IMPACT OF RAW SEWAGE DISCHARGES ON THE WATER QUALITY OF THE AVON RIVER CHRISTCHURCH, POST EARTHQUAKES

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ABSTRACT

Prior to the 2010 and 2011 Christchurch earthquakes, microbial water quality measurements of the Avon River intermittently exceeded recreational water quality guidelines. The 2011 earthquakes resulted in direct sewage discharges to the Avon River of more than 5,000 cubic meters a day over six months. A study was commissioned to test water and sediment samples from the Avon River tested for the presence of *E. coli* and *Campylobacter*, and sediment samples tested for *Giardia* and *Cryptosporidium.* Selected samples were also tested using faecal source tracking markers. The levels of *E. coli* at the Boatshed and Kerrs Reach were similar throughout the study with human and wildfowl sources identified. During the 2013 sampling the *E. coli* levels at Owles Terrace were <550 *E. coli* per 100ml. *Campylobacter* was detected in water from all three sites.

Concentrations of *E. coli* in 2013 were lower in sediments from the Boatsheds and Owles Terrace than observed in 2011-2102, while at Kerrs Reach, *E. coli* levels were higher than the average concentration previously The Kerrs Reach samples were also the only sediment samples in which *Campylobacter* was detected. There was a marked decrease in concentration of protozoa in sediments at all sites in 2013.

KEYWORDS

Faecal Source Tracking, water quality, *E. coli*, wastewater, Earthquake

1 INTRODUCTION

The Avon River is an intrinsic feature of the urban environment of Christchurch City and is popular for recreational and tourist activities. The Avon River traverses the city from its source in the western suburb of Avonhead through Hagley Park and the Central Business District to the eastern suburbs. It departs the built environment at the northern entrance to the Avon-Heathcote Estuary before amalgamating with the Heathcote River to flow into Pegasus Bay.

Urban rivers are susceptible to intermittent impacts from industrial and human effluents. In addition, animal faecal scats, including wildfowl, may cause deterioration in the quality of the water. Contamination of water from these faecal sources of pollution can result in increased risks of microbial diseases. Microbial water quality is measured by enumerating the presence of the bacteria *Escherichia coli*, which is common in faecal material. The *New Zealand Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas* (MfE, 2003) state that freshwater containing less than 260 *E. coli* per 100 mL is acceptable.

The Avon River has been monitored at various locations by the Christchurch City Council (CCC) and Environment Canterbury (ECan) over many years (Figure 1). A 2009 study applied faecal source tracking tools (faecal sterol analysis, fluorescent whitening agents, and PCR markers) to better understand contamination (Moriarty and Gilpin, 2009). This study found that the primary sources of water quality degradation in the Avon River appeared to be related to wildfowl and possibly dog faecal material. Rainfall resulted in significant degradation of the microbial water quality of the Avon River due both to wildfowl and dog faeces being washed into the river, and some low level human sewage inputs from the sewage system.

