NIWA
Taihoro Nukurangi

Waimea Inlet: microbiological water quality context

Prepared for Nelson Regional Sewerage Business Unit

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Executive summary

Wastewater reticulation is subject to unpredictable factors which may lead to failure, causing accidental discharge of raw sewage. The Nelson Region Regional Sewerage Business Unit (NRSBU) is currently seeking consent for discharge of these infrequent, unpredictable “aberrant” discharges of untreated sewage to the Waimea Inlet. The discharge of raw sewage to a marine area also creates the potential for measurable health risks. Separately, the NRSBU is seeking consent for the discharge of treated wastewater from the Bell Island wastewater treatment plant (WWTP).

This document provides a context that may be used to support the technical work associated with assessing the human health risk from either aberrant discharges of raw sewage or the discharge of treated wastewater. Existing data were used to identify and characterise known potential sources of faecal contaminants, or events likely to cause discharge of faecal contaminants. Where possible, the illness risk arising from these sources or events has been identified.

Bell Island WWTP discharge

Compliance monitoring data suggest that the load of faecal indicator bacteria (FIB) entering the wastewater treatment plant has increased slightly over time, and the volume of wastewater has decreased over the same time. Overall the load of FIB discharged in the treated wastewater is essentially unchanged over the preceding six-year period.

Recreational water quality

Seasonal 95th percentile concentrations of FIB suggest:

- a west/south to east/north increase in FIB concentrations
- higher FIB concentrations in areas
  - near urban storm water runoff, or
  - likely to be in the path of material transported by currents within southern Tasman Bay

The illness risks associated with contact recreation activities likely to cause immersion of the head, that occur in the Nelson City Council (NCC) jurisdictional area likely to be impacted by aberrant discharges of raw sewage are approximately:

- generally a 1-5% risk of gastroenteritis, and a 0.3-1.9% risk of Acute Febrile Respiratory Illness (AFRI), which may at times increase to
- a 5-10% risk of gastroenteritis, and a 1.9-3.9% risk of AFRI.

The risks associated with recreation at recreational sites near the Waimea Inlet reflect the impact of faecal contaminants from all sources, whereas the separate Quantitative Microbial Risk Assessment undertaken for the Bell Island WWTP reflects the incremental risk associated exclusively with the Bell Island WWTP discharge, **i.e. it does not account for other contaminant sources**.

Event-related stream water quality

Limited stream microbial water quality monitoring has been undertaken in creeks and streams draining into Waimea Inlet. These data suggest that the load of FIB input to the Inlet during a four-hour event may exceed the daily load discharged from the Bell Island WWTP, and have the potential to adversely impact on recreational water quality in the Inlet.

Recent winter condition sampling

Seven sites were sampled on four occasions during August and September 2017. Although relatively few data exist, these indicate:

- better water quality at sites unlikely to be impacted by storm water runoff
- deterioration in microbial water quality in response to rainfall.

Sites subject to storm water inflows are unlikely to achieve satisfactory grading in terms of the Ministry for the Environment and Ministry of Health "*Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas"* (MfE/MoH 2003). The risk factors identified in these Guidelines exist for much of the foreshore of the Waimea Inlet.

These illness risk factors exist in the absence of aberrant discharges of raw sewage from sewer pump stations.

1 Introduction

Nelson City Council (NCC) and Tasman District Council (TDC) provide wastewater reticulation and treatment services through the Nelson Regional Sewerage Business Unit (NRSBU), a non-incorporated association. Wastewater reticulation is subject to unpredictable factors which may lead to failure, causing accidental discharge of raw sewage. The NRSBU is currently seeking consent for these infrequent, unpredictable "aberrant" discharges of untreated sewage from four sewage pump stations to the Waimea Inlet.[1] The discharge of raw sewage to a marine area also creates the potential for measurable health risks.

Separately, the NRSBU is seeking consent for the discharge of treated wastewater from the Bell Island wastewater treatment plant (WWTP).

Human health risks arising from exposure to microbial contaminants during recreational activities are generally assessed using recreational bathing monitoring programmes. The Ministry for the Environment and Ministry of Health "*Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas"* (MfE/MoH 2003) provide guidance regarding establishment and operation of monitoring programmes, and when interpreting the results derived from monitoring. Monitoring recreational water quality generally relies on use of faecal indicator bacteria (FIB) – *E. coli* in freshwaters, and enterococci in saline waters. The guidelines are quite clear, however, that they should not be used during "exceptional circumstances".

Human health risks arising from possible exposure to pathogens during events such as periodic pump station discharges, and in areas likely to be impacted by treated wastewater were previously estimated for aberrational discharges using Quantitative Microbial Risk Assessment (QMRA) techniques (Hudson and McBride 2017a); these are currently being updated (Hudson and McBride 2017b), while a separate QMRA for the Bell Island wastewater treatment plant was recently completed (McBride 2017).

This report provides information derived from the following monitoring activities:

- compliance monitoring of the volume, discharge rate and microbial quality of the Bell Island WWTP discharge
- determining the microbiological quality of coastal recreational waters
- a limited duration monitoring programme intended to characterise the quality of water in the Waimea Inlet during winter, when recreational water quality is not assessed
- an event related water quality monitoring programme that assessed microbial water quality and microbial loading rates.

The locations of various sample points are indicated in Figure 1-1 and Figure 1-2.

[1] "Aberrant" conveys the idea of departing from an accepted standard, being out of the ordinary, e.g., "a year of aberrant weather was experienced—record rainfall in the winter, record heat in the autumn". Pump stations are designed to not discharge untreated sewage to the environment, but factors such as mechanical failure, electrical power outages and physical blockage of pumps may give rise to transient, unplanned discharge of sewage to surface waters.

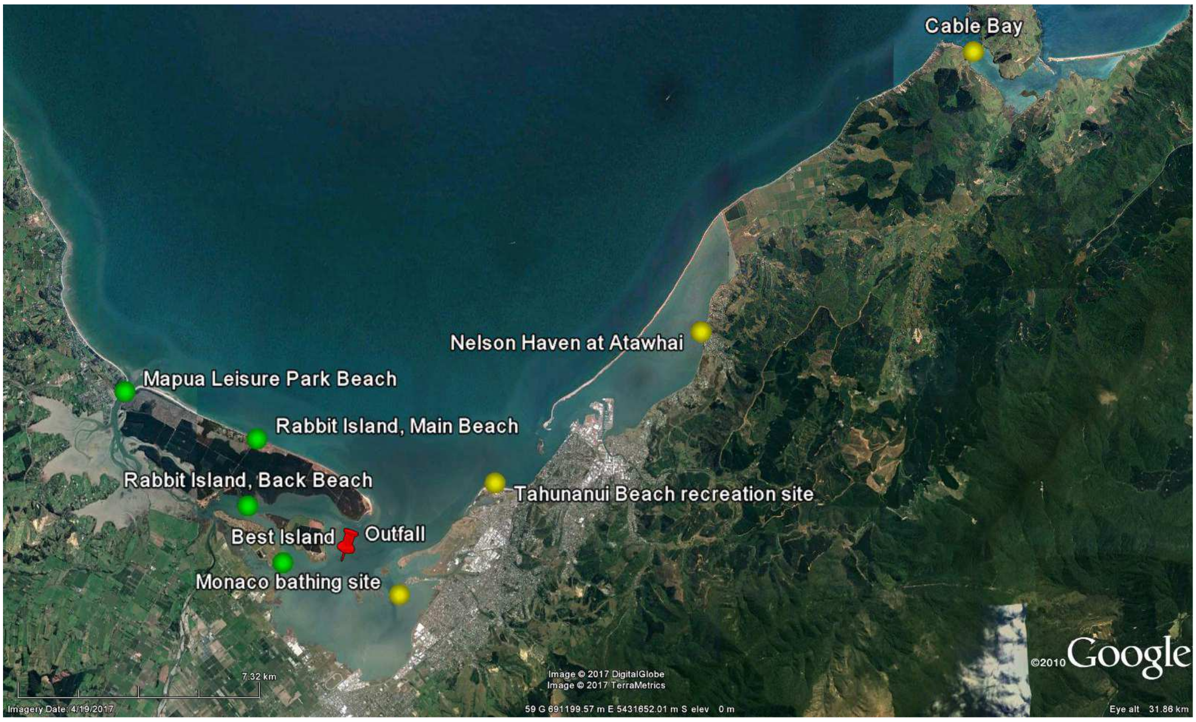

Figure 1-1: Location of Bell Island WWTP outfall and recreational water quality monitoring sites. NCC sites in yellow, TDC sites in green, outfall site is red.

