Suitability of NZ rivers for contact recreation

A pilot application of a water quality index to the National Rivers Water Quality Network (NRWQN)

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Executive summary

Water quality indexes (WQI) are a potentially powerful means for converting complex water quality data into information for policy-makers and the public. We applied an existing WQI for contact recreation in NZ to ‘characteristic’ values (medians) of water quality data for the 77 river sites in the National River Water Quality Network (NRWQN). The WQI is based on curves relating suitability-for-use to different variables developed by a NZ water quality expert panel. The key variables for contact recreational quality of waters are faecal pollution and visual clarity, so we used data for E. coli and visibility (black disc method) to assess NRWQN sites for contact recreation.

In the NRWQN, 30 sites (out of 77, i.e., 39%) are rated “unsuitable” for contact recreation in their median condition, about 3/4 of these owing to low visual clarity and ¼ owing to faecal pollution. Our resulting ‘league table’, ranking the NRWQN sites from most to least suitable, differed somewhat from a recent league table (that did not assess suitability-for-use) recently published by Ministry for Environment.

Faecal pollution strongly correlates with proportions of catchments in pastoral land use (Rs = 0.80), suggesting that *E. coli* in our rivers come predominantly from livestock sources. The Mataura River in its lower reaches (ranking 75th) is severely constrained for contact recreation by faecal pollution. Visual clarity is less strongly related to land use (Rs = –0.45 for % Pasture), because (light-attenuating) fine sediment in waters also reflects soil and geological conditions. The Waimakariri River is unsuitable for contact recreation (ranking 72nd and 76th at two sites) because, despite fairly low *E. coli*, its water has low clarity for purely natural reasons – glacial flour from alpine headwaters. More typically rivers have low visibility because of interaction of land use with geological/soil factors. For example, the Waipaoa River (ranked 77th), Waipa River (74th) and Waitara River (73rd) have low visibility (and are also somewhat faecally polluted) reflecting livestock disturbance of fine sediment particles in their catchments.

1. Introduction

A large amount of data on water quality is being collected in New Zealand, including at 77 sites in the National River Water Quality Network (NRWQN) and at about 1000 regional council State of the environment (SoE) sites. However, this data is challenging to interpret, even for water quality specialists. It is difficult to relate data on esoteric variables, like *E. coli* bacteria or nitrogen concentrations for instance, to, say, the suitability of a local river for swimming. To be useful, this complex environmental data needs to be transformed into information that is widely understood and addresses values associated with water. What is needed is a water quality index (WQI), broadly analogous to the consumer price index or a stock exchange index, which summarises several different water quality variables, in a meaningful way (Smith 1989, 1999). Internationally, however, there has been only limited progress towards development of such indices because of various technical difficulties, although the Canadian WQI seems to be well-established in that country (http://www.ccme.ca/ourwork/water.html?category_id=102#290).

Notable pioneering work was done on WQIs in New Zealand by Dr Dave Smith who also happened to be chief designer and first supervisor of the NRWQN. Smith (1989, 1990) surveyed a panel of New Zealand water quality experts to develop WQIs (for different major categories of water use or 'values' of water such as drinking supply or aquatic habitat) representing a consensus on how suitability-for-use (SFU) of water varies with different water quality variables. An important innovation in this work was the use of the minimum SFU score as the overall index score, rather than aggregating variables using (necessarily arbitrary – and contentious!) weighting functions (Smith 1990).

More recently, Nagels et al. (2000) reported an index for contact recreation in New Zealand developed following the design principles of Smith (1990). So far as we are aware, these indexes have not been applied – probably because at the time of their introduction, the need for such tools to convert water quality data into information was not widely recognized by water managers in New Zealand. However, recently the MfE (2009) published "league tables" for rivers in the National Rivers Water Quality Network (NRWQN) based on water quality percentiles for different variables. These tables, ranking rivers in terms of certain values (but not assessing underlying suitability-for-use), are really water quality indices by another name – so it would seem that the time to develop water quality indices in New Zealand has arrived.

By way of a pilot study, we have applied the NZ contact recreation index (Nagels et al. 2000) to river water quality data from the NRWQN, a network of 77 monitoring sites on 35 river systems distributed across New Zealand and draining about half the national land area. This paper reports the findings from application of the index and suggests – consistent with intuition and with the MfE (2009) league tables – that poor visual clarity and microbial pollution are the main concerns for contact recreation.