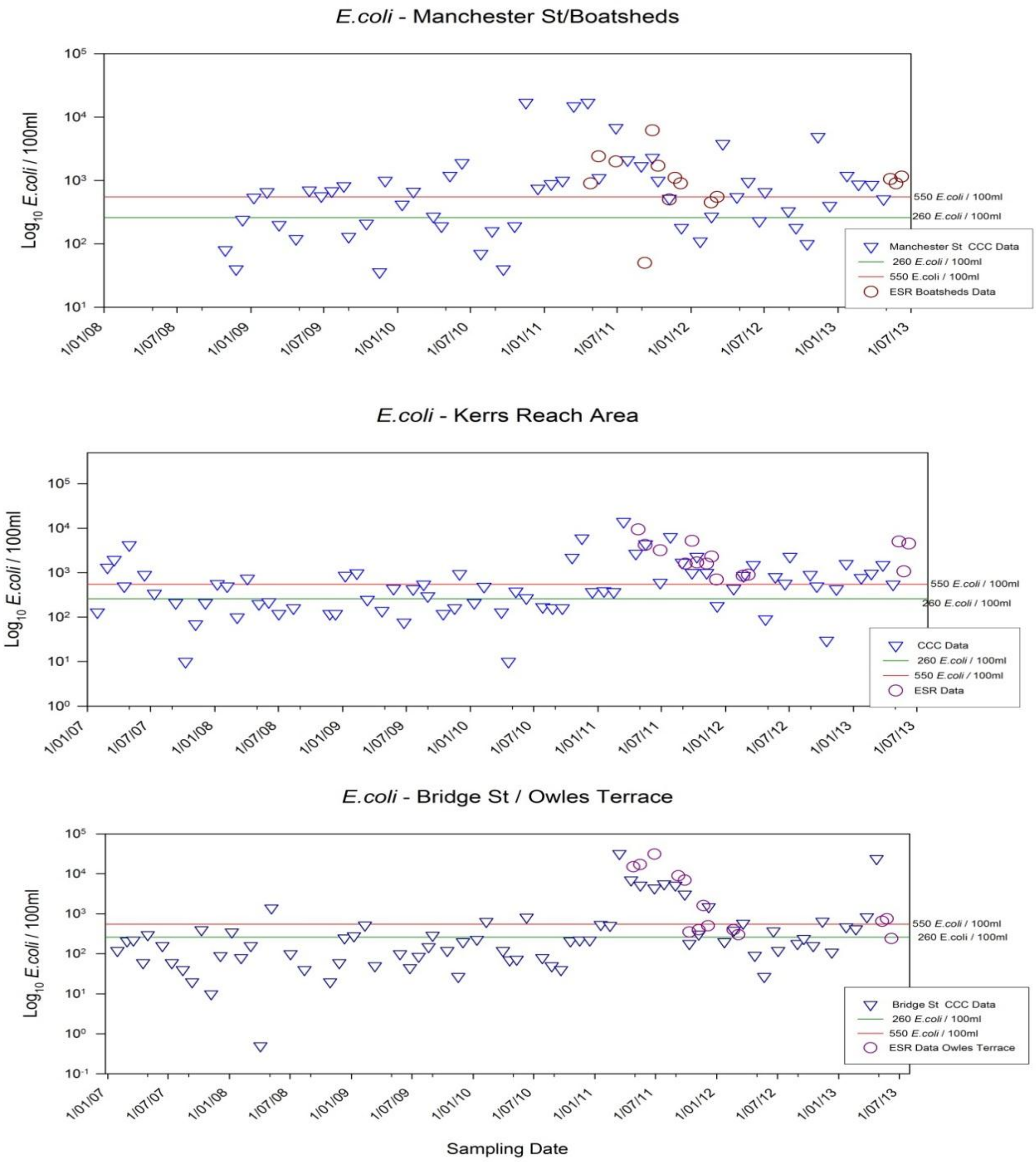


Figure 1**: Historical Christchurch City Council data. ESR data from sites close to the CCC routine sampling included.**

Canterbury and Christchurch, in particular, has experienced a series of damaging earthquakes since September 2010. The earthquake sequence began with a 7.1 magnitude (M) earthquake on 4th September 2010, followed by a second of 6.3 M on 22nd February 2011, a third of 6.4 M on 13th June 2011 and a fourth of 6.0 M on 23rd December 2011 In addition to severe damage to commercial and residential buildings, the succession of earthquakes has caused extreme disruption to water, wastewater and storm water infrastructure throughout much of Christchurch, particularly the eastern suburbs, and local towns including Kaiapoi. This resulted in the discharge of large volumes of raw sewage directly into Christchurch's rivers and the Avon/Heathcote Estuary until November 2011 (Figure 4).

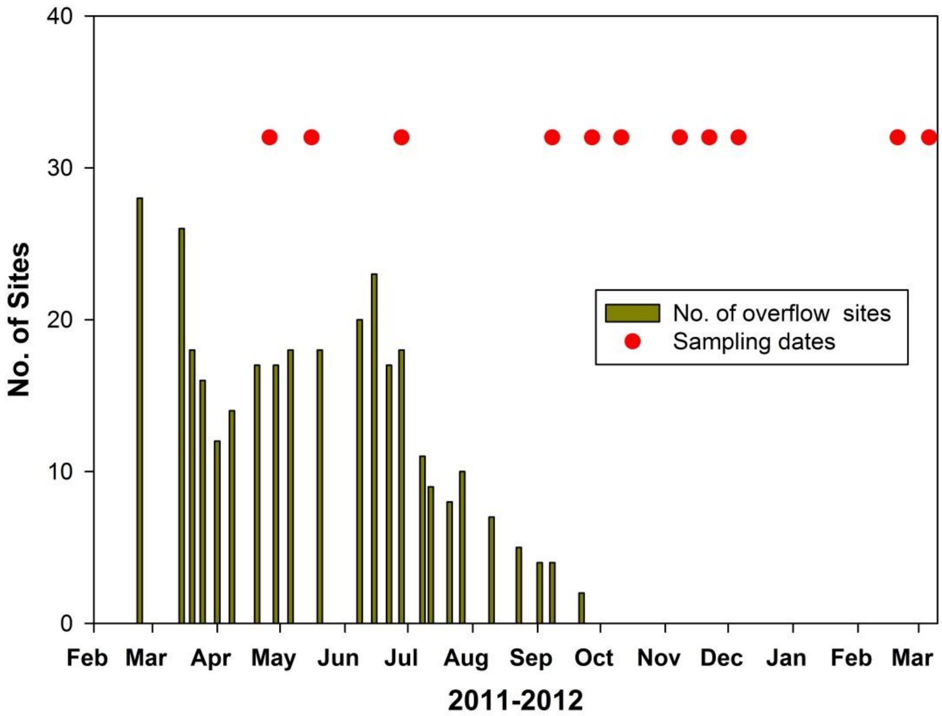


Figure 2 **Number of sites where overflows of untreated sewage occurred. The dates when ESR sampled are also noted.**

Raw human sewage can contain a number of pathogenic organisms including *Campylobacter* spp., *Escherichia coli* O157, *Cryptosporidium* spp., *Giardia* spp., and viruses such as enterovirus and norovirus (Coia 1999 , Fayer, Trout et al. 2000). Ingestion of these organisms can cause severe illness including vomiting, diarrhoea, kidney failure, haemolytic uraemic syndrome and, in some cases, death. When untreated sewage contaminates rivers or oceans, waterborne transmission of these pathogens can occur to those who use the water for swimming, boating, fishing and shellfish-gathering activities. Secondary transmission of these pathogens can also occur via animals exposed to the water.

Wastewater treatment removes or inactivates these pathogens before they enter rivers or oceans. Severe damage to the wastewater system in Christchurch caused by the earthquakes led to the discharge of up to 38,000 m^3 of raw sewage each day into the Avon River (Figure 3). The microorganisms in this sewage may remain suspended in the water column, and they may be discharged eventually into the Avon/Heathcote Estuary, or they may be deposited into the riverbed sediment.

The process of deposition and resuspension of microorganisms to and from sediments is poorly understood. There is also limited information about the rates of microbial survival in sediments, although reduced oxygen levels and protection from sunlight may allow microorganisms to survive longer in sediments (Davies, Long et al. 1995).

