LOWER MAITAI RIVER BACTERIOLOGICAL MONITORING RESULTS — A REVIEW

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by

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LOWER MAITAI RIVER BACTERIOLOGICAL MONITORING RESULTS — A REVIEW

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SUMMARY

Routine monitoring of the Lower Maitai River between July 06 and February 07, showed elevated *Escherichia coli* counts at the Collingwood Street bridge site. Intensive sampling on 22/12/06 and 22/1/07 neither confirmed nor explained these results, but the 22/1/07 sampling revealed a diurnal pattern in counts around the river mouth.

Data analyses showed that there were positive correlations between the Collingwood Street bridge *E. coli* counts and those in six parallel samples collected at the Trafalgar Street bridge. They also showed that, at most sampling sites up to the Normanby Bridge, there was a negative correlation between *E. coli* counts and both tidal height (which happened to peak around solar noon) and cumulative solar radiation.

A brief literature review indicates that there is no substantial evidence that *E. coli* can grow in sunlight-exposed natural waters in temperate regions. Thus, growth in the Maitai River may reasonably be ruled out as a source of the *E. coli*.

There is only equivocal evidence for *E. coli* growth in sediments, but substantial evidence of natural deposition and accumulation, to higher concentrations than in the overlying water. Thus, disturbed sediments may be contributing to *E. coli* counts in the Maitai River.

Possible reasons for the Collingwood Street bridge results could include:

1. A saline wedge transporting *E. coli* upstream, either from water in the Nelson Haven or from remobilised bottom sediments.
2. An as yet undetected discharge upstream of the bridge.
3. A contaminated groundwater seepage or spring upstream of the bridge.
4. Remobilisation of *E. coli* from sediments by an eddy or riffle upstream of the bridge.

Better identification of the source(s) of the contamination at the Collingwood Street bridge site is required before meaningful amelioration could be considered. Actions to identify the contamination source(s) could include one or more of the following:

1. A re-examination of the routine monitoring data for tidal patterns in *E. coli* counts.
2. A conductivity survey below the bridge to determine whether a saline wedge is present.
3. Parallel turbidity measurements to gauge the sediment contribution to *E. coli* counts.
4. The inclusion of *E. coli* counts in microbial monitoring of the Nelson Haven.
5. Sampling of river sediments downstream of the bridge, to determine *E. coli* levels.
6. A detailed river bank inspection for unauthorised discharges or drains.
7. A river gauging to indicate possible groundwater inflows in the vicinity of the bridge.
8. A one-off survey for one or more specific faecal source identifiers.

1. INTRODUCTION

The Nelson City Council (NCC; Mr Paul Sheldon, Environmental Monitoring Co-ordinator) has sought advice from ESR, through the Envirolink Fund, on possible reasons for, and microbial issues related to, elevated *Escherichia coli* counts at sampling sites in the lower reaches of the Maitai River (See Appendix 1).

Escherichia coli (*E. coli*) is an enteric bacterium; i.e., it normally grows only in the intestinal tract of humans and animals, and is present in their faeces. Most *E. coli* strains are harmless to humans, but the presence of this bacterium in water indicates faecal contamination, and the possible presence of other enteric microbes (bacteria, protozoans, and viruses) that cause gastrointestinal diseases. In general, the higher the *E. coli* count in the water, the greater the disease risk from consumption or contact recreation.

The Ministry for the Environment's New Zealand Microbiological Water Quality Guidelines (MfE, 2003) recommend three "alert and action levels" for *E. coli* counts in freshwater: **Acceptable/Green Mode** (no single sample > 260/100 mL); **Alert/Amber Mode** (a single sample > 260/100 mL); **Action/Red Mode** (a single sample > 550/100 mL). Although most of the samples collected from the lower Maitai River reaches (Plates 1 and 2) between July 06 and February 07 (a total of 20 samplings, although not all sites were sampled) were in the Green Mode, half of the samples collected from the Collingwood Street bridge site tended to be in the Amber and Red Modes (Table 1; Figure 1). Elevated counts were also recorded further downstream (at the Trafalgar Street bridge) on one occasion (Table 1; Figure 1).

The Red Mode action recommendations include the erection of warning signs, informing the public through the media, the undertaking of a sanitary survey, and a report to identify sources of contamination. Two intensive samplings of the lower river reaches by NCC — on 22/12/06 and 22/1/07 (Table 2; Figures 2 and 3) — neither confirmed nor explained the elevated Collingwood Street bridge counts. However, the 22/1/07 sampling revealed a strong diurnal pattern in *E. coli* counts around the river mouth and Saltwater Creek.

This report contributes to the "sanitary survey and report" recommendation in the MfE Guidelines. ESR was requested to undertake a literature survey (in particular, to address the question of whether elevated counts of *E. coli* be explained by growth of this indicator in the river system), undertake a basic analysis of the relevant survey data, and suggest possible sources of the elevated counts at the Collingwood Street bridge site (Appendix 1; P. Sheldon, NCC, pers. comm.).

2. SURVIVAL AND POSSIBLE GROWTH OF *E. COLI* IN SURFACE WATERS AND SEDIMENTS — A BRIEF REVIEW

2.1 Natural Surface Waters

A key assumption associated with the use of bacterial indicators is that they do not grow outside the gastrointestinal tract of warm-blooded animals. This assumption is widely considered to hold true for *E. coli* in natural waters. Although there is some evidence, reviewed by Winfield and Groisman (2003), that replication of *E. coli* may occur in nutrient-rich tropical waters, many of the studies purporting to show this replication have involved the use of microcosms from which sunlight was excluded.

McLellan et al. (2001) produced indirect evidence from clonal isolates that some non-*E. coli* faecal coliforms, such as *Citrobacter*, *Klebsiella*, and *Enterobacter* can replicate in temperate waters. However, there appears to be no published evidence of *E. coli* growth in sunlight-exposed waters in temperate regions.

In contrast, there is substantial published evidence of (usually rapid), post-discharge inactivation of *E. coli* in natural surface waters. The principal inactivating mechanism in sea and river water is solar radiation (Gameson, 1984; Davies-Colley et al., 1994; Sinton et al., 1994, 1999, 2002; Sinton, 2005). Temperature, pH, and grazing by natural microbiota contribute to inactivation (Sinton, 2005), but the main synergistic interaction is between sunlight and salinity. Increasing salinity significantly increases sunlight inactivation of enteric indicators, including faecal coliforms, *E. coli*, and enterococci (Sinton et al., 2002). On a cloudless midsummer day, in shallow seawater (less than 1 m depth), *E. coli* counts can be reduced by up to 5 Logs in 8 hours (Sinton et al., 1994, 1999, 2002). The equivalent reduction in fresh river water is up to 3 Logs (Sinton et al., 2002).

In short, with respect the lower Maitai River reaches, it can be reasonably assumed that: (1) *E. coli* cells are present there as a result of contamination from external faecal sources — both resuspended sediment (see below) and recent run-off, (2) they are being continuously inactivated by sunlight, and (3) growth in the river water itself can be discounted as a cause of the counts recorded at the Collingwood Street bridge.