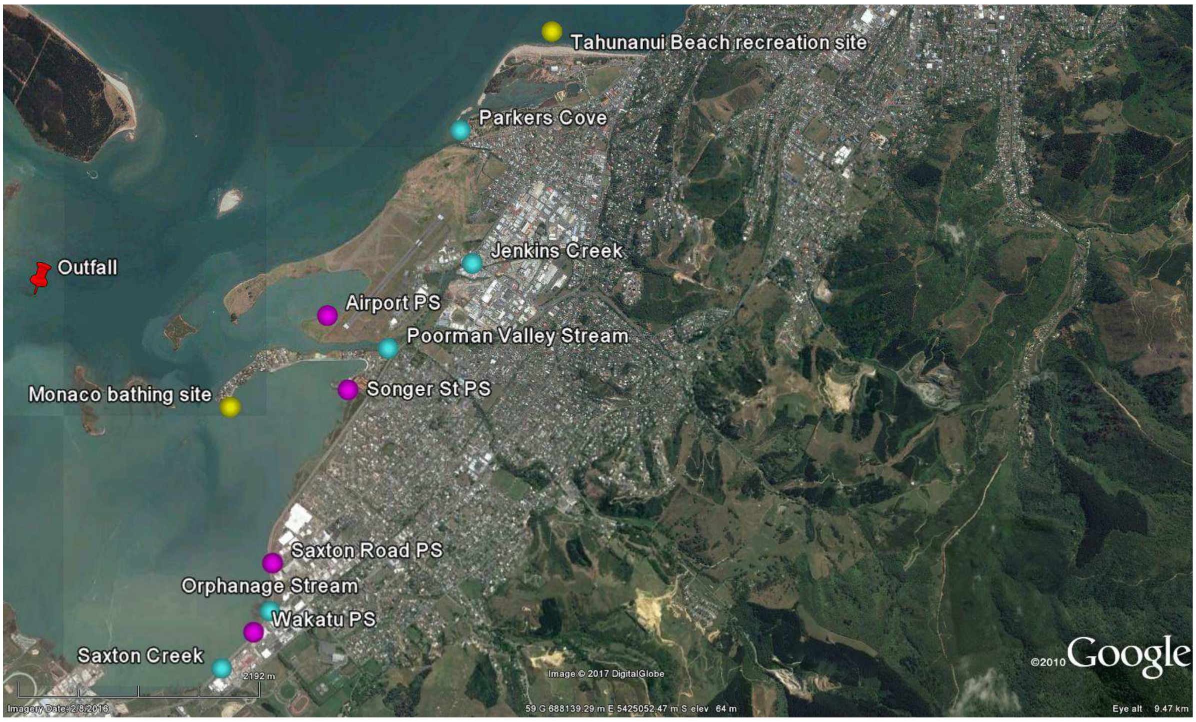

Figure 1-2: Location of pump stations (magenta), selected NCC recreational water quality monitoring sites (yellow), winter condition sampling sites (cyan). The four creek sites were used for event-related sampling.

2 Bell Island WWTP discharge

2.1 Discharge characteristics

2.1.1 Data sources

Data were derived from routine compliance monitoring undertaken by the NRSBU in accordance with consent conditions. The data used in this assessment were provided by StanTec, and were used with limited modification, including:

- replacement of results reported as less than a detection limit, with a value half of the detection limit
- calculation of instantaneous load as a product of the FIB concentration and the daily average wastewater flow (discharge rate) on the day the grab sample was collected
- summary statistics, graphical analysis was undertaken using Systat 13.

2.1.2 Treated wastewater discharge rates

Maximum daily discharge volumes are subject to consent conditions, as indicated in Figure 2-1. Limited between-year variability is demonstrated in Figure 2-1. The median discharge over the period January 2011 to December 2016 was 12,400 m^3/d, with annual median discharge rates ranging from 9,400 m^3/d to 15,400 m^3/d. The annual median value in 2016 was 14,100 m^3/d, the second highest in the assessment period. Detailed statistical summaries of discharge volumes and concentrations are provided in Appendix B.

Discharge rates will be determined principally by sewage inflow, which in-turn is determined by activities in the sewer catchment, including incident rainfall. There is evidence of seasonal variation in wastewater discharge, as indicated in Figure 2-2. Although daily average discharge rates are lowest in the November to March period, low values occur at other times of the year as well (e.g., September 2011).

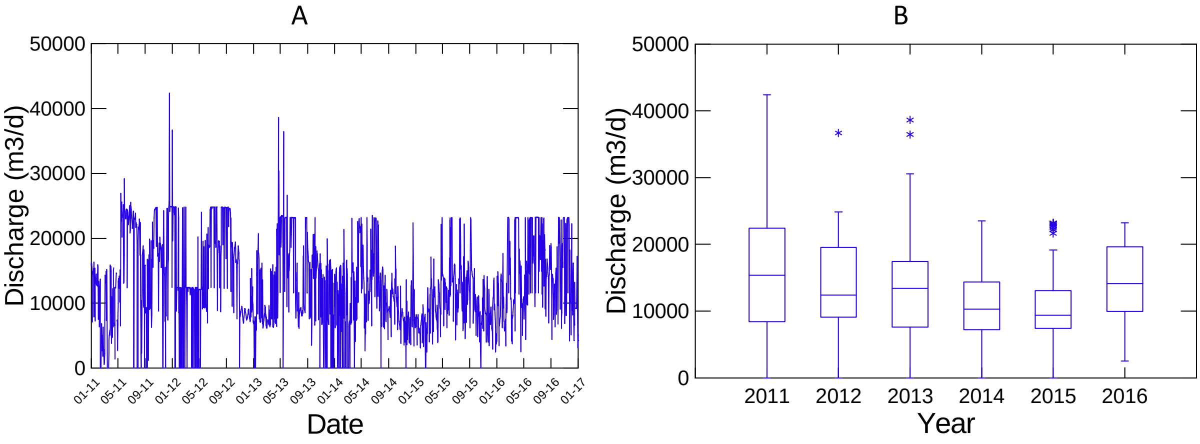

Figure 2-1: Daily and annual wastewater discharge characteristics, 2011-2016 calendar years. A) indicates daily average timeseries, and B) summarises the daily average flow on an annual basis. The horizontal line in the box represents the median value for the year.

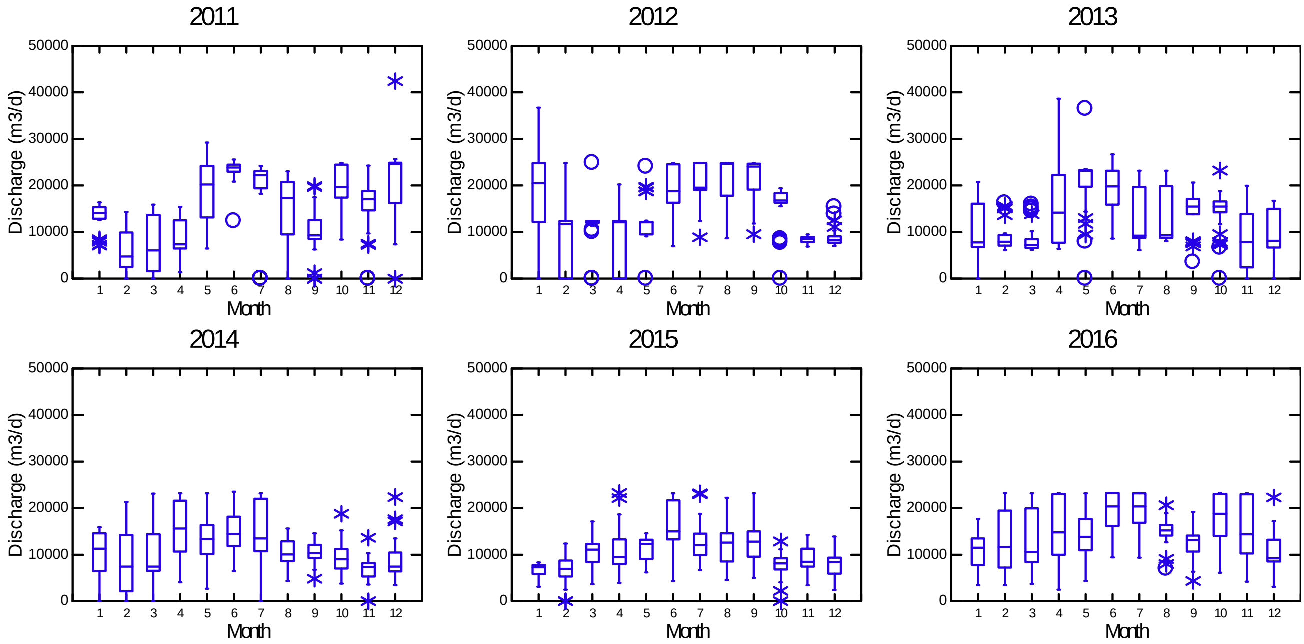

Figure 2-2: Seasonal (monthly) wastewater discharge characteristics, 2011-2016 calendar years. An explanation of a box and whisker plot and the symbols is provided in Appendix A.

2.1.3 Treated wastewater faecal indicator bacteria (FIB) characteristics

The efficacy of wastewater treatment in terms of removal of microbial constituents may be assessed using concentrations of two faecal indicator bacteria (FIB):

- Enterococci, more often applied to assessment of non-saline waters, as well as
- faecal coliform concentrations.

Enterococci comprise a sub-set of the organisms analysed and reported as faecal coliforms. Wastewater is assessed using approximately monthly grab samples (the number of samples collected per year vary from 15 (2011) to 22 (2015)). A time series of these two FIBs (i.e., enterococci and faecal coliforms) is provided as Figure 2-3.