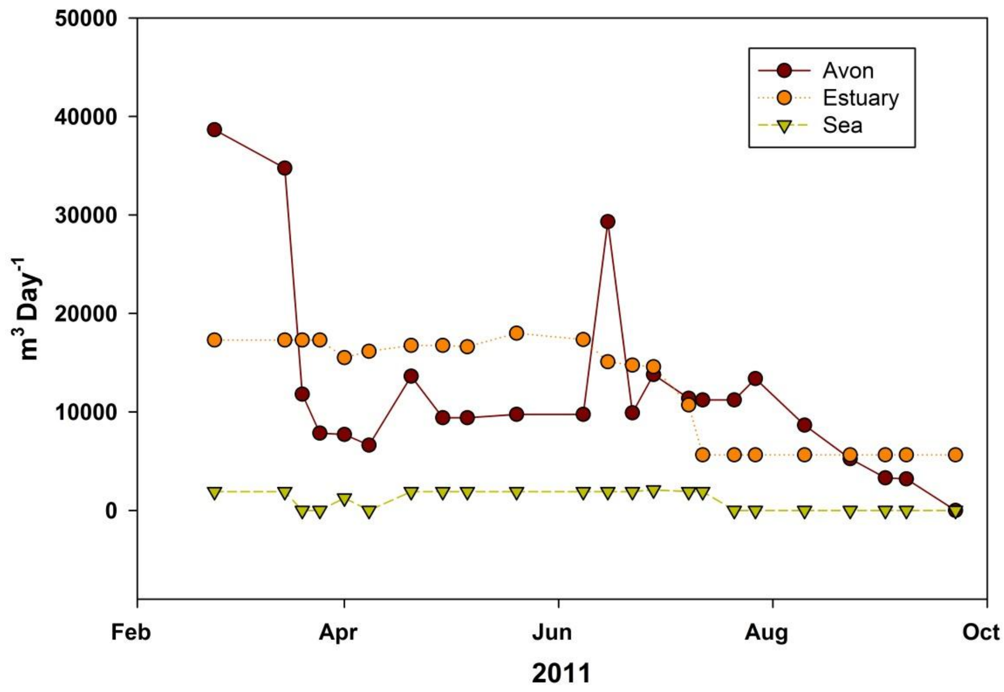


Figure 3: Volume and discharge environments for untreated sewage.

Following the major Christchurch earthquake on 22nd Feb 2011, a study was commissioned to 1) re-evaluate the validity of *E. coli* as an indicator of public health risk following contamination events; 2) to evaluate the relationship between concentrations of indicator bacteria and pathogens in recreational water during active sewage discharges, and in the period following cessation of sewage discharges; and 3) to investigate the potential of riverbed and seabed sediments to act as a sink for indicator bacteria and pathogens that might then be re-mobilised with disturbance. Water and sediment samples were collected from three sites on the Avon River – Antigua Boatsheds, Kerrs Reach and Owles Terrace. Samples were tested for the presence of microbial water quality indicators
(*E. coli*), potential pathogens (*Campylobacter*, *Giardia* and *Cryptosporidium*), and faecal source tracking markers (PCR markers, faecal sterols and fluorescent whitening agents (FWAs)). Detailed findings of this report can be found in the Moriarty *et al* report (2012).

1.1. Focus of this 2013 study

This study is a follow up to the previous Avon River studies to determine the concentration of microorganisms in the Avon River water and sediments relative to these previous studies. It has been a year since the last sampling occasion in the post-quake study and in order to ensure that the public health message remains relevant a further study was undertaken to establish the on-going concentrations of indicators and pathogens present in Avon River sediments.

1.2. Microorganisms examined in this study

This report describes microbial characterisation of water and sediments from three sites on the Avon River. Methodological details for analyses of target organisms and full description of the organisms are described in the report (Moriarty et al., 2012). Water samples were tested for the concentration of *E. coli* and *Campylobacter* spp. while the sediment was tested for *E. coli*, *Campylobacter* spp., *Cryptosporidium* spp. and *Giardia* spp.

1.3. Faecal source tracking

A range of faecal source tracking (FST) tools can identify whether faecal pollution is from human, dog or wildfowl sources (Field and Samadpour, 2007). In this study, FST tools were applied to a limited number of samples where the concentrations of microorganisms present warranted further investigation. FST markers evaluated were faecal sterols (indicative of human and wildfowl sources), fluorescent whitening agents (FWAs) (indicative of human sources) and PCR-based molecular markers (indicative of human, wildfowl and dog sources).

1.4 **Sampling locations and Sample analysis**

Three sites along the Avon River were chosen for analysis (Figure 4).