2.2 Sediments

Unattached bacteria sink in a water column at rates that depend on the specific gravities of the cells, water turbulence, and the degree of motility (Jassby, 1975; Pedros-Alio et al., 1989). In most natural waters, turbulence ensures that there is no significant sedimentation of individual cells. However, it appears that a high proportion (possibly around 50%) of bacteria in effluents (and probably in animal faeces) are attached to particles (Mitchell and Chamberlin, 1975), thereby enhancing their deposition rates.

Particle association and deposition concentrates enteric bacteria in bottom sediments, with the result that they are present there at far higher counts than in the overlying water, and persist far longer (e.g., Shiaris et al., 1987; Ashbolt et al., 1993; Davies et al., 1995; Wheeler Alm et al., 2003). Most importantly, bacteria in sediments are protected from sunlight, but other factors enhancing their survival include protection from motile predators and grazers, and the presence of accumulated organic matter, which may act as a nutrient source (Milne et al., 1989; Gauthier and LeRudulier, 1990; Ghoul et al., 1990).

Although sediments undoubtedly accumulate enteric bacteria, the evidence that they grow there is equivocal. Several studies have suggested that some enterococcus genotypes may replicate in warm marine and estuarine sediments (Jeng et al., 2005; V. Harwood, University of South Florida, pers. comm.). Indirect evidence for the growth of *E. coli* in sediments has also been presented by Kon et al. (2007), who found the same or similar genetic fingerprints in *E. coli* isolates from the same sampling location in beach sands, whereas isolates from different locations showed different patterns. However, most studies purporting to show growth of faecal coliforms and *E. coli* in sediments have been laboratory-based, involving manipulation of nutrients (Gerba and McLeod, 1976; Ghoul et al., 1990; Byappanahalli et al., 2006) or artificial suppression of natural microbiota (Davies et al., 1995).

Enteric bacterial counts in New Zealand river waters tend to increase as a result of sediment scouring by flood events (Muirhead et al., 2004) and disturbance by stock and human activities (Davies-Colley et al, 2004). The role of sediments in replenishing the supply of faecal microbes in river water during periods of low flow is poorly understood, but current studies suggest that, under these conditions, there is very little transfer of enteric microbes from interstitial water in the sediment to the overlying water column (unpublished data, ESR, Christchurch).

In short, with respect to the Maitai River system, there is substantial evidence from the literature to suggest that the river sediments will constitute a significant reservoir for *E. coli*. However, although some replication is possible, accumulation by natural deposition means that it is not necessary to invoke growth to explain their presence there. In addition, remobilisation of these microbes will probably require some form of turbulence or disturbance.

3. ANALYSIS OF THE ROUTINE SAMPLING RESULTS (JULY 06 – FEBRUARY 07)

The weekly and twice-weekly sampling results (20 samplings between July 06 and February 07) revealed significantly higher counts in the lower river reaches (Figure 1). Not all sites were sampled on all occasions, so the results from the six dates on which parallel samples were collected from the Trafalgar Street bridge, Collingwood Street bridge, Halifax Street bridge, and the Normanby Bridge were compared. This comparison showed that counts between the Trafalgar and Collingwood Street bridges were strongly correlated (p = 0.0001), but that there were no other significant relationships between these four sampling sites.

This suggests that whatever is affecting the *E. coli* counts at Collingwood Street is also affecting them lower in the river, but has little or no effect on counts further upstream. The samples in the routine monitoring programme were collected at different stages in the tidal cycle. If the *E. coli* counts are influenced by the tide, this may explain the high variation in counts at the Collingwood and Trafalgar Street bridge sites.

4. ANALYSIS OF THE INTENSIVE SAMPLING RESULTS (22/12/06 AND 22/1/07)

Simple regression analyses were performed on the intensive sampling data from 22/12/06 and 22/1/07. The *E. coli* counts were compared to the time (during daylight hours, on 22/12/06 and 22/1/07), tidal height (on 22/12/06 and 22/1/07), and cumulative solar radiation (on 22/1/07 only). One outlier was removed from these analyses — a count of 1,200 *E. coli* per 100 mL at 12:00 noon, at the Halifax Street footbridge site, on 22/12/06 (Table 2; Figure 2). The analyses make no allowance for any lag in the tidal height between sites. The results are presented in Table 3.

With two exceptions (the river mouth and in Saltwater Creek on 22/1/07), there was an overall decrease (a negative k value) in counts throughout the day at all sites on both sampling occasions.

With two exceptions, *E. coli* counts were negatively correlated with tidal height on both sampling occasions; i.e., the higher the tide, the lower the *E. coli* counts. This effect appeared to be most pronounced in the lower river reaches on 22/1/07 (the Maitai River Mouth, Saltwater Creek and upstream of Saltwater Creek).

All but one of the *E. coli* counts were also negatively correlated with the cumulative solar radiation level over the hour prior to the sampling time (i.e. counts tended to be lower around solar noon). The exception was the Shakespeare Walk site.

Although the intensive samplings revealed a strong association with tide, possibly acting synergistically with solar radiation around the river mouth (see below), they neither confirmed nor explained the elevated counts at the Trafalgar and Collingwood Street bridges.

5. THE EFFECTS OF SOLAR RADIATION AND TIDE

The two variables which were most likely to have influenced counts on 22/12/06 and 22/1/07 were sunlight and tide. Unfortunately, there were no marked similarities between the results from the two sampling occasions, particularly in the lower river reaches — the river mouth, Saltwater Creek and (to a lesser extent) upstream of Saltwater Creek. Overall, the 22/1/07 results demonstrate the strongest relationship with sunlight and tidal height (Table 1).

A correlation (positive or negative) does not necessarily imply causality. In addition, the tidal height coincided with solar radiation levels on both sampling days (i.e., high tide happened to be around solar noon), which makes it difficult to distinguish between their possible effects on the *E. coli* counts. A negative correlation with time may also simply indicate the effect of cumulative global solar radiation ("insolation" or sunlight "dose') throughout the day.

The local solar radiation record is available for 22 January 07, and is presented in Figure 4. No equivalent data are available for 22 December 2006, although 11.6 sunshine hours were reported from nearby Stoke, indicating a clear, sunny day (P. Sheldon, NCC, pers. comm.).

Negative correlations with both time and solar radiation were recorded at the uppermost site (Normanby Bridge) where the tidal effect is assumed to be the least. This suggests that the inactivating effects of solar radiation are contributing to the observed diurnal variation in *E. coli* counts.

Table 1 and Figure 3 also show that the greatest tidal effect was, as would be expected, at the lower sites (the river mouth and Saltwater Creek). The tide is most likely to have influenced *E. coli* counts at these sites in three ways:

1. If the incoming tide was low in *E. coli* concentrations, it would have reduced counts through dilution.

2. If the incoming tide significantly increased salinity levels, it would have increased sunlight inactivation of the *E. coli* cells.

