bridge (site 101625). Better riparian management appears possible from riparian condition surveys and should prioritise the exclusion of livestock and restoration of groundcover vegetation to reduce sediment loss in runoff (i.e., *Carex* spp., *Cortaderia fulvida*, *Cyperus ustulatus*, *Phormium tenax*). Ongoing weed and pest management will be essential to exclude creeping groundcover weeds (e.g., *Tradescanthia fluminensis* [Wandering Jew], *Lonicera japonica* [Japanese honeysuckle], *Clematis vitalba* [Old man's beard]). Plantings of native shrub and tree species suited to Northland should be prioritised for riparian margins which currently lack ≥60% shade, to restrict potential in-stream macrophyte or periphyton growth and thereby reduce diurnal DO variation (i.e., *Cassinia leptophylla*, *Coprosma* spp., *Cordyline australis*, *Kunzea ericoides*, *Leptospermum scoparium*, *Melicytus ramiflorus*, *Myrsine australis*, *Podocarpus totara*, *Pseudopanax arboreus*). This is a sustainable solution to better ensure a 7-day minimum of ≥5.0 mg/L DO is attained throughout the catchment year-round.
- Prioritise better water usage efficiency. The NPSFM (2011) calls for limits on water quantity as well as quality, and increased flow through the Mangere under current riparian condition as well as nutrient and faecal loading will result in greater oxygenation. Consequently, by improving water usage stakeholders will have greater water resource available but also should expect to improve water quality for "ecosystem health" through greater oxygenation at Knights Bridge (site 101625) (i.e., by physically mixing and entraining greater dissolved oxygen, and by reducing in-stream temperatures, thereby permitting greater absolute oxygen dissolution).
- Prioritise monitoring of algal biomass (periphyton) either in the Mangere catchment or elsewhere to determine the effects of nutrients on periphyton and macrophyte growth (i.e., determine the relative effects of shading, flow and nutrients on algal or macrophyte growth in clay-based, frequently scoured systems like the Mangere River, to reliably determine whether nuisance plants are likely to arise under current hydrological and nutrient regimes).
- Continue to invest in effluent best practices and septic tank upgrades, to maintain continuation of current trends to markedly better water quality for "human health". This might involve a whole of catchment approach to livestock exclusion rather than simply a focus on farm dairy effluent, though with the caveats that any changes should be supported by the whole catchment. Likewise, ensure that continued improvements in dairy effluent practices occur to better insulate against the risk that a highly conservative statistic be adopted for reporting against annual *E.coli* concentrations in McBride (2012) (i.e., to ensure that recent

gains in “human health” continue and that at least national bottom-lines are achieved should either flood-flows be included for reporting and/or a more conservative statistic such as an ‘annual maximum’ be employed against the guideline recommendation of 1000 MPN/100 ml *E.coli* for a 5% risk of Campylobacteriosis).

- Adaptively manage water quality objectives for the Mangere, as and when further information on the controls of “ecosystem health” and “human health” downstream in the Wairoa River and Kaipara Harbour is made available (i.e., account for the cumulative effects on downstream water quality of all upstream users in the CSG limit-setting approach). This should also include accounting for additional values and the cumulative impacts upon the latter, determined to be protected by the Mangere CSG (i.e., mahinga kai, primary contact recreation, irrigation, hydroelectricity generation).
- Further monitoring:
    - Determine whether recent (2010) increases in *E.coli* concentration at site 101206 have continued or been arrested (i.e., to maintain or improve “human health”).
    - Determine the nutrient, sediment and faecal bacterial loading contributed by the Mangere at the confluence with the Wairua River, to determine what apportionment of downstream loads should be made for future management of the Kaipara Harbour.
    - Bio-monitoring should be conducted using MCI at a regular interval to complement this report and wider regional assessment be undertaken to determine how to ensure the hydrology, riparian condition and geochemistry of a waterway can be set (with accuracy) to protect an MCI of known value (i.e., for a likely national bottom-line).
    - Monitoring should also be undertaken on the Knights Bridge (site 101625) and Mangapiu Stream (site 101626) to determine the cause of marked variation in DO and inputs of suspended sediment (i.e., instream plant growth and/or inputs of organic matter driving increased BOD).
    - Conduct higher resolution turbidity monitoring (weekly-daily) assessments during migratory months of juvenile banded kokopu (August-December) to better define current risks to recruitment of latter populations in the Pukenui Forest (i.e., as an attribute of “ecosystem health”). (A high resolution study by the NRC could be used to inform likely pressures region-wide in other intensive dairying Northland catchments).
- Consider a further assessment of water quality prior to and following the introduction of SMPs to more reliably demonstrate the effects of further changes in dairy farm practice and infrastructure (i.e., to ensure ready distribution of findings to other dairy-rich catchments, as a proof of concept and as evidence that actions being requested have been demonstrated to be successful at improving water quality in Northland catchments).

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Appendix A Mangere River catchment Fish Population Methodology

DairyNZ contracted Freshwater Solutions to undertake an assessment of the fish population of the Mangere River. The tasks identified in the scope agreed with DairyNZ and NRC are:

- Review of New Zealand Freshwater Fish Database to provide an historical perspective
- Assessments made at upto 15 representative sites throughout the catchment
- Methodology = electric fishing + netting (fyke and minnow traps) + spot-lighting in line with best practice methodology for fish assessments in New Zealand (i.e., excluders in fyke nets to isolate prey galaxiids from eels) using New Zealand Freshwater Fish Sampling Protocols (draft protocols – March 2013).
- Assessment of in-stream and riparian habitat condition at appropriately-located sampling sites using approved protocol – collected data to be linked in with an extensive survey of riparian condition in the catchment (being undertaken by DairyNZ).
- Semi-quantitative macroinvertebrate sampling (taxonomic identification and enumeration).
- Automated diurnal oxygen & temperature profile (24 hr per site at upto 6 sites) with appropriate QA
- Mapping of significant physical barriers to fish passage.
- Recommendations on potential catchment actions for improving native fish diversity and population density.
- Electric fishing to include appropriate NRC staff to assist with their training in electric fishing.

At the time that these tasks were agreed it was not possible to provide a detailed description of the survey methods and sites because a catchment visit had not been undertaken. A meeting was held with NRC and a catchment visit was undertaken on 19 – 20th March. This report sets out the proposed sampling sites and sampling methodology for each site.

Fish Sample Sites

Fish populations can be influenced by a wide range of factors including:

- In-stream and riparian habitat quality.
- Water quality.
- Distance from the sea.
- Dams, weirs and waterfalls.
- Fishing pressure.

These factors can in turn be influenced by a complex range of interacting factors such as climate, geology, land use, land management practises and economic conditions.

NRC has monitored water quality monthly at 6 sites in the Mangere Catchment since July 2007 (NRC 2011). The Mangere Catchment land use geology and climate are also described in NRC (2011). DairyNZ are currently assessing riparian habitat within the catchment.

Catchment information contained within NRC (2011) along with information provided by NRC (e.g. weir locations) was used along with information gathered during the catchment visit on 20th March to select sites. The sampling sites are shown on Figure 1 and presented in Table 1.

Fish Sampling Methodology

Sampling of mudfish sites will be undertaken in accordance with the national mudfish sampling protocols (Ling et al 2009). Sampling of electric fishing sites (Sites 6 and 7) and fyke and minnow trap sites (Sites 1 – 5 and Sites T1 – T4) will be undertaken in accordance with the draft New Zealand Freshwater Fish Sampling Protocols (Joy et al 2013).

Riparian Habitat Sampling Methodology

Riparian habitat conditions will be assessed at each fish sampling site using Protocol P2d from Stream Habitat Assessment Protocols for wadeable rivers and streams of New Zealand (Harding et al 2009). A detailed photographic record of riparian habitat conditions will also be made at each site.

Instream Habitat Sampling Methodology

Instream habitat conditions will be assessed at all mainstem and tributary sites using Protocol P2b and P2c from Stream Habitat Assessment Protocols for Wadeable rivers and streams of New Zealand (Harding et al 2009). Not all in stream habitat will be able to be collected from Site 1 – Site 4 as the river is too deep to wade at these sites. A detailed photographic record of instream habitat conditions will also be made at each site.