Concentrations of both indicator species generally vary over two orders-of-magnitude. Inter-annual variability is illustrated by comparing the inter-quartile distributions (i.e., boxes) in Figure 2-4, for each FIB.

Annual median faecal coliform concentrations in the treated wastewater range between 800 and 7,800/100 mL, while median enterococci concentrations are always less than 500/100 mL. A summary of more recent data only (Figure 2-5) confirms that the monthly median enterococci concentration is less than 500/100 mL.

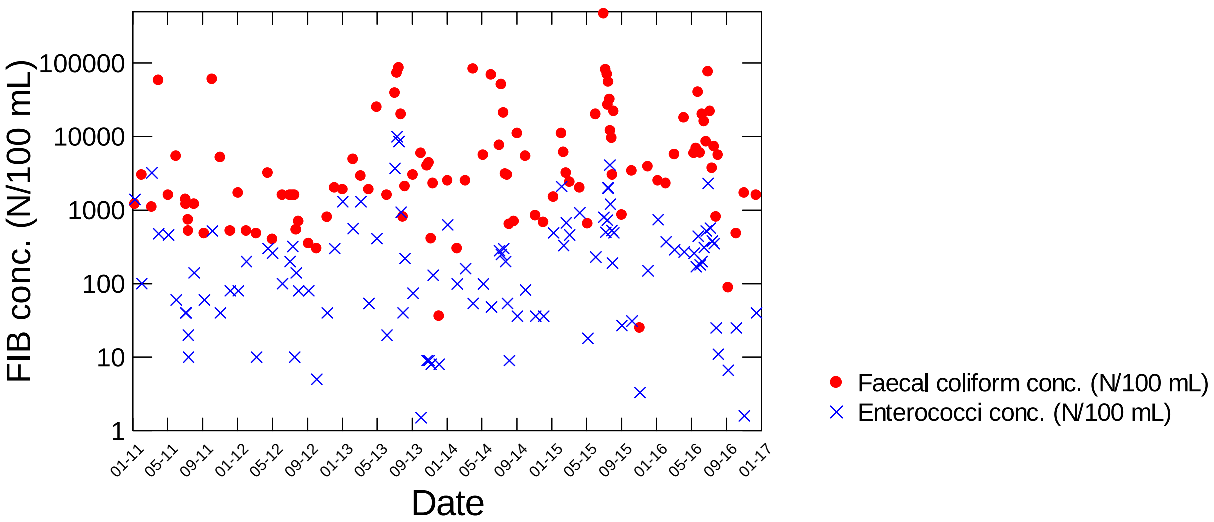

Figure 2-3: Time-series of FIB concentrations, 2011-2016 calendar years. The *y*-axis has log_{10} scale.

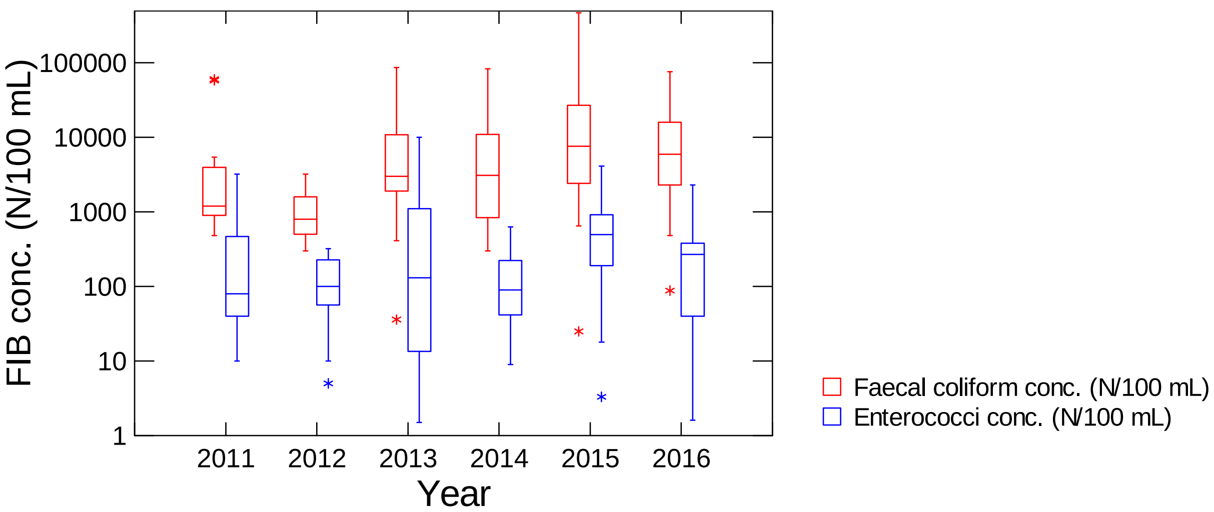

Figure 2-4: Annual summary of FIB concentrations, 2011-2016 calendar years. The *y*-axis has log_{10} scale.

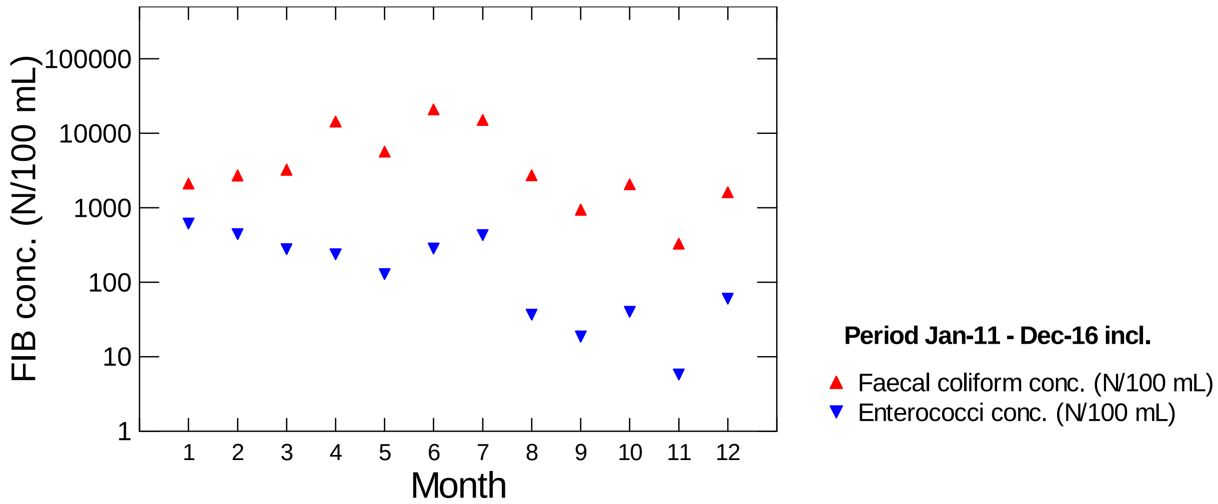

Figure 2-5: Median seasonal (monthly) FIB concentrations using data for 2014-2016 calendar years. Note the y-axis has $\log_{10}$ scale.

Combining daily discharge values with FIB concentrations for the day provide an estimate of the flux or instantaneous load of FIB (number per unit of time). These estimates provide an indication of likely impact on receiving waters (which is not possible using concentration data alone). In the three recent years where more extensive FIB concentration data exist (i.e., 2014 to 2016), the median faecal coliform flux varied from 2.9×10^{11} /day to 7.6×10^{11} /day. The enterococci flux was more variable, but was generally lower 8.3×10^{9} /day to 4.2×10^{10} /day. Several reasons are likely to contribute to the variability in FIB flux, including seasonal variability in the numbers of stock processed at the Alliance abattoir (which is reflected particularly in the numbers of faecal coliform in the discharge), and seasonal changes in the areal mass loading rate at Bell Island WWTP. The mass loading rate is considerably greater in summer than winter.

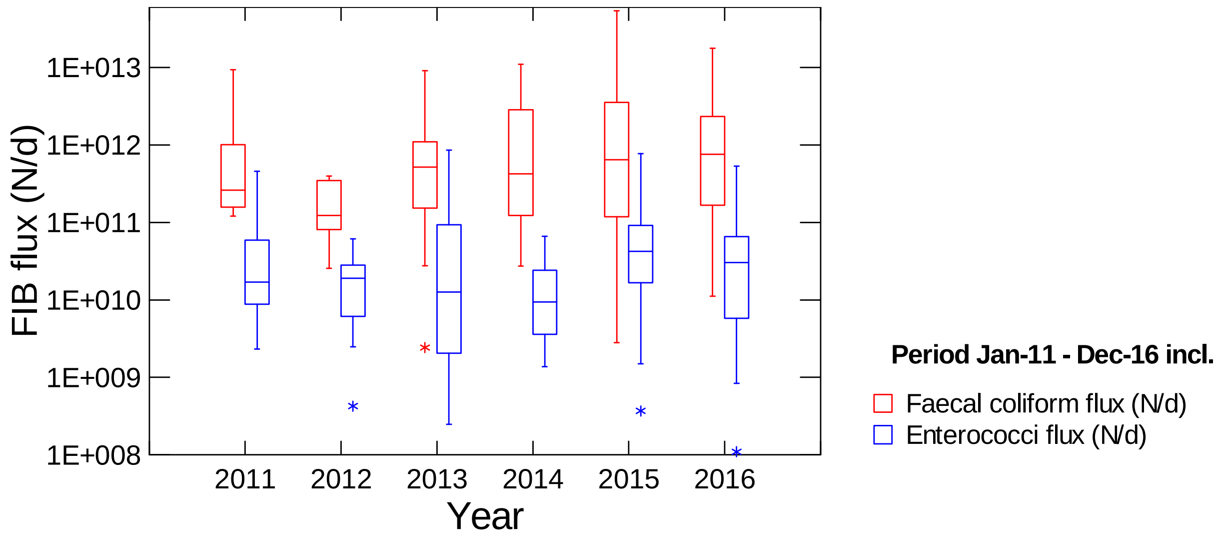

Figure 2-6: Annual summary of calculated daily wastewater FIB flux values, 2011-2016 calendar years. Flux or instantaneous load calculated as the product of the FIB concentration and the daily average wastewater flow (discharge rate) on the day the grab sample was collected. Note the *y*-axis values are $\log_{10}$ values. Relatively few data are available for the 2013 calendar year.

