BEFORE THE HEARINGS PANEL

IN THE MATTER of hearings on submissions concerning the Proposed One Plan notified by the Manawatu-Wanganui Regional Council

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SECTION 42A REPORT OF DR ROBERT JAMES DAVIES-COLLEY ON BEHALF OF HORIZONS REGIONAL COUNCIL

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1. INTRODUCTION

My qualifications/experience

1. I hold an MSc (Hons 1st class in Earth Sciences) from the University of Waikato, and a PhD (Environmental Engineering, Interdisciplinary Water Resources Option) from Oregon State University. I am a member of the NZ Freshwater Sciences Society and the International Water Association (IWA) (Specialist Groups on Waste Stabilisation Ponds, Health-related Water Microbiology, and Diffuse Pollution). I am an executive of the IWA Diffuse Pollution Specialist Group, and will host the 15th annual conference (DIPCON11) in Rotorua, in September 2011.

2. I have worked for NIWA and its predecessors as a researcher and consultant in the broad area of water quality since 1976. My main specialities are optical water quality (colour, visual clarity and the light climate of plants) and microbial water quality (including disinfection), but I have also worked on aspects of the ecology and geomorphology of streams and rivers; I have a particular interest in riparian management to meet multiple environmental goals, including controlling diffuse pollution and improving stream 'health'. I have been involved with the National Rivers Water Quality Network (NRWQN) since its inception in 1989, and recently led the preparation of a review to commemorate its 20th 'birthday'. I am a co-author of a report for Ministry for Environment (MfE) updating water quality trends in the NRWQN (Ballantine and Davies-Colley, 2009a). I have been involved in research within the Whatawhata Sustainable Land Management Project since 1992, and continue to research recovery of water quality and stream 'health' indices in response to changes in land use and riparian management. I was involved in a major interagency programme studying pathways of microbial pollution from livestock, culminating in an overview paper (Collins *et al*., 2007) on Best Management Practices (BMPs) for mitigating diffuse microbial pollution of waters by pastoral farming.

3. I have published more than 100 peer-reviewed scientific papers, and have authored a similar number of technical reports, statements of evidence and 'popular' articles. I am the first author of a specialist monograph on optical water quality (Davies-Colley *et al*., 2003). I wrote the technical report underpinning the Ministry for the Environment's (1994) Water Quality Guideline No 2 on colour and clarity of waters. I have been awarded a Science and Technology Bronze Medal (1998) by the Royal Society of New Zealand for, "significant contribution to the research and implementation of water quality and aquatic ecology science in New Zealand, in particular the science and management of optical water quality".

4. I have been an expert witness before the Environment Court on six occasions. I have read the Environment Court's practice note, Expert Witnesses – Code of Conduct, and agree to comply with it. This evidence is within my area of expertise, except where I state that I am relying on what I have been told by another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

My role in the Proposed One Plan

5. I am broadly aware (and supportive) of the philosophy of approach of the Proposed One Plan, particularly identifying values then specifying water quality standards at scales (Water Management Zones) for which numerical standards can be enumerated to protect those values. However, I had no direct involvement in the Proposed One Plan until recently. In April 2009, assisted by NIWA water quality scientist Deborah Ballantine, I conducted an assessment of water quality in Horizons' Region (Ballantine and Davies-Colley, 2009b), including an analysis of water quality state (versus established guidelines) and time-trends at regional State of the Environment (SoE) monitoring sites and seven National Rivers Water Quality Network (NRWQN) sites, and put this regional assessment in national context by comparison with river quality in the NRWQN (Ballantine and Davies-Colley, 2009a).

Scope of evidence

6. My evidence covers particularly optical water quality and microbial water quality concerns, and includes a comparison of water quality state and trends in Horizons' Region with guidelines to protect water quality and river water quality nationally as indicated by the NRWQN.

7. My evidence is in three parts. Part 1: Optical water quality, considers water clarity and colour and the protection of these attributes by numerical standards in the Proposed One Plan. Part 2: Microbial water quality, considers how microbial pollutants are generated in pastoral farming, their pathways to water, and attenuation processes in water as a basis for overviewing BMPs for mitigating microbial pollution. This section also deals with protection against health risks by standards in the Proposed One Plan. Part 3: State and trends of water quality in Horizons' Region. summarises a recent assessment of water quality in Horizons' Region by comparison with established guidelines for water quality and rivers nationally, as indicated by the NRWQN dataset.

2. EXECUTIVE SUMMARY OF EVIDENCE

8. In my evidence I discuss concepts of optical water quality, including the two aspects of water clarity (visual clarity and light penetration) and three aspects of water colour. Based on this discussion, I consider that proposed water quality standards in the Proposed One Plan protect optical water quality.

9. I consider that a maximum percent change in visual clarity and a minimum visual clarity to protect certain values (eg. a minimum of 1.6 m visibility for contact recreation) is appropriate (I do not recommend use of turbidity in standards). Protecting visual clarity also serves to protect other aspects of optical water quality (light penetration and colour) in most cases. However, I recommend that light penetration (which is not necessarily predictable from visual clarity, and not usually of concern in rivers) be considered for lakes and coastal waters.

10. I discuss (health risk) issues with microbial water pollution, from both human and livestock sources. I endorse the proposed microbial water quality standards, based on national guidelines (MfE/Ministry of Health, 2003), in the Proposed One Plan to protect the health of recreational water users. (Protection of contact recreation will also serve to protect water quality for livestock watering.)

11. Further, on microbial water quality, I discuss how microbial contaminants are generated in pastoral farming, their pathways to water, and environmental behaviour within waters. As regards microbial pollution from livestock, it is important to distinguish "direct" pathways to water (in which livestock actually contact waters) from "indirect" pathways involving rain or irrigation water washing microbes deposited on land, into water bodies.

12. This discussion of microbial pathways forms the basis for an overview of on-farm BMPs that are expected to be valuable for mitigating diffuse microbial pollution on farms in Horizons Region' as elsewhere, based on a comprehensive recent review (Collins *et al.,* 2007) of recent New Zealand research.

13. I provide an overview of a recent assessment of water quality (Ballantine and Davies-Colley, 2009b) based on data from Horizons' SoE monitoring sites and seven NRWQN sites in the Region. Water quality in the Region is generally good at ('baseline') sites high in catchments (compared both with water quality guidelines and with rivers nationally). However, water quality is appreciably degraded at many downstream ('impact') sites (mainly by pastoral agriculture but also by some point sources,

particularly in the Manawatu Catchment) with nutrient enrichment, comparatively high faecal pollution and sometimes low visual clarity.

14. Trend analyses (Ballantine and Davies-Colley, 2009a; Gibbard *et al*., 2005), document a deterioration in water quality in the Region since 1989, particularly increasing nutrient enrichment. However, we found few water quality trends in the Region since 2001 (Ballantine and Davies-Colley, 2009b), suggesting that deterioration has slowed or water quality has improved more recently. The water quality improvements apparently reflect both improved wastewater treatment and on-farm changes (such as stream fencing, improved dairy shed effluent disposal, reduced fertiliser use, and reduced sheep-beef stocking).

3. EVIDENCE

Optical Water Quality

15. Optical water quality may be defined (Kirk, 1988) as “the extent to which the suitability of water for its functional role in the biosphere or the human environment is determined by its optical properties”. There are two main aspects of optical water quality – water clarity and water colour (Davies-Colley *et al.,* 2003).

16. 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). Visual clarity is limited mainly by light scattering, which reduces the contrast of a submerged object versus the background light in water. Attenuation with depth into the water body of (sun)light is brought about more by light absorption than scattering, although scattering does weakly contribute – mainly by forcing light photons to take a tortuous path down through water, so increasing their likelihood of being extinguished by absorption over a given depth interval (Kirk, 1985). These two aspects of water clarity should be clearly distinguished because measurement of one does not quantify the other (although there is an overall correlation). Furthermore, protection of one does not necessarily guarantee protection of the other. Therefore, guidelines for *both* visual clarity and light penetration have been promulgated (MfE, 1994 and ANZECC, 2000).

Visual clarity

17. Visual clarity of waters is a fundamentally important attribute – as is recognised by the narrative standard in the Resource Management Act (1991): "The…visual clarity…shall not be changed to a conspicuous extent". Visual clarity is important for aquatic life because it controls the visual field (and thus reaction distance) of sighted animals such as fish and aquatic birds. Visual clarity is also important for human use of waters, affecting aesthetic quality and contact recreation safety (Davies-Colley *et al*., 2003). These characteristics of visual clarity, and its approximately inverse relationship to nephelometric turbidity and suspended solids concentration in waters, have been outlined by Davies-Colley and Smith (2001).

18. Visual clarity is best measured by the black disc method (horizontal extinction distance of a matte black disc (Davies-Colley, 1988), although the Secchi disc method (vertical extinction depth of a white or black-and-white disc (Davies-Colley *et al*., 2003) is easier to perform from boats and has historical importance where long term datasets already exist. Both methods are (surprisingly to some people) quite accurate with +/-5% precision (Smith, 2001), and more so than many other water quality measurements, notably including (inversely related) turbidity and suspended solids (Davies-Colley and Smith, 2001). Despite involving the human eye-brain system, the two methods are little affected by subjectivity. The visual range in waters for fish (and aquatic invertebrates and birds) is limited by the same optical processes as that of humans. Thus, despite optical adaptation to their aquatic environment, more to cope with low lighting and spectral shift than compressed visual range, fish can see through waters barely any further than humans. Therefore, black disc visibility is an excellent index of the visual field of fish as well as humans.

