Te Puke WWTP
Western Bay of Plenty District Council
16-Oct-2015

Public Health Risk Assessment

Te Puke Wastewater Treatment Plant

Revision – 16-Oct-2015
Prepared for – Western Bay of Plenty District Council – Co No.: 125014

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Client: Western Bay of Plenty District Council

Co No.: 125014

Prepared by

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1.0 Introduction

The Western Bay of Plenty District Council (WBOPDC) currently has consent (Resource Consent Numbers 02 4891 and 02 4889) to operate the Te Puke Waste Water Treatment Plant (WWTP) and discharge wastewater into the Waiari stream.

WBOPDC wishes to renew the existing resource consent which is set to expire in November 2016. In addition, WBOPDC seeks to obtain new Bay of Plenty Regional Council (BOPRC) resource consents for a 35-year term, to meet the future needs for the Western Bay of Plenty district and in particular, the current expected 30 % population increase by 2045.

This report summarises the findings of the public health risk assessment as part of Category One Investigation and Assessment Tasks as identified within the AECOM proposal dated 13 March 2015. Due to the additional requirements from WBOPDC to carry out a quantitative microbial risk assessment (QMRA) for the wastewater discharge, the scope of this assessment includes two main parts:

- A high level qualitative public health risk assessment based on projected pathogen load from the WWTP and the likely public health implication under the framework of Ministry of Health's microbial guidelines for freshwater.
- A quantitative microbial risk assessment (QMRA) for the treated effluent discharge for current and future scenarios.

Currently the wastewater reaching Te Puke WWTP undergoes a series of processes including screening, secondary reactor/clarifier, tertiary brush filtration, and UV disinfection. Effluent from UV disinfection is allowed to flow through a constructed up-flow wetland before being discharged into the Waiari Stream via a constructed riparian wetland. This public health risk assessment is focused on investigating the potential health risks associated with public contact with Waiari Stream and Kaituna River. As part of the QMRA investigation, considerations have been given to the current process units at Te Puke WWTP, except the constructed wetland. This is due to the questionable performance of the wetland, adding no discernible value in effluent polishing. Decommissioning of this wetland is currently being considered by WBOPDC.

2.0 Information Reviewed

In preparation of this report, AECOM has reviewed the following supporting documents provided by WBOPDC:

- Smart Growth WBOPDC Population and Household Projection 2013-2053 (as adopted by Finance and Risk Committee 4 July 2014.
- Historical plant data including influent analytical results (2013-2015), compliance monitoring results (1998-2015), and rainfall records (2009-2015).
- Current resource consent (024891) and associated original application report dated December 1996.
- Flow record for Kaituna River at Te Matai provided by BOPRC from 1986 to 2014.
- Flow record for Waiari Stream at Te Puke provided by NIWA for 2014.

3.0 Qualitative Assessment of Public Health Risks

A high-level microbial public health risk assessment was undertaken in the context of the requirements of the microbiological guidelines for freshwater inherent with the "Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas" (MfE 2003). The framework used in these guidelines is a combination of catchment risk grading and single samples to assess suitability for recreational contact, providing a qualitative ranking of faecal loading in a recreational water environment, supported by direct measurement of appropriate faecal indicators. For the purpose of this study, the expected bacteriological indicator concentrations are compared directly to the various levels of microbial quality levels to allow a qualitative assessment of potential public health risks that may be potentially posed by the discharge of wastewater effluent.

3.1 Current Microbial Water Quality in the Wider Catchment

Apart from pathogen load introduced by the discharge of treated effluent, the public health risks associated with direct recreational water use of Kaituna River or Waiari Stream may also be associated with the likely non-source or diffuse input within the wider catchment. This may include the rural runoff from the adjacent agricultural land use. For instance, as shown in Kaituna Catchment Control Scheme maps (BOPRC), among various agricultural drains into Waiari Stream and Kaituna River, the Managhs Drain drains into the Waiari Stream immediately downstream of the WWTP effluent discharge. other potential sources of microbial contamination within the studied streams (Waiari Stream and Kaituna River) may include the pathogen input from waterfowls, other birds, rodents; and grazing animals in vicinity of the area or further upstream.

Recently a water quality survey was undertaken by AECOM on 30 June and 1 July 2015. This one-off survey provides a "snapshot" of current bacteriological water quality within both Waiari Stream and Kaituna River by sampling at four locations covering both potentially impacted sites (downstream of WWTP discharge) and reference sites (upstream sites). Although it's not feasible to draw a conclusive statement based on a single sampling event, the analytical results indicated a generally good microbial water quality within Waiari Stream (up to 110 cfu/100ml of faecal coliform) and the lower reach of the Kaituna River (below 10 cfu/100 ml of faecal coliform). A slight increase in faecal coliform count was observed when comparing the site downstream of the WWTP discharge and the upstream site within Waiari Stream. However, other historical receiving environment monitoring undertaken by WBOPDC showed no statistical water quality differences between upstream and downstream sites (Refer to the AECOM report: water quality, stream and terrestrial ecology assessment, 2015).

A comprehensive review of microbial water quality within the wider catchment is beyond the scope of this work, which is focused only on the assessment of public risks associated with the treated effluent discharge. A detailed discussion on the likely contribution of pathogens from Te Puke WWTP into Waiari Stream and Kaituna River is presented in Section 3.4 below.

3.2 Public Exposure Routes

An important step in the assessment of public health risks of certain pathogen is the establishment of public exposure routes to the pathogen sources. The potential exposure routes of the public to pathogens contained within discharged wastewater include consumption of contaminated drinking water and mahinga kai; or direct recreational contact.

Based on direct communication with the local community in recent times, there are a number of activities undertaken within or near Waiari Stream and Kaituna River. These include, but may not be limited to, the following:

- Kayaking/canoeing and waka amo (outrigger canoes);
- Eeling, food gathering, and trout fishing;
- Boating from Bell Road boat ramp (rowing boats, small dinghies and power boats for water skiing, wake boarding and sea-biscuiting);
- Swimming, paddling, rafting and picnic type gatherings/BBQs on stream/river banks; and
- Customary and traditional practices for local Iwi/Hapu groups.

Many of these activities are seasonally based, and enjoyed by various sectors of the local community on a regular basis, unless there is a health warning such as a ban on food gathering or swimming in certain areas.

Drinking water source contamination can be ruled out because no private or community drinking water supplies are present in the study area. Te Puke water supply system is part of WBOPDC's Eastern water supply zone (ESZ). The drinking water supply for Te Puke township is sourced from secure groundwater including Bayliss bore and Motton Bore, both of which are deep bores located upstream of the WWTP. Tauranga City Council (TCC) have a resource consent to abstract water some few kilometres upstream of the WWTP, however TCC have not given effect to this consent.

In terms of fishing, the human pathogens of concern are not expected to infect fish. Therefore the risks of people who eat the fish being brought into contact with human pathogens will be very low. Cooking is also expected to further reduce this risk.

Shellfish may present a greater health risks due to their feeding habits resulting in higher concentration of waterborne microorganisms. Nevertheless, shellfish is not reported to be harvested in either Waiari Stream or Kaituna River at present. Therefore the threat of infectious disease following consumption of shellfish has not been considered in this public health risk assessment. At the timing of writing this report, a cultural impact assessment (CIA) has not been completed. Pending the findings of the CIA, other food gathering practices within the studied streams may be identified, which may trigger further consideration of the public health risk assessment.

An aquatic plant, watercress, also known as "kowhitiwhiti", is considered a traditional food by Maori. It was not found on site during AECOM's site visit on 30th June, probably because that it is a plant that commonly grows in slow moving streams; and the studied stretches of both Waiari Stream and Kaituna River have relatively high water flow velocities. Nevertheless, it may grow in some of the low-flowing marshy borders of the streams. Pathogens such as *Campylobacter* have been detected on watercress surveyed in Wellington (Edmonds & Hawke, 2004), but not detected in a recent survey undertaken in Hamilton (Donnison et al., 2009). The presence of faecal pathogens within watercress is usually associated with low flowing rural streams affected by pastoral farming, and the level of pathogens found in watercress is likely to be the same as that in the water. The risk is alleviated if the plant is cooked. When consumed raw, thorough washing with clean tap water can reduce the bacterial pathogen level in the leaves significantly (Donnison et al., 2009). Therefore for the purpose of this study, the public health risk associated with watercress consumption is not considered.

As mentioned above, recreational water use has been reported in Kaituna River, including canoeing and kayaking, particularly around the natural reserve area close to the river mouth. Boating may also occur within Waiari Stream. Considering the pathogen load within the treated effluent and potential non-point sources of pathogen from adjacent rural land use, the recreational water use of Kaituna River may pose potential public health risks, which are discussed further below.

3.3 Expected Pathogen Levels within Treated Effluent

Generally good compliance with current consent limits (i.e. post-UV median level of less than 200 cfu/100 mL and post-UV maximum level less than 1000 cfu/100 mL) has been demonstrated due to the satisfactory performance of the UV disinfection. Based on the compliance monitoring records provided by WBOPDC, an average of more than 2-log removal of pathogens (i.e. faecal coliform and enterococci) can be achieved when comparing pre-UV and post-UV measurements.

A detailed description of the faecal coliform analytical results within Te Puke treated effluent can be found in the AECOM report: water quality, stream and terrestrial ecology assessment, and is briefly summarised below in Table 1. Consistently low to moderate faecal coliform levels have been recorded within Waiari Stream, without a distinctive difference observed between downstream and upstream sites. Apart from very occasional high solid carry-over events that may occur at the WWTP, input of faecal coliform from the treated effluent is generally low.

Table 1 Faecal Coliform Monitoring Results Summary (2012-2015)

	Faecal Coliform Level (cfu/100 mL)		
Items	**WWTP Effluent (post UV)**	**Waiari Stream Upstream**	**Waiari Stream Downstream**
Median	12	62	63
Minimum	4	4	8
Maximum	20,400	230	250

This public health risk assessment assumes continuous satisfactory performance of the UV disinfection and that the same resource consent conditions regarding the pathogen discharge remain applicable. Note that due to the questionable performance of the wetland, this assessment does not consider any additional attenuation of pathogens within the wetland.

3.4 Dilution within Waiari Stream and Kaituna River

The flow records for Waiari stream for 2014 was provided by NIWA (attached as Appendix A) which was collected at Te Puke. The typical flow range for Waiari stream varies from 3500 L/s (5%ile) to 4400 L/s (95%ile). The minimum and maximum flow recorded in 2014 was 3399 L/s and 83270 L/s, respectively. For the purpose of the public health risk assessment, only the low flow condition of Waiari Stream (3500 L/s, 5%ile) was considered to provide a conservative assessment. Daily flow gauge data for Kaituna River at Te Matai were provided by BOPRC from 1986 to 2014. It was shown that from 2010 to 2014, the flow rate within Kaituna River ranges from approximately 25 m^3/s to 65 m^3/s with a maximum of 181 m^3/s. For the purpose of this assessment, the minimum flow (5%ile) level of 25 m^3/s was applied.

Based on the expected pathogen level within the treated effluent, and the low flow regime selected for the receiving water bodies (Waiari Stream and Kaituna River), a conservative estimate of the likely pathogen concentrations within the Waiari Stream and Kaituna River can be calculated and shown in Table 2 below. These calculations assume a dilution of approximately 166 -168 times within Waiari Stream and present only the pathogen contributions from the WWTP effluent, without any consideration of other background input from the wider catchment as mentioned in Section 3.1.

Table 2 Potential Dilution of Pathogens within Waiari Stream and Kaituna River

	Treated Effluent (current)	Treated Effluent (2051)	Waiari Stream[1] (current)	Waiari Stream[1] (2051)	Kaituna River[2] (current)	Kaituna River[2] (2051)
Average Flow	1800 m^3/d (20.8 L/s)	2348 m^3/d (27 L/s)	-	-	-	-
Minimum Flow*	-	-	3500 L/s		25,000 L/s	
Faecal Coliform (median)	200 cfu/100 mL	200 cfu/100 mL	1.2 cfu/100 mL	1.5 cfu/100 mL	0.16 cfu/100 mL	0.22 cfu/100 mL
Faecal Coliform (maximum)	1000 cfu/100 mL	1000 cfu/100 mL	6 cfu/100 mL	7.7 cfu/100 mL	0.8 cfu/100 mL	1.1 cfu/100 mL
E. Coli[§] (median)	126 cfu/100 mL	126 cfu/100 mL	0.75 cfu/100 mL	0.97 cfu/100 mL	0.10 cfu/100 mL	0.14 cfu/100 mL
E. Coli[§] (maximum)	630 cfu/100 mL	630 cfu/100 mL	3.74 cfu/100 mL	4.86 cfu/100 mL	0.52 cfu/100 mL	0.68 cfu/100 mL
Enterococci[§] (median)	35 cfu/100 mL	35 cfu/100 mL	0.21 cfu/100 mL	0.27 cfu/100 mL	0.03 cfu/100 mL	0.04 cfu/100 mL
Enterococci[§] (maximum)	175 cfu/100 mL	175 cfu/100 mL	1.04 cfu/100 mL	1.35 cfu/100 mL	0.15 cfu/100 mL	0.19 cfu/100 mL

Note: *: Minimum flow was calculated as 5%ile flow from the flow gauge.

§: Assuming 126 E. coli or 35 enterococci per 200 faecal coliforms (MfE 2003).

1: Based on 2014 flow records from NIWA.

2: Based on flow records provided by BOPRC from 2010 to 2014.

3.5 Qualifying Public Health Risks Associated with WWTP Effluent Discharge

Table 3 outlines the microbial assessment category (MAC) and various action mode levels identified in the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MfE 2003). The current and future (2051) levels of E. coli and Enterococci based on the existing consent conditions are shown in Table 2 above. Note that this estimate does not consider any other potential pathogen input within the wider catchment.

Due to the expected dilution factors that can be achieved when treated effluent reaches Waiari stream and subsequently Kaituna River, the E. coli or enterococci levels within the receiving water bodies were estimated to be reasonably low. For instance, when the E. Coli concentration reaches 630 cfu/100 mL in 2051 (maximum level allowed by the current consent), the resulting concentration of E. coli within Waiari Stream immediately after discharge is calculated to be slightly less than 5 cfu/100 mL, which will be further diluted to below 1 cfu/100 mL when the effluent reaches Kaituna River. Without consideration of other potential pathogen input within the wider catchment, this level of E. coli may be considered to be very good in terms of suitability for recreational water use for freshwater. No significant risk for public health is expected, should the public be in direct contact with the aquatic environment.

