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REGIONAL COUNCIL

Toxic benthic cyanobacteria proliferations in Wellington's rivers in 2005/06

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Executive summary

During spring 2005, thick mats of benthic cyanobacteria (blue-green algae) became established in several of the region's rivers commonly used for contact recreation, including the Otaki, Waikanae, Hutt, Mangaroa, Wainuiomata and Waipoua rivers. At least five dogs were reported to have died after coming into contact with cyanobacteria mats (*Phormidium* sp.) in the Hutt River catchment and tests confirmed that cyanotoxins in the mats were responsible for the death of at least one dog. An inter-agency response team was immediately established comprising Greater Wellington Regional Council, Regional Public Health and local councils. River monitoring was stepped up, media releases issued and health warning signs erected at common access points to affected rivers. Warnings remained in place for most of the 2005/06 summer.

The weather during spring 2005/06 was warmer, drier and more stable than usual, resulting in conditions highly favourable to the establishment and growth of benthic mat-forming cyanobacteria and filamentous algae in the region's rivers. Water temperatures were above average and there were fewer 'freshes' through the rivers to help control algal growth; the Otaki, Waikanae, Hutt and Wainuiomata rivers all had periods of at least 40 days with no significant fresh, which is highly unusual for the time of year. River flows were also very low for spring, with major abstractions for public water supply exacerbating the low flow conditions in the Waikanae, Hutt and Wainuiomata rivers.

Investigations into the causes of benthic algal growth in the Hutt River in November 2005 identified unauthorised discharges of nutrients and sediment into a tributary of the lower Mangaroa River. While these discharges caused a measurable deterioration in water quality downstream, it is unlikely that they were a major contributor to the benthic cyanobacteria proliferations further downstream in the Hutt River. It is considered that the most significant causal factors for cyanobacteria proliferations in all affected rivers were the climatic and hydrological conditions, in particular elevated water temperatures, a lack of 'flushing' flow events and sustained low flow conditions during spring 2005.

Regulatory agencies have now developed a protocol for responding to future benthic cyanobacteria problems in rivers in the Wellington region. The protocol outlines the key roles and responsibilities of the various organisations during both 'normal' and 'response' conditions, with the aim of improving response speed and effectiveness. Other actions taken include:

- improved training of field staff in the identification of cyanobacteria mats;
- more comprehensive periphyton assessments at freshwater bathing sites over the summer months (1 November to 31 March);
- the introduction of automated river flow alarms to warn of flow conditions that might lead to problematic periphyhton growth at bathing sites;

- the provision of further information about cyanobacteria on Greater Wellington's bathing webpage; and
- the development of template warning signs for use in the Wellington region.

There is currently a lack of national guidance to assist with responding to and managing benthic cyanobacteria proliferations. In addition, the extent, frequency, and causes of toxicity in benthic cyanobacteria are poorly understood.

Recommendations

1. Extend the automated river flow warning system to cover popular recreational rivers in the Wairarapa, in particular the Ruamahanga River and the lower Waipoua River.

2. Investigate options for expanding the existing river flow and continuous water temperature monitoring network to incorporate the lower Waikanae and Waipoua rivers.

3. Extend training in the identification of potentially problematic cyanobacteria growths to all council staff working in rivers.

4. Review, on at least an annual basis, the 'toxic benthic cyanobacteria response protocol'.

5. Promote wider public awareness about the potential risks benthic cyanobacteria pose to human and animal health by:

    - issuing media releases prior to and, if appropriate, during the summer bathing season; and
    - producing leaflets and/or posters that can be displayed in Greater Wellington and local council offices and distributed to vets, pet shops, dog clubs and water sports clubs.

6. Continue to work with other organisations to improve Greater Wellington's understanding of, and response to, toxic cyanobacteria proliferations.

Contents

1. Introduction

During spring 2005, thick mats of benthic[1] cyanobacteria (blue-green algae) became established in several of the region's rivers commonly used for contact recreation. The Hutt River was affected for much of the spring and summer, with thick, dark brown-black mats of cyanobacteria found in the channel and exposed along the river margins, particularly in the Boulcott-Avalon area in early November 2005 (Figure 1.1). Significant benthic cyanobacteria growth was also observed in the Otaki, Waikanae, Mangaroa and Wainuiomata rivers around the same time, and in the lower Waipoua River in March 2006 (Milne and Wyatt 2006).

At least five dogs were reported to have died after coming into contact with cyanobacteria mats in the Hutt River catchment during November and December 2005. Analytical tests confirmed the presence of cyanotoxins in samples from the mats and the stomach contents of one of the dead dogs. An inter-agency response team was immediately established comprising Greater Wellington Regional Council (Greater Wellington), Regional Public Health and local councils. River monitoring was stepped up, media releases issued and health warning signs erected at common access points to affected rivers. Warnings remained in place for most of the 2005/06 summer.

This report documents the benthic cyanobacteria proliferations that occurred in 2005/06 and examines the likely causal factors. Management actions taken in response to the proliferations are outlined, along with improved monitoring methods to assist with early detection of potential cyanobacteria problems in rivers managed by Greater Wellington for recreational use.

(PHOTO COURTESY OF CAWTHRON INSTITUTE)

Figure 1.1: Exposed mats of cyanobacteria in the Hutt River, November 2005.

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[1] attached, bottom-dwelling

1.1 Outline of report

This report comprises six sections. Section 2 provides a brief overview of benthic cyanobacteria and their potential toxicity to humans and animals. Section 3 documents the benthic cyanobacteria proliferations that were observed in the region’s rivers during 2005/06. Taxonomy is briefly discussed along with the results of cyanotoxin analyses performed on samples of cyanobacteria mats. Management actions taken in response to the cyanobacteria proliferations are also outlined. Factors responsible for the proliferations are examined in Section 4; the climatic and hydrological conditions that occurred during spring and summer 2005/06 are examined, along with an overview of water quality in the affected rivers. Management implications, actions and obstacles are discussed in Section 5. Overall conclusions and recommendations are presented in Section 6.

1.2 Cautionary note

The focus of this report is largely on those sites where significant cyanobacteria proliferations were observed and cyanotoxin analysis was subsequently carried out. It is acknowledged that proliferations may have been present at other locations on the same rivers, or in other rivers and streams in the region.

2. What are benthic cyanobacteria?

Cyanobacteria, commonly referred to as blue-green algae, are an ancient and ubiquitous group of microscopic organisms that are photosynthetic. There are approximately 2,000 species described worldwide, occurring naturally in a wide range of surface waters, from oligotrophic (low nutrient) to eutrophic (high nutrient) waters (Biggs and Kilroy 2000). Some cyanobacteria species are able to fix nitrogen from the atmosphere, enabling them to inhabit areas where low nitrogen availability normally inhibits growth.

Benthic cyanobacteria are those that grow on the bottom substrate of a waterbody. In contrast, planktonic cyanobacteria (typically associated with pond or lake environments) are free-floating, suspended in the top part of the water column where there is sufficient light for photosynthesis. Benthic cyanobacteria usually form dark brown-black mats that cover stable substrate such as large rocks, stones and cobbles (Figure 2.1). Together with other benthic algae, mat-forming cyanobacteria contribute to the biological productivity of aquatic ecosystems by providing food and habitat for a variety of aquatic invertebrates and other organisms (Biggs 2000).

Figure 2.1: Mat-forming cyanobacteria (*Phormidium* sp.) on cobble substrate in the Wainuiomata River, February 2006.

2.1 Benthic cyanobacteria proliferations

Benthic cyanobacteria proliferations or 'blooms' are the result of rapid multiplication of cells, linked with environmental conditions conducive to their growth, including low or stable river flows and warm, settled weather. Proliferations can occur at any time, but most often occur in late summer or early autumn.

Benthic cyanobacteria mats may have a 'dreadlock' appearance in slow moving parts of a river and abundant growths are often associated with a "musty" smell (Robertson[2], pers. comm. 2006). The mats are usually attached to the river bed, but can detach and float to the surface where they may appear

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[2] Anne Robertson, Kapiti Coast District Council laboratory manager

as scums along the river edge, particularly if water levels drop (Figure 2.2). The mats may also form floating 'rafts', which become caught in other debris in the river (Wood et al 2006). When the cyanobacteria mats die and dry out they may become light brown or white in colour.

Figure 2.2: Exposed mats of cyanobacteria in the Hutt River, November 2005.

2.2 Toxicity

Some species of cyanobacteria can produce natural toxins (cyanotoxins) which are potentially harmful to humans and animals, particularly dogs. The factors that trigger or increase cyanotoxin production in cyanobacteria are not completely understood. It appears that toxin production is controlled genetically[3] while cyanotoxin regulation may be controlled by environmental variables (i.e., an increase in temperature can result in an increase in the amount of toxin produced). However research on toxin regulation in benthic cyanobacteria has not yet been undertaken (Wood[4] pers. comm. 2007).

People can be exposed to cyanotoxins by swallowing or drinking the water, by skin contact with cyanobacteria mats or affected water, and by consuming fish or shellfish from affected waters. The mechanisms for toxicity are diverse, ranging from toxicity to the liver (hepatotoxicity) and nervous system (neurotoxicity), to skin rashes, hives or blisters (dermatoxicity), (Wood et al 2006).

Almost all known cases of cyanotoxin poisoning in New Zealand have involved animals and have been related to planktonic cyanobacteria (Hamill 2001, Wood et al 2006). The only documented poisoning incidences involving

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[3] A cyanobacterial strain must have the genes responsible for toxin production present to be able to produce toxins (although they can have the genes and not be producing the toxins).

[4] Dr Susie Wood, Freshwater Scientist, Cawthron Institute

benthic cyanobacteria in New Zealand occurred when multiple dogs died after contact with cyanobacteria mats (*Oscillatoria*-like species) in the Waikanae River and the Mataura River (Southland) during the 1998/99 summer (Hamill 2001)[5]. A further dog death was recorded from the Mataura River the following summer. All deaths occurred during periods of low river flow when periphyton (algae and cyanobacteria) growth had become relatively dense (Hamill 2001).

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[5] At the time of finalising this report, it was confirmed that two dogs had recently died after consuming cyanobacteria mats in the lower Ashley River, North Canterbury (refer Section 5).

3. Benthic cyanobacteria proliferations in 2005/06

This section provides an overview of the benthic cyanobacteria proliferations observed in the Wellington region's rivers during 2005/06. The focus is largely on those sites where significant cyanobacteria proliferations were observed and cyanotoxin analysis was subsequently carried out. It is acknowledged that proliferations may have been present at other locations on the same rivers, or in other rivers and streams in the region. For example, cyanobacteria mats are commonly observed in many parts of the Ruamahanga River in late summer.

Periphyton[6] data drawn from Greater Wellington's Rivers State of the Environment (RSoE) and recreational water quality monitoring programmes are used to demonstrate the extent of the benthic cyanobacteria proliferations during spring and summer 2005/06. Information from the latter monitoring programme is of limited value as weekly sampling is restricted to the official summer bathing season (1 November to 31 March inclusive). Moreover, the periphyton assessments undertaken in the western part of the Wellington region historically placed greater emphasis on the extent of nuisance growths of green filamentous algae, rather than mat-forming algae.

3.1 Affected rivers

During spring 2005, thick mats of benthic cyanobacteria became established in several of Wellington region's rivers commonly used for contact recreation (Figure 3.1). The Hutt River was affected for much of the spring and summer, with thick, dark brown-black mats found in the channel and exposed along the river margins in the Boulcott-Avalon area in early November 2005 (refer Figure 1.1, Figure 2.2). Although this was the only reach of a river where exposed mats of this nature were observed, stretches of the Otaki, Waikanae, Mangaroa and Wainuiomata rivers also had significant coverage of benthic cyanobacteria mats around the same time. Dense mats were also found in the lower reaches of the Waipoua River in March 2006.

Periphyton data collected for Greater Wellington's RSoE monitoring programme indicate that there was significant coverage of benthic mat-forming algae (including cyanobacteria) as early as July and August 2005 in many of the affected rivers (Table 3.1)[7]. The monitoring record is too short to gauge whether this spring cyanobacteria growth is particularly unusual; monthly semi-quantitative assessments of periphyton coverage date from the early to mid 1990s at some sites in the Wellington region, but focused on either nuisance growths of green filamentous algae or total periphyton cover. Assessments that distinguish the percentage periphyton cover by both filamentous algae and mats have only been undertaken since September 2003 (Milne and Perrie 2005).

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[6] Periphyton refers to the slime coating on a riverbed, composed largely of algae and cyanobacteria.

[7] Filamentous algae cover was also high in some rivers during this period (e.g., lower Waikanae River).

Figure 3.1: Locations where prolific growths of benthic cyanobacteria were observed at some stage during 2005/06. Prolific growths are likely to have been present in other rivers and streams not routinely monitored by Greater Wellington.

Table 3.1: Average cover of mat-forming algae (including cyanobacteria) observed at selected RSoE sites on the Otaki, Waikanae, Hutt, Mangaroa, Wainuiomata and Waipoua rivers, during monthly sampling over August 2005-March 2006.

Location	Percentage mat cover (>0.3 cm thick) based on the average cover at up to 10 points* across the visible/wadeable river bed								
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Otaki R at Pukehinau	0	0	0	0	10	0	0	0	0
Otaki R at Mouth	0	15	0	0	32	22	31	68	16
Waikanae R at Mangaone Wk	0	0	0	0	2	0	0	0	0
Waikanae R at Greenaway Rd	45	0	0	0	0	7.5	NR	5	24.5
Hutt R at Te Marua	1.5	0	0	0	0	0	0	0	5
Hutt R opp. Manor Park G.C.	40	0	17	0	45	NR	20	0	20
Hutt R at Boulcott	20	NR	6	0	4.5	NR	10.5	0	3.5
Mangaroa R at Te Marua	20	0	0	0	0	0	0	0	0
Wainuiomata R at Manuka Tr.	0	0	0	1	0	0	0	0	0
Wainuiomata R u/s White Br	72	0	11	54.5	55	0	0	0	0
Waipoua R at Colombo Rd	0	9.5	0	0	0	0	0	0	50

*River depth or turbidity often limits the number of observations across the river. Note also that assessments are undertaken on different days at different sites.