3. If the outgoing tide remobilised the sediments in the lower river reaches, it may have increased *E. coli* counts at the beginning and end of the day.

The salinity profile of the lower river reaches is unknown. However, the river is tidal up as far as the Collingwood Street bridge on a neap tide, and the Normanby Bridge on a spring tide. Saltwater crabs inhabit the area up to Collingwood Street bridge, suggesting regular saltwater exchange. Conductivity changes have been noted at the Halifax Street footbridge, suggesting salinity changes may extend that far upstream (P. Sheldon, NCC, pers. comm.).

Thus, assuming a reasonably constant input to the river, the variations in *E. coli* counts are consistent with the presumed effects of sunlight inactivation of enteric microbes in the lower river reaches, being highest at solar noon and lowest at morning and night. There is also an overall decrease in counts throughout the day. Although not consistent between the two intensive sampling occasions, the tidal height also appears to have an effect on counts around the river mouth, possibly acting synergistically with sunlight.

6. THE COLLINGWOOD STREET BRIDGE SITE

Figure 1 shows that between June 06 and February 07, most of the *E. coli* counts recorded at the Collingwood Street bridge were significantly higher than those at sites further upriver. Two samples collected on 22/12/05 (earlier survey; data not presented here) were also reasonably high — 531 and 624/100 mL.

However, the pattern of elevated counts at Collingwood Street encountered in the routine surveys was not evident in the intensive sampling surveys on 22/12/06 and 22/1/07 (Table 2). In fact, 13 of the 14 counts in the intensive samplings were below 550/100 mL (Table 2), as were 13 of the 20 counts in the routine sampling (Table 1). In addition, on 22/12/06, in contrast to the other sites, the counts at the Collingwood Street bridge appeared to rise, rather than fall, with the tidal height (Table 3).

Thus, the Collingwood Street (and possibly the Trafalgar Street) *E. coli* results are an apparent anomaly, and there is no immediately obvious explanation for them. However, four possibilities are listed below:

- **Saline intrusion**: A saline water wedge may move upstream from the Nelson Haven along the river bed, past Trafalgar Street, as far as the Collingwood Street bridge, particularly at periods of low flow and still water around high tide. This phenomenon has apparently been observed (P. Sheldon, NCC, pers. comm.). If this occurs, it would have two possible effects:
    - It would bring estuarine water from the Haven and river mouth area up as far as Collingwood Street. Since the heavier saline water would move along the bottom of the river, it would have the greatest protection from the inactivating effects of sunlight.

      This explanation would require the existence, even periodically, of high *E. coli* counts in the Haven water. However, the Haven monitoring programme is based on enterococci (MfE, 2003) and there appear to be no equivalent *E. coli* data (P. Sheldon, NCC, pers. comm.). The Maitai River itself could be a significant contributor to indicator counts in the Haven, but there may also be an input from seabirds and waterfowl.

- It would remobilise river bed sediments as it moved upstream. As previously noted, these sediments are likely to contain significantly higher *E. coli* counts than the overlying water column.

Although this is considered to be the most likely reason for the Collingwood and Trafalgar Street bridge results, it should be noted that this explanation is not supported by the results from the counts from lower in the river (Figure 3), which tended to *decrease* at high tide. An alternative explanation would therefore be the existence of a salt wedge at low tide, or elsewhere in the tidal cycle.

In addition, to explain the results, it would probably be necessary to assume that the bridge area is the usual upstream limit of any saline wedge; i.e., the point at which the upstream wedge movement is overcome by river flow, and returns downstream in the overlying fresh water.

- **An unauthorised surface discharge or leak**: This could be occurring anywhere between the Collingwood Street bridge and the next upstream sampling site (the Halifax Street footbridge). This would need to be either a reasonably large flow or a concentrated discharge to produce the results regularly observed at the Collingwood and Trafalgar Street bridges, and it seems unlikely that such a input would remain undetected for long.

- **A contaminated groundwater seepage or spring**: This could also be occurring anywhere between Collingwood Street and the Halifax Street footbridge. Unless it was in the form of an above-ground spring, it would be more difficult to detect than a surface discharge. Furthermore, to produce the observed results, the seepage would need to be highly contaminated. The only likely candidate would therefore be a continuously leaking sewer. However, dye testing of local sewer mains has apparently shown no evidence of leakage (P. Sheldon, NCC, pers. comm.).

- **An undetected standing eddy or riffle:** The Collingwood Street bridge samples are collected from the shallow sandbank on the south side of the river, downstream of the bridge. It is possible that this sampling site is in a plume of higher suspended sediment levels, remobilised by an upstream eddy or riffle. However, it is highly unlikely that such a plume would go unnoticed over sequential samplings, or that its effects would extend as far as the Trafalgar Street bridge.

7. POSSIBLE REMEDIAL OR AMELIORATIVE MEASURES

Any fixes will obviously depend on which of the suggested causes above is correct. If the problem is one of saline intrusion, there are probably no cost-effective remedial measures available. If the problem is one of contaminated groundwater re-entry, both detecting the source of the contamination and preventing re-entry would be very difficult. The easiest cause to address (although possibly difficult to locate) would be an unauthorised surface drain or discharge.

8. RECOMMENDATIONS

To better understand the reasons for the elevated *E. coli* counts at the Collingwood and Trafalgar Street bridge sites, one or more of the following actions are recommended:

1. Re-examine the *E. coli* counts at the Collingwood and Trafalgar Street bridges from the routine sampling programme and compare them with the tidal record at the time of sampling. This may provide some insight into the effect of tidal height on the observed counts in the lower river reaches.

2. Determine whether a saline wedge is present during particular phases of the tide by establishing the depth profile of salinity below the Collingwood Street bridge over a complete tidal cycle. A sensitive conductivity meter may be adequate for this purpose.

3. Include parallel turbidity measurements (Nephelometric Turbidity Units — NTUs) and/or total suspended solids (TSS) assays in microbiological surveys of the Lower Maitai River reaches. Elevated turbidities, and/or positive correlations with *E. coli* counts during periods of low rainfall and low flow may indicate remobilisation of river sediments as a result of upstream saline water movement along the river bottom.

4. If the presence of a saltwater wedge is confirmed, include *E. coli* (in addition to enterococci) in microbiological monitoring of the Nelson Haven, and possibly add additional sites in the vicinity of the Maitai River mouth.

5. Sample river sediments downstream of the Collingwood Street bridge to determine whether they contain *E. coli* concentrations high enough to explain, or contribute to, the Collingwood Street bridge counts.

6. Conduct a detailed inspection of both banks of the river between the Collingwood Street bridge and the Halifax Street footbridge to confirm that there are no hitherto unidentified inputs from drains or springs.

7. Undertake river gauging above and below the Collingwood Street bridge site to indicate whether there is any significant groundwater inflow in the vicinity of the bridge.