Table 3 Microbiological Assessment Categories and Relevant Levels for Marine and Freshwater

Items	Marine Water	Fresh Water
Bacteriological Indicators	Enterococci	*E. coli*
Microbiological Assessment Category (MAC)	a) Sample 95 percentile ≤ 40 enterococci/100 mL b) Sample 95 percentile 41–200 enterococci/100 mL c) Sample 95 percentile 201–500 enterococci/100 mL d) Sample 95 percentile > 500 enterococci/100 mL	a) Sample 95 percentile ≤ 130 E. coli per 100 mL b) Sample 95 percentile 131–260 E. coli per 100 mL c) Sample 95 percentile 261–550 E. coli per 100 mL d) Sample 95 percentile >550 E. coli per 100 mL
Acceptable/Green Mode	No single sample greater than 140 enterococci/100 mL	No single sample greater than 260 *E. coli*/100 mL
Alert/Amber Mode	Single sample greater than 140 enterococci/100 mL	Single sample greater than 260 *E. coli*/100 mL
Action/Red Mode	Two consecutive single sample greater than 280 enterococci/100 mL	Single sample greater than 550 *E. coli*/100 mL

The estimates presented in Table 2 should be considered relatively conservative due to the following reasons:

- Only direct dilution is allowed in the calculation, without any consideration of other potential pathogen attenuation routes such as natural die-off, sedimentation, adsorption, and diffusion of the pathogens as they travel along the natural waterway.
- Only low flow conditions of the Waiari stream and Kaituna River have been allowed in the calculation. For 95% of the time, the waiari stream and Kaituna river flow rates are expected to be higher than the figures used in the calculation. This will provide a much higher dilution factor than what was applied, which would further reduce any potential public health risks associated with the treated effluent discharge, if any.
- This assessment was based on the current consent limits for pathogens, which have been generally complied with based on historic compliance monitoring results. The pathogen level within the treated effluent was usually at a much lower level than the consent limit, providing additional margin of safety in protecting human health downstream of the discharge.

As mentioned above, this assessment does not allow any potential pathogen attenuation or addition within the wetland before the treated effluent reaches Waiari Stream. Previous monitoring results showed a general increase of pathogens when the disinfected effluent flows through the existing wetland. The under-performance of the wetland has been confirmed and it was recommended that the wetland be decommissioned or by-passed as a short-term solution (Refer to AECOM Report: Te Puke WWTP – Process Performance Review dated September 2015).

4.0 Quantitative Microbial Risk Assessment

4.1 Overview

Quantitative Microbial Risk Assessment (QMRA) can be defined as a quantitative characterisation and estimation of potential adverse health effects associated with exposure of individuals or populations to microbial hazards (Haas *et al.* 1999). Following a series of historic studies and reports on risk assessment by the National Academy of Sciences (1983), the four sequential components as identified in the risk assessment paradigm for human health effects are as follows:

1) Hazard identification
   - To describe acute and chronic human health effects associated with any particular hazard.
2) Dose-response assessment
   - To characterise the relationship between various doses administered and the incidence of the health effects.
3) Exposure assessment
   - To determine the size and nature of the population exposed and the route, amount, and duration of the exposure.
4) Risk characterisation
   - To integrate the information from exposure, dose-response, and health steps in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty.

The methodology applied in this study follows the risk assessment paradigm above, with the detailed approaches and assumptions described in the following sections.

4.2 Hazard Identification

There is a long list of waterborne microbial pathogens that may pose public health hazards, with particular hazards identified to be viruses. For instance, for contact recreation, adenovirus, rotavirus, enterovirus have been highlighted to be significant; whilst for raw shellfish consumption, hepatitis A, rotavirus, and enterovirus are identified to pose high risks.

For the purpose of this study, rotavirus was used as the representative hazard for the following reasons:

- It has been widely detected in both raw and treated domestic wastewater (Patrinca *et al.* 2009; Carducci *et al.* 2009; Curtis *et al.* 1987; Gerba *et al.* 1996).
- It is highly infectious, and would be of concern were children to be affected.
- There are good clinical trial data to support relatively reliable dose-response relationship (Haas *et al.* 1993; Ward *et al.* 1986).
- It has been widely applied in other QMRA studies within NZ and across the world (Gerba *et al.* 1996; McBride et al 2005; Stott and McBride 2008; Palliser 2011).

4.3 Dose-Response Assessment

The dose-response curve for rotavirus has been established by Ward *et al.* (1986), summarised by Haas *et al.* (1999), and adopted by others (WHO 2008). Based on the clinical test results of subsets of volunteers with known mean doses of rotavirus, the dose-infection curve was established by fitting the data with a Beta-Poisson dose-response model.

The general equation describing the Beta-Poisson dose-response model is given below in Equation 4-1:

$$\boldsymbol{P_i(d) = 1 - \left(1 + \frac{d}{\beta}\right)^{-\alpha}} \qquad \textbf{Equation 4-1}$$

Where

$$P_i = Probability\ of\ Infection$$

$$d = mean\ dose$$

$$\alpha = a\ nonnegetive\ shape\ factor$$

$$\beta = location\ parameter$$

As shown in the solid line in Figure 1, the Beta-Poisson model appears to be relatively shallower when compared to an exponential model. This indicates that some people are notably more susceptible to infection than others. The “bend over” after the median infective dose reflects the observation that some people are especially resistant to this virus. When α, the shape factor, approaches infinity (∞); the Beta-Poisson model approaches the exponential model, which indicates that each organism has an independent and identical survival probability in any host.

This is considered as an appropriate dose-response relationship when a population are given known mean doses of the virus. In this study, however, each individual may be exposed to a none-random dose of the virus arising from the WWTP effluent discharge; therefore a Beta-Binomial curve of conditional dose-response relationship shall be applied (McBride 2005). This relationship is given in Equation 4-2 below and illustrated as the dash line in Figure 1.

$$\boldsymbol{P_i(i) = 1 - \frac{B(\alpha,\beta+i)}{B(\alpha,\beta)}}$$ **Equation 4-2**

Where

$$P_i(i) = Probability\ of\ Infection$$

$$i = individual\ dose$$

$$\boldsymbol{B(\alpha,\beta)}^{1} = \int_0^1 x^{\alpha-1}(1-x)^{\beta-1}dx = \frac{\Gamma(\alpha)\,\Gamma(\beta)}{\Gamma(\alpha+\beta)}$$ **Equation 4-3**

As shown in Figure 1, adopting the conditional dose-response curve for a single individual on each exposure occasion will result in higher risks compared to the mean dose curve, hence providing a more conservative approach. This is the dose-response curve applied in this study.

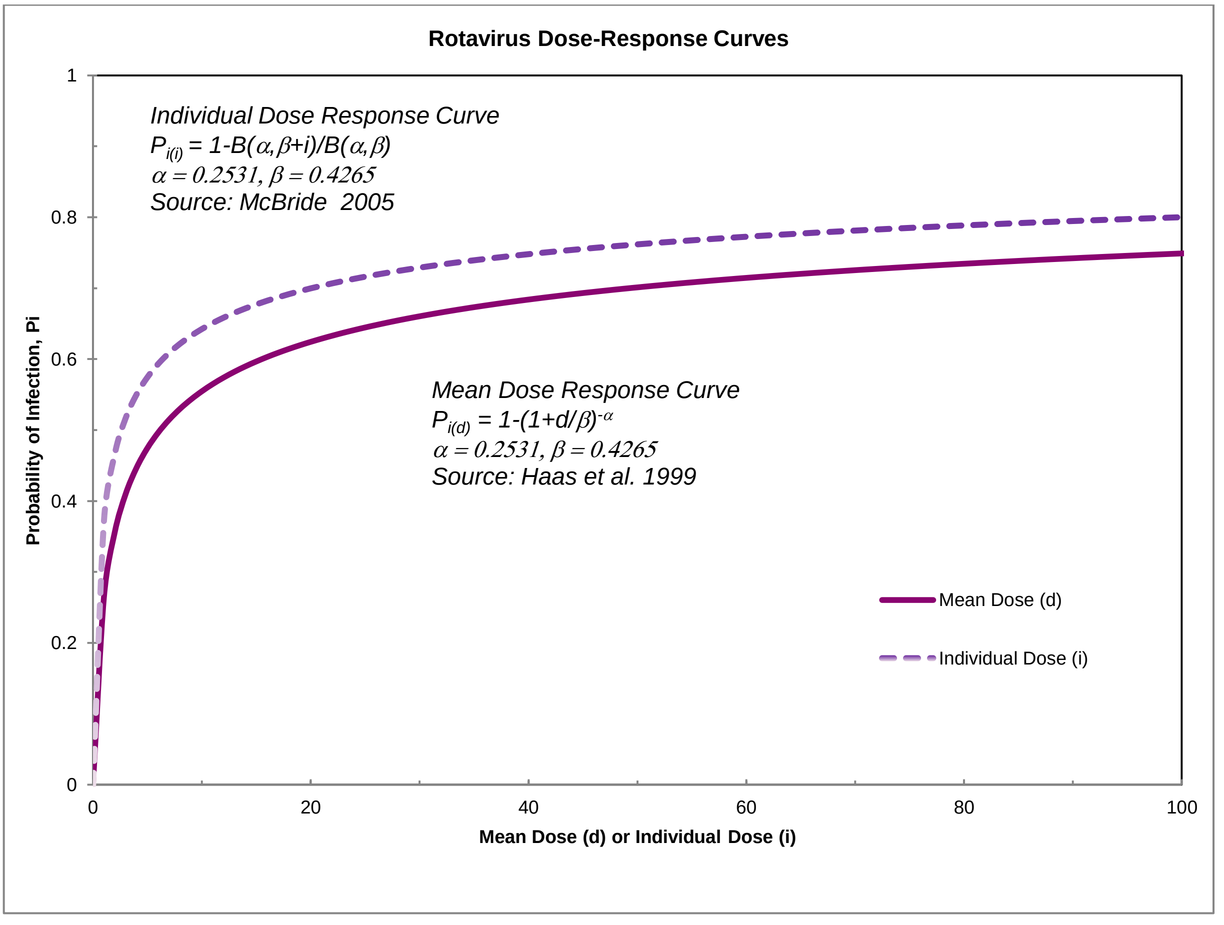

Figure 1 **Comparison of the Beta-Poisson mean dose-response model with the Beta-Binomial conditional dose-response model for Rotavirus**

[1] B (α,β) is a Beta function, which can be solved using a Gamma function, as shown in Equation 4-3.

4.4 Exposure Assessment

The level of exposure is dependent on a variety of factors:

- Recreational use profiles by the community along Waiari Stream and Kaituna River downstream of WWTP dsicharge (no mahinga kai consumption such as fish, eel, shellfish, or watercress is considered in this QMRA as discussed in Section 3.2). Recreational water use such as swimming is focused in this study because it is considered to pose the highest risk compared to other exposure routes.
- The range of virus concentrations in the influent sewage delivered to Te Puke WWTP. This may include an extreme virus inflow concentration measured within the region as a worst-case scenario, possibly indicating a rotavirus outbreak in the community.
- The efficacy of the WWTP in virus removal. This refers to the removal efficiency throughout the whole plant including secondary treatment process, and the UV disinfection chamber.
- The dilution and inactivation (if any) of the virus in the receiving waters while being transported to the Waiari Stream and eventually within Kaituna River.

The detailed discussion of the factors above are summarised in the following sections. A complete summary of all the factors including all major assumptions/rules and distribution patterns applied in this study is provided in Section 4.4.5.

4.4.1 WWTP Effluent Discharge Location, Sites of Interest, and Community Use of the Receiving Water

The Te Puke WWTP effluent from the UV disinfection chamber is gravity discharged continuously (24/7) via a riparian wetland along the Waiari Stream. Boating, kayaking, are among the most popular recreational activities occurring along the Kaituna River, and to a lesser extent, may occur within Waiari stream as well. Swimming or other kinds of activities that involve immersion in the water may also occur in the studied waterbodies, although not officially reported. Based on the discussion presented in Section 3.2, recreational water use is considered as the paramount exposure route from a public health perspective.

The recreational contact of the water can be described by the duration of a swim, multiplied by the likely ingestion/inhalation rate during the swim. The surface water ingestion/inhalation rate during swimming was determined to be approximately 50 ml/hr by USEPA (1989). In this study, the distribution of swim duration and water ingestion/inhalation rates during swimming were set up following the previous methodology adopted by McBride *et al.* (2005). A summary of the key parameters and their specific distribution functions applied in this QMRA is presented in Section 4.4.5.

No specific sites of interest have been identified for the purpose of this study, as the main recreational water use of the water bodies (e.g. kayaking or occasional swimming, etc.) is not restricted to isolated locations. Considering the nature of continuous wastewater discharge, it is assumed that wastewater plume can be completely mixed within the receiving waters (Waiari Stream and subsequently Kaituna River) within a relatively short period of time, and no pathogen level difference is considered along the whole stretch of the receiving water bodies. Further discussion of the dilution capacity calculations is presented in Section 4.4.4.

4.4.2 Wastewater Flows and Rotavirus in Raw Wastewater

4.4.2.1 Wastewater Flows

Annual daily average wastewater flow into the WWTP has been relatively stable on an average of approximately 1800 m^3/day over the past few years, with occasional spikes of peak flows reaching up to 3000 m^3/day as discussed in AECOM Report: Te Puke WWTP Process and Operation Review. The flow pattern shows a relatively weak correlation with rainfall records, without any obvious seasonal trend. The peak inflows rarely reached above 4000 m^3/day, which indicated a very low observed peaking factor. The current daily flow measurements can be fitted with a standard negative binomial distribution function as illustrated in Figure 2 below. Based on the Smart Growth WBOPDC population projection, projected annual average flow in 2051 is expected to be approximately 2348 m^3/day. The distribution pattern is however assumed to be the same as the current.