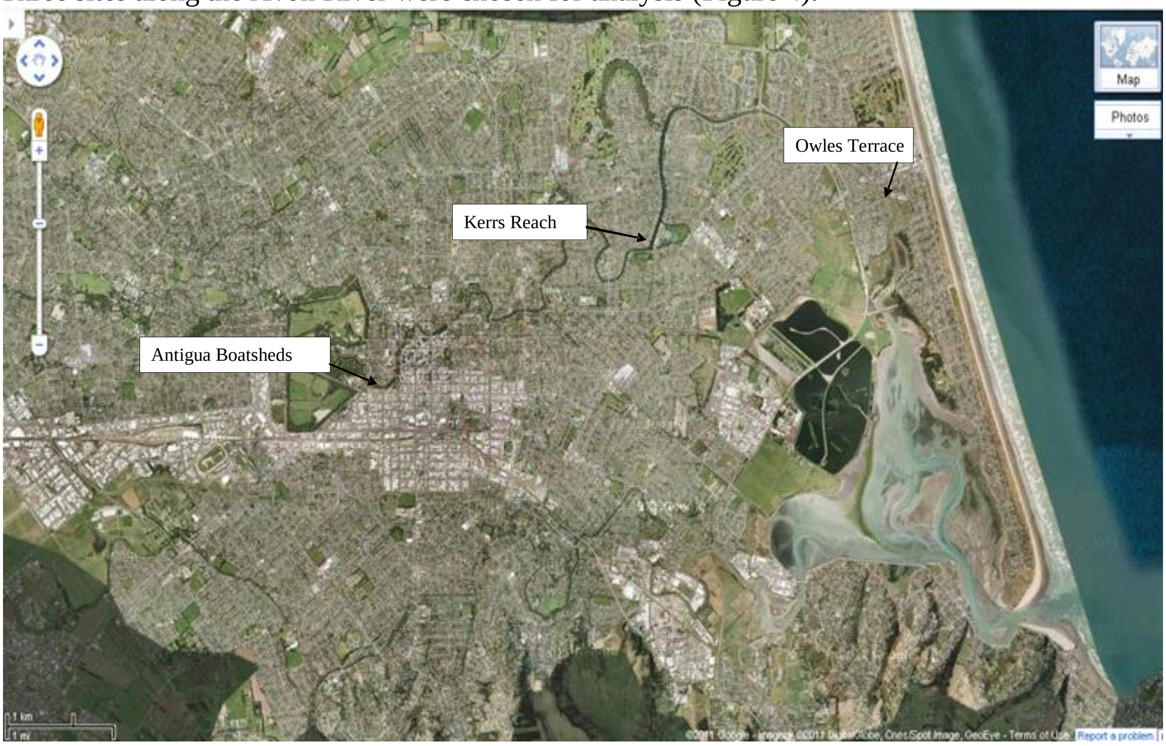


Figure 4 Location of sampling sites

2 RESULTS

1.4. *E. coli* in Avon River water

The concentration of *E. coli* in Avon river water sediment and estuarine sediment from April 2011 to April 2013 is shown in Figure 5 and a summary of the data is displayed in Table 1 and Table ***2***. At the Boatsheds, the *E. coli* concentration in this study (1,035 CFU per 100 ml) is lower in average concentration compared with the Active Discharge average concentration (average 1,338 *E. coli* per 100 ml) and the Post Discharge average concentration (1,629 *E. coli* per 100 ml).

The concentration of *E. coli* in the water at Kerrs Reach during the 2013 sampling (average 3,523 *E. coli* per 100 ml) was lower than the average concentration while direct sewage discharges were occurring (4,600 *E. coli* per 100 ml). It was significantly higher than the level recorded following the cessation of sewage discharges at Kerrs Reach (1,893 *E. coli* per 100 ml).

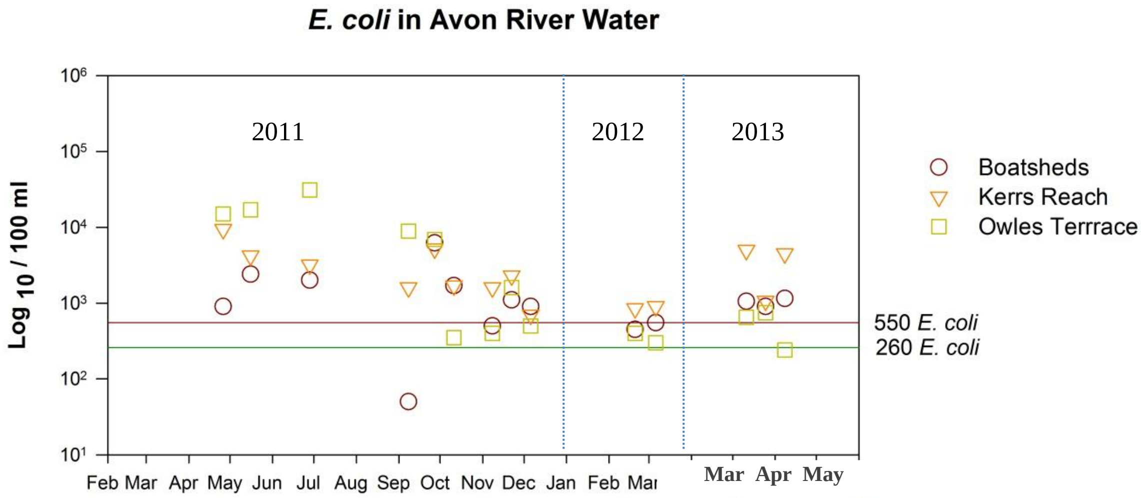
On all three sampling occasions in 2013, Owles Terrace had the lowest concentration of *E. coli* relative to the other two upstream sites. The first two samples (650 and 750 *E. coli* per 100 ml) were similar in concentration to those seen post sewage discharge. The final sample (240 *E. coli* per 100 ml) was the lowest recorded at this site over the entire 2011-2013 study.

1.5. *E. coli* in Avon River Sediment

The concentration of *E. coli* in the sediment at the Boatsheds during the 2013 sampling (average 132 *E. coli* per g dry weight) was significantly lower than that during known sewage discharges (average 1,287 *E. coli* per g dry weight) and similar to those seen post discharge (average 250 *E. coli* per g dry weight).

The concentration of *E. coli* at Kerrs Reach was significantly different to the other sites with the highest concentration of *E. coli* recorded (91, 635 *E. coli* per g dry weight) over the course of the two year study. All three 2013 samples were higher than the average concentration seen during active sewage discharges (2,875) *E. coli* per g dry weight) and following the cessation of discharges (5,119) *E. coli* per g dry weight). It must be noted due to problems with access to the river at Kerrs Reach the 2nd and 3rd sampling of 2013 were taken approximately 50 m downstream of the other samples, close to the last pontoon in the vicinity of Christ's College Boat Club.