Semi quantitative macroinvertebrate Sampling Methodology

A single macroinvertebrate sample will be collected from main stem and tributary sites. Protocol C1 will be used for hard bottom sites (Sites 5, 6 and 7) and Protocol C2 will be used for soft bottom sites taken from Protocols for sampling macroinvertebrates in wadeable streams (Stark et al 2001). Samples will be preserved and processed using Protocol p3 – full count with subsampling. Biological Indices such as taxa number, abundance, MCI, %EPT and EPT taxa number will be presented.

Dissolved Oxygen Sampling

Calibrated dissolved oxygen data sondes, supplied by NRC will be deployed for 24 hours at Site 1, Site 3, Site 4, Site 5, Site 6 and Site T2.

Mapping of Fish Barriers

NRC has a database of potential fish barriers (weirs and dams) within the catchment. Information from this database will be used to show all potential fish barriers on a map. Some of the barriers will be visited and their potential to act as a barrier will be assessed.

Table A1: Sample Site Summary

Site code	Location	Type	Sampling method	Survey timing
1	Lower river, downstream of falls	Main stem	Fyke nets and mesh minnow traps	Summer and Spring
2	Lower river, downstream of falls	Main stem	Fyke nets and mesh minnow traps	Summer and Spring
3	Lower river, upstream of falls, Knights Road Bridge.	Main stem	Fyke nets and mesh minnow traps	Summer and Spring
4	Middle reaches, Kokopu Road Bridge.	Main stem	Fyke nets and mesh minnow traps	Summer and Spring
5	Upper river, Kara Road Bridge.	Main stem	Fyke nets and mesh minnow traps, EFM.	Summer and Spring
6	Upper river, downstream of weir.	Main stem	EFM	Summer and Spring
7	Upper river, upstream of weir.	Main stem	EFM	Summer and Spring
T1	Upper river tributary off McKinlay Road.	Tributary	Mesh minnow traps	Summer and Spring
T2	Middle reach tributary off Kokopu Road.	Tributary	Mesh minnow traps	Summer and Spring
T3	Middle reach tributary off Roydon Road.	Tributary	Mesh minnow traps	Summer and Spring
T4	Middle reach tributary off Gumtown Road.	Tributary	Mesh minnow traps	Summer and Spring
Mudfish 1	Lower river wetland off Knight Road.	Wetland	Fine mesh wire traps	Spring
Mudfish 2	Lower river wetland off Knight Road.	Wetland	Fine mesh wire traps	Spring
Mudfish 3	Middle river wetland.	Wetland	Fine mesh wire traps	Spring
Mudfish 4	Middle river wetland off Kokopu Road.	Wetland	Fine mesh wire traps	Spring
Mudfish 5	Middle river wetland off Greys Road.	Wetland	Fine mesh wire traps	Spring

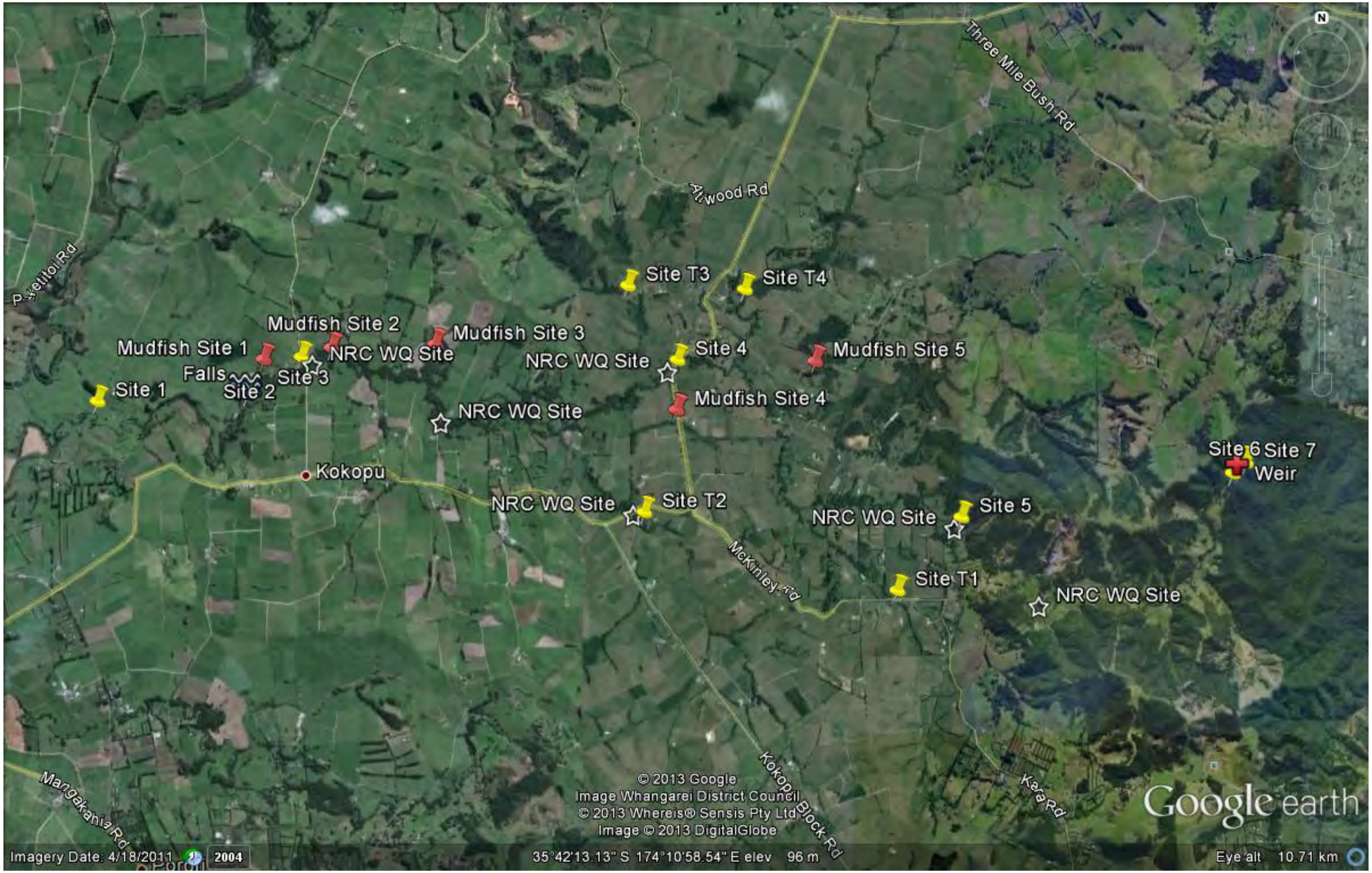

Figure A1: Sampling Site Locations.

Appendix B Mangere River catchment Riparian Survey (P2 Protocol)

Assessor:
River or Tributary:
GPS Coordinates:
Site Number:
Photo Numbers:

Notes:

Attributes	L	R	Scores 1	Scores 2	Scores 3	Scores 4	Scores 5
Shading of Water			Little or None	10-25%	25-50%	50-80%	>80%
Buffer Width	m	m					
Buffer Intactness			Absent	50-99% gaps	20-50% gaps	1-20% gaps	Completely Intact
Vegetation Composition of Buffer and Land Adjacent	B/L	B/L	Grazed pasture to stream edge/impervious surface	Weedy shrubs or mainly high grass or low native shrubs	Deciduous trees dominated. Native shrubs dominant or plantation with <25% cover. Natural tussock	Regen. native forest with > 25% sub-canopy trees but <10% canopy trees	Maturing native forest with high canopy % or natural wetland or natural tussock veg.
Bank Stability			Very low. Uncohesive sed. with few roots	Low: Uncohesive sed and few roots/low vege with 15-40% recently eroded	Moderate: Stabilised by geology, veg cover &/or roots >5-15% recently eroded	High: Stabilised by geolody, veg cover &/or roots and 1-5% recently eroded	Very high: Stabilised by geology, veg cover &/or roots <1% recently eroded
Livestock Access/Crossings			High. Unfenced, unmanaged.	Moderate. Some stock access.	Limited. Unfenced, but low stocking, bridges, troughs, natural deterrents	Very limited. Temp fencing of all livestock or naturally limited	None. Permanent fencing or no livestock.
Riparian Soil Denitrification potential			Soils dry/firm underfoot or moist-wet but frequent tile drains bypass riparian soils	1-30% streambank soils moist but firm or moist-wet with infrequent bypass drains	>30% streambank soils moist but firm underfoot. No drains	1-30% soils waterlogged, soft underfoot with black soils. No drains	>30% streambank soils waterlogged, surface moist/fluid underfoot. No drains
Bank Slope			>35°	>20-35°	>10-20°	>5-10°	0-5°
Groundcover of Buffer and Land Adjacent Effectiveness *(Note plant types present if possible).*	B/L	B/L	Scores 1 Short/regularly grazed	Scores 2 Pasture grass/tussock with bare flow paths or light tree litter layer	Scores 3 Moderate density groundover or dense tree litter layer	Note:	
Soil Drainage			Impervious or extensively pugged/ compacted soils	Low permeability or moderately pugged/compacted	Low-moderate permeability and not pugged/compacted	Mod-high permeability and not pugged/compacted	Very high permeability and not pugged/compacted

