Review of Faecal Indicator Bacteria Contaminant Loads

Kaiate Stream, Tauranga Harbour catchment

Prepared for Bay of Plenty Regional Council

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Executive summary

NIWA was engaged by Bay of Plenty Regional Council (BOPRC) to review water quality data for the Kaiate Stream, which discharges into Rangataua Bay, is in the southeast of Tauranga Harbour. The microbiological quality in this stream was degraded, and BOPRC is working with the local community to improve it.

The bulk of data were for *E. coli*, a Faecal Indicator Bacteria (FIB). Data exists for the period 2015-2019, and NIWA reviewed all of these data, but focused on the 2018/19 summer, which include other water quality variables (such as turbidity, electrical conductivity and pH), and several analytical tests which enable faecal source tracking (i.e., assist with identification of the source of microbial contaminants).

Key information requirements identified by BOPRC included:

1. Which parts of the catchment were the primary sources of *E. coli*?
2. Were there relationships between FIB concentrations and other water quality variables?
3. How should BOPRC proceed with their monitoring investigation?

Sources of *E. coli*

- The faecal source tracking data identified that bovine species were the overwhelmingly dominant source of FIB across all sub-catchments. The absence of ovine markers is notable, but is probably a result of the screening level test that was used.
- Concentrations of FIB across all sub-catchments were generally elevated, and at all sites sample concentrations exceeded the MfE/MoH guideline values for single samples. Although these thresholds are used predominantly to guide monitoring effort at recreational sites, they indicate that exceedance of these thresholds confirms that water quality is impaired.
- There was no consistent relationship between stream flow and FIB concentrations at all sites but one, or between sites:
  - during one event however, increasing stream flow appeared to dilute FIB across all sites.
- Concentration data alone does not identify the dominant source of FIB. Combining FIB concentration data with flow to estimate flux (the product of flow and concentration data) allows relative contribution of FIB loads to be identified.
- The Otawera Stream is the major source of FIB contaminants, and the Owairoa Stream is the dominant source of FIB within that sub-catchment.

Relationships between FIB concentrations and other water quality variables

- Relatively few data were available for these variables, and the relationship between FIB and other variables was weak.

- Although measurement of other variables may not substitute FIB enumeration, the other water quality data will assist with interpreting the concentrations of FIB in response to hydrological events. The value of supporting water quality variables is increased if they are available at higher frequency (i.e., continuous monitoring).

Recommendations for monitoring

- There is little benefit in continuing with faecal source tracking – bovine species are the overwhelmingly dominant source of FIB. Consideration could be given to one survey of ovine markers, using a more sensitive analytical test to confirm the apparent absence of ovine-derived FIB.

- As far as possible, site-specific flow gauging is recommended for key sites for each sampling event. However, a good relationship between flow at Site 1 and several upstream sites was identified (sites 6, 7, 11, 12 and 15). Using simple relationships, the flow at these sites may be estimated adequately to quantify the load at these sites. This is important for sites 6 and 7, which appear to be the two sub-catchments that should be prioritised for mitigation.

- Flow proportional sampling using automatic samplers should be undertaken over a few rainfall events to better understand the flow-FIB concentration relationship.

- Automatic samplers may also be used to collect samples during low-flow conditions to better quantify FIB loads during these periods.

- Consideration should be given to use of water quality data sondes, particularly during event-related monitoring.

1 Introduction

Bay of Plenty Regional Council (BOPRC) has responsibility for managing water resources on behalf of communities to ensure sustainable management of freshwater. The Kaiate Stream is a tributary of the Waitao Stream, which discharges into Rangataua Bay, which is in the southeast of Tauranga Harbour. The Kaiate Stream is a focus for investigation because summer monitoring has identified persistently elevated Faecal Indicator Bacteria numbers. These results indicate that water quality does not meet contact recreation requirements, and a permanent health warning is in place for the Kaiate Stream. Contamination of the estuary may also occur.

NIWA was engaged to review data that have been collected from a series of monitoring campaigns, with two key objectives:

1. Summarise the results of these monitoring efforts.
2. Make recommendations for further monitoring.

As part of objective 1, assessment and interpretation of these data have also been undertaken.

2 Materials and methods

All data and information were provided by BOPRC. These comprised water quality data (primarily microbial water quality data based on concentrations of *E. coli*, a Faecal Indicator Bacteria (FIB)), derived from monitoring undertaken over the period January 2015 to April 2019. Additional data included specialised analyses of a selection of faecal indicator markers – tests that allow the likely sources of faecal contaminants to be better estimated. Data were provided for a series of tests of samples collected in December 2018 and March and April 2019. These analyses were conducted by ESR in Christchurch.

Other data provided included river discharge data (measured continuously at the "Kaiate at Kaiate Falls Rd" site), and rainfall from the "Waimapu at McCarrols" site, located to the south west of the catchment.

Water samples were enumerated for *E. coli* using a membrane filtration procedure (APHA 9213D)(APHA-AWWA-WEF 2018).

Details of the sites, variables and numbers of results are summarised in Table 2-1.

Table 2-1: Sites, variables and numbers of results per variable, May 2017 - February 2019.

Site code	BOPRC site reference code	Site name	Avian GFD	Human BAC	Ruminant BAC	Dog BAC	DO conc. (mg/L)	DO sat. (%)	*E. coli* conc. (cfu/ 100 m)	Elect. conductivity	Field elec. conductivity	Field pH (units)	Temp. (deg. C)	General BAC	Human BiADO	pH (units)	Discharge – site specific gauging	Ruminant BAC cow (/100 mL)	Ruminant BAC sheep (/100 mL)	Turbidity (NTU)
SITE1	EO564565	Kaiate at Kaiate Falls Rd	3	3	3	3	12	12	52	12	12	6	12	3	3	12	8	3	3	12
SITE2	EO565558	Kaiate L/B Trib u/s Kaiate Falls Rd	2	2	2	2	8	8	21	8	8	7	8	2	2	8	8	-	-	8
SITE3	EO570550	Kaiate L/B Trib d/s Otawera confluence	-	-	-	-	8	8	51	8	8	7	8	-	-	8	8	-	-	8
SITE4	EO588533	Otawera 200m u/s Kaiate confluence	1	1	1	1	8	8	21	8	8	1	8	1	1	8	-	1	1	8
SITE5	EO605526	Otawera R/B Trib u/s Owairoa confluence	2	2	2	2	8	7	22	8	8	1	8	2	2	8	8	1	1	8
SITE6	EO610523	Otawera u/s Owairoa confluence	3	3	3	3	12	12	25	12	12	1	12	3	3	12	8	3	3	12
SITE7	EO604523	Owairoa u/s Otawera confluence	1	1	1	1	12	12	24	12	12	1	12	1	1	12	5	1	1	12
SITE8	EO551573	Kaiate L/B Trib at Kaiate Falls Rd Culvert	-	-	-	-	8	8	21	8	8	7	8	-	-	8	8	-	-	8
SITE9	EO552582	Kaiate at Kaiate Falls Reserve	-	-	-	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-
SITE10	EO594561	Kaiate u/s Otawera confluence	-	-	-	-	8	8	48	8	8	1	8	-	-	7	5	-	-	8
SITE11	EO568553	Kaiate 120m u/s Kaiate Falls Rd	-	-	-	-	8	8	36	8	8	7	8	-	-	8	4	-	-	8
SITE12	EO578551	Kaiate 220m u/s Kaiate Falls Rd	-	-	-	-	8	8	36	8	8	7	8	-	-	8	5	-	-	8
SITE13	EO571525	Kaiate L/B Trib 270m u/s Kaiate confluence	-	-	-	-	-	-	29	-	-	-	-	-	-	-	-	-	-	-
SITE14	EO566479	Kaiate L/B Trib 750m u/s Kaiate confluence	-	-	-	-	-	-	29	-	-	-	-	-	-	-	-	-	-	-
SITE15	EO583549	Otawera u/s Kaiate confluence	-	-	-	-	8	8	36	8	8	5	8	-	-	8	5	-	-	8
SITE16	EO606570	Kaiate 100m u/s culvert	-	-	-	-	-	-	27	-	-	-	-	-	-	-	-	-	-	-
SITE100	EO719481	Otawera L/B trib at N Whareotetarakeho	-	-	-	-	4	4	4	4	4	-	4	-	-	4	-	-	-	4
SITE200	EO703432	Otawera L/B trib at SW Whareotetarakeho	2	2	2	2	4	4	4	4	4	-	4	2	2	4	-	-	-	4
SITE300	EO667451	Otawera L/B trib at SW Whareotetarakeho	-	-	-	-	4	4	4	4	4	-	4	-	-	4	-	-	-	4
Total			14	14	14	14	120	119	504	120	120	51	120	14	14	119	72	9	9	120

Where necessary data were combined to provide two data sets:

- a data set of FIB and stream discharge data, which was used to assess relationships between discharge and FIB concentrations over time, during events, and spatially, and
- a limited data set where relationships between FIB and other water quality variables were assessed.

The location of sample sites is indicated in Figure 2-1 and Figure 2-2.

Analysis of these data were undertaken using Systat for Windows v13.2.

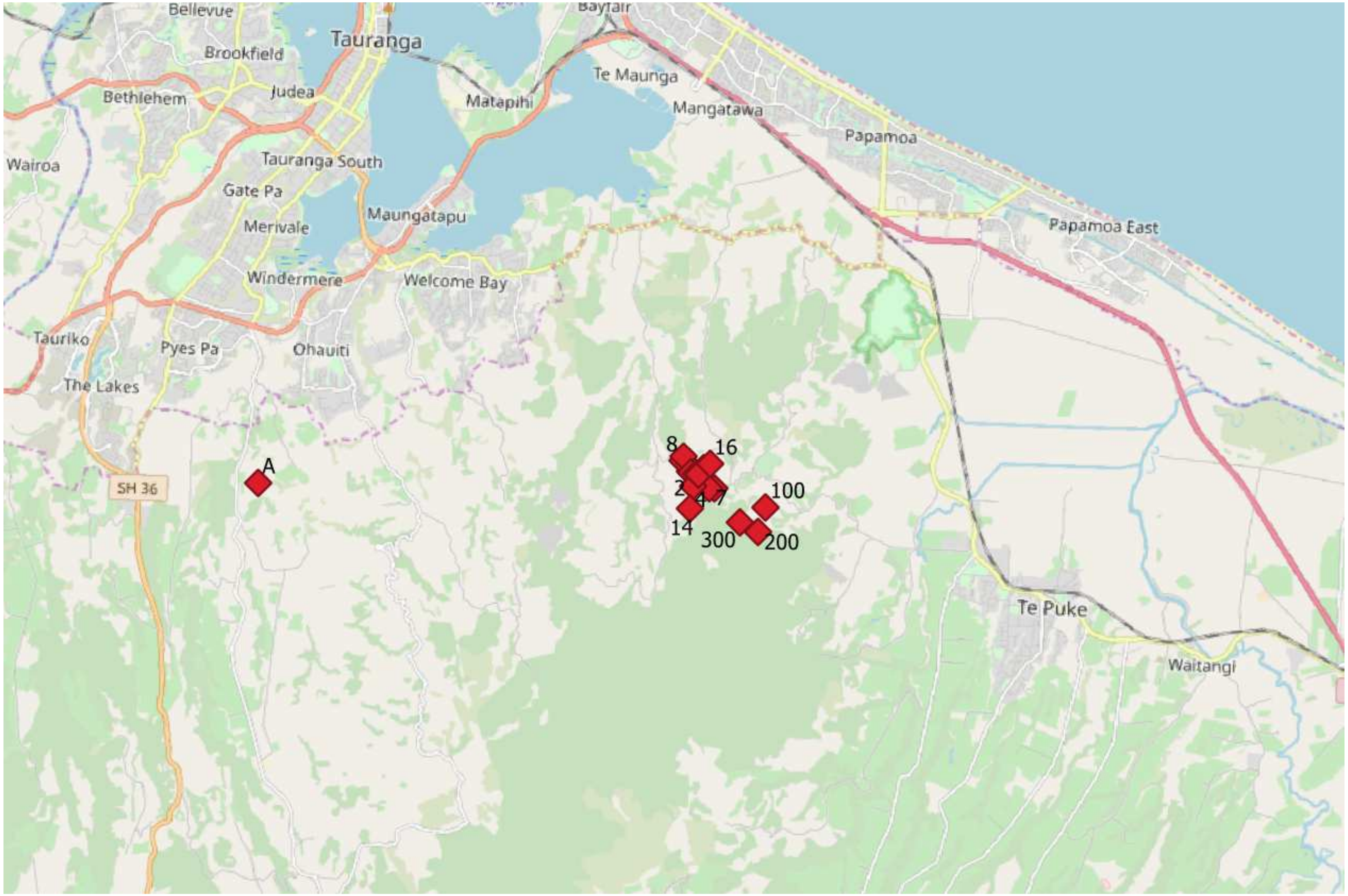


Figure 2-1: Location of rainfall measurement site (A) and water quality monitoring sites, Kaiate Stream catchment, in relation to Tauranga Harbour. Site codes and names are provided in Table 2-1.

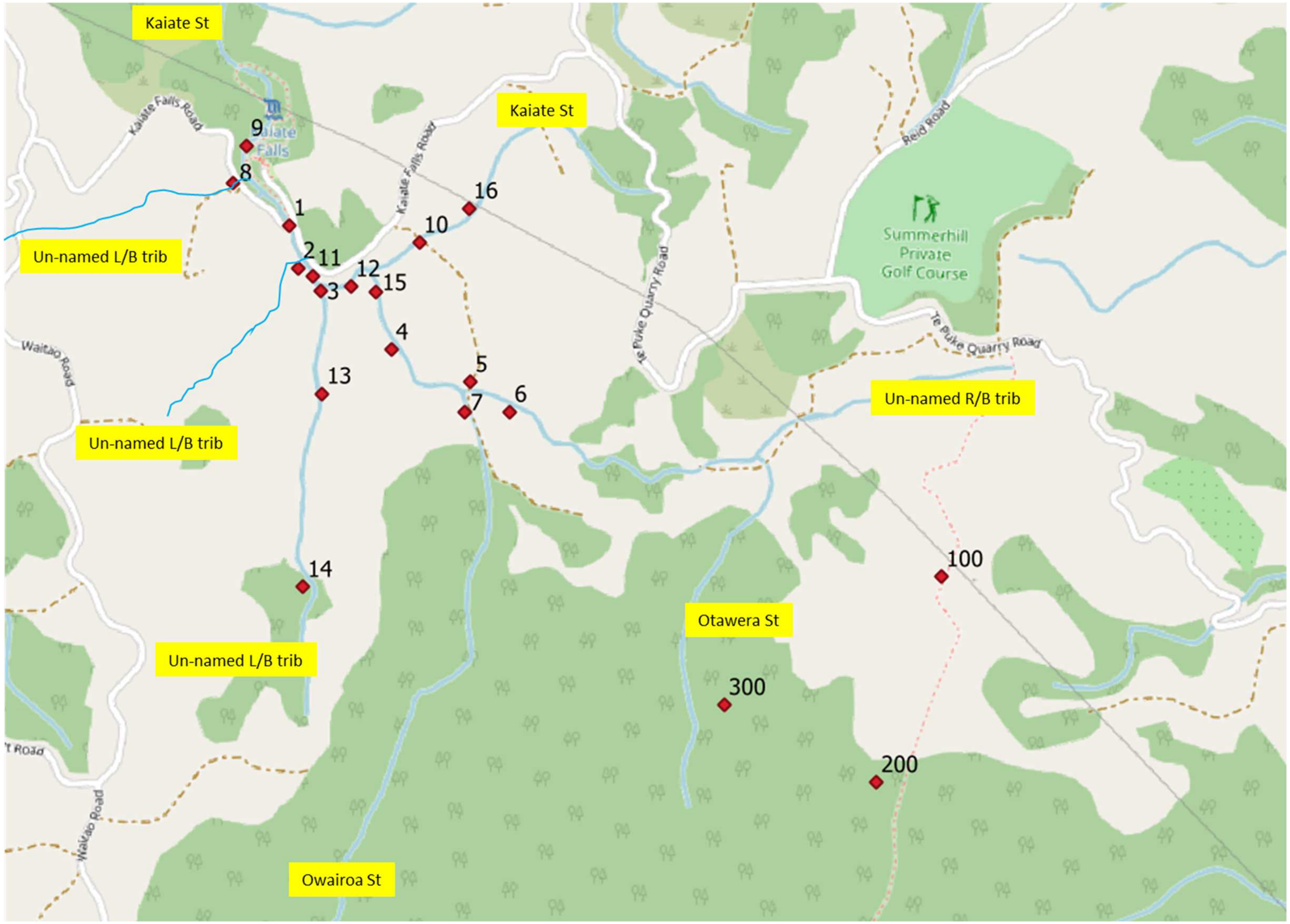


Figure 2-2: Location of water quality monitoring sites, Kaiate Stream catchment. Discharge is continuously measured at site 1. For site codes and names see Table 2-1.