The concentration of *E. coli* in the sediment at Owles Terrace appears to be decreasing over time. The average concentration seen during the 2013 sampling (144 *E. coli* per g sediment dry weight), was significantly lower than those during direct discharges (3,603 *E. coli* per g dry weight) and following discharges (620 *E. coli* per g sediment dry weight).



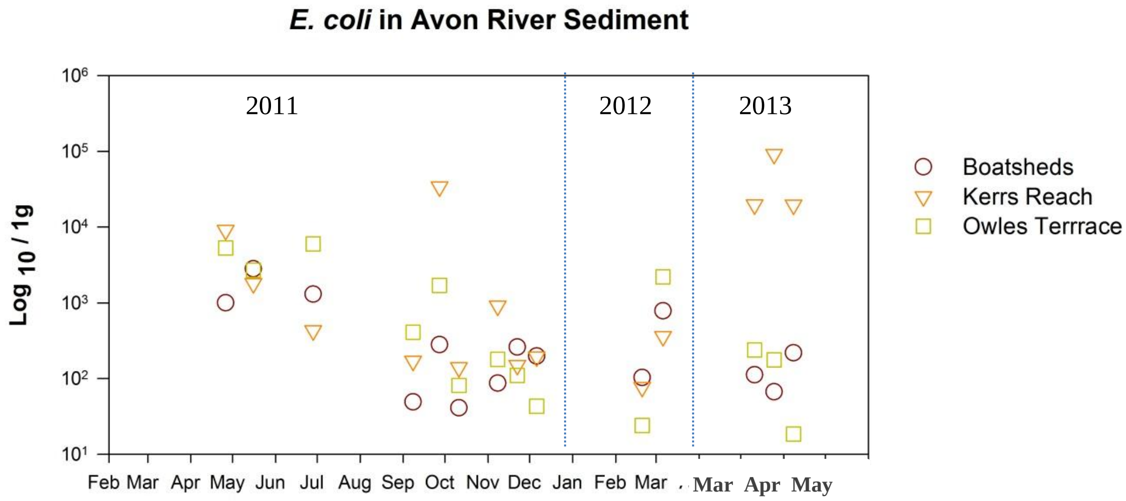
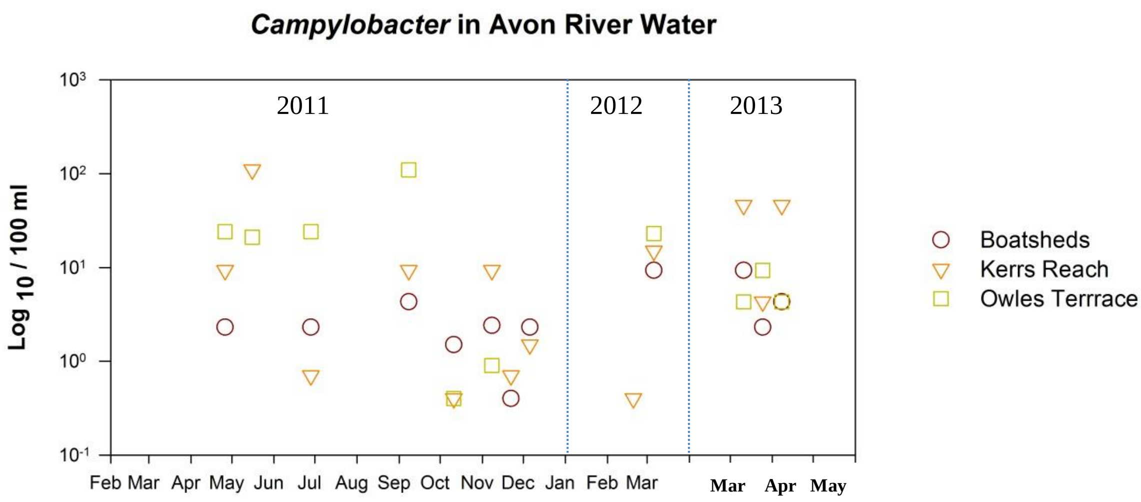


Figure 5 Concentration of *E. coli* present in Avon River water and sediment

1.6. *Campylobacter* spp.

All water and sediment samples were tested for the presence of *Campylobacter spp*. It was detected in the river water on all three sampling occasions at each of the sampling sites in 2013. The concentration in the water ranged from 2.3 to 46 *Campylobacter* MPN (most probable number) per 100 ml. While numbers in the water at The Boatsheds and Owles Terrace were low, Kerrs Reach had the highest concentrations on two occasions (46 MPN per 100 ml on 11th May and 8th June 2013 seen since sewage discharges ceased.

In the river sediment samples *Campylobacter* spp. were detected only in the sediments in Kerrs Reach during the 2013 sampling. Previously, *Campylobacter* spp. had been detected in all sediment samples over the course of the study, at low concentrations. The level of campylobacters detected in the sediment at Kerrs Reach on the second sampling occasion of 2013 (11.08 MPN per g sediment dry weight) was the highest seen throughout the study. *Campylobacter* spp. were detected again at Kerrs Reach on the final sampling occasion, but were significantly lower (0.54 MPN per g dry weight) than the previous sample.