2. Background

The contact recreational (CR) index reported by Nagels et al. (2000) consists of a set of 'sub-index' curves relating suitability-for-use (SFU) to different variables. These sub-index curves (the 'consensus' curves approved by a panel of water quality experts) recognize that SFU does not go precipitously from suitable to unsuitable as a particular water quality variable changes past a guideline or standard value, but changes rather gradually (e.g., Davies-Colley & Wilcock 2004).

For example, Figure 1 shows the individual curves for suitability-for-use versus visibility drawn (on blank graph paper) by the expert panel members. There was appreciable diversity of opinion as indicated by the spread of curves. The 'consensus' curve (superimposed bold curve), henceforth referred to as the 'sub-index' curve, was obtained by averaging individual curves. The 'sub-index' curve has SFU rising from "unsuitable" at visibilities lower than 1.2 m, through "marginally suitable" centred on the guideline for contact recreation (1.6 m; MfE, 1994) to "eminently suitable" at visibilities exceeding about 3.3 m. Note that visibility is not merely an aesthetic concern for contact recreation, it is also a safety concern as regards visual detection and avoidance of underwater hazards.

Variables included in the CR index are: visual water clarity (affecting aesthetic quality and CR safety), turbidity (likewise, affecting aesthetics and CR safety), dissolved phosphorus and inorganic nitrogen concentrations (together promoting nuisance algae), Munsell hue (colour – affecting aesthetics), pH (because alkaline or acid conditions can irritate the human eye subjected to water contact) and *E. coli* bacteria (an indicator of the risk of disease-causing faecal microbes being present in the water).

To use these sub-index curves, water quality data must be interpolated so as to estimate SFU on a scale from 100 ('perfect' for use) to zero ('completely unsuitable' for use). The variable with the lowest SFU for a given water is interpreted as most limiting of water use – in practice, by taking that minimum sub-index value as the overall water quality index value. (The philosophy underlying this approach is cogently argued in Smith 1990.)

3. Methods

We applied the Nagels et al. (2000) index for CR to 'characteristic' (median) values of variables measured (monthly) at the 77 sites in the NRWQN for the four years 2005-08 (N = 48). The choice of data to summarize was driven by a compromise between the need for moderate-sized datasets to provide robust estimates of 'characteristic' water quality and the likelihood that data is trending at some sites over the period summarised. (Trends in the NRWQN were recently reported by Ballantine & Davies-Colley 2009).

The Nagels et al. (2000) index has no supporting software for calculating SFU, so we fitted polynomials to the original sub-index consensus data (verifying, graphically, that the polynomial line adequately followed the SFU trend over the full range of NRWQN medians) and used these polynomial equations to estimate SFU for the NRWQN median values. Calculations were carried out in MS EXCEL.

We chose to drop nutrients (nitrogen and phosphorus) from the index calculations since these constituents only affect CR indirectly (via promotion of nuisance algal growth) and then only if all other conditions for growth (other nutrients and other variables such as light, substrate) are suitable. An index for aquatic life would have to include nitrogen and phosphorus of course, but also consider the mole ratio of these elements (in relation to needs of plants) rather than regarding them as acting independently (as may be reasonably assumed for other water quality variables). We also chose to drop pH from the calculations since pH is almost never an issue for CR in larger rivers (in the absence of gross industrial or mining pollution) owing to buffering by the carbonate system (Davies-Colley & Wilcock 2004). No data is available in the NRWQN on water colour, so Munsell hue in the CR index could not be examined. Finally we chose to drop turbidity from the index because this variable is redundant given visual clarity (to which it is strongly – inversely – correlated, Smith et al. 1997). (In any case, as Nagels et al. 2001 pointed out, the turbidity sub-index curve is inconsistent with that for visual clarity.) This leaves just E. coli and visual clarity as the key variables affecting SFU for contact recreation.