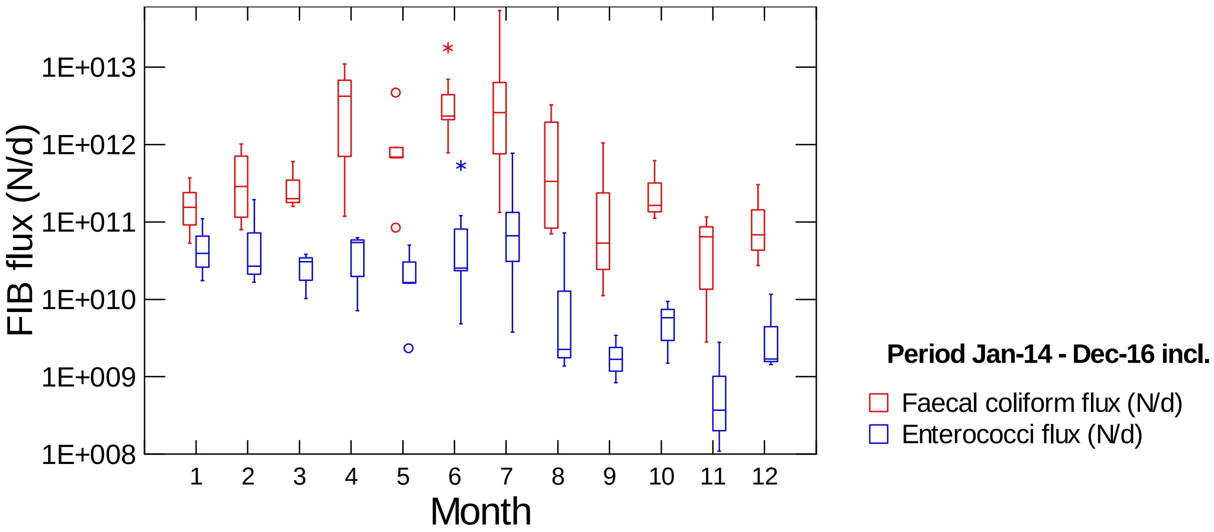

Figure 2-7: Seasonal (monthly) wastewater discharge characteristics, 2014-2016 calendar years. Flux or instantaneous load calculated as the product of the FIB concentration and the daily average wastewater flow (discharge rate) on the day the grab sample was collected. Note the *y*-axis values are $\log_{10}$ values.

The enterococci flux (and to lesser extent faecal coliform flux) is lowest between November and March annually. This indicates that a smaller number of indicator bacteria are discharged during the time of year when human exposure is most likely. This observation is however limited to faecal coliform and enterococci as indicators of the likely presence of pathogens – the relationship between numbers of FIB and true pathogens (specifically viruses) has not been established for the Bell Island WWTP. Consequently, these results should be regarded as indicative only.

2.2 Recreational water quality

Water samples collected from three locations within the Nelson City Council and from four locations within the Tasman District Council jurisdictional areas to assess recreational water quality are relevant for this receiving water quality context description. The location of these sites is indicated in Figure 1-1.

Samples are collected from most sites in accordance with the general requirements of the MfE/MoH recreational water quality guidelines, namely weekly collection in the bathing season (generally between November and April, providing approximately 20 samples/season). Additional samples are occasionally collected in response to the results obtained from routinely collected samples. Two of the TDC sites (Best Island, and Rabbit Island, Back Beach) are sampled every other year, and for a period of approximately three months duration.

Data were available from both NCC and TDC and for most sites for the 2014/15 to 2016/17 bathing seasons, and this assessment was restricted to this period. Ideally these assessments make use of 100 data (representing an approximately five-year sampling period) – in this instance more than 60 data were available for most sites, and 15 for the two sites sampled biannually by TDC (Rabbit Island, Back Beach, and Best Island). All statistical values for recreational monitoring are provided in Appendix A.

The data available for the three bathing seasons selected are summarised in Figure 2-8 and Figure 2-9 A and B.

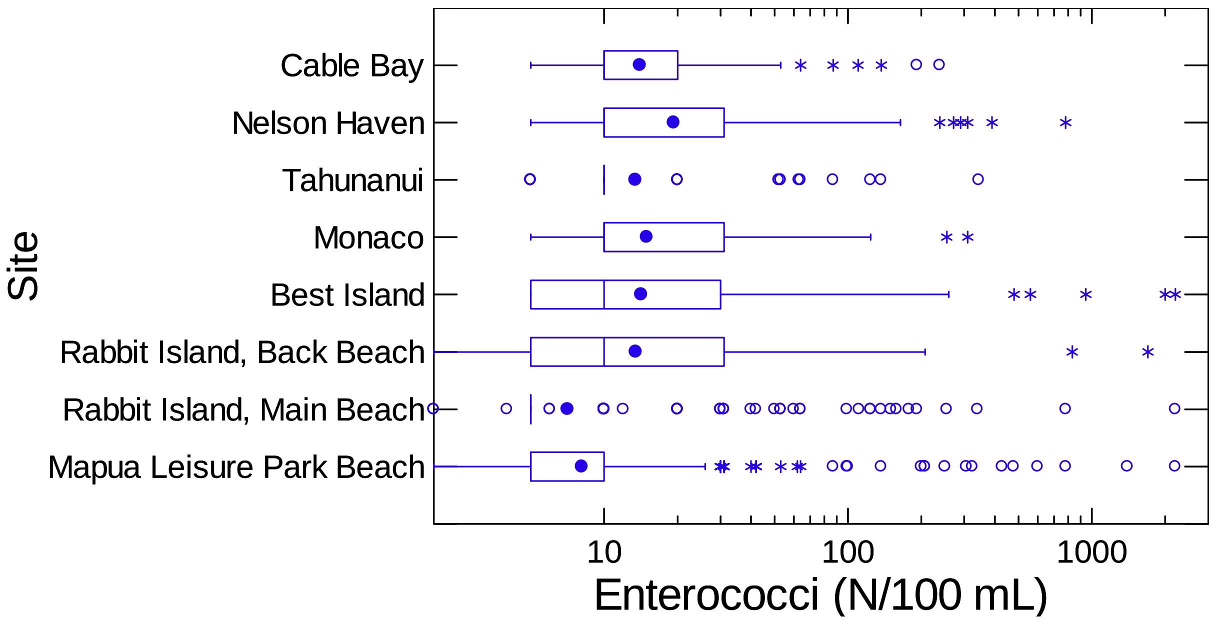

Figure 2-8: Recreational water quality data for the three summer seasons, 2014-2016 years. Note the x-axis has log_{10} scale. The filled dot represents the arithmetic mean value for each site over the period. The median value is represented by the line within each box – where it is not visible, it has coincided with the left-hand edge of the box. This occurs when the data are strongly skewed, i.e. many low values. For these data, many of the results were reported as less than the detection limit, and have been coded as half the detection limit value for the calculation of statistics or preparation of graphs.