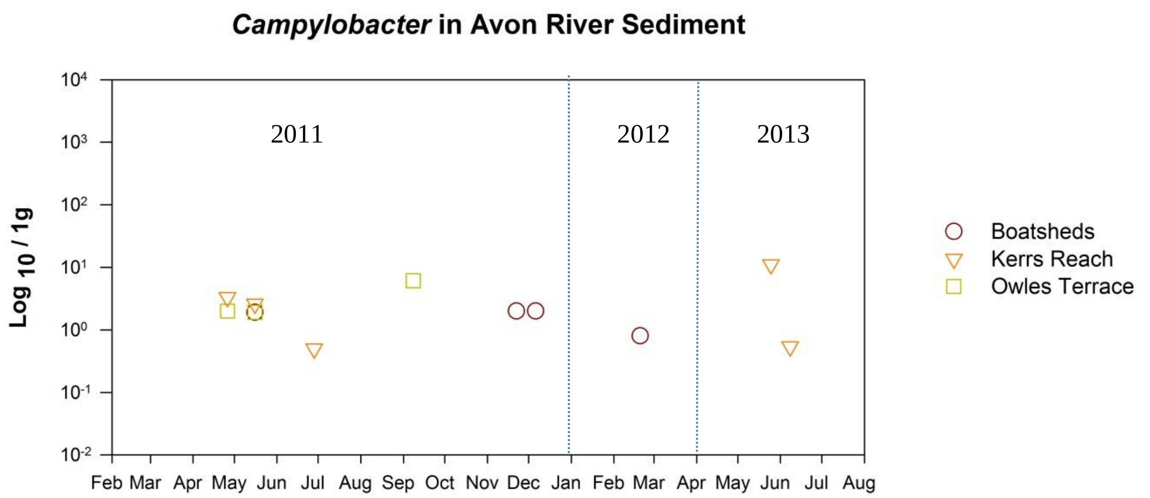


Figure 6 Concentration of *Campylobacter spp*. present in Avon river water, sediment

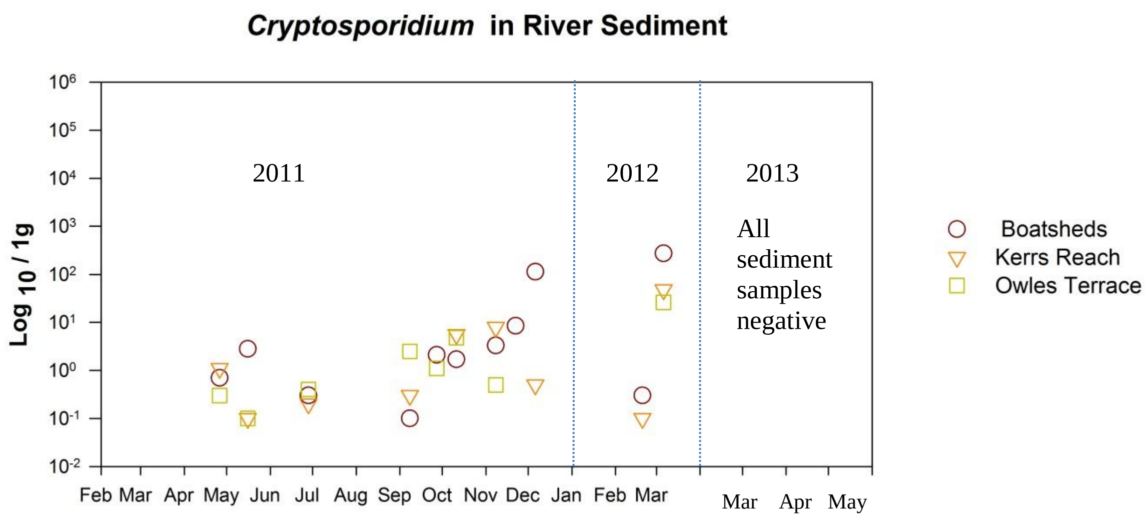


Figure 7 Concentration of *Cryptosporidium spp.* present in Avon river sediment

1.7. *Cryptosporidium* and *Giardia* spp.

In the 2013 study, only the sediment samples were analyzed for *Cryptosporidium* and *Giardia spp.* All sediment samples analysed were negative for *Cryptosporidium spp*. Giardia *spp*. which had previously been detected at very high levels (2,254 cysts per g dry weight sediment) was detected on only one occasion at Kerrs Reach. This sample had low concentrations of *Giardia spp.* (<1 per g dry weight sediment), which may have come from a number of environmental sources such as birds, dogs etc.

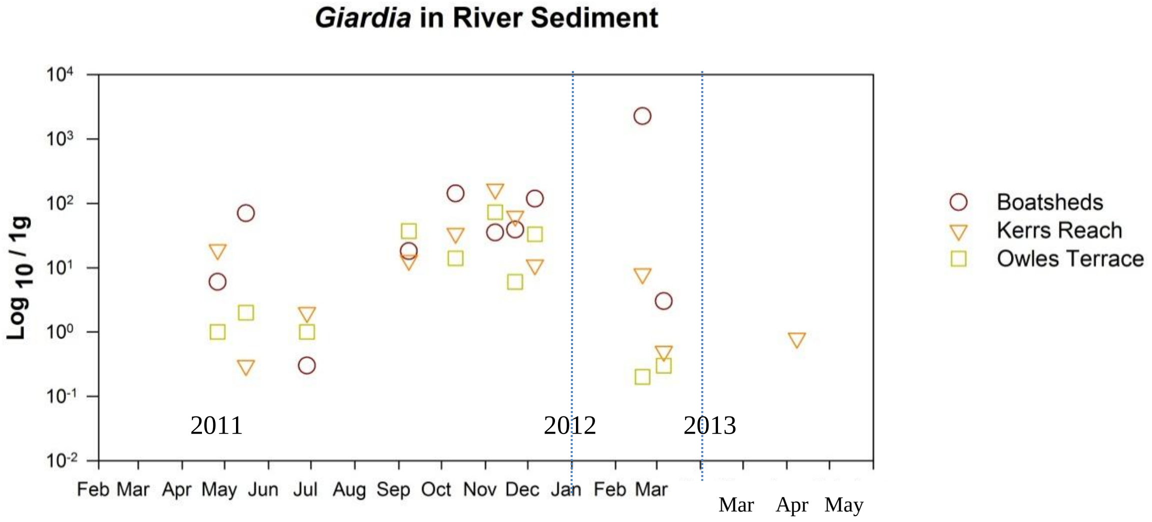


Figure 8 Concentration of *Giardia spp.* present in Avon river sediment

Comparisons during active discharge, immediately post-discharge and 2013 sampling events