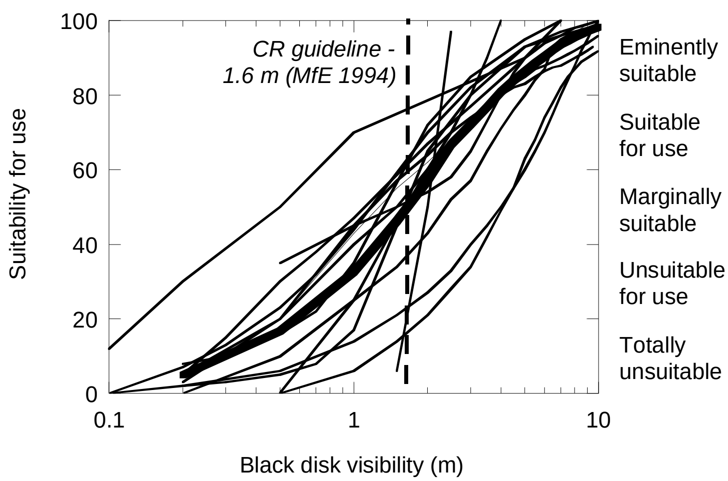

Figure 1. Suitability for use (SFU) curves for visual clarity in the water quality index.
Developed by Nagels et al. (2000) after Davies-Colley & Willcock 2004). The MfE (1994) guideline for contact recreation is shown as a dashed vertical line at 1.6 m.

4. Results

Table 1 (Appendix 1) lists the four-year medians of the two key variables affecting contact recreation at NRWQN sites, together with corresponding SFU values. The rivers are listed in Table 1 from ‘most suitable’ to ‘least suitable’ in terms of the overall CR index value – that is, the lower of the two sub-index values for each contributing variable. The highest-ranked river is the Motueka River at the Gorge (NN2) which is the clearest river in the NRWQN and has very low faecal pollution, although several other rivers are also highly suitable such as (unsurprisingly) the Waikato close to its source in Lake Taupo. The lowest ranked river is the Waipaoa at Kanakanaia (site GS1) owing to its extremely low visual clarity (median = 11 cm), although several other rivers are very unsuitable such as the Mataura (Site DN5) in its lower reaches owing to high faecal pollution.

Consistent with the SFU scale in Figure 1, rivers with (overall) index values for contact recreation <40 are identified as “unsuitable” for contact recreation, and rivers with CR index values greater >60 are considered “suitable”, with intermediate rivers identified as “marginally suitable” (Table 1). There are 30 NRWQN sites in the “unsuitable” (orange shading of the final two columns) or “totally unsuitable” (rose shading) categories with CR index <40. Another 27 rivers fall into the “marginally suitable” category (CR index values ranging from 40-60; yellow shading), while the remaining 20 rivers are “suitable” (turquoise shading) or ”eminently suitable” (blue shading) with CR index >60.

In several river systems with multiple NRWQN sites, suitability-for-use for contact recreation declines moving downstream. For example, the Ngaruroro River at Kuripapango (Site HV4) in Kaimanawa Forest Park ranks 3rd, but this river falls to 46th at Chesterthorpe (Site HV3) near the river mouth where it enters Hawke Bay. Most spectacular of these downstream declines, the Waikato River ranks 2nd at Reids Farm (Site RO6), not far below its source in Lake Taupo, but has dropped to 50th as it flows through Hamilton (Site HM3) and further to 64th at Rangiriri (Site HM4) in its lower reaches.

The table identifies, in each case, the variable that most limits contact recreation. Visual clarity is more often limiting of contact recreation than faecal pollution. For example, of the 30 “unsuitable” or “totally unsuitable” rivers, 22 (nearly 3/4) are limited by low visual clarity, while the remaining 8 rivers are limited by faecal pollution indicated by high median *E. coli* values. Of the “marginally suitable” rivers, 17 are limited by (moderately low) visibility and 10 by (fairly high) *E. coli.*

5. Discussion

In this pilot study we applied an existing water quality index for contact recreation (CR) to characteristic (median) values of water quality variables at NRWQN sites, rather than to data for individual sampling occasions. In future, (when software is available to support index calculations) it may be useful to calculate SFU for individual water samples, so as to construct a time series from which to estimate proportion of time a particular monitoring site is good, bad, or indifferent for a particular use such as contact recreation – and identify the reasons for unsuitability. This would be a valuable further development of the approach, because use of median values, while 'indicative', gives no useful information as regards individual rivers at different states of flow.

Faecal pollution at NRWQN sites, indicated by *E. coli*, is strongly correlated (Rs = 0.80) with proportion of catchment area in pasture (Davies-Colley 2009), which in turn suggests that livestock farming dominates faecal pollution at the national scale. That this faecal pollution constrains contact recreation in some of our rivers (as well as shellfish harvest and contact recreation in downstream waters such as lakes, estuaries and coastal waters) points towards the importance of stream fencing to deny livestock access and riparian planting to reduce faecal microbial runoff (Collins et al. 2007).