NR = No Record

Despite the short periphyton monitoring record and observations being limited to monthly intervals, it would appear that the extent of benthic cyanobacteria in the affected rivers was much greater in spring 2005 than in spring 2003 or 2004. For example, no thick (>0.3 cm) mat growths were recorded during monthly sampling at RSoE sites on the lower Otaki, Waikanae, Hutt or

Wainuiomata rivers in spring 2003 or 2004. Historical periphyton data from the RSoE and recreational water quality programmes indicate that (total) algal cover is usually highest in late summer.

3.2 Taxonomy and toxicity

At least five dogs were reported to have died (and others to have become ill) suddenly and dramatically after coming into contact with the cyanobacteria mats in the Hutt River catchment during November and December 2005. Greater Wellington was first alerted to a potential cyanobacteria toxicity problem on 8 November 2005 when a vet advised that a dog had suddenly become sick after consuming some dark 'algae-like' material from the Hutt River adjacent to the Belmont Domain (Figure 3.2). Samples of the material were collected from the river that day and later sent to the Cawthron Institute for identification. The material was found to contain the potentially toxic cyanobacterium *Phormidium* sp. (originally identified as *Oscillatoria* sp.[8]) at high abundance.

(PHOTO COURTESY OF CAWTHRON INSTITUTE)

Figure 3.2: Cyanobacterial mat amongst stones in the Hutt River adjacent to the Belmont Domain in November 2005.

Further samples of the *Phormidium* sp. mats were subsequently collected from the Hutt River at Belmont Domain and analysed for a range of cyanotoxins. Two neurotoxic cyanotoxins (homo-anatoxin-a and anatoxin-a) and their degradation products (dihydro-anatoxin-a and dihydro-homo-anatoxin-a) were detected in the samples (Table 3.2), which corresponded with toxins identified in the stomach contents of one of the dead dogs. This is the first report of

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[8] *Phormidium* is similar in morphology to *Lyngbya* and *Oscillatoria*. Phylogenetic (16S rRNA) analysis demonstrated that the cyanobacterium was most likely to be *Phormidium autumnale* (Wood et al 2007).

homo-anatoxin-a and its associated degradation product in New Zealand (Milne et al 2006, Wood et al 2007).

Table 3.2: Anatoxin-a and homo-anatoxin-a concentrations recorded in samples of cyanobacteria mats collected from various rivers in the Wellington region during 2005/06.

River	Site	Sample date	Toxin analysis*	
			Anatoxin-a (µg/L)	Homo-Anatoxin-a (µg/L)
Drinking Water Standards for New Zealand (2005)#			6	2
Hutt	Belmont Domain	20 Nov 2005	27	4,400
Waikanae	Water Treatment Plant intake	23 Nov 2005	11	64
Otaki	SH 1	24 Nov 2005	9.4	51
Wainuiomata	Upstream Wainuiomata Landfill	14 Dec 2005	25	120
	Wainuiomata Water Treatment Plant	23 Feb 2006	<0.5	34
	Confluence with Black Stream	23 Feb 2006	<0.5	10
Waipoua	Colombo Rd	13 Mar 2006	<0.5	110

* Samples were analysed for other cyanotoxins (e.g., microcystins, saxitoxins) but only anatoxin-a and homo-anatoxin-a were detected.

In the absence of national guidelines for recreational waters, the Provisional Maximum Acceptable Values (PMAV) from the Drinking-Water Standards for New Zealand (Ministry of Health 2005) are provided (for comparative purposes only).

By late November 2005, Kapiti Coast District Council staff conducting routine weekly monitoring for Greater Wellington's summer recreational water quality monitoring programme confirmed the presence of *Phormidium* sp. at bathing spots on the Otaki and Waikanae Rivers. Mats of *Phormidium* sp. were also present on the Waikanae River water treatment plant intake (Robertson, pers. comm. 2005). Cyanotoxin analysis again detected the presence of homo-anatoxin-a and anatoxin-a, although the concentrations were two orders of magnitude lower than those reported for the Hutt River sample (Table 3.2).

In December 2005 cyanotoxin analysis was also performed on a sample of a cyanobacteria mat collected from the lower Wainuiomata River where Greater Wellington Pollution Control officers observed significant mat growth. The analysis confirmed an abundance of *Phormidium* sp. and the presence of both homo-anatoxin-a and anatoxin-a (Table 3.2).

As a precautionary measure, in February 2006 Greater Wellington Pollution Control officers inspected a number of river and stream sites visited by school children participating in the Council's *Take Care* educational programme. This led to the collection of two further cyanobacteria samples from the Wainuiomata River. Homo-anatoxin-a was detected in both samples, although the concentrations were again much lower than that reported for the Hutt River sample (Table 3.2).

In March 2006, Greater Wellington environmental monitoring officers conducting routine weekly recreational water quality sampling noted extensive mats of cyanobacteria at a popular bathing site on the lower Waipoua River. Analysis of a sample of the mats confirmed the presence of homo-anatoxin-a (Table 3.2).

3.3 Management response

Following the identification of toxins in cyanobacteria samples from the Hutt River in November 2005, an inter-agency response team was established comprising Greater Wellington, Regional Public Health and local councils. Media releases were issued and up to 80 health warning signs erected by Upper Hutt City and Hutt City councils, advising against the use of a large part of the Hutt river system (Figure 3.3). Warning signs were also erected at popular access points to other affected rivers. Low river flows and the persistence of cyanobacteria mat proliferations in the Waikanae River led the Kapiti Coast District Council to switch its potable water supply from river water to bore water in January 2006.

Figure 3.3: Examples of warning signs erected at access points to the Hutt River in 2005.

From mid November 2005, Greater Wellington's Pollution Control Team and local council environmental health officers commenced weekly visual inspections of cyanobacteria growth at a selection of popular recreational access points to the Hutt River and other affected rivers in the western part of the region. These inspections were *in addition* to the routine weekly visual assessments of periphyton cover undertaken at 23 popular freshwater bathing spots as part of Greater Wellington's summer recreational water quality monitoring programme (1 November to 31 March inclusive). The increased number of inspection points was necessary because the extent of *Phormidium* sp. in the Hutt River away from popular bathing sites was unknown and there was significant coverage of *Phormidium* sp. mats in rivers not represented in the recreational water quality monitoring programme (e.g., Mangaroa and Wainuiomata rivers).

When investigating the potential causes of benthic algal growth in the Hutt River in November 2005, Greater Wellington's Pollution Control Team noted significant benthic cyanobacteria growth in the Mangaroa River, and directed its investigation toward possible agricultural sources of nutrients. The Mangaroa River is a major tributary of the Hutt River, and has long exhibited elevated nutrient concentrations (Milne and Perrie 2005). Investigations in the lower catchment confirmed excessive spreading of piggery slurry in close proximity to watercourses, indicating a high probability of nutrient export to the Mangaroa River. This is discussed further in Section 4.3.4.

In addition to regular media releases updating the public on the status of affected rivers, a set of "Frequently Asked Questions" about benthic cyanobacteria was developed with the assistance of the Cawthron Institute. This information was accessible on Greater Wellington, Regional Public Health and some local council websites.

Over the 2005/06 summer holidays, health warnings remained in force for more than 60% of river catchments in the west of the Wellington region, severely affecting recreational users. Warnings were eventually lifted in early autumn after storm events generated sufficient flow to flush the majority of the cyanobacteria mats from affected rivers[9].

Following the 2005/06 summer, Greater Wellington, Regional Public Health and local councils completed a protocol for responding to future benthic cyanobacteria proliferations in rivers in the region. The protocol and other management initiatives and actions implemented since 2005/06 are outlined in Section 5.

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[9] Health warnings were temporarily lifted in late January 2006 following heavy rain but subsequently reinstated after field inspections confirmed cyanobacteria mats were still present in some rivers.

4. Environmental conditions

Periphyton establishment and accrual in most rivers and streams in New Zealand tends to reflect local flow regimes, in particular the frequency of flood events and duration of stable (low) flows (Biggs 2000). Flow regimes in turn reflect climatic conditions. This section therefore documents the climatic and hydrological conditions that occurred during spring and summer 2005/06. An overview of water quality in the affected rivers is also provided, with a focus on the variables that commonly affect periphyton growth: namely water temperature, water clarity and nutrient concentrations.

4.1 Climate

4.1.1 General climate of spring and summer 2005/06

The climate of the period August to November 2005 was dominated by higher than average mean sea level pressures in the Southern Ocean and south easterly winds over New Zealand (Salinger and Burgess 2005a & 2005b). Due to the influence of anticyclones and easterly quarter air flow, the north westerly rainfall events that usually dominate spring were less frequent than usual during August to November 2005. In general the weather was warmer, drier and more stable than average spring conditions, particularly in the west of the region.

Climate data collected in Wellington City (Kelburn) and on the Kapiti Coast (Paraparaumu Aerodrome) show that sunshine hours were about 30% higher than the long-term average during August 2005, and about 20% higher than average during spring 2005 (September to November) (Salinger and Burgess 2005a & 2005b). The average temperature recorded at Kelburn during August 2005 was 1.5°C above average, making it the second warmest August since records began in 1862. The trend continued into spring 2005, which was 0.6°C warmer than average. The Wairarapa plains were also warmer than usual; the average temperature for the period August to November 2005 was 1°C above the long-term average at the MetService station East Taratahi.

The weather pattern returned to more usual conditions in December 2005, with northerly winds prevailing and several frontal rain systems passing over the region. However, temperatures remained slightly above average.

January to March 2006 brought a mixed pattern. In January, westerly air flows prevailed and temperatures were about normal for the month. February was dominated by anticyclones and it was slightly warmer and sunnier than usual (Salinger and Burgess 2006a), particularly in the Wairarapa, Wellington City and Wainuiomata. During March, low pressure systems to the east of the North Island created southerly air flows and relatively cool and wet conditions in the Wairarapa and Wellington City (Salinger and Burgess 2006b).

4.1.2 Rainfall

Data from selected monitoring stations were used to analyse the rainfall in the affected catchments (Table 4.1, Figure 4.1).

Table 4.1: Details of rainfall stations discussed in this report.

Station	Number in Fig 4.1	Recording authority	Record start date	Catchment/Area
Otaki Depot	1	Greater Wellington	1984	Otaki
Water Treatment Plant	2	Greater Wellington	1995*	Waikanae
Paraparaumu Aerodrome	3	MetService / NIWA	1945	Paraparaumu
Bull Mound	4	Greater Wellington	1976	Tararua Range
Kaitoke Headworks	5	Greater Wellington	1951	Hutt
Wallaceville	6	AgResearch / NIWA	1939	Upper Hutt city
Tasman Vaccine	7	Greater Wellington	1968	Mangaroa
Wainuiomata Reservoir	8	Greater Wellington	1890	Wainuiomata
Mt Bruce	9	Greater Wellington	1984	Upper Ruamahanga

* Waikanae Waterworks (1969-1998) is used to augment the Water Treatment Plant rainfall record.

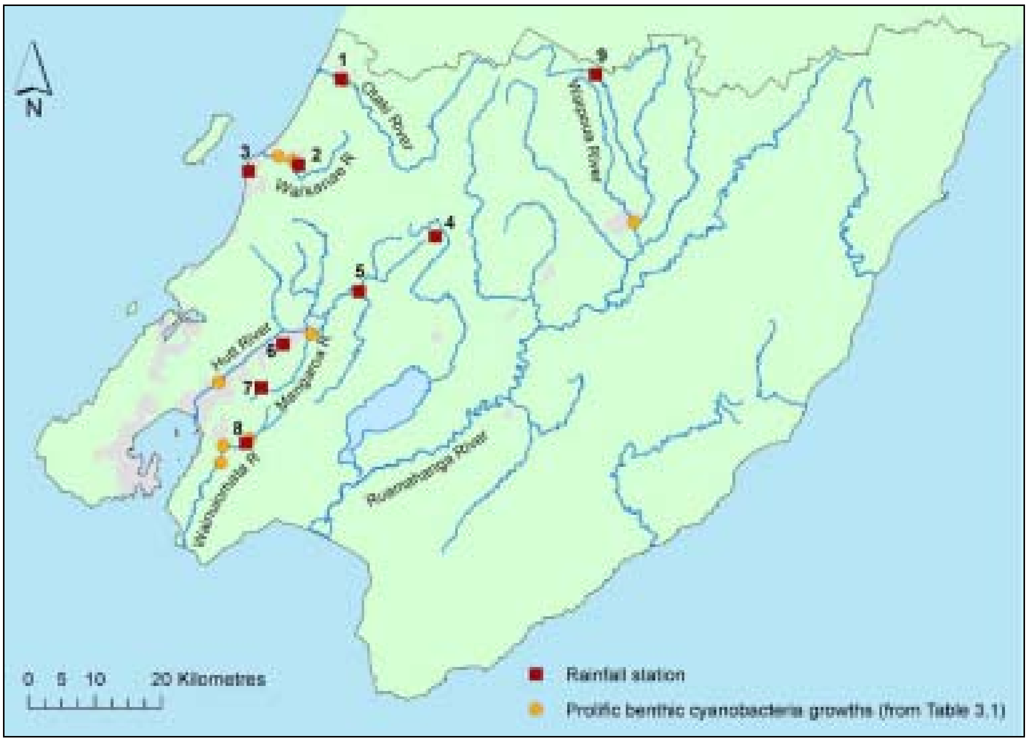

Figure 4.1: Location of representative rainfall stations used in this report.

