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Recommended biological and water quality limits for trout fishery and trout spawning waters in the Wellington Region

May 2013

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Cover photographs: Top: Ruamahanga River at Mt Bruce (Photograph by Summer Greenfield); Bottom Left: Mangatarere Stream downstream of Dalefield Road (photograph by Olivier Ausseil); Bottom Right: Hutt River at Te Marua Photograph by Summer Greenfield)

EXECUTIVE SUMMARY

Greater Wellington Regional Council (GWRC) is in the process of developing technical recommendations to support its second generation Regional Plan. This report is one of a series of technical reports on the Wellington Region's streams and rivers, destined to inform and support the policy development process, in particular the development of biological and water quality limits in relation to different management purposes.

Trout fishery is one of the management purposes identified in GWRC's proposed Regional Policy Statement (RPS). A number of other freshwater management purposes, such as aquatic ecosystem health, contact recreation, amenity and stock drinking water have also been identified in the Wellington Region. Separate technical reports make recommendations for biological and water quality limits in relation to these management purposes.

"Trout fishery" as a management purpose includes a number of aspects, some directly relating to the requirements of healthy trout populations (e.g. habitat, food, reproduction) and some relating to the "human" aspects of a trout fishery, such as aesthetic, amenity and natural character values, "fishability", quality or quantity of fish, etc. Where possible, this report recommends biological and water quality limits in relation to these different aspects. Limits are recommended in relation to key biological and water quality determinands that were considered to have direct relevance to the state of trout fisheries and trout spawning.

Under the current provisions of the proposed RPS, the trout fishery management purpose applies in some selected waterbodies and comes in addition to the aquatic ecosystem management purpose. As a result, the limits recommended in this report are in addition to the biological and water quality limits recommended for water to be managed for aquatic ecosystem health (Greenfield, 2013a and 2013b; Ausseil, 2011a).

The biological and water quality limits recommended in this report for waters to be managed for trout fishery in the Wellington Region are summarised in Table A.

In order to present a comprehensive and consistent set of recommended biological and water quality limits for each water body, catchment or any other freshwater "management unit" that may be defined, for inclusion in the regional plan, the following steps are recommended:

- identify and compile the management purposes that apply to each "management unit";
- compile all the biological and water quality limits that apply to each management purpose in each "management unit";
- for each biological and water quality determinand, identify a limit that will enable the maintenance of all management purposes.

Further work is also recommended in relation to the development of in-stream sedimentation limits and the application of the recommended limits in the Regional Plan and subsequent resource management processes.

Table A: Summary of recommended biological and water quality limits for waters managed for trout fishery and trout spawning purposes.

Water quality determinand	Trout Fishery Class	Recommended limit	Limit application
MCI (minimum score)	Locally significant	100	Year round, all river flows
	Regionally significant	120	
	Trout spawning	120	
QMCI change (maximum % change)	All	20%	Year round, all river flows
Periphyton biomass (mg Chlorophyll *a*/m^2)	All	120 mg/m^2	Year round, River flows< 3 × median
Periphyton cover (%stream bed, filam. algae >2cm long)	All	30%	Year round, River flows< 3 × median
Temperature (°C, Daily maximum)	Locally significant	24°C	Year round, all river flows
	Regionally significant	19°C	
	Trout spawning	11°C	May - October
Temperature change (°C, maximum change)	Locally significant	±3°C	Year round, all river flows
	Regionally significant	±2°C	
	Trout spawning	±3°C	May - October
pH (pH units, Range)	Locally significant	6.0 to 9.0	Year round, all river flows
	Regionally significant	6.3 to 8.4	
	Trout spawning	6.3 to 8.4	May - October
pH Change (pH units, maximum change)	Locally significant	±0.5	Year round, all river flows
	Regionally significant	±0.5	
	Trout spawning	±0.5	May - October
DO (% saturation , daily minimum)	Locally significant	70%	Year round, all river flows
	Regionally significant	80%	
	Trout spawning	80%	May - October
ScBOD$_5$ (mg/L, maximum daily average)	All	2 mg/L	Year round, River flows< median
POM (mg/L, maximum average)	All	5 mg/L	Year round, River flows< median
Visual clarity (m, minimum)	Locally significant	2.0 m	Year round, River flows< median
	Waikanae River	2.0 m	
	Wainuiomata River	2.0 m	
	Ruamahanga River	3.0 m	
	Waiohine River	2.5 m	
	Hutt River	2.1 m	
Visual clarity change (% change, maximum)	Locally significant	33%	Year round, all river flows
	Regionally significant	20%	
Total Ammonia-N (**Chronic**) (mg/L, maximum average concentration at pH=8.0, Temp=20°C)	All	0.916 mg/L	Year round, all river flows
Other toxicants (protection level)	Locally significant	95%	Year round, all river flows
	Regionally significant	99%	
	Trout spawning	99%	

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1. Introduction

1.1. Background

Greater Wellington Regional Council (GWRC) is in the process of developing technical recommendations to support its second generation Regional Plan. This report is one of a series of technical reports on the Greater Wellington Region's streams and rivers, destined to inform and support the policy development process, in particular the development of biological and water quality limits in relation to different management purposes.

The term "limit" is used here as a generic term to describe a numeric or narrative threshold that defines a particular state for a river or stream. The way in which these limits will be used in the Regional Plan is a policy decision and is outside the scope of this report. In particular, it is important to note that since this report was initiated, the form of GWRC's regional plan process has changed from a 'traditional' single stage plan process to a two-stage 'collaborative' process. It is expected the two-stage process will involve firstly a regional plan which will include river and stream objectives appropriate at a regional scale and secondly collaborative development of catchment or 'whaitua' based river and stream objectives and resource use limits. This means that some of the in-stream 'limits' identified in this report will be used to inform the first stage, i.e. the definition of regional scale river and stream objectives, while some will be considered during the collaborative 'whaitua' second stage. Identification of at what stage the limits proposed here will be considered is outside the scope of this report.

Trout fishery is one of the management purposes identified in GWRC's proposed Regional Policy Statement (RPS). "Trout fishery" as a management purpose includes a number of aspects, some directly relating to the requirements of healthy trout populations (e.g. habitat, food, reproduction) and some relating to the "human" aspects of a trout fishery, such as aesthetic, amenity and natural character values, "fishability", quality or quantity of fish, etc.

This report should be read in conjunction with the other reports in the series, which recommend biological and water quality limits for waters managed for aquatic ecosystem (Greenfield, 2013a and 2013b; Ausseil, 2013b) and contact recreation, amenity and stock drinking water values (Ausseil, 2013a). One should also refer to the report that recommends in-stream nutrient limits (Ausseil, 2013c) to give effect to the different periphyton biomass and cover limits defined in relation to the management purposes mentioned above.

1.2. Aim and scope of this report

As stated above, the primary aim of this report is to recommend biological and water quality limits for waters to be managed for trout fishery or trout spawning purposes in the Wellington Region. Limits are recommended in relation to key biological and water quality determinands that were considered to have direct relevance to the state of trout fisheries and trout spawning, as summarised in Table 1. Key determinands, or groups of determinands, include physico-chemical stressors, such as water temperature, pH, clarity and dissolved oxygen, sediments, toxicants, nutrients, and biological indicators relating to macroinvertebrate and periphyton communities.

The recommendations relating to water quality limits for deposited sediments and toxicants (other than ammonia) are kept general in this report. Detailed examination of toxicant guidelines is undertaken as part of a separate project (Pawson and Milne, 2011). Since this report was initiated in 2010 and primarily written in 2010/2011, guidelines published after that time have not been considered in this report. This concerns in particular the sediment assessment protocols (Clapcott *et al*. 2011), the review of the instream plant and nutrient guidelines (Matheson *et al.*, 2012) and some additional work undertaken by NIWA on nitrate toxicity (e.g. Hickey, 2013). Similarly this report does not reference or consider recent changes in

Regional Plan provisions (such as summarised in Table 3) and/or recent technical work on water quality limits (e.g. Uytendaal and Ausseil, 2013).

For the purpose of this report, it was necessary to identify and classify the streams and rivers that support significant trout fisheries and trout spawning in the Wellington Region. This was primarily based on information provided by the Wellington Fish and Game Council, but it should be noted that additional checks and consultation may be required to refine the identification of trout fishery and trout spawning values in the region.

Finally, the maintenance or protection of significant trout fisheries certainly does not depend entirely on maintaining biological or water quality determinands between certain limits; other aspects, such as the quality of riparian and in-stream habitat, and the management of trout population are essential but fall outside the scope of this report.

1.3. Policy context

1.3.1. RMA

The purpose of the Resource Management Act (RMA) (1991) is to promote the sustainable management of the natural and physical resources. This particularly includes "safeguarding the life-supporting capacity of […] water […] and ecosystems" and "avoiding, remedying or mitigating any adverse effect of activities on the environment".

Other Sections of Part 2 of the RMA identify matters that directly relate to different aspects of the trout fishery. For example, Section 6 identifies matters of national importance, including the preservation of the natural character of rivers and lakes, the protection of outstanding features and landscapes and the maintenance and enhancement of public access, which are relevant to the quality of the fishing experience. Part 7 identifies other matters that are also relevant to trout fishery values, including the maintenance and enhancement of amenity values, intrinsic values of ecosystems and the protection of the habitat of trout and salmon.

Sections 70(1) and 107(1) set five narrative standards with respect to permitted and consented discharges to water or to land. These standards relate to different potential impacts of a discharge, ranging from visual impact to adverse effects on aquatic life.

Section 69 enables the following approaches to rules relating to water quality:

- Section 69(1) refers to Schedule 3, which defines 11 water classes, corresponding to management purposes. Schedule 3 defines a suite of numerical or narrative water quality standards for each class. Section 69(1) also gives mandate to the Regional Councils to use and apply these classes and narrative water quality standards in Regional Plans. Where the Council is of the opinion that these standards are not adequate or appropriate, it may define more stringent or specific water quality standards;
- Section 69(2) allows the Regional Council to define new classes where it is not satisfied that the classes/standards defined in Schedule 3 provide for certain management purposes.

In addition, Section 69(3) prohibits the setting of standards in a plan which result or may result in a reduction of the quality of the water in any waters at the time of the public notification, unless it is consistent with the purpose of the Act to do so.

Table 1: Summary of water quality determinands relevant to the Trout Fishery (TF) and Trout Spawning (TS) management purposes.

Main issue	Water quality determinand	Management purpose	Notes
Physico-chemical stressors	pH	TS, TF	High or low pH can have detrimental effects on trout growth; extreme pH can cause direct toxic effects
	Temperature	TF, TS	Elevated water temperature can cause direct effects on trout behaviour (e.g. feeding), growth, spawning, egg development and survival; Elevated temperature can also alter macroinvertebrate communities, affecting one of the trout's food sources.
	Dissolved oxygen (DO)	TF, TS	Water column DO for adult trout, intra-gravel DO for trout spawning
	Water clarity	TF	Essential for sight-feeding trout
Toxicants	Ammonia	TF, TS	Acute and chronic toxic effects on trout
	Nitrate	TF, TS	Acute and chronic toxic effects on trout
	Other toxicants	TF, TS	Relevant to both TF and TS Only general recommendations in this report – refer to Pawson and Milne (2011)
Sediment	Turbidity	TF	Often used as a surrogate for water clarity and SS
	Total Suspended Solids	TF	Indicator of clarity and sedimentation
	Deposited fine sediments	TF, TS	Particularly relevant to TS, but also to TF through effects on macroinvertebrates
Organic enrichment and Eutrophication	Algal biomass	TF, TS	Effects on macroinvertebrates, DO and pH
	Algal cover	TF, TS	Effects on aesthetic and trout fishing experience (e.g. long filamentous algae foul fishing lines)
	Heterotrophic growths	TF, TS	Effects on dissolved oxygen, macroinvertebrate communities and aesthetic values
	Organic matter (BOD, COD, TOC, DOC, etc…)	TF, TS	Effects on dissolved oxygen and heterotrophic growths
	Dissolved nutrients (DIN, DRP)	TF, TS	Promote algal growth Covered in a separate report (Ausseil, 2011c)
Macroinvertebrate communities	MCI/QMCI	TF TS	Relevant as source of food for all life stages of trout, and as general water quality/ecosystem health indicator.
	MCI/QMCI change	TF TS	

The narrative standards in Schedule 3 to the RMA provide essential guidance for the definition of water quality limits in the context of this report. Of particular relevance to this report, are the “Fishery” and “Fish Spawning” management purposes and standards. They read as follows:

> *“2.*
> *Class F Water (being water managed for fishery purposes)*
> *(1) The natural temperature of the water*
> *(a) Shall not be changed by more than 3^o Celsius. and*
> *(b)Shall not exceed 25^o Celsius*
> *(2) The concentration of dissolved oxygen shall exceed 80% of saturation concentration*
> *(3) Fish shall not be rendered unsuitable for human consumption by the presence of contaminants.*
> *3.*
> *Class FS Water (being water managed for fish spawning purposes)*
> *(1) The natural temperature of the water shall not be changed by more than 3^o Celsius. The temperature of the water shall not adversely affect the spawning of the specified fish species during the spawning season.*
> *(2) The concentration of dissolved oxygen shall exceed 80% of saturation concentration.*
> *(3) There shall be no undesirable biological growths as a result of any discharge of a contaminant into the water.”*

1.3.1. National Policy Statement – Freshwater Management 2011

On 12th May 2011, a National Policy Statement (NPS) for freshwater management was gazetted. The NPS’s preamble identifies recreational activities as one of the national values of freshwater. It also identifies values that:

“relate to recognising and respecting fresh water’s intrinsic values for: safeguarding the life-supporting capacity of water and associated ecosystems; and sustaining its potential to meet the reasonably foreseeable needs of future generations. Examples of these values include:

- *the interdependency of the elements of the freshwater cycle*
- *the natural form, character, functioning and natural processes of water bodies and margins, including natural flows, velocities, levels, variability and connections*
- *the natural conditions of fresh water, free from biological or chemical alterations resulting from human activity, so that it is fit for all aspects of its intrinsic values*
- *healthy ecosystem processes functioning naturally*
- *healthy ecosystems supporting the diversity of indigenous species in sustainable populations […]”*

It is interesting to note that none of the values identified in the NPS explicitly relates to exotic sport fisheries such as trout fisheries, although trout fishery is a recreational activity and trout populations depend heavily on the healthy functioning of aquatic ecosystems.

