Appendix 13: Water Quality

1. Introduction

What are the issues requiring action?

This Appendix evaluates the Waikato River's water quality, specifically the nutrients nitrogen (N) and phosphorus (P), phytoplankton (measured as chlorophyll a), clarity and colour under existing and possible future management options. Water clarity and colour are degraded compared with upstream values and targets in the Lower Waikato, Waipa River and tributaries that drain farmland. Base flow water clarity affects: the safety and enjoyment of people using the river for recreation; the ability of animals to see and capture their prey (Rowe et al., 2002); the amount of light reaching aquatic plants growing under the water; and, together with colour, the appearance and aesthetic appeal of the river. Sensitive native fish avoid tributaries with high suspended solids concentrations (Boubée et al., 1997). The change in water colour (from blue in Lake Taupoo to yellow-brown at Te Puuaha near the mouth) makes the lower Waikato River less attractive to people using the river.

The concentrations of nutrients are high in the hydro dams, lower Waikato and shallow lakes compared with upstream values and targets. High nutrient concentrations increase the growth rate of phytoplankton (microscopic plants suspended in the water column), which contributes to low clarity and colour change. High concentrations of cyanobacteria (also called 'blue-green algae', a type of phytoplankton) in the hydro lakes, lower Waikato and shallow lakes pose a significant public health risk because they may release toxins.

What are the causes of the problems?

Water clarity decreases, and colour changes, because of increases in the concentration of one or more of the following constituents: fine suspended sediment, dissolved organic compounds (yellow substance) and phytoplankton pigments (chlorophyll). Chlorophyll concentrations increase between Taupoo and Te Puuaha because of the increase in nutrient concentrations (nitrogen and phosphorus), and because the long residence time in the hydro lakes allows time for phytoplankton to grow to high concentrations.

All four constituents (turbidity, yellow substance, nutrients, chlorophyll) need to be considered together, although their relative importance varies within the catchment - turbidity dominates colour and clarity in the Waipa River, nutrients and chlorophyll dominate in the hydro lakes, and the combination of all four are important in the Lower Waikato.

Clarity and colour would have changed naturally between Taupoo and Te Puuaha prior to development in the catchment because of natural erosion and inflows from peat areas. However, pastoral farming, towns and waste discharges have caused significant increases to the inputs of fine sediment, nutrient and yellow substance which have degraded clarity and colour. For example, where peat soils predominate (notably in the lower Waikato basin), lake and tributary waters were historically stained by yellow substance, but in their undisturbed state they were clear. Farming of peat land has increased the input of fine sediment and its combination with yellow substance now degrades the appearance of these waters.

High concentrations of phytoplankton chlorophyll (notably in the lakes) reduce clarity and make the water green. Most of the time, phytoplankton affects aesthetics in a relatively minor way. However, some species of cyanobacteria can release toxins. 'Blooms' of such species occur only very occasionally, but when they do occur they threaten the safety of water supplies taken from the river and pose a health risk to river users.

What this Section covers

This section describes:

1. Modelling the effects that waste discharges and runoff from farmland, forest and towns have on clarity, colour, nutrients and chlorophyll.
2. Predicting the effects of several scenarios of proposed actions (e.g., farming practice, land use change, improved waste treatment).
3. Comparing predictions with targets for health and wellbeing.
4. Hence, determining the actions required to restore the health and wellbeing of the Waikato.

The issue of phytoplankton 'blooms'; is considered in this Section rather than the appendices dealing with public health (see Appendix 10: Pathogens; Appendix 20: Cyanotoxin treatment; Appendix 21: Toxic contaminants), because it is strongly linked to nutrients and clarity.

A computer model, the Waikato Catchment Model (WCM) (Rutherford et al., 2001), is used to quantify the cumulative effects of the numerous point sources (waste discharges) and non-point sources (runoff from farmland, forest and urban areas) in the Waikato and Waipa catchments. A description of the WCM model and its application to this study is given at the end of this appendix in Section 5.3.

While water clarity is lowest during wet weather - when sediment is washed into rivers, re-suspended from the river bed, and/or released by bank erosion - the greatest use is made of the river for recreation during base flows. Moreover, phytoplankton 'blooms' tend only to occur during summer low flows. Thus, in this section we focus on modelling clarity, colour and chlorophyll at 'base' flow, but 'mean' flow is also modelled since this may be affected by events such as floods and droughts.

Section 4 of the main report describes the targets used in this project which, if attained, will restore the health and wellbeing of the Waikato. Those relevant to clarity, nutrients, colour and chlorophyll are shown in Table 1.

Table 1: Targets for nutrients, chlorophyll, clarity and colour. Refer to Section 4 for details of how these targets are derived. Along the Waikato, distance is measured downstream from Lake Taupoo. 190 km is Karaapiro; 240 km is where the Waipa joins the Waikato.

			Waikato River			**Waipa River**
			Upper (0–190 km)	**Middle (190–240 km)**	**Lower (> 240 km)**	
Phosphorus	TP	mg/m^3	20	35	35	35
Nitrogen	TN	mg/m^3	300	500	500	500
Chlorophyll – trigger	CHL	mg/m^3	5	5	5	5
Chlorophyll – warning	CHL	mg/m^3	10	10	10	10
Chlorophyll – filters	CHL	mg/m^3		20	20	20
Clarity	BD	m	4	1.6	1.6	1.6
Colour	Munsell		10 Munsell units below the values that are predicted to have existed in the river in the 1920s prior to the hydro dams being built			

Section 6 of the main report describes possible combinations of actions (i.e., scenarios) to restore the health and wellbeing of the Waikato River. The Current State is the present situation both in terms of farming practice and land use.

- Scenario 1 (Current Best Practice) involves the uniform adoption of standard farming practices that should be being utilised at present to meet existing rules in the regional plan, and industry codes of practice (e.g., Dairying and Clean Streams Accord practices).
- Scenario 2 involves all of the actions of Scenario 1 plus an “optimised” combination of proven, but more costly practices than Scenario 1, with the aim of achieving significant rehabilitation to acceptable levels of many of the desired values identified in the consultation processes.
- Scenario 3 is the same as Scenario 2 with the addition of riparian buffers on sheep-beef farms, and 60% of sheep-beef farming on steep hill country and 25% of sheep-beef farming on easy hill country being converted to forestry. The changes in land use are aimed at achieving a higher level of restoration.

Tables 2 and 3 give the percentage reductions from the Current State in total nitrogen (TN), total phosphorus (TP), suspended sediment (SS), fine suspended sediment (FSS) and dissolved colour (G440) for Scenarios 1, 2 and 3 respectively for the various land uses. These reductions are calculated from the yields in Table 7

Appendix 9: Farms, estimated by Dr. Ross Monaghan (AgResearch, Invermay). Note that the Monaghan table reports the expected reductions in suspended sediment (SS) yield but similar reductions are expected for fine suspended sediment (FSS) (Dr. Ross Monaghan, AgResearch, Invermay, pers. comm.). The SS reductions have also been assumed to apply to G440.

Table 2: Scenario 1 - Percentage reductions from the Current State in the yields of nitrogen, phosphorus, suspended sediment, fine suspended sediment and dissolved colour.

	Nitrogen (TN)	Phosphorus (TP)	Suspended sediment (SS)	Fine suspended sediment (FSS)	Dissolved colour (G440)
Dairy on well-drained soils	16	75	15	15	15
Dairy on poorly-drained soils	17	61	15	15	15
Dairy on peat soils	26	35	7	7	7
Sheep-beef on steep hill country	4	6	18	18	18
Sheep-beef on easy hill country	4	6	18	18	18
Sheep-beef on easy rolling country	4	6	18	18	18
Horticulture & cropping	68	79	50	50	50
Forestry (Planted forest)	10	15	20	20	20
Native forest and scrub	0	0	0	0	0
Urban	0	0	0	0	0

Table 3: Scenarios 2 and 3 - Percentage reductions from the Current State in the yields of nitrogen, phosphorus, suspended sediment, fine suspended sediment and dissolved colour.

	Nitrogen (TN)	Phosphorus (TP)	Suspended sediment (SS)	Fine suspended sediment (FSS)	Dissolved colour (G440)
Dairy on well-drained soils	62	89	42	42	42
Dairy on poorly-drained soils	44	74	43	43	43
Dairy on peat soils	64	63	73	73	73
Sheep-beef on steep hill country	6	9	34	34	34
Sheep-beef on easy hill country	6	9	34	34	34
Sheep-beef on easy rolling country	6	9	34	34	34
Horticulture and cropping	68	79	50	50	50
Forestry (Planted forest)	10	15	20	20	20
Native forest and scrub	0	0	0	0	0
Urban	0	0	0	0	0

Inputs from the 29 point source discharges into the Waipa and Waikato are given in the Tables 5 and 6 below. Currently, point source discharges contribute approximately 5% of the combined annual yield of total nitrogen load to the river from point sources plus diffuse sources from production land (farms, forests and horticulture) and 11% of the total phosphorus load. These percentages are higher at baseflow – 18% for total nitrogen and 22% for total phosphorus. Sewage accounts for 30% of the point source N load and 50% of the point source P load, with the balance from industrial inputs.

River iwi have expressed a desire for sewage discharges to be discharged to land/wetlands to meet cultural requirements and this has potential co-benefits for nutrient reduction. Scenario 2 includes land/wetland treatment of priority discharges from Hamilton City (largest discharge to river) and Te Kauwhata (discharged to a riverine lake) and Scenario 3 includes all sewage being discharged to land/wetlands. These actions have co-benefits for nutrient management. For the purposes of this scoping study we assumed that discharge to land/wetlands will reduce the N and P loads from sewage point sources by 70%.

The following describes results of the WCM modelling of the cumulative effect of the actions in each of the three scenarios that will reduce the inputs of nutrient, sediment and dissolved colour. The model predicts the benefits in terms of increased clarity, improved colour and reduced nutrient and phytoplankton chlorophyll concentrations – all of which are important water quality parameters that strongly influence the health and wellbeing of the Waikato River. For the Current State the WCM is 'calibrated' to match the measured data for both 'mean' and 'base' flow. Results are presented first for the Waipa River, since it is the largest tributary of the Waikato and its outputs become inputs for the mainstem Waikato model.

2. Waipa River

2.1 Current State of Waipa River water quality

Figures 1 and 2 show the current state of water quality in the Waipa River, assessed from measurements and WCM predictions at 'base' and 'mean' flow respectively.

Water clarity (BD)

Degraded water clarity is one of the most important issues for the Waipa identified by Maniapoto, science and community consultation.

At the top site (Mangaokewa Road 8 km), where the catchment is mostly native or exotic forest, the measured clarity averages 1.6 m at base flow and 1.7 m at mean flow. Clarity declines with distance downstream from Otewa. There is a large step decrease in clarity at Otorohanga (60 km) (Figures 1 and 2) which is caused by dirty water from the Mangapu (0.9 ± 0.4 m at base flow) and Waitomo (1.0 ± 0.5 m at base flow) joining the Waipa River. At Whatawhata (127 km) clarity is degraded at base flow (0.7 ± 0.3 m, average ± standard deviation) and severely degraded at mean flow (0.4 ± 0.2 m). In the lower Waipa, the main contributors to low clarity are farm roads and animal tracks, exposed soils, stream banks and the streambed.

Clarity values predicted by the WCM at base flow are close to the measured values in the upper part of the catchment but slightly under predict measured values in the lower catchment (Figure 1). At mean flow, the model predicts the measured clarity values well at all sites except at the top site (Mangaokewa Road 8 km) (Figure 2).

Clarity is significantly better at base flow (Figure 1) than at mean flow (Figure 2) – possible reasons are bank and bed erosion, release of material from the Tunawaea slip (see below), and runoff from pasture. Figure 1 shows that at base flow the measured black disc water clarity (BD) meets the 1.6 m clarity target at the top two monitoring sites (Mangaokewa Road 8 km, Otewa 43 km) but not at the remaining three monitoring sites (Otorohanga 60 km, Pirongia-Ngutunui Bridge 95 km, Whatawhata 127 km). Figure 2 shows that at mean flow the measured BD only meets the target at the top site (Mangaokewa Road 8 km).

Sedimentary rocks in parts of the catchment (notably near Te Kuuiti, Waitomo and in the Rangitoto Ranges) are associated with low clarity even when covered by undisturbed native forest. Because water clarity is naturally low in such lithology, it will be difficult to achieve very high water clarity throughout the Waipa catchment and may be unrealistic when the cost/benefits are considered. The highest clarity in any Waipa tributary occurs in the Mangauika Stream, which is 95% native forest on the slopes of Pirongia, where base flow clarity averages 3.5 m. Elsewhere in the Waikato catchment, clarity in native and exotic forest streams ranges from 1.0–4.5 m. We would expect forested streams in the Waipa catchment to have a base flow clarity of 1.7–3.5 m based on monitoring results in similar lithology.

A major contributor to low water clarity in the steep, upper reaches of the Waipa River is fine sediment from slips (landslides). In 1991 the Tunawaea slip deposited a large volume of sediment into the Tunawaea Stream. Environment Waikato and other stakeholders have stabilised the slip area but material that slipped into the river is likely to still be releasing fine sediment especially at mean flow and above. Over time, the effects of the Tunawaea slip are expected to decline, but this may take decades.

Colour (G440 and Munsell)

Measured dissolved colour (G440) does not vary significantly with flow or distance (Figures 1 and 2). The WCM predictions are close to the measurements. Note that there is no guideline value for dissolved colour. G440 makes a relatively small contribution to clarity in the Waipa River.

Munsell colour is not measured in the Waipa River and there are no data points to compare with WCM predictions. Munsell colour is a function of CHL, G440 and FSS.

There is a large step decrease in Munsell colour at 60 km where the Mangapu Stream joins the Waipa River (Figures 1 and 2). FSS and G440 are larger at mean flow than at base flow, resulting in Munsell colour being lower at mean flow. The WCM predicts that Munsell colour decreases (viz., colour becomes less blue and more brown) with distance from the headwaters.

Chlorophyll (CHL)

Phytoplankton chlorophyll (CHL) concentration is not routinely measured in the Waipa River although there are few measurements at the top site (Mangaokewa Road 8 km) – mean at base flow 6.3 mg/m^3 (Figure 1). Phytoplankton numbers are low in the Waipa because the waters are turbid, their growth rates are low and water does not remain in the Waipa long enough for numbers to build up. The WCM has assumed that there is no growth of CHL in the Waipa and assigned it a constant concentration of 5 mg/m^3 at both base and mean flow.

Nutrients (TP and TN)

The principal sources of phosphorus in the Waipa River are farm runoff, soil erosion and treated sewage. The principal source of nitrogen is leaching of nitrate from farmland.

Figure 1 shows that at base flow the measured total phosphorus (TP) and total nitrogen (TN) meet the targets (35 mg/m^3 for TP, 500 mg/m^3 for TN) in the upper part of the Waipa River (Mangaokewa Road 8 km, Otewa 43 km, Otorohanga 60 km). At the lower two sites (Pirongia-Ngutunui Bridge 95 km, Whatawhata 127 km), the guideline concentrations are exceeded. TP and TN concentrations increase significantly with flow – at mean flow the measured data only meet the guideline at the top site (8 km) for TP (Figure 2) and at the top two sites (8 km and 43 km) for TN. The measured data at mean flow exceed the targets for the sites downstream (Figure 2) being over twice the guideline values in the lower part of the river.

At base flow the WCM predicts measured nutrient values well except at Mangaokewa Road in the headwaters (Figure 1). At mean flow the WCM predicts the measured values well at all sites (Figure 2).

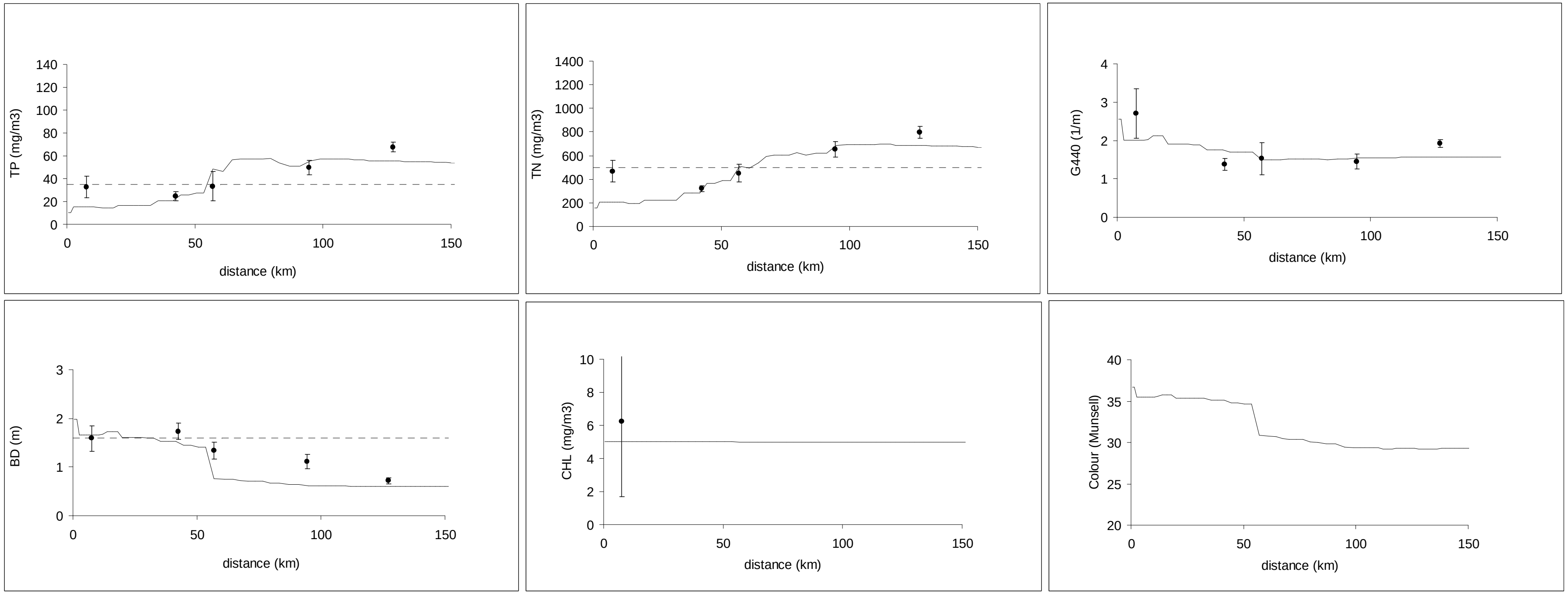

Figure 1: **Current State** (current farming practice and land use) of water quality at **base flow** in the **Waipa River** – Variation with distance downstream of phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell). Black circles are observed data (mean ± 95% confidence interval) (Source: NIWA and EW monitoring). The dashed lines are targets (Table 1). The solid lines are predicted by the WCM model.

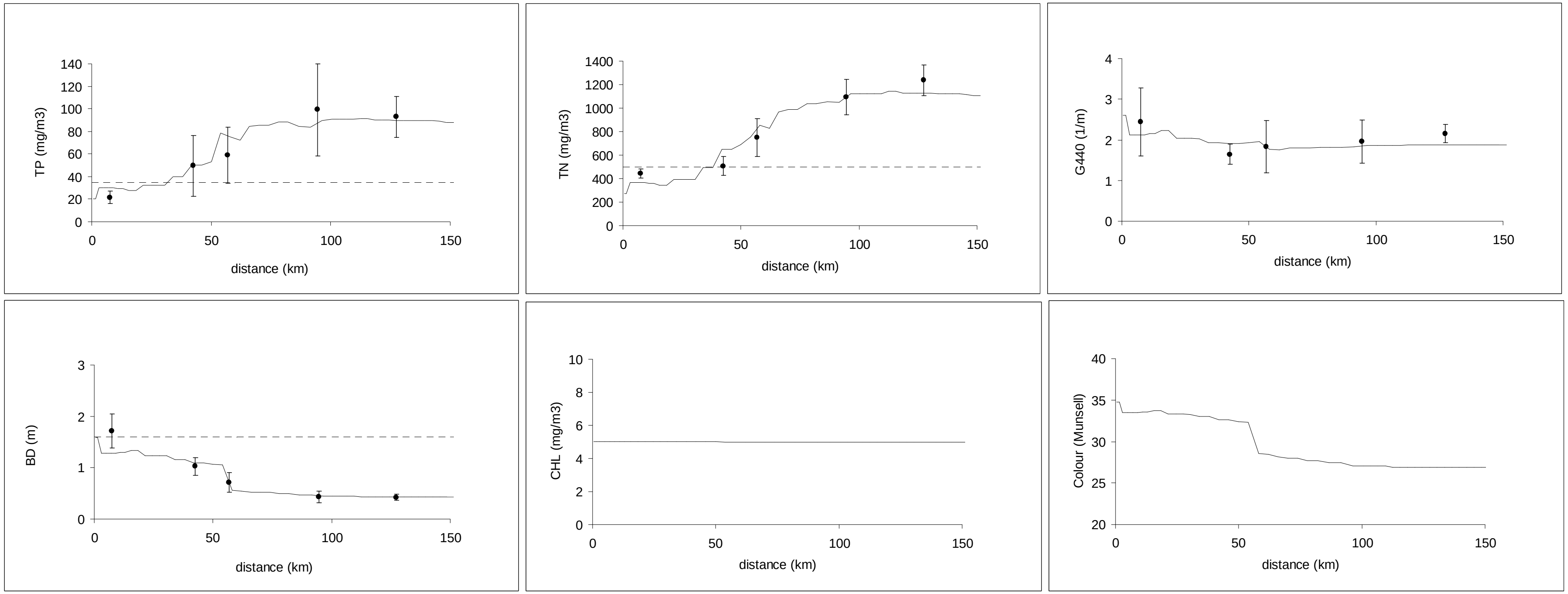

Figure 2: Current State (current farming practice and land use) of water quality at **mean flow** in the **Waipa River** – Variation with distance downstream of phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell). Black circles are observed data (mean ± 95% confidence interval) (Source: NIWA and EW monitoring). The dashed lines are targets (Table 1). The solid lines are predicted by the WCM model.