RIll or Channels		Frequent > 9 per 100m or larger channels carry all/most runoff	Common 4-9 per 100m or 1-2 large channels	Infrequent rills and no large channels	Rare rills and no larger channels	None
Natural Sediment Sources	Note:					
Undercut Banks		99-50% undercut	50-20% undercut	20-10%	10-5% undercut	<5% undercut
Overhanging Vegetation	(Percentage of immediately overhanging vegetation):					
Note Substrates	Note:					
Run, Riffle, Pool %	Run	Riffle	Pool	Notes:		

Appendix C Graphical goodness-of-fit for OLS regression of NNN and NO_3-N at Knights Bridge (2007-2012)

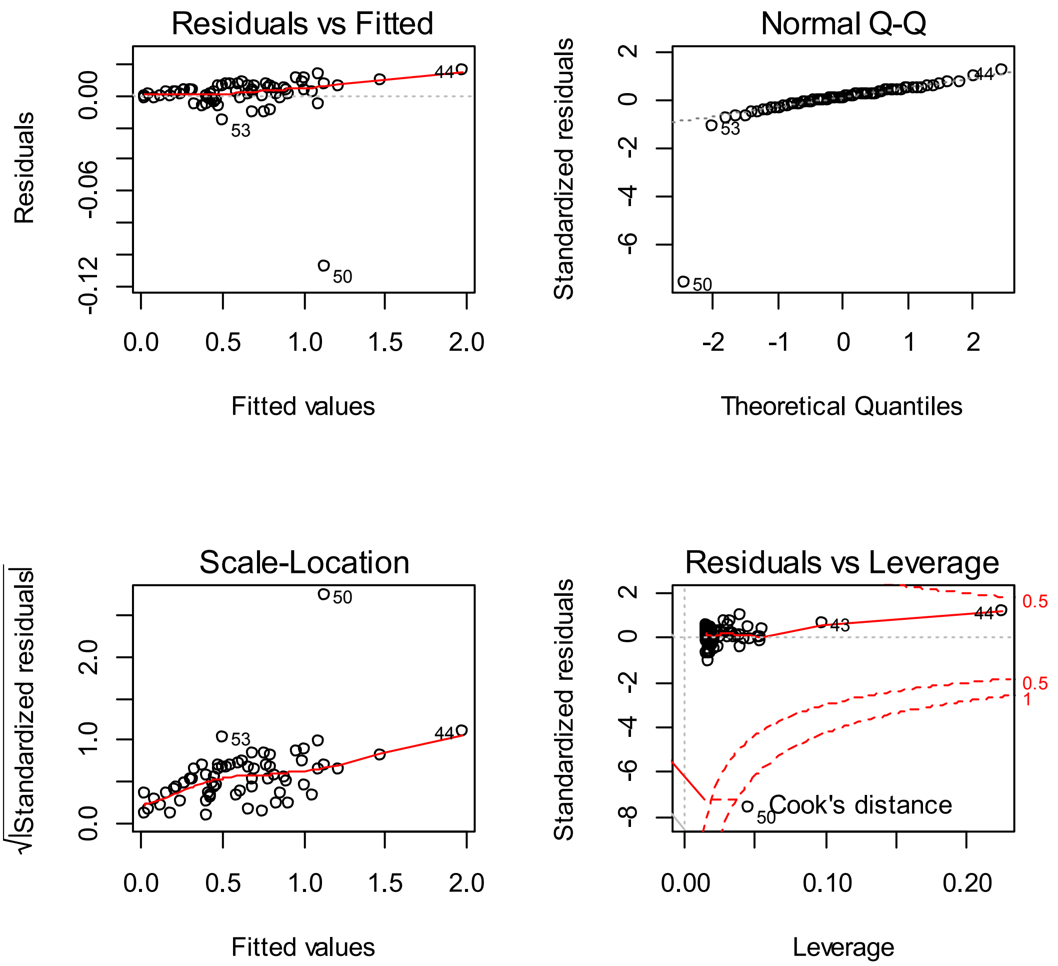

Figure C1. Performance graphs from OLS regression of NO_3-N (y) on NNN (x) for Knight's Bridge (site 101625) during 2007-2012. The regression demonstrated heteroskedasticity of residuals in NO_3-N (top left – residuals exhibit an increasingly pattern with *x*) but met the conditions of normality (top right, Q-Q plot).

Appendix D Mangere River catchment statistics (2007-2010)

Table D1. Summary statistics by monitoring site (upstream from Knights Bridge) for the period 2007-2010 (2008-2010 for site 109166). The Mangapiu site (101626) that enters the Mangere River above site 105719 is shaded to distinguish it from other sites that are on the Mangere Stream and River. *indicates non detectable observation (either over or under the detection limit).

Site **101625**	**Statistic**	**NO_3-N (g/m^3)**	**NH_4-N (g/m^3)**	**TKN (g/m^3)**	**TN (g/m^3)**	**DRP (g/m^3)**	**TP (g/m^3)**	**Turbidity (NTU)**	**DO (%)**	**DO (mg/L)**	***E.coli* (MPN / 100ml)**	**Flow (m^3/s^1)**
2007-2010 (*n* = 99) Furthest downstream	5%ile	0.054	0.003	0.154	0.264	0.027	0.044	2.7	64.4	6.0	187	0.099
	25%ile	0.398	0.021	0.320	0.710	0.041	0.072	5.2	79.1	7.7	405	0.251
	Median	0.654	0.050	0.420	1.190	0.058	0.110	6.9	84.5	8.6	712	0.622
	Mean	0.648	0.067	0.504	1.140	0.068	0.124	9.2	83.2	8.5	1881	1.121
	Std. Dev.	0.400	0.063	0.306	0.594	0.043	0.079	10.3	10.5	1.4	4715	1.387
	75%ile	0.900	0.100	0.600	1.410	0.084	0.150	8.8	88.4	9.4	1081	1.402
	95%ile	1.188	0.1664	1.092	2.180	0.144	0.272	18.8	97.3	10.2	6131	3.449
	Minimum	0.019	0.005*	0.05	0.055	0.005	0.034	1.0*	38.3	3.5	74	0.062
	Maximum	1.990	0.350	1.600	2.700	0.318	0.494	90.0	119.2	12.6	24192*	9.216
Annual median	2007	0.74	0.095	0.50	1.32	0.086	0.138	7.3	84.0	8.8	1027	0.748
	2008	0.68	0.05	0.45	1.30	0.071	0.129	7.3	83.7	8.2	875	0.650
	2009	0.53	0.03	0.41	0.92	0.049	0.083	6.9	86.8	8.9	496	0.622
	2010	0.32	0.0255	0.33	0.60	0.038	0.061	5.2	83.9	8.6	496	0.430