The NPS contains five main parts relating to: A. Water quality, B. Water Quantity, C. Integrated Management, D. Tangata whenua role and interests and E. Progressive implementation programme. In Part A. (Water quality), Objectives A1 and A2 set the overall objectives, whilst Policy A1 directs every regional council to establish freshwater objectives and set freshwater quality limits for all bodies of fresh water in their region. Policy A2 directs the regional councils to set targets where water bodies do not meet the freshwater objectives.

The text of Objectives A1 and A2 and Policies A1 and A2 is reproduced below for use of reference.

> *"Objective A1*
> *To safeguard the life-supporting capacity, ecosystem processes and indigenous species including their associated ecosystems of fresh water, in sustainably managing the use and development of land, and of discharges of contaminants.*
>
> *Objective A2*
> *The overall quality of fresh water within a region is maintained or improved while:*
> *a) protecting the quality of outstanding freshwater bodies*
> *b) protecting the significant values of wetlands and*
> *c) improving the quality of fresh water in water bodies that have been degraded by human activities to the point of being over-allocated.*
>
> *Policy A1*
> *By every regional council making or changing regional plans to the extent needed to ensure the plans:*
> *a) establish freshwater objectives and set freshwater quality limits for all bodies of fresh water in their regions to give effect to the objectives in this national policy statement, having regard to at least the following:*
> *i) the reasonably foreseeable impacts of climate change*
> *ii) the connection between water bodies*
> *b) establish methods (including rules) to avoid over-allocation.*
>
> *Policy A2*
> *Where water bodies do not meet the freshwater objectives made pursuant to Policy A1, every regional council is to specify targets and implement methods (either or both regulatory and non-regulatory) to assist the improvement of water quality in the water bodies, to meet those targets, and within a defined timeframe."*

1.3.2. Existing Regional Policy

GWRC has an operative Regional Freshwater Plan (1999) with specific policies that manage the water quality of all surface water bodies for the following identified purposes:

- aquatic ecosystems (all water bodies)
- contact recreation (identified water bodies)
- natural state (identified water bodies)
- trout fishery and fish spawning (identified water bodies)
- water supply (identified water bodies).

Both narrative and prescriptive receiving water quality guidelines associated with each water quality purpose are identified in appendices that are linked to each relevant policy (although the guidelines are very limited, reflecting the date of the plan). Some water bodies that are known to be degraded are identified separately as needing enhancement, so that water quality guidelines for aquatic ecosystems, contact recreation or fishery and fish spawning purposes are met.

1.3.3. Greater Wellington's proposed Regional Policy Statement

GWRC's proposed Regional Policy Statement sets the proposed directions for the management of natural resources in the region, including freshwater quality (GWRC, 2010)[1]. Of particular relevance to this work is:

Policy 11

"Regional Plans will establish limits for water quality, flows and water levels that safeguard aquatic habitats and ecosystems in water bodies.
The narrative standard for aquatic ecosystems in the Third Schedule to the Resource Management Act will be used as the basis for safeguarding what is needed for aquatic ecosystem protection in terms of water quality."

Policy 11 also indicates that some water bodies may also be managed for other purposes, such as trout fishery, contact recreation, water supply, groundwater protection or cultural purposes. Where more than one management purposes is assigned to a waterbody, water quality "*shall not be less than the limits established for aquatic ecosystem health*".

Appendix 1 of the RPS lists the rivers and lakes with significant amenity and recreational values, including fishing. This list is reproduced in Table 2 below.

Table 2: Rivers and lakes with significant amenity and recreational values, as identified in Appendix 1, Table 15 of GWRC's proposed RPS (GWRC 2010).

River or lake	Recreational uses
Lake Waitawa (Forest Lakes)	kayaking, windsurfing, sailing
Otaki River	fishing, swimming, kayaking, canoeing, tubing, rafting, picnicking, camping
Waikanae River	fishing, swimming, camping
Kaiwharawhara Stream	picnicking, walking, running
Korokoro Stream	walking, running, mountain biking
Hutt River	fishing, swimming, kayaking, canoeing, tubing, rafting, power boating, radio controlled boats, jet skis, picnicking, walking, running, mountain biking
Pakuratahi River	fishing, swimming, picnicking
Akatarawa River	fishing, swimming, kayaking, bird watching, picnicking, walking, running, mountain biking, trail biking, horse riding, 4-wheel driving
Upper Gollan's Stream (including Butterfly Creek	picnicking, tramping walking, running, bird watching
Wainuiomata River	fishing, swimming, canoeing, kayaking, walking, horse riding
Orongorongo River	fishing, tramping
Kohangapiripiri and Kohangatera Lakes	bird watching, picnicking, walking, mountain biking
Ruamahanga River	fishing, swimming, kayaking, canoeing, tubing, rafting, power boating, jet skiing, picnicking, walking, duck shooting
Tauherenikau River	fishing, swimming, walking, picnicking, rafting
Waingawa River	fishing, swimming, kayaking, tubing, rafting, walking
Waiohine River	fishing, swimming, kayaking, canoeing, tubing, rafting, camping
Kopuaranga River	fishing
Waipoua River	fishing, swimming, running, trail biking
Henley Lake, Masterton	kayaking, dragon boating, radio controlled boats, picnicking, running, biking

[1] GWRC's Regional Policy Statement became operative in April 2013.

River or lake	Recreational uses
Lake Wairarapa	fishing, kayaking, canoeing, boating, duck shooting, bird watching, walking, photography

1.3.4. Other regional policy statements and regional plans

Most Regional Councils in New Zealand have produced regional policy statements and regional plans. Although most regional policy statements and regional plans identify management objectives and/or values associated with waterbodies, only a relatively small number of regions have operative or proposed numerical water quality standards or limits (Table 3). One of the first regional plans to contain numerical water quality standards was the Manawatu Catchment Water Quality Regional Plan, which became operative in 1998. The Waikato Regional Plan (2007) also contains a small number of numerical water quality standards, primarily relating to the protection of recreational values (contact recreation and trout fishery).

More recently, Canterbury's Proposed Natural Resources Regional Plan (April 2011 version) contains numerical water quality and ecological objectives relating to the protection of a number of management purposes, including significant habitat for salmonids (trout and salmon).

The Regional Water Plan for Southland (2010) contains water quality standards to ensure that the water bodies are suitable for a number of values, including trout and natural character (which includes aesthetics). One of the objectives (Objective 4) of the Plan is to achieve measurable improvement in surface water quality in four of its stream/river classes. Objective 4 sets a minimum of 10 % improvement over 10 years in levels of four key water quality determinands: microbiological contaminants, nitrate, phosphorus and clarity.

The Manawatu-Wanganui combined Regional Policy Statement and Regional Plan, the Proposed One Plan, was notified in 2008. Submissions on the notified plan were heard and the panel decision released in August 2010. The One Plan (2010) includes a framework of 19 river values (ecological, recreational and cultural, consumptive use and social and economic values) and water quality targets, superimposed over a spatial framework constituted of 44 water management zones and 117 water management sub-zones. The values framework identifies 3 classes of trout fisheries (Outstanding/ Regionally Significant/ Other trout fishery) and trout spawning waters. The One Plan is currently under appeal to the Environment Court.

1.4. Biological and water quality limits

Biological and water quality numerical thresholds can be expressed in a number of ways in regional plans: as objectives, limits, standards, targets or guidelines. The actual term used for each threshold, and its applicability in different circumstances will be defined by the regional planning framework (RPS and Regional Plan). This report is a technical report, and it is outside its scope to make detailed recommendations regarding the policy framework.

This report generally uses the term "limits" in relation to biological and water quality thresholds, although the use of these limits as actual standards directly applicable to consented activities is suggested where particularly relevant.

1.5. Management purposes

Policy 11 in the proposed RPS indicates that water bodies shall be managed as a minimum for the purpose of maintaining or enhancing aquatic ecosystem health. Policy 11 indicates that some water bodies may also be managed for other purposes, such as trout fishery, contact recreation, water supply, groundwater protection or cultural purposes. Where more than one management purposes is assigned to a waterbody, water quality "*shall not be less than the limits established for aquatic ecosystem health*".

This report makes recommendations for biological and water quality limits in relation to the maintenance and/or protection of trout fishery and trout spawning values in the Wellington region. Under the current provisions of the proposed RPS, management purposes associated with recreational activities such as fishing apply to identified water bodies and come in addition to the aquatic ecosystem management purpose. As a result, any biological or water quality limit defined in relation to the protection of trout fishery and trout spawning values will only become applicable if it brings an additional level of protection to the waterbody. Where the limits defined in this report in relation to, say, trout fishery, are less stringent than those defined for the protection of aquatic ecosystems, they will be superseded by the aquatic ecosystems limits. More generally, the biological and water quality limits recommended in this series of technical reports in relation to different management objectives or values will have to be collated in order to present a coherent set of limits for each water body in the Region. This exercise is beyond the scope of this report.

Table 3: Summary of numerical water quality standards, guidelines or targets for trout fishery and trout spawning waters in selected operative or proposed regional plans.

Region	Plan	Values/	Determinand	Limit	Comment
Manawatu-Wanganui	Manawatu Catchment Water Quality Regional Plan	"General" standards	Water clarity (change)	30%	MCWQ Rule 1 "general" standards are a numerical translation of Section 70(1) and 107(1) of the Act Standards apply at all times
			Water colour (change)	10 points (Munsell scale)	
			Euphotic depth	20% reduction	
			Total Ammonia-N	0.8 mg/L at T ≥ 15°C 1.1 mg/L at T < 15°C	
			$ScBOD_5$	2 g/m^3	
		Contact Recreation standards	Sewage Fungus	No visible growth	MCWQ Rule 2 Standards are primarily for the purpose of contact recreation, which includes aesthetics (i.e. relevant to the trout fishery management purpose). These standards apply in addition to Rule 1 standards, at or below half median flows
			(POM)	5 g/m^3	
			Periphyton cover	40% (mats + filam. >2cm)	
			Periphyton biomass	100 mg/m^2 (*Chlorophyll a*)	
			Water clarity	1.6m	
		Fishery Standards	Temperature *(max daily)*	25°C	MCWQ Rule 3 Standards apply in addition to Rule 1 and Rule 2 standards, at or below half median flows. Standards apply to identified trout fishery rivers
			Temperature *(change)*	±3°C	
			DO *(min. daily)*	80%	
			Human consumption	RMA Class F(3) standard	
		Fish Spawning Standards	Temperature *(change)*	±3°C	MCWQ Rule 4 Standards apply in addition to Rule 1 and Rule 2 standards, at or below half median flows. Standards apply to identified trout spawning streams
			DO *(min. daily)*	80%	
			Biological growths	No undesirable biological growths	
			Sedimentation	No significant deposition of sediment or particulate organic matter	

Region	Plan	Values/	Determinand	Limit	Comment
	One Plan (2010)	Trout fishery (3 classes)	pH	[7 - 8.2] to [7 -8.5]	Apply at all times. Water management zone-specific target
			Temperature *(max daily)*	19°C to 24°C	
			DO *(min. daily)*	70% to 80%	
			$ScBOD_5$ *(monthly average)*	1.5 to 2 mg/L	Applies at flows below 20^{th} flow exceedance percentile. Water management zone-specific target
			POM (average)	5 mg/L	Applies at flows below median flow. Identical target for all water management zones
			QMCI	20% change	Applies at all times. Identical target for all water management zones
			MCI	100 to 120	Applies at all times. Water management zone-specific target
			Periphyton biomass	120 mg/m^2 (*Chlorophyll a*)	
			DRP	0.006 to 0.015 mg/L	Applies at flows below 20^{th} flow exceedance percentile. Water management zone-specific target
			DIN	0.070 to 0.444 mg/L	
			Total Ammonia-N	0.320 to 0.400 mg/L	Average concentration, applies at all times
				1.7 to 2.1 mg/L	Maximum concentration, applies at all times.
			Toxicants	95 to 99 %	2000 ANZECC Guidelines protection level
			Water clarity	2 to 3.4m	Applies at flows below median. Water management zone-specific target
			Water clarity change	20 to 30%	Applies at all times. Water management zone-specific target
		Trout Spawning	Temperature *(max daily)*	11°C	Applies 1 May to 30 September to specified sties/reaches with identified trout spawning value
			Temperature *(change)*	±2°C	
			DO *(min. daily)*	80%	
			Sedimentation	No measurable increase of deposited sediment or particulate organic matter	
			Toxicants	99 %	
Southland	Regional Water Plan for Southland	Native fish Aquatic habitat Trout	pH	[6.5 – 9.0] to [7.2 - 8.0]	Applies at all times. Class-specific standard
			Temperature *(max daily)*	21°C to 23°C	Applies at all times. Class-specific standard
			Temperature (change)	1 to 3°C	Allowable temperature changes depends on background temperature