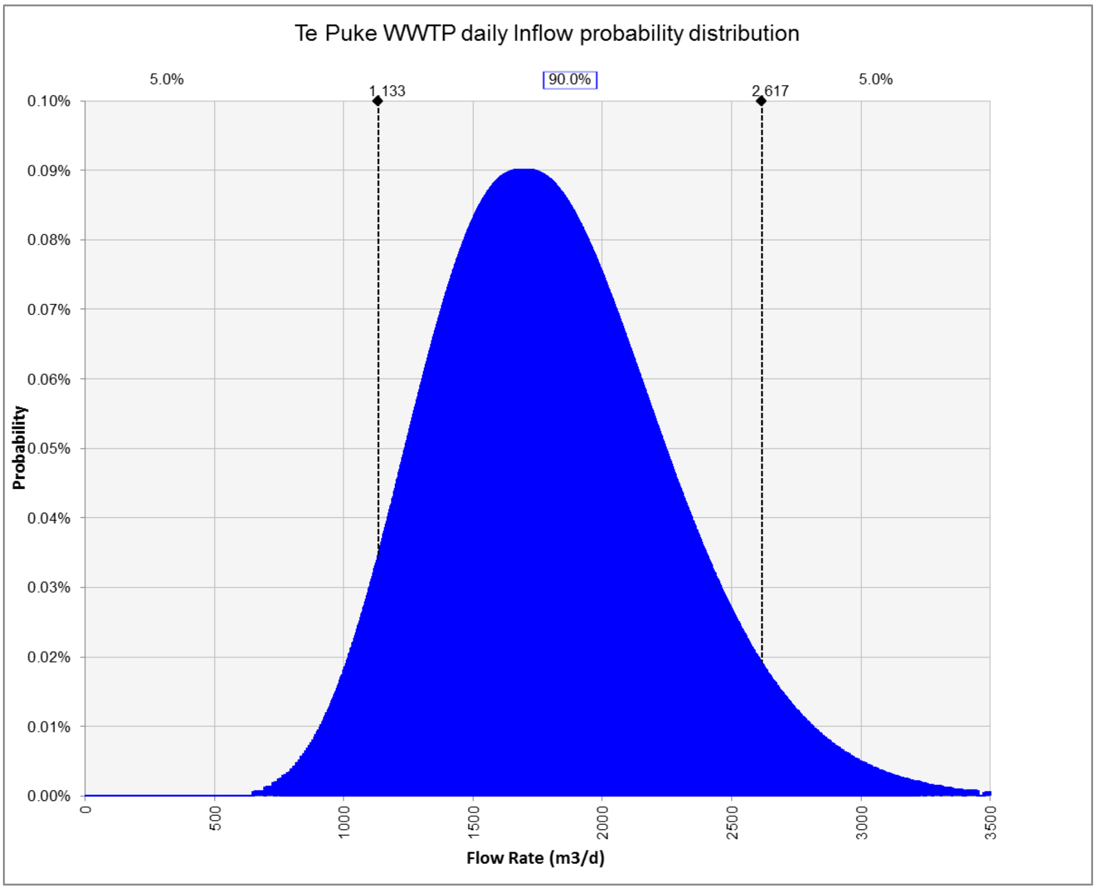

Figure 2 **Best-fitted distribution pattern for daily wastewater inflow rate based on observed records at Te Puke WWTP**

4.4.2.2 Rotavirus in Raw Sewage

Limited studies have been conducted regarding the occurrences of rotavirus in raw wastewater within New Zealand. This is largely due to the relatively high cost of viral monitoring with current analytical capabilities. Consequently, previous QMRA work has adopted international rotavirus occurrence study results or used limited NZ occurrence data for other viruses. This is the approach taken for this study as well.

According to a study conducted in the US, the raw sewage rotavirus concentrations ranged from 14 particles/L to 2980 particles/L, with an average of 443 particles/L (Rao *et al.* 1987). Therefore, it may be appropriate to apply an empirical triangular distribution for rotavirus concentrations in the raw sewage, with the minimum set at 10 particles/L, the median at 500 particles/L, and the maximum at 3000 particles/L. However, occurrences of rotavirus in raw sewage can show significant geographical and temporal variety. Some studies showed that rotavirus concentrations in raw wastewater can vary from below 1 particle/L to 650,000 particles/L among various WWTPs from different countries (Gerba *et al.* 1996). An investigation on pathogens in the raw sewage flowing into Mangere WWTP showed that the concentrations of culturable human enteric viruses (including enteroviruses, hepatitis A virus, calicivirus, rotavirus, adenovirus and astrovirus) in Mangere WWTP influent were typically 10 times higher than those found in the US, and can be 1000 times higher under certain circumstances (Simpson *et al.* 2003). For instance, the 90 percentile of adenovirus occurrences was found to be 10,000 $TCID_{50}$[2]/L during normal circumstances, and this figure can sometimes increase up to 3 x10^6 $TCID_{50}$/L (Simpson *et al.* 2003). For the purpose of this study, an empirical triangular distribution of (100, 5000, 30,000) was applied to represent the occurrences of rotavirus in the raw wastewater. This is 10 times higher than the rotavirus concentrations used in other QMRA work previously completed (Stott and McBride 2008; McBride *et al.* 2005; Palliser 2011), providing a relatively more conservative approach. In addition, a rotavirus concentration of 3 x 10^6 particles/L was used to model the extreme scenarios (*i.e*. there is a rotavirus outbreak within the community). This is 1000 times higher

[2] $TCID_{50}$: Median tissue culture infective dose; the amount of a pathogenic agent that will produce pathological change in 50% of cell cultures inoculated. It may be estimated that 1 $TCID_{50}$/ml produces approximately 0.7 PFU/ml. The difference between $TCID_{50}$ and PFU is not considered in this study.

than the high end of rotavirus concentration range found in the US, and close to the 90 percentile of adenovirus concentrations found in Mangere WWTP during a short monitoring period (Simpson *et al*. 2003).

It shall be noted that the rotavirus survey data for Mangere WWTP may not be representative of Te Puke WWTP, which serves a much smaller and less diverse community. Due to the general lack of rotavirus occurrence data within NZ, particularly for smaller communities, the adopted rotavirus concentration profile for this study was in line with the Mangere WWTP survey results and is considered conservative.

4.4.3 Rotavirus Removal by the WWTP Processes

4.4.3.1 Reduction of Rotavirus by the Secondary Treatment

Current secondary treatment processes applied in the Te Puke WWTP have been shown to be highly effective in removing various pathogens, especially some indicator microorganisms such as Faecal Coliforms (FC). As commonly observed in other WWTPs across NZ and around the world, a consistent log-reduction of between 2.5 and 2.8 for these microbial indicators can be typically achieved through secondary treatment (Jacangelo *et al.* 2003, Carducci *et al.* 2009). However, the presence of faecal indicators is not usually predictive of the presence of enteric viruses (Petrinca *et al.* 2009; Simpson *et al.* 2003). The removal rates for these microbial indicators cannot be readily applied for viral removal (Carducci *et al.* 2009).

Some researchers have applied a 4-log viral reduction throughout the WWTP processes including both secondary treatment and UV disinfection (Palliser 2011). A recently conducted investigation on viral removal in a WWTP in Auckland region suggested a relatively low log-removal rate for adenovirus at approximately 2.9-log (Stott 2012). An extensive monitoring programme completed in the Mangere WWTP revealed an average enteric viruses (*i.e*. adenovirus and enterovirus) removal rate of 2-log, ranging from 1.5-log to 2.5-log. For this study, we have assumed a normal distribution on the viral reduction rate through the secondary treatment only, with a mean survival rate value of 0.01 (corresponding to a 2-log reduction) and a standard deviation of 0.005 (in survival rate, corresponding to approximately ±0.25-log reduction).

4.4.3.2 Viral Reduction by UV Disinfection

A UV disinfection process (Trojan UV3000Plus) is currently applied at Te Puke WWTP for the post-treatment of effluent from the tertiary brush filter, as means of improving the overall efficiency in pathogen removal.

Very effective pathogen removal has been demonstrated at Te Puke WWTP, based on the provided compliance monitoring record. Up to 3-log removal has been often achieved when comparing the pre-UV and post-UV faecal coliform analytical data. For the purpose of this study, a distribution of log inactivation from 1 to 3-log was adopted. This was based on general observation of UV disinfection of secondary effluent and the local records at Te Puke WWTP. Specifically, a versatile Project Evaluation and Review Techniques (PERT) distribution: PERT(0.001, 0.01, 0.1) was used to describe the rotavirus survival rate distribution through the UV disinfection system. This corresponds to 1 to 3-log reduction with 2-log as the most likely reduction rate.

4.4.4 Virus Reduction by Dilution at the Waiari Stream and Kaitua River

The estimation of viral concentration derived from the WWTP within the receiving water bodies including Waiari Stream and Kaituna River is based on direct dilution calculation from the effluent flow rate and the receiving waterbodies' flow rates. The distribution pattern of the treated effluent flow rate is demonstrated in Figure 2 above. The relevant flow patterns for Waiari Stream and Kaituna River were derived based on the flow gauge records provided to AECOM, and are shown below in Figure 3 and Figure 4, respectively.

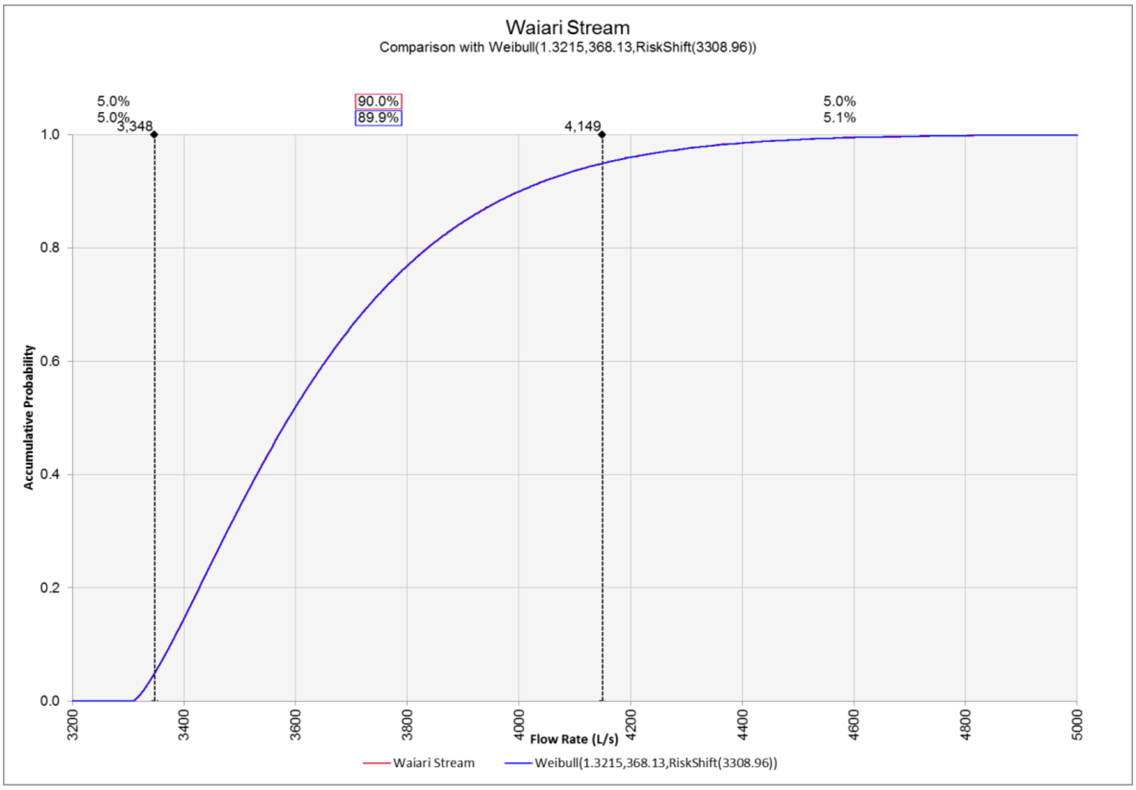

Figure 3 Fitted flow rate distribution graph for Waiari Stream based on flow gauge records

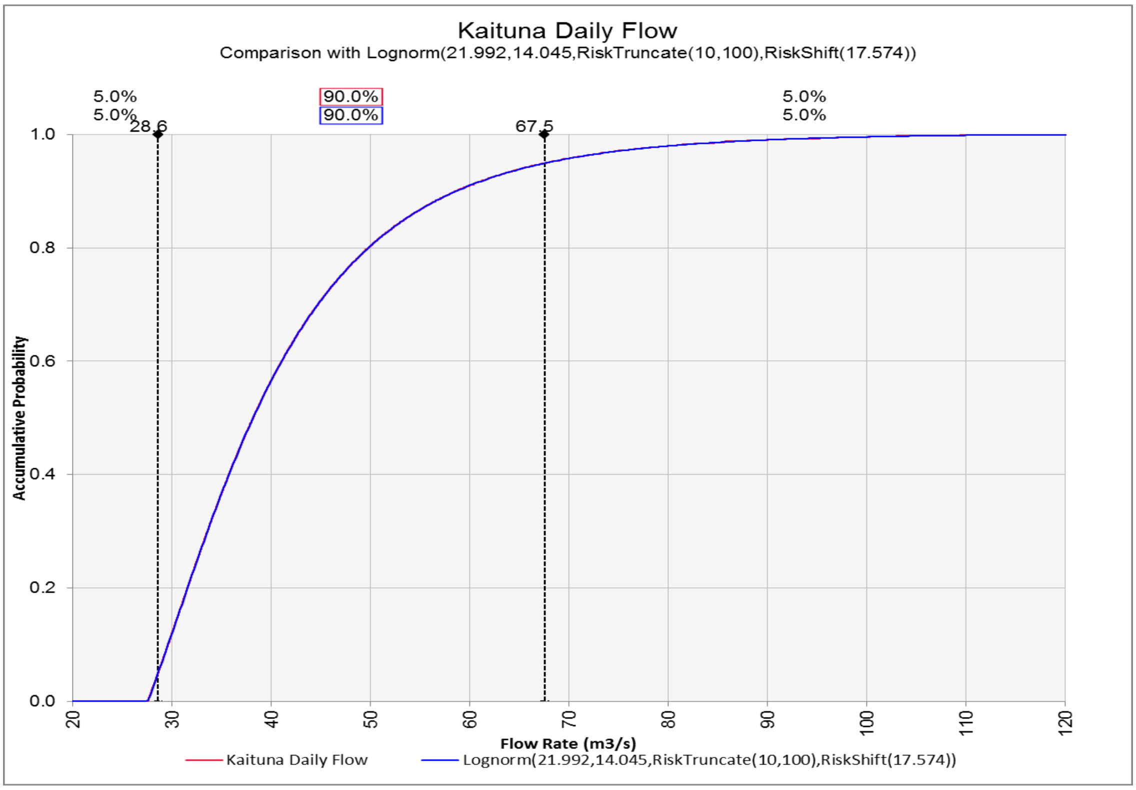

Figure 4 Fitted flow rate distribution graph for Kaituna River based on flow gauge records

For the purpose of this QMRA simulation, a random sampling of flow rates for the treated effluent, Waiari stream, and Kaituna River was undertaken by the QMRA model using a Monte Carlo method. The values of these randomly generated flow rates are always in agreement with the corresponding distribution patterns as observed from the actual records. This allows generating a random series of dilution factors within Waiari Stream and Kaituna River. This is more suitable for producing a realistic concentration profile of the Rotavirus within both Waiari Stream and Kaituna River, when compared to the conservative estimations presented in Section 3. As shown in Figure 5 and Figure 6, the dilution factors within Waiari Stream and Kaituna River follow patterns that can be described with suitable distribution functions.