8. Carry out at least one survey of faecal source identifiers in the Lower Maitai River, including one or more of the following:

   - Fluorescent whitening agents (FWAs). These are "brighteners" in washing powders, and are recognised as reliable indicators of human effluents (Sinton et al., 1998).

   - Faecal sterols. Different faecal sterols can assist in apportioning the contribution of human and animal sources to faecal contamination of waters (Sinton et al. 1998).

   - Molecular markers of human and animal sources, particularly members of the anaerobic *Bacteroidetes* group (Shanks et al., 2006).

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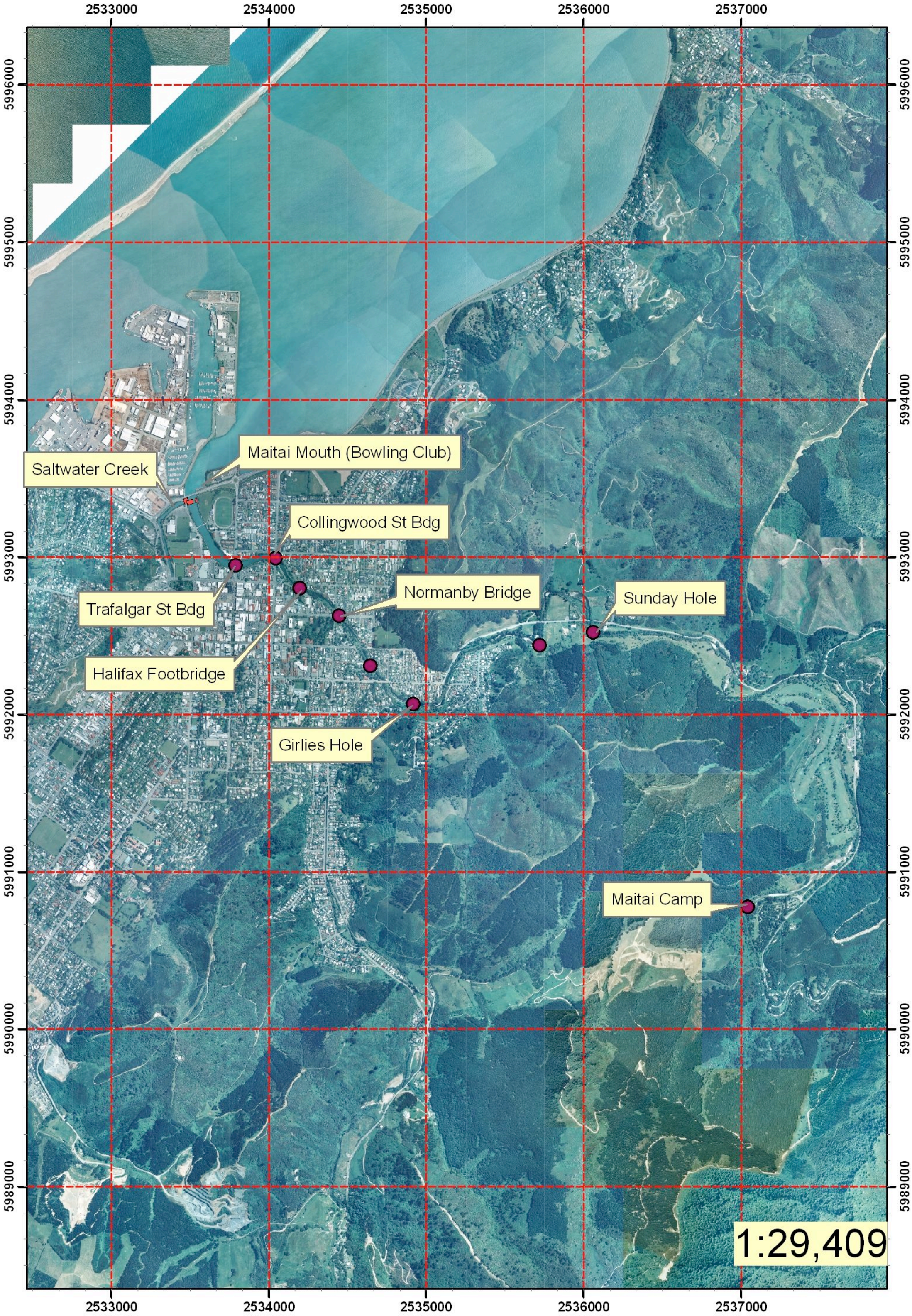


Plate 1: The Maitai River sampling sites (map provided by P. Sheldon, NCC).

Plate 2: The Lower Maitai River sampling sites (map provided by P. Sheldon, NCC).

Table 1: Routine surveillance results, Lower Maitai River (*E. coli* counts per 100 mL).
Green — Acceptable Mode (no single sample > 260/100 mL; Amber — Alert Mode (a single sample > 260/100 mL); Red — Action Mode (a single sample > 550/100mL). Adapted from a spreadsheet supplied by P. Sheldon, NCC.

Sampling date	Trafalgar Street Bridge	Collingwood Street Bridge	Halifax Street Footbridge	Normanby Bridge	Domett Street Bridge	Girlies Hole	Sunday Hole	Maitai Camp	Smiths Ford
Distance (m)*	512	767	1022	1352	1708	2111	3926	7756	11000
7/28/06		10							
8/15/06		30							
9/6/06		5							
10/11/06		99							
11/21/06		697				178	192	99	99
11/28/06		40				40	30	5	
12/5/06		2005				429	254	64	
12/12/06		192				288	20	429	
12/19/06		75				30	64	10	
12/29/06		782		30		75	64	53	
1/5/07		2005		222		178	53	137	53
1/9/07		2005		306		429	137	178	
1/16/07	344	271	111	87	111	99	64	30	
1/18/07	238	192	124	87	150	40	64	40	
1/22/07		288				64	75	271	30
1/25/07	111	192	75	30	53	87	53	10	
2/7/07	150	207	53	40	64	40	40	10	
2/15/07	288	478	178	40	87	87	124	53	
2/21/07		2005		111		10	20	164	
2/28/07	2005	2000	111	99		30	30	99	30

* – From the Maitai River mouth

Table 2: Results of the intensive sampling surveys of the Lower Maitai River on 22/12/06 and 22/1/07 (*E. coli* counts per 100 mL). Adapted from a spreadsheet supplied by P. Sheldon, NCC.

Date and Time	Tide Height (m)	Saltwater Creek	Maitai Mouth	Upstream of Saltwater Creek	Downstream of Trafalgar St Bridge	Upstream of Trafalgar St Bridge	Collingwood St Bridge	Halifax St Footbridge	Normanby Bridge
22/12/06									
6:00	0.7	254	429	504	429	531	384	531	406
8:00	1.7	178	99	478	306	344	364	364	238
10:00	3.25	20	10	20	178	238	384	207	192
12:00	4	75	75	344	40	87	324	1200	207
14:00	3.1	111	222	697	364	222	137	137	192
16:00	1.5	137	124	271	99	150	137	64	192
18:00	0.77	87	64		111	99	178	150	75
22/1/07									
7:00	0.4	1300	364	782	560	324	697	384	344
9:00	1.4	697	344	344	238	222	207	429	697
11:00	3.3	99	124	164	178	306	478	238	207
13:00	4.2	87	53	99	87	271	207	531	192
15:00	3.3	591	429	192	324	164	111	192	87
17:00	1.6	1700	659	99	75	178	124	87	111
19:00	0.5	2000	782	271	111	254	150	178	192

Table 3: Results of regression analyses on the intensive sampling data from 22/12/06 and 22/1/07.