Site **105719**	**Statistic**	**NO_3-N (g/m^3)**	**NH_4-N (g/m^3)**	**TKN (g/m^3)**	**TN (g/m^3)**	**DRP (g/m^3)**	**TP (g/m^3)**	**Turbidity (NTU)**	**DO (%)**	**DO (mg/L)**	***E.coli* (MPN / 100ml)**
2007-2010 *(n = 45)* Downstream of confluence with Mangapiu Stream	5%ile	0.091	0.003	0.180	0.293	0.027	0.039	3.8	71.9	6.9	358
	25%ile	0.335	0.026	0.275	0.620	0.033	0.058	6.4	80.4	7.8	814
	Median	0.600	0.040	0.390	1.100	0.048	0.082	7.3	86.1	8.8	1178
	Mean	0.617	0.044	0.452	1.073	0.054	0.113	8.0	84.5	8.7	2087
	Std. Dev.	0.389	0.032	0.266	0.536	0.037	0.133	3.0	7.6	1.2	3458
	75%ile	0.880	0.050	0.575	1.385	0.060	0.126	9.3	88.4	9.5	1666
	95%ile	1.120	0.098	0.826	2.060	0.099	0.174	14.2	94.8	10.5	5650
	Minimum	0.033	0.005*	0.100	0.220	0.015	0.036	3.3	67.2	6.5	259
	Maximum	1.900	0.160	1.400	2.500	0.250	0.920	16.3	103.1	11.0	19863
Annual median	2007	0.786	0.060	0.400	1.260	0.050	0.105	13.4	85.8	9.1	1315
	2008	0.610	0.040	0.505	1.195	0.058	0.117	7.4	86.2	8.6	1250
	2009	0.530	0.030	0.390	1.100	0.047	0.079	7.0	87.4	9.1	1187
	2010	0.280	0.035	0.265	0.545	0.033	0.058	6.4	82.7	8.4	758

Site **102109**	**Statistic**	**NO_3-N (g/m^3)**	**NH_4-N (g/m^3)**	**TKN (g/m^3)**	**TN (g/m^3)**	**DRP (g/m^3)**	**TP (g/m^3)**	**Turbidity (NTU)**	**DO (%)**	**DO (mg/L)**	***E.coli* (MPN / 100ml)**
2007-2010 *(n = 49)* Upstream of confluence with Mangapiu Stream	5%ile	0.071	0.003	0.025	0.242	0.014	0.026	3.2	75.6	7.2	262
	25%ile	0.320	0.010	0.200	0.600	0.021	0.038	4.9	85.8	8.3	512
	Median	0.500	0.020	0.280	0.850	0.026	0.052	5.6	89.7	9.4	650
	Mean	0.541	0.021	0.318	0.891	0.029	0.064	6.8	88.8	9.2	1030
	Std. Dev.	0.340	0.019	0.225	0.448	0.014	0.048	3.6	7.2	1.1	1294
	75%ile	0.770	0.030	0.400	1.200	0.030	0.066	7.3	93.2	10.0	1019
	95%ile	0.992	0.040	0.744	1.848	0.048	0.163	14.2	99.2	10.8	2664
	Minimum	0.032	0.005*	0.050	0.190	0.013	0.023	2.9	68.6	7.0	221
	Maximum	1.600	0.100	1.100	2.100	0.092	0.260	19.4	107.7	11.5	7270
Annual median	2007	0.677	0.025	0.300	0.950	0.030	0.067	12.9	89.8	9.6	990
	2008	0.542	0.020	0.290	0.860	0.025	0.059	6.2	87.9	9.0	805
	2009	0.500	0.010	0.270	0.800	0.023	0.041	5.4	93.2	9.7	554
	2010	0.251	0.013	0.240	0.510	0.025	0.041	4.8	87.3	8.8	611

Site **102106**	**Statistic**	**NO_3-N (g/m^3)**	**NH_4-N (g/m^3)**	**TKN (g/m^3)**	**TN (g/m^3)**	**DRP (g/m^3)**	**TP (g/m^3)**	**Turbidity (NTU)**	**DO (%)**	**DO (mg/L)**	***E.coli* (MPN / 100ml)**
2007-2010 *(n = 49)* Mid-catchment	5%ile	0.044	0.003	0.025	0.238	0.001	0.014	2.4	85.5	8.1	212
	25%ile	0.280	0.003	0.130	0.480	0.007	0.017	4.1	88.8	8.7	355
	Median	0.600	0.003	0.170	0.820	0.010	0.026	5.0	92.8	9.6	613
	Mean	0.588	0.009	0.202	0.799	0.012	0.036	6.0	92.7	9.6	1057
	Std. Dev.	0.342	0.011	0.130	0.368	0.009	0.041	3.1	6.0	1.0	1715
	75%ile	0.870	0.010	0.240	1.110	0.013	0.038	6.6	95.5	10.3	933
	95%ile	1.072	0.030	0.440	1.300	0.021	0.074	11.6	101.3	11.3	3267
	Minimum	0.011	0.005*	0.050	0.130	0.002*	0.013	2.1	77.7	7.9	31
	Maximum	1.240	0.060	0.600	1.480	0.063	0.290	16.8	112.4	11.7	10462
Annual median	2007	0.670	0.010	0.260	0.930	0.010	0.039	10.0	93.9	10.1	645
	2008	0.650	0.010	0.160	0.890	0.014	0.034	5.7	89.8	9.5	624
	2009	0.660	0.005*	0.180	0.790	0.011	0.017	5.1	94.9	10.0	441
	2010	0.307	0.005*	0.160	0.465	0.010	0.018	3.7	90.6	9.3	918

Site **109166**	**Statistic**	**NO_3-N (g/m^3)**	**NH_4-N (g/m^3)**	**TKN (g/m^3)**	**TN (g/m^3)**	**DRP (g/m^3)**	**TP (g/m^3)**	**Turbidity (NTU)**	**DO (%)**	**DO (mg/L)**	***E.coli* (MPN / 100ml)**
2008-2010 *(n = 35)* Headwater	5%ile	0.126	0.003	0.025	0.220	0.006	0.014	2.8	50.4	4.8	156
	25%ile	0.300	0.003	0.145	0.560	0.008	0.016	4.4	66.6	6.5	350
	Median	0.540	0.010	0.180	0.760	0.012	0.022	5.0	82.6	8.7	554
	Mean	0.623	0.016	0.203	0.838	0.020	0.044	5.6	77.4	8.0	624
	Std. Dev.	0.371	0.030	0.113	0.390	0.052	0.111	2.5	15.1	1.9	376
	75%ile	0.995	0.017	0.275	1.200	0.013	0.034	6.1	88.9	9.6	789
	95%ile	1.186	0.031	0.400	1.409	0.023	0.060	10.7	96.5	10.5	1328
	Minimum	0.075	0.005*	0.050	0.200	0.005	0.005	2.2	45.5	4.8	30
	Maximum	1.300	0.180	0.410	1.590	0.320	0.680	14.3	100.5	11.1	1467
Annual median	2008	0.665	0.020	0.230	0.910	0.013	0.035	5.5	82.1	8.3	767
	2009	0.680	0.010	0.170	0.780	0.011	0.018	5.0	86.3	9.1	512
	2010	0.355	0.008	0.175	0.565	0.010	0.020	4.1	75.9	7.7	594

Site **101626**	**Statistic**	**NO_3-N (g/m^3)**	**NH_4-N (g/m^3)**	**TKN (g/m^3)**	**TN (g/m^3)**	**DRP (g/m^3)**	**TP (g/m^3)**	**Turbidity (NTU)**	**DO (%)**	**DO (mg/L)**	***E.coli* (MPN / 100ml)**
2007-2010 *(n = 43)* Mangapiu Stream	5%ile	0.008	0.017	0.063	1.087	0.054	0.105	4.0	40.0	3.9	152
	25%ile	0.485	0.055	1.075	1.575	0.1565	0.288	7.2	54.0	5.3	301
	Median	0.770	0.120	1.300	2.000	0.240	0.380	9.1	68.3	7.1	583
	Mean	0.695	0.211	1.354	2.050	0.270	0.468	9.5	63.4	6.6	1997
	Std. Dev.	0.384	0.237	0.479	0.283	0.180	0.283	4.3	15.3	1.8	4656
	75%ile	0.885	0.270	1.555	2.555	0.345	0.608	10.9	72.9	7.9	1357
	95%ile	1.341	0.727	2.200	2.993	0.675	1.001	18.8	81.1	9.2	6184
	Minimum	0.001*	0.005*	0.470	0.630	0.020	0.084	2.5	20.7	2.1	31
	Maximum	1.420	1.100	2.500	3.720	0.760	1.350	25.0	98.3	9.5	24192*
Annual median	2007	0.810	0.355	2.105	2.745	0.265	0.410	11.3	70.1	7.5	798
	2008	0.840	0.155	1.295	1.855	0.280	0.543	8.7	56.4	5.6	782
	2009	0.760	0.082	1.260	1.950	0.310	0.500	8.7	68.3	7.1	728
	2010	0.540	0.069	1.195	1.705	0.161	0.320	9.1	72.9	7.3	238

Appendix E Summary statistics by month for Knights Bridge (2000-2012)

Table E1. Monthly medians derived for water quality attributes observed at site 101625 over the period 2000-2012. Number of observations by month in (*n*).

