# Lower Kaituna River – Maketu Estuary

## Water Quality Modelling

Final Report
December 2010

# Lower Kaituna River – Maketu Estuary

# Water Quality Modelling

# Final report

DHI Water and Environment
e-Centre, Gate 5, Oaklands Road
Massey University, Albany, 0632
PO Box 300-705
Albany 0752, Auckland
New Zealand

Tel: +64 99 12 96 38
Fax: +64 99 12 96 39
www.dhigroup.com

| Client | Client's representative |
|---|---|
| Environment Bay of Plenty | Steven Park |

| Project | Project No |
|---|---|
| Lower Kaituna River – Maketu Estuary | 44800055 |
| Authors<br>Jørgen Krogsgaard Jensen, Ben Tuckey, Aurélien Gasc | Date<br>December 2010<br>Approved by<br>Colin Roberts |

| Revision | Description | By | Checked | Approved | Date |
|---|---|---|---|---|---|
| 1 | Draft final report for client comment | JOK | AUG | CJR | 07/2010 |
| 2 | Final report | JOK | AUG | CJR | 12/2010 |
| | | | | | |

| Key words | Classification |
|---|---|
| 3D Modelling, hydraulic, water quality, bluegreen algae, bacteria, Kaituna, Maketu | ☐ Open<br>☐ Internal<br>☒ Proprietary |

| Distribution | | No of copies |
|---|---|---|
| EBoP (electronic pdf) | Stephen Park | 1 |
| DHI: | Library | 1 |

# CONTENTS


1 SUMMARY .....1

2 BACKGROUND .....2

3 OBJECTIVES .....4

4 AVAILABLE DATA AND DATA ANALYSIS .....5
4.1 Hydraulic data .....5
4.2 Water quality data .....5

5 WATER QUALITY CRITERIA .....8
5.1 Algae concentrations .....8
5.2 Bacteria concentrations .....9

6 MODEL CONCEPT AND SET-UP .....10
6.1 Hydrodynamic .....10
6.2 Water quality .....11
6.2.1 Eutrophication modelling .....11
6.2.2 Water quality model set-up .....14

7 HYDRAULIC MODEL .....15
7.1 Model set up .....15
7.2 Calibration .....15

8 POTENTIAL FOR ALGAL BLOOM .....17
8.1 Calibration of the eutrophication model .....17
8.2 Sensitivity analysis .....18
8.3 Existing layout .....21
8.4 Future layout .....21

9 DILUTION IN THE ESTUARY .....23

10 QUANTITATIVE ASSESSMENT OF THE DIVERSION .....36
10.1 Blue green algae .....36
10.2 F. Coliforms .....39
10.3 Enterococci .....42
10.4 Summary .....44

11 RECOMMENDATION FOR FURTHER ACTIVITIES .....45

12 REFERENCES .....47

## DRAWINGS

Figure 2-1: Overview of the Kaituna River – Maketu Estuary system ........................................2
Figure 4-1: Measured chlorophyll concentrations 2008-2009. ..................................................6
Figure 4-2: Chlorophyll concentration and Bluegreen Algae cell count at Te Tumu station. ........6
Figure 4-3: E. coli concentration on the Kaituna River and in Maketu Estuary............................7
Figure 6-1 : Model bathymetry for existing situation (Moturiki datum).......................................10
Figure 6-2 : Model bathymetry for proposed situation (Moturiki datum)....................................11
Figure 6-3: The MIKE ECOLab standard Eutrophication..........................................................12
Figure 7-1 : Kaituna River flow.................................................................................................15
Figure 7-2 : Water levels (Moturiki datum) for open ocean boundaries. ...................................15
Figure 7-3 : Comparison of predicted and observed salinities within Maketu Estuary................16
Figure 8-1 : Locations for presentation of time series plot. ......................................................19
Figure 8-2: **Existing conditions** - Simulated chlorophyll concentration (25-30 May) of October upstream inflow concentration ..........................................................................................19
Figure 8-3: **Existing conditions** - high tide - Algae biomass (in mg/l chlorophyll) - October concentration (0.030 mg/l) ......................................................................................................20
Figure 8-4 : **Existing conditions –** Low tide - Algae biomass (in mg/l chlorophyll) - October concentration (0.030 mg/l) ......................................................................................................20
Figure 8-5 : **Future Scenario**: Simulated chlorophyll concentration (25-30 May) - October upstream inflow concentration ..........................................................................................22
Figure 8-6 : **Future scenario -** Algae biomass (in mg/l chlorophyll) – High tide - October concentration (0.030 mg/l) ......................................................................................................22
Figure 8-7 : **Future scenario -** Algae biomass (in mg/l chlorophyll) – Low tide - October concentration (0.030 mg/l) ......................................................................................................23
Figure 9-1 : Frequency distribution of flow in Kaituna River – full year periods.........................24
Figure 9-2: Frequency distribution of flow in Kaituna River – algae sampling periods ...............25
Figure 9-3: Dilution-decay factor for Faecal coliforms (expressed as percentage of the 20 days simulation period) - Existing layout - Lower Mid Maketu Estuary.............................................27
Figure 9-4: Dilution-decay factor for Faecal coliforms (expressed as percentage of the 20 days simulation period) - Future layout - Lower Mid Maketu Estuary. ...............................................27
Figure 9-5: Dilution-decay factor for Enterococci (expressed as percentage of the 20 days simulation period) - Existing layout - Boat Ramp station .........................................................28
Figure 9-6: Dilution-decay factor for Enterococci (expressed as percentage of the 20 days simulation period) - Future layout - Boat Ramp station.............................................................28
Figure 9-7: Dilution factor for Bluegreen algae (expressed as percentage of the 20 days simulation period) - Existing layout - Lower Mid Maketu Estuary..............................................29
Figure 9-8: Dilution factor for Bluegreen algae (expressed as percentage of the 20 days simulation period) - Future layout - Lower Mid Maketu Estuary. ...............................................29
Figure 9-9: Existing condition- frequency of dilution (incl. decay) for F. coliform at the station in the Lower Mid Maketu Estuary. ..........................................................................................30
Figure 9-10: Future situation- frequency of dilution (incl. decay) for F. coliform at the station in the Lower Mid Maketu Estuary. ..........................................................................................31
Figure 9-11: Existing situation - frequency of dilution (incl. decay) for Enterococci at the station Boat Ramp in the Maketu Estuary.........................................................................................32
Figure 9-12: Future situation - frequency of dilution (incl. decay) for Enterococci at the station Boat Ramp in the Maketu Estuary.........................................................................................33
Figure 9-13: Existing condition- frequency of dilution of Bluegreen algae at the station in the Lower Mid Maketu Estuary.....................................................................................................34
Figure 9-14: Future condition- frequency of dilution of Bluegreen algae at the station in the Lower Mid Maketu Estuary.....................................................................................................35
Figure 10-1: Frequency of bluegreen algae concentration in the lower Kaituna River based on monitoring data from March 2005 to May 2010. ......................................................................37
Figure 10-2 Frequency distribution of bluegreen algae concentration in the lower Kaituna River based on monitoring data .....................................................................................................40

Figure 10-3: Frequency distribution of bluegreen algae concentration in the lower Kaituna River based on monitoring data ....................................................................................................43

## *APPENDICES*

A Data availability used for the project

B Model parameters

# 1 SUMMARY

A water quality study of the Lower Kaituna River and Maketu Estuary was carried out to make a broad comparative assessment of the water quality and hydro-ecological health of the Maketu Estuary under two different configurations of discharge of the Kaituna River to the Ocean through the establishment and exploitation of a computer model describing the relevant 3D hydrodynamic and water quality processes.

In the existing condition, there is an open connection from the river to the ocean through Te Tumu cut and the river flows to the estuary through Fords cut. The propose layout considers a closure of the Te Tumu cut, the opening (or "full diversion") of the Papahikawai channel and removal of the Fords cut controls.

The parameters to be used to make that assessment were Bacteria (E-Coli and Enterococci) and Algae.

The Kaituna River – Maketu Estuary system was modelled using a 3 dimensional hydraulic model and an eutrophication model. Analysis of simulation results showed that in the current situation, no algal growth occurs in the estuary with any algal bloom issue in the estuary arising from algal blooms upstream (carried from the Kaituna River to estuary). In the future case, less estuary mixing occurs, leading to a higher retention time in the estuary. The model then shows a slight algal development within the estuary but not enough to trigger an algal bloom as such.

A more statistical analysis was carried out to compare the probability of non-compliance with the New Zealand regulation on bathing and shellfish gathering waters. Simulations were carried out to provide a dilution pattern (from Te Matai to two locations in the estuary: Boat ramp and Lower-mid estuary). Different dilutions were assigned probabilities which were then related to actual Algae and Bacteria concentration recorded upstream of the model boundary to provide a probability of exceeding the guidelines values in the estuary. This showed that full diversion will have a significant negative impact on the estuary water quality by decreasing the dilution of a pollutant load.

A number of recommendations have been made to the data collections plan to allow such data to be used to support hydro-ecological modelling.

# 2 BACKGROUND

The Kaituna River – Maketu Estuary system is shown in Figure 2-1. The system comprises the catchments that drain to Lake Rotorua and Lake Rotoiti; the outlet structures from the Lake to the Kaituna River; the Upper Kaituna River; the lower Kaituna River; the Maketu Estuary and the Bay of Plenty coastal waters.

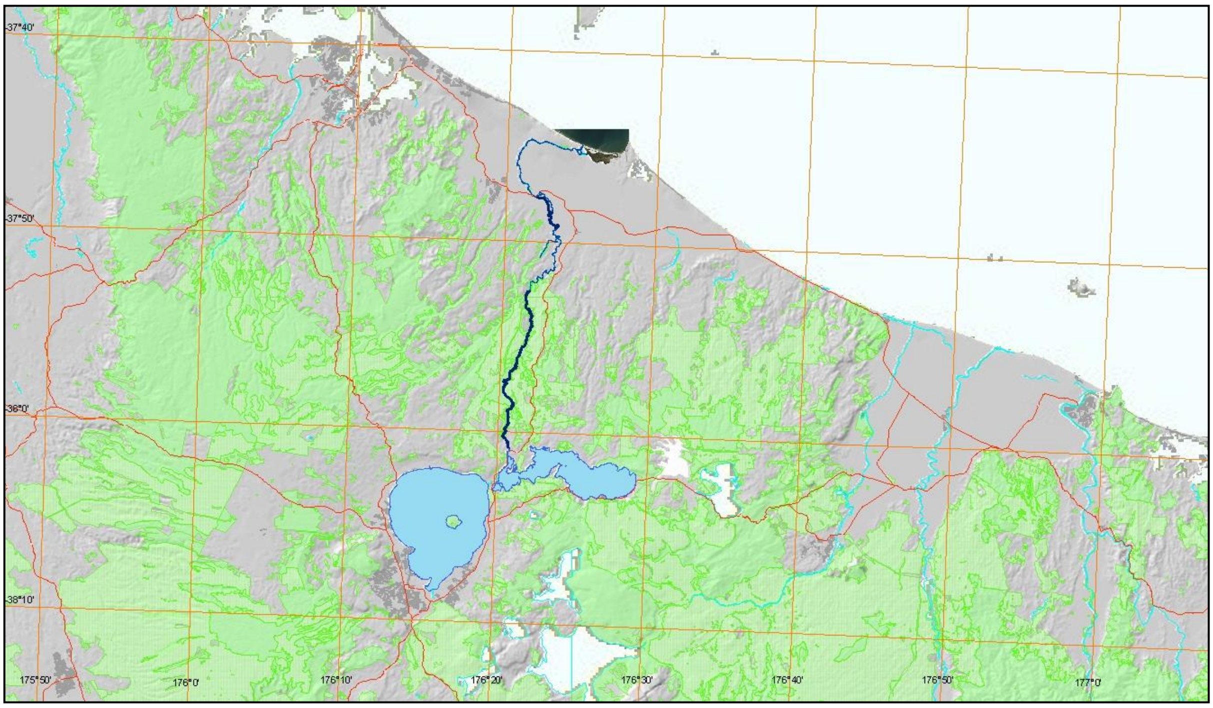

*Figure 2-1: Overview of the Kaituna River – Maketu Estuary system*

Water Quality (WQ) loadings to the lakes are urban point sources (residential and industrial storm water and waste water around the lakes) and agricultural diffuse sources (farming and forestry) within the catchments. The water quality loading to the Kaituna River and Maketu Estuary are generally from rural land use and the marine environment.

There have been major water quality issues in Kaituna River resulting from algal blooms developing when waters from Lake Rotorua enter into the waters in Lake Rotoiti. The Ohau Channel diversion was constructed so that the majority of Lake Rotorua water will bypass Lake Rotoiti and limit algal bloom development in the lake (which has significant recreational use).

The Lower Kaituna land has been recovered for agricultural use by implementing flood protection works over many years (since the 1970's). These works have chopped and changed and today the main flood mitigation measures are: levees along parts of the river banks; opening of an ocean outlet (Te Tumu cut); and construction of flow control structures (Fords cut) that control the flow from the Lower Kaituna River in to the Maketu Estuary. The control is essentially a number of flap gated culverts that allow flows to pass from the river to the estuary if the driving head is sufficient (river head greater than estuary head).

As a result of the bypass of river the flow into the estuary there is a perception that the Maketu Estuary water quality and hydro-ecology has suffered. The community and Council have been in discussions and the Council wishes to investigate an estuary remediation measure known as the ‘full diversion’ where all river flow is put back to discharge through the estuary.

This will entail closing the sea opening at Te Tumu cut and providing some form of flow passage to the estuary e.g., by either by removing the Fords cut flow controls; engineering a spill way between the river channel and the Te Tumu cut; or opening the Papahikawai channel.

# 3 OBJECTIVES

The objectives of this study are to make a broad comparative assessment of the water quality and hydro-ecological health of the Maketu Estuary under two different configurations of discharge of the Kaituna River to the Ocean through the establishment and exploitation of a computer model describing the relevant 3D hydrodynamic and water quality processes. Three parameters were used to make that assessment: Bacteria (E. Coli and F. coliform) and Algae.

The two different discharge configurations were represented by:

- Existing drainage path layout (Te Tumu cut and Fords cut active)
- Proposed drainage path layout (Te Tumu cut closed and Fords cut taking all river discharge).

Note that the proposed option studied represents only one possible option for a drainage path layout to achieve the 'full diversion'.

First of all, the existing data was analysed to gain insight on the current health of the system. Then, a complex ecological model was developed and coupled to a 3D hydraulic model to qualitatively describe the impact on the estuary of water quality loads coming from the Kaituna River. Finally, a more statistical analysis was carried out to quantify the probability of exceeding the New Zealand guidelines values for bathing water and shellfish collection water.

# 4 AVAILABLE DATA AND DATA ANALYSIS

## 4.1 Hydraulic data

A variety of hydraulic data was made available by EBOP for the earlier development of a three dimensional hydrodynamic model of the Kaituna River and Maketu Estuary system, to assess the impact of re-diversion of additional flow from Kaituna River to Maketu Estuary. Refer to DHI (2009) for details of this data.

## 4.2 Water quality data

An overview of the data that was available and used for the water quality modelling work is given in Appendix A. In addition, data on bacterial concentration in shellfish was also available. However they were not used directly because the modelling does not describe the concentration within the shellfish.

The water quality data provided was analysed prior to development of the model. The scope of the analysis was specifically to aid in schematising the system for computer modelling and in interpreting the modelling results. In the following paragraphs, some specific findings that have implications on the modelling work are described together with a short presentation of data that illustrate these findings.

The most recent observed algae biomass concentrations (measured as chlorophyll) in the Kaituna River system and the Maketu Estuary are shown in Figure 4-1. Within the model area, the concentrations were measured along the Kaituna River (upstream boundary at Te Matai; river mouth at Te Tumu; and half way between these two stations downstream of the Walari Stream confluence). Within the Maketu Estuary, chlorophyll concentrations were monitored at only one station, close to the estuary outlet (at the Boat Ramp).

In the river, the measured chlorophyll concentrations were low to moderate (between 1 and 9 µg/l) at 5 of the 9 sampling dates and the remaining 4 had high chlorophyll concentrations of 20 - 37 µg/l.

The concentration in the estuary was only measured at one location close to the outlet, where high dilution with coastal water occurs and consequently a relative low concentration of chlorophyll (up to 3 µg/l) was measured. Only once, in October 2008, a higher value of approx. 6 µg/l was measured at that location. This measurement was made 5 days after a high level was observed in the river system. Due to the sparse spatial coverage of the estuary WQ data no good description exists of algae biomass (measured as chlorophyll) within the centre of the Maketu Estuary.

Cell counting for blue-green algae have been carried out at some stations on the Kaituna River, as indicated in Appendix A. No cell counting of water samples were available for the Maketu Estuary. Within the modelling area, Te Tumu (close to the mouth of the river) was the only station to have available data for both cell counting and chlorophyll analysis. Figure 4-2 shows a comparison of these data. Both of these variables were monitored coincidently at 2 dates only. However for the period November 2008 to November 2009 the overall picture presented by the data indicates that there is a positive correlation. These data are too sparse and not synchronized enough to give a sound analysis of a relationship between chlorophyll and potential risk of a high number to blue-green algae cells. However the data does indicate that the chlorophyll levels should exceed 20 µg/l before the Estuary becomes at risk of having more than 1,000 cells/ml of blue-green algae.

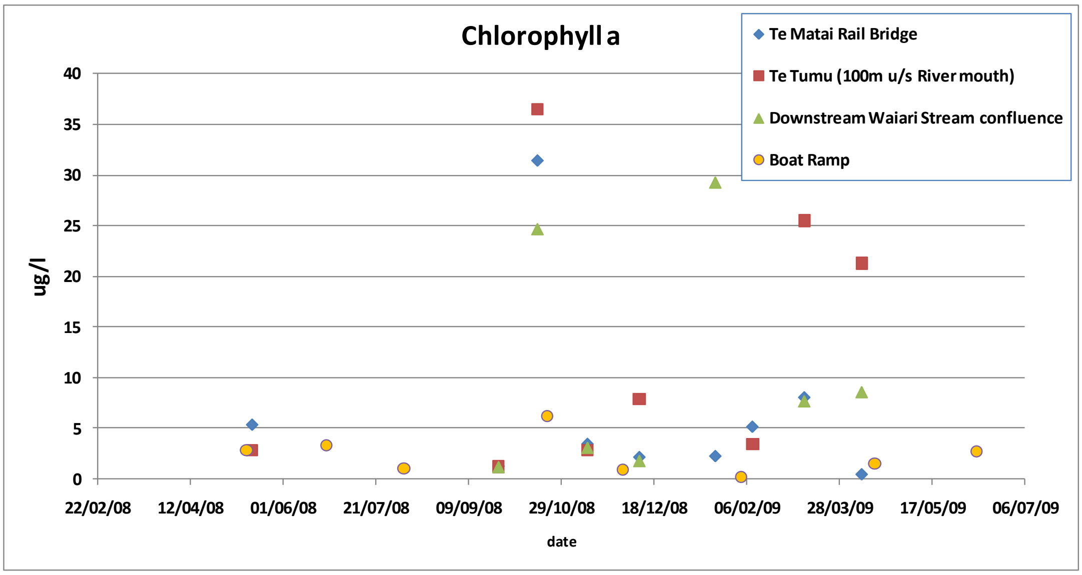


*Figure 4-1: Measured chlorophyll concentrations 2008-2009.*

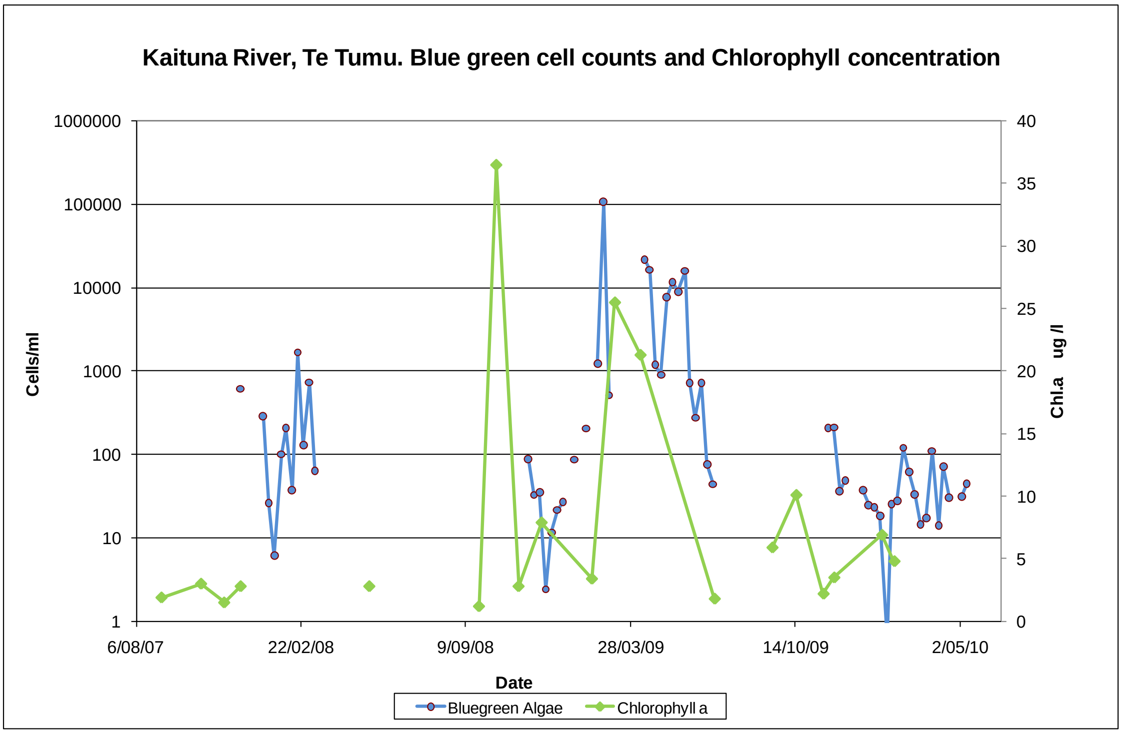


*Figure 4-2: Chlorophyll concentration and Bluegreen Algae cell count at Te Tumu station.*

The lack of time coincidence between monitoring in Kaituna River and the Maketu Estuary, the lack of time coincidence between cell count and chlorophyll analysis and the sparse spatial coverage of the Maketu Estuary limits the ability to fully calibrate the eutrophication model and to correlate the simulated chlorophyll concentrations to a concentration of blue-green algae.