Visual clarity is rather less strongly (but still highly significantly) related to percentage pasture in catchments (Rs = –0.45, Davies-Colley 2009), probably because land use typically interacts with geological factors in determining river water clarity. The correlation is weakened in as much as some rivers are turbid for partly or wholly natural reasons. For example, the Waimakariri at two sites (ranked 72nd and 76th in Table 1) has low visibility owing to finely-ground sediment ('glacial flour') from its glaciated headwaters. For most other turbid rivers in Table 1, the low visibility can be attributed to the interaction of land use and geology. For example, the Waipaoa River, ranked 77th in Table 1, has very low visual clarity because of widespread pastoral farming on highly erodible mudstone rocks. The Waipa River (ranked 74th at its Whatawhata site in Table 1) and Waitara River (ranked 73rd) are turbid because of widespread disturbance of clay-rich soils in their catchments by livestock (which also produce fairly high *E. coli* concentrations – Table 1).

We expected that faecal pollution might most constrain contact recreation in New Zealand rivers, so the finding that visual clarity is more often limiting is somewhat surprising. However, it is interesting to note that median *E. coli* and median visual clarity of rivers in the NRWQN are moderately (inversely) correlated (Rs = –0.64) showing that turbid rivers tend also to be faecally polluted rivers. Pastoral farming degrades recreational quality of waters by mobilising both *E. coli* and fine sediment.

The question arises, how does our league table (Table 1), based on application of a published WQI, compare with the MfE (2009) league table for CR? There is a moderate overall correlation of our ranking and the MfE league table (Rs = 0.79), but appreciable differences in the ranking of some individual rivers. The MfE table identifies the Motueka River at the Gorge (Site NN2) as the most suitable river (as do we – Table 1), and Waitara at Bertrand Road (WA1) as least suitable (this is ranked 73rd in Table 1). The greatest discrepancy in ranking is for the Makaroro River at Burnt Bridge (HV1), which MfE rank 4th but we rank 37th. The main differences in overall rankings result from the different index construction underlying the two league tables. An index that assesses the underlying suitability-for-use of the water, like that applied here, is to be preferred.

6. Conclusions

An existing water quality index (WQI) for contact recreation (CR) has been applied to characteristic (median) water quality conditions at 77 river sites in the NRWQN. The resulting overall CR index values enable preparation of a 'league table' (ranking the river sites from 'best' to 'worst') in terms of contact recreation. Major take-home findings from this analysis are as follows:

- Visual clarity and faecal pollution (indicated by *E. coli* bacteria) are the two variables most limiting of contact recreation in NZ rivers.
- More than a third (30 out of 77 or 39%) of NRWQN sites are rated "unsuitable" for CR at their median condition – about 3/4 of these owing to poor visual clarity and the remainder owing to faecal pollution.
- A further 25 sites are rated "marginally suitable", with the remaining 22 sites considered "suitable" or "eminently suitable" (reflecting relatively high visual clarity and low faecal pollution).
- The most suitable river in the NRWQN for contact recreation is the (very clear) Motueka at the Gorge, although several other rivers are almost as good overall. The least suitable river is the Waipaoa at Kanakanaia (with very poor visual clarity reflecting livestock farming interacting with unfavourable mudstone geology), although several other rivers are almost as unsuitable, such as the Mataura which is severely faecally polluted in its lower reaches.
- Low visual clarity of river waters usually reflects interaction of land use and geology or soil type. However low visibility in alpine rivers is predominantly natural, as with the (glacial-flour laden) Waimakariri River at two NRWQN sites.
- Pastoral farming land use degrades recreational water quality by mobilising both fine sediment (that degrades clarity) and faecal microbes from livestock.

Further development of water quality indexing seems desirable so as to convert water quality data, which is difficult to interpret even for specialists, into information that informs policy-makers and the public. In particular, it would be valuable to apply the CR index to all states of flow at river sites so as to categorise proportions of time (overall or by season) when particular rivers are good, bad, or indifferent for contact recreation. Furthermore, development of WQIs would be valuable for categories of water use (water values) other than contact recreation under New Zealand conditions, notably for aquatic habitat.

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Appendix 1. Ranking NRQWN rivers by their contact recreational index value.

Ranking NRWQN rivers by their contact recreational index value. Comparison is made with the MfE CR ranking. Shading of the two final columns (giving overall index value and limiting variable) indicates categories of suitability for use for contact recreation as follows: Blue – 'Eminently suitable'; Turquoise – 'Suitable'; Yellow – 'Marginally suitable'; Orange – 'Unsuitable'; Rose – 'Highly unsuitable'.