19. Both black disc visibility (y_{BD}) and Secchi depth (z_{SD}) are closely related to a fundamental optical property of water, the beam attenuation coefficient (c, 1/m):

$y_{BD} = 4.8/c$ (Zanevald and Pegau, 2003) (1)

$z_{SD} \sim 6/c$ (Gordon and Wouters, 1978) (2)

20. Equations (1) and (2) imply that black disc is not numerically equal to Secchi depth. Indeed, by eliminating the beam attenuation coefficient (c) between these two equations, we get $z_{SD} \sim (6/4.8)\ y_{BD} = 1.25\ y_{BD}$, that is Secchi depth is approximately 25% higher than black disc visibility. Black disc visibility is a close approximation to visual ranges of practical importance for humans or fish in waters (Davies-Colley and Smith, 2001), so Secchi depth over-estimates such visual ranges.

21. To protect the visual clarity of waters for both humans and aquatic life, MfE (1994) recommends no more than 20% change in visual clarity in waters in which optical quality is a particularly valued attribute, and no more than 30-50% change in other waters (depending on undefined "site conditions"). MfE (1994) also recommends that, for safety in primary contact recreation, and to meet bather preferences, the black disc range should exceed 1.6 m (which corresponds to a vertical Secchi depth of 2.0 m). These visual clarity guidelines have been adopted, essentially unchanged, by ANZECC (2000).

22. Note that I am of the view that nephelometric turbidity, measured in (arbitrary) NTU units, is not appropriate for enumeration of guidelines or standards. This is because turbidity 1) is not a proper 'scientific' measurement amenable to absolute physical calibration; and 2) is appreciably instrument-specific. Turbidity measurement can be useful for measurements at night and for continuous monitoring, but should always be locally calibrated to the issue of real concern, usually visual clarity or suspended sediment concentration (Davies-Colley and Smith, 2001).

Light penetration

23. Although the RMA does not specifically mention light penetration of waters, this aspect is also fundamentally important and is protected by the narrative standard (sections 70 and 107) protecting aquatic life from "significant adverse effects". A change in the light climate of aquatic plants can have a significant adverse effect on whole aquatic ecosystems. For example, many shallow lakes in New Zealand have been 'flipped' into a new, and less desirable, state characterised by extremely turbid water with very high phytoplankton biomasses, including scum-forming blue-greens, following loss of their bed sediment-stabilising macrophyte cover owing to light extinction by turbid flood water or mine water plumes (Davies-Colley *et al*., 2003).

24. Light, measured as Photosynthetically Available Radiation (PAR), falls off approximately exponentially with depth into water bodies. A useful index of light penetration into waters is the euphotic depth (the depth at which light has fallen to 1%), which is often close to the maximum depth in water of plant growth (Kirk, 1994). MfE (1994) guidelines recommend no more than 10% change in the euphotic depth. In waters that are shallower than the (virtual) euphotic depth, such as many rivers, there still needs to be protection of the light for photosynthesis. The recommended guideline is that the PAR at the bottom of the water body should not be changed by more than 20% when water is shallower than half the (virtual) euphotic depth. This is less restrictive than requiring that

virtual euphotic depth be changed by no more than 10%. These light penetration guidelines have also been adopted by ANZECC (2000).

Water colour

25. Colour of waters is also fundamentally important, as is recognised by the narrative standard in the RMA (1991): "The… colour…shall not be changed to a conspicuous extent". Water colour, in common with colours generally, has three main aspects (Davies-Colley *et al*., 2003). *Hue* relates to the dominant wavelengths in the spectrum of light, and is interpreted by the human eye-brain system as red, green, blue etc. *Saturation* (colour purity) depends on the spread of wavelengths in the spectrum, and can range from pure spectral lines to 'neutral' grays where all wavelengths are represented in the spectrum. Finally, *brightness* depends on the amount of light energy in the spectrum, weighted by the sensitivity of the human eye, which is most sensitive in the green part of the spectrum.

26. Water colours, although highly variable, tend to be dark (low brightness) and of rather low purity, so hue is usually the most important aspect. All three aspects of colour can be specified in many different ways, but the Munsell system is a scientifically well-defined system that has a long history in colour science, and was adopted by the author and colleagues (Davies-Colley *et al*., 1997) for specification of water colours – in practice by matching water colours as viewed through an underwater periscope, like the black disc viewer, to Munsell standard patches. However, brightness of water colours is often low and beyond the range of Munsell standard patches. Fortunately, this is not a 'fatal' problem because water brightness is strongly related to the reflectance of light from waters (the ratio of light upwelling within the water to the incident light), which is conveniently measured with light sensors such as Photosynthetic Active Radiation (PAR) sensors.

27. People seem instinctively to know that blue-violet is the true hue of optically pure water, perhaps from their familiarity with deep ocean waters, tropical reefs, or optically pure spring waters. We also know from panel studies (Smith *et al*., 1995) that yellow to orange colours are not favoured – probably because people recognise light-absorbing constituents that cause hue shift to yellow or orange (and probable concomitant increase in brightness giving 'muddy' colours) as 'pollution'.

28. The MfE (1994) guidelines recognise that it is important to protect water colour, not merely to maintain the visual amenity for human use, but to maintain the spectral quality

of the light field for aquatic life. Therefore, guidelines to protect hue and brightness are recommended: Hue should be changed by no more than 10 Munsell units (protecting spectral quality), and reflectance should not be changed by more than 50% (protecting against large changes in brightness). No guideline was given by MfE (1994) for protecting saturation in the absence of any research criteria, but it is difficult to imagine how brightness and hue might be shifted in practice without affecting saturation. Again, ANZECC (2000) has adopted these guidelines virtually unchanged.

Protection of optical water quality in the Proposed One Plan

29. An overview of the approaches taken in the Proposed One Plan to protecting optical water quality is given in Ausseil and Clark (2007). I am broadly in agreement with and endorse the approach outlined in this report towards developing standards, mainly for visual clarity.

30. However, there are some misconceptions in this overview. For example, the statement is made (p 23) that “turbidity is a better indicator than black disc in the ‘muddy water’ end of the spectrum (when water clarity is < 0.5 m)”. Actually, visual clarity by the black disc method is a preferred measure across the spectrum of visibility (Davies-Colley and Smith, 2001). It is worth noting that visual clarity has been measured by the black disc method routinely in the National Rivers Water Quality Network (NRWQN). Turbidity is also measured in the NRWQN, but only as a backup to visual clarity. Furthermore, visual clarity can be measured accurately down to about 0.1 m, although at still lower visibilities the presence of the viewer seems to begin to interfere by distorting the light field in the water. However, useful observation can be made at appreciably lower visual ranges, including measurements on effluents, with a water sample contained in a trough by using a 20 mm diameter rod-mounted black disc. The sample can be volumetrically diluted as necessary with clear tap water (Davies-Colley and Smith, 1992), so that visual clarity measurements can be extended indefinitely towards the low clarity end.

31. Ausseil and Clark (2007) are correct where they note (p 23) that turbidity has some important advantages in that it can be measured continuously (and at night). However, they go on to recommend (p 24) monitoring all three (correlated) variables: visibility, turbidity, and Total Suspended Solids (TSS), despite quoting Davies-Colley and Smith (2001), who recommend that turbidity should only be used as a relative guide – with a local calibration to the variable of real interest (ie. visual clarity or TSS). Furthermore, given the cost of measuring TSS compared with visibility (Davies-Colley and Smith give a comparison table) I would strongly recommend *not* monitoring TSS at SoE sites. (An

exception might be where sediment load is of special interest at sites that are also SoE sites, such as catchments with erosion protection measures in place in Horizons' Sustainable Land Use Initiative (SLUI).) Black disc visibility is the appropriate measurable, and the most appropriate basis for environmental standards, in view of specific protection in the RMA. Turbidity can be used as a surrogate, including from continuous monitoring, but standards and guidelines should always be expressed in terms of the attribute of concern, ie. visual clarity.

32. In Section 2.3.2.2, Ausseil and Clark (2007) seem to confuse visual clarity with light penetration, and appear to assume that protecting visual clarity necessarily protects light penetration. Thereafter, there is no mention of light penetration in their report. This fails to recognise that light penetration and visual clarity are not perfect correlates, and the former may sometimes be adversely affected, without affecting visual clarity beyond guidelines. Euphotic depth may sometimes be changed more than 10% without being associated with more than 20% or 30% change in visual clarity.

33. Ausseil and Clark (2007) recognise (Section 3.2.3.5) that visual clarity in rivers varies with the geological nature of the catchment, with rivers (including in Horizons' Region) being much clearer in hard rock lithology than in soft sedimentary rocks that erode to yield fine, efficiently light-attenuating, sedimentary particles. Reference sites in Horizons' SoE network were identified in different geology classes, and the 20 percentile black disc visibility data examined consistent with the approach of ANZECC (2000 "trigger values").

Visual clarity

34. Ausseil and Clark (2007) outline (Sections 2.1 and Section 7) the standards Horizons proposes in order to protect visual water clarity of its waters (Ausseil and Clark, 2007; Table 24). The philosophy of approach is that the *most stringent* standard protecting 'values' for each water quality variable, in each Water Management Zone (WMZ), is to be adopted – so that *all* values are protected, including the value that is most demanding of high quality (high clarity in this case). For each defined WMZ, three visual clarity standards are enumerated:

- A minimum visual clarity at < median flow
- A minimum visual clarity at < 3 X median flow
- A maximum % change in visual clarity.