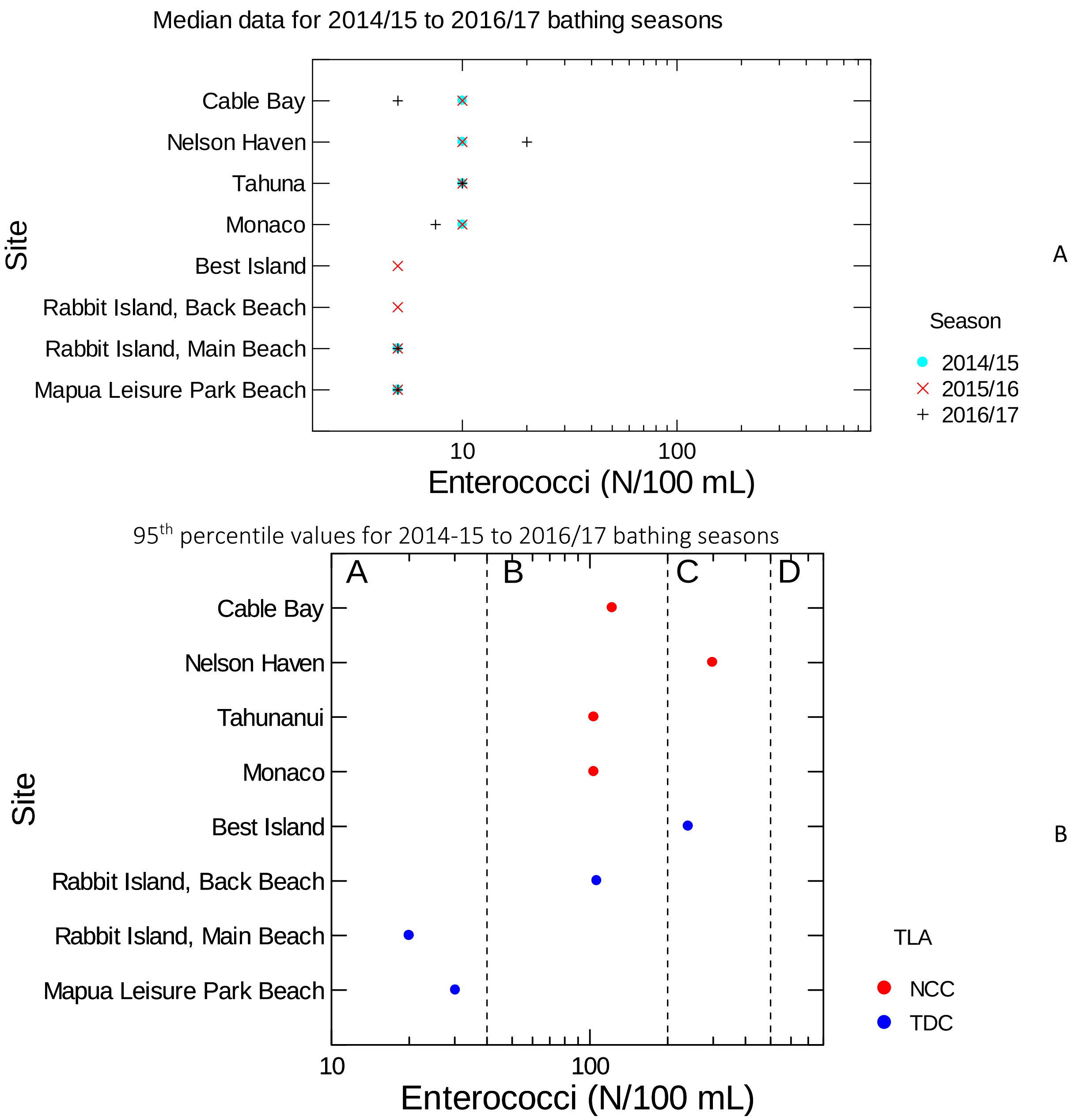

Figure 2-9: Recreational water quality, 2014/15 – 2016/17, expressed in terms of the seasonal median (A) and 95th percentile (B). Note the x-axis has log_{10} scale. A, B, C and D refer to guideline values identified in the MfE/MoH recreational water quality guidelines (MfE/MoH 2003).

Figure 2-8 and Figure 2-9 A and B suggest a general decline in water quality from west to east. Figure 2-9 B includes three threshold concentration values that are related to estimated risk in the NZ recreational water quality guidelines. In this figure, the relationship of risk to these thresholds may be considered approximate, because ideally 100 data points are used for this purpose (representing monitoring over approximately five seasons – here we have used three for most sites and just a single season for two sites). The concentration thresholds and associated risks are explained in Table 2-1:

Table 2-1: Risks associated with 95th percentile concentration. From MfE/MoH (2003) guidelines, Table H1, and associated text. "GI" is gastrointestinal illness, and "AFRI" is Acute Febrile Respiratory Illness.

Category	Threshold value (95th percentile value of enterococci/100 mL)	Estimated risk (%)		Commentary
		GI	AFRI	
A	≤ 40	<1	<0.3	Less than No Observable Adverse Effects Level (NOAEL) <1 case of gastroenteritis/100 exposures
B	41 - 200	1 - 5	0.3 – 1.9	1 case of gastroenteritis/20 exposures 1 case of AFRI/50 exposures
C	201 – 500	5 – 10	1.9 – 3.9	1-2 cases of gastroenteritis/10 exposures 1-2 cases of AFRI/50 exposures
D	>500	>10	>3.9	1 case of gastroenteritis/10 exposures 1 case of AFRI/25 exposures

These data suggest:

- slight, general increase in risk from west to east
- variability in risk from year to year
- similar risk levels for the four NCC sites
- of the three "urban" NCC sites, a generally greater risk at the Nelson Haven site.

It is not possible to identify the source of elevated enterococci numbers from these data. The three urban NCC sites are likely to be impacted by sources within Nelson City, as well as by contaminants from other sources. The modelling work undertaken by MetOcean (2017) indicates a general transport of contaminants from west to east. It is possible that these FIBs could also originate from the Bell Island WWTP – Figure 2-6 and Figure 2-7 indicate that a reasonably consistent load of FIB are discharged into the inshore waters of Tasman Bay, some of which may impinge on the down-current recreational sites. This is consistent with the generally low FIB numbers observed at Mapua Leisure Park Beach and Rabbit Island Main beach, which are less likely to be exposed to contaminants derived from the Bell Island discharge because of the currents in Tasman Bay.

Risk summary

Using the data summarised in Figure 2-9 B and the risk thresholds identified in Table 2-1, the recreational water quality data collected in the preceding three summer periods suggest that for sites in the Nelson City recreational monitoring programme nearest to the aberrational discharge sites:

- For approximately two years in three:
  - A 1-5% risk of GI illness exists.
  - Up to 2% risk of AFRI illness exists.
- For approximately one year in three:
  - A 1-5% risk of GI illness exists.

- An approximately 2-4% risk of AFRI illness exists.

It should be noted that these risks were estimated using fewer data than recommended by the MfE/MoH guidelines (approximately 65 data collected over a three-year period, vs 100 data collected over a five-year period). These risks apply to contact recreation that involves activities such as swimming, surfing, scuba diving and dinghy-boat sailing. These are illness risks, not infection risks. These risks do not apply to “non-normal” circumstances, i.e., when an epidemic status exists in the community.

It is possible that these conditions are independent of the aberrant discharges, which occur infrequently, and over relatively short duration. As such, it is appropriate to consider these risks as indicative of the influence of general background activities that introduce faecal contaminants into Tasman Bay and the Waimea Inlet.

The risks associated with recreation at recreational sites near the Waimea Inlet are larger than those indicated by the separate Quantitative Microbial Risk Assessment undertaken for the Bell Island WWTP (McBride, 2017). This outcome is consistent with the lower Bell Island QMRA estimates, which provide **the incremental risk associated exclusively with the Bell Island WWTP discharge**, i.e. it does not account for other contaminant sources.

2.3 Recent winter condition sampling

To provide information regarding the microbiological condition of waters near the four pump stations from which aberrant discharge may occur, a short monitoring programme was implemented. Samples were collected from seven locations around the Waimea Inlet, from the NCC recreational water quality sample sites, as well as other locations where contact recreation occurs at other times. The location of these sites is indicated in Figure 1-2. The Wakatu, Songer, Saxton and Airport sample sites specifically represented the receiving environment for the associated pump stations – samples were collected immediately offshore from the end of each discharge pipe. Samples were collected on four occasions in a four-week period during August-September 2017. Samples were collected within one hour following high tide and analysed to determine FIB concentrations.

These data are summarised in Figure 2-10 and Figure 2-11, where they are listed in west/south to north/east order. In Figure 2-10, the FIB concentration data are plotted together with rainfall measured on the day preceding - and on the day of sample collection. In Figure 2-12 these data are presented as a median value of the four discrete samples for each sample location. The Tahunanui site is probably least subject to storm water inflow (it is situated on a sandy peninsula, with no major infrastructure), and the storm water catchment on the Monaco Peninsula is very small. All other sites are located close to stream inflows and storm water discharge points.

These data indicate:

- A strong relationship between rainfall (mm) and FIB concentration, particularly for *E. coli*, existed at several sites, but:
    - a weak relationship existed between FIB concentration and rainfall at the Monaco site
    - no obvious relationship between FIB concentration and rainfall at the Tahunanui site.

- Consistency in the relative concentrations of enterococci and *E. coli* at all locations.
- Two, or possibly three groups of samples:
  - Poorest microbiological quality at the Wakatu and Parkers Cove sites.
  - Intermediate water quality at the Saxton and Airport sites.
  - Highest microbiological water quality at the Monaco and Tahunanui sites.