2.2 Priority actions to restore the Waipa River

Major issues for water quality in the Waipa River are high suspended sediment and nutrient concentrations and low water clarity. Actions likely to improve water quality in the Waipa River are:

1. Reducing point source discharges.
2. Changing farming practice to reduce the loss of fine sediment and nutrients to streams.
3. Retiring and reforesting pasture to reduce erosion.
4. Revegetating stream banks to reduce bank erosion.

2.2.1 Reducing point source discharges

One action suggested by the community is the further treatment (possibly including land disposal) of municipal sewage and industrial discharges. Point source waste discharges contribute to low clarity and high nutrient concentrations in some Waipa tributaries (notably in the Mangaokewa Stream at Te Kuuiti and the Mangapiko Stream at Te Awamutu). Figure 3 shows, however, that point source discharges have only a minor impact on TN, G440, BD, CHL and Munsell colour in the mainstem of the Waipa River at base flow.

The point sources do, collectively, make a significant contribution to TP concentrations in the lower reaches of the Waipa. The same is true at mean flow (details omitted for brevity). Therefore phosphorus removal from waste discharges would reduce TP concentrations in the Waipa River. This is unlikely to benefit water clarity or chlorophyll concentrations in the Waipa River because phytoplankton appear not to grow to high concentrations in the swift and turbid waters of the Waipa. Reducing nutrient inputs is also unlikely to affect the abundance of aquatic weeds which is more strongly influenced by current, habitat and shading than by nutrient concentration in the Waipa River. A reduction of nutrient input will, however, has some benefits in the lower Waikato below its confluence with the Waipa River – as is discussed in the next section.

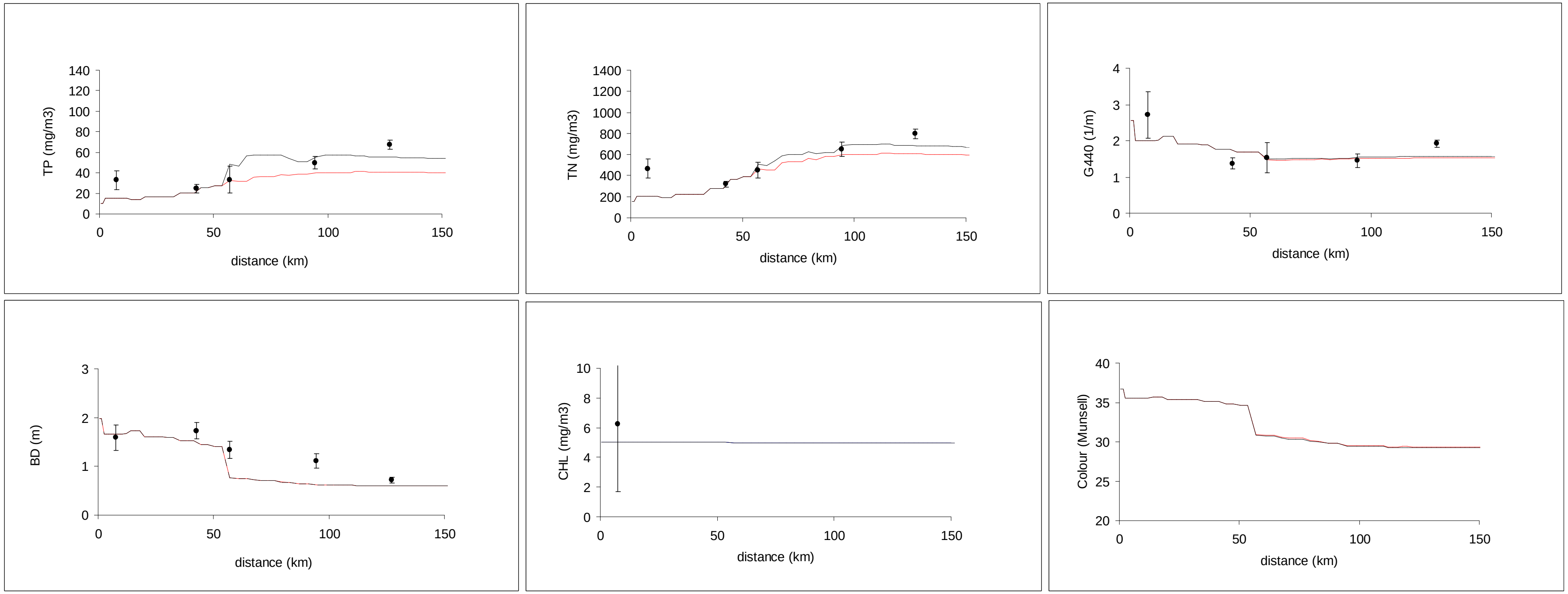

Figure 3: Predicted effects of point source discharges on the **Waipa River** water quality at **base** flow – Predicted phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell) with (black line) and without (red line) the point source discharges. Black circles are observed data (mean ± 95% confidence interval) (Source: NIWA and EW monitoring).

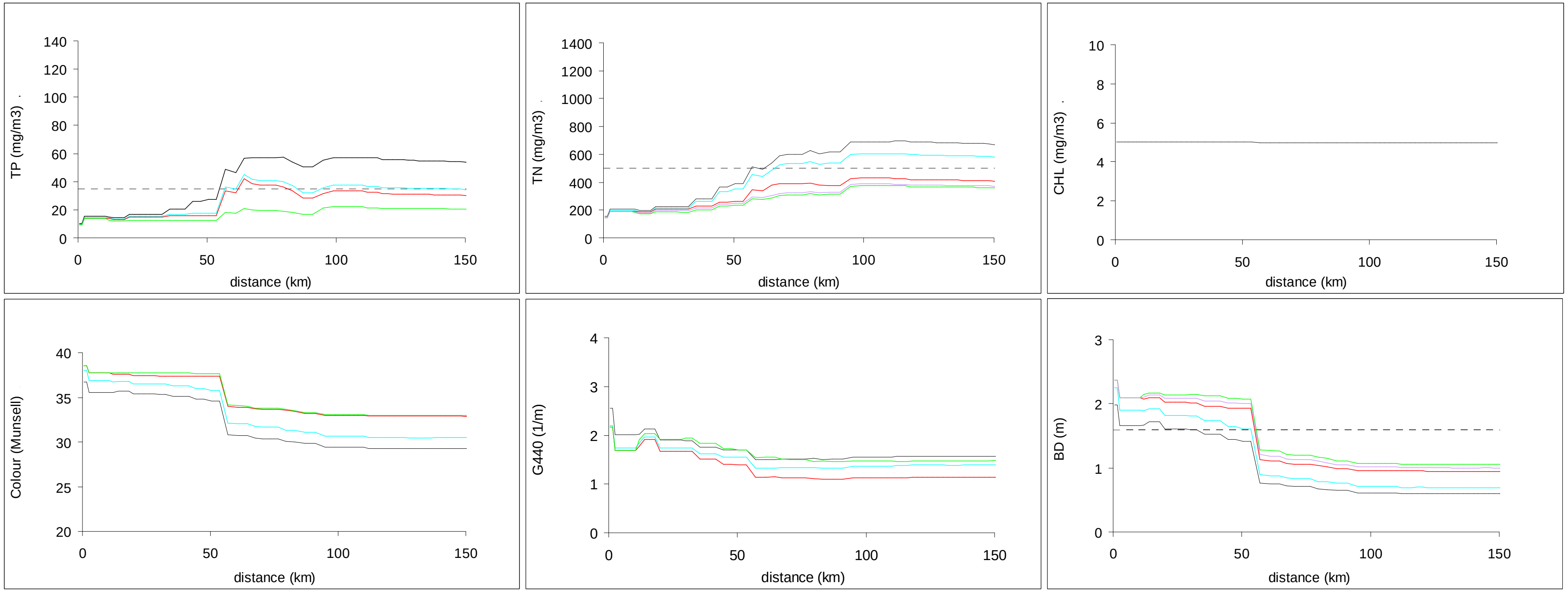

Figure 4: Predicted variation in **Waipa River** water quality with distance downstream at **base flow**: phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell) for the Current State (black line), Scenario 1 (blue line), Scenario 2 (red line) and Scenario 3 (green line). The dashed lines are targets (Table 1).

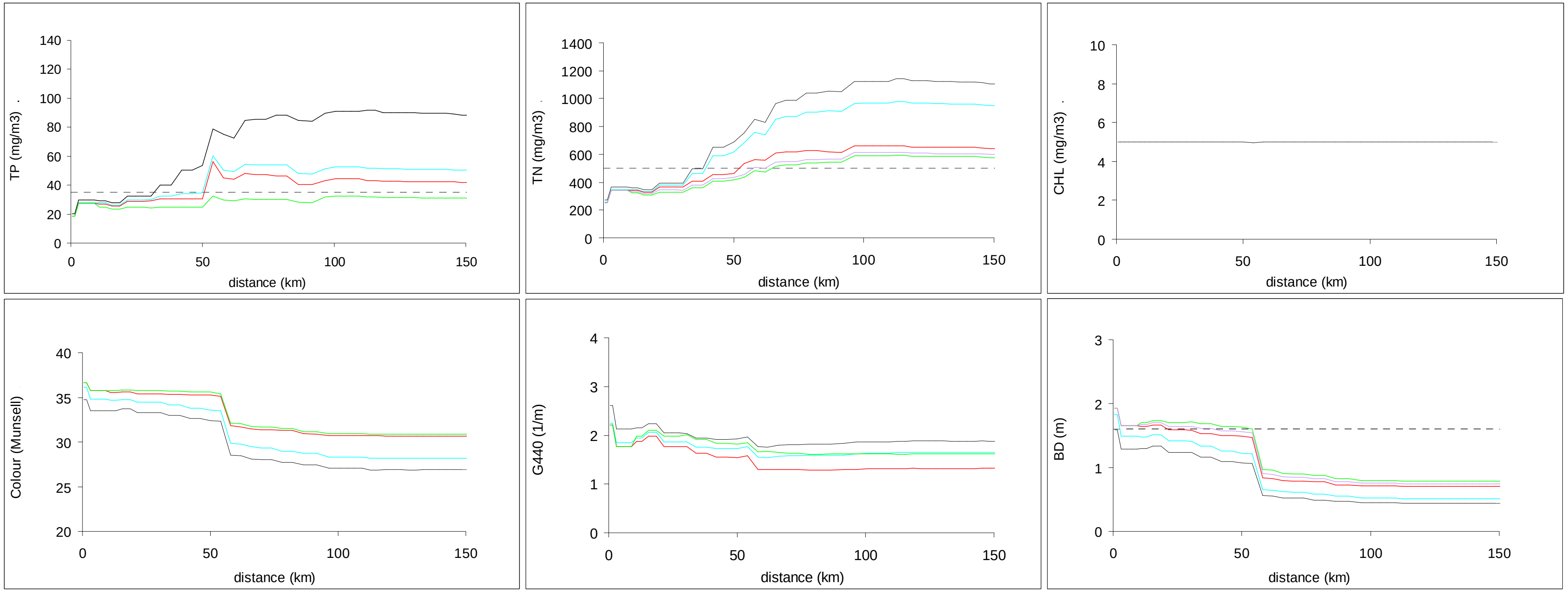

Figure 5: Predicted variation in the **Waipa River** water quality at **mean flow** with distance downstream: phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell) for the Current State (black line), Scenario 1 (blue line), Scenario 2 (red line) and Scenario 3 (green line). The dashed lines are targets (Table 1).

2.2.2 Changing farming practice and land use

Figures 4 and 5 compare WCM predictions for the Current State with the changes in farming practice and land use described earlier for Scenarios 1 – 3.

Water clarity (BD)

Because BD water clarity is a function of CHL, G440 and FSS (Section 5.3) and there are reductions in FSS and G440 from the Current State for Scenarios 1, 2 and 3 for all land uses (except native forest, scrub, and urban – see Table 2), there are improvements in water clarity along the entire length of the Waipa River at both base flow (Figure 4) and mean flow (Figure 5). Note that it is assumed there is no growth of CHL in the Waipa and that its concentration is 5 mg/m^3 at both base and mean flow.

For Scenario 1 the 1.6 m clarity guideline is met everywhere upstream from where the Mangapu Stream joins the Waipa (57 km) at base flow. However, at mean flow the clarity guideline is only attained in the headwaters (Figure 5). Downstream from Mangapu, BD remains below the 1.6 m guideline at both base and mean flow (Figures 4 and 5).

For Scenario 2 there is more of an improvement in BD because of further reductions in FSS and G440 input for farmland (Tables 2 and 3). At both base flow and mean flow BD clarity is complies with the 1.6 m guideline upstream from the Mangapu (57 km) (Figures 4 and 5). However, downstream from the Mangapu, BD clarity remains below the 1.6 m guideline at base and mean flow (Figures 4 and 5).

Scenario 3 includes all the changes in farming practice in Scenario 2 plus the retirement and reforestation of 60% of sheep-beef farming on steep hill country and 25% of sheep-beef farming on easy hill country. Figures 4 and 5 show that the actions of Scenario 3 result in further improvement in BD clarity. However, downstream from the Mangapu BD clarity remains below the 1.6 m guideline at both base and mean flow.

Colour (G440 and Munsell)

As with the Current State, dissolved colour (G440) does not vary significantly with flow across Scenarios 1–3 (Figures 4 and 5). The actions of Scenarios 1 and 3 produce similar, small reductions from the Current State at both base (Figure 4) and mean flow (Figure 5). Scenario 2 results in a larger reduction in G440 at both flows.

There is a small improvement in Munsell colour as a result of the actions of Scenario 1 (Figures 4 and 5). The actions of Scenario 2 result in a significant improvement in Munsell colour at both base and mean flow. Scenario 3 produces approximately the same reductions as Scenario 2 (Figures 4 and 5).

Nutrients (TP and TN)

At base flow Scenario 1 results in significant decreases in TP concentrations such that compliance with the 35 mg/m^3 guideline is achieved along the entire length of the Waipa River (Figure 4). At mean flow Scenario 1 reduces TP concentrations, but the guideline is not achieved downstream from Otorohanga (60 km) (Figure 5). Scenario 1 also results in reduced TN concentrations, but they are not as large as for TP. However, at base flow TN achieves the guideline (500 mg/m^3) upstream from Pirongia-Ngutunui Bridge (95 km), and is only just above it downstream from Pirongia-Ngutunui Bridge (Figure 4). At mean flow TN remains non-compliant with the guideline downstream from Otewa (43 km).

At base and mean flow Scenarios 2 and 3 both result in further slight reductions in TP concentrations (Figure 4). The differences between Scenarios 1 and 2 and between Scenarios 2 and 3 are small compared to the differences between Current State and Scenario 1 (Figure 5). At mean flow Scenario 3 achieves compliance with the TP guideline (35 mg/m^3) everywhere except at Otorohanga (60 km) where the TP concentration spikes to 50 mg/m^3 (Figure 5).

The decrease in TN concentrations between Scenarios 1 and 2 is larger than that between Current State and Scenario 1 at both base and mean flows (Figures 4 and 5). At base flow Scenario 2 achieves compliance with the TN guideline (500 mg/m^3) along the entire length of the Waipa River (Figure 4). At mean flow Scenario 2 achieves compliance upstream from Otorohanga (60 km) and TN concentrations are much closer to the 500 mg/m^3 guideline downstream from Otorohanga. The actions of Scenario 3 result in a further small reduction in TN at both flows – compliance remains as for Scenario 2.

3. Waikato River

3.1 Current State of Waikato River water quality

The current state of water quality along the mainstem of the Waikato River, assessed from measurements and WCM predictions at 'base' and 'mean' flow, are shown in Figures 6 and 7 respectively.

Water clarity (BD)

Observed clarity is similar at base flow (Figure 6) and mean flow (Figure 7) – unlike the Waipa where clarity is significantly lower at mean flow than at base flow. Measured water clarity is high in water leaving Lake Taupoo, but decreases with distance downstream (Figures 6 and 7). Observed clarity currently exceeds the 4 m guideline upstream from the hydro lakes but not in the hydro lakes themselves (50 – 190 km). Downstream from the hydro lakes observed clarity is just below the 1.6 m guideline, and downstream from the Waipa confluence (240 km) is below 1 m.

Rutherford et al., (2001) showed that water clarity in the hydro lakes and lower Waikato River is strongly influenced not only by fine suspended sediment (as in the Waipa River) but also by dissolved colour (yellow substance) and phytoplankton chlorophyll. The hydro lakes slow the Waikato River and allow sediment to settle out, thereby increasing water clarity. However, this is counteracted by a decrease in water clarity and a change in colour caused by phytoplankton spending enough time in the hydro lakes to grow and increase the phytoplankton chlorophyll concentration. The Kinleith mill (117 km) discharges dissolved colour into Lake Maraetai and, even though colour inputs have been reduced by c. 50% since the early 1990s, this point source has a detectable effect on dissolved colour (G440), Munsell colour and clarity.

The BD values predicted by the WCM are close to the observed values along the entire length of the Waikato River at both base and mean flow (Figures 6 and 7).

Colour (G440 and Munsell)

Unlike the Waipa River, the observed dissolved colour (G440) increases with distance downstream at both base and mean flow (Figures 6 and 7). There is a step increase around the Kinleith mill discharge site (117 km) and another step increase at the Waipa confluence (240 km). WCM overestimates the increase in G440 at Kinleith and in the Lower Waikato (Figures 6 and 7) but this has only a minor impact on predicted clarity and Munsell colour.

Similar to water clarity, measured Munsell colour decreases with distance downstream, with the highest values occurring in the headwaters (Figures 6 and 7). Colour changes significantly between Taupoo (Munsell 55 – blue), the lower hydro lakes (Munsell 40 – green-brown) and Te Puuaha (Munsell 35 – yellow-brown). There is little change in observed colour between mean and base flow. The guideline for colour is a change of no more than 10 Munsell (MfE, 1994)[1]. In this Study, the colour guideline is set to 10 Munsell units below the values that are predicted to have existed in the river in the 1920s prior to the hydro dams being built – these 1920 values are reported in Rutherford et al., (2001). The observed colour easily complies with this guideline throughout the length of the river at both base and mean flow (Figures 6 and 7). The predicted values are close to the observed.

Chlorophyll (CHL)

The measured phytoplankton chlorophyll concentration does not change much in the first 50 km downstream from the river's source at Taupoo but then increases significantly in the hydro lakes (50–190 km) at base flow (Figure 6) and mean flow (Figure 7). Near Taupoo the observed chlorophyll concentration complies with both the trigger (5 mg/m3) and warning (10 mg/m3) guideline for cyanobacteria blooms at both flows. In the hydro lakes the warning guideline is met at both flows, but not the trigger guideline. At base flow measured CHL lies between the warning guideline of

[1] Water Quality Guidelines No. 2. Guidelines for the management of water colour and clarity. June 1994. Ministry for the Environment. www.mfe.govt.nz/publications/water/water-quality-guidelines-2.pdf

10 mg/m3 and the filters guideline of 20 mg/m3 downstream from the hydro lakes (Figure 6) until Rangiriri (265 km), after which the filters guideline is exceeded. At mean flow measured CHL lies between the warning and filters guidelines all the way to Te Puuaha (Figure 7). Measured CHL is higher at base flow than mean flow, because at base flow phytoplankton spend longer in the hydro lakes and lower Waikato and grow to higher concentrations.

The CHL values predicted by the WCM are close to the observed values at both base and mean flow (Figures 6 and 7). Predicted chlorophyll concentrations decrease near each of the hydro dams – this is particularly noticeable at base flow – because of settling in the tranquil and deep water. Predicted chlorophyll concentrations increase in the lower Waikato River where nutrient concentrations are high – especially at base flow when the residence time is high.

Nutrients (TP and TN)

Figures 6 and 7 show that observed TP concentrations comply with the guideline of 20 mg/m^3 in the upper Waikato but exceed it in the hydro lakes (50–190 km) - more so at base than at mean flow. Measured TP continues to increase downstream from the hydro lakes at both flows with a large increase just downstream from Hamilton (219 km) where there are three significant point source discharges - Hamilton City, Te Raapa dairy factory and Horotiu meatworks. There is an increase in the observed TP below the confluence of the Waikato and the Waipa (240 km). This is because the TP concentration in the lower Waipa (70 ± 20 mg/m^3 at base flow, Figure 1) is higher than that in the Waikato River at the Waipa confluence (50 ± 11 mg/m^3, Figure 6). Observed TP exceeds the 35 mg/m^3 guideline for the reaches below the hydro lakes (> 190 km) at both base flow and mean flow (Figures 6 and 7).