3 Results and discussion

3.1 Rainfall and discharge

The catchment receives significant rainfall, with the lowest monthly rainfall received during the assessment period being 25 mm (November 2017), with more than 150 mm of rain falling in 14 of the 34-month period. Faecal contaminants are essentially small particles, and mobilisation of particulate material within the landscape in response to rainfall is well-established (e.g., Nagels et al. 2002; Collins et al. 2005; Collins et al. 2007; McKergow and Davies-Colley 2010; Ballantine and Davies-Colley 2013; Wu 2019).

Table 3-1: Total monthly rainfall, May 2017 - February 2019. These data are summarised graphically in Figure A-1.

Year	Monthly rainfall total by year (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016					91	178	147	65	181	83	102	57
2017	57	193	383	361	224	78	140	221	171	193	25	40
2018	156	252	110	187	132	188	125	145	42	96	146	315
2019	35	38										

The stream response to rainfall is rapid, and flow is "flashy", with many transient spikes in the flow record, shown in Figure 3-1.

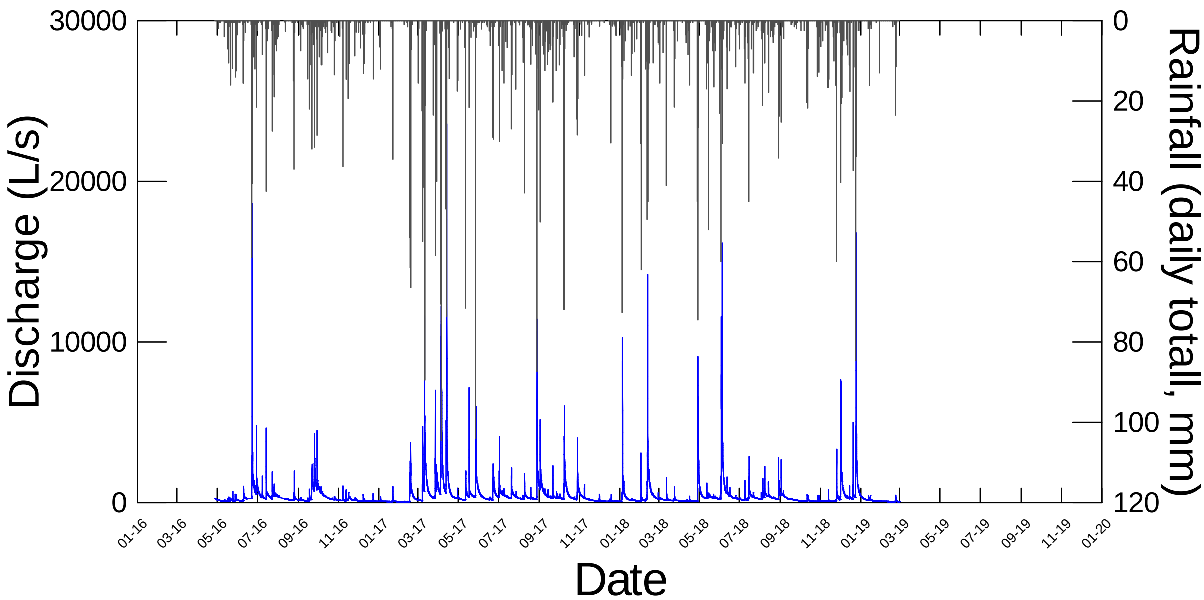


Figure 3-1: Daily rainfall and hourly average stream discharge in the Kaiate Stream. Discharge is the blue line, rainfall is black.

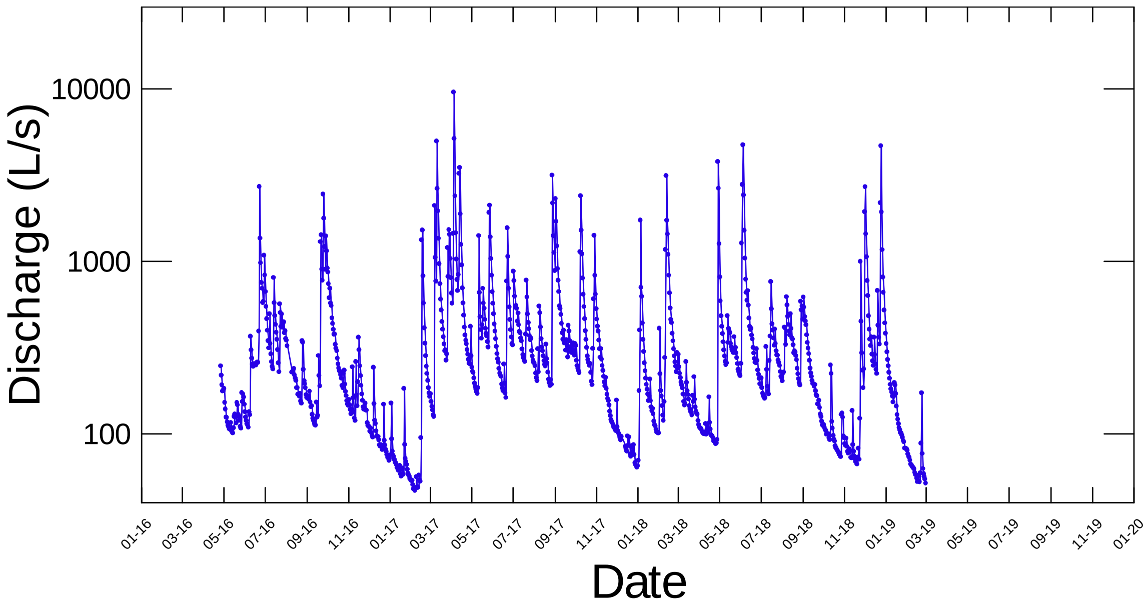


Figure 3-2: Daily median stream discharge in the Kaiate Stream.

In Figure 3-2, daily median flows are plotted on $\log_{10}$ scale. This figure indicates several periods of low flow, coinciding with each summer, as well as a period of prolonged relatively elevated flow in the winter of 2017. The latter is associated with Cyclone Debbie and Cyclone Cook in April 2017, which caused widespread flooding in the region. The flashy nature of the stream and fairly rapid recession from flood to base flows is also evident.

3.2 Flow relationships between sites

The relationship between flows gauged at selected water quality sample sites and continuously measured flow at Site 1 was briefly investigated. The results are summarised in Figure 3-3 through Figure 3-5. Key points include:

From Figure 3-3:

- An essentially linear relationship exists between flows measured at Site1 and at Site 11, Site12 and Site7.
- A model for all four sites is included in Appendix A – this could be optimised for each site individually.
- The optimised relationship for each site could be used to estimate contaminant loads from historical concentration data, and for future water quality campaigns.

From Figure 3-4:

- A relatively simple model based on square root of Site1. Concentrations describes flow at Site6 (explaining more than 95 of the variance in the data).

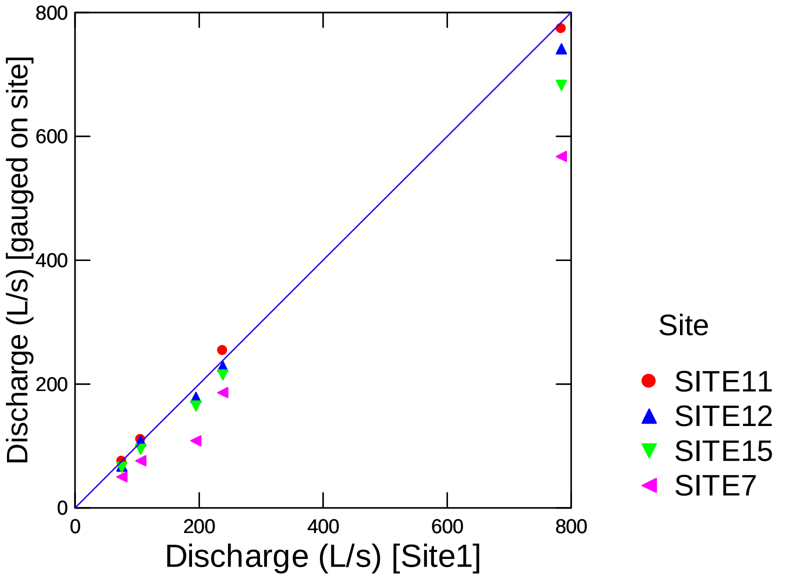


Figure 3-3: Relationship between continuously measured stream discharge in Kaiate Stream at Site1 and spot flow gauging results at selected sample sites. The blue line is the 1:1 relationship. A linear model that was fitted to these data is included in Appendix A.

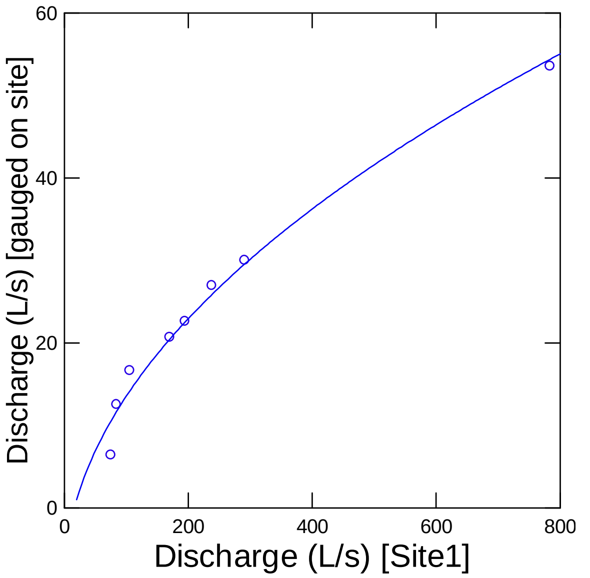


Figure 3-4: Relationship between continuously measured stream discharge in Kaiate Stream at Site1 and spot flow gauging results at Site6. The non-linear model used to describe this relationship is included in Appendix A.

From Figure 3-5:

- There is a large disparity between flows in these tributaries (where smaller predominate) and those at Site1.
- No obvious relationship exists between flows in tributary streams (e.g., Site2, Site3, Site5 and Site8), or between the upper reaches of Kaiate Stream (Site10) and flows measured at Site1.
- It is likely that additional gauging will need to be undertaken on each sampling occasion to provide reasonable estimates of contaminant loads – these additional data may allow flow relationships to be developed in future.

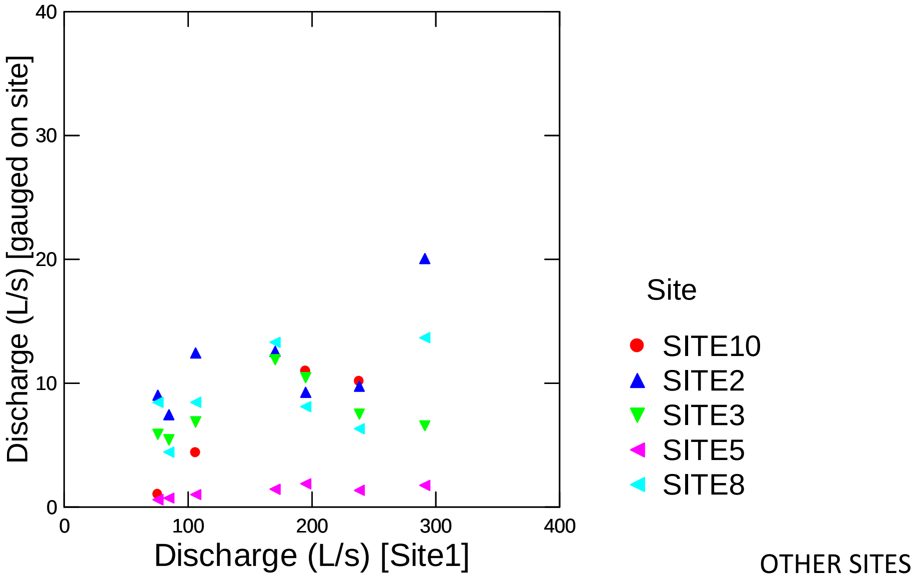


Figure 3-5: Relationship between continuously measured stream discharge in Kaiate Stream at Site1 and spot flow gauging results at selected sample sites.

3.3 Flow and *E. coli* concentration relationships

Statistics were calculated from the stream flow record (Table A-1). The flow record was then classified or "binned" according to flow decile, and the number of samples collected in various flow conditions were estimated. These are summarised in Table 3-2 for all sites, and for individual sites in Table A-2. The average *E. coli* concentration per site in each flow decile is summarised in Table 3-3.

- Points to note from Table 3-2:
  - Approximately half of all samples were collected when flows were less than 40th percentile (an approximation for "low flow"). This proportion could be larger, because flow conditions are unknown at present for 57 results.
  - Higher flow conditions (70th percentile and greater) are represented by approximately 17% of samples. Although this proportion is smaller than for the lower-flow conditions, these samples should adequately represent all flow conditions.

From Table 3-3:

- Average *E. coli* concentrations >550 /100 mL occur at all sites but four:
  - *E. coli* concentrations > 550/100 mL are observed across all flow deciles except the first and eighth (no samples appear to have been collected under the latter flow conditions) - average values have been used because of the relatively few results available for each site.
  - A larger proportion of elevated average *E. coli* concentrations occur in the second and third decile range. This could be a reflection of the larger proportion of samples collected under these conditions (noted above).
  - These data suggest that there is no immediately obvious relationship between flow and *E. coli* concentrations, consistent with previous results.