Table 1 Mean levels of microorganisms in the river water during discharge, post-discharge and the current study

Organism	**Time**	**Boatsheds**	**Kerrs Reach**	**Owles Terrace**
E. coli **CFU per 100 ml**	During discharge	1,338	4,600	17,975
	Post discharge	1,629	1,893	1,493
	Current study	1,035	3,523	547
Campylobacter spp. **MPN per 100 ml**	During discharge	2	32	45
	Post discharge	3	5	4
	Current study	5	32	6

Table 2 Mean levels of microorganisms in the <u>sediment</u> during discharge, post-discharge and the current study

Organism	Time	Boatsheds	Kerrs Reach	Owles Terrace
E. coli **CFU g dw**	During discharge	1,287	2,875	3,603
	Post discharge	250	5,119	620
	Current study	132	43,661	144
Campylobacter spp. **g dw**	During discharge	0	2	3
	Post discharge	1	0	0
	Current study	0	4	0
Cryptosporidium spp. **g dw**	During discharge	1.0	0.4	0.8
	Post discharge	57.3	8.9	4.6
	Current study	0.0	0.0	0.0
Giardia spp. **g dw**	During discharge	23.6	8.6	10.3
	Post discharge	431.8	47.1	21.1
	Current study	0.0	0.3	0.0

Dates: **During discharge**: 1st April – 8th Sept 2011 **Post discharge**: 27th Sept – March 2012 **Current study**: March-April 2013

1.8. Faecal Source Tracking (FST) in Avon River water and selected sediments

Faecal source tracking tools (PCR markers, faecal sterols and fluorescent whitening agents) were applied to all river water samples collected and three sediment samples from Kerrs Reach and the Boatsheds with final FST interpretations in Table 3.

All of the river water samples analysed by FST tools had elevated levels of *E. coli*, with the exception of a sample from Owles Terrace collected on 8th April, which was below the alert level for recreational water. All samples contained > 2000 parts per trillion (ppt) of sterols which is sufficient for interpretation of sterol ratios. Details of the FST results are presented in **Table 3**

Table 3: Summary of collated Faecal Source Tracking results in Avon River water and sediments

Location	Sample type	Date 2013	*E. coli* CFU/100mL /g dry wtg.	Human PCR markers			Non-human PCR markers		Sterols	FWAs	**Interpretation
				BiAdo	HumM3	BacH Reischer	Wildfowl	Canine			
Boatsheds	water	11-Mar	1,055	ND	ND	Weak Positive	Positive	ND	wildfowl/**plant decay**	NT	**Wildfowl,** plant decay
Kerrs Reach	water		5,000	ND	ND	ND	Positive	ND	**wildfowl**/plant decay	NT	**Wildfowl,** plant decay
Owles Terrace	water		650	ND	ND	ND	Positive	ND	**wildfowl**/plant decay	NT	**wildfowl**/plant decay
Boatsheds	water	25-Mar	900	Positive	ND	Weak Positive	Positive	ND	Wildfowl/**plant decay**	NT	**Human, wildfowl**
Kerrs Reach	water		1,070	Positive	Weak Positive	Weak Positive	Positive	ND	Wildfowl/**plant decay**	<0.01	**Fresh human, wildfowl, plant decay**
Owles Terrace	water		750	Weak Positive	ND	ND	Positive	ND	**Wildfowl**/plant decay	NT	**wildfowl,** plant decay
Boatsheds	water	8-Apr	1,150	Positive	ND	Weak Positive	Positive	ND	***plant decay**	0.03	**Human, wildfowl, plant decay**
Kerrs Reach	water		4,500	Positive	ND	Weak Positive	Positive	ND	Wildfowl/plant decay	0.03	**Human, wildfowl,** plant decay
Owles Terrace	water		240	Weak Positive	ND	ND	ND	ND	low level human, plant decay	NT	**(aged?/ low level human), plant decay**
Kerrs Reach	sediment	25-Mar	91,600	NT	NT	NT	NT	NT	**Wildfowl**/plant decay	NT	**Wildfowl**/plant decay
Boatsheds	sediment	8-Apr	220	NT	NT	NT	NT	NT	**Wildfowl**/plant decay	NT	**Wildfowl**/plant decay
Kerrs Reach	sediment		19,600	NT	NT	NT	NT	NT	**Wildfowl**/plant decay	NT	**Wildfowl**/plant decay

ND = sample analysed and target not detected *some evidence for weak signal from mammalian indicators NT = sample not analysed **words in bold suggest the major contributor to pollution as determined by these assays, however, other faecal sources may be present/dominate that were not targeted.

3 CONCLUSIONS

This study was undertaken a year after a comprehensive study which investigated the post-earthquake microbial quality of the following matrices: Avon River water and sediment, coastal and estuarine water and sediment. The aim of this current study was to assess the microbial loading of the Avon River water and sediment 18 months after the last active sewage discharge into the Avon River. Table 1 and Table 2 in the report detail the average concentrations of microorganisms detected in the Avon River water and sediment over the course of the entire study (April 2011-March 2013).