Measured TN concentrations increase steadily downstream from Taupoo until Hamilton (219 km) at both base flow and mean flow (Figures 6 and 7). Just downstream Hamilton there is a large increase in TN concentration associated with point source discharges from Hamilton City, Te Rapa dairy factory and Horotiu meatworks (Figures 6 and 7). There is also a large increase in observed TN concentrations below the confluence of the Waikato and Waipa Rivers (240 km) which occurs because the concentration of TN at the mouth of the Waipa (800 ± 220 mg/m^3 at base flow, Figure 1) is higher than that in the Waikato River at the Waipa confluence (400 ± 80 mg/m^3, Figure 6). At base flow observed TN concentrations are below the 300 mg/m^3 guideline in the hydro lakes, and below the 500 mg/m^3 guideline for the entire length of the Waikato River (Figure 6). At mean flow observed TN concentrations are below the 300 mg/m^3 guideline in the hydro lakes, but exceed the 500 mg/m^3 downstream from the Waipa confluence (Figure 7).

The WCM's predictions of TP and TN concentration are good at mean flow but slightly over estimate concentrations in the lower Waikato at base flow (Figures 6 and 7).

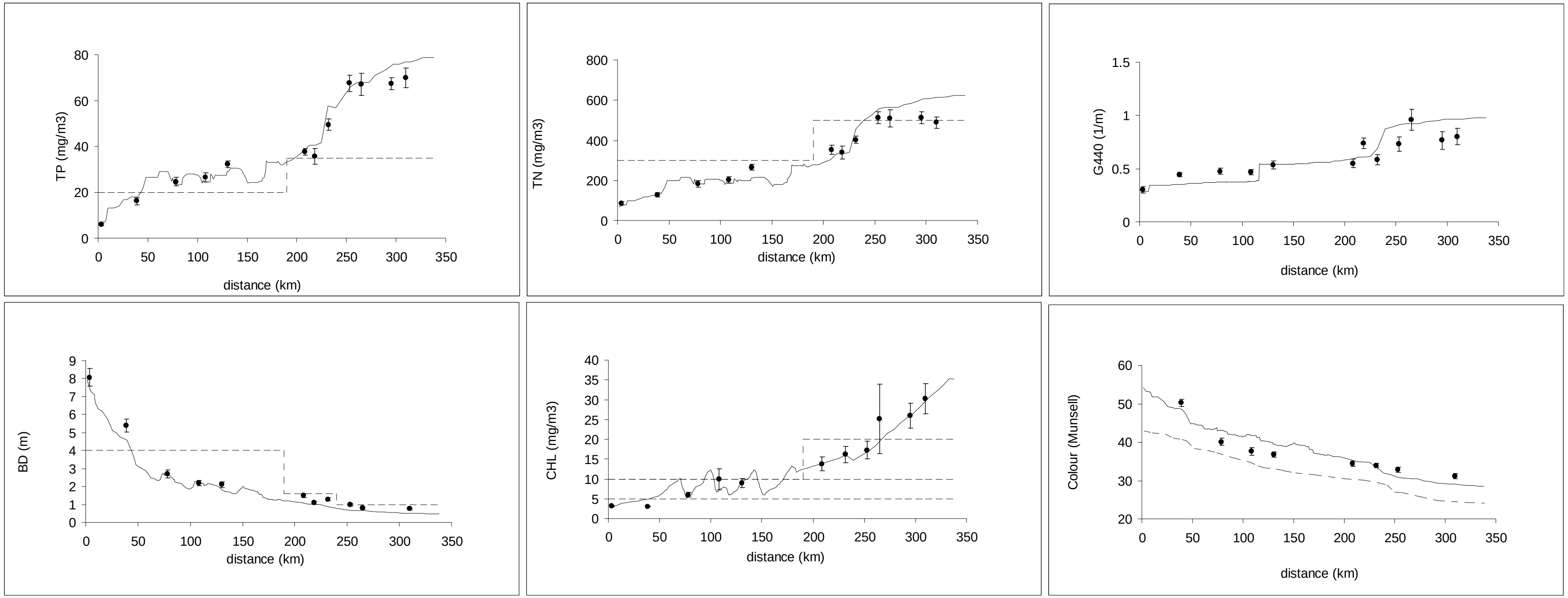

Figure 6: Current State (current farming practice and land use) of water quality in the Waikato River at **base flow** showing variation with distance downstream of phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell). Black circles are observed data (mean ± 95% confidence interval) (Source: NIWA and EW monitoring). The dashed lines are targets (Table 1). The solid lines are predicted by the WCM model.

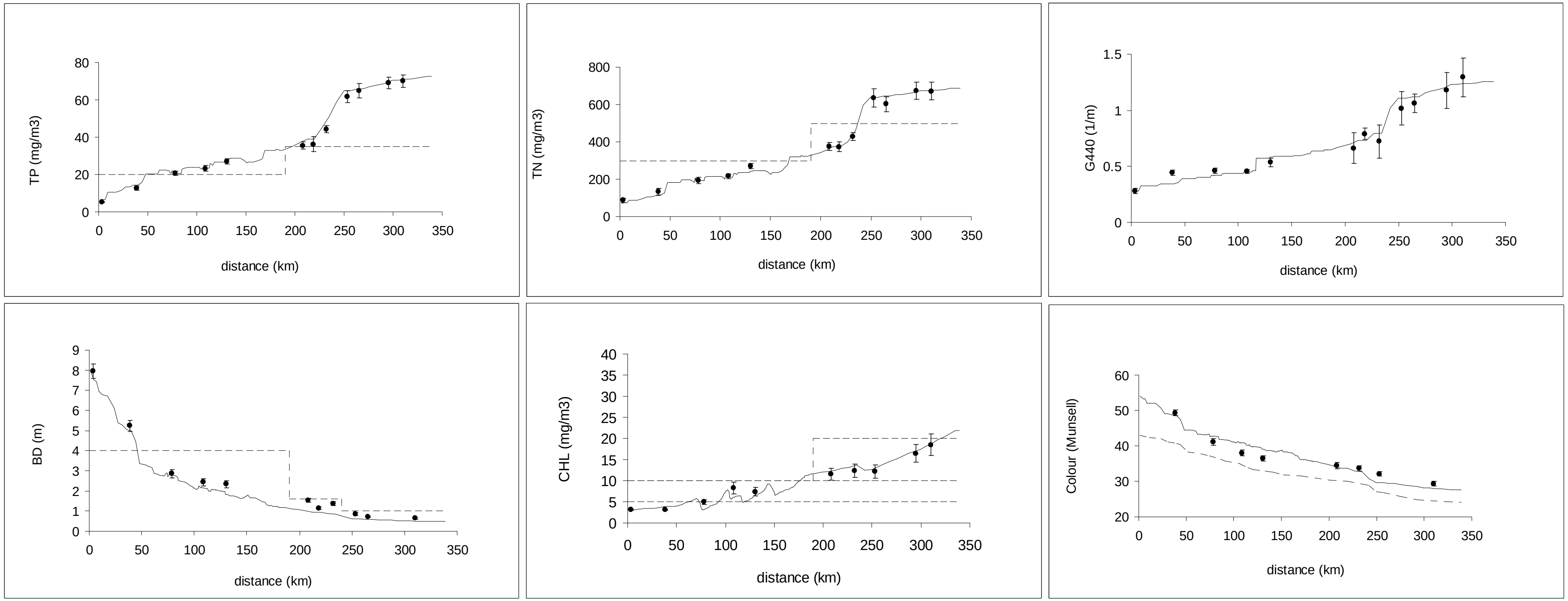

Figure 7: Current State (current farming practice and land use) of water quality in the Waikato River at **mean flow** – Variation with distance downstream of phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell). . Black circles are observed data (mean ± 95% confidence interval) (Source: NIWA and EW monitoring). The dashed lines are targets (Table 1). The solid lines are predicted by the WCM model.

3.2 Priority actions to restore Waikato River water quality

Actions to improve water quality in the Waikato River include:

1. Further treatment of point source waste discharges.
2. Changing farming practice.
3. Retiring and reforesting erodible pasture.

3.3 Reducing point source waste discharges

There are 23 major point source discharges of waste along the length of the Waikato River (cf. 6 in the Waipa River) (Table 6). One action suggested by the community is the further treatment (possibly including land disposal) of municipal sewage and industrial discharges. Point source waste discharges contribute to low clarity and high nutrient concentrations in some Waikato tributaries. Figure 8 shows, however, that these point source discharges have only a minor impact on clarity and Munsell colour in the main stem of the Waikato River.

Point source discharges do not impact significantly on dissolved colour (G440) except for the Kinleith mill (117 km) which has a high G440 concentration.

Therefore, further treatment of waste discharges to reduce sediment and nutrient inputs is not likely to have significant beneficial effects for water quality in the Waikato River, with the possible exception of phosphorus - see below. Note, however, that the further treatment (notably land disposal) of sewage may have benefits in terms of reducing public health risk and will help meet Maaori aspirations for zero discharge of human waste to waterways.

Discharges have a minor impact on TP and TN in the upper Waikato, but below Hamilton (228–232 km) discharges from Hamilton City, Te Raapa dairy factory and the Horotiu meatworks cause an increase in TP and TN concentration. The point source discharges of nutrients contribute to the high CHL concentrations below Horotiu (232 km) especially at base flow, and at the mouth the point sources are responsible for 20% of the base flow CHL concentration.

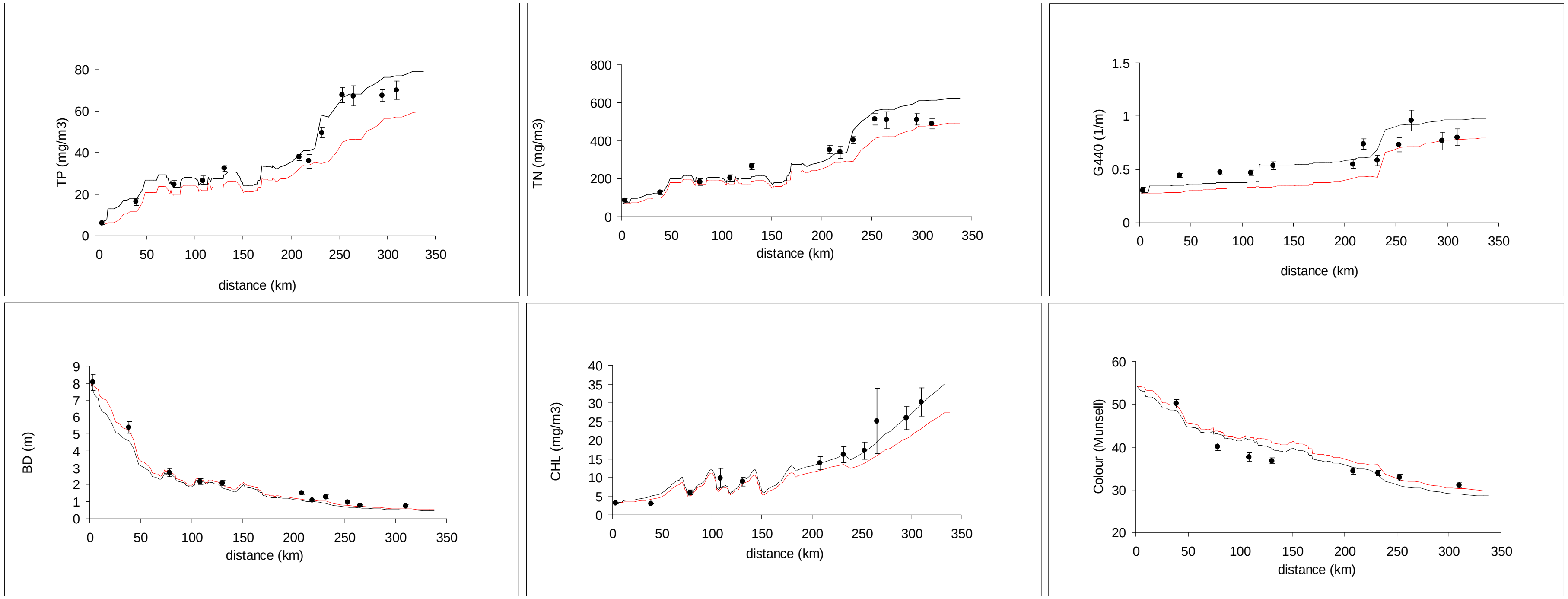

Figure 8: Effects of point source discharges on the Waikato River water quality at **base** flow – Predicted phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell) with (black line) and without (red line) the point source discharges. Black circles are observed data (mean ± 95% confidence interval) (Source: NIWA and EW monitoring).

3.4 Changing farming practice and land use

Figures 9 and 10 compare the WCM predictions for the Current State with the farming practice and land use changes in Scenarios 1–3 (described earlier) at 'base' and 'mean' flow respectively.

Water clarity (BD)

The actions of all three scenarios result in improvement to BD water clarity at base flow (Figure 9) and mean flow (Figure 10). Scenarios 2 and 3 result in BD complying with the 1.6 m guideline immediately below the hydro lakes (190–230 km). However, downstream from the Waipa confluence (240 km) water clarity is still less than 1 m at both base flow and mean flow (Figures 9 and 10). At base flow (Figure 9) BD is below the 4 m guideline in all the hydro lakes. However at mean flow, the 4 m guideline is met in the upper hydro lakes as well as in the headwaters, but not in the lower hydro lakes or further downstream (Figure 10).

Colour (G440 and Munsell)

Dissolved colour (G440) is predicted to decrease significantly downstream from the Waipa confluence (240 km) for Scenarios 2 and 3 at both flows (Figures 9 and 10). None of the scenarios includes additional colour removal at Kinleith (120 km) where there is a step increase in G440.

Munsell colour improves for Scenarios 2 and 3 as a result of lower G440, FSS and CHL (Munsell colour is a function of G440, FSS and CHL). Predicted Munsell colour is well above the guideline (Figures 9 and 10) although the water remains yellow-brown in the Lower Waikato.

Chlorophyll (CHL)

At base flow Scenarios 2 and 3 achieve significant reductions in CHL (Figure 9) – the filters guideline of 20 mg/m^3 is met almost everywhere in the Waikato River. The warning guideline of 10 mg/m^3 is met above the Waipa confluence (240 km) – which means that if a cyanobacteria bloom occurs it is unlikely to pose a health risk to humans or animals except perhaps in the lower Waikato River (Huntly-Tuakau). At mean flow the warning guideline of 10 mg/m^3 is met upstream from the Waipa confluence, and the filters guideline of 20 mg/m^3 continues to be met everywhere.

Nutrients (TP and TN)

The actions of Scenario 1 significantly reduce predicted TP concentrations at base flow (Figure 9) and mean flow (Figure 10). At both flows TP complies with 35 mg/m^3 guideline upstream from Hamilton (220 km) and TP nearly complies with the 20 mg/m^3 guideline in the hydro lakes (50 – 190 km). Scenarios 2 and 3 result in further reductions in TP concentration at both base flow and mean flow, but compliance remains as for Scenario 1.

There is a slight reduction in predicted TN concentrations under Scenario 1 at base flow (Figure 9) and mean flow (Figure 10). This results in the predicted TN at base flow meeting the 500 mg/m3 guideline everywhere upstream from Rangiriri (265 km) (Figure 9). At mean flow predicted TN concentrations exceed the 500 mg/m3 guideline below the Waipa confluence (240 km) (Figure 10). There is a significant improvement in predicted TN between Scenarios 1 and 2 at both flows (Figures 9 and 10). This means that the TN targets are met for the entire length of the Waikato River at both base flow and mean flow. The actions of Scenario 3 produce similar results to Scenario 2 (Figures 9 and 10).

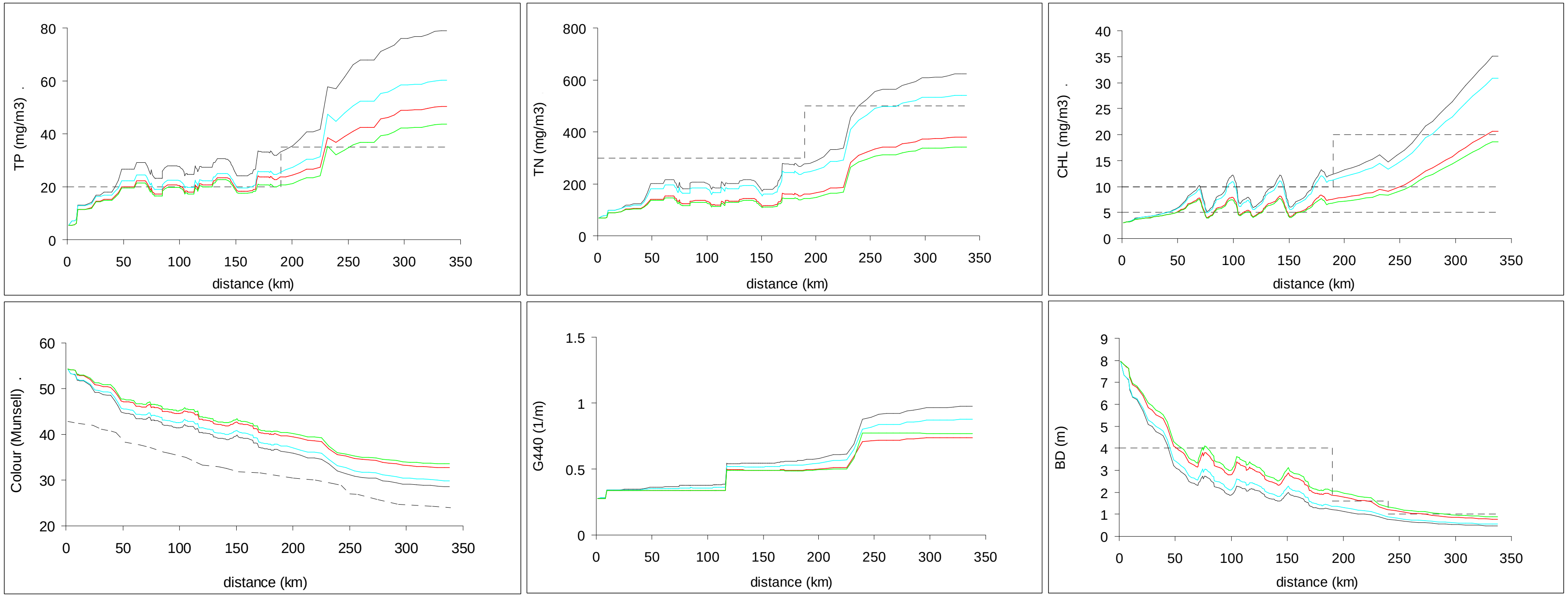

Figure 9: Variation in Waikato River water quality with distance downstream at **base flow** predicted by the WCM : phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell) for the Current State (black line), Scenario 1 (blue line), Scenario 2 (red line) and Scenario 3 (green line). The dashed lines are targets (Table 1).

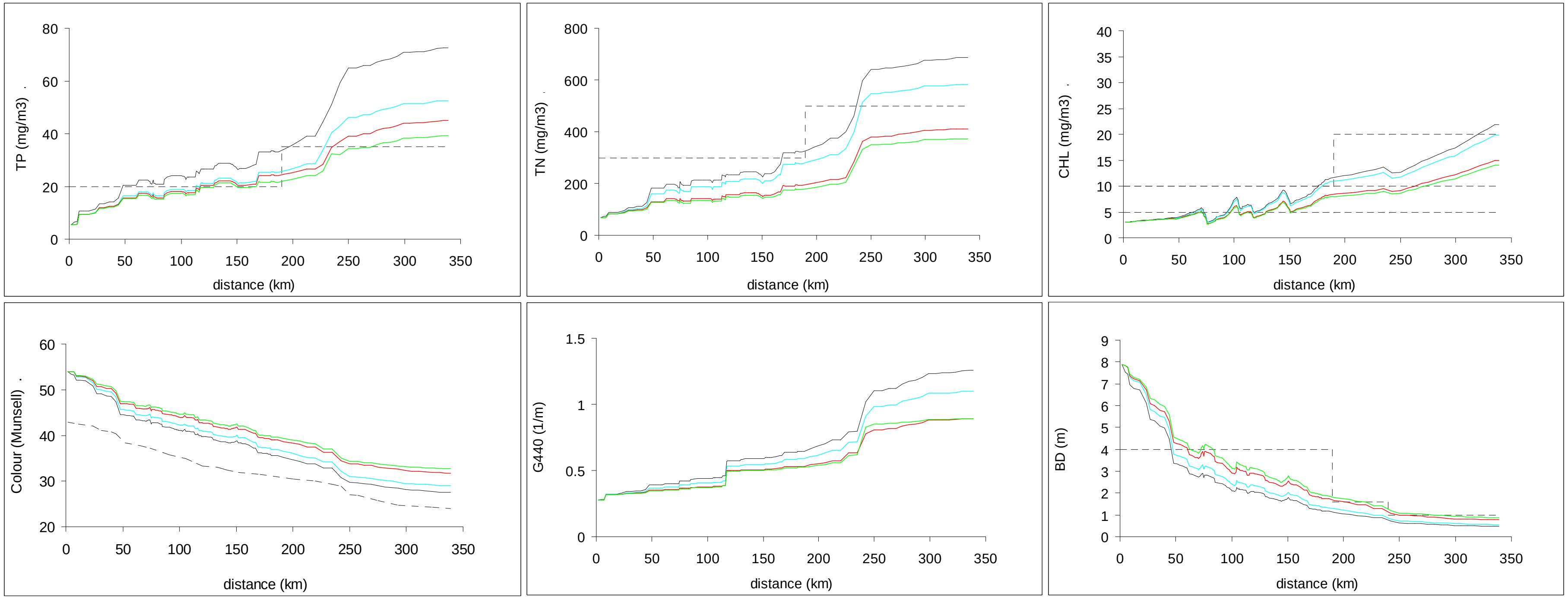

Figure 10: Variation in water quality at **mean flow** in the Waikato River with distance downstream as predicted by the WCM: phosphorus (TP), nitrogen (TN), dissolved colour (G440), water clarity (BD), chlorophyll (CHL) and colour (Munsell) for the Current State (black line), Scenario 1 (blue line), Scenario 2 (red line) and Scenario 3 (green line). The dashed lines are targets (Table 1).