Table 3-2: Number of *E. coli* results per flow decile for all sites (data for period 31/05/2016 – 05/02/2019). This excludes samples collected when flow data were not available Decile bins derived from the data summarised in Table A-1 for Kaiate Stream at Site 1.

Flow decile	No samples	Proportion of results (%)
P0-P10	32	8
P10-P20	103	24
P20-P30	112	26
P30-P40	34	8
P40-P50	39	9
P50-P60	22	5
P60-P70	49	12
P80-P90	32	8

Table 3-3: Statistics for *E. coli* concentration for each site per flow decile for Site1 (data for period 31/05/2016 – 05/02/2019). Decile bins derived from data summarised in Table A-1 for Kaiate Stream at Site 1. Excludes data where no flow information exists.

Site	Statistic	Range of *E. coli* concentration at each site according to flow decile							
		P0-P10	P10-P20	P20-P30	P30-P40	P40-P50	P50-P60	P60-P70	P80-P90
SITE9	Min.	430	510	57	100	.	140	.	43
	Mean	505	510	57	100	.	140	.	202
	Max.	580	510	57	100	.	140	.	360
SITE8	Min.	130	260	24	42	75	53	.	63
	Mean	323	420	227	211	75	82	.	158
	Max.	490	580	430	380	75	110	.	300
SITE1	Min.	460	130	77	110	350	190	260	42
	Mean	513	1487	649	605	373	645	508	261
	Max.	540	4200	1320	1100	390	1100	730	530
SITE2	Min.	300	130	38	270	310	60	.	45
	Mean	330	200	339	735	310	325	.	818
	Max.	380	270	640	1200	310	590	.	2000
SITE11	Min.	320	270	280	220	240	390	270	220
	Mean	320	1326	603	337	378	390	424	220
	Max.	320	3600	1180	540	490	390	540	220
SITE3	Min.	310	140	130	140	160	90	250	97
	Mean	437	820	650	285	275	260	667	386
	Max.	540	1300	1400	640	400	430	1430	630
SITE13	Min.	.	300	540	220	210	.	590	.
	Mean	.	1248	764	310	263	.	652	.
	Max.	.	3400	1200	400	310	.	710	.
SITE14	Min.	.	210	50	250	250	.	200	.
	Mean	.	902	702	285	293	.	386	.
	Max.	.	1800	1000	320	340	.	520	.
SITE12	Min.	410	150	60	230	230	480	300	130
	Mean	410	1140	598	677	255	480	412	130
	Max.	410	2500	1400	1500	290	480	560	130
SITE10	Min.	140	150	53	42	500	190	1040	17
	Mean	253	468	365	571	578	265	1280	182
	Max.	350	1000	690	1100	700	340	1620	300
SITE16	Min.	.	460	160	.	410	.	760	.
	Mean	.	1693	380	.	520	.	1422	.
	Max.	.	6600	730	.	590	.	3600	.

Site	Statistic	Range of *E. coli* concentration at each site according to flow decile							
		P0-P10	P10-P20	P20-P30	P30-P40	P40-P50	P50-P60	P60-P70	P80-P90
SITE15	Min.	310	160	310	150	180	270	230	95
	Mean	310	493	655	263	290	270	322	95
	Max.	310	1100	2000	460	560	270	450	95
SITE4	Min.	220	60	14	54	150	58	270	50
	Mean	283	530	132	242	150	384	270	140
	Max.	340	1000	250	430	150	710	270	280
SITE5	Min.	110	83	57	20	210	150	570	19
	Mean	290	297	139	1160	210	725	570	390
	Max.	480	510	220	2300	210	1300	570	970
SITE6	Min.	210	640	51	200	250	73	160	57
	Mean	347	6320	206	290	250	587	160	129
	Max.	450	12000	360	380	250	1100	160	220
SITE7	Min.	240	130	4	24	120	29	.	18
	Mean	307	165	167	342	120	125	.	156
	Max.	410	200	330	660	120	220	.	260

During late 2018 and early 2019, stream discharge was estimated at most sites where water quality samples were collected, on each sampling occasion. These data were also assigned into various flow bins based on flows measured at site 1 (assuming that the flows at all sites were likely to be related to those measured at site 1), and the total number of results available for each flow bin are shown in Table 3-4. The number of results per site and flow bin are shown in Table 3-5.

Table 3-4: Number of *E. coli* results per flow decile for each site where site-specific flow gauging was undertaken (data for period 05/12/2018 – 05/02/2019). Decile bins derived from the data summarised in Table A-1 for Kaiate Stream at Site 1.

Flow decile	Number of samples	Proportion of samples (%)
P0-P10	11	16
P10-P20	6	9
P20-P30	11	16
P30-P40	6	9
P40-P50	10	14
P50-P60	11	16
P60-P70	3	4
P80-P90	11	16

Table 3-5: Number of *E. coli* results per flow decile for Site1 for each site where site-specific flow gauging was undertaken (data for period 05/12/2018 – 05/02/2019). Decile bins derived from the data summarised in Table A-1 for Kaiate Stream at Site 1.

Site	Number of results per flow decile								
	P10-P20	P20-P30	P30-P40	P40-P50	P50-P60	P60-P70	P80-P90	below P10	Total
SITE8	1	1	1	1	1	1	1	1	8
SITE1	1	1	1	1	1	1	1	1	8
SITE2	1	1	1	1	1	1	1	1	8
SITE11	0	1	0	0	1	0	1	1	4
SITE3	1	1	1	1	1	1	1	1	8
SITE12	0	1	0	1	1	0	1	1	5
SITE10	0	1	0	1	1	0	1	1	5
SITE15	0	1	0	1	1	0	1	1	5
SITE5	1	1	1	1	1	1	1	1	8
SITE6	1	1	1	1	1	1	1	1	8
SITE7	0	1	0	1	1	0	1	1	5
Total	**6**	**11**	**6**	**10**	**11**	**6**	**11**	**11**	**72**

At most, single results were available for each site and flow bin. These data are shown in Table 3-6, where values are colour-coded according to the MfE/MoH recreational water quality guideline values for freshwater surveillance (MfE/MoH 2003). The guidelines identify single sample threshold concentrations as **acceptable** (<260 *E. coli*/10 mL – green mode), **alert** (≥260 and <550 *E. coli*/100 mL – amber mode, and **action** (≥550 *E. coli*/100 mL – red mode) levels, respectively. Although these classifications are intended to trigger monitoring response during recreational monitoring programmes, they indicate increasing health risk. Approximately 25% of results fell in the green or red category, and half of results were in the amber category. These results confirm generally poor microbiological water quality in the upper Kaiate Stream catchment.

Table 3-6: *E. coli* concentrations per flow decile for each site where site-specific flow gauging was undertaken (data for period 05/12/2018 – 05/02/2019). Concentrations are single sample values per decile bin (i.e., there were no replicates). Decile bins derived from the data summarised in Table A-1 for Kaiate Stream at Site 1. Colour codes according to MfE/MoH guidelines (MfE/MoH 2003).

Site	*E. coli* concentration per site per flow decile							
	P0-P10	P10-P20	P20-P30	P30-P40	P40-P50	P50-P60	P60-P70	P80-P90
SITE1	540	750	420	1100	350	1100	.	210
SITE8	350	580	430	380	75	110	.	110
SITE2	310	270	640	1200	310	590	.	2000
SITE11	320	.	280	.	.	390	.	220
SITE3	460	520	590	640	400	430	250	430
SITE12	410	.	260	.	240	480	.	130
SITE10	350	.	690	.	510	340	.	300
SITE15	310	.	440	.	230	270	.	95
SITE5	480	510	220	2300	210	1300	570	970
SITE6	450	12000	360	380	250	1100	160	110
SITE7	270	.	330	.	120	220	.	190

In many river catchments, there is a relationship between stream flow and the concentration of water quality – as flow increases, the concentration may increase (indicating runoff input of contaminants to surface water), or decrease (the contaminant is diluted as flow increases, characteristic for point sources). The relationship is complex and determined by the nature of the contaminant source, the proximity of the contaminant source to the stream, and the role of groundwater in mobilising the contaminant. Prior to December 2018, flow data were available only for site 1, where a continuous record exists. Relationships between concentration measured at each and a single flow record may not be strong.

The relationship between flow and *E. coli* concentrations is summarised for all sites in Figure 3-6, Figure 3-7 and Figure 3-8.

For Figure 3-6:

- The relationship between concentration at each site and flow measured at site 1 is shown by the blue crosses, and where available, the relationship between concentration and flow measured on site is shown by the red dots.
- At all sites (with possible exception of site 10):
  - An almost invariant, possibly inverse relationship between *E. coli* concentration and flow is suggested, i.e., *E. coli* numbers decrease in response to flow (dilution is occurring).
  - At site 10, a slight increase in *E. coli* concentration in response to flow is suggested.
  - On-site measurement of flow does not appear to alter the general flow-concentration relationship.

From Figure 3-7:

- the sample site concentrations appear to move as "groups", related by weather, flow or conditions at the time of sampling – this is discussed further in Section 3.4.

In Figure 3-8 the relationship between flow and concentration for all sites and all dates is indicated for samples where on-site flow gauging was conducted at the time of sampling. The overall decrease in concentration with flow is confirmed; there is also sign of some grouping of sites – these are single samples/date for each sample date.

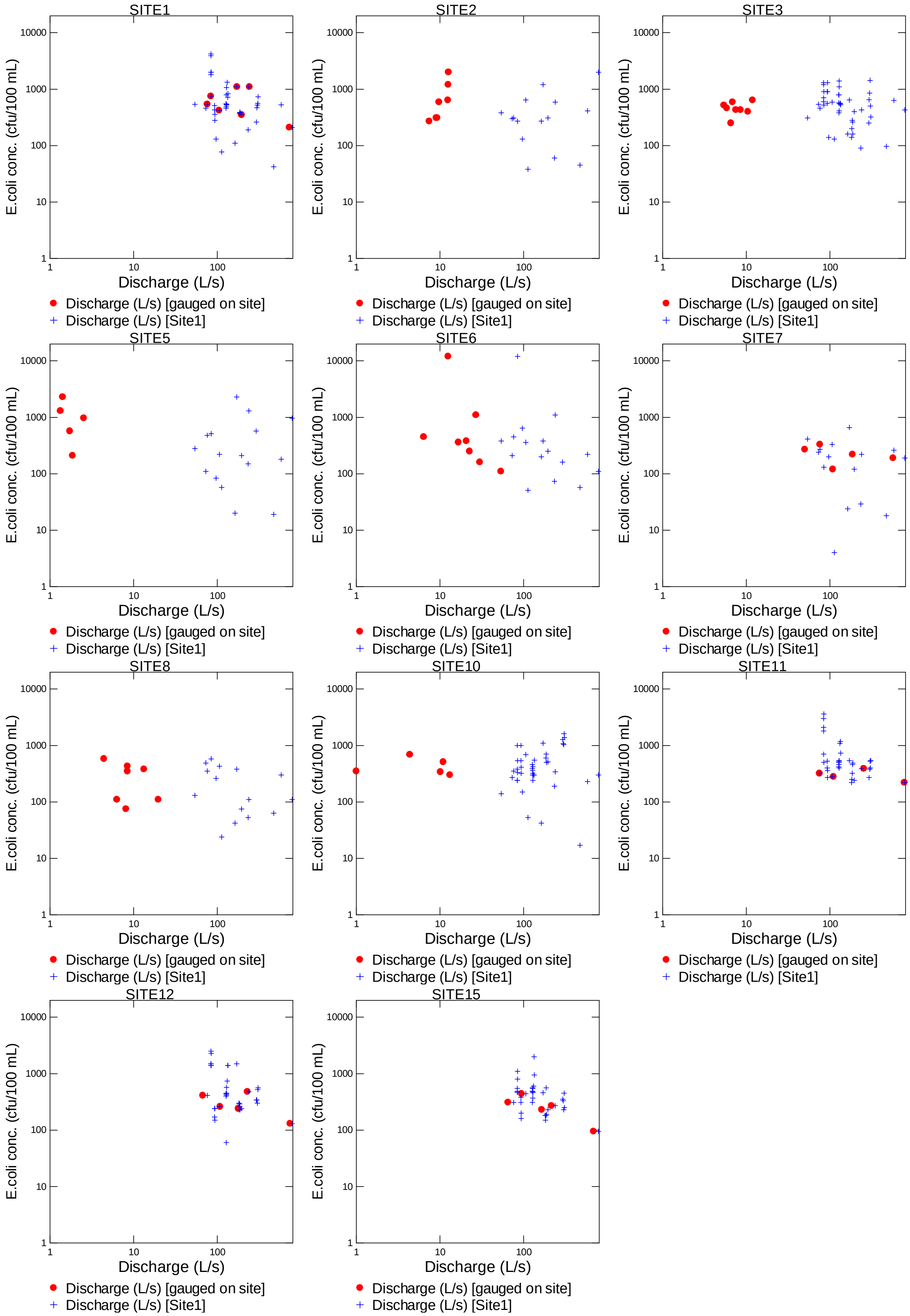


Figure 3-6: Relationship between *E. coli* concentrations and discharge. Note x- and y-axes have $\log_{10}$ scale. Red dots are relationship for at-site gauged flow, blue crosses are relative to Site 1 flows.