A number of comments on the data, in relation to the bacteria model calibration and set-up, are presented in the following paragraphs.

Most of the measured level of E. coli is relatively low (below 500 bac./100 ml). This threshold value was exceeded only on a few occasions during the most recent years and no exceeding events were observed in the estuary except for one measured value on the 31 January 2008. On that date no measurement was carried out in the rivers.

The comparison of the upstream boundary (at Te Matai) with the most downstream station (Te Tumu) shows an increase in bacteria concentration, which mean that the river receives loadings along this stretch.  No quantitative information on the loading along this river stretch is available. All measurements taken at the upstream end of the Maketu Estuary (downstream of Fords Cut) show that the E. coli inflow concentration is very low. This may indicate that the increase at Te Tumu compared to Te Matai can be due to very local sources close to the river mouth. Otherwise higher concentration at the inflow to the Estuary would have been expected. All this indicates that there are high uncertainties on the bacterial concentration flowing into the Maketu Estuary.

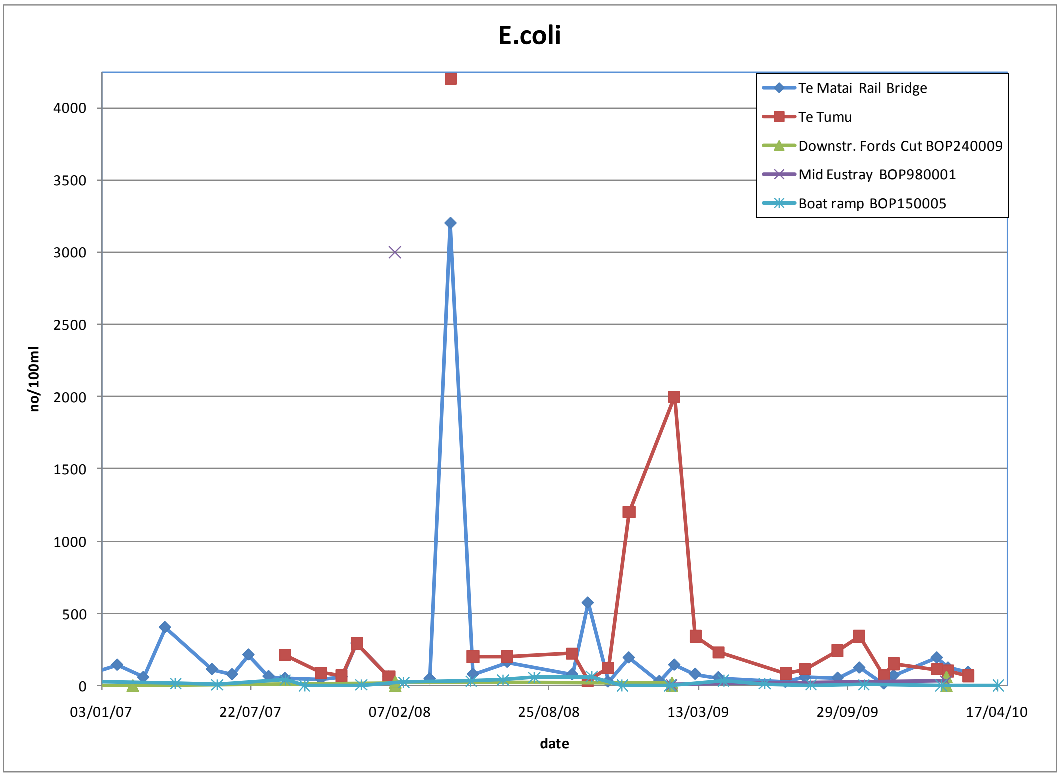


*Figure 4-3: E. coli concentration on the Kaituna River and in Maketu Estuary*
*Kaituna River: Te Matai and Te Tumu*
*Maketu Estuary: BOP240009 downstream Fords Cut, BOP980001 in the centre of the estuary and BOP150005 Boat Ramp close to the opening of the estuary into the sea.*

# 5 WATER QUALITY CRITERIA

Of special concern with respect to this study are the algae concentration, and especially the concentration of Blue-green Algae (or Cyanobacteria), and the bacteria concentrations. Criteria are discussed in the following paragraphs, in relation to the model results.

## 5.1 Algae concentrations

In the first part of this study, the ecological model that was selected describes, among other variables, the total amount of algae biomasses as chlorophyll concentration. Other water quality models are available within the water quality model templates, some of them allowing the distinction between algae species. Given the available data (see discussion Chapter 4.) and the limited possibilities for the calibration of a multi-species algae model, it was decided to keep the ecological model as simple as possible. However, the model will still retain the ability to analyse the growth potential for harmful algae bloom with emphasis on the blue-green algae. Chapter 6.2 discusses in more details the model that was used.

In general, for the Maketu Estuary, the blue-green algae will be introduced with the freshwater from the Kaituna River. Most of these blue-green algae will be stressed when brought into a more salty environment in the estuary and most likely be hampered in their growth by the salinity. In the modelling, conservatively, no such growth inhibition has been assumed. Furthermore, the simulated chlorophyll concentrations are directly compared to the above levels. This approach (no inhibition of growth and using the total amount of chlorophyll) imply that the evaluation will be on the conservative side from an environmental standard exceedance point of view.

These assumptions are judged reasonable given the uncertainties included in the modelling data.

In general, simulations were carried out for the situation where the general chlorophyll level in the river water was relatively high and where the blue green algae may occur in significant amounts.

For contact recreation, it was agreed with EBoP (Stephen Park) that 15,000 cells per 100ml is considered critical for algae. In the second part of the study, this value will be used as threshold to quantify the probability of breaching NZ guidelines.

## 5.2 Bacteria concentrations

There are at least two concerns for ensuring sufficiently low bacterial concentrations:

- Protection of humans swimming in the water or by other means have a risk of consuming water

- Protection of shellfish used for consumption against critical bacteria levels

The modelling that was carried out does not include simulation of bacteria within the shellfish. It is anticipated that if the water quality fulfils the requirements for bathing water, the bacterial concentration within the shellfish will not be critically high.

The most relevant NZ guidelines concerning bacteria is the Micrological Water Quality guidelines for Marine and Freshwater Recreational Areas (June 2003). It states that for marine and freshwater, Enterococci concentration must not exceed 280 cells per 100ml.

The recreational shellfish-gathering bacteriological guidelines says that "the median faecal coliform content of samples taken over a shellfish gathering season shall not exceed a Most Probable Number (MPN) of 14/100 mL, and not more than 10% of samples should exceed an MPN of 43/100mL". It was agreed with EBoP (Stephen Park) that in the Maketu estuary case, the shellfish gathering season is the whole year long.

# 6 MODEL CONCEPT AND SET-UP

## 6.1 Hydrodynamic

A MIKE3 hydrodynamic (HD) model of the Kaituna River and Maketu Estuary system was previously built for EBOP to assess the impact of re-diversion of additional flow from Kaituna River to Maketu Estuary. For details of the model concept, schematisation and set-up refer to DHI modelling report (DHI 2009).

When the initial study was carried out for EBOP, to assess the impact of re-diverting additional flow from Kaituna River to Maketu Estuary, it was proposed that the additional flow to the estuary would be achieved by reopening Papahikawai Channel with culverts. This option has been reassessed and now it is proposed that Te Tumu Cut will be closed and both Fords Cut and Papahikawai Channel will be opened with no culverts. It is also proposed to open Fords Cut loop. This option has been labelled Option H in previous studies (EBOP, 2008). The bathymetry for existing and proposed configurations is the same except that the Fords Cut loop has been opened up and deepened to -1m bed level (Moturiki datum) and the upper 400m of Papahikawai Channel has been engineered with a cross section of approximately 30m width and -1.2m bed level (Moturiki datum). See Figure 6-1 for existing and Figure 6-2 for proposed model bathymetries, focused in to the lower Kaituna River and Maketu Estuary.

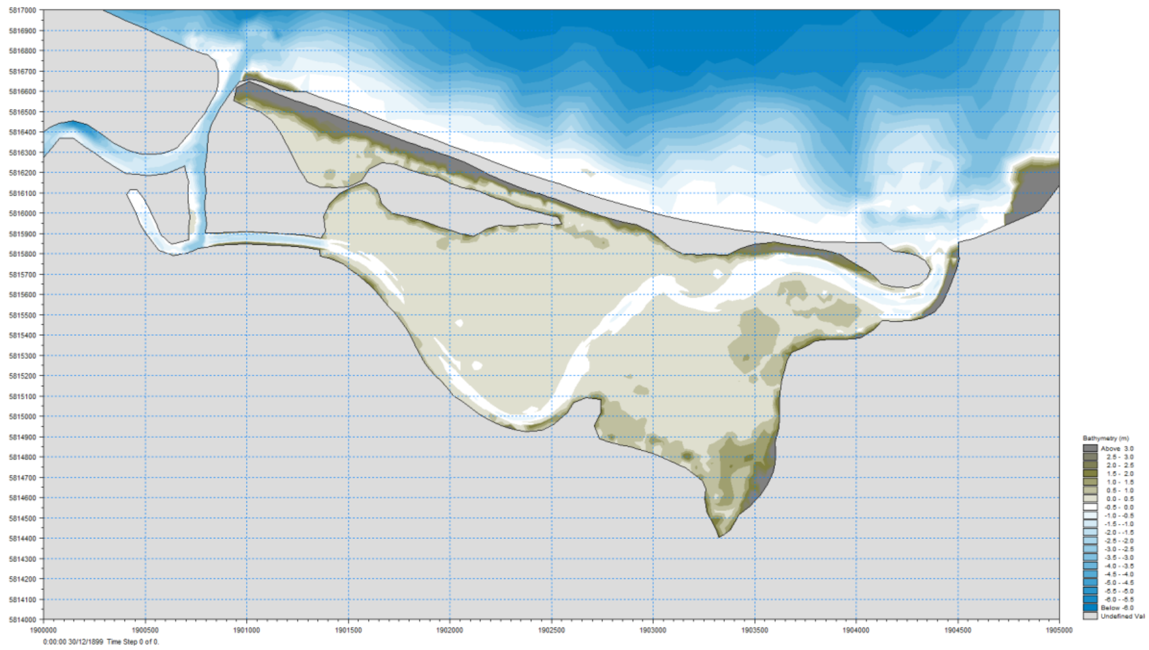


*Figure 6-1 : Model bathymetry for existing situation* (Moturiki datum)

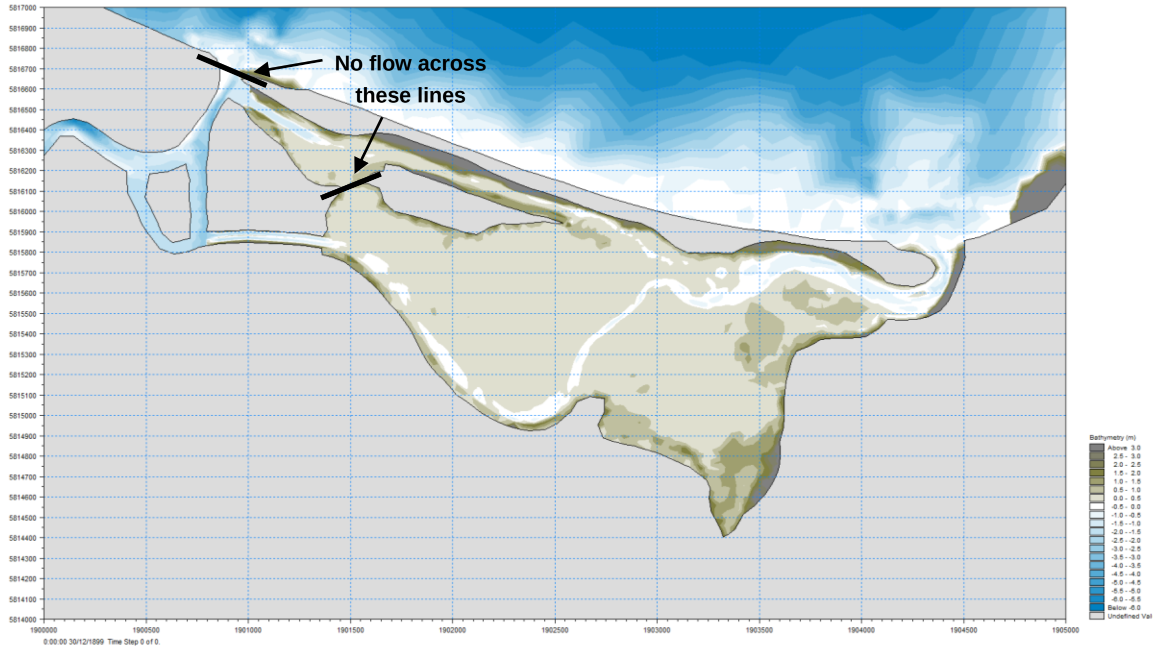


*Figure 6-2 : Model bathymetry for proposed situation* (Moturiki datum)

## 6.2 Water quality

The water quality model (DHI ECOLab) dynamically uses the hydrodynamic results from the MIKE 3 HD model.

To aid with a time efficient calibration the water quality model was initially calibrated in a 2D (depth averaged) mode. Once an initial model calibration had been achieved the water quality model was transferred to the 3D simulation and the calibration verified prior to undertaking the final simulations (in 3D).

The water quality model was run for the May 2008 period, for which the MIKE3 HD model is set-up and calibrated.

The ECOLab water quality model template that was used is the Eutrophication (EU) template. This modelling template and the processes included are briefly described in the following paragraphs.

### 6.2.1 Eutrophication modelling

The algae growth is described by DHIs Eutrophication ECOLab template. This template was adjusted to the local condition with respect to model constants during the model set up and calibration. The model describes in general terms the total algae growth, productivity and biomass as a function of among others the nutrient level, light condition and retention within the system. The state variables and the processes included are, in general terms, illustrated in Figure 6-3.

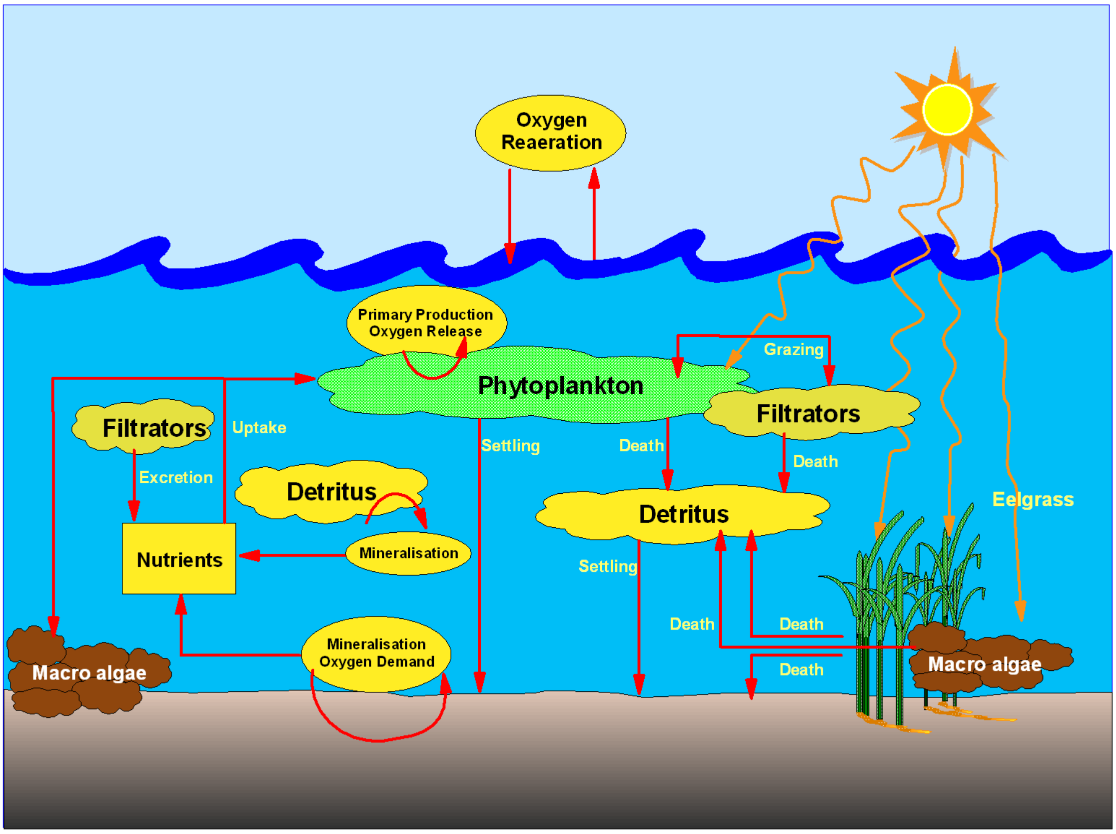


*Figure 6-3: The MIKE ECOLab standard Eutrophication*

DHI's MIKE ECOLab standard Eutrophication model is based on a mass preserving book-keeping system for the cycling of nitrogen, phosphorus and carbon within the various compartments of the water column. Compartments of nitrogen and phosphorus comprise a dissolved fraction, a dead organic fraction and an intracellular fraction of phytoplankton.

Phytoplankton production is controlled by a description of the intracellular concentration of nitrogen and phosphorus, light availability, temperatures. The description of detritus C, N and P includes build-up of detritus via death and sloughing of phytoplankton, zooplankton and benthic vegetation.

In the biochemical model the dependency of nutrients on growth of phytoplankton is described in a two-step process. Firstly, the inorganic nutrients are taken up into an internal pool in the algal cells. Secondly, nutrients from this pool are utilized in production of organic matter. This approach has proven to be very strong in modeling growth of phytoplankton.

Grazing on phytoplankton by zooplankton (also including benthic filter-feeders) can have a regulating effect on the phytoplankton biomass; hence, grazing on algae is modeled explicitly. The model does not include secondary producers at a higher trophic level than zooplankton. The predation on zooplankton is included in the models in the description of the death of zooplankton.

Regeneration of nutrients from detritus and other transformation processes such as nitrification and denitrification are explicitly modelled.

Dissolved oxygen is modelled based on the re-aeration at the water-air interface, primary production and respiration, nitrification, degradation of detritus and sediment oxygen demand.

The controlling factors for growth and death processes of benthic vegetation are incorporated in the model structure, and the interaction with the other components in the eutrophication module is an integral description of the model. The model includes the inter-specific competition on nutrient uptake and nutrient availability between the benthic vegetation and the phytoplankton in the water column.

The sediment model describes the nitrogen and phosphorous cycles as well as the linkage to nutrient concentrations in the water phase. The simulated concentration distribution in the water column affects the processes occurring in the sediment, which again affect the concentration in the water column. The processes involved in the pathway from phytoplankton production in the water phase, deposition of organic material, turnover in sediment, oxygen consumption and nutrient fluxes between sediment and water phase, are all explicitly modelled.

The basic module and the different governing processes included are described in more detail in DHI software manuals (DHI 2008 & DHI 2009).

In summary, the ecosystem model computes the concentration of phytoplankton, chlorophyll-a, zooplankton, plankton eating fish, dead organic particulate material as well as the nutrients N and P in the water phase. The pelagic system includes the following state variables:

- Phytoplankton (C, N, P)
- Chlorophyll-a
- Zooplankton (C)
- Detritus (C, N, P)
- Inorganic Nitrogen ($NH_4$-N+ NOx-N)
- Inorganic P ($PO_4$-P)
- Dissolved Oxygen
- Benthic Vegetation Biomass.

Some of these state variables are only described by their carbon content (C) and a fixed C:N:P ratio is assumed to ensure mass conservation.

The risk for blue-green algae blooms to occur in the Maketu Estuary is evaluated based on the simulated algae biomass (chlorophyll concentration), the nutrient levels and the salinity.

It is possible to extend the MIKE ECOLab model to distinguish between different algae species and describe blue-green algae specifically. This could be carried out once sufficient data became available that would facilitate a calibration of such a detailed model.

### 6.2.2 Water quality model set-up

The water quality model covers the same domain as the hydrodynamic model - see section 6.1 for details. For the ocean boundary a constant level of the water quality variables has been estimated based on data from the Bay of Plenty Shelf Water Properties Data Report 2003-2004 (Longdill et al, 2005). Although the transects covered by these data are not located exactly along the ocean boundary for this model set-up and do not cover the period of modelling it is judged that the data from this report is representative and can be used as boundary condition.

The only relevant pollution source flowing into the system is assumed to be at the upstream river boundary. It is acknowledged that other inflows occur along the Kaituna River between the upstream boundary and Fords Cut, before the water flows into the Maketu Estuary. However, for the algae growth assessment, this assumption is considered acceptable as modelling analysis indicates that nutrient levels are not the limiting factor for the algae biomass levels in the Maketu estuary. The upstream algae concentration that is brought down from the upstream lakes by the river and the dilution and the retention time within the estuary are more important. Furthermore there was not enough quantitative data (e.g. coincident water flow and concentration) in the tributaries to include them in the model.