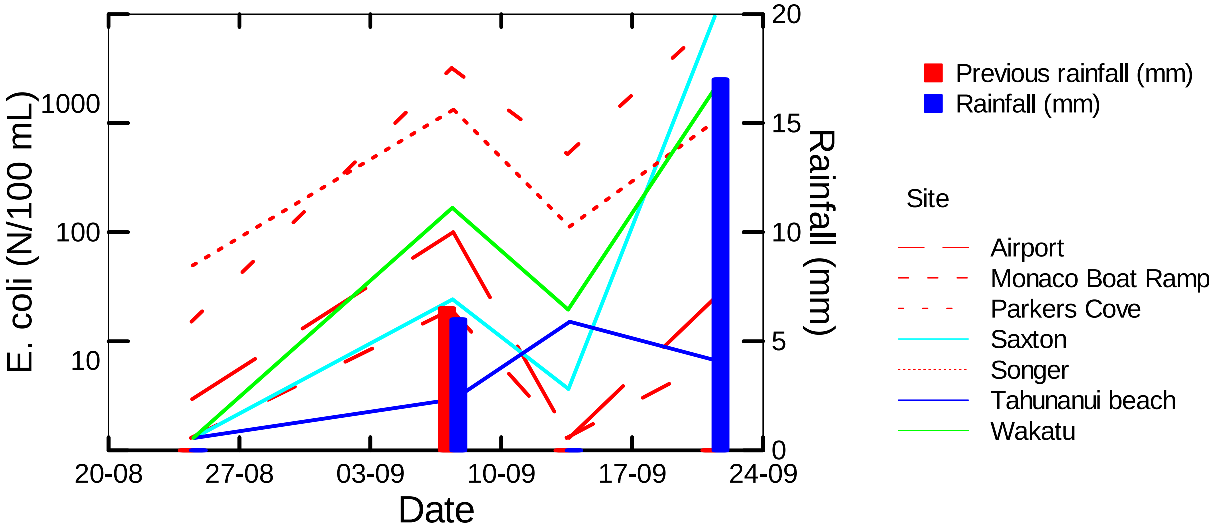

Figure 2-10: *E. coli* concentrations measured during the special sampling campaign of August-September 2017.

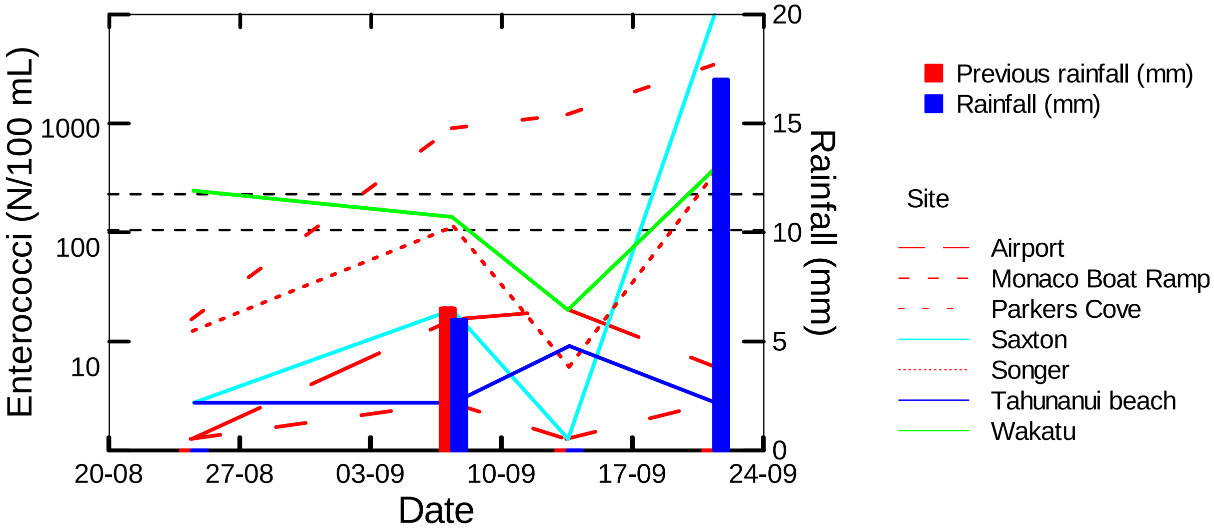

Figure 2-11: Enterococci concentrations measured during the sampling campaign of August-September 2017. The horizontal broken lines represent the MfE/MoH Guideline single sample “Amber” (140 enterococci/100 mL) and “Red” (280 enterococci/100 mL) thresholds respectively.

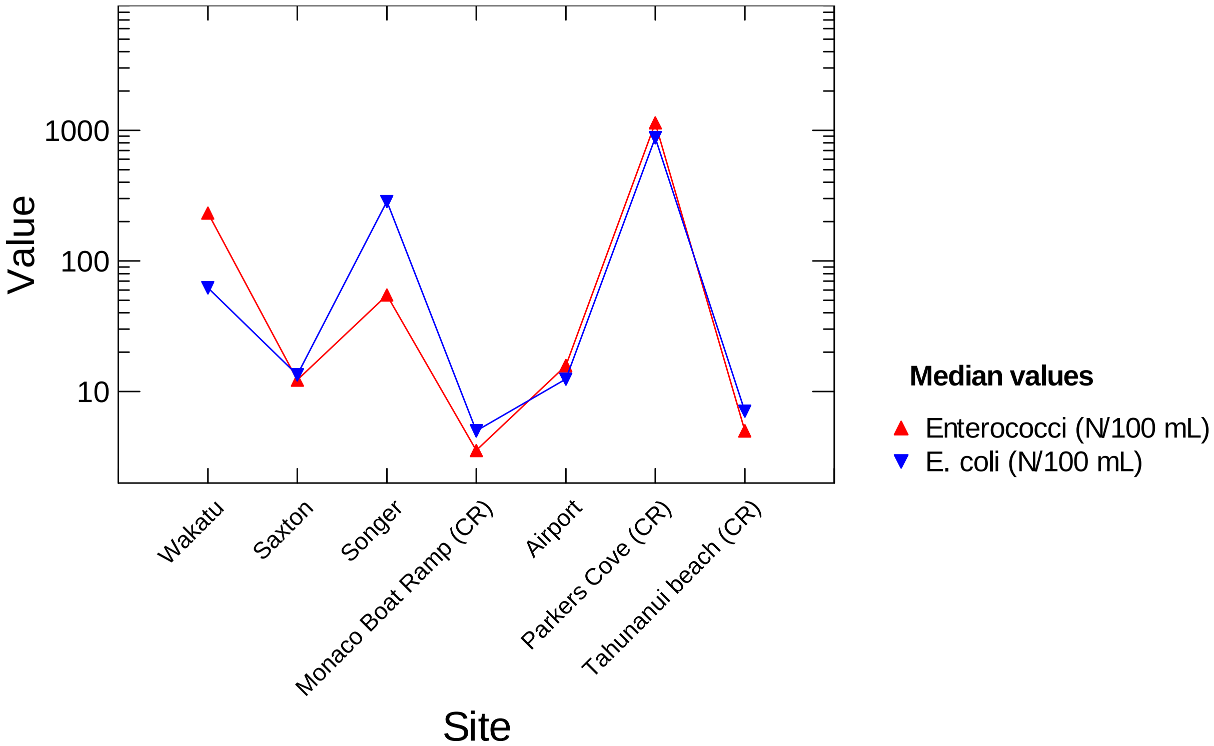

Figure 2-12: Median enterococci and *E. coli* concentrations measured during the sampling campaign of August-September 2017. Similar results were obtained for average values. Note *y*-axis has log_{10} scale.

2.4 Event-related stream water quality

In 2013, NCC published the results of a series of water quality investigations of the Stoke Valley streams (NCC 2013). Samples were collected at various stages of the flood hydrograph for a series of rainfall events. During all events, water quality deteriorated with increasing stream flow. This was demonstrated using *E. coli* and suspended sediment concentrations. Although the raw data derived from these investigations were not available for assessment, it was possible to estimate the instantaneous load or flux of FIB during several of these events from the figures included in the report. Results for two streams and several events are summarised in Table 2-2.

Table 2-2: Approximate *E. coli* flux estimated from several measurements made during rainfall events in streams in the Stoke Valley during 2012. From NCC (2013).

Site	Date	Flow (L/s)	*E. coli* concentration (N/100 mL)	Duration of event (h)	*E. coli* flux (N/4 h)
Orphanage Creek	27/04/12	2000	6000	4	1.73E+11
Poormans Creek	05/06/12	2000	2100	4	6.05E+10
Poormans Creek	06/06/12	4000	2100	4	1.21E+11
Poormans Creek	17/03/12	90	10000	4	1.30E+11
Poormans Creek	18/03/12	25	1000	4	3.60E+09
Poormans Creek	18/03/12	40	1000	4	5.76E+09

Although the flux of FIB is likely to be generally much smaller than that estimated in the Bell Island WWTP discharge, the estimates in Table 2-2 indicate that on occasions, the streams flowing into Waimea Inlet contribute larger loads of FIBs to the Waimea Inlet/Nelson Bay than the does the Bell Island WWTP discharge. For example, in 2016 the median daily enterococci flux for the Bell Island WWTP was approximately 3.0×10^{10} (Figure 2-6 and Appendix C), which is a smaller value than those estimated for rainfall events in Table 2-2.

The streams, rivers and storm water pipes may discharge these loads directly to the Waimea Inlet under any tidal condition, whereas the wastewater discharge is to a channel leading to Tasman Bay, and these discharges occur only on the ebb tide. The river discharges during rainfall events are likely, therefore, to have a greater impact on water quality in Waimea Inlet than the Bell Island discharge.

3 Summary

Bell Island WWTP discharge

In the previous six calendar years, median daily discharge ranged from 9,400 m^3/d to 15,400 m^3/d. The discharge in 2016 was the second largest in the six-year period, and indicated a reversal in the downward trend observed in the previous five years. The discharge rate is greater in winter than summer.