Rank	MfE	Site code	River name	Clar	Clar-SFU	EcMOD	Ec-SFU	Min(SFU)	Reason
1	1	NN2	Motueka @ Gorge	11.49	98.0	1	100.0	98.0	Clar
2	3	RO6	Waikato @ Reids Farm	7.51	93.3	1	100.0	93.3	Clar
3	2	HV4	Ngaruroro @ Kuripapango	6.65	91.7	2	100.0	91.7	Clar
4	5	DN10	Monowai below Gates	6.53	91.5	1	100.0	91.5	Clar
5	16	AX1	Clutha @ Luggate Br.	5.70	89.2	2	100.0	89.2	Clar
6	7	RO1	Tarawera @ Lake outlet	5.35	87.9	1	100.0	87.9	Clar
7	13	WN2	Hutt @ Kaitoke	4.93	86.2	4	96.9	86.2	Clar
8	29	WN5	Ruramahanga @ SH2	4.35	83.2	13	83.3	83.2	Clar
9	6	TK5	Hakatakamea above MH Br.	4.10	81.6	13	83.3	81.6	Clar
10	8	NN1	Motueka @ Woodstock	4.37	83.3	16	80.3	80.3	E. coli
11	11	GY3	Grey @ Waipuna	3.62	78.0	11	85.9	78.0	Clar
12	10	TK4	Waitaki @ Kurow	3.44	76.4	1	100.0	76.4	Clar
13	17	TU2	Tongariro @ Turangi	3.14	73.5	16	80.3	73.5	Clar
14		NN3	Wairau @ Dip Flat	2.84	70.0	2	100.0	70.0	Clar
15	15	HV6	Mohaka @ Glenfalls	2.83	69.8	26	71.4	69.8	Clar
16	23	AX4	Clutha @ Millers Flat	2.73	68.6	11	86.2	68.6	Clar
17	26	GY4	Haast @ Roaring Billy	2.42	64.2	3	98.7	64.2	Clar
18	18	TK3	Opuha @ Skipton Br.	2.41	64.1	33	66.9	64.1	Clar
19	47	HM6	Ohinemuri @ Karangahake	2.59	66.8	43	62.0	62.0	E. coli
20	21	CH1	Hurunui @ Mandamus	2.18	60.3	9	89.4	60.3	Clar
21	28	NN4	Wairau @ Tuamarina	2.12	59.3	6	93.1	59.3	Clar
22	36	GY2	Grey @ Dobson	2.12	59.2	37	64.8	59.2	Clar
23	32	TK6	Waitaki @ SH1 Br.	2.09	58.8	32	67.8	58.8	Clar
24	22	DN7	Oreti @ Lumsden	4.25	82.6	50	58.6	58.6	E. coli
25	33	AX2	Kawarau @ Chards	2.06	58.2	3	98.7	58.2	Clar
26	14	TK1	Opihi @ Waipopo	4.04	81.2	52	57.9	57.9	E. coli
27	34	RO3	Rangitaiki @ Murapara	2.01	57.2	20	76.2	57.2	Clar
28	43	CH2	Hurunui @ SH1 Br.	1.88	54.8	65	53.5	53.5	E. coli
29	63	DN6	Mataura @ Parawa	2.29	62.2	66	53.0	53.0	E. coli
30	25	RO4	Whirinaki @ Galatea	1.76	52.4	42	62.3	52.4	Clar
31	30	HV2	Tukituki @ Red Br.	1.68	50.7	34	66.5	50.7	Clar
32	59	GY1	Buller @ Te Kuha	1.68	50.6	20	76.2	50.6	Clar
33	49	WN4	Ruamahanga @ Wardells	1.87	54.6	75	50.3	50.3	E. coli
34	39	WH1	Waipapa @ Forest Ranger	2.26	61.6	82	48.7	48.7	E. coli
35	9	NN5	Buller @ Longford	1.57	48.3	23	73.8	48.3	Clar
36	58	DN9	Waiau @ Tuatapere	1.87	54.6	88	47.2	47.2	E. coli
37	4	HV1	Makaroro @ Burnt Br.	1.50	46.6	12	84.4	46.6	Clar
38	20	TK2	Opihi @ Rockwood	2.18	60.3	91	46.5	46.5	E. coli
39	45	DN4	Clutha @ Balclutha	1.46	45.5	42	62.4	45.5	Clar
40	65	WN3	Ruamahanga @ Waihenga	1.45	45.3	96	45.4	45.3	Clar
41	40	WA5	Rangitikei @ Mangaweka	1.41	44.4	82	48.7	44.4	Clar