Region	Plan	Values/	Determinand	Limit	Comment
			DO *(min. daily)*	80% to 99% 5 to 6 mg/L	Applies at all times. Class-specific standard
			Total Ammonia-N	0.32 to 0.9 mg/L	pH–dependant standard Applies at all times. Class-specific standard
			Periphyton biomass	50 to 120 mg/m^2 (*Chlo. a*) 35 g/m^2 (AFDW)	Applies at all times. Class-specific standard
			Periphyton cover	30% (filamentous. >2cm)	Applies at all times. Class-specific standard
			Sewage Fungus	No visible growth	This standard applies to within the zone of reasonable mixing
			Water clarity	1.6 to 3 m	Applies at flows below median flow. Class-specific standard
			sQMCI	4.5 to 5.5	Applies at all times. Class-specific standard
			MCI	90 to 100	
Canterbury	Natural Resources Regional Plan (NRRP – October 2010)		pH	6.5 to 8.5	Standard, applicable to consented activities
			Temperature *(max daily)*	20°C	Objective
			Temperature (change)	2°C	Standard, applicable to consented activities
			DO *(min. daily)*	70% to 90%	Numerical objective depends on waterbody class
			Toxicants	90 to 99 %	2000 ANZECC Guidelines protection level, Class-spcific standard applicable to consented activities
			Periphyton biomass	50 to 200 mg/m^2 (Chlorophyll *a*)	Numerical objective depends on waterbody class
			Periphyton cover	10 to 30% (filamentous >2cm)	Numerical objective depends on waterbody class
			Macrophyte cover	20 to 30% (emergent) 30 to 60% (total)	Numerical objective depends on waterbody class
			Deposited sediment	10 to 40% cover	Numerical objective depends on waterbody class
			QMCI	3.5 to 6	Numerical objective depends on waterbody class
			Water clarity change	20 to 35%	Class-specific standard, applicable to consented activities
			Water colour change	5 to 10 pts (Munsell Scale)	

Region	Plan	Values/	Determinand	Limit	Comment
Waikato	Waikato Regional Plan (2007)	CR (CR Water Class)	Sewage Fungus	No visible growth	Set as a standard for Contact Recreation Class
			Periphyton cover	25%	Set as a Policy (Policy 6) for Contact Recreation Class
				40%	Set as a standard for Contact Recreation Class
			Periphyton biomass	100 mg/m^2 (Chlorophyll a)	
			Water clarity	1.6m	Set as a standard for Contact Recreation Class
			Other contaminants	Narrative standard	"The water shall not be rendered unsuitable for contact recreation activities by the presence of contaminants"
		Significant Trout Fisheries and Trout Habitat	Temperature *(max daily)*	20°C	Permitted activity rule standards for significant trout fishery and trout habitat waters
			Temperature (change)	3°C	
			Ammoniacal – Nitrogen	0.88 g/m^3	
			DO *(min. daily)*	80%	No change allowed if DO is already below 80%
			Human consumption	RMA Class F(3) standard	
			TSS increase	10%	Permitted activity rule standards
			TSS in discharge	100 mg/L	Permitted activity rule standards for significant trout fishery and trout habitat waters
			TSS in receiving environment	25 mg/L	
		Trout Spawning	Temperature *(max daily)*	12°C	Applies May to September

2. Data and methods

2.1. Monitoring data

The development of water quality limits recommended in this report was supported by monitoring data and data summaries provided by GWRC. These monitoring data were collected as part of GWRC's River State of the Environment (RSoE) monitoring programme during the period July 2004 to June 2009. GRWC's RSoE monitoring programme for this period included 56 river/stream sites across the Wellington region[2]. A number of these sites are located on regionally and locally significant trout fisheries (Table 4) and/or on or near trout spawning grounds (Appendix A).

GWRC also continuously monitors river flow at 42 sites across the region. However, only 19 of these sites are directly associated with a SoE water quality monitoring site. GWRC has therefore undertaken work to provide flow estimates at many water quality sites. To provide an informative dataset for this work, GWRC have developed flow estimates for an extra 33 sites. The following data were made available for this study:

- Mean daily flow on each sampling day, available at 12 sites;
- A flow category estimate on each sampling day, given as one of four flow categories: below half median flow, half median flow to median flow, median flow to three times median flow and above three time median flow. Flow category data were available for 45 sites (including the 12 sites where mean daily flow data were available).

2.2. Trout fisheries in the Wellington Region

The Wellington region contains a number of significant trout fisheries. In particular, the Hutt and Ruamahanga Rivers attract a large number of anglers each year. A number of their tributaries, such as the Waiohine River also have a reputation for being excellent backcountry trophy fisheries. These are primarily brown trout (*Salmo trutta*) fisheries, although rainbow trout (*Oncorhynchus mykiss*) are also present. Chinook Salmon (*Oncorhynchus tshawytscha)* have also been anecdotally reported in the Wellington Harbour, Lower Hutt River and Lake Onoke, but there are currently no significant salmon fisheries in the Wellington region.

In consultation with the Wellington Fish and Game Council, the known significant trout fisheries in the Wellington region have been identified and categorised as:

- "Regionally Significant": this includes the main stems of the Hutt and Ruamahanga Rivers, as well as the Waiohine, Waikanae and Wainuiomata Rivers. These rivers are the most utilised in the region: based on National Angler Survey (NAS) data, they account together for more than 85% of the trout fishing activity in the region's rivers and streams (Table 4);
- "Locally Significant", which includes all other trout fisheries in the Region, i.e. fisheries with lower angler use than the regionally significant fisheries, and fisheries that are anecdotally known to be regularly used but for which no NAS survey data were available.

This approach is similar to that of the One Plan, although an additional class for nationally and internationally significant trout fisheries is defined in the One Plan (Ausseil and Clark, 2007a). No nationally or internationally significant trout fisheries were identified in the Wellington region.

Spawning grounds are essential in sustaining trout fisheries, and known spawning streams were also identified, as summarised in Appendix A.

[2] Monitoring at RS01 (Mangapouri Stream at Rahui Rd) was discontinued in October 2009. As a result, the SoE water quality monitoring network currently comprises 55 sites.

Table 4: Significant trout fisheries in the Wellington Region, angler usage estimates (angler days) from the NAS, and GWRC's RSoE water quality monitoring sites. RSoE sites in grey-shaded cells are reference/ low impact sites. Angler days data from the National Angler Survey. (-): no data.

Class	River/Stream	Angler days per year			RSoE Sites	
		1994/95	2001/02	2007/08	No	Name
Regionally significant	Waikanae River	750	420	1,420	RS09	Waikanae @ Mangaone Walkway
					RS10	Waikanae @ Greenaway Rd
	Wainuiomata River	2,390	750	1,560	RS28	Wainuiomata @ Manuka Track
					RS29	Wainuiomata u/s White Bridge
	Ruamahanga River	7,390	6,910	6,540	RS31	Ruamahanga @ McLays
					RS32	Ruamahanga @ Te Ore Ore
					RS33	Ruamahanga @ Gladstone
					RS34	Ruamahanga @ Pukio
	Waiohine River	1,330	960	860	RS47	Waiohine @ Gorge
					RS48	Waiohine at Bicknells
	Hutt River	19,960	6,160	3,790	RS20	Hutt River @ Te Marua
					RS21	Hutt River @ Manor Park
					RS22	Hutt River @ Boulcott
Locally Significant	Otaki River	690	350	700	RS05	Otaki @ Pukehinau
					RS06	Otaki @ Mouth
	Taueru River	50	140	300	RS36	Taueru @ Castlehill
					RS37	Taueru @ Gladstone
	Huangarua River	-	60	60	RS51	Huangarua @ Ponatahi Bridge
	Kopuaranga River	520	520	310	RS38	Kopuaranga @ Stewarts
	Tauherenikau River	360	220	160	RS55	Tauherenikau @ Websters
	Waingawa River	430	140	140	RS41	Waingawa @ South Rd
	Mangatarere Stream	260	160	-	RS50	Mangatarere at SH2
	Beef Creek	-	-	-	RS49	Beef Creek @ headwaters
	Waipoua River	140	260	80	RS40	Waipoua @ Colombo Rd
	Akatarawa River	70	320	220	RS25	Akatarawa @ Hutt Confluence
	Whakatikei River	70	80	20	RS26	Whakatikei @ Riverstone
	Pakuratahi River	50	50	-	RS23	Pakuratahi Below Farm Creek
	Mangaroa River	120	10	-	RS24	Mangaroa @ Te Marua
	Orongorongo River	-	40	-	RS30	Orongorongo River
	Mangaone Stream	-	-	-	RS07	Mangaone @ Sims Rd
	Waitohu Stream	-	-	70	RS03	Waitohu @ Forest Park
	Makara Stream	100	70	-	RS17	Makara @ Kennels
	Karori Stream	120	-	-	RS18	Karori @ Makara Peak
	Kaiwharawhara S.	20	-	-	RS19	Kaiwharawhara @ Ngaio Gorge
	Korokoro Stream	20	-	-	-	-
	Pahaoa River	-	10	-	-	-
	Wainuioru River	-	-	-	-	-

2.3. General approach and level of protection

As explained in Section 2.2 of this report, two classes of significant trout fisheries were identified in the Wellington region: regionally and locally significant trout fisheries. The overall philosophy of the approach taken in this report is to use this classification to define water quality and biological limits corresponding to two levels of protection:

- in "locally significant" trout fisheries, the limits aim at maintaining biological and water quality within the "tolerable to good" range of conditions, to enable the long-term survival of trout populations;
- in "regionally significant" trout fisheries, the recommended objectives and standards are based on a higher level of protection, aiming at corresponding to "good to excellent" conditions for trout and other components of the aquatic ecosystem that are key to maintaining good trout populations.

Only one class of trout spawning (TS) waters have been identified following consultation with the Wellington Fish and Game Council. This results in only one recommended level of protection common to all TS waters in the region. In this report, the corresponding biological and water quality limits are purposely placed at a relatively conservative level, to reflect the role of these waters in sustaining significant trout fisheries. However, the blanket application of the recommended limits to all TS waters may result in un-necessarily stringent restrictions, and there may be grounds for relaxation of the recommended limits on a case-by-case basis, for example, in spawning grounds that are seldom used by trout, or that are demonstrated to be only minor contributors to the recruitment in a particular trout fishery.

Trout spawning, egg development and hatching and alevin (larvae) development are highly seasonal. The spawning and incubation period may vary from year to year and is different for brown and rainbow trout, brown trout being autumn spawners and rainbows primarily spring spawners, although rainbows sometimes exhibit extended spawning from May to November or even later (e.g. Taupo). Nevertheless, in most catchments where brown and rainbow trout co-occur, May to October covers the combined spawning period but is generally inside the May to October period (Hay *et al.*, 2006). In those catchments where brown just brown trout occurs, May to October includes the spawning season and embryo incubation period; with most fry emerging over September – October. Where spring spawning rainbow trout are present, the incubation period usually extends to early December. Trout fisheries in the Hutt and Ruamahanga catchments are dominated by brown trout, although rainbow trout are present. It is recommended that the biological and water quality limits defined in this report for trout spawning waters generally be applied during the May to October (inclusive) period, primarily to protect brown trout spawning and incubation periods, but consideration could be given to extending this period to November in some waters if/where protection of the incubation of late spawning rainbow trout was considered particularly important for the maintenance of the fishery.

Certain water quality limits may only need to apply in some places, at some times of the year, and/or under some river flow conditions. Where required, this report includes recommendations relating to the location and timing of their applicability.

2.4. Determinands

A number of measurable biological, water quality and habitat determinands are relevant to the protection of the values associated with trout fisheries and spawning. They are either directly relevant to the trout's physiological requirements at different life stages (e.g. temperature, toxicants), their physical habitat (e.g. water clarity, deposited sediments), or macroinvertebrates (a major food source for trout).

As indicated above, trout spawning and egg and juvenile development are highly seasonal. Trout spawning streams also tend to occur in smaller tributaries of the larger waterbodies that constitute the actual fishery. Finally, trout eggs and embryos have specific water quality and habitat requirements. For these reasons, separate sets of limits are defined in this report for trout spawning waters and the two classes of trout fisheries. Where both trout fishery and trout spawning values have been identified for a given stream or river, it is recommended that the trout spawning limits apply in addition to the trout fishery limits.

A number of determinands also directly relate to the "human" aspects of the trout fishery, i.e. things that will influence the quality of the fishing experience, such as water clarity or periphyton cover. Table 1 summarises the determinands selected, the management purpose(s) they apply to and the reasons for their selection. It is noted that, to a large extent, this list of determinands is consistent with those recommended by Hayward *et al*. (2009) and Ausseil and Clark (2007b) for the protection of trout fishery values in the Canterbury and Manawatu-Wanganui regions respectively.

3. Recommended water quality and biological limits

3.1. Macroinvertebrate communities

3.1.1. MCI limits

The composition of aquatic macroinvertebrate communities is commonly used in New Zealand as a biomonitoring tool to assess the likely level of ecosystem degradation or enrichment (Stark, 1985). Because of their continuous presence in the stream or river, and their sensitivity to a number of water quality and habitat "issues" (such as organic enrichment, eutrophication, sedimentation, toxicants), the state of macroinvertebrate communities constitutes an integrated indicator of ecosystem "health".

A number of indices, such as the Macroinvertebrate Community Index (MCI), the Quantitative Macroinvertebrate Community Index (QMCI), and the proportion of ephemeroptera (mayflies), plecoptera (stoneflies) and trichoptera (caddisflies) numbers or taxa (%EPT, %EPT taxa) are commonly used to assess and summarise the state of macroinvertebrate communities in a number of resource management situations in New Zealand.

The macroinvertebrate species that score highly in the calculation of the different macroinvertebrate community indices are also generally good quality prey for drift feeding trout. The different indices therefore have the potential to provide an indication of the relative availability of trout food (Hay *et al*., 2006).

The use of the MCI in the definition of numerical objectives or standards for the protection of trout fishery values was recommended by Hay *et al.* (2006), and more recently by Quinn (2009) for the protection of ecological and recreational values (including trout fishery and trout spawning) in the Manawatu-Wanganui Region.

Greenfield (2013a) identified objectives relating to macroinvertebrate communities for the protection of aquatic ecosystems. These numerical objectives are also based on the Macroinvertebrate Community Index (MCI) as the indicator of macroinvertebrate community health. The MCI is the most commonly used indicator of macroinvertebrate community health in large-scale monitoring and reporting in New Zealand, such as State of the Environment monitoring and reporting undertaken by Regional Councils and TLAs[3]. It is therefore recommended that the MCI be used for the definition of numerical limits for the protection of the trout fishery values in the Wellington region.

For regionally significant trout fisheries, a minimum MCI score of 120, indicative of clean water (Stark, 1985) is recommended. For other, locally significant trout fisheries, a MCI score of 100 (indicative of

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possible mild pollution) is recommended (Table 5). These recommendations are consistent with those of Hay *et al*. (2006).