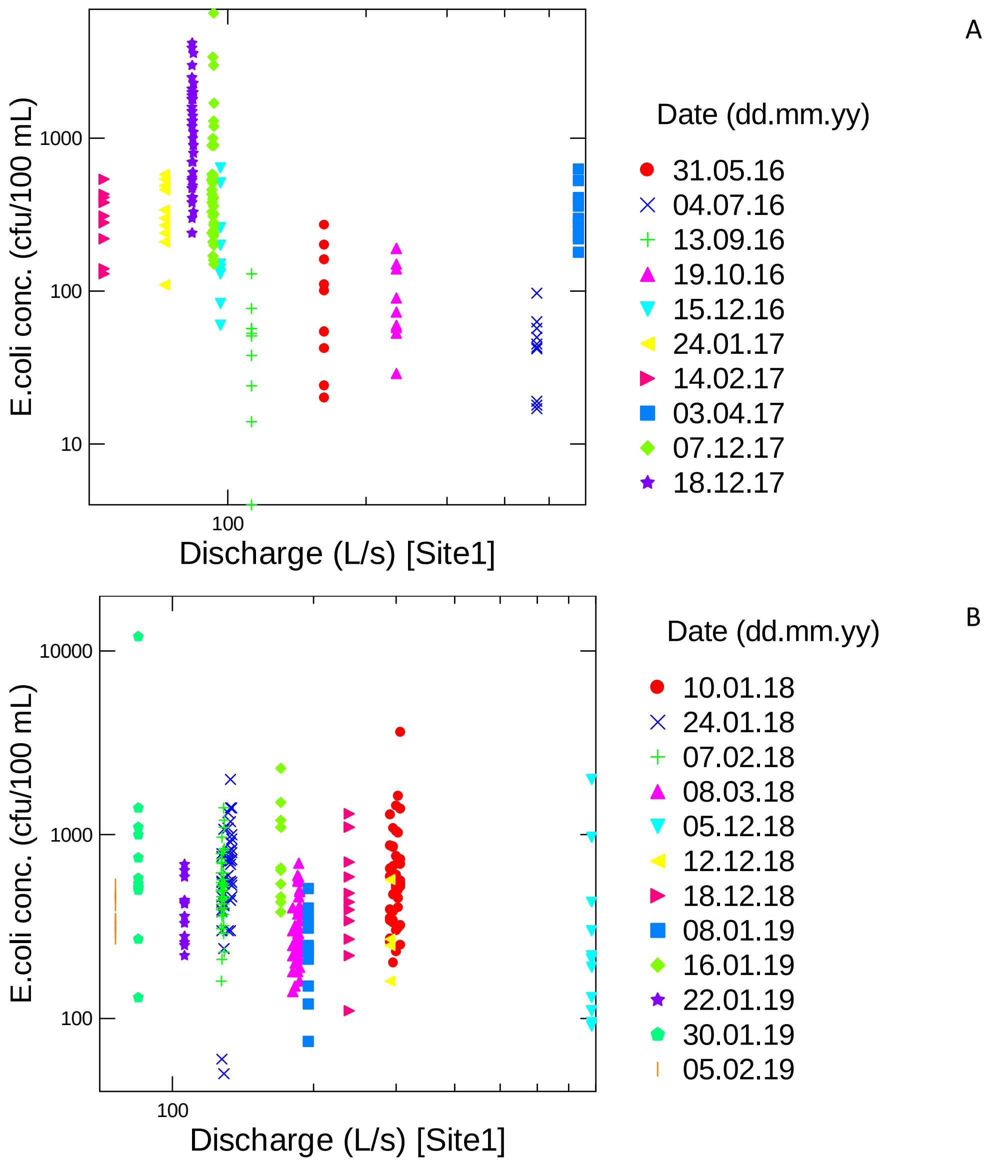


Figure 3-7: Relationship between *E. coli* concentrations at all sites and discharge by sampling date A) = 2016 and 2017, and B = 2018 and 2019. Discharge data are from Site1. Note x- and y-axes have $\log_{10}$ scale.

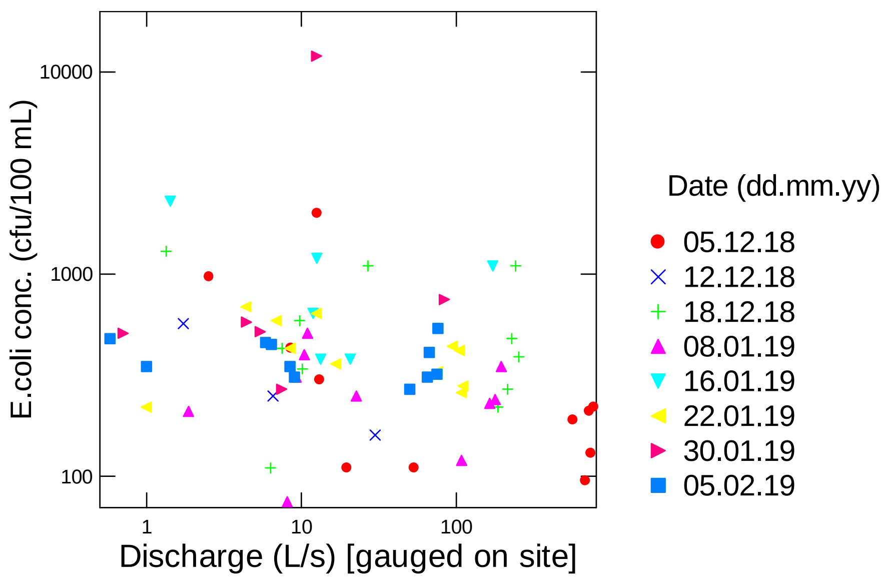


Figure 3-8: Relationship between *E. coli* concentrations at all sites and discharge by sampling date, 2018/2019. Discharge data are from on-site gauging. Note x- and y-axes have $\log_{10}$ scale.

In Figure 3-9 the relationship between flow and concentration is explored for four sites along the mainstem of the Kaiate Stream on four different sampling visits. Concentrations at sites 1, 11 and 12 are reasonably close under all flow conditions.

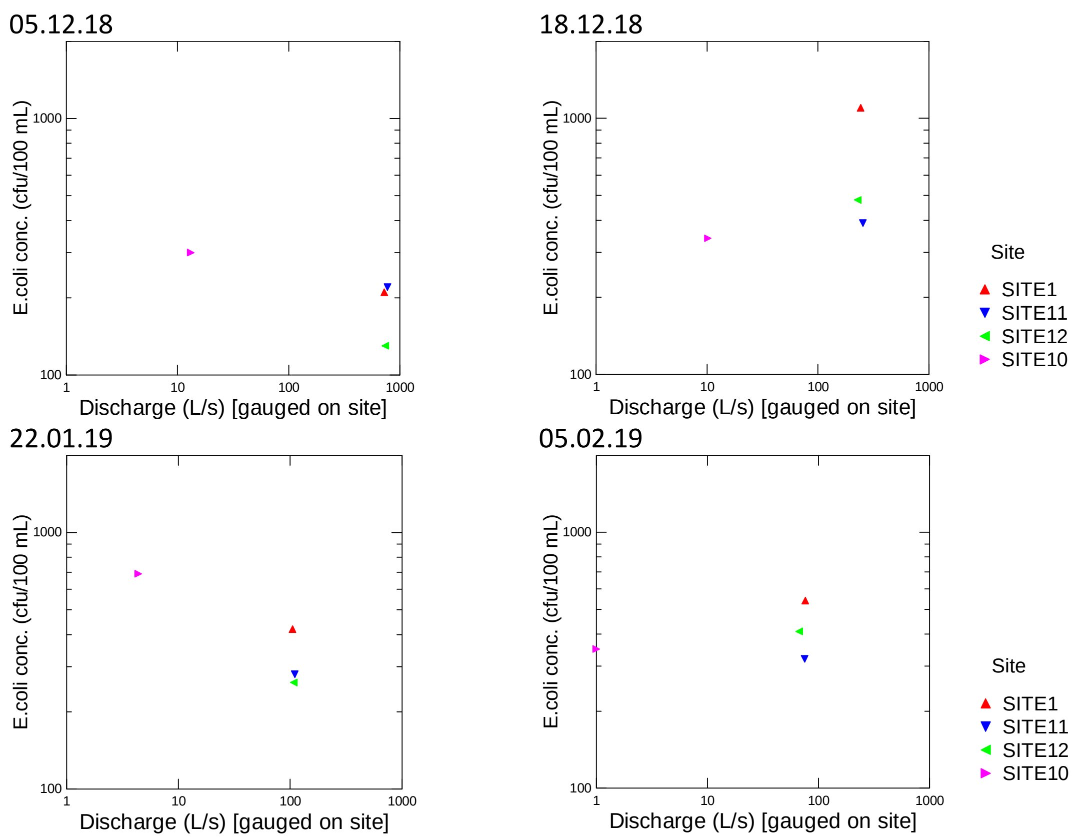


Figure 3-9: Relationship between concentration and flow at four sites along the Kaiate Stream mainstem during four sampling events.

3.4 Temporal nature of *E. coli* concentrations

The range of concentrations and average concentration across all sites by sampling date was indicated in Figure 3-7. These data indicate that from sampling date to sampling date, the concentrations of *E. coli* at all sites tend to move together. This suggests a common type of source across the catchment, and common mobilisation factors between sites. In Figure 3-10 the influence of flow is demonstrated – during a flood event in July 2017, *E. coli* concentrations at all sites were diluted. Thereafter the relatively weak response to flow indicated earlier is confirmed.

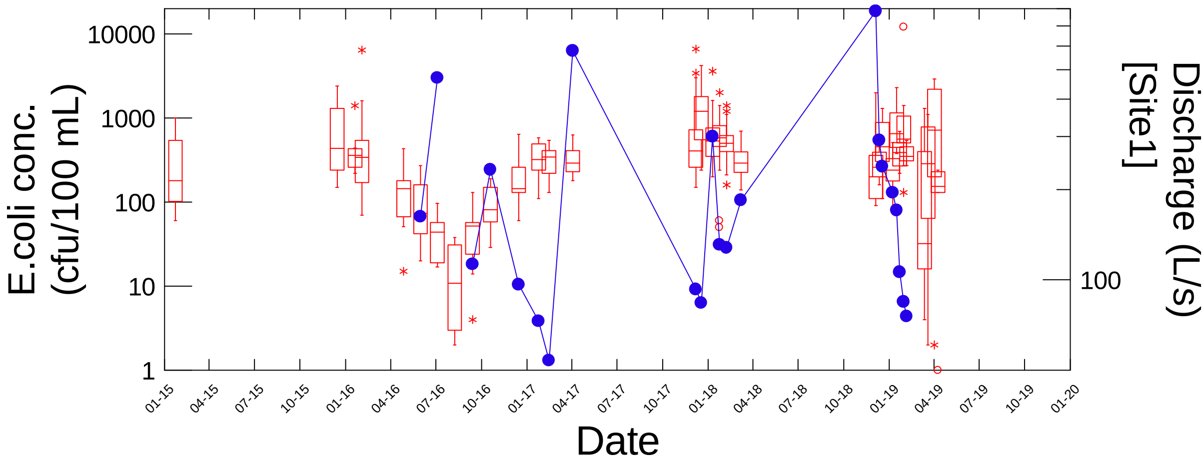


Figure 3-10: *E. coli* concentrations over time – data for all sites by sample date. Flow data derived from Site1 historical record. Flow data (blue line and dots) not available for all sample dates. Note y-axis has $\log_{10}$ scale. An explanation of the box and whisker plot is included in Appendix B.

In Figure 3-11 through Figure 3-14 data are summarised for mainstem sites and tributary sites by year. In Figure 3-15 the Otawera Stream sub-catchment sites are considered separately. In all cases, the tendency for groups of sites to "move" in terms of *E. coli* concentration between sample dates is evident. This suggests that common (and similar) factors (climate, flow, land use, source type) determine the mobilisation of *E. coli*.

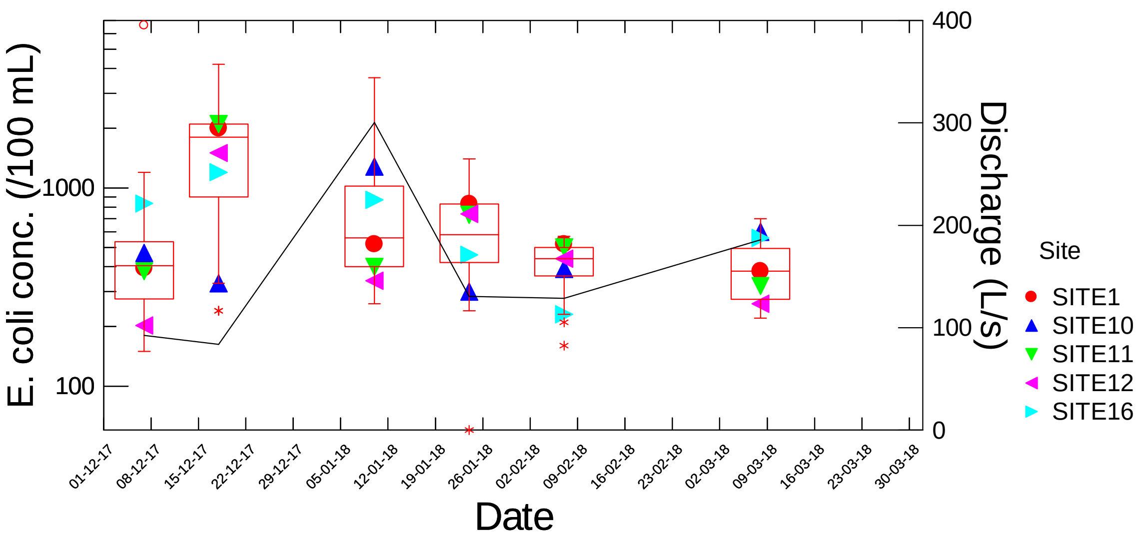


Figure 3-11: *E. coli* concentrations for 2017/18 summer for mainstem sites (symbol) by sample date. All data for each sample date represented by box and whisker plot, with available flow data (black line). Note primary y-axis has $\log_{10}$ scale.

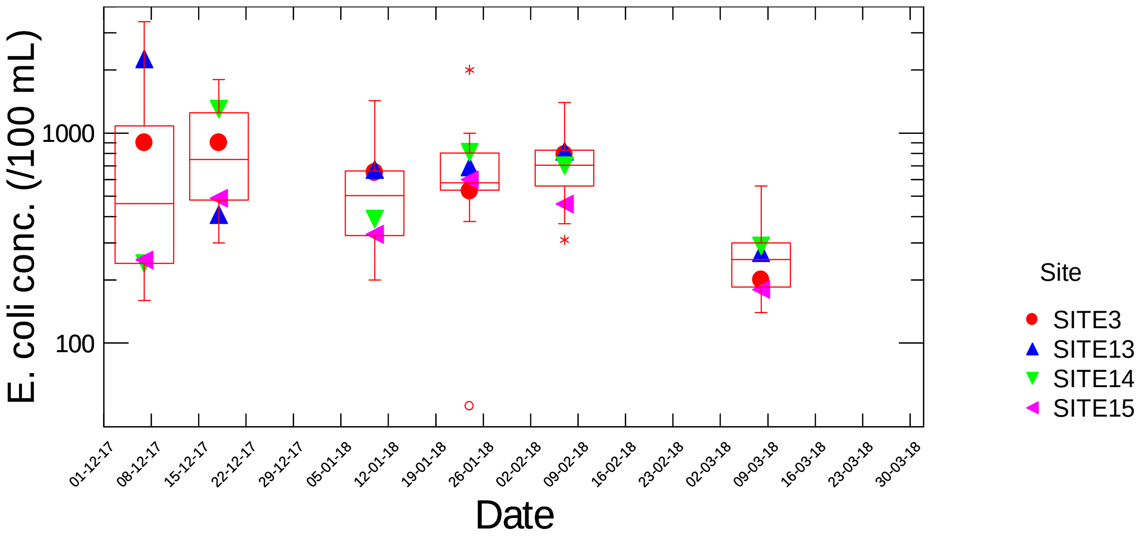


Figure 3-12: *E. coli* concentrations 2017/18 summer for tributary sites (symbol) by sample date. All data for each sample date represented by box and whisker plot. Note y-axis has log_{10} scale.