4. Other priority actions to improve water quality

4.1 Re-vegetating stream banks

The contribution made by stream bank erosion to suspended sediment loads and water clarity in streams has not yet been measured in the Waipa or Waikato catchments, although studies are underway that will help to quantify stream bank erosion. There is evidence from NIWA and Environment Waikato studies in the Waikato basin that stream banks covered with pasture grasses are more likely to be actively eroding than stream banks covered with woody vegetation (Kotze et al., 2008). This is consistent with overseas studies which show that woody vegetation is more deeply rooted and protects stream banks from the effects of the current (Abernathy and Rutherfurd, 2000). Suspended sediment loads have been measured at a small number of sites in the Waikato, and water clarity has been monitored at a larger number of sites. This study re-analysed that data but found there was no reliable way to separate the effects of stream bank erosion from other sources of sediment.

Two studies in the Waikato have measured suspended sediment loads, turbidity and water clarity before and after stream bank revegetation and other catchment restoration. McKerchar and Hicks (2001) found that fencing streams and planting erosion-prone areas in the Waitomo catchment reduced suspended sediment loads at a given flow by about 40%. They focused on high flow events which delivered the majority of suspended sediment and they did not quantify changes in water clarity. Dr Deborah Ballantine performed a trend analysis on turbidity measurements in the Waitomo Stream (Dr Deborah Ballantine, NIWA, pers. comm.) and found that there had been no significant change over time. This suggests that although riparian restoration had reduced the supply of coarse sediment, it had not reduced the supply of fine sediment - which is the main contributor to turbidity and low water clarity. Dr Ballantine did not examine changes in turbidity at base flow which is when the majority of contact recreation occurs. Quinn et al., (2009) found that stream fencing to exclude cattle and replanting the riparian zone with poplars has resulted in a significant increase in water clarity (roughly a doubling) in the stream PW3 at the Whatawhata study site in the Waipa catchment. However, in the adjacent PW2 catchment, retirement and reforestation with pine trees has not resulted in any significant change in water clarity for reasons that are not fully understood but may include channel widening and the disappearance of small riparian wetlands.

Elsewhere in New Zealand, studies have shown that suspended sediment yields from pasture catchments are significantly higher than yields from forest catchments. Fahey (2003) reports that in the Hawkes Bay pasture yields = 2–3 x forest yields. Hicks (1988, 1990) analysed data from paired catchment studies at several locations around New Zealand and concluded that for a given rainstorm pasture yield = 6–8 x exotic forest yield. Thus, the retirement and reforestation of pasture is likely to reduce sediment loads in streams significantly. Note, however, that Fahey (2003) and Hicks (1988, 1990) quantified the change in mean annual yield of suspended sediment which is dominated by loads during storms, whereas the principal concern for contact recreation is with turbidity and water clarity at base flow. There are good reasons for believing that reducing the annual suspended sediment yield will have benefits in terms of increased base flow water clarity. However, those benefits have not been quantified and may not be as large as the 2–3 and 6–8 fold differences cited above.

4.2 Input reductions

The WCM model estimates the yields of fine sediment and dissolved colour from different land uses from monitoring data gathered in the catchment. For Scenarios 1, 2 and 3 the WCM model reduces these yields by the amounts shown in Tables 2 and 3. These reductions have been estimated from the results of detailed studies in a number of farming catchments throughout New Zealand (Dr Ross Monaghan, AgResearch, pers. comm.). It is important to note that these reductions relate to what leaves the farm. They do not include the reductions in bank erosion that are likely to occur when stream banks are retired and replanted with woody vegetation. The effects of replanting and increasing the strength of stream banks are not modelled in the WCM predictions described earlier. Consequently, additional benefits beyond those predicted for water clarity are likely if stream bank erosion can be decreased below that in typical pasture streams by re-vegetating the stream banks.

At the stakeholders' workshop held on 16th February 2010, anecdotal evidence was presented suggesting that the current low clarity in the Waipa near Otorohanga was the result of injudicious willow removal that had damaged the river banks and left them susceptible to erosion. If this is the case then revegetation of the river banks should be a priority action. There is clear evidence of active bank erosion in several Waikato tributaries. Erosion occurs in places along straight parts of the channel through undercutting and bank slumping. Revegetation straighter parts of the channel is likely to reduce undercutting and bank slumping. Erosion also occurs on the outside of bends where the current 'attacks' the bank. Efforts to reduce bank erosion in such 'hot spots' including re-vegetation and the placement of protection (e.g., logs or rock) may have benefits, but it may simply move the erosion 'hot spot' further downstream.

In conclusion, revegetation of stream banks with woody vegetation (trees and shrubs) in the Waipa and Waikato catchments will almost certainly have benefits in terms of reduced bank erosion, with ongoing benefits to water clarity. Currently, however, it is not possible to quantify accurately what the benefits will be. The modelling described in this Section does not include the effects that riparian revegetation is expected to have on reducing sediment inputs, and consequently predictions are conservative (viz., under-estimate the likely benefits).

4.3 Legacy sediment

As discussed earlier, material deposited into the Waipa River by the Tunawaea slip in 1991 is thought to be contributing to degraded water clarity. The same may also be true for material deposited elsewhere in the river by major erosion events that have occurred periodically since land clearance commenced. If this is the case, and if remedial actions reduce the supply of new fine sediment into the river, then over time the effects of 'legacy' sediment in the river channel should decline. There is not enough information available to make a reliable estimate of how long this might take, or the contribution 'legacy' sediment is making to current water clarity. Work in East Cape, the Motueka catchment and in Glenbervie Forest (Northland) suggests that the effect of large erosion events decays exponentially over a period of several years (Hicks and Harmsworth, 1989; Hicks and Basher, 2008).

4.4 Land disposal

Land disposal of municipal effluent is listed as one of the priority actions in Section 8 in the main report. The primary benefits of land disposal are cultural health with co-benefits being reduced human health risk and improved water quality. However, the WCM modelling above shows that, with the exception of phosphorus in Hamilton sewage, the co-benefits of land disposal in terms of reduced nutrient and phytoplankton concentrations, increased water clarity and improved colour are minor.

5. Summary of input data for the WCM model

5.1 Scenarios

Table 4: Scenarios from Monaghan (2010).

	Dairy	Sheep-beef	Forestry (Planted forest)	Horticulture
Current State	**Present situation**			
Scenario 1 – Current Best Practice	Full stock exclusion from streams using single-wire fencing. Soil Olsen P levels reduced from 38 to 32 (economic optimum). Effluent areas enlarged appropriate to effluent K (potassium) and N loading rates. Additional 1 month's effluent pond storage; low application depth.	Exclusion of cattle from streams using single-wire electric fencing and provision of stock troughs and water supply.	10 m stream buffer for blocks > 50 ha. 5 m stream buffer for blocks 20 – 50 ha.	Reduced fertiliser inputs. Sediment control measures.
Scenario 2 – Changing farm practice	All Scenario 1 actions adopted. Use of nitrification inhibitors (5% pasture production response assumed). Wetlands installed on 1% of farm area (fencing out of seeps and bogs). Berms on sections of lanes to	As per Scenario 1. Wetlands installed on 1% of farm area (fencing out of seeps and bogs). Poplar plantings (with sleeves) at 10 m spacings on each side of streams.	As per Scenario 1.	As per Scenario 1.

Table 4: (cont.)

	Dairy	Sheep-beef	Forestry (Planted forest)	Horticulture
Current State	**Present situation**			
	direct runoff away from streams. 5 m buffer on each side of streams, planted with natives. Existing fences relocated to protect the natives. Farm inputs of purchased feed and fertiliser N reduced to nil.			
Scenario 3	All Scenario 2 actions adopted.	15 m fenced and planted buffers on all streams. 60% of steep sheep-beef farms retired and planted in pines 25% of easy sheep-beef farms retired and planted in pines	As per scenario 1 60% of steep sheep-beef farms retired and planted in pines 25% of easy sheep-beef farms retired and planted in pines	As per scenario 1

5.2 Point sources

Table 5: Point source discharges of TP (total phosphorus), TN (total nitrogen), SS (suspended sediment), G440 (dissolved colour), CHL (chlorophyll), and FSS (fine suspended sediment) into the Waipa River. The bold values are from AEE (Assessment of Environmental Effects) documents and the rest from EW consents.

	Km from source	**Average dry weather flow (m^3/d)**	**TP**			**TN**			**SS**		**G440 (1/m)**	**CHL (mg/m^3)**	**FSS (1/m)**
			Load (kg/d)	**Concentration (mg/m^3)**	**% of pt source load**	**Load (kg/d)**	**Concentration (mg/m^3)**	**% of Pt source load**	**Load (kg/d)**	**Concentration (mg/m^3)**			
Te Kuuiti Sewage*	55	**4,200**	**34**	**8,000**	**43.6**	**92**	**22,000**	**25.5**	**55**	**13,000**	15	0	20
Otorohanga Sewage	65	600	12	20,000	**15.4**	50	83,333	**13.9**	55	91,667	15	0	20
Te Awamutu Dairy Factory	94	5,128	14	2,691	**17.9**	154	30,031	**42.7**	154	30,000	15	0	20
Te Awamutu Sewage	96	600	12	20,000	**15.4**	50	83,333	**13.9**	55	91,667	15	0	20
Roto-o-Rangi Piggery	97	330	1	3,939	**1.3**	7	19,697	**1.9**	10	30,000	15	0	20
Templeview	100	**750**	5	6,000	**6.4**	**8**	**10,000**	**2.2**	**23**	**30,000**	15	0	20

Table 6: Point source discharges of TP (total phosphorus), TN (total nitrogen), SS (suspended sediment), G440 (dissolved colour), CHL (chlorophyll), and FSS (fine suspended sediment) into the Waikato River. The flow, TP load, TN load, SS load and G440 values for Kinleith are measured; the bold values are from AEE documents, and the rest are from EW consents. Figures in italics are discharged to land.

	Km from Taupoo	**Average dry weather flow (m^3/d)**	**TP**			**TN**			**SS**		**G440 (1/m)**	**CHL (mg/m^3)**	**FSS (g/m^3)**
			Load (kg/d)	**Concentration (mg/m^3)**	**% of pt source load**	**Load (kg/d)**	**Concentration (mg/m^3)**	**% of pt source load**	**Load (kg/d)**	**Concentration (mg/m^3)**			
Taupo Sewage	*4*	*8,640*	*12*	*1,389*	*2.6*	*60*	*6,944*	*2*	*259*	*30,000*	*5*	*5*	*30*
Taupoo Timber Mill	8	0	0	0	0.0	0	0	0.0	0	0	5	0	0
Prawn Farm Wairaakei	8	864	4	4,051	0.9	4	4,051	0.1	26	30,000	5	0	0
Wairaakei Power Station	10	95,040	36	378	8.1	131	1,373	4.5	0	0	5	0	0
Oohaakii Power Station	48	86	0	0	0.0	0	0	0.0	0	0	5	0	0
Reporoa Dairy Factory	*48*	*0*	*0*	*0*	*0.0*	*0*	*0*	*0.0*	*0*	*0*	*5*	*0*	*10*
Kinleith Pulp Mill	117	87,600	52	594	11.8	431	4,920	14.9	5,900	67,352	**40**	0	10
Litchfield Dairy Factory	*167*	*2,200*	*4*	*1,773*	*0.9*	*115*	*52,273*	*4.0*	*22*	*10,000*	*5*	*0*	*10*
Tokoroa Sewage	168	**4,000**	38	9,500	8.6	**160**	**40,000**	5.5	**48**	**12,000**	5	5	30
Cambridge Sewage	*196*	*2,000*	*11*	*5,600*	*2.4*	*20*	*9,850*	*0.7*	*60*	*30,000*	*5*	*5*	*30*
Hautapu Dairy Factory	*214*	*2,200*	*4*	*1,773*	*0.9*	*115*	*52,273*	*4.0*	*22*	*10,000*	*5*	*0*	*10*
Hamilton Sewage (summer)	228	**224,000**	**100**	446	22.6	**450**	2,009	15.5	**700**	**15,000**	5	5	30
Te Raapa Dairy Factory	232	10,000	25	2,500	5.7	400	40,000	13.8	100	10,000	5	0	10

Table 6: (cont.)

	Km from Taupoo	Average dry weather flow (m^3/d)	TP			TN			SS		G440 (1/m)	CHL (mg/m^3)	FSS (g/m^3)
			Load (kg/d)	Concentration (mg/m^3)	% of pt source load	Load (kg/d)	Concentration (mg/m^3)	% of pt source load	Load (kg/d)	Concentration (mg/m^3)			
AFFCo Horotiu	233	**4,838**	100	20,670	22.6	800	165,358	27.6	**97**	**20,000**	5	0	10
Ngaaruawaahia Sewage* (summer)	245	**2,000**	**16**	**8,000**	3.6	**50**	20,000	1.7	**60**	**30,000**	5	5	30
Huntly Power Station	258	0	0	0		0	0		0	0	5	0	0
Huntly Sewage* (summer)	262	**1,500**	**12**	**8,000**	0.0	**38**	**17,600**	0.0	**45**	**30,000**	5	5	30
Johnson Piggery	292	104	4	40,385	**5.7**	21	200,000	**1.3**	3	30,000	5	0	50
PIC Maramarua Piggery	294	88	4	39,773		18	198,864		3	30,000	5	0	50
Tuakau Sewage	314	4,500	18	3,978	0.9	33	7,400	0.7	62	13,778	5	5	30
Waikato By-Products	316	**1,000**	10	10,000	0.9	**100**	100,000	0.6	**62**	62,000	5	0	5
Te Kauwhata Sewage*	275	**1,100**	**3**	**2,800**	4.1	**9**	**8,000**	1.1	**17**	**15,000**	5	5	30
Meremere Sewage	292	**160**	**1**	**5,400**	2.3	4	25,000	3.4	**8**	**48,000**	5	5	30

* Consents currently under application. Actual limits once consent granted may differ from those tabulated.

5.3 The catchment water quality model

Background

The Waikato Catchment Model (WCM, Rutherford et al., 2001) was originally developed under contract to Mighty River Power in connection with consents for the hydro dams. It has subsequently been used by Environment Waikato to examine the effects of land use change and to model blue-green algal blooms. The model has several unique features, including its ability to model not only nutrients and suspended sediment but also phytoplankton growth, water clarity and colour. The model assumes steady flow but can be run at a number of different flow regimes. It divides the river into segments c. 100–200 m long and predicts the changes in concentration that occur from Taupoo (headwaters) to Te Puuaha (near the mouth). For this study, the WCM was modified so that it also models changes along the Waipa River from its headwaters to Ngaaruawaahia (confluence with the Waikato River) and the effects that the Waipa has on the lower Waikato River. Other tributaries are not modelled in detail but their inputs into the Waikato or Waipa are estimated using information about landuse and point source discharges in their sub-catchment.

The river is sub-divided into a number of segments each of which is assumed to be well-mixed vertically, transversely and longitudinally. The number of segments varies depending on the flow and the specified time step and is calculated within the model. Where the channel is riverine, segments are long, narrow, shallow and the velocity is swift. In the hydro lakes segments are short, wide, deep and the velocity is slow. Longitudinal dispersion is neglected.

The river water quality sub-model calculates the concentration profiles along the Waikato and Waipa River systems of total phosphorus (TP), total nitrogen (TN), phytoplankton chlorophyll (CHL), fine inorganic suspensoids (FSS), suspended sediment (SS), dissolved colour (G440), black disc clarity (BD) and colour (Munsell). Flow is assumed steady, the phytoplankton growth equations are averaged over 24 hours, and steady-state solutions are sought.

Mass balance equations are used to predict the concentration of total phosphorus and total nitrogen in each segment. Both TP and TN are both assumed to be biologically inactive, with settling the only removal process. The inflow or initial concentration is set equal to the average concentration measured in the outflow from Lake Taupoo. The model determines whether N or P limits maximum phytoplankton biomass in the hydro lakes and river based on published information on the N:P ratio in phytoplankton.

Assuming a linear relationship between G440 (light absorbance at 440 nm) and yellow substance (dissolved colour) mass concentration, a “mass” balance equation is used for the prediction of G440. Dissolved colour is assumed to be biologically inactive and, because it is a dissolved constituent, to have a negligibly small settling velocity.

A mass balance equation is used to predict the concentration of SS in each segment. Assuming a linear relationship between FSS and SS mass concentration, a 'mass' balance equation is also used for the prediction of FSS. Settling is included in the model although the majority of beam attenuation is caused by very small particles which have a very low settling velocity.

The WCM incorporates the model of Pridmore and McBride (1983) for phytoplankton chlorophyll (CHL), which accounts for the effects of nutrient concentration and flushing. This model is modified to include the effects of settling and by making the growth rate a function of temperature and light.

Water clarity varies with changes in the concentrations of phytoplankton, yellow substance and other fine suspensoids (e.g., clay, silica, detritus etc.). Water clarity is taken to be the horizontal visibility of a black disc (termed black disc clarity, BD). Black disc clarity (in segment i) is inversely related to the beam attenuation coefficient (c):

$$BD_i = \frac{4.8}{c_i} \quad (1)$$

The beam attenuation coefficient varies with the concentrations of phytoplankton, yellow substance and other suspensoids and the following relationship is assumed:

$$c_i = c_o + \alpha_1 CHL_i^{\beta_1} + \alpha_2 G440_i^{\beta_2} + \alpha_3 FSS_i^{\beta_3} \quad (2)$$

where co = background beam attenuation coefficient of pure water (m-1) = 0.064, and β and α are empirical coefficients.

$$\beta_1 = \beta_2 = \beta_3 = 1, \alpha_1 = 0.10, \alpha_2 = 0.17, \alpha_3 = 1.00.$$

Colour is quantified in the model by Munsell hue which changes as a result of increases of yellow substance, chlorophyll and inert suspensoid concentrations. A regression model is used (derived using monitoring data)

$$Munsell = m_o + m_1 \ln(FSS) + m_2 \ln(G440) + m_3 \ln(CHL) \quad (3)$$

where m are constants estimated during calibration.

This Study

The model was firstly calibrated to the measured data (Figures 1, 2, 6 and 7) using the Current State yields (Table 7). Two flow regimes were considered, namely 'mean' and 'base' flow and the measured data were categorised using these two flows. A flow scaling factor depending on these two flows along with attenuation or amplification of the Current State yields at various reaches of the rivers were included in the calibration. For the calibration to the chlorophyll concentrations, the settling velocity and maximum growth rate of the phytoplankton chlorophyll were adjusted. For Scenarios 1–3, the yields varied (Table 7) but the scaling factors, the attenuations or amplifications, the settling velocity and growth rate remained unchanged.

The following describes how the concentrations of TP, TN, SS, G440 and FSS are predicted in each sub-catchment which are then used in the "mass" balance equations for each segment.

There are a number of sites along the Waikato and Waipa Rivers and each one is associated with a sub-catchment or a point source discharge. There are various land use types in each sub-catchment and these include forestry or planted forest (PF), sheep-beef on steep hill country (class 3) (SB3), sheep-beef on easy hill country (class 4) (SB4), sheep-beef on easy rolling country (class 5) (SB5), diary on peat soils (DPe), dairy on well-drained soils (DW), dairy on poorly-drained soils (DPo), cropping and horticulture (CH), native forest (NF) and urban (U) (Appendix 9: Farms).

Firstly the 'yield' of TP, TN, SS, G440 or FSS from a land use in a sub-catchment is calculated by multiplying the yield from that land use by the fraction of area that it occupies in the sub-catchment. These yields are then summed across the land use types (PF, SB3, SB4, SB5, DPe, DW, DPo, CH, NF, U) to give a total yield of TP, TN, SS, G440 or FSS for the sub-catchment.

For TP, TN and SS the yield has units of kg/ha/yr. Concentrations of TP (mg/m^3), TN (mg/m^3) and SS (g/m^3) are calculated from their yields using the sub-catchment area and flow rate. For G440 and FSS the yield units are m^2/m^3 = 1/m, and these are also used for their 'concentrations'.

The yield from the land use is scaled according to the flow so that

Yield from land use$_j$ of substance$_v$ from sub-catchment$_k$ =

Yield from land use$_j$ of substance$_v$ x Flow scaling factor

x Area of land use$_j$ in sub-catchment$_k$/Area of sub-catchment$_k$;

where j = PF, SB3, SB4, SB5, DPe, DW, DPo, CH, NF or U;

v = TP, TN, SS, G440 or FSS and k = a sub-catchment

Or if Y = yield;

SF = (flow) scaling factor;

A = area;
r = Waikato River (Wk) or Waipa River (Wp);
s = Pasture (P) or Forest (F); and
t = Mean flow (M) or Base flow (B) then

$$Y_{j,v,k} = Y_{j,v} \times SF_{r,s,t,v} \times \frac{A_{j,k}}{A_k} \quad (4)$$

and for the total yield of substance$_v$ from sub-catchment$_k$

$$= \sum_j Y_{j,v} \times SF_{r,s,t,v} \times \frac{A_{j,k}}{A_k} \quad (5)$$

If j = PF, NF or U then $SF_{r,s,t,v} = SF_{r,s=F,t,v}$ else if j = SB3, SB4, SB5, DPe, DW, DPo, or CH then $SF_{r,s,t,v} = SF_{r,s=P,t,v}$. "Yields", $Y_{j,v}$ for v = TP, TN and SS were obtained from Dr Ross Monaghan (AgResearch, pers. comm.) for Current State and Scenarios 1, 2 and 3 for TN, TP and SS (Table 7). $Y_{j,v=TP}$ for the Waipa needed to be different to that for the Waikato in order to calibrate the model for the Current State (Table 7).