At the representative stations monthly rainfall totals were below average for August and through spring 2005, with August and November being particularly dry (Figure 4.2). It was the driest August on record at Otaki, Waikanae, Hutt, Mt Bruce and in the Tararua Range (Bull Mound), and the second driest in Mangaroa, Wainuiomata (115 years of record) and Paraparaumu (60 years of record). November saw record-low rainfall at Otaki, Waikanae, Paraparaumu, Mt Bruce, Bull Mound and Kaitoke Headworks (54 years of record). In other parts of the Hutt catchment (Tasman Vaccine and Wallaceville), November was the driest since 1970. Rainfall was generally about average for the months December to March.

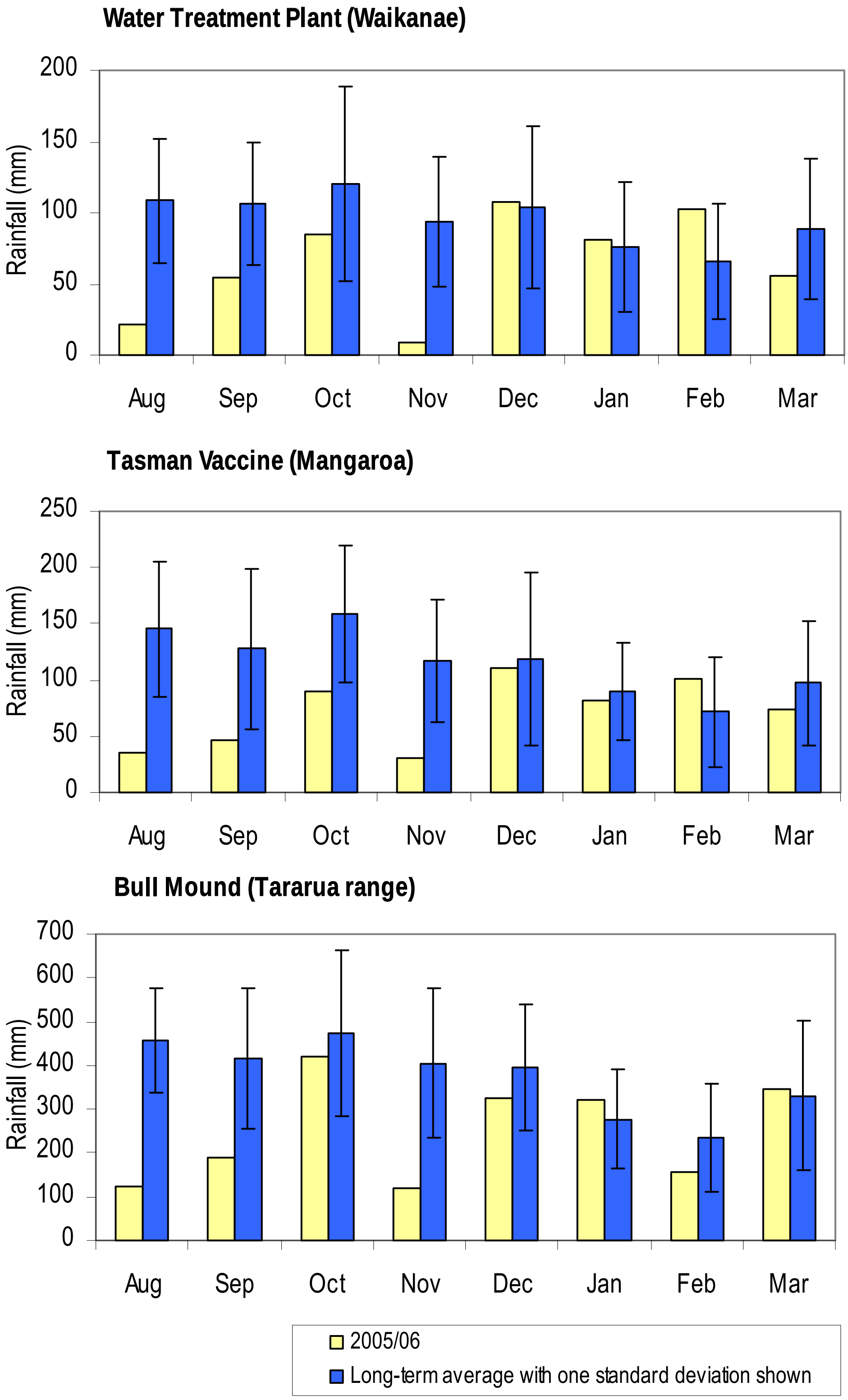

Figure 4.2: Monthly rainfall totals, August 2005 to March 2006 inclusive, compared to long-term average rainfall, at selected recording stations in the Wellington region.

Consecutive months of below-average rainfall meant that the total rainfall for spring 2005 was significantly below average (Figure 4.3). The west of the region was particularly dry, due to the relative absence of northwesterly rainfall events that usually occur during spring. On the Kapiti Coast, spring rainfall was as low as 30% of the long-term average, and in the headwaters of all the affected rivers rainfall was generally less than 60% of average.

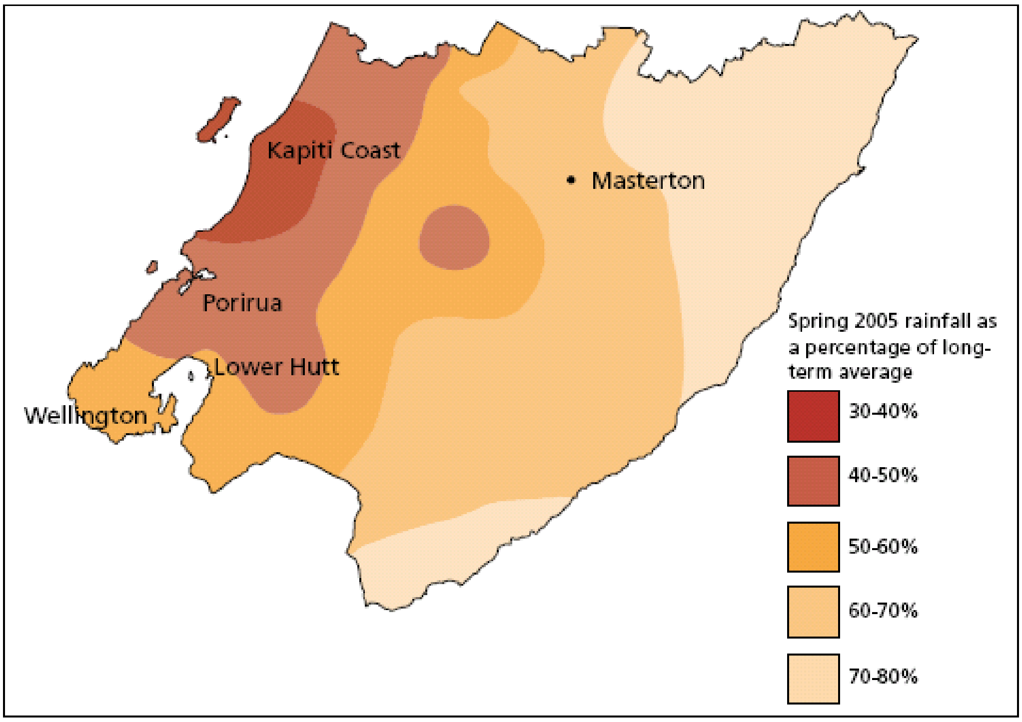

Figure 4.3: Rainfall during September to November 2005 as a percentage of the long-term average for the season.

4.1.3 Dry spells

In addition to the monthly rainfall totals being low, there were more days without rainfall during August, September and November 2005 compared to usual. Between 1 August and 30 November there were 20-58% more 'dry' days compared to the long-term average at the representative rainfall stations.

Spring 2005 had longer than usual dry spells (consecutive days of less than 1 mm rainfall) for the time of the year due to the predominance of anticyclones. The longest dry spells during the period August to December 2005 were:

- 27 days in the Hutt, Mangaroa and Wainuiomata catchments;
- 23 days in the Otaki and Waikanae catchments;
- 17 days in the Tararua Range (Bull Mound) and Masterton.

The driest periods were from late August to mid-September, and from late October to mid or late November (Figure 4.4). The 27 day dry spell recorded at

Wainuiomata Reservoir was the longest dry spell during spring since records began at that site in 1890[10].

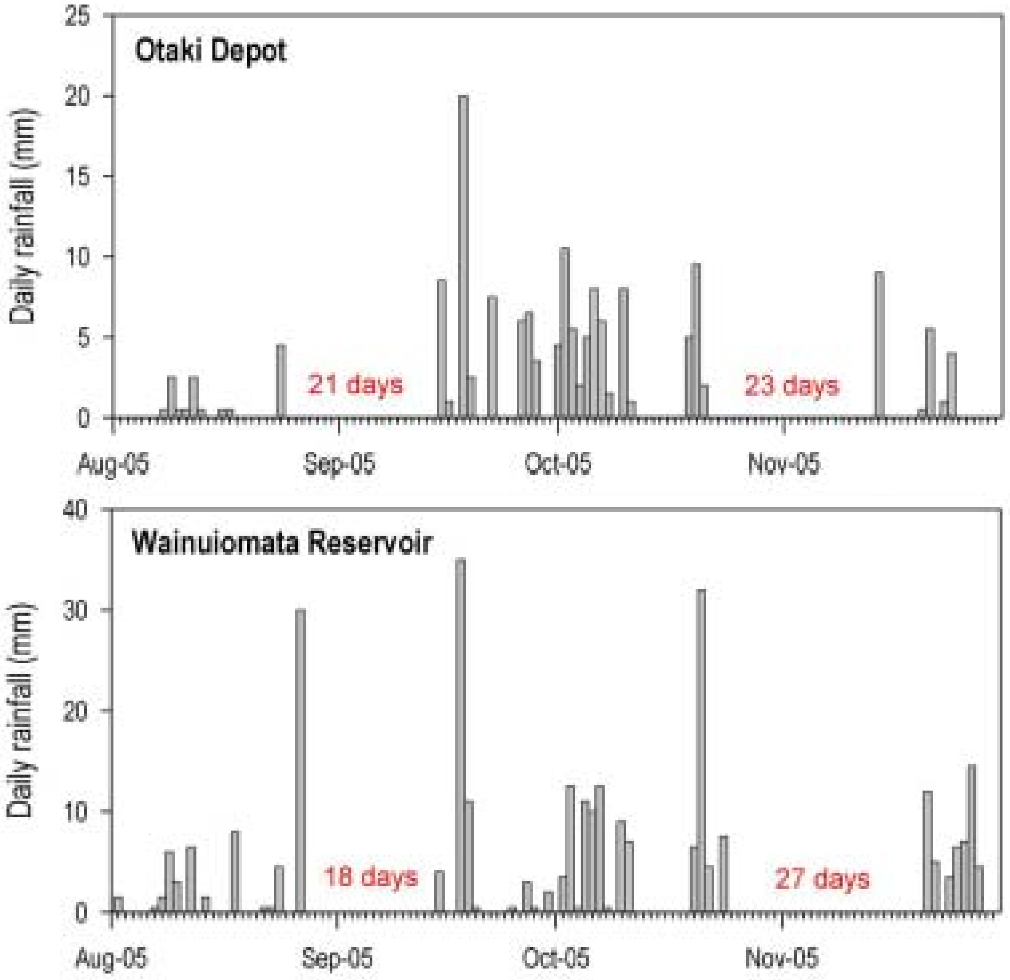

Figure 4.4: Daily rainfall during August to November 2005 at representative rainfall stations, with length of significant dry spells labelled in red.

4.2 River flow conditions

River flow data from selected monitoring stations (Table 4.2) were used to assess the hydrological conditions in the affected catchments during spring and summer 2005/06 (Figure 4.5). Because there is no permanent low flow monitoring station in the Waipoua catchment, Ruamahanga River at Mt Bruce was used as in indicator of flow conditions in the Waipoua River.

Data from two Hutt River flow stations are included in the report, Hutt River at Kaitoke and Hutt River at Taita Gorge. Hutt River at Kaitoke is a short distance upstream of Greater Wellington's abstraction for public water supply and therefore shows the 'natural' flows. Hutt River at Taita Gorge is impacted by abstraction, and shows actual flows in the reach most affected by the cyanobacteria proliferations. Wainuiomata River at Leonard Wood Park is also

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[10] Wainuiomata Reservoir is one of the longest running rainfall stations in the Wellington region, and also provides a good indication of rainfall in the Hutt and Mangaroa catchments.

affected by abstraction for public water supply, whereas Wainuiomata River at Manuka Track is upstream of the water supply intake.

Table 4.2: River flow monitoring stations in this report.