35. The standards include:

- No more than 20% change in visual clarity in comparatively clear river waters, in which visual clarity is a particularly valued feature (eg. in valued trout fisheries) and no more than 20% change in lakes.
- No more than 30% change in visual clarity in rivers generally.
- Visual clarity to exceed 1.6 m (MfE, 1994; ANZECC, 2000 contact recreation guideline) in most rivers at less than 3 X median flow, the exception being those rivers in which visual clarity is naturally rather low owing to 'unfavourable' geology (HSS class, such as the Whanganui River in its lower reaches) where visual clarity is to exceed 1.6 m (suitable for contact recreation) at less than median flow.
- Visual clarity to exceed higher values (eg. 2.5 m, 3 m at less than 3 X median flow) in rivers valued as trout fisheries.
- Visual clarity to exceed 2.8 m Secchi depth in lakes (corresponding to the mesotrophic/eutrophic boundary in the Lake Trophic Index).

36. The standards proposed by Ausseil and Clark (2007) are broadly consistent with the MfE (1994) guidelines on colour and clarity (for which I wrote the under-pinning consulting report – Davies-Colley, 1991) and with ANZECC (2000) guidelines on recreational water quality and protection of aquatic life.

37. These standards seem to me to be well-justified by past research, well documented by Horizons staff (Ausseil and Clark, 2007) and appropriate for proposed WMZ-specific application in Horizons' Region. I recommend that they be adopted into the One Plan (replacing the turbidity standards in Section D of the Proposed One Plan).

38. However, I have the following minor issues:

- I am not sure that a standard requiring that black disc visibility exceeds 0.5 m (at less than 3 x median flow) in certain rivers, presumably to protect native fish even in geologically 'unfavourable' systems, is strictly necessary.
- I have an overall concern that the standards for visual clarity (three separate standards for each WMZ) are rather complicated, with the possibility of internal inconsistencies (that may not matter) and confusion in administration (which probably *will* matter). For simplicity, I would recommend simply a clarity standard for flows less than median and a % change standard (both as currently), and drop the standards for 3 X median flow. The % change standard will serve to protect clarity over all flows.
- No visual clarity standards appear to have been enumerated for coastal waters and estuaries. Section 7.5 of Ausseil and Clark (2007) gives microbiological

standards for coastal waters and it seems strange that their visual clarity is not also protected. I propose that the following standard be adopted in coastal waters: not more than 20% change in visibility and not less than 1.6 m visibility.

Key Points

- I endorse standards focusing on visual water clarity in the Proposed One Plan.
- A combination of a maximum % change standard for visual clarity with a minimum visual clarity to protect certain values (eg. 1.6 m for contact recreation) seems a good approach that is consistent with national guidelines.

Standards for other optical quality aspects

39. Horizons does not propose to enumerate standards to protect colour of regional waters (Ausseil and Clark, 2007; p 25). I do not regard this as a major shortcoming, because it would be a rare situation where water colour could be shifted beyond guidelines (10 Munsell colour units and 50% change in reflectance, MfE ,1994) without simultaneously shifting visual clarity more than 30%. That is, I expect that the proposed standards for visual clarity will serve to protect the colour of waters in Horizons' Region. An important exception would be a highly coloured but non-turbid discharge, such as diversion of humic-stained wetland water to a clear river or the discharge from a kraft pulp mill. For example, the discharge of dark orange-coloured kraft pulp effluent from the Kawerau mill only slightly shifts the visual clarity of the Tarawera River after complete mixing, but noticeably shifts the river water hue. Any such major development in Horizons' Region would presumably engender high interest and special focus on optical impacts, so the omission of specific numerical standards for colour is probably not of any practical importance.

40. More problematic, in my opinion, is that Horizons does not appear to be proposing any protection of the light climate for aquatic plants – apparently assuming (Ausseil and Clark, 2007; p 24) that protection of visual clarity protects light climate for plants. I recommend that light climate of aquatic plants is protected by specific enumeration of an appropriate standard in lakes and coastal (but not river) waters – following the guideline of a maximum 10% change in euphotic depth recommended by MfE (1994) and ANZECC (2000). I recommend that no activity consented by the One Plan should allow more than a 10% change in euphotic depth, with particular care being taken to protect light penetration in lakes and coastal waters. I recognise that light penetration is seldom a constraint in rivers, but it might be an issue in lakes and coastal waters. However, a

standard protecting light penetration need not be an ‘active’ standard, in the sense that specific monitoring for euphotic depth would not be routinely performed. Horizons could rely on routine monitoring of visual clarity, and general awareness of pressures, to detect any change that might be accompanied by restricted light penetration.

41. Finally, I note that the recommendations for protection of optical water quality are consistent with those recommended to Horizons by McBride and Quinn (1993) for the Manawatu Water Quality Regional Plan.

Key Points

- Protection of visual water clarity in the One Plan will serve to protect water colour.
- In order to protect light penetration, particularly in lakes and coastal waters, I recommend that the One Plan permit no more than 10% change in euphotic depth.

4. MICROBIAL WATER QUALITY

42. Microbial quality of waters is important because of the health risk to people who are exposed to waters contaminated by pathogenic microbes of faecal origin during contact recreation (during which a small volume of water tends to be ingested), or by consumption of bivalve shellfish contaminated by such pathogens (MfE/MoH, 2003). Bivalve shellfish are filter feeders and so tend to concentrate microbes out of water along with other fine organic particles that form their food source.

43. Additionally, faecal microbial quality of waters is of concern for livestock watering safety (ANZECC, 2000). Ironically, in New Zealand, the majority of microbial contamination of our waters appears to be caused by livestock – which then contaminate the water supply of livestock further downstream.

44. Faecal contamination of freshwaters is widespread in New Zealand (McBride *et al*., 2002; Parliamentary Commissioner for the Environment (PCE), 2004) with concentrations of the faecal indicator *Escherichia coli (E. coli)* often exceeding recommended guidelines for contact recreation, and with *Campylobacter* and other pathogens often present. The high reported incidence in New Zealand of campylobacteriosis and cryptosporidiosis, compared to other developed countries, has raised concerns over the public health risk from pathogens of livestock faecal origin (MfE/MoH, 2003).

Pathogens and indicators

45. The pathogenic microbes of faecal origin that can be found in waters and wastewaters include four main groups (in order of complexity): viruses, bacteria, protozoan parasites, and worm parasites (Bitton, 1999). Water-borne viral pathogens include Hepatitis A virus, Enteroviruses and Norwalk viruses, and infection can cause a range of unpleasant symptoms and sometimes long-term health effects (as in the case of hepatitis) (MfE/MoH, 2003; Table G1). Viruses are usually very host-specific, so humans are generally only at risk from human-sourced viruses (ie. viruses contaminating waters from human sewage), although infection can be particularly severe when viruses jump from animal to human hosts (eg. 'bird flu', 'swine flu', Ebola virus). Bacterial pathogens including *Salmonella*, *Shigella*, (pathogenic strains of) *Escherichia coli*, and *Campylobacter*, cause a range of symptoms from mild to severe or life-threatening, but are sometimes considered less risky than viruses as they are amenable to treatment with antimicrobial drugs. Protozoan parasites include *Giardia* and *Cryptosporidiium*, which cause unpleasant diarrhea and nausea, but are seldom fatal. The cysts or oo-cysts of these organisms are remarkably robust in the environment, including waters. Worm parasites tend to be considered a minor issue in developed countries like New Zealand, where incidence of infection is usually low compared to developing countries.

46. Although the concern with microbes of faecal origin in waters centers on pathogenic micro-organisms, for various reasons it is not usually feasible to monitor waters for those pathogens. Firstly, the pathogens are only sporadically present, when sick individuals – either animals or humans – are shedding *and* the pathogens are polluting natural waters. Secondly, there are a large number of pathogens that potentially may be present in faecally-polluted waters (Bitton, 1999), so it is usually not clear which should be monitored for, considering that the vast majority of laboratory returns might be negative except for a very few particularly prevalent pathogens (such as *Campylobacter* in New Zealand). Finally, and related to the previous point, monitoring for pathogens is usually expensive, requiring specialist microbiological laboratories, and not suitable for routine 'surveillance' (MfE/MoH, 2003).

47. For these reasons, faecal microbial quality of waters is usually indicated by testing for recognised faecal indicator organisms that indicate recent contamination by the faeces of warm-blooded animals (including humans) and therefore the risk of faecal pathogens being present (Bitton, 1999). For the moment, testing for pathogens is almost exclusively in the research arena. Faecal microbial indicators are usually bacteria, although certain phages (viruses that infect bacteria rather than people) have been

proposed and used as indicators and models, particularly, of human viruses. As might be expected, Faecal Indicator Bacteria (FIB) tend to indicate the risk of bacterial pathogens, such as *Campylobacter* in New Zealand, rather better than they indicate risk of human viruses or protozoan parasites, because these other groups of pathogens are of very different physical size (viruses c. 0.1 micrometer, bacteria c. 1 micrometer and protozoan cysts up to 10 micrometres) and have different environmental behaviour, including susceptibility to various environmental stressors such as sunlight exposure.

48. Traditionally, the faecal coliform group of bacteria has been used as an indicator of faecal microbial pollution of waters. The test usually involves growing the coliform group of bacteria (an even wider group, including common, mostly non-faecal, soil and water bacteria such as *Citrobacter* and *Enterobacter*) at high temperature (44.5^{o} C), above the tolerance of most non-faecal coliform organisms and close to the upper limit of tolerance of truly faecal organisms. Therefore, the faecal coliforms are often referred to as Thermo-Tolerant Coliforms (TTC), recognising that some organisms detected in the test, notably coliforms of the genus *Klebsiella*, may not truly be of faecal origin (Bitton 1999).