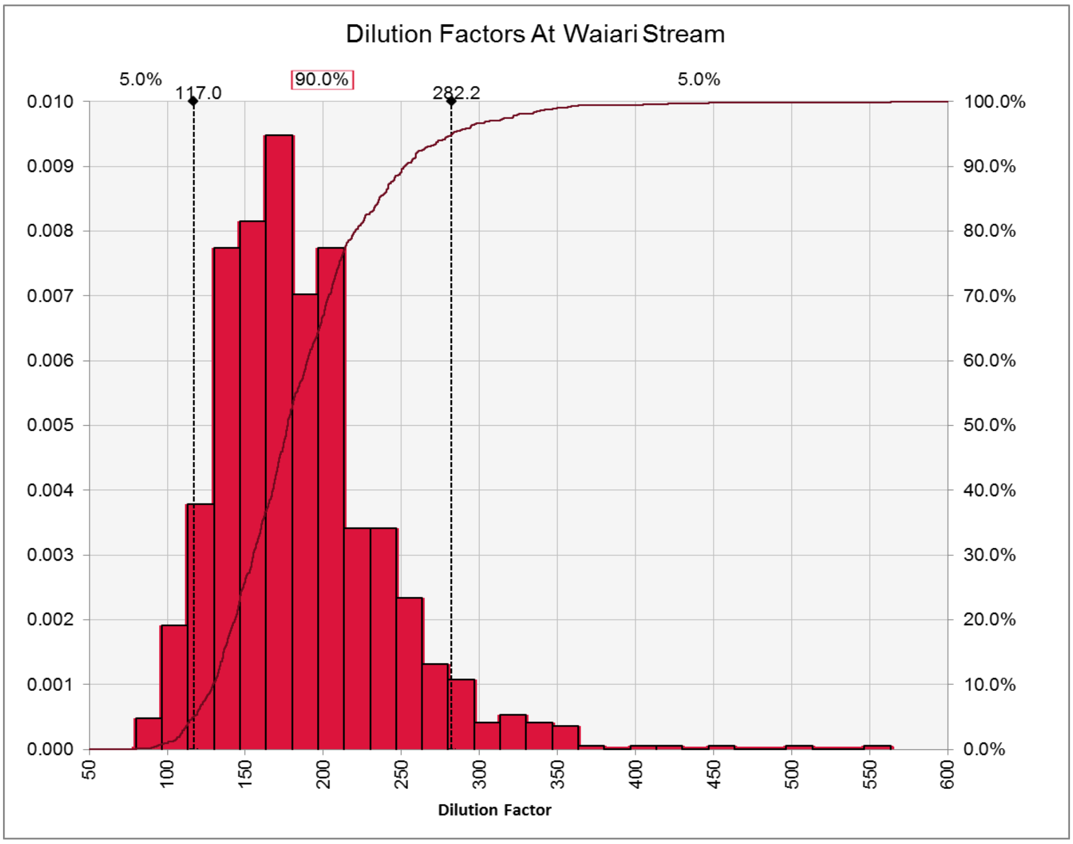

Figure 5 **Fitted distribution pattern for the dilution factor within Waiari Stream**

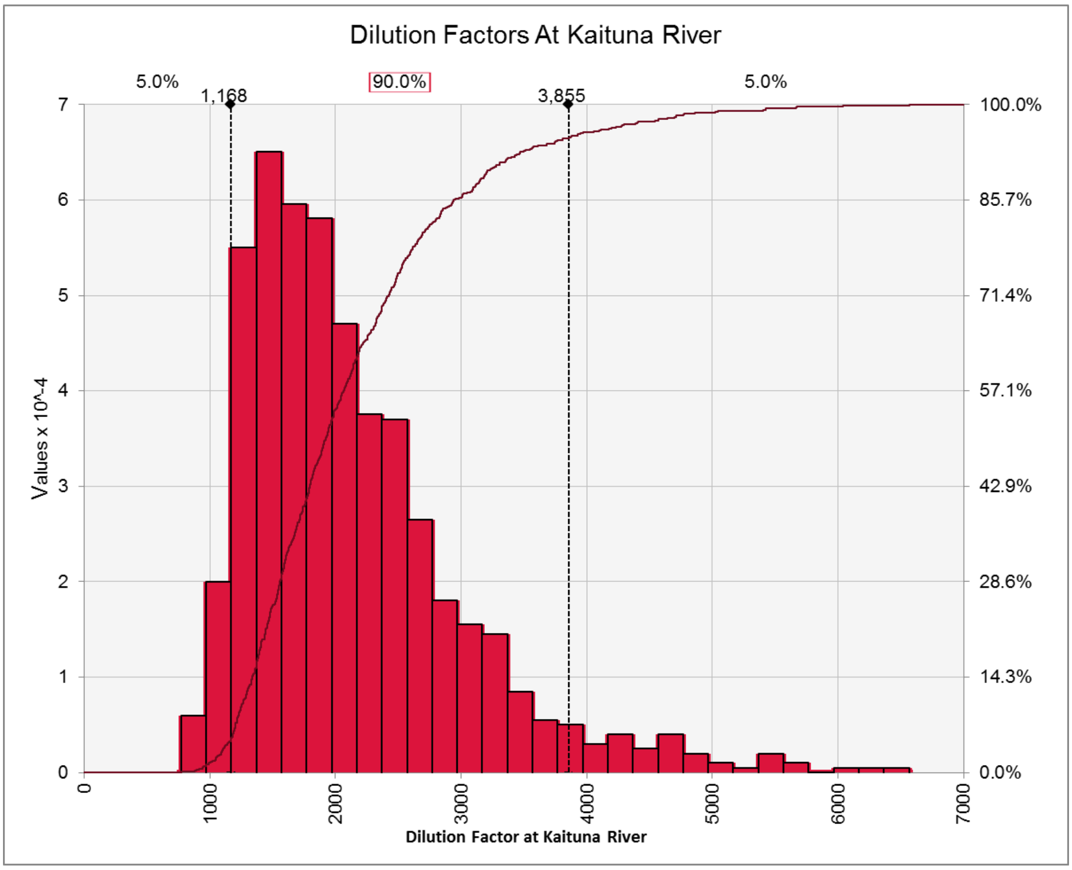

Figure 6 Fitted distribution pattern for the dilution factor within Kaituna River

4.4.5 Summary of the parameter settings

The distribution details applied for the key parameters for the risk assessment are summarised in Table 4.

Table 4 Summary of parameter settings applied in the QMRA modelling

Parameters	Settings	Comments
Influent Rotavirus Concentration (particles/L)	Minimum = 100, Median = 5,000, Maximum = 30,000	Triangular distribution (refer Section 4.4.2.2)
Rotavirus survival rate through secondary treatment	Mean = 0.01, SDEV = 0.005	Normal Distribution (refer Section 4.4.3.1)
Rotavirus survival rate through UV disinfection of the pond effluent	Minimum = 0.001, Mode = 0.01, Maximum = 0.1	PERT Distribution (refer Section 4.4.3.2)
Te Puke wastewater flow rate	Mean = 1810.55 m3/d	NegBin (16, 0.0087597)
Waiari Stream flow rate	Mean = 3647.86 L/s; Minimum = 3309L/s	Weibull (1.3215, 368.13) Shift= 3308.96
Kaituna River flow rate	Minimum = 27.574 m3/s Maximum = 117.574 m3/s Mean = 41.794 m3/s	Lognorm (21.992, 14.045); Truncate (10, 100); Shift = 17.574
Duration of Swim (hr)	Minimum = 0.25, Mode = 0.5, Maximum = 2	Refer Section 4.4.1
Ingestion/Inhalation Rate (ml/hr)	Minimum = 10, Mode = 50, Maximum = 100	Refer Section 4.4.1

4.5 Risk Characterisation

For the purpose of this study, risk profiles are generated by assuming exposure of a group of 100 people during 1000 visits to the waterways for recreational use, across a whole year, without any knowledge of any water contamination situation. Therefore the total number of exposures is 10^5. During each of these exposures, random statistical samplings of the variables within their defined distribution patterns (summarised in Section 4.4.5) were accomplished by Monte Carlo simulation using @Risk software (Palisade, NY).

Based on the calculated risk profiles of these simulations, the individual's infection risk (IIR) can be calculated as the total number of infection cases divided by the total number of exposures. It needs to be mentioned that only a portion of the infection leads to actual illness; and only a portion of illness cases lead to death, as illustrated in Equation 4-4:

$$\boldsymbol{P_i \rightarrow P_{D:i} \rightarrow P_{m:d}}$$ **Equation 4-4**

Information on the illness/infection ratio for human rotavirus infection is limited. A disease/infection ratio of 0.05 was applied in the *Numerical Guide to Volume 2 of the Guidelines and Practical Advice on How to Transpose Them into National Standards: Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture* (WHO 2007). An epidemiology study conducted on the Great Lakes in the US showed that the percentage of infections resulting in gastrointestinal illness from ingestion of rotavirus was approximately 35% (Soller *et al.* 2010). In this study, an illness/infection ratio of 0.35 was applied, which was also adopted by other previous QMRA work (Stott and McBride, 2005; Palliser 2011).

Two major WWTP operation scenarios were considered in this study:

- Scenario A: Normal viral load with normal operation
- Scenario B: Extreme viral load in raw sewage due to rotavirus outbreak within the community and normal WWTP operation

Note that this study does not consider the potential impact on public health by other types of pathogens such as bacteria and protozoa. In addition, this QMRA does not include other potential pathogen sources into the receiving water bodies that may pose public health risks. These may include agricultural runoff and other potential pathogen input from grazing animals and waterfowl.

4.6 QMRA Modelling Results

As mentioned above, the recreational water use of the Waiari Stream or Kaituna River by local community may occur almost all year around and potentially high during summer season. Therefor the target of this QMRA work is to provide an estimate of potential public health risks for recreational water users of these waterways.

4.6.1 Probability of Infection and Relative Frequency

The results of the 1000 simulations (representing 1000 visits for a group of 100 people) as described in Section 4.5, including the probability of infection for all water users for all modelled scenarios are provided in Appendix B, along with the accumulative distribution curves, sensitivity analysis and statistical summaries. The statistical summary of infection probabilities for recreational users in Scenario A (normal viral load) is shown in Table 5. The 95 percentile values (*i.e.* below which 95% of observations fall) of infection probability for all modelled scenarios are shown in Table 6.

Table 5 Statistical Summary of Infection Probability for Recreational Users (Scenario A: Normal Viral Load)

Percentile	Waiari Stream (current)	Waiari Stream (2051	Kaituna River (Current)	Kaituna River (2051)
5%ile	0.0000	0.0000	0.0000	0.0000
10%ile	0.0001	0.0001	0.0000	0.0000
15%ile	0.0001	0.0001	0.0000	0.0000
20%ile	0.0001	0.0002	0.0000	0.0000
25%ile	0.0002	0.0002	0.0000	0.0000
30%ile	0.0002	0.0003	0.0000	0.0000
35%ile	0.0002	0.0003	0.0000	0.0000

Percentile	Waiari Stream (current)	Waiari Stream (2051	Kaituna River (Current)	Kaituna River (2051)
40%ile	0.0003	0.0004	0.0000	0.0000
45%ile	0.0004	0.0005	0.0000	0.0000
50%ile	0.0004	0.0005	0.0000	0.0001
55%ile	0.0005	0.0006	0.0000	0.0001
60%ile	0.0006	0.0007	0.0001	0.0001
65%ile	0.0007	0.0009	0.0001	0.0001
70%ile	0.0008	0.0011	0.0001	0.0001
75%ile	0.0010	0.0013	0.0001	0.0001
80%ile	0.0013	0.0016	0.0001	0.0002
85%ile	0.0016	0.0020	0.0002	0.0002
90%ile	0.0021	0.0028	0.0002	0.0003
95%ile	0.0033	0.0046	0.0003	0.0004
Minimum	0.0000	0.0000	0.0000	0.0000
Maximum	0.0208	0.0128	0.0022	0.0022
Mean	0.0009	0.0011	0.0001	0.0001

Table 6 95 Percentile Values of Infection Probability (As Percentage) under Various Modelled Scenarios

Site	Scenario A: Normal Viral Load		Scenario B: Extreme Viral Load	
	Current	2051	Current	2051
Waiari Stream	0.33%	0.46%	31.91%	34.80%
Kaituna River	0.03%	0.04%	6.07%	7.16%

The infection probability represents the likelihood of infection cases among 100 people in a random visit to the studied waterway (being Waiari Stream and Kaituna River). The infection probability for recreational water users was found to be generally low, as long as the viral load in the raw sewage is normal. The 95 percentile probability values for recreational users were found to be below 0.5% for Waiari Stream and below 0.05% for Kaituna River, when rotavirus load in the influent was normal. This means that for 95% of the time, less than 1 person out of a group of 100 people is expected to be infected by rotavirus on a random visit to swim in the investigated streams.

When there is a Rotavirus outbreak within the community, the estimated infection probability arising from recreational water contact can be elevated significantly, reaching to approximately 32-35% for swimming in Waiari Stream and approximately 6-7% for recreational use of Kaituna River. This may trigger a health risk notification or other applicable communication measures from local district health board to prevent public recreational water contact.

4.6.2 Individual Infection Rate (IIR)

The Individual Infection Risks (IIRs) are calculated by dividing the total number of infection cases by the total number of exposures. This represents the possibility (or risk) of any individual to contract rotavirus on any random visit to the waterways. The total number of exposures as described previously was 10^5, and the IIRs were expressed as percentages as shown in Table 7. The individual Gastrointestinal (GI) Illness Risk was calculated by introducing the stoichiometric coefficient of 0.35 as the illness/infection ratio, indicating that approximately 35% of infection cases will lead to actual diseases.

Following the guidelines established by WHO (2001), MfE and MoH (2003) set the guideline values for microbiological quality of recreational marine waters based on estimated GI illness[3] risks or AFRI[4] risks. For instance, 40 faecal streptococci/100 ml as 95%ile value is considered below the NOAEL[5] in most epidemiological studies, due to the estimated risk being below 1% for GI illness or below 0.3% for AFRI. Not adequate information is available for freshwater due to limited epidemiological studies undertaken. Based on a quantitative risk assessment for *Campylobacter* infection in NZ, 130 *E. coli*/100mL as 95%ile value is considered equivalent to a 0.1% occurrence of *Campylobacte*r infection. This is considered as a no-calculated-risk level (NCRL) in the current MfE's microbiological guideline for recreational fresh water. For the purpose of this study, the calculated Individual Infection Risks (IIRs) were compared to the 0.1 % infection occurrence risk and the estimated GI illness risks were compared to the 1% GI illness risk.

As shown in Table 7, the IIRs for recreational water users were all found to be below 0.1% when the rotavirus load in raw sewage is normal. And the GI illness risks were found to be below 1% for recreational users for all year around. This indicates that the gastrointestinal illness risk posed by the rotavirus associated with the treated WWTP effluent is considered no more than minor within the studied waterways. This estimate excludes the scenario when there is a rotavirus outbreak within the community. As the rotavirus load in the raw sewage increases, the IIR for the recreational water users of Waiari Stream increases up to 0.4-0.6%, although the gastrointestinal illness risk is still calculated to be below 1% for both Waiari Stream and Kaituna River.