Station	Number in Fig 4.5	Recording authority	Record start date	Record length
Otaki River at Pukehinau	1	NIWA	1980	26 years
Waikanae River at Water Treatment Plant	2	Greater Wellington	1975	31 years
Hutt River at Kaitoke	3	NIWA	1967	39 years
Hutt River at Taita Gorge	4	Greater Wellington	1979	27 years
Mangaroa River at Te Marua	5	Greater Wellington	1977	29 years
Wainuiomata River at Manuka Track	6	Greater Wellington	1982	24 years
Wainuiomata River at Leonard Wood Park	7	Greater Wellington	1977	29 years
Ruamahanga River at Mt Bruce	8	Greater Wellington	1975	31 years

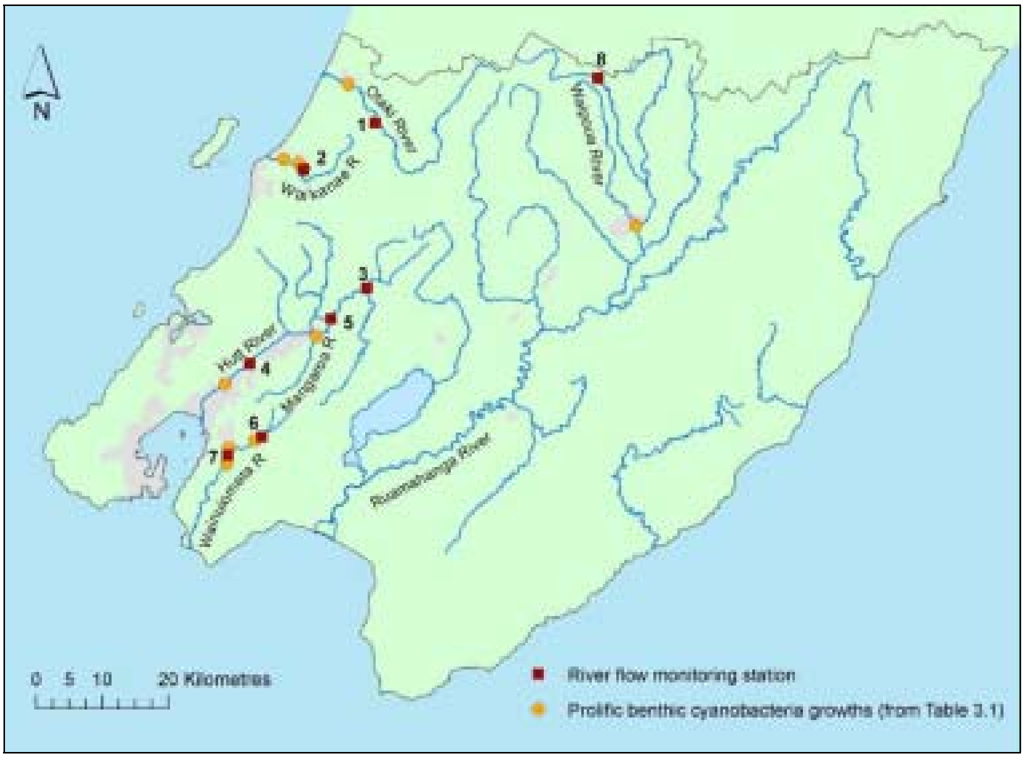

Figure 4.5: Location of river flow monitoring stations used in this report.

4.2.1 General flow conditions

In all of the affected rivers, daily mean flows during August to November 2005 tended to be below the long-term average (Figures 4.6 and 4.7). At times during late August to mid-September, and in November 2005, most of the rivers experienced the lowest daily mean flows on record for the time of year. These lowest flows occurred for extended periods particularly in the Waikanae, Hutt and Mangaroa rivers.

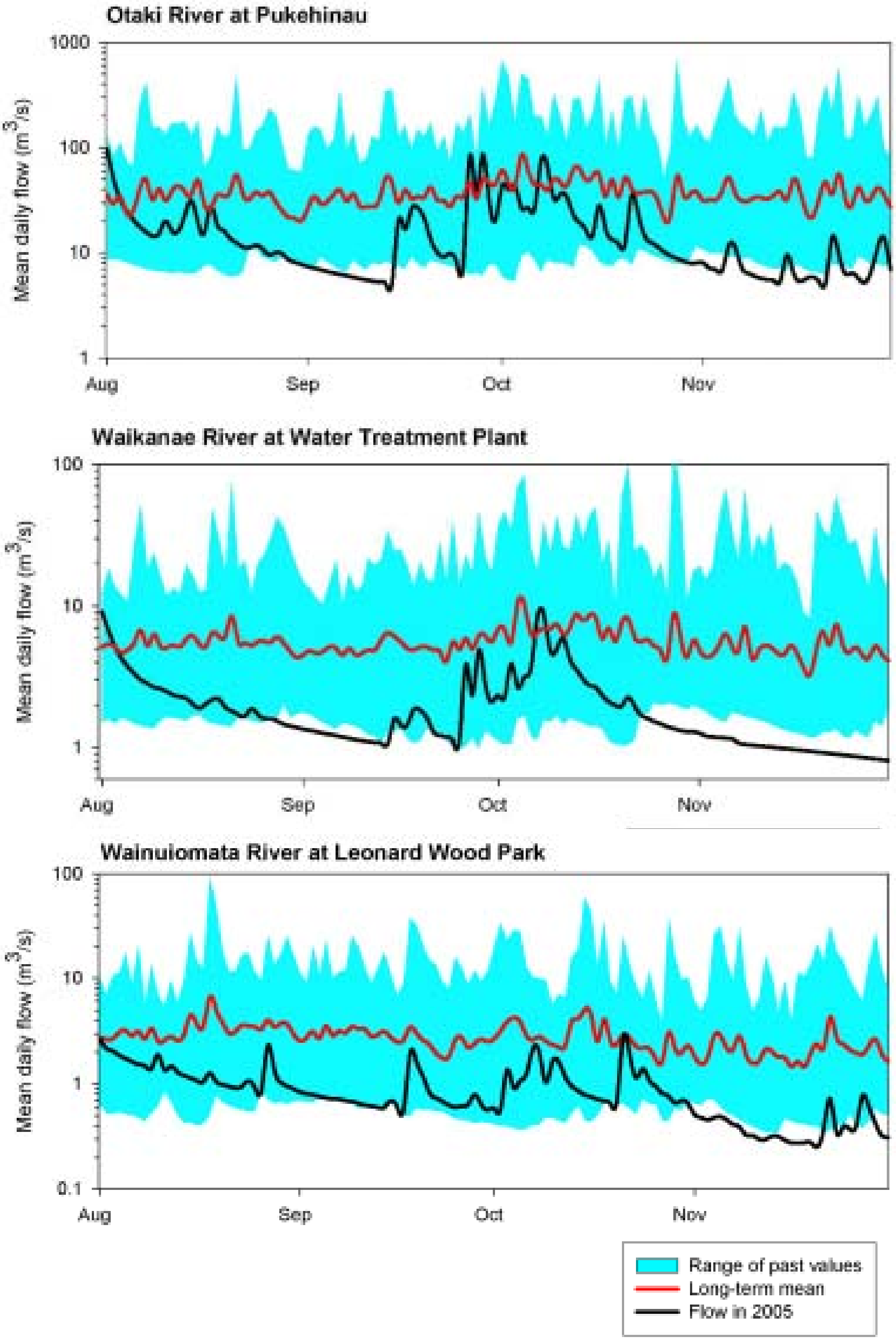

Figure 4.6: Daily mean flows in the Otaki, Waikanae and Wainuiomata rivers, August to November 2005 inclusive (note logarithmic scale on the y-axis). The lowest flows on record for any given day are indicated by the black line (flow in 2005) dropping below the blue shaded area.

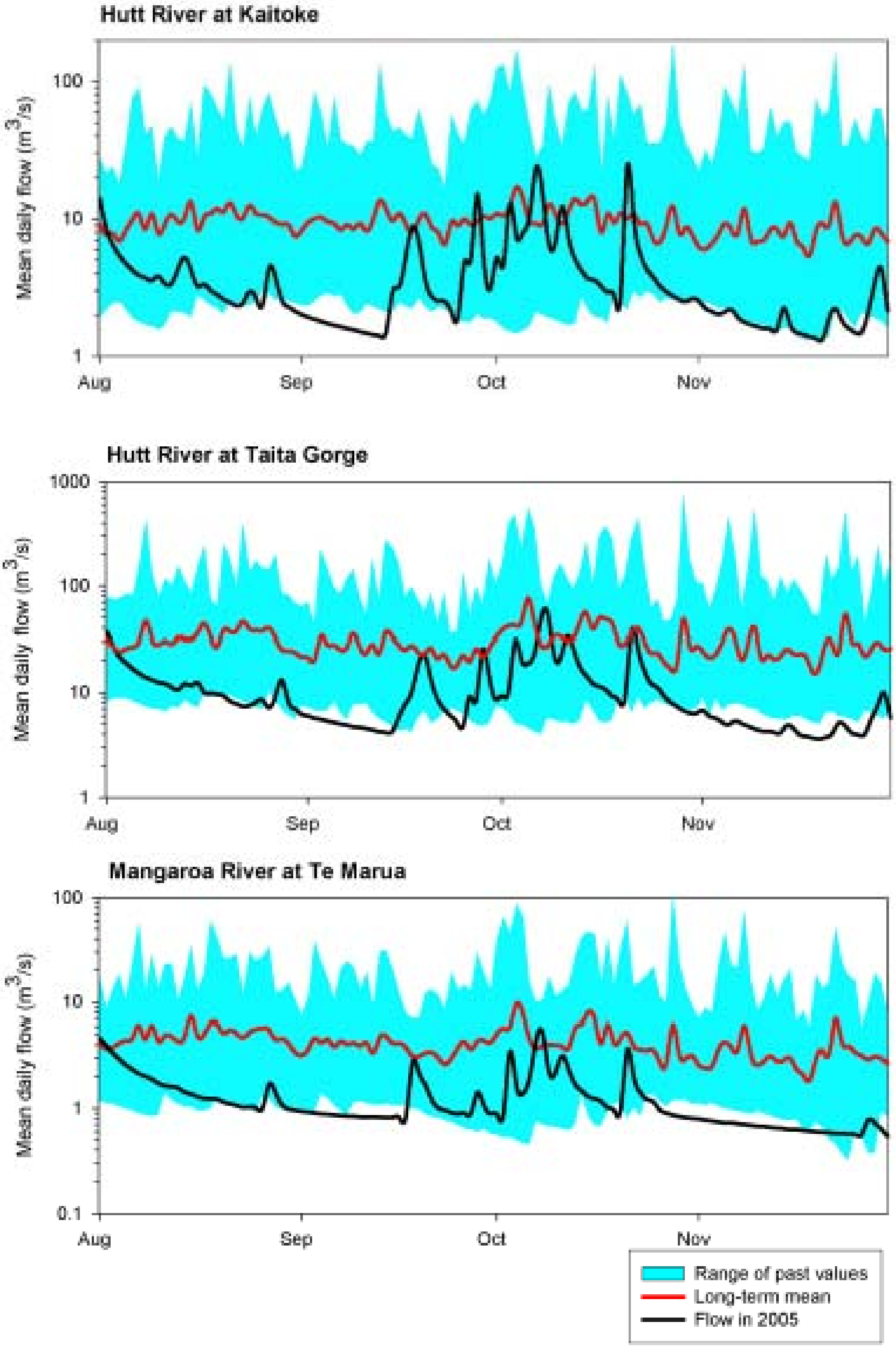

Figure 4.7: Daily mean river flows in the Hutt catchment, August to November 2005 inclusive (note logarithmic scale on the y-axis). The lowest flows on record for any given day are indicated by the black line (flow in 2005) dropping below the blue shaded area.

Although extensive benthic cyanobacteria mats were not apparent in the Waipoua River until March 2006, daily mean flows – inferred from the Ruamahanga River at Mt Bruce – were at their lowest in September and were generally very low compared to the long-term mean throughout spring 2005 (Figure 4.8). River flows generally remained below average during January to March 2006 but there were no long periods of stable river flows as occurred during August and September 2005.

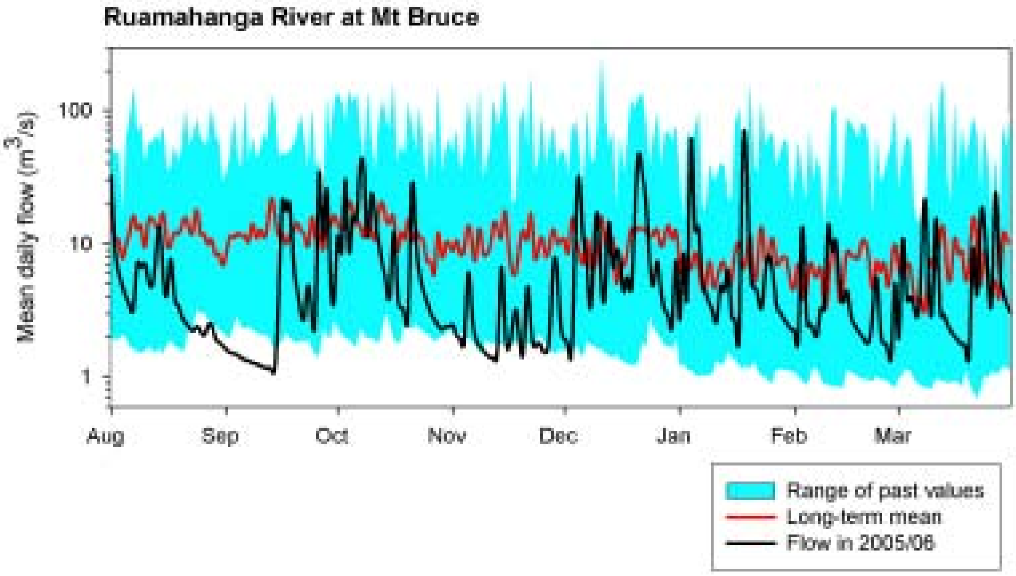

Figure 4.8: Daily mean river flows in Ruamahanga River, August 2005 to March 2006 inclusive (note logarithmic scale on the y-axis). The lowest flows on record for a given day are indicated by the black line (flow in 2005/06) dropping below the blue shaded area.

The monthly mean river flows were below average for the entire period August 2005 to March 2006, with the exception of January 2006 in some rivers (Table 4.3). November river flows were particularly unusual with the mean flow being the lowest on record for that month in all of the affected rivers. The Hutt catchment also had record-low monthly mean river flows in August and September 2005. River flows generally remained below average over the summer months, even though rainfall was about normal for the time of the year. The lower than average summer flows were therefore a result of low base-flows (following on from the dry spring).