Numeric Attribute	**Jan (*n* = 19)**	**Feb (*n* = 18)**	**Mar (*n* = 20)**	**Apr (*n* = 18)**	**May (*n* = 18)**	**Jun (*n* = 18)**	**Jul (*n* = 18)**	**Aug (*n* = 18)**	**Sep (*n* = 17)**	**Oct (*n* = 17)**	**Nov (*n* = 17)**	**Dec (*n* = 17)**
NO_3-*N* (g/m^3)	0.350	0.250	0.360	0.627	0.450	0.985	1.020	0.830	0.695	0.650	0.415	0.220
NH_4-*N* (g/m^3)	0.030	0.055	0.030	0.040	0.052	0.065	0.086	0.069	0.110	0.120	0.040	0.090
TKN (g/m^3)	0.395	0.395	0.300	0.400	0.500	0.510	0.525	0.535	0.600	0.590	0.380	0.480
TN (g/m^3)	0.750	0.565	0.775	1.300	0.910	1.260	1.600	1.400	1.265	1.045	0.760	0.460
DRP (g/m^3)	0.067	0.082	0.051	0.070	0.057	0.060	0.048	0.055	0.070	0.086	0.067	0.094
TP (g/m^3)	0.111	0.122	0.114	0.140	0.115	0.102	0.110	0.133	0.153	0.140	0.110	0.146
Turbidity (NTU)	4.9	4.4	5.4	5.2	7.4	7.3	8.9	9.8	11.3	7.4	6.4	5.5
DO (%)	74.2	77.4	80.0	84.6	85.1	86.8	88.5	91.3	84.9	88.0	85.4	77.6
DO (mg/L)	7.1	7.1	7.7	8.6	8.6	9.4	9.8	10.1	9.0	9.1	8.2	7.3
E.coli (MPN/100ml)	472	576	538	697	835	496	656	475	921	645	369	425
pH (SI)	7.2	7.2	7.2	7.2	7.0	6.9	7.1	7.0	7.0	7.1	7.3	7.2
Discharge m^3/s)	0.269	0.266	0.276	0.780	0.874	1.283	1.663	1.962	1.149	0.664	0.342	0.250

Appendix F Summary riparian condition statistics (2013)

Table F1. Summary statistics of riparian condition surveyed with the P2 protocol (Harding et al., 2009). Refer to Appendix B for a description of riparian condition attribute scores.

Riparian Condition Attribute	**Percentile**					**Mode**	**Number of observations by score (*n* = 64)**				
	5th%	**25th%**	**Median**	**75th%**	**95th%**		**1**	**2**	**3**	**4**	**5**
Shading						4	5	6	19	24	10
Width (m)	2	5	8	14	50						
Intactness						3	6	14	22	15	7
Stability						3	4	23	18	18	1
Livestock access						5	7	10	5	11	31
Denitrification						3	1	21	34	7	1
Slope						1	57	6	1	0	0
Groundcover						3	0	19	40	4	1
Drainage						3	2	10	40	12	0
Rills or channels						3	0	18	25	18	3

Appendix G Exploration of controls on dissolved oxygen

This appendix offers precursory examination of potential controls on DO (mg/L) aimed at determining what conditions are associated and might be indicative of hypoxia. For the purposes of analysis, the entire gradient of DO observations were examined in a subset of the monitored physico-chemistry at Knights Bridge (site 101625) from 2000-2010 – including only observations where all potential explanatory variables were observed simultaneously (i.e., excluding monitored observations of DO lacking equivalent observations of nutrients, turbidity, flow, temperature and *E.coli*).

Multiple Linear Regression (MLR)

A full MLR of DO (mg/L) by explanatory variables was constructed in “R” (v.3.0). Explanatory variables selected included flow (normal [Shapiro-Wilks *p*<0.05], as a measure of physical entrainment of oxygen), temperature (normal [Shapiro-Wilks *p*<0.05], as a control on oxygen dissolution), organic nitrogen (normal [Shapiro-Wilks *p*<0.05], as a measure of biochemical oxygen demand, being a proxy of total organic matter) and *E.coli* (normal [Shapiro-Wilks *p*<0.05], as an alternative measure of biochemical oxygen demand; a proxy for effluent organic matter). The response variable (y) was normalised DO (Log$_{10}$ DO [mg/L] Shapiro-Wilk *p*<0.05).

```
Call:
lm(formula = log10(data$DO) ~ data$FLOW + data$TEMP + data$ON +  data$ECOLI, data = data)
Residuals:
     Min       1Q    Median       3Q       Max
-0.225186 -0.018835  0.003438  0.029149  0.136740
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.180e+00  2.104e-02  56.054  < 2e-16 ***
data$FLOW    9.951e-04  2.257e-03   0.441 0.659876
data$TEMP   -1.692e-02  1.297e-03 -13.048  < 2e-16 ***
data$ON      4.015e-03  1.466e-02   0.274 0.784469
data$ECOLI  -3.251e-06  9.537e-07  -3.409 0.000823 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 0.04911 on 163 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared: 0.5616,     Adjusted R-squared: 0.5509
F-statistic: 52.21 on 4 and 163 DF,  p-value: < 2.2e-16
```

The MLR of Log_{10}-normalised DO (mg/L) of all explanatory variables performed moderately, with an R^2 of 0.56 (Adj. R^2=0.55). Only water temperature and *E.coli* concentration were statistically significant predictors of Log_{10}DO (see signif. codes above and ANOVA below).

```
Analysis of Variance Table

Response: log10(data$DO)

          Df  Sum Sq Mean Sq  F value    Pr(>F)

data$FLOW    1 0.00867 0.00867   3.5972 0.0596470 .

data$TEMP    1 0.46397 0.46397 192.3886 < 2.2e-16 ***

data$ON      1 0.00299 0.00299   1.2380 0.2674943

data$ECOLI   1 0.02802 0.02802  11.6180 0.0008231 ***

Residuals  163 0.39309 0.00241

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Variance Inflation Factors

data$FLOW  data$TEMP    data$ON data$ECOLI

  1.666128   1.088329   1.727334   1.555854
```

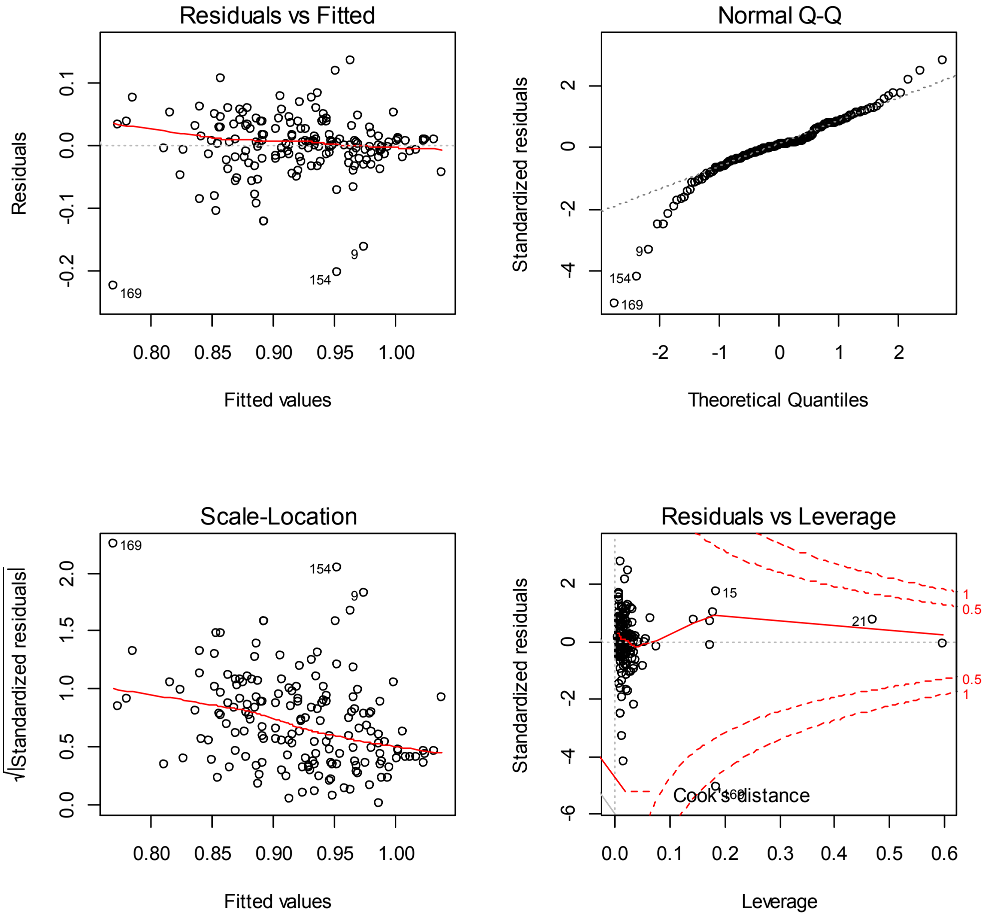

Figure G1. Performance graphs for MLR (Log_{10}DO~FLOW+TEMP+ON+ECOLI).