Sampling location	22 December 2006 — 06:00 - 18:00				22 January 2007 — 07:00 - 19:00					
	Counts *vs* Time		Counts *vs* Tidal Height		Counts *vs* Time		Counts *vs* Tidal Height		Counts *vs* Insolation†	
	k (hr^{-1})	R^2	k (m^{-1})	R^2	k (hr^{-1})	R^2	k (m^{-1})	R^2	k (MJ^{-1})	R^2
Maitai River Mouth	-14.9	0.21	-46.3	0.18	+39.1	0.41	-123.6	0.5	-81.5	0.23
Saltwater Creek	-8.7	0.25	-38.1	0.43	+82.1	0.22	-424.6	0.71**	-323.6	0.43
Upstream Saltwater Creek	-2.6	0.002	-40.8	0.05	-35.6	0.41	-105.2	0.44	-124.5	0.64*
Downstream Trafalgar St.	-21.1	0.38	-34.9	0.09	-27.3	0.47	-40.7	0.12	-54.8	0.24
Upstream Trafalgar St.	-30.3	0.70*	-51.0	0.18	-7.9	0.31	-5.1	0.02	-16.2	0.17
Collingwood Street	-23.6	0.76**	+10.3	0.01	-38.8	0.58	-36.4	0.06	-66.1	0.21
Halifax Street Footbridge	-32.4	0.78**	-60.0††	0.21	-24.1	0.43	+25.9	0.06	+0.33	0.00001
Normanby Bridge	-19.4	0.72**	-19.4	0.72**	-31.2	0.42	-50.4	0.13	-62.3	0.21

k = slope of the regression line
Shaded cells are the exceptions to the prevaling slope
† – Cumulative global solar radiation over the previous hour
†† – One outlier from this site (1,200 cfu 100 mL^{-1} at 12:00 noon) was removed for the regression analysis
* – Significant at $p = 0.1$
** – Significant at $p = 0.05$