The validity of the assumption for the bacteria modelling is less robust as higher bacterial concentrations are recorded at the estuary outlet (Te Tumu) than at the upstream boundary (Te Matai). This observation also indicates that for more detailed modelling study nutrient loads along the downstream part of Kaituna River should ideally be included.

It is highly recommended to perform a load estimation based on a quantitative monitoring program for future modelling studies.

# 7 HYDRAULIC MODEL

## 7.1 Model set up

The period 12:00 am 25th May 2008 to 8:40 pm 29th May 2009 was selected for the simulations carried out in this study. One dimensional model (MIKE 11) derived flows were used for the Kaituna River inflow (presented in Figure 7-1) with a salinity of 0 PSU. Figure 7-2 presents the open ocean boundary conditions used for the simulation. A salinity of 35 PSU was selected for the open ocean boundaries.

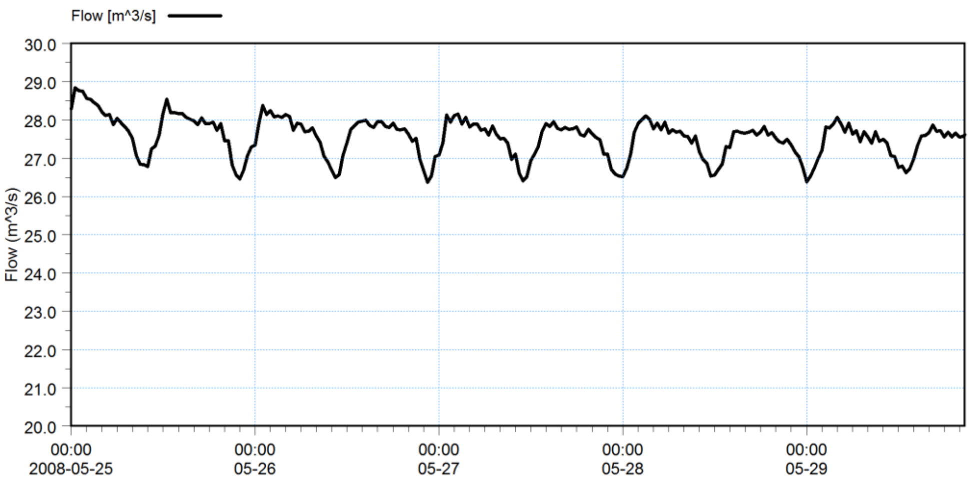


*Figure 7-1 :* Kaituna River flow

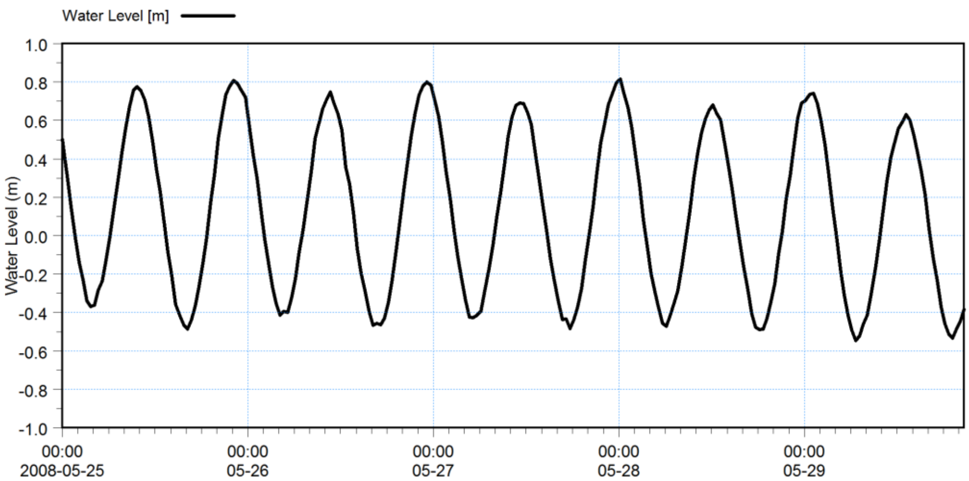


*Figure 7-2 :* Water levels (Moturiki datum) for open ocean boundaries.

## 7.2 Calibration

The model that was built to assess the impact of re-diversion of additional flow from Kaituna River to Maketu Estuary (DHI, 2009) was sufficiently calibrated to predict freshwater / saltwater inflows to the estuary from the river. However there was not such a good agreement between the observed and predicted salinities within the estuary. It was concluded that the model did not sufficiently resolve the processes that disperse the freshwater plume from Maketu Estuary mouth. The freshwater plume was drawn back into the estuary on the flood tide, resulting in lower predicted salinities in the estuary than measured values.

In an effort to improve the model validity in the estuary (for salinity) a number of methods were tested to prevent re-circulation of the freshwater plume into the estuary without having develop a model to include bay wide phenomena such as long shore current or wave driven currents. The most effective method was to generate a spatially varying wind field with a 10m/s easterly wind for model domain on seawards side of Kaituna River and Maketu Estuary mouth and no wind for the river or estuary. A horizontal dispersion scaling factor of 3 (previously = 1 in 2009 work) was also selected to further improve comparison of the predicted salinities within the estuary. Figure 7-3 presents a comparison of predicted and observed salinities within Maketu Estuary for 29th May 2008. 66% of predicted salinities agree within 5 PSU of observed salinities and 81 % of predicted salinities agree within 7 PSU of observed salinities.

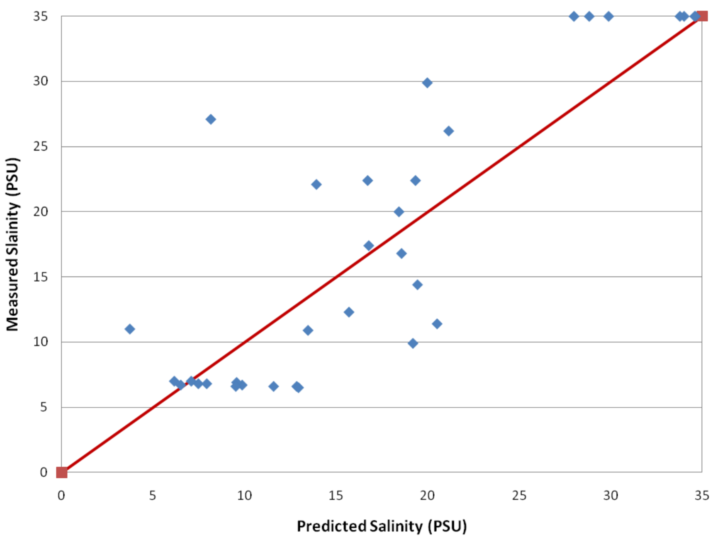


*Figure 7-3 : Comparison of predicted and observed salinities within Maketu Estuary for 29th May 2008.*

# 8 POTENTIAL FOR ALGAL BLOOM

The hydraulic model (described in Chapter 6.1) was coupled to an Eutrophication model (described in Chapter 6.2) to assess the potential for algal bloom in the Kaituna River – Maketu Estuary system.

## 8.1 Calibration of the eutrophication model

A traditional calibration with detailed comparison of the simulated and measured values has not been possible due the limited synchronous, high resolution time series data availability

The Monitoring programmes in the Kaituna River and the Maketu Estuary have not been coordinated at a sufficient synchronisation in time so the data is not ideal to be used in a traditional model calibration process as samplings are often more than a week apart. As the concentrations in the river system are highly varying from one sampling to the other, the upstream concentration and to the Maketu Estuary they cannot be temporally interpolated. The consequence is that one of the most important driving forces for the concentration levels in the estuary are very uncertain or even unknown when looking at a specific measures concentration levels in the estuary. Furthermore the only location in the Maketu Estuary where algae biomass data (chlorophyll) exist is the station Boat Ramp which is very close to the mouth of the estuary where the dilution due to inflowing costal water is very high. This station does not give a good representation of the algae levels in the central area and upstream part of the estuary.

Consequently, the eutrophication model has been coarsely calibrated based on concentrations that have been observed during two typical inflow situations with respect to algae and nutrient concentration at the upstream boundary at the Te Tamai Bridge.

One situation represents normal algae concentration level for May with approximately 5 µg/l chlorophyll. Such a level was observed, among others, on the 15 May 2010. The situation with the high chlorophyll concentration of 30 µg/l, as observed on 16 October 2008, was also used. For both situations, the available hydrological and hydraulic condition of May 2008 was used.

For these two events, samplings on the Kaituna River and at the Boat Ramp in the Maketu Estuary were carried out at dates relative close together. However for the May situation the downstream station at the Boat Ramp was monitored on 12 May 2008, 3 days before the monitoring in the river system. It is therefore uncertain whether the inflow data in the simulation is correct for a calibration against the levels measured at the Boat Ramp or not. For the October situation the monitoring at the Boat ramp in the Maketu estuary was carried out on the 21 October 2008, 5 days after the monitoring in the river system.

For the other available data, the time differences between the monitoring in the river system and in the Maketu Estuary are larger. To obtain more ideal data for the calibration of a water quality model, it is highly recommended to coordinate the monitoring in the two part of the water system. A monitoring program should ideally take into account the travelling time and retention time within the water bodies. Furthermore it is highly recommended that more stations in the Maketu Estuary be included to give a more reasonable coverage of the algae biomass distribution.

The results from simulations with the calibrated model of situations corresponding the May and the October inflow concentrations and the existing set-up for the inflow to Maketu Estuary are shown in Figure 8-1 to Figure 8-4.

For the May inflow situation, the model shows that a 5 µg/l Chlorophyll (15 May 2008) input at the upstream boundary (Te Matai) induces a concentration at the Boat Ramp of around 2.5 µg/l. This is very close to the measurement values of 2.8 µg/l three day before (12 May 2008). In the case of an October inflow, 30 µg/l Chlorophyll (16 October 2008) discharged at the upstream boundary (Te Matai) gives a chlorophyll concentration at the Boat Ramp between 6 and 10 µg/l (depending on tidal cycle dilution). Taking the uncertainties of the driving forces (especially the inflow concentration) into account this is very close to the measurement values five day later of 6.2 µg/l (21 October 2008).

Based on these results it is concluded that the algae growth model has been sufficiently well calibrated for description of the chlorophyll concentration in a future situation with changes in the flow pattern in the Maketu Estuary.

## 8.2 Sensitivity analysis

During the calibration, a sensitivity analysis of the model responses to changes in algae growth rate was carried out. It is well know that blue-green algae in general have relative low specific growth rates, typical between 0.5 and 1.5 per day (Chorus & Bartram, 1999). Unicellular green algae and diatom have typical growth rate between 1 and 2.5 per day. The growth rate in relation to the retention within the estuary is important for the risk of build-up of an algae bloom in the water body. Simulation with growth rates up to 10 per day did not indicate any risk of the creation of blooms under the existing flow condition due growth within the estuary. The level in the estuary was primarily regulated by the inflow concentration from the Kaituna River in the days before the simulation start date. The reason is the relatively low retention time within the estuary (days to a week). In the final simulation a growth rate of 2 per day has been used. This may be considered to be a little high in the case of blue-green algae dominance but is regarded as representative for the algae species in the area in general. For the blue-green algae risk it will give an assessment on the conservative side.

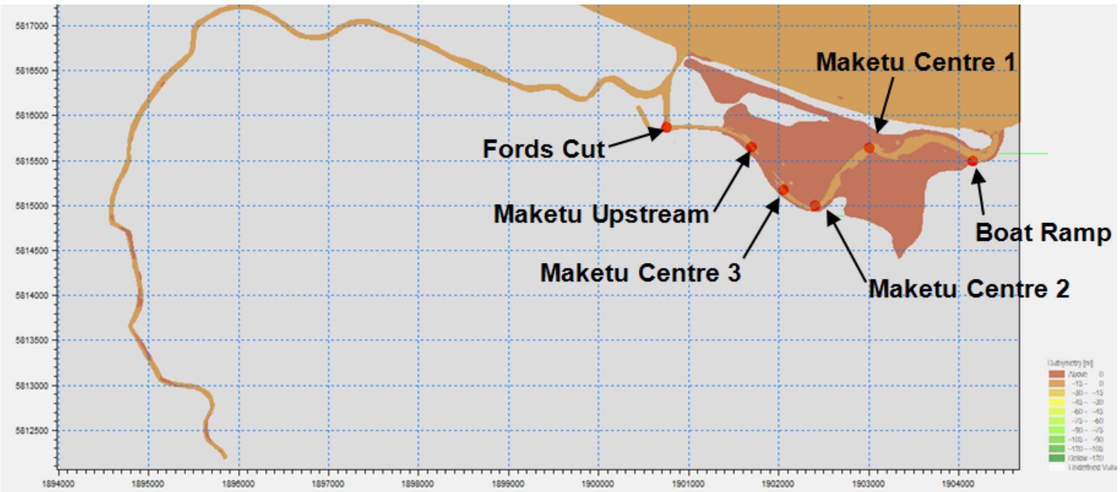


*Figure 8-1 : Locations for presentation of time series plot.*

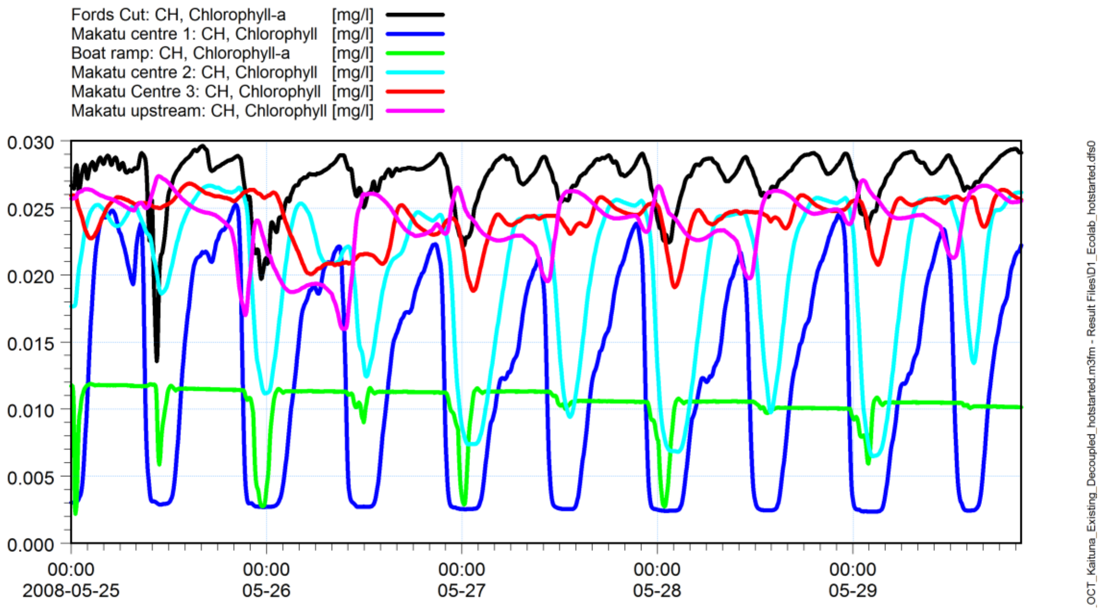


*Figure 8-2: **Existing conditions** - Simulated chlorophyll concentration (25-30 May) of October upstream in-flow concentration*

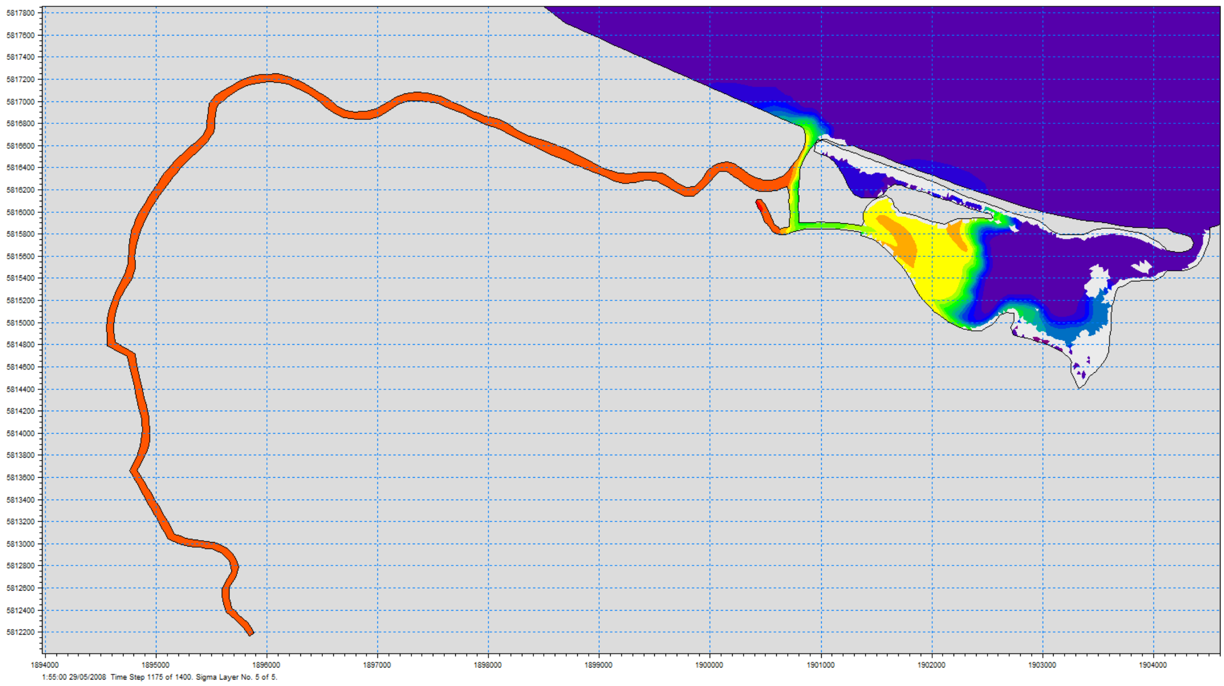

*Figure 8-3: **Existing conditions** - high tide - Algae biomass (in mg/l chlorophyll) - October concentration (0.030 mg/l)*

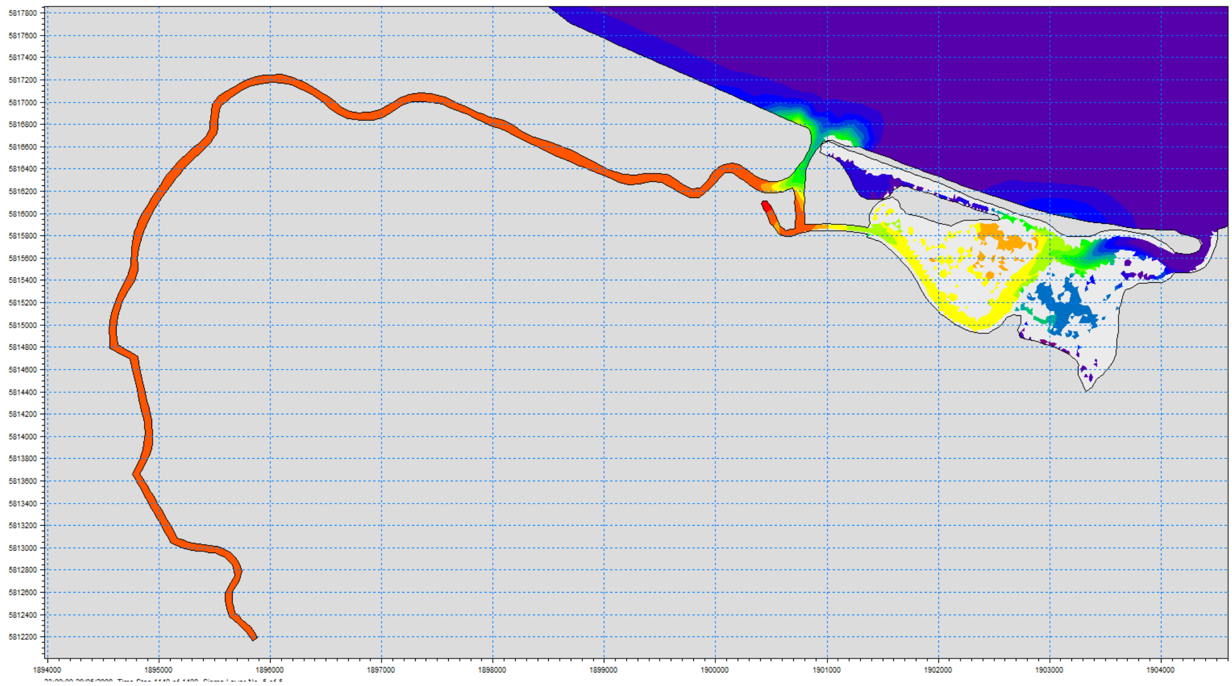

*Figure 8-4 : **Existing conditions** – Low tide - Algae biomass (in mg/l chlorophyll) - October concentration (0.030 mg/l)*

## 8.3 Existing layout

From the modelling results presented above and the sensitivity test with an unrealistically high algae growth rate it can be concluded that with the existing physical lay-out of the Kaituna River – Maketu Estuary system there is no risk of creation of a blue-green algae bloom due to growth within the water bodies. The retention time within the modelled time period is far too low to allow such growth. In the upstream part (inner-part) of the estuary high concentrations of blue-green algae are dominated with by river water which contains high concentrations of blue green algae due blooming upstream of the modelled area.