Best-subsets regression (optimal step-wise regression) confirmed earlier analysis that Log_{10}-normalised DO was best predicted by water temperature and *E.coli* at Knights Bridge, for the period 2000-2010 (in order of explanatory significance). A subset MLR of $Log_{10}DO$ by temperature and *E.coli* offered an R^2 of 0.57 (Adj. R^2=0.56) with ANOVA highlighting significance of variables ($p<0.05$).

```
Call:
lm(formula = log10(data$DO) ~ data$TEMP + data$ECOLI, data = data)
Residuals:
     Min       1Q    Median       3Q       Max
-0.231876 -0.017213  0.003955  0.028115  0.137109
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.186e+00  1.871e-02  63.381  < 2e-16 ***
data$TEMP   -1.717e-02  1.225e-03 -14.019  < 2e-16 ***
data$ECOLI  -2.891e-06  7.591e-07  -3.808 0.000197 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.04873 on 166 degrees of freedom
Multiple R-squared:  0.5651,    Adjusted R-squared:  0.5599
F-statistic: 107.8 on 2 and 166 DF,  p-value: < 2.2e-16
```

```
Analysis of Variance Table
Response: log10(data$DO)
            Df  Sum Sq Mean Sq F value    Pr(>F)
data$TEMP    1 0.47777 0.47777 201.185 < 2.2e-16 ***
data$ECOLI   1 0.03445 0.03445  14.505 0.0001965 ***
Residuals  166 0.39421 0.00237
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

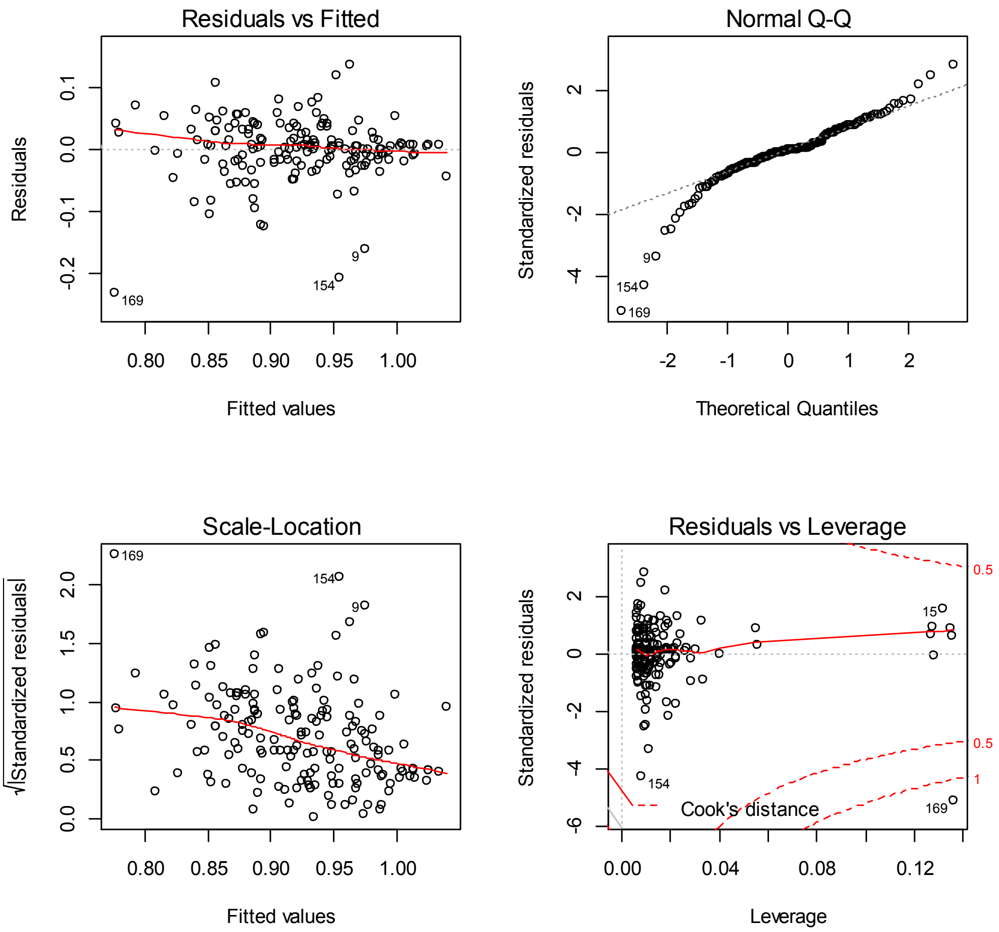

Figure G2. Performance graphs for MLR (Log_{10}DO~TEMP+ECOLI).

Graphical performance of the revised MLR (Log_{10}DO~TEMP+ECOLI) is displayed above which demonstrates lack of trend in residuals and near-normality of variance (Figure G2). To improve the latter, outliers were identified and further excluded from the revised model (excluded observations from 18/07/2001, 03/05/2010 and 15/12/2010). This revised and filtered model (Log_{10}DO~TEMP+ECOLI) performed better than the earlier models, with an R^2 of 0.63 (Adj. R^2 = 0.63) as shown overleaf and better adherence to rules on linear regression (i.e., normality of residuals and homoscedastic [Figure G3]). The revised and filtered equation to predict DO (mg/L) from TEMP (°C) and ECOLI (MPN/100 ml) is:

$$Log_{10}DO = -0.01693*TEMP - 0.000001622*ECOLI + 1.184$$
$$(R^2 = 0.6329;\ Adj.\ R^2 = 0.6283;\ p<0.001)$$

From this relationship, lower DO (mg/L) is associated most strongly with increased water temperature (°C) as theory dictates that higher temperature limits the absolute solubility of oxygen, and *E.coli* concentration (MPN/100 ml) can be interpreted as a surrogate for effluent associated BOD, with greater inputs of effluent driving greater BOD and reducing the absolute availability of DO (mg/L).

```
Call:

lm(formula = log10(data2$DO) ~ data2$TEMP + data2$ECOLI, data = data2)

Residuals:

     Min       1Q    Median       3Q      Max

-0.125667 -0.019267 -0.000916  0.021972  0.135941

Coefficients:

             Estimate Std. Error t value Pr(>|t|)

(Intercept)  1.184e+00  1.564e-02  75.670   <2e-16 ***

data2$TEMP  -1.693e-02  1.020e-03 -16.596   <2e-16 ***

data2$ECOLI -1.622e-06  6.672e-07  -2.431   0.0162 *

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Residual standard error: 0.0402 on 163 degrees of freedom

Multiple R-squared:  0.6329,    Adjusted R-squared:  0.6283

F-statistic: 140.5 on 2 and 163 DF,  p-value: < 2.2e-16
```

```
Analysis of Variance Table

Response: log10(data2$DO)