49. Because of some such difficulties with the coliform and faecal coliform tests, *Escherichia coli*, the main constituent species of thermotolerant coliforms of faecal origin, is now preferred as a FIB – at least in freshwaters. Most recent microbiological guidelines for freshwaters (eg. ANZECC, 2000; MfE/MoH, 2003) are enumerated in terms of *E. coli*.

50. However, *E. coli* is less persistent in marine waters than in fresh waters, mainly because cells with sunlight-damaged membranes are rapidly killed by ingress of salt from the external medium. Epidemiological studies of sickness (notably gastro-intestinal symptoms and also respiratory symptoms) in bathers exposed to faecally-contaminated waters have generally shown a stronger relationship to the enterococci group of FIB than to *E. coli*, so the former is now the favoured indicator for saline waters. enterococci have similar persistence over a wide range of salinity, while *E. coli* are less persistent than enterococci in saline waters and more so in fresh waters (Sinton *et al*., 2002).

51. The relationship between concentrations of enterococci and *E. coli* in natural waters is not simple, because their ratio seems to vary with faecal source (*E. coli* seems to be about 10-fold higher in fresh human sewage), as well as with time owing to different die-off rates in the environment. However, MfE/MoH (2003; H12) give a power-law type expression by way of an approximate inter-conversion of enterococci and faecal coliforms, and in raw faecal wastes *E. coli* is typically about 90% of the faecal coliform group.

52. In my opinion, monitoring enterococci in saline waters and *E. coli* in freshwaters creates a conundrum, because much of the faecal microbial pollution of coastal waters and estuaries comes from land via freshwaters. Therefore, it would be preferable for modeling and other purposes if the *same* FIB was used in these connected aquatic environments. The 'disconnect' as regards favoured FIB in fresh *versus* marine waters is particularly severe when, for example, a wastewater in which *E. coli* has been used to monitor treatment efficacy, including disinfection, discharges to the marine environment in which enterococci is used to assess suitability for bathing. Furthermore, Sinton *et al*. (2002) suggest that enterococci are not appropriate for assessing waste stabilisation pond discharges to the marine environment, because the susceptibility of enterococci to sunlight die-off in the saline receiving water is enhanced by their prior exposure to sunlight within the pond system.

53. Difficulties with microbial monitoring are further exacerbated by the existing guidelines for shellfish gathering waters and for shellfish flesh testing being enumerated, still, in terms of the otherwise less-favoured faecal coliform group.

54. For these reasons, in my opinion *E. coli* rather than enterococci should be measured at saline, as well as freshwater, SoE sites, and enterococci reserved only for particularly important marine bathing beaches, for bathing season surveillance following MfE/MoH, 2003 guidelines. Application of only one indicator has the major advantage of laboratory simplicity and that, in future, datasets will be available to link coastal water quality to land sources of microbial pollution. I note that the MfE/MoH (2003; Section G) guidelines seem to recognise the difficulty with different indicators in different environments, and anticipate the need for 'rationalising' between general SoE monitoring *versus* specific beach microbial monitoring, including measuring *E. coli* in saline waters in some situations. (I understand that, currently, Horizons has no saline SoE sites and the only coastal monitoring is of bathing quality.) Table 2, below, gives approximate conversion of guidelines for enterococci to *E. coli*, based on the power expression of MfE/MoH (2003; H12); assuming that 90% of the faecal coliform group are *E. coli*, it could be used to interpret monitoring data for *E. coli* in saline waters.

55. It is important to note that existing guidelines for microbial quality do not distinguish human versus animal sources of the FIB. This recognises that routine methods for distinguishing, say, *E. coli* from livestock *versus E. coli* from humans are not yet available, although so-called microbial source tracking is an active research area. But, in any case, faecal microbial pollution by animals poses a threat to human health from bacteria such as *Campylobacter* and protozoan parasites such as *Cryptosporidiium*,

even if not the highly host-specific viruses. Therefore, faecal pollution of waters by livestock or waterfowl, for example, represents a real risk to human health that should not be diminished or dismissed as of low concern compared to pollution by human wastes. I note that livestock sources of faecal contamination dominate impacts on recreational water quality in Horizons' Region (refer to the evidence of Barry Gilliland).

56. The main routes of microbial infection of humans from contaminated waters is via contact recreation in circumstances where water may be ingested, and via consumption of contaminated shellfish. Furthermore, we are also concerned with microbial infection of livestock from drinking water that is contaminated by faeces of livestock or humans. (MfE/MoH, 2003). Therefore, faecal microbial guidelines have been enumerated in terms of various FIB for contact recreation, shellfish gathering waters and livestock drinking supply.

Standards for microbial water quality in the Proposed One Plan

Contact recreation

57. For protection of contact recreational water safety, ANZECC (2000) recommend guidelines of 150 faecal coliforms/100 mL in freshwaters and 35 enterococci/100 mL in saline waters. More recently, MfE/MoH (2003) have promulgated a classification system for recreational beaches, based on sampling through the bathing season (Table 1). The MfE/MoH (2003) guidelines recommend that *both* monitoring data and a sanitary inspection is used for beach grading, so it is possible that the sanitary survey may modify the Microbiological Assessment Category (MAC) indicated by the microbial data taken alone (Table 1).

Table 1. Microbiological Assessment Category (MAC) for beach grading (MfE/MoH, 2003)

MAC	Marine (Table D1&2)	Freshwater (Table E1&2)	Suitability for recreation grade*
	enterococci	***E. coli***	
A	<40/100 mL	<130/100 mL	"Very good"
B	40-200/100 mL	130-260/100 mL	"Good"
C	200-500/100 mL	260-550/100 mL	"Fair" to "poor"
D	>500/100 mL	>550/100 mL	"Poor" to "very poor"

*Expected Suitability For Recreation Grade (SFRG). It is intended that these MACs be used together with a sanitary survey. An 'unexpected' sanitary inspection result may modify the SFRG.

58. MfE/MoH (2003) propose surveillance monitoring be conducted through the bathing season, with interpretation of results as follows:

- Acceptable (green) mode: no sample >140 enterococci/100 mL (saline water) or > 260 *E. coli*/100 mL (freshwater).
- Alert (amber) mode: single sample >140 enterococci/100 mL (saline water) or > 260 *E. coli*/100 mL (freshwater).
- Action (red) mode: two samples >280 enterococci/100 mL (saline water) or > 550 *E. coli*/100 mL (freshwater).

59. Ausseil and Clark (2007; p 75) propose that the One Plan adopt the MfE/MoH (2003) guidelines as regional standards, with the slight refinement, for rivers, that the "Acceptable" (green) guideline (no sample > 260 *E. coli*/100 mL) be adopted as a standard at less than median flow during the bathing season and the "Alert" guideline (no more than a single sample > 550 *E. coli* 100 mL) at other times, ie.out of the bathing season and at higher flows within the bathing season. For marine waters they propose that the "Acceptable" guideline (no sample > 140 enterococci/100 mL) be applied during the bathing season and the "Alert" guideline (no more than a single sample > 280 enterococci/100 mL) at other times.

60. Broadly, I endorse the adoption of the carefully designed national guidelines (MfE/MoH, 2003) for designated swimming beaches. Horizons' approach in the Proposed One Plan seems eminently practical and should provide good protection of contact recreational quality.

61. However, I note again the difficulty implied by having to monitor different indicators in different waters (saline and fresh). One possible way forward would be to interpret guidelines for marine waters approximately in terms of *E. coli* rather than enterococci, so that monitoring for *E. coli* can be used to assess microbial quality for contact recreation in marine as well as freshwaters (refer Table 2 below). As mentioned earlier (paragraph 54), measuring only *E. coli* has the major advantage that faecal microbial impacts in coastal waters can be explicitly linked to pollution by river plumes contaminated with run-off from land.

Shellfish gathering waters

62. For protection of shellfish gathering in mostly coastal waters, ANZECC (2000) (and also MfE/MoH 2003)) recommend a median concentration of less than 14 faecal coliforms/ 100 mL and a 90 percentile of less than 43 faecal coliforms/100 mL. Ausseil and Clark (2007; p 78) propose that the One Plan adopt these guidelines as regional standards.

63. I endorse the broad approach, but again note the difficulty implied by having to monitor different microbial indicators for different purposes in different waters. One possibility would be to monitor only *E. coli* and interpret compliance or otherwise with the faecal coliform standard for shellfish gathering, assuming that the great majority (eg. 90%) of faecal coliforms likely to be present are *E. coli*. This would only be an issue if an unusually large proportion of faecal coliforms were actually *Klebsiella* rather than *Escherichia* as the environmental protection would then be somewhat *higher* than otherwise. I recognise that at marine farms where bivalve shellfish are grown for export, monitoring of faecal coliforms is required under international agreements.

64. Table 2 tabulates *E. coli* values (potential standards) that correspond approximately to MfE/MoH (2003) guidelines for contact recreation and shellfish gathering, and ANZECC (2000) guidelines for livestock watering. The conversions assume, 1) the power expression relating faecal coliforms to enterococci as given by MfE/MoH (2003; H 12); and 2) that *E. coli* represent about 90% of the faecal coliform group of bacteria. I recommend that, for simplicity, the *E. coli* values in Table 2 are adopted in the One Plan, so that monitoring can be simplified and so that microbial pollution impacts in the coastal zone can be explicitly linked to freshwater transport from land sources.