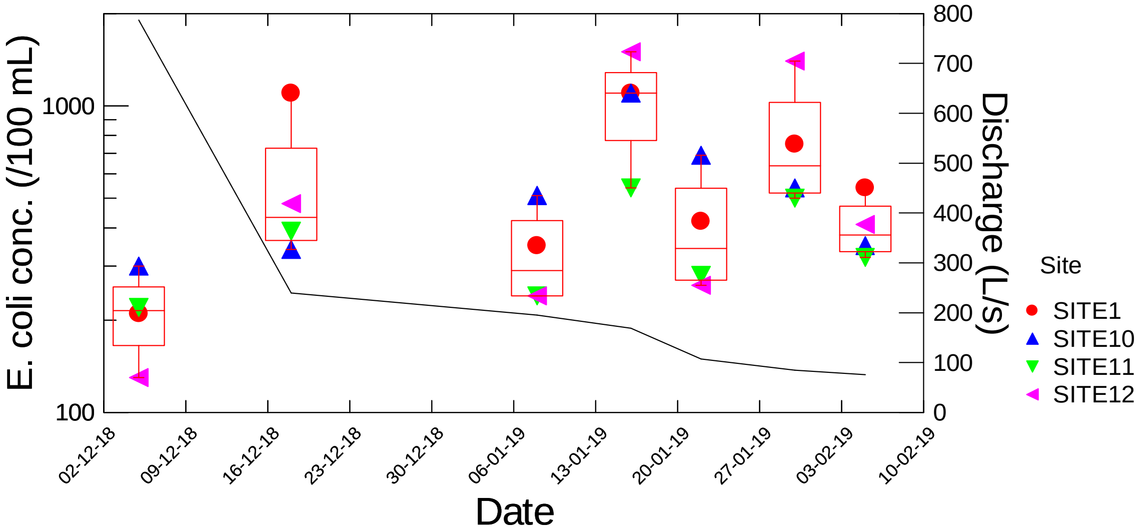


Figure 3-13: *E. coli* concentrations for 2018/19 summer –concentration for mainstem sites by sample date (symbol). Each dot represents a single sample. All data for each sample date represented by box and whisker plot, with available flow data (black line). Note y-axis has log_{10} scale.

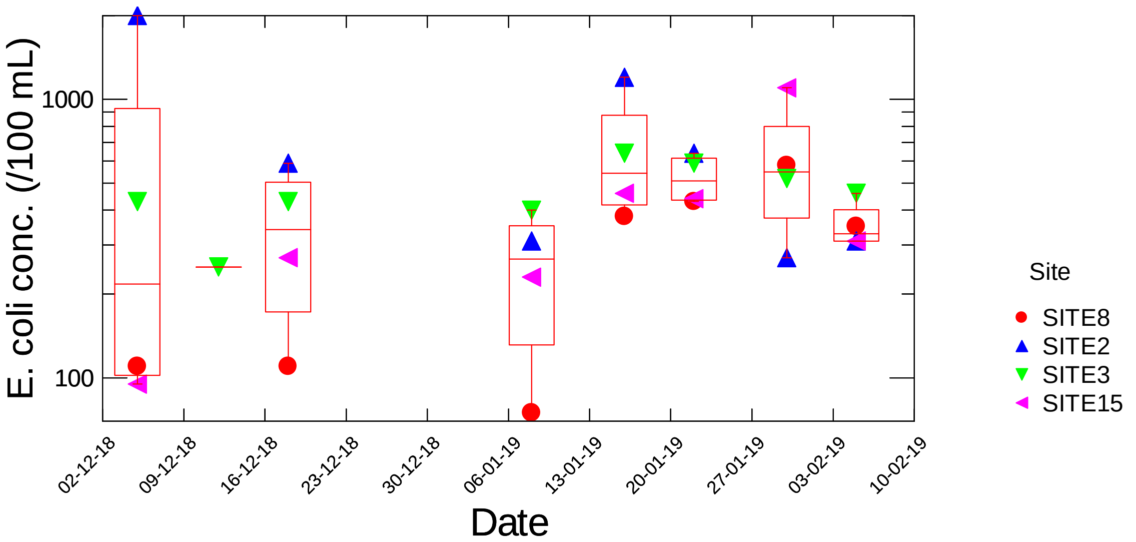


Figure 3-14: *E. coli* concentrations for 2018/19 summer –concentrations for tributary sites by sample date (symbol). Each dot represents a single sample .All data for each sample date represented by box and whisker plot, with available flow data (black line). Note y-axis has log_{10} scale.

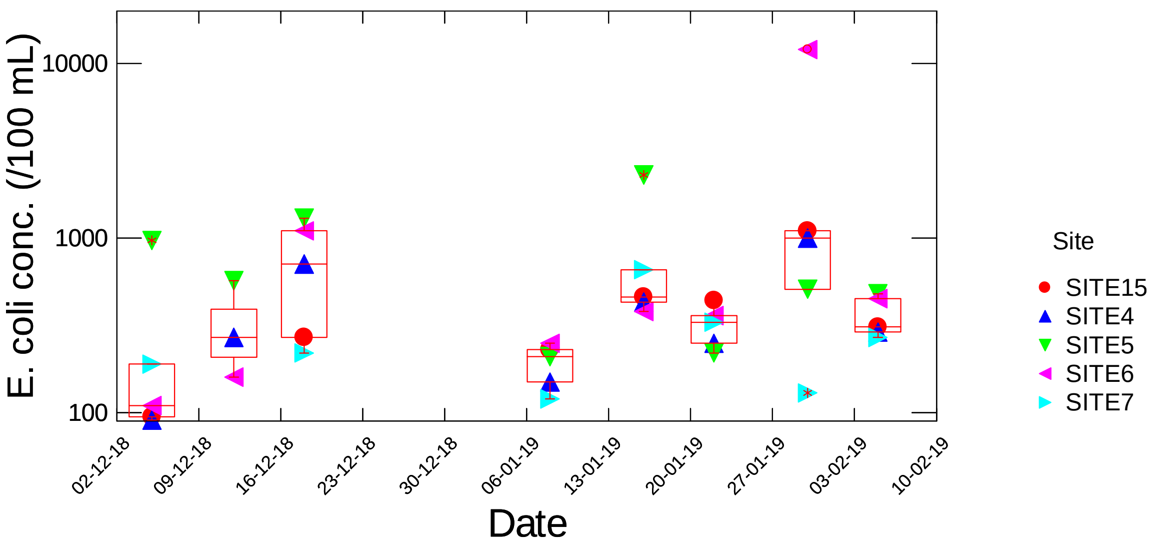


Figure 3-15: *E. coli* concentrations 2018/19 summer for sites on Otawera Stream (upstream of site 15) by sample date (symbol). Each dot represents a single sample. All data for each sample date represented by box and whisker plot. Note y-axis has log_{10} scale.

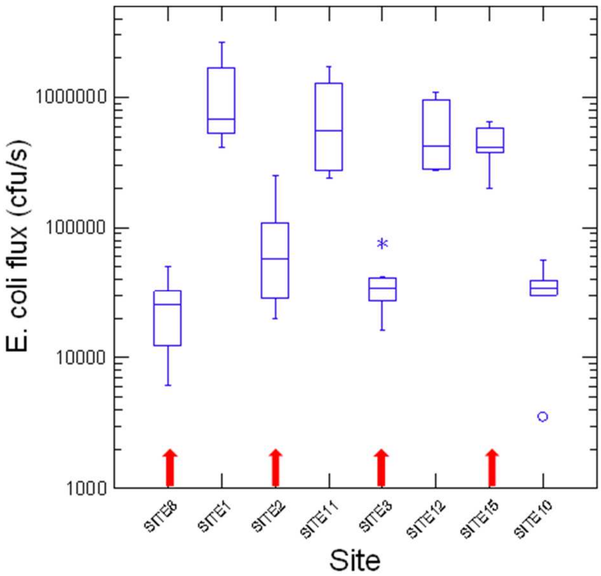
3.5 Spatial differences in *E. coli* concentrations

Statistics for all *E. coli* concentration results for all sites are summarised in Table C-1.

- Ninety-fifth percentile concentrations above 550 cfu/100 mL occur across all the sample points (orange shaded cells in Table C-1).
- Median concentrations across all sites and flow conditions range from 195 /100 mL to 620 /100 mL. Three sites have higher median concentrations than the other sites, and these are close to or exceed 550 cfu/100 at three sites– Site 3, Site 13 and Site 16.
- Median concentrations at Site 14 (upstream of Site 13) are also elevated (520/100 mL).

It is difficult to predict the impact that contaminant inputs from individual catchments with elevated FIB concentrations may have on downstream water quality without knowledge of the flow as well. The product of flow and concentration at the time of sampling provides an estimate of flux or instantaneous load. Flux is expressed in terms of contaminant mass (or FIB numbers) per unit of time. Summary statistics for flux estimates are provided in Appendix D.

Flux estimates are shown for all sites where site-specific flow data exist in Figure 3-16.



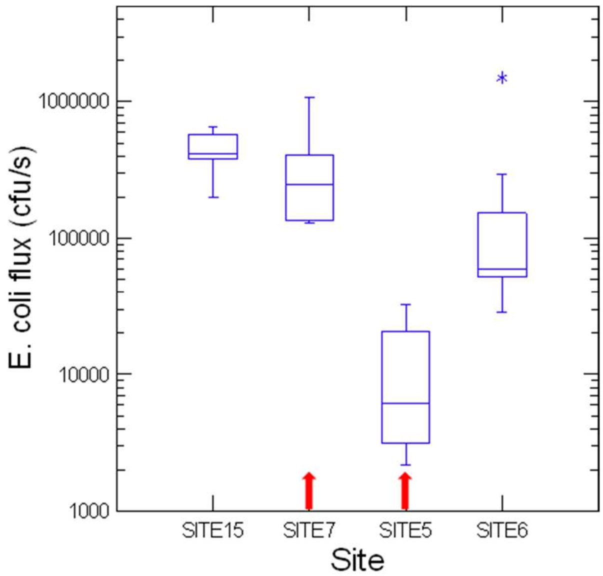


Figure 3-16: *E. coli* flux for all sites where site-specific flow data are available. Sites are arranged from downstream to upstream (left to right). The left-hand figure is the mainstem of the Kaiate Stream. The right-hand figure is for sites in the Otawera Stream. Inflows or tributary streams indicated with red arrows. Note y-axis has $\log_{10}$ scale.

Considering the Otawera Stream first (Figure 3-16, right):

- *E. coli* flux increases in a downstream direction, with median flux increasing from approximately 60,000 cfu/s (Site6) to 400,000 cfu/s (Site15).
- Site 5 (median flux 6,000 cfu/s) is a relatively minor contributor of FIB relative to Site 7 (median approximately 250,000 cfu/s).
- Load or flux values are additive – the upper three sites contribute approximately 320,000 cfu/s, i.e., more than 75% of the FIB load measured at Site 15.

- If the relative areas of the contributing sites is estimated, the yield (cfu/unit area/unit time) may be estimated.
- The yield helps identify which catchment streams should be prioritised for further investigation or mitigation.
- These data suggest that the contribution of FIB in the upper catchment (increasing order) is Site 5, Site 6 and Site 7.

A similar trend (increasing flux in a downstream direction) is indicated in the Kaiate Stream (Figure 3-16, left):

- Site 10 contributes a similar load of FIB as the smaller tributary streams (sites 3, 2 and 8), which range from 25,000 cfu-50,00 cfu.
- The Otawera Stream (Site 15) is obviously the major source of FIB to the Kaiate Stream, increasing FIB flux by more than one log order (1000 times).
- Although the un-named stream represented by site 3 contributes FIB to the Kaiate Stream, the flux from this tributary appears too small to explain the increase in flux observed between site 12 and site 11. It is possible that stock access or other inflows are also contributors.
- Site 2 accounts for most of the increase in FIB flux between site 11 and site 1.
- Site 8 is the smallest FIB contributor in the lower catchment.

The FIB flux data "normalises" the contributions of all tributaries, and allows the catchments to be prioritised for mitigation actions. The Otawera Stream catchment appears to be the major source of FIB, and within the sub-catchment the branch represented by site 7 dominates.

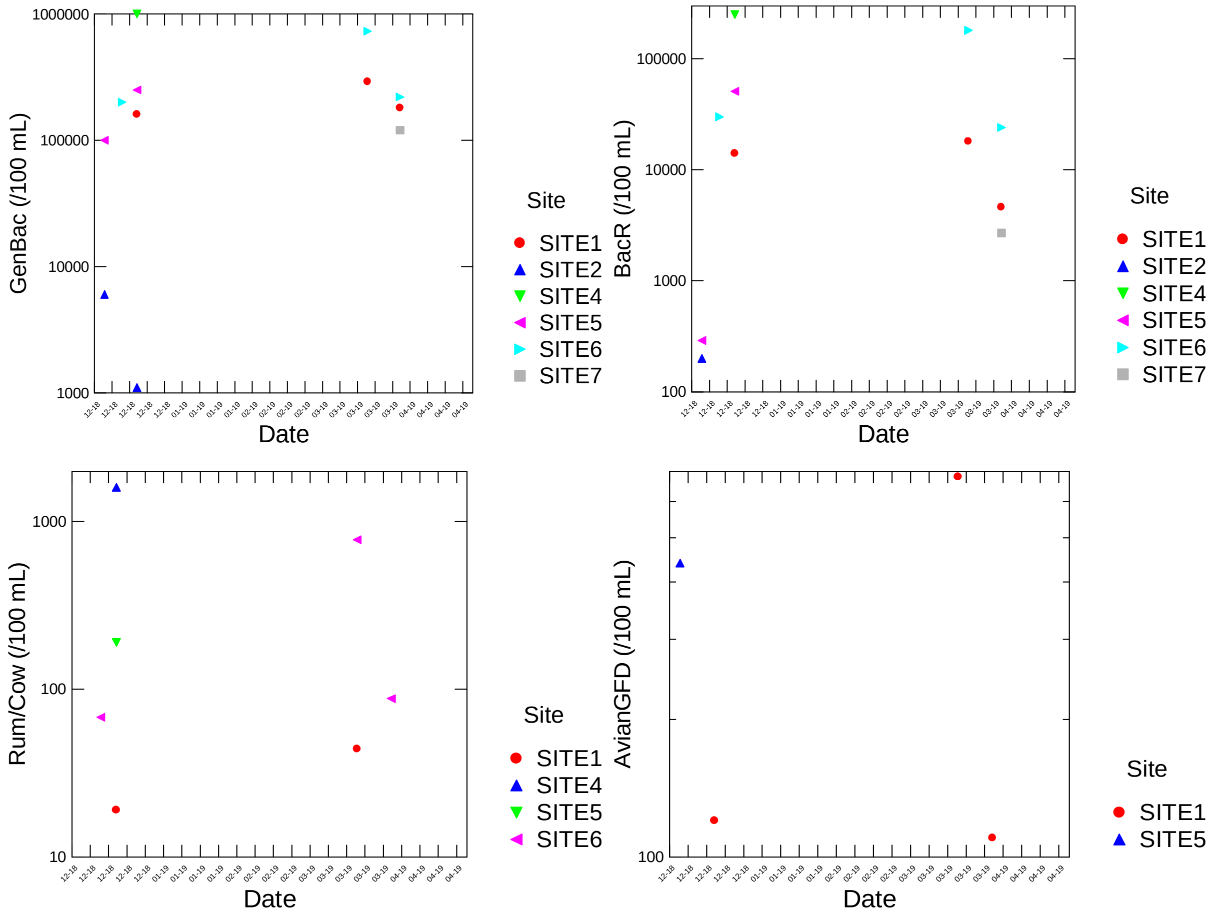
3.6 Faecal source tracking

In 2018 and 2019 several surveys were conducted where samples were collected for different analyses to determine the likely source and source type of faecal contaminants. Data derived from surveys conducted on 5/12/18, 12/12/18, 18/12/18, 20/03/19, and 2/04/19 are summarised in Figure 3-17. Points to note:

- The concentrations of the general marker (GenBac) and ruminant marker (BacR) behaved similarly over time, with elevated concentrations at sites 4 and 6 in the Otawera Stream.
- Site 1 concentrations were generally elevated as well, reflecting all upstream inputs.
- Site 2 (unnamed LB tributary) had generally low concentrations, and is probably a less significant source of faecal contaminants.
- Ruminant/cow marker concentrations were lowest at site 1, and ranged over an order of magnitude at sites in the Otawera Stream catchment.
- Avian markers were generally low, detected but not quantified at site 6, and quantified at sites 1 (three observations) and 6 (single result).