            Df  Sum Sq Mean Sq F value  Pr(>F)

data2$TEMP    1 0.44450 0.44450 275.053 < 2e-16 ***

data2$ECOLI   1 0.00955 0.00955   5.908 0.01616 *

Residuals   163 0.26342 0.00162

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

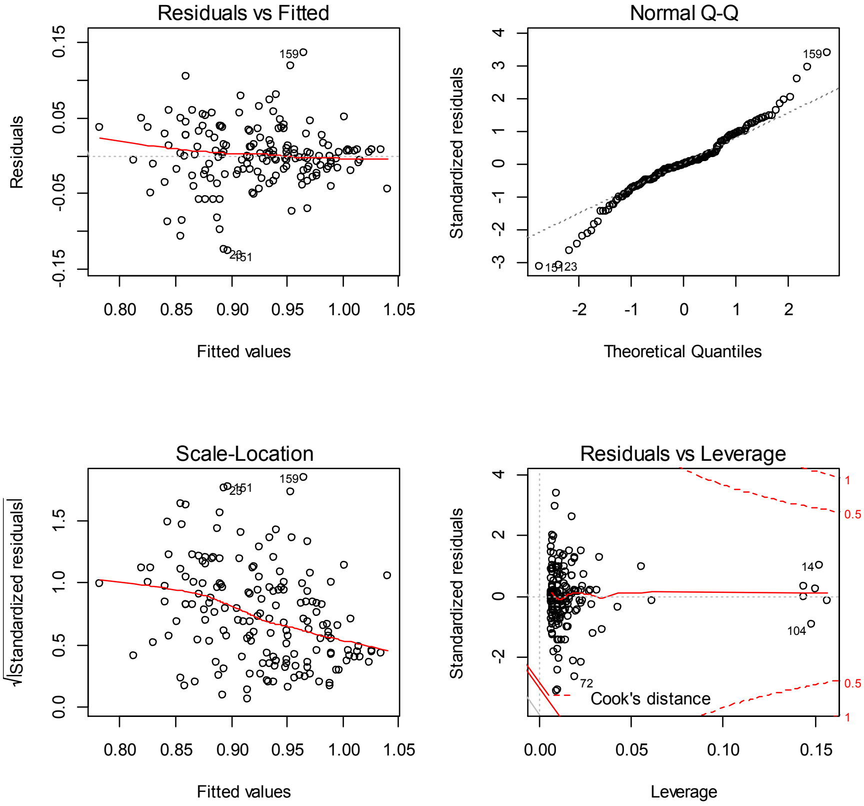

Figure G3. Performance graphs for MLR with outlier excluded (Log$_{10}$DO~TEMP+ECOLI).

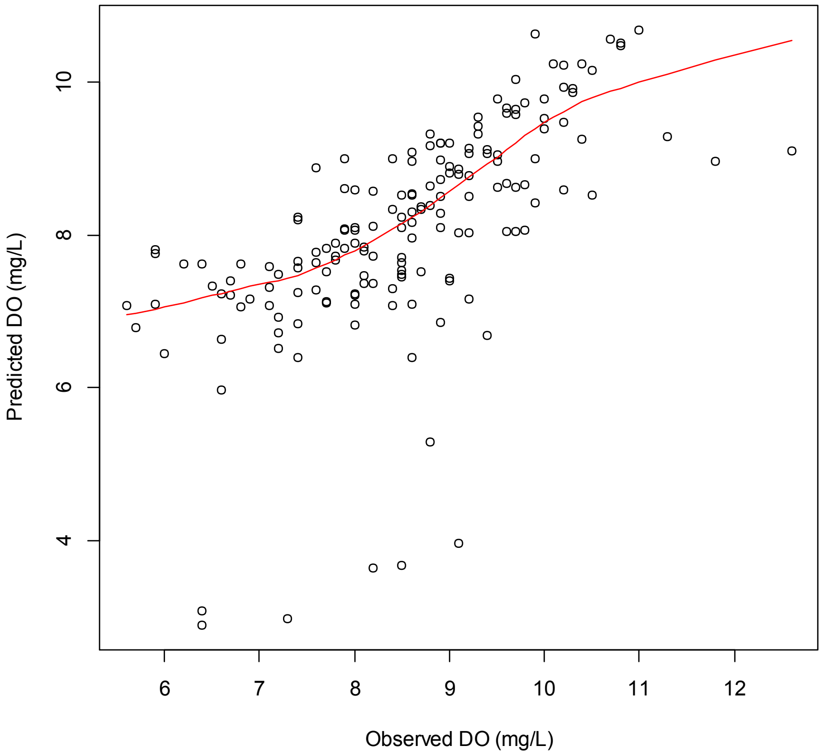

Figure G4. Predicted vs. observed DO (mg/L) at Knights Bridge (2000-2010) – LOWESS smoother (n=30%) shown to highlight error in modelling (Log$_{10}$DO~TEMP+ECOLI).

Regression Tree

A regression tree predicting Log_{10}-normalised DO (mg/L) from TEMP and ECOLI only (and excluding DO outliers noted above) was developed in “R” (using the previous dataset of observations from 2000-2010 at Knights Bridge). Summary output of the unpruned regression tree is displayed below (Figure G5), which includes a root-mean squared error of prediction of ±1.08 mg/L (RMSEP) (though this is likely underestimated as unpruned trees typically overfit the dataset – see below).

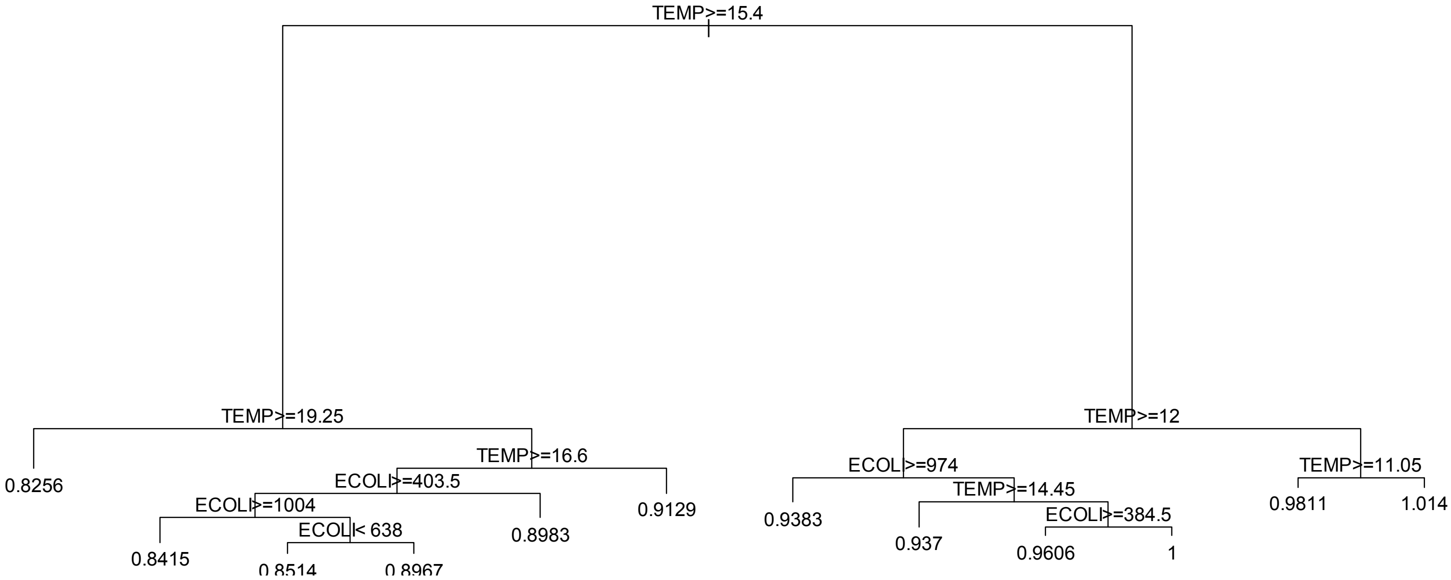

Figure G5. Unpruned regression tree of data from 2000-2010 at Knight’s Bridge ($Log_{10}DO \sim TEMP+ECOLI$).

```
Regression tree:

rpart(formula = log10(data2$DO) ~ TEMP + ECOLI, data = data2, method = "anova")

Variables actually used in tree construction:

[1] ECOLI TEMP

Root node error: 0.71746/166 = 0.0043221

n= 166

CP nsplit rel error  xerror    xstd

1  0.506695      0   1.00000 1.01432 0.113960

2  0.060995      1   0.49330 0.55824 0.058332

3  0.049622      2   0.43231 0.54864 0.063809

4  0.024335      3   0.38269 0.48319 0.058021

5  0.018089      4   0.35835 0.48976 0.058046

6  0.013264      5   0.34026 0.46896 0.058876

7  0.012023      6   0.32700 0.47542 0.060454

8  0.010578      7   0.31498 0.46160 0.057935

9  0.010040      9   0.29382 0.45924 0.058024

10 0.010000     11   0.27374 0.45353 0.057740
```