Table 7 Summaries of Individual Infection Risks and Individual Illness Risks under Various Modelled Scenarios

Site	Rates	Scenario A: Normal Viral Load		Scenario B: Extreme Viral Load	
		Current	2051	Current	2051
Waiari Stream	Individual Infection Risk (%)	0.0128	0.0208	0.4681	0.5629
	GI Illness Risk (%)	0.0045	0.0073	0.1638	0.1970
Kaituna River	Individual Infection Risk (%)	0.0022	0.0022	0.2015	0.2500
	GI Illness Risk (%)	0.0008	0.0008	0.0705	0.0875

4.7 Other considerations

Due to the lack of available information, some assumptions have been applied in this study. These assumptions lead to various limitations of the study, which need to be taken into account when interpreting the results. This section presents a discussion on a few key limitations of this study and their implications in interpreting the results of the study.

It is highly likely that the dilution factors derived in this study produced a conservative estimate of the possible concentrations of the virus in the receiving waterways, because no plume dispersion is considered in this assessment. Depending on various boundary conditions such as temperatures, flow rates, wind direction/speed, etc. the mixing behaviour of the plume can vary significantly and result in a much lower viral concentration than what has been currently considered in this study. In addition, no virus die-out was assumed to occur in the receiving water. Theoretically viruses don't die, because they are not alive. Their reproduction and physiological impact only occur when they are attached to a host. Nevertheless the virus DNA or RNA damage can be induced by environmental factors such as solar irradiation, pH changes, and other biotic or abiotic factors. In addition, there has been strong evidence showing that viruses (*e.g.* rotavirus) tend to be absorbed onto sediment and removed from water column both in freshwater and marine water environment (Rao *et al.* 1984; Pommepuy *et al.* 2006). Therefore, viruses do "die" or can be naturally-attenuated in certain ways. The viral decay model can be described by Chick's Law[6] with a decay rate as expressed in T_{90}[7] in the range of 10 – 30 days (Pommepuy *et al.* 2006), depending on the environment.

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[3] GI illness: Gastrointestinal illness.
[4] AFRI: Acute febrile respiratory illness.
[5] NOAEL: No-observed-adverse-effect level.
[6] Chick's Law: $\ln(N_t/N_o)=-kt$
[7] T_{90}: time necessary for the viral counts to decrease by 1-log.

As discussed previously, due to the lack of available monitoring data, the rotavirus concentrations in raw sewage and viral removal rates throughout the treatment train are unknown for Te Puke WWTP. For the purpose of this study, a suite of distributions for various key parameters have been applied to capture the uncertainty and variability of these parameters within a reasonable range, so that statistically-realistic risk profiles can be established. The selection of the parameter distribution patterns were based on research results conducted overseas and within NZ, and largely consistent with the settings applied in other QMRA work previous conducted within NZ. A relatively large safety margin has been applied in various estimation steps, such as high influent viral concentration and low to moderate removal rates throughout the treatment train.

This study focuses only on the health risks potentially caused by the effluent discharge located along the Waiari stream. Any background contamination or viral input from stormwater runoff, sewage overflow, septic tank seepage, and other sources are not considered in this study.

As discussed in the previous chapter, the calculated individual infection risks or gastrointestinal illness risks were found to be no more than minor for recreational use of the waterway, as long as the WWTP operation is normal and influent rotavirus load is normal. This finding was based on various assumptions such as effective viral removal within the WWTP, effective dilution of the effluent in the Waiari stream, etc. Note that this QMRA was based on expected annual performance of the WWTP, reflecting the overall likelihood of viral removal all year around without weighting any specific season. Seasonal or weather-induced variation of the effluent quality can be significant under some circumstances. For instance, the stormwater runoff can have significant impact on bacterial water quality of the raw wastewater during wet weather conditions.

This QMRA was conducted based on current effluent and ambient environmental conditions. Future change in the various key inputs of the assessment model such as stream/river flow rate may require further consideration. In addition, this QMRA is focused on potential human health risks posed by rotavirus associated with the WWTP effluent discharge. Any environmental effects that are likely to occur due to the effluent discharge are not considered in this study.

5.0 Conclusion

Based on a qualitative public health risk assessment, the microbial water quality within the receiving waters (Waiari Stream and Kaituna River) is not expected to be adversely impacted by the wastewater discharge from Te Puke WWTP. This is due to the high dilution factors that are likely to be achieved within Waiari stream and subsequently in Kaituna River. This however does not take into account of the pathogen input of grazing animals, birds, and rodents that may raise the bacteriological level within the wetland.

This study also presents a quantitative microbial risk assessment (QMRA) of potential human health adverse effects by the Te Puke WWTP effluent discharge. The study follows the risk assessment paradigm for human health effects and estimated the Individual Infection Risks (IIRs) and gastrointestinal illness risks considering various scenarios and likely fate and transport patterns of the pathogen (rotavirus). Various conservative approaches have been adopted in this QMRA study, which need to be taken into consideration when interpreting the results of this study. For instance, the rotavirus load in the raw wastewater was assumed to be 10 times higher than that adopted by previous QMRA work by others. No viral die-out was considered in this study, and the viral reduction rates through the WWTP unit processes were also set at much lower levels compared to some other QMRA studies previously completed in NZ. These provide a larger safety margin when assessing the potential public health risks arising from the WWTP effluent discharge and contribute to an overall conservative approach.

The guideline or threshold values used for the risk assessment were obtained from *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas* (MfE/MoH 2003). The guideline specified a 0.1 % infection occurrence risk as no-calculated-risk level for freshwater or a 1% gastrointestinal illness (GI) risk to be associated with no-observed-adverse-effects level (NOAEL) for marine water. This level of infection or illness risk is classified as “very good” grading for recreational water. This study adopted these threshold values and compared the calculated IIRs with the 0.1% occurrence risk and the estimated gastrointestinal illness risks with the 1% GI illness risk.

The dilution factors were shown to reach over 150 in Waiari Stream and over 1500 in Kaituna River. This significantly reduces the health risks downstream of the discharge point. The QMRA modelling showed that public health risk associated with recreational use of both Waiari Stream and Kaituna River is no more than minor (below the non-calculated-risk level). This was based on 10^5 exposures of any individual swimming in the waterway on any random day of the year, and assumed that the viral load in the raw sewage is normal and all WWTP unit processes are in normal operating conditions. This is reasonably expected due to the good performance of the UV disinfection system. An extreme scenario simulation (*e.g*. there is a rotavirus outbreak within the community) showed elevated health risk associated with recreational water use of the water bodies. This extreme scenario, unusual as it is, may occur occasionally, as demonstrated in the Mangere WWTP monitoring results in 1999 (Simpson *et al.* 2003).

Considering the fact that swimming is not a common recreational water use activity within these waterbodies, these QMRA findings should be deemed relatively conservative. Most common recreational activities in Kaituna River or Waiari stream include boating, kayaking, canoeing, etc. which involves much less of direct water contact when compared with swimming.

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7.0 Standard Limitation

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Any estimates of potential costs which have been provided are presented as estimates only as at the date of the Report. Any cost estimates that have been provided may therefore vary from actual costs at the time of expenditure.

Appendix A

Waiari Stream Flow Record

```
                             Waiari flow record.txt
~~~ NIWA Tideda ~~~ NIWA                                   23-JUN-2015 15:58
~~~ PDIST ~~~
Source is Q:\ARCHIVE\ROT.MTD Site 1114671 Waiari at TDC Intake
From 20140101 000000 to 20150101 240000
Item 1R
Waipaoa Temperature
Distribution computed in the range      3000 to      8000
DISTRIBUTION                PERCENTAGE OF TIME "VALUE" IS EQUALLED OR EXCEEDED

 DAYS  HHMMSS  "VALUE"   %  0        20        40        60        80        100
                 83270      *MAXIMUM  |         |         |         |         |
    5  45119      7900  1.4 |*        |         |         |         |         |
    0  22828      7800  1.4 |*        |         |         |         |         |
    0  31923      7700  1.5 |*        |         |         |         |         |
    0  33654      7600  1.5 |*        |         |         |         |         |
    0  30915      7500  1.6 |*        |         |         |         |         |
    0  32333      7400  1.6 |*        |         |         |         |         |
    0  24817      7300  1.6 |*        |         |         |         |         |
    0  33548      7200  1.7 |*        |         |         |         |         |
    0  44952      7100  1.7 |*        |         |         |         |         |
    0  31743      7000  1.8 |*        |         |         |         |         |
    0  50236      6900  1.8 |*        |         |         |         |         |
    0  41043      6800  1.9 |*        |         |         |         |         |
    0  45531      6700  1.9 |*        |         |         |         |         |
    0  34756      6600  2.0 |*        |         |         |         |         |
    0  52247      6500  2.0 |*        |         |         |         |         |
    0  43422      6400  2.1 |*        |         |         |         |         |
    0  44124      6300  2.1 |*        |         |         |         |         |
    0  40532      6200  2.2 |*        |         |         |         |         |
    0  45237      6100  2.2 |*        |         |         |         |         |
    0  40333      6000  2.3 |*        |         |         |         |         |
    0  52605      5900  2.3 |*        |         |         |         |         |
    0  53149      5800  2.4 |*        |         |         |         |         |
    0  63810      5700  2.5 |*        |         |         |         |         |
    0  54428      5600  2.6 |*        |         |         |         |         |
    0  60716      5500  2.6 |*        |         |         |         |         |
    0  65603      5400  2.7 |*        |         |         |         |         |
    0  83907      5300  2.8 |*        |         |         |         |         |
    0  84045      5200  2.9 |*        |         |         |         |         |
    0 122646      5100  3.0 | *       |         |         |         |         |
    0 133713      5000  3.2 | *       |         |         |         |         |
    0 171209      4900  3.4 | *       |         |         |         |         |
    0 192309      4800  3.6 | *       |         |         |         |         |
    1  93038      4700  4.0 | *       |         |         |         |         |
    1   5316      4600  4.3 | *       |         |         |         |         |
    1 121823      4500  4.7 | *       |         |         |         |         |
    2   1743      4400  5.2 |  *      |         |         |         |         |
    2 105535      4300  5.9 |  *      |         |         |         |         |
    6  92420      4200  7.7 |   *     |         |         |         |         |
   11 151310      4100  11. |    *    |         |         |         |         |
   39  40551      4000  22. |         |*        |         |         |         |
   39 182526      3900  32. |         |     *   |         |         |         |
   62  43000      3800  49. |         |         |    *    |         |         |
   57 190208      3700  65. |         |         |         |  *      |         |
   58 161205      3600  81. |         |         |         |         |*        |
   51  74019      3500  95. |         |         |         |         |       * |
   17  95159      3400 99.9 |         |         |         |         |         *
    0   1834      3399 100. |MINIMUM  |         |         |         |         *

  366 000000=TOTAL          MEAN=   4055.41             STD.DEV.=   2440.00

This table uses   47 classes.
Percentages in the printplot table are accurate only to the
precision shown (e.g. 5.0% is 5.0% +/- 0.05%)

End of process
```

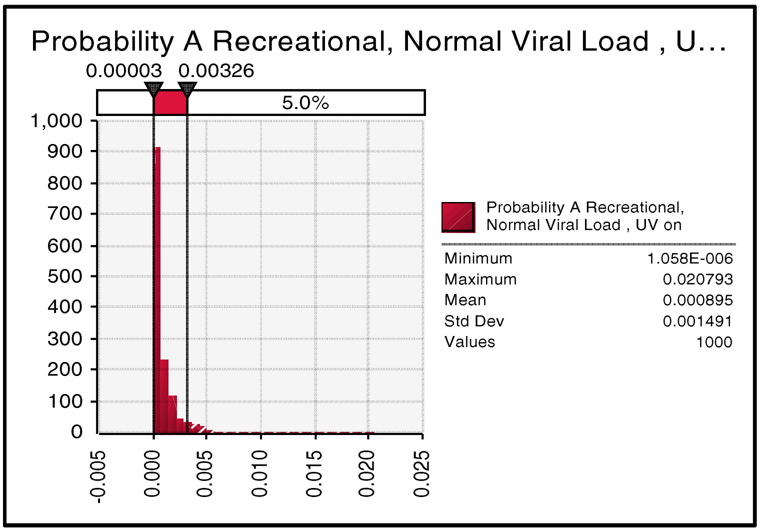
Appendix B

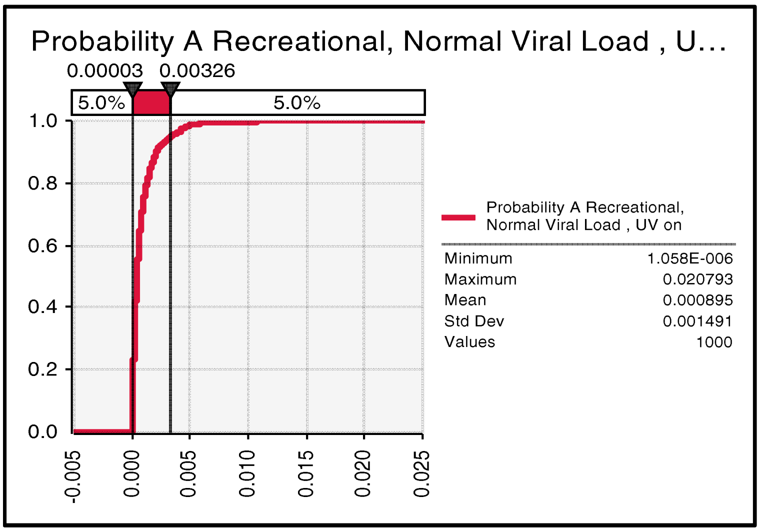
QMRA Result Sheets

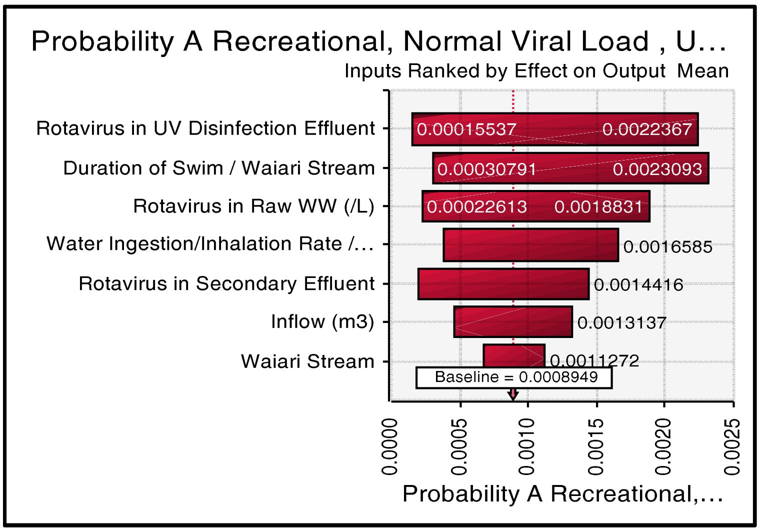
@RISK Output Report for Probability A Recreational, Normal Viral Load ,

Performed By: zhuo_chen

Date: Thursday, 27 August 2015 3:10:32 p.m.