The MCI is sensitive to fine sediment and organic enrichment – both of which combine to reduce DO concentration in the substrate where trout eggs are deposited. A high MCI score (120) is also recommended as a limit for trout spawning streams, applicable during the main spawning and egg and alevin (larvae) development season (May – October).

It should be noted however, that these limits are general recommendations, which may not be realistically achieved in some stream or river types. It is recommended that these limits be checked against those recommended in relation to the aquatic ecosystem management purpose (Greenfield, 2013a) when the limits recommended for the different management purposes are compiled for each water quality management unit (e.g. stream, river, sub-catchment or catchment).

3.1.2. QMCI change limits

Specific activities, such as point-source discharges or works in the beds of rivers and streams, can have a direct detrimental impact on macroinvertebrate communities. In this context, it is recommended to also define numerical limits relating to changes in macroinvertebrate community health. These limits would be well suited for use as standards, directly applicable to specific activities.

Whilst MCI is well suited to SoE reporting and the setting of management objectives or targets, QMCI is considered better adapted to direct comparisons between different sets of data collected to assess the effects of a specific activity, such as upstream/downstream comparisons. Because it is a quantitative rather than a qualitative (like the MCI) index, the QMCI is considered less likely to be influenced by upstream macroinvertebrate communities [4], and more able to detect changes in community composition (Quinn, 2009). Stark and Maxted (2007) also maintained that QMCI (and SQMCI) were more suited to compliance monitoring than SoE monitoring.

For both regionally and locally significant trout fisheries, as well as for trout spawning streams, a maximum QMCI change of 20% as a result of a specific activity or a group of activities, is recommended as a standard. This threshold is consistent with what was recommended for the protection of the aquatic ecosystem values (Greenfield, 2013a), and essentially corresponds to a degree of change that is generally ecologically significant, can be statistically detected with an acceptable level of sampling effort and can be tested using relatively simple statistical methods (Stark, 2010).

3.1.3. Application of macroinvertebrate limits

The overall health of macroinvertebrate communities within a stream or river system is governed by a number of catchment-wide processes and activities. The MCI score is an indicator of overall macroinvertebrate community health, and is well suited for use in general SoE reporting.

The recommended QMCI change limits relate to the degree of change in space or time, in the overall health of macroinvertebrate communities. As such, they appear particularly well suited to situations where the effects of a specific activity are being assessed, e.g. upstream/downstream of a discharge.

Although good practice requires that macroinvertebrate communities be sampled following stable flow conditions, macroinvertebrates and trout live in the streams and rivers year-round, and at all flow conditions. This includes trout spawning waters, which generally are important rearing grounds for juvenile trout beyond the main spawning season. Thus, it is recommended that all macroinvertebrate limits should apply at all times.

[4] In the context of upstream/downstream comparisons, downstream MCI is more easily influenced by a small numbers of macroinvertebrate species that may drift from the upstream site.

Table 5: Recommended MCI and QMCI change limits for locally and regionally significant trout fisheries and trout spawning streams in the Wellington Region. The "measured range" corresponds to the range of median MCI recorded at RSoE sites (2004-2009 period).

Management Objective	MCI (minimum score)	Measured range		QMCI change (%change)
		Reference	Impacted	
Locally significant trout fishery	100	115-150	78-147	20%
Regionally significant trout fishery	120	133-154	79-150	20%
Trout spawning (year-round)	120	123-153	78-147	20%

3.2. Periphyton

Excessive periphyton growth can have detrimental effects on benthic habitat quality and macroinvertebrates, which can in turn influence trout growth and abundance (Jowett, 1992; Hayes *et al*. 2000). It can also cause wide daily changes in pH (Section 3.4) and dissolved oxygen concentration, which can also have detrimental effects on trout.

Excessive algal growth can also have a direct effect on the quality of the fishing experience for the angler. Long filamentous algae can become a nuisance by fouling fishing lures and lines. Excessive long filamentous algae and thick mats are unsightly and can also adversely affect the quality of the angling experience.

Biological limits associated with other types of biological growths, including heterotrophic growths (sewage fungus) and macrophytes are considered in a separate report for waters to be managed for aquatic ecosystem health (Greenfield, 2013b). It is considered that the limits recommended in relation to aquatic ecosystem health are also suitable for Trout Fishery and Trout Spawning waters, thus no additional limits are recommended.

The New Zealand Periphyton Guidelines (Biggs, 2000) define maximum periphyton biomass and cover in relation to trout habitat and angling. These guidelines have become widely accepted in New Zealand, and they are recommended for inclusion in GWRC's Regional Plan (Table 6).

The New Zealand Periphyton Guidelines recommend a maximum Ash-Free Dry Weight (AFDW) of 35 g/m^2 for the protection of trout habitat and angling, which corresponds approximately to 120 mg chlorophyll *a* $/m^2$ for communities dominated by filamentous algae, and 200 mg chlorophyll *a* $/m^2$ for communities dominated by mat-forming cyanobacteria and /or diatoms. Application of the guidelines using the two chorophyll *a* thresholds may give rise to problems in common situations where periphyton communities are mixed filamentous/cyanobacteria/diatoms assemblages. For simplicity, a unique biomass limit (120 mg chlorophyll *a* $/m^3$) could be used, for the protection of both classes of trout fisheries and trout spawning waters, but this may be un-necessarily conservative where/when the periphyton communities are heavily dominated by cyanobacteria (e.g. Phormidium-dominated periphyton at times in the Hutt River). For this reason, the AFDW guideline, is recommended for the protection of trout habitat and angling.

It is noted however that the periphyton biomass limits recommended by Greenfield (2013b) for the protection of aquatic ecosystem values are based on chlorophyll *a* concentrations that are not dependent on the composition of the periphyton community. It is probable that these limits will supersede the periphyton biomass thresholds recommended in this report in many locations.

3.2.1.Application of periphyton limits

Periphyton biomass influences macroinvertebrate communities, which are in turn an essential food source for trout year-round. It is therefore recommended that the periphyton biomass limits apply year-round, at all river flows.

The periphyton cover limits relate more directly to the usage humans make of the fishery (aesthetic and "fishability" aspects). For this reason, it is recommended that the periphyton cover limits apply to the open fishing season, which can vary depending on the stream or river (some fisheries are open year-round, whilst some are subject to seasonal closures).

Table 6: Recommended periphyton biomass and cover limits for locally and regionally significant trout fisheries and trout spawning streams in the Wellington Region. The "measured range" corresponds to the range of median periphyton biomass recorded at RSoE sites (2004-2009 period).

Management Objective	Periphyton biomass			Measured range (mg Chlo *a*/m²)		Periphyton cover (%stream bed, Filamentous algae >2cm long, during the fishing season)
	AFDW (g/m²)	Filam. Algae (mg Chlo *a*/m²)	Mats (mg Chlo *a*/m²)	Reference	Impacted	
Locally significant trout fishery	35	120	200	1-6	3-293	30%
Regionally significant trout fishery	35	120	200	0-9	1-57	30%
Trout spawning (May – October)	35	120	200	1-9	3-293	30%

3.3. Water temperature

3.3.1.Generalities

The functioning of aquatic ecosystems, their biological, chemical and physical processes, are closely regulated by water temperature. An organism's food consumption, metabolism, growth, reproduction, mobility, migration patterns and survival may all be influenced by changes in ambient water temperature (ANZECC, 2000; Hokanson et al., 1977, Elliott, 1994). Temperature changes may occur as part of natural diurnal and seasonal cycles, or as a consequence of human activities. Water temperature in a stream or river typically fluctuates diurnally around a seasonal daily mean, with a faster rise to the mid-afternoon daily maximum temperature than fall to the daily minimum near dawn (Davies-Colley and Wilcock, 2004).

Excess heat or cold are considered to be forms of thermal pollution. Anthropogenic point sources of thermal pollution can include discharges of relatively warm (e.g. industrial cooling water) or cold (bottom water from dams) water. Loss of riparian vegetation, water abstraction and global warming may also lead to temperature increases in streams, representing the non-point source component of thermal pollution.

3.3.2.Effects of temperature on trout

Similarly to a number of other general water quality determinands (such as pH and dissolved oxygen), the temperature requirements of trout are well documented in the scientific literature. The intention in this report is not to provide a comprehensive literature review on the effects of temperature on trout; rather it is to focus on the definition of water quality limits corresponding to the levels of protection sought for the different classes of trout fisheries and trout spawning waters.

Rainbow and brown trout are cold water species, with limited tolerance to high water temperature. The growth optima are 14 ^{o}C to 17 ^{o}C for brown trout and 16 ^{o}C to 18^{o}C for rainbow trout, depending on whether the diet comprises invertebrates or fish (the higher optima are for fish diet) (Hay *et al.*, 2006). These optima are for trout that are not food limited (i.e., that are able to feed to satiation). When food is limited the optimal temperature for growth declines (Elliott 1994). Behavioural disturbances, such as cessation of feeding, can be expected at temperatures above 19 ^{o}C for both brown and rainbow trout (Elliott, 1994; Hay *et al.*, 2006).

The incipient lethal temperature (i.e. that can be tolerated for a prolonged period) for brown trout increases with acclimation to a plateau at 24.7^{o}C, and 26.2^{o}C for rainbow trout. The ultimate lethal temperatures (i.e. that cannot be tolerated even for a short period of time) are 29.7 ^{o}C and 30 ^{o}C for brown and rainbow trout respectively (Elliott, 1994 and 1995). Trout are less tolerant to high temperatures when they are not slowly acclimatised to the maximum temperature, i.e. they are sensitive to sudden changes in temperatures.

Trout eggs are also sensitive to temperature changes and high temperatures. Reported temperature optimum for trout spawning, egg development and hatching range between 1 and 12^{o}C, with maximum temperatures of 15-16^{o}C. Large-scale modelling also indicates that high winter temperatures may limit brown trout recruitment in New Zealand rivers (Scott & Poynter 1991; Jowett 1992; both cited in Hay *et al.* 2006).

3.3.3. Recommended limits

The available scientific literature indicates that trout and trout eggs are sensitive to both temperature changes and high temperatures. It is thus recommended to establish numerical thresholds for daily maximum water temperature and a maximum relative change in water temperature.

Water temperature in streams or rivers generally largely depends on catchment-wide processes, and it is recommended that daily maximum temperature limits be used in the Regional Plan as overall limits, particularly suited for SoE reporting purposes. Sudden, localised temperature changes that may result from a specific activity may be best controlled by way of directly enforceable temperature change standards.

The RMA Third Schedule standards for waters managed for fisheries set a maximum temperature of 25^{o}C. However, a number of scientific studies suggest that, although a temperature of 25^{o}C can probably be tolerated by rainbow trout, and, to a lesser extent, by brown trout, sub-lethal effects are likely at lower temperatures, between 19^{o}C and 25^{o}C.

As defined in Section 2.3, the overall philosophy for the definition of water quality limits for regionally significant trout fisheries is that they should remain close to the trout's optimum requirements. A temperature limit of 25^{o}C is unlikely to provide the relatively high level of protection sought, and a maximum temperature of 19^{o}C is recommended for regionally significant trout fisheries. This recommendation is consistent with those of Hay *et al.* (2006).

A lesser level of protection is sought for locally significant trout fisheries. Water temperature below 24^{o}C would ensure that lethal effects of high water temperatures are avoided. This is also the limit recommended by Hay *et al.* (2006) for the protection of locally significant trout fisheries in the Manawatu-Wanganui Region. A similar daily maximum water temperature limit of 24^{o}C is recommended for locally significant trout fisheries.

A maximum water temperature of 11^{o}C between May and October is recommended for trout spawning waters. This temperature limit is close to the optimum temperature for trout eggs and should avoid any significant adverse effects of the water temperature on trout spawning success.

The RMA Third Schedule sets a maximum water temperature change of 3^{o}C for both fishery and fish spawning waters. It is recommended that this threshold be used as a standard in the Regional Plan in relation to specific activities, such as discharges to water or water abstraction, and that this standard apply within the bounds of the maximum temperature limit.

Table 7: Recommended water temperature and water temperature change limits for locally and regionally significant trout fisheries and trout spawning streams in the Wellington Region. The "measured range" corresponds to the range of 95th percentile of water temperature data recorded monthly at RSoE sites (2004-2009 period).

Management Objective	Recommended maximum temperature (daily maximum)	Recommended Temperature change standard (°C)	Measured range (95th percentile)	
			Reference	Impacted
Locally significant trout fishery	24°C	±3°C	15.6 – 17.7	15.4 – 23.6
Regionally significant trout fishery	19°C	±3°C	14.4 – 16.2	19.0 – 22.15
Trout spawning (May – October)	11°C	±3°C	10.0 – 11.3	11.2 – 15.7

3.3.4. Application of water temperature limits

The maximum daily water temperature and water temperature change limits recommended above for trout fisheries should apply at all times/all river flows. The limits relating to trout spawning waters should apply between May and October, at all river flows.

For general State of the Environment reporting, it is recommended that compliance with the daily maximum water temperature limits be assessed against the 95th percentile of data collected year-round for monthly RSoE data.

Both daily maximum water temperature and water temperature change limits are recommended. The way these two limits are intended to work is for the temperature change limit to apply within the bounds of the daily maximum temperature limit. In other words, if the background water temperature is, say, 18°C and the water temperature limits are 19°C (maximum daily) and ±3°C (change), then the temperature should be allowed to increase to 19°C, not 21°C, unless site/case-specific investigations show that the effects of doing so are acceptable.