$Y_{j,v}$ for v = FSS and G440 for the Current State were estimated in order to calibrate the model to the measured data. for FSS and G440. For Scenarios 1–3, the yields for FSS and G440 were obtained by applying the same reductions in SS yields between the Current State and Scenarios 1–3.

These estimations included looking at plots of Forest (both planted and native) and Total Pasture versus FSS and G440 (Figure 11) in order to estimate the yields of FSS and G440 in mainly forested sub-catchments compared with mainly pastured sub-catchments. If it is assumed that mainly pastured sub-catchments are dairy farms and sheep-beef farms are a mixture of pasture and forest, then from Figure 11 (a) and (b), the FSS yield for the dairy farms is about 10, for sheep-beef farms is about 5, and for forested sub-catchments is about 1(Table 7). Similarly, from Figure 11 (c) and (d), the G440 yield for the dairy farms is about 4, for sheep-beef farms is about 3, and for forested sub-catchments is about 2 (Table 7).

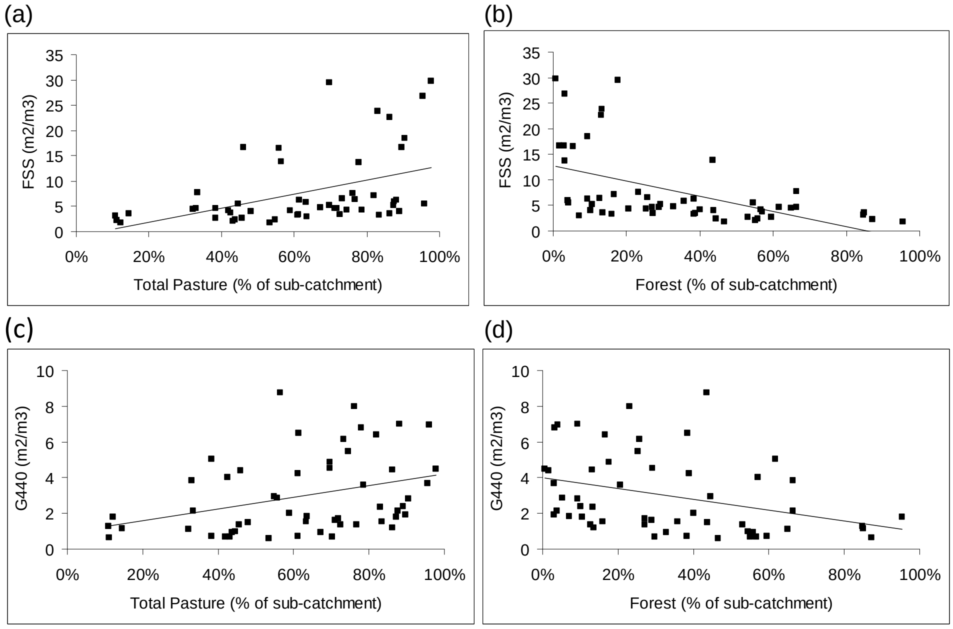

Figure 11: Variation with percentage of Forest (planted and native) and Total Pasture in various sub-catchments of the Waikato and Waipa Rivers versus observed FSS and G440 with trendlines.

$Y_{j,v=FSS}$ and $Y_{j,v=G440}$ for the Waipa needed to be different to those for the Waikato in order to calibrate the model for the Current State (Table 7).

Flow scaling factor, $SF_{r,s,t,v}$

In this study, two flow regimes are modelled: the 'mean' and 'base' flows. The flow scaling factor is given by

$$SF_{r,s,t,v} = \alpha_{r,s,v} \times Q_t^{\beta_{r,s,v}} \quad (6)$$

where α and β (Table 8) are coefficients estimated during calibration.

Since $\alpha_{r,s,v} = 1$ for all r, s, v Equation 6 becomes

$$SF_{r,s,t,v} = Q_t^{\beta_{r,s,v}} \quad (7)$$

For "mean" flow, the minimum and maximum are set at 75% and 125% respectively of the measured mean flow (at Rangiriri in the Waikato River, at Whatawhata in the Waikato River) giving an average of 100% of the flow, viz. the 'mean' flow ($Q_{t=M}$) in Equation 7 = 1. For "base flow", the minimum and maximum are set at 25% and 75% respectively of the measured mean flow giving an average of 50% of the flow, viz. the 'base' flow ($Q_{t=B}$) in Equation 7 = 0.5.

Therefore for mean flow $SF_{r,s,t=M,v} = 1$ (8)

and for base flow $SF_{r,s,t=B,v} = 0.5^{\beta_{r,s,v}}$ (9)

≤ 1 since $\beta_{r,s,v} \geq 0$ for all r, s, v (Table 8).

For mean flow then, Equation 5 becomes

$$\sum_j Y_{j,v} \times \frac{A_{j,k}}{A_k} \tag{10}$$

and for base flow, the flow scaling factor attenuates the 'yield' when $\beta_{r,s,v} > 0$, and when $\beta_{r,s,v} = 0$ then Equation 10 applies.

Table 7: The 'yields', $Y_{j,v}$ j = PF, SB3, SB4, SB5, DPe, DW, DPo, CH, NF or U; v = TP, TN, SS, G440 or FSS. If the Waipa values are different to the Waikato ones then the Waipa values are given in the brackets. For the Current State (CS), $Y_{j=NF,v}$ and $Y_{j=U,v}$ were set equal to $Y_{j=PF,v}$. The reduction in $Y_{j,v}$ resulting from the actions of Scenarios 1–3 (S1 – 3) did not apply to $Y_{j=NF,v}$ or $Y_{j=U,v}$. The Current State yields were used for calibrating the model.

		j = PF	j = SB3	j = SB4	j = SB5	j = DPe	j = DW	j = DPo	j = CH
v = TN	CS	$Y_{PF,TN}$ = 4.00	$Y_{SB3,TN}$ = 9.20	$Y_{SB4,TN}$ = 12.40	$Y_{SB5,TN}$ = 15.50	$Y_{DPe,TN}$ = 30.40	$Y_{DW,TN}$ = 44.30	$Y_{DPo,TN}$ = 40.40	$Y_{CH,TN}$ = 70.50
	S1	$Y_{PF,TN}$ = 3.60	$Y_{SB3,TN}$ = 8.81	$Y_{SB4,TN}$ = 11.87	$Y_{SB5,TN}$ = 14.84	$Y_{DPe,TN}$ = 22.36	$Y_{DW,TN}$ = 37.26	$Y_{DPo,TN}$ = 33.36	$Y_{CH,TN}$ = 22.35
	S2, S3	$Y_{PF,TN}$ = 3.60	$Y_{SB3,TN}$ = 8.64	$Y_{SB4,TN}$ = 11.64	$Y_{SB5,TN}$ = 14.55	$Y_{DPe,TN}$ = 11.03	$Y_{DW,TN}$ = 17.03	$Y_{DPo,TN}$ = 22.53	$Y_{CH,TN}$ = 22.35
v = TP	CS	$Y_{PF,TP}$ = 1.00 (0.25)	$Y_{SB3,TP}$ = 1.30 (1.00)	$Y_{SB4,TP}$ = 1.30 (1.00)	$Y_{SB5,TP}$ = 1.10 (1.00)	$Y_{DPe,TP}$ = 3.70 (3.00)	$Y_{DW,TP}$ = 1.10 (3.00)	$Y_{DPo,TP}$ = 1.80 (3.00)	$Y_{CH,TP}$ = 4.60 (3.00)
	S1	$Y_{PF,TP}$ = 0.85 (0.21)	$Y_{SB3,TP}$ = 1.22 (0.94)	$Y_{SB4,TP}$ = 1.22 (0.94)	$Y_{SB5,TP}$ = 1.03 (0.94)	$Y_{DPe,TP}$ = 2.39 (1.94)	$Y_{DW,TP}$ = 0.27 (0.74)	$Y_{DPo,TP}$ = 0.70 (1.17)	$Y_{CH,TP}$ = 0.96 (0.62)
	S2, S3	$Y_{PF,TP}$ = 0.85 (0.21)	$Y_{SB3,TP}$ = 1.18 (0.91)	$Y_{SB4,TP}$ = 1.19 (0.91)	$Y_{SB5,TP}$ = 1.01 (0.91)	$Y_{DPe,TP}$ = 1.37 (1.11)	$Y_{DW,TP}$ = 0.13 (0.34)	$Y_{DPo,TP}$ = 0.47 (0.79)	$Y_{CH,TP}$ = 0.96 (0.62)
v = SS	CS	$Y_{PF,SS}$ = 457.00	$Y_{SB3,SS}$ = 989.30	$Y_{SB4,SS}$ = 436.80	$Y_{SB5,SS}$ = 174.70	$Y_{DPe,SS}$ = 18.20	$Y_{DW,SS}$ = 55.40	$Y_{DPo,SS}$ = 95.80	$Y_{CH,SS}$ = 405.30
	S1	$Y_{PF,SS}$ = 365.60	$Y_{SB3,SS}$ = 808.26	$Y_{SB4,SS}$ = 356.87	$Y_{SB5,SS}$ = 142.73	$Y_{DPe,SS}$ = 16.92	$Y_{DW,SS}$ = 46.98	$Y_{DPo,SS}$ = 81.48	$Y_{CH,SS}$ = 202.65
	S2, S3	$Y_{PF,SS}$ = 365.60	$Y_{SB3,SS}$ = 657.39	$Y_{SB4,SS}$ = 290.25	$Y_{SB5,SS}$ = 116.09	$Y_{DPe,SS}$ = 4.85	$Y_{DW,SS}$ = 31.88	$Y_{DPo,SS}$ = 54.22	$Y_{CH,SS}$ = 202.65
v = FSS	CS	$Y_{PF,FSS}$	$Y_{SB3,FSS}$	$Y_{SB4,FSS}$	$Y_{SB5,FSS}$	$Y_{DPe,FSS}$	$Y_{DW,FSS}$	$Y_{DPo,FSS}$	$Y_{CH,FSS}$

Table 7: (cont.)

		j = PF	j = SB3	j = SB4	j = SB5	j = DPe	j = DW	j = DPo	j = CH
		= 1.00 (1.50)	= 5.00	= 5.00	= 5.00	= 10.00 (17.50)	= 10.00 (5.00)	= 10.00 (5.00)	= 10.00 (5.00)
	S1	$Y_{PF,FSS}$ = 0.80 (1.20)	$Y_{SB3,FSS}$ = 4.09	$Y_{SB4,FSS}$ = 4.09	$Y_{SB5,FSS}$ = 4.09	$Y_{DPe,FSS}$ = 9.30 (16.27)	$Y_{DW,FSS}$ = 8.48 (4.24)	$Y_{DPo,FSS}$ = 8.50 (4.25)	$Y_{CH,FSS}$ = 5.00 (2.50)
	S2, S3	$Y_{PF,FSS}$ = 0.80 (1.20)	$Y_{SB3,FSS}$ = 3.32	$Y_{SB4,FSS}$ = 3.32	$Y_{SB5,FSS}$ = 3.32	$Y_{DPe,FSS}$ = 2.66 (4.66)	$Y_{DW,FSS}$ = 5.75 (2.88)	$Y_{DPo,FSS}$ = 5.66 (2.83)	$Y_{CH,FSS}$ = 5.00 (2.50)
v = G440	CS	$Y_{PF,G440}$ = 2.00 (4.00)	$Y_{SB3,G440}$ = 3.00 (1.50)	$Y_{SB4,G440}$ = 3.00 (1.50)	$Y_{SB5,G440}$ = 3.00 (1.50)	$Y_{DPe,G440}$ = 4.00 (3.00)	$Y_{DW,G440}$ = 4.00 (3.00)	$Y_{DPo,G440}$ = 4.00 (3.00)	$Y_{CH,G440}$ = 4.00 (3.00)
	S1	$Y_{PF,G440}$ = 1.60 (3.20)	$Y_{SB3,G440}$ = 2.45 (1.23)	$Y_{SB4,G440}$ = 2.45 (1.23)	$Y_{SB5,G440}$ = 2.45 (1.23)	$Y_{DPe,G440}$ = 3.72 (2.79)	$Y_{DW,G440}$ = 3.39 (2.54)	$Y_{DPo,G440}$ = 3.40 (2.55)	$Y_{CH,G440}$ = 2.00 (1.50)
	S2, S3	$Y_{PF,G440}$ = 1.60 (3.20)	$Y_{SB3,G440}$ = 1.99 (1.00)	$Y_{SB4,G440}$ = 1.99 (1.00)	$Y_{SB5,G440}$ = 1.99 (1.00)	$Y_{DPe,G440}$ = 1.07 (0.80)	$Y_{DW,G440}$ = 2.30 (1.73)	$Y_{DPo,G440}$ = 2.26 (1.70)	$Y_{CH,G440}$ =2.00 (1.50)

Table 8: The values of $\beta_{r,s,v}$, r = Waikato River (Wk) or Waipa River (Wp); s = Pasture (P) or Forest (F) and v = TP, TN, SS, G440 or FSS. These were obtained during the calibration of the model to the Current State.

		s = P	s = F
v = TN	r = Wk	$\beta_{Wk,P,TN}$ = 0.40	$\beta_{Wk,F,TN}$ = 0.40
	r = Wp	$\beta_{Wp,P,TN}$ = 1.35	$\beta_{Wp,F,TN}$ = 1.35
v = TP	r = Wk	$\beta_{Wk,P,TP}$ = 0.10	$\beta_{Wk,F,TP}$ = 0.10
	r = Wp	$\beta_{Wp,P,TP}$ = 1.50	$\beta_{Wp,F,TP}$ = 1.50
v = SS	r = Wk	$\beta_{Wk,P,SS}$ = 2.50	$\beta_{Wk,F,SS}$ = 1.00
	r = Wp	$\beta_{Wp,P,SS}$ = 2.50	$\beta_{Wp,F,SS}$ = 1.00
v = FSS	r = Wk	$\beta_{Wk,P,FSS}$ = 0.25	$\beta_{Wk,F,FSS}$ = 0.00
	r = Wp	$\beta_{Wp,P,FSS}$ = 0.50	$\beta_{Wp,F,FSS}$ = 0.50
v = G440	r = Wk	$\beta_{Wk,P,G440}$ = 0.75	$\beta_{Wk,F,G440}$ = 0.75
	r = Wp	$\beta_{Wp,P,G440}$ = 0.40	$\beta_{Wp,F,G440}$ = 0.00

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Appendix 14: Wastewater Management

1. Introduction

Point source discharges of municipal and industrial effluent contribute organic, suspended solid, nutrient and pathogen loadings to the river. All municipal and industrial point source discharges must have resource consents. The resource consents stipulate the flow and load or concentration limits that the discharge must comply with. Most discharges will require some degree of onsite treatment to comply with these conditions.

Within the Study area, there are a total of 13 sewage discharges. The consents and Assessment of Environmental Effects (AEEs), where available, have been reviewed for all municipal wastewater treatment plant (WWTP) discharges greater than 100m^3/d. These are summarised in Table 1. There are also 16 industrial discharges, some of which are discharged to land. These are also summarised in Table 1.

The Waikato Catchment Model (refer Appendix 13: Water quality) has shown that the overall contribution of the municipal and industrial discharges to the organic, solid, pathogen and nitrogen load is minor when compared to the diffuse source loads. In a few locations the phosphorus contribution associated with some (but not all) municipal discharges has been shown to have a significant impact on water quality. This is primarily associated with the large point source discharges to the lower Waikato. Specifically reducing the phosphorus load from targeted discharges could be achieved through onsite treatment (for example chemical dosing, volume reduction, biological phosphorus removal) or by eliminating the discharge to the river altogether and disposing to land.

In addition, land disposal of effluent from municipal WWTPs is seen by many Waikato iwi as preferable to water discharge, as they and many other Maori have a strong cultural belief that human wastes should be cleansed through contact with land before returning to water bodies.

Based on the findings of the water quality modelling described in Appendix 13, there are a small number of discharges that may require targeted phosphorus reduction. However the primary driver for land disposal is for cultural wellbeing. This appendix considers the costs and implications of implementing land disposal schemes for all municipal wastewater treatment plants discharges greater than 100 m^3/d within the study area.

Table 1: Point source discharges in the Study area (DWF = dry weather flow).

Municipal			Industrial		
Discharge	**Average DWF (m³/d)**	**Receiving River**	**Discharge**	**Average DWF (m³/d)**	**Receiving River**
Te Kuuiti WWTP	**4,200**	Waipa	Te Awamutu Dairy Factory	5,128	Waipa
Otorohanga WWTP	600	Waipa	Roto-o-rangi Piggery	330	Waipa
Te Awamutu WWTP	600	Waipa	Taupoo Timber Mill	Land	Waikato
Templeview WWTP	**750**	Waipa	Prawn Farm Wairakei	864	Waikato
Taupoo WWTP	8,640	Land	Wairakei Power Station	95,040	Waikato
Tokoroa WWTP	**4,000**	Waikato	Ohaaki Power Station	86	Waikato
Cambridge WWTP	2,000	Land	Reporoa Dairy Factory	Land	Waikato
Hamilton WWTP	**224,000**	Waikato	Kinleith Pulp Mill	87,600	Waikato
Ngaaruawaahia WWTP	**2,000**	Waikato	Litchfield Dairy Factory	2,200	Waikato
Huntly WWTP	**1,500**	Waikato	Hautapu Dairy Factory	2,200	Waikato
Tuakau WWTP	4,500	Waikato	Te Rapa Dairy Factory	10,000	Waikato
Te Kauwhata WWTP	**1,100**	Waikato	Affco Horotiu	4,838	Waikato
Meremere WWTP	**160**	Waikato	Johnson Piggery	104	Waikato
			PIC Maramarua Piggery	88	Waikato
			Waikato By-Products	1,000	Waikato

Notes: 1. Flows shown in bold taken from AEEs or consents. All others sourced from NIWA or EW monitoring.

2. Methods

WWTPs within the Study area that do not currently have land disposal have been identified from the Environment Waikato (EW) consents GIS dataset. The AEEs for these plants were examined to see which land disposal options, if any had been considered in the applications for resource consent.

Land disposal can be achieved in many ways with the most common in New Zealand being either slow rate irrigation (SRI) to pasture or forest, discharge via a wetland or discharge to a Rapid Infiltration Basin (RIB).

Slow rate irrigation (SRI) is the application of effluent to land at rates that infiltrate into the soil without overloading it (in terms or moisture or nutrients). The land may be used to grow crops or pasture, though the end use of anything grown on the land needs to be considered when considering the suitability of it for effluent application. For example, land used for dairy pasture requires that the standard of effluent applied to it is of a much higher quality than for other land uses[1].

Wetlands involve the creation of an area where the water surface is at or above the ground surface for a long enough period to maintain saturated soil conditions and the growth of related wetland vegetation. Wetlands can be designed either as a treatment system or as an effluent polishing system. The degree of removal of Biochemical Oxygen Demand (BOD, a measure of organic waste strength), total suspended solids (TSS) and faecal coliforms/*E. coli* will be a function of the hydraulic, solid and biological loading. The longer the residence time, the greater the degree of treatment will be. It is not uncommon for some communities to have wetlands as either a primary or secondary treatment stage. To achieve the objective of land disposal the wetland needs to be loaded at a "polishing" rate. Many of the Waikato WWTPs already have wetlands as part of the treatment process.

Rapid Infiltration (RI) is when wastewater infiltrates vertically into the ground from basins that are periodically flooded. The water percolates through the soil to the groundwater and eventually flows to a surface water body. The soil conditions are important for RI; highly permeable soils such as sands gravels or sandy loams that drain efficiently are required. For example, in the Waikato region, the Cambridge WWTP discharges via RI beds. Once inundated with effluent the RI bed requires several days to drain and refresh ready for the next application. As a consequence RI systems require relatively large areas to allow for cycling through individual beds.

[1] Fonterra require that any municipal wastewater which is applied to dairy land pasture is treated to meet the California Title 22 Standards (Fonterra Public Statement "*Human Effluent to Pasture*" 2007) disinfection standards.

Two WWTPs in the study area have full scale land disposal systems consisting of either land irrigation or rapid infiltration beds (Table 1). A small number of WWTPs have tertiary rock filters or rock lined channels which are intended to bring the effluent into cleansing contact with the land prior to discharge to surface water. Usually the use of rock filters/channel process have been developed in consultation with local iwi and granted consent. We have therefore considered it to be a culturally acceptable solution specific to that site. The WWTPs where “land disposal” is used are:

- Cambridge Rapid Infiltration Beds
- Taupoo Land irrigation
- Te Awamutu Rock lined channel
- Meremere Rock filter
- Templeview Rock lined channel

3. Goals

Provide a wastewater treatment process that produces a high quality effluent and that, where economically feasible, meets the cultural aspirations of Maori by including land treatment.