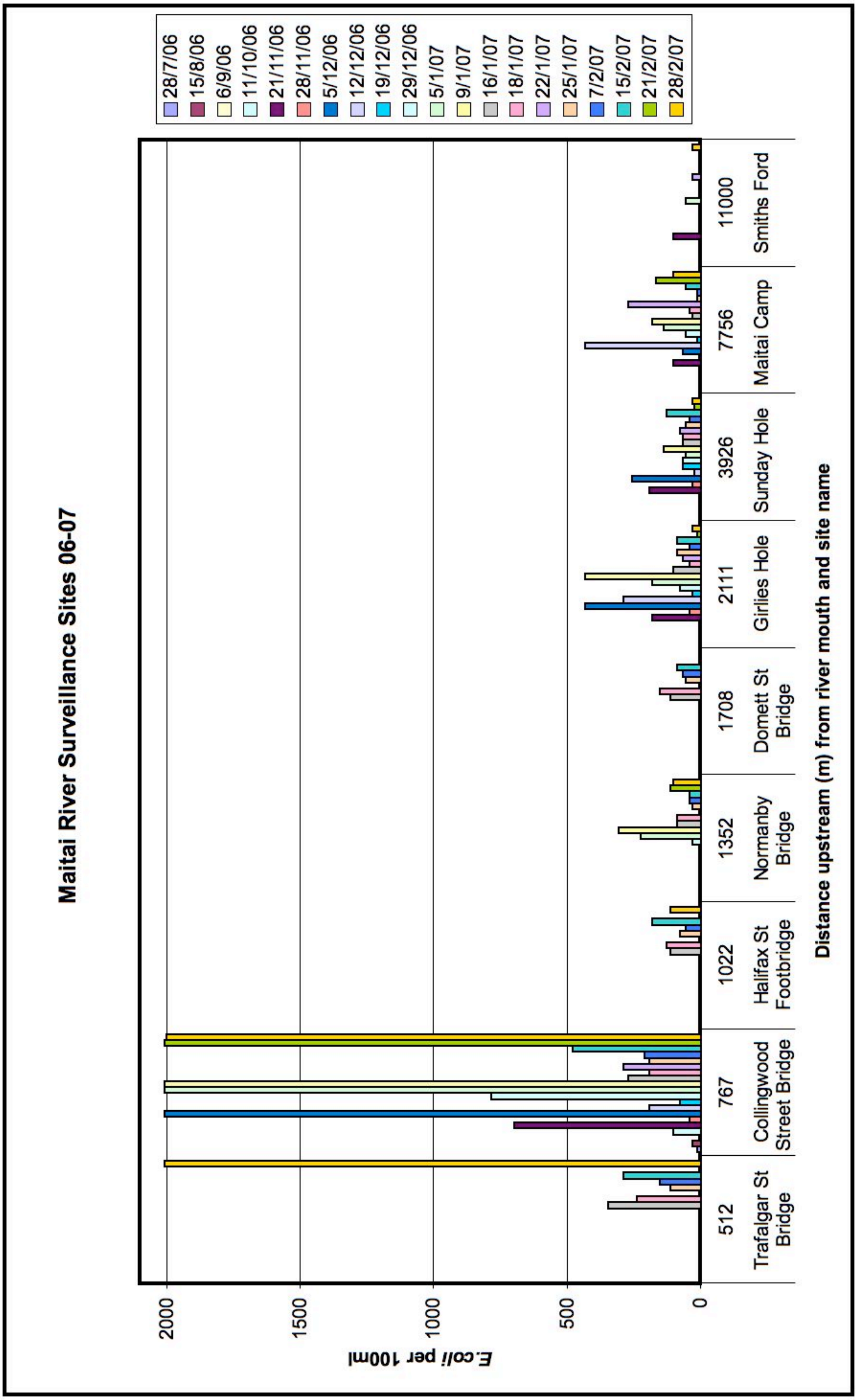
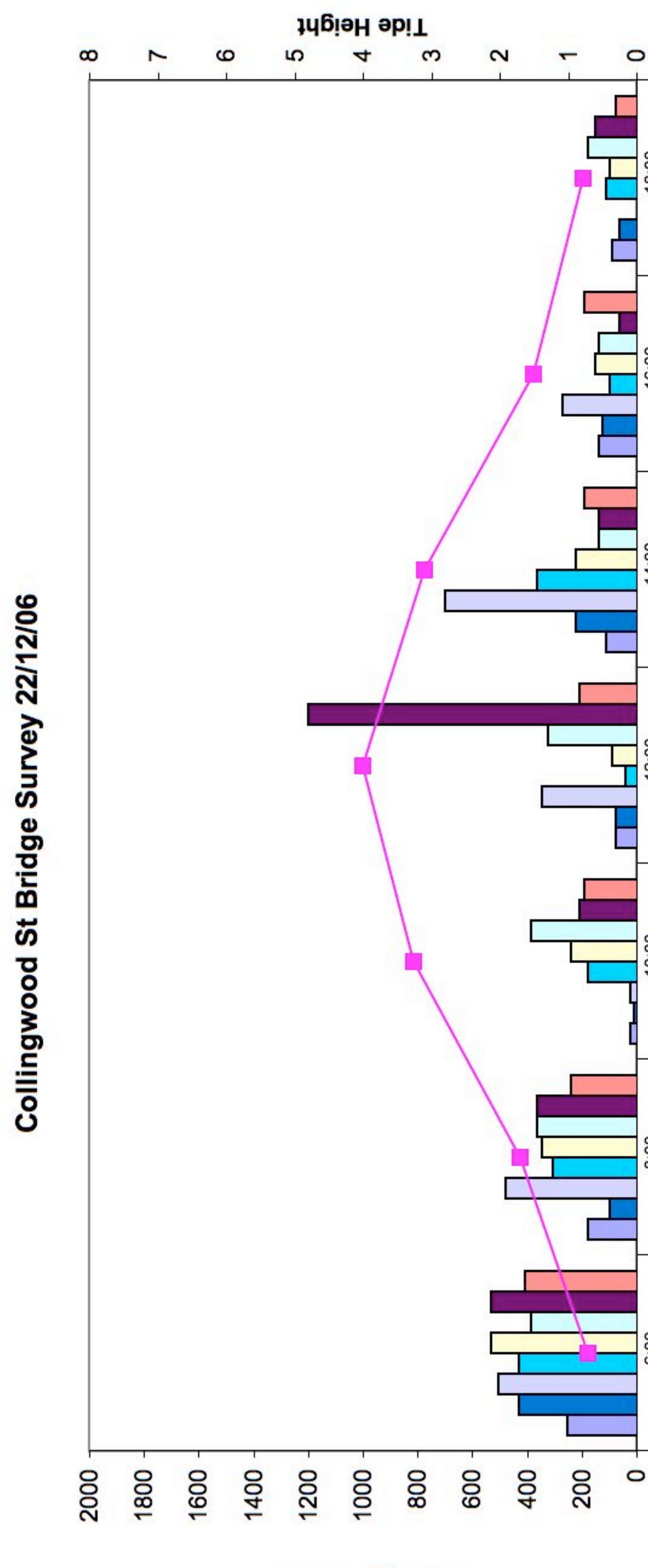
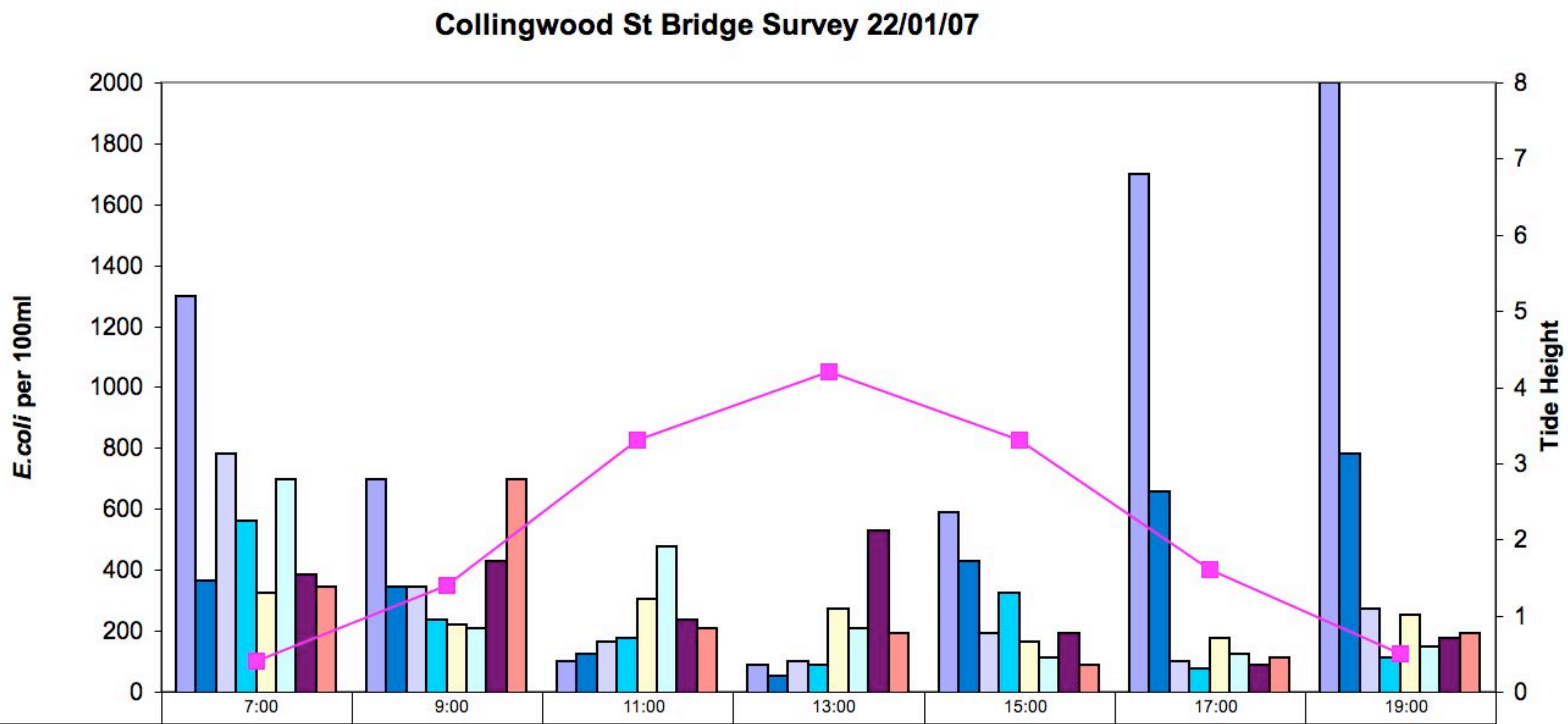


Figure 1: Routine surveillance results, Lower Maitai River (graph supplied by P. Sheldon, NCC).



	6:00	8:00	10:00	12:00	14:00	16:00	18:00
Saltwater Creek	254	178	20	75	111	137	87
Maitai Mouth (Maitai Club)	429	99	10	75	222	124	64
Upstream of Saltwater Ck	504	478	20	344	697	271	
Downstream of Trafalgar St	429	306	178	40	364	99	111
Upstream of Trafalgar St Br	531	344	238	87	222	150	99
Collingwood St Bridge	384	364	384	324	137	137	178
Halifax St Footbridge	531	364	207	1200	137	64	150
Normanby Bridge	406	238	192	207	192	192	75
Tide height	0.7	1.7	3.25	4	3.1	1.5	0.77

Figure 2: Intensive sampling results, Lower Maitai River, 22/12/06 (graph supplied by P. Sheldon, NCC).