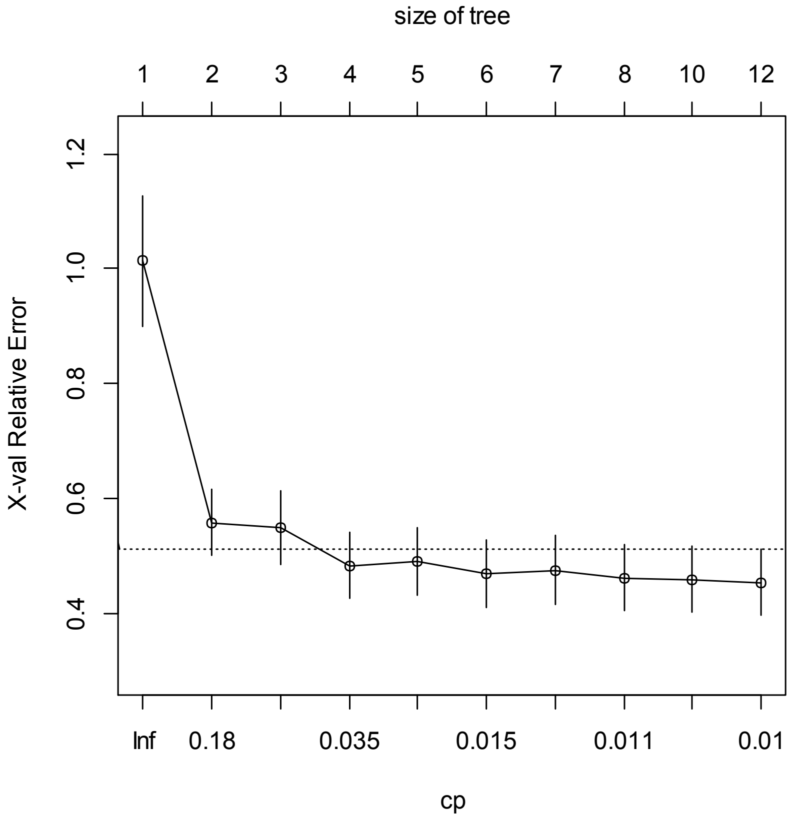

Figure G6. Unpruned regression tree of data from 2000-2010 at Knight’s Bridge demonstrating that the most parsimonious tree requires a complexity parameter (cp) > 0.035 ($Log_{10}DO$~TEMP+ECOLI).

Adopting a complexity parameter cut-off < 0.035 (cp), the pruned regression tree of Log_{10}-normalised DO (mg/L) by TEMP (°C) and ECOLI (MPN/100 ml) excluding outliers, offers an RMSEP of ±1.10 mg/L (DO). From this pruned regression tree, only TEMP is demonstrated to be a significant explanatory factor in predicting DO, with DO<6.7 mg/L predicted to occur at temperature >19.25°C. Although not as definitive as the MLR, this further reinforces the importance of reducing in-stream temperatures to avoid hypoxia in the Mangere River (at Knight’s Bridge).

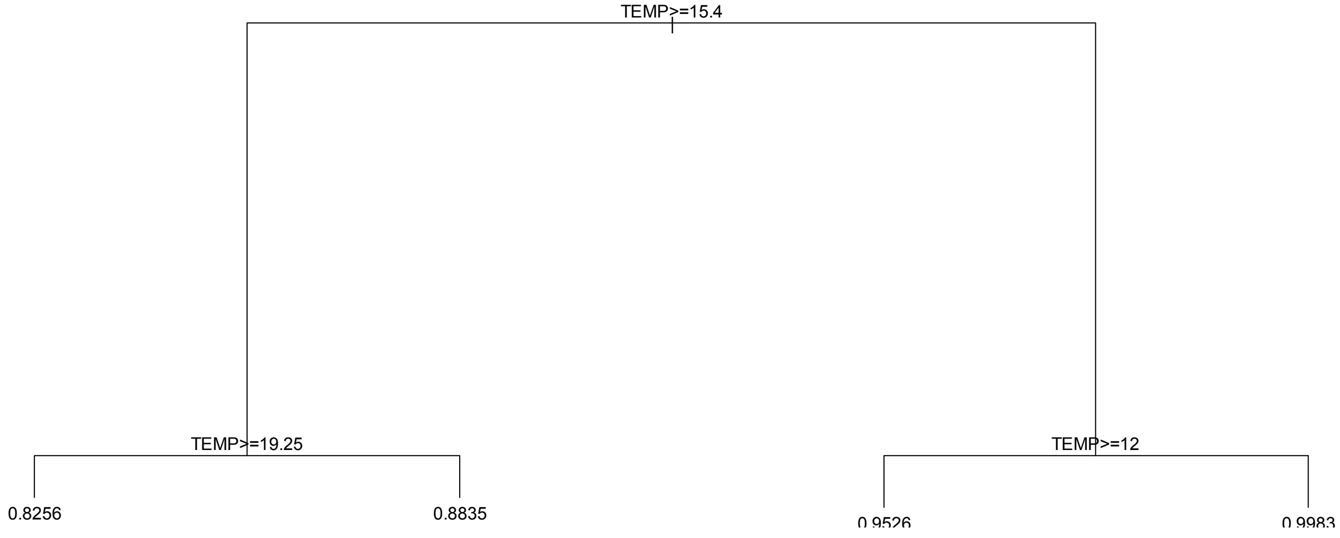

Figure G6. Pruned regression tree of data from 2000-2010 at Knight’s Bridge demonstrating that DO <6.69 mg/L ($Log_{10}DO$ <0.8256) are predicted from a TEMP ≥19.25 °C ($Log_{10}DO$~TEMP+ECOLI).

```
Regression tree:

rpart(formula = log10(data2$DO) ~ TEMP + ECOLI, data = data2, method = "anova")

Variables actually used in tree construction:

[1] ECOLI TEMP

Root node error: 0.71746/166 = 0.0043221

n= 166

        CP nsplit rel error  xerror     xstd

1  0.506695      0   1.00000 1.01432 0.113960

2  0.060995      1   0.49330 0.55824 0.058332

3  0.049622      2   0.43231 0.54864 0.063809

4  0.024335      3   0.38269 0.48319 0.058021

5  0.018089      4   0.35835 0.48976 0.058046

6  0.013264      5   0.34026 0.46896 0.058876

7  0.012023      6   0.32700 0.47542 0.060454

8  0.010578      7   0.31498 0.46160 0.057935

9  0.010040      9   0.29382 0.45924 0.058024

10 0.010000     11   0.27374 0.45353 0.057740
```

Appendix H New Zealand Freshwater Fish Database

Table H1. Records of fish sampling in the Mangere River catchment, included in the NZFFD (updated 21/02/2014). The catchment code is 466.12 and all localities are in the Mangere Stream (search term catchment of Wairoa River). Species codes are *Paranephrops* sp. (Parane), *Anguilla dieffenbachii* (Angdie), *Anguilla australis* (Angaus), *Gobiomorphus cotidianus* (Gobcot) and *Gobiomorphus basalis* (Gobbas). Abundance codes are abundant (A), common (C) and not common (N). Lengths are in mm.

Card identifier	**Month**	**Year**	**Organisation**	**NZ Reach**	**Easting**	**Northing**	**Method**	**Sp. code**	**Abundance**	***n***	**Min length**	**Max length**
6980	Jan	1986	NFFG	1018174	2622600	6609200	EF	Parane		10		
								Angdie		2	300	500
								Angaus		1	300	
								Gobcot		1	100	
6981	Jan	1986	NFFG	1018299	2621300	6608700	EF	Angdie		2	400	500
								Angaus		10	400	700
13311	Feb	1992	DOCX	1018174	2622600	6609200	UTT	Parane	C			
								Gobcot	C			
28184	Feb	2010	DOCX	1018243	2623500	6609000	EFP	Parcur	N			
								Angdie		5	600	1000
								Gobbas		40	31	89
								Parane	A			