Simulation Summary Information

Workbook Name	QMRA Assessment.xlsm
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	48
Number of Outputs	42
Sampling Type	Latin Hypercube
Simulation Start Time	26/08/2015 16:07
Simulation Duration	00:01:44
Random # Generator	Mersenne Twister
Random Seed	2071383517

Summary Statistics for Probability A Recreational, N

Statistics		**Percentile**	
Minimum	1.05764E-06	**5%**	3.31202E-05
Maximum	0.020792684	**10%**	6.48035E-05
Mean	0.000894921	**15%**	9.27258E-05
Std Dev	0.00149077	**20%**	0.000123931
Variance	2.22239E-06	**25%**	0.000160689
Skewness	6.08894419	**30%**	0.000200296
Kurtosis	62.61628667	**35%**	0.000247675
Median	0.000441007	**40%**	0.000311572
Mode	5.3554E-05	**45%**	0.000359361
Left X	3.31202E-05	**50%**	0.000441007
Left P	5%	**55%**	0.000509187
Right X	0.003262001	**60%**	0.000588588
Right P	95%	**65%**	0.000693927
Diff X	0.003228881	**70%**	0.000832271
Diff P	90%	**75%**	0.001013167
#Errors	0	**80%**	0.001292843
Filter Min	Off	**85%**	0.001603649
Filter Max	Off	**90%**	0.002123349
#Filtered	0	**95%**	0.003262001

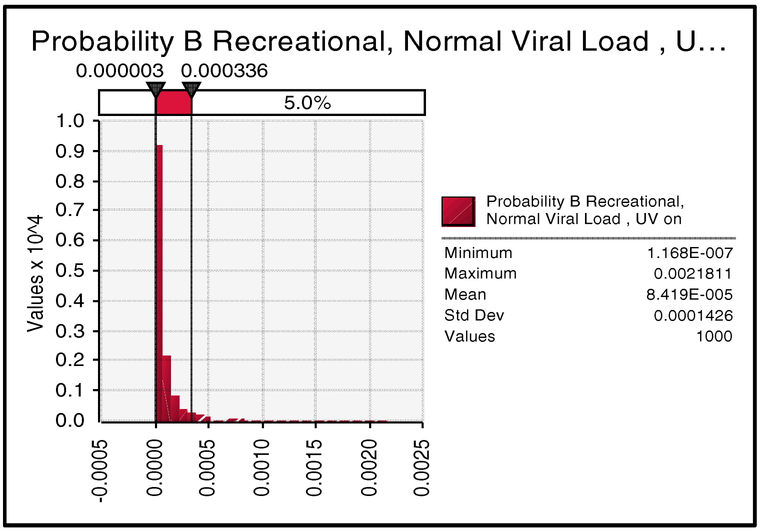
Change in Output Statistic for Probability A Recreat

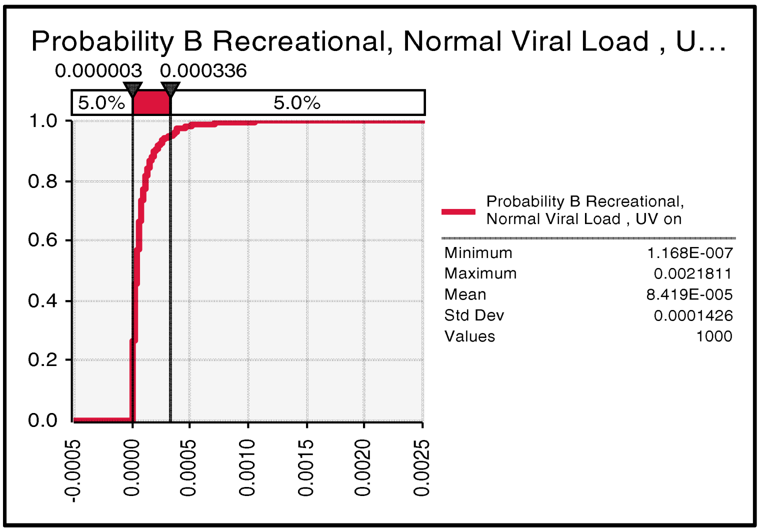
Rank	**Name**	**Lower**	**Upper**
1	Rotavirus in UV Disi	0.000155367	0.002236656
2	Duration of Swim /	0.000307909	0.002309292
3	Rotavirus in Raw W	0.000226127	0.001883099
4	Water Ingestion/Inl	0.000380339	0.001658482
5	Rotavirus in Second	0.000206161	0.001441646
6	Inflow (m3)	0.000460576	0.001313672
7	Waiari Stream	0.000670511	0.00112718

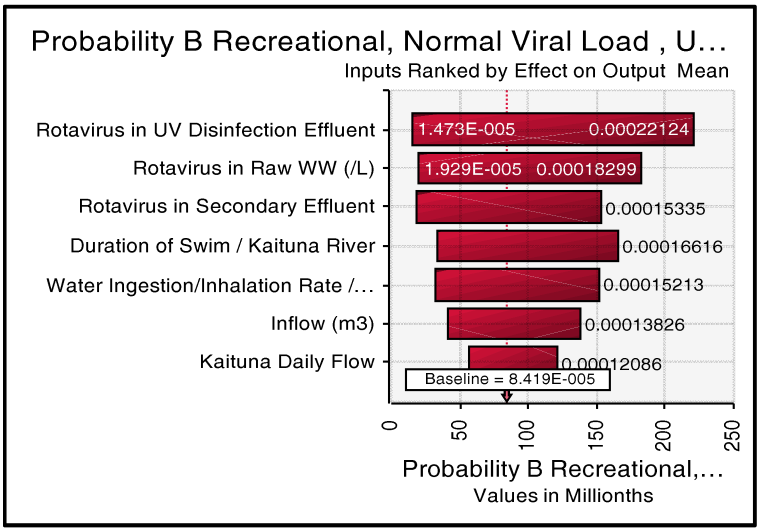
@RISK Output Report for Probability B Recreational, Normal Viral Load ,

Performed By: zhuo_chen

Date: Thursday, 27 August 2015 3:10:33 p.m.







Simulation Summary Information	
Workbook Name	QMRA Assessment.xlsm
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	48
Number of Outputs	42
Sampling Type	Latin Hypercube
Simulation Start Time	26/08/2015 16:07
Simulation Duration	00:01:44
Random # Generator	Mersenne Twister
Random Seed	2071383517

Summary Statistics for Probability B Recreational, N

Statistics		**Percentile**	
Minimum	1.16778E-07	**5%**	3.07626E-06
Maximum	0.002181078	**10%**	5.23744E-06
Mean	8.41869E-05	**15%**	8.06302E-06
Std Dev	0.000142635	**20%**	1.12493E-05
Variance	2.03447E-08	**25%**	1.4071E-05
Skewness	5.881254168	**30%**	1.71671E-05
Kurtosis	62.03995802	**35%**	2.20338E-05
Median	3.88139E-05	**40%**	2.79763E-05
Mode	4.03499E-06	**45%**	3.22056E-05
Left X	3.07626E-06	**50%**	3.88139E-05
Left P	5%	**55%**	4.61539E-05
Right X	0.000336345	**60%**	5.69841E-05
Right P	95%	**65%**	6.67748E-05
Diff X	0.000333269	**70%**	7.85125E-05
Diff P	90%	**75%**	9.41489E-05
#Errors	0	**80%**	0.000116328
Filter Min	Off	**85%**	0.000150142
Filter Max	Off	**90%**	0.000204464
#Filtered	0	**95%**	0.000336345

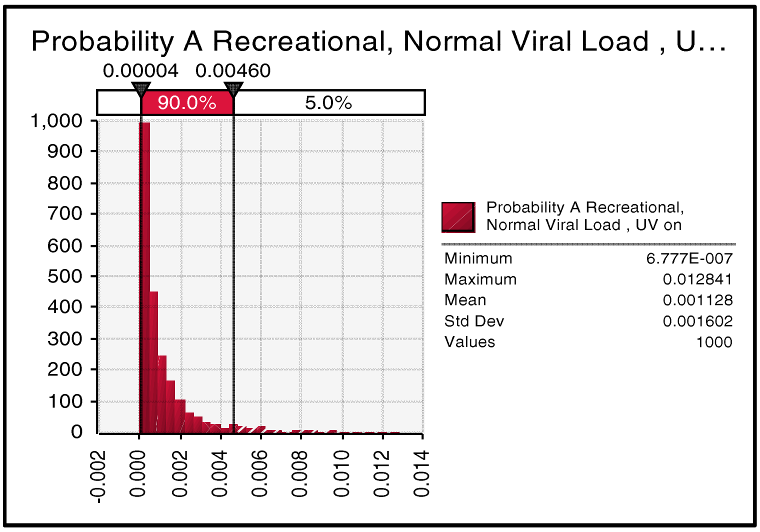
Change in Output Statistic for Probability B Recreat

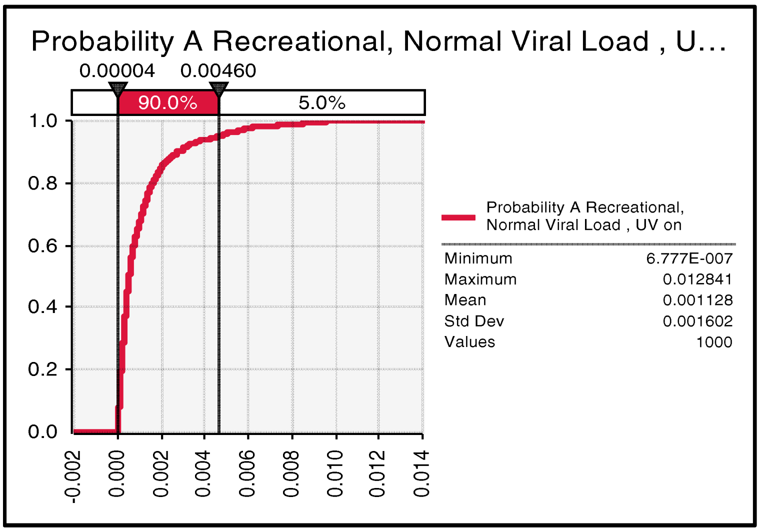
Rank	**Name**	**Lower**	**Upper**
1	Rotavirus in UV Disi	1.47291E-05	0.000221242
2	Rotavirus in Raw W	1.92854E-05	0.000182994
3	Rotavirus in Second	1.90393E-05	0.000153349
4	Duration of Swim /	3.36801E-05	0.000166155
5	Water Ingestion/Inl	3.22254E-05	0.000152129
6	Inflow (m3)	4.21479E-05	0.000138264
7	Kaituna Daily Flow	5.6686E-05	0.00012086

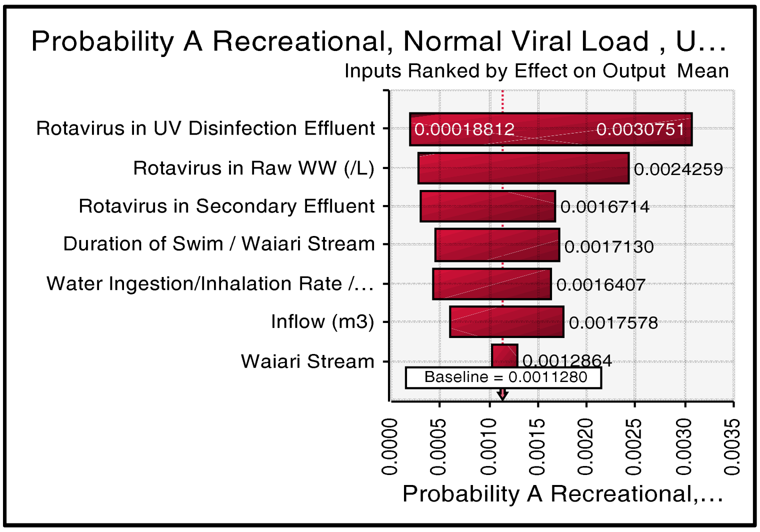
@RISK Output Report for Probability A Recreational, Normal Viral Load ,

Performed By: zhuo_chen

Date: Thursday, 27 August 2015 3:10:34 p.m.