	7:00	9:00	11:00	13:00	15:00	17:00	19:00
Saltwater Creek	1300	697	99	87	591	1700	2000
Maitai Mouth (Maitai Club)	364	344	124	53	429	659	782
Upstream of Saltwater Ck	782	344	164	99	192	99	271
Downstream of Trafalgar St	560	238	178	87	324	75	111
Upstream of Trafalgar St Br	324	222	306	271	164	178	254
Collingwood St Bridge	697	207	478	207	111	124	150
Halifax St Footbridge	384	429	238	531	192	87	178
Normanby Bridge	344	697	207	192	87	111	192
Tide height	0.4	1.4	3.3	4.2	3.3	1.6	0.5

Figure 3: Intensive sampling results, Lower Maitai River, 22/1/07 (graph supplied by P. Sheldon, NCC).

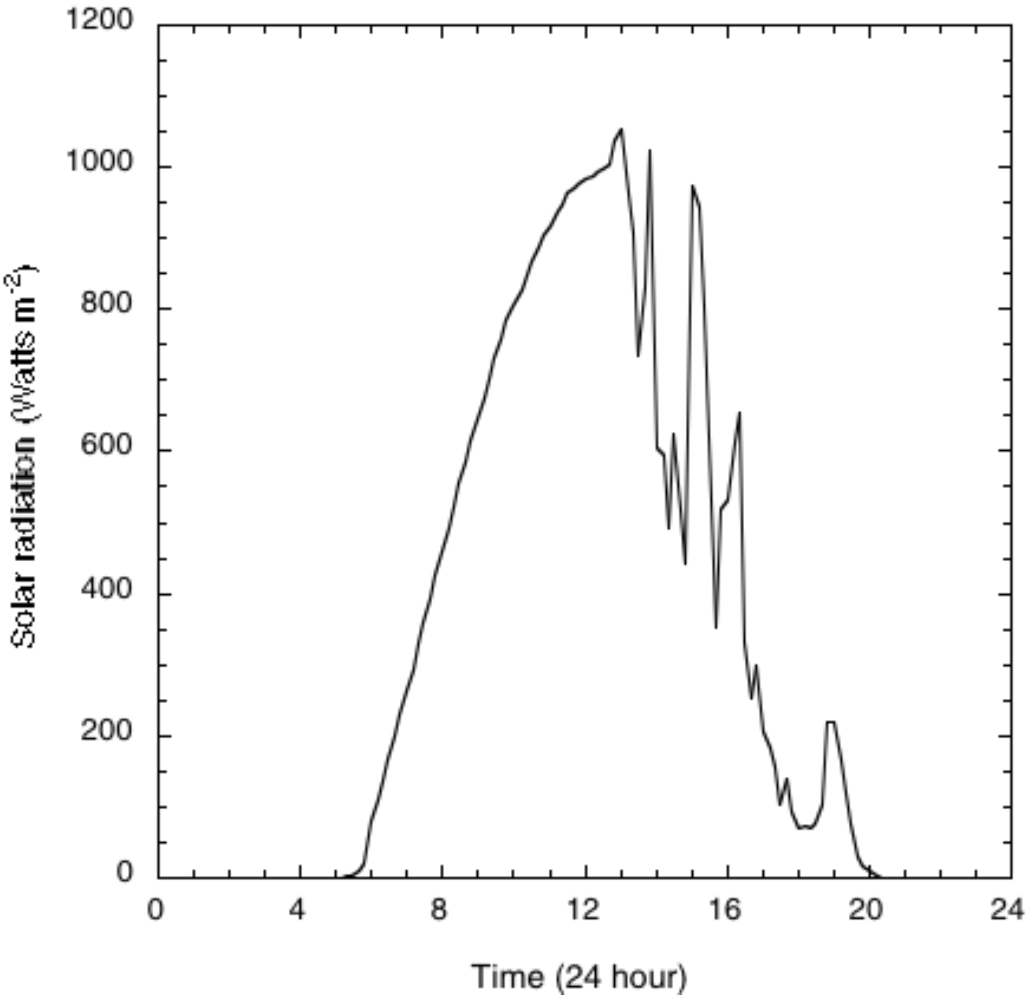


Figure 4: Solar radiation recorded at the Princess Drive met station, Nelson, on 22/1/07.

REFERENCES

Ashbolt, N. J., G. S. Grohmann, and C. Kueh. 1993. Significance of specific bacterial pathogens in the assessment of polluted receiving waters of Sydney. Water Science and Technology 27:449–452.

Byappanahalli, M. N., Whitman, R. L., Shively, D. A., Evert Ting, W. T., Tseng, C. C., and Nevers, M. D. 2006: Seasonal persistence and population characteristics of Escherichia coli and enterococci in deep backshore sand of two freshwater beaches. Journal of Water and Heath 4: 313-320.

Davies, C. M., Long, J. A. H., Donald, M., and Ashbolt, N. J. 1995: Survival of Fecal Microorganisms in Marine and Freshwater Sediments Applied and Environmental Microbiology 61: 1888–1896.

Davies-Colley, R. J., Bell, R. G., and Donnison, A. M. 1994: Sunlight inactivation of enterococci and fecal coliforms within sewage effluent diluted in seawater. Applied and Environmental Microbiology 6: 2049-2058.

Davies-Colley, R. J., Nagels, J. W., Smith, R. A., Young, R. G., and Phillips, C. J. 2004: Water quality impact of a dairy cow herd crossing a stream. New Zealand Journal of Marine and Freshwater Research 38: 569–576.

Gameson, A. L. H. 1984: Bacterial mortality, Part 1. In Investigations of sewage discharges to some British coastal waters. WRc Technical Report TR 201, WRc Environment, Medmenham, U.K. TR 201, WRc Environment, Medmenham, U.K.

Gauthier, M. J. and Le Rudulier, D. 1990: Survival in seawater of *Escherichia coli* cells grown in marine sediments containing glycine betaine. Applied and Environmental Microbiology 56: 2915-2918.

Gerba, C. P. and McLeod, J. S. 1976: Effect of sediments on the survival of *Escherichia coli* in marine waters. Applied and Environmental Microbiology 32: 114-120.

Ghoul, M., Bernard, T., and Cormier, M. 1990: Evidence that *Escherichia coli* accumulates glycine betaine from marine sediments. Applied and Environmental Microbiology 56: 551-554.

Jassby, A. D. 1975: The ecological significance of sinking to planktonic bacteria. Canadian Journal of Microbiology 21: 270-274.