## 8.4 Future layout

For the future layout, the evolution of the Chlorophyll concentrations through the simulation (Figure 8-5) does not change much when compared to the existing case (Figure 8-2). A comparison of Figure 8-6 and Figure 8-7 shows that in the future scenario the water level does not vary significantly from high tide to low tide. In the future situation, all the river flow passes through the estuary, decreasing the relative impact of the tide. Less mixing occurs with the water coming from the sea and the concentration does not really evolve anymore with the tidal cycle.

The simulated algae concentrations for the future scenario, presented in Figure 8-5 to Figure 8-7, show a slight increase in the algae biomass in the downstream part of the estuary compared with the inflow concentration. This means that the model predicts some growth within the estuary. No such growth was simulated for the existing situation due to high wash and dilution with coastal water discussed above. The results show that in general a much higher proportion of the estuary can be expected to be exposed to high algae concentrations for the future situation.

The results indicate that in cases where blooms of blue-green algae are transported through the river from upstream water bodies, the entire estuary will be impacted for the future situation. Although a minor algae growth is simulated by the model, such growth will most probably not by itself create blue-green algae blooms in the estuary. High inflow concentration would be required to trigger the growth blue-green algae in the estuary.

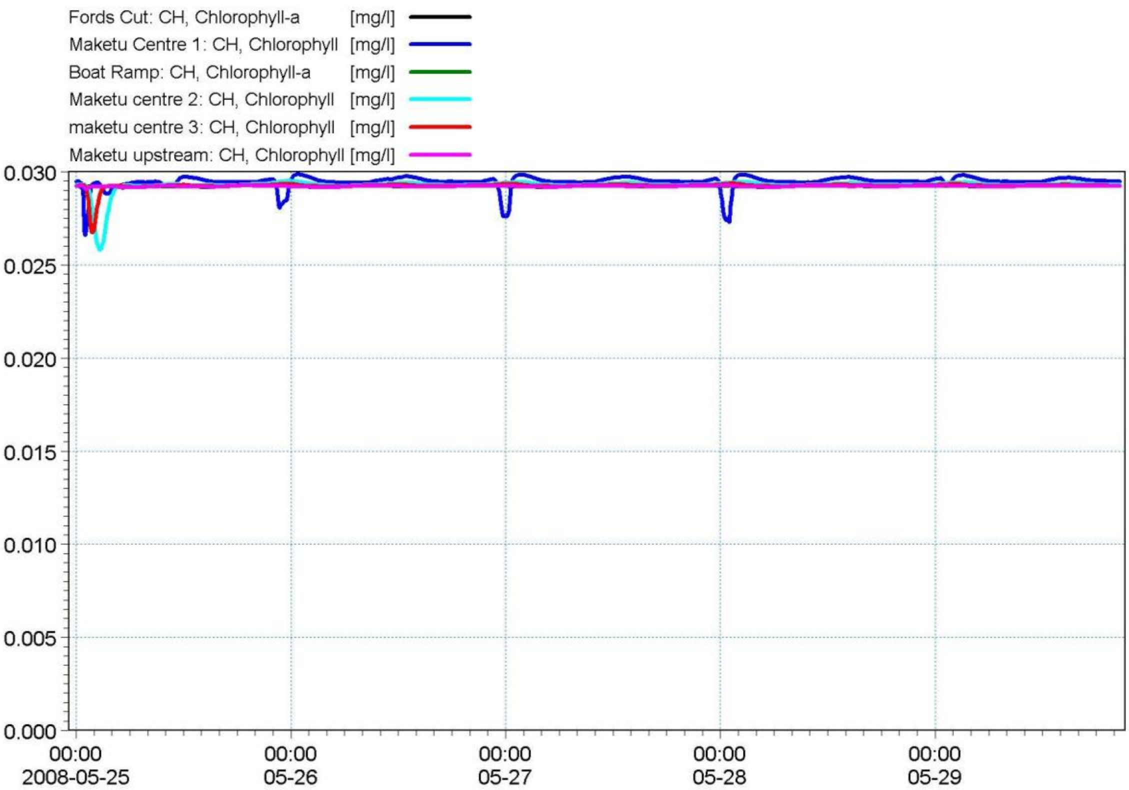


*Figure 8-5 : **Future Scenario**: Simulated chlorophyll concentration (25-30 May)*
*- October upstream inflow concentration*

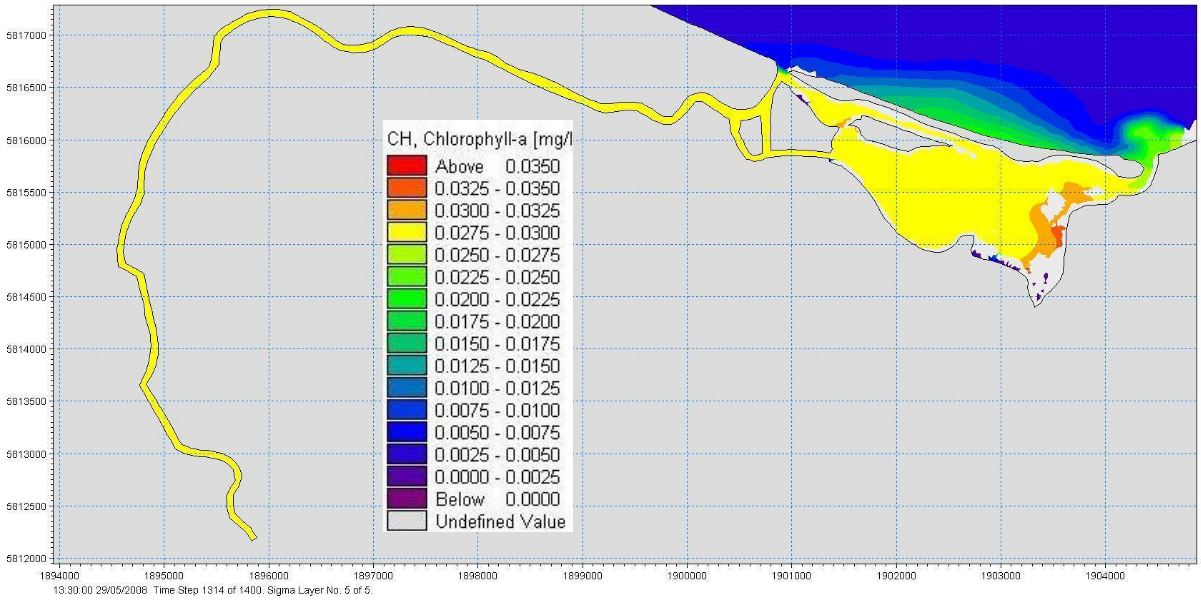


*Figure 8-6 : **Future scenario -** Algae biomass (in mg/l chlorophyll) – High tide*
*- October concentration (0.030 mg/l)*

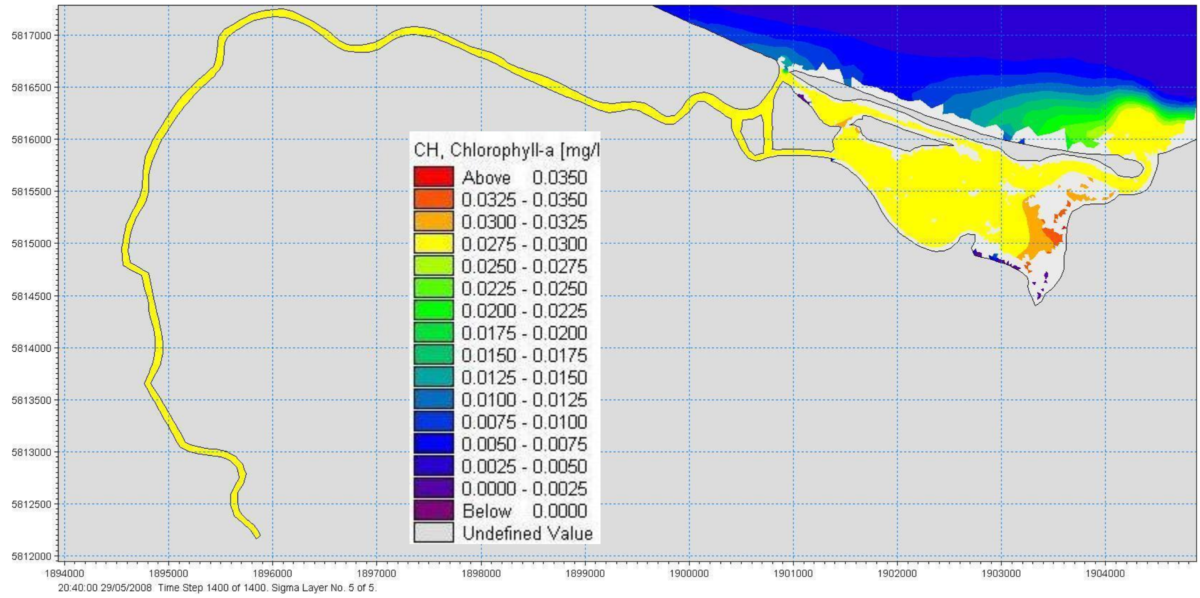


*Figure 8-7 : **Future scenario -** Algae biomass (in mg/l chlorophyll) – Low tide - October concentration (0.030 mg/l)*

## 9 DILUTION IN THE ESTUARY

The qualitative assessment of the diversion's impact showed that by decreasing the mixing with the ocean water, the diversion could have an adverse effect on the estuary in case of a pollutant load coming from upstream. In this chapter, the dilution of a pollutant (algae and bacteria) from Te Matai to the estuary will be studied.

The dilution in the Maketu Estuary depends on the tidal exchange as well as the inflow from the Kaituna River.

The variation in the dilution due to tidal exchange is included in the model simulation of 20 days, which includes tide conditions (neap as well as spring tide) representing the variation of a full year.

The impact of the river discharge on the dilution was analysed based on a number of simulations. Different constant discharges representing different fractiles of discharge occurring in the lower Kaituna River gave different dilution in the estuary.

The discharge frequency distribution used in the bacteria assessment was established for a 10 years period including all months of the year. The river flow for a 10 years period was analysed and the resulting frequency distribution is given in Table 9-1 and Figure 9-1. They show how often a given discharge Q is exceeded in the discharge dataset recorded at Te Matai.

*Table 9-1: Frequency distribution of flow (in $m^3$/s) in Kaituna River –full year periods*

| Occurrence | 100% | 99% | 95% | 90% | 80% | 70% | 60% | 50% | 40% | 30% | 20% | 10% | 5% | 1% | 0.5% | 0% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q | 13 | 22 | 23 | 25 | 27 | 28 | 30 | 32 | 34 | 36 | 39 | 45 | 51 | 70 | 86 | > 257 |

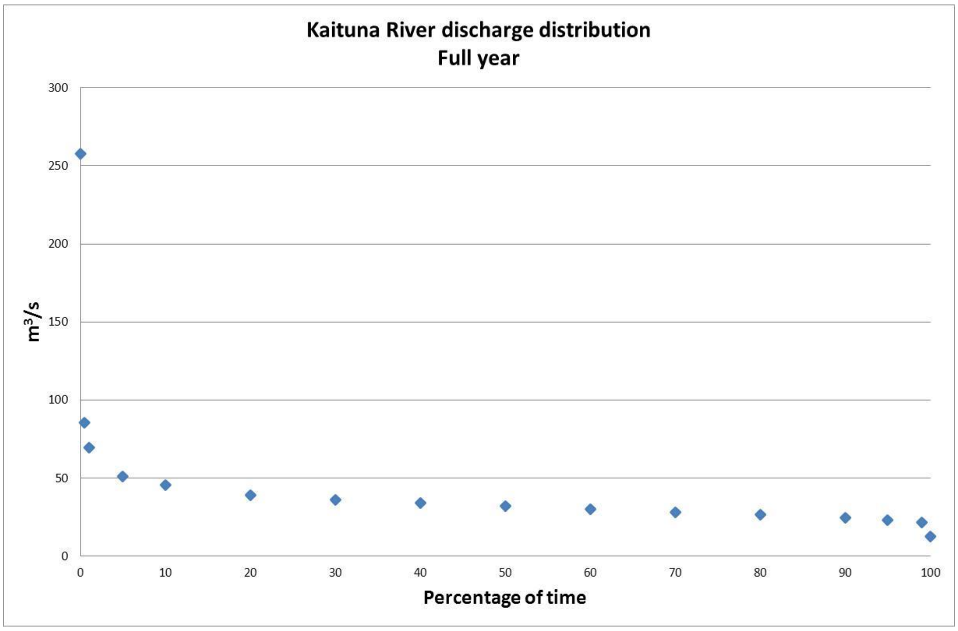


*Figure 9-1 : Frequency distribution of flow in Kaituna River – full year periods.*

For the bluegreen algae assessment, the frequency distribution was based only on the period of the year from which sampling for algae were carried out. The river flow analysis for this period is reported in Table 9.2 and Figure 9-2.

*Table 9-2: Frequency distribution of flow (in $m^3$/s) in Kaituna River – Algae sampling periods*

| **Occurrence** | 100% | 99% | 95% | 90% | 86% | 80% | 65% | 50% | 40% | 30% | 20% | 14% | 10% | 5% | 3% | 1% | 0% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Q** | 13 | 21 | 23 | 24 | 25 | 26 | 28 | 31 | 32 | 34 | 37 | 39 | 42 | 47 | 51 | 62 | >156 |

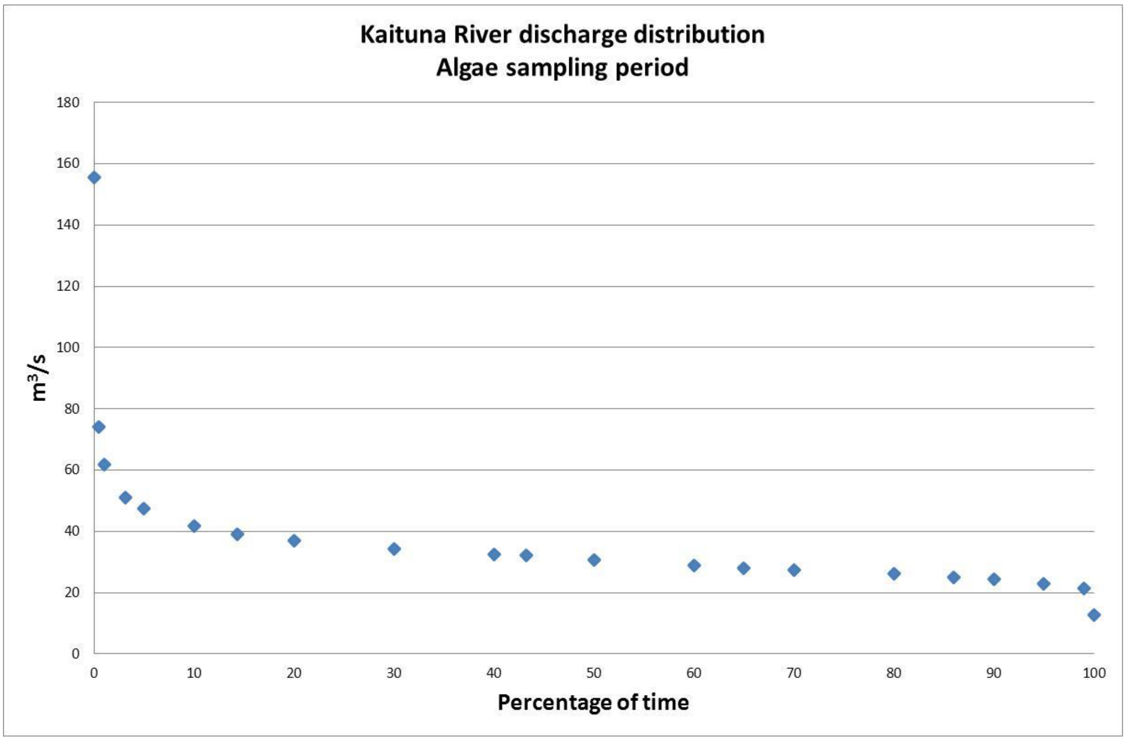


*Figure 9-2: Frequency distribution of flow in Kaituna River – algae sampling periods*

Based on this frequency distribution, six different constant river discharges were selected (Table 9-3). Each of these flows represents a flow interval which occurs during a certain percentage of time.

*Table 9-3: Discharges use for simulation*

| Simulation flow Q ($m^3/s$) | Represent the interval of Q ($m^3/s$) | Percentage of full year period | Percentage of algae sampling period |
|---|---|---|---|
| 51 | Q > 51 | 5 | 3 |
| 39 | 51 > Q < 35 | 30 | 32 |
| 32 | 35 > Q < 30 | 25 | 20 |
| 28 | 30 > Q < 26 | 25 | 25 |
| 25 | 26 > Q < 22 | 14 | 19 |
| 13 | 22 > Q <13 | 1 | 1 |

Each of these discharges was run as a constant inflow over a simulation period of 20 days (including 5 days warm up period to ensure the initial conditions do not influence the results) with a tidal ocean boundary.

The dilution in the estuary was calculated for each of these constant discharges based on the constant inflow concentration applied at the upstream boundary.

For the algae assessment, an advection dispersion simulation with no decay or growth was used. Based on the eutrophication simulations (that includes algae growth, see Chapter 8), it was assessed that, given the retention times occurring within the Maketu estuary, no significant growth will occur. Decay of the bluegreen algae may occur when exposed to saline water. However the bluegreen algae can still cause toxic impacts as these may release the toxins in the cells. It will therefore be a sound assessment to assume no decay and evaluate the occurrence of critically high cell number in the Maketu Estuary based on pure advection dispersion simulations.

In the case of bacteria (Enterococci and Faecal coliforms), a decay is to be expected. The 3D simulation looking at the relationship between the inflow bacteria concentration and the bacteria concentration in the estuary did include a constant bacterial decay of:

Enterococci: 0.8 $day^{-1}$
F. coliform: 0.4 $day^{-1}$

The parameter used to assess pollution in bathing water was Enterococci and the dilution in the estuary was analysed at the Boat Ramp location, which is a bathing spot. Dilution of Faecal coliforms (used to assess the pollution of shellfish gathering water) was analysed at Lower Mid Estuary.

The results are presented in Figure 9-3 to Figure 9-8 as duration (or frequency distribution) curves for the dilution factor (for algae) and dilution-decay factor (for the bacteria) for the existing and the future layout (where the entire Kaituna flow is diverted into the estuary).

The dilution factor is the factor by which the inflow concentration (on the Kaituna River) has to be multiplied by to give the concentration at the station in the Lower mid Kaituna Estuary. The dilution factor is the reciprocal of the dilution. A lower dilution, therefore, corresponds to a higher dilution in the estuary. In the case of bacteria, this factor includes as well the bacterial decay.

Table 9-4 to Table 9-9 give the percentage of time a given dilution is exceeded within the 20 day simulation period for each of the flow modelled (both for existing and future situation). These occurrences of dilutions are related to the occurrence of their associated flow interval (see Table 9-3) to give the absolute occurrence of a given dilution. The cumulative durations where a given dilution is expected to be exceeded, are calculated using the equation below. These values are reported in the last columns of these tables plotted in Figure 9-9 to Figure 9-14.