Simulation Summary Information

Workbook Name	QMRA Assessment.xlsm
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	48
Number of Outputs	42
Sampling Type	Latin Hypercube
Simulation Start Time	26/08/2015 16:07
Simulation Duration	00:01:44
Random # Generator	Mersenne Twister
Random Seed	2071383517

Summary Statistics for Probability A Recreational, N

Statistics		**Percentile**	
Minimum	6.77696E-07	**5%**	4.39754E-05
Maximum	0.012840751	**10%**	8.55708E-05
Mean	0.001127971	**15%**	0.000129493
Std Dev	0.001601878	**20%**	0.00016949
Variance	2.56601E-06	**25%**	0.0002183
Skewness	3.025501453	**30%**	0.000284882
Kurtosis	14.30613145	**35%**	0.000338866
Median	0.000544234	**40%**	0.000397045
Mode	1.6282E-05	**45%**	0.000456171
Left X	4.39754E-05	**50%**	0.000544234
Left P	5%	**55%**	0.000627068
Right X	0.00460336	**60%**	0.000745941
Right P	95%	**65%**	0.000912875
Diff X	0.004559385	**70%**	0.001118551
Diff P	90%	**75%**	0.001346927
#Errors	0	**80%**	0.001612494
Filter Min	Off	**85%**	0.002002833
Filter Max	Off	**90%**	0.002760466
#Filtered	0	**95%**	0.00460336

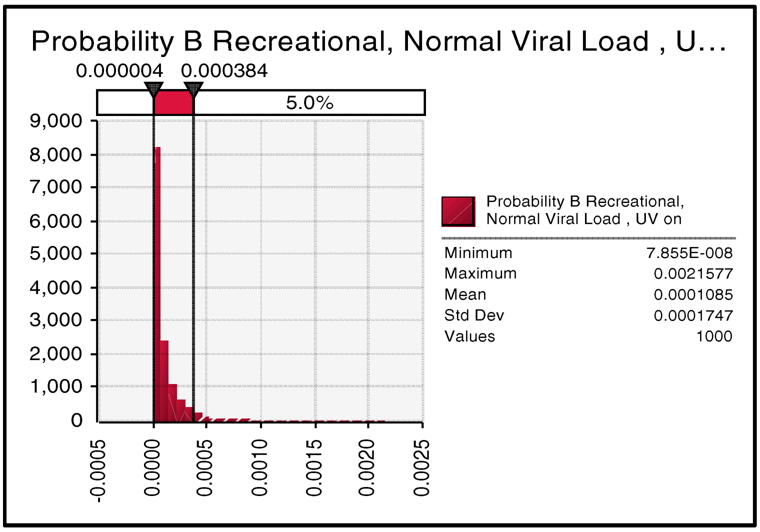
Change in Output Statistic for Probability A Recreat

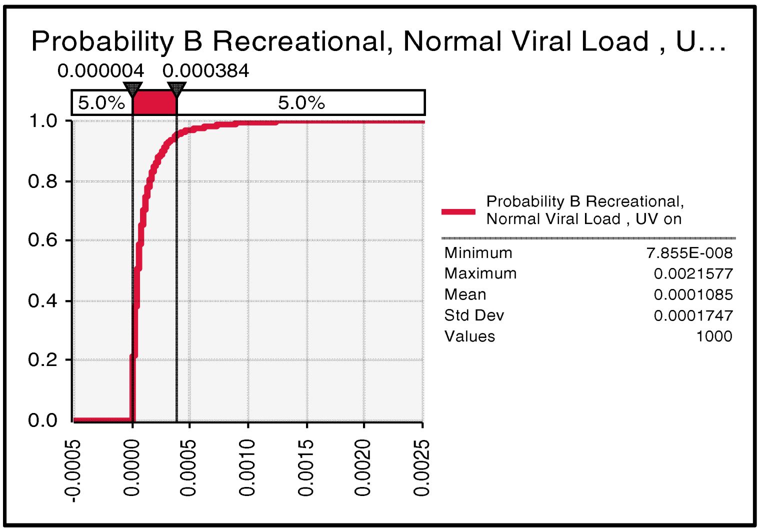
Rank	**Name**	**Lower**	**Upper**
1	Rotavirus in UV Disi	0.000188123	0.003075074
2	Rotavirus in Raw W	0.000286559	0.002425907
3	Rotavirus in Second	0.000290017	0.001671363
4	Duration of Swim /	0.000446151	0.001713041
5	Water Ingestion/Inl	0.00043756	0.001640698
6	Inflow (m3)	0.000592893	0.001757813
7	Waiari Stream	0.001033188	0.001286436

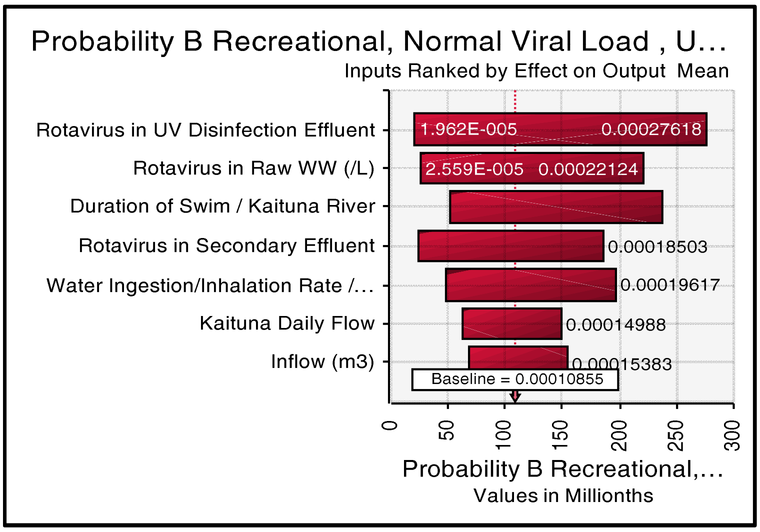
@RISK Output Report for Probability B Recreational, Normal Viral Load ,

Performed By: zhuo_chen

Date: Thursday, 27 August 2015 3:10:35 p.m.







Simulation Summary Information

Workbook Name	QMRA Assessment.xlsm
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	48
Number of Outputs	42
Sampling Type	Latin Hypercube
Simulation Start Time	26/08/2015 16:07
Simulation Duration	00:01:44
Random # Generator	Mersenne Twister
Random Seed	2071383517

Summary Statistics for Probability B Recreational, N

Statistics		**Percentile**	
Minimum	7.85528E-08	**5%**	4.03791E-06
Maximum	0.002157685	**10%**	7.08309E-06
Mean	0.00010855	**15%**	1.11052E-05
Std Dev	0.000174716	**20%**	1.37432E-05
Variance	3.05256E-08	**25%**	1.81301E-05
Skewness	4.847249773	**30%**	2.29408E-05
Kurtosis	39.96271424	**35%**	2.87807E-05
Median	5.02671E-05	**40%**	3.47722E-05
Mode	1.18668E-05	**45%**	4.22095E-05
Left X	4.03791E-06	**50%**	5.02671E-05
Left P	5%	**55%**	6.05851E-05
Right X	0.000384089	**60%**	7.17939E-05
Right P	95%	**65%**	8.64423E-05
Diff X	0.000380051	**70%**	0.000103017
Diff P	90%	**75%**	0.000126756
#Errors	0	**80%**	0.000156065
Filter Min	Off	**85%**	0.000197072
Filter Max	Off	**90%**	0.000270055
#Filtered	0	**95%**	0.000384089

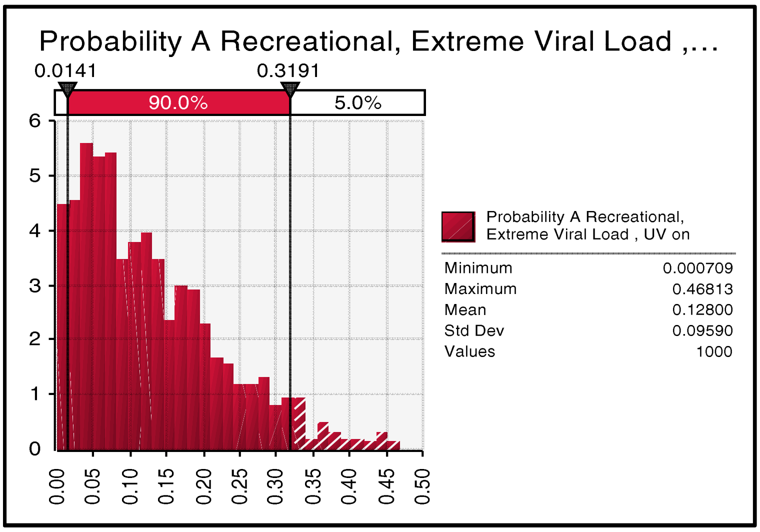
Change in Output Statistic for Probability B Recreat

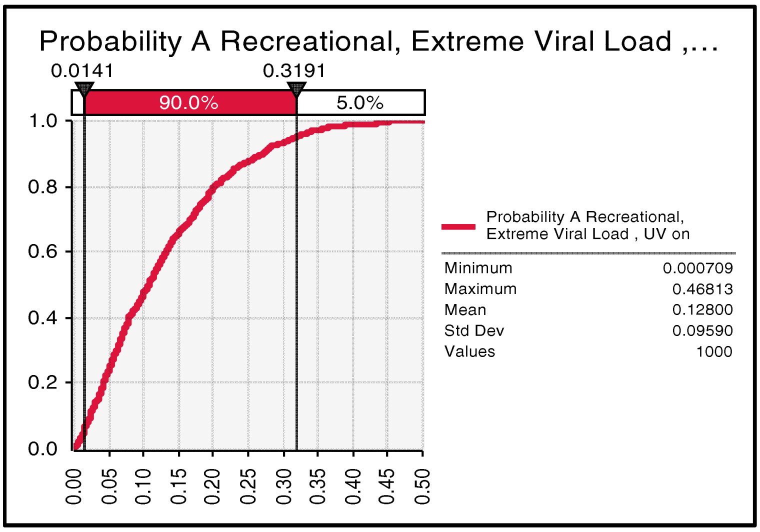
Rank	**Name**	**Lower**	**Upper**
1	Rotavirus in UV Disi	1.96195E-05	0.000276181
2	Rotavirus in Raw W	2.5592E-05	0.000221243
3	Duration of Swim /	5.1338E-05	0.000236646
4	Rotavirus in Second	2.42197E-05	0.00018503
5	Water Ingestion/Inl	4.73255E-05	0.000196165
6	Kaituna Daily Flow	6.29763E-05	0.000149885
7	Inflow (m3)	6.79817E-05	0.00015383

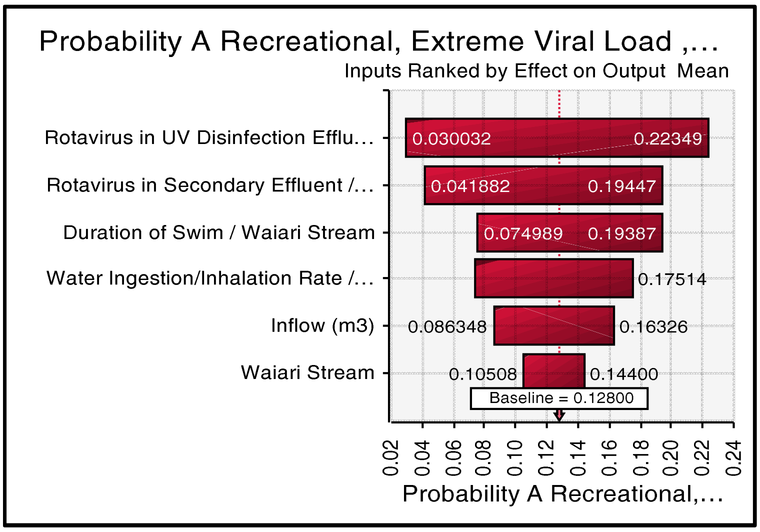
@RISK Output Report for Probability A Recreational, Extreme Viral Load ,

Performed By: zhuo_chen

Date: Thursday, 27 August 2015 3:10:50 p.m.







Simulation Summary Information	
Workbook Name	QMRA Assessment.xlsm
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	48
Number of Outputs	42
Sampling Type	Latin Hypercube
Simulation Start Time	26/08/2015 16:07
Simulation Duration	00:01:44
Random # Generator	Mersenne Twister
Random Seed	2071383517

Summary Statistics for Probability A Recreational, E

Statistics		Percentile	
Minimum	0.000709238	**5%**	0.014121445
Maximum	0.468128251	**10%**	0.023238574
Mean	0.128000118	**15%**	0.034177975
Std Dev	0.095902412	**20%**	0.042938321
Variance	0.009197273	**25%**	0.051894804
Skewness	0.974082073	**30%**	0.060879288
Kurtosis	3.5078416	**35%**	0.069748526
Median	0.106870276	**40%**	0.079006587
Mode	0.037247796	**45%**	0.094884668
Left X	0.014121445	**50%**	0.106870276
Left P	5%	**55%**	0.118932632
Right X	0.319109883	**60%**	0.132476125
Right P	95%	**65%**	0.146533555
Diff X	0.304988438	**70%**	0.167420676
Diff P	90%	**75%**	0.184839177
#Errors	0	**80%**	0.201426803
Filter Min	Off	**85%**	0.229676392
Filter Max	Off	**90%**	0.270323692
#Filtered	0	**95%**	0.319109883

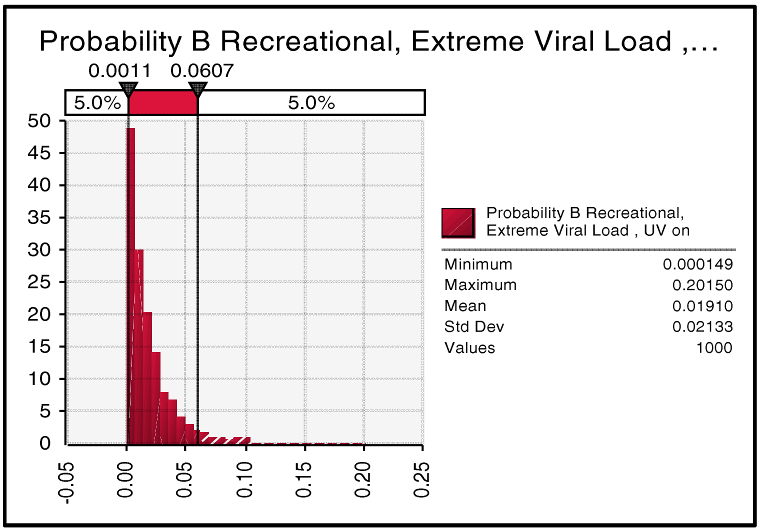
Change in Output Statistic for Probability A Recreat

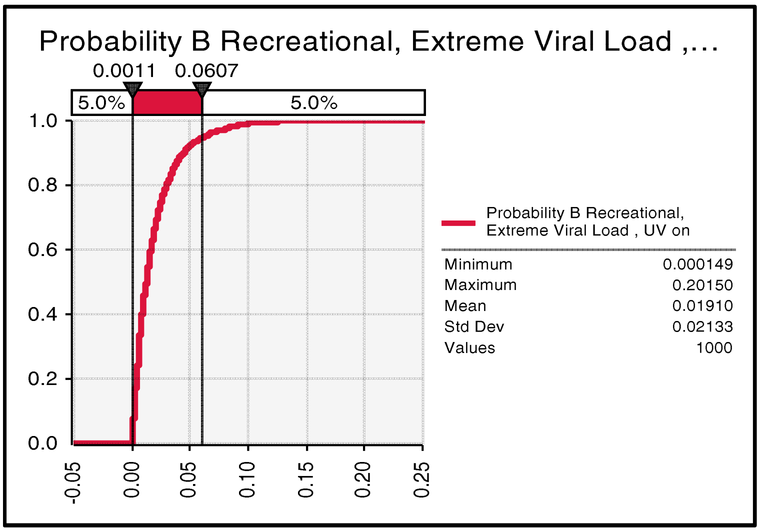
Rank	Name	Lower	Upper
1	Rotavirus in UV Disi	0.030032315	0.223492416
2	Rotavirus in Second	0.041882078	0.194474132
3	Duration of Swim /	0.074988721	0.193867608
4	Water Ingestion/Inl	0.073639	0.1751379
5	Inflow (m3)	0.086348324	0.16325835
6	Waiari Stream	0.105080193	0.143997424

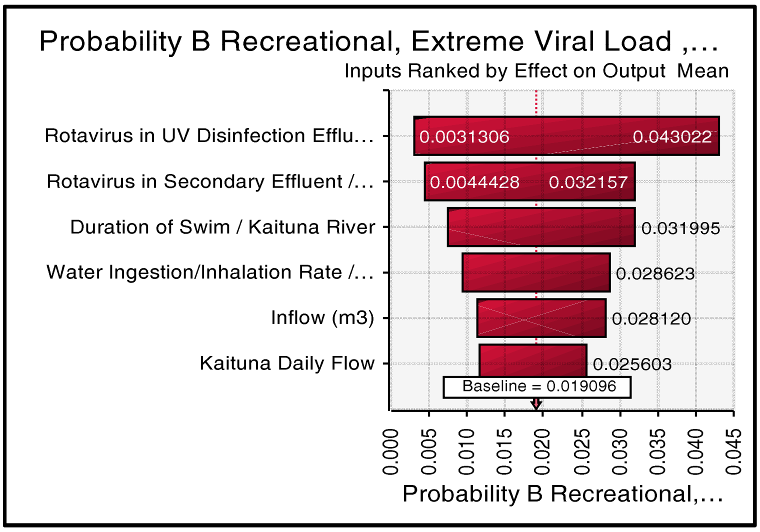
@RISK Output Report for Probability B Recreational, Extreme Viral Load ,

Performed By: zhuo_chen

Date: Thursday, 27 August 2015 3:10:51 p.m.