Rank	MfE	Site code	River name	Clar	Clar-SFU	EcMOD	Ec-SFU	Min(SFU)	Reason
42	24	HV5	Mohaka @ Raupunga	1.36	43.2	20	76.7	43.2	Clar
43	12	WA2	Manganui @ SH3	3.83	79.7	108	43.0	43.0	E. coli
44	51	DN8	Oreti @ Riverton HW Br.	1.35	42.9	61	54.8	42.9	Clar
45	37	TU1	Whanganui @ Te Maire	1.31	41.8	91	46.6	41.8	Clar
46	19	HV3	Ngaruroro @ Chesterhope	1.30	41.7	29	69.8	41.7	Clar
47	48	WN1	Hutt @ Boulcott	2.75	68.8	121	40.7	40.7	E. coli
48	35	DN2	Sutton @ SH87	2.31	62.6	129	39.5	39.5	E. coli
49	27	RO5	Rangitaiki @ Te Teko	1.20	39.0	31	68.3	39.0	Clar
50	41	HM3	Waikato @ Hamilton Traffic Br.	1.19	38.6	56	56.6	38.6	Clar
51	52	DN3	Taieri @ Outram	1.14	37.4	44	61.2	37.4	Clar
52	71	WA7	Manawatu @ Weber Rd	1.10	36.2	155	35.9	35.9	E. coli
53	31	GS3	Motu @ Waitangirua	1.69	50.9	158	35.5	35.5	E. coli
54	68	WA3	Waingongoro @ SH45	1.36	43.3	161	35.2	35.2	E. coli
55	53	WH2	Waitangi @ Wakelins	1.46	45.5	167	34.4	34.4	E. coli
56	67	WA9	Manawatu @ Opiki Br.	0.99	33.0	91	46.5	33.0	Clar
57	72	WA8	Manawatu @ Teachers Coll.	0.97	32.4	141	37.7	32.4	Clar
58	75	WA4	Whanganui @ Paetawa	0.96	32.2	105	43.7	32.2	Clar
59	44	DN1	Taieri @ Tiroiti	0.96	32.0	99	44.9	32.0	Clar
60	73	WA6	Rangitikei @ Kakariki	0.86	29.0	124	40.3	29.0	Clar
61	42	GS2	Waikohu @ No. 1 Br.	1.70	51.0	225	28.9	28.9	E. coli
62	61	GS4	Motu @ Houpoto	0.85	28.7	21	75.8	28.7	Clar
63	62	RO2	Tarawera @ Awakaponga	0.81	27.2	86	47.6	27.2	Clar
64	56	HM4	Waikato @ Rangiriri	0.79	26.8	123	40.4	26.8	Clar
65	46	HM1	Waipa @ Otewa	1.49	46.4	276	25.3	25.3	E. coli
66	70	HM5	Waihou @ Te Aroha	0.69	23.2	238	27.8	23.2	Clar
67	66	AK2	Rangitopuni @ Walkers	0.68	22.9	236	28.0	22.9	Clar
68	57	AK1	Hoteo @ Gubbs	0.66	22.3	126	40.0	22.3	Clar
69	54	WH4	Wairu @ Purua	0.65	22.1	99	44.9	22.1	Clar
70	64	WH3	Mangakahia @ Titoki Br.	0.65	22.0	249	27.1	22.0	Clar
71	50	AX3	Shotover @ Bowens Peak	0.63	21.1	2	100.0	21.1	Clar
72	38	CH3	Waimakariri @ Gorge	0.60	20.2	67	52.8	20.2	Clar
73	76	WA1	Waitara @ Bertrand Rd	0.59	19.7	344	21.6	19.7	Clar
74	74	HM2	Waipa @ Whatawhata	0.50	16.5	273	25.5	16.5	Clar
75	60	DN5	Mataura @ Seaward Down	0.90	30.1	488	16.2	16.2	E. coli
76	69	CH4	Waimakariri above old HW Br.	0.29	8.4	36	65.2	8.4	Clar
77	55	GS1	Waipoa @ Kanakanaia	0.11	0.7	126	40.0	0.7	Clar