4. Phosphorus removal actions

Tables 5 and 6 of Appendix 13 summarise the nutrient loads to the Waipa and Waikato Rivers. The two biggest contributors of phosphorus to the Waikato are the Hamilton WWTP (Consented 700kg/d during winter and 100kg/d during summer) and the AFFCo Horotiu Meatworks (100kg/d).

The Hamilton WWTP is currently in the process of installing a chemical dosing system to remove phosphorus in order to comply with their consented phosphorus limit. The alum dosing system will be in place by December 2010 and is intended as a five year temporary installation whilst Hamilton City Council (HCC) investigates the feasibility of modifying the existing biological treatment process to achieve biological phosphorus removal. The dosing is only required during the summer period (i.e., December through to May) when the impact of the phosphorus load on the river is at its greatest. The phosphorus concentration in the effluent is currently 4 to 5 mg/l. Once chemical dosing is implemented the concentration is expected to drop to approximately 2.2 to 2.3 mg/l.

The capital cost to implement the chemical dosing is $500,000, with a further $500,000 annual operating cost. The operating costs are primarily associated with the chemical consumption. However chemical dosing will result in approximately 30 percent more biosolids production. Until the solids stream upgrade is finalised (currently being implemented) the WWTP may incur a further $300,000 annual sludge disposal costs.

It should be noted that there is a practical limitation in what a chemical dosing or biological removal system can achieve in terms of final effluent phosphorus concentration. Chemical dosing can achieve concentrations as low as 0.5 to 1 mg/l however the quantity of chemical required to achieve this level is extremely high as the alum to phosphorus molar ratio increases rapidly with diminishing final effluent concentration. Some biological processes can achieve phosphorus concentrations of 1 mg/l when operated well and provided the influent Biochemical Oxygen Demand (BOD) to phosphorus ratio is maintained at 20:1 or greater. For both chemical and biological systems the influent composition needs to be carefully managed in order to maintain a consistent final effluent phosphorus quality.

The AFFCo Horotiu Meatworks currently treats it's wastewater in an anaerobic pond followed by an aerobic pond prior to discharge to the river. The site is currently undergoing a program of works to improve the treatment process. Covers are being installed on the ponds. A new evaporator process is being installed in the rendering plant and AFFCo will soon begin treating selected beef processing effluent streams with dissolved air floatation (DAF). The evaporator and DAF treatment will allow additional product recovery (protein and fat) with the co-benefit of reducing the nutrient load to the river.

The AFFCo discharge consent was granted in 2001 although Affco have recently been granted a variation to allow for a future dairy processing factory (not built yet) to discharge their waste stream to their treatment plant. The consent variation did not result in any changes to the consented volume or concentration limits. The timing of the future dairy factory is uncertain and may be several years away. The new treatment processes (evaporator and DAF) will allow the WWTP to have capacity for the future waste stream with the additional benefit of having discharge volumes and loads reduced below their consented limits in the interim.

With the AFFCo evaporator installation and waste reduction improvements the net reduction of nutrients to the river is expected to be 30 percent for nitrogen and 10 percent for phosphorus (this includes the dairy effluent).

Given that both sites are currently implementing works that within practical limitations that will reduce the phosphorus load to the river, we have not developed cost estimates for further load reduction. The extreme method for reducing the phosphorus load would be to implement a land disposal scheme which is evaluated further in this building block under the Land Disposal Actions

5. Land disposal actions

The technical and economic feasibility of land disposal has been investigated by the associated Local Territorial Authorities (LTAs) in some detail as part of the resource consent process for the following treatment plants:

• Pukete (Hamilton)	Middle Waikato
• Huntly	Lower Waikato
• Ngaaruawaahia	Waipa
• Te Kuuiti	Waipa
• Te Kauwhata	Lower Waikato
• Templeview	Middle Waikato

The most recent AEEs for the WWTPs within the study region were reviewed to see what options had already been explored for land disposal of their effluent.

Huntly and Ngaaruawaahia propose to obtain cultural acceptance of the wastewater discharge by undertaking a treatment plant upgrade and installation of a rock passage. The rock passage is claimed to meet Tainui acceptance as a means of obtaining cleansing contact with the land. Tainui have provided documented support of this proposal in the consent application AEE. The consent for both plants has not yet been granted for this discharge.

Hamilton - Pukete, Te Kuuiti and Te Kauwhata found land disposal to be technically feasible but uneconomic because of the cost of land. The Terra 21 study looked in great detail at the range of options for land disposal at Pukete and the suitability for application in the regional environment. Although three options were developed in some detail for Hamilton, and tertiary treatment with a habitat wetland was selected as the preferred option the scheme did not proceed. It was decided that the environmental benefits of implementing the scheme did not match the cost to the community. The Pukete plant recently renewed their discharge consent on the basis that they would upgrade the WWTP to achieve a better quality effluent. This upgrade is currently under construction and includes reduced daily load limits for nitrogen and phosphorus.

WWTPs within the study region that do not have land disposal costs publically available are:

• Otorohanga	Waipa
• Tokoroa	Middle Waikato
• Te Kuuiti	Waipa

South Waikato District Council (SWDC) advises that the Tokoroa WWTP is within the city limits and that the WWTP already occupies the full site footprint. Land disposal costs have not been developed as it has been deemed to be technically and economically unfeasible due to the lack of suitable land, high local land prices due to dairy farming usage, and long pumping distances to extend beyond city limits. It should be noted that the Tokoroa WWTP has advanced treatment processes including tertiary sand filters to remove nitrogen and are currently reviewing options to increase the treatment standard further.

Waitomo District Council advises that land disposal was investigated for Te Kuuiti WWTP and deemed to be technically and economically unfeasible. Their findings were reported in detail in the 2009 AEE. Costs have not been publically reported, however one of the major technical hurdles is that the soil moisture deficit is typically positive for no more than 6 – 8 weeks of the year which would mean that any irrigation or infiltration type scheme would be seasonal at best. In February 2010 Waitomo District Council received a Section 92 Request for Information as part of the consent process. The request specifically requires the Council to provide further information as to the options and costs for full and/or partial land disposal. Council advise that they are currently working through that process and developing costs. They are also consulting with the Joint Working Group regarding options. The group has representatives from the Maniapoto Trust Board.

Land disposal of municipal wastewater has been identified as a priority action primarily for cultural and wellbeing reasons. However, there are too many site specific constraints and considerations to develop a capital or operating cost that is meaningful. The consent holders are required to investigate the feasibility of land disposal as part of any consent renewal process. As the costs associated with land disposal schemes are particularly sensitive to the individual locations, the treatment processes already at the site, the soil types in the vicinity of the WWTP, the topography, the local climate, the soil deficit, local land values and predominant land use we cannot give an accurate estimate for land disposal for the sites within the study area.

To give an indication of the range of possible costs, we have created a 'cost curve' for land disposal schemes in New Zealand. The cost curve has been developed by collating information from a number WWTP schemes throughout the country where land disposal has either been investigated or implemented. The costs have been escalated to 2010 for comparison purposes (based on a 3 percent inflation rate). Due to the considerable number and range of variables the costs cover a large range and have been presented in terms of upper and lower bounds.

This cost curve has then been used to provide a range of possible costs for land disposal at WWTPs in the study area, based on their average daily design flows. This requires a number of assumptions to be made:

- There is suitable land in the vicinity of the WWTP. Pumping effluent excessively long distances is not allowed for within the cost curve.
- Climatic conditions make disposal to land possible.
- The majority of schemes used to develop the cost curve were based on slow rate irrigation. The curve is therefore biased towards this disposal option. Other methods may be more technically and economically feasible and would need to be evaluated on a site by site basis.

6. Risks and probability of success

Implementation of a land disposal scheme will either reduce or completely remove (depending on the selected process) the organic, solid, nutrient and pathogen loading to the river associated with municipal point source discharges of wastewater. However the Waikato Catchment Model has shown that the overall contribution of the municipal discharges to organic, solid, pathogen and nitrogen load is minor when compared to the diffuse source loads. In a few locations the phosphorus contribution associated with some (but not all) municipal discharges has been shown to have a significant impact on water quality. However, the phosphorus contribution of specific municipal discharges could also be reduced through advanced treatment, i.e., Biological Nutrient removal (BNR) or chemical dosing, at potentially less cost to implement than a full sized land disposal scheme. It can be concluded that the driver for land disposal is primarily for cultural reasons not water quality.

The land required will typically be high class soils/sand and probably already be used for farming or forestry and so an economic disbenefit would be the retirement of this land from rural productive use and loss of potential future income. The use of large areas of land previously zoned for reserve or recreational use for effluent disposal can also be a drawback, although there are a number of wastewater wetland schemes in New Zealand where these areas have the co-benefit of being special habitat areas where perhaps these did not exist under the previous land use.

The economic feasibility of land disposal is heavily reliant on a number of local conditions such as:

- The proximity of land with suitable ground conditions.
- The purchase cost of suitable land.

- Land use – for example land used for dairy pasture requires a higher quality of effluent.
- The proximity of sensitive environments.
- The climate and soil moisture deficit

For example, SRI to crops, pasture or forestry is often limited by the availability and proximity of suitable land, as well as seasonal issues such as rainfall, evaporation rates, groundwater levels and effluent volumes. In the case of the Waikato, much of the land is used for dairy farm pasture. Fonterra, who take the vast majority of milk produced in the Waikato region, have stated that they will accept the discharge of municipal effluent to dairy pasture only if it is treated to meet the California Title 22 standards, which is the standard required for non-potable reuse of treated municipal wastewater in California and other parts of the USA. This requires a significantly higher treatment standard than that required to discharge to wetlands or RI basins and in many cases is considered economically unfeasible.

The recent 2008 AEE submitted to Environment Waikato for both the Huntly and Ngaaruawaahia discharges stated that the disposal of effluent to land was not considered feasible, for the following reasons:

- Suitable land is likely to be used for, or associated with, dairy farming and an extremely high standard of wastewater treatment could be required, and even then, there could be questions about the acceptability of this practice with dairying.
- This land may not be available and land owners would want significant compensation.
- New treatment plants with disinfection would be required.
- Extensive infrastructure would be required for piping wastewater long distances.
- Discharges to the river would still be required for wet weather/seasonal events.
- The capital, operational and maintenance cost estimates are of a level that will not be affordable by the communities.

Upgrading the Huntly and Ngaaruawaahia WWTPs to the Title 22 standards alone was estimated to cost $14 - $27 million per plant. This does not include the costs for constructing the piping and irrigation infrastructure required for the land disposal schemes.

Te Kuuiti assessed RIB for its recent AEE and concluded that it was not feasible on the basis that either a large land area would be required due to the low soil permeability or it would need to be situated away from the WWTP. The Hamilton City Council Terra 21 study identified two sites that may be suitable for RIB for the Hamilton WWTP (Pukete); however for the remaining WWTPs there may not be suitable soils in the vicinity for RIB to be feasible.

Under current legislation territorial local authorities are responsible for collection, appropriate treatment and permitted disposal of wastewater from the communities in their districts. Many Councils in the Waikato Region have already considered "land disposal" when reconsenting their wastewater discharges. As is described in this report, some have proceeded to dispose of treated effluent "to land", while others have concluded that land disposal is not the preferred option for their communities based on social, cultural, environmental or economic grounds.

Nonetheless, when existing consents eventually expire, or new regional rules are enacted, Councils need to reconsider options for disposal of their treated wastewater - including revisiting land disposal. For such schemes designation, resource consenting and acquisition of land - including any buffer zones and service corridors - is likely to be difficult and time consuming. Indeed, for any disposal scheme - be they already established or new, land based or point source discharge disposal - the initial investigation, option development, consultation and consenting (or reconsenting) processes can take several years to get to point of lodging applications. Given their nature, they are typically publicly notified, with the submission, hearing and appeal processes often taking several more years to conclude before detailed design can commence.

The use of the cost curve to estimate the probable cost for implementing land disposal for all the Waikato WWTPs must be treated carefully. The curve will give an indication of the range and magnitude of what land disposal costs could possibly be. The costs for the schemes used to develop the cost curve varied significantly in terms of what was included or excluded, for example:

- Land purchase costs.
- Costs to upgrade treatment processes if higher effluent quality is required.
- Length and size of pumping mains to disposal site/s.
- Engineering and construction margins.

We do not have the detail to be able to delve into the costs and present them on a normalised basis, however, as previously discussed, there are already large variations in cost between schemes due to local conditions, and the variability in cost due to the above listed items being included or excluded reflects this. For example, the difference between two schemes of similar size but in different locations may be due to land purchase costs, where one scheme already has land available for land disposal, and the other must purchase land.

The majority of the costs used in the cost curve are for slow rate irrigation schemes. As a disposal option it is one of the least high tech but does require the largest land area. For this reason, for large urban areas, such as Hamilton, it is unlikely to be a feasible disposal option.

The vast majority of costs used to construct the cost curve are based on concept designs, and already inherently have large uncertainties associated with them. They also range in date from 1996 to 2010. Although we have escalated the costs by 3 percent/annum to bring them all to 2010 rates, this may not accurately represent the large increase in cost of land, pumps, pipes and irrigation equipment in the last 10-15 years.

We have not included all known costs in the cost curve. In particular, costs for Pukete (Hamilton) from the Terra 21 report, one cost estimate for the Blenheim WWTP and those for Templeview from the 1996 AEE (refer Table 2) have been excluded. We felt the data for these plants skewed the curve for the following reasons:

- The Terra 21 reports generally focused on more high-tech land disposal schemes such as RI and sub surface injection treatment or hybrid schemes whereas the majority of the other costs presented in the curve relate to SRI. SRI is typically more suited to smaller communities, as the land area required to dispose of effluent from a large urban community becomes restrictive.
- Some of the Terra 21 schemes were not designed to treat the entire effluent stream.
- One of the cost estimates we received for Blenheim STP was for a seasonal discharge scheme that only disposed of a portion of the treated effluent stream. This was not comparable to other schemes where the full effluent stream was disposed of.
- The cost estimate for Templeview was done 14 years ago. It is difficult to assess whether the 3 percent/annum escalation used for the other schemes still applies to a cost estimate done so long ago, particularly when it is known that the costs for land, pumps, pipes and irrigation equipment have increased significantly over the past 15 years.
- It is particularly unclear from the Templeview AEE what was included or excluded from the estimate and there were very few details of the scheme.

7. Costs and timelines

Table 2 summarises the existing available information regarding land disposal that have been considered in AEEs or other supporting documents for WWTPs that discharge to the Waikato River.

Figure 1 shows the cost curve developed to assist with cost estimation for land disposal schemes throughout New Zealand. Note the scatter of the data points which clearly shows the variability in land disposal costs between schemes. The yellow lines represent upper and lower bounds of cost and the black line is a medium estimate of cost.

The cost curve has been used to predict costs for implementing land disposal, primarily irrigation to land, schemes for WWTP that discharge to the Waikato River. In some cases, for example Pukete (Hamilton) and Te Kauwhata, site specific preliminary costs for land disposal have already been developed by others during the resource consent processes (these are presented in Table 2). In these cases, it would be more prudent to use the costs determined for the resource consent process rather than those developed by the cost curve.

When considering the results from the cost curve for the other WWTPs in the Waikato (refer Table 3), it is important to remember that these costs have been created in isolation of knowledge surrounding the local conditions for these WWTPs. In some cases the associated council may already have considered land disposal and considered it unfeasible for technical reasons. For example, at Te Kuuiti the soil moisture deficit is only positive for 6-8 weeks of the year. Extraordinary measures to change this type of situation have not been allowed for within the cost curves.

For a discussion on why cost estimates for Hamilton, Blenheim and Templeview have been excluded from the cost curve in Figure 1, refer to the final paragraph in Section 8 of this appendix. Table 3 summarises the outcomes from the cost model. Note that the costs have been presented as a range of values due to the high level of uncertainty associated with them. All costs have been presented to three significant figures. The locations of the WWTP discharges are shown in Figure 2.

Table 2: Review of AEEs for WWTPs Discharging to the Waikato River (see glossary for abbreviation definitions).

WWTP	Consent Number	Consent period	Land disposal info source and year	Design Flow (m^3/d)	Existing treatment	Existing disposal	Existing Land Disposal	Land Disposal Options Explored	Capital Cost Estimate	Annual Operating Cost Estimate
Hamilton	114674	20 years from 2007 i.e., expiry in 2027	2001	Based on average flow of 60,000	Preliminary treatment, primary settling, activated sludge with seasonal nutrient removal, clarification and UV disinfection	Multiport diffuser outfall in Waikato River	None	Subsurface injection	$10.0 mill (2001)	$540,000
								Rapid infiltration	$10.4 mill (2001)	$170,000
								Habitat wetland	$8.1 mill (2001)	$110,000
Te Kauwhata	117991	Previous consent expired July 2008. Application requests 20 year consent period i.e., expiry 2028	2008 AEE	1,100 ADWF	2x Aquamat ponds in series + wetland	Via wetland into Lake Waikare	Wetland not performing well	Construction of new wetlands	$3.0 – 4.8 mill (2008)	$160,000 – 180,000
				3570 Peak				Slow rate infiltration	$5.7 – 13.8 mill (2008)	$280,000 – 400,000
								Rapid infiltration	$4.5 mill (2008)	$320,000
								Gravel Seep	$2.8 mill (2008)	$190,000
Huntly	119647	Previous consent expired 2009. 20 year consent period sought i.e., expiry 2029	2009 AEE	1,500 ADWF	Two stage oxidation ponds, two stage wetlands for tertiary treatment and gravel filter (proposed to remove rock filter due to poor performance)	Discharge pipe and multi port diffuser to Waikato River	Gravel filter installed in 1999 as result of WDC/Tainui negotiations	Consent application based on construction of rock lined channel which is stated to meet Tainui approval subject to conditions.		
				11,500 Peak				Capital cost not stated. Operating cost also not stated but assumed to be minimal.		
Ngaaruawaahia	119642	Previous consent expired 2010. 20 year consent period sought from 2009 i.e., expiry 2029	2009 AEE	2,000 ADWF	Oxidation pond, wetland for tertiary treatment and rock lined channel. Wetland and gravel filter performing poorly - proposed to remove them	Discharge pipe and multi port diffuser to Waikato River	Gravel filter installed in 1999 as result of WDC/Tainui negotiations	Consent application based on construction of rock lined channel which is stated to meet Tainui approval subject to conditions.		
				11,200 Peak				Capital cost not stated. Operating cost also not stated but assumed to be minimal.		
Meremere	105031	Previous consent expired 2001. new consent expires 2018	2007 NIWA report	160 ADWF	Oxidation pond and wetland rock filter	Pumped to diffuser outlet in Waikato River	Wetland rock filter performing modestly	At the time of the AEE (2001) it was considered that the only land suitable for land disposal was too far from the WWTP to be economically feasible. Discharges to two existing wetlands was also considered, but was dismissed because of concerns over increasing the nutrient loads to these wetlands.		
				480 Peak						
Te Kuuiti	112639	Previous consent expired in 2005.	2009 AEE	4200 median	Activated sludge and clarifier with overflow to oxidation pond. UV disinfection.	Discharged to Mangaokewa stream	None. Local soils have low permeability and there are only a few weeks/year with positive soil moisture deficit.	Discharge to land (RI or Irrigation)	No costs presented but considered unviable due to unsuitable land/high purchase costs	
			Conversation with C. Van Ruen at WDC	5,750 88 percentile				Discharge to wetland	No costs presented but considered unviable.	
								Waitomo DC currently revising land disposal options and costs as response to Section 92 request.		