Table 2. Approximate enumeration of established microbial guidelines in terms of *E. coli*

Water Use	Guideline	Reference	*Converted guideline	
			Faecal coliforms	*E. coli*
Contact recreation – fresh	260 *E. coli*/100 mL (bathing season)	MfE/MoH(2003)	(no conversion required)	260 *E. coli*/ 100 mL
	550 *E. coli*/100 mL (other times)	MfE/MoH(2003)	(no conversion required)	550 *E. coli*/ 100 mL
Contact recreation – saline	140 enterococci/100 mL (bathing season)	MfE/MoH(2003)	208 faecal coliforms/100 mL	187 *E. coli*/ 100 mL
	280 enterococci/100 mL (other times)	MfE/MoH(2003)	315 faecal coliforms/100 mL	284 *E. coli*/ 100 mL
Shellfish gathering – saline	14 faecal coliforms/100 mL (median)	MfE/MoH(2003)		13 *E. coli*/ 100 mL
	43 faecal coliforms/100 mL (90 percentile)	MfE/MoH(2003)		39 *E. coli*/ 100 mL
Livestock drinking – fresh	100 faecal coliforms/100 mL (median)	ANZECC(2000)		90 *E. coli*/ 100 mL
	400 faecal coliforms/100 mL (80 percentile)	ANZECC(2000)		360 *E. coli*/ 100 mL

***Conversions are based on approximate conversion of enterococci to faecal coliforms using the power expression in MfE/MoH(2003:H12) and assuming that 90% of the faecal coliform group are *E. coli*.**

Livestock drinking water

65. For protection of livestock drinking water safety, ANZECC (2000) recommends a median <100 faecal coliforms/100 mL and an 80 percentile < 400 faecal coliforms/100 mL. (MfE/MoH 2003 do not consider livestock drinking water requirements.) Ausseil and Clark (2007; p 95) proposed that the One Plan follow ANZECC (2000) guidelines as regards stock drinking water supply. However, I understand that Horizons has decided not to adopt a specific livestock watering standard, but to simply rely on protection of waters for contact recreation, with standards enumerated in terms of *E. coli* (refer paragraphs 57-60 above) to also protect livestock supply. That is, if fresh water is suitable for contact recreation, it should be broadly suitable for livestock watering. (Refer evidence of Dr Bob Wilcock.)

Key Points
• I endorse the microbial water quality standards proposed for the One Plan, which are basically an adaptation of established national guidelines for contact recreation and shellfish gathering.

Sources and movement of faecal microbes

66. I have been asked to comment on the sources and movement of faecal microbes from rural catchments, where livestock, and some feral animals, vastly outweigh human sources, ie. septic tanks. Recent research in New Zealand, including the author's own work, has elucidated the pathways by which faecal microbes from livestock faeces reach waters, and the behaviour of these contaminants in natural waters. Much of this research was done within the Pathogen Transmission Routes Research Programme (PTRRP, 2002-2005) led by Dr Rob Collins (ex-NIWA, Hamilton) and funded through the NZ Cross-departmental Research Programme. The research findings are summarised in a review paper (Collins *et al*., 2007), of which I was a co-author.

67. Collins *et al*., (2007) distinguish between "direct" pathways, where faecal matter is deposited directly into waters, *versus* "indirect" pathways in which faecal matter is transported to water via surface run-off and subsurface seepage or drainage. This distinction is important because direct deposition provides no opportunity for die-off of faecal microbes before they reach water, so short-lived pathogens, notably *Campylobacter*, are much more likely to be present at high concentrations where direct contamination predominates. Indirect pathways, in contrast, are dependent on rainfall or irrigation water to transport microbes, and there are opportunities for attenuation via

immobilisation or die-off. Soil characteristics, slope and land management are crucial factors contributing to indirect transfer risk. Direct pathways of faecal microbes, seem likely to dominate over indirect pathways during base flows (and therefore for a majority of the time) while the indirect pathways may contribute most to total yields of microbes – which are dominated by storm flows (eg. Davies-Colley *et al*., 2008).

Direct pathways

68. Cattle are specifically attracted to water, and often directly deposit faeces in water bodies that they can access. Other livestock, notably sheep and goats, are less attracted to water bodies, although deer cause direct microbial pollution because of their habit of wallowing in headwater channels and wetlands (Collins *et al*., 2007).

69. Direct deposition of faecal matter into streams occurs when dairy cows cross the stream on their way to or from the milking shed. A study of the water quality impacts of a dairy herd crossing the Sherry River, Tasman District (Davies-Colley *et al*., 2004) showed very high levels of faecal contamination, with concentrations of *E. coli* temporarily elevated to more than 100X background levels of c. 300/100 mL. The crossing impact was exacerbated by the increased defecation rate of dairy cows while standing in water. The Sherry study suggests that such crossings may approximately double the typical (eg. median) *E. coli* concentrations in streams draining dairying land.

70. Studies of cattle behaviour in New Zealand conducted on both hill country (dry stock) and dairy farms provide a means to quantify direct deposition associated with cattle access to unfenced streams flowing through pasture (Collins *et al*., 2007). Beef cattle were found to defecate about 2% of their daily faecal production directly into the stream channel in hill country land (Bagshaw *et al*., 2008). Studies of dairy cattle by Bagshaw (*pers. comm*.) over two summers and one spring showed disproportionately high instream defecation, whereby the cows spent only 0.1% of their time in channels but deposited about 0.5% of their waste there. In associated work, stream water *E. coli* concentrations were found to be greatly increased downstream of the paddocks in which dairy herds were grazing, often by an order of magnitude or more compared to background levels (Davies-Colley and Nagels, 2008). The yields of *E. coli* measured over grazing episodes, ie. between morning and afternoon milkings, were consistent with the observations of cattle behaviour by Bagshaw and co-workers (Collins *et al*., 2007).

71. Deer, like cattle, are attracted to water. De Klein *et al*., (2002) reviewed the environmental impacts of deer farming, including intense water pollution broadly

comparable to that by cattle. Wallowing behaviour by deer in small streams and wetlands is a particular concern for mobilising contaminants (McDowell, 2007), including microbes, sediment and nutrients.

Indirect pathways

72. "Indirect" pathways involve faecal microbes being transferred to water bodies via the flow of water from rain or irrigation over the surface of the land (surface run-off) or down through the soil horizons (subsurface flow). The nature and relative importance of indirect pathways varies with a range of factors, including the type of farming, livestock density, management practices, magnitude of a rain or irrigation event, soil type, slope angle and distance to waterways. Surface run-off is probably more important to surfacewater microbial contamination, although soil leaching can cause localised groundwater contamination as well as microbial pollution in subsurface drains which eventually discharge to surface water.

73. *Pathways in hill country*. On hill country farmland in New Zealand, mostly used for sheep-beef grazing, the generally steep topography promotes the generation of significant surface run-off under heavy and/or prolonged rainfall (Collins *et al*., 2005a). This provides an efficient mechanism by which faecal microbes, deposited by livestock on contributing areas of pasture, are delivered to streams. Experiments with rainfall simulators suggest that large amounts of faecal pollution are mobilised in surface run-off by heavy rainfall events (Collins *et al*., 2005). The yield of *E. coli* in these experiments was inversely related to the time elapsed since the last grazing episode.

74. The convergence of surface and subsurface flows in hill country tends to promote formation of small wetlands which, where accessed/grazed by livestock, can mobilise large amounts of faecal pollution during heavy rainfall (Collins, 2004). Exclusion of livestock from these wetlands might be a particularly important BMP (see below).

75. *Dairy shed effluent.* Dairy cattle spend about 10% of their time in milking sheds, which therefore collect a commensurate daily load of faeces. Standard dairy shed waste treatment for many years in New Zealand has been by two-stage waste stabilisation pond systems (Sukias *et al*., 2001) in which faecal indicator bacteria die-off averages about 90-99%. However, the disinfection is highly inconsistent, suggesting that further treatment is desirable before discharge to waters. Land disposal of dairy shed effluent has the potential to markedly reduce the transfer of faecal microbes and nutrients to waters, and is increasingly favoured by most regional councils in New Zealand. Ideally,

existing two-pond systems would be used to store dairy shed wastes, providing useful disinfection prior to "deferred" effluent irrigation (as discussed below).

76. *Artificial drains.* Artificial drains are commonly installed in pastures where drainage is constrained, particularly on dairy land. Subsurface drains reduce saturation of the soil and the likelihood of surface run-off, which would otherwise mobilise microbes. However, drains are themselves capable of rapidly transferring microbes, and other contaminants, to streams (Collins *et al*., 2007). This transfer can occur in response to rain storm events but also to irrigation of effluent whenever the soil water deficit is exceeded (eg. Houlbrooke *et al*., 2004).

77. Microbial contamination of subsurface drain flows under effluent irrigation was studied by Monaghan and Smith (2004). They found that when the soil was wet, *E. coli* concentrations in the resulting drain flows approached those of the applied effluent. At greater soil moisture deficits, *E. coli* concentrations in drain flows were appreciably lower. Similarly, Ross and Donnison (2003) found that when preferential flow occurred, *Campylobacter* concentrations in drainage water approached those in the applied effluent. Monaghan and Smith (2004) reported non-uniform patterns of effluent application, with the outside of a small rotating irrigator applying double the average application depth, which could promote ponding and bypass flow.

78. Research summarised by Collins *et al.* (2007) shows that on some soil types, appreciable surface run-off, can be generated on flat to rolling dairy land by effluent irrigation in wet conditions with consequent mobilisation of microbes, despite artificial drainage. For example, surface run-off generated by rain upon a study plot underlain by a Tokomaru silt loam soil was heavily contaminated by faecal microbes, with concentrations of *E. coli* and *Campylobacter* peaking at $>10^5$/100 mL and $>10^3$/100 mL, respectively, immediately following grazing. Peak *Campylobacter* concentrations in surface run-off, generated following the application of effluent, were also $>10^3$/100 mL.