3.4. Water pH

3.4.1. Generalities

pH is a measure of water acidity or alkalinity, on a scale of 0 (extremely acidic) to 14 (extremely alkaline). Pure distilled water is neutral at pH 7. Most natural freshwaters have a pH in the range 6.5-8.5, whilst the pH of marine waters is close to 8.2 (ANZECC, 2000).

pH is a central determinand in natural waters and interacts with other major physico-chemical or biological determinands of freshwater ecosystems. For example:

- Low or high pH can cause direct adverse effects on aquatic life;
- Changes in pH affect the bioavailability (hence the toxicity) of numerous toxicants. For example, a lowering in pH increases the bioavailability of certain metals, such as aluminium and cadmium, and inorganic toxicants such as hydrogen sulphide. Conversely, ammonia toxicity increases with pH (and temperature);
- pH can follow more or less pronounced diurnal changes controlled by in-stream primary production (photosynthesis), with minima generally observed at dawn and maxima late afternoon. During the day, the algal production uses CO_2 faster than it can be replaced from the atmosphere, causing the

dominant CO_2/HCO_3^- equilibrium[5] to be displaced so that the pH is increased. As a result, pH maxima in streams are generally observed during low river flow conditions in the late afternoon.

3.4.2. Bibliography

Raleigh *et al.* (1986) suggest that the tolerable pH range for brown trout is between 5 and 9.5, with an optimal range of 6.7 to 7.8. Kwak and Waters (1997) found a positive correlation between salmonids production and alkalinity in North American streams, i.e. salmonid production is lower in acidic waters. Hay *et al.* (2006) suggest that maintaining pH within a circum-neutral range should avoid any adverse effects on trout, although guidelines may need to account for the natural range of pH in each system.

3.4.3. Recommended water quality limits

Similarly to what is recommended for water temperature, it is recommended to establish numerical thresholds for absolute pH values as overall limits, whilst maximum pH relative change limits as a result of an activity could be used as a standard.

As defined in Section 2.3 of this report, the overall philosophy for the definition of water quality limits for regionally significant trout fisheries is that they should remain close to the trout's optimum. In terms of pH, the trout's optimal range is 6.7 to 7.8. As per Hay *et al.*'s (2006) recommendations, it should also remain circum-neutral (around 7), whilst accounting for the natural range of pH in each system. Reference sites are available in both regionally (4 sites) and locally significant trout fisheries (5 sites). The range of pH observed at these sites is representative of natural conditions for these rivers.

The 5th percentile of the data distribution (i.e. the lower end of the range for each site) at the regionally significant trout fishery reference sites is 6.4 to 6.8, and the 95th percentiles range from 7.8 to 7.9. A pH range of 6.4 to 7.9 could therefore be recommended. However, the SoE data is unlikely to capture the whole range of natural variations, and it seems reasonable to consider extending both ends of this range to account for this natural variability. The lowest 5th percentile across all RSoE sites is a pH 6.3, indicating that a lower bound of 6.3 would probably adequately capture the natural lower end of the range. The upper end of the range could be extended by 0.5 pH units (the recommended pH change limit) to 8.4 (Table 8). This range would ensure that the pH remains circum-neutral, and close to optimal pH range for trout, whilst still accounting for natural variability across the different systems covered by the regionally significant trout fishery management purpose. The same range is recommended for trout spawning waters.

Water quality limits for locally significant trout fisheries should ensure that water quality is not outside the range of tolerable values (refer to Section 2.3). Based on data collected at reference sites, the natural pH in these rivers appear to range from 6.6 to 7.9. A range of 6.0 to 9.0 would ensure that the pH remains well within the tolerable pH range defined by Raleigh *et al.* (1986), whilst still allowing a wider variation than in regionally significant trout fisheries (Table 8).

In addition to the above management targets, a standard allowing a maximum pH change of 0.5 units after reasonable mixing as a result of a given activity is recommended. This recommended standard is consistent with the recommendations of the ANZECC (1992) guidelines.

[5] $HCO_3^- + H^+ \leftrightarrow CO_2 + H_2O$

Table 8: Recommended pH range and pH change limits for locally and regionally significant trout fisheries and trout spawning streams in the Wellington Region. The "measured range" corresponds to the range of 5th -95th percentile of water temperature data recorded monthly at RSoE sites (2004-2009 period).

Management Objective	Recommended pH range limits	Recommended pH change limits	Measured range (5th and 95th percentiles)	
			Reference	Impacted
Locally significant trout fishery	6.0 to 9.0	±0.5	6.6 – 7.3 to 7.8 – 8.0	6.3 – 7.7 to 7.4 – 8.8
Regionally significant trout fishery	6.3 to 8.4	±0.5	6.4 - 6.8 to 7.8 – 7.9	6.3 – 7.1 to 7.7 – 9.1
Trout spawning (May –October)	6.3 to 8.4	±0.5	6.6 – 7.0 to 7.8 – 8.3	6.2 – 7.7 to 7.5 - 8.9

3.4.1. Application of water pH limits

The pH range and pH change limits recommended above for trout fisheries should apply at all times/all river flows. The limits relating to trout spawning waters should apply between May and October, at all river flows.

For general State of the Environment reporting, it is recommended that compliance with the pH range limits be assessed against the 5th-95th percentile of data collected year-round.

Similarly to water temperature, the pH change limits are intended to apply within the bounds of the pH range limits.

3.5. Dissolved Oxygen

3.5.1. Generalities

Dissolved oxygen (DO) is essential for aerobic forms of river life, including most plants and animals. As explained by Davies-Colley and Wilcock (2004), the dissolved oxygen concentration at any point in time will be a resulting balance between a number of processes:

- Oxygen-consuming respiration by aquatic life (bacteria, plants and animals);
- Oxygen-producing photosynthesis by aquatic plants and cyanobacteria; and
- Exchanges between the water and the atmosphere that tend to re-establish equilibrium at "saturation" level (in turn largely dependent on the water temperature). This process (reaeration) is mostly controlled by the degree of turbulent mixing occurring. Thus, a swift-flowing river is well re-aerated, whereas a sluggish stream has poor uptake of atmospheric oxygen.

The DO concentration in the water is subject to diurnal variations governed by the three processes above, leading to maximum levels (which can be significantly higher than the equilibrium 100% saturation) in mid-afternoon when photosynthesis is at maximum intensity, and minimum levels at dawn (after a whole night of oxygen consuming respiration, and no photosynthesis). Low levels of DO can be a major stressor to aquatic life, including fish, invertebrates and micro-organisms, which depend upon oxygen for their efficient functioning.

3.5.2. Bibliography

The DO requirements of trout and other salmonids are well documented in the scientific literature. Rainbow trout are more sensitive to low dissolved oxygen concentrations than most New Zealand native fish species (Dean and Richardson, 1999). The incipient lethal DO concentration for both brown and rainbow trout is approximately 3 mg/L (Raleigh *et al.*, 1984 and 1986). Dean and Richardson (1999) also observed some mortality and consistent surfacing behaviour at DO concentrations of 3 mg/L and some surfacing behaviour at 5 mg/L DO concentration. Free swimming trout can tolerate DO concentrations of 5 to 5.5 mg/L, but the saturation should be at least 80%. (Hay *et al.*, 2006).

The effects of DO and water temperature on trout are interlinked: the oxygen requirements of salmonids increase with water temperature due to increased metabolism (Elliott, 1994). The oxygen saturation also depends on temperature. The link between temperature and DO is essential in the context of this work, where temperature objectives are also defined.

The ANZECC (1992) guidelines recommend a minimum DO concentration of 6 mg/L and 80% saturation. Hay *et al.* (2006) suggest that these limits should be seen as short-term exposure levels (i.e. days), as data suggests that long-term exposure to DO levels of 6 mg/L can chronically impair the growth of salmonids (BCME, 1997). The British Columbia Ministry of the Environment (BCME) guidelines set a minimum long-term concentration (30 day average) of 8 mg/L for best protection of salmonids waters.

The USEPA (1986) DO criteria associates minimum DO concentrations with a degree of impairment of the trout fishery, both for waters containing and not containing early life stages (Table 9).

With regards to trout spawning waters, the USEPA (1986) criteria identify a minimum DO concentration of 9 mg/L in the water column to maintain near optimum conditions ("slight impairment"). The BCME (1997) defines a similar guideline, which is also recommended by Hay *et al.* (2006) for the protection of trout spawning waters in the Manawatu-Wanganui Region.

Table 9: Dissolved oxygen (DO) concentrations (mg/L) recommended by the USEPA to confer five levels of protection for waters containing adult and juvenile (early life stages) salmonids (adapted from Dean and Richardson 1999), and DO saturation corresponding to the "adults" water column DO concentrations at different temperatures.

Degree of impairment acceptable	Early life stages		Adults	Saturation at			
	Water column DO (mg/L	Intra-gravel DO (mg/L)	Water column DO (mg/L)	10 °C	16 °C	19 °C	24 °C
None	11	8	8	71	81	86	95
Slight	9	6	6	53	61	65	71
Moderate	8	5	5	44	51	54	59
Severe	7	4	4	35	41	43	48
Acute	6	3	3	27	30	32	36

3.5.3. Recommended DO limits

The Third Schedule of the RMA defines that "the concentration of dissolved oxygen shall exceed 80% saturation concentration dissolved oxygen concentration saturation" in class F (fisheries) waters. This section of the report therefore examines the suitability of using the 80% threshold as a limit for trout fishery and trout spawning waters in the Wellington Region.

The recommended water temperature objective for regionally significant trout fisheries is 19°C (Section 3.3 of this report). At this temperature, a DO saturation of 80% corresponds to a concentration of 7.5 mg/L, which is just under the USEPA limit for "no impairment" (8mg/L) for adult trout and well above the "slight impairment" limit (6 mg/L), which corresponds well to the level of protection sought for regionally significant trout fisheries, as defined in Section 2.3 of this report.

With regards to locally significant trout fisheries, the literature establishes that a DO concentration of 6 mg/L is generally acceptable to trout, although long-term exposures to concentrations near 6 mg/L may lead to sub-lethal effects, such as decreased growth rates. The ANZECC (1992) Guidelines recommended a minimum DO concentration of 6 mg/L. At a water temperature of 24°C (the recommended standard for locally significant trout fisheries in this report), 6 mg/L corresponds to a saturation of 71% (Table 9). A minimum saturation of 70% would ensure that DO concentrations remain above 6 mg/L as long as the temperature does not exceed 24°C. At temperatures in excess of 24°C, 70% saturation will correspond to DO concentrations below 6 mg/L, which may compound the direct effects of high water temperatures.

The maximum recommended temperature for trout spawning waters is 11°C during the May to October period. At 11°C, a concentration of 9 mg/L corresponds approximately to 80% saturation. A minimum saturation of 80% would ensure that DO concentrations remain above the 9 mg/L limit (recommended by Hay *et al*., 2006) at water temperatures below 11°C. This limit is consistent with the RMA Third Schedule standard for fisheries waters, and is consequently recommended for GWRC's Regional Plan (Table 10).

Table 10: Recommended Dissolved Oxygen (DO) saturation limits for locally and regionally significant trout fisheries and trout spawning streams in the Wellington Region. The "measured DO" columns reports the range of 5th percentile of monthly DO saturation data measured at RSoE sites (2004-2009 period).

Management Objective	Recommended minimum DO limit (% saturation)	Measured DO (5th percentiles at individual sites)	
		Reference	Impacted
Locally significant trout fishery	70%	85 - 93%	55 - 92%
Regionally significant trout fishery	80%	86 – 94%	81 - 94%
Trout spawning (May –October)	80%	82 – 96%	80 - 94%

3.5.4. Application of DO limits

Dissolved oxygen being indispensable to most superior forms of aquatic life, it is recommended that the DO saturation objectives apply at all times, at all river flows.

The limits recommended above are daily minima, and compliance against them should be assessed accordingly.

A significant point to note is that day-time instantaneous ("spot") measurements, generally taken as part of GWRC's routine SoE monitoring programme, only provide a snapshot of the DO concentration in the river at the time of sampling, but provide little information on the daily minimum concentrations. As such, they are of limited value in terms of SoE reporting or to assess compliance with the DO objectives. Although low daytime DO measurements do indicate a possible significant issue, reasonably high concentrations do not mean that the DO concentration remains acceptable at night.

Ideally, continuous monitoring records should be obtained at least during summer, although spot measurements taken at or near dawn can provide a useful measure of daily minimum DO concentration/saturation.

The existing SoE "spot measurement" DO data can still be useful in identifying existing issues associated with DO, although it will not enable a thorough assessment at all sites. Basically daytime "spot" measurements that regularly fall below the saturation guideline strongly indicate the existence of a DO issue. The opposite is not true however: high daytime DO readings are inconclusive. As a result the lower end of the range of values measured at each site (5th percentile is recommended in this case) should be compared with the recommended limits and used as a trigger for further investigations.

3.6. Organic matter

Water quality limits relating to soluble carbonaceous five-day biochemical oxygen demand ($ScBOD_5$) and particulate organic matter (POM) have been recommended in relation to the Aquatic Ecosystem management purpose (Ausseil, 2011b). The same numerical limits are recommended for both regionally and locally significant trout fisheries in the Wellington Region:

- a maximum monthly average $ScBOD_5$ concentration of 2 mg/L, applicable under base flow conditions (below median flow); and
- a maximum monthly average POM concentration of 5 mg/L, also applicable under base flow conditions (below median flow).

The above water quality limits are recommended for inclusion in the Regional Plan, but only in relation to point source discharges.

$ScBOD_5$, and to a lesser extent POM, analysis are relatively expensive and it is not recommended that routine monitoring of $ScBOD_5$ or POM be undertaken across the region (e.g. as part of the RSoE monitoring programme) in response to including this limit in the Regional Plan. Monitoring of these determinands should only be undertaken on a case-by-case basis, generally in relation to an existing or suspected point-source discharge.

3.7. Water clarity

3.7.1. Background

Water clarity refers to light transmission through water, and has two important aspects: visual clarity (sighting range for humans and aquatic animals) and light penetration for growth of aquatic plants (Davies-Colley and Smith, 2001; Davies-Colley *et al.*, 2003). Changes (generally reduction) of water clarity can affect a number of values associated with streams and rivers, including recreational, amenity, and, of relevance to this report, aquatic life (including trout) values.