∑ *((percentage duration of each discharge) * (Percentage of time exceeding that discharge))*

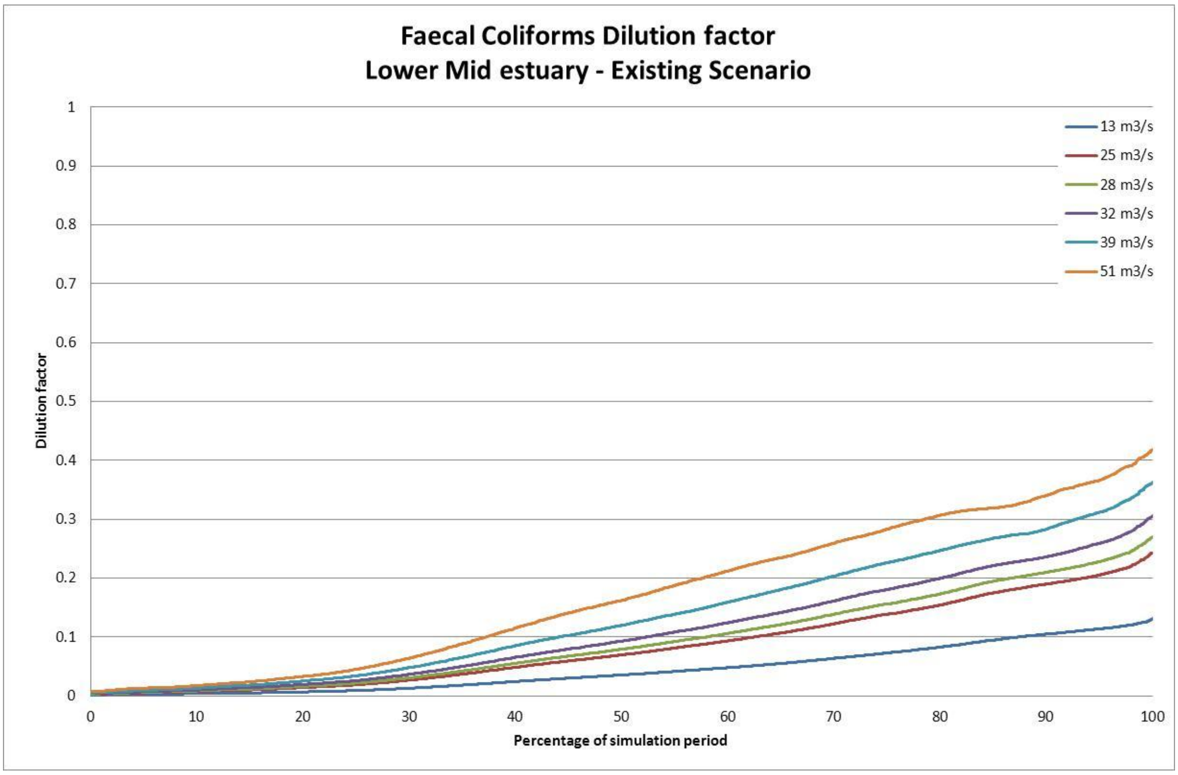


*Figure 9-3: Dilution-decay factor for Faecal coliforms (expressed as percentage of the 20 days simulation period) - Existing layout - Lower Mid Maketu Estuary.*

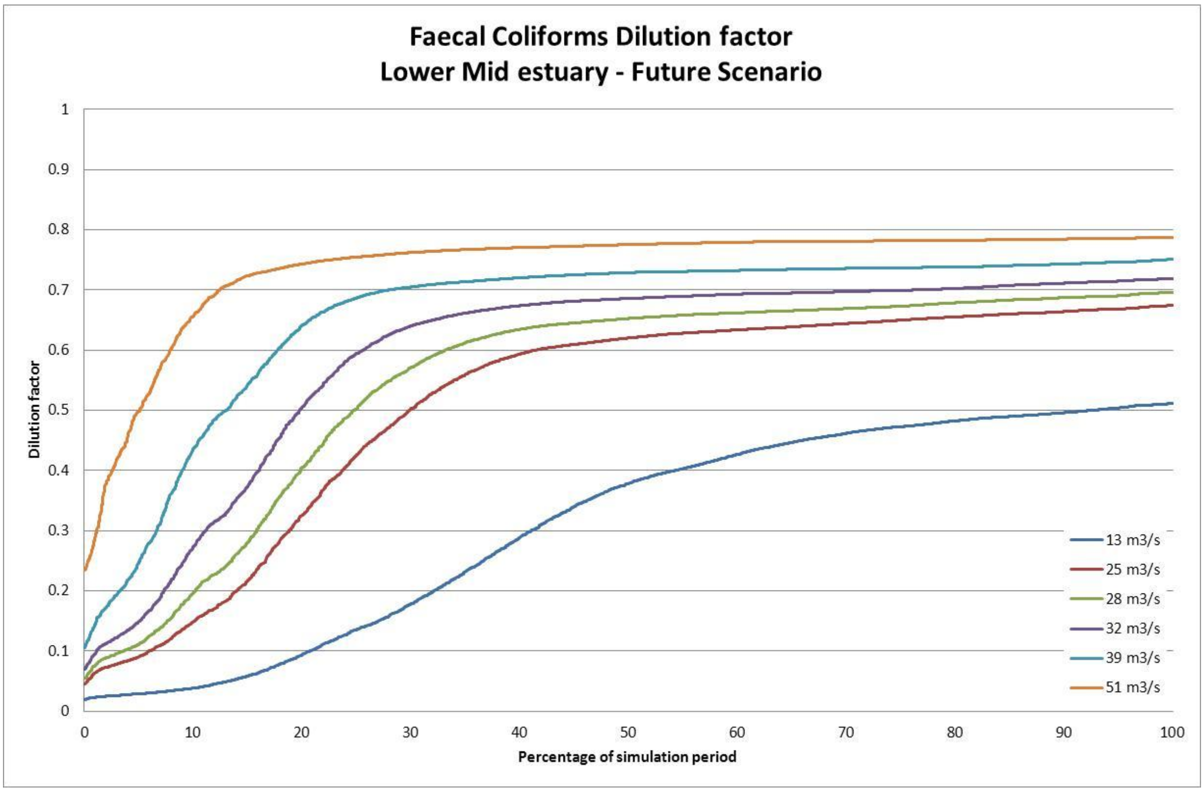


*Figure 9-4: Dilution-decay factor for Faecal coliforms (expressed as percentage of the 20 days simulation period) - Future layout - Lower Mid Maketu Estuary.*

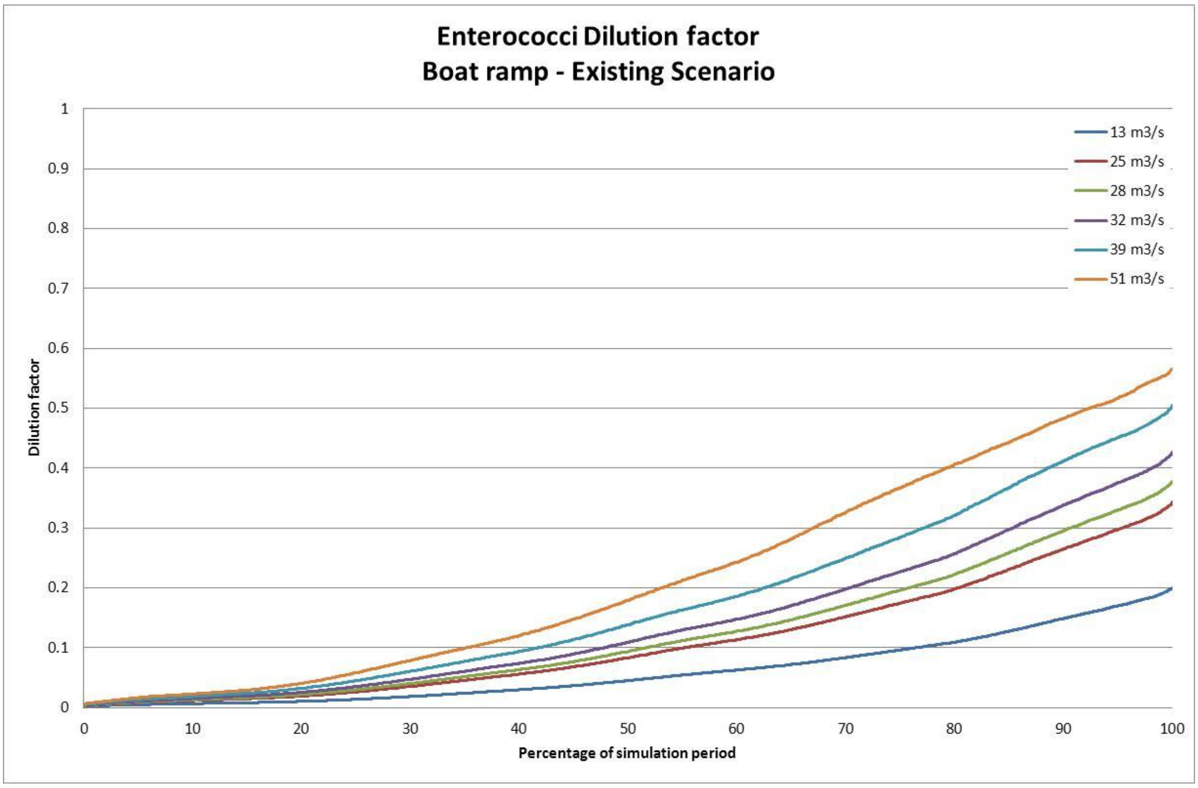


*Figure 9-5: Dilution-decay factor for Enterococci (expressed as percentage of the 20 days simulation period) - Existing layout - Boat Ramp station*

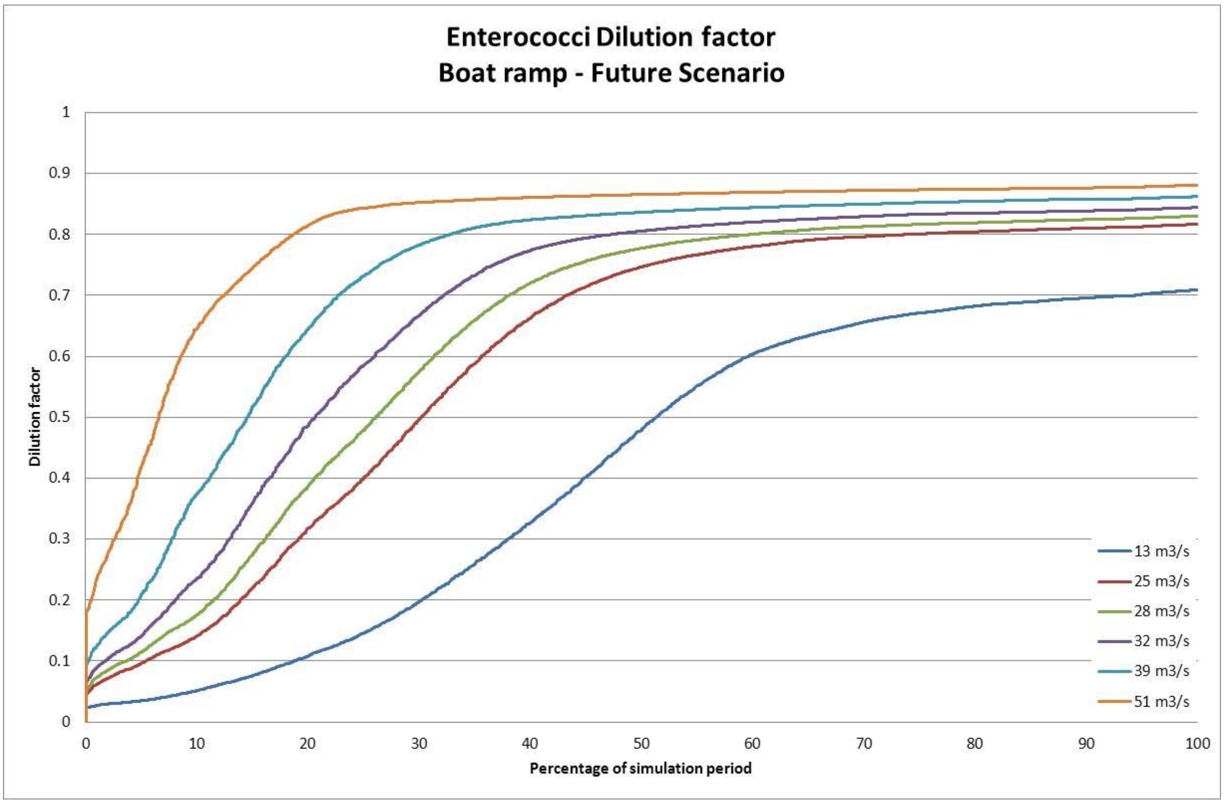


*Figure 9-6: Dilution-decay factor for Enterococci (expressed as percentage of the 20 days simulation period) - Future layout - Boat Ramp station*

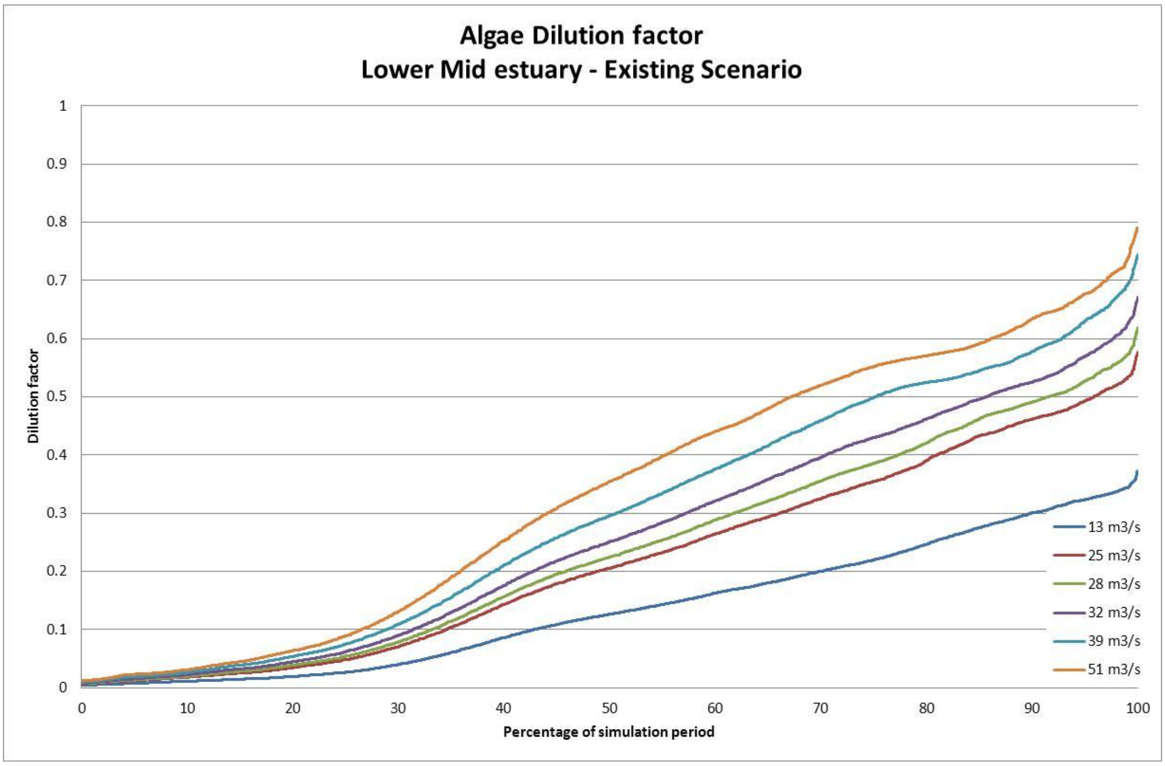


*Figure 9-7: Dilution factor for Bluegreen algae (expressed as percentage of the 20 days simulation period) - Existing layout - Lower Mid Maketu Estuary.*

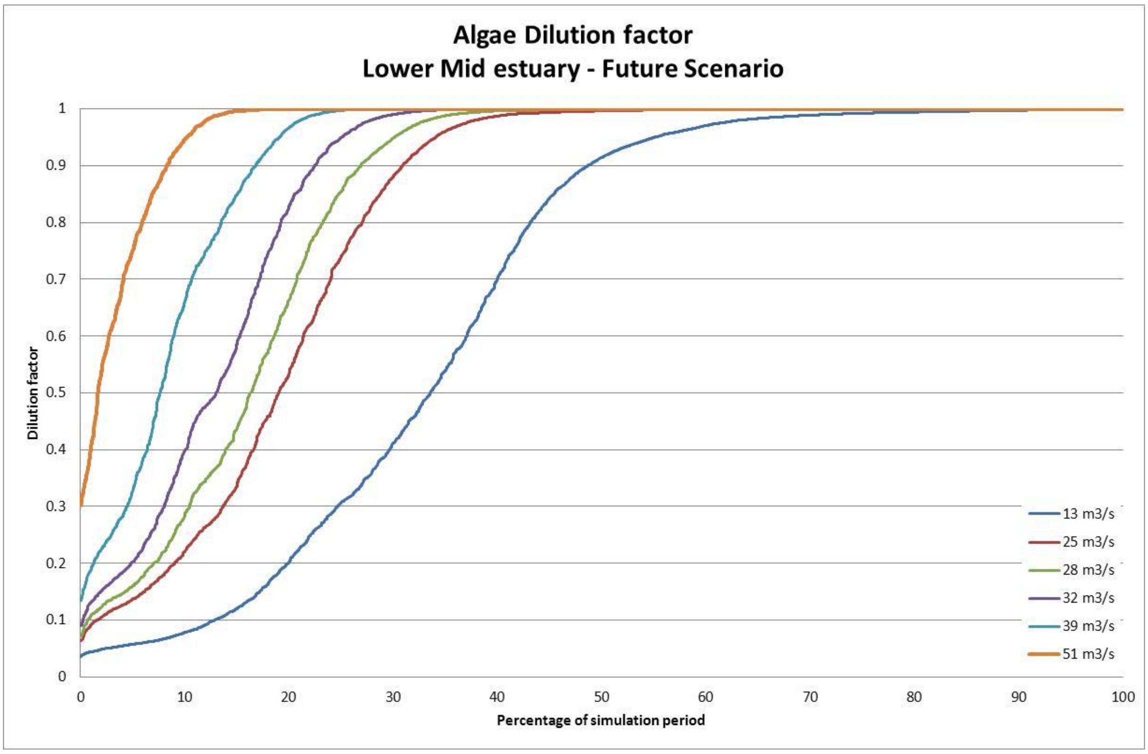


*Figure 9-8: Dilution factor for Bluegreen algae (expressed as percentage of the 20 days simulation period) - Future layout - Lower Mid Maketu Estuary.*

*Table 9-4: Existing condition- frequency of dilution (incl. decay) for F. coliform at the station in the Lower Mid Maketu Estuary.*

| dilution | dilution factor | Percentage of time during the 20 day simulation where the dilution is exceeded | | | | | | Percentage of time represented by the dischage | | | | | | Percentage of time exceeding the dilution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | |
| 666.7 | 0.0015 | 0.79 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 0.01 |
| 200.0 | 0.005 | 16.27 | 5.32 | 3.75 | 2.11 | 0.44 | 0.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 2.50 |
| 100.0 | 0.01 | 26.98 | 15.34 | 12.52 | 10.30 | 6.53 | 2.48 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 10.20 |
| 50.0 | 0.02 | 36.80 | 26.06 | 24.02 | 20.83 | 16.73 | 12.24 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 20.86 |
| 25.0 | 0.04 | 54.11 | 36.61 | 34.27 | 31.47 | 27.52 | 23.42 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 31.53 |
| 20.0 | 0.05 | 61.88 | 40.78 | 38.19 | 35.13 | 30.85 | 26.52 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 35.24 |
| 15.0 | 0.0665 | 71.74 | 48.76 | 44.74 | 40.55 | 35.36 | 30.62 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 41.00 |
| 10.0 | 0.1 | 87.55 | 62.67 | 58.09 | 52.46 | 44.16 | 37.28 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 52.40 |
| 5.0 | 0.2 | 100.00 | 93.50 | 86.81 | 80.12 | 69.29 | 57.67 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 79.49 |
| 4.0 | 0.25 | 100.00 | 100.00 | 98.45 | 93.17 | 80.79 | 68.25 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 90.56 |
| 3.0 | 0.33 | 100.00 | 100.00 | 100.00 | 100.00 | 97.29 | 88.34 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 98.60 |
| 2.0 | 0.5 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 100.00 |

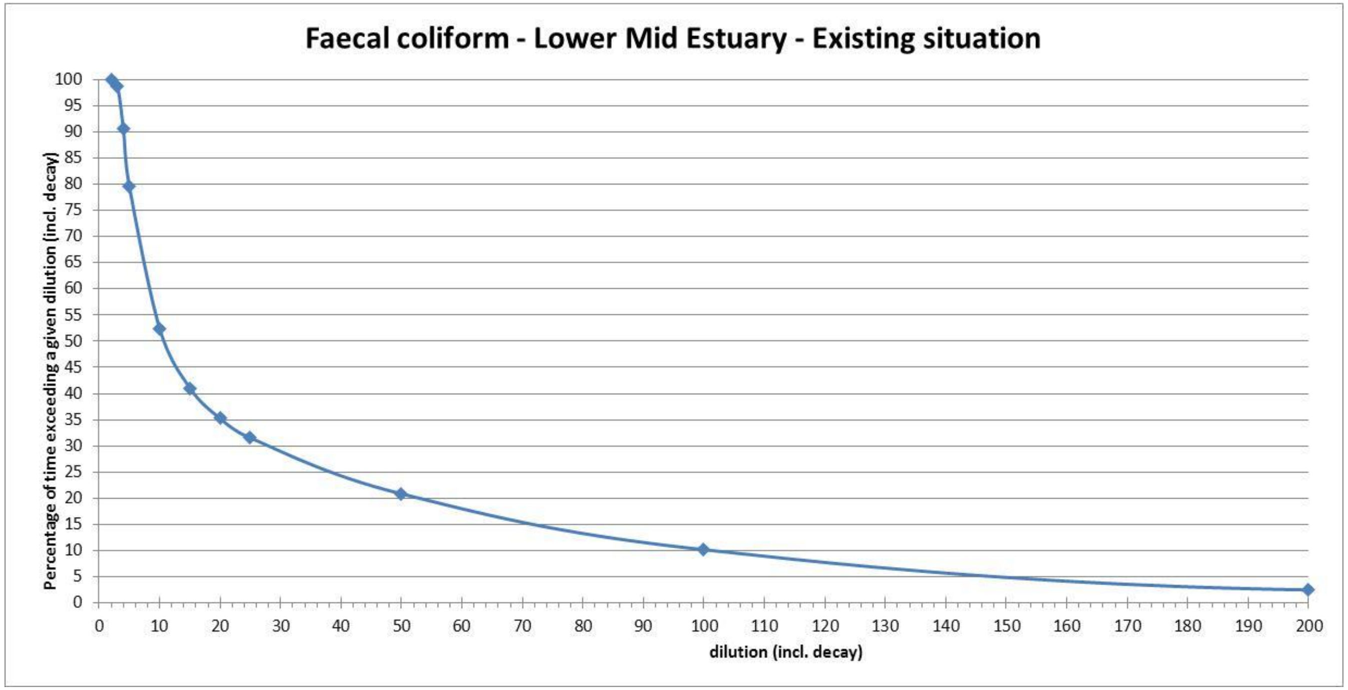


*Figure 9-9: Existing condition- frequency of dilution (incl. decay) for F. coliform at the station in the Lower Mid Maketu Estuary.*