79. *Groundwater.* Microbial contamination of groundwaters seems to be mainly an issue with unconfined, very permeable systems, including the Last Glacial alluvial deposits in the Horowhenua area and Rangitikei delta area of Horizons' Region, and kaast (ie. limestone or marble rock) systems. The irrigation of water to encourage pasture growth can promote the flushing of faecal microbes, from faeces deposited on pasture by livestock, down through the soil horizons to groundwater. Close *et al.*, (2008) demonstrated statistically increased incidence of campylobacteriosis, cryptosporidiosis, and salmonellosis in people drinking bore water contaminated by border-dyke irrigation

of pasture on the Canterbury Plains, compared to control groups elsewhere in Canterbury.

Key Points

- "Direct" and "indirect" pathways of microbes from livestock to water should be distinguished.
- *Direct pathways* involve contact of livestock, notably cattle, with water; *indirect* pathways involve the movement of water over land or through soil.

Behaviour of microbes in waters

80. Once faecal microbes reach waters, they are exposed to a range of stressors, notably sunlight, that tend to reduce their numbers fairly rapidly (eg. Sinton *et al.*, 2002). Additionally, microbes in waters are uptaken in stream and river sediments by the process of hyporheic exchange. The actual sites of entrapment are not well understood, but probably crucially involve aquatic biofilms. Both die-off and microbial uptake in sediments contribute to reduction in microbial concentrations as water moves down streams and rivers, and is a primary reason why balances on Faecal Indicator Bacteria (FIB) fluxes (cfu/s) over river reaches do not work, ie. microbes are not 'conserved'. Modelling studies suggest that microbial attenuation, like nitrate attenuation, scales inversely with the size of streams (Graham McBride, *pers. comm.*), being much more rapid in small shallow streams in which both sunlight die-off and hyporheic exchange are far more rapid than in large, deep rivers.

81. Once incorporated into sediments or on plant surfaces within water bodies, microbes are much less exposed to sunlight and thereafter die off more slowly, with some contribution by intrinsically slower processes such as ingestion by protozoans. However, disturbance of sediments or plant surfaces can entrain these stored microbes back into the water column. 'Disturbances' include, particularly, accelerating currents on the ascending limb of the hydrograph on storm events, but also, more ominously, children playing in streams and thus resulting in their exposure to a microbial hazard.

82. Storm flows tend to have much higher concentrations of FIBs such as *E. coli* than base flows, and this is usually attributed to land wash-off in overland flow. However, the dynamics of FIBs over storm hydrographs are not usually consistent with this wash-in mechanism. FIBs usually precede the water flow over storm hydrographs, peaking on the rising limb (Davies-Colley, 2009), whereas wash-in of microbes would be expected

to cause faecal indicator bacteria to *lag* the hydrograph, because the flood wave travels more rapidly down channels than the polluted water it mobilises. Most likely, the main mechanism of microbial pollution during storms is not wash-in, but sediment disturbance by accelerating currents on the flood wave front (Wilkinson *et al.*, 2007). Experiments with artificial floods in streams (Nagels *et al.*, 2002; Muirhead *et al.*, 2004), during dry weather , when no wash-in is occurring, produce high FIB concentrations comparable to natural floods, proving that channel stores of microbes are responsible for the faecal pollution dynamics over floods, and most of the total yield in such events (Davies-Colley, 2009).

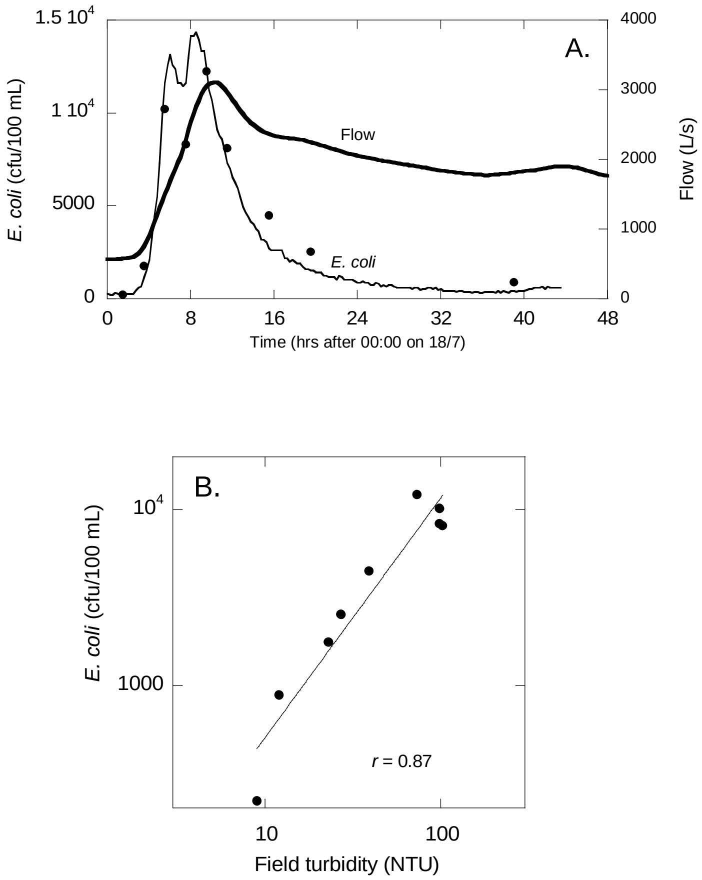

Figure 1. Typical faecal pollution dynamics during stormflow as illustrated by data for the Toenepi Stream in an area of intensive dairying, Waikato Region, New Zealand (event of 17 July 2005). A. Time series for *E. coli* as measured (solid points) and simulated from the turbidity correlation (continuous line calculated from the continuous turbidity record using the relationship in panel B) are shown in relation to the flow hydrograph (heavy line). B. *E. coli* versus turbidity as measured *in situ* by a continuously-recording nephelometer (from Davies-Colley, 2009).

83. A study of flood events in the Toenepi Stream draining intensively dairy-farmed land in the Waikato (Davies-Colley *et al.*, 2008) found that 95% of the total *E. coli* yield from the catchment occurred in 35 storm events over a year occupying only about 24% of total time. Recent studies on the same stream (Rebecca Stott and Graham McBride NIWA-Hamilton, *pers. comm.)* show that *Campylobacter* follow a different time-course over storm flows than *E. coli. Campylobacter* peak nearly co-incident with the hydrograph peak, probably because this micro-organism does not survive long in sediments, in contrast to *E. coli* with which the sediments are heavily loaded (Donnison *et al.*, 2006), and is coming mainly from wash-in of recent faecal deposits (McBride and Mittinty, 2008).

Key Points

- During base flows, most of the microbial contaminants in streams are located in the sediments.
- However, these temporary sediment stores of microbes can be mobilised, by the accelerating currents, on the rising limb of storm hydrographs.
- As a result, impacts on downstream waters for bathing, shellfish gathering and water supply are most severe during and after storm flows.

BMPs for controlling faecal pollution from livestock

84. The Collins *et al.* (2007) paper built on an overview of research on microbial pollution pathways, both direct and indirect, to discuss best management practices (BMPs) capable of mitigating microbial pollution. Table 3 categorises the BMPs discussed by Collins *et al.* (2007) as outlined below.

Direct pathways

85. *Bridging dairy herd crossings.* Dairy herd crossings are a key pathway for faecal microbial pollution, so construction of bridges or culverts to replace crossings should appreciably reduce faecal pollution (Table 3). Monitoring data for the Sherry River, site of the crossing study by Davies-Colley *et al.* (2004), shows that bridging of all four dairy crossings along that water body has appreciably improved water quality, with a two-fold reduction in *E. coli* concentrations (author's unpublished data). However, guidelines for contact recreation are still often exceeded in the Sherry River because of continuing pollution via indirect pathways, and direct deposition where dairy cattle have access to unfenced tributary streams and drains.

86. *Fencing of stream banks.* Fencing of streams and other water bodies is the most "obvious" approach for preventing direct faecal pollution by cattle access (Davies-Colley and Nagels, 2008). In principle, fencing the bank crest so as to prevent livestock accessing the channel will greatly reduce faecal pollution. However, fencing with a set-back from the bank so as to provide a riparian buffer is preferable because this provides a site for infiltration and entrapment of microbes in overland flow from upslope (Collins *et al.*, 2007), that is, riparian fencing with a set-back from the stream addresses some indirect as well as direct pathways of faecal pollution (see discussion below on riparian buffers). A number of suggestions for permanent and electric fencing near and across streams have been made by Askey-Doran (1999), including methods to avoid flood damage to fencing infrastructure. Fencing right on the bank crest is to be discouraged because any lateral cutting of stream banks, ie. channel meandering, as occurs naturally during floods, may undercut fences.