4.2.2 Low flow analysis

The 'severity' of the low flows that occurred in spring 2005 was assessed by comparing the lowest 7-day average flows of the 2005/06 hydrological year against the 7-day long-term mean annual low flow (Table 4.4). The low flows of 2005/06 were generally about equal to, or slightly less than, the long-term mean annual low flow. Therefore the conditions experienced are not considered 'extreme'. However, the lowest flows for the hydrological year usually occur between February and April. In 2005/06, some of the rivers in the Wellington region reached lower flows in spring than in summer, which is unusual.

Table 4.3: Monthly average flows (m^3/s), August 2005 to March 2006 inclusive, compared with long-term average flows. Yellow shading indicates a record-low total for that month.

Station		August	September	October	November	December	January	February	March
Otaki River at Pukehinau	Long-term average	33.73	34.55	44.77	32.31	40.24	23.27	18.83	19.71
	Flow in 2005-06	19.93	17.11	24.40	7.45	28.19	22.49	11.43	12.75
Waikanae River at Water Treatment Plant	Long-term average	5.71	5.03	6.21	5.21	5.25	3.78	3.45	2.84
	Flow in 2005-06	2.67	1.61	2.99	0.99	2.28	1.71	2.17	1.20
Hutt River at Kaitoke	Long-term average	9.79	9.22	10.50	7.72	7.54	5.26	4.87	5.09
	Flow in 2005-06	4.01	3.29	6.87	1.95	4.49	5.86	3.14	4.00
Hutt River at Taita Gorge	Long-term average	31.82	25.54	36.35	27.82	25.77	17.23	15.32	15.14
	Flow in 2005-06	12.33	8.12	18.03	4.94	10.83	10.92	9.17	9.07
Mangaroa River at Te Marua	Long-term average	4.88	3.67	4.85	3.39	2.86	1.88	1.67	1.41
	Flow in 2005-06	1.73	1.04	1.75	0.66	0.65	0.65	0.69	0.82
Wainuiomata River at Leonard Wood Park	Long-term average	3.43	2.76	2.99	2.36	1.92	1.48	1.49	1.28
	Flow in 2005-06	1.37	0.77	1.11	0.40	0.80	0.44	0.86	1.13
Ruamahanga River at Mt Bruce	Long-term average	12.15	12.27	12.80	10.88	10.67	7.40	7.02	7.46
	Flow in 2005-06	5.44	6.36	10.79	2.67	10.28	9.31	4.17	6.35

In all cases the low flows of spring 2005 were either the lowest or the second lowest on record for the time of the year (Table 4.4). The Hutt River experienced the lowest 7-day flow for spring since November 1969.

Table 4.4: Lowest 7-day mean flows during 2005/06 hydrological year (July to June) compared to mean annual conditions.

Station	7-day mean annual low flow (m^3/s)	Lowest 7-day flow 2005/06 (m^3/s)	Start date	Comment
Otaki River at Pukehinau	5.354	5.405	8 September	Lowest flow on record for spring
Waikanae River at Water Treatment Plant	1.062	0.830	27 November	Lowest flow on record for spring
Hutt River at Kaitoke	1.458	1.486	7 September	2nd lowest flow on record for spring
Hutt River at Taita Gorge	3.744	3.784*	11 January	
		3.917#	14 November	Lowest flow on record for spring
Mangaroa River at Te Marua	0.399	0.325*	21 February	
		0.572#	20 November	2nd lowest flow on record for spring
Wainuiomata River at Leonard Wood Park	0.291	0.359*	4 January	
		0.274#	14 November	Lowest flow on record for spring
Ruamahanga River at Mt Bruce	1.346	1.190	8 September	Lowest flow on record for spring

*Lowest flow for 2005/06 hydrological year
#Lowest flow for August to December 2005

4.2.3 Impact of abstraction on low flows

Resource consents authorise major abstractions for public water supply from the Waikanae, Hutt and Wainuiomata rivers[11]. Table 4.5 shows the average abstraction rate during the period of lowest 7-day mean flows (taken from Table 4.4) and November 2005, which was the month when flows were lowest compared to 'average'.

During the period of lowest flows about 7% of the flow in the Waikanae River was being abstracted at the Waikanae Water Treatment Plant intake. On average during November, flow in the Waikanae River was being reduced by about 18% due to this abstraction[12].

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[11] At Water Treatment Plant, Kaitoke, and Manuka Track, respectively.

[12] The resource consent held by Kapiti Coast District Council requires 0.75 m^3/s to be left in the river below the WTP.

Table 4.5: Average abstraction rate[13] for public water supply during low flows and November 2005; Waikanae, Hutt and Wainuiomata rivers.

Station	7-day low flow of spring 2005 (m^3/s)	Average abstraction rate during lowest flows (m^3/s)	Average river flow for November (m^3/s)	Average November abstraction rate (m^3/s)
Waikanae River at WTP*	0.830	0.061	0.99	0.179
Hutt River at Kaitoke*	1.486	0.868	1.95	1.004
Hutt River at Taita Gorge#	3.917		4.94	
Wainuiomata River at LWP#	0.274	0.081	0.40	0.090

*Flow recorded upstream of abstraction

#Flow recorded downstream of abstraction

In the Hutt River, approximately 50-60% of the flow at Kaitoke was being abstracted during the period of lowest flows in November (although the minimum residual flow of 0.6 m^3/s, a condition of resource consent, was complied with at all times). The effect of this abstraction on the river flow downstream (where the cyanobacteria proliferations occurred) is unknown. According to the flow statistics in Table 4.5, the flow at Taita Gorge may have been reduced by about 20%. Similarly, abstraction from the Wainuiomata River probably reduced flow at Leonard Wood Park by about 20% during the lowest flows of spring 2005[14].

Although authorised by resource consents, the public water supply abstractions resulted in significant flow reductions in the Waikanae, Hutt and Wainuiomata rivers during the lowest flows of spring 2005. River flows were naturally low at the time and it is not possible to determine what effect, if any, the abstractions had on the cyanobacteria proliferations.

There are also several resource consents that authorise taking of water from the Waipoua River, for irrigation and for Masterton's Queen Elizabeth Park lake. It is possible that up to 0.075 m^3/s was being taken from the river during the time the cyanobacteria proliferations occurred. However, because Greater Wellington does not monitor low flows in the Waipoua River it is not possible to determine the degree to which low flows were exacerbated by abstraction in that river.

4.2.4 Flow losses to groundwater

Many rivers in the Wellington region are affected by losses to, and gains from, groundwater. The Waikanae and Hutt rivers in particular lose a significant amount of their flow to groundwater in certain reaches. The Waikanae River loses flow downstream of the Waikanae Water Treatment Plant, until approximately State Highway 1 (Wellington Regional Council 1994). The Hutt River loses water downstream of Taita Gorge until about Kennedy Good

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[13] Waikanae River abstraction data were obtained via telemetry from Kapiti Coast District Council's water treatment plant. Data for the Hutt and Wainuiomata River abstractions were provided by Greater Wellington's Water Supply, Parks and Forests Division.

[14] The resource consent held by Greater Wellington requires the abstraction to cease when flow at Manuka Track falls below 0.1 m^3/s; flow did not drop below this threshold during 2005/06.

Bridge (Avalon), which is the reach in which extensive cyanobacteria proliferations occurred in November 2005.

4.2.5 'Flushing' flows

The extensive periods without any significant rainfall (Section 4.1.3), indicate that there were also long periods of stable river flows, without any significant 'freshes'. As previously noted, the frequency of flood events and duration of stable or low river flows are key controlling factors of periphyton establishment and accrual. Although there is no conclusive scientific evidence as to the velocity (and therefore the flow) required to slough or 'flush' periphyton from the riverbed, a threshold of three times the median flow is used in this report to qualify a 'flushing flow'[15].

All affected rivers experienced significantly less time than usual with flows greater than three times the median flow during August and spring 2005 (Figure 4.9), which indicates that significantly fewer flushing flows occurred compared to usual. November appears to be particularly unusual as there were no flushing flows in the Otaki, Waikanae, Hutt, Mangaroa or Wainuiomata rivers. In the Otaki and Hutt rivers, November 2005 is the only November on record (record length 26 and 27 years respectively) when flushing flows did not occur.

The longest periods with no flushing flow during the analysis period were:

- Otaki River – 43 days from 22 October;
- Waikanae River – 65 days from 2 August, and 57 days from 9 October;
- Hutt River – 47 days from 2 August, and 44 days from 22 October;
- Mangaroa River – 59 days from 22 October;
- Wainuiomata River – 59 days from 22 October; and
- Ruamahanga River at Mt Bruce – 32 days from 15 August[16].

In all cases these are long durations without significant flushing flows. In particular, the Tararua-fed rivers (Otaki, Waikanae, Hutt and Ruamahanga/Waipoua rivers) usually have frequent hydrological disturbance during spring due to the predominance of northwesterly rainfall events.

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[15] The threshold of three times the median flow follows Clausen & Biggs (1997), who use this statistic to assess disturbance to biological communities from flushing flows.

[16] Likely to be a longer duration in the Waipoua River.

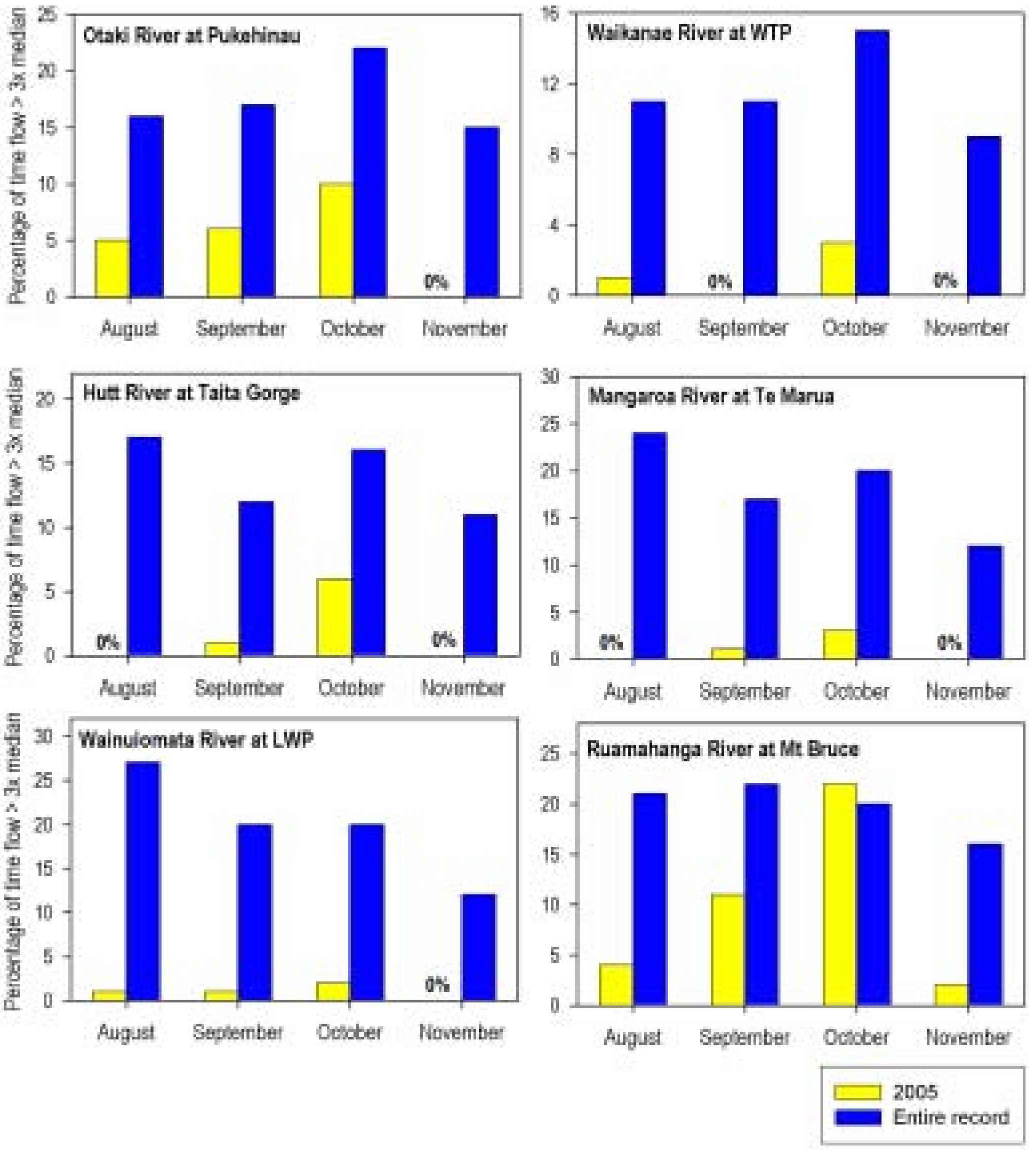

Figure 4.9: The percentage of time river flows exceeded three times the long-term median flow (i.e., indicative flushing flow threshold) during August to November 2005, compared with the long-term exceedance percentages.

4.3 Water quality

This section provides an overview of water quality in the affected rivers, with a focus on the variables that commonly affect periphyton growth: water temperature, water clarity and nutrients. The information presented is largely drawn from Greater Wellington's RSoE monitoring programme (Table 4.6). This programme comprises 56 sites that are monitored on a monthly basis for a range of physico-chemical and microbiological variables. In addition, macroinvertebrate community health and periphyton taxonomic richness are assessed on an annual basis during summer-autumn.

Table 4.6: RSoE water quality monitoring sites used in this report, including proximity to sites where cyanobacteria proliferations and/or cyanotoxins were confirmed in 2005/06.