*Table 9-5: Future situation- frequency of dilution (incl. decay) for F. coliform at the Lower Mid Maketu Estuary.*

| dilution | dilution factor | Percentage of time during the 20 day simulation where the dilution is exceeded | | | | | | Percentage of time represented by the dischage | | | | | | Percentage of time exceeding the dilution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | |
| 10.0 | 0.1 | 20.78 | 6.06 | 3.56 | 1.16 | 0.00 | 0.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 2.24 |
| 5.0 | 0.2 | 32.15 | 14.02 | 10.21 | 7.34 | 3.26 | 0.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 7.65 |
| 3.3 | 0.3 | 41.10 | 18.84 | 15.85 | 11.15 | 6.64 | 1.13 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 11.85 |
| 2.5 | 0.4 | 54.34 | 23.70 | 19.86 | 16.06 | 9.03 | 2.57 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 15.68 |
| 2.0 | 0.5 | 92.76 | 29.90 | 24.81 | 19.74 | 13.03 | 5.11 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 20.42 |
| 1.7 | 0.6 | 100.00 | 41.54 | 33.19 | 25.62 | 17.77 | 7.91 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 27.25 |
| 1.4 | 0.7 | 100.00 | 100.00 | 100.00 | 76.76 | 28.10 | 12.40 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 68.24 |
| 1.3 | 0.8 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 100.00 |

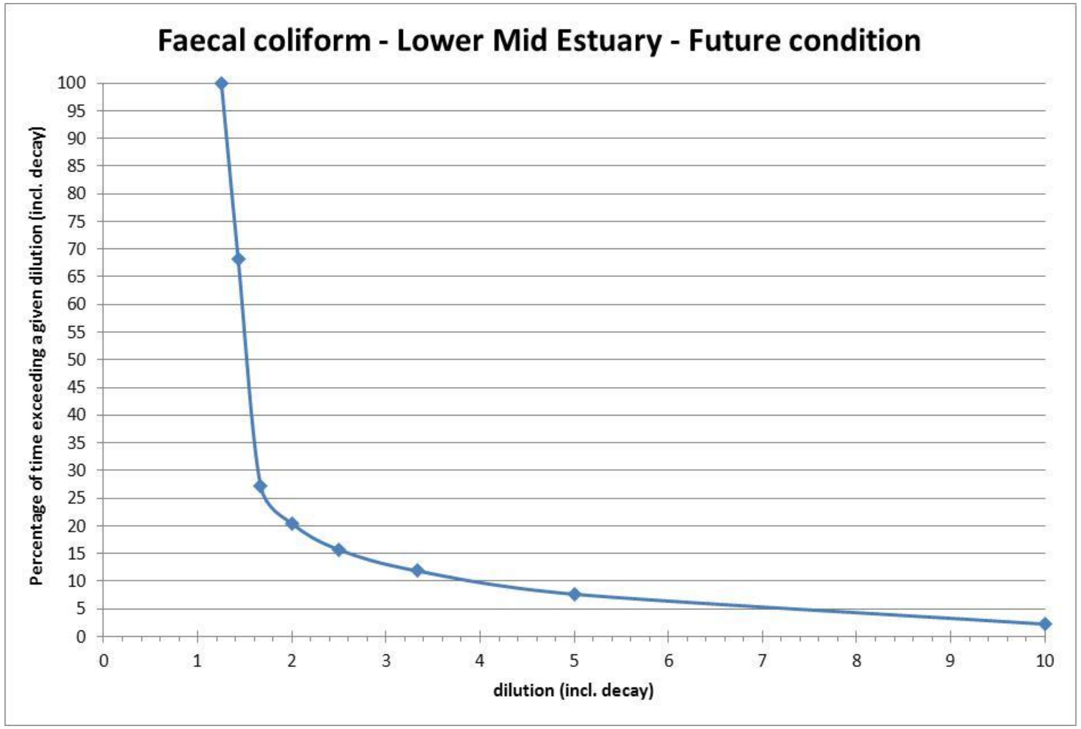


*Figure 9-10: Future situation- frequency of dilution (incl. decay) for F. coliform at the station in the Lower Mid Maketu Estuary.*

*Table 9-6: Existing situation- frequency of dilution (incl. decay) for Enterococci at the station Boat Ramp in the Maketu Estuary.*

| dilution | dilution factor | Percentage of time during the 20 day simulation where the dilution is exceeded | | | | | | Percentage of time represented by the dischage | | | | | | Percentage of time exceeding the dilution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | |
| 666.7 | 0.0015 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 0.00 |
| 200.0 | 0.005 | 6.32 | 1.64 | 1.30 | 0.86 | 0.25 | 0.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 0.91 |
| 100.0 | 0.01 | 19.81 | 7.87 | 6.36 | 4.72 | 2.87 | 1.85 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 5.02 |
| 50.0 | 0.02 | 31.75 | 20.85 | 18.79 | 15.95 | 11.57 | 7.87 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 15.79 |
| 25.0 | 0.04 | 47.26 | 32.45 | 30.09 | 27.22 | 23.26 | 19.97 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 27.32 |
| 20.0 | 0.05 | 52.79 | 37.10 | 34.37 | 31.22 | 26.75 | 22.98 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 31.29 |
| 15.0 | 0.0665 | 62.44 | 44.57 | 41.33 | 37.21 | 31.94 | 27.17 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 37.44 |
| 10.0 | 0.1 | 76.51 | 55.26 | 51.72 | 47.91 | 41.75 | 35.22 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 47.70 |
| 5.0 | 0.2 | 100.00 | 80.44 | 75.86 | 70.47 | 62.53 | 53.16 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 70.26 |
| 4.0 | 0.25 | 100.00 | 87.87 | 83.87 | 79.03 | 70.08 | 61.07 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 78.10 |
| 3.0 | 0.33 | 100.00 | 99.17 | 95.02 | 89.10 | 81.05 | 70.40 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 88.75 |
| 2.0 | 0.5 | 100.00 | 100.00 | 100.00 | 100.00 | 99.88 | 92.46 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 99.59 |
| 1.7 | 0.6 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 100.00 |

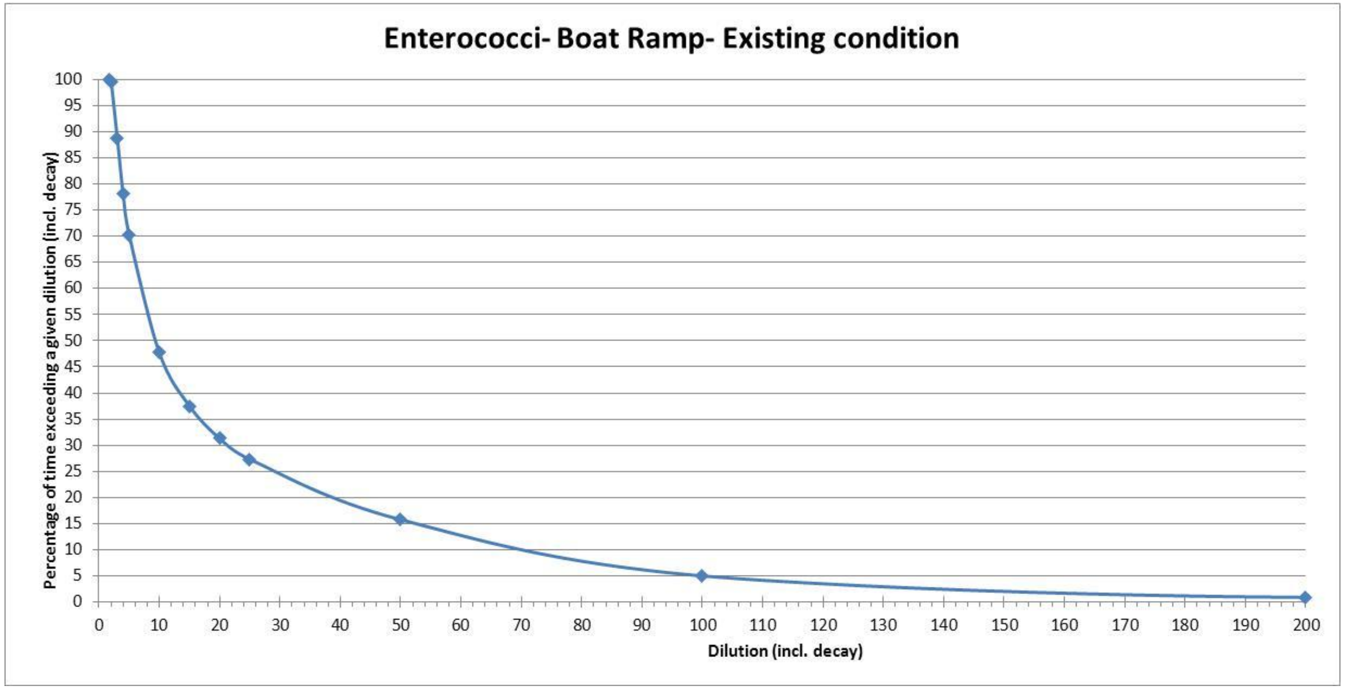


*Figure 9-11: Existing situation - frequency of dilution (incl. decay) for Enterococci at the station Boat Ramp in the Maketu Estuary.*

*Table 9-7: Future situation- frequency of dilution (incl. decay) for Enterococci at the station Boat Ramp in the Maketu Estuary.*

| dilution | dilution factor | Percentage of time during the 20 day simulation where the dilution is exceeded | | | | | | Percentage of time represented by the dischage | | | | | | Percentage of time exceeding the dilution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | |
| 10.0 | 0.1 | 18.84 | 5.42 | 3.70 | 1.81 | 0.00 | 0.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 2.32 |
| 5.0 | 0.2 | 30.20 | 13.91 | 11.50 | 8.03 | 4.74 | 0.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 8.56 |
| 3.0 | 0.33 | 40.18 | 20.69 | 17.40 | 14.00 | 8.61 | 3.33 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 13.90 |
| 2.5 | 0.4 | 44.83 | 24.97 | 20.57 | 16.55 | 11.13 | 4.65 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 16.80 |
| 2.0 | 0.5 | 51.33 | 30.18 | 26.08 | 20.64 | 14.53 | 6.57 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 21.11 |
| 1.7 | 0.6 | 59.62 | 35.59 | 31.31 | 26.01 | 17.98 | 8.56 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 25.73 |
| 1.4 | 0.7 | 94.56 | 43.21 | 38.09 | 32.21 | 22.73 | 12.40 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 32.01 |
| 1.3 | 0.8 | 100.00 | 74.17 | 59.96 | 47.35 | 32.77 | 18.75 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 48.98 |
| 1.1 | 0.9 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.01 | 0.14 | 0.25 | 0.25 | 0.3 | 0.05 | 100.00 |

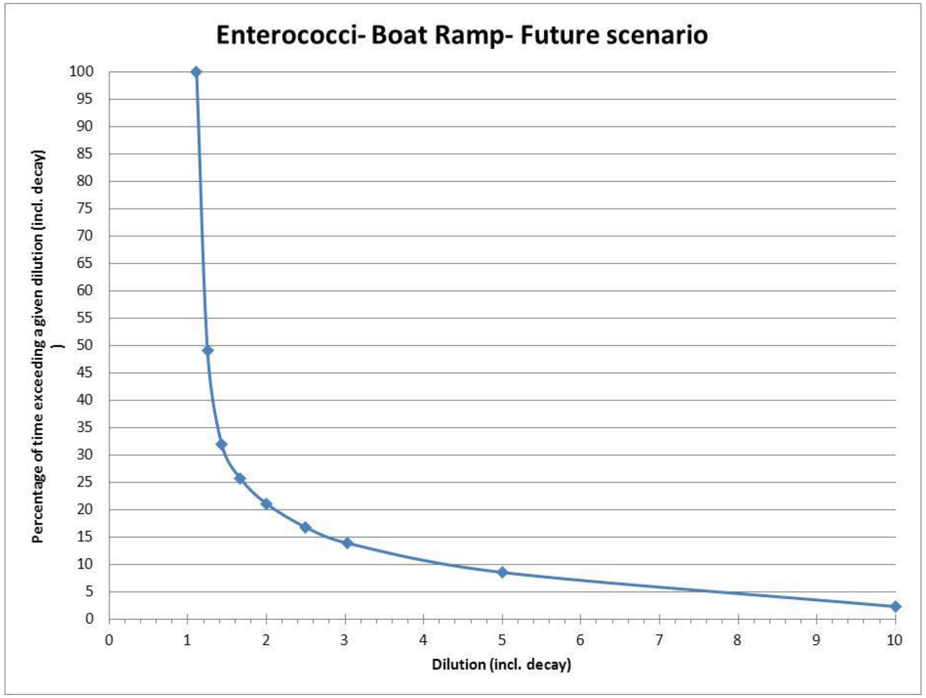


*Figure 9-12: Future situation - frequency of dilution (incl. decay) for Enterococci at the station Boat Ramp in the Maketu Estuary.*

*Table 9-8: Existing condition- frequency of dilution of bluegreen algae at the station in the Lower Mid Maketu Estuary*

| dilution | dilution factor | Percentage of time during the 20 day simulation where the dilution is exceeded | | | | | | Percentage of time represented by the dischage | | | | | | Percentage of time exceeding the dilution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | |
| 200.0 | 0.005 | 1.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 0.01 |
| 100.0 | 0.01 | 8.63 | 3.05 | 2.34 | 1.78 | 0.44 | 0.00 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 1.75 |
| 50.0 | 0.02 | 20.76 | 11.53 | 10.41 | 8.75 | 6.06 | 3.56 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 8.80 |
| 25.0 | 0.04 | 30.13 | 22.31 | 20.53 | 18.58 | 15.71 | 13.21 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 18.81 |
| 16.7 | 0.06 | 34.85 | 27.91 | 26.54 | 24.69 | 21.82 | 19.14 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 24.78 |
| 12.5 | 0.08 | 38.81 | 31.57 | 30.25 | 28.40 | 25.92 | 23.68 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 28.63 |
| 10.0 | 0.1 | 43.00 | 34.51 | 33.16 | 31.43 | 28.88 | 26.52 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 31.60 |
| 5.0 | 0.2 | 69.94 | 48.90 | 45.85 | 42.81 | 39.09 | 35.85 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 43.60 |
| 4.0 | 0.25 | 80.54 | 57.88 | 54.36 | 49.90 | 44.09 | 39.71 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 50.67 |
| 3.0 | 0.33 | 96.57 | 70.70 | 66.42 | 61.24 | 54.50 | 47.28 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 62.11 |
| 2.0 | 0.5 | 100.00 | 95.81 | 91.51 | 85.72 | 75.19 | 67.28 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 85.30 |
| 1.7 | 0.6 | 100.00 | 100.00 | 99.75 | 97.71 | 92.80 | 86.16 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 96.76 |
| 1.4 | 0.7 | 100.00 | 100.00 | 100.00 | 100.00 | 99.24 | 97.04 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 99.67 |
| 1.3 | 0.8 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 100.00 |

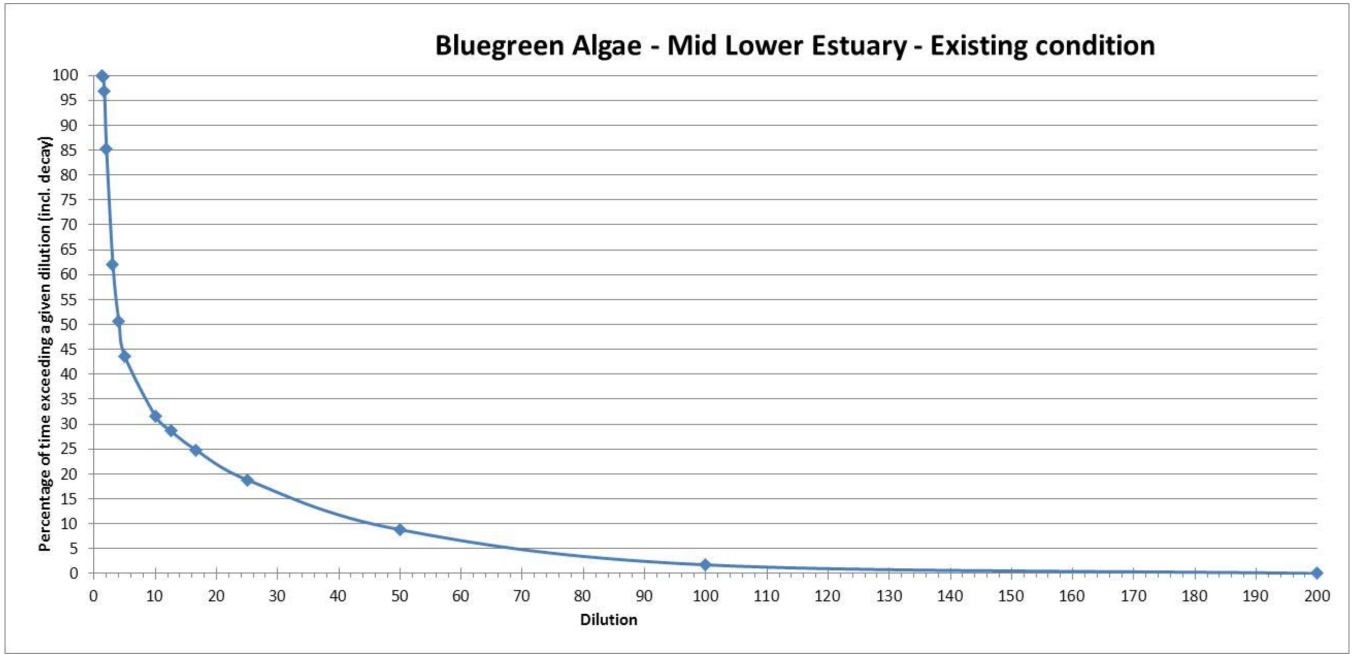


*Figure 9-13: Existing condition- frequency of dilution of Bluegreen algae at the station in the Lower Mid Maketu Estuary.*

Table 9-9: *Future condition- frequency of dilution of bluegreen algae at the station in the Lower Mid Maketu Estuary*

| dilution | dilution factor | Percentage of time during the 20 day simulation where the dilution is exceeded | | | | | | Percentage of time represented by the dischage | | | | | | Percentage of time exceeding the dilution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | 13 m3/s | 25 m3/s | 28 m3/s | 32 m3/s | 39 m3/s | 51 m3/s | |
| 10.0 | 0.1 | 12.91 | 1.62 | 0.72 | 0.23 | 0.00 | 0.00 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 0.66 |
| 5.0 | 0.2 | 19.93 | 9.03 | 7.04 | 4.84 | 1.27 | 0.00 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 5.05 |
| 4.0 | 0.25 | 22.08 | 11.22 | 8.96 | 6.67 | 2.94 | 0.00 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 6.87 |
| 3.0 | 0.33 | 26.64 | 14.83 | 11.27 | 8.61 | 5.05 | 0.00 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 9.24 |
| 2.0 | 0.5 | 33.53 | 18.98 | 16.32 | 13.03 | 7.59 | 1.67 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 13.10 |
| 1.7 | 0.6 | 37.05 | 21.38 | 18.58 | 15.30 | 8.91 | 2.71 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 15.07 |
| 1.5 | 0.665 | 38.81 | 23.14 | 20.06 | 16.43 | 10.09 | 3.82 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 16.43 |
| 1.4 | 0.715 | 40.43 | 24.09 | 21.06 | 17.43 | 10.97 | 4.35 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 17.37 |
| 1.3 | 0.77 | 42.12 | 25.83 | 22.29 | 18.58 | 12.71 | 5.30 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 18.84 |
| 1.2 | 0.835 | 44.69 | 28.05 | 24.25 | 20.20 | 14.58 | 6.62 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 20.74 |
| 1.1 | 0.91 | 49.60 | 31.40 | 27.45 | 22.80 | 17.17 | 8.56 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 23.64 |
| 1.0 | 1 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.01 | 0.19 | 0.25 | 0.2 | 0.32 | 0.03 | 100.00 |

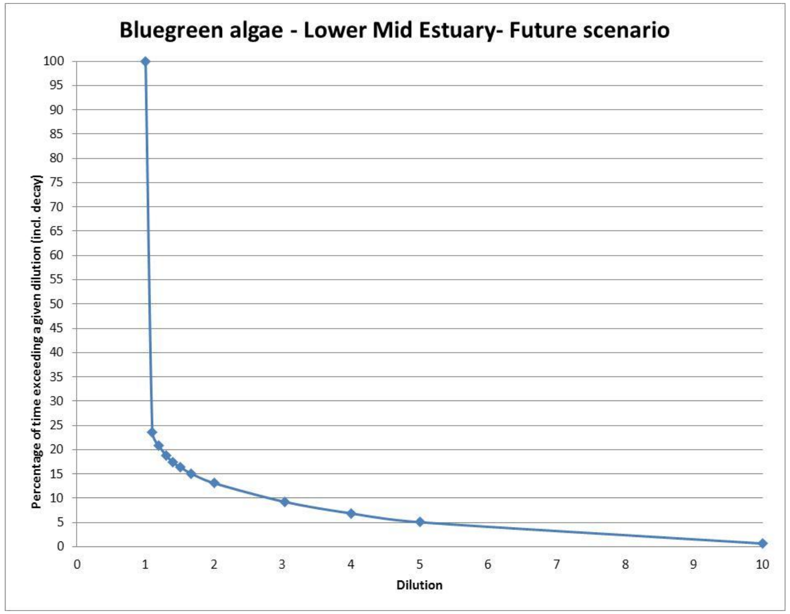


*Figure 9-14: Future condition- frequency of dilution of Bluegreen algae at the station in the Lower Mid Maketu Estuary.*

# 10 QUANTITATIVE ASSESSMENT OF THE DIVERSION

The previous chapter analysed the dilution pattern from Te Matai to the estuary for Algae and Bacteria. The dilution varies with the river flow, the tidal cycle and the decay (for Bacteria). In Chapter 9, the occurrence of different dilutions was quantified. In this chapter, this dilution pattern will be related to actual recorded concentrations to assess the risk of exceeding the water quality guidelines in the estuary.

## 10.1 Blue green algae

For shell fish gathering, the water quality criterion is 15,000 blue green algae cells per 100 ml in the water bodies.