Table 3. BMPs to mitigate microbial pollution by livestock (based on Collins *et al.*, 2007)

BMP	Description	Rationale
Direct pathways		
Bridging/culverting of dairy crossings	Stream crossings by dairy raceways are bridged or culverted to isolate the dairy cattle from water	Dairy cattle 'loiter' in streams during crossings, and cause a disproportionate amount of faecal pollution
Fencing of streams, drains and other water bodies	Fencing prevents access to waters of livestock, particularly cattle	Livestock, particularly cattle, deposit faecal matter directly in waters in which they tend to 'loiter', so exclusion by fencing eliminates direct pollution
Indirect pathways		
Identify at-risk soils (avoid certain activities on such soils)	Poorly drained soils promote surface run-off. High bypass flow soils promote faecal microbe movement to drains or groundwater	Grazing and irrigation of at-risk soils is very likely to convey faecal microbes to surface or groundwaters and should be avoided where possible
Manage grazing (location and timing)	Graze livestock away from riparian zones or poorly drained paddocks in wet weather. Use wintering pads or herd homes to avoid pasture damage	In wet weather, paddocks are easily damaged ('pugged') and faecal matter can be washed with overland flow into nearby streams or drains. Wintering pads or herd homes can reduce pasture damage and faecal pollution in wet seasons
Manage irrigation of effluent and water, with regard to location and timing	Monitor soil moisture, and avoid irrigation when soils are wet. Practice deferred irrigation of dairy effluent. Irrigate effluent only on paddocks remote from streams/drains. Irrigate at high travelling speed to avoid surface ponding	This raft of measures is intended to reduce the likelihood of surface ponding of water/effluent causing overland flow and conveying microbes to surface waters, or high bypass flow causing drainage pollution, or pollution of groundwaters

BMP	Description	Rationale
Improved dairy shed waste treatment	Add further maturation ponds for improved disinfection, or construct wetlands for microbial filtration; upgrade to Advanced Pond Systems (APS). Convert to land disposal	Conventional 2-pond dairy shed waste ponds often cause appreciable microbial pollution because their disinfection is inconsistent and sometimes poor, but these systems are amenable to further treatment or upgrading
Riparian buffers	Exclude livestock from the riparian zone by fencing. Ideally, the riparian buffer is suitably planted with trees and shrubs, with valuable co-benefits, although a grass buffer that is maintained by light grazing, by sheep, should also be effective	Fenced riparian buffers reduce faecal pollution by three main mechanisms - 1) the source of direct faecal pollution is removed; 2) the source of soil and vegetation damage to riparian zones and stream banks is removed; and 3) the riparian zone vegetation and soil promotes infiltration with entrapment of microbes from upslope
Fencing of wetlands	Fence wetlands, particularly small in-channel or near-channel systems, to exclude livestock, particularly cattle	Livestock, particularly cattle and deer, damage vegetation and defecate while in wetlands, which makes these systems sources of microbes in wet weather
Construct wetlands for treating drain pollution	Constructed wetlands can 'filter' microbes and other pollutants in drainage waters	Drainage water can contain high concentrations of faecal microbes, approaching those of overland flow in wet conditions

87. Potentially, encouraging livestock away from waters through off-stream provision of resources such as water, shade and shelter could reduce faecal pollution, even in the absence of fences (Collins *et al.,* 2007). In semi-arid cattle land in the United States, such off-stream incentives have indeed reduced cattle access to streams and resulting pollution. However, under intensive stocking conditions in New Zealand, alternative water sources, located on hilltops, did not reduce stream access by beef cattle (Bagshaw *et al.,* 2008). The usefulness of alternative water sources or other off-stream resources for dairy cattle within New Zealand remains untested.

Indirect pathways

88. *Identifying at-risk soils.* The identification of soils with risk of high transfer to waterways is a key step towards mitigating accelerated microbial pollution of waters from grazing and/or irrigation by effluent and water. The ability of a given soil to attenuate microbes is strongly dependent on the degree to which water from rainfall or irrigation can infiltrate, rather than generate, surface run-off which rapidly transports microbes to waters downslope. Collins *et al.* (2003) found that poorly-drained soils with a low infiltration rate tend to be associated with high faecal contamination of streams in the Waikato Region. McLeod *et al.* (2005) mapped relative soil surface run-off potential across New Zealand,

based on drainage class, depth to impermeable layer, permeability above an impermeable layer (based on measurements of hydraulic conductivity), and slope angle.

89. The ability of a soil to attenuate infiltrating microbes strongly affects the transfer of faecal microbes to waterways. Soil microbial attenuation is strongly dependent upon the degree to which infiltrating water passes through the fine pores of the soil matrix and contacts reactive internal surfaces. There is little microbial attenuation in water that bypasses these fine pores (bypass flow through macropores such as cracks, large pores and worm channels). Soils characterised by strong bypass flow should be subject to less intensive grazing and application of effluent (Collins *et al.,* 2007).

90. Results from microbial breakthrough curves using undisturbed soil cores have been combined with the New Zealand Soil Classification to extrapolate the relative risk of rapid microbial transport through New Zealand soils (McLeod *et al.,* 2005). Approximately 50% of North Island soils on flat to rolling land have a high potential for microbial bypass flow, including soils in the Manawatu.

91. *Grazing management.* Pugging damage to soils from livestock trampling in wet weather can promote surface run-off that can wash faecal matter directly to water bodies. Therefore, during wet weather, exclusion of livestock from paddocks located adjacent to streams and drains should greatly reduce faecal pollution. Grazing rotations on dairy farms could ensure cows are grazed on paddocks away from stream channels when heavy rain is predicted (Collins *et al.,* 2007).

92. Improved water quality may result through the relocation of stock from paddocks to feed or wintering pads, or herd homes during wet seasons (Luo *et al.,* 2006). However, appropriate treatment/disposal of livestock wastes is required to ensure that benefits to water quality are realised.

93. *Irrigation management.* Timing and location of effluent and water irrigation are key considerations for minimising microbial pollution of waters. Irrigation when soils are wet (ie. at or near saturation) can transport microbes in surface run-off to waters or bypass flow down through the soil horizons to either groundwater or to surface water bodies via subsurface drains. Ideally, irrigation should not be practised when the volume to be applied will exceed the water storage capacity of the soil, but effluent should be stored until soil moisture conditions are suitable. This 'deferred irrigation' can greatly reduce nutrient loss to waters (Houlbrooke *et al.,* 2004; Monagahan and Smith, 2004) and is likely to be similarly effective at reducing faecal pollution. Monitoring of soil moisture is

crucial for deferred irrigation. Additionally, sufficient wastewater storage capacity (eg. a traditional 2-pond system) is a key requirement, particularly during winter and spring, when soil moisture deficits are small or non-existent (Houlbrooke *et al.,* 2004). For example, Monaghan and Smith (2004) estimated that between 44 and 109 days of effluent storage would be required per year in West Otago.

94. Where possible, land application of dairy shed effluent should be restricted to those soils that have a low transfer risk from surface run-off and/or bypass flow. On soils with high and medium bypass flow, application should be confined to paddocks remote from streams and drains to maximise the opportunity for microbial entrapment and die-off to occur in soils.

95. Irrigator type and operating practice can influence microbial loss. For travelling irrigators, a high irrigator groundspeed should be used so as to apply effluent at a low rate to any given ground area (eg. Monaghan and Smith, 2004).

96. Many of the principles that apply to effluent irrigation also apply to water irrigation on grazed land. A delay between grazing and irrigation permits change in the physical and chemical properties of faecal material and, usually, some net microbial die-off, reducing the transfer of microbes (Collins *et al.,* 2007).

97. *Improved dairy shed waste treatment*. Treatment by conventional 2-stage dairy shed waste stabilisation ponds can be improved by a number of add-ons, including further maturation ponds or addition of wetlands (Sukias and Tanner, 2006) or upgrade to an Advanced Pond System (APS). APS consist of four types of ponds in series (in order: anaerobic pond, high rate pond, algal settling ponds, maturation pond) which together produce effluent of considerably higher quality, including much better and more consistent microbial quality, than the traditional two-stage oxidation ponds (Craggs *et al.,* 2004). APS have particular application where soil and climatic conditions are unfavourable for land application of dairy effluent.

98. *Riparian buffers.* Fencing to exclude livestock from stream channels and a proportion of riparian land has the potential to be particularly effective for reducing faecal contamination of pastoral streams. Not only do fenced riparian buffers prevent the deposition of faecal material directly into streams and near-channel contributing areas (see discussion above under BMPs for mitigating pollution by direct pathways), the dense vegetation and uncompacted soil in Riparian Buffer Strips (RBS) aids infiltration, so promoting the entrapment of faecal material (Collins *et al.,* 2007). Riparian retirement

can provide important co-benefits, notably to stream habitat owing to the shading provided by riparian shrubs and trees (Parkyn *et al.,* 2003).

99. Studies reviewed by Collins *et al.* (2007) suggest that the effectiveness of riparian buffers in attenuating faecal microbes in surface run-off is influenced by: slope angle, soil type, buffer width, type of faecal material, the degree of attachment of microbes to soil, and the rate of surface run-off. Currently, it is not possible to derive quantitative riparian buffer design guidelines for microbial pollution control in New Zealand from the few studies that have been undertaken. Instead, guidelines for attenuation of faecal bacteria in riparian buffers have been derived from those reported for sediment attenuation (Collier *et al.,* 1995).

100. *Wetlands.* Water quality improvements should be achieved by fencing livestock out of wetlands and seepages on pastoral land. For example, studies of hill country wetlands (Collins, 2004) have shown that cattle are strongly attracted to small, shallow wetlands for grazing, though not to large, deep wetlands, presumably for fear of entrapment. Consequently, these smaller wetlands are critical source areas with respect to faecal microbes, sediment and nutrients. Exclusion of livestock, particularly cattle, by fencing should result in wetlands being a microbial contaminant sink, rather than source. Deer exclusion to prevent wallowing is not so straightforward, and an alternative off-channel wallowing area may need to be provided (McDowell, 2007).

101. *Constructed wetlands for treatment of drain flows.* Recent studies of constructed wetlands have shown good potential for the treatment of drain flows from grazed and irrigated dairy pasture that are commonly polluted by microbes as well as nutrients and sediment (Tanner *et al.,* 2005), and research is ongoing (Dr Chris Tanner, *pers. comm*.).