The trend in concentrations of FIB in the treated wastewater is inversely related to the wastewater discharge rate – annual median concentrations increased over the period 2011 to 2015, and decreased in 2016.

The flux (instantaneous load) of FIB (the product of concentration and discharge rate, expressed as number of organisms/unit of time) has increased slightly over time for faecal coliforms and to a lesser extent for enterococci.

The incremental risk associated with the Bell Island WWTP was recently assessed by McBride (2017). This work indicated low illness risk to contact recreational water users at Monaco Beach and Tahunanui Beach for well-treated wastewater.

Recreational water quality

Recreational water quality data were available for the preceding three summer seasons only. Median concentrations indicate little spatial or temporal variation over this period. Seasonal 95th percentile concentrations suggest:

- a west/south to east/north increase in enterococci concentrations
- similar year-to-year trends in concentrations across all sites
- higher FIB concentrations in areas:
  - near urban storm water runoff, or
  - likely to be in the path of material transported by currents within southern Tasman Bay.

Illness risks associated with contact recreation in the NCC jurisdictional area likely to be impacted by aberrational discharges are generally:

- one case of gastroenteritis/20 exposures (1-5%), and one case of AFRI/50 exposures (0.3-1.9%), and may at times increase to
- one to two cases of gastroenteritis/10 exposures (5-10%), or one to two cases of AFRI/50 exposures (1.9-3.9%)
- these are illness risks, and apply to recreational activities likely to cause immersion of the head.

The risks associated with recreation at recreational sites near the Waimea Inlet reflect the impact of faecal contaminants from all sources, and are greater than those estimated in the separate Quantitative Microbial Risk Assessment undertaken for the Bell Island WWTP. The latter reflects the incremental risk associated exclusively with the Bell Island WWTP discharge, **i.e. it does not account for other contaminant sources**.

Recent winter condition sampling

Seven sites were sampled on four occasions during August and September 2017. Although relatively few results exist, these indicate:

- better water quality at sites unlikely to be impacted by storm water runoff
- deterioration in microbial water quality in response to rainfall.

Sites subject to storm water inflows are unlikely to achieve satisfactory grading in terms of the MfE/MoH Guidelines. These results are not unexpected from the perspective of the Guidelines, which recommend that sanitary surveys be undertaken to identify potential sources of contaminants. Among the land uses identified that may lead to contamination of recreational sites are:

- storm water outlets that may be subject to sewage contamination
- urban storm water that is protected from sewage ingress
- rainfall events that trigger contamination events
- exceedance of the national guideline single sample threshold (280 enterococci/100 mL) on any occasion.

Available information suggests that these risk factors exist for much of the foreshore of the Waimea Inlet, and that these risks exist without aberrational discharge from sewer pump stations.

Event-related stream water quality

Limited stream microbial water quality monitoring has been undertaken in creeks and streams draining into Waimea Inlet. Available data suggest that the load of FIB input to the Inlet during a four-hour may exceed the daily load discharged from the Bell Island WWTP. Although these large stream inflow loads are likely to be intermittent and of relatively short duration, they have the potential to impact on recreational water quality in the Inlet directly.

4 Acknowledgements

The assistance of Dr Paul Fisher, NCC (provision of recreational water quality data and other information), Mr Trevor James, TDC (provision of recreational water quality data and other information), Ms Emma Reeves, NCC (provision of stream flow statistics), Ms Olivia Johnstone (Cawthron) for coordinating sample collection, providing data, comments and other useful information, and Mr Jeremy Butler (Landmark Lile) for coordinating the activities of the various teams.

5 References

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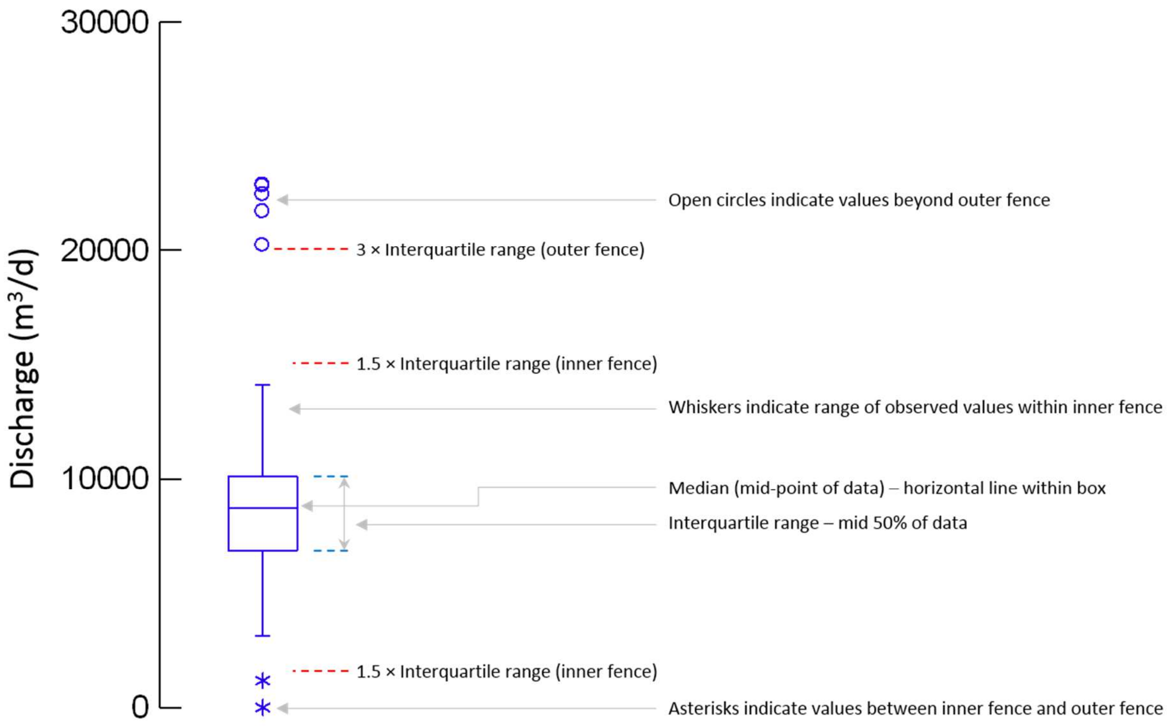
Appendix A How to interpret a box-and-whisker plot

The box-and-whisker plot provides a simple way to summarise one or more data sets. Although several formats exist for box-and-whisker plots, all use the box to represent the first and third quartiles of data, with the median represented as a horizontal line within the box.

The whiskers and other symbols, may however represent different values according to the software used to generate the plot.[2] The following figure presents the conventions used in Systat v 13.[3]



[2] e.g., https://en.wikipedia.org/wiki/Box_plot

[3] https://systatsoftware.com/products/systat/ and user help files

Appendix B Summary statistics – recreational water quality

Data for 2014/15 - 2016/17 summer recreation periods

Statistic	Enterococci concentration measured at each site (N/100 mL)							
	Tahunanui	Monaco	Nelson Haven	Cable Bay	Rabbit Island, Main Beach	Mapua Leisure Park Beach	Best Island	Rabbit Island, Back Beach
N of Cases	61	61	61	61	65	66	15	15
Arithmetic Mean	24.9	29.5	56.3	26.2	8.9	8.8	37	22.1
Geometric Mean	13.5	15	19.3	14	6.2	6.8	10.7	10.9
Percentile								
1.00%	5	5	5	5	5	5	5	5
5.00%	5	5	5	5	5	5	5	5
10.00%	5	5	8	5	5	5	5	5
20.00%	10	10	10	10	5	5	5	5
25.00%	10	10	10	10	5	5	5	5
30.00%	10	10	10	10	5	5	5	5
40.00%	10	10	10	10	5	5	5	5
50.00%	10	10	10	10	5	5	5	5
60.00%	10	10	10	10	5	5	5	7.5
70.00%	10	12	22.2	12	5	5	10	20
75.00%	12.5	31	31	20	5	10	17.5	28.3
80.00%	20	42	53	23.3	7.5	10	25.5	36
90.00%	57	68.4	193.6	57.4	10	20	185	63
95.00%	103.6	103.6	299	122.1	20	30.2	240.5	106.5
99.00%	321.2	303.8	738.9	232.9	139	57	259	121

Data for 2014/15 summer recreation period

Statistic	Enterococci concentration measured at each site (N/100 mL)							
	Tahunanui	Monaco	Nelson Haven	Cable Bay	Rabbit Island, Main Beach	Mapua Leisure Park Beach	Best Island	Rabbit Island, Back Beach
N of Cases	20	20	20	20	22	22	No data	No data
Minimum	10	10	10	10	5	5		
Maximum	63	310	390	110	10	62		
Arithmetic Mean	15.3	26.6	58.5	18.1	5.7	11.1		
Standard Deviation	14.7	66.9	118.3	23.7	1.8	13.9		
Percentile								
1.00%	10	10	10	10	5	5		
5.00%	10	10	10	10	5	5		
10.00%	10	10	10	10	5	5		
20.00%	10	10	10	10	5	5		
25.00%	10	10	10	10	5	5		
30.00%	10	10	10	10	5	5		
40.00%	10	10	10	10	5	5		
50.00%	10	10	10	10	5	5		
60.00%	10	10	10	10	5	5		
70.00%	10	10	10	10	5	5		
75.00%	10	10	10	10	5	10		
80.00%	10	10	15	15	5	11		
90.00%	36	25.5	300	36	10	31		
95.00%	57.5	170.5	350	81	10	43.4		
99.00%	63	310	390	110	10	62		