Trout are visual predators and feeding on drifting prey (drift feeding) is the predominant foraging behaviour in most rivers, especially those of moderate to steep gradient (Hay *et al.*, 2006), typical of river trout fisheries in the Wellington region. Decreases in visual clarity, or equivalent increases in water turbidity, have been shown to reduce foraging efficiency (i.e. more energy is spent consuming the same amount of prey, or less prey are consumed). Sweka and Hartman (2001) showed that increased turbidity had no significant effect on brook trout mean daily prey consumption but resulted in a significant reduction in growth rates. This was because trout abandoned drift feeding in favour of active searching - which is energetically more expensive - as turbidity increased. Bioenergetic models, described in Hay *et al.* (2006) have been developed to link foraging efficiency with water turbidity or clarity. Water clarity/turbidity and suspended solids can also have an influence on plant/algae and macroinvertebrate communities (Ryan, 1991; Quinn and Hickey, 1990), which in turn may affect trout populations.

Water clarity is also a significant attribute of a number of river trout fisheries. Poor water clarity reduces angling opportunities and the range of usable angling methods, such as fly fishing and casting to sighted sight fishing opportunities. Poor water clarity may also reduce the aesthetic values of the stream or river and may be inconsistent with angler’s expectations; it is generally perceived as having a negative impact on the quality of the angling experience.

Three water clarity determinands are commonly monitored in relation to particles present in the water column: visual water clarity, turbidity and total suspended solids (TSS).

- Visual clarity is generally measured using the “black disc” method, which determines the underwater horizontal sighting range of a black disc.

- TSS is a direct measurement of the concentration of sediment suspended in the water column. As such, it is the best determinand to estimate sediment loads transported by a waterway.
- Turbidity is an index of light scattering by suspended particles that is widely used in scientific monitoring and research. Turbidity can be measured in a water sample, which means physical conditions at the site (poor light conditions, small streams) do not prevent measurement. Importantly, turbidity probes allow continuous turbidity monitoring.

Provided sufficient data are collected, robust site-specific correlations can be drawn between the three determinands. As a result, continuous turbidity probes are particularly useful monitoring tools, as they enable the indirect (i.e. via statistical correlations) continuous monitoring of TSS, in turn enabling the estimation of sediment loads transported by a waterway. Continuous turbidity monitoring also enables the indirect continuous monitoring of visual clarity.

In a review of the available scientific literature, Davies-Colley and Smith (2001) assessed the suitability of the three indicators for use in water quality applications, including environmental standards. The use of TSS is not recommended in the context of water quality values protection, as much of the impact while sediment remains suspended is related to its light attenuation, which reduces visual range in water and light availability for photosynthesis. Thus measurement of the optical attributes of suspended matter in many instances is more relevant than measurement of its mass concentration. Turbidity is a widely used, simple, cheap instrumental surrogate for suspended sediments that also relates more directly than mass concentration to optical effects of suspended matter. However, turbidity is only a relative measure of scattering that has no intrinsic environmental relevance until calibrated to a "proper" scientific quantity. The authors conclude that visual clarity or beam attenuation should supplant Nephlometric turbidity in many water quality applications, including environmental standards.

Visual clarity limits have also been defined (in preference to turbidity or TSS limits) in most recent regional plans that contain river water quality limits, including the Regional Water Plan for Southland, the Canterbury NRRP, and Manawatu-Wanganui's One Plan.

Based on the above considerations and because of its direct relevance to the sight feeding of trout and the aesthetic and angling experience values, it is recommended that visual clarity, measured as the horizontal sighting range of a black disc, be used for the definition of limits in relation to the trout fishery management purpose.

Trout spawning, and in particular the development and hatching of eggs is sensitive to the amount of sediment deposited in and on the gravels that constitute trout spawning grounds, rather than to sediments suspended in the water column. As a result, it is recommended to define narrative, and then numerical limits relating to deposited sediments for the protection of trout spawning (refer to Section 3.8 of this report), rather than water clarity limits.

3.7.2. Recommended visual clarity limits

RMA Sections 70 and 107 set that discharges of contaminants into water shall not give rise to "any conspicuous change in the colour or visual clarity" in the receiving waters. The Ministry for the Environment Water Quality Guidelines No. 2 (MfE, 1994) provide guidance as to what degree of water clarity change constitutes a "conspicuous change": 20% change in waters where visual clarity is an important characteristic of the waterbody, and 33% to 50% in other waters.

As indicated above, water clarity not only influences the biological (i.e. trout themselves and macroinvertebrates) but also the human aspects of trout fisheries. It is thus postulated that water clarity is likely to be an important characteristic for trout fishery waters, particularly regionally significant trout fishery waters. The following limits setting maximum change in visual clarity as a result of a given activity are recommended (Table 11):

- 20% water clarity change in regionally significant trout fisheries; and

- 33% water clarity change for locally significant trout fisheries.

It is expected that water clarity change limits will adequately cover potential issues associated with changes in water colour and euphotic depth, except in exceptional cases (Davies-Colley, 2009).

Hay *et al.* (2006) predict that a 5 to 10% reduction in the foraging area of drift feeding trout (compared with clear water conditions, of 5m black disc clarity) would correspond to approximately 4.75 and 3.75m black disc clarity. The authors recommend water clarity thresholds of 5m for outstanding and regionally significant trout fisheries to maintain optimum drift feeding conditions, and 3.5m for the locally significant trout fisheries, to maintain reaction distances of drift-feeding trout at reasonable levels. These guidelines should apply only under base flow conditions (i.e. below median flow). The authors acknowledge however, that these thresholds may need to be adapted to local conditions and values. For example, the thresholds may need to be decreased in situations where they may not be attainable due to catchment characteristics, such as underlying geology, and may need to be set at more conservative levels in other situations.

As a result, the reference, or natural, conditions pertaining to each trout fishery needs to be considered in the definition of water clarity objectives. Reference conditions are available for all regionally significant trout fisheries and for some of the locally significant trout fisheries (Table 11). The setting of water clarity objectives that exceed reference conditions would be unattainable, and would carry the risk of setting unreasonable expectations, and is not recommended. The acceptable change in water clarity can also be used to define an acceptable degree of departure (or change) from reference conditions. A 33% departure from reference conditions would result in water clarity objective of 1.7m for the Otaki River and Waitohu Stream. A 20% departure from reference conditions would result in the following water clarity limits in regionally significant trout fisheries:

- 1.8 m for the Waikanae and Wainuiomata Rivers;
- 3.3m for the Ruamahanga River;
- 2.5m for the Waiohine River;
- 2.1m for the Hutt River.

Angling opportunities are considerably reduced when the visual clarity is less than 2m (Peter Taylor, pers. comm. in Ausseil and Clark 2007b); a visual clarity of 2m should also maintain the foraging area of trout when they are feeding on average-sized preys (12 mm or less) (Hay *et al.*, 2006). A visual clarity limit of 2m is recommended as the bottom line for all trout fisheries (locally and regionally significant in the region). This threshold is met at all currently monitored reference/low pressure sites.

A water clarity of 3m maintains good sight feeding range for drift-feeding trout (Hay *et al.*, 2006), and also maintains good angling opportunities, including sight-fishing (Ausseil and Clarke, 2007b). A visual clarity limit of 3.0 m could therefore be recommended for regionally significant trout fisheries and is recommended where reference conditions are significantly better (e.g. the Ruamahanga River). However, a water clarity objective of 3m would be very close to the reference conditions measured in the upper Waiohine River (3.1m), and would only allow a minimal departure from reference conditions. Consequently, a limit of 2.5m (corresponding to a 20% decrease from reference conditions) is recommended for the Waiohine River. A water clarity limit of 3m would not be met at reference/low pressure sites on the Waikanae, Wainuiomata and Hutt Rivers (assessed against the 20th percentile of the base flow visual clarity data distribution), so would be unrealistic for these systems. It is recommended to revert to the 2m bottom-line limit for trout fisheries as described above for the Waikanae and Wainuiomata Rivers, and an objective of 2.1m for the Hutt River, corresponding to a 20% departure from its reference conditions.

Table 11: Recommended water clarity limits for individual rivers to be managed for trout fishery purposes. The "measured visual clarity" corresponds to the range of 20th percentile of monthly black disc sighting range data recorded monthly at RSoE sites (2004-2009 period).

Management Objective	River/Stream	Recommended water clarity limit (m)	Measured visual clarity (m) (20th percentiles at flows below median at individual RSoE sites)	
			Reference	Impacted
Locally significant trout fishery	All	2.0m	2.5m (RS05, RS03)	1.3m (RS04) - 2.2m (RS06)
Regionally significant trout fishery	Waikanae River	2.0 m	2.3m (RS09)	1.5m (RS10)
	Wainuiomata River	2.0m	2.2m (RS28)	1.2m (RS28)
	Ruamahanga River	3.0m	4.1m (RS31)	0.8 - 1.5m (RS32-34)
	Waiohine	2.5m	3.1m (RS47)	0.4m (RS48)
	Hutt River	2.1m	2.7m (RS20)	1.8 – 1.9m (RS21-22)

3.7.3. Notes on monitoring methods and compliance assessment

The most common method of measuring visual clarity in rivers in New Zealand is by measuring the horizontal sighting range of a black disc (Davies-Colley, 1988). It is a simple field method that can be used to directly estimate the beam attenuation coefficient, the primary factor controlling underwater visual ranges for both humans and aquatic animals (Davies-Colley, 1988; Davies Colley *et al.*, 2003). The direct black disc measurement can be limited by high turbidity and/or physical conditions at the sites (e.g. very small, shallow streams). In these cases, visual clarity can be measured ex-situ in a steel trough. These measurements have been shown to be closely correlated with both in-situ measurements and the beam attenuation coefficient (Davies-Colley and Smith, 1992).

Another out-of-stream method uses a 1m long clear plastic tube, with a small black disc sliding inside the tube. This method was originally developed as part of the Stream Health Monitoring and Assessment Kit (SHMAK) (Biggs *et al.*, 2002). The clarity tube measurements have been shown to be correlated with in-situ clarity measurements, particularly in relatively low water clarity environments (Kilroy and Biggs, 2002).

Nephlometric turbidity provides a relative measure of light scattering and has no direct environmental relevance (Davies-Colley, 1991). Turbidity and water clarity and turbidity and total suspended solids are generally well correlated, although specific relationships vary between rivers. Turbidity probes can be directly installed on site and provide a continuous turbidity record. Turbidity monitoring, in particular continuous monitoring, can be a very useful way of providing a continuous (including at night) assessment of compliance with water clarity limits, provided that specific turbidity/water clarity relationships are established at each site.

All three methods above are acceptable as surrogates for direct visual clarity measurements, within their respective field of application, and it is recommended that any Regional Plan limit or standard allow for the use of these methods where dictated by conditions.

The recommended limits should apply year-round under base flow conditions, i.e. below median flow. Compliance should be assessed such that a site will be deemed to comply with the recommended objective if 80% or more of the measurements undertaken at this site when the flow is below median flow are better than the recommended objective. In practice, this means comparing the limit with the 20th percentile of the data collected at the site when the flow is at or below median flow.

The RMA S107 and S70 standards relating to conspicuous change in water colour or clarity do not specify any acceptable frequency or duration of breach of these standards. The recommended water clarity change standards may thus be applied to single water clarity measurements. It is noted however, that specific situations may require a modification or relaxation of this standard. For example, in situations where a conspicuous change in water clarity is inevitable as the result of an activity (e.g. infrastructure works in the bed of a river), then a duration or frequency at which the standard may be breached may need to be defined (e.g. 8 hours in a row, or 2 hours after the cessation of the works).

3.8. Deposited sediments

The deposition of fine sediment on and in the bed of streams and rivers can affect a number of values, including ecological, and aesthetic/recreational values (Matthaei *et al.*, 2006; Ryan, 1991; Death *et al.*, 2003). Although there seems to be a general acceptance of the significance of the issue in New Zealand, there are no nationally accepted protocols for the measurement of deposited sediments, or guidelines to interpret the results in relation to ecological values. In this situation it is difficult to provide robust recommendations in relation to acceptable levels of deposited sediments.

Nuisance /excessive fine sediment deposition can occur as a result of accelerated erosion within a given catchment, generally influenced by catchment-wide processes such as geological characteristics and landcover/landuse. In this context it is recommended that numerical objectives or targets be defined for each catchment/river type, setting the general level of fine sediment deposition at which each waterbody should be managed.

Sediment deposition can also occur as a result of specific activities, such as earthworks, river works or stock crossing. In this context, it seems appropriate that specific standards be defined in relation to these activities, possibly defining a maximum level of change in fine sediment deposition that may result from a given activity.

A Regional Council-led Envirolink Tools project is currently underway to develop national protocols for the measurement of fine sediment deposition, and national guidelines for the protection of a number of common river values, including macroinvertebrate communities and trout spawning. As this project is expected to be completed in late 2011, it is recommended to await its outcome prior to making detailed recommendations for GWRC's Regional Plan. In any case, it is recommended that RMA Third Schedule standards for class AE be used to guide the definition of numerical thresholds:

"(2) The following shall not be allowed if they have an adverse effect on aquatic life:
(b) any increase in the deposition of matter on the bed of the water body or coastal water:"

3.9. Ammonia

3.9.1.Background

Ammonia is a common pollutant in raw or treated domestic, agricultural and industrial wastewater, and can be toxic to many aquatic species. Ammonia is a toxicant, but also a directly bioavailable nutrient[6]. This report only considers the potential effects of ammonia as a toxicant; aspects relating to ammonia as a nutrient are covered in a separate report (Ausseil, 2011c).

When in solution in the water, ammonia occurs under two main chemical forms: the ammonium cation (NH_4^+) and unionised ammonia (NH_3). The respective proportion of these two forms is determined by a chemical equilibrium governed by pH and temperature. The higher the pH and temperature, the higher the proportion of unionised ammonia. Unionised ammonia being much more toxic to aquatic life, the toxicity of total ammonia (being the sum of unionised and ionised forms) increases with pH and/ or temperature.

[6] Total ammoniacal-nitrogen is one of the components of Dissolved Inorganic Nitrogen (DIN), which also contains nitrate- and nitrite- nitrogen.

In setting ammonia limits, the pH and temperature dependency of ammonia toxicity must be carefully considered.