3.1 MICROORGANISMS IN RIVER WATER

The average *E. coli* concentrations at the Boatsheds have decreased in our current study compared with during and post active discharge phases. Faecal source tracking analyses at the Boatsheds suggest wildfowl contamination is present during all sampling periods of the current study and human faecal pollution was identified in the river water on the last two sampling occasions. Identification of human contamination may be related to the increased activity in the area such as dredging of the river bed, construction of new pipelines and contamination issues adjacent to and upstream of the Boatsheds. These factors may also contribute to the presence of wildfowl indicators which were identified in both sediment (8 April) and overlying water (all events) at the Boatsheds. Immediately post-quake no known direct discharges were occurring upstream of the Boatsheds. Since then various investigations undertaken by CCC have uncovered problems particularly relating to drains feeding into the Avon (Riccarton Main Drain, Addington Main Drain). Prior to the September 2010 earthquake, and subsequent sewage discharges, the water quality at the Boatsheds frequently did not comply with Recreational Water Quality. The source of the pollution was determined in an ESR Report 2009 (Moriarty *et al*.) to be wildfowl and dog faeces, with no human pollution detected in the pre-earthquake study.

At Kerrs Reach a higher average concentration of *E. coli* per 100 ml (3,523 CFU) was detected compared with the post-discharge average concentration of E. coli (1, 629 CFU). FST analysis identified wildfowl markers in the water and sediment, and human markers were present in the water on the last two sampling events. A number of overflow events had occurred in the area around the time of sampling and weed cutting had been undertaken. Several new water and wastewater pipes had also been laid in the area. All of these activities have the potential to add to the microbial loading in the river. These potential contamination activities are in an area where significant recreational activity takes place, water users should be kept up to date on the water quality and warning signs erected where appropriate.

Owles Terrace which received significant volumes of direct discharge post-quake, has the lowest concentration of *E. coli* per 100 ml in the water in this current study. The FST analyses did not identify human markers in the water at Owles Terrace, except for a weak signal on the last sampling occasion when strong human indicators were present at both upstream sites. This site is also tidally impacted so would be expected to have the highest input of non-sewage impacted sea water compared with other sites.

Campylobacter concentrations in the river water samples were similar throughout the study at the Boatsheds, with the current study having the highest average concentration per 100 ml. At Kerrs Reach the concentration decreased following the cessation of discharges, but has increased significantly again in the final sampling round. This may be due to a high number of wildfowl in the area and continual sewage pipe repairs which may lead to discharges to the river. Owles Terrace which had the highest average concentration of campylobacters during discharge has remained relatively low since discharges ceased.

3.2 MICROORGANISMS IN SEDIMENT

In terms of microorganisms present in riverbed, the most significant finding was at Kerrs Reach. Here the sediments were 15 times more contaminated with E. coli than during active discharges. This may reflect a build-up of *E. coli* over time in the sediments due to known (and unknown) discharges to the river. The Boatsheds had reduced on average by 47% since the post discharge study and Owles Terrace by 77%.

Cryptosporidium was not detected in any Avon river sediment samples. Giardia which had previously recorded high levels (maximum 2,254 cysts per gram, February 2012) at the Boatsheds was not detected there on this current sampling round. It was, however, detected at a low level at Kerrs Reach (0.8 per gram). Due to the lack of fresh inputs, the concentrations seen in 2013 were significantly lower than those recorded during discharge and post –discharge. The decrease may also be related to the dredging of the riverbed at Kerrs Reach between March and May 2013 which may have removed the sediment where the *Giardia* were concentrated.

The results of this follow-up study on the Avon River water and sediment highlight the on-going water quality issues. The Boatsheds at Antigua St continue to have poor water quality similar to the levels measured throughout the active discharges and post discharges. Historically, the water quality at the Boatsheds has been poor and this continues to be the case. FST tools have indicated the likely sources of pollution at the Boatsheds to be wildfowl, with intermittent human pollution. The water quality at Kerrs Reach is also unsatisfactory in terms of public health risk with the average *E. coli* concentration close to those seen during active sewage discharges. FST results indicate fresh human inputs as well as wildfowl faeces at this site. Finally, Owles Terrace has seen the greatest improvement in water quality post-discharge with the final sample (240 *E. coli* per 100 ml) below alert level for the recreational water guidelines 260 *E. coli* per 100 ml), and FST reporting the source of *E. coli* as wildfowl.

Post cessation of direct discharges to the Avon, the sediments of the river contained a significant number of protozoa. The results from this study showed a marked decrease in concentration, which indicates improvements for the long term quality of the water. At Kerrs Reach the highest concentration of *E. coli* per gram of sediment was detected. FST determined the source as wildfowl. It should be noted that the 2nd and 3rd sampling of this study, sediment and water samples were taken further downstream at Kerrs Reach than previously sampled due to problems accessing the original sampling location due to earthworks/maintenance? Also dredging of the River Bed and weed cutting was occurring intermittently during sampling. This may have disturbed sediment bound microorganisms and redistributed them to other locations within the river bed.

As the Avon River is used year round for recreational activity, users should be kept updated with the water quality, particularly at the Boatsheds where a number of people unfamiliar with the water quality of the Avon have recreational contact with it. Due to the presence of *Giardia* and *Campylobacter* spp. present in the sediment, care should always be advised in relation to disturbance of the sediments, especially at Kerrs Reach, where a high concentration of *E. coli* was recorded/observed in the sediments

ACKNOWLEDGEMENTS

The authors wish to thanks Environment Canterbury for their funding and assistance throughout this study. We would also like to acknowledge the technical assistance of members of the Water and Food Group, ESR, Christchurch.

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