The frequency (percentage of time) at which this critical concentration level is estimated to be exceeded at the Lower Mid Maketu Estuary, for the existing and the future layout, will be studied in this chapter.

The frequency of bluegreen algae concentrations in the Kaituna River (Figure 10.1 was estimated based on monitoring data from Waitangi and Maungarangi stations (from March 2005 to May 2010).

The duration of different dilution intervals was estimated based on the dilution frequencies discussed in Chapter 9. The intervals and the percentages of time where the dilution is expected to occur are given in column 2 and 3 of Table 10.1 and 10.2. They are derived from Table 9-3.

To combine the blue green algae inflow concentration with the dilutions discussed above, it was assumed that the collected bluegreen algae data are representative of the blue green algae concentrations at these discharges; and that there is no correlation between the discharge and the concentration. A correlation analysis between the river discharge and the blue green algae concentration validated this assumption by showing that the bluegreen algae concentrations occur nearly completely randomly to the discharges.

As mentioned in Chapter 9, the blue-green algae dilution analysis was performed using only flow representative of the bluegreen algae sampling period. The bluegreen data is collected for the majority of the year, except for the month August, September and October.

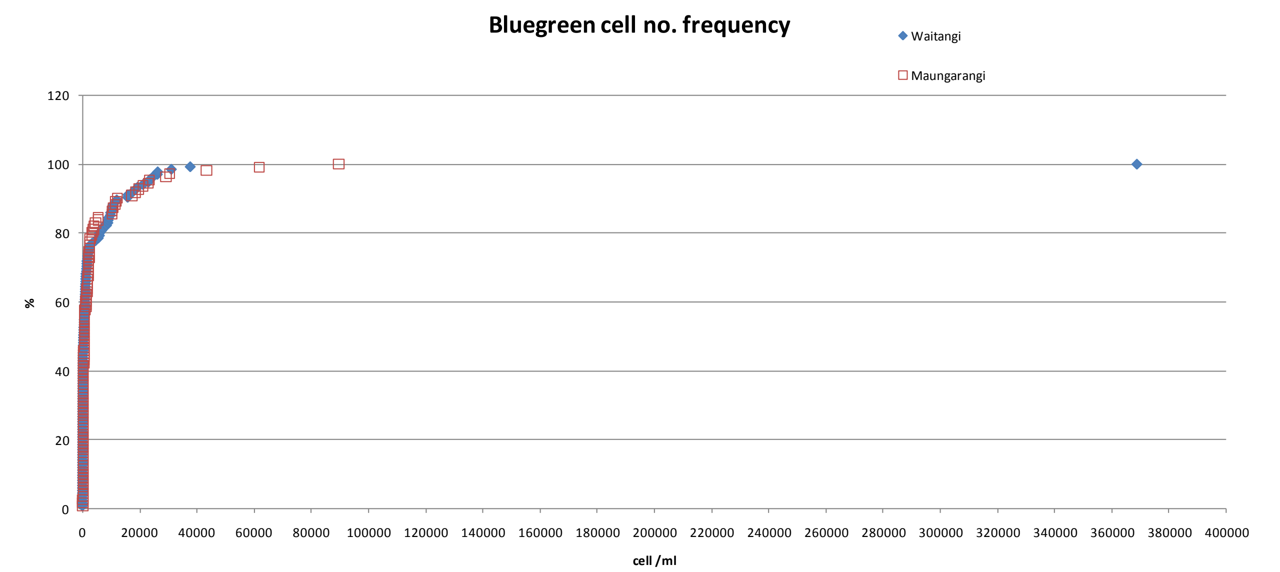


*Figure 10-1: Frequency of bluegreen algae concentration in the lower Kaituna River based on monitoring data from March 2005 to May 2010.*

Using the minimum dilution within each of the intervals (see Table 10.1 and 10.2) the maximum acceptable concentration in the inflow is calculated. These maximum inflow concentrations (that would induce 15,000 cell/100ml at the Lower Mid estuary) are given in column 4 of Table 10-1 and Table 10-2.

The frequency of bluegreen algae concentration higher than this maximum acceptable concentration in the river inflow is estimated based on the frequency distribution shown in Figure 10-1. The frequencies are given in column 5 of the Table 10-1 and Table 10-2.

The contribution to the exceedance of the critical level from each discharge/dilution interval is calculated in column 6 of the tables.

From the tables it can be seen that for the existing conditions the critical bluegreen cell concentration is expected to be violated approximately 0.5 % of time. For the future situation it is estimated to occur 6 % of time.

*Table 10-1: Existing condition– exceeding critical levels – Bluegreen algae.*

| Minimum dilution | Dilution interval | Occurrence of this dilution interval at Lower Mid Esturay | Maximum inflow concentration | Percentage of time that concentration is exceeding | Percentage of time 15,000 cell/ml will be exceeded in the estuary |
|---|---|---|---|---|---|
| 200 | >200 | 0.01 | 3,000,000 | 0 | 0 |
| 100 | 100 - 200 | 1.7 | 1,500,000 | 0 | 0 |
| 50 | 50 - 100 | 7 | 750,000 | 0 | 0 |
| 25 | 25 - 50 | 10 | 375,000 | 0 | 0 |
| 10 | 10 - 25 | 12.8 | 250,000 | 0.08 | 0.01 |
| 5 | 5 - 10 | 12 | 187,500 | 0.09 | 0.01 |
| 4 | 4 - 5 | 7.1 | 150,000 | 0.1 | 0.01 |
| 3 | 3 - 4 | 11.4 | 75,000 | 0.5 | 0.06 |
| 2 | 2 - 3 | 23.2 | 60,000 | 1 | 0.23 |
| 1.3 | 1.3-2 | 14.7 | 45,455 | 1.3 | 0.19 |
| | Sum | 100 | | Sum | 0.51 |

*Table 10-2: Future condition – exceeding critical levels – Bluegreen algae.*

| Minimum dilution | Dilution interval | Occurrence of this dilution interval at Lower Mid Esturay | Maximum inflow concentration | Percentage of time that concentration is exceeding | Percentage of time 15,000 cell/ml will be exceeded in the estuary |
|---|---|---|---|---|---|
| 10 | <10 | 0.66 | 150,000 | 0.1 | 0 |
| 5 | 5 - 10 | 4.39 | 75,000 | 0.5 | 0.02 |
| 4 | 4 - 5 | 1.82 | 60,000 | 1 | 0.02 |
| 3 | 3 - 4 | 2.37 | 45,000 | 1.3 | 0.03 |
| 2 | 2 - 3 | 3.87 | 30,000 | 3 | 0.12 |
| 1.7 | 1.7-2 | 1.97 | 25,500 | 4.5 | 0.09 |
| 1.5 | 1.5-1.7 | 1.36 | 22,500 | 6 | 0.08 |
| 1.4 | 1.4-1.5 | 0.94 | 21,000 | 7 | 0.07 |
| 1.3 | 1.3-1.4 | 1.47 | 19,500 | 8.2 | 0.4 |
| 1.2 | 1.2-1.3 | 1.9 | 18,000 | 9 | 0.78 |
| 1.1 | 1.1-1.2 | 2.89 | 16,500 | 10.2 | 1.54 |
| 1 | 1-1.1 | 76.36 | 15,000 | 10.8 | 2.96 |
| | Sum | 100 | | Sum | 6.1 |

## 10.2 F. Coliforms

For shell fish gathering, the water quality criterion is 14 Faecal coliforms per 100ml (e.g. this concentration must not be exceeded more than 50 % of time). In addition, the concentration are only allowed to exceed 43 F. coliform/100ml during 10 % of the time (MfE, 2002).

The frequency (percentage of time) at which this critical concentration level is estimated to be exceeded at the Lower Mid Maketu Estuary, for the existing and the future layout, will be studied in this chapter.

The frequency of F. Coliform bacteria concentrations in the Kaituna River (Figure 10-2) was estimated based on monitoring data from Waitangi and Maungarangi stations (from March 2005 to May 2010).

The duration of different dilution intervals was estimated based on the dilution frequencies discussed in Chapter 9. The intervals and the percentages of time where the dilution is expected to occur are given in column 2 and 3 of Table 10-3 to Table 10-6. They are derived from Table 9-3.

To combine the Faecal coliform inflow concentration with dilution discussed above, it was assumed that there is no correlation between the discharge and the concentration. The F. coliform data is collected throughout most of the year and cover most observed inflow discharges. A correlation analysis between the river discharge and the bacteria concentration showed no correlation.

Using the minimum dilution within each of the intervals (see Table 10-3 to Table 10-6), the maximum acceptable concentration in the inflow is calculated if the criteria of 14 bacteria/100ml (Table 10-3 and Table 10-4) and 43 bacteria/100ml (Table 10-5 and Table 10-6) are not to be exceeded. Theses maximum inflow concentrations are given in column 4 of Table 10-3 and Table 10-4.

The frequency of F. coliform bacteria concentration higher than this maximum acceptable concentration in the river inflow is estimated based on the frequency distribution shown in Figure 10-2. The frequencies are given in column 5 of the Table 10-3 to Table 10-6.

The contribution to the exceedance of the critical level from each discharge/dilution interval is calculation in column 6 of the tables and summarized.

From Table 10-3 and Table 10-4, it can be seen that for the existing condition it is calculated that the critical F coli concentration of 14 bac./100ml is expected to be violated approximately 46 % of time. For the future situation it is estimated to occur 92 % of time.

From Table 10-5 and Table 10-6, it can be seen that for the existing condition it is calculated that the critical F. coliform concentration of 43 bac./100ml is expected to be violated approximately 27 % of time. For the future situation it is estimated to occur 65 % of time.

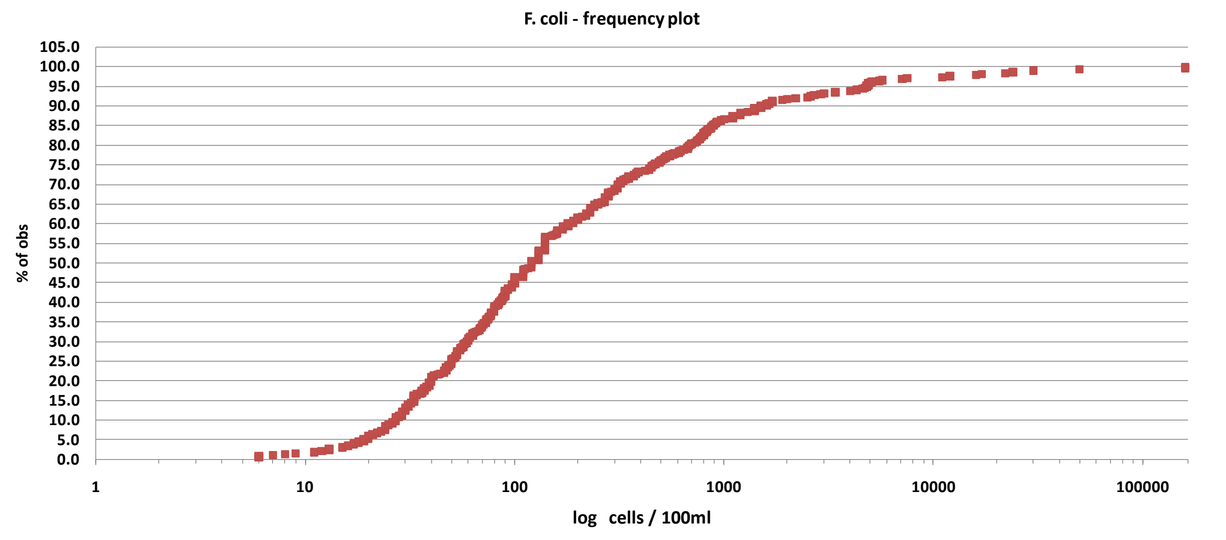


*Figure 10-2 Frequency distribution of bluegreen algae concentration in the lower Kaituna River based on monitoring data*

*Table 10-3: Existing condition– exceeding critical levels of 14 F coli/100ml*

| Minimum dilution | Dilution interval | Occurrence of this dilution interval at Lower Mid Esturay | Maximum inflow concentration | Percentage of time that concentration is exceeding | Percentage of time 15,000 cell/ml will be exceeded in the estuary |
|---|---|---|---|---|---|
| 200 | >200 | 2.5 | 2,800 | 7.2 | 0.18 |
| 100 | 100-200 | 7.7 | 1,400 | 11 | 0.85 |
| 50 | 50-100 | 10.7 | 700 | 19.5 | 2.08 |
| 25 | 25-50 | 10.7 | 350 | 28 | 2.99 |
| 20 | 20-25 | 3.7 | 280 | 32.5 | 1.21 |
| 15 | 15-20 | 5.8 | 211 | 38.2 | 2.2 |
| 10 | 10 - 15 | 11.4 | 140 | 45 | 5.13 |
| 5 | 5 - 10 | 27.1 | 70 | 66 | 17.88 |
| 4 | 4 - 5 | 11.1 | 56 | 71.5 | 7.91 |
| 3 | 3 - 4 | 8 | 42 | 58 | 4.67 |
| 2 | 2 - 3 | 1.4 | 28 | 72 | 1 |
| | Sum | 100 | | Sum | 46.09 |

*Table 10-4: Future condition– exceeding critical levels of 14 F coli/100ml*

| Minimum dilution | Dilution interval | Occurrence of this dilution interval at Lower Mid Esturay | Maximum inflow concentration | Percentage of time that concentration is exceeding | Percentage of time 15,000 cell/ml will be exceeded in the estuary |
|---|---|---|---|---|---|
| 10 | <10 | 2.2 | 140 | 45 | 1.01 |
| 5 | 5 - 10 | 5.4 | 70 | 66 | 3.57 |
| 3 | 3 - 5 | 4.2 | 42 | 78.5 | 3.3 |
| 2.5 | 2.5-3 | 3.8 | 35 | 83.5 | 3.2 |
| 2 | 2-2.5 | 4.7 | 28 | 89 | 4.22 |
| 1.7 | 1.7-2 | 6.8 | 24 | 92 | 6.28 |
| 1.4 | 1.4-1.7 | 41 | 20 | 94.5 | 38.74 |
| 1.3 | 1.3-1.4 | 31.8 | 18 | 99.8 | 31.7 |
| | Sum | 100 | | Sum | 92.01 |

*Table 10-5: Existing condition– exceeding critical levels of 43 F coli/100ml*

| Minimum dilution | Dilution interval | Occurrence of this dilution interval at Lower Mid Esturay | Maximum inflow concentration | Percentage of time that concentration is exceeding | Percentage of time 15,000 cell/ml will be exceeded in the estuary |
|---|---|---|---|---|---|
| 200 | >200 | 2.5 | 8,600 | 0.5 | 0.01 |
| 100 | 100-200 | 7.7 | 4,300 | 5.8 | 0.45 |
| 50 | 50-100 | 10.7 | 2,150 | 8.2 | 0.87 |
| 25 | 25-50 | 10.7 | 1,075 | 13.7 | 1.46 |
| 20 | 20-25 | 3.7 | 860 | 15.7 | 0.58 |
| 15 | 15-20 | 5.8 | 647 | 21.2 | 1.22 |
| 10 | 10 - 15 | 11.4 | 430 | 26.4 | 3.01 |
| 5 | 5 - 10 | 27.1 | 215 | 38 | 10.3 |
| 4 | 4 - 5 | 11.1 | 172 | 40.8 | 4.51 |
| 3 | 3 - 4 | 8 | 130 | 48 | 3.86 |
| 2 | 2 - 3 | 1.4 | 86 | 59.7 | 0.83 |
| | Sum | 100 | | Sum | 27.11 |

*Table 10-6: Future condition– exceeding critical levels of 43 F coli/100ml*

| Minimum dilution | Dilution interval | Occurrence of this dilution interval at Lower Mid Esturay | Maximum inflow concentration | Percentage of time that concentration is exceeding | Percentage of time 15,000 cell/ml will be exceeded in the estuary |
|---|---|---|---|---|---|
| 10 | <10 | 2.2 | 430 | 26.4 | 0.59 |
| 5 | 5 - 10 | 5.4 | 215 | 38 | 2.06 |
| 3 | 3 - 5 | 4.2 | 129 | 48 | 2.02 |
| 2.5 | 2.5-3 | 3.8 | 108 | 53.6 | 2.05 |
| 2 | 2-2.5 | 4.7 | 86 | 59.7 | 2.83 |
| 1.7 | 1.7-2 | 6.8 | 73 | 65 | 4.44 |
| 1.4 | 1.4-1.7 | 41 | 60 | 69.5 | 28.49 |
| 1.3 | 1.3-1.4 | 31.8 | 56 | 71.5 | 22.71 |
| | Sum | | | Sum | 65.18 |

## 10.3 Enterococci

For bathing water, the water quality criterion is 280 Enterococci per 100ml in water bodies (MfE, 2002).

The frequency (percentage of time) at which this critical concentration level is estimated to be exceeded at the Boat Ramp station (in the Maketu Estuary) for the existing situation and the future will be studied in this chapter.

The frequency of Enterococci concentrations in the Kaituna River (Figure 10-3) was estimated based on monitoring data from Waitangi and Maungarangi stations (from March 2005 to May 2010).

The duration of different dilution intervals was estimated based on the dilution frequencies discussed in Chapter 9. The intervals and the percentages of time where the dilution is expected to occur are given in column 2 and 3 of Table 10-7 and Table 10-8. They are derived from Table 9-3.

To combine the Enterococci bacteria inflow concentration frequency with the dilutions discussed above, it was assumed that there is no correlation between the discharge and the concentration. The Enterococci data is collected nearly throughout the year and cover the most observed inflow discharges. An analysis of the river discharge and of the bacteria concentration showed no correlation between them.

Using the minimum dilution within each of the intervals in Table 10-7 and Table 10-8, the maximum acceptable concentration in the inflow is calculated for the criteria of 280 bacteria/100ml not to be violated at the Boat Ramp. Theses maximum inflow concentrations are given in column 4 of Table 10-7 and Table 10-8.

The frequency of Enterococci concentration higher than this maximum acceptable concentration in the river inflow is estimated based on the frequency distribution shown in Figure 10-3. The frequencies are given in column 5 of the Table 10-7 and Table 10-8.

The contribution to the exceedance of the critical level from each discharge/dilution interval is calculation in column 6 of the tables and summarized.

From the Table 10-7 and Table 10-8, it can be seen that for the existing condition it is calculated that the critical Enterococci concentration of 280 bacteria per 100ml is expected to be violated approximately 5.8 % of time. For the future situation it is estimated to occur 9.6 % of time.

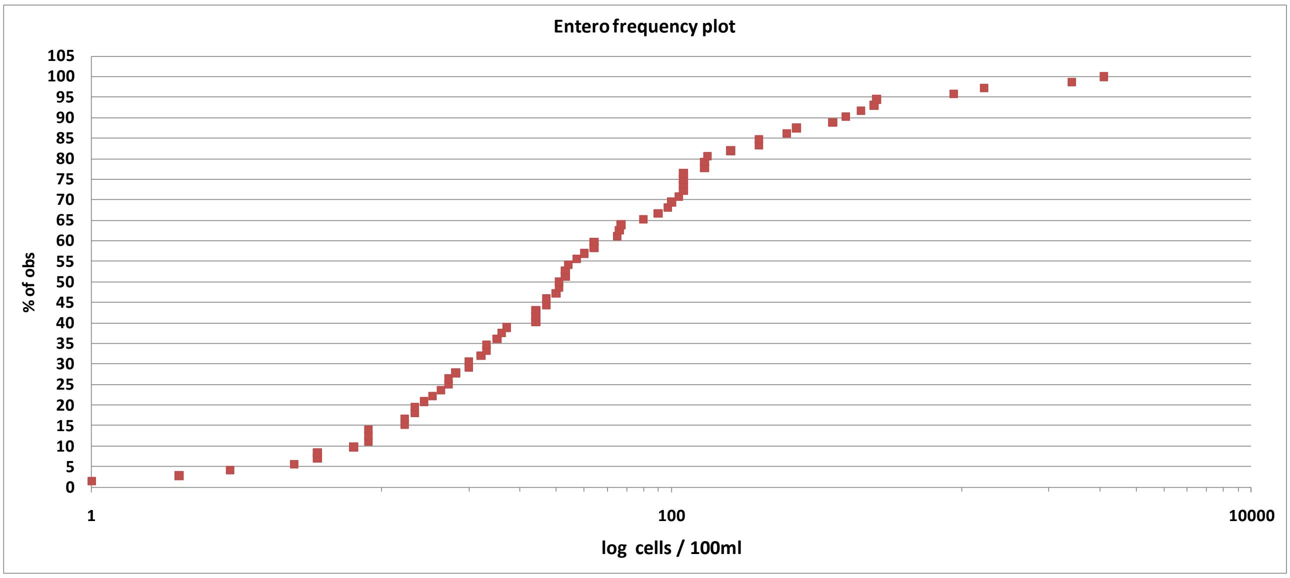


*Figure 10-3: Frequency distribution of bluegreen algae concentration in the lower Kaituna River based on monitoring data*

*Table 10-7: Existing condition– exceeding critical levels of 280 Enterococci/100ml at Boat Ramp*

| Minimum dilution | Dilution interval | Occurrence of this dilution interval at Lower Mid Esturay | Maximum inflow concentration | Percentage of time that concentration is exceeding | Percentage of time 15,000 cell/ml will be exceeded in the estuary |
|---|---|---|---|---|---|
| 200 | >200 | 0.9 | 56,000 | 0 | 0 |
| 100 | 100-200 | 4.1 | 28,000 | 0 | 0 |
| 50 | 50-100 | 10.8 | 14,000 | 0 | 0 |
| 25 | 25-50 | 11.5 | 7,000 | 0 | 0 |
| 20 | 20-25 | 4 | 5,600 | 0 | 0 |
| 15 | 15-20 | 6.1 | 4,200 | 0 | 0 |
| 10 | 10 - 15 | 10.3 | 2,800 | 0.4 | 0.04 |
| 5 | 5 - 10 | 22.6 | 1,400 | 2 | 0.45 |
| 4 | 4 - 5 | 7.8 | 1,120 | 3 | 0.24 |
| 3 | 3 - 4 | 10.6 | 848 | 4.7 | 0.73 |
| 2 | 2 - 3 | 10.8 | 560 | 6.6 | 1.46 |
| 1.7 | 1.7-2 | 0.4 | 467 | 7.7 | 2.91 |
| | Sum | 100 | | Sum | 5.82 |

*Table 10-8: Future condition– exceeding critical levels of 280 Enterococci/100ml at Boat Ramp*

| Minimum dilution | Dilution interval | Occurrence of this dilution interval at Lower Mid Esturay | Maximum inflow concentration | Percentage of time that concentration is exceeding | Percentage of time 15,000 cell/ml will be exceeded in the estuary |
|---|---|---|---|---|---|
| 10 | <10 | 2.3 | 2,800 | 0.4 | 0.01 |
| 5 | 10-May | 6.2 | 1,400 | 2 | 0.12 |
| 3 | 5-Mar | 5.3 | 840 | 4.7 | 0.25 |
| 2.5 | 2.5-3 | 2.9 | 700 | 5.6 | 0.16 |
| 2 | 2-2.5 | 4.3 | 560 | 6.6 | 0.28 |
| 1.7 | 1.7-2 | 4.6 | 476 | 7.7 | 0.36 |
| 1.4 | 1.4-1.7 | 6.3 | 392 | 10.1 | 0.63 |
| 1.3 | 1.3-1.4 | 17 | 364 | 11 | 1.87 |
| 1.1 | 1.1-1.3 | 51.02 | 308 | 11.6 | 5.92 |
| | Sum | 100 | | Sum | 9.61 |

## 10.4 Summary

The above results are summarised in Table 10-9. We can see that overall, the proposed layout (all flow diverted from the Kaituna River) significantly increases the risk of exceeding the New Zealand regulation for bathing and shellfish gathering waters.