3.9.2. Bibliography

Ammonia being a very common water pollutant, its toxicity to aquatic biota, including trout and other fish and macroinvertebrates is well studied. The report recommending water quality limits for waters to be managed for aquatic ecosystems (Ausseil, 2011b) provides a bibliographic summary of ammonia toxicity on New Zealand native fish and macroinvertebrates. The ANZECC (2000) guidelines and USEPA (1999) ammonia criteria documents provide excellent summaries of the effects of ammonia on different components of aquatic ecosystems, including trout, and the reader is encouraged to refer to these documents for additional information.

3.9.1. Recommended ammonia limits

The ANZECC (2000) guidelines were based on the toxicity studies available at the time, and recommend a default trigger value based on a concentration of 0.035 mg/L (35 ppb) as unionised ammonia-N for the 95% protection level. It is considered that the ANZECC (2000) 95% protection level trigger value will adequately protect trout and other components of the ecosystem that are key to maintaining healthy trout populations, including macroinvertebrate communities. It is recommended to use this trigger value as the basis for the chronic total ammonia-N concentration limits for GWRC's Regional Plan. The limit recommended) is based on an unionised ammonia-N concentration of 0.035 mg/L, corresponding to approximately 0.916 mg/l as total ammonia-N at pH=8 and water temperature =20°C..

Because of the pH and temperature dependency of ammonia toxicity, the pH and temperature measured at the time and place of sampling should be used to calculate the percentage of unionised ammonia in the sample, and the result compared with the recommended limits. The ANZECC (2000) guidelines provide the necessary equations. Table 12, **Error! Reference source not found.** and **Error! Reference source not found.** provide examples of Total ammonia-N limits at different water pH and temperatures

Ausseil (2011b) recommends the inclusion of an acute total ammonia-N concentration limit for waters to be managed for Aquatic Ecosystem health (i.e. all streams and rivers), to apply in cases where the exposure to ammonia is of known short duration. These limits would provide adequate protection to trout and macroinvertebrate communities, and no additional limits are recommended specifically for trout fishery and trout spawning waters.

Table 12: Recommended chronic total ammonia-N concentration (mgN/L) limit for trout fisheries, at different water pH and temperature.

		Temperature			
		15°C	**20°C**	**25°C**	**30°C**
pH	**6.5**	40	28	19	14
	7	13	8.8	6.2	4.4
	7.5	4.1	2.8	2.0	1.4
	8	1.314	0.916	0.649	0.469
	8.5	0.440	0.314	0.229	0.172
	9	0.163	0.123	0.096	0.078

3.9.2. Application of ammonia limits

All ammonia concentration limits should apply at all river flows. The chronic limit should be applied to situations with constant or variable and/or repetitive exposures (e.g. for a given duration every day) to ammonia occurring for extended periods (e.g. more than four days in a row). This number should be compared with the average concentration of total ammonia nitrogen, calculated over a period exceeding four days.

It is recommended that the chronic exposure limit be considered the default limit, but it is also recommended that the plan provide for the use of an acute limit, for situations where the exposure to ammonia is of known short duration. This limit should not be exceeded for more than one hour (in effect it means that it is applicable to individual samples, as it is very rare to have more than one sample taken in less than one hour).

3.10. Other toxicants

A very large number of other toxicants, including metals and organic micro-contaminants (such as pesticides, hydrocarbons, etc.), may be released in the aquatic environment, and cause toxic effects. Listing them and defining concentration limits for each of them is beyond the scope of this report. The general recommendation in this report is to use the trigger values provided in Table 3.4.1 of the ANZECC (2000) guidelines, with the level of protection recommended below. Detailed examination of toxicant guidelines is undertaken as part of a separate project (Pawson and Milne, 2011).

The ANZECC (2000) water quality guidelines define different protection levels, depending on the type of receiving environment. The approach is based on calculations of a probability distribution of aquatic toxicity end-points, and attempts to protect a pre-determined percentage of species. A percentage of species protected of 95% is generally used, but the approach enables quantitative alteration of protection levels.

The 95% protection level is the most commonly applied level of protection, and should be applied to "slightly to moderately disturbed" ecosystems. The ANZECC (2000) guidelines recommend the use of a higher (99%) protection level as the default value for ecosystem with high conservation values. Finally, the ANZECC (2000) guidelines recognise that it can be appropriate, depending on the state of the ecosystem, the management goals and in consultation with the community, to apply less stringent protection levels (90% or 80%), as intermediate targets for water quality improvement.

Hay *et al.* (2006) note that trout are generally located towards the more sensitive end of the continuum of sensitivity to toxic substances in the environment, and accordingly, recommend that the 99% protection level should provide for the protection of the trout fishery values. This is particularly the case for juvenile trout, and it is recommended that the 99% protection level should generally be applied to trout spawning waters. It is also recommended that this level of protection generally be applied to regionally significant trout fisheries, in line with the relatively high level of protection sought for these waters (Section 2.3 of this report). It is recommended that the 95% protection level be applied to locally significant trout fisheries, corresponding to a slightly lower level of protection than recommended for regionally significant trout fisheries.

It is noted however, that these are general recommendations, and that it may be useful to be able to review them on a case-by-case basis, for example to provide for a lower protection for a given water body and/or in relation to a given toxicant level if information available allows one to determine that this would not result in a significant degradation of the trout fishery or trout spawning values. It is recommended that the provisions of the Regional Plan allow for such flexibility.

3.10.1. Application of toxicant limits

It is essential to note that the numerical limits provided in Table 3.4.1 of the ANZECC (2000) guidelines are "trigger values", and are not intended to be used as absolute water quality limits or standards. They "represent the best current estimates of the concentrations of chemicals that should have no significant adverse effects on the aquatic ecosystems" (ANZECC 2000, Section 3.4.3). The ANZECC (2000) guidelines provide a risk-based decision scheme for applying the guideline trigger values. The process is summarised in Figure 3.4.1, p 3.4-14 of the guidelines document. Basically the recommended process involves comparing the expected contaminant concentration with the default trigger guideline value. If the expected contaminant concentration is below the guideline, this indicates a low risk of significant adverse effects on the aquatic ecosystems. If the contaminant concentration exceeds the guideline, this indicates a potential risk, and the guideline trigger values should be reviewed in the light of site-specific factors and/or a site-specific guideline should be calculated. If the site-specific guideline is still exceeded, the ANZECC framework recommends that either further investigation of the risk of effects (e.g. direct toxicity assessments) or remediation action be undertaken.

These considerations have direct implications when considering the translation of these trigger values into the policy framework, and into resource consent conditions.

The ANZECC (2000) guidelines could be used as thresholds helping the determination of an activity's status, with non-compliance with the trigger value leading to a change in activity status (e.g. from discretionary to non-complying as in the Canterbury Regional Plan), and the risk of environmental effects should be refined through the application process. Caution should also be exerted when considering translating ANZECC trigger values directly into resource consent conditions, to ensure that limits imposed through the consent conditions are consistent with the intent of the ANZECC (2000) guidelines. In particular:

- trigger value concentrations should be applied to the bioavailable (not total) fraction of toxicants; and
- most of ANZECC (2000) Table 3.4.1 trigger values are chronic exposure values, and should, as a first approach, be compared with the median value of monitoring results. Requiring an absolute compliance with a chronic toxicity threshold is likely to be inconsistent with the intent underpinning the number.

The other important point to note is that the ANZECC (2000) guidelines are currently under review. The review, and the release of the updated guidelines are likely to be a relatively lengthy and staged (i.e. individual guidelines may be released as work is completed) process. It is recommended that sufficient flexibility be built into GWRC's Regional Plan to allow for the use of revised guidelines as they become available.

4. Conclusions and recommendations

4.1. Summary

The biological and water quality limits recommended in this report for waters to be managed for trout fishery and trout spawning purposes in the Wellington Region are summarised in Table 13.

A number of other freshwater management purposes, such as aquatic ecosystem, contact recreation, amenity and stock drinking water have also been identified in the Wellington Region. Separate technical reports make recommendations for biological and water quality limits in relation to these management purposes.

In order to present a comprehensive and consistent set of recommended biological and water quality limits for each water body, catchment or any other freshwater "management unit" that may be defined, for inclusion in the regional plan, the following steps are recommended:

- identify and compile the management purposes that apply to each "management unit";
- compile all the biological and water quality limits that apply to each management purpose in each "management unit";
- for each biological and water quality determinand, identify a limit that will enable the maintenance of all management purposes.

4.2. Further work

It is also recommended that existing stream and river monitoring data be compared with the limits recommended in the different reports in this series, to assess the current state of the region's streams and rivers in relation to the different management purposes.

This report presents some preliminary work undertaken to identify and classify the streams and rivers that support significant trout fisheries and trout spawning in the Wellington Region. This work was primarily based on data and information provided by the Wellington Fish and Game Council, but it is recommended that additional checks and consultation be undertaken to refine the identification of trout fishery and trout spawning values in the region.

As indicated previously in this report, further work is required in relation to the definition of in-stream limits for deposited sediments, for both trout fishery and trout spawning waters. This work should follow the release of national guidelines for in-stream sedimentation, anticipated in late 2011.

This report recommends in-stream biological and water quality limits for waters to be managed for trout fishery and trout spawning purposes. Other aspects, such as those relating to the management of the riparian and in-stream physical habitat (e.g. riparian vegetation, works in the beds of rivers, etc.), or the management of trout population are also essential for the management of the trout fishery values. It is recommended that the management of these aspects be considered for their potential incorporation in the Regional Plan.

4.3. Application of limits

This report makes technical recommendations relating to biological and water quality limits. Their inclusion in a Regional Plan will inevitably lead to a number of issues and questions. The policy response to these questions (which is beyond the scope of this report) will essentially determine the status and applicability of the biological and water quality limits within the regulatory and non-regulatory components of the Regional Plan. Issues commonly arising in a number of resource management processes include:

- Where water quality exceeds (i.e. is better than) a given water quality limit (or objective, target or standard), should an activity or a group of activities be allowed to degrade water quality down (or up) to the limit?
- Where water quality is worse than the water quality limits, should an activity or a group of activities be allowed to degrade water quality further?
- Where water quality is much worse than the water quality limits, should the water quality limits apply, or should management "targets" be set, some way between the current state and the water quality limit?
- How should limits be translated into consent conditions? The consenting process is designed to assess each application on its own merits, and account for site- or activity-specific conditions. However, to ensure consistency in the way similar activities are treated, it is recommended that a

practice guide document be produced, to provide guidance on how numerical limits should be included in consent conditions.

Table 13: Summary of recommended biological and water quality limits for waters managed for trout fishery and trout spawning purposes.

Water quality determinand	Trout Fishery Class	Recommended limit	Limit application
MCI (minimum score)	Locally significant	100	Year round, all river flows
	Regionally significant	120	
	Trout spawning	120	
QMCI change (maximum % change)	All	20%	Year round, all river flows
Periphyton biomass (mg Chlorophyll *a* / m^2)	All	120 mg/m^2	Year round, River flows< 3 × median
Periphyton cover (%stream bed, filam. algae >2cm long)	All	30%	Trout fishing season, River flows< 3 × median
Temperature (°C, Daily maximum)	Locally significant	24°C	Year round, all river flows
	Regionally significant	19°C	
	Trout spawning	11°C	May - October
Temperature change (°C, maximum change)	Locally significant	±3°C	Year round, all river flows
	Regionally significant	±2°C	
	Trout spawning	±3°C	May - October
pH (pH units, Range)	Locally significant	6.0 to 9.0	Year round, all river flows
	Regionally significant	6.3 to 8.4	
	Trout spawning	6.3 to 8.4	May - October
pH Change (pH units, maximum change)	Locally significant	±0.5	Year round, all river flows
	Regionally significant	±0.5	
	Trout spawning	±0.5	May - October
DO (% saturation , daily minimum)	Locally significant	70%	Year round, all river flows
	Regionally significant	80%	
	Trout spawning	80%	May - October
$ScBOD_5$ (mg/L, maximum daily average)	All	2 mg/L	Year round, River flows< median
POM (mg/L, maximum average)	All	5 mg/L	Year round, River flows< median
Visual clarity (m, minimum)	Locally significant	2.0 m	Year round, River flows< median
	Waikanae River	2.0 m	
	Wainuiomata River	2.0 m	
	Ruamahanga River	3.0 m	
	Waiohine	2.5 m	
	Hutt River	2.1 m	
Visual clarity change (% change, maximum)	Locally significant	33%	Year round, all river flows
	Regionally significant	20%	
Total Ammonia-N (**Chronic**) (mg/L, maximum average concentration at pH=8.0, Temp=20°C)	All	0.916 mg/L	Year round, all river flows
Other toxicants (protection level)	Locally significant	95%	Year round, all river flows
	Regionally significant	99%	
	Trout spawning	99%	

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APPENDICES

Appendix A:

Identified trout spawning waters in the Wellington Region, and GWRC's RSoE water quality monitoring sites. RSoE sites in grey –shaded cells are reference/ low impact sites. Data from Wellington Fish and Game Council.