Jeng, H., Sinclair, R., Daniels, R., Andrew, E. 2005: Survival of *Enterococci faecalis* in estuarine sediments. International Journal of Environmental Studies 62: 283-291.

Kon, T., Weir, S. C., Howell, E. T., Lee, H., and Trevors, J. T. 2007: Genetic relatedness of *Escherichia coli* isolates from a Lake Huron (Canada) beach. Applied and Environmental Microbiology 73: 1961-1967.

McLellan, S. L., Daniels, A. D., Salmore, A. K. 2001: Clonal Populations of Thermotolerant Enterobacteriaceae in Recreational Water and Their Potential Interference with Fecal *Escherichia coli* Counts. Applied and Environmental Microbiology 67: 4934–4938.

Milne, D. P., Curran, J. C., Findlay, J. S., Crowther, J. M., and Wallis, S. G. 1989: The effect of estuary type suspended solids on survival of *E. coli* in saline waters. Water Science and Technology 21: 61-65.

Ministry for the Environment. 2003: Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Published by the Ministry for the Environment, Wellington, New Zealand. ISBN: 0-478-24091-0. 159 pp.

Mitchell, R. and Chamberlin, C. E. 1975: Factors influencing the survival of enteric microorganisms in the sea: An overview. *In* A. L. H. Gameson, *editor*. Discharge of sewage from sea outfalls. Pergamon Press, Oxford. 237-251.

Muirhead, R. W., Davies-Colley, R. J., Donnison, A. M., and Nagels, J. W. 2004: Faecal bacterial yields in artificial flood events: quantifying in-stream stores. Water Research 38: 1215–1224.

Pedros-Alio, C., Mas, J., Gasol, J. M., and Guerrero, R. 1989: Sinking speeds of free-living phototrophic bacteria determined with covered and uncovered traps. Journal of Plankton Research 11: 887-905.

Shanks, O. C., Nietch, C., Simonich, M., Younger, M., Reynolds, D., and Field, K. G. 2006: Basin-wide analysis of the dynamics of fecal contamination and fecal source identification in Tillamook Bay, Oregon. Applied and Environmental Microbiology 72: 5537–5546.

Shiaris, M. P., Rex, A. C., Pettibone, G. W., Keay, K., McManus, P., Rex, M. A., Ebersole, J., and Gallagher, E. 1987: Distribution of indicator bacteria and *Vibrio parahaemolyticus* in sewage-polluted intertidal sediments. Applied and Environmental Microbiology 53: 1756-1761.

Sinton, L. W. 2005: Survival of enteric bacteria in seawater: Biotic and abiotic factors. In Oceans and Health: Pathogens in the Marine Environment: 69-92. S. S. Belkin and R. R. Colwell, editors. Kluwer Academic/Plenum Publishers, New York ISBN: 0-387-23708-9.

Sinton, L. W., Davies-Colley, R. J., and Bell, R. G. 1994: Inactivation of enterococci and faecal coliforms from sewage and meatworks effluents in seawater chambers. Applied and Environmental Microbiology 60: 2040-2048.

Sinton, L. W., Finlay, R. K., and Hannah, D. J. 1998: Distinguishing human from animal faecal contamination in water: a review. New Zealand Journal of Marine and Freshwater Research 32: 323-348.

Sinton, L. W., Finlay, R. K., and Lynch, P. A. 1999: Sunlight inactivation of faecal bacteriophages and bacteria in sewage-polluted seawater. Applied and Environmental Microbiology 65: 3605-3613.

Sinton, L. W., Hall, C. H., Lynch, P. A., and Davies-Colley, R. J. 2002: Sunlight inactivation of faecal indicator bacteria and bacteriophages from waste stabilization pond effluent in fresh and saline waters. Applied and Environmental Microbiology 68: 1122-1131.

Wheeler-Alm, E., Burke, J. and Spain, A. 2003: Fecal indicator bacteria are abundant in wet sand at freshwater beaches. Water Research 37: 3978-3982.

Whitman, R. L. and Nevers, M. B. 2003 Foreshore sand as a source of Escherichia coli in nearshore water of a Lake Michigan beach. Applied and Environmental Microbiology 69: 5555 - 5562.

Winfield, M. D. and Groisman, E. A. 2003: Role of Nonhost Environments in the Lifestyles of *Salmonella* and *Escherichia coli*. Applied and Environmental Microbiology 69: 3687–3694.

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APPENDIX 1a: Nelson City Council Application for Envirolink Funding.

Foundation for RESEARCH SCIENCE & TECHNOLOGY
Tūāpapa Rangahau Pūtaiao

Envirolink application for small advice grants (up to $5,000 excluding GST)

Regional Council Advice number: NLCC 6 Date: 19/02/07

Regional Council: Nelson City Council

Advice requested by: Paul Sheldon

Phone number: 35460435 Email address: paul.sheldon@ncc.govt.nz

Proposed research organisation: ESR

Type of ecosystem involved: Freshwater

Please answer all questions so that your application can be fully considered.

1. Please give a short description that outlines the environmental management issue you are seeking advice on.

The issue relates to elevated E.coli numbers in the tidal reaches of the Matai River for which there is no obvious source despite routine weekly sampling, targeted sampling of all likely discharge points, and complete tidal cycle surveys.

2. How will the advice allow you to positively address this issue to create benefit for your local community?

It will allow Nelson City Council to access current research and expert advice to better understand factors influencing E.coli numbers in estuarine environments and in particular the Lower Matai River.

It will provide an independent expert review of monitoring data for the Lower Maitai River

It will assist Nelson City Council decide if the Temporary Health Warning currently in place for the Lower Maitai River should be confirmed as a Permanent Health Warning or if the area can be managed to be suitable for swimming and other contact recreation.

It will provide advice on the future monitoring and management of this part of the Maitai River.

It will assist the people of Nelson to better understand why elevated E.coli levels are occurring in the Lower Matai River (there is considerable media interest).

3. How do you intend to use this advice?

To better inform future management of the Lower Matai River, and in particular its

Foundation for Research Science and Technology, PO Box 12-240, Wellington, New Zealand

APPENDIX 1b: Nelson City Council Application for Envirolink Funding (contd.).

suitability for swimming and other contact recreation.

To better target future monitoring of the Lower Maitai River and to aid the interpreation of the data collected.

4. Please choose which service(s) you would like the research organisation to provide.

☐ Seminar ☐ Training ☐ Informal Verbal Consultation

☒ Services ☒ Literature Survey ☒ Collating Research Material

Other (Please specify) Review monitoring data and advice on future monitoring

Can you attest that this request, to your knowledge, has not been answered in the past by either your council or another council's activities? Yes

This application has been sighted by your Council's Envirolink Coordinator. Yes

Name of person completing form: Paul Sheldon

Please email completed form to the Envirolink contact for your selected research organisation.

To be filled in by research organisation

Approval is contingent upon the request for advice meeting Envirolink criteria and the ability of selected research organisation to fulfil the request.

Approval: Decision not made yet Approval date:

If no, give brief explanation:

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