Data for 2015/16 summer recreation period

Statistic	Enterococci concentration measured at each site (N/100 mL)							
	Tahunanui	Monaco	Nelson Haven	Cable Bay	Rabbit Island, Main Beach	Mapua Leisure Park Beach	Best Island	Rabbit Island, Back Beach
N of Cases	21	21	21	21	21	21	15	15
Minimum	10	10	10	10	5	5	5	5
Maximum	344	254	782	238	31	20	259	121
Arithmetic Mean	42.8	38.9	81.4	45.9	7.7	6.4	37	22.1
Standard Deviation	76.7	59	178.2	65.5	6.4	3.6	76.8	32.4
Percentile								
1.00%	10	10	10	10	5	5	5	5
5.00%	10	10	10	10	5	5	5	5
10.00%	10	10	10	10	5	5	5	5
20.00%	10	10	10	10	5	5	5	5
25.00%	10	10	10	10	5	5	5	5
30.00%	10	10	10	10	5	5	5	5
40.00%	10	10	10	10	5	5	5	5
50.00%	10	10	10	10	5	5	5	5
60.00%	10	10	11	11	5	5	5	7.5
70.00%	26.6	33.2	22.2	53	5	5	10	20
75.00%	53	47.5	36.5	53	6.2	5	17.5	28.3
80.00%	56.3	67.3	86.3	63.2	10	6.5	25.5	36
90.00%	107	101.8	251.2	159	14	10	185	63
95.00%	230.1	182.5	500.9	212.7	24.9	14.5	240.5	106.5
99.00%	344	254	782	238	31	20	259	121

Data for 2016/17 summer recreation period

Statistic	Enterococci concentration measured at each site (N/100 mL)							
	Tahunanui	Monaco	Nelson Haven	Cable Bay	Rabbit Island, Main Beach	Mapua Leisure Park Beach	Best Island	Rabbit Island, Back Beach
N of Cases	20	20	20	20	22	23	No data	No data
Minimum	5	5	5	5	5	5		
Maximum	124	75	99	64	158	30		
Arithmetic Mean	15.7	22.5	27.8	13.6	13.3	8.7		
Standard Deviation	26.1	23.3	25.9	14.7	32.5	6.9		
Percentile								
1.00%	5	5	5	5	5	5		
5.00%	5	5	5	5	5	5		
10.00%	5	5	5	5	5	5		
20.00%	5	5	5	5	5	5		
25.00%	5	5	5	5	5	5		
30.00%	5	5	7.5	5	5	5		
40.00%	7.5	5	10	5	5	5		
50.00%	10	7.5	20	5	5	5		
60.00%	10	15	31	10	5	5		
70.00%	10	36.5	36.5	15	5	8		
75.00%	15	47.5	47.5	20	5	10		
80.00%	20	53	53	20	10	10		
90.00%	20	53	58.5	31	13	20		
95.00%	72	64	81.5	47.5	75.2	23.5		
99.00%	124	75	99	64	158	30		

Appendix C Summary statistics – Bell Island discharge

Annual statistics - Discharge, faecal indicator bacteria concentrations and loads

Results for Year = 2014

Statistic	Discharge (m^3/d)	Faecal coliform conc. (N/100 mL)	E. coli conc. (N/100 mL)	Faecal coliform flux (N/d)	E. coli flux (N/d)
N of Cases	365	17	16	17	16
Minimum	0.0	300.0	9.0	0.0	0.0
Maximum	23540.0	83000.0	630.0	1.1E+013	6.6E+010
Median	10310.0	3100.0	90.5	2.9E+011	8.3E+009
Arithmetic Mean	10989.4	15756.5	148.3	2.0E+012	1.7E+010
Mode	0.0	2500.0	36.0	.	.
Standard Deviation	5622.5	25913.3	159.1	3.2E+012	2.2E+010
Percentiles					
1%	0.0	300.0	9.0	0.0	0.0
5%	263.3	419.0	17.1	9.5E+009	4.1E+008
10%	4368.0	648.0	36.0	3.5E+010	1.4E+009
20%	6710.0	698.0	36.0	7.0E+010	2.4E+009
25%	7202.3	805.0	42.0	9.1E+010	3.1E+009
30%	7469.0	1836.0	49.8	1.3E+011	3.5E+009
40%	8694.5	2650.0	54.0	1.7E+011	4.7E+009
50%	10310.0	3100.0	90.5	2.9E+011	8.3E+009
60%	12115.5	5540.0	105.1	8.3E+011	1.1E+010
70%	13742.0	8960.0	188.0	1.3E+012	1.8E+010
75%	14349.8	13500.0	225.0	2.5E+012	2.5E+010
80%	15092.0	24000.0	259.0	4.8E+012	3.3E+010
90%	19449.0	65400.0	298.0	6.8E+012	6.1E+010
95%	22648.5	78100.0	531.0	9.6E+012	6.5E+010
99%	23181.6	83000.0	630.0	1.1E+013	6.6E+010

Results for Year = 2015

Statistic	Discharge (m^3/d)	Faecal coliform conc. (N/100 mL)	E. coli conc. (N/100 mL)	Faecal coliform flux (N/d)	E. coli flux (N/d)
N of Cases	365	22	22	22	22
Minimum	0.0	25.0	3.3	2.8E+009	3.7E+008
Maximum	23200.0	470000.0	4100.0	5.4E+013	7.7E+011
Median	9366.0	7800.0	495.0	6.6E+011	4.2E+010
Arithmetic Mean	10324.2	38024.3	816.8	4.4E+012	1.0E+011
Mode	0.0	.	.	.	.
Standard Deviation	4485.8	99203.0	973.4	1.1E+013	1.7E+011
Percentiles					
1%	2250.9	25.0	3.3	2.8E+009	3.7E+008
5%	4017.5	400.0	12.1	3.3E+010	1.0E+009
10%	5338.0	797.0	24.3	5.3E+010	1.6E+009
20%	6722.5	1950.0	138.1	8.2E+010	1.1E+010
25%	7412.8	2400.0	190.0	1.2E+011	1.7E+010
30%	7955.0	3020.0	240.0	1.7E+011	1.8E+010
40%	8654.0	3550.0	469.0	3.2E+011	2.6E+010
50%	9366.0	7800.0	495.0	6.6E+011	4.2E+010
60%	11055.5	11700.0	628.0	1.6E+012	5.7E+010
70%	12377.0	21800.0	793.0	3.1E+012	7.2E+010
75%	13067.0	27000.0	920.0	3.5E+012	9.1E+010
80%	13735.0	34300.0	1280.0	6.0E+012	1.9E+011
90%	15380.0	73300.0	2030.0	7.9E+012	2.6E+011
95%	18835.0	236600.0	2900.0	2.7E+013	4.6E+011
99%	23183.8	470000.0	4100.0	5.4E+013	7.7E+011

Results for Year = 2016

Statistic	Discharge (m^3/d)	Faecal coliform conc. (N/100 mL)	E. coli conc. (N/100 mL)	Faecal coliform flux (N/d)	E. coli flux (N/d)
N of Cases	366	21	21	21	21
Minimum	2529.0	88.0	1.6	1.1E+010	1.1E+008
Maximum	23221.0	76000.0	2300.0	1.8E+013	5.3E+011
Median	14136.0	5900.0	270.0	7.6E+011	3.0E+010
Arithmetic Mean	14753.1	11956.1	355.2	2.2E+012	6.5E+010
Mode	.	.	25.0	.	.
Standard Deviation	5783.9	17574.8	490.2	3.9E+012	1.1E+011
Percentiles					
1%	3484.8	88.0	1.6	1.1E+010	1.1E+008
5%	5903.0	303.6	4.3	4.2E+010	5.1E+008
10%	7498.1	678.0	9.2	9.4E+010	1.4E+009
20%	9242.1	1670.0	25.0	1.3E+011	3.5E+009
25%	9957.0	2150.0	36.3	1.6E+011	5.4E+009
30%	10800.2	2460.0	144.0	3.3E+011	1.4E+010
40%	13030.1	5410.0	198.0	6.6E+011	2.3E+010
50%	14136.0	5900.0	270.0	7.6E+011	3.0E+010
60%	15687.0	6940.0	314.0	1.2E+012	5.1E+010
70%	18341.3	10000.0	372.0	2.0E+012	6.3E+010
75%	19641.0	16500.0	395.0	2.4E+012	6.9E+010
80%	22823.7	18600.0	464.0	3.2E+012	8.7E+010
90%	23202.0	29200.0	638.0	4.8E+012	1.3E+011
95%	23211.0	56200.0	1442.0	1.1E+013	3.1E+011
99%	23217.8	76000.0	2300.0	1.8E+013	5.3E+011