WWTP	Consent Number	Consent period	Land disposal info source and year	Design Flow (m^3/d)	Existing treatment	Existing disposal	Existing Land Disposal	Land Disposal Options Explored	Capital Cost Estimate	Annual Operating Cost Estimate
Templeview	101668	Existing consent expires 2015	1996 AEE	750 dry weather	Oxidation pond 2 stage. Information possibly out of date	Discharge to farm drain/tributary Koromatua stream	None (as at time of AEE) - stone lined passage on discharge may count as land disposal	Discharge to wetland	$22,000 - $42,000	Not given
				2000 peak storm				Irrigation to land is looked at but no cost is given		
								Construction of wetlands and overland flow are considered as tertiary treatment options but no costs are given		
Otorohonga	953619	Existing consent expires 2012	Resource consent document 1998 and annual monitoring report 08/09.	750 dry weather 5000 peak storm	Oxidation pond, treatment wetland and rock filled trench	Discharge to Mangaorongo stream	Rock lined trench may count as land disposal			
Tokoroa	930693	Consent expires 2011. Looking at 10 year consent period	Conversation with A Pascoe at SWDC	4000 m3/day dry weather or 6000 m3/day wet weather	Primary settling, activated sludge aeration, sandfilter, 2 digesters and UV	Discharge to Whakauru stream	None	The WWTP is situated within the town limits. Any land purchased for land disposal of effluent would have to be outside the town limits at a high purchase cost (due to dairy land use) and pumping/piping costs		
Cambridge		Existing consent expires 2016	Waipa 10 year plan and Waipa 2050 Base case wastewater profile. Telecon with B. Shaw at WDC.		Currently not complying with all resource consent conditions due to high inorganic nitrogen. $15mill upgrade planned for 2012-2014. Anaerobic pond, aeration lagoon, settlement basin, wetlands and rapid infiltration.	RI beds adjacent to Waikato River	RI beds	RI basins were part of an existing industrial site which Council took over. Costs associated to establish land based disposal therefore minimal and associated with refurbishment of existing beds.		
Te Awamutu	103373	Existing consent expires 2015. new consent under application	Waipa 10 year plan and Waipa 2050 Base case wastewater profile		Oxidation ponds converted to BNR activated sludge plant, clarifier, tertiary filter and UV disinfection (Unconfirmed)	Rock filter to Mangapiko stream	Rock lined trench may count as land disposal.			
Taupoo	116596	Discharge to land. Expires 31/12/2032	Telecon with E. Ensor at TDC	15,000 m^3/d	Irrigated to land at View Rd and Rakanui	Irrigation to land	Irrigation to land	$5,500,000 (1995)		

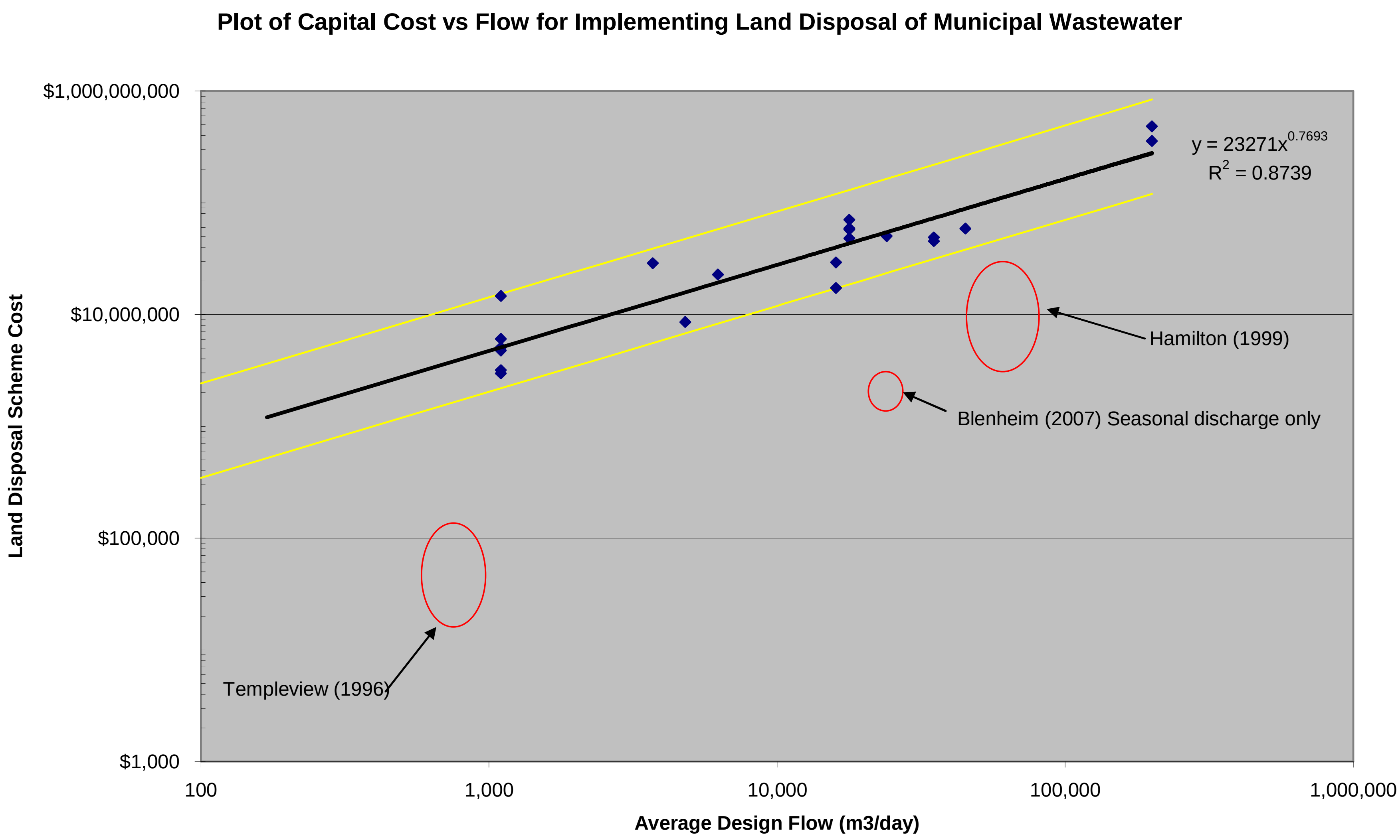

Figure 1: Cost curve showing the spread of cost estimates for land disposal schemes in New Zealand.

Table 3: Capital cost summary for land disposal options based on cost curve

Economic Zone	WWTP	Design Average Daily Flow (m^3/day)	Estimate of Probable Capital Cost ($2010, millions)			
			Low	Med	High	Notes
Upper Waikato	Taupoo	4,800	Already has a slow rate irrigation scheme			
Middle Waikato	Cambridge		Already has a rapid infiltration scheme, with a $13.5M upgrade over 5 years begun			
	Pukete (Hamilton)	60,000	$47.4	$110	$332	1
	Templeview	750	$1.63	$3.79	$11.4	2
	Tokoroa	4,000	$5.90	$13.7	$41.3	
Waipa	Te Awamutu	4,700	$6.68	$15.6	$46.8	2
	Te Kuuiti	4,200	$6.13	$14.3	$42.9	
	Otorohonga	750	$1.63	$3.79	$11.4	
	Ngaaruawaahia	2,000	$3.46	$8.06	$24.2	3
Lower Waikato	Huntly	1,512	$2.79	$6.50	$19.5	3
	Meremere	160	$0.496	$1.15	$3.47	4
	Te Kauwhata	1,100	$2.19	$5.09	$15.3	5
Total			**$78.3**	**$182**	**$548**	

Notes:

1. These costs vary significantly from those developed under Terra 21 and presented in Table 1. Costs used to develop the cost curve are primarily based on slow rate irrigation schemes which require a large amount of land. This may be impractical for a large urban centre such as Hamilton. The Terra 21 options were based on schemes requiring smaller footprints, which is why the costs under Terra 21 are less than those presented here.
2. Has an existing rock lined channel. These costs are for a more extensive land disposal scheme
3. For the Huntly and Ngaaruawaahia WWTPs, the predominant surrounding land use would more than likely require any effluent disposed to land to be treated to the Title 22 Standards. The additional cost to treat to this standard is estimated at between $14 and 22 million (as presented in the Huntly and Ngaaruawaahia 2009 AEE).
4. Costs had to be extrapolated from the cost curve due to the low flow
5. Compare to the costs presented in the 2008 AEE which ranged between $2.8 and $13.8 million

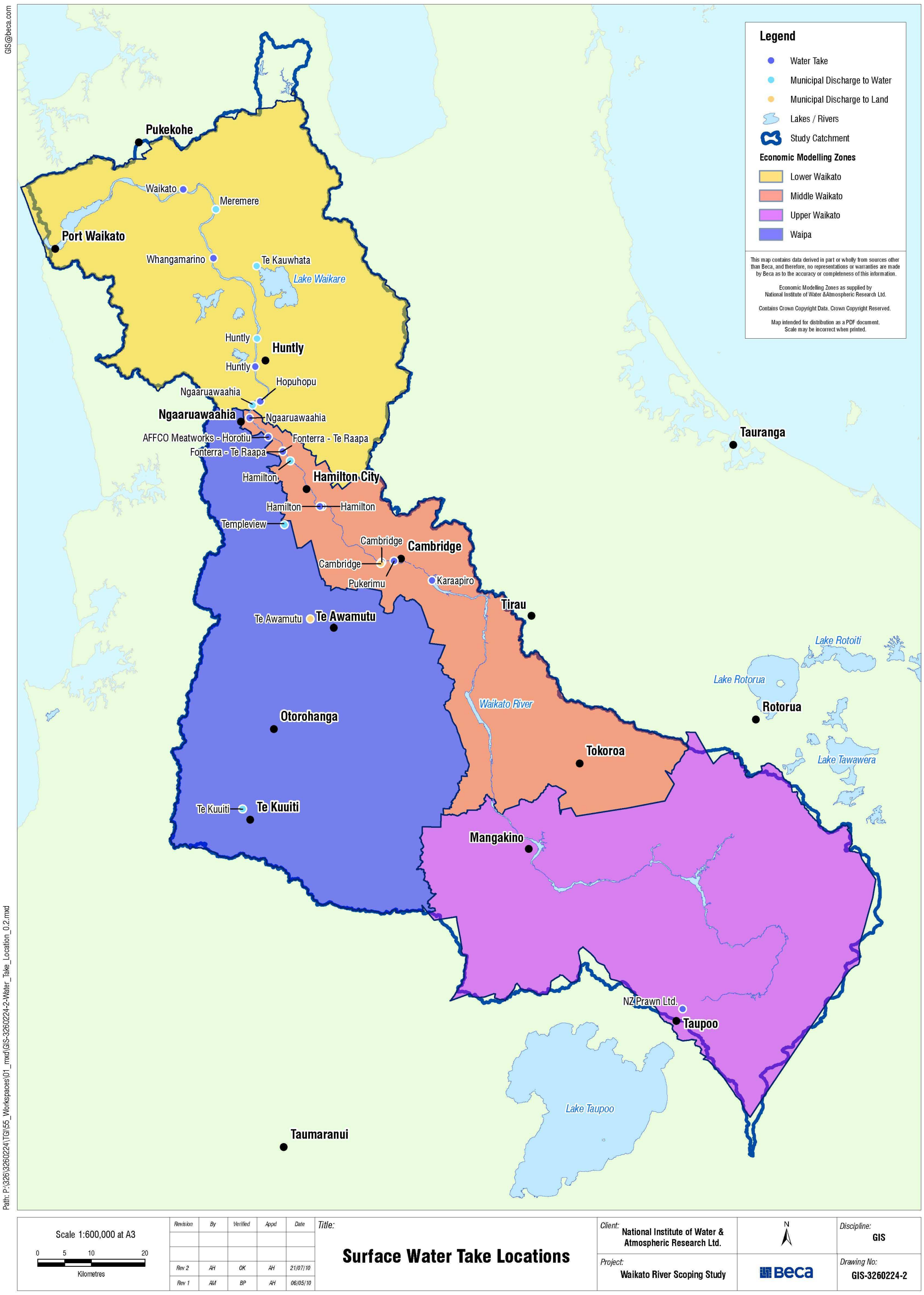

Figure 2: Locations of WWTP discharges in the Waikato River catchment.

Operation and Maintenance (O&M) costs will depend on the type of land disposal scheme implemented. Wetlands for example, are low-tech schemes and the operation and maintenance costs will be associated with monitoring effluent quality and maintaining and renewing vegetation etc. Other schemes, including SRI are more high tech and require continuous monitoring and maintenance of ground conditions, automatic control mechanisms, weed control etc. For all schemes a large cost component is for pumping the effluent to the disposal site. The distance to the site, the pumped flow and the topography of the rising main route will have a significant impact on the power consumption.

Table 4 summarises the estimates of O&M costs that were available from the Waikato WWTP AEEs. In these cases, the operating cost range from 1-7 percent of the scheme capital cost. At the Masterton WWTP preliminary investigations estimated that for SRI schemes the net operating costs, including revenue received from selling baleage, ranged from 2-5 percent of the capital cost of the irrigation scheme.

For the purposes of economic analysis, O&M costs for a wetland were assumed to be 2 percent of the capital cost and for SRI 4 percent of the capital cost.

Table 4: Operating cost summary for land disposal options as reported in AEEs.

WWTP	Order of Annual Operating Costs ($2010) [Percentage of capital cost]					
	Rock lined channel	**Gravel seep**	**SI**	**SRI**	**Wetlands**	**RIB**
Hamilton			$700,000 [5 percent]		$140,000 [1 percent]	$220,000 [2 percent]
Te Kauwhata		$200,000 [7 percent]		$300,000-$420,000 [3-5 percent]	$170,000 - $190,000 [4-5 percent]	$340,000 [7 percent]
Huntly	Proposed, cost not given					
Ngaaruawaahia	Proposed, cost not given					
Meremere					Considered unfeasible, costs not given	
Te Kuuiti					Considered unfeasible, costs not given	
Templeview					Considered, but costs not given	

For the purposes of economic modelling the following scenarios were used (Table 5):

Table 5: Modelling scenarios.

Scenario	Description
1	Based on compliance with existing resource consents. No additional cost for land disposal. Assume Huntly and Ngaaruawaahia consents for rock lined passage are granted.
2	Based on providing wetland treatment systems for those WWTPs that do not already have land disposal schemes (excluding rock lined passages). The flows can be deemed to have come into cleansing contact with the land but will ultimately end up in the river. Assume Scenario 1 for all others. It is assumed that the cost for wetland treatment corresponds to the medium cost from the cost curve.
3	Based on providing RIB or slow rate irrigation for all WWTPs that do not already have land disposal schemes (excluding rock lined passages). It is assumed the cost for RIB and SRI corresponds to a high cost from the cost curve.

Table 6 summarises the costs to be used in the economic analysis. For Pukete (Hamilton) and Te Kauwhata the costs from their respective AEEs have been used where available. Where a range of costs have been given for a scheme, the upper bound has been used.

For all other WWTPs where costs have been presented in Table 6, capital costs have been taken from the cost curve. O&M costs are based on 2 percent of the capital cost for BMP and 4 percent for EBMP. All costs are in $2010.

The timeframe for implementing a land disposal scheme can be relatively long due to the consulting and consenting requirements for implementing such a scheme. The initial investigation, option development, consultation and consenting can take several years. The detailed design and construction of the scheme could take anywhere between 1 and 3 years depending on the size of the scheme, once consent has been obtained.

Table 6: Costs for Economic Modelling Scenarios

Economic Zone	WWTP	Scenario 2		Scenario 3	
		Capital Cost ($mill)	Annual O&M Cost ($)	Capital Cost ($mill)	Annual O&M Cost ($)
Upper Waikato	Taupoo	Already has a slow rate irrigation scheme			
Subtotal Upper Waikato		**$-**	**$-**	**$-**	**$-**
Middle Waikato	Cambridge	Already has a rapid infiltration scheme			
	Pukete (Hamilton)	$10.6[2]	$140,000	$332	$13,300,000
	Templeview	$3.79	$76,000	$11.4	$460,000
	Tokoroa	$13.7	$270,000	$41.3	$1,650,000
Subtotal Middle Waikato		**$28.1**	**$490,000**	**$385**	**$15,400,000**
Waipa	Te Awamutu	$15.6	$310,000	$46.8	$1,870,000
	Te Kuuiti	$14.3	$290,000	$42.9	$1,720,000
	Otorohonga	$3.79	$76,000	$11.4	$460,000
	Ngaaruawaahia	$8.06	$160,000	$24.2	$970,000
Subtotal Waipa		**$41.8**	**$840,000**	**$125**	**$5,020,000**
Lower Waikato	Huntly	$6.50	$130,000	$19.5	$780,000
	Meremere	$1.15	$23,000	$3.47	$140,000
	Te Kauwhata[3]	$5.10	$190,000	$14.6	$420,000
Subtotal Lower Waikato		**$12.8**	**$340,000**	**$37.6**	**$1,340,000**
Total		**$82.7**	**$1,670,000**	**$548**	**$21,760,000**

[2] This is for a habitat wetland adjacent to the treatment plant which will not treat the full effluent stream, but does provide contact with the earth.

[3] Te Kauwhata already has a wetland, but it is not performing well. The cost presented here is to construct new wetlands.

Appendix 15: Water Allocation

1. Introduction

Until recent times, the Waikato region generally (with the exception of the Pukekohe region) has not had major issues allocating water, with relatively high water availability and modest demand (Enivornment Waikato, 2005). However, as stated in Enivornment Waikato (2008), "in recent times the method by which surface and ground water is allocated in the region has come under increasing scrutiny and sometimes criticism from both political and technical perspectives. The Ministry for Agriculture and Forestry and Ministry for the Environment (2002) recently projected a 202 percent increase in demand for irrigation water by 2010 in the Waikato region (an increase of 9,100 hectares over the present 4,500 hectares of irrigated land). In addition, there is also an increasing demand for water for community supplies, industry and stock water supplies. More and more frequently issues of resource scarcity and the equity and fairness of the present allocation strategies are being questioned in consent hearings and before the Environment Court."

The key issue around water availability for the purposes of this Study is that policies and rules about minimum flow supports restoration actions, particularly in respect to ecological flows and assimilative capacity of water (e.g., dilution of contaminants).

2. Water takes

As decscribed above, there is the general recognition that in many parts of the region, demand for surface water and ground water resources exceeds, or has the potential to exceed, surface and groundwater resources to sustainably meeting demands. Therefore a carefully managed water allocation regime is necessary.

The proposed variations to Policies and Rules in the Regional Plan Variation 6 (RPV6) addresses many of the implications of water take in respect to restoration. These include the implications for ecology, assimilative capacity and dilution of contaminants, tangata whenua values, water supply, efficient use of water, hydroelectric power generation, water contamination, holistic management and cumulative effects (Environment Waikato, 2008).

Policies and rules establish allocable and environmental flows from surface water and how surface water will be allocated. Priority for consideration for allocation has been given to water for domestic and municipal supply and replacement of existing water takes. Rules and policies have been set to ensure that water is available to:

- Meet the reasonable needs of individual and communities.

- Ensure ontinued water is available for renewable energy generation.

- Ensure water is available for in-stream requirements (i.e., 'ecological flows') during water shortages and droughts.

- Ensure consideration is given for sediment transport, flushing and erosion.

- Ensure that decisions on water allocation take account of the contaminant assimilative capacity of water bodies and take into account tangata whenua values, including mauri of the water.

Policy and rules are also included which manage the use of water, to ensure the efficient use of water, so that where water is in high demand, water use is maximised and wastage is minimised. In addition there are restrictions around the use of water for crop and pasture irrigation in the catchment of the Waikato River above the Karaapiro Dam and in the catchments of some peat and riverine lakes and wetlands. Consents require nutrient plans because the use of water for crop and pasture irrigation can result in increased discharges of nutrients to either surface water or ground water. These rules benefit the water quality and sustainability of shallow lakes and wetlands.

With controlled or discretionary takes, Environment Waikato reserves control over a number of matters including the following of direct relevance to restoration:

- Measures to satisfy the intake screening requirement to protect aquatic fauna.

- Effects on any waahi tapu or other taonga.

- Effects on the relationship of tangata whenua and their culture and traditions with the site and any waahi tapu or other taonga affected by the activity.

- Effects on the ability of tangata whenua to exercise their kaitiaki role in respect of any waahi tapu or other taonga affected by the activity.

Overall, the Study team concluded that RPV6 covers most of the implications of water take on restoration. There is one exception – it is described below.

3. Land use change

Low flows are are not only affected by water takes but also by land use change. This is not explicitly stated in RPV6. Appendix 24: Flow Effects concludes that land use change between forest and pasture alters the flow regime because vegetation type affects evaporation, interception losses of incident rainfall and soil moisture, which in turn affects runoff and grioundwater recharge. Changes in flow have additional implications for sediment and nutrient yields and resulting water quality, asimilative capacity, flushing sediment transport, flooding and instream habitat. They will also affect the availability of water for water take and power generation.

A review of relevant information available indicates that major land use change from pasture to forestry will reduce low and flood flows substantially (see Table 1). Both pine or native afforestation of catchments reduces runoff, but the impact of land use change to pine forest appears to be in the order of 5 times greater than native forest (see Table 1). Riparian forests have a small but possibly significant effect as well.

Table 1: Effects of land use change on flows.

Action	Low flow	Annual runoff reduction	Maximum flood flows in < 100 km^2 catchments
Pine afforestation of pasture	minus 50%	minus 300-400 mm (~35-45%)	minus 30% (~5-50%)
Native restoration of pasture	plus 10%	minus 70 mm (~7%)	minus 20%
15 m native riparian buffers	minus 3%	minus 30 mm (~3%)	minus 10%
5 m riparian buffers	minus 1%	minus 10 mm (~1%)	minus 3%
Wetland restoration effect per 1% increase in catchment area as wetland	plus 8%	nil	minus 4%

Therefore, the impact of land use change and riparian planting may need to be considered in deciding water takes. Default allocable proportions of total flow are given for catchments in the Waikato Region in RPV6 (Environment Waikato, 2008). The allocable flows are based on environmental flows and are typically within the range 0–30 percent of the one-in-five-year 7-day low flow (Q5).[1] Land use change from pasture to pine and native forests and extensive riparan planting may reduce Q5 (see Table 1). This needs to be considered when classifying water takes as controlled, restricted discretionary, discretionary or non-complying activity, and in calculating Q5 used to define environmental flows and allocable flows.

5. Recommendations

The Study team recommends the following targets be set for water allocation:

[1] The stream flow at any point that has a 20 percent chance of occurring in any one year (or a likelihood of occurrence of once in every five years, also termed a '5-year return period'). The Q5 is calculated from the lowest seven consecutive days of flow in each year.

- The Waikato River Authority keeps a watching brief on the ratification of RVP6 to ensure all proposed variations are included in the Regional Plan.

- Targets defined under Section 4.2.7 to improve water quality should be used when considering the effect of takes on the assimilative capacity of water bodies.

- Setting of environmental and allocable flows takes into account potential land use change under any funded restoration actions, in particular changes from pasture to exotic or native forests and creation of riparian forests.