102. The Mowhanau Stream catchment, North of the Whanganui River has been identified in the Proposed One Plan as a priority catchment, requiring the use of BMPs, due to microbial contamination of the stream and nearby Kai Iwi Beach. Most of the Mowhanau Stream catchment is in sheep and beef farming, with only a small proportion in dairying land use. McArthur (2009) found that *E. coli* concentrations at different sites in this catchment were not highly correlated to stream flow. Instead, elevated *E. coli* during base flows are more likely to reflect contamination by direct livestock access. The Mowhanau Stream would benefit from fencing to exclude cattle as discussed above.

Key Points

- A range of BMPs is available for reducing microbial pollution from livestock farming (refer Table 3)
- BMPs that address direct pathways, where livestock contact waters, include fencing stream banks to exclude livestock, particularly cattle, and bridging of raceways that would otherwise intersect streams.
- BMPs that address indirect pathways emphasise soil properties and condition, and timing and location of farm activities such as grazing and effluent irrigation. Included here are riparian buffers and fencing of wetlands (refer Table 3).

5. WATER QUALITY STATE AND TREND IN HORIZONS' REGION

Introduction

103. In order to have an up-to-date overview of water quality in Horizons' Region as background to the Proposed One Plan, Horizons staff recently commissioned an analysis by NIWA of water quality state and trend over time. Ballantine and Davies-Colley (2009b) examined water quality monitoring data from some of Horizons' State of Environment (SoE) sites (23 in all) as well as from seven National Rivers Water quality Network (NRWQN) sites in the Region. At SoE sites, dissolved reactive phosphorus (DRP), soluble inorganic nitrogen (SIN) (compiled by adding ammoniacal-N to total oxidised nitrogen), visual clarity (black disc method), turbidity and *E. coli* are measured, along with some other variables. These variables are all measured, together with some others, at NRWQN sites.

104. To provide an overview of water quality state in the region, median values of water quality variables at SoE sites were compared with: 1) water quality in the NRWQN so as to provide a national perspective; and (2) guidelines and 'trigger values', which are intended to trigger a management response, for water quality as promulgated by ANZECC (2000).

105. To provide an overview of water quality trends in the Region, formal trend analysis was performed on flow-adjusted data using NIWA's TimeTrend software (http://www.niwa.co.nz/ncwr/tools/). The trend analysis closely followed completion of a recent analysis of national water quality trends using NRWQN data (Ballantine and Davies-Colley, 2009a; see http://www.mfe.govt.nz/publications/water/water-quality-trends-1989-2007/index.html). The formal trend analysis was applied to 16 SoE sites for

the full length of record available and separately, for the years 2001-2008, and also for seven historic sites at which monitoring has been discontinued, for the length of records available. The trend analysis involved, firstly, flow adjustment of the data, because most water quality variables are subject to either dilution (ie. decreasing concentration with increasing flow, eg. conductivity) or land run-off (ie. increasing concentration with increasing flow, eg. total phosphorus). A non-parametric indicator of relative trend strength was enumerated so as to permit direct comparison between sites as % change per year.

106. Here I give a brief summary of the findings of the state and trends report (Ballantine and Davies-Colley, 2009b), which should be consulted for more detail and recommendations regarding SoE monitoring and future time-trend analysis.

Key Points

- A recent report (Ballantine and Davies-Colley, 2009b) summarises state and trend of water quality in Horizons' Region.
- This report should be consulted for any more detail than is given in my evidence below.

Water quality state

107. Water quality is highly variable across Horizons' Region. In some of the least disturbed parts of the Whanganui and Rangitikei catchments, water quality is generally good, but elsewhere, notably in the Manawatu and its tributaries, water quality is appreciably degraded. On a national scale (ie. relative to the NRWQN), nutrient concentrations of soluble inorganic nitrogen (SIN) and dissolved reactive phosphorus (DRP) in the Manawatu are among the highest in the country. In contrast, nutrient concentrations in most parts of the Rangitikei and Whanganui catchments are low relative to guideline values and when compared nationally (ie. relative to the NRWQN). Visual clarity is fairly high in upper reaches of all three rivers, but is low, when compared nationally, throughout much of the Region. This reflects extensive areas of soft sedimentary rocks, which erode to yield fine particles that are efficiently light scattering. Natural erosion in these areas is exacerbated by land use, particularly livestock grazing.

108. Diffuse pollution from livestock agriculture appears to have a strong adverse influence on water quality in the Region, where the main land use is sheep and beef farming, although dairying is expanding in some areas of the Manawatu. Correlations strongly

suggest that both sheep and beef farming, and dairying, have a negative effect on water quality. SIN, DRP and *E. coli* concentrations are all positively correlated, and visual clarity negatively correlated, with % of catchment land area used for pastoral agriculture. Conversely, forests have a positive effect on water quality, as shown by SIN, DRP and *E. coli* concentrations being inversely related to % land in native forest and total forest cover (ie. native plus plantation forests).

109. While diffuse inputs from agriculture have the dominant influence on water quality state throughout the Region, there are also numerous point sources, particularly in the Manawatu Catchment. High DRP concentrations are typical of the Oroua, the Manawatu, and the Hautapu upstream of its confluence with the Rangitikei River. The median DRP concentration (2001-2008) in the Oroua River near Fielding was the highest nationally when compared to the NRWQN, reflecting discharge of treated sewage and the AFFCO meat works, as well as pastoral influences. High DRP concentrations in the Hautapu River apparently reflect both the high percentage of sheep and/or beef farming in the catchment (66.4%) and discharge of treated sewage from Taihape. Similarly, high DRP concentrations in the Upper Manawatu at Hopelands and Upper Gorge monitoring sites are attributable to the combined influence of diffuse pastoral and point sources.

110. High SIN concentrations occur in the Mangatainoka, Makuri, and the Manawatu at Hopelands. The Mangatainoka has significant point sources (ie. brewery and treated sewage) and a large area in dairying. High SIN and *E. coli* concentrations in the Makuri River are attributable to a high proportion of the catchment being in sheep-beef. Both the Mangatainoka and Makuri Rivers load the mainstem Manawatu with nitrogen. The catchment of the Manawatu at Hopelands is 85% pastoral, consistent with high SIN concentrations.

111. Catchment geology has a strong influence on visual clarity and turbidity. On a national scale, ie. compared to the NRWQN, visual clarity in the Manawatu, Whanganui and Rangitikei is low, consistent with soft sedimentary rock types that erode readily, and intensely light-scattering fine particles. The steep hill country in these catchments tends to be very unstable and susceptible to slip erosion, which is greatly exacerbated when the land is used for pasture (eg. Parkyn *et al*., 2006).

112. *E. coli* concentrations frequently exceed guidelines for contact recreation in the Manawatu Catchment and at one site in both the Rangitikei (Hautapu) and Whanganui (downstream of Retaruke) catchments. Land use in the catchments upstream of these

sampling sites is mainly sheep-beef farming, and the high *E. coli* numbers probably reflect, in particular, the presence of cattle in streams.

Key Points

- Water quality in Horizons' Region is good at 'baseline' sites high in catchments, but often appreciably degraded lower in catchments, particularly by livestock farming, although some point sources also contribute.
- There is widespread nutrient enrichment in the Region, particularly in the Manawatu Catchment, and water quality is also degraded by high faecal contamination (ie. high *E. coli* concentrations).
- Low visual water clarity in much of the Region reflects large areas of soft sedimentary rocks that yield abundant, highly light-scattering fine sediment when erosion is accelerated under livestock farming.

Water quality trends

113. Water quality data in the Region was previously analysed for trends, using data from SoE sites for the period 1989-2000, by Gibbard *et al*. (2005). These authors reported increasing trends in DRP, nitrate and turbidity concentrations (indicating deteriorating water quality), similar to national trends towards declining water quality over two decades in the NRWQN (Ballantine and Davies-Colley, 2009a). In contrast, our very recent analysis of both Horizons' SoE data over the period 2001-2008, and NRWQN data from seven sites in Horizons' Region over the period 2001-2007, found few time-trends, suggesting mostly stable water quality (Ballantine and Davies-Colley, 2009b).

114. As regards nutrients, we found reducing SIN at six SoE sites and three NRWQN sites in the Region. We could not detect trends in DRP at SoE sites, for which data precision is low, but DRP was reducing at three NRWQN sites. This steady, or even improving, regional nutrient status over the past 7-8 years may reflect both reduced point source pollution and farming changes leading to reduced diffuse pollution. Increased stream fencing on dairying land, improvements in dairy shed effluent disposal by being increasingly applied to land (Roygard and McArthur, 2008), reduced fertiliser use, and reduced stocking rate, particularly in extensive sheep-beef country, may all contribute to reducing nutrient enrichment in the Region.

115. We found few trends for visual clarity and *E. coli* in the Region, but improvements at certain sites, particularly in the Manawatu Catchment (notably at Hopelands). Major upgrades to reduce faecal contaminants in the Dannevirke sewage treatment plant

discharge are likely to have contributed to improvements in *E. coli* at this site, as well as some of the on-farm changes mentioned in connection with reduced nutrients.

116. Overall, our trend analysis suggests that water quality is stabilising or even improving in the Region (Ballantine and Davies-Colley, 2009b). This encouraging trend may reflect a combination of improved wastewater treatment and changes in livestock farming that are reducing diffuse pollution, such as reduced sheep-beef stocking, reduced fertiliser use, increasing stream fencing, and improved dairy shed effluent disposal.

Key Points

- Recent trend analysis suggests an encouraging trend since 2001 towards stabilising or improving water quality (ie. nutrients and faecal contamination), in Horizons' Region.
- These improvements are consistent with reduced point and diffuse pollution sources in the Region.

6. REFERENCES

Note – those references in **bold** type I consider to be key references that may be useful to consult to amplify points made in my evidence. Other references are listed – and cited in evidence – mainly for scholarly 'authority'.

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