Human and avian faecal sources are limited, and detectable at site 1. This is unexpected, because recreation is most likely at the Falls, which are downstream of this site (a road bridge). Further investigation may indicate that people do access the river or river channel at this site, and if vehicles are stopping near this site, it is possible the birds are attracted to potential food sources. These suggestions are speculative.

These data clearly indicate that ruminants (specifically bovine species) are the dominant source of faecal contaminants in the catchment – the BacR marker was detected in all samples but one. It is notable that ovine markers were not detected in any samples (all results reported as below the limits of detection (100/100 mL)). It would be prudent to confirm these results in another survey where the samples are subject to a more sensitive test. When combined with the FIB load estimates, stock access to the river channel in Otawera Stream could be prioritised for further investigation.



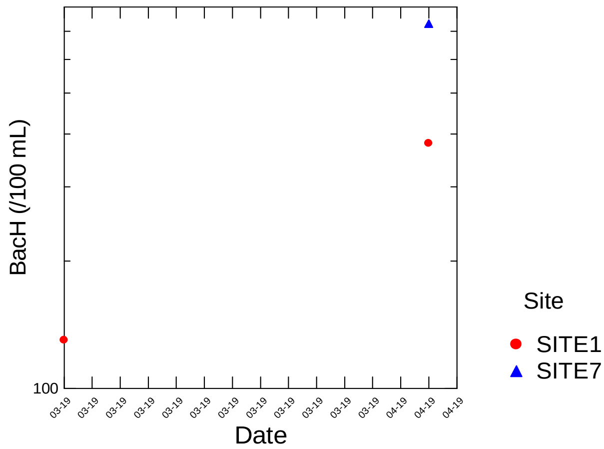


Figure 3-17: Concentrations of various source tracking markers for sites (symbol) by sample date. Note y-axis has $\log_{10}$ scale.

3.7 Relationships between FIB and other water quality variables

Available data were summarised on a site-specific basis in Appendix E. Sites were grouped as Kaiate Stream main stem sites, Otawera Stream catchment sites, and lower Kaiate Stream tributaries. Data are presented to visualise the relationship between *E. coli* and turbidity, electrical conductivity and pH.

None of these variables appear immediately suitable as surrogates that allow estimation of *E. coli* concentrations. Further investigation is required to detmonstrate how they may be used to help explain some of the variability in *E. coli* that is observed. For example, turbidity may prove useful to demosntrate that elevated FIB conscentrations are linked with transient spikes in turbidity. For this to be posible, it would be necessary to have a continuous turbidity record.

4 Recommendations for monitoring

These data indicate that land use activities, rainfall and other catchment-wide factors generate similar levels of faecal contamination in terms of concentration. When combined with site-specific flow estimates, however, the dominant sources of FIB are indicated quite clearly.

We note that concentrations at all sites tend to "move" as a group between events. This behaviour could be used to reduce the number of sites at which monitoring occurs. Suggestions for monitoring follow:

1. As far as possible, site-specific flow gauging is recommended for key sites. Where a good relationship between flow at Site 1 and upstream sites exists (sites 11, 12 15, 7, and 6), the flux may be estimated adequately to quantify the load at these sites. This is important for sites 6 and 7, which appear to be the two sub-catchments that should be prioritised for mitigation.

2. If the number of sites were reduced, we recommend that flow-proportional or flow-related sampling is undertaken at a few key sites (particularly in the Otawera Stream), to better understand the relationship between concentration and flow, and to estimate the FIB flux. This can be done efficiently by using automatic samplers, which can be triggered remotely in response to flow or some other variable.

3. Collection of flow-related samples will also allow relationships between *E. coli* concentrations and other variables, such as turbidity or electrical conductivity to be established. If these relationships can be demonstrated, then variables such as turbidity, electrical conductivity or possibly even dissolved organic matter may be used to better predict faecal contaminant loads. This is useful, because these surrogates may be measured unattended using water quality sondes or other field instruments.

4. Sites recommended for initial event-related monitoring include Site 15, Site 5, Site 6 and Site 7 (Otawera Stream) and Site 10 (upper Kaiate Stream). Once data from one or more events are available, consideration could be given to examining other sites within these catchments, guided by the monitoring results.

5. The dominant source of faecal contamination are ruminants (cows), and there is little value in enumerating specific markers for this source.

6. For ovine markers, all samples returned a below detection limit result. We note that sensitivity of the test is related to the volume of sample filtered. It would be prudent to confirm the low incidence of ovine FIB in at least one additional survey, where fewer but larger samples of water are analysed to ensure that as many quantifiable results are obtained as possible.

7. Human faecal markers were detected at site 1, upstream of the Kaiate Falls recreation site – this is unexpected given the access to the river at site 1. Comparison of the *E. coli* concentration data against the MfE/MoH recreational water quality guidelines indicates that in 2017/18:

    - The 95th percentile value was nearly 4000 *E. coli*/100 mL (suggesting that contact recreation at this site poses a risk to recreational users). There is a permanent health warning in place for the Kaiate Stream.

    - Approximately 50% of samples exceeded the single-sample action level (550/100 mL).

- Specific response may be required at this site to mitigate risks. One method may include deployment of an in-situ analyser (such as the Coliminder), which will enable faecal contamination to be related to activities at or upstream of the site

8. If LIDAR data exist for the Kaiate Stream catchment, it may be useful to assess these data to determine critical source areas and then consider whether the riparian protection in place is optimal. This assessment could be extended to the other subcatchments as well – it may be a cost-effective method to determine where mitigation tools could be deployed to achieve water quality objectives.

5 References

APHA-AWWA-WEF (2018) *Standard methods for the examination of water and waste water*. American Public Health Association, American Waterworks Association, Water Environment Federation, Washington, DC.

Ballantine, D.J., Davies-Colley, R.J. (2013) Nitrogen, phosphorus and E. coli loads in the Sherry River, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 47(4): 529-547. 10.1080/00288330.2013.815640.

Collins, R., Elliott, S., Adams, R. (2005) Overland flow delivery of faecal bacteria to a headwater pastoral stream. *Journal of Applied Microbiology*, 99(1): 126-132. 10.1111/j.1365-2672.2005.02580.x.

Collins, R., McLeod, M., Hedley, M., Donnison, A., Close, M., Hanly, J., Horne, D., Ross, C., Davies-Colley, R., Bagshaw, C., Matthews, L. (2007) Best management practices to mitigate faecal contamination by livestock of New Zealand waters. *New Zealand Journal of Agricultural Research*, 50(2): 267-278. 10.1080/00288230709510294.

McKergow, L.A., Davies-Colley, R.J. (2010) Stormflow dynamics and loads of Escherichia coli in a large mixed land use catchment. *Hydrological Processes*, 24(3): 276-289. 10.1002/hyp.7480.

MfE/MoH (2003) Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. . Report no. MfE 474, 124 pp.

Nagels, J.W., Davies-Colley, R.J., Donnison, A.M., Muirhead, R.W. (2002) Faecal contamination over flood events in a pastoral agricultural stream in New Zealand. *Water Science and Technology*, 45(12): 45-52. 10.2166/wst.2002.0408.

Wu, J. (2019) Linking landscape patterns to sources of water contamination: Implications for tracking fecal contaminants with geospatial and Bayesian approaches. *Science of The Total Environment*, 650: 1149-1157. https://doi.org/10.1016/j.scitotenv.2018.09.087.

Appendix A Hydrological information

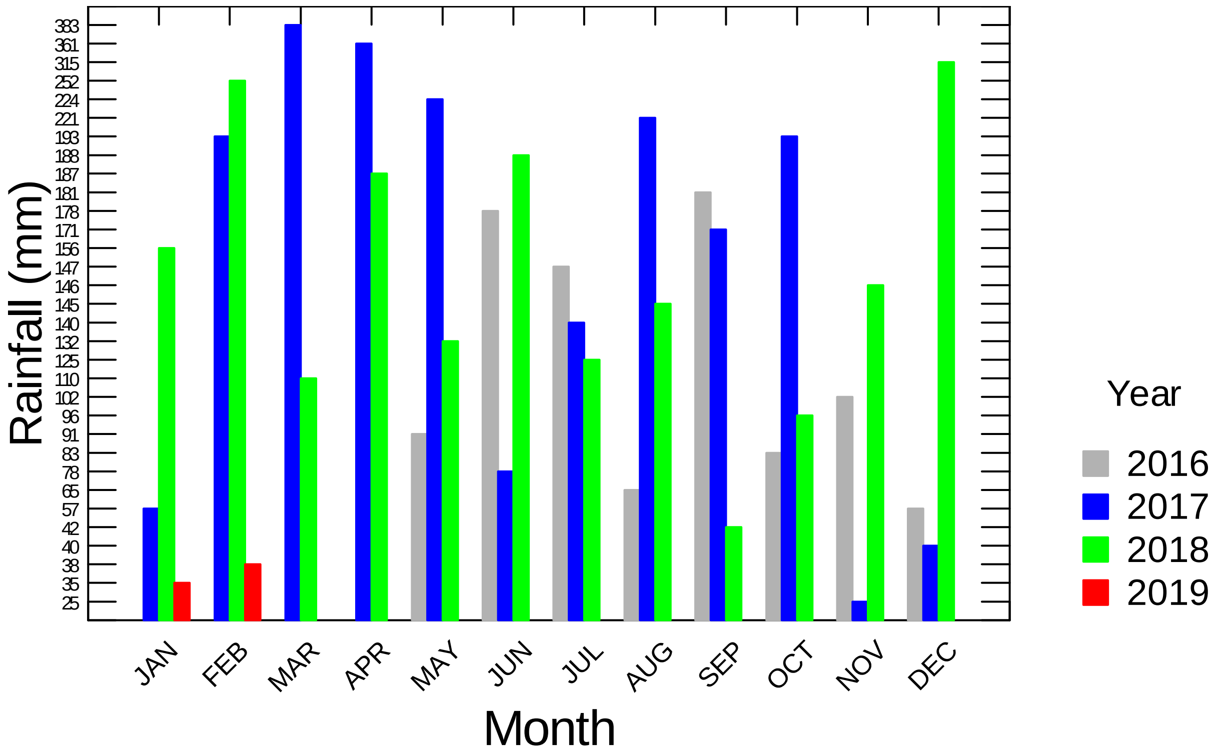


Figure A-1: Monthly total rainfall.

Table A-1: Flow statistic for period 27/4/2016 - 1/3/2019. Calculated from hourly average flow data.

Statistic	Discharge (L/s)
N of Cases	24588
Minimum	45
Maximum	23585
Median	230
Arithmetic Mean	419
Standard Error of Arithmetic Mean	5
95.0% LCL of Arithmetic Mean	408
95.0% UCL of Arithmetic Mean	429
Standard Deviation	810
Cleveland percentile	
1%	52
5%	66
10%	79
20%	106
25%	119
30%	140
40%	183
50%	230
60%	278
70%	346
75%	390
80%	454
90%	793
95%	1356
99%	3704

Table A-2: Number of *E. coli* results per flow decile for Site1 for each site (data for period 31/05/2016 – 05/02/2019). Decile bins derived from the data summarised in Table A-1 for Kaiate Stream at Site 1. Note that no samples were collected when flows were known to be in decile 8 or decile 10.

Site No.	No flow	Flow decile bins derived from discharge data for Site 1								Total
		P0-P10	P10-P20	P20-P30	P30-P40	P40-P50	P50-P60	P60-P70	P80-P90	
1	12	3	11	12	4	4	3	6	3	58
2	6	3	11	12	4	4	3	6	4	53
3	6	3	11	12	4	4	2	6	3	51
4	6	3	11	12	4	4	3	6	3	52
5	6	3	11	12	4	4	3	6	4	53
6	12	3	11	12	4	4	2	7	3	58
7	11	3	11	12	4	4	2	6	3	56
8	6	3	11	12	4	4	2	6	3	51
9	6	2	10	11	3	3	1	5	2	43
10	6	3	11	12	4	4	2	6	3	51
11	6	3	11	12	4	4	2	6	3	51
12	6	3	11	12	4	4	2	6	3	51
13	6	2	10	11	3	3	1	5	2	43
14	6	2	10	11	3	3	1	5	2	43
15	6	3	11	12	4	4	2	6	3	51
16	6	2	10	11	3	3	1	5	2	43
100	4									4
200	6									6
300	4									4
Total	127	44	172	188	60	60	32	93	46	822

Flow relationships between site 1 and sites 11, 12, 15 and 7

Data for the following results were selected according to
SELECT SITETXT2$ ="SITE11" OR SITETXT2$ ="SITE12 " OR SITETXT2$ ="SITE15" OR SITETXT2$ ="SITE7"

Iteration History			
No.	Loss	CONSTANT	A
0	86993.15	-1.01	1.02
1	32819.38	-2.45	0.89
2	32808.85	-1.70	0.88
3	32808.84	-1.67	0.88
4	32808.84	-1.67	0.88
5	32808.84	-1.67	0.88
6	32808.84	-1.67	0.88
7	32808.84	-1.67	0.88
8	32808.84	-1.67	0.88

Dependent Variable:Q_LS_GAGE
Zero weights, missing data or estimates reduced degrees of freedom

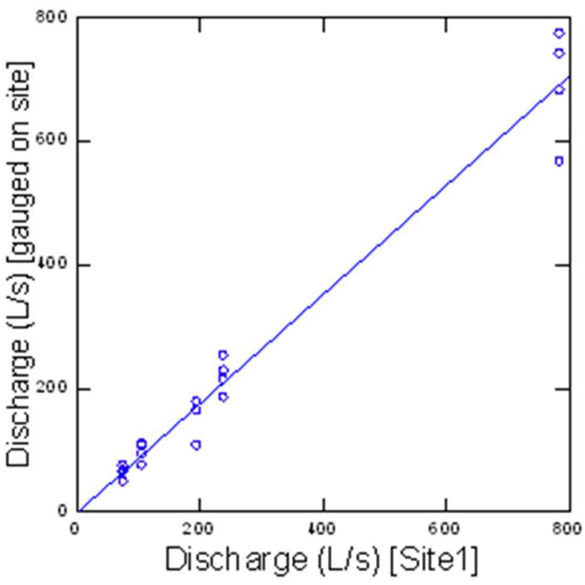
Sum of Squares and Mean Squares			
Source	SS	df	Mean Squares
Regression	2225273.78	2	1112636.89
Residual	32808.84	17	1929.93
Total	2258082.62	19	
Mean corrected	1074195.08	18	