Simulation Summary Information	
Workbook Name	QMRA Assessment.xlsm
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	48
Number of Outputs	42
Sampling Type	Latin Hypercube
Simulation Start Time	26/08/2015 16:07
Simulation Duration	00:01:44
Random # Generator	Mersenne Twister
Random Seed	2071383517

Summary Statistics for Probability B Recreational, E

Statistics		**Percentile**	
Minimum	0.00014915	**5%**	0.001131391
Maximum	0.201497893	**10%**	0.002032476
Mean	0.019096058	**15%**	0.003052429
Std Dev	0.021326856	**20%**	0.004125996
Variance	0.000454835	**25%**	0.00523414
Skewness	2.70184522	**30%**	0.006246267
Kurtosis	15.13408036	**35%**	0.007247426
Median	0.012470325	**40%**	0.008693748
Mode	0.001170722	**45%**	0.010238908
Left X	0.001131391	**50%**	0.012470325
Left P	5%	**55%**	0.014223447
Right X	0.060704419	**60%**	0.016436195
Right P	95%	**65%**	0.018937872
Diff X	0.059573027	**70%**	0.021605123
Diff P	90%	**75%**	0.025286546
#Errors	0	**80%**	0.029565549
Filter Min	Off	**85%**	0.035813439
Filter Max	Off	**90%**	0.045192998
#Filtered	0	**95%**	0.060704419

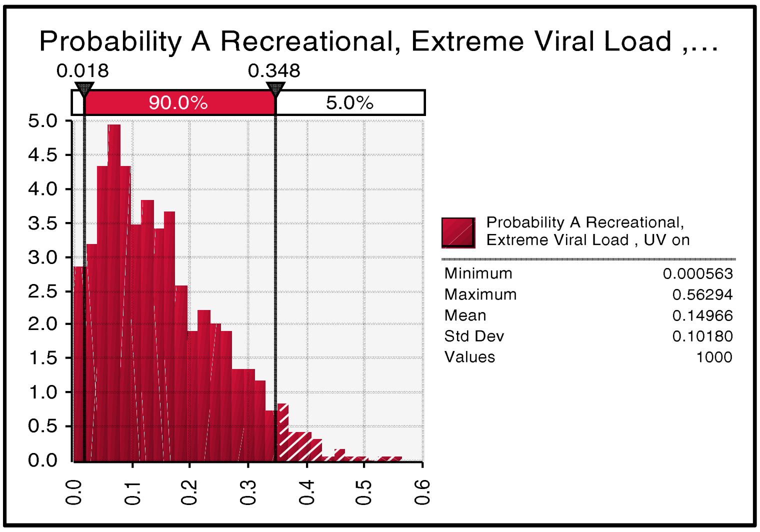
Change in Output Statistic for Probability B Recreat

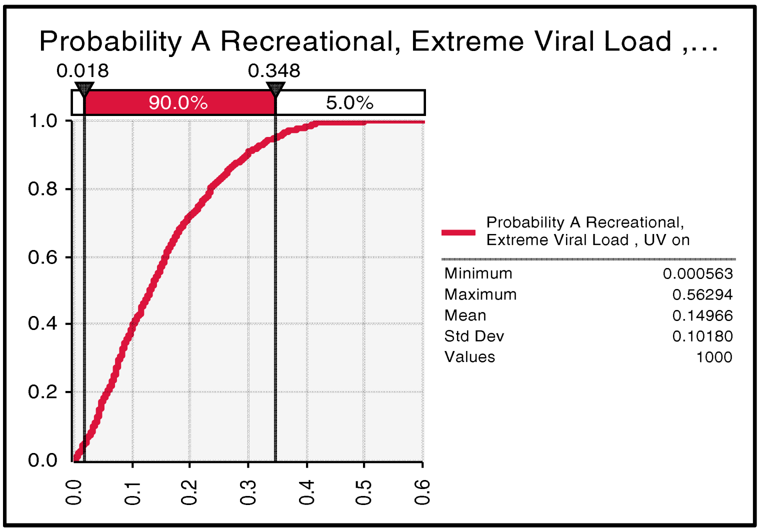
Rank	**Name**	**Lower**	**Upper**
1	Rotavirus in UV Disi	0.003130568	0.04302206
2	Rotavirus in Second	0.004442754	0.032156525
3	Duration of Swim /	0.007529794	0.031994741
4	Water Ingestion/Inl	0.009309187	0.028622743
5	Inflow (m3)	0.011319898	0.028120049
6	Kaituna Daily Flow	0.011607285	0.025603451

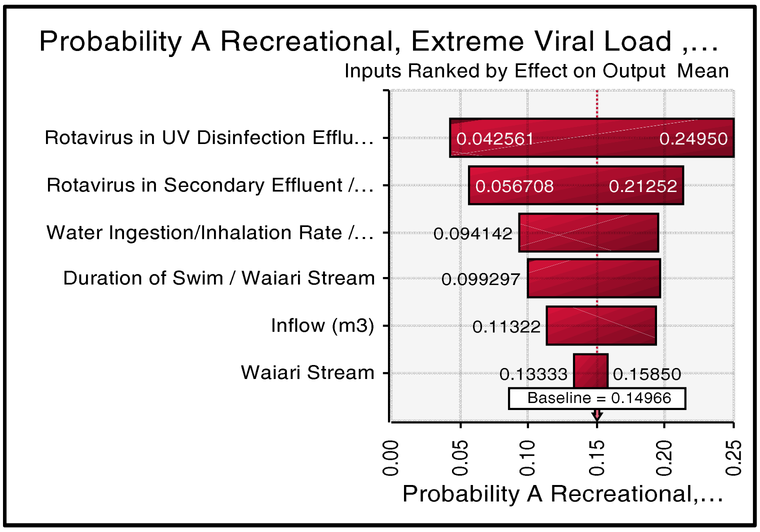
@RISK Output Report for Probability A Recreational, Extreme Viral Load ,

Performed By: zhuo_chen

Date: Thursday, 27 August 2015 3:10:52 p.m.







Simulation Summary Information	
Workbook Name	QMRA Assessment.xlsm
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	48
Number of Outputs	42
Sampling Type	Latin Hypercube
Simulation Start Time	26/08/2015 16:07
Simulation Duration	00:01:44
Random # Generator	Mersenne Twister
Random Seed	2071383517

Summary Statistics for Probability A Recreational, E

Statistics		**Percentile**	
Minimum	0.000562585	**5%**	0.018110494
Maximum	0.562941532	**10%**	0.03446303
Mean	0.149658732	**15%**	0.044922294
Std Dev	0.101801887	**20%**	0.057256847
Variance	0.010363624	**25%**	0.069924988
Skewness	0.805199456	**30%**	0.079295184
Kurtosis	3.195197345	**35%**	0.088615637
Median	0.131185561	**40%**	0.103007933
Mode	0.048327973	**45%**	0.117118053
Left X	0.018110494	**50%**	0.131185561
Left P	5%	**55%**	0.14472681
Right X	0.347988693	**60%**	0.157785881
Right P	95%	**65%**	0.17200879
Diff X	0.329878199	**70%**	0.19217492
Diff P	90%	**75%**	0.21524329
#Errors	0	**80%**	0.236084354
Filter Min	Off	**85%**	0.263353798
Filter Max	Off	**90%**	0.297614795
#Filtered	0	**95%**	0.347988693

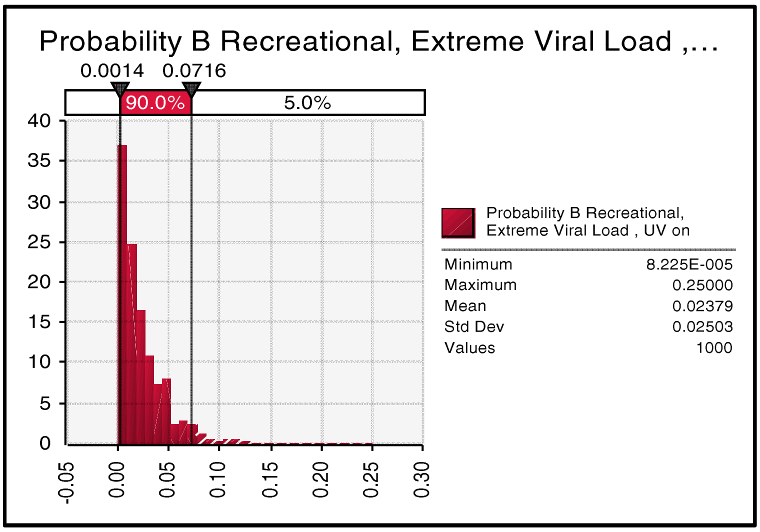
Change in Output Statistic for Probability A Recreat

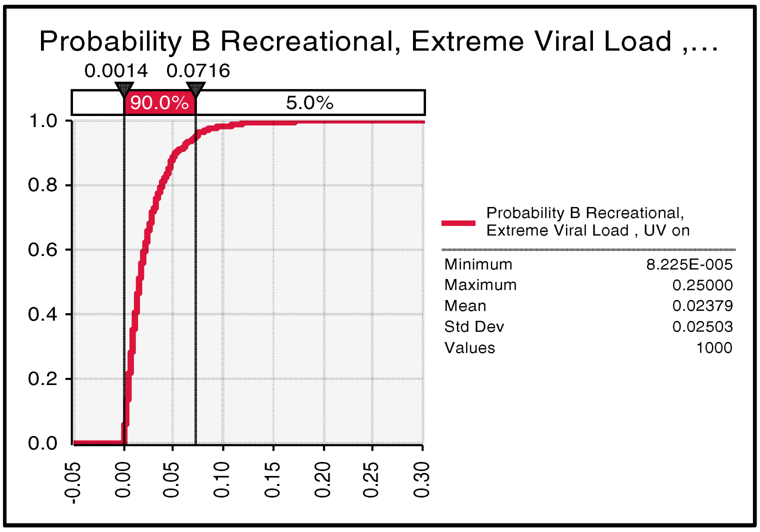
Rank	**Name**	**Lower**	**Upper**
1	Rotavirus in UV Disi	0.04256099	0.249497924
2	Rotavirus in Second	0.056708114	0.212518079
3	Water Ingestion/Inh	0.094141723	0.19537838
4	Duration of Swim /	0.09929704	0.196065285
5	Inflow (m3)	0.113221009	0.193942261
6	Waiari Stream	0.133327914	0.158499711

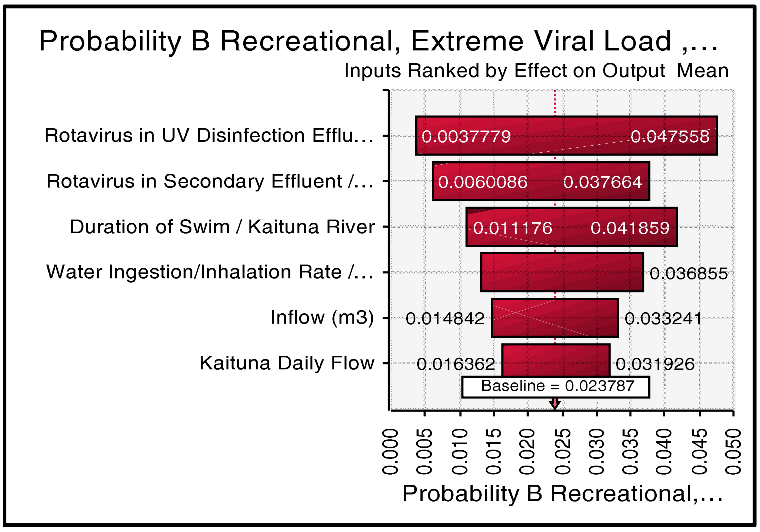
@RISK Output Report for Probability B Recreational, Extreme Viral Load ,

Performed By: zhuo_chen

Date: Thursday, 27 August 2015 3:10:53 p.m.







Simulation Summary Information	
Workbook Name	QMRA Assessment.xlsm
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	48
Number of Outputs	42
Sampling Type	Latin Hypercube
Simulation Start Time	26/08/2015 16:07
Simulation Duration	00:01:44
Random # Generator	Mersenne Twister
Random Seed	2071383517

Summary Statistics for Probability B Recreational, E

Statistics		**Percentile**	
Minimum	8.22457E-05	**5%**	0.001385625
Maximum	0.250003528	**10%**	0.002736293
Mean	0.023786891	**15%**	0.004170484
Std Dev	0.025031643	**20%**	0.005359468
Variance	0.000626583	**25%**	0.006858035
Skewness	2.587641008	**30%**	0.008359558
Kurtosis	14.70791101	**35%**	0.009884427
Median	0.015927824	**40%**	0.011989926
Mode	0.003320365	**45%**	0.013858938
Left X	0.001385625	**50%**	0.015927824
Left P	5%	**55%**	0.01819264
Right X	0.071628696	**60%**	0.020874321
Right P	95%	**65%**	0.024225217
Diff X	0.070243071	**70%**	0.027784706
Diff P	90%	**75%**	0.032336008
#Errors	0	**80%**	0.038314958
Filter Min	Off	**85%**	0.045836848
Filter Max	Off	**90%**	0.052379357
#Filtered	0	**95%**	0.071628696

Change in Output Statistic for Probability B Recreat

Rank	**Name**	**Lower**	**Upper**
1	Rotavirus in UV Disi	0.003777871	0.04755777
2	Rotavirus in Second	0.006008623	0.037664036
3	Duration of Swim /	0.011175878	0.041859414
4	Water Ingestion/Inl	0.013287285	0.036854979
5	Inflow (m3)	0.014841964	0.033241039
6	Kaituna Daily Flow	0.016361789	0.031926425