This is consistent with the results provided by the Eutrophication modelling (Chapter 8). The new layout tends to decrease the mixing of the polluted fresh water (coming from the Kaituna River) with the less polluted ocean water. Thus, the impact of a pollution load coming from the river is more acute in the new layout. The pollutant concentration is higher all across the estuary, as highlighted by the fact that both Lower Mid Estuary and Boat Ramp perform worst.

However, this study is based on the available data. This analysis is valid if the measured flow and the bacteria / Algae measured concentration are representative of the system flow and concentration occurrence. Furthermore, the current dataset did not allow a full understanding of the different pollutant loads. This study did not account for any pollution input along the River (other than the upstream load).

*Table 10-9 Expected exceedance frequencies*

| Location | Guidelines exceedance | Existing case % of time | Proposed case % of time |
|---|---|---|---|
| Lower Mid Estuary | 15,000 bluegreen algae cells/ ml | 1 | 6 |
| Lower Mid Estuary | 14 F. Coli/ 100 ml | 46 | 92 |
| Lower Mid Estuary | 43 F coli /100 ml | 27 | 65 |
| Boat ramp | 280 Enterococci / 100 ml | 6 | 10 |

## 11 RECOMMENDATION FOR FURTHER ACTIVITIES

We propose several activities to improve the validity of the hydro-ecological simulation models developed. Whilst we appreciate that the EBoP water quality data collection programme is not solely for obtaining data for use in simulation modelling, we would suggest a modification and improved coordination of the monitoring activities that are currently carried out. The existing monitoring is most likely designed for surveillance and monitoring of the ecosystem state. For achieving a description of the growth rate for algae biomasses and other process rates the existing monitoring data has some weaknesses. Information on process rates and short term changes in state variables is important for the calibration of models and for the evaluation of future scenarios, e.g. with the changed flow condition.

As previously mentioned more detailed models can be used to describe individual algae species or different functional groups of algae species (e.g. filamentous green algae, unicellular green algae, diatoms, flagellates, blue-green algae etc.). If a higher level of description is considered necessary then monitoring of the development of the different algae groups should be included in any revised monitoring programme.

A more general description of the algae biomasses was used in this study. This more simple description, that did not completely remove the distinction between species either, was considered more straightforward and still sufficient for the purpose of the study.

Independently of the levels of detail required for the biological model, we highly recommend a fully coordinated monitoring program which covers both the river system and the estuary. This should be fully coordinated with respect to hydrodynamics, water chemistry and biological variables. Such a programme is recommended to cover at least a period representing 3 times the retention time of the system and with focus on the most productive period of the year, where the risk of blue-green algae blooms is at its highest. Based on the modelling carried out in this study, an intensive monitoring programme for improvement of the models is recommended. This should be carried out during a period with the inflow of high algae concentration at the upstream boundary, to include:

- Daily (or every second) sampling during at least 9-10 days
- For at least 2 of these sampling days, the tidal cycle has to be covered with a minimum of two samples per cycle (e.g. high and low tide).

Sampling in the Kaituna River is recommended to be carried out at least at:

- The upstream boundary (Te Matai)
- The inflow to the estuary (Fords Cut).

Additionally (ideally) sampling half way between Te Matai and Fords Cut and at the river mouth (Te Tumu) is recommended.

Sampling in the Maketu Estuary is recommended to at least include the following:

- 2 stations in centre of the estuary

- 1 station close to the mouth (could be at the Boat Ramp)

The water chemistry monitoring programme carried out so far has included the following most relevant variables:

- Salinity
- pH
- oxygen
- suspended solids
- inorganic faction of nitrogen
- inorganic P
- Total N
- Total P
- Chlorophyll a
- Biomass distribution between domination algae species

In an estuary like the Maketu benthic vegetation and especially the benthic filtration organism (e.g. shellfish) can also play an important role. More focus on their function and biomass is recommended for further modelling studies of the estuary. However, before deciding which variables are important and require monitoring, additional assessment and eventually a survey can be recommended to fully understand the system.

In this study only the bacterial level in the water has been described, which for an initial assessment is regarded as sufficient. However, it is possible to include a shellfish model to describe the potential bacterial contamination within the shellfish. Although a shellfish model already exists for the ECOLab system the existing module does not focus on the bacterial contamination of the shellfish. The open structure of the ECOLab modules makes it possible to expand the existing model with such a description as long as the processes regulating the variables to be described are known.

# 12 REFERENCES

Chorus I & J. Bartram; 1999: Toxic Cyanobacteria in Water. A guide to their public health consequences, monitoring and management. Pub. on behalf of WHO by E & FN Spon. ISBN 0-419-23930-8.

Queensland Government; Natural Resources and Water, 2008: Water Monitoring. Monitoring Standard for Freshwater Blue-Green Algae. Natural Resources and water.

DHI, 2009: Kaiuna River to Maketu Estuary Re-diversion: Model Calibration and Initial Hydrodynamic Impact Assessment. Report to Environment Bay of Plenty.

DHI, 2008: ECO Lab – Short Scientific Description. 2008. MIKE by DHI.

DHI, 2007: Eutrophication model 1 Ecolab template - scientific description. MIKE by DHI.

Environment Bay of Plenty, 2008. Kaituna River to Maketu Estuary re-diversion - recommended options.

Longdill P., K. Black, S. Park and T Healy, 2005: Bay of Plenty Shelf Water Properties Data Report 2003-2004: Aquaculture Management Areas. Report to Environment Bay of Plenty, Regional Council from ASR Marine Consulting and Research.

MfE, 2002: Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. 2002. Ministry for the Environment.

# A P P E N D I C E S

# A P P E N D I X   A

***Data availability used for the project***

## Water chemical and bacteriological analysis available from the Kaituna River System

| Site_ref | Name | Easting | Northing | Type_period | River | DO | TEMP | COND | SS | TURB | pH | DRP | NH4N | NNN | TKN | TN | TP | Ecoli | ENT | FC | Chl-a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BOP110026 | Okere | 2803800 | 6348500 | Monthly sampling - on going | Kaituna and tribs | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y |
| BOP110027 | Maungarangi Rd Br | 2808527 | 6368170 | Monthly sampling - on going | Kaituna and tribs | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y |
| BOP110028 | Te Matai | 2806100 | 6373600 | Monthly sampling - on going | Kaituna and tribs | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y |
| BOP110029 | Te Tumu | 2810960 | 6377890 | Monthly sampling - on going | Kaituna and tribs | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y |
| | | | | | | | | | | | | | | | | | | | | | |
| Site_ref | Name | Easting | Northing | Type_period | River | | TEMP | COND | SS | TURB | pH | DRP | NH4N | NNN | TKN | TN | TP | Ecoli | ENT | FC | Chl-a |
| BOP210274 | Mangorewa | 2808620 | 6369159 | Monthly sampling - 06/2007 to 07/2008 only | Kaituna and tribs | | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y |
| BOP210052 | Parawhenuamea | 2806711 | 6372958 | Monthly sampling - 06/2007 to 07/2008 only | Kaituna and tribs | | y | y | y | y | y | y | y | y | y | y | y | y | y | y | |
| BOP210053 | Waiari | 2804217 | 6373698 | Monthly sampling - 06/2007 to 07/2008 only | Kaituna and tribs | | y | y | y | y | y | y | y | y | y | y | y | y | y | y | |
| BOP210275 | Te Puke East | 2803779 | 6374090 | Monthly sampling - 06/2007 to 07/2008 only | Kaituna and tribs | | y | y | y | y | y | y | y | y | y | y | y | y | y | y | |
| BOP210001 | Ohineangaanga | 2802286 | 6374692 | Monthly sampling - 06/2007 to 07/2008 only | Kaituna and tribs | | y | y | y | y | y | y | y | y | y | y | y | y | y | y | |
| BOP210002 | Raparapahoe | 2801430 | 6376420 | Monthly sampling - 06/2007 to 07/2008 only | Kaituna and tribs | | y | y | y | y | y | y | y | y | y | y | y | y | y | y | |
| BOP210159 | Kopuroa | 2801057 | 6378241 | Monthly sampling - 06/2007 to 07/2008 only | Kaituna and tribs | | y | y | y | y | y | y | y | y | y | y | y | y | y | y | |

## Water chemical and bacteriological analysis available from the Maketu Estuary

| Site_ref | Name | Easting | Northing | Type_period | River | | TEMP | SALN | | | DRP | NH4N | TOXN | TKN | TN | TP | ecoli | COL | ENT | FC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BOP240009 | Fords cut (site 1) | 2811110 | 6377350 | Water sampling February each year (low,mid high tide) | Maketu Estuary | | y | y | | | y | y | y | y | y | y | y | y | y | y |
| BOP240021 | Site 5 | 2812830 | 6376610 | Water sampling February each year (low,mid high tide) | Maketu Estuary | | y | y | | | y | y | y | y | y | y | y | y | y | y |
| BOP240025 | Site 9 | 2813590 | 6376990 | Water sampling February each year (low,mid high tide) | Maketu Estuary | | y | y | | | y | y | y | y | y | y | y | y | y | y |

| Site_ref | Name | Easting | Northing | Type_period | River | | TEMP | SALN | SS | TURB | pH | DRP | NH4N | NNN | TKN | TN | TP | Ecoli | ENT | FC | Chl-a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BOP150005 | Boat Ramp | 2814600 | 6377000 | Water sampling every second month | Maketu Estuary | | y | y | y | y | y | y | y | y | y | y | y | y | y | y | y |

## Algae counting data from the Kaituna River System

| Site_ref | Name | Easting | Northing | Type_period | River |
|---|---|---|---|---|---|
| BOP110026 | Okere | 2803800 | 6348500 | Weekly blue-green algal cell counts 15 Nov - 30 Mar each yr | Kaituna and tribs |
| BOP160112 | Trout pool | 2803600 | 6349600 | Weekly blue-green algal cell counts 15 Nov - 30 Mar each yr | Kaituna and tribs |
| BOP110028 | Te Matai | 2806100 | 6373600 | Weekly blue-green algal cell counts 15 Nov - 30 Mar each yr | Kaituna and tribs |
| BOP110029 | Te Tumu | 2810960 | 6377890 | Weekly blue-green algal cell counts 15 Nov - 30 Mar each yr | Kaituna and tribs |

# A P P E N D I X   B

## Model Constants used in the Eutrophication and the Bacteria Decay Model

Eutrophication model constants

| No. | Description | Type | Value | |
|---|---|---|---|---|
| 1 | Latitude | Built-in | | |
| 2 | Pelagic paramenters: Growth rate diatoms | Constant | 2 | (/d) |
| 3 | Pelagic paramenters: Growth rate green algae | Constant | 2 | (/d) |
| 4 | Pelagic paramenters: Sedimentation rate <2m | Constant | 0.1 | (/d) |
| 5 | Pelagic paramenters: Sedimentation rate >2m | Constant | 0.5 | meter/day |
| 6 | Pelagic paramenters: Max. grazing rate | Constant | 1.5 | (/d) |
| 7 | Pelagic paramenters: Death rate phytoplankton | Constant | 0.02 | (/d) |
| 8 | Pelagic paramenters: Zooplankton death rate 1st order | Constant | 0.1 | (/d) |
| 9 | Pelagic paramenters: Zooplankton death rate 2nd order | Constant | 12 | (/d) |
| 10 | Pelagic paramenters: Oxygen reaeration constant | Constant | 1.5 | (/d) |
| 11 | Pelagic paramenters: Detritus C mineralisation rate | Constant | 0.05 | (/d) |
| 12 | Pelagic paramenters: Detritus C settling rate <2m | Constant | 0.05 | (/d) |
| 13 | Pelagic paramenters: Detritus C settling rate >2m | Constant | 0.1 | meter/day |
| 14 | Pelagic paramenters: Light extinction constant phytoplankton | Constant | 20 | m2/g Chl-a |
| 15 | Pelagic paramenters: Light extinction background constant | Constant | 0.35 | m2 |
| 16 | Pelagic paramenters: Light extinction detritus C | Constant | 0.1 | m2/g detritus C |
| 17 | Pelagic paramenters: Light extinction constant macroalgae | Constant | 0.02 | m2/g macroalgae C |
| 18 | Pelagic paramenters: Light extinction constant suspended solids | Constant | 0.1 | m2/g SS |
| 19 | Macroalgea parameters: Sloughing rate at 20 degrees | Constant | 0.01 | (/d) |
| 20 | Macroalgea parameters: Production rate at 20 degrees | Constant | 0.25 | (/d) |
| 21 | Macroalgea parameters: Respiration rate at 20 degrees | Constant | 0 | (/d) |
| 22 | Simple sediment description: Proportional factor for sediment respiration | Constant | 1 | dimensionless |
| 23 | Simple sediment description: Proportional factor for N release from sediment | Constant | 1 | dimensionless |
| 24 | Simple sediment description: Proportional factor for P release from sediment | Constant | 1 | dimensionless |
| 25 | Phytoplankton ecosystem parameters: Temperature dependency growth rat | Constant | 1.05 | dimensionless |
| 26 | Phytoplankton ecosystem parameters: Temperature dependency growth rat | Constant | 1.05 | dimensionless |
| 27 | Phytoplankton ecosystem parameters: 0. order dependency of grazing rate | Constant | 3 | dimensionless |
| 28 | Phytoplankton ecosystem parameters: 1. order dependency of grazing rate | Constant | 25 | (/d) |
| 29 | Phytoplankton ecosystem parameters: Temperature dependency for max. gr | Constant | 1.05 | dimensionless |
| 30 | Phytoplankton ecosystem parameters: Day no. depicting change to green al | Constant | 1 | dimensionless |
| 31 | Phytoplankton ecosystem parameters: Coefficient for min. chlorophyll-a prod | Constant | 0.04 | 1/(E/m2/day) |
| 32 | Phytoplankton ecosystem parameters: Coefficient for max. chlorophyll-a pro | Constant | 1.1 | 1/(E/m2/day) |
| 33 | Oxygen ecosystem parameters: Half-saturation constant | Constant | 2 | mg/l |
| 34 | Oxygen ecosystem parameters: Half-saturation constant in sediment | Constant | 2 | mg/l |
| 35 | Oxygen ecosystem parameters: Coefficient for oxygen dependency | Constant | 1 | dimensionless |
| 36 | Detritus ecosystem parameters: Temperature dependency for C mineralisati | Constant | 1.14 | dimensionless |
| 37 | Detritus ecosystem parameters: Propertional factor for release of N from mi | Constant | 1 | dimensionless |
| 38 | Detritus ecosystem parameters: Propertional factor for release of P from min | Constant | 1 | dimensionless |
| 39 | Macroalgea ecosystem parameters: Threshold values for self-shading | Constant | 20 | g C/m2 |
| 40 | Macroalgea ecosystem parameters: Temperature dependency sloughing rat | Constant | 1.07 | dimensionless |
| 41 | Macroalgea ecosystem parameters: Temperature dependency production ra | Constant | 1.05 | dimensionless |

## Eutrophication model constants

| No. | Description | Type | Value | |
|---|---|---|---|---|
| 42 | Sediment ecosystem parameters: Temperature dependency sediment N rele | Constant | 1.1 | dimensionless |
| 43 | Sediment ecosystem parameters: Temperature dependency sediment P rele | Constant | 1.1 | dimensionless |
| 44 | Sediment ecosystem parameters: N-relase under anoxic conditions | Constant | 0.05 | g N/m2/day |
| 45 | Sediment ecosystem parameters: P-relase under anoxic conditions | Constant | 0.01 | g P/m2/day |
| 46 | Sediment ecosystem parameters: Temperature dependency sediment respir | Constant | 1.07 | dimensionless |
| 47 | Phytoplankton physiological parameters: Min. intracellular concentration of ni | Constant | 0.07 | g N/g C |
| 48 | Phytoplankton physiological parameters: Max. intracellular concentration of n | Constant | 0.17 | g N/g C |
| 49 | Phytoplankton physiological parameters: Min. intracellular concentration of p | Constant | 0.002 | g P/g C |
| 50 | Phytoplankton physiological parameters: Max. intracellular concentration of p | Constant | 0.03 | g P/g C |
| 51 | Phytoplankton physiological parameters: Half-saturation concentration for ph | Constant | 0.005 | g P/g C |
| 52 | Phytoplankton physiological parameters: N uptake under limiting conditions | Constant | 0.3 | g N/g C/day |
| 53 | Phytoplankton physiological parameters: P uptake under limiting conditions | Constant | 0.05 | g P/g C/day |
| 54 | Phytoplankton physiological parameters: Half-saturation constant for N uptak | Constant | 0.3 | g N/m3 |
| 55 | Phytoplankton physiological parameters: Half-saturation constant for P uptak | Constant | 0.2 | g P/m3 |
| 56 | Phytoplankton physiological parameters: Fraction of nutrients released at ph | Constant | 0.1 | dimensionless |
| 57 | Phytoplankton physiological parameters: Correction for dark reaction | Constant | 1.3 | dimensionless |
| 58 | Phytoplankton physiological parameters: Light saturation intensity | Constant | 23 | E/m2/d |
| 59 | Phytoplankton physiological parameters: Temperature dependency for light s | Constant | 1.04 | dimensionless |
| 60 | Phytoplankton physiological parameters: Specification for nutrient saturation | Constant | 0.001 | dimensionless |
| 61 | Zooplankton physiological parameters: Growth efficiency | Constant | 0.28 | g C/g C |
| 62 | Zooplankton physiological parameters: N to C ratio in zooplankton | Constant | 0.07 | g N/g C |
| 63 | Zooplankton physiological parameters: P to C ratio in zooplankton | Constant | 0.002 | g P/g C |
| 64 | Zooplankton physiological parameters: Respiration constant zooplankton car | Constant | 0.3 | dimensionless |
| 65 | Oxygen chemical parameters: Production/consumption relative to carbon | Constant | 3.5 | g DO/g C |
| 66 | Macroalgea physiological parameters: N to C ratio | Constant | 0.137 | g N/g C |
| 67 | Macroalgea physiological parameters: P to C ratio | Constant | 0.016 | g P/g C |
| 68 | Macroalgea physiological parameters: Half-saturation concentration for N up | Constant | 0.5 | mg/l |
| 69 | Macroalgea physiological parameters: Half-saturation concentration for P up | Constant | 0.01 | mg/l |
| 70 | Macroalgea physiological parameters: Light saturation intensity at 20 deg. | Constant | 20 | E/m2/day |
| 71 | Macroalgea physiological parameters: Temperature dependency for light sat | Constant | 1.04 | dimensionless |

## Bacteria decay model

| No. | Description | Type | Value | |
|---|---|---|---|---|
| 1 | Latitude | Built-in | | |
| 2 | Oxygen processes/Coliform: Secchi disk depths | Constant | 0.4 | m |
| 3 | Coliform: 1st order decay 20 deg. C, fresh, dark (faecal) | Constant | 0.8 | (/d) |
| 4 | Coliform: 1st order decay 20 deg. C, fresh, dark (total) | Constant | 0.8 | (/d) |
| 5 | Coliform: Temperature coefficient for decay rate | Constant | 1.09 | dimensionless |
| 6 | Coliform: Salinity coefficient for decay rate | Constant | 1.006 | dimensionless |
| 7 | Coliform: Light coefficient for decay rate | Constant | 7.4 | dimensionless |
| 8 | Coliform: Maximum insolation at noon | Constant | 0.5 | kW/m2 |
| 9 | Oxygen processes: Time correction for at noon | Constant | 0 | |