R-squares

Raw R-square (1-Residual/Total)	:	0.99
Mean Corrected R-square (1-Residual/Corrected)	:	0.97
R-square(Observed vs. Predicted)	:	0.97

Parameter Estimates					
Parameter	Estimate	ASE	Parameter/ASE	Wald 95% Confidence Interval	
				Lower	Upper
CONSTANT	-1.67	14.79	-0.11	-32.86	29.53
A	0.88	0.04	23.23	0.80	0.96

Scatter Plot



Flow relationships between site 1 and site 6

Data for the following results were selected according to
SELECT SITETXT2$ ="SITE6"

Iteration History			
No.	Loss	CONSTANT	A
0	948.01	1.01	-1.02
1	29.81	-7.40	-2.15
2	26.09	-8.97	-2.26
3	26.04	-9.15	-2.27
4	26.04	-9.17	-2.27
5	26.04	-9.17	-2.27
6	26.04	-9.17	-2.27
7	26.04	-9.17	-2.27
8	26.04	-9.17	-2.27

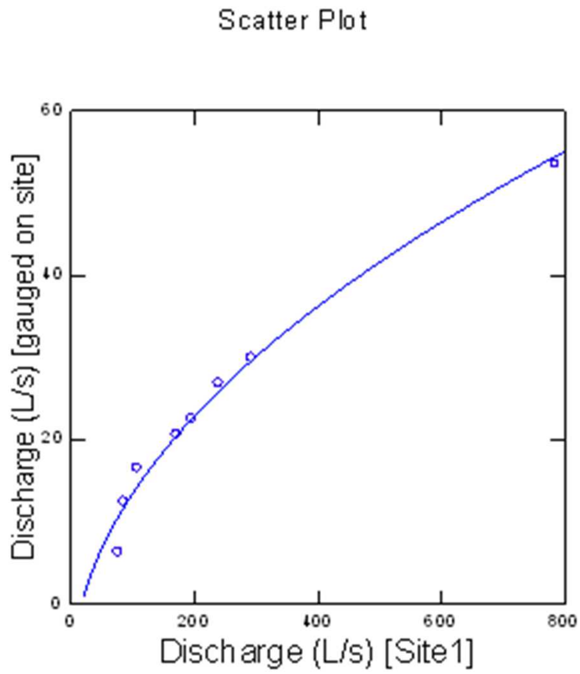
Dependent Variable:Q_LS_GAGE
Zero weights, missing data or estimates reduced degrees of freedom

Sum of Squares and Mean Squares			
Source	SS	df	Mean Squares
Regression	5874.74	2	2937.37
Residual	26.04	6	4.34
Total	5900.79	8	
Mean corrected	1425.14	7	

R-squares

Raw R-square (1-Residual/Total) : 1.00
Mean Corrected R-square (1-Residual/Corrected) : 0.98
R-square(Observed vs. Predicted) : 0.98

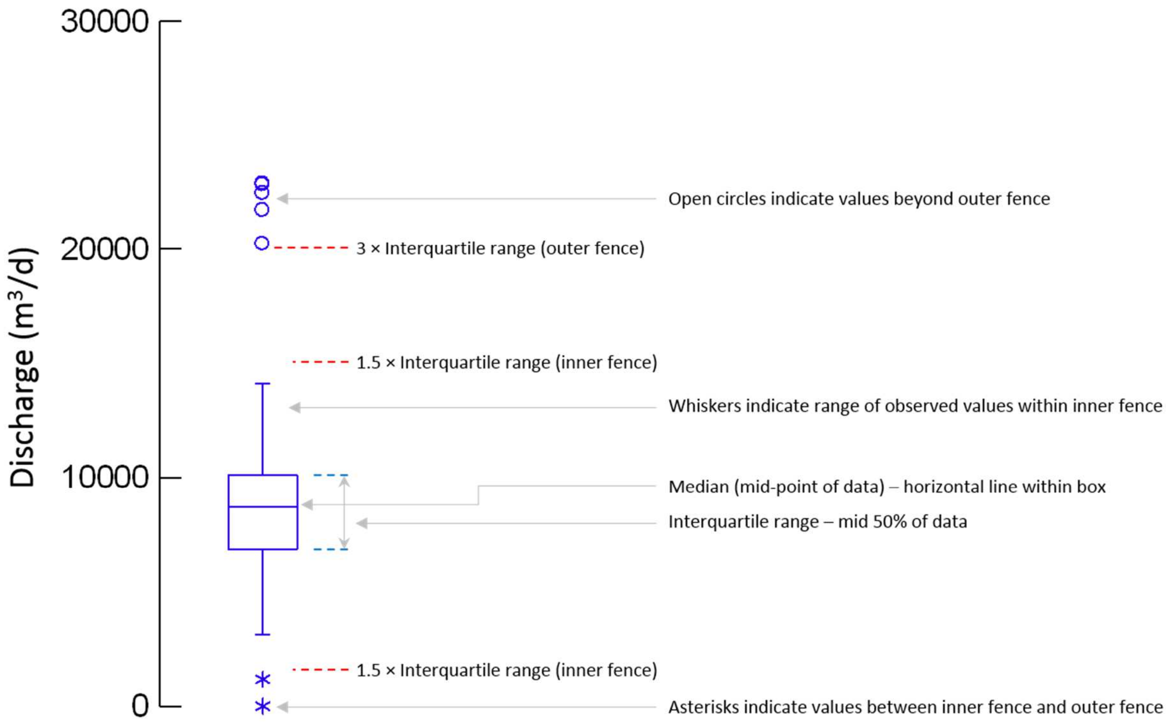
Parameter Estimates					
Parameter	Estimate	ASE	Parameter/ASE	Wald 95% Confidence Interval	
				Lower	Upper
CONSTANT	-9.17	1.97	-4.65	-14.00	-4.35
A	-2.27	0.13	-17.95	-2.58	-1.96



CONSTANT+(-A)*(SQR(Q_SITE1_LS))

Appendix B Explanation of Box and Whisker plot symbology

The symbology used in box and whisker plots produced by Systat may differ from that generated in other software, particularly with regard to the whiskers.



Appendix C Summary statistics for *E. coli* concentrations for all sites

Table C-1: Summary statistics for *E. coli* concentrations by site (data for period 31/05/2016 – 05/02/2019). Orange shading indicates 95th percentile value exceeds 550 cfu/100 mL. Grey shading indicates highest four median concentrations.

Statistic	Summary statistics for *E. coli* concentration data by site							
	SITE1	SITE2	SITE3	SITE4	SITE5	SITE6	SITE7	SITE8
N of Cases	48	21	51	21	22	21	20	21
Minimum	9	9	13	2	19	14	2	3
Maximum	4200	2000	1600	1400	2300	12000	660	1000
Median	515	270	530	220	195	250	195	200
Arithmetic Mean	765	387	579	306	379	866	208	255
Standard Deviation	866	455	405	351	538	2563	167	238
Cleveland percentiles								
1%	9	9	13	2	19	14	2	3
5%	74	25	90	9	20	34	3	15
10%	130	42	130	36	33	55	11	35
20%	262	109	188	57	56	99	27	60
25%	355	145	265	60	60	148	74	72
30%	379	166	318	66	71	160	125	103
40%	451	216	428	144	122	209	155	119
50%	515	270	530	220	195	250	195	200
60%	540	310	572	271	220	380	230	273
70%	721	386	660	300	415	432	265	352
75%	770	417	790	362	480	443	300	365
80%	1046	485	900	442	516	468	345	395
90%	1940	864	1300	826	1069	824	395	526
95%	2550	1560	1395	1180	1700	6005	535	769
99%	4200	2000	1598	1400	2300	12000	660	1000

Table C-1: Summary statistics for *E. coli* concentrations by site (data for period 31/05/2016 – 05/02/2019). (continued)

Statistic	Summary statistics for *E. coli* concentration data by site							
	SITE9	SITE10	SITE11	SITE12	SITE13	SITE14	SITE15	SITE16
N of Cases	14	48	36	36	29	29	36	27
Minimum	31	17	220	60	210	50	95	160
Maximum	1400	6400	3600	2500	3400	1800	2000	6600
Median	310	355	475	415	620	520	410	590
Arithmetic Mean	372	597	707	670	812	639	455	1026
Standard Deviation	364	932	757	627	731	448	343	1319
Cleveland percentiles								
1%	31	17	220	60	210	50	95	160
5%	33	41	226	136	220	193	153	203
10%	42	98	252	176	282	218	180	242
20%	70	240	308	240	403	250	221	382
25%	100	240	340	250	410	280	240	418
30%	128	269	383	269	532	312	282	452
40%	188	314	400	336	581	345	328	566
50%	310	355	475	415	620	520	410	590
60%	423	423	503	453	690	692	461	751
70%	454	540	537	567	734	800	487	882
75%	510	575	540	1070	805	857	520	990
80%	559	699	709	1400	876	973	553	1200
90%	752	1094	1738	1500	1500	1300	780	1880
95%	1256	1404	2730	2060	3020	1610	1055	4050
99%	1400	6400	3600	2500	3400	1800	2000	6600

Appendix D Summary statistics for *E. coli* concentrations and flux (instantaneous load) estimates

Results for Site = SITE1

Data for the following results were selected according to
SELECT SITETXT2$ ="SITE1"

	E. coli conc. (cfu/100 mL)	E. coli flux (cfu/s) Gauging data only	E. coli flux (cfu/s) Continuously measured flow
N of Cases	52	7	42
Minimum	9	410317	86741
Maximum	4200	2662927	3513650
Median	515	682500	704257
Arithmetic Mean	782	1176819	1080648
Standard Error of Arithmetic Mean	124	327827	134693
95.0% LCL of Arithmetic Mean	534	374654	808629
95.0% UCL of Arithmetic Mean	1031	1978984	1352666
Standard Deviation	893	867350	872911
Method = CLEVELAND			
1.000%	9	410317	86741
5.000%	46	410317	157375
10.000%	124	416300	242114
20.000%	239	437239	391166
25.000%	315	487185	442019
30.000%	371	552922	484342
40.000%	439	644385	673161
50.000%	515	682500	704257
60.000%	540	1270665	992739
70.000%	729	1670030	1499271
75.000%	785	1798913	1646820
80.000%	1073	1968167	1685799
90.000%	2000	2508536	2355693
95.000%	2850	2662927	3144445
99.000%	4194	2662927	3513650

Results for Site = SITE8

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	7	7
Minimum	75	6070
Maximum	580	50485
Median	350	25634
Arithmetic Mean	291	25238
Standard Error of Arithmetic Mean	73	5962
95.0% LCL of Arithmetic Mean	111	10649
95.0% UCL of Arithmetic Mean	470	39826
Standard Deviation	194	15774
Method = CLEVELAND		
1.000%	75	6070
5.000%	75	6070
10.000%	82	6244
20.000%	107	6856
25.000%	110	10633
30.000%	110	15798
40.000%	182	22881
50.000%	350	25634
60.000%	371	28368
70.000%	400	32240
75.000%	417	34604
80.000%	445	37711
90.000%	550	47647
95.000%	580	50485
99.000%	580	50485

Results for Site = SITE2

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	7	7
Minimum	270	20117
Maximum	2000	252923
Median	590	57481
Arithmetic Mean	760	88203
Standard Error of Arithmetic Mean	240	32317
95.0% LCL of Arithmetic Mean	173	9126
95.0% UCL of Arithmetic Mean	1347	167280
Standard Deviation	635	85503
Method = CLEVELAND		
1.000%	270	20117
5.000%	270	20117
10.000%	278	21678
20.000%	306	27141
25.000%	310	28113
30.000%	310	28381
40.000%	394	37326
50.000%	590	57481
60.000%	625	72973
70.000%	864	108038
75.000%	1060	132911
80.000%	1280	160902
90.000%	1840	232474
95.000%	2000	252923
99.000%	2000	252923

Results for Site = SITE11

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	4	4
Minimum	220	240000
Maximum	390	1701738
Median	300	649039
Arithmetic Mean	303	809954
Standard Error of Arithmetic Mean	36	342068
95.0% LCL of Arithmetic Mean	189	-278659
95.0% UCL of Arithmetic Mean	416	1898567
Standard Deviation	71	684136
Method = CLEVELAND		
1.000%	220	240000
5.000%	220	240000
10.000%	220	240000
20.000%	238	260488
25.000%	250	274147
30.000%	262	287806
40.000%	284	376443
50.000%	300	649039
60.000%	316	921634
70.000%	341	1203369
75.000%	355	1345760
80.000%	369	1488152
90.000%	390	1701738
95.000%	390	1701738
99.000%	390	1701738

Results for Site = SITE3

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	8	8
Minimum	250	16367
Maximum	640	76040
Median	445	34510
Arithmetic Mean	465	37337
Standard Error of Arithmetic Mean	43	6247
95.0% LCL of Arithmetic Mean	364	22564
95.0% UCL of Arithmetic Mean	566	52110
Standard Deviation	121	17671
Method = CLEVELAND		
1.000%	250	16367
5.000%	250	16367
10.000%	295	19535
20.000%	403	27049
25.000%	415	27538
30.000%	427	28028
40.000%	430	31020
50.000%	445	34510
60.000%	478	37876
70.000%	527	40585
75.000%	555	41098
80.000%	583	41611
90.000%	625	65749
95.000%	640	76040
99.000%	640	76040

Results for Site = SITE12

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	5	5
Minimum	130	274700
Maximum	480	1096445
Median	260	427402
Arithmetic Mean	304	608534
Standard Error of Arithmetic Mean	63	175509
95.0% LCL of Arithmetic Mean	130	121244
95.0% UCL of Arithmetic Mean	478	1095825
Standard Deviation	140	392450
Method = CLEVELAND		
1.000%	130	274700
5.000%	130	274700
10.000%	130	274700
20.000%	185	277578
25.000%	213	279018
30.000%	240	280457
40.000%	250	353929
50.000%	260	427402
60.000%	335	695535
70.000%	410	963668
75.000%	428	996863
80.000%	445	1030057
90.000%	480	1096445
95.000%	480	1096445
99.000%	480	1096445

Results for Site = SITE15

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	5	5
Minimum	95	201500
Maximum	440	648092
Median	270	414776
Arithmetic Mean	269	444395
Standard Error of Arithmetic Mean	56	78738
95.0% LCL of Arithmetic Mean	114	225782
95.0% UCL of Arithmetic Mean	424	663008
Standard Deviation	125	176065
Method = CLEVELAND		
1.000%	95	201500
5.000%	95	201500
10.000%	95	201500
20.000%	163	289828
25.000%	196	333993
30.000%	230	378157
40.000%	250	396466
50.000%	270	414776
60.000%	290	497112
70.000%	310	579449
75.000%	343	596610
80.000%	375	613771
90.000%	440	648092
95.000%	440	648092
99.000%	440	648092