6. References

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Appendix 16: Rural Water Supply

1. Overview

Rural water supplies are currently compromised through high nitrate in groundwater and poor quality of surface (stream) waters. There is also the risk of contamination of groundwater through improper use of pesticides. This is an issue of concern in the Waikato River ctachment. These are discussed below.

1.1 High nitrate concentrations

The high nitrate concentrations are mainly located in dairying catchments and reflect high nitrate leachate from intensively grazed pasture. In many areas groundwater quality is declining due to[1]:

- An increase in the amount of waste water discharged onto land – to about 460,000 m3/day.
- Increased use of nitrogen fertiliser.
- A doubling of stocking rates over the last forty years as animal waste from intensive farming contaminates groundwater with nitrate.

1.2 Faecal contaminations

Faecal contamination of waters is discussed in Appendix 10: Pathogens.

1.3 Pesticides

There is a risk of groundwater contamination by pesticides. Large quantities of pesticides are used in the Waikato River catchment. Environment Waikato surveys found that 335 tonnes of herbicide, 84 tonnes of insecticide and 155 tonnes of fungicide were used annually between 1985 and 1987[2].

Most pesticides break down at the surface or in shallow soil, but some mobile and persistent chemicals reach groundwater. In 1995, Environment Waikato investigated pesticide occurrence in groundwater at well sites where these chemicals were in regular use and the aquifers were considered vulnerable (Hatfield and Smith, 1999).

[1] http://www.ew.govt.nz/Environmental-information/Groundwater/
[2] As above.

Pesticides were detected in groundwater at 74 percent of this 'worst case' selection of 35 wells. Of the 20 different compounds detected, only dieldrin from sheep dip sites exceeded the drinking water guideline.

More recent surveys of 40 randomly-chosen community supplies and 40 regional supplies considered potentially susceptible to contamination show that[3]:

- Pesticides are contaminating some groundwater (about 10 percent of randomly-chosen community supplies surveyed).
- The concentrations of most pesticides detected are well below drinking water guideline levels, but the Ministry of Health's Maximum Allowable Concentration was exceeded for one pesticide in one community supply in 2004.
- Pesticides are more likely to be found in vulnerable, shallow, unconfined aquifers where use of relatively mobile and persistent pesticide chemicals is high, as shown in the regional survey of potentially susceptible supplies. Most pesticide contamination is because of poor management practices and historic use.

Health and environmental concerns have increased awareness of the need for careful pesticide management and have led to a decrease in use nationally in the last two decades. Also, much less persistent chemicals are now being used that more readily degrade to less environmentally harmful compounds.

3. A description of prioritied actions

On-farm management of nitrate contamination actions (outlined in Appendix 9: Farms) would reduce nitrate leaching as illustrated below (see Table 1).

[3]http://www.ew.govt.nz/Environmental-information/Environmental-indicators/Inland-water/Groundwater/gw2-keypoints/

Table 1: Impacts of on-farm management on nitrate leaching under an assumed infiltration rate of 400 mm/y.

	Current practice	Option 1	Option 2
Nitrate leaching rate (kg/ha/y)	39	17	15
Rainfall infiltration rate (mm/y)	400	400	400
Nitrate concentration in groundwater (mg/L)	9.8	4.3	3.8

The estimates in Table 1 are only approximate because nitrate concentrations depend on many processes and other factors. Present day nitrate levels under dairying typically approach the Water Quality Guideline of 11 mg/L. The estimates indicate that these on-farm management techniques will 'arrest' the trend for higher nitrate in groundwaters provided dairy intensification through increased stocking does not occur. Note that because of other factors some groundwater may still exceed the Water Quality Guideline of 11 mg/L, and so drinking water supply wells must still be tested and, if necessary, water treatment installed or alternative water supplies found.

Restoration actions to reduce fecal contamination of streams (fencing, riparian buffers, runoff controls) will substantially reduce the risk associated with drinking untreated surface waters, but will not eliminate them altogether because of feral animals (e.g., birds, possums), stock fence and effluent irrigation failures and contaminated surface runoff still reaching streams in some situations. Therefore, surface water will still need to be treated to eliminate that risk.

Environment Waikato is undertaking the following actions in respect to pesticide contamination[4]:

- Research and monitoring (as described above) to better understand pesticide contamination of groundwater in the Waikato River catchment. A range of information has been developed, including risk assessment tools and fact sheets.

- Encouraging farmers and other users of pesticides to use New Zealand Standard for Agrichemical Users Code of Practice known as Growsafe, to encourage careful application, storage and disposal of chemicals, especially around wellheads and water supply infrastructure.

[4] http://www.ew.govt.nz/Policy-and-plans/Regional-Policy-Statement/Regional-Policy-Statement-Review/RPSdiscussiondocument/2-Community-wellbeing/27-Hazardous-substances-and-contaminated-land/

- There are a number of rules and policies related to pesticide use. They include the promotion of land-use practices that minimise pesticide residue leaching and soil contamination.

- Helping develop national guidelines for the management of contaminated sheep dip sites.

The most important actions in respect to drinking water supplies and pesticide contaminantion is the safe and responsible use of pesticides and monitoring potential legacy issues. The Study team concludes that the actions currently being undertaken by Enviornment Waikato appear appropriate to address the potential risks.

4. References

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Appendix 17: Marae Water Supply

1. Introduction

There are approximately 67 marae within the Waikato and Waipa River catchments that have been identified as lacking access to a reticulated treated drinking water supply. The tribal affiliations of these marae and their distribution within the various zones of the Waikato and Waipa catchments are shown in Table 1.

Table 1: Estimated number of marae with non-reticulated water supplies**.**

Zone	Estimated number of marae
Lower Waikato	15
Waipa	27
Middle Waikato	17
Upper Waikato	8
Total	67

The exact size of these marae is unknown, but it can be assumed that an average marae may have a population as follows:

- 10-20 people on a daily basis
- 200-400 people once a month
- 2000+ people four or five times a year

Because of the range of numbers that might be present on a marae at any particular time, it is assumed that water supply planning should be based on a once-a-month sized event. For larger events, tankered water (from a municipal supply meeting national drinking water standards) will need to be brought in to meet demand and to match the quality standards.

A per person water consumption rate of 400 L/person/day has been assumed, though this is probably generous. Per capita water demand at marae is typically lower than for residential dwellings. Visitors to the marae, for example, do not necessarily expect to bathe as frequently or wash their clothes as often as they do at home. Water is mainly used for drinking, food preparation, washing hands, and toilet flushing.

For most marae a 'point of entry' type water treatment system will be suitable. A reliable source of raw water is required and the system treats the water as it enters the site.

2. Goals

The majority of New Zealanders, most of them Maaori, on average visit marae as their primary Maaori cultural experience, (Statistics New Zealand and Ministry for Culture and Heritage, 2003). Of the three Maaori cultural activities experienced during the 12-month reference period prior to this study, the most popular was visiting a marae, with 543,000 people, or one in five New Zealand adults, having done this. Over a 12 month period 25 percent of people living in the Waikato region visited a marae.

With the marae as the centrepiece of Maaori community life, a reliable and safe marae water supply was identified as a priority by the five river iwi (NIWA et al., 2009). While the typical day to day marae population may be relatively small, there will be times (e.g., hui and tangi) where large groups may gather. During these times, the water supply and other sanitary services come under pressure. The goal is that these communities have access to safe drinking water (meeting the national drinking water standards) at all times.

3. Actions

In the absence of access to a reticulated treated water supply a suitable standard of treatment can be achieved by a locally available water treatment plant (WTP) package. A range of cartridge filtration/UV disinfection WTPs are available with capacities able to meet the needs of marae with monthly gatherings of 108 to 612 people.

If properly operated and maintained package WTPs should provide water of a sufficient standard and maintenance is relatively simple. The recommended action therefore is that WTPs are installed at all marae.

4. Risks and probability of success

The recommended WTPs are suitable for the numbers expected at a typically sized monthly marae gathering. At larger events tankered water will need to be brought in to cope with demand. It is uneconomic to design a water treatment system for large gatherings of people when it will be used relatively infrequently. Also, such large sudden demands on a water source such as a spring or well can cause flowrates that will draw contaminants into the supply from the surrounding soils.

The reliability of a WTP relies on regular maintenance. A member of the local community will need to be trained to carry out day-to-day maintenance of the plant, including changing the filters. If the plant is not properly maintained drinking water quality declines.

A reasonable standard of source water has been assumed to be available at all marae. If the source water is of poor quality (e.g., has high turbidity or high concentrations of heavy metals or other contaminants) more extensive treatment may be required to bring the water to the same quality (at an additional cost). Sources with slightly elevated turbidity may result in higher operating costs, due to the need to replace filters more frequently as they become clogged.

If the water source is not close by there will be additional costs associated with piping the water to the marae.

It is assumed that the amount of water able to be supplied to the marae is limited by the water treatment plant, and not by the amount of raw water taken from the source (e.g., in summer, low river flows will not restrict the amount of water treated and supplied to the marae). If the reliability of the source is not good, the marae may have to rely on other water sources (e.g., tankered water) during times of short supply.

5. Costs and Timelines

The following cost estimates has been based on an average monthly population of 360 people. This will not be appropriate for some marae where the average size of monthly gatherings could be smaller or larger. Also, costs have been based on the assumption that the raw water supply is of a reasonable quality. The actual costs may vary on a case by case basis due to differing raw water qualities.

The WTP package includes the following:

- Raw water pump, turbidity meter and settling tank.
- Multimedia sand filter.
- Cartridge pre-filter and filter.
- UV disinfection unit.
- Chlorine storage tanks and dosing equipment.
- pH correction filter.
- Installation.

- Three days treated water storage.

The cost estimates in Table 2 are based on figures provided by a local WTP supplier who specialises in the supply, installation, commissioning and servicing of water treatment equipment. Note that the cost estimates are GST exclusive.

Table 2: Costs for a package WTP suitable for marae use.

Item	People attending a monthly event			
	108	**234**	**360**	**612**
Capital Cost per package plant	$38,400	$73,100	$106,200	$143,000
Preliminary and General (12%)	$4,600	$8,800	$12,700	$17,200
Design (5% as package plant)	$2,200	$4,100	$5,900	$8,000
Contingency (30%)	$13,600	$25,800	$37,400	$50,500
Total Capital Cost	$60,000	$112,000	$160,000	$218,000
Annual Operating Cost	$2,000	$4,200	$6,300	$16,100

The total costs to construct package WTPs at all marae within the Waikato/Waipa catchment are given in Table 3. It is likely to take 3 to 6 months from time of order for a WTP to be installed.

Table 3: Cost estimates for providing marae WTPs (based on a monthly gathering size of 360 people).

Item	Zone			
	Lower	**Waipa**	**Middle**	**Upper**
Estimated number of marae	15	27	17	8
Cost per package WTP	$106,200	$106,200	$106,200	$106,200
Annual operating cost per package plant	$6,300	$6,300	$6,300	$6,300
Subtotal	$1,590,000	$2,870,000	$1,810,000	$850,000
Preliminary and General (12%)	$191,000	$344,000	$217,000	$102,000
Design (5% as package plant)	$89,000	$161,000	$101,000	$48,000
Contingency (30%)	$561,000	$1,013,000	$638,000	$300,000
Total Capital Cost	$2,430,000	$4,390,000	$2,770,000	$1,300,000
Annual Operating Cost	$95,000	$1,700,000	$107,000	$50,000

6. Uncertainties and information gaps

NIWA is leading a research programme on *"Ecotechnologies for sustainable wastewater management for Māori communities"*. Although the primary focus of this research is the development of appropriate wastewater treatment systems for marae and papa kaainga, some of the information gathered (e.g., marae usage, occupancy numbers, and water usage) would be useful in the planning for marae water supplies. This programme will also provide training for Maaori to undertake water usage monitoring; provide decision support tools that identify water and wastewater management options that align with the cultural, health and environmental sustainability aspirations of Maaori; and provide educational materials (e.g., on water conservation) specifically for marae communities. This research programme is due to be completed by October 2012 but some of the data relevant to marae water supply planning should be available by July 2011.

The costs for WTP installation could be refined if typical daily and peak monthly population figures could be provided for all of the marae within the catchment which lack reticulated water supplies.

7. References

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Appendix 18: Urban Stormwater

1. Introduction

This paper examines the impacts of urban stormwater on receiving waters and assesses potential actions for the Waikato River catchment to remedy those impacts. In urban areas, stormwater flowing off surfaces such as roads, pavements and roofs can contain elevated levels of a range of pollutants including vehicle fuel and oil, heavy metals, rubbish, fertilisers, pesticides and fine sediment. This stormwater can cause adverse effects when it enters the streams and rivers flowing through an urban area, as has been described for Hamilton streams (Williamson, 2001; Collier et al., 2008) and comprehensively studied in Auckland streams (as reviewed in Mills and Williamson, 2009).

As well as the effects of the quality of stormwater, urban streams may also be affected by higher flows during rainfall, and sometimes lower flows during dry weather. Channels may be extensively altered physically by channelisation and culverting, disruption to fish passage and loss of riparian vegetation. Thus these aquatic ecosystems may be affected by a large number of stressors including increased light levels, deposition of fine sediments and elevated turbidity, physical changes, high (and low) flow, and presence of toxic contaminants. The effect that this has on stream ecology is decreased biodiversity with fewer species of fish and invertebrates and dominance by a few tolerant species, and sometimes higher concentrations of algae and more macrophytes. This has found to be the situation for Hamilton's urban streams (Williamson, 2001; Collier et al., 2009). Stormwater can also affect larger aquatic systems such as lakes and large rivers but the impacts are mainly associated with contaminants and fine sediment (Williamson, 1999; NIWA, 2001).

The severity of the effect that stormwater runoff has is usually proportional to the area of urban land use directly connected to the receiving water. This can be measured as the percentage of the catchment with impervious cover (%IC) and has been shown to be a useful predictor of potential impacts of urbanisation on stream health (ARC, 2004). It has been found, both overseas and in New Zealand, that catchments with <10 %IC can support aquatic communities that are largely unmodified (Stark, 2006). This can vary from site to site depending on local differences in instream habitat and riparian quality. When %IC increases beyond 10 – 15 percent it is common for stream health to be affected. Beyond 25 percent, streams can become highly modified. This is consistent with the findings of a recent study of Hamilton City streams (Collier et al., 2009). Within the Waikato River catchment, the extent of aquatic habitat degradation caused by urban stormwater will be confined to a relatively small area because the proportion of the streams and rivers that have more than 10 %IC in their catchment area is relatively small. As a consequence the effect on larger water bodies is relatively minor. For example, the effect that Hamilton has on the Waikato River will be highly localised to where urban streams discharge into the main stem (NIWA, 2001), because contaminant concentrations and flow effects are likely to be rapidly diluted and attenuated (Williamson, 1999).

Urban stormwater discharges from other towns along the Waikato River (i.e., Cambridge, Huntly, Ngaaruawaahia, and Tuakau) are also unlikely to have any significant widespread impact. Te Awamutu may have minor effects on the Mangawhero but Otorohanga is unlikely to have any significant widespread impact on the Waipa River. However, all these towns will have impacts on any small streams in these urban areas or on streams flowing through the town where urban landuse forms more that 10 – 25 percent of the catchment area.

2. Actions

It has been suggested that urban stream restoration needs to focus on actions within the catchment itself rather than instream or riparian habitat (Roy et al., 2006). Drainage systems need to be designed to reduce the amount of impervious surface area causing stormwater to flow directly into urban streams through stormwater pipes by maximising runoff detention, infiltration and off-channel retention of water (Taylor et al., 2004; Walsh 2004; Walsh et al., 2005) but at the same time still serving their primary function of flood control. This has multiple benefits: reducing stormwater runoff volumes, increasing infiltration (and hence low flow), reducing the mobilization and transport of contaminants to receiving waters and reducing instream erosion and the need for channel works to safely convey high flows. Appropriate technology can be implemented with relative ease in many new developments, but there are obvious difficulties and costs associated with retrospectively disconnecting stormwater systems. There is a growing trend in New Zealand to implement these designs in new developments. The major issue is the slowness with which these measures and new technologies are adopted by territorial authorities.

Older urban areas pose the biggest challenges for effective management of stormwater as it is technically difficult and costly to retrofit environmentally-sensitive design and treatment. Local authorities are deterred from using these new technologies and methods because of the extremely high cost and the uncertainty of the significant benefits which might accrue. Based on cost estimates of about $11b (in 2004) to meet stormwater goals for the greater Auckland area (Infrastructure Auckland 2004), comprehensively addressing stormwater impacts in Hamilton and regional towns would be estimated to cost around $1b.

In older urban areas, where options for catchment management options are more limited and expensive, some impacts can be addressed in the receiving waters. Gully restoration in Hamilton has been achieved at relatively low cost and produced clear environmental benefits for local streams.[1] Restoring natural vegetation and fostering native terrestrial biodiversity in the gullies of Hamilton City has also linked terrestrial restoration with the protection and enhancement of aquatic values (Clarkson and McQueen, 2004).

A recent study has examined restoration options for the aquatic habitat and fauna of Hamilton City streams (Collier et al., 2009). The four tributary stream/gully systems in the city have been recognised as major geomorphological features and part of Hamilton's character (Wall and Clarkson, 2001; Clarkson and McQueen, 2004). They have a combined length of about 120 kilometres and form 8 percent (750 hectares) of the city's area. The headwaters of these streams lie outside the city boundaries in farmland and water quality is therefore affected by both rural and urban runoff, as well as groundwater inputs containing high iron concentrations (Williamson, 2001). Collier et al., (2009) found that the occurrence of macroinvertebrates (e.g., insects, snails, and kooura) indicated that stream habitat in the city ranged from poor to good, and occasionally very good. They also supported a reasonably diverse fish population. Shortfinned and longfinned tuna were reasonably common, while giant and banded kookopu, iinanga, and smelt were found at 2-6 sites in the city.

Factors impacting restoration actions considered included:

- Cities are where people interact with biodiversity most often, so restoration of urban streams was considered a priority.

- Restoration appeared to be constrained by hydrology and possibly by contaminants. Minimising the connection between urban streams and impervious area was seen as high priority for protecting high-value streams and seepages.

- The presence/absence of animals indicated that riparian planting to provide shade, organic matter, and woody debris would be beneficial. However, because of potential flooding issues, the addition of wood debris would need to be handled carefully. (The ongoing gully restoration will hopefully fully utilise riparian planting as a management technique).

- There were 46 barriers to fish migration created by poorly-positioned road culverts. However, there is the danger that removing the barriers would allow ingress by troublesome pest fish, so fish ladders may be the preferred option.

- Restoration of fish communities was seen as challenging – apart from restoring passage and riparian vegetation as described above. Rather, the

1 http://www.gullyguide.co.nz/files/Gully%20Book%20Mar%2007.pdf

addition and enhancement of iconic native species (e.g., giant kookopu) was seen as attainable goal, by introducing farm-raised species.

Hamilton City Council and Environment Waikato have made considerable progress in the management of Hamilton's urban stormwater. As a result additional attention to urban stormwater does not need to be a high priority. There is already sufficient guidance and technology available for local authorities to continue to address stormwater issues in new subdivisions. If these were carried out then there should be a good fit with other restoration activities in the Waikato River catchment. The Study team concluded that given that there are sufficient means available to address new urbanisation in the Waikato River catchment urban stormwater impacts in new areas should be a relatively low priority for the Waikato River Authority, compared with other issues considered.

However, the issue of comprehensively addressing the impact of existing urban areas is very challenging and expensive. Comprehensively retrofitting urban-sensitive designs or stormwater treatment devices in older areas, so that runoff volumes, flow rates and contaminant levels are reduced to levels that do not seriously impact streams is possible but will be very costly.

In older urban area, the Study team recommends the following actions:

- Restore stream and riparian habitat to the extent possible and investigate means to increase aquatic life (e.g., restocking iconic native species).
- Restore fish passage, by using devices that allow the passage of climbing glaxiides but not pest fish. Where these are installed eliminate pest fish upstream and restock with iconic native species.
- Reduce runoff volumes and flows by encouraging controls at the source (e.g., financial incentives for land owners to slow and treat runoff). These could also include incentives that reduce runoff rates by encouraging the reduction in impervious areas, the implementation of ground soakage (where possible) and installation of simple on-site treatment (such as rain gardens). Because there are risks associated with these measures, it is essential that there is clear guidance available (e.g., 'how to' and 'where to' handbooks).
- Continue, and enhance, education programmes for the community about connectivity of urban areas to waterways and the danger created by disposal of wastes on impervious areas and stormwater systems.
- Continue, and enhance, inspections of businesses (and their stormwater systems) that store and use substances that could contaminate stormwater, especially those businesses that fall within those categories recognised as potentially hazardous (on the Hazardous Activities and Industries List[2]).

[2] http://www.ew.govt.nz/Environmental-information/Hazardous-substances-and-contaminated-sites/Contaminated-sites/Managing-contaminated-sites/

These actions would restore aquatic resources in areas where people interact with biodiversity most often. While they will not result in full restoration, the measures are comparable with those proposed for the wider, and much larger, rural environment (e.g., see Appendix 11: Riparian Aesthetics). There would be restoration of 1st and 2nd order streams comparable with riparian planting in pasture land, enhancement of aesthetics and access, restoration of banded kookopu, tuna habitat, and other taonga species, as well as addressing education and engagement. The Study team concluded that while these measures are largely the responsibility of town and city councils, the Waikato River Authority could work with councils to expand restoration activities to include taonga species. In addition, the links between restoration in 'town and country' should be part of the Waikato River Authority's education and engagement programmes.

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