Site No.	RSoE site	Record start date	Proximity to closest affected site
RS05	Otaki River at Pukehinau*	Sept 1991	9 km upstream of SHI bathing site
RS06	Otaki River at Mouth	Apr 1990	3.7 km downstream of SHI bathing site
RS09	Waikanae River at Mangaone Walkway	Sept 2003	10.5 km upstream of Waikanae WTP intake and 12 km upstream of SHI bathing site
RS10	Waikanae River at Greenaway Rd*	Sept 2003	At site
RS20	Hutt River at Te Marua Water Intake	May 1987	24.5 km upstream of Belmont Domain
RS21	Hutt River opp. Manor Park Golf Course	Jul 1997	5.5 km upstream of Belmont Domain
RS22	Hutt River at Boulcott*	Sept 2003	2 km downstream of Belmont Domain
RS24	Mangaroa River at Te Marua	Sept 1987	5 km downstream of Mangaroa Hill Rd
RS28	Wainuiomata River at Manuka Track	Jun 1987	1.2 km upstream of Wainuiomata WTP
RS29	Wainuiomata River u/s White Br	Jul 1997	15 km downstream of Wainuiomata Landfill
RS40	Waipoua River at Colombo Rd*	Feb 1997	At site

*Also represent bathing sites that are monitored weekly during the summer (1 November to 31 March) under Greater Wellington's recreational water quality monitoring programme.

The RSoE programme has been revised on a number of occasions since water quality monitoring began in 1987. As a result, there have been a number of changes to the location of monitoring sites, the range of water quality variables monitored, and the methods of water quality analysis (Milne and Perrie 2005). The most significant changes occurred in August 2003. Therefore examination of water quality in this section is largely limited to data collected since August 2003.

4.3.1 Overview

Table 4.7 provides an overview of water quality in the rivers affected by extensive growths of *Phormidium* sp. during spring and/or summer 2005/06. Overall, the Otaki, Waikanae and Hutt rivers, and the upper Wainuiomata River, exhibit good to very good water quality, reflecting the large proportion of upstream catchment area under unmodified indigenous forest cover (Figure 4.10, Milne and Perrie 2005). In contrast, water quality is significantly poorer in the Mangaroa and Waipoua rivers; dissolved nutrient concentrations recorded at RSoE sites on the lower reaches of these rivers frequently exceed ANZECC (2000) guidelines (Table 4.7). Under the River Environment Classification (REC) system (Appendix 1), the dominant land cover in the catchment area above these sites is pastoral. In the Wellington region, as is the case in other regions in New Zealand, water quality is known to be poorer in rivers and streams draining predominantly agricultural catchments than those under predominantly indigenous forest cover (Milne and Perrie 2005).

Table 4.7: Summary of physico-chemical water quality data and compliance (%) with guideline values* for selected RSoE sites on rivers affected by cyanobacteria proliferations during 2005/06, based on monthly monitoring over September 2003 to January 2007 inclusive.

Site Name	Temperature (ºC)					Dissolved Oxygen (% saturation)					pH					Visual Clarity (m)					Turbidity (NTU)					Conductivity (uS/cm)				Total Organic Carbon (mg/L)			
	Median	Min	Max	*n*	% Results >20 ºC	Median	Min	Max	*n*	% Results <80%	Median	Min	Max	*n*	% Results <6.5 or >9	Median	Min	Max	*n*	% Results <1.6 m	Median	Min	Max	*n*	% Results >5.6 NTU	Median	Min	Max	*n*	Median	Min	Max	*n*
Otaki R at Pukehinau	10.5	5.9	18.9	41	0	99.9	91.4	114.9	41	0	7.4	6.7	8.3	41	0	1.55	0.06	8.75	41	53.7	2.3	0.4	126	41	19.5	59	29	76	41	1.4	0.8	9.2	41
Otaki R at Mouth	11.8	7.6	20.8	41	2.4	102.5	79.8	115.3	41	0	7.5	6.8	8.3	41	0	1.50	0.05	4.32	41	56.1	2.3	0.6	261	41	26.8	62	30	85	41	1.2	0.7	11.2	41
Waikanae R at Mangaone Wk	11.5	5.9	16.9	41	0	97.8	85.8	107.3	41	0	7.5	6.8	7.9	41	0	3.13	1.19	6.10	41	7.3	0.6	0.2	2.9	41	0	83	60	264	41	1.3	0.8	4.5	41
Waikanae R at Greenaway Rd	13.7	7.1	20.0	41	0	103.5	90.3	133.5	41	0	7.3	6.5	7.9	40	0	2.06	0.10	7.84	41	31.7	1.0	0.2	30	41	17.1	102	74	162	41	1.2	0.8	5.3	41
Hutt R at Te Marua	10.9	6.1	17.0	41	0	100.1	83.7	119.3	40	0	7.5	6.5	8.3	41	0	2.90	0.06	5.90	41	17.1	0.9	0.3	75	41	12.2	67	34	96	41	2.1	1.2	12.3	41
Hutt R opp. Manor Park G.C.	13.2	8.8	20.4	41	7.3	102.8	88.5	113.7	40	0	7.3	6.6	8.6	41	0	1.99	0.04	4.00	41	39.0	1.7	0.3	218	41	26.8	93	59	110	41	2.2	1.2	12.3	41
Hutt R at Boulcott	12.9	8.2	21.2	41	7.3	102.9	89.0	120.4	39	0	7.3	6.7	8.5	40	0	1.64	0.04	3.92	41	48.8	2.4	0.3	216	41	24.4	88	43	125	41	2.0	1.0	12.6	41
Mangaroa R at Te Marua	12.5	7.9	19.5	41	0	100.7	89.6	122.3	40	0	7.2	6.0	8.8	40	2.5	1.52	0.05	7.80	41	53.7	1.8	0.6	118	41	19.5	105	71	118	41	3.9	1.7	20.9	41
Wainuiomata R at Manuka Track	10.7	6.6	16.1	41	0	100.1	93.9	124.1	41	0	7.4	6.8	7.8	41	0	2.71	0.92	5.87	40	10.0	0.7	0.4	5.2	41	0	104	70	117	39	1.8	1.1	4.4	41
Wainuiomata R u/s White Br	13.8	7.4	20.0	40	0	97.6	82.3	122.3	41	0	7.3	6.6	8.6	41	0	1.15	0.27	2.41	41	87.8	2.7	1.2	29	41	22.0	143	107	159	40	1.7	1.0	4.6	41
Waipoua R at Colombo Rd	13.8	8.0	22.1	41	12.2	100.8	87.8	117.6	40	0	7.5	6.9	8.4	41	0	2.04	0.15	4.23	40	42.5	1.3	0.3	37	41	19.5	102	64	133	41	1.9	0.3	3.4	41

Site Name	Nitrite-Nitrate Nitrogen (mg/L)					Ammoniacal Nitrogen (mg/L)					Total Nitrogen (mg/L)					Dissolved Reactive Phosphorus (mg/L)					Total Phosphorus (mg/L)					*E. coli* (cfu/100 mL)				
	Median	Min	Max	*n*	% Results >0.444	Median	Min	Max	*n*	% Results >0.021	Median	Min	Max	*n*	% Results >0.614	Median	Min	Max	*n*	% Results >0.010	Median	Min	Max	*n*	% Results >0.033	Median	Min	Max	*n*	% Results >550
Otaki R at Pukehinau	0.037	0.003	0.134	41	0	0.005	0.005	0.15	41	9.8	0.076	0.025	0.54	41	0	0.007	0.002	0.014	41	4.9	0.011	0.003	0.173	41	14.6	5	<1	420	41	0
Otaki R at Mouth	0.047	0.003	0.132	41	0	0.005	0.005	0.05	41	4.9	0.099	0.025	0.50	41	0	0.006	0.002	0.015	41	4.9	0.012	0.002	0.233	41	19.5	25	1	900	41	2.4
Waikanae R at Mangaone Wk	0.109	0.032	0.261	41	0	0.005	0.005	0.06	41	7.3	0.174	0.050	0.592	41	0	0.015	0.003	0.025	41	85.4	0.019	0.003	0.037	41	2.4	19	2	1,200	41	4.9
Waikanae R at Greenaway Rd	0.238	0.019	0.423	41	0	0.005	0.005	0.08	41	7.3	0.300	0.087	3.01	41	4.9	0.010	0.002	0.176	41	41.5	0.015	0.003	0.311	41	14.6	38	11	4,200	41	7.3
Hutt R at Te Marua	0.104	0.024	0.224	41	0	0.005	0.005	0.05	41	2.4	0.200	0.050	0.446	41	0	0.007	0.002	0.012	41	7.3	0.011	0.003	0.086	41	7.3	18	6	2,900	41	2.4
Hutt R opp. Manor Park G.C.	0.260	0.071	0.468	41	9.8	0.005	0.005	0.03	41	4.9	0.362	0.090	0.761	41	4.9	0.007	0.002	0.016	41	14.6	0.014	0.003	0.298	41	9.8	100	13	4,300	41	17.1
Hutt R at Boulcott	0.216	0.066	0.797	41	2.4	0.005	0.005	0.04	41	2.4	0.320	0.070	1.12	41	7.3	0.007	0.002	0.021	41	17.1	0.015	0.002	0268	41	17.1	57	11	5,200	41	14.6
Mangaroa R at Te Marua	0.633	0.003	1.20	41	80.5	0.010	0.005	0.13	41	14.6	0.801	0.173	1.45	41	80.5	0.014	0.003	0.043	41	82.9	0.025	0.003	0.261	41	34.1	200	19	18,000	41	22.0
Wainuiomata R at Manuka Track	0.083	0.015	0.131	41	0	0.005	0.005	0.06	41	14.6	0.148	0.050	0.214	41	0	0.013	0.003	0.026	41	61.0	0.018	0.003	0.057	41	2.4	8	<1	740	41	2.4
Wainuiomata R u/s White Br	0.206	0.003	0.636	41	12.2	0.020	0.005	0.10	41	34.1	0.389	0.109	0.839	41	12.2	0.014	0.002	0.026	41	65.9	0.028	0.011	0.087	41	34.1	80	7	2,600	41	9.8
Waipoua R at Colombo Rd	1.20	0.336	2.76	39	95.1	0.005	0.005	0.23	41	4.9	1.280	0.470	3.00	41	95.1	0.010	0.002	0.030	41	39.0	0.016	0.003	0.080	41	14.6	86	12	1,900	41	4.9

* Most of the guidelines used here are the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) "default trigger values" for aquatic ecosystems (herewith denoted as ANZECC 2000). These trigger values are intended to be compared with the *median* value from independent samples at a site. They are not statutory standards and exceedances do not necessarily mean an adverse environmental effect will result. Rather an exceedance is an "early warning" mechanism to alert resource managers to a potential problem or emerging change that may warrant site-specific investigation or remedial action (ANZECC 2000). The ANZECC (2000) guidelines provide different trigger values for New Zealand upland (>150 m altitude) and lowland ecosystems. While Greater Wellington's RSoE monitoring programme encompasses both upland and lowland sites, for simplicity in comparing water quality between sites, only the lowland trigger values were used in the assessment of compliance with water quality guidelines.

Other points to note in relation to the reported variables and guidelines:

- There are no formal guidelines for water temperature, but it is accepted that prolonged exposure to temperatures above 20^{o}C are detrimental to some aquatic biota (MfE 2001), including sensitive macroinvertebrate species such as mayflies and stoneflies (Quinn and Hickey 1990).
- The dissolved oxygen guideline is the "bottom line" value in the Third Schedule of the Resource Management Act (RMA) 1991; the ANZECC (2000) guidelines (98 to 105% for lowland waters) are considered overly stringent.
- The guideline range for pH is from the ANZECC (1992) water quality guidelines because the range quoted in the 2000 guidelines (pH 7.2 to 7.8 for lowland waters) is considered overly stringent.
- The ANZECC (2000) trigger values for visual clarity are problematic (see Milne and Perrie 2005) so the Ministry for the Environment's (1994) standard for bathing waters is used here.
- The ammoniacal nitrogen guideline used here relates to aquatic ecosystems (Table 3.3.10, ANZECC 2000) and not ammonia toxicity; toxicity depends on water temperature and pH.
- The *E. coli* guideline is the action mode the Ministry for the Environment/Ministry of Health (2003) microbiological water quality guidelines for freshwater recreational areas and is indicative only – strictly speaking the guidelines should apply to the summer bathing season only (1 November to 31 March inclusive).

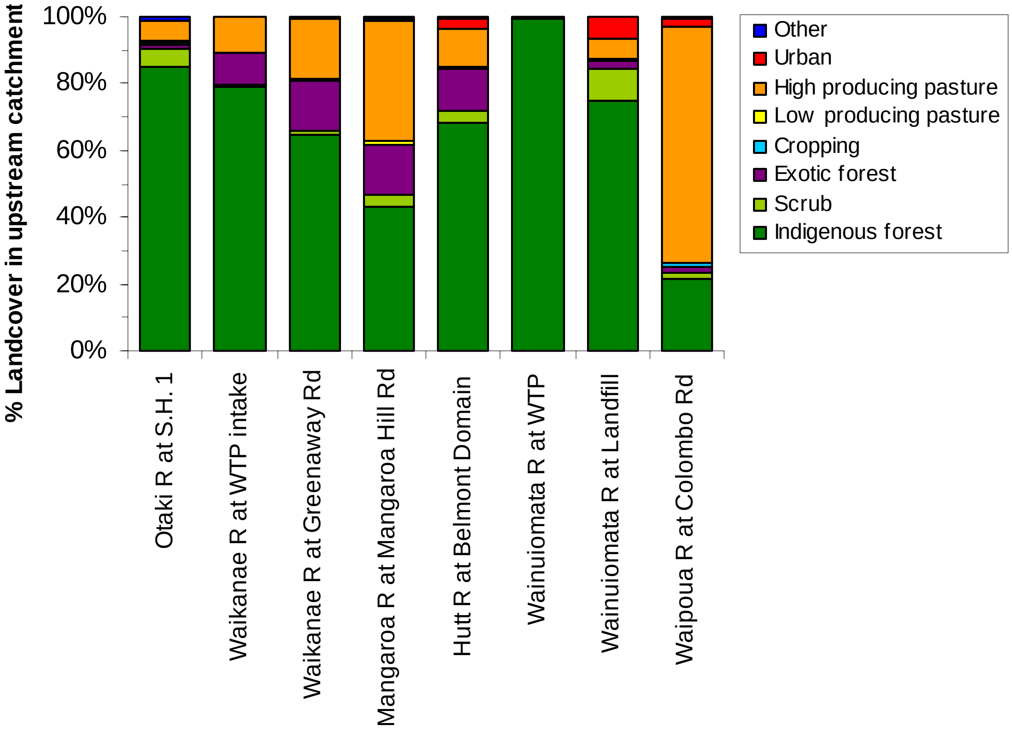

Figure 4.10: Predominant land cover types in the catchment area upstream of selected locations where significant and/or toxic growths of *Phormidium* sp. were observed during spring and/or summer 2005-06.