Results for Site = SITE10

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	5	5
Minimum	300	3500
Maximum	690	55846
Median	350	34441
Arithmetic Mean	438	32680
Standard Error of Arithmetic Mean	72	8496
95.0% LCL of Arithmetic Mean	237	9091
95.0% UCL of Arithmetic Mean	639	56268
Standard Deviation	162	18998
Method = CLEVELAND		
1.000%	300	3500
5.000%	300	3500
10.000%	300	3500
20.000%	320	16824
25.000%	330	23487
30.000%	340	30149
40.000%	345	32295
50.000%	350	34441
60.000%	430	36952
70.000%	510	39463
75.000%	555	43559
80.000%	600	47654
90.000%	690	55846
95.000%	690	55846
99.000%	690	55846

Results for Site = SITE7

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	5	5
Minimum	120	129733
Maximum	330	1078171
Median	220	250128
Arithmetic Mean	226	400373
Standard Error of Arithmetic Mean	36	176879
95.0% LCL of Arithmetic Mean	127	-90722
95.0% UCL of Arithmetic Mean	325	891468
Standard Deviation	80	395514
Method = CLEVELAND		
1.000%	120	129733
5.000%	120	129733
10.000%	120	129733
20.000%	155	132366
25.000%	173	133683
30.000%	190	135000
40.000%	205	192564
50.000%	220	250128
60.000%	245	329481
70.000%	270	408834
75.000%	285	576168
80.000%	300	743502
90.000%	330	1078171
95.000%	330	1078171
99.000%	330	1078171

Results for Site = SITE5

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	8	8
Minimum	210	2182
Maximum	2300	32701
Median	540	6887
Arithmetic Mean	820	12128
Standard Error of Arithmetic Mean	248	4093
95.0% LCL of Arithmetic Mean	233	2449
95.0% UCL of Arithmetic Mean	1407	21806
Standard Deviation	702	11577
Method = CLEVELAND		
1.000%	210	2182
5.000%	210	2182
10.000%	213	2362
20.000%	246	2864
25.000%	350	3191
30.000%	454	3518
40.000%	501	3819
50.000%	540	6887
60.000%	690	12114
70.000%	1003	18096
75.000%	1135	20990
80.000%	1267	23885
90.000%	2000	30274
95.000%	2300	32701
99.000%	2300	32701

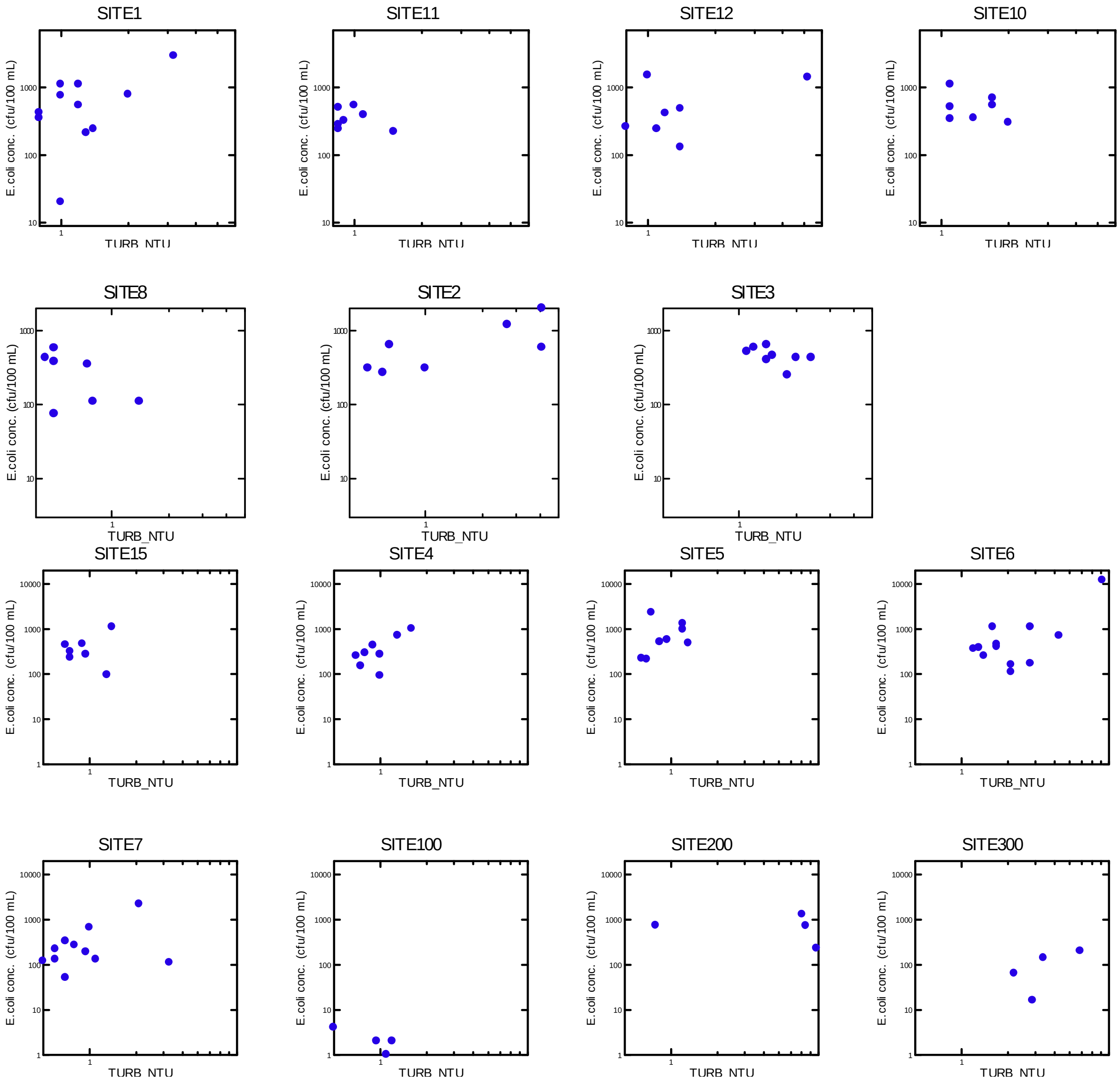
Results for Site = SITE6

Data for the following results were selected according to
SELECT Q_LS_GAGE <>.

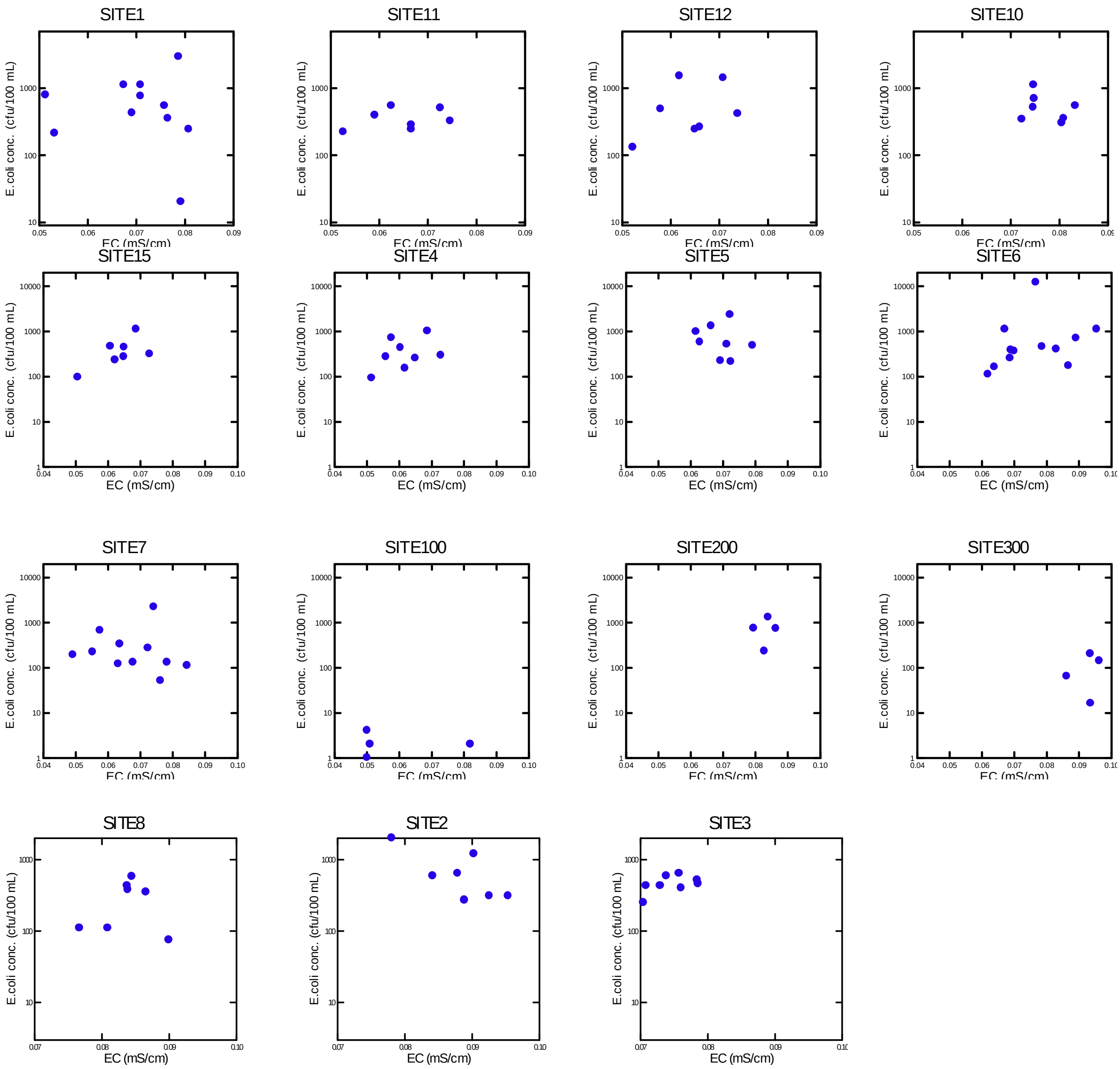
	E.coli conc. (cfu/100 mL)	E. coli flux (cfu/s)
N of Cases	8	8
Minimum	110	28748
Maximum	12000	1500487
Median	370	59369
Arithmetic Mean	1851	265899
Standard Error of Arithmetic Mean	1454	178942
95.0% LCL of Arithmetic Mean	-1587	-157231
95.0% UCL of Arithmetic Mean	5289	689029
Standard Deviation	4112	506124
Method = CLEVELAND		
1.000%	110	28748
5.000%	110	28748
10.000%	125	34514
20.000%	169	48822
25.000%	205	52235
30.000%	241	55647
40.000%	327	58168
50.000%	370	59369
60.000%	401	65456
70.000%	515	100293
75.000%	775	187374
80.000%	1035	274454
90.000%	8730	1139208
95.000%	12000	1500487
99.000%	12000	1500487

Appendix E Relationships between water quality variables

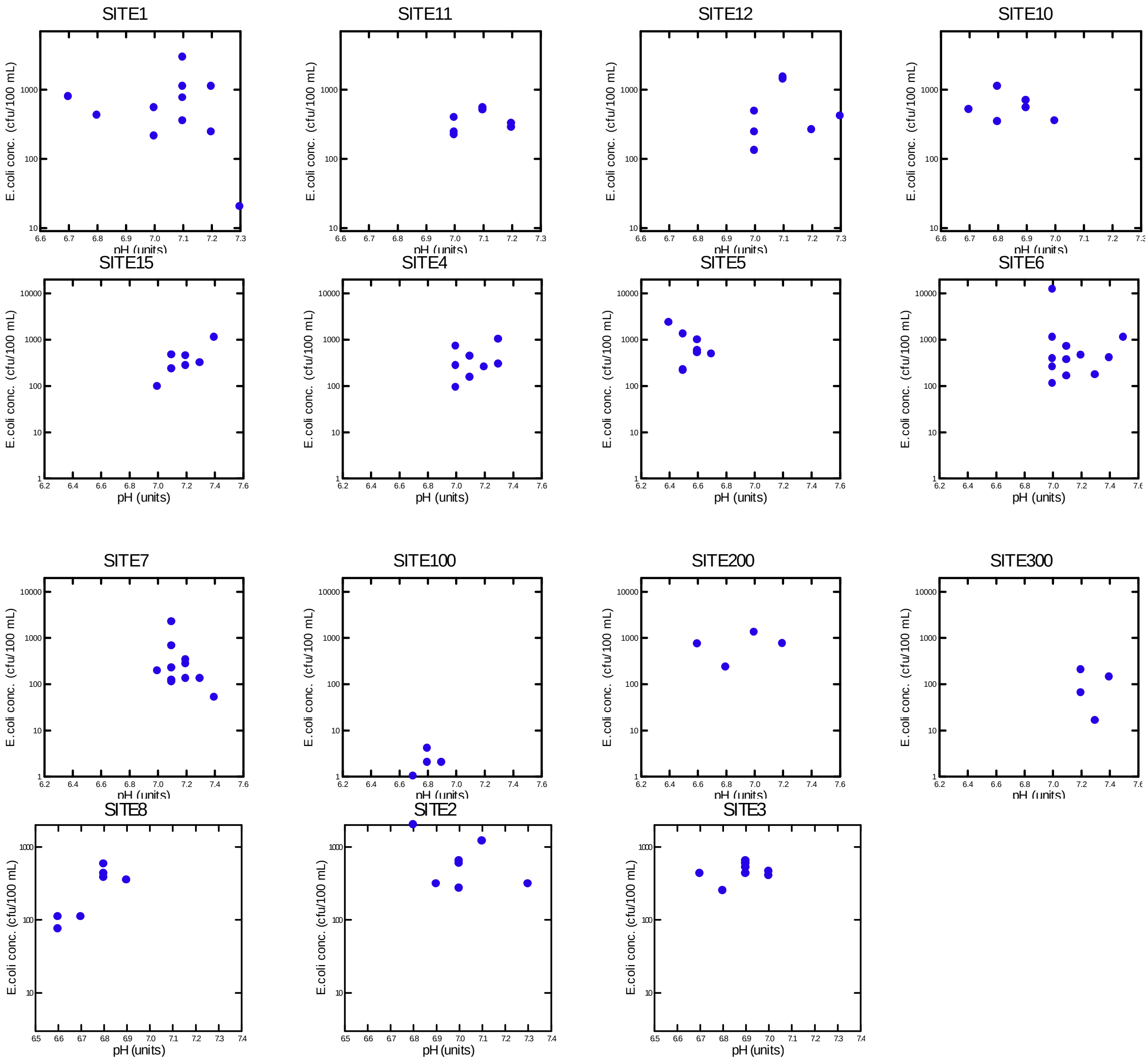
E. coli vs turbidity



E. coli vs electrical conductivity



E. coli vs pH


SITE1
SITE11
SITE12
SITE10
SITE15
SITE4
SITE5
SITE6
SITE7
SITE100
SITE200
SITE300
SITE8
SITE2
SITE3
E. coli conc. (cfu/100 mL)
pH (units)