Catchment	River/Stream	Tributary/Stream	RSoE Sites	
			No	Name
Hutt	Akatarawa River	Akatarawa River	RS25	Akatarawa @ Hutt Confluence
		Akatarawa West		
		Deadwood Stream		
		Frances Stream		
	Whakatikei River	Whakatikei River	RS26	Whakatikei @ Riverstone
		Wainui Stream		
		Flightys Creek		
	Pakuratahi River	Pakuratahi River	RS23	Pakuratahi Below Farm Creek
		Farm Creek		
		Rimutaka Stream		
	Mangaroa River	Mangaroa River	RS24	Mangaroa @ Te Marua
		Collins Stream		
		Cooleys Stream		
		Collets Stream		
		Narrow Neck Stream		
		Plateau Stream		
	Hutt River	Moonshine Stream		
		Birchville Stream		
		Hutt River	RS20	Hutt River @ Te Marua
			RS21	Hutt River @ Manor Park
			RS22	Hutt River @ Boulcott
Ruamahanga	Ruamahanga River	Ruamahanga River (upper reaches)	RS31	Ruamahanga @ McLays
			RS32	Ruamahanga @ Te Ore Ore
	Huangarua River	Huangarua River	RS51	Huangarua @ Ponatahi Bridge
		Whangaehu Stream		
		Ruakokoputuna Stream		
	Kopuaranga River	Kopuaranga River		
	Taueru River	Taueru River	RS36	Taueru @ Castlehill
			RS37	Taueru @ Gladstone
		Tupurupuru Stream		
	Waingawa River	Waingawa River	RS41	Waingawa @ South Rd
		Atiwhakatu Stream		
		Blakes Stream		
	Waiohine River	Waiohine River	RS47	Waiohine @ Gorge
			RS48	Waiohine at Bicknells
		Mangatarere Stream	RS50	Mangatarere at SH2
		Kaipaitangata Stream		
		Beef Creek	RS49	Beef Creek @ headwaters
		Enaki Stream		
		Papawai Stream		

Catchment	River/Stream	Tributary/Stream	RSoE Sites	
			No	Name
Others	Tauherenikau River	Tauherenikau River (upper reaches)	RS55	Tauherenikau @ Websters
	Wainuiomata River	Wainuiomata River	RS28	Wainuiomata @ Manuka Track
			RS29	Wainuiomata u/s White Bridge
		Catchpool Stream		
	Kaiwharawhara Stream	Kaiwharawhara Stream	RS19	Kaiwharawhara @ Ngaio Gorge
	Otaki River	Otaki River	RS05	Otaki @ Pukehinau
			RS06	Otaki @ Mouth
		Waiotauru Stream		
		Pukeatua Stream		
		Rahui Stream		
		Pukehinau Stream		
		Waitatapia Stream		
	Waikanae River	Waikanae River	RS09	Waikanae @ Mangaone Walkway
			RS10	Waikanae @ Greenaway Rd
	Waitohu Stream	Waitohu Stream	RS03	Waitohu @ Forest Park

Appendix B:

Peer review comments from Dr John Hayes (Cawthron Institute) were received in the form of a "track-changes" version of the draft report. The table below summarises the comments from Dr Hayes and the author's response.

Comments from Dr John Hayes			Response from author	
No.	**Reference**	**Comment**	**Comment**	**Action**
1	Executive Summary	Specify what category of periphyton. 120 mg/m^2 applies to filamentous algae. No limit is recommended for diatoms and cyanobacteria (Hay et al. 2006) recommended 200 mg/m^2 for these based on Biggs 2000.	Refer to response to comment 9 below	Changed to 35 g/m^2 AFDW
2	Section 2.2 and Table 4	Replace angler survey by "National Angler Survey (NAS)" and consequential wording suggestions	Agree	Changes made to text as per suggestions
3	Section 2.3	Suggested additions to text to better characterise timing of brown vs. rainbow trout spawning	Agree	Changes made to text as per suggestions
4	Section 2.3	Give consideration to extending the period of application of the recommended water quality limits for trout spawning waters limit to include November for rivers in which rainbow trout occur	Agree in principle, however the key trout fisheries in the Wellington Region, i.e. the Ruamahanga and Hutt Rivers and their tributaries are primarily recognised as brown trout fisheries.	No change to the recommended limits Added a comment suggesting that consideration should be given to extending the period of application of the recommended water temperature limit if/where protection of the incubation of late spawning rainbow trout was considered particularly important for the maintenance of the fishery
5	Section 2.4, second para.	The eggs/embryos – not the fry – have lower temperature requirements than free swimming trout.	Agree	Replace "fry" by "embryo"
6	Section 3.1.1 (MCI Limits)	In relation to the recommended MCI limit for trout spawning waters: Some more justification for this would be helpful rather than just the MCI being indicative of clean water. More importantly the MCI is sensitive to fine sediment and organic enrichment – both of which combine to reduce DO concentration in the substrate where trout eggs are deposited.	Agree	Comment added as suggested
7	Section 3.2 First para	Add references to Jowett, 1992 and Hayes et al. 2000	Agree	Added references to Jowett, 1992 and Hayes et al. 2000
8	Section 3.2, third para	Referring to the NZ periphyton Guidelines (Biggs, 2000): "But they are based on little more than expert opinion for trout fisheries. They actually need to be underpinned by a more thorough analysis. Barry Biggs developed the trout periphyton guidelines by rating a	Agree – however to the author's knowledge no other guidelines have been developed that might supersede the Biggs (2000) guidelines. The Biggs (2000) guidelines are widely used in RMA	No changes made

Comments from Dr John Hayes			Response from author	
No.	**Reference**	**Comment**	**Comment**	**Action**
		few rivers covering a gradients in peripyton biomass and chlorophyl a concentrations by the quality of their trout fisheries (based on expert opinion) and to set the trout fishery standards"	processes, including regional plans and consents/compliance processes	
9	Sectiom 3.2, fourth para.	The implication is that 120 mg Chl a /m^2 limit applies to all algal communities whereas in Biggs's periphyton guidelines it applied to filamentous algae. This limit could be accused as being environmentally conservative when applied to diatom/cyanobacteria given Biggs guideline for these was 200 mg/m^2 Chl a. The 120 mg limit may come under the spot light in submissions where dairy enrichment is affecting N&P and periphyton. There needs to be a convincing reason for it. The Environment Court decision on the One Plan in respect of this matter will be a useful guide. The periphyton limits summary in Hay et al. (2006) includes both types of algal community (i.e., or Lowland streams, Diatoms and cyanobacteria: 200 mg/m^2 Chlorophyll a 35 g/m^2 AFDW Filamentous algae: 120 mg/m^2 Chlorophyll a 35 g/m^2 AFDW) Hay et al. also recommend a more stringent limit for upland streams 50 mg/m^2 Chlorophyll a maximum 15 mg/m^2 Chlorophyll a mean monthly These are all based on Bigg's periphyton guidelines. Recent research on cyanobacteria at Victoria University & Cawthron might also be useful for informing cyanobacteria limits (contact Susie Woods or Mark Heath) http://researcharchive.vuw.ac.nz/bitstream/handle/10063/1102/thesis.pdf?sequence=1	Agree with regards to the potential for the recommended limit potentially being overly conservative when/where periphyton communities are heavily dominated by mat-forming species, as is commonly the case in the Hutt River. However, the difficulties of applying the Biggs (200) recommended chlorophyll a limits in situations where the periphyton communities are mixed filamentous/mats assemblages are also noted.	Recommend using the Biggs (2000) 35 g/m^2 AFDW threshold, noting however the possible inconsistencies with the chlorophyll a limits recommended by Greenfield (2013b) for the protection of aquatic ecosystem values.
10	Section 3.3.1, first para	Include references to Hokanson et al 1977 and Elliott, 1994 Editorial changes in text	Agree	References added Changes made to text as per suggestions
11	Section 3.3.2, second paragraph	Suggested additions to text relating to the relationship between growth temperature optima depending on fish diet and food limitation.	Agree	Changes made to text as per suggestions
12	Section 3.3.2, last paragraph	Add references to Scott and Poynter 1991 and Jowett 1992 as cited in Hay et al. 2006	Agree	Changes made to text as per suggestions
13	Section 3.3.3	The Hokanson et al (1977) paper cited in Hay et al. (2006) provides the best rationale for justifying a maximum temperature	Agree	No changes made to report, but point noted.

Comments from Dr John Hayes			Response from author	
No.	Reference	Comment	Comment	Action
		limit. It defines for both a constant and daily fluctuating temperature regime the temperature at which the production of a rainbow trout population will be zero. This takes account of individual growth rate and probability of survival. The latter point is important and always overlooked in rationales for setting maximum temperatures. Survival of fish declines with increasing temperature above the temperature preferenda (usually similar to the optimal temperature for growth). When the population production (mean individual growth x number of fish in the population) is used as a measure of population fitness the growth and survival can be combined and plotted against temperature to find the point at which population biomass rate of increase = zero. Hokanson et al. estimated that the maximum temperature at which a rainbow trout population can be expected to maintain its weight (biomass) was a constant temperature of 23°C and a fluctuating [daily] mean temperature of 21 °C (*i.e.* the temperature at which population production is zero). Hay et al. (2006a) suggested that given the differences in temperature preference between the species, an equivalent zero production temperature for brown trout is likely to be 19 °C.		
14	Section 3.3.3, Table 7	These limits apply to brown trout, but given that there are no rainbow trout only rivers in the Wellington region they are appropriate. In rainbow trout only rivers in NZ the limits could be slightly higher.	Agree	No changes made to report, but point noted.
15	Section 3.3.4	Consider including November for rivers that also support rainbow trout (unless F&G have information on rainbow trout spawning and fry emergence periods that would argue otherwise.	Refer to response to comment 4 above	No changes made to report.
16	Section 3.7.1	I think it is worth following this sentence with the explanation in Hay et al. (2006) – see below This is because trout abandoned drift feeding in favour of active searching - which is energetically more expensive - as turbidity increased	Agree	Changes made to text as per suggestions
17	Section 3.7.1, 3rd paragraph, 1st sentence	Meaning unclear. Do you mean that water clarity is an important attribute influencing angling/fishabilty?	Yes, this is what is meant. The two sentences that follow this statement are, in the author's view, sufficient and appropriate to clarify its meaning: "Poor water	No changes made to report.

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			clarity reduces angling opportunities and the range of usable angling methods, such as fly fishing and casting to sighted fish. Poor water clarity may also reduce the aesthetic values of the stream or river and may be inconsistent with angler's expectations; it is generally perceived as having a negative impact on the quality of the angling experience"	
18	Section 4.7.2	I made some calculations using the reaction distance and foraging area equations and the black disc vs NTU relationship in Fig.3 of Davies-Colley & Close 1990. A 20% reduction in black disc equates to about 50% increase in NTU and this results in about 13 – 20% reduction in the foraging area of a 50 cm drift feeding trout eating 12 mm prey over the black disc range 1 – 4m. Percent reduction in foraging area is higher at lower black disc (i.e., at higher NTU). I did the same calculations for 33% reduction in black disc. This equates to 82.5% increase in NTU resulting in 20-29% reduction in foraging area over the black disc range 1 – 4m. These reductions in foraging area will be proportional to energy intake and growth. So if you framed the question in these terms would you feel comfortable with imposing a water clarity change limit that could reduce the profitability of drift feeding by trout by 13-20% or 20-29% - and potentially the growth of trout by the same amounts?	This is useful information that was not available to the author's at the time of writing the report. It is noted the author understands that actual reductions in growth rates will to a large extent depend on the duration of the reduction in the foraging area and the ability for the trout to fulfil its energetic requirements, e.g. by switching to alternative food sources or feeding behaviour. With regards to the duration of the reduction in foraging area/growth, it is noted that the limit is recommended in the context of point-source discharges, immediately downstream of the zone of reasonable mixing. As specified in Section 3.7.3, it is the author's recommendation that these limits be applied to single water clarity measurements. As a result, the long-term median reductions in water clarity (and associated reductions in foraging area) will have to be significantly lesser than the limit in order to comply at all times.	No changes made to report, but point noted.
19	Table 11	The method used to estimate reference clarity conditions should be given. The reference clarities presented in Table 11 look low to me. Are these reference estimates free from pastoral and exotic forestry land use? Clear-water rivers are usually able to be drift-dived for counting trout. The minimum clarity for drift diving is 4 m. So only one of the rivers listed in Table 11, the Ruamahanga, would qualify for that status. If reference condition is not actually reference, but rather something lower owing to past land use change, then further degradation by 20% could be argued to be not protective.	The numbers provided in Table 11 are 20th percentiles of the water clarity distribution at flows below the median flow. This is because it is recommended that the minimum water clarity limits should be met at least 80% of the time at flows below median flow. This is probably the reason why the numbers look low – median values are significantly higher for the same sites. Reference sites utilised in the report to define reference conditions are "true" reference sites, based on >95% native cover in their catchment.	No changes made to report.

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20	Section 3.9.1 First paragraph	Note that concentrations of unionised ammonia-N as low as 0.013 mg/L have been associated with reduced growth in juvenile rainbow trout at temperatures > 16oC (Linton et al. 1997). And there are other studies cited in the same paper reporting sub-lethal effects of ammonia on growth rate. Linton TK, Reid SD, Wood CM. 1997. The metabolic costs and physiological consequences to juvenile rainbow trout of a simulated summer warming scenario in the presence and absence of sublethal ammonia. Transactions of the American Fisheries Society 126: 259-272.	The ANZECC Guidelines trigger values derivation method make use of suitable data available at the time, including the Linton et al. 1997 and studies referenced in that article. It is the author's understanding that for each species the geometric mean of the chronic values is used in the trigger value derivation, which may explain why some studies may have effects at lower concentrations, and that data relating to several salmonid species entered the calculations of the "high reliability" trigger value. The ANZECC guidelines note that the 95% protection species level is considered sufficiently protective of most slightly-moderately disturbed system, although the figure may not be sufficiently protective of the freshwater clam. It was beyond the scope of this report to provide a review of the ANZECC Guidelines trigger values. It is also noted that higher species protection level (99%) has been recommended for some aquatic ecosystem classes, which cover most upland sections of the region's regionally significant trout fisheries.	No changes made to report.
21	Section 3.9.1, second paragraph	The acute limits from Ausseil (2011b) should be repeated in the present report. Or is that what the Acute limit column in Table 12 is?	Agree	Table 12 removed
22	Section 3.9.1, second paragraph and table 12	Are these the actual limits proposed for the sites/rivers or what has been measured. It looks like the latter given that 0.9 mg/l total ammonia N has been recommended as the chronic ammonia limit in Table 13. But neither the 0.9 mg/l limit to the Chronic and Acute Total ammonia limits listed in Table 12 are put in context of the 0.035 mg/l unionised ammonia ANZEC 2000 guideline above which you appear to support. I am confused?	Agree re. the potential for confusion. The limit recommended is 35 ppb of unionised ammonia. There are several ways to express this limit.	For consistency with other reports, the limit is expressed as a total ammonia-N concentration at a given water temperature (20˚C) and pH (8), and a table has been included to provide examples of the corresponding total ammonia-N concentrations at different pH/temperature combinations.