4.3.2 Water temperature

With above average sunshine hours and air temperatures, and low river flows recorded across the Wellington region during spring 2005 (Sections 4.1.1 and 4.2.1), it is expected that instream temperatures were also above average during this period. However, demonstrating this is difficult with the data available. RSoE water temperature measurements are only taken at monthly intervals and at different times of the day at different sites. Moreover, monitoring sites and sampling times have changed over the years, preventing an accurate assessment of inter-annual differences in water temperatures. Continuous records provide for a more comprehensive analysis of changes in water temperature, but continuous temperature monitoring has only been in place for a few years and is largely limited to river flow recording sites.

Despite these limitations, Greater Wellington's monitoring records do provide evidence of above average water temperatures in stretches of the Hutt River that had dense mats of *Phormidium* sp. during spring 2005. Monthly spot temperature records for the RSoE site opposite the Manor Park Golf Course indicate that the mean water temperature during August to November 2005 (13.75°C) was 2.0°C higher than the August to November mean recorded over the period 1997-2006 inclusive. Although the increase is not statistically significant, the temperature reading for November 2006 (19.7°C on 4 November) is the highest spot measurement recorded in the month of November to date.

Greater Wellington has monitored water temperature on a continuous basis in the Hutt River at Taita Gorge (approximately 0.5 km downstream of Manor Park) since April 2001. Despite the relatively short length of record, instream temperatures measured during spring 2005 were higher than in previous years. The August to November mean temperature was 1.8ºC higher than the mean temperature for the equivalent period in any previous year, and the November 2005 mean temperature (16.8°C) was 3.0°C higher than the mean November temperature recorded in the preceding four years (13.8°C)[17].

4.3.3 Water clarity (turbidity and visual clarity)

The RSoE monitoring programme assesses optical properties of water, including turbidity and visual clarity (horizontal black disc). Monthly monitoring undertaken from September 2003 to January 2007 inclusive revealed that all RSoE sites recorded a median turbidity value well within the ANZECC (2000) guidelines for both upland and lowland ecosystems (Table 4.7). Visual clarity was also good at the majority of sites, with median values over 2 m at many sites. Four sites had a median value less than the Ministry for the Environment (1994) contact recreation standard of 1.6 m; the Otaki River at both Pukehinau and the mouth[18], the Mangaroa River at Te Marua and the Wainuiomata River upstream of White Bridge.

Although visual clarity is only measured on a monthly basis, measurements made in September and November 2005 in the Hutt River opposite the Manor Park Golf Course were above the long-term 90th percentile value (3.9 m, July 1997-January 2007 inclusive), suggesting very high water clarity during spring 2005. This is consistent with the lack of rainfall during spring (Section 4.1.2), although water clarity may have been affected for short periods by instream works associated with flood protection and erosion control, and/or gravel extraction. Such works occur quite frequently in sections of most of the affected rivers (Milne and Perrie 2005).

4.3.4 Nutrients

Nutrient concentrations are a key variable controlling periphyton growth, with concentrations of dissolved inorganic nutrients being particularly important as they are readily available for uptake by plants (Ministry for the Environment 1992). The median nutrient concentrations listed in Table 4.7 suggest that RSoE sites on the Otaki, Waikanae and Hutt rivers, and the site on the upper Wainuiomata River (Manuka Track), are characterised by oligotrophic (low nutrient) conditions or oligotrophic-mesotrophic (low to medium nutrient) conditions[19]. In contrast, RSoE sites on the lower reaches of the Mangaroa River (Te Marua), Wainuiomata River (White Bridge) and Waipoua River

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[17] November 2002 data were suspect and have been omitted from this calculation.

[18] The median values for these sites are surprisingly low and are at odds with those reported by Milne and Perrie (2005) for the 1997-2003 period.

[19] The median dissolved reactive phosphorus concentrations for the upper Waikanae and Wainuiomata RSoE sites are surprisingly high and are at odds with those reported by Milne and Perrie (2005) for the 1997-2003 period.

(Colombo Road) have higher nutrient concentrations. The median nitrite-nitrate nitrogen for the Waipoua River is particularly high (1.2 mg/L).

No obvious trends are apparent in nutrient concentrations during spring 2005, although the mean nitrate nitrogen concentration recorded in the Hutt River at Manor Park during August to November 2006 (0.22 mg/L) was the lowest recorded for that period since monitoring began in 1997. The significance of this, if any, is unclear (nitrogen is not the limiting nutrient in the Hutt River).

There are no longer any known discharges of municipal or agricultural wastewater directly to water within the affected river catchments. Diffuse source inputs therefore represent the major source of nutrients, and are considered to be particularly significant for the Mangaroa and Waipoua rivers. As outlined in Section 3.3, Greater Wellington's Pollution Control officers initiated a targeted water quality investigation in the Mangaroa catchment in response to the first report of toxic cyanobacteria proliferations in the Hutt River in November 2005. The investigation revealed that active spreading of piggery slurry was occurring onto land in the lower catchment, resulting in substantial unauthorised discharges (runoff) of sediment and nutrients into a tributary of the lower Mangaroa River. These discharges led to formal enforcement action by Greater Wellington.

Sampling results from the Mangaroa catchment investigation confirmed slurry-sourced sediment and nutrients as the cause of a measurable deterioration in water quality in the lower Mangaroa River and Hutt River (immediately downstream of the Mangaroa confluence). However, it is unlikely that these discharges were a major contributor to the benthic cyanobacteria proliferations seen in the Hutt River at Belmont. *Phormidium* sp. mats were observed at multiple locations along the Mangaroa River, including sites upstream of the nutrient discharges. Moreover, mats were present around the same time in several other rivers that exhibited relatively low concentrations of dissolved nutrients. Therefore, it is considered that nutrient inputs were probably a less significant causal factor than elevated water temperatures, the lack of flushing flows and sustained low flow conditions experienced during spring 2005.

4.4 Synthesis

Environmental conditions experienced during spring 2005 were highly favourable for the establishment and growth of periphyton in the region's rivers, including both filamentous algae and benthic mat-forming cyanobacteria such as *Phormidium* sp. The weather during spring was warmer, drier and more stable than usual, particularly in the west of the Wellington region. These conditions resulted in below average river flows in all of the rivers affected by cyanobacteria proliferations. Major water abstractions for public water supply during spring exacerbated the low flow conditions in the Waikanae, Hutt and Wainuiomata rivers. The extended dry spells in spring 2005 also meant that there were fewer 'freshes' through the rivers, particularly in August, September and November, which is highly unusual for the time of year.

Greater Wellington’s long-term water quality monitoring records for the Hutt River at Manor Park indicate that spring water temperatures were above average, as a consequence of above average sunshine hours and air temperatures during this period. In addition, several visual clarity measurements made at Manor Park during spring were above the long-term 90th percentile value, suggesting that low rainfall and associated stable river flows provided for high water clarity at this time. Warm water temperatures and good clarity (light supply) are both conducive to periphyton growth (Biggs 2000).

Other than above average water temperatures, and possibly water clarity, there is nothing unusual in Greater Wellington’s river water quality monitoring records for spring 2005. The presence of extensive mats of *Phormidium* sp. in multiple rivers of varying nutrient status, including the relatively pristine upper reaches of the Otaki and Wainuiomata rivers, is consistent with its widespread distribution reported in the literature (e.g., Biggs and Kilroy 2000). Overall, it is concluded that the climatic and hydrological conditions experienced during spring had a more significant influence on the proliferations of *Phormidium* sp. in 2005/06.

5. Management implications

Phormidium species are common and widespread, with extensive attached or detached mats documented in many countries (Wood et al 2007). In the Wellington region alone, *Phormidium* spp. were present (but not necessarily abundant) at 30 of 46 RSoE sites sampled by Greater Wellington for periphyton during summer and autumn 2006[20]. Other potentially toxic species of benthic cyanobacteria are also present in the region, including *Oscillatoria* spp. and *Lyngbya* spp. Given the wide-ranging distribution of these cyanobacteria genera, it is perhaps surprising that more animal deaths have not been reported.

Environmental conditions conducive to cyanobacteria proliferations may occur again in the Wellington region in the future. Already in 2007, warm, dry weather during February accelerated the growth of benthic cyanobacteria in a number of the rivers affected in 2005/06, prompting one local council to erect health warning signs as a precautionary measure. In the South Island, similar conditions have led to proliferations of *Phormidium* spp. in the lower Ashley River (North Canterbury). At the time this report was being finalised at least two dogs had died, and another had been seriously ill, after chewing on mats in the Ashley River (Hayward[21], pers. comm. 2007). Toxin analysis performed on samples of the mats confirmed the presence of cyanotoxins (Appendix 2).

As discussed in Section 2, until recently cyanotoxin production has primarily been associated with planktonic cyanobacteria, typically in lake environments. The dog deaths in the Hutt River catchment in late 2005, coupled with the recent dog deaths in north Canterbury, have increased awareness of the potential toxicity of benthic cyanobacteria, including the presence of homo-anatoxin-a and its associated degradation product (previously unreported in New Zealand).

5.1 Management actions and initiatives taken since 2005/06

Following the 2005/06 summer, Greater Wellington, Regional Public Health and local councils agreed on a protocol for responding to future benthic cyanobacteria proliferations in rivers in the region. The protocol outlines the key roles and responsibilities of the various organisations (Appendix 3) during both 'normal' and 'response' conditions, with the aim of improving response speed and effectiveness.

Other actions taken to assist with early detection of, and response to, problematic cyanobacteria proliferations include:

- the introduction of automated alarms to act as an 'early warning system' of river flow conditions that might lead to a potential problem with benthic periphyton growth at bathing sites;
- a review of weekly semi-quantitative periphyton assessments undertaken at freshwater bathing sites over the summer months (1 November to 31

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[20] *Phormidium* spp. were present at 17 sites in 2004 and at 22 sites in 2005 (sampling began in 2004).

[21] Shirley Hayward – Surface Water Quality Scientist, Environment Canterbury

March) so that both filamentous and mat-forming periphyton cover are assessed at all sites;

- improved training of field staff in the identification of cyanobacteria mats, in particular, in recognising and reporting potentially problematic growths;
- the provision of further information about cyanobacteria on Greater Wellington's *On the Beaches* bathing webpage, including a facility for regular updates on rivers where warnings are in place; and
- the development of template warning signs for use in the Wellington region.

The automated river flow warning system was introduced in spring 2006 and has two complementary levels of alarm based on flow conditions as follows:

- First level (yellow) alarm: no flushing flow
  The first level alarm triggers when there has not been a flushing flow for two weeks. Three times the median river flow was selected as an indicative 'flushing flow' (see Section 4.2.5) and following an assessment of the events of spring 2005 two weeks was determined to be an appropriate (and conservative) duration.
- Second level (orange) alarm: low flow, no flushing flow
  This alarm occurs in conjunction with the first level alarm, indicating that there has not been a flushing flow for at least two weeks <u>and</u> river flows are low (set at lowest 10th percentile flow for each river). The justification for a low flow alarm is that water temperatures may be elevated (promoting algae growth), and any cyanobacteria growths may become exposed or near exposed at the river edges.

The alarm system is currently operative for automated flow monitoring stations on the Otaki, Waikanae, Hutt, Mangaroa and Wainuiomata rivers (using data obtained from Greater Wellington/NIWA flow recorders located at Pukehinau, Waikanae Water Treatment Plant, Taita Gorge, Te Marua and Leonard Wood Park respectively). In accordance with the 'benthic cyanobacteria response protocol', Regional Public Health and the relevant local council(s) are notified when the second level alarm is triggered, particularly if weekly summer periphyton assessments confirm the presence of significant coverage of cyanobacteria mats. Although very much in a trial phase, the automated alarm system was successful in providing advance warning of the potentially 'risky' flow conditions – and associated dense benthic cyanobacteria growth – that occurred during February 2007. Work is now needed to extend the system to the Ruamahanga and Waipoua rivers.

Further steps could be taken to assist in the early detection of problematic cyanobacteria proliferations in the region's rivers and streams. For example:

- expand the existing continuous water temperature monitoring network to include the lower Waikanae and Waipoua rivers;

- extend training in the identification of potentially problematic cyanobacteria mat growths and conditions to all council staff that work in rivers; and
- implement further public education and awareness initiatives, including press releases prior to and during the bathing season and the production of leaflets or posters that can be displayed in Greater Wellington and local council offices and distributed to vets, pet shops, dog clubs and water sports clubs.

Ongoing public education about the potential risks benthic cyanobacteria pose to human and animal health is particularly important because community awareness is currently low. It is not practicable to monitor all of the river reaches where benthic cyanobacteria may proliferate and people or animals may visit. Informing the public of what to look out for promotes user-responsibility.

5.2 Current obstacles and knowledge 'gaps'

Despite implementing measures to assist with the early detection of benthic cyanobacteria proliferations, responding to proliferations remains problematic. This is because there is a lack of national guidance for managing proliferations in benthic environments and several public agencies have overlapping responsibilities (Appendix 3). In addition, the extent, frequency and causes of toxicity in benthic cyanobacteria are poorly understood.

5.2.1 National guidance

Existing national guidance on toxic cyanobacteria proliferations is limited to planktonic environments (Wood et al 2007), with some guidance also provided in the Drinking Water Standards for New Zealand (Ministry of Health 2005). The lack of national guidance for benthic environments undoubtedly reflects the fact that the health risks associated with benthic cyanobacteria are less widely acknowledged or understood, and because few recorded illnesses or fatalities are attributed to them. It is hoped that this may change given the publicity surrounding recent dog deaths in both Wellington and Canterbury.

Practical guidance is urgently required to manage the response to benthic cyanobacteria proliferations. Toxin analysis is expensive to conduct on a regular basis and testing other than to confirm the existence of a suspected problem is of limited value given the factors affecting cyanotoxin production are poorly understood (refer Section 5.2.2). In lake environments (and some slow-moving rivers) affected by planktonic cyanobacteria blooms, cell counts are often used as a surrogate measure for toxicity. However these monitoring methods and associated guidelines are not directly applicable to benthic cyanobacteria in running waters (Wood et al 2007).

5.2.2 Toxicity research

Further research is needed into the extent, frequency, and causes of toxicity in benthic cyanobacteria (Hamill 2001, Wood et al 2006). Toxin analysis performed on samples of *Phormidium* sp. collected from various rivers in the Wellington region in 2005/06 (refer Table 3.2, Section 3.2) and the Canterbury region in February-March 2007 (Appendix 2) revealed homo-anatoxin-a concentrations ranging from <2 ug/L to 4,400 ug/L. While it can be inferred that the risk to human and animal health increases with increasing toxin concentrations, it is unclear whether there is some threshold above which the risk is significantly higher.

Another problem, which Hamill (2001) suggests may be one reason why there have not been more reports of animal deaths in New Zealand attributed to benthic cyanobacteria, is that benthic cyanobacteria may only release cyanotoxins under specific environmental conditions or when in a particular physiological state. Wood et al (2006) note (in reference to water supplies) that cyanobacteria mats may pose little risk while healthy, as the majority of cyanotoxins are likely to be intracellular and therefore are not being released into the water column. However, if the mats die or detach from their substrate, they may potentially release massive pulses of cyanotoxins.

Based on the observations of Hamill (2001), and the findings of the limited toxin testing performed on benthic cyanobacteria samples from the Wellington and Canterbury regions, it would appear that the greatest risk to human and animal health is posed by thick mats, especially those that are 'stranded' exposed, or near-exposed, at the river's edge. Samples of these mats returned very high toxin concentrations relative to other samples collected from areas where mat growth was less dense; the Hutt River sample had a homo-anatoxin-a concentration of 4,400 ug/L, up to two orders of magnitude higher than the concentrations found in other samples taken from Wellington rivers. In addition, mats that are exposed or near exposed at the river's edge are easily accessible to animals, and attractive to dogs.

5.2.3 Effects of river works

Another unknown is what, if any, effect river works have on cyanobacteria establishment and growth. Most of the rivers affected by proliferations in 2005/06 are subject to frequent disturbance associated with river works/profiling for flood protection and erosion control purposes, and/or gravel extraction.

The release of fine silts does not appear to hinder cyanobacteria establishment; *Phormidium* sp. mats are commonly observed growing on stable substrate that is covered by a thin film of fine sediment. Biggs (2000) notes that thick mats of *Phormidium* sp. can also occur over silty substrates in low-velocity areas during summer low flows. However, the disturbance caused by channel profiling may prevent or reduce cyanobacteria (and algae) proliferations in some areas.

Channel profiling works influence river hydraulics by altering channel width, channel depth and flow velocity. If the channel is made wider and shallower, conditions for periphyton growth may be enhanced by increasing water temperature (and light penetration). In addition, a wider, shallower channel may result in increased exposure of the riverbed as flows decrease, thus exposing periphyton, including cyanobacteria mats. However, the potential impacts of river works do not appear to have been researched or documented in New Zealand.

6. Conclusions and recommendations

The weather during spring 2005/06 was significantly warmer, drier and more stable than usual, resulting in conditions highly favourable to the establishment and growth of benthic mat-forming cyanobacteria in the region's rivers. Water temperatures were above average and river flows were very low for spring, with major abstractions for public water supply exacerbating the low flow conditions in the Waikanae, Hutt and Wainuiomata rivers. There were also fewer 'freshes' through the rivers compared to usual for the time of the year; the Otaki, Waikanae, Hutt and Wainuiomata rivers all had periods of at least 40 days with no significant fresh.

The presence of extensive mats of *Phormidium* sp. in multiple rivers of varying nutrient status, including the relatively pristine upper reaches of the Otaki and Wainuiomata rivers, is consistent with its widespread distribution reported in the literature. Overall, it is considered that the climatic and hydrological conditions experienced during spring were the most significant causal factors for cyanobacteria proliferations in all affected rivers; in particular elevated water temperatures, the lack of 'flushing' flow events and sustained low flow conditions.

There is currently a lack of national guidance to assist with responding to and managing benthic cyanobacteria proliferations. In addition, the extent, frequency, and causes of toxicity in benthic cyanobacteria are poorly understood.

6.1 Recommendations

1. Extend the automated river flow warning system (for early detection of flow conditions conducive to benthic cyanobacteria proliferations) to cover popular recreational rivers in the Wairarapa, in particular the Ruamahanga River and the lower Waipoua River.

2. Investigate options for expanding the existing river flow and continuous water temperature monitoring network to incorporate the lower Waikanae and Waipoua rivers.

3. Extend training in the identification of potentially problematic cyanobacteria mats growths to all council staff working in rivers.

4. Review, on at least an annual basis, the 'toxic benthic cyanobacteria response protocol'.

5. Promote wider public awareness about the potential risks benthic cyanobacteria pose to human and animal health by:

    - issuing media releases prior to and, if appropriate, during the summer bathing season; and

    - producing leaflets and/or posters that can be displayed in Greater Wellington and local council offices and distributed to vets, pet shops, dog clubs and water sports clubs.

6. Continue to work with other organisations to improve Greater Wellington’s understanding of, and response to, toxic cyanobacteria proliferations.

Recommendations 4, 5 and 6 should be implemented in conjunction with Regional Public Health and local councils.

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Appendix 1: River Environment Classification system

The River Environment Classification (REC) system recognises that rivers and streams are diverse and some may have differing water quality simply due to their size, climate and underlying geology rather than due to human-induced impacts. The REC system therefore characterises river environments at six hierarchical levels, corresponding to a controlling environmental factor (Snelder et al 2003). The factors, in order from the largest spatial scale to the smallest, are climate, source-of-flow, geology, land cover, network position and valley landform. The first four factors – climate, source-of-flow, geology and land cover – are outlined in the table below.

REC classification levels, classes, mapping characteristics, and criteria used to assign river segments to REC classes.

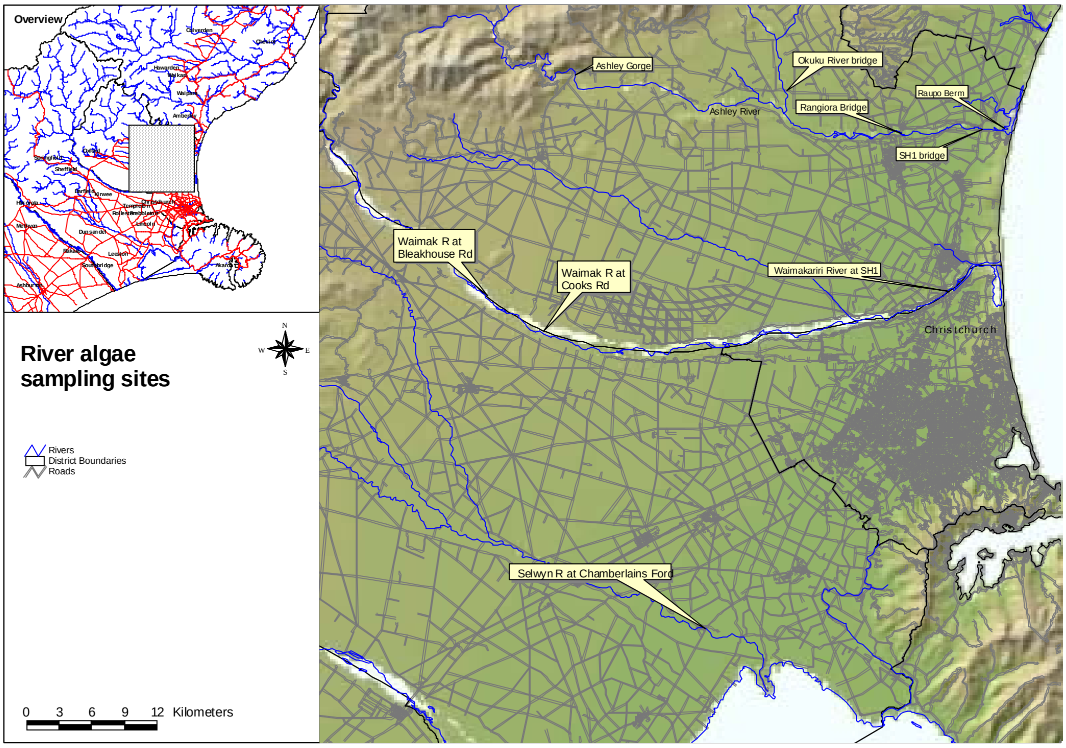
Classification Level and Scale	Classes and Notation	Mapping Characteristics	Class Assignment Criteria
Climate (10^3 – 10^4 km^2)	Warm extremely wet (WX) Warm wet (WW) Warm dry (WD) Cool extremely wet (CX) Cool wet (CW) Cool dry (DC)	Mean annual precipitation, mean annual potential evapotranspiration, mean annual temperature.	*Warm:* mean annual temperature ≥ 12˚C *Cool:* mean annual temperature <12˚C *Extremely wet*: mean annual effective precipitation ≥ 1500 mm *Wet*: mean annual effective precipitation >500 mm and < 1500 mm *Dry:* mean annual effective precipitation ≤ 500 mm
Source of Flow (10^2 – 10^3 km^2)	Mountain (M) Hill (H) Low elevation (L) Lake (Lk)	Catchment rainfall volume in elevation categories, lake influence index.	*M:* >50% annual precipitation volume > 1000 m ASL *H:* 50% precipitation volume 400 to 1000 m ASL *L:* >50% rainfall < 400 m ASL *Lk:* Lake influence index > 0.033
Geology (10 – 10^2 km^2)	Alluvium (Al) Hard sedimentary (HS) Soft sedimentary (SS) Volcanic basic (VB) Volcanic acidic (VA) Plutonic (Pl) Miscellaneous (M)	Proportions of each geological category in section catchment.	Class = spatially dominant geology category unless combined soft sedimentary geological categories exceed 25% of catchment area, in which case class = SS.
Land Cover (10 km^2)	Bare (B) Indigenous forest (IF) Pastoral (P) Tussock (T) Scrub (S) Exotic forest (EF) Wetland (W) Urban (U)	Proportions of each land cover category in section catchment.	Class= spatially dominant land cover category unless pastoral exceeds 25% of catchment area, in which case class = P, or unless urban exceeds 15% of catchment area, in which case class = U.

Source: adapted from Larned et al (2005).

Appendix 2: Cyanotoxin results from Canterbury rivers

Data provided courtesy of Environment Canterbury. Black cyanobacteria mats were sampled at each site. Anatoxin-a and homo-anatoxin-a were the only cyaontoxins detected in the samples.

Date sampled	Location	Anatoxin-a (µg/kg)	Homo-Anatoxin-a (µg/kg)	Cyanobacteria mat cover description
1 Mar 2007	Waimakariri R at SH 1	<2	<2	<5% - just occasional rocks.
1 Mar 2007	Ashley R at Raupo Berm	28	890	20-40% in riffles, <10% in runs. Also frequent sloughed mats floating downstream.
1 Mar 2007	Ashley R at SH 1	22	1,500	20-40% in riffles, <10% in runs. Mats thick, strong musty smell.
1 Mar 2007	Ashley R at SH 1	8.5	410	Sample of exposed mat within wetted channel.
8 Mar 2007	Ashley R at Rangiora Bridge	3	24	30-40% in riffles, <10% in runs. Mats look like they are just starting to develop.
8 Mar 2007	Ashley R at Gorge	2	<2	30-40% in riffles, <10% in runs. Mats look like they are just starting to develop.
8 Mar 2007	Okuku R Bridge	2	3.3	Not much in riffles, approx 10% on large rocks in runs
13 Feb 2007	Waimakariri R at Bleakhouse Cnr	<2	<2	
13 Feb 2007	Waimakariri R at Cooks Rd	<2	<2	
14 Feb 2007	Selwyn R at Chamberlains Ford	22	12	



Appendix 3: Legislative framework and responsibilities

The Resource Management Act 1991 (RMA) and the Health Act 1956 (HA) are the two principal statutes that address water quality aspects of recreational water use. Responsibility for fulfilling the functions under these Acts is shared between regional councils (RMA), city and district councils (RMA and HA), and district health boards (HA). Neither Act specifies which agency has primary responsibility for recreational water quality monitoring, although the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (Ministry of Health (MoH), Ministry for the Environment (MfE), 2003) attempt to outline the various responsibilities.

In the Wellington region, Greater Wellington has taken responsibility as the lead agency for coordinating and reporting on the results of recreational water quality monitoring. City and district councils often assist with routine water sampling (especially in marine waters), and are responsible for additional sampling and erecting health warning signs (and conducting sanitary surveys) when results indicate a bathing site should be closed. The issuing of health warnings is undertaken in close liaison with the relevant public health authority (Regional Public Health or Wairarapa Public Health) which has a responsibility for informing the public when results indicate the water may pose a health risk.